AD-A101 186 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 1/3
SURVIVABILITY STUDY OF A FLIR EQUIPPED FIGHTER ON A NIGHT PENET--ETC(U)
MAR 81 W J LEEK, R W SCHMITT
UNCLASSIFIED AFIT/GST/OS/81-M-9 NL

1 OF 2
AD
A101186

LEVEL

AD A101186

DTIC FILE COPY

SURVIVABILITY STUDY OF A FLIR EQUIPPED FIGHTER ON A NIGHT PENETRATION OF A SOVIET ARMY

THESIS

AFIT/GST/OS/81M-9

Warren J. Leek
Maj

Richard W. Schmitt
Maj

81 7 09 044

AFIT/GST/OS/81-M-9

SURVIVABILITY STUDY OF A FLIR EQUIPPED FIGHTER ON A NIGHT PENETRATION OF A SOVIET ARMY

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Warren J. Leek
Major USAF

[redacted]

Richard W. Schmitt
Major USAF

Graduate Strategic and Tactical Sciences

Mar[redacted]81

Approved for public release; distribution unlimited.

Preface

The use of forward looking infrared (FLIR) systems as an aid in conducting low altitude operations in fighter aircraft is receiving widespread attention. As experienced fighter pilots, the authors of this research project were interested in quantitatively evaluating the FLIR's enhancement of fighter survivability. The thesis specifically addresses its effect on the night battlefield air interdiction mission.

We wish to gratefully acknowledge the assistance of Mr. Frank Campanile and Mr. Dick Sudheimer, from the Mission Area Analysis branch of the Aeronautical Systems Division, in providing background information for the project. We also wish to thank Lt Col Tom Clark, our faculty advisor, for his assistance and support throughout the research effort.

Finally, we wish to thank our wives, Cindy Leek and Claudia Schmitt, for their patience and understanding throughout the long hours spent on this project.

Warren J. Leek

Richard W. Schmitt

Contents

List of Figures

Figure | Page

List of Tables

Abstract

The LANTIRN system provides the fighter pilot with a forward looking infrared (FLIR) system, which allows him to fly the aircraft lower and faster than he would otherwise be able to fly. The objective of this research effort was to determine whether this increased capability will significantly improve the fighter's survivability in the night interdiction role. The problem was studied in the context of the threats and terrain found in the central region of West Germany.

A model of the terrain features and threat scenario was constructed using the SLAM computer simulation language. The Soviet defensive systems can be moved around as desired, and aircraft can enter the system at a variety of arrival intervals, airspeeds, and altitudes. Defensive systems that are within range of the aircraft will shoot at it, provided they are not tied up with a previous aircraft, blocked by terrain, or prevented from shooting because of a low probability of kill.

The capability to fly faster did not significantly increase the fighter's survivability. A decrease in altitude from 1000 feet to 500 feet increased survivability to a minor degree, while a further decrease to 250 feet improved survivability significantly. These findings led to the conclusion that a strong effort should

be made to develop a FLIR of high enough resolution to allow the pilot to fly the mission at an altitude of 250 feet or below.

SURVIVABILITY STUDY OF A FLIR EQUIPPED FIGHTER ON A NIGHT PENETRATION OF A SOVIET ARMY

I Introduction

Background

United States Air Force efforts in the close air support and interdiction roles have traditionally emphasized daytime applications of airpower. The reason for this emphasis is that we simply do not have aircraft capable of delivering weapons at night with the accuracy needed to destroy pinpoint targets.

Admittedly, the F-111 is heavily committed to the night interdiction role; however, its usefulness is restricted to large stationary targets which can be located on the basis of a radar prediction that was prepared long before the mission was flown. It has virtually no capability to locate small, mobile targets, such as tank columns, nor does it have a substantial ability to destroy such targets if it does locate them.

To improve the night capabilities of our fighter force, several USAF agencies are working on a system known as Low Altitude Navigation and Targeting Infrared System for Night (LANTIRN). Basically, LANTIRN is a pod which will be attached to an F-16 or an A-10. The pod has a

Forward Looking Infrared (FLIR) capability which will link up with the pilot's head-up display (HUD) to give him a video raster representation of the terrain in front of the aircraft, within a limited (30° wide by 20° high) field of view. Another section of the pod will automatically acquire targets within the HUD's field of view, point them out to the pilot, and fire Imaging Infrared (IIR) Maverick missiles at the targets if the pilot consents. The goal specified for the system is an ability to acquire, classify, and fire at up to 6 targets in a 7 second time period.

The LANTIRN system, when it is fully developed, will represent a substantial advance in the state of the art in several fields. Development of the CO2 laser, which is to provide surreptitious terrain following information, will require some major technological breakthroughs. Developing the ability to automatically find and classify targets will also be a formidable task. A 6-rail Maverick launcher must be developed, and the missiles themselves will very likely have to be modified so that the second through sixth missiles fired will stay locked on to their targets rather than locking on to the missiles fired just before them. These are just a few of the problems that must be solved before the system can become operational.

Problem Statement

Before discussing the technology required to develop and optimize the system, a very basic question must be addressed. How is LANTIRN going to affect the survivability of the aircraft that is carrying it?

This thesis compares the survivability of a hypothetical tactical fighter employing a FLIR system on a night battlefield air interdiction (BAI) mission with the same aircraft flying the same mission without the FLIR. The fighters penetrate the forward edge of the battle area (FEBA) and fly through a typical array of defenses of a Soviet ground army to strike a target at the rear of the ground army's area of operations. The FEBA is assumed to be somewhere near the East German border in central West Germany.

Objective

Because of the pilot's ability to "see" the terrain ahead of him using the FLIR, he will be able to fly lower and faster than he would be able to fly without the FLIR. The objective of this thesis is to determine whether the increased capability of the aircraft provided by the FLIR will significantly improve its survivability in the night interdiction role.

Scope

In this thesis,[1] the fighter's survivability in the night BAI role is analyzed, with the constraint that the fighter must perform a low altitude penetration of the enemy army to reach the target area. Under certain, perhaps most, conditions, a high altitude ingress might result in a better probability of survival for the fighter, but this does not reduce the need to determine the FLIR's enhancement of survivability in a low altitude penetration. Weather conditions might, for example, make it impossible to perform a high altitude ingress and subsequent letdown to low altitude approaching the target. Furthermore, a low altitude ingress will allow the fighter to acquire and engage targets of opportunity enroute to the target area; these targets would be out of range if a high altitude ingress were made.

The model studies the problem only in the context of the terrain features of central West Germany, which consists predominantly of rolling farmland mixed with thick forests. The trends shown in the study should apply to other terrain types, but this claim can not be categorically made.

Finally, it is important to note that the survivability figures developed by the model are useful only for comparing the various alternatives evaluated. Undoubtedly there are factors not considered in the model which will affect significantly the survivability of an aircraft flying the scenario. Thus when the model predicts that twelve out of twenty aircraft will survive under one set of conditions and sixteen will survive under another set of conditions, the important result is the comparison between the two alternatives rather than the exact survival figures.

Threat Scenario

Each of the five Soviet ground armies stationed in East Germany has approximately 1000 surface-to-air missile (SAM) launchers and 1000 anti-aircraft artillery (AAA) units (Ref 6:46). These defenses are concentrated within an area 27 nautical miles (NM) wide by 54 NM long. Because the mission analyzed in the model will be flown at low altitude at night, those weapon systems which do not have the ability to acquire and engage the aircraft with radar or some other non-visual system can be eliminated. Using this criterion, four SAM systems and one AAA system were selected as representative threats in the model. They are designated as shown below:

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

The approximate locations of these threats in the Soviet

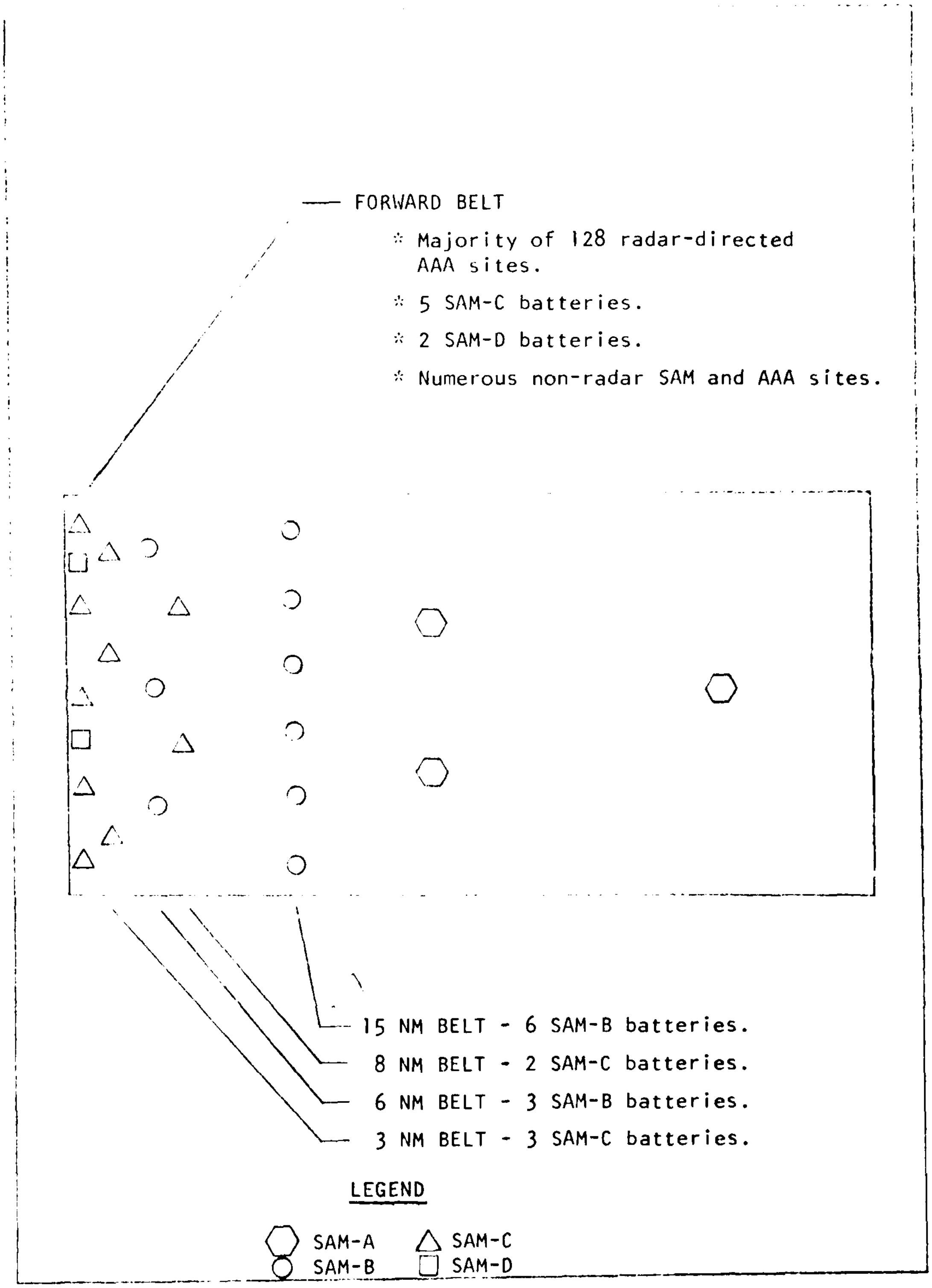


Figure 1. Radar-Directed Air Defense Systems

army area are shown in Figure 1.

Soviet airpower is not expected to be a threat, since Soviet doctrine calls for air defense in the forward part of the battle area to be the responsibility of the SAM and AAA units in the early stages of the war (Ref 6:46). Furthermore no known Soviet aircraft has a credible capability against a high speed, low altitude aircraft at night.

Appendix K (SECRET) describes the threat scenario in more detailed and specific terms.

Structural Model

Figure 2 is a structural model of the air defense elements of a typical field army, as discussed in the previous subsection. It is essentially an expanded version of Figure 1, with the 5 defensive systems which pose a significant threat to the fighter arranged in "belts" which correspond as closely as possible to the positions they would actually occupy. Note that the first five belts in the structural model make up what is called the "forward" belt in Figure 1.

Figure 2 shows only the number of defensive systems in each belt; it does not show their locations. In this experiment, it is assumed that a large part of the enemy's movement of mechanized vehicles, troops, and supplies occurs along a single line of communication (LOC) which runs the length of the area of operations. Two typical

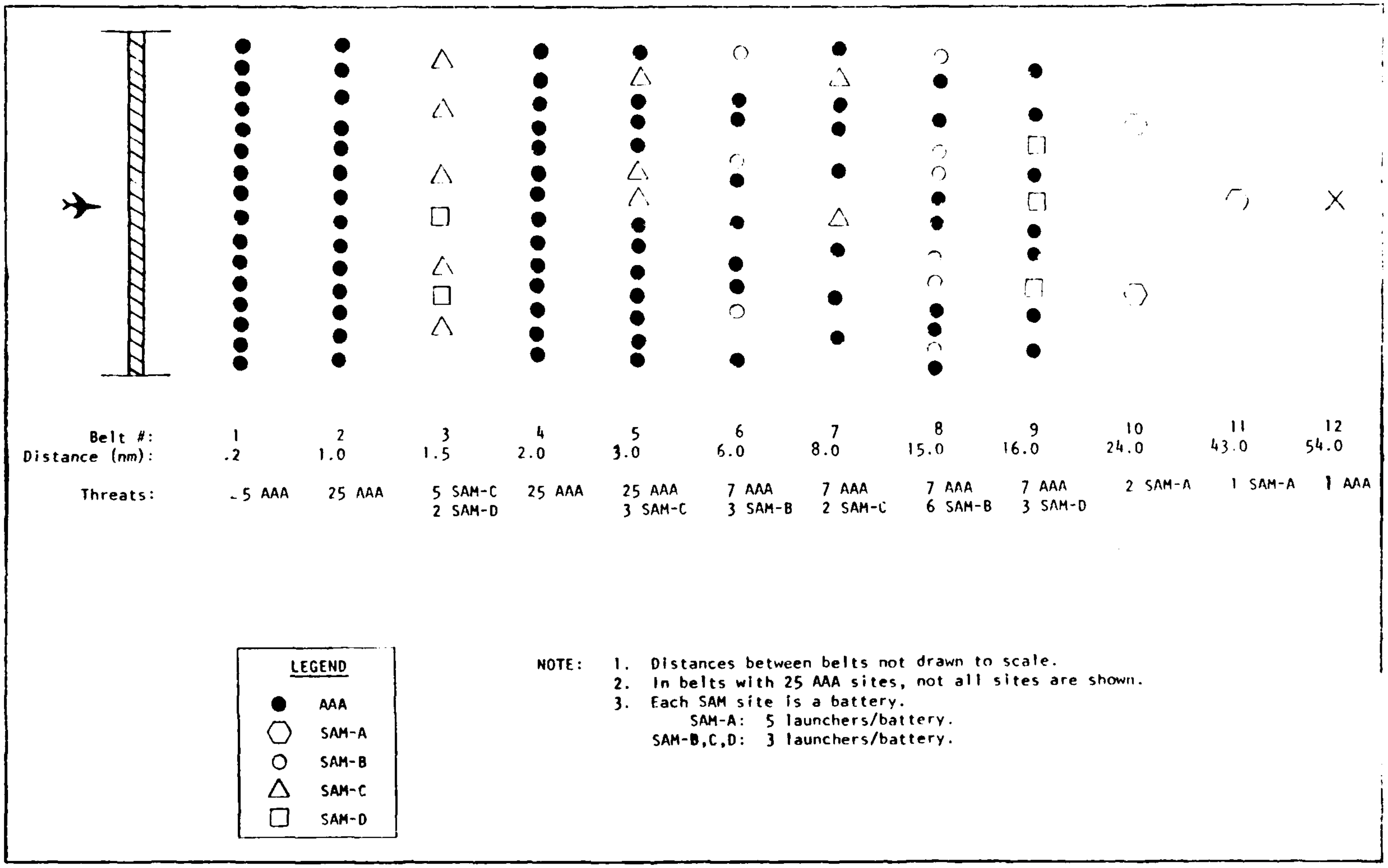


Figure 2. Structural Model

LOC's are shown in Figures 3 and 4. The tickmarks along the road networks in these figures represent the defensive weapon belts, while the "x" marks the target area. The weapons are spread laterally along each belt, but they are concentrated most heavily near the LOC. Note that the defensive belts in Figures 3 and 4 are drawn to scale; they are not drawn to scale in Figure 2.

The fighter can theoretically enter the FEBA at any point along its 27 NM front. In the model, however, it enters within a 3 NM corridor centered at the midpoint of the area of operations (that is, the entry point can be up to 1.5 NM either side of the midpoint).

Methodology

In order to analyze the fighter survivability problem, a computer simulation model was developed from the structural model, using the SLAM simulation language.

The lateral distribution of the defensive sites along each of the twelve belts in the computer model can be varied by specifying the midpoint and the standard deviation of the defenses in the belt. The mean point of the defenses in a belt is the point at which the primary LOC crosses the belt. Aircraft can enter the system at a variety of arrival intervals, airspeeds, and altitudes. Terrain is modeled as a probability of blockage - the rougher the terrain, the higher the probability that it will block a defensive system's shot at the aircraft.

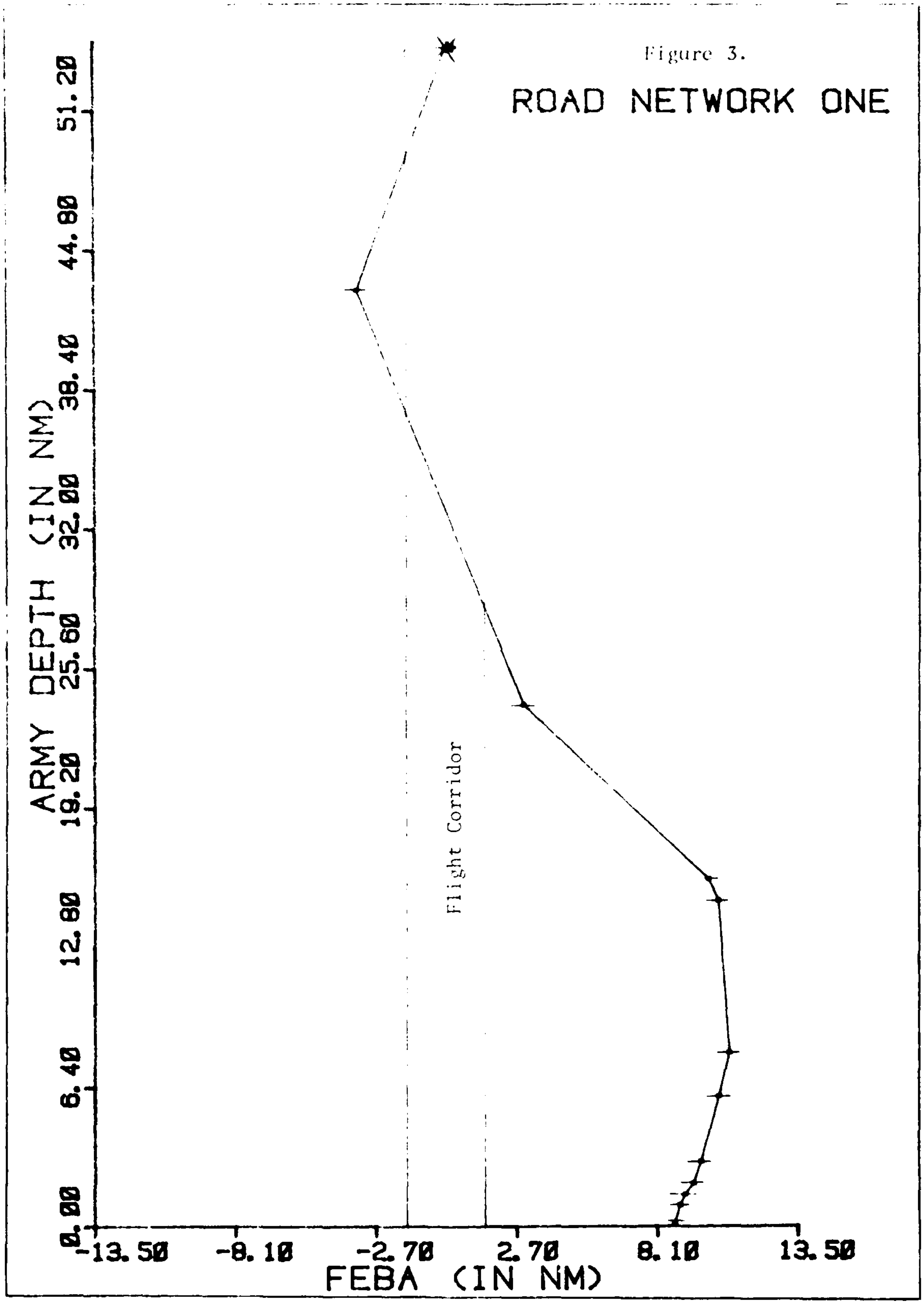

ROAD NETWORK ONE
Flight Corridor
ARMY DEPTH (IN NM)
0.00
6.40
12.80
19.20
25.60
32.00
38.40
44.80
51.20
FEBA (IN NM)
-13.50
-8.10
-2.70
2.70
8.10
13.50

Figure 3.

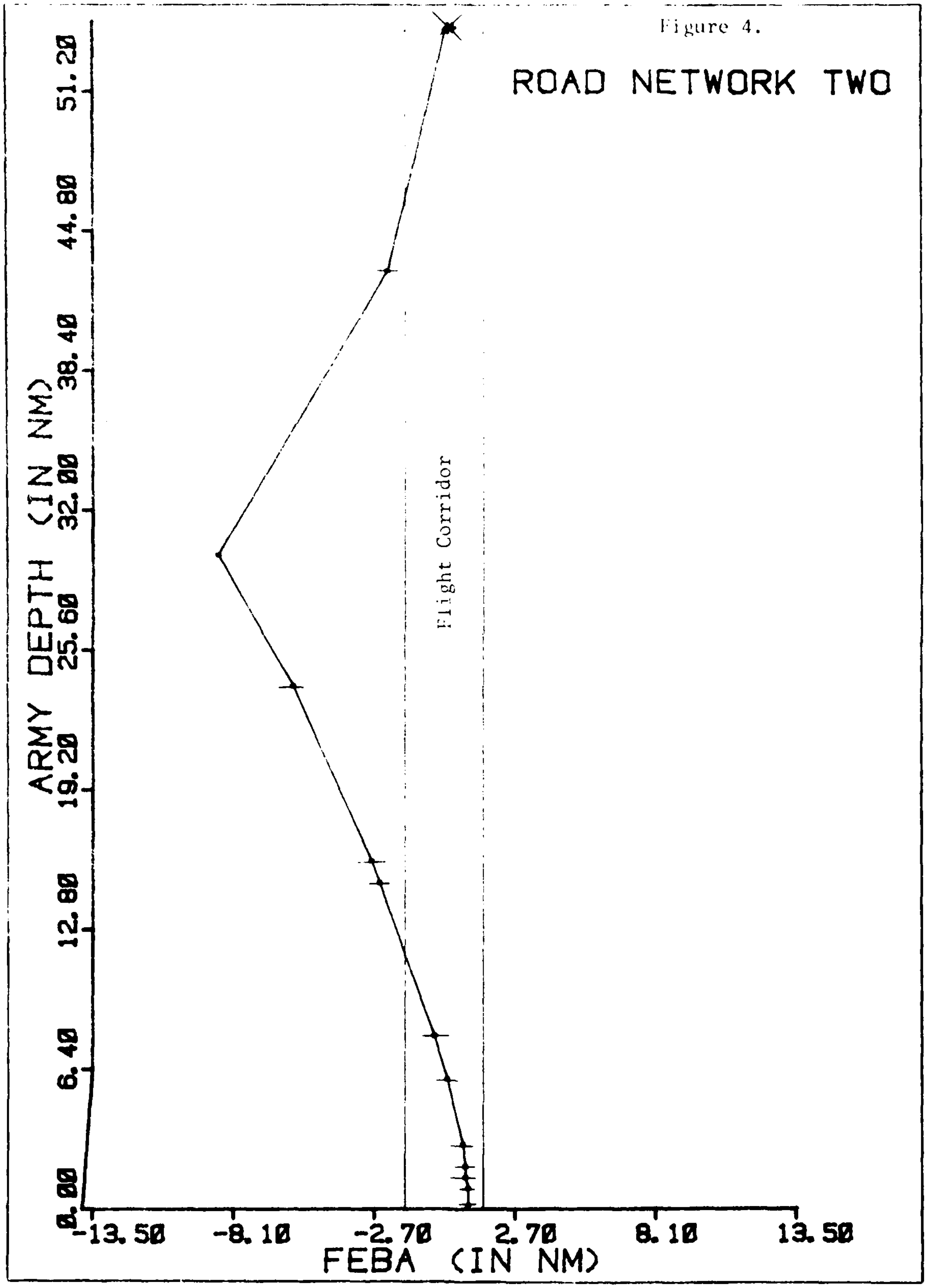


Figure 4.
ROAD NETWORK TWO
ARMY DEPTH (IN NM)
51.20
44.80
38.40
32.00
25.60
19.20
12.80
6.40
0.00
Flight Corridor
-13.50
-8.10
-2.70
2.70
8.10
13.50
FEBA (IN NM)

Defensive systems which shoot at an aircraft are tied up for a period of time following the shot; at the end of this period, they are released and allowed to engage other aircraft. The properties and capabilities of the model are discussed in more detail in Chapter III.

Overview

The remainder of this thesis explains in detail the simulation effort and the analysis of results. Chapter II discusses the components and concepts incorporated in the simulation model, while Chapter III discusses the model itself. In Chapter IV the data collection process and experimental design are discussed; the analysis of the data is discussed in Chapter V. Verification and validation of the model are discussed in Chapter VI. The overall results of the thesis effort are presented in Chapter VII. Finally, recommended areas for follow-on study are discussed in Chapter VIII.

II System Structure

The system structure is composed of four basic ingredients:

1. Characteristics of the offensive aircraft
2. Characteristics of the defensive weapons
3. Terrain
4. Command, Control, and Communications (C3) structure.

These factors are discussed in detail in the remainder of this chapter. Many of the concepts in the chapter are described in more detailed and specifi terms in Appendix K (SECRET).

Defensive System Envelopes

The defensive systems modeled have the maximum and minimum ranges shown in Table I.

The minimum altitude at which a SAM can engage an aircraft is determined by the multipath angle. The aircraft must be above the horizon by at least the distance subtended by the multipath angle at the aircraft's range, for the SAM to get a shot. If there are hills, trees, or any other high terrain between the SAM and the aircraft, a straight line between the SAM site and the terrain feature can be considered to define the

TABLE I

Range Envelopes of Defensive Systems.

	Minimum Range	Maximum Range
AAA	None	1.35 NM
SAM-A	2.7 NM	19.4 NM
SAM-B	4.3 NM	54 NM
SAM-C	2.2 NM	13.0 NM
SAM-D	1.1 NM	6.5 NM

"effective" horizon. Figure 5 shows an example of this principle for a SAM with a multipath angle of $.35^0$ engaging an aircraft 40,000 feet away, with a 500 foot hill halfway between the radar and the aircraft.

The terrain in this example essentially adds 1.43^0 to the multipath angle, or 1000 feet to the altitude which the aircraft must have in order to be seen by the radar. Thus the aircraft must be at least 1250 feet above ground level (AGL) for the SAM to have a shot.

In addition to the multipath angle, each SAM system has an absolute minimum altitude. Any aircraft below this altitude can not be shot down by the SAM. If the SAM system in the above example had a minimum altitude of 2000 feet, it could not shoot down any aircraft below that altitude. If, on the other hand, it had a minimum altitude of 1000 feet, the lowest altitude at which it could engage the aircraft would be 1250 feet AGL, as

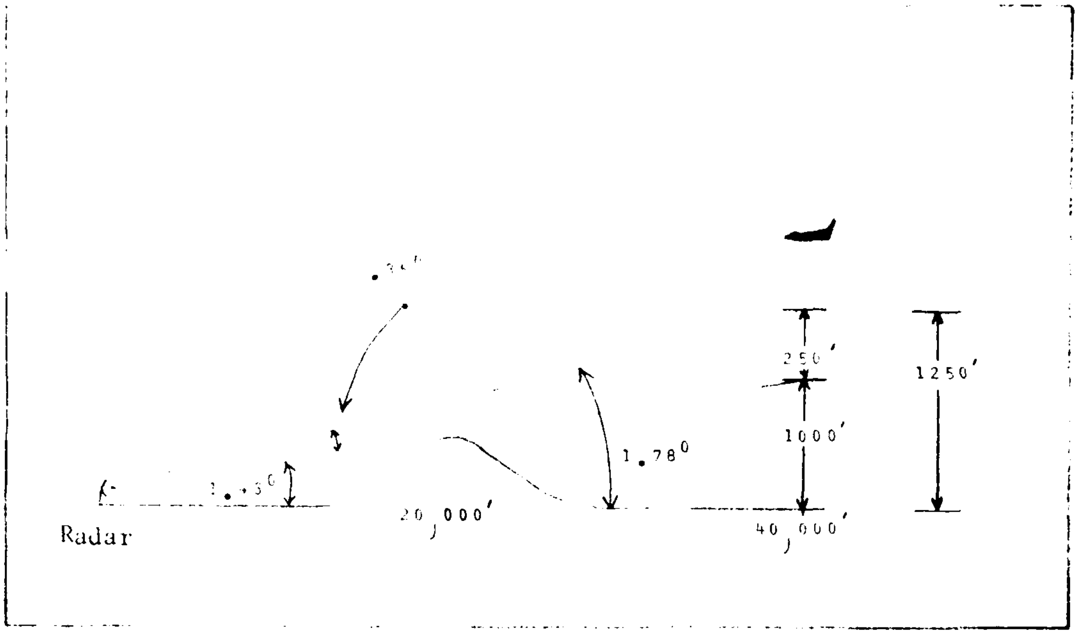


Figure 5. Terrain Blockage and Multipath Angle

computed previously.

