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THESIS

A SIMULATION OF A COMBINED ACTIVE AND ELECTRONIC
WARFARE SYSTEM FOR THE DEFENSE OF A NAVAL SHIP
AGAINST MULTIPLE LOW-ALTITUDE MISSILES THREAT

by

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A computer simulation model was developed (Interactive Simulation of System Performance, or ISSP) simulating the integrated performance of hard-kill (surface-to-air missile, or SAM and close-in weapon system, or (CIWS) and soft-kill (defensive jammer, or ECM, and Chaff) systems in the defense of a single naval ship against attack threat by four anti-ship missiles (ASM). The quantitative contribution of each system to ship survivability is evaluated. The hard-kill and soft-kill weapon systems are the focus of the two major anti-air warfare (AAW) improvement plans assessed in this simulation. Based on these plans, six decision options were created. In addition, this study provides an analysis and comparison of the results of the inner air battle abstracted from various weapon models. Finally, the use of the simulation results in making choice among candidate weapon systems is illustrated.

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ABSTRACT

A computer simulation model was developed (Interactive Simulation of System Performance, or ISSP) simulating the integrated performance of hard-kill (surface-to-air missile, or SAM, and close-in weapon system, or CIWS) and soft-kill (defensive jammer, or ECM, and Chaff) systems in the defense of a single naval ship against attack threat by four anti-ship missiles (ASM). The quantitative contribution of each system to ship survivability is evaluated. The hard-kill and soft-kill weapon systems are the focus of the two major anti-air warfare (AAW) improvement plans assessed in this simulation. Based on these plans, six decision options were created. In addition, this study provides an analysis and comparison of the results of the inner air battle abstracted from various weapon models. Finally, the use of the simulation results in making choices among candidate weapon systems is illustrated.

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I. INTRODUCTION

A. BACKGROUND

An Iraqi anti-ship missile struck the USS Stark on the evening of May 17, 1987. Stark's SLQ-32 did not detect the incoming missile. None of the defensive weapons, missiles, guns or chaff decoys were employed. As a general rule, the Stark's combat system should have had a high probability of shooting down the anti-ship missile if any of the sensors had detected the inbound threat. As illustrated by this tragedy, the question of how to improve ship survivability has become a matter of great importance for modern warfare.

The anti-ship missiles can be launched from aircraft, surface vessels, or underwater submarines, and this potential threat can cause extreme damage, as the Stark tragedy indicates. Because of the complexity of the defense problem and the variety of defensive systems available, it is often helpful to estimate the combat effectiveness of combinations of various weapon systems by analytic techniques before developing or purchasing those systems. Furthermore, it is necessary to include tactical considerations. To enhance the defense, Electronic Warfare (EW) systems should be used on the ship to reduce the effectiveness of attacking, low flying missiles, therefore increasing the survivability of the ship. This includes Electronic Warfare Support measures (ESM), Active Electronic Counter Measures (ECM), and Chaff decoys.

The ship whose defense is to be simulated, is assumed to be equipped with an Anti-air Warfare (AAW) combat system which consists of an air search radar, two missile fire control radars, one missile launcher, a close-in weapon system (CIWS),

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and electronic warfare systems. The electronic warfare simulations in this thesis project, focus on the jamming and decoying of a radar guided anti-ship missile and leave the discussion of an infra-red guided threat for future work.

B. GOALS AND OBJECTIVES

The primary goal of this thesis is to simulate the performance of a combined active and Electronic Warfare system in the defense of a single naval ship against simultaneous attack by four low flying anti-ship missiles (ASM) and to evaluate the contribution of the total system to ship survivability.

Another objective is to simulate the interactions between alternative hard-kill (SAM, CIWS) and soft-kill (ECM, Chaff) systems, to analyze the outcomes, and to show the contribution of each sub-system in defeating the incoming threat. Finally, the use of the simulation results in making choices between candidate weapon systems is illustrated.

C. THESIS OUTLINE

The scope of this thesis will be limited to an AAW operation conducted by a number of defense layers which depends on the weapon systems assumed to be on the ship. This work does not fully describe an operational capability. It deals with an abstraction of the sort typically used to support decision-making in the areas of system research, development and acquisition. Most of the components and factors used here are generic since the real ones are specific to particular systems and are generally classified.

The basic defense scenario is discussed in Chapter II. This depicts the employment of combinations of active and EW weapon systems, including the Surface-

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to-air Missiles (SAM), CIWS, defensive jammer and Chaff. Chapter III covers the simulation program, language, and flow charts. Two major modules, are also provided there, covering hard-kill and soft-kill systems. The SAM and CIWS sub-modules are taken from an earlier Naval Postgraduate School thesis.[1] The simulation of the performances of the electronic warfare components of the defense and their interactions with the hard-kill systems are contributions of this effort. The simulation results and the analysis of them are included in Chapter IV, along with an evaluation of improvement plans for AAW weapon systems, integrated performance of active and EW systems, and their performance under hostile jamming conditions. The results of these evaluations provide data useful in making choices among various systems options. Chapter V summarizes conclusions based on this study.

II. THE DEFENSE SCENARIO

A. ACTIVE SYSTEMS

1. Surface-to-Air Missile (SAM)

From the point of view of the ship which carries it, the primary attributes of a SAM system are the size and number of the missiles, their propellants (which may require special storage), the rate of fire demanded, and the size and weight of the guidance system(s). All add together as ship effectiveness: a ship which carries a high effectiveness SAM system is first of all a SAM ship and second something else, but almost any ship can carry a low effectiveness SAM.[Ref. 2, p. 103]

The SAMs are the most effective weapons against anti-ship missiles or aircraft, although guns are used at very short distances. Naval SAMs are generally classified as area defense which protect several ships and point defense that are self-protective only. In fact, the differentiation between area defense and point defense is not as clear as might be supposed. Of course, the former is for long range defense, and the latter is for short range defense, but where the transition occurs is not well defined. In looking at SAM systems, effectiveness is the preferable distinction. Those that have higher effectiveness should have greater capability as they affect the ships which carry them.

In the past, the radar systems were not sufficient to determine accurate target position or characteristics and an additional Target Indication radar was required, but modern radars can combine both tasks. Having identified a target, the information is passed to a tracker radar assigned to it. The Tracker radar antenna is mounted with

an antenna which provides the illuminating beam for the missile homing and a small antenna used to communicate with the missile.[Ref. 3, p. 24]

Point defense missiles can be used against anti-ship missiles, but were not originally designed for this, and, at least initially, did not have the right kind of warhead. Because the time between detection of an approaching missile and its impact on the target ship may be very short, especially if the incoming missile is at low altitude, a point defense missile must have a very short reaction time.

The point defense missiles have different ranges. Britain has the Sea Cat with a range of 4.5 km and a missile weighing 68 kg. France uses the Sea Crotale with a range of 8.5 km and a missile weighing 80 kg. America has developed the Sea Sparrow with a range of 25 km and a missile launch weight of 220 kg, over three times that of the Sea Cat. In addition, Sea Chaparral(US), Sea Wolf(UK), SLAM(UK), Hirondelle(France), Marine Roland(France/Germany), Albatross(Italy), SAN7(USSR) are in current inventories.

The area defense missile system must have a long-range surveillance radar which consistently scans the horizon for potential enemy targets. The defensive missiles have a range varying from 45 km to about 100 km. The British Sea Dart has a range of 55 km and a missile launch weight of 550 kg. The United States uses the Standard SM-1 with a range of 60 km and a missile launch weight of 590 km, Standard SM-2 with a range of 100 km and a missile launch weight of 1,060 kg. The French Masurka MK2 has a range of 45 km and a missile launch weight of 1,850 kg. Besides these, US Talos(120 km), UK Sea Slug II(45 km), USSR SAN2(40 km), SAN3(32 km), SAN4(32 km) are also involved.

Most of the SAMs use semi-active homing to home onto their target. In this guidance system a radar beam from the ship is aimed at the target; the missile homes on the reflected radar energy which is detected by a radar receiver in the missile. The advantages of this system are that there is no radar transmitter required for the missile itself and the homing becomes more accurate as the missile approaches its target compared to the method which controls the missile from the ship.

2. Close-in Weapon System

Modern fast-firing, automatic guns, known as Close-in Weapon Systems (CIWS), have shown from experience that if properly controlled they are able to shoot down anti-ship missiles. The guns generally do not initiate this engagement until the anti-ship missile is some 3,700 meters from the ship, because it only takes a short time for the tracking radar to track the missile. This does not provide much firing time, but given that the guns can shoot down or explode the missile before it reaches some 185 meters away, no damage should come to the ship.