The minimum altitudes and multipath angles for SAMs in the model are given in Table II.

TABLE II

Minimum Altitudes and Multipath Angles of Defensive Systems.

	Minimum Altitude	Multipath Angle
SAM-A	1000 feet	0.35°
SAM-B	330 feet	0.35°
SAM-C	75 feet	0.15°
SAM-D	60 feet	0.25°

Jammer Capability

The fighter in the model carries a repeater jammer which radiates power uniformly in all directions in the hemisphere below the aircraft. The effective radiated power (ERP) of the jammer against the target tracking radars of the threats in the model is shown in Table III.

TABLE III

Effective Radiated Power of Jammer Against Defensive Systems.

	ERP
AAA	1694 Watts
SAM-A	1694 Watts
SAM-B	914 Watts
SAM-C	914 Watts
SAM-D	914 Watts

Weapon System Capabilities Against an Aircraft with Jamming

The range at which a target tracking radar can pick up an aircraft is a function of the radiated power of the radar, the radar gain, the radar cross-section of the aircraft, the effective radiated power of the jammer, and the jamming-to-signal (J/S) ratio at which the radar operator is able to break through the clutter on his scope and lock on to the aircraft. All these terms are well defined except the J/S ratio, which can vary according to weather, operator proficiency, maintenance status of the equipment, and a number of other factors. A good rule of thumb, however, is that a J/S ratio of about 20 decibels (db) is required to jam most target tracking radars under most circumstances (Ref 4). As a result, it was assumed the target tracking radars of the weapon systems would be able to lock onto the aircraft as soon as a J/S ratio of 20 db or less was achieved. The formula for translating the J/S ratio into a range at which the aircraft enters the weapon system's lethal zone is

$$R = \sqrt{\frac{(J/S)\ Pr\ Gr\ \sigma t}{(4\pi)\ (ERP)j}} \qquad (1)$$

where

(J/S) = jamming-to-signal ratio (dimensionless)

R = maximum lethal range (in meters)

Pr = radiated power of the radar (in watts)

Gr = radar gain (dimensionless)

σt = radar cross-section (in square meters)

(ERP)j = radiated power of the jammer (in watts)

(Ref 3:101-102)

The above formula, expressed in decibels, is

$$Rdb = (1/2)\left[(J/S)db+(Pr)db+(\sigma t)db-(4\pi)db-(ERPj)db\right] \qquad (2)$$

The appropriate values for the defensive systems in the model are shown in Table IV.

TABLE IV

Values for Radar Range Equation

	(J/S)	Pr	Gr	4π	(ERP)j
AAA	20 db	123 kw (50.9 dbw)	40 db	11 db	1694 w (32.3 dbw)
SAM-A	20 db	600 kw (57.8 dbw)	31.7 db	11 db	1694 w (32.3 dbw)
SAM-B	20 db	100 kw (50 dbw)	42 db	11 db	914 w (29.6 dbw)
SAM-C	20 db	200 kw (53 dbw)	41 db	11 db	914 w (29.6 dbw)
SAM-D	20 db	100 kw (50 dbw)	43 db	11 db	914 w (29.6 dbw)

Substitution of the appropriate values in the radar range formula results in the following expressions:

AAA $$R_{dbm} = 34.3 + (1/2)\ (\sigma t)_{dbm^2} \qquad (3)$$

SAM-A $$R_{dbm} = 33.1 + (1/2)\ (\sigma t)_{dbm^2} \qquad (4)$$

SAM-B $$R_{dbm} = 35.7 + (1/2)\ (\sigma t)_{dbm^2} \qquad (5)$$

SAM-C $$R_{dbm} = 36.7 + (1/2)\ (\sigma t)_{dbm^2} \qquad (6)$$

SAM-D $$R_{dbm} = 36.6 + (1/2)\ (\sigma t)_{dbm^2} \qquad (7)$$

The ranges in decibel-meters, found in the preceding formulas, can be translated into ranges in meters by the following formula:

$$R = 10^{(Rdba/10)} \qquad (8)$$

The radar cross-section of the aircraft varies according to the aspect at which the radar is viewing the aircraft and the operating frequency of the radar. Because the target tracking radars of the AAA and the SAM-D operate at close to the same frequency, they will see equal cross-sections at a given aspect. The SAM-B and SAM-C can be grouped together for the same reason. Table V shows the radar cross-sections of the fighter, at various aspects, for all five weapon systems. A 0^0 aspect equates to a head-on view, a 90^0 aspect to a side profile, and a 180^0 aspect to a tail view.

Table VI shows the maximum range at which the aircraft is within the lethal zone (J/S of 20 or greater) for each weapon system for various aspects. These values were computed by using equations (3) through (8) in the RANGES computer program (Appendix C). Note that, in many cases, the range falls inside the minimum range of the weapon system. This indicates that the weapon system has no capability against the aircraft at that aspect. At some aspects, the maximum range given in Table VI is greater than the maximum range of the weapon system given in Table I; in these cases, the value in Table I applies.

The circular error probable (CEP) is a sphere around the aircraft, within which 50% of the missiles fired under a given set of conditions will detonate. The lethal

TABLE V

RADAR CROSS-SECTION OF FIGHTER AGAINST DEFENSIVE SYSTEMS.

RADAR CROSS-SECTION (IN DBM)

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.	4.50	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.	20.83	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

Table VI

Maximum Ranges at Which a J/S Ratio of 20 or Above is Obtained

DETECTION RANGE (IN NM)

ANGLE (DEGREES)	AAA	SAM-A	SAM-B	SAM-C	SAM-D
0.	[illegible].74	[illegible].30	3.04	3.82	5.79
5.	3.14	1.90	2.10	2.64	4.87
10.	1.81	1.88	2.69	3.39	2.80
15.	2.17	.84	2.84	3.58	3.36
20.	1.60	1.92	2.44	3.07	2.48
25.	2.29	1.51	2.68	3.37	3.55
30.	2.64	1.27	6.84	8.61	4.10
35.	1.27	.91	5.01	6.31	1.96
40.	1.77	1.41	2.98	3.76	2.74
45.	[illegible].02	1.89	3.07	3.87	4.68
50.	2.08	1.35	1.80	2.26	3.22
55.	1.63	1.25	1.86	2.34	2.53
60.	1.81	.70	1.80	2.26	2.80
65.	1.50	1.16	2.02	2.54	2.32
70.	3.73	3.19	5.31	6.68	5.78
75.	6.82	5.36	10.71	13.49	10.56
80.	9.94	5.51	13.18	16.59	15.39
85.	9.25	7.27	12.66	15.94	14.33
90.	24.06	21.62	35.59	44.81	37.27
95.	13.30	12.20	19.95	25.11	20.60
100.	9.80	7.80	12.30	15.48	15.18
105.	2.84	2.48	5.79	7.28	4.40
110.	4.34	3.41	5.48	6.90	6.72
115.	2.97	1.35	3.05	3.84	4.60
120.	3.59	1.01	2.62	3.30	5.56
125.	2.38	1.07	2.88	3.62	3.68
130.	2.17	.84	2.84	3.58	3.36
135.	2.40	1.11	1.77	2.23	3.71
140.	2.28	.95	1.49	1.87	3.53
145.	2.90	.89	2.13	2.68	4.49
150.	2.65	1.52	2.14	2.69	4.11
155.	3.23	2.34	2.11	2.65	5.00
160.	2.04	1.17	2.14	2.70	3.16
165.	2.51	1.17	4.18	5.26	3.88
170.	4.56	1.78	4.25	5.36	7.06
175.	6.88	1.88	5.56	7.00	10.65
180.	8.22	1.23	5.98	7.52	12.73

radius (LR) is that distance from the SAM detonation within which as many aircraft survive as are killed by detonations beyond it. It is a function of both the type missile and the type aircraft. The lethal radius concept allows the model to assume a "cookie cutter" approach in that all aircraft within the lethal radius will be killed and all aircraft beyond it survive. The lethal radius of each of the SAM systems in the model, with respect to the fighter modeled, is given in Table VII.

TABLE VII

Lethal Radii of SAM Systems

	Lethal Radius
SAM-A	185 feet
SAM-B	143 feet
SAM-C	86 feet
SAM-D	72 feet

The probability of kill is related to both the CEP and the lethal radius by the following formula:

$$Pk = 1 - .5^{(LR/CEP)^2} \quad (9)$$

The specific capabilities of the five defensive systems in the model are described in the remainder of this sub-section.

SAM-A. The kill zone (the area in which the J/S ratio is 20 db or less) of the SAM-A is shown in Figure 6. Note that, with the exception of small "spikes" near the 0^0 and 155^0 points, the entire kill zone lies within a narrow band near the 90^0 aspect angle. The target tracking radar can not begin tracking the aircraft until it reaches the leading edge of the kill zone, and, because the missile is command guided, it must reach the aircraft before it is masked by jamming at the trailing edge of the kill zone.

As stated previously, the Pk outside the kill zone is zero. Within the kill zone, the CEP is related to the J/S ratio at the time of intercept by the following formula:

$$CEP = \sqrt{.0000252\ (J/S)\ R^2 + 9610\ (J/S) + 671} \qquad (10)$$

where R is in meters, and

(J/S) is a real number (not in decibels).

Obviously, the lowest CEPs will result when the aircraft is close to the SAM site and the aspect is 90^0 (maximum radar cross-section, minimum J/S ratio). However, an intercept at the 90^0 point will never occur with the SAM-A because of the narrow kill zone. Engagements will occur near the trailing edge of the kill zone, if they occur at

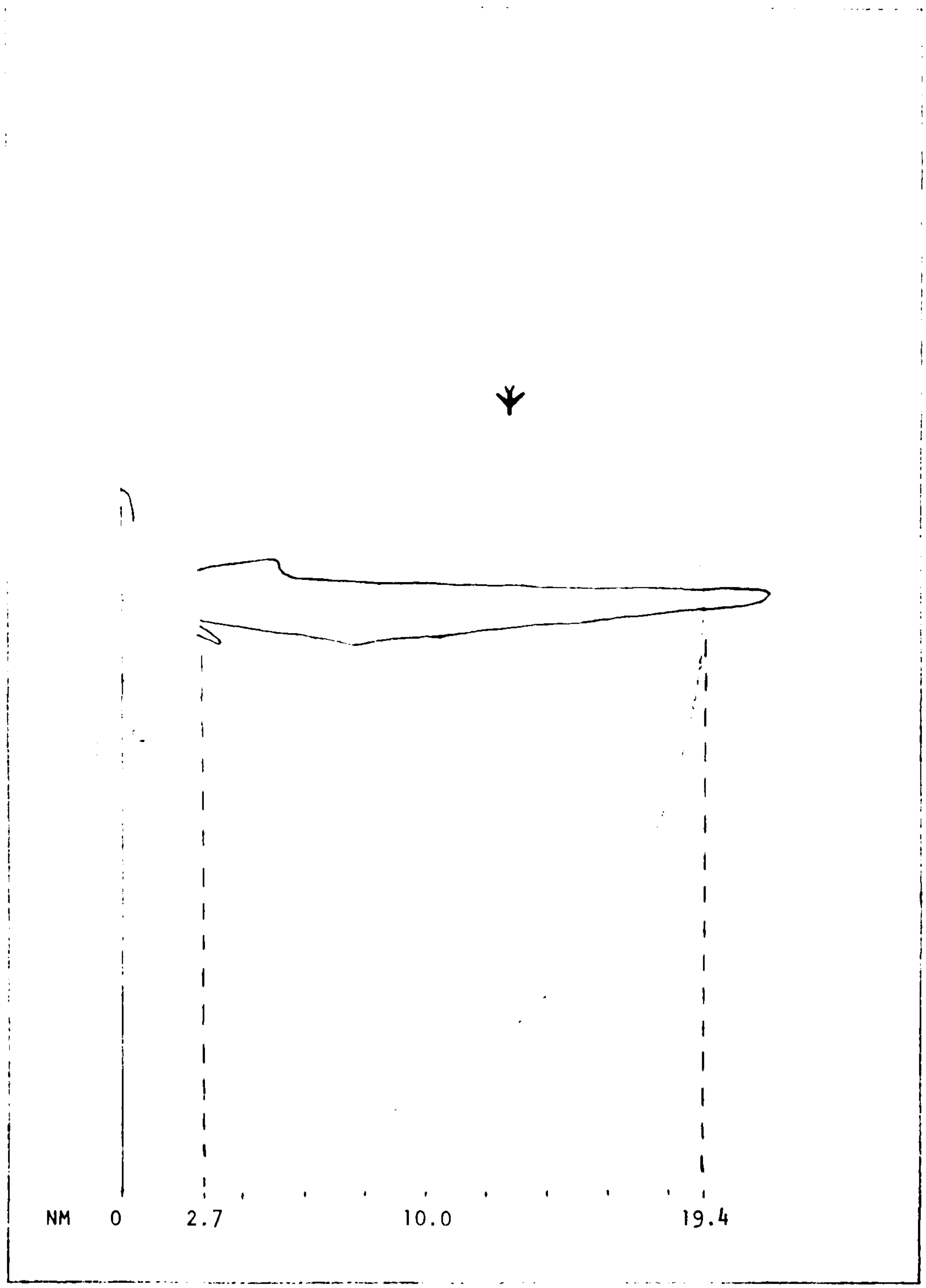


Figure 6. Lethal Envelope of SAM-A

all.

SAM-B . The kill zone of the SAM-B is shown in Figure 7. While the missile has a maximum range of about 54 NM, it is shown out to only 20 NM because the kill zone becomes too narrow for the missile to have a chance of intercepting an aircraft beyond that range. The "spikes" at the 30^0 and 180^0 aspects are too small to give the SAM-B a shot at the aircraft. Thus the kill zone is restricted to the band near the 90^0 aspect. The CEP for the SAM-B is computed using the formula:

$$CEP = \sqrt{.00000562\ (J/S)\ R^2 + 2500\ (J/S) + 232} \qquad (11)$$

SAM-C . The kill zone of this missile is shown in Figure 8. The CEP of the missile is determined by the formula:

$$CEP = \sqrt{(.00000071)\ (J/S)\ R^2 + 2200\ (J/S) + 58} \qquad (12)$$

Unlike the SAM-A and SAM-B, the SAM-C appears to have a significant chance of killing the aircraft at aspects other than those near the 90^0 point; the spikes near 25^0 and 180^0 look particularly promising. The 25^0 spike is the longer of the two; however, an aircraft entering this area would be well past the 25^0 point before a missile could reach it, even with minimum reaction times. Since the radar cross-section in the 30^0-40^0 region (where the

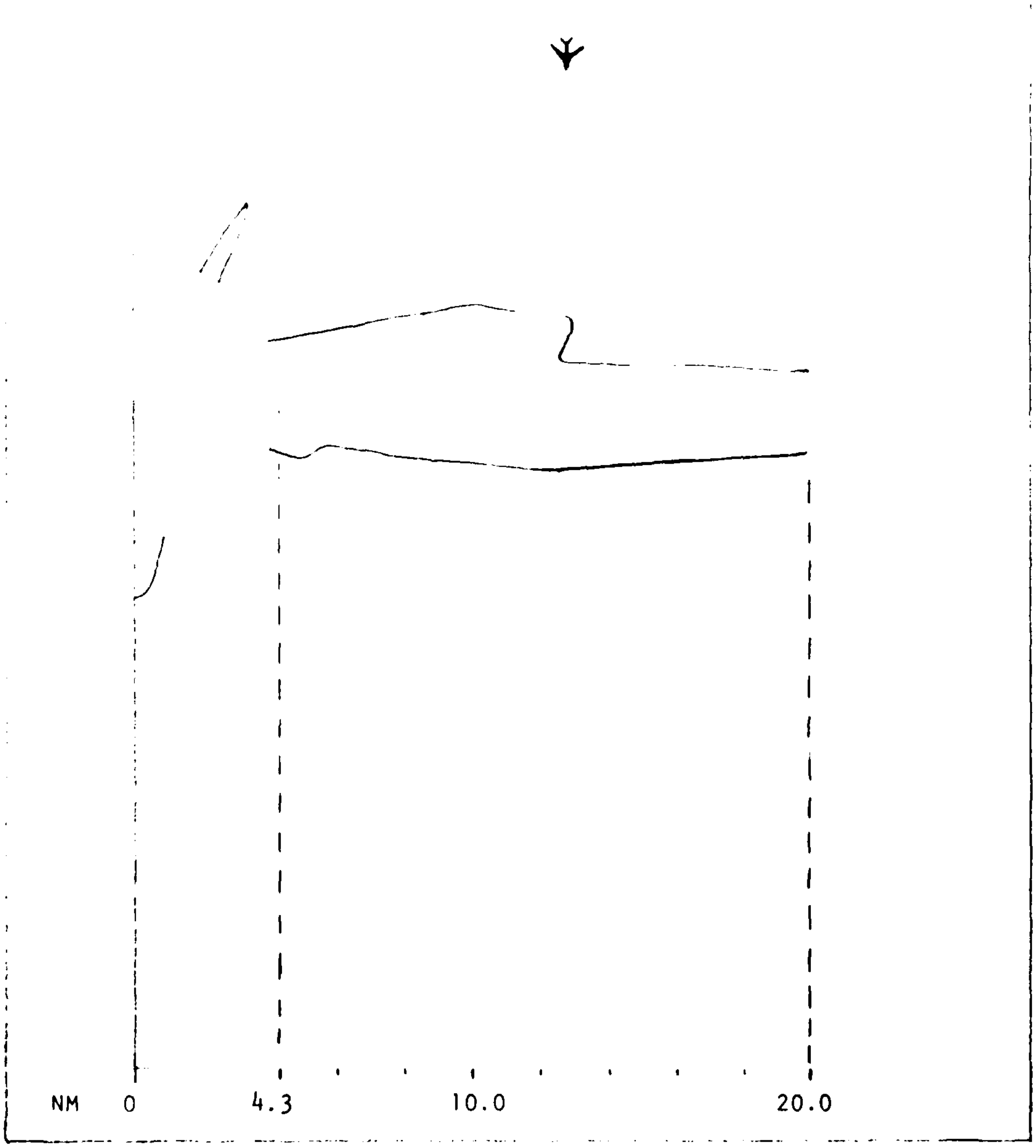


Figure 7. Lethal Envelope of SAM-B

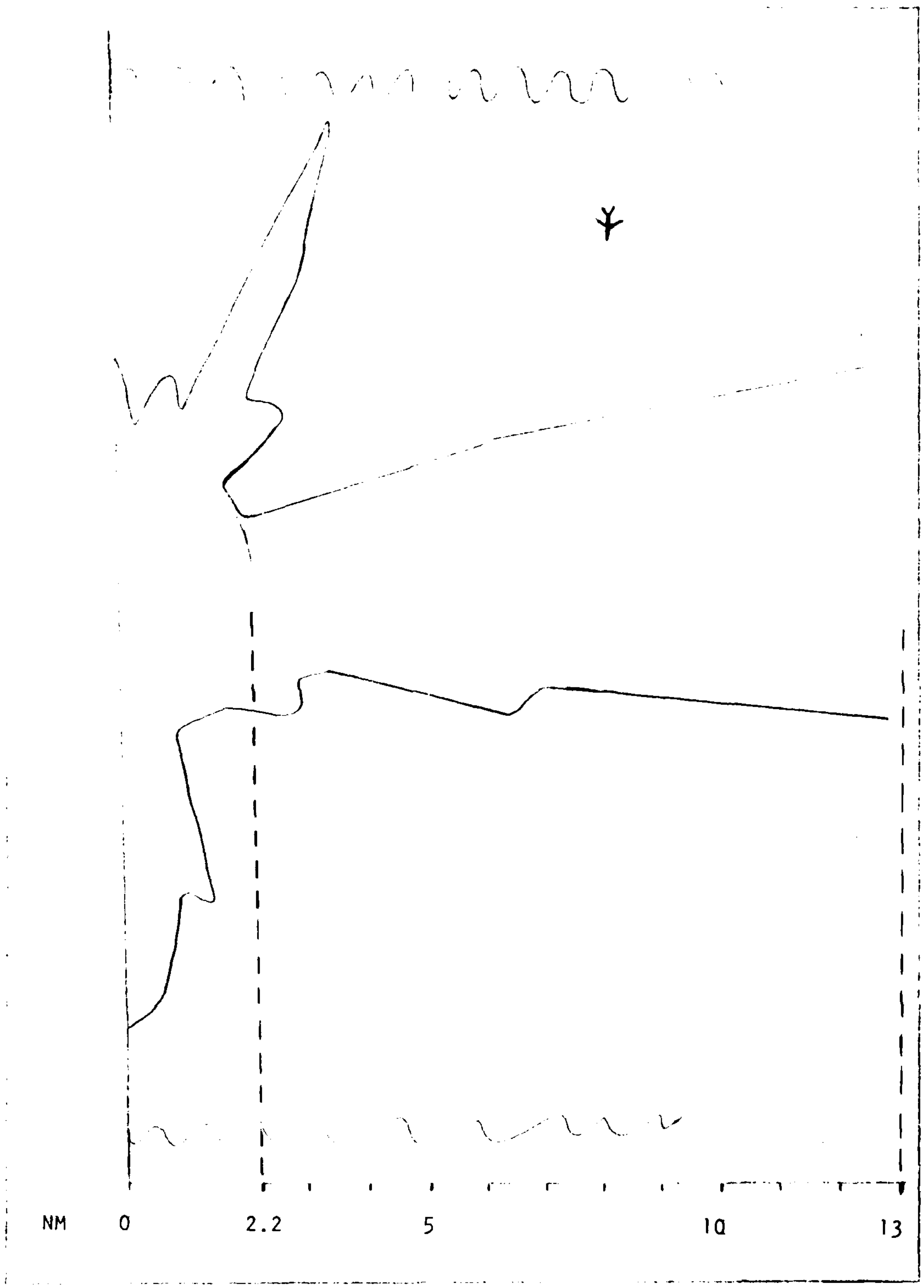


Figure 8. Lethal Envelope of SAM-C

intercept would occur even under the most favorable conditions for the SAM) are less than those at the 180° point, an intercept at the 130° point was investigated.

For the 180° intercept, the missile would be able to fire two seconds (minimum lock-on time) after the aircraft reentered the kill zone at 2.2 NM. The range of the aircraft at the time the missile is fired, assuming an aircraft velocity of 480 knots, is

$$Rf = 2.2 + (480\ NM/hr)\ (hr/3600\ sec)\ (2\ sec)$$
$$= 2.467\ NM.$$

The point of intercept was computed iteratively, using the formula

$$R = 3600\ (Re - Rf)\ /\ (TAS)\ (Tf) \qquad (13)$$

where

R = range to intercept (in NM)

Re = estimated range to intercept (in NM)

Rf = range of aircraft when missile is fired (2.466 NM)

Tf = missile flyout rate (in sec/NM)

TAS = aircraft velocity (in knots)

3600 = conversion factor (knots to NM/sec).

The final iteration yielded

$$R = 3600\ (4.20 - 2.467)\ /\ (480)\ (3.09) \quad = 4.20\ NM.$$

Thus the engagement occurs at 4.20 NM for an aircraft travelling at a velocity of 480 knots. This range equates to 7778 meters, or 38.9 dbm. The J/S ratio for a SAM-C target tracking radar looking at the tail of the aircraft at this range is

$$J/S = (ERPj)\ (4\pi)\ R^2\ /\ Pr\ Gr\ \sigma t$$

OR

$$(J/S)db = (ERPj)db + (4\pi)db + 2(R)dbm - (Pr)db - (Gr)db - (\sigma t)dbm$$

$$= 29.6 + 2(38.9) - 53 - 41 - 9.48$$

$$= 14.92\ db$$

$$J/S = 10^{(14.92/10)} = 31.05$$

The CEP is

$$CEP = \sqrt{(.00000071)(31.05)(7778)^2 + (2200)(31.05) + 58}$$

$$= 264\ m.$$

$$= 866\ ft.$$

The probability of kill is

$$Pk = 1 - .5^{(86/866)^2}$$

$$= .007$$

Since this is the best shot that the SAM-C can expect to get against any aircraft that pass inside 2.2 NM lateral range of the missile site, the enemy doctrine modeled dictates that the SAM-C only shoots at aircraft that pass at a lateral range of 2.2 NM or more.

SAM-D. The kill zone is shown in Figure 9. The CEP is determined by the formula

$$CEP = \sqrt{.000000325\ (J/S)\ r^{2} + 1890\ (J/S) + 25} \qquad (14)$$

Like the SAM-C, the SAM-D appears to have a significant chance of killing the aircraft at a wide variety of aspects. The most promising are the head-on view (0^{0} aspect) and the rear view (180^{0} aspect).

For the head-on view, the shot was assumed to be timed so that the intercept would occur just as the missile reached the minimum range of 1.1 NM (2037 meters or 33.1 dbm). The calculations for this shot are shown below:

$$(J/S)db = 29.6 + 11 + 2(33.1) - 50 - 43 - 8.2$$

$$= 5.6\ db$$

$$J/S = 3.63$$

$$CEP = \sqrt{.000000325\ (3.63)\ (2037)^{2} + 1890\ (3.63) + 25}$$

$$= 83\ m.$$

$$= 272\ ft.$$

$$Pk = .5^{(72/272)^{2}}$$

$$= .047$$

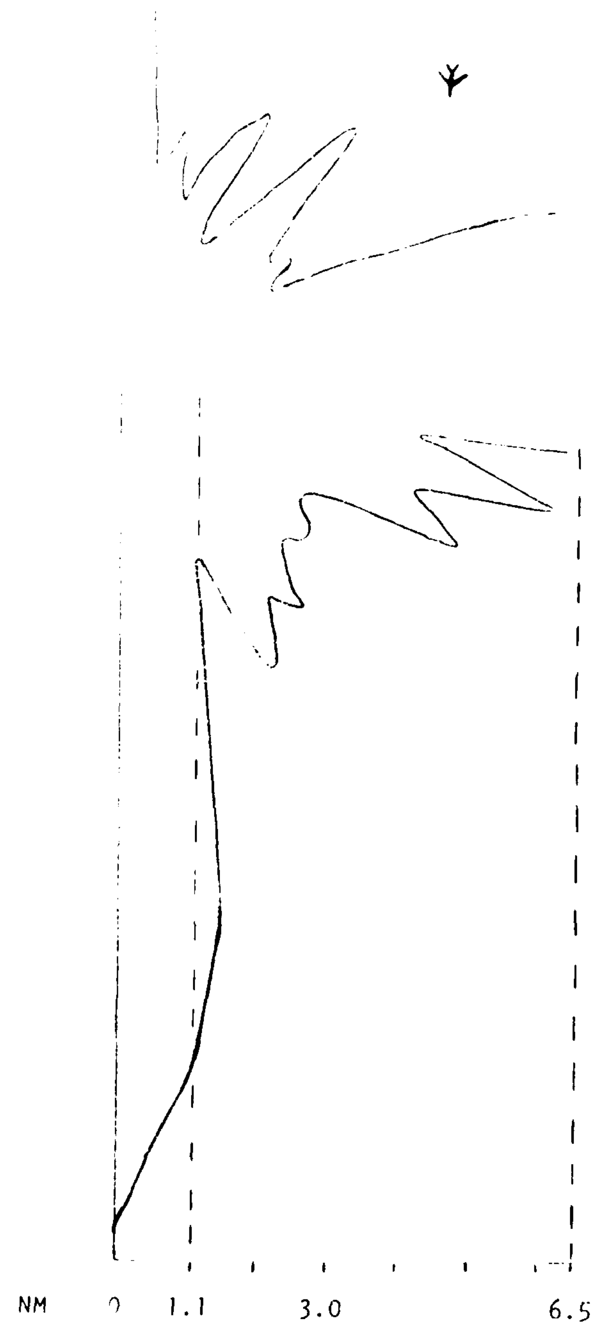


Figure 9. Lethal Envelope of SAM-D

Solving in a similar manner for an aircraft at a 5° aspect (approximately .1 NM lateral displacement at the engagement range of 1.1 NM), a Pk of .033 was obtained. For aspects of 10° or more, the Pk's are too low to make the shot worth taking.

For the rear view, the missile was assumed to be able to fire two seconds (minimum lock-on time) after the aircraft reentered the kill zone at 1.1 NM. This problem was solved iteratively using equation (13); however, in this case

$$Rf = 1.1 + (480\ NM/hr)\ (hr/3600\ sec)\ (2\ sec)$$
$$= 1.367\ NM$$

assuming the aircraft has a velocity of 480 knots. The final iteration yielded:

$$R = (2.58-1.367)(3600)\ /\ (480)(3.53) = 2.58\ NM.$$

Thus the intercept occurs at 2.58 NM for an aircraft travelling at a velocity of 480 knots. This range equates to 4778 meters or 36.8 dbm. The calculations for this shot are shown below:

$$(J/S)db = 29.6 + 11 + 2(36.8) - 50 - 43 - 15.05$$
$$= 6.15\ db$$
$$J/S = 4.12$$
$$CEP = \sqrt{.000000325\ (4.12)\ (4778)^2 + (1890)\ (4.12) + 25}$$
$$= 88.6\ m$$
$$= 291\ ft$$

$$Pk = 1 - .5^{(72/291)^2}$$

$$= .941$$

The above result is extremely sensitive to the aircraft's lateral displacement from the SAM-D site. An aircraft displaced only .2 NM from the site will have a 175° aspect rather than a 180° aspect at the time of intercept, and the Pk will drop to .029. An aircraft displaced .4 NM has a 170° aspect and a Pk of .013.

For an aircraft flying at 540 knots, the final iteration yielded an intercept range of 2.98 NM (5526 meters or 37.4 dbm). This range resulted in

J/S = 7.35

CEP = 388 feet

Pk = .023

for a direct tail shot and correspondingly lower Pk's for lateral displacements that denied the gunner a direct tail shot. The results of the above calculations are summarized in Table VIII.

TABLE VIII

Probability of Kill for SAM-D Site Within .2 NM of the Site.

Lateral Displacement	TAS	Best Shot	Pk
0.0 NM	480/540	Frontal	.047
0.1 NM	480/540	Frontal	.033
0.2 NM	480	Rear	.029
0.2 NM	540	Rear	.023

Beyond .2 NM lateral displacement, the Pk's fall below 2%, which is the minimum Pk at which the missile is allowed a shot according to the C3 assumptions of the experiment. The C3 structure is explained later in this chapter. The coverage of the SAM-D falls into three regions, as shown in Table IX:

TABLE IX

Engagement Parameters of the SAM-D.

Lateral Displacement	Aspect at Which Shot is Taken
0 - .2 NM	Front or Rear
.2 - 1.1 NM	None
1.1 - 6.5 NM	Side

AAA. The maximum detection ranges of the AAA lie well outside the lethal envelope of the gun itself, with the exception of a small band at the 35° aspect angle. As with the SAMs, these ranges assume the J/S ratio must be less than 20 db for the tracking radar to lock on to the aircraft. Because the AAA radar can see the aircraft well before it enters the lethal envelope, it is assumed that the AAA can engage any aircraft that is within its lethal envelope.

The lethal envelope of the AAA is shown in Figure 10, with the points at which the AAA gunner is expected to attempt to engage an incoming aircraft indicated by the heavy line. If the aircraft passes the AAA site at close enough a range, it is assumed that the gunner will attempt to engage it at a slant range of about 3000 feet. This allows him to avoid the mechanical difficulties associated with tracking an aircraft moving at a high angular velocity overhead. Once the 3000 foot ring reaches a 45° aspect, however, the gunner is dealing with an aircraft moving at a high angular velocity in the horizonal plane. Therefore the gunner is expected to attempt to engage the aircraft along the 45° line until the maximum range of the gun is reached. If an aircraft passes the 45° line outside the AAA's lethal range, the gunner will shoot as soon as the aircraft hits the maximum lethal range of 8200 feet.

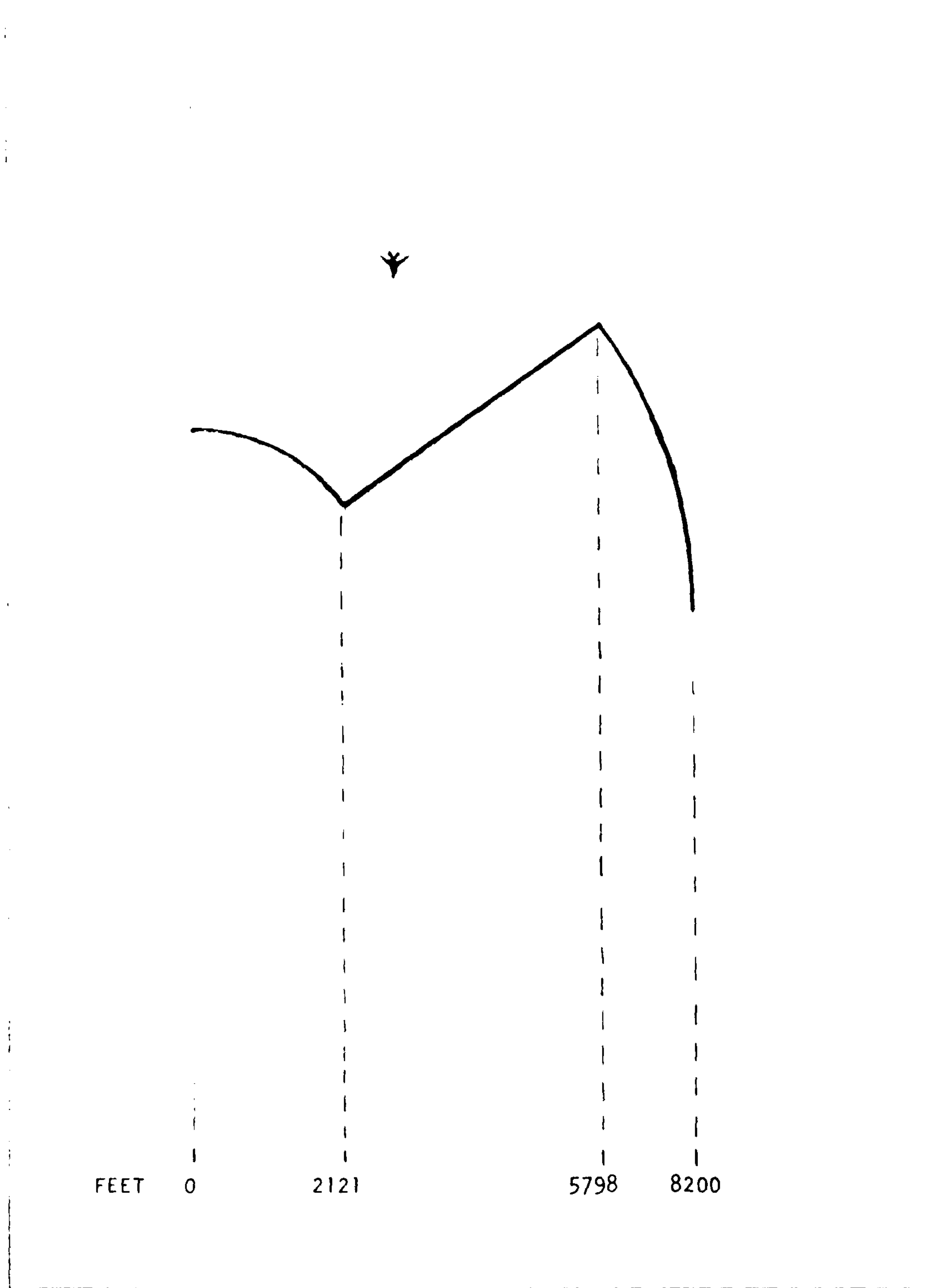


Figure 10. Lethal Envelope of AAA

To determine a Pk for the AAA, it is necessary to first determine the velocity of the bullet at the time of intercept. This is determined by the equation

$$Vf = Vi\ e^{-(p\ Cd\ A\ R/\ 2\ m)} \qquad (15)$$

where

Vf = intercept velocity

Vi = muzzle velocity (3050 ft/sec for the AAA)

p = air density (.002378 slugs/cu ft)

Cd = drag coefficient (.38 is a good average value)

A = cross sectional area (.004477 sq ft for the AAA)

R = intercept range (in thousands of feet)

m = mass of the bullet (.43 pounds for the AAA)

(Ref 2:32).

When the above values are used in equation (15), it reduces to

$$Vf = 3050\ e^{-.1513\ R} \qquad (16)$$

Once the velocity of the bullet at intercept is known, the time of flight of the bullet can be calculated by the equation

$$TOF = \frac{2\ m}{p\ Cd\ A}\left(\frac{1}{Vf} - \frac{1}{Vi}\right) \qquad (17)$$

where TOF is the time of flight in seconds, and all other values are the same as they were defined previously (Ref

2:34). When the appropriate values are used in equation (17), it reduces to

$$TOF = (6601.76/Vf) - 2.1645 \tag{18}$$

Once the bullet time of flight has been determined, the single shot probability of kill can be computed using the equation

$$Pkss = \frac{A_v}{2\pi\sigma^2 + A_v} e^{\frac{-.5(32.2g)(TOF)^2}{2\pi\sigma^2 + A_v}} \tag{19}$$

(Ref 7:98)

Av is the vulnerable area of the fighter and is determined by the formula

$$Av = (PA)\ (\%VA) \tag{20}$$

where

PA = presented area (total area exposed to the gun)

%VA = percentage of the presented a... that will result in a kill of the aircraft if hit.

The PA varies according to the aspect at which the gun site is viewing the fighter, but a good average figure for the fighter in the model is 265 square feet. Similarly, the %VA varies with aspect, but 21% can be used as an average figure. Thus

$$Av = (265)\ (.21)$$

$$= 55.65 \text{ sq ft}$$

for the fighter in the model.

σ is the mil dispersion of the gun. A one mil dispersion produces up to one foot of error for each thousand feet of range between the gun and the target. A reasonable estimate of a value of for the AAA under combat conditions is 20 mils. Thus

$$\sigma = 20 \, R$$

for the AAA, since R is expressed in thousands of feet (at a range of 2500 feet, R = 2.5).

The term g is the number of "g"s being pulled by the pilot at the time the bullet is fired. All other terms in equation (20) are as defined previously.

When the appropriate values are used in equation (19), the equation becomes

$$Pkss = \frac{55.65}{2\pi(20R)^2 + 55.65} \, e^{\frac{-16.1g \, (TOF)^2}{2\pi(20R)^2 + 55.65}} \qquad (21)$$

Finally, the overall Pk for a burst from the AAA is found using the formula

$$Pk = 1 - (1 - Pkss)^n \qquad (22)$$

where n = number of rounds fired in the burst.

In this experiment, the gunner is assumed to always shoot a 50 round burst (about 2/3 of a second). This is tactically sound because longer bursts will heat up the barrels and do permanent damage to the gun. Thus

$$P_K = 1 - (1 - P_{KSS})^{50} \quad (23)$$

Engagement Times for Weapon Systems

All the SAM's in the model must go through four distinct stages in order to engage an aircraft. At the end of the fourth stage they are ready to engage the next aircraft. The stages are listed below:

1. Target acquisition.
2. Tracking and missile firing.
3. Missile flyout time (the SAM operator must monitor and guide the missile until it either hits or misses the target).
4. Confounding delay (all delays associated with getting the launchers and radars ready for the next target).

The AAA goes through the same stages except the flyout time stage. Once the bullets have left the muzzle, the gunner has no control over them and thus does not need to monitor them.

The times associated with the above four stages are given in Table X.

TABLE X

Times Required for AAA and SAM Operations.

	Acquisition		Track / Fire		Flyout Time	Confounding Delay
	min	max	min	max		
AAA	-	-	6 sec	25 sec	-	30 sec
SAM-A	14 sec	47 sec	4 sec	4 sec	3.13 sec/nm	13 sec
SAM-B	10 sec	22 sec	2 sec	4 sec	2.44 sec/nm	15 sec
SAM-C	15 sec	30 sec	2 sec	3 sec	3.09 sec/nm	30 sec
SAM-D	8 sec	20 sec	2 sec	3 sec	3.53 sec/nm	30 sec

The acquisition time of the AAA is included in the track/fire column in Table X.

Because the jammer concentrates its effort on the target tracking radars, the acquisition radars of the weapon systems are assumed to be locked on to the aircraft by the time it reaches the leading edge of the kill zone. Thus the missile has a shot at the aircraft if the sum of the tracking/firing time and the missile flyout time is less than or equal to the time during which the aircraft is in the kill zone.

For example, a SAM-C firing against a 480 knot aircraft whose displacement from the missile site is 5 NM at the point of closest approach can get a missile out to the aircraft in a minimum of

$$2 + 3.09 (5) = 17.45 \text{ sec}$$

and a maximum of

$$8 + 3.09\ (5) = 23.45 \text{ sec.}$$

The aircraft will be in the kill zone for about 3.8 NM, or 28.5 seconds, so the missile will have a shot at the aircraft. If the missile is launched in the minimum time, the aircraft will be 2.3 NM past the leading edge of the kill zone and its aspect will be 97° at the time of intercept. If the missile is launched at the maximum time, the aircraft will be 3.1 NM past the leading edge and its aspect will be 105°. The Pk of the missile would be lower in the latter case because of the higher J/S ratio at this aspect.

After firing, the missile site remains tied up until the end of its confounding delay. After the confounding delay, it is ready to acquire another aircraft. Thus the site is unable to track and fire at another aircraft until a time period equal to the sum of the confounding delay and acquisition time has passed.

The SAM-C mentioned above will be able to begin tracking another aircraft in a minimum of

$$30 + 15 = 45 \text{ seconds}$$

and a maximum of

$$30 + 30 = 60 \text{ seconds}$$

after the previous missile has reached its target aircraft.

Terrain

The terrain in the area modeled consists of rolling farmland mixed with thick forests. Figure 11 shows the probability of a clear line of sight existing between the weapon site and the target aircraft in this type of terrain (Ref 1:48). The probability of a clear line of sight is a function of the aircraft's altitude and the ground range from the weapon site to the aircraft. The data in Figure 11 is translated into a series of mathematical approximations in the computer model.

Command, Control, and Communications

The AAA's are assumed to operate relatively antonomously and will be allowed to shoot at any aircraft that come within their lethal envelopes. However, in an effort to keep all of them from getting tied up on the first aircraft that they see, only the five guns with the highest Pk in a given belt are allowed to shoot at any particular aircraft. The SAM's will be subject to more rigorous control and will not be allowed to engage an aircraft unless their probability of killing the aircraft is sufficiently high. In this model a Pk of .02 has been used as the cut-off point; if the Pk is computed to be less than .02, the missile will not fire. Only two

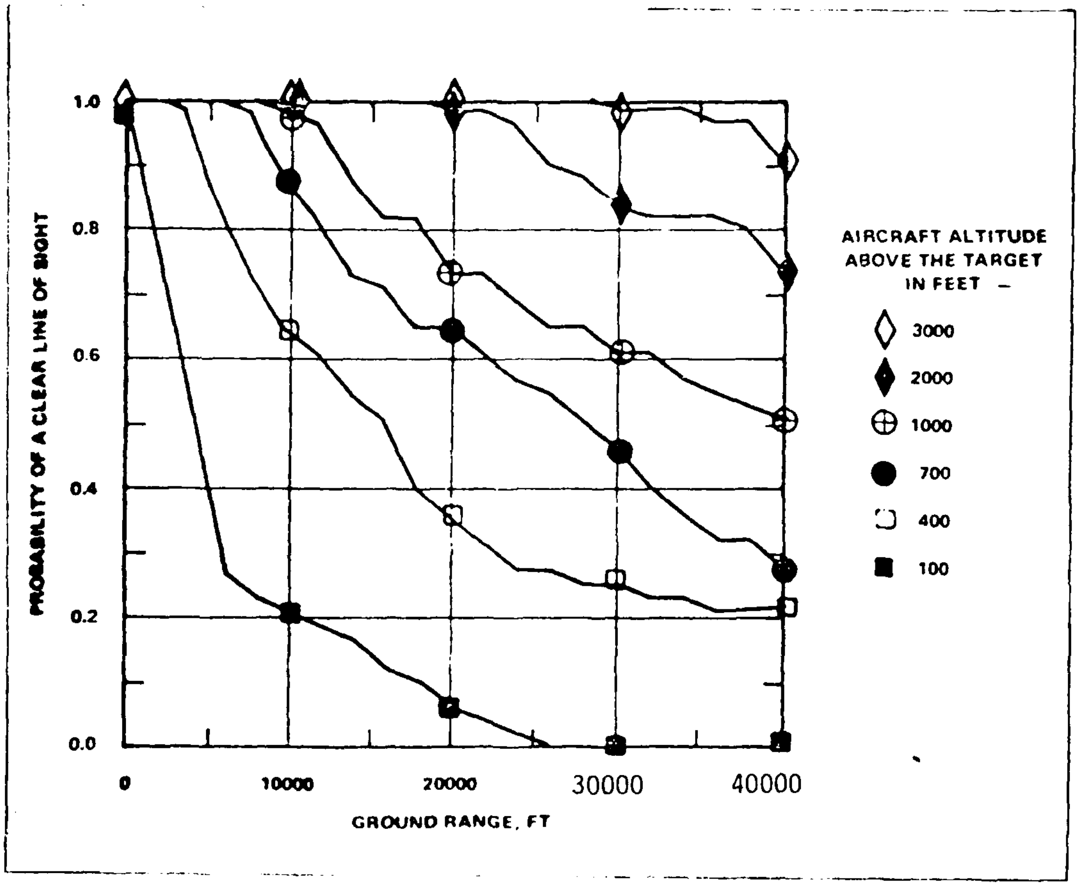


Figure 11. Terrain Blockage Data for Rolling Farmland with Thick, Close-in Forests

missile sites from any given belt are allowed to fire at the same aircraft.

Summary

This section has discussed the characteristics of the offensive aircraft and defensive weapons which comprise the system structure of the model. It has also outlined the terrain and C3 features which influence the interactions between the aircraft and the defenses. The following chapter discusses the specific steps accomplished in creating a computer model of the system.

III Simulation Model

The night interdiction problem was modeled into the SLAM network shown in Appendix A. The network merely routes the aircraft through the army area, ultimately sending each aircraft to a "kill" node if it is shot down, or a "survive" node if it successfully negotiates the defensive array. The major portion of the modeling effort is contained in a series of discrete subroutines; some of these are called by the network, while others are called by other subroutines. The network and subroutines are described in more detail in the following subparagraphs.

Network

A total of 20 aircraft enter the network, representing the commitment of roughly a squadron of aircraft to the target complex. The time between entries is set at one of two values. When the first aircraft enters the system at a time of zero, it is routed to event node 1, which fixes the positions of all the defensive sites. These positions remain fixed for the remainder of the run. All the remaining aircraft bypass event node 1.

Each fighter crosses the FEBA as it enters the network. At .2 NM after entering, it encounters the first belt of threats, consisting of 25 AAA sites. Event node 2 determines which AAA sites shoot at the aircraft and whether it is killed. If it is killed, ATRIB(7), the kill status variable, is set equal to zero, and the aircraft entity is sent to a pair of collect nodes which gather applicable statistics. If it is not killed, the clock advances and it proceeds another .8 NM to belt 2, which contains 25 more AAA sites.

If the fighter successfully negotiates belt 2, the clock is again advanced and it proceeds to belt 3, which contains 5 SAM-C sites and 2 SAM-D sites. It is engaged by the SAM-C's first. Event node 3 handles the SAM-C engagements. If the fighter evades the SAM-C's, it then encounters the SAM-D's at event node 4. If it is not killed by the SAM-D's, the clock is advanced once more and the fighter proceeds to belt 4, which contains 25 more AAA sites. The model proceeds in this manner until the target area, defended by one AAA site, is reached.

If the fighter penetrates all the threats in the model, it enters a collect node. The model continues to run until all 20 aircraft have been accounted for.

The computer coding of the network is found in lines 4580 through 5410 of the computer model (Appendix B).

Initialization Subroutine (Event Node 1)

The defensive sites in each belt are arranged normally along the belt, with the mean of the normal distribution being the point where the primary LOC crosses the belt. Thus the tickmarks along the road networks in

Figures 3 and 4 represent the mean points for weapon sites in each of the belts. The weapon sites in any belt can be tightly or loosely grouped about the LOC by varying the standard deviation of the normal distribution. While the standard deviation of the weapons in the first eleven belts in this experiment are varied, the AAA site in the target area is kept relatively close to the target with a standard deviation of only .25 NM. The initialization subroutine is contained in lines 350 through 1010 of the computer model.

<u>Weapon System Engagement Subroutines (Event Nodes 2,3,4,5,6)</u>

Each weapon type has its own event node, regardless of where it is physically located in the army area. These event nodes first calculate the closest point that the aircraft will pass from each weapon site during its run (lines 1460 through 1560). An aircraft altitude adjustment factor is then added to account for the inability of the pilot to precisely hold the nominal ingress altitude (lines 1570 through 1590). Subroutine PROBKIL is then called to determine the Pk of each weapon site in the belt; PROBKIL assumes the weapon site has an unobstructed shot at the aircraft (line 1610).

The next step is to determine whether the weapon site actually has a clear shot at the aircraft. Since the aircraft altitude and the horizonal distance from the weapon site are known, the look-up angle is easily determined. If the distance subtended by the multipath angle at the aircraft's horizonal range is subtracted from the aircraft altitude, an "equivalent" look-up angle can be computed. The equivalent look-up angle accounts for the fact that the aircraft must be above the altitude necessary to achieve a line-of-sight by at least the distance subtended by the multipath angle, for the weapon site to engage the aircraft. If the aircraft in Figure 5 were at an altitude of 1250 feet, for example, its equivalent altitude would be 1000 feet. The look-up angle would be 1.78^0, while the equivalent look-up angle would be 1.43^0. Once the equivalent look-up angle is determined, it is tested against a mathematical expression of the data in Figure 11 to determine the probability that the site is blocked by terrain. A random draw is then made to determine whether the weapon site was actually blocked. If so, Pk is set equal to zero; if not, the Pk is as determined in the PROBKIL subroutine. These steps are accomplished in lines 1630 through 1800 of the model.

If the weapon site is determined to have a shot at the aircraft, the model checks to see whether the site is already engaged with an earlier aircraft (lines 1820 through 1910). Once the model has determined which sites have an opportunity to engage the aircraft and are not already tied up with another aircraft, subroutine SORT is called (line 1930). This subroutine (lines 2550 through

2300) uses a bubble sort technique to rank the weapon sites according to their Pk's. It then picks the five AAA sites, or two SAM sites, which have the highest Pk's, and allows them to fire at the aircraft if their Pk's are high enough to meet the minimum criteria (lines 1950 through 2080). The missile systems must have a minimum Pk of .02 to be allowed to fire, while the top five AAA sites can fire at any aircraft within their lethal envelopes, as discussed in the Command, Control, and Communications portion of Chapter II.

Missile sites which are allowed to fire at the aircraft are then tied up and placed on the event calendar; they are released and permitted to engage another aircraft at the end of a time period equal to the sum of their track/fire time, flyout time, confounding delay, and acquisition time. AAA sites are treated in the same manner, except that their tie-up time is the sum of only the track/fire time and the confounding delay, as discussed in Chapter II. These steps are accomplished in lines 2100 through 2240 and lines 2340 through 2530 of the program.

Finally, the model determines which weapon sites actually achieve a kill by comparing a number obtained from a random drawing to the Pk determined in the PROBKIL subroutine. If the aircraft is killed, ATRIB(7) is set equal to one, and the aircraft is terminated in the network. These steps are accomplished in lines 2260 through 2310.

Probability of Kill Subroutine

This subsection discusses the probability of kill calculations for the AAA, and it discusses the SAM-D as a representative SAM system. The method used is the same for all SAM systems.

The AAA portion of the PROBKIL subroutine first determines whether the aircraft is within range. If so, the subroutine then determines the number of "g"s on the aircraft. Because of the high density of AAA sites in the front four AAA belts, the pilot is assumed to begin jinking maneuvers approaching the FEBA. The purpose of jinking is to defeat the tracking capability of the AAA; this is accomplished by making a series of random turns. The pilot will have an average of 2 "g"s on the aircraft while performing the jinking maneuvers, and he will continue jinking until he is one minute past the FEBA. He will then maintain an average of 1.3 "g"s in wings level, terrain following flight, until reaching the target area. In the target area he will maintain an average of 3 "g"s while delivering his ordnance. Once the "g" loading is determined, the intercept range is computed in accordance with Figure 10 of Chapter II. Finally, the amount of time the gun will be tied up is calculated. These steps are shown in lines 3230 through 3450 of the model.

The SAM-D portion of the PROBKIL subroutine first looks at the lateral range of the aircraft from the site. If the range is less than or equal to .25 NM, the Pk's are assigned according to Table VI. If the range is between .25 and 1.1 NM, Pk is set equal to zero and no shot is taken. These steps are shown in lines 3520 through 3680 of the program. If the range is between 1.1 and 6.5 NM, the point of intercept must be found. The point at which the aircraft is picked up by the tracking radar is determined in lines 3840 through 3990, while the point at which the aircraft is lost by the tracking radar is determined in lines 4000 through 4060. If the missile site is able to intercept the aircraft prior to the time the aircraft reaches the 90^0 aspect point, the site delays its shot so that the intercept will occur at the 90^0 aspect, to maximize the Pk. If the site is able to intercept the aircraft within the lethal envelope, but not at or prior to the 90^0 aspect point, it will fire as soon as it is able. If it cannot intercept the aircraft within the lethal envelope, it will not fire. These determinations are made in lines 4070 through 4140. The Pk of the missile shot and the tie up time of the missile are then computed in lines 4070 through 4140 of the program.

Model Implementation

The computer simulation model described in this chapter allows a number of factors to be varied in the night interdiction study. The specific factors used in the experiment, and manner in which these factors were allowed to vary and interact, are described in the next chapter.

IV Data Collection

Measure of Merit

In this thesis, a squadron level of twenty aircraft was put through the system in each simulation run. The measure of merit is the number of aircraft that survive each run.

Sample Size Determination

The required number of replications was determined by performing a trial experiment of five simulation runs with each factor set at level one. The results of the trial experiment were as shown below:

Run Number	Aircraft Survived
1	10
2	12
3	12
4	12
5	17

The objective was to be at least 95% confident that the sample mean would be within one aircraft of the true mean. To determine the number of runs required to achieve this level of accuracy, Stein's method (Ref 5:482) was used. The minimum number of runs required to achieve the desired level of accuracy is computed by the formula:

$$n_{min} = \frac{t_{n-1}^{\alpha/2}}{c} S^2$$

where

n_{min} - minimum number of simulation runs required.

C = maximum units wrong allowable.

S^2 = estimate of variance obtained in the trial experiment.

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

For the trial experiment,

$$n_{min} = \frac{t_4^{.025}}{c} S^2 = (2.776/1)\ (6.8) = 18.9 \sim 19$$

Based on this result, it was decided that five replications of each cell would be adequate. As will be shown in Chapter V. this results in 20 or more observations for all main effects. two-way interactions. and three-way interactions of the experimental factors.

Experimental Design

To quantify a solution to the problem statement of this thesis. it was necessary to design an experiment that would provide enough data about the problem to allow valid inferences to be drawn about the system behavior. The design provides a plan for executing the experiment by structuring the inputs into a logical pattern, thereby dictating the number of experimental trials required. Five factors were considered necessary and sufficient:

1. Speed of the fighter.
2. Altitude of the fighter.
3. Arrival rate of fighters (saturation of defensive network).
4. LOC network.
5. Standard deviation of defensive sites along belts.

The first factor, speed, is set at two levels: 480 knots and 540 knots. Both levels are compatible with the capabilities of the fighter and represent the airspeeds that would most likely be flown on an actual combat profile.

Altitude is considered at three levels: 1000 feet, 500 feet, and 250 feet AGL. Level one (1000 feet) represents the minimum altitude at which an aircraft not equipped with a FLIR could fly the night mission. Level two (500 feet) represents the altitude at which the mission could be flown by an aircraft with a FLIR with moderate resolution, while level three (250 feet) is the altitude at which the mission could be flown by an aircraft employing a high resolution FLIR.

The third factor, saturation, has two levels. At level one, the arrival interval is exponential with a mean of 30 seconds, while at level two, arrivals occur every ten minutes. Thus some of the weapon sites will be tied up with previous aircraft when the arrival rate is set at level one, while all sites will be able to engage any aircraft within range when arrivals are set at level two.

The fourth factor is the LOC network, representing the variety of possible distances between the fighters' ingress corridor and the major LOC in the sector. Level one is the LOC network shown in Figure 3, while level two is the network in Figure 4. Note that at level one the fighter crosses the FEBA at a relatively long distance from the LOC, while at level two his entry point is close to the LOC.

The fifth factor is the standard deviation of the defensive sites along the belt. At level one, the defenses are relatively spread out, with σ = 6.25 NM; at level two, they are more tightly clustered along the road network, with σ = 3.0 NM.

The factors and levels are summarized in Table XI.

TABLE XI

Factors and Levels to be Analyzed in the Experiment.