The location of the CIWS in the vessel is generally a compromise. To avoid stability problems it is best to keep a system low down on the ship. However, this very often conflicts with the need to establish good operating arcs. In an integrated system, the effect of radar sidelobes on surrounding structure might give rise to a higher false-alarm rate. Fire-control channels should offer balanced cover around the ship, with each positioned to optimize the firing arcs. In particular, firing arcs should overlap as far as possible, to minimize dead zones lacking defensive cover.

The gun has an apparent advantage at very short range: it can come into action more rapidly than a missile, and, moreover, it does not share the minimum range problem of the missile. Therefore, it is useful against targets that give very little

warning time, such as low-altitude anti-ship missiles. Nevertheless, such applications are quite different from the typical use of naval guns for anti-aircraft purpose. The ideal close-in weapon system offers the following:[Ref. 4, p. 115]

- Reliable, long-range target detection over a wide coverage arc, with sophisticated ECCM, anti-clutter and all-weather capability.

- Fast reaction time, with completely automatic functioning from threat evaluation and designation to target destruction.

- Image-free tracking from dual-frequency radars together with whatever sensor(s) are appropriate for the conditions.

- Accurate fire control incorporating automatic spotting corrections, particularly for longer-range engagements, and curved-course prediction for use against missiles with pre-programmed course-change capabilities.

- High-response mount with "stiff" servos for rapid reaction and engagement of close-in targets, and wide arcs of fire.

- Cannon with high muzzle velocity and rate of fire.

- Ammunition with low ballistic dispersion and high energy content, plus proximity-fuzed rounds for use at longer ranges.

Most of these qualities could be embodied in a modular fire-control system which consists of a single quite accurate medium-range gun (40 mm/50 mm) with nearby correlated radar and electro-optical tracking system. Hostile target detection, selection and designation would be executed by an individual centralized facility. An example is the Phalanx system which uses a Vulcan 20 mm, six-barrelled Gatling gun, giving a rate of fire up to 3,000 rpm.

B. ELECTRONIC SYSTEMS

Electronic Warfare is defined as that division of the military employment of electromagnetic energy involving, on the one hand, actions taken to determine, exploit, prevent, or reduce an enemy's effective use of radiated electromagnetic energy and, on the other hand, action taken to retain one's own effectiveness. There are three categories in Electronic Warfare: Electronic Warfare Support Measures (ESM) which must be able to detect and classify the enemy signals within a given frequency band; Electronic Counter-Measures (ECM) which include the techniques that permit one to disturb or interfere with hostile electronic systems; and Electronic Counter-Countermeasures (ECCM), a term covering all those actions taken to protect friendly electronic systems from hostile ECM and to diminish enemy detection and utility of one's own EW systems. Some components of EW systems, relating to this study, will be discussed as follows:

1. Electronic Warfare Support Measures

ESM is that division of Electronic Warfare involving actions taken to search for, intercept, locate, and immediately identify radiated electromagnetic energy for the purpose of immediate RF emitter recognition. Thus, ESM provides a source of information required for immediate action involving ECM, ECCM, avoidance, targeting, and other tactical employment of forces.[Ref. 5, p. 421]

ESM systems can operate in a very dense electromagnetic environment, can classify emitters by type from an internal "Data Base" and can be employed to direct jammers. A receiver that detects signals over a wide band of frequencies may be used by an ESM system. An example of that is a radar warning receiver (RWR) which intercepts radar signals and identifies their relative threat in real time. Using deliberate

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and non-deliberate enemy radiations, ESM is the ears and the eyes of the military commander. ESM data, compared with an appropriate data base, can offer the commander a complete picture of the RF-emitters active in a particular area.

ESM has the capacity of identifying enemy radiations from such sensors as radars, lasers, and sonars at much longer distances than the maximum detection range of those sensors. There is a very important advantage of ESM: it is completely passive when used as a detector of hostile systems. On the other hand, its disadvantage is that it gives bearing-only data on an emitter. The distance to the intercepted target must be determined by triangulation from multiple ESM receiver tuned to the emitter or by active reconnaissance.

To defeat ESM systems, a military force generally practices emission control (EMCON), which restricts transmissions until it knows it has been detected. Active or radiating weapons are often designed such that the active sensor is only turned on for the terminal phase of the attack (on the order of 10 to 30 seconds), so that minimum warning and reaction time is given to the target. Completely passive weapons such as anti-radiation missiles and heat-seeking missiles provide no warning from ESM.[Ref. 6, p. 8]

ESM is different from signal intelligence (SIGINT). The former focuses on tactical functions that require instant actions. SIGINT is for intelligence gathering and contains three parts: electronic intelligence (ELINT), communications intelligence (COMINT), and radiation intelligence (RADINT). Electronic Warfare is very highly reliant on intelligence and it is important to collect in peacetime as much detail as possible about potential enemy systems. It is necessary to get detailed information on radar and other signals associated with foreign systems. A variety of platforms

surface, airborne or satellite can collect the information and provide it to an ESM "Data Base". It is also very important for intelligence to observe and project trends in science, weapon technology and military philosophy to make sure that any element of EW equipment will be useful when it is finally developed and enters service.

2. Electronic Countermeasures

The first large-scale application of electronics in military operations occurred during World War II. Since that time, the weapons systems have increasingly used electronics, frequently to the point of dominance. However, the importance of countermeasures has grown correspondingly due to the growing dependence of modern weapons on electronics and in recognition of their vulnerability.

There are three categories that are used to classify individual ECM tactics or techniques. But it should be noted that many ECM techniques from all categories could be applied simultaneously in a given tactical situation:[Ref. 5, p. 151]

- The first category, known as Active ECM, includes all jammers; i.e. all ECM devices that radiate electromagnetic energy of themselves. Noise jammers and repeater jammers are the two major groups within this category. Either can be used for self-screening of the jamming platform of for support of multi-platform forces. Active Expendable Jammers and Active Decoys are also included.

- The second category, known as passive ECM, comprises all ECM devices that do not radiate electromagnetic energy of themselves and that are not part of the vehicle/s involved. Although absorptive or refractive chaff and passive reflector are included, the most important technique in this area is reflective chaff.

- The third category includes all ECM techniques which would diminish the radar cross section of a vehicle by using special vehicle construction methods or

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materials. Confusing or attempting to deny proper enemy weapon system operation by Maneuvering Tactics are involved. Also included are Absorption Coverings. The primary actions of Electronic Countermeasures are to prevent the function of enemy surveillance devices, communications, weapons, and in general to reduce his ability to exploit the electromagnetic spectrum. The function of these devices can be prevented in varying degrees by giving wrong information or contradicting information. The final result of the use of ECM may be a practical destruction, as in the premature firing of a warhead due to confusion of a radar fusing system.

ECM includes jamming and deception. The deliberate radiation or reflection of electromagnetic energy with the object of impairing the employment of electronic devices, equipment, or systems being used by a hostile force belongs to jamming. Deception is the deliberate radiation, reradiation, alteration, absorption, reflection of electromagnetic energy in a manner intended to mislead a hostile force in the interpretation or use of information received by his electronic systems. Manipulative and imitative are the two categories of deception. Manipulative implies the alteration or simulation of friendly electromagnetic signals into hostile channels which imitates a hostile emission.

Disrupting, and deceiving are the other two major features of ECM. The broad objectives of most ECM systems are to deny the enemy the information he seeks, or to surround his return with so much false target data that the information cannot be extracted, or to supply so much false data that the information handling capacity of the victim system is swamped.

3. Chaff

Chaff is defined in standard dictionaries, as the husks of grain or anything that is useless. This definition applies to the electronic field today, because the radar operator sees chaff reflections as useless false targets.

Chaff is now a general term that is defined as follows: elemental passive reflectors, absorbers, or refractors of radar, communication and other weapons system radiations, which can be floated or otherwise suspended in the atmosphere or exoatmosphere for the purpose of confusing, screening or otherwise adversely effecting the performance of victim electronic systems. Examples are: metal foils, metal coated dielectrics (aluminum, silver and zinc on nylon or glass being the most common), aerosols, stringballs, rope, and semiconductors. The most usual reference is made to the thin metallic or metallic-coated dielectric strips or rods of various lengths and frequency responses that passively reflect confusion targets, clouds, or corridors to victim radars.

Chaff is the oldest, and still the most widely used, radar countermeasure.[Ref. 6, p. 183] Naval ships use chaff for self-protection against radar guided anti-ship missile. Shipboard personnel can use chaff very efficiently to protect their own ship or to save other units in their own task force. Because of the speed of threatening weapons, it is important that the reaction time from fire initiation to chaff bloom be short and that the chaff cloud be placed accurately. Because it has a limited effective lifetime, it is also necessary that the chaff clouds be renewed at the correct interval.