FACTOR \ LEVEL	1	2	3
Speed	480 knots	540 knots	--
Altitude	1000 ft	500 ft	250 ft
Saturation (interval between acft arrivals)	expon (.5 min)	10 min	--
Mean Point of Defenses	road net 1 (not over LOC)	road net 2 (over LOC)	--
of Defenses	6.25 NM	3.0 NM	--

A full factorial design was used for this experiment. That is to say, the model was run with every possible combination of the factors and levels. This allowed identification and interpretation of factor interactions. Furthermore, the effect of each factor is estimated at several levels of the other factors, and thus the conclusions reached hold over a wide range of conditions. A total of

$$(2)^4(3) = 48$$

cells were analyzed. Using five replications of each cell, as discussed in Sample Size Determination, a total of 240 simulation runs was required. These runs were made in blocks of sixty, with the levels for the road network and arrival rate in each block set as shown in Table XII.

TABLE XII

Design Matrix for Blocks of Sixty Simulation Runs.

		Road Network	Arrival Rate
	1 - 60	1	1
Run	61 - 120	1	2
Number	121 - 180	2	1
	181 - 240	2	2

Within each block, the levels for airspeed, altitude, and standard deviation of the defenses (σ) were set as shown in Table XIII.

TABLE XIII

Design Matrix Within Each Block of Sixty Simulation Runs.

		FACTORS		
		Airspeed	Altitude	Sigma
Run Number	1 - 5	1	1	1
	6 - 10	2	1	1
	11 - 15	2	2	1
	16 - 20	2	3	1
	21 - 25	1	3	1
	26 - 30	1	2	1
	31 - 35	1	2	2
	36 - 40	1	1	2
	41 - 45	2	1	2
	46 - 50	2	2	2
	51 - 55	2	3	2
	56 - 60	1	3	2

Once the measure of merit, the appropriate sample size, and the experimental design were determined, the experiment was run. In the next chapter the method of analysis of the results is presented and interpreted.

V Data Analysis

Data analysis was accomplished in four phases. The first phase was a five-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS). This output, along with input data showing the number of aircraft survived in each run, is listed in Appendix E. The second phase was a five-way ANOVA with altitude level three omitted: the output of this analysis is also found in Appendix E. The third phase was two four-way ANOVA runs with sigma held constant: this output is listed in Appendix F. The fourth phase was a four-way ANOVA using only the four factors that were found to be significant in the five-way ANOVA. This output is listed in Appendix G.

Five-Way ANOVA

This test showed that four of the five main effects (road network, aircraft arrival rate, aircraft altitude, and the standard deviation of the defenses) were significant using an alpha of .05. One main effect, aircraft velocity, was found to be statistically insignificant. Four of the two-way interactions were found to be significant, while the remaining six were not. None of the three-, four-, or five-way interactions were significant.

The residual term had more than four times as many degrees of freedom as the explained variation term, indicating that enough data points were available to produce a high degree of confidence in the results.

Main Effects. The only main effect found to be statistically insignificant was the aircraft velocity. This result is not unexpected, since the two levels of velocity considered in the model are fairly close to each other. The statistical insignificance of velocity in the model means that the value of increasing the fighter's airspeed from 480 to 540 knots is small. It is probably not worth the the substantial fuel consumption increase that it would require. This result should not be interpreted to mean that airspeed is totally insignificant as a factor in fighter survivability. In fact, the verification runs showed that survivability against SAMs decreased substantially when the airspeed was decreased to 60 knots, which is well below the levels considered in the model.

The main effects found to be statistically significant are shown graphically in Figure 12. In interpreting this figure and all subsequent graphs in this chapter, it is important to note that the only data points are the aircraft survival rates associated with specific levels of the factors listed at the bottom of the graph. The lines drawn between the points only serve to emphasize the change in aircraft survival between levels. The fact

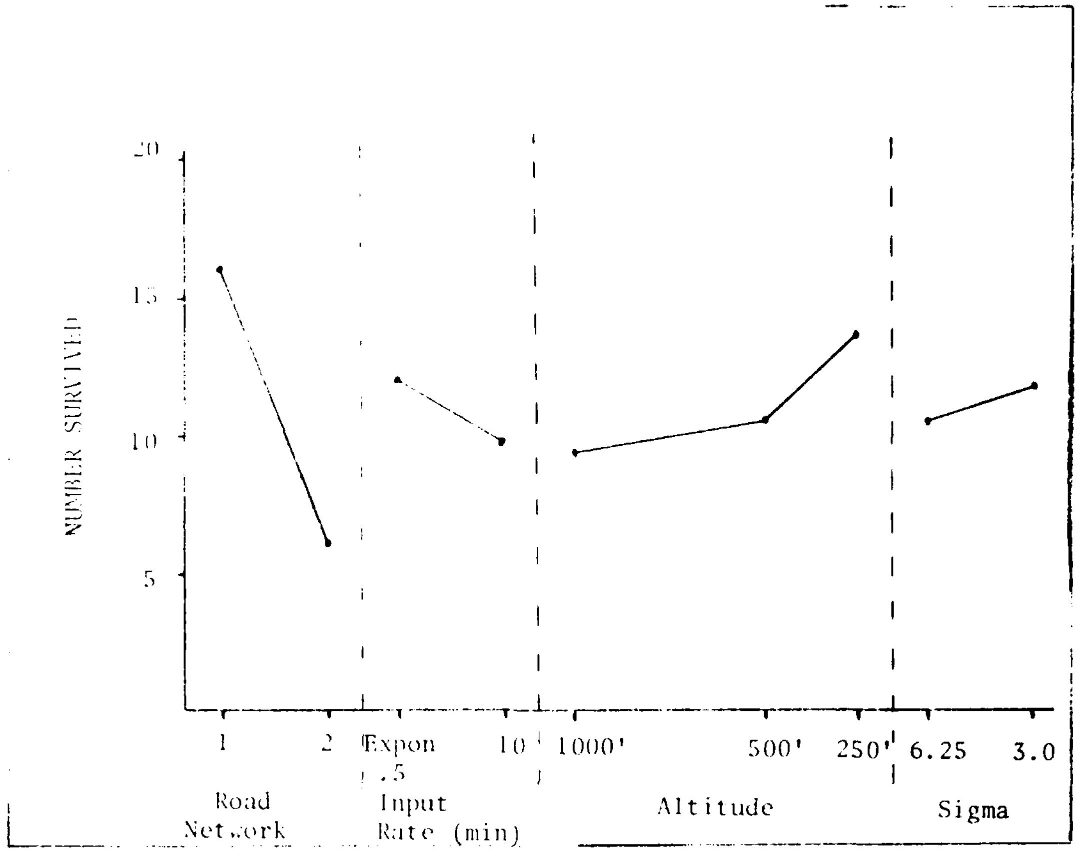


Figure 12. Influence of Main Effects

that the lines are straight does not imply a linear relationship; in fact, no attempt is made to estimate survival rates at levels other than those stated in the research design. A more complete description of how to interpret ANOVA results is presented in chapter 6 of "Fundamental Concepts in the Design of Experiments," by Charles R. Hicks.

All the main effects behaved as expected. A great many more aircraft survived using road network 1 than road network 2, making the obvious point that the fighters' chances of survival increase if they avoid areas where defensive sites are likely to be heavily concentrated. Saturating the defensive network by running the fighters through the network close together also increased their probability of survival. Decreasing ingress altitude from 1000 feet down to 500 feet helped the fighters somewhat, but going down to 250 feet increased the probability of survival much more dramatically. Finally, the fighters' probability of survival tended to be higher when the defenses were more tightly grouped, since the probability of flying over a portion of terrain relatively free of defenses was increased by concentrating the defenses into a small area. The effect of σ is influenced sharply, however, by its interaction with other factors. This will be explained in the next subsection.

<u>Two-Way Interactions.</u> The following two-way interactions were found to be statistically significant:

1. Road network vs. Aircraft altitude.
2. Road network vs. σ of defensive array.
3. Arrival rate vs. σ of defensive array.
4. Aircraft altitude vs. σ of defensive array.

These interactions are discussed next.

The interaction between the road network and aircraft altitude is not an especially strong one. As is seen in the left hand portion of Figure 13, the advantage of road network one over road network two is somewhat less pronounced when the aircraft is at an altitude of 250 feet than when the altitude is 500 or 1000 feet. Specifically, an average of 10.5 more aircraft survive with road network one than with road network two when the ingress altitude is 1000 feet, 10.05 more survive if the altitude is 500 feet, and 8.77 more survive if the altitude is 250 feet. Even though more aircraft survive at an altitude of 250 feet than at either of the other two altitudes, the increase in survival provided by road network one is less than at the higher altitudes. This relationship is

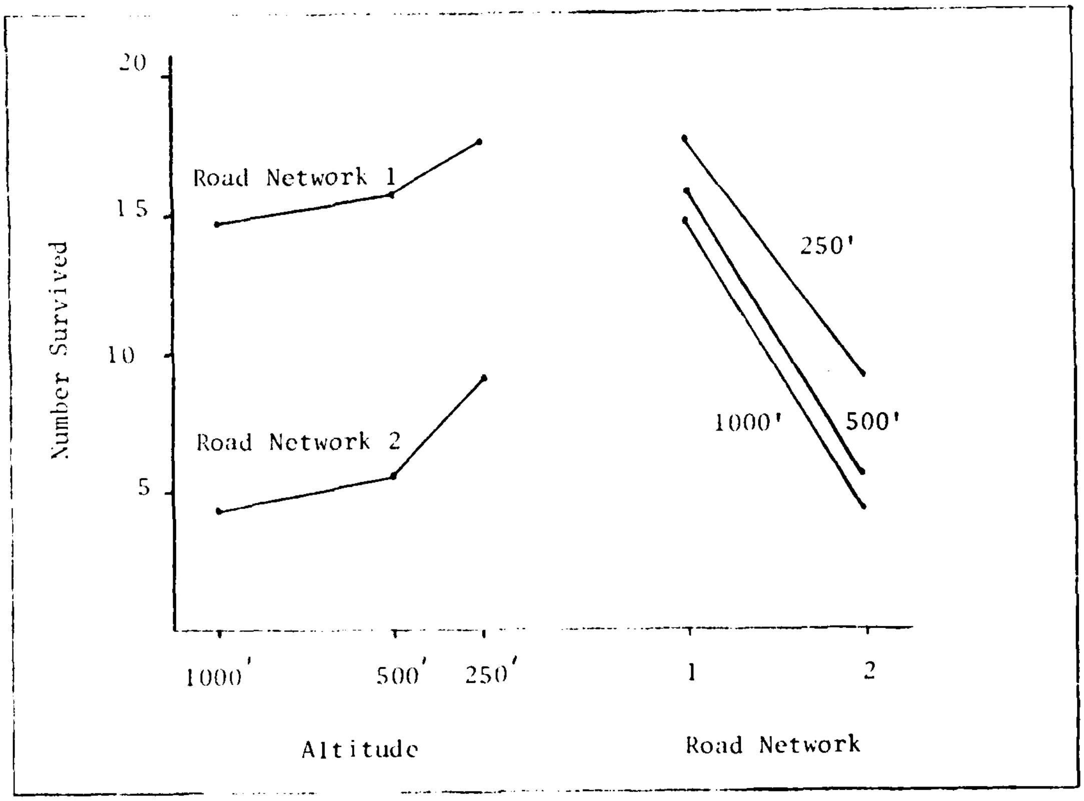


Figure 13. Interaction Between Road Network and Aircraft Altitude

explained by the fact that the number of aircraft that survive using road network one is much higher than the number that survive using road network two, regardless of altitude. This makes the benefit of going lower less dramatic.

The interaction between the road network and the standard deviation of the defensive array, shown in Figure 14, is an important one. With road network one, the fighters are a considerable distance from the primary LOC

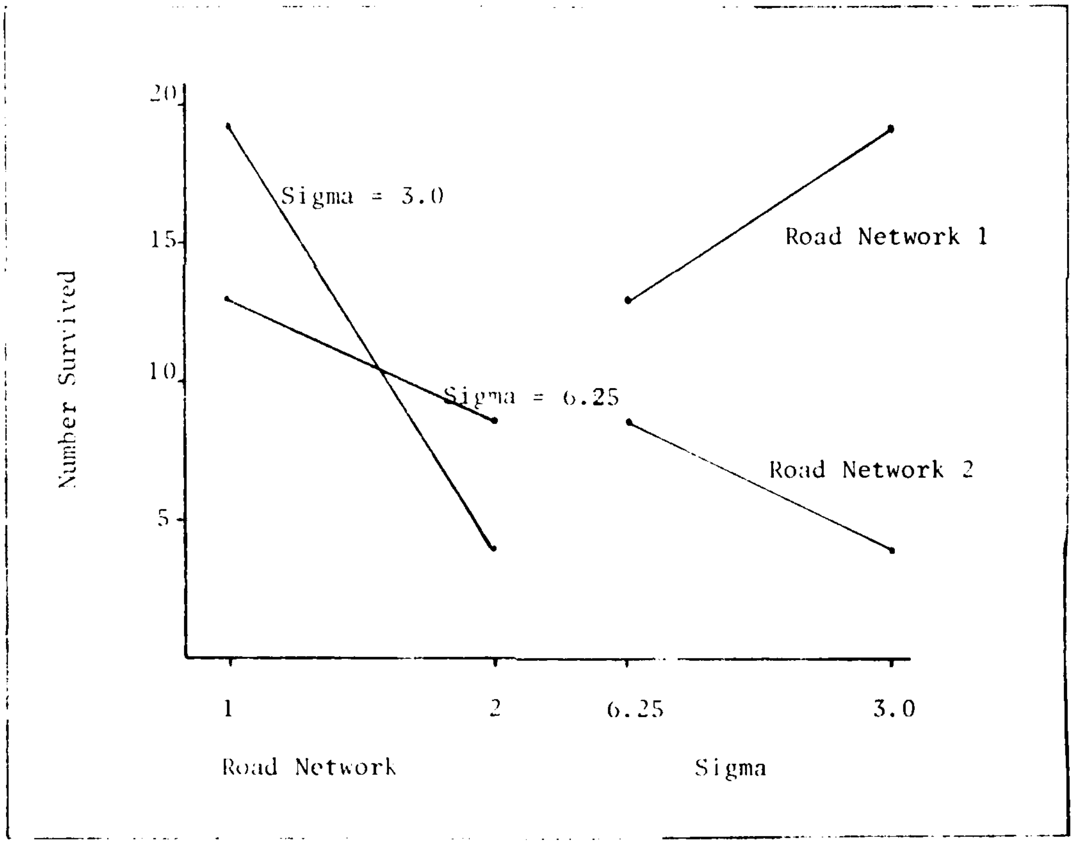


Figure 14. Interaction Between Road Network and Standard Deviation of Defensive Array

during the major portion of the mission, and the number of aircraft that survive would be expected to decrease when the defenses are spread more widely across the belts. When road network two is used, on the other hand, the fighters are close to the LOC, and the number that survive would be expected to increase as the standard deviation is increased. Figure 14 shows that these two factors interact as expected. The right hand portion of this graph shows that, when road network one is used, survival rates increase as sigma is reduced, while when road network two is used, survival rates decrease as sigma is reduced.

Figure 15 shows that the degree to which the defensive sites are spread out across the belts has virtually no effect on aircraft survivability when the defenses are saturated by incoming aircraft; note the nearly horizontal line associated with the exponential arrival rate on the right hand side of the graph. Tightening the defenses has a positive effect on survivability when arrivals are too far apart to saturate the defenses, however, as shown by the upward sloping line associated with the 10 minute arrival interval. Because the aircraft enter in a narrow corridor, the first aircraft through the network will tie up most, if not all, of the guns within range, regardless of the density of the defenses near the corridor. As a result, relatively few defensive sites are able to shoot at subsequent aircraft

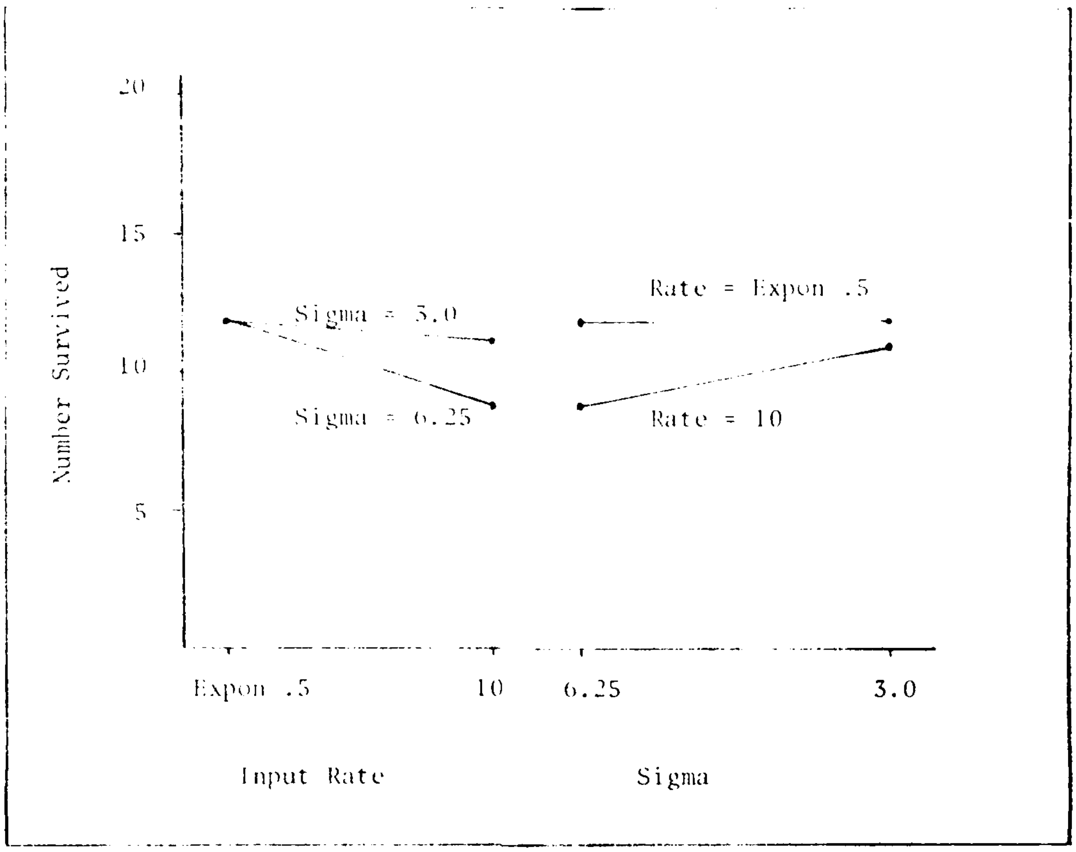


Figure 15. Interaction Between Aircraft Arrival Rate and Standard Deviation of Defensive Array

until the weapon sites are released. The effect of the standard deviation of the defensive array is thus nullified for a large number of the incoming aircraft when the defensive array is saturated. When the defenses are not saturated, on the other hand, the standard deviation of the defensive array influences the system in the same manner that it influenced it as a main effect.

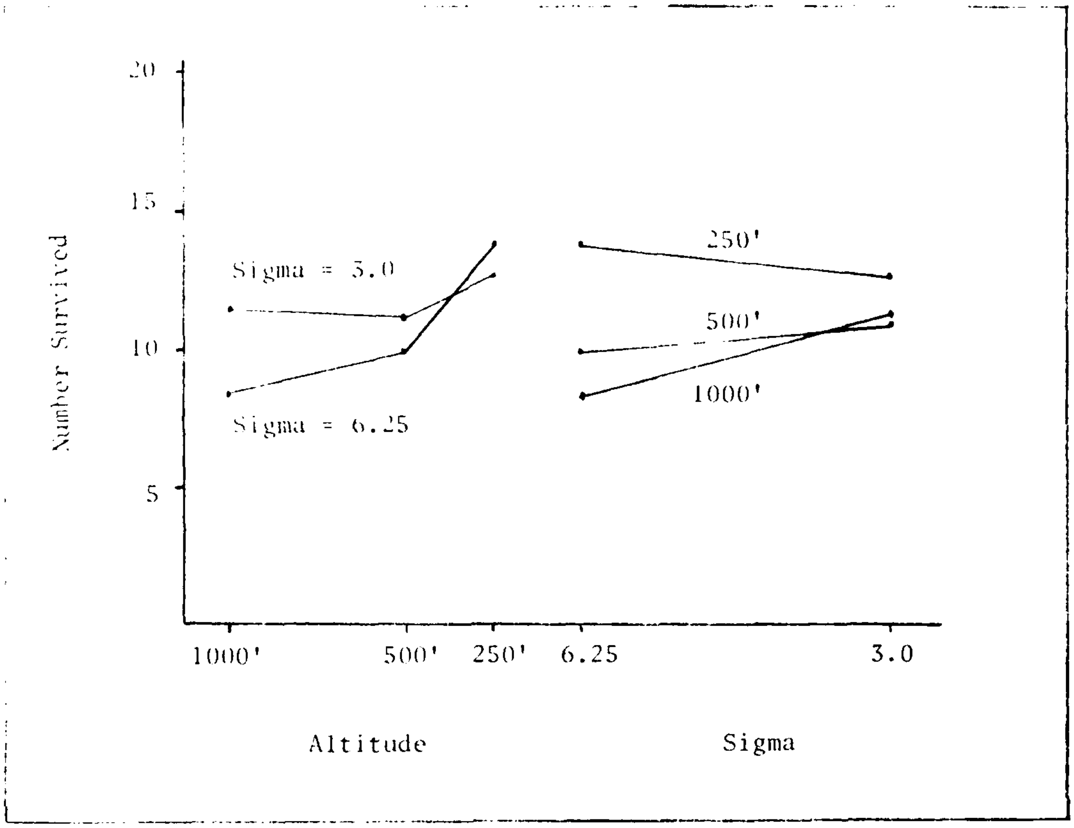


Figure 16. Interaction Between Aircraft Altitude and Standard Deviation of the Defensive array

Figure 16 shows that survivability is higher at an ingress altitude of 250 feet than it is at an altitude of 500 or 1000 feet, regardless of the degree to which the defenses are spread out; note the upper line on the right hand side of the graph. At an ingress altitude of 250 feet, tightening the distribution of the defensive array tends to decrease aircraft survivability, while at 500 and 1000 feet, it tends to increase survivability. This concept is illustrated by the fact that the 250 foot line has a downward slope, while the 500 and 1000 foot lines slope upward. Another interesting feature is that when the defenses are spread out, with sigma equal to 6.25 NM, survivability is clearly higher at 500 feet than at 1000 feet, while when they are more tightly clustered, with sigma equal to 3.0 NM, there is virtually no difference in survivability between the two altitudes. This concept is illustrated by the two lower lines in the figure; an average of two more aircraft survive at 500 feet than at 1000 feet when sigma is set at 6.25 NM, while the average survival rates are nearly equal with sigma set at 3.0 NM.

Five-Way ANOVA with Altitude Level Three Omitted.

Because an altitude decrease from 500 feet down to 250 feet had a considerably larger effect on the model's output than a decrease from 1000 feet to 500 feet, a five-way ANOVA which looked only at simulation runs with ingress altitudes of 500 feet and 1000 feet was performed. Ingress altitude was still a statistically significant factor when only these levels were considered, but it was considerably less significant than it was when all three levels were included in the data base. Furthermore, the interaction between ingress altitude and the standard deviation of the defensive network, while still significant, was less significant than it was when the altitude was considered at all three levels. The interaction between the road network and aircraft altitude became statistically insignificant.

Four-Way ANOVA with Sigma Held Constant.

Because sigma was a player in three of the four significant interactions in the five-way ANOVA, additional ANOVA runs were made with sigma held constant at each of its two levels.

In the first run, sigma was held constant at level one (0.25 NM); that is, all observations in which sigma was set at level two (3.0 NM) were disregarded. This run provided some interesting information. The road network, aircraft arrival rate, and aircraft altitude remained statistically significant factors, and aircraft velocity remained statistically insignificant. None of the two-, three-, or four-way interactions, however, were significant. This implies that all the interactions of the variables were occuring when sigma equalled 3.0 (sites tightly bunched).

In the second run, sigma was held constant at level two (3.0 NM). The main effects were unchanged from the previous ANOVA runs. The following two-way interactions were statistically significant:

1. Road network vs. Aircraft arrival rate.
2. Road network vs. Aircraft altitude.

None of the three- or four-way interactions were significant.

The interaction between the road network and aircraft altitude was explained in the discussion of the five-way ANOVA results. This interaction is more significant when sigma is set at 3.0 NM than when sigma is not held constant, while it is insignificant when sigma is set at 6.25 NM.

As shown on the left hand side of Figure 17, the advantage of saturating the defenses is less pronounced using road network one than when using road network two;

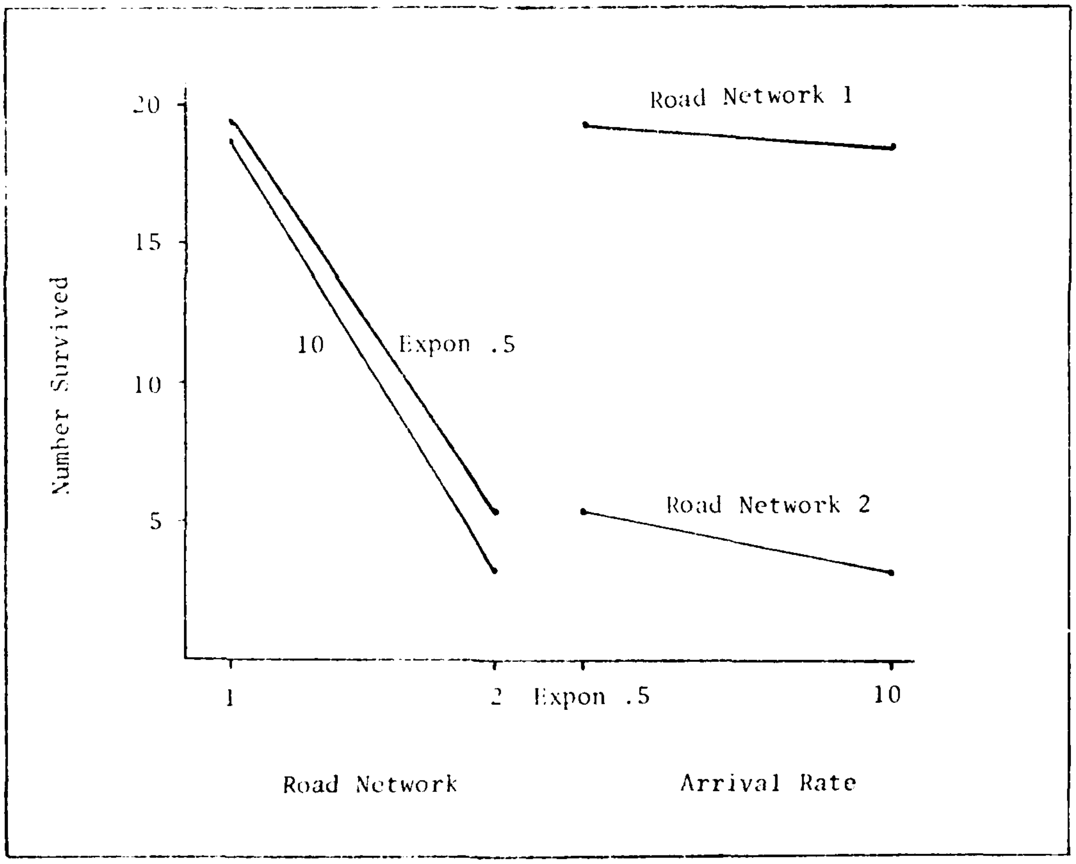


Figure 17. Interaction Between Road Network and Aircraft Arrival Rate (Sigma Held at 3.0 NM)

approximately one more aircraft survives by changing from a 10 minute interval to the exponential arrival rate with road network one, while approximately two more aircraft survive when the same change is made with road network two. This relationship is explained by the fact that the number of aircraft that survive using road network one is much higher than the number that survive using road network two, regardless of the aircraft arrival rate. This makes the benefit of saturating the defenses less dramatic with road network one than with road network two. This interaction becomes statistically significant only when sigma is held constant at 3.0 NM because the number of aircraft that survive increases dramatically using a combination of network one and sigma equal to 3.0 NM, regardless of the levels of other factors.

Four-Way ANOVA with Airspeed Excluded

Because airspeed was found to be statistically insignificant in the five-way ANOVA runs, a four-way ANOVA was accomplished with airspeed excluded as a factor. The results were the same as the results of the original five-way ANOVA. The elimination of one factor, however, doubled the number of observations in each cell. The close agreement of the four-way ANOVA results and the five-way ANOVA results thus provided a high degree of confidence that five observations in each cell was adequate to achieve accurate results.

This chapter has explained the analysis of the data obtained in the experiment. The next chapter explains the testing performed to validate the model.

VI The Validation Process

Validation is the process of developing confidence in the model's ability to accurately draw inferences about the true behavior of the system. Shannon divides the validation process into three categories:

1. Verification - insuring that the model behaves as it was intended to behave.

2. Validation - testing the agreement between the behavior of the model and that of the real system.

3. Problem analysis - the drawing of statistically significant inferences from the data generated by the computer model (Ref 8:30).

The third aspect of the validation process, problem analysis, was discussed in detail in the previous chapter. This chapter addresses the first two processes - verification and validation.