For the naval application, chaff is most commonly ejected from rockets, shells, or mortars. Naval rockets can carry up to 7 kg of chaff, and mortar systems

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typically dispense up to 3 kg of chaff from several grenades fired simultaneously. There are two major modes of chaff use at sea:

a. Before anti-ship missiles are launched at some distance from the vessel, a pattern of several rockets or shells fired in different directions is used to provide alternate targets to them. Rockets and shells can dispense the distraction decoys at range up to 2 km from the vessel. The decoys may last for several minutes, and, if the threat is still present, more decoys are periodically sown. Therefore, the hostile force is confused by the chaff cloud and can not distinguish between real and false targets.

b. This mode is used closer to the vessel, denying range information to the seeker, and in conjunction with active jamming to lure the attacking missile away. It should be realized that there is a large echoing area within a few seconds of firing the chaff near the ship. The centroid of the chaff is very close to the ship, when the chaff cloud is dispensed at a range of about 100 to 400 meters. The ship then moves quickly out of, and away from, the chaff echo and the missile is lured away, thus avoiding a direct hit.

The second mode can be achieved with rockets or mortars and is regarded as a last resort tactic, which will succeed best with vessels of relatively small radar cross section, such as small, fast patrol boats. For naval use, multipath effects can be used with advantage where the free-space radar cross section of a chaff cloud is greatly enhanced by its proximity to the sea. Significant enhancement can be achieved with clouds up to 200 meters above the sea surface, depending upon the height and range of the seeker. Naval chaff systems are generally designed to achieve the required radar cross section in the order of 30 to 60 seconds.

C. DEFENSE PLATFORM

There are various kind of trajectories that anti-ship missiles can be programmed to pursue, such as diving at steep angles from high elevation and sea-skimming. By using multiple way-point manoeuvers, several can arrive from different directions simultaneously (see Fig II-1). In order to be efficient against such attacks, the defensive system must have a very short reaction time, approximately hemispherical coverage and a high kill probability against multiple attacks. In the real world, a task force of ships would depend on a layered defense containing combat air patrols, electronic jamming, anti-missile missiles and guns to counter the anti-ship missile attack.

In general, a warship is equipped with weapons systems, such as missiles and guns, with which it can assault assailants or protect itself. This is the so called hard-kill. In addition to these equipments which defend by destroying their targets, a ship will be equipped with soft-kill equipment, for example, the electronic warfare systems discussed above, which can be applied in defense to confuse and deflect enemy hard-kill weapons. It requires information which is provided by sensors, primarily radars and ESM equipment, in order to operate these components properly. The information would be computed and controlled by the ship's combat information center, then sent to the individual defensive elements. In high speed modern warfare, the coordinating function, giving an efficient integration when various kinds of weapon operate together, is very important.

An anti-ship missile, whether launched from an aircraft or a ship, essentially has to be guided all the way to its target It can be implemented by semi-active radar or
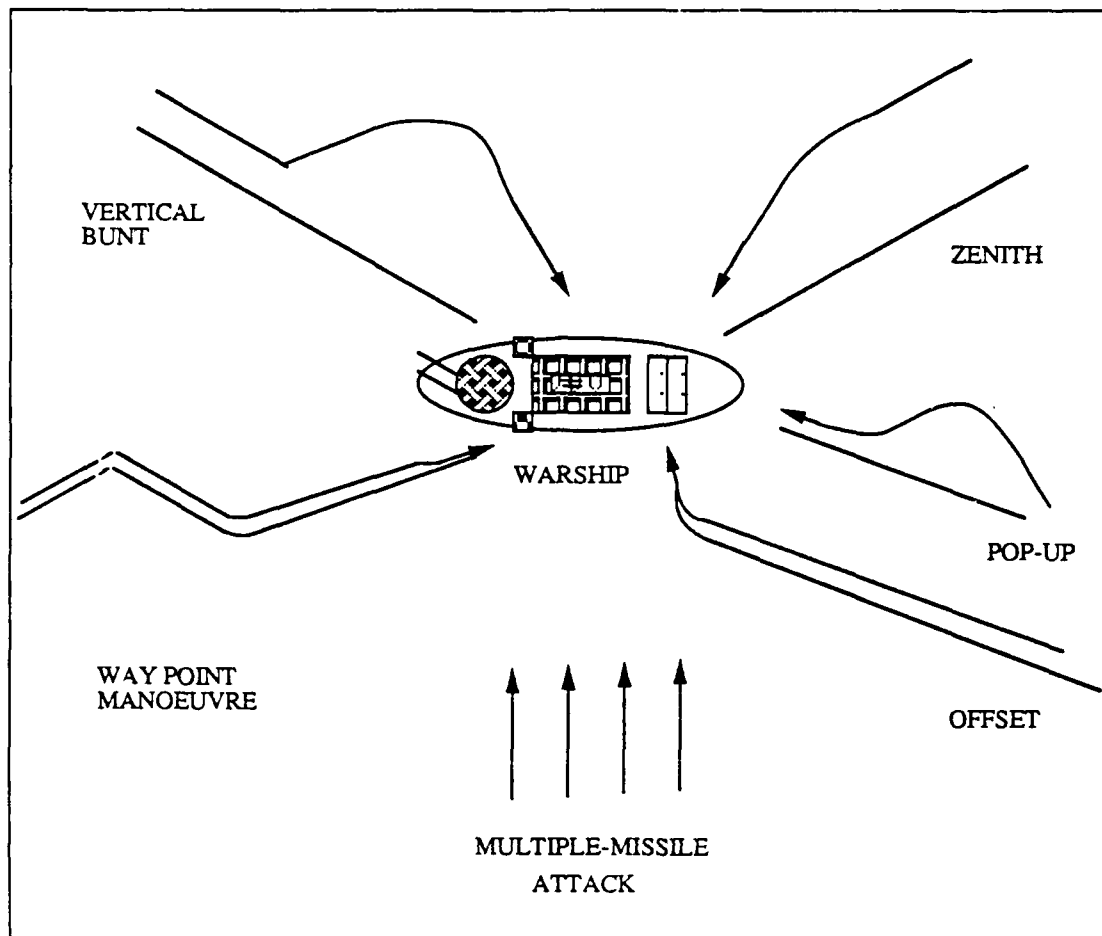
Figure II-1   The various types of trajectories which anti-ship missile can be programmed.

active radar, by infrared sensors, by a TV camera carried in the missile or by the missile homing on to the radar transmission beam of the ship. So far the most general method is active radar where the missile carried its own radar and uses the reflected beam from the target to home on it.

ECM has been developed to deal with all these methods. Radar jammers, chaff and IR decoy launchers are provided. The radar lock of incoming missiles can be broken and TV homers can be defeated by smokescreens and strong lights shone on the missiles' TV camera.

The anti-missile guns of the close-in weapons system (a hard-kill weapon) will be assigned to defeat the missiles which are not destroyed (i.e. succeed in penetrating the defenses) when they are within 3.8 kilometers of the warship. CIWS is assigned to explode the warhead of the incoming missile prematurely. Even though some fragments at such close range will very likely reach the ship, these will result in much less damage than a warhead exploding directly on the warship.

This simulation includes three layers of platform self-defense. The first layer is SAM for medium range defense . The second layer is EW for countering the missiles which leak through the first layer up to the point of impact. The last layer is CIWS for those missiles within its defensive region.

III. THE SIMULATION PROGRAM

A. BRIEF OF THE SIMULATION

Interactive simulation of system performance (ISSP) is an interactive Monte Carlo simulation of an engagement between a warship and attacking anti-ship missiles (ASM). The engagement is complicated due to the many factors that are involved. The simulation is able to simulate the operations of the engagements between four simultaneously attacking ASM and three different defense layers. The defense scenario follows the systems' performance from the search phase to the eventual kill or impact of the ASMs.

The simulation is based on a simplified operational model of the reality. It has been simplified by giving deterministic values for operational parameters, such as radar detection range, probability of kill, reaction time for hard-kill and soft-kill systems, and the impact of enemy jamming. The present simulation is in the form of a desk-top computer program consisting of two modules. The hard-kill module includes Surface-to-air Missiles (SAM) which deal with medium range defense and Close-in Weapon Systems (CIWS) which deal with short range defense. This module was reported in an earlier Naval Postgraduate School thesis[1] and has been combined by the author into one large program with the soft-kill module. The soft-kill module contains an EW system, simulating the defense of the ship by defensive jammer (ECM) and Chaff.

To begin a simulation run, assumed values for all of the parameters are input into the computer. The models are then run, using the parameters and random numbers to evaluate the outcomes of the interactions between elements of the defense and the

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attacking ASM. After storing the results, the models are run again and again with new sets of random numbers to generate a sample size adequate for statistical analysis. At the end of the simulation, the results for the desired number of iterations are computed, the output data are displayed as the expected number of SAM fired and ASM leaking through each defense configuration, the percentage of the anti-ship missiles destroyed by hard-kill and/or soft-kill systems, and the basic analysis of the ship survivability.

B. THE PROGRAM LANGUAGE

ISSP is written in Borland TURBO BASIC, which is a programming language commonly supplied with PC-DOS. This language version is a compiled language, therefore, much faster than a strictly interpreted language, such as Advanced Basic (BASICA) from IBM. But, the speed is not as fast as other computer simulation languages, such as FORTRAN, SIMSCRIPT, GPSS, and SLAM. In order to follow the previous development of the hard-kill module simulation package at the Naval Postgraduate School, the compiled language TURBO BASIC was preferred. This is due to the fact that speed is not important in this simulation. The user needs to be able to input some basic information at the beginning of the program and to follow the output events at the end of the program.

The computer used for this simulation is an IBM personal computer (IBM-PC) or 100 % IBM-PC compatible clone. In order to run the simulation, one of these computers must be equipped with a color/black-white monitor, at least one floppy disk driver, and the TURBO BASIC software must be available. The simulation program, ISSP, was written using the PC-DOS disk operating system Version 3.2, but any PC-

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DOS Version developed after Version 3.2 will work. Since the simulation must interact with TURBO BASIC software and the disk operation system, therefore, no guarantee can be provided that the simulation will run on other than IBM-PC or 100 % IBM-PC compatible computer.

The built-in RND Function in TURBO BASIC, which satisfactorily generates the uniformly distributed pseudo-random numbers, was used to provide the random numbers needed for this simulation. An input statement gives the seed value of the random number generator and it is easily accessible from the main program. The random numbers are used throughout ISSP to assess the outcome of a particular event, whether it is successful or a failure.

C. FLOW OF THE PROGRAM

The flow of the program is summarized in Figure III-1. First, the simulation is started and it asks for the input parameters to be loaded, such as sample size, ASM spacing, and mode number illustrated in Table III-1. Based on the mode chosen, it will ask for P_k values of ECM and/or Chaff, and the jamming conditions to be simulated. If jamming is used by the attackers, an effective detection range will be requested. When the simulation starts running, it sets an elapsed time clock to zero, because the clock can be used to track the total execution time, which is a reference point for the user.

Since a number of variables are used for cumulative statistical purposes, it is also necessary to set all these variables to zero at the beginning of the program. On the other hand, those variables which will change with each repetition also must be set to zero at the beginning of each repetition. Thus, we have discussed how to start the
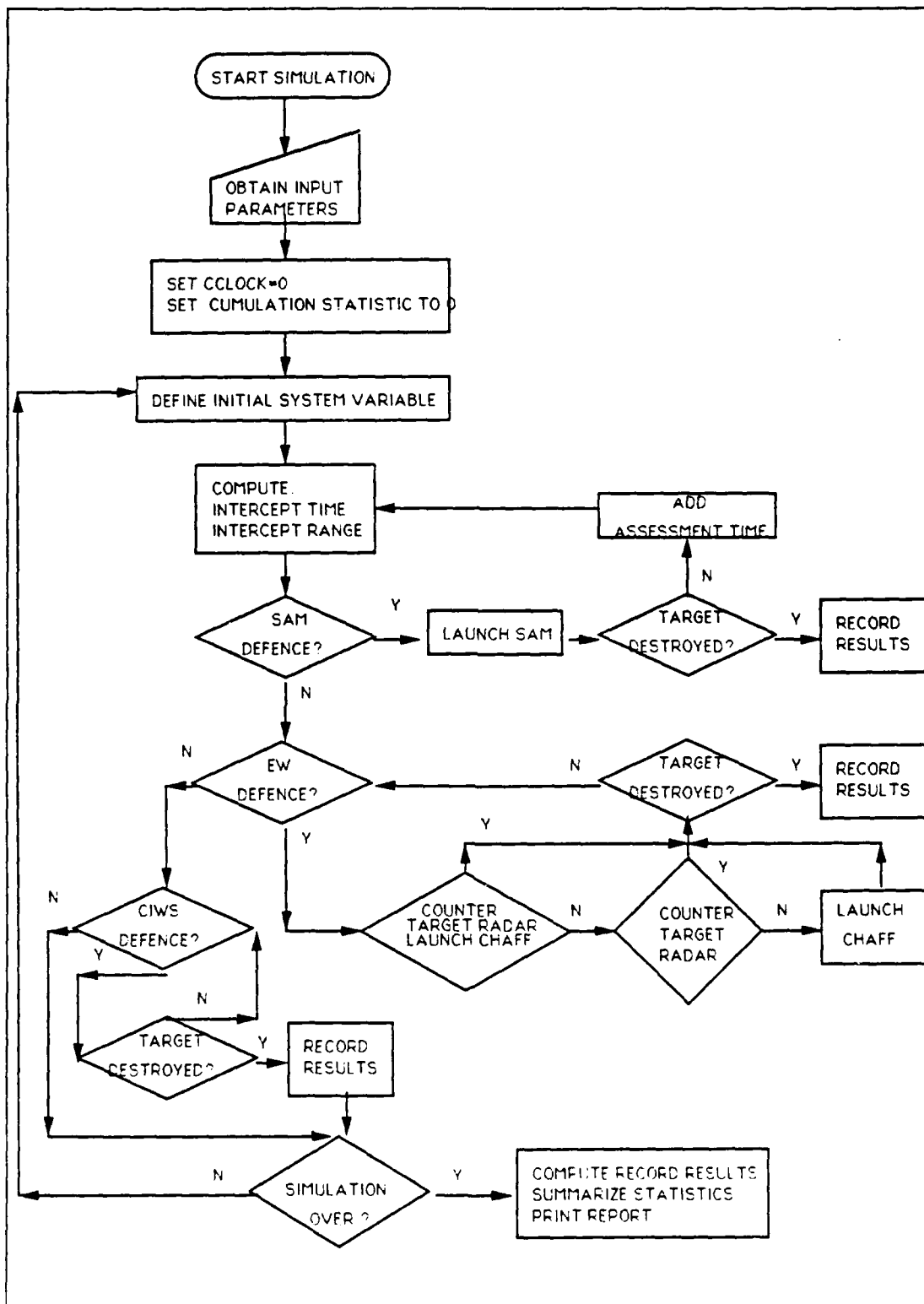
Figure III-1 Flow of the program.

program and how the program works in the first few stages. The following paragraphs deal with the simulation of the air defense engagement.

TABLE III-1   The Definition of Each State

MODE	WEAPON SYSTEM
0	hard-kill system
1	hard-kill system and ECM
2	hard-kill system and Chaff
3	hard-kill system and combined ECM and Chaff

Once the search radar detects the incoming targets, the program will automatically note the operational data, such as speed and heading of the incoming ASM targets, and compute their position and time of impact. Furthermore, it can provide this information to the simulated tracking radar for launching SAM against the threat. The longer the detection range, the longer the time to impact. This increases the chances for SAM to destroy the incoming targets. This program will calculate and check the time and range of intercept, where the intercept time is the time from detection of the incoming targets to intercept by SAM, and the intercept range is the distance from the warship to intercept point. It is very important to check the intercept range, because unless the range is above a pre-specified threshold value, the gyros' in the SAM guidance system will not be stabilized.

Assessment time is the time lost in assessing whether a SAM has destroyed its assigned target. If not, the ASM position and time to impact the warship are updated and the engagement is repeated. Several loops in this program determine the effectiveness of the SAM defense.

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From the EW defense point of view, ESM is activated all the time. Two kinds of EW application are available in the real war. One is dealing with the outer battle, the other is dealing with the inner battle. The former is to reduce or destroy the capability of an enemy to launch or fire its weapon and this is beyond the scope of this study. The latter is to counter or interrupt the weapon already fired by the enemy. Once ESM detects the incoming ASM when it turns on its seeker, it will link to defensive jammer (ECM) and Chaff. The defensive jammer could break the lock of the incoming ASM seeker, so the seeker has to recycle again in order to track its target. If the Chaff is launched and bloomed during the proper time, the seeker of the incoming ASM might lock on the large radar cross section (RCS) provided by Chaff instead of only on the warship. Then, the warship can be maneuvered away to avoid the attack. The combination of defensive jammer and Chaff is the best case for EW system to counter the threat. But, under some circumstances, this combination may not be feasible. However, this program can simulate the individual defense of defensive jammer and/or Chaff at the option of the user.