Verification

Three categories of tests were performed to verify the internal consistency of the model. They are listed below:

1. Statistical testing to determine whether distributions used in the model behaved properly.

2. Monitoring of activities and computations to verify that they performed as desired.

3. Testing the factors at their extremes to assure

that results were logical within the framework of the model.

The specific testing accomplished in the verification process is discussed below.

Aircraft Arrival Times. For runs specifying arrivals spaced 10 minutes apart, the arrival times at the first AAA belt were checked; all arrivals were spaced correctly. To check that the exponentially distributed arrivals behaved properly, a sample of 38 arrivals times was obtained from two consecutive runs of the model (20 aircraft arrivals per run with the first arrival at time zero). The 38 data points were analyzed using a Chi-Square Goodness of Fit Test. The hypotheses for this test are shown below:

> H_0: The 38 arrival intervals are from an exponential (.5 minutes) distribution.
>
> H_1: The arrival intervals are not from an exponential (.5 minutes) distribution.

The null hypothesis could not be rejected by this test, using an alpha of .05. This led to the conclusion that the arrival rates came from the desired distribution. The results of the test are shown in Appendix H.

Distribution of Defensive Sites. The first part of this analysis was to verify that none of the defensive sites fell outside the limits of -13.5 NM to +13.5 NM. After this was verified, two sample AAA belts, one with a standard deviation of 6.25 NM and the other with a standard deviation of 3.0 NM, were tested using Kolmogorov-Smirnov tests. For the AAA belt with a standard deviation of 6.25 NM, the hypotheses for the test were as shown below:

H_0: The AAA sites come from a normal distribution with a standard deviation of 6.25 NM.

H_1: The AAA sites do not come from a normal distribution with a standard deviation of 6.25 NM.

For the AAA belt with a standard deviation of 3.0 NM, the hypotheses for the test were the same, with the exception of replacing 6.25 with 3.0. In both cases, the null hypothesis could not be rejected using an alpha of .05. This led to the conclusion that the defensive sites were distributed as desired. Both tests are described in detail in Appendix H.

<u>Probabilities of Kill.</u> This part of the verification process analyzed the [illegible] of the model to determine at what point an aircraft could be picked up by a weapon system's tracking radar, and then compute an accurate probability of kill based on the aircraft's position at the time of intercept by the missile or bullets. All five weapon systems in the model were analyzed, and the results calculated by the model were found to be consistent with those calculated by hand. Two examples of the calculations in this part of the verification process are shown in Appendix I.

<u>Tie-Up Times of Weapon Systems.</u> The first step in this phase was to insure that only those SAMs having a probability of kill of .02 or above were allowed to shoot at an aircraft. After this was verified, the tie-up times

of the weapon systems were checked to insure that they fell within the correct range. Next, tied-up weapon sites were monitored to insure that they did not shoot at subsequent aircraft until after their scheduled release time. Finally, the weapon sites were monitored to verify that they actually released at the scheduled times. All of these concepts are illustrated by the sample computer output shown in Appendix J.

Testing the Model at its Extremes. During this phase of the verification process, the model was tested with certain factors set well beyond the limits studied in the experiment. All behaved as expected. When the aircraft velocity was set at 60 knots, for example, missile kills went up dramatically, when it was set at 3000 knots, no missile kills were recorded. When the aircraft altitude was set at zero, no missile kills and very few AAA kills were recorded. The model was not run with extremely high altitudes, because it is not designed to reliably handle them. When the saturation of the defensive array was increased by reducing the mean time of the exponential arrivals to .1 minutes, aircraft survival increased substantially. The opposite extreme is already tested in the experiment, since there is no saturation of the defenses with a 10 minute arrival interval.

Validation

The validation effort centered primarily around establishing face validity. The primary vehicle in achieving this aim was a Turing test. The test consists of finding people who are experts in the system being modeled, presenting them with sets of input-output data from the real system and other sets of data from the model, and then asking them to differentiate between the two sets of data (Ref 8:28?). Because the system in the model has never been tested in the real world, the test was modified slightly. The experts were given sets of input data, and they were then asked to predict the results as the factors ranged over the levels considered in the computer model. Their predictions were then compared to computer generated results.

It should be reemphasized at this point that the survivability figures developed by the model are ordinal data; they are useful only for comparing the various alternatives evaluated and are not intended to be predictors of actual combat survival rates. Nevertheless, changes in various factors of the experiment should change the output (aircraft survival) in a logical manner.

When all the factors were set at levels which should have enhanced survivability the most, the model did in fact produce the second highest number of surviving aircraft of the 48 cells evaluated. Specifically, the levels were:

Airspeed = 540 knots,

Altitude = 250 feet,

Arrival rate = exponential (.5 minutes mean),

Road network 1,

σ = 3.0 NM.

The results of 5 runs of 20 aircraft each were:

19
20
19
20
20

for a total of 98 of 100 aircraft surviving. The highest number of surviving aircraft (99) was attained in a run in which aircraft arrived at 10 minute intervals and all other factors were set as shown above.

When all factors were set at levels which should have reduced survivability the most, the model produced the lowest number of surviving aircraft of the 48 cells evaluated. These levels were:

Airspeed = 480 knots,

Altitude = 1000 feet,

Arrival rate = 10 minutes,

Road network 2,

σ = 3.0 NM.

The results of the 5 runs were:

3
0
1
1
3

for a total of only 8 aircraft surviving.

The results discussed above illustrate the model's output at the extremes of the five factors. These results, coupled with more gradual changes in survivability as the factors are varied one at a time, are intuitively appealing.

To further substantiate the intuitive appeal of the model's results, Turing tests were conducted with five pilots and one navigator. All had extensive backgrounds in fighter aircraft. Three of the pilots had served tours in Central Europe and were intimately familiar with the terrain and threat array represented by the model. All six agreed that the model's output was reasonable.

Once the model was developed and validated and the results of the experiment collected and analyzed, the only steps remaining in the thesis were to draw conclusions from the results and make recommendations based on the conclusions. The conclusions and recommendations are presented in the next chapter.

VII Conclusions and Recommendations

The objective of this thesis, as stated in Chapter I, was to determine whether the increased capability of the fighter to fly lower and faster, provided by the LANTIRN FLIR, will improve significantly its survivability in the night interdiction role. The conclusions are as follows:

1. The capability to increase airspeed does not significantly increase survivability.

2. A decrease in ingress altitude from 1000 to 500 feet will increase survivability to a minor degree.

3. A further decrease in ingress altitude to 250 feet will significantly improve the fighter's survivability.

The results of the experiment also led to some conclusions which do not directly relate to the objectives of the thesis effort. These conclusions are as follows:

1. The most important single factor in fighter survivability is the avoidance of heavy concentrations of anti-aircraft threats.

2. Fighter survivability can be significantly enhanced by saturating the enemy defensive network.

3. The AAA is the single greatest threat to a fighter flying a night battlefield air interdiction mission, due primarily to the large number of them in the army area.

4. The SAM-D and SAM-C are also significant threats in this scenario.

5. The SAM-B and SAM-A have virtually no capability against the fighter in this scenario.

Based on the above conclusions, the following recommendations are made:

1. That every effort be made to develop a FLIR of high enough resolution to allow the fighter pilot to fly the mission at an altitude of 250 feet or below.

2. That tactics emphasize the avoidance of enemy defenses and the use of corridors to saturate the enemy defensive network.

3. That our ECM efforts concentrate on defeating the AAA, SAM-D, and SAM-C.

VIII Recommended Areas for Follow-On Study

Like most research efforts, this thesis was unable to cover all the aspects of the system studied or address all the questions that need to be asked. Some recommended areas for follow-on study of the night BAI survivability problem are discussed in the following paragraphs.

Conclusion one in the preceding chapter was that the capability to increase airspeed does not significantly increase survivability. This conclusion is only valid for the airspeeds studied in the experiment - 480 and 540 knots. Further study to determine a point at which airspeed does become significant would be worthwhile, especially in the study of survivability of aircraft incapable of the high speeds considered in this experiment.

Conclusions two and three stated that survivability is increased as altitude is decreased. This research effort, however, did not address the problem of increased risk of the aircraft impacting the ground while the pilot was attempting to fly at the lower altitudes. A study of the trade-off between the increased protection against enemy defenses and the increased risk of flying the aircraft into the ground at the lower altitudes would be worthwhile.

It should be noted that the model developed in this thesis can be easily adapted to analyze a variety of problems. It could, for instance, serve as a framework for analyzing various jamming systems against a typical Soviet air defense array. It could also be used to determine the impact of various routes of flight and degrees of saturation of the enemy defensive network in an attempt to develop improved fighter tactics. Both these areas were considered in the experiment, but they were not developed in depth. Furthermore, the model could serve as a framework upon which a model to study the night target acquisition process could be developed.

Finally, it should be noted that the validity of the output of the model might be improved by a more detailed treatment of several areas. Some suggestions are listed below:

1. The output of the jamming pod could be made directional rather than radiating uniformly in the hemisphere beneath the aircraft.

2. Features such as radar polarity and frequency agility could be treated.

3. Enemy acquisition radars could be explicitely treated.

4. A range of J/S ratios could be considered in modeling the lock-on process of the target tracking radars.

5. The elevation of the aircraft with respect to the radar could be considered in determining radar cross-sections. The model presently considers only the aspect of the aircraft in this computation.

6. Terrain could be modeled in more detail. The

model makes only one calculation to determine whether a given weapon site is blocked by terrain. It does not allow for the case in which an aircraft alternately passes behind terrain features and then comes back into the radar's view as time progresses.

7. A C3 structure between the acquisition radars and various radar-controlled weapon systems could be explicitely modeled.

8. SAM and AAA sites could be given multiple shots at the aircraft if conditions appeared favorable.

Undoubtedly, many more details could be added to the model. but those listed above are the major ones. It is not possible to say at this time whether incorporation of any, or even all, of the details listed above would significantly improve the validity of the model's output. This can only be determined by actually adding the features and observing the results. The model in its present form, however, accomplishes the purpose for which it was designed with the necessary degree of accuracy.

Bibliography

1. Burge, C. J. and J. H. Lind. Line of Sight Handbook. Naval Weapon Center Report. TP 5908. China Lake, California. January 1977.

2. Breuer, Walter. Lecture materials distributed in SE 5.80. Analytical Aspects of Weapons Delivery. School of Engineering. Air Force Institute of Technology. Wright-Patterson AFB, Ohio, 1980.

3. Golden, Maj August. Lecture materials distributed in EE 5.73, Electronic Warfare. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1980.

4. Golden, Maj August. School of Engineering, Air Force Institute of Technology (personal interview). Wright-Patterson AFB, Ohio, 10 December 1980.

5. Kleijnen, Jack P. C., Statistical Techniques in Simulation, Part II. New York: Marcel Dekker, 1975.

6. Robinson, Clarence A. "Increasing Soviet Offensive Threat Spurs Stronger Air Arm", Aviation Week, 107 : 38-46 (1 August 1977).

7. Severson, J. and T. McMurchie. "Antiaircraft Artillery Simulation Computer Program - AFATL Program P-001", JTCG Technical Note 4565-16-73.

8. Shannon, Robert E. Systems Simulation - The Art and Science. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1975.

AD-A101 186 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 1/3
SURVIVABILITY STUDY OF A FLIR EQUIPPED FIGHTER ON A NIGHT PENET--ETC(U)
MAR 81 W J LEEK, R W SCHMITT

UNCLASSIFIED AFIT/GST/OS/81-M-9 NL

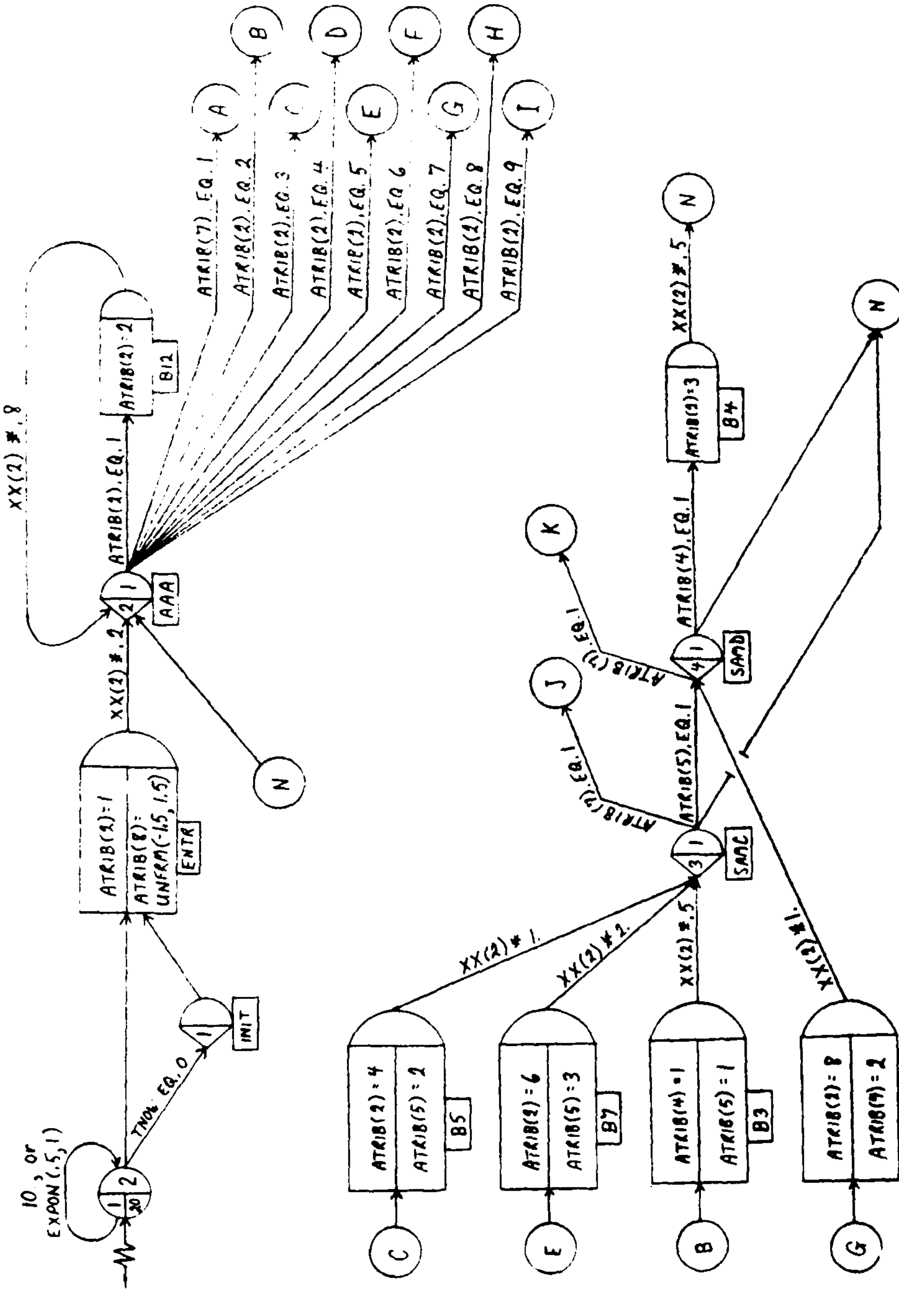
2 of 2
AD
A101186

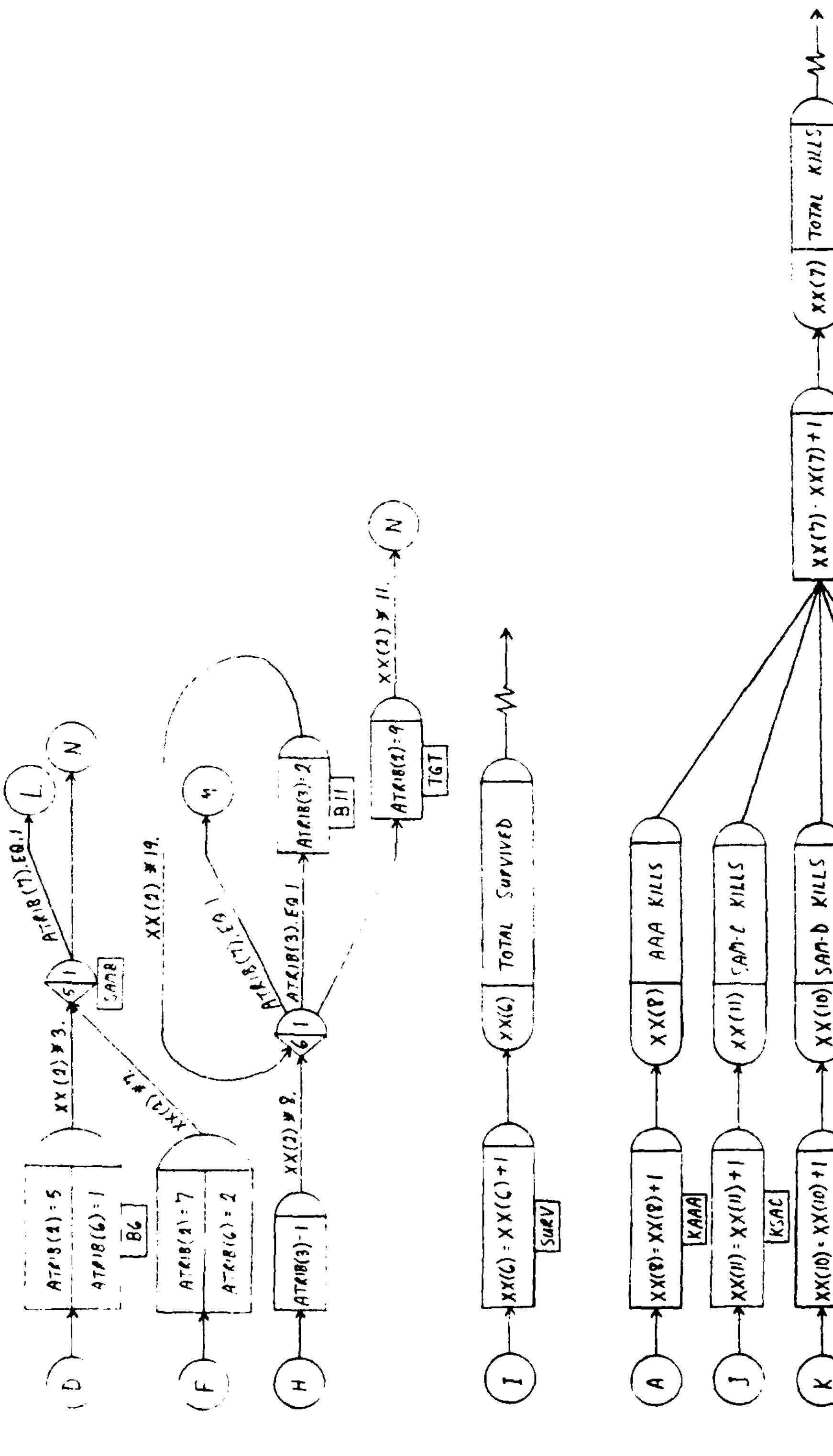
END
DATE FILMED
7-81
DTIC

END
DATE FILMED
7-81
DTIC

Appendix A

SLAM Network Diagram





D
F
H
I
A
J
K
L
M
ATRIB(2) = 5
ATRIB(6) = 1
B6
ATRIB(2) = 7
ATRIB(6) = 2
ATRIB(3) = 1
XX(2) ≠ 3.
XX(2) ≠ 7.
XX(2) ≠ 8.
SAMB
ATRIB(7).EQ.1
L
N
XX(2) ≠ 19.
ATRIB(7).EQ.1
ATRIB(3).EQ.1
M
ATRIB(3) = 2
B11
ATRIB(2) = 9
TGT
XX(2) ≠ 11.
N
XX(6) = XX(6) + 1
SURV
XX(6)
TOTAL SURVIVED
XX(8) = XX(8) + 1
KAAA
XX(8)
AAA KILLS
XX(11) = XX(11) + 1
KSAC
XX(11)
SAM-C KILLS
XX(10) = XX(10) + 1
KSAD
XX(10)
SAM-D KILLS
XX(12) = XX(12) + 1
KSAB
XX(12)
SAM-B KILLS
XX(9) = XX(9) + 1
KSAA
XX(9)
SAM-A KILLS
XX(7) = XX(7) + 1
KILL
XX(7)
TOTAL KILLS

Appendix B

SLAM Computer Model

In the model printed out below, road network one has been used and aircraft arrive at an exponential rate with a mean of .5 minutes. The road network can be changed by changing the input data on lines 260 and 270, while the arrival rate can be changed on line 4590. All other factors are changed with initialization cards placed prior to the simulate cards in lines 5430 through 6130 of the model.

```
100=W L,CM137000,T120,IO100.     T790546,LEEK
110=ATTACH,PROCFIL,SLAMPROC,ID=AFIT.
120=FTN,SYSEDIT,PMD.
130=BEGIN,SLAM,,M=LGO,PMD=PMD.
140=*EOR
150=      SUBROUTINE EVENT(N)
160=      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,
170-     +II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,
180=     +NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
190=      COMMON/ALL/PK(25),HI(15,9,5),AA(25),NB(9,25),R,A,IA,IC,L,B(25)
200=      DIMENSION AAA(9,25),SAMD(2,3),SAMC(3,5),
210=     +SAME(2,6),SAMA(2,2)
220=      DIMENSION RNGLOC(12)
230=      DIMENSION NAAA(9),TERR(11),NSAMA(2),NSAMB(2),NSAMC(3),NSAMD(2)
240=     +,C(6),AMTPATH(5)
250=      DATA AAA,SAME,SAMC,SAMB,SAMA,RNGLOC/262*99.99,
260=     + 6.3,9.0,9.2,9.5,9.8,10.5,10.9,10.5,10.1,3.0,
270=     + -3.4,0.0/
280=      DATA AMTPATH/0.,.15,.25,.35,.35/
290=      DATA NAAA/25,25,25,25,7,7,7,7,1/
300=      DATA TERR/7.5,4.7,3.3,2.6,1.8,1.44,1.25,1.,.55,.32,.22/
310=      DATA NSAMD,NSAMC,NSAMB,NSAMA/2,3,5,3,2,3,6,2,1/
320=      DATA PK,HI,AA,NB,R,A,IA,IC/954*0./
330=      GO TO (1,2,3,4,5,6,7)N
```

```
[illegible]
C     ARE TREATED IN SAME MANNER.
C
C
C  AAA'S
      DO 2[illegible] I=1,2
      III = I
      IF (I.EQ.2) III = I + 1
      XX(3) = RNGLOC(III)
      DO 21 J=1,5
 22   AAA(I,J) = RNORM(XX(3),XX(4),1)
      IF (ABS(AAA(I,J)).GT.13.5) GO TO 22
 21   CONTINUE
 2[illegible]   CONTINUE
C
C  SAM-D'S
      DO 42 J=1,2
      XX(3) = RNGLOC(3)
 41   SAMD(1,J) = RNORM(XX(3),XX(4),1)
      IF (ABS(SAMD(1,J)).GT.13.5) GO TO 41
 42   CONTINUE
      DO 45 J=1,3
      XX(3) = RNGLOC(9)
 46   SAMD(2,J) = RNORM(XX(3),XX(4),1)
      IF (ABS(SAMD(2,J)).GT.13.5) GO TO 46
 45   CONTINUE
C
C  SAM-C'S
      DO 53 I=1,3
      III = (2*I) + 1
      XX(3) = RNGLOC(III)
      DO 51 J=1,5
 52   SAMC(I,J) = RNORM(XX(3),XX(4),1)
      IF(ABS(SAMC(I,J)).GT.13.5) GO TO 52
 51   CONTINUE
 53   CONTINUE
C
C  SAM-B'S
      DO 60 I=1,2
      III = 6
      IF (I.EQ.2) III = 8
      XX(3) = RNGLOC(III)
      DO 61 J=1,6
 62   SAMB(I,J) = RNORM(XX(3),XX(4),1)
      IF (ABS(SAMB(I,J)).GT.13.5) GO TO 62
 61   CONTINUE
```

```
[illegible]
      AAA(9,1) = RNORM(XX(3),XX(3),1)
C
C
C
      VEL = 60.*XX(2)
      PRINT *,"**************************"
      PRINT *,"AIRCRAFT VELOCITY = ",VEL,"  ALTITUDE = ",XX(1)
      PRINT *,"AIRCRAFT ARRIVAL RATE = EXPON(.5 MINUTES)"
      PRINT *,"ROAD NETWORK 1 "
      PRINT *,"STANDARD DEVIATION OF THE DEFENSIVE SITES = ",XX(4)
      PRINT *,"**************************"
      RETURN
C
C
C     LOOK UP THE NUMBER OF SITES IN THE BELT AND COMPUTE THE
C     RANGE FROM THE A/C TO EACH SITE.
C
2     L = ATRIB(2)
      ATRIB(7) = 0.
      K = NAAA(L)
      IA = 1
      GO TO 9
C
3     IA = 2
      L = ATRIB(5)
      K = NSAMC(L)
      GO TO 9
C
4     IA = 3
      L = ATRIB(4)
      K = NSAMD(L)
      GO TO 9
C
5     IA = 4
      L = ATRIB(6)
      K = NSAMB(L)
      GO TO 9
```

```
      R = ABS( AMB(L,J) - ATRIB(8))
      GO TO 22
      R = ABS( AMA(L,J) - ATRIB(8))
      A = A( TI DE + PILOTAGE)
12    A = X(1) + RNORM(0.,50.,1)
      IC =

      CALL PROBKIL

C   CHECK IF THE GUN IS BLOCKED BY THE TERRAIN.
C
C   COMPUTE THE LOOK UP ANGLE.
      R = R * 6076.
      ANG = AMPATH(IA)
      A = A - R * TANG(ANG)
      ALPHA = ATAN(A/R) * 57.29578
      IF (ALPHA .LE. 0.22) GO TO 19
      IF (ALPHA .GE. 7.5) GO TO 8
      DO 23 I=2,11
      IM = I
      IF (ALPHA.GT.TERR(I)) GO TO 24
23    CONTINUE
24    IB = IM-1
      FE = (TERR(IB) - ALPHA)/(TERR(IB) - TERR(IM))
      FG = (IM - 2. + FE)/10.
C   TEST AGAINST PROBABILITY OF BLOCKAGE.
      IF (DRAND(1).LE.FG) GO TO 19
C
C   CHECK IF THE GUN IS BUSY
C
      INE = NE(L,IA)
      IF (INE.EQ.0) GO TO 10
      DO 18 IK=1,INE
      IF (J.EQ.HI(IK,L,IA)) GO TO 19
18    CONTINUE
      GO TO 10
```

```
      [illegible] 0.
      [illegible]TINUE
C
      [illegible] [illegible]ORT
C
C     [illegible] THE TOP [illegible] OR [illegible]
C
      [illegible] = NB([illegible]
      [illegible]
      IF (IA.EQ.1) [illegible]
      MM = NB([illegible]
      [illegible] J=MM,INB
      IF (AA([illegible]).GE.0.0[illegible]) GO TO [illegible]
      IF (IA.EQ.[illegible] .AND. AA([illegible]).GE.0.01) GO TO 30
      HI([illegible],L,IA) = 0.
      AA([illegible]) = 0.
      NB(L,IA) = NB(L,IA) - 1
30    CONTINUE
      IF (NB(L,IA).EQ.0) RETURN
C
C     IF THE SITE OR GUN MEETS A MINIMUM CRITERIA, TIE IT UP FOR "B"
C     TIME UNITS.
C
      IF (AA(MM).EQ.0) RETURN
      INB = NB(L,IA)
      DO 34 M=MM,INB
      C(1) = HI(M,L,IA)
      C(2) = L
      C(3) = IA
      DO 31 NN=4,8
      C(NN) = 0.
31    CONTINUE
      E = B(C(1))/60.
      CALL SCHDL(7,E,C)
34    CONTINUE
C
C     TEST FOR A KILL. (ATRIB(7)=1 MEANS KILL, ATRIB(7)=0 MEANS NO KILL.)
C
      DO 40 K=MM,INB
      IF (DRAND(1).LE.AA(K)) ATRIB(7)=1
40    CONTINUE
      RETURN
C
C
C     RELEASE THE SITE OR GUN TO FIRE AGAIN.
C
7     L = ATRIB(2)
      IA = ATRIB(3)
      IHI = ATRIB(1)
      INB = NB(L,IA)
      DO 50 J=1,INB
      JM = J
```

```
      [illegible](IA)[illegible] GO TO 55
      [illegible]NUE
C
55    HI([illegible]M,L,IA) = 0
      [illegible] IR8 - 1
      [illegible] K[illegible]
      [illegible] K [illegible]
      HI([illegible],L,I[illegible]) = HI(K[illegible],L,IA)
      [illegible]INU[illegible]
      [illegible](L,IA) = N[illegible](L,IA) - 1
      RE[illegible]RN
      [illegible]ND
C
      SUBROUTINE [illegible]
      [illegible]MMON/[illegible]M[illegible]/ATRIB(100),[illegible](100),DDL([illegible]),[illegible],II,MFA,MSTOP,NCLNR
     +,NCRDR,NPRNT,NN[illegible],NN[illegible],N[illegible]APE,SS(100),[illegible](100),TNEXT,TNOW,XX(100)
      [illegible]MMON/ALL/ PK(25),[illegible](15,9,5),AA([illegible]5),N[illegible](9,2[illegible]),R,A,IA,IC,L,B(25)
      M=NB(L,I[illegible]) + 1
      IR = 4
      K = M + 1
      IF(IA.GT.1) GO TO 5
      IR = 24
      K = M + 4
5     DO 20 I=M,K
      HI(I,L,IA) = 1.
      AA(I) = PK(1)
      DO 10 J=1,IR
      JJ = J+1
      IF (PK(J).GE.PK(JJ)) GO TO 10
      IF (PK(JJ).LE.AA(I)) GO TO 10
      HI(I,L,IA) = JJ
      AA(I) = PK(JJ)
10    CONTINUE
      PK(HI(I,L,IA)) = 0.
20    CONTINUE
      NB(L,IA) = NB(L,IA) + 2
      IF (IA.EQ.1) NB(L,IA) = NB(L,IA) + 3
      RETURN
      END
C
C
      SUBROUTINE PROBKIL
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     +,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON /ALL/ PK(25),HI(15,9,5),AA(25),NB(9,25),R,A,IA,IC,L,B(25)
      DIMENSION ASPECT(37,5), SIGMA(37,3)
      DATA ((ASPECT(I,J),J=1,5),I=1,37)/ 0. ,3.80, 3.04, 3.82,5.79,
     +   5., 1.90, 2.10, 2.64, 4.07,  10., 1.88, 2.69, 3.39, 2.80,
     +  15.,  .84, 2.84, 3.58, 3.36,  20., 1.92, 2.44, 3.07, 2.48,
     +  25., 1.51, 2.68, 3.37, 3.55,  30., 1.27, 6.84, 8.61, 4.10,
     +  35.,  .91, 5.01, 6.31, 1.96,  40., 1.41, 2.98, 3.76, 2.74,
     +  45., 1.89, 3.07, 3.87, 4.68,  50., 1.35, 1.80, 2.26, 3.22,
```

```
     + [illegible] 2.24, [illegible] .79, 1.10, 2.21, 2.60,
     + [illegible] .54, [illegible] 70., [illegible] 5.78,
     + [illegible] 15.35,
     + [illegible] 1.52, 5.55, 44.81, 7.27,
     + [illegible] 100., 7.60, [illegible] 11.48, 15.18,
     + [illegible] 4.40, 110., 3.41, 5.48, [illegible] 6.72,
     + [illegible] 120., 1.31, [illegible] 5.30, 5.56,
     + [illegible] 130., .84, [illegible] 3.36,
     + [illegible] 140., .35, 1.45, 1.87, [illegible] .53,
     + [illegible] 150., [illegible] 2.14, [illegible]
     + [illegible] 2.65, [illegible] 160., [illegible] 2.14, 2.70, [illegible] .16,
     + [illegible] 1.17, [illegible] 170., [illegible] 4.25, 5.36, [illegible] .06,
     + [illegible] 7.00, [illegible] 180., 1.23, 5.56, 7.51, [illegible] .73/
     [illegible] (SIGMA [illegible] /10.75, 3.60, 8.20,
     + 4.75,   .40,  [illegible] 4. [illegible] .55,  1.90,
     + [illegible] 3.4 [illegible] 4. [illegible] 1.70,   .85,
     + [illegible] .75, [illegible] .50,  3.95,  1.20, 10.65,  5.20,
     + 1.65, [illegible] .45,  1.20,  2.15, [illegible] .45,  1.70,
     + 4.70, [illegible] .70, [illegible] 1.75,   .95,  3.10,
     + 1.10, [illegible] .65,  1.00, -4. [illegible] -.95,  1.90,
     +  .40,   .05,   .25, [illegible] 8.45,  8.19,
     + [illegible] .75, 14.55, [illegible] 13.98, [illegible] .35, 16.70,
     + 16.38, 16.00, [illegible] 25.05, 24.98, 24.35,
     + 20.88, 19.95, 19.23, 17.00, 15.75, 16.58,
     + 7.03,  9.20,  5.83,  9.90,  6.73,  9.50,
     + 1.75,  3.65,  6.20,  -.75,  2.33,  7.85,
     + -.23,  3.13,  4.28, -2.33,  3.03,  2.48,
     +  .08, -1.08,  4.35, -1.28, -2.60,  3.90,
     + 1.90,   .50,  6.00,  2.75,   .55,  5.23,
     + 6.55,   .43,  6.93,   .50,   .58,  2.95,
     +  .55,  6.38,  4.73,  4.15,  6.53,  9.93,
     + 4.63,  3.85, 13.50,   .98,  9.48, 15.05/
C
      GO TO (1,2,3,4,5) IA
C   AAA
C    IF AIRCRAFT IS OUT OF RANGE, SET PK(IC)=0.
1     IF (R.GT.1.35) GO TO 99
C    2 G JINK FOR FIRST MINUTE AFTER FEBA PENETRATION, 1.3 G
C    AFTER THAT.
      G = 1.3
      TIME = TNOW - ATRIB(1)
      IF(TIME.LE.1.) G = 2.
      IF (TIME.GT.3.) G = 3.
C   COMPUTE INTERCEPT RANGE IN THOUSANDS OF FEET.
      X = 8.2
      IF ( R.LE..954) X = (R*6.08/.7071)
      IF (R.LE..3488) X = 3.0
C  COMPUTE BULLET VELOCITY AT INTERCEPT AND BULLET TIME OF FLIGHT
      VF = 3050.*EXP(-.1513*X)
      TOF = (6601.76/VF)-2.1645
C   COMPUTE SINGLE SHOT PK.
      DENOM = 6.2832*((20.*X)**2.) + 55.65
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] GO TO 99
[illegible]
[illegible]
[illegible]
[illegible]
  C    [illegible]-B
       [illegible] = [illegible]
       IF (R.[illegible]) GO TO 6
       [illegible]
       RETURN
       IF (R.[illegible]) GO TO [illegible]
       [illegible] = .0
       RETURN
       IF (R.G[illegible]) GO TO 9
       PK(IL) = .029
       IF (XX([illegible].124) PK(IL) = .025
       RETURN
  9    IF (R.GT.1.1 .AND. R.LE.[illegible]) GO TO 7
       GO TO 99
  7    IAA = 5
       SM = 3.5[illegible]
       GO TO 10
  C    [illegible]-B
  4    IF (A.LE.[illegible]30.) GO TO 99
       IF (R.LE.4.3) GO TO 99
       IAA = 3
       TL = UNFRM(2.,4.,1)
       SM = 2.44
       GO TO 10
  C    [illegible]-A
  5    IF (A.LE.1000.) GO TO 99
       IF (R.LE.2.7 .OR. R.GE.1[illegible].4) GO TO 99
       IAA = 2
       TL = 4.
       SM = [illegible].3
       GO TO 10
  C
  C    COMPUTE THE LOOK AHEAD ANGLE
  C
  10   DO 11 I=2,19
       IBB = 20 - I
       RE = R/SIND(ASPECT(IBB,1))
       IF (ASPECT(IBB,IAA).LT.RE) GO TO 12
  11   CONTINUE
  12   ICC = IBB + 1
       RA = (ASPECT(IBB,IAA)*COSD(ASPECT(IBB,1)))-(ASPECT(IBB,IAA)
```

```
[illegible]
[illegible]                                                    + ANG-
[illegible]
      RL = R + 185.
      RDBM = (A-DG10(RL)) + 10.
[illegible]
      GO TO (31,32,33,34,35) JA
[illegible]
72    RJS = 2. + RDBM - 53.4 - SIGMA(JA,2)
      RJ = 10.**(RJS/10.)
      CEP = SQRT(2.1E-7*RJ*RL**2. + 2.2E+3*RJ +50.) *3.28084
      H = (8../CEP)**2.
      PK(IC) = 1. - .5**H
      B(IC)= TI + 30. + UNFRM(15.,30.,1)
      RETURN
C     SAM-D
3     RJS = 2. + RDBM - 52.4 - SIGMA(JA,3)
      RJ = 10.**(RJS/10.)
      CEP = SQRT(3.25E-7*RJ*RL**2. + 1.89E+3*RJ + 25.)*3.28084
      H = (72./CEP)**2.
      PK(IC) = 1. - .5**H
      B(IC)= TI + 20. + UNFRM(8.,20.,1)
31    RETURN
C     SAM-B
4     RJS = 2.*RDBM - 15.4 - SIGMA(JA,2)
      RJ = 10.**(RJS/10.)
      CEP = SQRT(5.62E-6*RJ*RL**2. + 2.5E+3*RJ + 232.) * 3.28084
      H = (143./CEP)**2.
      PK(IC) = 1. - .5**H
      B(IC)= TI + 15. + UNFRM(10.,22.,1)
      RETURN
C     SAM-A
35    RJS = 2. + RDBM - 46.2 - SIGMA(JA,1)
      RJ = 10.**(RJS/10.)
      CEP = SQRT(2.52E-5*RJ*RL**2. + 9.61E+3*RJ+671.)*3.28084
      H = (185./CEP)**2.
      PK(IC) = 1. - .5**H
```