When the incoming ASM approaches to the CIWS defensive area, this system is on and continues to carry out the defense. After five seconds reaction time to process the data and lock on the target, it starts firing at the incoming ASM when it is within the CIWS maximum intercept range, which is two NMs. Its maximum continuous firing time is eight seconds. The assessment of results requires one second, and it will be carried out following each firing procedure. If CIWS has not shot down the engaged target, the above procedure will be recycled again until the engaged target passes the minimum intercept range which is 0.1 NM. The ISSP program is able to

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implement the above process and compute the data needed to assess each event, such as intercept time and intercept range.

After the pre-set number of simulation repetitions is completed, the final step is to compute and summarize the data. The result could be printed out by either an image writer or laser printer. The display includes the following information: the expected number of SAM fired, the expected number and percentage of ASM destroyed by SAM, CIWS, with/without EW system, the expected number of targets which penetrate through and hit the warship successfully, the P_k value for hard-kill system and soft-kill system, and the ship survivability.

D.   WEAPON SYSTEMS MODULE

As mention before, two major types of weapon systems are used in this simulation known as hard-kill system and soft-kill systems. The discussion of this section and the following section will be based on these two weapon modules.

1.   Hard-Kill Systems Module

a.   SAM Sub-Module

The SAM sub-module is the first one called by the program when the simulation starts. Logically, it is the first engagement of the threat; the target has to be detected if any engagement is to occur. This module simulates the major functions of a SAM defense. The fundamental process of simulating the interactions of four incoming targets and the SAM defense is summarized in Figure III 2. This network shows the possible sequences of events as a SAM system operates against the incoming threat. The real network in the program is more complicated due to the accurate calculation of the timing of the impact and intercept events, and the sequencing of the

23
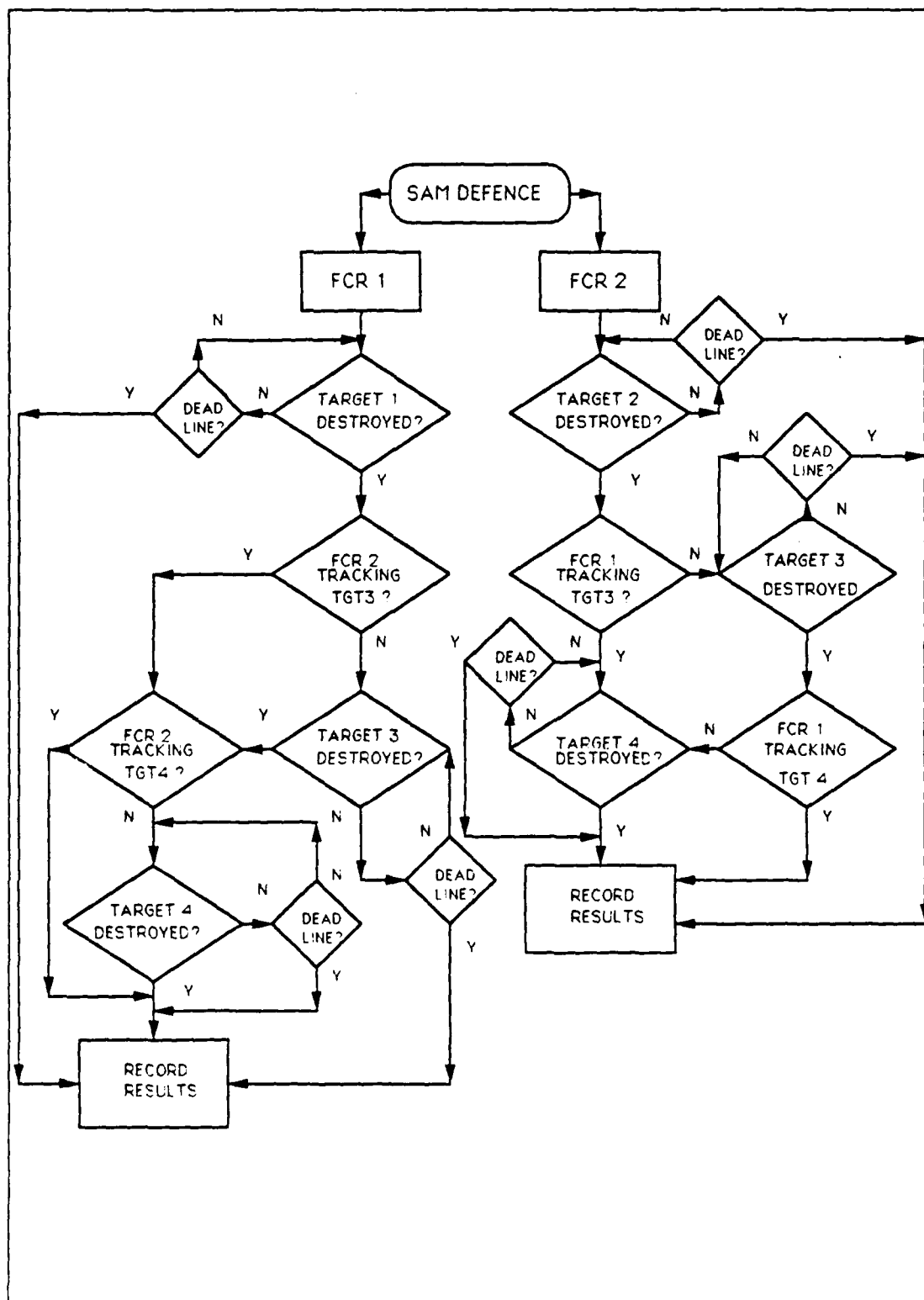
Figure III-2   SAM Sub-Module.

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activities of the Fire Control Radar (FCR) and SAM launches.

The input for this module is the position of the target at detection (detection range), which at this time is simply on a straight and level flight path. The predicted point of initial interception by a SAM can be determined as following:[Ref. 1, p.14]

$$R_L = R_{Det} - (T_L \times V_{TGT}) \quad (3\text{-}1)$$

$$V_{SAM} \times T_{Fly} = R_L - (V_{TGT} \times T_{Fly})$$

$$T_{Fly} (V_{SAM} + V_{TGT}) = R_L$$

$$T_{Fly} = R_L / (V_{SAM} + V_{TGT}) \quad (3\text{-}2)$$

$$T_{Int} = T_{Fly} + T_{Fly} \quad (3\text{-}3)$$

$$R_{Int} = V_{SAM} \times T_{Int} \quad (3\text{-}4)$$

or

$$R_{Int} = R_{Det} - (T_{Int} \times V_{TGT}) \quad (3\text{-}5)$$

where

*[1] R_{Det} : Detection range in NM

R_L : Target current range at time of SAM launch in NM

R_{Int} : Intercept range in NM

* V_{TGT} : Target velocity in NM/sec

* V_{SAM} : SAM velocity in NM/sec

* T_1 : The response time to launch SAM in seconds

T_{Int} : Intercept time in seconds

---

[1]"*" : These quantities are assumed parameter values input to the simulation program at the beginning of each run.

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T_{Fly} : Flying time of SAM in seconds

Note : The range is measured between warship and current SAM position.

The time of SAM is measured since detection occurred.

Example 3.1 This example illustrates the computation of time and range for initial intercept

Suppose that the weapon systems have the following characteristics:

Reaction time = 30 sec; R_{Det} = 30 NMs; V_{TGT} = 10 NMs/Min = 0.167 NM/sec

V_{SAM} = 20 NMs/Min = 0.333 NM/sec

Find the time and range for intercept.

Solution: After 30 seconds, the current target position can be found from

Eq. 3-1

$$R_L = R_{Det} - (T_L \times V_{TGT})$$

where T_L = 30 sec

Thus, we have

$$R_L = 30 \text{ NMs} - (30 \text{ sec} \times 0.167 \text{ NM/sec}) = 25 \text{ NMs}$$

For intercept time, using Eq. 3-2 and Eq. 3-3

$$T_{Fly} = R_L / (V_{SAM} + V_{TGT}) = 25 \text{ NMs} / (0.167 + 0.333) \text{ NM/sec} = 50 \text{ sec}$$

$$T_{Int} = T_{Fly} + T_L = 50 \text{ sec} + 30 \text{ sec} = \underline{80 \text{ sec,}}$$

Therefore, from either Eq. 3-4 or Eq. 3-5 which gives the intercept range

$$R_{Int} = V_{SAM} \times T_{Fly} = 0.333 \text{ NM/sec} \times 50 \text{ sec} = \underline{16.67 \text{ NMs,}}$$

or

$$R_{Int} = R_{Det} - (T_{Int} \times V_{TGT}) = 30 \text{ Nms} - (80 \times 0.167) \text{ NMs}$$

$$= 30 - 13.33 \text{ Nms} = \underline{16.67 \text{ NMs,}}$$

After the incoming target is detected, the Identification-Friend-or-Foe (IFF) systems will identify the target, the surveillance radar data will link to the Fire Control Radar (FCR), the personnel will take proper action, SAM will be ready. The time taken by the above actions is called reaction time. Two FCR are used in this simulation and both have the same reaction time, however, they both control the same missile launcher. When the first target is found, FCR 1 will be assigned against the target and control a SAM. The second target will be assigned to FCR 2. The first engaged target might not be destroyed by the first SAM firing. However, the FCR will not shift to another target unless the previous target was destroyed and checking the results requires additional FCR time (the assessment time). The FCRs have to check each other after they have destroyed the first assigned target. Then, after the lapse of a second reaction time, they will shift to the second priority target in order to achieve the maximum performance of SAM defense. The above processing sequence has been illustrated in Figure III-2.

b. CIWS Sub-Module

This module becomes active when the incoming target arrives at the CIWS defended area. After this, the program reads the present position of the incoming target and continuously fires at it. This requires five seconds reaction time. The process of CIWS defense is demonstrated in Figure III-3.

The probability of kill varies with continuous firing time. The greater the time the more bullets that can be fired at the engaged target, and hence the higher the probability of kill. Therefore, the program will predict the continuous firing time and, as mention before, the maximum is 8 seconds. The kill probability is determined using equations shown below:[Ref 1. p 48]

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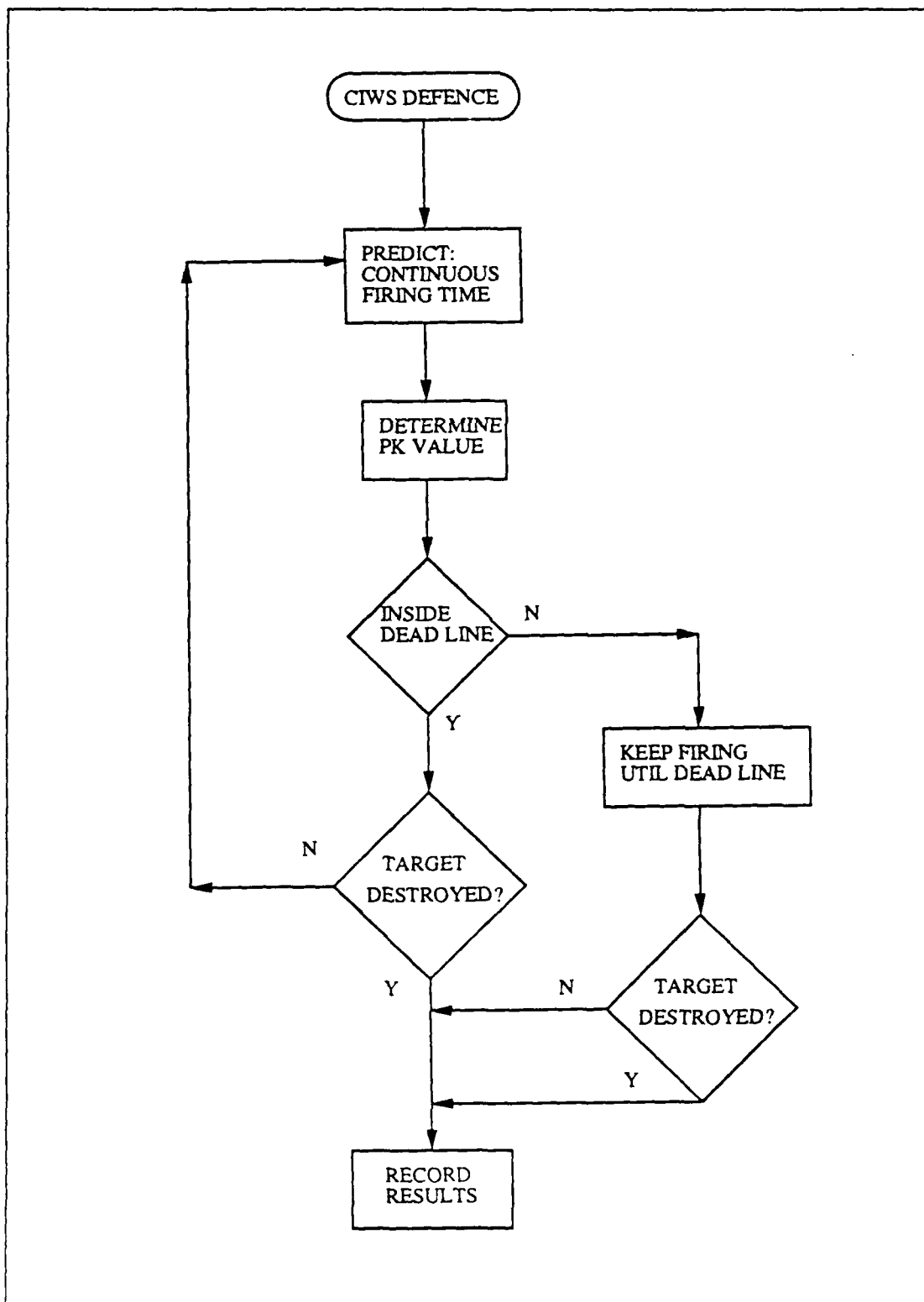
Figure III-3 CIWS Sub-Module.

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(1). T_{CF} between (0, 4)

$$P_k = 0.075 \times T_{CF} \qquad (3\text{-}6)$$

(2). T_{CF} between (4, 6)

$$P_k = 0.1 \times T_{CF} - 0.1 \qquad (3\text{-}7)$$

(3). T_{CF} between (6, 8)

$$P_k = 0.05 \times T_{CF} + 0.2 \qquad (3\text{-}8)$$

where

T_{CF} = Continuous firing time in second

P_k = Probability of kill

The program will determine the predicted intercept distance according to the above process. If it is in excess of the minimum intercept range of CIWS, Then CIWS will develop fire up to maximum continuous firing time. If not, it will keep firing at the engaged target until it passes through the final defensive line. A uniform random number is compared with the proper P_k value of CIWS to determine whether the engaged target is destroyed or not.

2.   Soft-Kill Systems Module

The defensive jammer and chaff are available in the soft-kill systems. In order to search for, intercept, locate, and identify sources of enemy electromagnetic radiation, the ESM receivers are used. They provide the information which is used for the purpose of threat recognition and for the tactical employment of ECM equipment. The process of employing an EW defense is illustrated in the diagram shown simplified in Figure III-4, and it will be discussed in the following paragraphs.
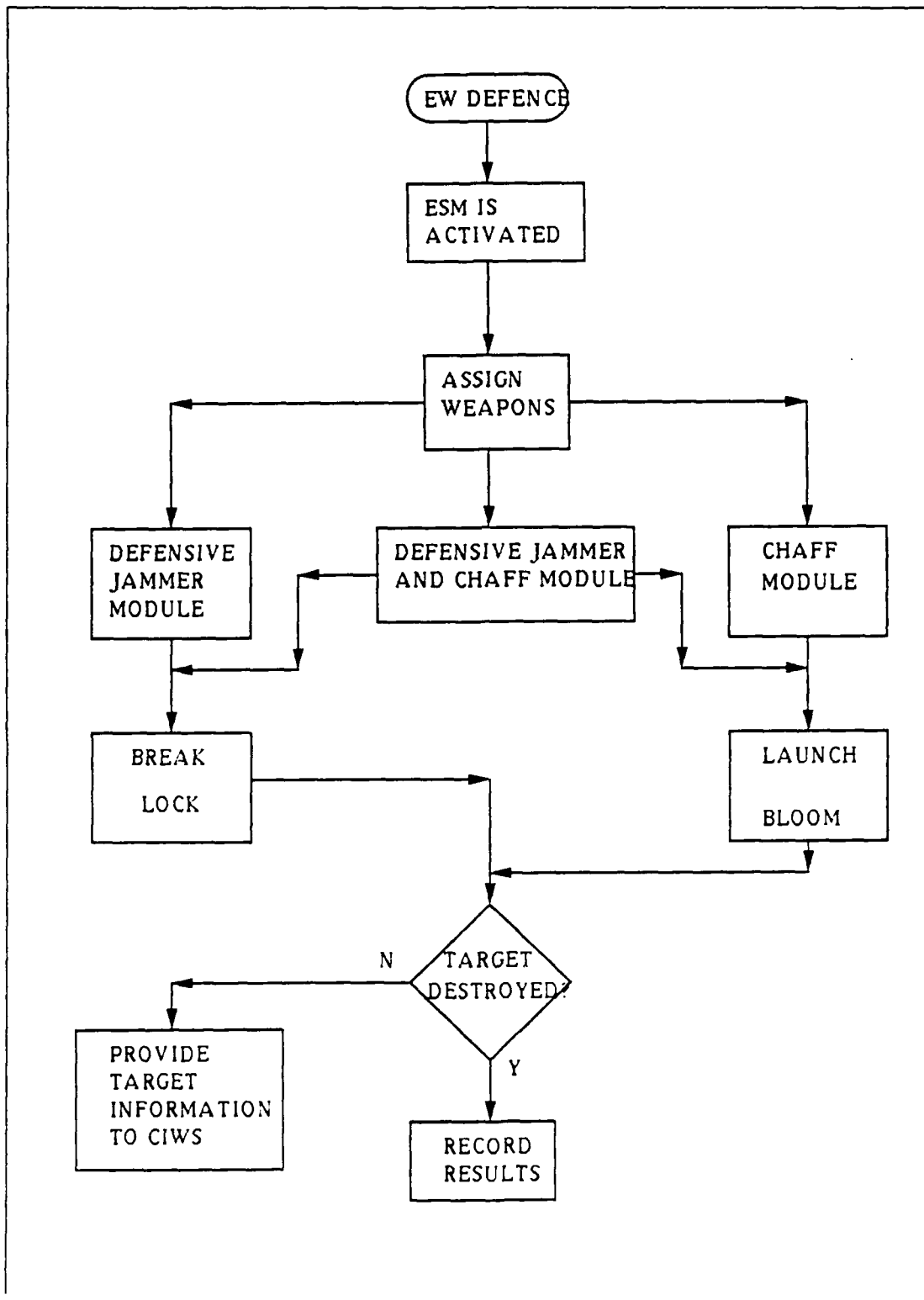
Figure III-4 EW Module.