[illegible]

```
[illegible]
4[illegible]      ACT[illegible]XX[illegible]AAA;
[illegible]       ASSIGN,A[illegible];
[illegible]       ACT,,XX[illegible],,,AAA;
4[illegible]      EVENT,[illegible];
4[illegible]=     ACT,,ATRIB[illegible].EQ.1,,AAA;
4[illegible]0=    ACT,,ATRIB[illegible].EQ.3[illegible];
4720=             ACT,,A[illegible].EQ.2[illegible];
4[illegible]      ACT,,ATR[illegible].EQ.3[illegible];
4[illegible]0=    ACT,,ATRIB[illegible].EQ.4,B[illegible];
4740=             ACT,,ATRIB(2)[illegible].5,[illegible];
4[illegible]0=    ACT,,ATRIB(2).EQ.6,E[illegible];
4[illegible]0=    ACT,,AT[illegible](2).EQ.7,D[illegible];
4[illegible]0=    ACT,,AT[illegible].EQ.8,B10;
4[illegible]0=    ACT,,ATR[illegible](2).EQ.9,SC[illegible];
4790=E1           ASSIGN,A[illegible]IB(2)=2.;
4800=             ACT,XX([illegible]).5,,AAA;
4810=;
4[illegible]=B[illegible] ASSIGN,ATRIB(4)=1.,ATRIB(5)=1.;
4[illegible]0=    ACT,XX(2)[illegible].5,,,AMC;
4[illegible]0=SAMC EVENT,3,1;
4850=             ACT,,ATRIB(7).EQ.1,,SAC;
4[illegible]0=    ACT,,ATRIB(5).EQ.[illegible],AMC;
4[illegible]0=    ACT,,,AAA;
4[illegible]0=SAMD EVENT,4,1;
4[illegible]0=    ACT,,ATRIB(7).EQ.1,,SAD;
4[illegible]0=    ACT,,ATRIB(4).EQ.1,B[illegible];
4[illegible]0=    ACT,,,AA[illegible];
4[illegible]0=;
4[illegible]0=B5  ASSIGN,ATRIB(2)=4.,ATRIB(5)=2.;
4940=             ACT,XX(2)[illegible],,,SAMC;
4950=B6           ASSIGN,ATRIB([illegible])=5.,ATRIB([illegible])=1.;
4[illegible]0=    ACT,XX(2)[illegible],,,AMB;
4970=SAMB         EVENT,5,1;
4[illegible]0=    ACT,,ATRIB(7).EQ.1,,SAE;
4990=             ACT,,,AAA;
5000=B7           ASSIGN,ATRIB(2)=[illegible],ATRIB(5)=[illegible];
5010=             ACT,XX(2)[illegible]2.,,,AMC;
```

```
[illegible]      A[illegible]GN[illegible]
[illegible]      A[illegible]),,,SAME;
[illegible]      A[illegible]
[illegible]      ACT[illegible],,,SAME;
[illegible];
[illegible]      AS[illegible]1.;
[illegible]      A[illegible],,,SAM[illegible];
[illegible]
[illegible]      ACT,,,[illegible].EQ.1[illegible]AA;
[illegible]      ACT,,[illegible].EQ.1[illegible];
[illegible]      ACT,,,[illegible];
[illegible]      A[illegible]9.;
[illegible]      A[illegible]1),,,AAA;
[illegible]      A[illegible];
[illegible]      ACT,,,[illegible],,,SAMA;
[illegible]
[illegible]      AS[illegible]XX(6)+1.;
[illegible]      COLCT,XX(6),TOTAL SURVIVED;
5[illegible]0=      TERM;
5210=;
5220=KAAA  ASSIGN,XX(8)=XX(8)+1.;
5230=      COLCT,XX(8),AAA KILLS;
5240=      ACT,,,KILL;
5250=KSAC  ASSIGN,XX(11)=XX(11)+1.;
5260=      COLCT,XX(11),SAM C KILLS;
5270=      ACT,,,KILL;
5280=KSAD  ASSIGN,XX(10)=XX(10)+1.;
5290=      COLCT,XX(10),SAM D KILLS;
5300=      ACT,,,KILL;
5310=KSAE  ASSIGN,XX(12)=XX(12)+1.;
5320=      COLCT,XX(12),SAM E KILLS;
5330=      ACT,,,KILL;
5340=KSAA  ASSIGN,XX(9)=XX(9)+1.;
5350=      COLCT,XX(9),SAM A KILLS;
5360=      ACT,,,KILL;
5370=;
5380=KILL  ASSIGN,XX(7)=XX(7)+1.;
5390=      COLCT,XX(7),TOTAL KILLS;
5400=      TERM;
5410=      ENDNETS;
5420=INIT,0.;
5430=INTLC,XX(2)=.125,XX(14)=.25,XX(1)=1000.,XX(4)=6.25;
5440=SIMULATE;
5450=SIMULATE;
5460=SIMULATE;
5470=SIMULATE;
5480=SIMULATE;
5490=INTLC, XX(2)=.111111111111;
5500=SIMULATE;
5510=SIMULATE;
5520=SIMULATE;
5530=SIMULATE;
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]LATE;
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
5[illegible]0=INTLC,XX(1)=500.;
5[illegible]40=[illegible]MULATE;
5[illegible]SIMULATE;
5[illegible]0=[illegible]LATE;
5[illegible]70=SIMULATE;
5[illegible]0=SIMULATE;
5[illegible]90=INTLC,XX(4)=3.0;
5[illegible]0=SIMULATE;
5[illegible]0=SIMULATE;
5[illegible]20=SIMULATE;
5[illegible]30=SIMULATE;
5[illegible]40=SIMULATE;
5[illegible]50=INTLC,XX(1)=1000.;
5[illegible]60=SIMULATE;
5[illegible]70=SIMULATE;
5[illegible]80=SIMULATE;
5[illegible]90=SIMULATE;
5[illegible]0=SIMULATE;
5[illegible]10=INTLC,XX(2)=.111111111111;
5[illegible]20=SIMULATE;
5[illegible]30=SIMULATE;
5[illegible]40=SIMULATE;
5[illegible]50=SIMULATE;
5[illegible]60=SIMULATE;
5[illegible]70=INTLC,XX(1)=500.;
[illegible]0=SIMULATE;
5[illegible]90=SIMULATE;
6[illegible]00=SIMULATE;
6[illegible]10=SIMULATE;
[illegible]20=SIMULATE;
6[illegible]0=INTLC,XX(1)=250.;
6[illegible]40=SIMULATE;
6[illegible]50=SIMULATE;
```

The sample output shown below is from the **first run** of the model (all factors at level one):

```
                                S L A M   S U M M A R Y   R E P O R T


                         SIMULATION PROJECT THESIS NETWORK          BY LEEK AND SCHMITT

                         DATE 11/20/1980                            RUN NUMBER    1 OF   60


                         CURRENT TIME    .2199E+02
                         STATISTICAL ARRAYS CLEARED AT TIME  0.



                         **STATISTICS FOR VARIABLES BASED ON OBSERVATION**

                    MEAN         STANDARD      COEFF. OF     MINIMUM       MAXIMUM       NUMBER OF
                    VALUE        DEVIATION     VARIATION     VALUE         VALUE         OBSERVATIONS

TOTAL SURVIVED     .5500E+01     .3028E+01     .5505E+00     .1000E+01     .1000E+02          10
AAA KILLS          .3000E+01     .1581E+01     .5270E+00     .1000E+01     .5000E+01           5
SAM C KILLS                        NO VALUES RECORDED
SAM D KILLS        .3000E+01     .1581E+01     .5270E+00     .1000E+01     .5000E+01           5
SAM B KILLS                        NO VALUES RECORDED
SAM A KILLS                        NO VALUES RECORDED
TOTAL KILLS        .5500E+01     .3028E+01     .5505E+00     .1000E+01     .1000E+02          10
```

Appendix C

RANGES Computer Program

This program computes the maximum range at which each of the defensive systems in the model can see the fighter, assuming the J/S ratio must be 20 or less for the fighter to be seen. The input data for the program, Tape 1, are the radar cross-sections given in Table V. The output of the program is shown in Table VI.

```
      PROGRAM RANGES(INPUT,OUTPUT,TAPE1,TAPE2)
C
C
       DIMENSION RNG(37,5),XSCTN(37,4)
       DATA RNG,XSCTN/333*0./
C
C
 100   FORMAT(F4.0,3F7.2)
 150   FORMAT(////,21X,"DETECTION RANGE (IN NM)")
 200   FORMAT(//,3X,"ASPECT (DEGREES)",5X,"AAA",5X,"SAM-A",5X,
      *"SAM-B",5X,"SAM-C",5X,"SAM-D",/)
 250   FORMAT(9X,F4.0,8X,F6.2,3X,4(F6.2,4X))
C
C
C  READ ASPECT ANGLE AND ASSOCIATED RADAR CROSS-SECTIONS.
       DO 10 I=1,37
       READ (1,100) (XSCTN(I,J),J=1,4)
 10    CONTINUE
C
C
       DO 20 I=1,37
C
C  COMPUTE AAA DETECTION RANGE.
       DBAAA = 34.3 + (.5 * XSCTN(I,4))
       RNG(I,1) = (10. ** (DBAAA/10.))/1852.
C
C  COMPUTE SAM-A DETECTION RANGE.
       DBSAMA = 33.1 + (.5 * XSCTN(I,2))
       RNG(I,2) = (10. ** (DBSAMA/10.))/1852.
```

```
C
C     COMPUTE SAM-B DETECTION RANGE.
      DBSAMB = [illegible].7 + 1.5 * XSCTN(I,[illegible])
      RNG(I,3) = (10. ** (DBSAMB/10.))/1852.
C
C     COMPUTE SAM-C DETECTION RANGE.
      DBSAMC = [illegible].7 + 1.5 * XSCTN(I,[illegible])
      RNG(I,4) = (10. ** (DBSAMC/10.))/1852.
C
C     COMPUTE SAM-D DETECTION RANGE.
      DBSAMD = 36.[illegible] + 1.5 * XSCTN(I,4))
      RNG(I,5) = (10. ** (DBSAMD/10.))/1852.
   20 CONTINUE
C
C
      PRINT 150
      PRINT 200
      DO 30 I=1,37
      PRINT 250,XSCTN(I,1),(RNG(I,J),J=1,5)
      WRITE (2,250) XSCTN(I,1),(RNG(I,J),J=1,5)
   30 CONTINUE
C
C
      STOP
      END
```

Appendix D

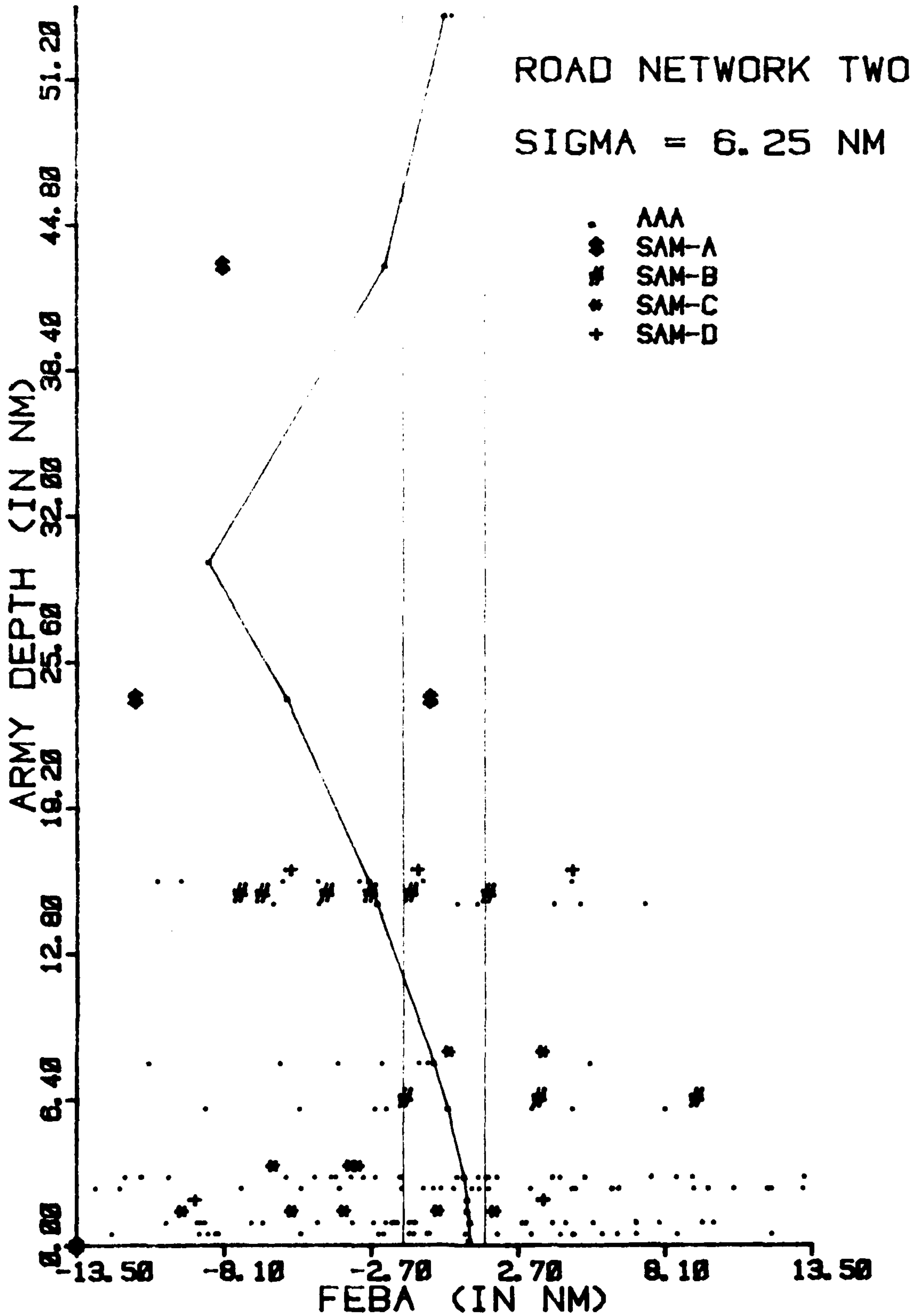
Defensive Arrays

The defensive array shown below was computed using road network two and a standard deviation of 6.25 NM. The locations of the AAA sites in belt five of this output were used in the statistical testing described in Appendix H.

```
                              DEFENSIVE ARRAY



BELT  1

     AAA

  4.76  -8.31  -2.24  -1.13   4.74 -12.21  -6.69   6.35   4.25  12.03
 -8.42   1.94  -2.43   7.05   8.57  [illegible]  -9.02  -9.39   4.71    .76
 -5.29   3.19   -.56   5.80   -.65



BELT  2

     AAA

 -8.82   2.98  -6.70   1.09  -1.14   2.80  -4.68   7.04  -2.63  -8.99
 -1.75   7.88  -9.11   5.45   3.41   4.44  -2.1[illegible]   9.47  -1.32  -7.12
-10.24  -1.96   9.87  -1.06   3.95
```

```
[illegible]
[illegible]=       -[illegible]  [illegible]  [illegible]   -.42   -[illegible] -7.48   -.14   3.15   6.15   9.16
[illegible]=       [illegible]    [illegible] -[illegible] -[illegible]  [illegible]  1.26 -11.93  -1.58   9.69   6.39
[illegible]=       [illegible]    .99 10.6[illegible]   4.80  [illegible]
[illegible]=
[illegible]=
[illegible]=
[illegible]=  [illegible]
[illegible]=
[illegible]40=       A[illegible]
[illegible]50=
[illegible]=     [illegible]  5.1[illegible] -4.7[illegible] -10.15  -2.98   4.24  -5.82   1.60   7.61 -11.74
[illegible]70=     [illegible]  [illegible]  [illegible]    .44  -1.66   1.52   9.11  -2.56  -4.17 -11.12
[illegible]=     -[illegible] -[illegible]1.16  13.[illegible]   8.52  -4.00
[illegible]=
[illegible]=       [illegible]
[illegible]=
[illegible]=     -[illegible].4[illegible]  -6.30  -3.[illegible]
[illegible]=
[illegible]340=
[illegible]=
[illegible]=  BE[illegible]
[illegible]=
[illegible]=       SAM-B
[illegible]=
[illegible]=     [illegible]  -1.45   [illegible].47
[illegible]10=
[illegible]=       AAA
[illegible]=
[illegible]40=     4.6[illegible]  -2.15   [illegible].20  -5.34   8.11  -2.57  -8.80
[illegible]=
```

```
[illegible]
...
[illegible]          AAA
[illegible]
[illegible]      .22   [illegible]   [illegible]  [illegible].57   [illegible]   [illegible].5  -2.90
[illegible]
[illegible]
[illegible]
[illegible]   BELT [illegible]
[illegible]
[illegible]       SAM-B
[illegible]
[illegible]    [illegible]  -4.[illegible]  -1.25   [illegible]0  -2.74  -6.71
[illegible]
0360=       AAA
0370=
0380=   [illegible]  -4.[illegible]   4.07   1.19   7.37    .46   4.99
0390=
0400=
0410=
0420=   BELT  9
0430=
0440=       SAM-D
0450=
0460=     -.98  -5.66   4.71
0470=
0480=       AAA
0490=
0500=    -3.14   4.67  -9.69   -.80  -5.96  -4.66 -10.57
0510=
0520=
0530=
0540=   BELT 10
0550=
0560=       SAM-A
0570=
0580=   -11.37   -.53
0590=
0600=
0610=
0620=   BELT 11
0630=
0640=       SAM-A
0650=
0660=    -8.15
0670=
0680=
0690=
0700=   TARGET AREA
0710=
0720=       AAA
0730=
0740=      .29
```



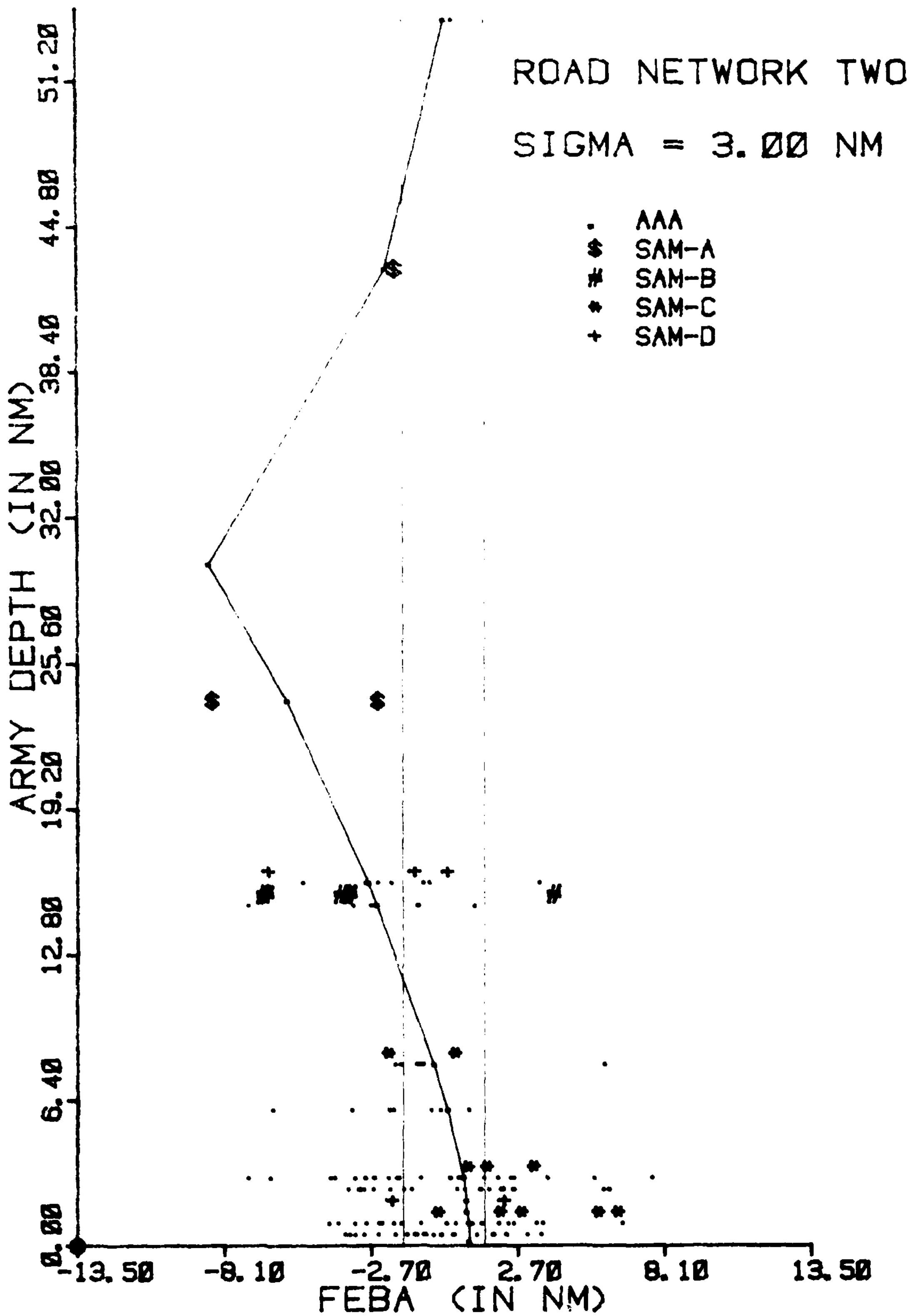
ROAD NETWORK TWO
SIGMA = 6.25 NM
AAA
SAM-A
SAM-B
SAM-C
SAM-D
ARMY DEPTH (IN NM)
51.20
44.80
38.40
32.00
25.60
19.20
12.80
6.40
0.00
-13.50
-8.10
-2.70
2.70
8.10
13.50
FEBA (IN NM)