There are three different modules in this program. Before going into the three modules, two statements will help to understand the principle used in this section:

- To reduce the ASM kill probability, deceptive jamming is often employed against fire control and missile guidance radars. A defensive jammer may be able to degrade the accuracy of both angular and range information developed by the radar and may, therefore, greatly reduce the kill probability. In some cases, it may be able to cause break-lock of the tracking radar, causing it to become completely unlocked from the target. The radar must then reacquire its target and valuable time is lost, along with a great deal of information about the target position. The technique used to degrade the accuracy of the azimuth and elevation tracking circuits is a function of the tracking technique used. Thus defensive jammers must be tailored to the characteristics of the victim radar.

- Chaff can be manufactured to be effective over wide frequency ranges. It does not depend on a priori knowledge or detailed information about victim weapon systems. Also, when properly deployed, it is effective against many radars simultaneously.

a. Defensive jammer & Chaff Module

Detection of the main-beam radiation from a seeker on the incoming target will be done by an ESM receiver. The defensive jammer and chaff will not react until the order and information are delivered. The function of these systems is to cause the seeker of the engaged target to break its lock on the ship being defended. The roles of defensive jammer and chaff in naval operations are correspondingly complex and a general discussion of the theory of employment of these systems is beyond the scope of the present paper. However, this simulation program will implement this module in accordance with the assumptions on weapons configuration

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which are adopted for the purposes of a parametric study. Therefore, after ESM provides the necessary information, the EW systems automatically react and provide the proper jamming method and appropriately deploy the chaff.

For example, suppose that the weapon systems have the same characteristics as example 3.1. Using the same method as illustrated in example 3.1, four impact points can be found in the SAM defense area. The launch time, launch range, flying time, intercept time, and intercept range of SAM are shown in Table III-2. There is no fifth impact point because the intercept range falls below the minimum intercept range of the SAM defense. If the engaged targets were not shot down in the first three impact points, then the next action will shift to the fourth impact point. In the meantime, it is assumed that the seeker of the engaged targets turned on at 6 NMs. Once this action was detected, the defensive jammer made the appropriate response. It required ten seconds reaction time, and jamming continues throughout the remainder of the engagement.

TABLE III-2 The Information of Each Impact Point for a Sample Event

Impact Point	T_1(sec)	R_1(NM)	T_{Fly} (sec)	T_{Int}(sec)	R_{Int}(NM)
1	30	25	50	80	16.67
2	88	15.33	30.67	118.67	10.22
3	126.67	8.89	17.78	144.45	5.93
4	152.45	4.59	9.18	161.63	3.06

The chaff was also activated at 6 NM target range. It required ten seconds reaction time from chaff assignment to launch and an additional ten seconds

from launch to bloom. The cloud of chaff is able to stay in the sky about 45 seconds at the effective area close to the warship. According to the velocity of the target, it can fly 3.34 NMs during 20 seconds. This means that the range of the engaged target will decrease from 6 NMs to 2.67 NM before the chaff blooms and generates defensive effectiveness.

Two kinds of defensive modules (SAM + jamming) are active against the engaged targets before the impact point 3, in accordance with the above example. However, they do not interfere with each other operationally and there kills are not double counted in the simulation. For instance, the intercept range is 5.93 NM for impact point 3. If failure occurred, the next intercept range is 3.06 NM, which is the last intercept point for SAM. If SAM could not shoot down the engaged target, then the EW and CIWS will take over the defense action. Of course, a lot of different situations will be generated in this simulation and they can be analyzed and compared based on the process which is discussed above.

b. Defensive Jammer Sub-Module

For the defensive jammer, the reaction is as described above. The following are illustrations of the various jamming techniques applied at present.

- The technique commonly employed for disrupting range tracking circuits is called range-gate pull off (RGPO). The defensive jammer initially repeats the each incoming pulse to capture the radar automatic gain-control (AGC) circuitry, the time delay is then gradually increased. Usually the RGPO cycle is repeated as long as the radar represents a threat.

- The jamming technique applicable against the conical-scan tracker is called inverse gain. The object is to produce, in the radar, error voltages in the vertical and

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horizontal channels respectively. Experience has shown that inverse gain jamming can result in break-lock, and the loss of the target by the tracking radar.

- The countermeasure commonly employed against conical-scan on receive only (COSRO) is swept audio. While it is possible to achieve break-lock by using swept audio against COSRO tracking radars, the soft-kill probability is much less than for inverse gain against conical-scan trackers. Moreover, since the jammer is only effective for a fraction of the time, the tracking radar may reacquire the target after the track is broken.

- The objective of AGC jamming techniques is to deny target tracking information to tracking radars which employ amplitude information and use AGC to control the receiver gain. The technique can be effective against conical scan or track-while-scan systems, either active or passive (COSRO, TWSRO). This technique goes by various names including AGC deception, countdown, stripper, modulation stripper, AGC capture, and duty-cycle jamming.

In ISSP, the effect of all of these types of jamming is simulated by the use of a jamming "kill probability" ($P_{kt(jamming)}$) in estimating the number of ASM that leak through to impact on the target ship.

c. Chaff Sub-Module

From the ship's viewpoint, chaff must be launched to an altitude of several hundred feet by means of rockets or mortar shells. The lifetime of a chaff cloud is limited by the length of time required for the chaff to fall to the sea level. Isolated chaff blooms can serve as confusion targets and make it more difficult for the seeker to identify the true warship because that identification can be difficult when many radar targets are present. Based on this concept, the better way is to have the

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chaff launched and bloomed before the missile seeker is turned on. In order to provide enough false targets interspersed with the real one to saturate the seeker attack, several chaffs bundles have to be ejected in different directions. Several waves of chaff launches may be required to maintain the false targets. The effect of the use of chaff is simulated by a chaff "kill probability" ($P_{k(chaff)}$).

E. SAMPLE SIZE

The degree of plausibility of any point estimate from this simulation will be specified by a confidence interval. We speak of a 95% confidence interval which means there is a degree of confidence of 95% that the true population parameter lies with the interval. If the confidence level is high and the interval is small this provides a reasonably precise knowledge of the value of the parameter.

For a large sample size, the Central Limit Theorem implies that the sample mean has approximately a normal distribution whatever the nature of the population distribution. The general formula for the sample size N necessary to ensure an interval of width 2ε is obtained from the following:[2]

$$N = (Z_{\alpha/2})^2 P(1-P) \; / \; \varepsilon^2$$

where

N: Sample size

ε: Accuracy criterion, assume to be 0.01.