The defensive array shown below was computed using road network two and a standard deviation of 3.0 NM. The locations of the AAA sites in belt four of this output were used in part of the statistical testing described in Appendix H.

```
6200                      DEFENSIVE ARRAY
6210=
6220=
6230=
6240=  BELT 1
6250=
6260=     AAA
6270=
6280=    [illegible] -1.39 [illegible] -2.98  1.75 -3.31  -.42  -.79  -.12  2.25
6290=   -1.12  -.79  1.81  2.55  3.04  1.17 -1.03 -3.67   .36 -1.83
6300=   -2.45  -.69 -3.50  1.75  -.15
6310=
6320=
6330=
6340=  BELT 2
6350=
6360=     AAA
6370=
6380=    3.61 -2.42   .08   .05  6.55  3.38 -3.92  2.54   .88   .40
6390=    4.26 -2.30 -1.61  1.99   .67  1.37 -2.89  1.02  2.34  -.88
6400=    1.34 -3.31   .64  1.99 -1.86
6410=
6420=
6430=
6440=  BELT 3
6450=
6460=     SAM-C
6470=
6480=    -.40  2.07  5.68  -.23  2.85
6490=
6500=     SAM-B
6510=
6520=    1.72  2.21
6530=
```

```
[illegible]
[illegible]    [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  6.46  [illegible].57  [illegible].63    .46
[illegible]    [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
[illegible]
[illegible]    [illegible]  5.57  [illegible]  [illegible]  [illegible]  [illegible]  3.80  -2.60  7.66  -6.40
[illegible]    [illegible]  -2.57  [illegible]  2.44  [illegible]  -.87  -2.90  1.97  2.56    .72
[illegible]    [illegible]  4.1[illegible]  4.04  2.92    .53
[illegible]        SAM-C
[illegible]
[illegible]=   3.91   1.58     .88
6770=
6780=
6790=
6800=   BELT  6
6810=
6820=        SAM-B
6830=
6840=   -1.24    .63  -1.03
6850=
6860=        AAA
6870=
6880=     .69  -2.04    -.15    -.49  -6.33  -1.89  -3.42
6890=
6900=
6910=
6920=   BELT  7
6930=
6940=        SAM-C
6950=
6960=   -2.04    .41
6970=
6980=        AAA
6990=
7000=     -.92    -.93    -.77  -1.81  -1.62  -1.01   5.91
```

```
BELT [illegible]

    SAM [illegible]

 [illegible]

    AAA

 [illegible]  .58  [illegible]  -.95  [illegible]

BELT [illegible]

    SAM [illegible]

 -1.[illegible]  [illegible]  [illegible]

    AAA

 -2.90  [illegible]  -1.94  [illegible].43  [illegible].52  -.54  -.77

BELT 10

    SAM-A

 -2.44  -0.55

BELT 11

    SAM-A

 -1.93

TARGET AREA

    AAA

 .7[illegible]
```

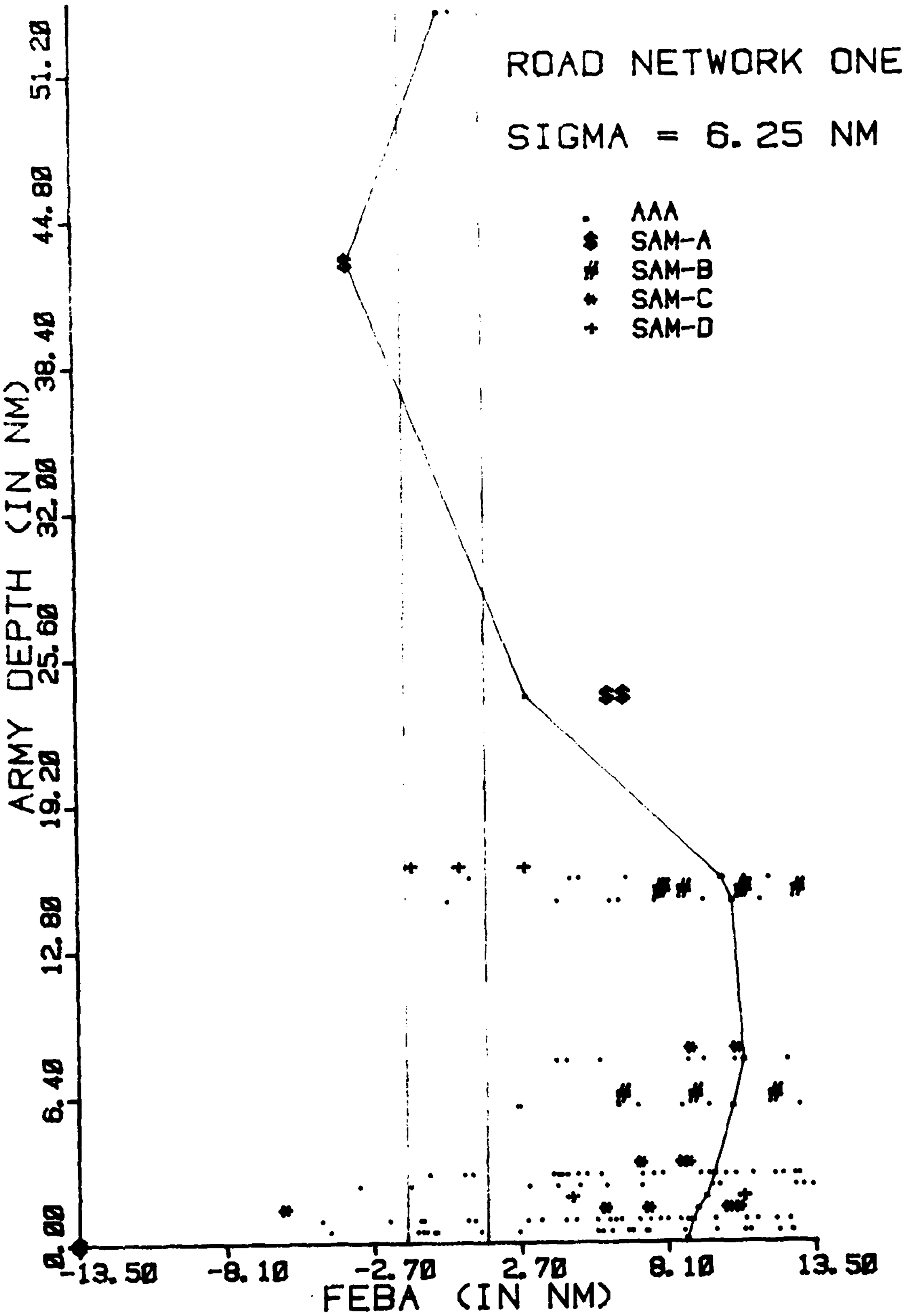

ROAD NETWORK TWO
SIGMA = 3.00 NM
AAA
SAM-A
SAM-B
SAM-C
SAM-D
ARMY DEPTH (IN NM)
0.00
6.40
12.80
19.20
25.60
32.00
38.40
44.80
51.20
FEBA (IN NM)
-13.50
-8.10
-2.70
2.70
8.10
13.50

The following defensive array is for road network one and a standard deviation of 6.25 NM.

```
[illegible]                 [illegible]
[illegible]
[illegible]
[illegible]
[illegible]  BELT [illegible]
[illegible]
[illegible]     [illegible]
[illegible]
[illegible]0=  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  .57  9.84
[illegible]0=  5.4[illegible]  [illegible]  [illegible]  .4[illegible]  [illegible]  [illegible]  [illegible]  [illegible]  7.34  7.[illegible]
[illegible]  [illegible]  10.[illegible]  [illegible]  [illegible].01  6.[illegible]
[illegible]0=
[illegible]0=
[illegible]
[illegible]10=  BELT [illegible]
[illegible]20=
[illegible]0=    AA[illegible]
[illegible]0=
[illegible]50=  10.[illegible]  3.4[illegible]  5.47  -.99  [illegible]  -1.01  4.[illegible]9  12.54  5.92  6.78
9660=   .[illegible]  -2.14  [illegible].14  7.0[illegible]  [illegible]  4.31  7.[illegible]  7.41  .72  8.06
[illegible]70=  11.[illegible]  8.52  [illegible]  -4.5[illegible]  [illegible]
9680=
9690=
9700=
[illegible]10=  BELT [illegible]
[illegible]20=
[illegible]30=    SAM-[illegible]
[illegible]40=
[illegible]50=  -5.[illegible]  5.79  10.[illegible]  10.6[illegible]  7.37
[illegible]60=
[illegible]70=    SAM-D
[illegible]80=
9790=   4.58  10.09
9800=
[illegible]10=
9820=
[illegible]30=  BELT 4
[illegible]40=
[illegible]50=    AAA
9860=
[illegible]70=   9.[illegible]  -[illegible]  7.[illegible]  1[illegible]  9.69  4.84  12.76  4.02  -1.35  5.82
[illegible]80=  1[illegible].04  2.98  10.40  -2.[illegible]  5.[illegible]  1[illegible].03  10.72  9.24  7.14  10.32
[illegible]90=   6.[illegible]4  4.63  -[illegible]  7.[illegible]  2.[illegible]
```

```
[illegible]

[illegible]

[illegible]  7.[illegible]  [illegible]  [illegible]  [illegible]  .40  4.[illegible]  4.77  10.56  [illegible].29
[illegible]  [illegible]  [illegible]  3.40  [illegible]  [illegible]  [illegible].00  7.[illegible]  7.[illegible]  4.17
[illegible]  7.[illegible]  [illegible]  4.[illegible]  [illegible]

[illegible]

[illegible]  [illegible]  [illegible].36

BELT 6

    SAM-B

[illegible].05  6.4[illegible]  [illegible]

    AAA

[illegible].99  8.60  9.60  7.58  12.92  2.70  6.28

BELT 7

    SAM-C

8.97  10.64

    AAA

12.48  9.42  5.60  4.39  8.85  10.56  4.01

BELT 8

    SAM-B

[illegible].74  10.97  7.87  12.92  10.86  7.98

    AAA

[illegible].64  4.07  6.00  11.52  9.43  .04  6.33
```

```
[illegible]
[illegible]
[illegible]   10.?4   .25   [illegible]   4.54   11.?4
[illegible]
[illegible]   5.9?
0640=
0610=
[illegible]
0630=   BELT 11
[illegible]
0650=      SAM-A
[illegible]
0670=   -?.46
[illegible]
[illegible]
0700=
0710=   TARGET AREA
0720=
0730=      AAA
0740=
[illegible]      .4?
```



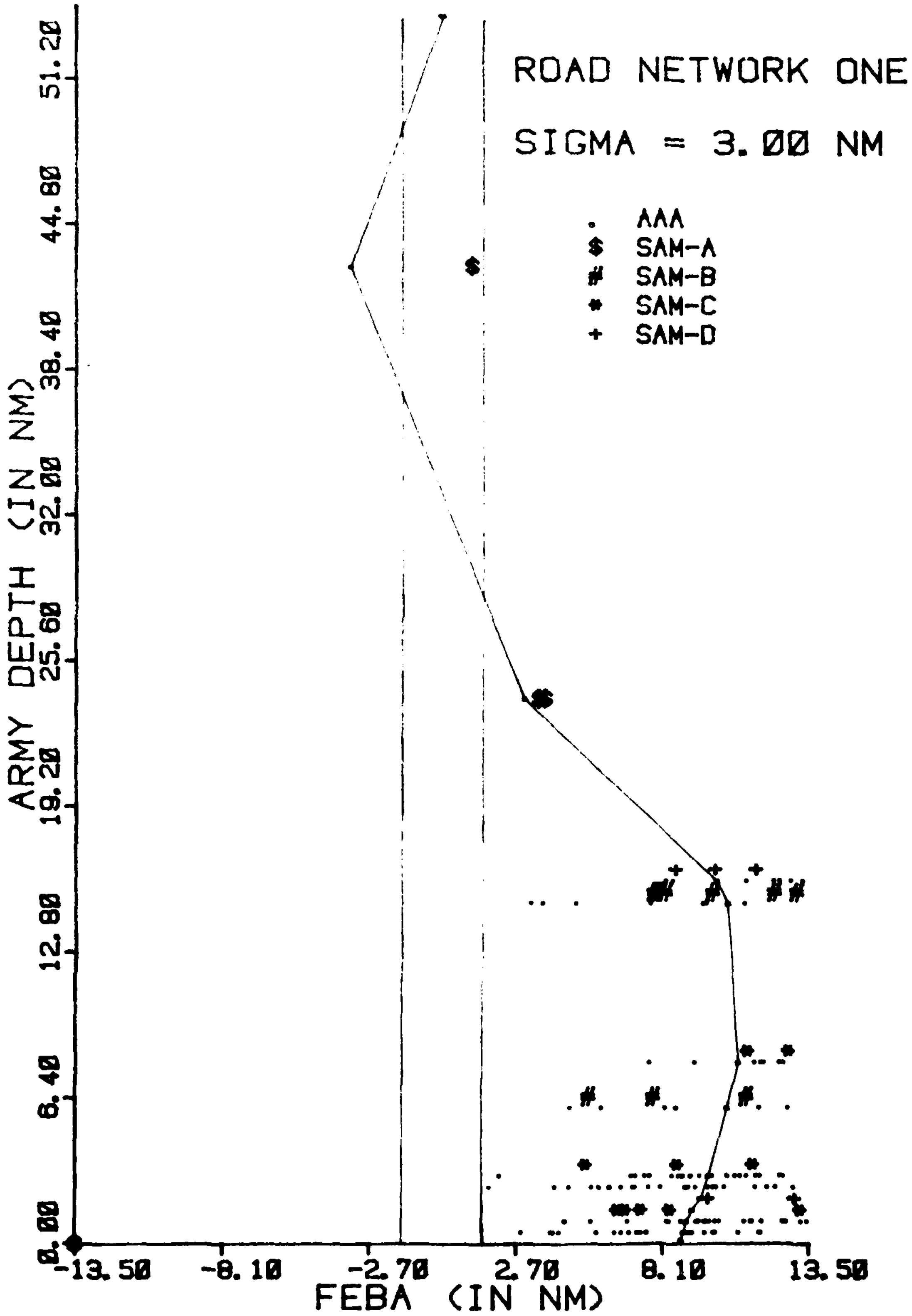
ROAD NETWORK ONE
SIGMA = 6.25 NM
AAA
SAM-A
SAM-B
SAM-C
SAM-D
ARMY DEPTH (IN NM)
51.20
44.80
38.40
32.00
25.60
19.20
12.80
6.40
0.00
-13.50
-8.10
-2.70
2.70
8.10
13.50
FEBA (IN NM)

The following defensive array is for road network one and a standard deviation of 3.0 NM.

```
                  [illegible]

[illegible]   [illegible]   [illegible]   4.[illegible]   [illegible]   [illegible]   3.98   7.17   4.07  11.73
[illegible]   [illegible]   [illegible]   3.[illegible]   [illegible]   [illegible]   9.98   7.50   8.84   9.21
[illegible]   [illegible]   [illegible]   1[illegible]   5.[illegible]

BELT 2

   AAA

[illegible]   9.65   [illegible]   8.36   [illegible]  12.54  11.42   4.49   9.71  11.37
[illegible]   9.04   [illegible]   8.[illegible]   [illegible]  10.06   6.80   9.71  11.13   9.44
 6.82  13.22  10.20  11.77   5.47

BELT 3

   SAM-C

13.[illegible]   7.30   6.72   6.43   6.37

   SAM-B

 7.79  12.98

BELT 4

   AAA

 [illegible]   9.05  12.26  11.95   6.15   9.77   5.74   6.12   7.00   9.95
 [illegible]   9.[illegible]   6.56   7.50   4.11   5.76  10.38   4.63   8.96  11.52
 8.87  12.92   7.07   1.67  10.08
```

```
[illegible]

     AAA

     [illegible]  [illegible]  [illegible].94  [illegible]  [illegible].43  [illegible]  [illegible]  [illegible]  7.62  [illegible].54
     [illegible].61  [illegible]  [illegible].77  [illegible]  [illegible].44  [illegible]  [illegible].34  7.1[illegible]  12.55  [illegible].50
     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

     AM[illegible]

     [illegible]  [illegible]  [illegible]



BELT 6

     SAM-E

     [illegible].77   5.38  11.21

     AAA

     4.69   5.85   8.63   8.59  12.73   8.20  11.68



BELT 7

     SAM-C

    1[illegible].76  11.24

     AAA

    12.41   9.26  11.83   7.62  11.49  11.73  12.56



BELT 8

     SAM-B

     7.69   8.21   7.77   9.94  13.04  12.21

     AAA

     9.70   4.90  11.11   3.[illegible]   3.67   7.64   9.58
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]   12.[illegible]
[illegible]
[illegible]
[illegible]
[illegible]   1.[illegible]   .4[illegible]   [illegible]   [illegible]   [illegible].40   1.[illegible]   13.[illegible]
[illegible]
[illegible]
[illegible]
5[illegible]70   [illegible]
[illegible]
[illegible]        SAM A
5[illegible]00=
[illegible]10=     3.5[illegible]   [illegible].77
5[illegible]20=
5[illegible]30=
5[illegible]40=
5[illegible]50=   BELT 11
[illegible]60=
5870=        SAM-A
5[illegible]80=
5[illegible]90=     1.06
5[illegible]00=
5910=
5920=
5930=   TARGET AREA
5940=
5[illegible]50=        AAA
5[illegible]60=
5[illegible]70=     -.13
```



ROAD NETWORK ONE
SIGMA = 3.00 NM
AAA
SAM-A
SAM-B
SAM-C
SAM-D
ARMY DEPTH (IN NM)
51.20
44.80
38.40
32.00
25.60
19.20
12.80
6.40
0.00
-13.50
-8.10
-2.70
2.70
8.10
13.50
FEBA (IN NM)

Appendix F

Five-Way ANOVA

The SPSS program for the five-way ANOVA is listed below, along with the data, which consists of the results of all 240 simulation runs. The first five entries on each data line are the levels at which the LOC network, aircraft arrival rate, aircraft velocity, aircraft altitude, and standard deviation of the defensive array were tested. The sixth entry is the number of aircraft that survived.

```
100=RUN NAME        AIRCRAFT SURVIVAL
110=VARIABLE LIST   NET,RATE,VEL,ALT,SIGMA,SURVIVAL
120=N OF CASES      240
130=INPUT MEDIUM    CARD
140=INPUT FORMAT    FREEFIELD
150=ANOVA           SURVIVAL BY NET,RATE,VEL(1,2),ALT(1,3),SIGMA(1,2)
160=STATISTICS      ALL
170=READ INPUT DATA
```

```
180=1 1 1 1 1 16        330=1 1 2 3 1 14
190=1 1 1 1 1 12        340=1 1 2 3 1 16
200=1 1 1 1 1 12        350=1 1 2 3 1 17
210=1 1 1 1 1 12        360=1 1 2 3 1 18
220=1 1 1 1 1 17        370=1 1 2 3 1 14
230=1 1 2 1 1 13        380=1 1 1 3 1 16
240=1 1 2 1 1 12        390=1 1 1 3 1 15
250=1 1 2 1 1 11        400=1 1 1 3 1 17
260=1 1 2 1 1 16        410=1 1 1 3 1 15
270=1 1 2 1 1 13        420=1 1 1 3 1 19
280=1 1 2 2 1 19        430=1 1 1 2 1 13
290=1 1 2 2 1 11        440=1 1 1 2 1 16
300=1 1 2 2 1 15        450=1 1 1 2 1 14
310=1 1 2 2 1 14        460=1 1 1 2 1 12
320=1 1 2 2 1 12        470=1 1 1 2 1 17
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
640=1 1 2 2 2 20
650=1 1 2 2 [illegible] 16
660=1 1 2 2 2 19
670=1 1 2 2 2 20
680=1 1 2 3 2 19
690=1 1 2 3 2 20
700=1 1 [illegible] 3 2 19
710=1 1 2 3 2 20
720=1 1 2 3 2 20
730=1 1 1 3 2 20
740=1 1 1 3 2 20
750=1 1 1 3 2 20
760=1 1 1 3 2 17
770=1 1 1 3 2 20
780=1 2 1 1 1 3
790=1 2 1 1 1 8
800=1 2 1 1 1 12
810=1 2 1 1 1 11
820=1 2 1 1 1 12
830=1 2 2 1 1 10
840=1 2 2 1 1 7
850=1 2 2 1 1 5
860=1 2 2 1 1 13
870=1 2 2 1 1 5
880=1 2 2 2 1 12
890=1 2 2 2 1 8
900=1 2 2 2 1 12
910=1 2 2 2 1 12
920=1 2 2 2 1 16
930=1 2 2 3 1 19
940=1 2 2 3 1 19
950=1 2 2 3 1 16
960=1 2 2 3 1 11
970=1 2 2 3 1 14
980=1 2 1 3 1 13
990=1 2 1 3 1 20
1000=1 2 1 3 1 13

[illegible] 10
[illegible] 11
[illegible] 6
[illegible] 1 7
[illegible]
[illegible] 13
1070=1 2 1 [illegible] 11
[illegible] 17
1090=1 [illegible] 15
1100=1 [illegible] 19
1110=1 2 1 [illegible] 16
1120=1 2 1 [illegible] 16
1130=1 [illegible] 1 1 [illegible]
1140=1 2 1 1 [illegible] 19
1150=1 [illegible] 1 1 [illegible] 20
1160=1 2 1 1 2 16
1170=1 2 1 1 2 17
1180=1 2 2 1 2 19
1190=1 2 2 1 2 19
1200=1 2 2 1 2 18
1210=1 2 2 1 2 18
1220=1 2 2 1 2 15
1230=1 2 2 2 2 18
1240=1 2 2 2 2 18
1250=1 2 2 2 2 17
1260=1 2 2 2 2 18
1270=1 2 2 2 2 20
1280=1 2 2 3 2 20
1290=1 2 2 3 2 20
1300=1 2 2 3 2 20
1310=1 2 2 3 2 20
1320=1 2 2 3 2 19
1330=1 2 1 3 2 19
1340=1 2 1 3 2 17
1350=1 2 1 3 2 20
1360=1 2 1 3 2 20
1370=1 2 1 3 2 19
1380=2 1 1 1 1 7
1390=2 1 1 1 1 9
1400=2 1 1 1 1 6
1410=2 1 1 1 1 8
1420=2 1 1 1 1 9
1430=2 1 2 1 1 6
1440=2 1 2 1 1 5
1450=2 1 2 1 1 7
1460=2 1 2 1 1 10
1470=2 1 2 1 1 10
1480=2 1 2 2 1 8
1490=2 1 2 2 1 5
1500=2 1 2 2 1 9
1510=2 1 2 2 1 13
1520=2 1 2 2 1 15
1530=2 1 2 3 1 13
```

```
[illegible] 14
[illegible] 1 10
[illegible] 1 14
[illegible]
[illegible] 10
[illegible] 1 1 1 6
[illegible]
[illegible] 14
[illegible] 1 1
[illegible] 1 2
[illegible] 1 5
[illegible] 1 1 2 1 7
[illegible] 1 2 1 11
1670=2 1 1 2 1 [illegible]
1680=2 1 1 2 2 [illegible]
1690=2 1 1 2 2 2
1700=2 1 1 2 2 [illegible]
1710=2 1 1 2 2 5
1720=2 1 1 2 2 7
1730=2 1 1 1 2 3
1740=2 1 1 1 2 4
1750=2 1 1 1 2 8
1760=2 1 1 1 2 3
1770=2 1 1 1 2 2
1780=2 1 2 1 2 6
1790=2 1 2 1 2 2
1800=2 1 2 1 2 1
1810=2 1 2 1 2 6
1820=2 1 2 1 2 3
1830=2 1 2 2 2 2
1840=2 1 2 2 2 2
1850=2 1 2 2 2 6
1860=2 1 2 2 2 11
1870=2 1 2 2 2 4
1880=2 1 2 3 2 10
1890=2 1 2 3 2 7
1900=2 1 2 3 2 6
1910=2 1 2 3 2 9
1920=2 1 2 3 2 8
1930=2 1 1 3 2 7
1940=2 1 1 3 2 4
1950=2 1 1 3 2 8
1960=2 1 1 3 2 4
1970=2 1 1 3 2 10
1980=2 2 1 1 1 2
1990=2 2 1 1 1 2
2000=2 2 1 1 1 4
2010=2 2 1 1 1 5
2020=2 2 1 1 1 5
2030=2 2 2 1 1 3
2040=2 2 2 1 1 2
2050=2 2 2 1 1 2
2060=2 2 2 1 1 2
[illegible] 2 2 1 1 [illegible]
2080=2 2 2 2 1 1
2090=2 2 2 2 1 4
2100=2 2 2 2 1 8
2110=2 2 2 2 1 9
2120=2 2 2 2 1 4
2130=2 2 2 2 1 9
2140=2 2 2 3 1 13
2150=2 2 2 3 1 11
2160=2 2 2 3 1 11
2170=2 2 2 3 1 13
2180=2 2 1 [illegible] 1 8
2190=2 2 1 3 1 9
2200=2 2 1 3 1 11
2210=2 2 1 3 1 5
2220=2 2 1 3 1 10
2230=2 2 1 2 1 7
2240=2 2 1 2 1 5
2250=2 2 1 2 1 4
2260=2 2 1 2 1 11
2270=2 2 1 2 1 5
2280=2 2 1 2 2 4
2290=2 2 1 2 2 2
2300=2 2 1 2 2 2
2310=2 2 1 2 2 2
2320=2 2 1 2 2 2
2330=2 2 1 1 2 3
2340=2 2 1 1 2 0
2350=2 2 1 1 2 1
2360=2 2 1 1 2 1
2370=2 2 1 1 2 3
2380=2 2 2 1 2 3
2390=2 2 2 1 2 2
2400=2 2 2 1 2 5
2410=2 2 2 1 2 2
2420=2 2 2 1 2 4
2430=2 2 2 2 2 3
2440=2 2 2 2 2 1
2450=2 2 2 2 2 3
2460=2 2 2 2 2 2
2470=2 2 2 2 2 3
2480=2 2 2 3 2 6
2490=2 2 2 3 2 2
2500=2 2 2 3 2 5
2510=2 2 2 3 2 2
2520=2 2 2 3 2 5
2530=2 2 1 3 2 2
2540=2 2 1 3 2 3
2550=2 2 1 3 2 6
2560=2 2 1 3 2 4
2570=2 2 1 3 2 6
2580=FINISH
```

The overall results of the ANOVA are given below. Statistically significant main effects and interactions are underlined.

```
* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
              SURVIVAL
           BY NET
              RATE
              VEL
              ALT
              SIGMA
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			6669.325	6	1111.554	213.846	.001
NET			5733.037	1	5733.037	1102.949	.001
RATE			352.837	1	352.837	67.881	.001
VEL			10.004	1	10.004	1.925	.167
ALT			516.408	2	258.204	49.675	.001
SIGMA			57.037	1	57.037	10.973	.001
2-WAY INTERACTIONS			1828.425	14	130.602	25.126	.001
NET	RATE		13.538	1	13.538	2.604	.108
NET	VEL		.937	1	.937	.180	.672
NET	ALT		32.025	2	16.012	3.081	.048
NET	SIGMA		1565.704	1	1565.704	301.218	.001
RATE	VEL		1.204	1	1.204	.232	.631
RATE	ALT		6.475	2	3.238	.623	.537
RATE	SIGMA		53.204	1	53.204	10.236	.002
VEL	ALT		12.158	2	6.079	1.170	.313
VEL	SIGMA		.504	1	.504	.097	.756
ALT	SIGMA		142.675	2	71.337	13.724	.001
3-WAY INTERACTIONS			52.133	16	3.258	.627	.860
NET	RATE	VEL	4.537	1	4.537	.873	.351
NET	RATE	ALT	14.725	2	7.363	1.416	.245
NET	RATE	SIGMA	2.604	1	2.604	.501	.480
NET	VEL	ALT	1.675	2	.837	.161	.851
NET	VEL	SIGMA	2.204	1	2.204	.424	.516
NET	ALT	SIGMA	1.158	2	.579	.111	.895
RATE	VEL	ALT	5.858	2	2.929	.564	.570
RATE	VEL	SIGMA	1.504	1	1.504	.289	.591
RATE	ALT	SIGMA	15.008	2	7.504	1.444	.239
VEL	ALT	SIGMA	2.858	2	1.429	.275	.760

```
1210= 4-WAY INTERACTIONS                      45.338     9     5.038    .969   .467
1220=     NET       RATE      VEL             25.675     2    12.838   2.470   .087
1230=               ALT
1240=     NET       RATE      VEL               .937     1      .937    .180   .672
1250=               SIGMA
1260=     NET       RATE      ALT              1.058     2      .529    .102   .903
1270=               SIGMA
1280=     NET       VEL       ALT              3.108     2     1.554    .299   .742
1290=               SIGMA
1300=     RATE      VEL       ALT             14.558     2     7.279   1.400   .249
1310=               SIGMA
1320=
1330= 5-WAY INTERACTIONS                       3.775     2     1.887    .363   .696
1340=1AIRCRAFT SURVIVAL
1350=
1360=     NET       RATE      VEL              3.775     2     1.888    .363   .696
1370=               ALT       SIGMA
1380=
1390= EXPLAINED                             8598.996    47   182.957  35.198   .001
1400=
1410= RESIDUAL                               998.000   192     5.198
1420=
1430= TOTAL                                 9596.996   239    40.155
```

Cell means of the main effects and statistically significant interactions are given below. This data is graphed in Figures 12 through 16.

```
* * * * * * * * * * * *   C E L L   M E A N S   * * * * * * * * * * * *
                 SURVIVAL
              BY NET
                 RATE
                 VEL
                 ALT
                 SIGMA
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


TOTAL POPULATION

     11.00
 (   240)


NET
         1          2

     15.89       6.12
 (   120)  (   120)


RATE
         1          2

     12.22       9.79
 (   120)  (   120)


VEL
         1          2

     10.80      11.21
 (   120)  (   120)


ALT
         1          2          3

      9.55      10.45      13.01
 (    80)  (    80)  (    80)


SIGMA
         1          2

     10.52      11.49
 (   120)  (   120)
```

NET \ ALT	1	2	3
1	14.80	15.47	17.40
	(40)	(40)	(40)
2	4.30	5.42	8.63
	(40)	(40)	(40)

NET \ SIGMA	1	2
1	12.85	18.93
	(60)	(60)
2	8.18	4.05
	(60)	(60)

RATE \ SIGMA	1	2
1	12.20	12.23
	(60)	(60)
2	8.83	10.75
	(60)	(60)

ALT \ SIGMA	1	2
1	8.10	11.00
	(40)	(40)
2	10.00	10.90
	(40)	(40)

When altitude level 3 was omitted, altitude remained a statistically significant factor, but it was less significant than it was in the original five-way ANOVA. Similarly, the interaction between altitude and sigma remained significant, but at a reduced level of significance. The interaction between the road network and altitude became statistically insignificant. These changes are underlined in the output shown below.

```
* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
                    SURVIVAL
                 BY NET
                    RATE
                    VEL
                    ALT
                    SIGMA
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION		SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS		4681.950	5	936.390	171.323	.001
NET		4223.025	1	4223.025	772.652	.001
RATE		280.900	1	280.900	51.394	.001
VEL		1.225	1	1.225	.224	.637
ALT		32.400	1	32.400	5.928	.016
SIGMA		144.400	1	144.400	26.420	.001
2-WAY INTERACTIONS		1183.050	10	118.305	21.645	.001
NET	RATE	.625	1	.625	.114	.736
NET	VEL	.400	1	.400	.073	.787
NET	ALT	2.025	1	2.025	.370	.544
NET	SIGMA	1071.225	1	1071.225	195.993	.001
RATE	VEL	.225	1	.225	.041	.840
RATE	ALT	.400	1	.400	.073	.787
RATE	SIGMA	62.500	1	62.500	11.435	.001
VEL	ALT	5.625	1	5.625	1.029	.312
VEL	SIGMA	.025	1	.025	.005	.946
ALT	SIGMA	40.000	1	40.000	7.318	.008

Appendix F

Five-Way ANOVA with Sigma Held Constant

When sigma was held constant at level one (6.25 NM), only one major change occurred: the interaction between the road network and aircraft altitude became statistically insignificant.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	1589.333	5	317.867	41.642	.001
NET	653.333	1	653.333	85.590	.001
RATE	340.033	1	340.033	44.546	.001
VEL	7.500	1	7.500	.983	.324
ALT	588.467	2	294.233	38.546	.001
2-WAY INTERACTIONS	50.100	9	5.567	.729	.681
NET RATE	2.133	1	2.133	.279	.598
NET VEL	.133	1	.133	.017	.895
NET ALT	11.467	2	5.733	.751	.475
RATE VEL	2.700	1	2.700	.354	.553
RATE ALT	20.267	2	10.133	1.328	.270
VEL ALT	13.400	2	6.700	.878	.419
3-WAY INTERACTIONS	31.933	7	4.562	.598	.756
NET RATE VEL	4.800	1	4.800	.629	.430
NET RATE ALT	4.467	2	2.233	.293	.747
NET VEL ALT	3.267	2	1.633	.214	.808
RATE VEL ALT	19.400	2	9.700	1.271	.285
4-WAY INTERACTIONS	15.800	2	7.900	1.035	.359
NET RATE VEL ALT	15.800	2	7.900	1.035	.359
EXPLAINED	1687.167	23	73.355	9.610	.001
RESIDUAL	732.800	96	7.633		
TOTAL	2419.967	119	20.336		

when sigma was held constant at level two (3.0 NM), the interaction between the road network and aircraft altitude again became statistically significant. In addition, the interaction between the road network and the aircraft arrival rate became statistically significant.

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			6785.042	5	1357.008	491.225	.001
NET			6645.408	1	6645.408	2405.578	.001
RATE			66.008	1	66.008	23.894	.001
VEL			3.008	1	3.008	1.089	.299
ALT			70.617	2	35.308	12.781	.001
2-WAY INTERACTIONS			41.575	9	4.619	1.672	.106
NET	RATE		14.008	1	14.008	5.071	.027
NET	VEL		3.008	1	3.008	1.089	.299
NET	ALT		21.717	2	10.858	3.931	.023
RATE	VEL		.008	1	.008	.003	.956
RATE	ALT		1.217	2	.608	.220	.803
VEL	ALT		1.617	2	.808	.293	.747
3-WAY INTERACTIONS			14.525	7	2.075	.751	.629
NET	RATE	VEL	.675	1	.675	.244	.622
NET	RATE	ALT	11.317	2	5.658	2.048	.135
NET	VEL	ALT	1.517	2	.758	.275	.761
RATE	VEL	ALT	1.017	2	.508	.184	.832
4-WAY INTERACTIONS			13.650	2	6.825	2.471	.090
NET	RATE ALT	VEL	13.650	2	6.825	2.471	.090
EXPLAINED			6854.792	23	298.034	107.886	.001
RESIDUAL			265.200	96	2.763		
TOTAL			7119.992	119	59.832		

The cell means of the interactions between the road network and aircraft arrival rate are shown below. This data is presented graphically in Figure 17.

```
920=            RATE
930=                         1          2
940= NET
950=          1     19.[illegible]      18.53
960=             (      30)  (      30)
970=
980=          2      5.13       2.97
990=             (      30)  (      30)
```

Four-Way ANOVA with Airspeed Excluded

Results of the four-way ANOVA with airspeed excluded were the same as the results of the five-way ANOVA.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	6659.521	5	1331.864	264.050	.001
NET	5733.037	1	5733.037	1136.610	.001
RATE	352.837	1	352.837	69.952	.001
ALT	516.408	2	258.204	51.191	.001
SIGMA	57.037	1	57.037	11.308	.001
2-WAY INTERACTIONS	1813.621	9	201.513	39.951	.001
NET RATE	13.538	1	13.538	2.684	.103
NET ALT	32.025	2	16.013	3.175	.044
NET SIGMA	1565.704	1	1565.704	310.410	.001
RATE ALT	6.475	2	3.238	.642	.527
RATE SIGMA	53.204	1	53.204	10.548	.001
ALT SIGMA	142.675	2	71.337	14.143	.001
3-WAY INTERACTIONS	33.496	7	4.785	.949	.470
NET RATE ALT	14.725	2	7.363	1.460	.235
NET RATE SIGMA	2.604	1	2.604	.516	.473
NET ALT SIGMA	1.158	2	.579	.115	.892
RATE ALT SIGMA	15.008	2	7.504	1.488	.228
4-WAY INTERACTIONS	1.058	2	.529	.105	.900
NET RATE ALT SIGMA	1.058	2	.529	.105	.900
EXPLAINED	8507.496	23	369.891	73.333	.001
RESIDUAL	1089.500	216	5.044		
TOTAL	9596.996	239	40.155		

Appendix H

Tests of Statistical Distributions

SPSS tests for the following distributions are presented in this Appendix:

1. Exponential distribution of arrival times.
2. Normal distribution of AAA sites in belt 4, using road network 2 and sigma equal to 3.0 NM.
3. Normal distribution of AAA sites in belt 5, using road network 2 and sigma equal to 6.25 NM.

The distribution of arrival times was tested using a Chi-Square test, while the distribution of the AAA sites were tested with a Kolmogorov-Smirnov test. All three tests used an alpha of .05, and in all three cases the null hypothesis that the data came from the desired distributions could not be rejected.

Distribution of Arrival Times

The arrival intervals, taken from 2 consecutive runs of 20 aircraft each, are listed below:

1.20	1.17	0.16	0.27	0.04	0.01	0.11	0.12
2.01	0.15	0.06	0.18	0.56	0.69	0.18	0.39
0.67	0.05	0.39	1.15	2.70	0.31	0.07	1.82
0.82	0.85	0.46	0.17	0.65	0.32	0.22	
1.60	0.03	0.04	0.72	0.41	0.31	0.95	

H_o: The 38 arrival intervals are from an exponential (.5 minutes) distribution.

H_1: The arrival intervals are not from an exponential (.5 minutes) distribution.

$\nu = K - 1 - m = 5 - 1 - 0 = 4$

$\chi^2_{crit} = \qquad = 9.49$

```
                    RUN NAME       ARRIVAL RATE EXPONENTIAL (.5 MINUTES)
                    VARIABLE LIST  INTERVAL,FREQ
                    INPUT FORMAT   FREEFIELD
                    INPUT MEDIUM   CARD
                    WEIGHT         FREQ
                    N OF CASES     5
                    NPAR TESTS     CHI-SQUARE = INTERVAL/
                                   EXPECTED = 6.89  5.64  8.40
                                   7.70  9.37
                    READ INPUT DATA


 - - - - - CHI-SQUARE TEST

    INTERVAL

   VALUE          1.0        2.0        3.0        4.0        5.0
   COUNT          7.         7.         7.         6.         11.
  EXPECTED        6.89       5.64       8.40       7.70       9.37

          CHI-SQUARE                 D.F.         SIGNIFICANCE
              1.222                    4               .874

1ARRIVAL RATE EXPONENTIAL (.5 MINUTES)
```

$1.222 < 9.49$

$\chi^2_{calc} < \chi^2_{crit}$ for alpha equal to .05

Therefore we must fail to reject H_o.

Distribution of AAA Sites in Belt 4

This test was made to verify the normal distribution of weapon sites when sigma is set at 3.0 NM. Road network 2 was used because road network 1 would have produced a truncated normal distribution. The LOC is .8 NM to the right of the center of the army area when it crosses belt 4. Thus the defenses can fall up to

$$\frac{13.5 - .8}{3.0} = 4.23$$

standard deviations to the right of the mean point and up to

$$\frac{13.5 + .8}{3.0} = 4.77$$

standard deviations to the left. This will include, for all practical purposes, 100% of the random numbers drawn from a Normal (0.8, 3.0) distribution.

H_0: The 25 AAA sites come from a Normal (0.8. 3.0) distribution.

H_1: The 25 AAA sites do not come from a Normal (0.8, 3.0) distribution.

$$D_{crit} = D_{.05,25} = .27$$

The computer program and data points are shown below:

```
100=RUN NAME        AAA DISTRIBUTION FOR BELT 4 (SIGMA = 3.0)
110=VARIABLE LIST   POSITION
120=INPUT FORMAT    FREEFIELD
130=INPUT MEDIUM    CARD
140=N OF CASES      25
150=NPAR TESTS      K-S (NORMAL .8,3.0) = POSITION
160=READ INPUT DATA
170=-2.63  1.29 -2.01  2.07 -1.22
180= 2.51  6.08  2.57  1.63   .46
190= 5.86 -1.50  2.16  2.15  6.05
200= 1.34  2.17 -3.18 -3.16 -3.08
210=  .74 -2.97 -3.54 -3.10  2.17
220=FINISH
230=*EOR
240=*EOF
```

The results are shown below:

```
480= - - - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST
490=
500=     POSITION
510=
520= TEST DIST. - NORMAL (MEAN =        .8000 STD. DEV. =       3.0000)
530=
540=             CASES      MAX(ABS DIFF)     MAX(+ DIFF)     MAX(- DIFF)
550=               25           .1576            .1576          -.0849
560=
570=             K-S Z         2-TAILED P
580=              .788            .564
590=
600=1AAA DISTRIBUTION FOR BELT 4 (SIGMA = 3.0)
```

$.1576 < .27$

$|D|_{max} < D_{crit}$ for alpha equal to .05

Therefore the null hypothesis can not be rejected.

Distribution of AAA Sites in Belt 5

This test was made to verify the normal distribution of weapon sites when sigma is set at 6.25 NM. Road network 2 is .7 NM to the right of the center of the army area when it cross belt 4. Thus the defenses can fall up to

$$\frac{13.5 - .7}{6.25} = 2.05$$

standard deviations to the right of the mean point and up to

$$\frac{13.5 + .7}{6.25} = 2.27$$

standard deviations to the left. This will include approximately 97% of the random numbers drawn from a Normal (0.7,6.25) distribution. Thus the actual distribution should not be expected to behave perfectly, but it should closely approximate the theoretical distribution.

H_0: The 25 AAA sites come from a Normal (0.7,6.25) distribution.

H_1: The 25 AAA sites do not come from a Normal (0.7,6.25) distribution.

$$D_{crit} = D_{.05,25} = .27$$

The computer program and data points are shown below:

```
100=RUN NAME       AAA DISTRIBUTION FOR BELT 5 (SIGMA = 6.25)
110=VARIABLE LIST  POSITION
120=INPUT FORMAT   FREEFIELD
130=INPUT MEDIUM   CARD
140=N OF CASES     25
150=NPAR TESTS     K-S (NORMAL .7,6.25) = POSITION
160=READ INPUT DATA
170=  3.96   5.16  -4.78 -10.15  -2.98
180=  4.24  -5.82   1.60   7.61 -11.74
190= -3.44   1.23   1.92    .44  -1.66
200=  1.52   9.11  -2.56  -4.17 -11.12
210= -1.59 -11.16  13.23   8.52  -4.00
220=FINISH
230=*EOR
240=*EOF
```

The results are shown below:

```
480= - - - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST
490=
500=     POSITION
510=
520= TEST DIST. - NORMAL (MEAN =        .7000 STD. DEV. =       6.2500)
530=
540=            CASES      MAX(ABS DIFF)      MAX(+ DIFF)      MAX(- DIFF)
550=               25           .1630            .1630           -.0256
560=
570=            K-S Z        2-TAILED P
580=             .815           .520
590=
600=1AAA DISTRIBUTION FOR BELT 5 (SIGMA = 6.25)
```

$.1630 < .27$

$D_{max} < D_{crit}$ for alpha equal to .05

Therefore the null hypothesis can not be rejected.

Appendix I

Probability of Kill Computions

This Appendix contains probability of kill computions for the AAA and SAM-C. These results are compared to computer generated results in order to verify the accuracy and logic of the PROBKIL subroutine of the model.

AAA

The incoming aircraft is offset .3 NM (1824 feet) from the gun and therefore will be engaged at a slant range of 3000 feet. There are 2 "g"s on the aircraft at the time it is fired upon.

The velccity of the AAA round at intercept is:

$$V_f = 3050\ e^{-.1513(3.0)} = 1937 \text{ ft/sec}$$

The time of flight of the bullet is:

$$TOF = \left(\frac{6601.76}{1937}\right) - 2.1645 = 1.244 \text{ seconds}$$

The single shot probability of kill is:

$$P_{k_{ss}} = \frac{55.65}{2\pi(20\cdot 3)^2 + 55.65}\ e^{\frac{-.5(2)(32.2)(1.244)^2}{2\pi(60)^2 + 55.65}} = .00245$$

The probability of kill for a 50 round burst is:

$$Pkss = 1 - (1 - .0024486)^{50} = .11536$$

The attached computer output shows that the model generated the same Pk as was calculated by hand.

SAM-C

The incoming aircraft is offset 5 NM (9260 meters or 39.67 dbm) laterally from the missile site. It is travelling at a velocity of 480 knots. The missile can intercept the aircraft

$$2 + 5(3.09) = 17.45 \text{ sec}$$

after the aircraft first enters the kill zone, assuming it is able to track and lock-on to the aircraft in the minimum time possible.

Since a 480 knot aircraft is moving at a rate of 7.5 sec/NM, it will travel

$$\frac{17.45 \text{ sec}}{7.5 \text{ sec/NM}} = 2.33 \text{ NM}$$

past the leading edge of the kill zone before being intercepted by the missile. From Figure 9, it can be determined that the aircraft will have an aspect of about

97° relative to the missile site at the time of intercept. Since the model uses the radar cross-section of the nearest 5° increment, 19.95 dbm, the radar cross-section at the 95° aspect is used to calculate the jamming-to-signal ratio at the time of intercept.

$$J/S = 29.6 + 11 + 2(39.67) - 53 - 41 - 19.95 = 5.99 \text{ db}$$
$$= 3.97$$

The circular error probable of the missile is

$$CEP = \sqrt{(.00000071)(3.97)(9260)^2 + (2200)(3.97) + 58}$$
$$= 95.0 \text{ meters} = 312 \text{ feet}$$

The probability of kill of the missile is:

$$Pk = 1 - .5^{(86/312)^2} = .051$$

The attached computer output agrees with the above results.

```
SAM-[illegible]

LATERAL RANGE =  5.00 NM.
RANGE AT INTERCEPT =  5.04 NM.
PK = .051
```

The missile's highest Pk will occur if it can intercept the aircraft when the aircraft's aspect is 90^0 with respect to the site. The calculations for this intercept are as follows:

$$J/S = 29.6 + 11 + 2(39.37) - 53 - 41 - 24.98$$

$$= .96 \text{ db} = 1.25$$

$$CEP = \sqrt{(.00000071)(1.25)(9260)^2 + (2200)(1.25) + 58}$$

$$= 53.7 \text{ meters} = 176 \text{ feet}$$

$$Pk = 1 - .5^{(86/176)^2} = .153$$

Such an intercept is not possible in the model because the kill zone is too narrow and the aircraft is moving too fast. However, the logic pattern of the PROBKIL subroutine was tested on a verification run by setting the missile flyout time equal to zero. Under these circumstances, the intercept could have occured near the leading edge of the kill zone. The model had the site wait until it could achieve the intercept at a 90^0 aspect, which is consistent with the desired logic pattern. The results, shown below, agree with the prediction.

```
SAM-C

 LATERAL RANGE =  5.00 NM.
RANGE AT INTERCEPT =  5.00 NM.
          PK =  .153
```

Appendix J

Tie-Up Times of Weapon Systems

This Appendix contains examples of computer generated output which illustrate the logic and accuracy of the model in determining which weapon sites are allowed to fire at an aircraft and how long the sites are tied up after firing.

In the output listed below, the first aircraft reaches the first AAA belt .025 minutes after crossing the FEBA (the AAA is referred to as weapon 1 in this output). At least five AAA sites are within range of the aircraft. The following sites fire and are tied up for the time periods listed:

Site	Tie-Up Time (in minutes)
23	.652
25	.703
4	.837
16	.730
20	.732

The aircraft reaches the second AAA belt .125 minutes after FEBA penetration. Three sites in this belt are within range. They fire and are tied up as listed below:

Site	Tie-Up Time (in minutes)
24	.831
5	.637
19	.609

Based on the above information the sites would be expected to be released as shown:

Belt	Site	Release Time (in minutes)
1	23	.025 + .652 = .677
1	25	.025 + .703 = .728
2	19	.125 + .609 = .734
1	16	.025 + .730 = .755
1	20	.025 + .732 = .757
2	5	.125 + .637 = .762
1	4	.025 + .837 = .862
2	24	.125 + .831 = .956

The weapon sites do release at the times given above, as the computer output shows:

```
0840= BELT 1 OF WEAPON 1
0850= TNOW = .025
0860= 0 SITES ARE ALREADY TIED UP.
0870
0880= PK OF SITE 23. = .115375814585[illegible]
0890= PK OF SITE 25. = .115375814585[illegible]
0900= PK OF SITE 4. = .024444127416[illegible]
0910= PK OF SITE 16. = .016599[illegible]5016575
0920= PK OF SITE 20. = .016240619775[illegible]5
0930= SITE 23. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .6517491742066 MINUTES
0940= SITE 25. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .7034866958805 MINUTES
0950= SITE 4. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .8373513388346 MINUTES
0960= SITE 16. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .7297435644773 MINUTES
0970= SITE 20. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .732349897998 MINUTES
```

```
[illegible]
[illegible] MINUTES
[illegible] MINUTES
[illegible] MINUTES
[illegible]
[illegible] BELT [illegible] WEAP[illegible]
[illegible] TNOW [illegible]
[illegible] SITES ARE A[illegible] TIED UP.
[illegible]
[illegible] OF SITE [illegible]
[illegible] SITE [illegible]
[illegible]= SITE 2[illegible] OF BELT 1[illegible] WEAPON [illegible] IS TIED UP FOR 1.147341615611 MINUTES
[illegible]
[illegible]= SITE 23 IS RELEASED AT TIME .67[illegible]491742066 FROM BELT 1 OF WEAPON 1
[illegible]=
1220= SITE 25 IS RELEASED AT TIME .7[illegible]4[illegible]6958805 FROM BELT 1 OF WEAPON 1
[illegible]=
1240= SITE 19 IS RELEASED AT TIME .7[illegible]42804337913 FROM BELT 2 OF WEAPON 1
[illegible]
[illegible]= SITE 16 IS RELEASED AT TIME .7[illegible]474[illegible]5644772 FROM BELT 1 OF WEAPON 1
1270=
12[illegible]0= SITE 20 IS RELEASED AT TIME .7[illegible]57349837998 FROM BELT 1 OF WEAPON 1
12[illegible]0=
1[illegible]00= SITE 5 IS RELEASED AT TIME .762[illegible]722275544 FROM BELT 2 OF WEAPON 1
1310=
[illegible]= SITE 4 IS RELEASED AT TIME .86[illegible]5513388346 FROM BELT 1 OF WEAPON 1
1[illegible]0=
1[illegible]40= SITE [illegible]4 IS RELEASED AT TIME .9564167757031 FROM BELT 2 OF WEAPON 1
```

Other properties of the model are illustrated when the third and fourth fighters enter the network. Aircraft number three enters, tying up four AA sites in belt one. When aircraft number four enters, the four sites in belt one tied up by aircraft number three are unable to engage it.

```
2050= [illegible] WEA[illegible]
2060= TNOW = 2.1984[illegible]
2070= 0 SI[illegible] ARE ALREADY TIED UP.
2100=
2110= PK [illegible]ITE 23. = .1[illegible]758145[illegible]
2120= PK [illegible]ITE 25. = .1152758145[illegible]
2130= PK OF SITE 4. = .0350050170[illegible]
2140= PK OF SITE 16. = .0[illegible]2240003452672
2150= PK OF SITE 1. = 0.
2160= SITE [illegible]. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .9120937154233 MINUTES
2170= SITE 25. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .6730041146171 MINUTES
2180= SITE 4. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .6090100009086 MINUTES
2190= SITE 16. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .6464012505524 MINUTES
2200=
2210= SITE 2 IS RELEASED AT TIME 2.4831737711124 FROM BELT 1 OF WEAPON 3
2220=
2230= BELT 2 OF WEAPON 1
2240= TNOW = 2.4904925066648
2250= 0 SITES ARE ALREADY TIED UP.
2260=
2270= PK OF SITE 24. = .04164383715585
2280= PK OF SITE 5. = .03412139987481
2290= PK OF SITE 19. = .02188807908899
2300= PK OF SITE 1. = 0.
2310= PK OF SITE 1. = 0.
2320= SITE 24. OF BELT 2. OF WEAPON 1. IS TIED UP FOR .6424880130581 MINUTES
2330= SITE 5. OF BELT 2. OF WEAPON 1. IS TIED UP FOR .7140992894937 MINUTES
2340= SITE 19. OF BELT 2. OF WEAPON 1. IS TIED UP FOR .8992477962203 MINUTES
2350=
2360= BELT 1 OF WEAPON 1
2370= TNOW = 2.5479578160788
2380= 4 SITES ARE ALREADY TIED UP.
2390=
2400= PK OF SITE 20. = .05905224949717
2410= PK OF SITE 1. = 0.
2420= PK OF SITE 1. = 0.
2430= PK OF SITE 1. = 0.
2440= PK OF SITE 1. = 0.
2450= SITE 20. OF BELT 1. OF WEAPON 1. IS TIED UP FOR .8496394058775 MINUTES
```

Aircraft #3 enters (lines 2050–2070)

Aircraft #4 enters (lines 2360–2380)

The output below shows an aircraft entering the second SAM-D belt (the SAM-D is referred to as weapon 3). Two SAM-D sites are within range of the aircraft, but only one is allowed to fire because the Pk of the second site is below .02.

```
[illegible]
[illegible]
[illegible] ARE [illegible]
[illegible]
[illegible]
[illegible]
[illegible] IS TIED [illegible] FOR [illegible] MINUTES
```

Appendix K

Modeling Current Weapon Systems

This appendix is classified SECRET. It is kept and maintained by the Air Force Institute of Technology, AFIT/ENA.

Vita

Warren J. Leek was born on 4 June 1944 in Wellington, New Zealand. He graduated from high school in Midlothian, Illinois in 1962 and then attended the United States Air Force Academy. He was awarded a Bachelor of Science degree in Engineering Science and was commissioned in June 1966. He completed pilot training and received his wings in August 1967. He served in operational assignments in the EC-47, F-100, A-7D, and OV-10 aircraft before entering the School of Engineering, Air Force Institute of Technology, in August 1979.

Permanent Address: 17772 South Anthony Avenue
Country Club Hills, Illinois

Vita

Richard W. Schmitt was born on 14 March 1945 in Orlando, Florida. He graduated from Mira Loma High School, Sacramento, California in 1963 and then attended the United States Air Force Academy. He was awarded a Bachelor of Science degree and was commissioned in June 1967. He completed pilot training and received his wings in September 1968. He has served in operational F-4 assignments in Korea, South Viet Nam, Thailand, United Kingdom, and Iran. He served as Commander, 4950th Organizational Maintenance Squadron, Wright-Patterson AFB, before entering the School of Engineering, Air Force Institute of Technology, in August 1979.

Permanent Address: 141 Carpenter
Hollister, California

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/GST/OS/81M-9	2. GOVT ACCESSION NO. AD-A101186	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Survivability Study of a FLIR Equipped Fighter on a Night Penetration of a Soviet Army		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Warren J. Leek, Major USAF and Richard W. Schmitt, Major USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology (EN) Wright-Patterson AFB, OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE March 1981
		13. NUMBER OF PAGES 159
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Fredric C. Lynch

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

16 JUN 1981

18. SUPPLEMENTARY NOTES

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fighter survivability
FLIR
Night battle air interdiction

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

The LANTIRN system provides the fighter pilot with a forward looking infrared (FLIR) system, which allows him to fly the aircraft lower and faster than he would otherwise be able to fly. The objective of this research effort was to determine whether this increased capability will significantly improve the fighter's survivability in the night interdiction role. The problem was studied in the context of the threats and terrain found in the central region of West Germany.

(continued on reverse)

A model of the terrain features and threat scenario was constructed using the SLAM computer simulation language. The Soviet defensive systems can be moved around as desired, and aircraft can enter the system at a variety of arrival intervals, airspeeds, and altitudes. Defensive systems that are within range of the aircraft will shoot at it, provided they are not tied up with a previous aircraft, blocked by terrain, or prevented from shooting because of a low probability of kill.

The capability to fly faster did not significantly increase the fighter's survivability. A decrease in altitude from 1000 feet to 500 feet increased survivability to a minor degree, while a further decrease to 250 feet improved survivability significantly. These findings led to the conclusion that a strong effort should be made to develop a FLIR of high enough resolution to allow the pilot to fly the mission at an altitude of 250 feet or below.

DATE
LMED
-8

DATE

ILMED

8