P: Population proportion to be estimated, the ship survivability in this program

α: Significance level = 0.05 for confidence interval of 95%

$Z_{\alpha/2}$: Critical value = 1.96 for confidence interval of 95%

A choice of sample size N can be made by taking advantage of the fact that P(1-P) is maximized for P = 1/2 and decreases as P moves away from 1/2 in either direction. The most conservative approach is to use P = 1/2, for then the accuracy criterion will be $\leq \varepsilon$ no matter what P is actually observed.

Ref. 1, p. 19; Ref. 12, p. 427; Ref. 13, p. 263

For this program, let P denote the population proportion which is ship survivability, and we calculate a 95% confidence interval of half width 0.01 for P, based on this data. Therefore, the sample size N required to yield a 95% confidence interval whose accuracy criterion is at most 0.01, whatever the resulting value of P, is

$$N = (Z_{\alpha/2})^2 P(1-P) / \epsilon^2 = (1.96)^2(0.5)^2 / (0.01)^2 = 9604$$

It would be necessary to test 9604 iterations in order to fulfill the requirement. The 10000 iterations has been selected in this program to ensure the accuracy is within 0.01.

IV. THE ISSP PERFORMANCE AND ANALYSIS

A. THE IMPROVEMENT PLAN FOR AAW WEAPON SYSTEM

Anti-air Warfare (AAW) is a term for actions required to destroy, or reduce to an acceptable level, the hostile air and missile threat. It includes such measures as the use of airborne interceptors, bombers, high fire rate antiaircraft guns, surface-to-air and air-to-air missiles, and electronic countermeasures to destroy the air or missile threat both before and after it is launched. Other measures taken to minimize the effects of hostile air action are cover, concealment, dispersion, deception (including electronic) and mobility.

A major problem, experienced in many countries, is how best to use a limited budget to upgrade ship survivability. There are several approaches. One can improve or enhance the capability of existing combat systems, or add new and more powerful systems. The first approach includes increasing the loading speed of the launcher, the probability of kill, the velocity, and the intercept range of the SAM; and decreasing the system reaction time, the assessment speed and the data processing speed in the computer. Several alternative plans for improving the existing SAM defense of a warship are summarized in Table IV-1. The four plans call for increasing SAM kill probability and reducing reaction time with and without the addition of defensive jammer (ECM) and chaff.

The following will discuss the first two cases which is the hard-kill defense by active systems (SAM & CIWS) and integration of the soft-kill defense will be introduced in the next sections.

Improving the P_k value of the SAM is an obvious way to enhance the survivability of the warship. This is illustrated for the defense against a simultaneous attack by four anti-ship missiles. The expected number of leaking missiles through to the ship for different detection ranges and different P_ks is shown in Figure IV-1(a). For example, at detection range 20 Nm, the expected value of leaking missiles is 2.24 for P_k equals 0.3, the mean value of expected leaking missile is 1.37 for P_k equals 0.7, the difference is 0.87 or about 22%. In Figure IV-2 shows the performance of the

hard-kill system, in terms of missiles destroyed. At detection range 20 Nm, the expected number of the anti-ship missiles destroyed by the SAM is 1.09 for P_k equals 0.3, and 1.96 for P^k equals 0.7, the difference is 0.90. This means about one more anti-ship missile can be destroyed in term of increasing P_k value of SAM. The ship survivability is illustrated in Figure IV-3(a). This figure shows that higher P_k and longer detection range both yield higher ship survivability.

TABLE IV-1   The Modified Plan for AAW Performance

CASE	PK(SAM)	PK(ECM)	PK(CHAFF)	REACTION TIME	EW
1	0.3	0.0	0.0	30	NO
2	0.7	0.0	0.0	20	NO
3	0.3	0.3	0.4	30	YES
4	0.7	0.5	0.6	20	YES

The other way which has been chosen for improving the effectiveness is to reduce the reaction time. Figure IV-1(b) shows for a 20 second reaction time, the expected number of leaking missiles and the reduction in missile leakage is shown in Figure IV-4(a). Although there is some fluctuation, the expected leaking missiles have been reduced at each detection range and different P_k. For the hard-kill systems, Figure IV-5 summarizes the results for reaction time equal 20 seconds. Comparing this figure with Figure IV-2, Illustrates the importance of reaction time at both short and long detection ranges, especially at higher P_k values. Figure IV-3(b) shows the ship survivability at different P_k for reaction time equal to 20 seconds. The differences due to different reaction times at different detection range and different P_k are demonstrated in Figure IV-4(b).

Clearly, the higher P_k and shorter reaction time can improve the performance of hard-kill defense and upgrade the survivability of the warship. Figure IV-6 shows the
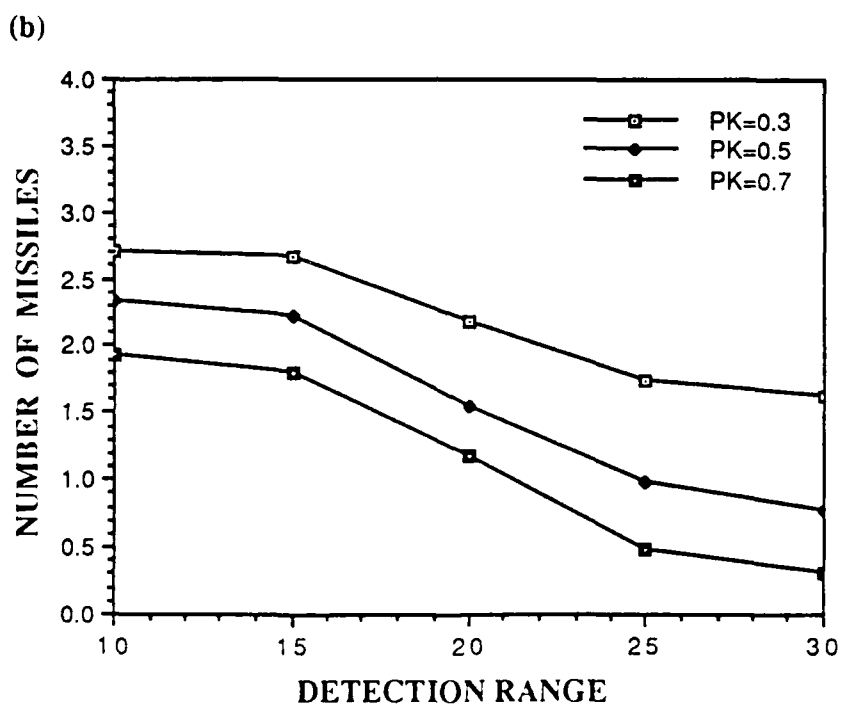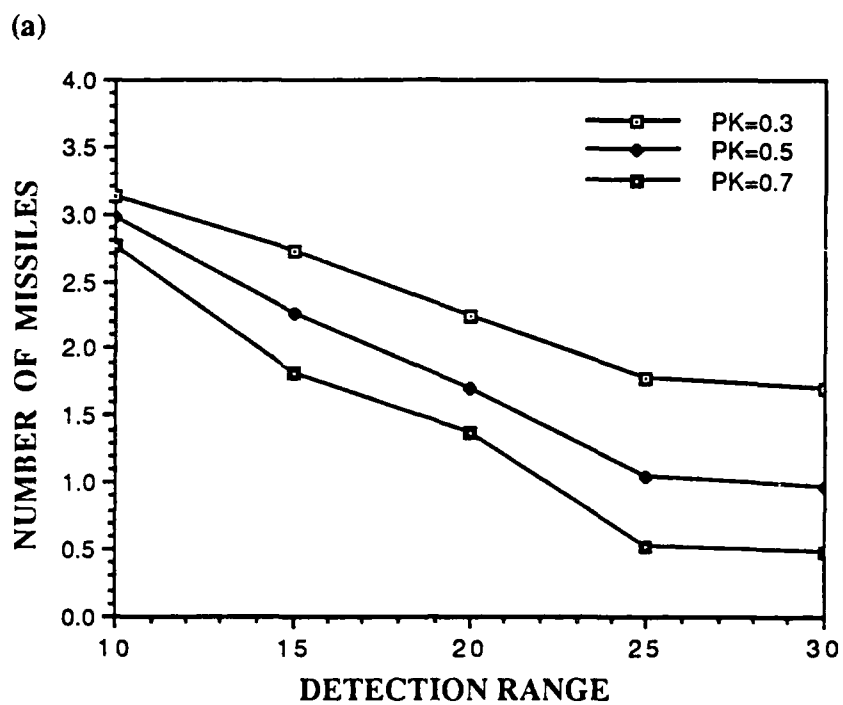
Figure IV-1 Expected leaking missiles vs. detection range
(a) SAM RT=30   (b) SAM RT=20.

(a). PK=0.3

(b). PK=0.5

(c). PK=0.7
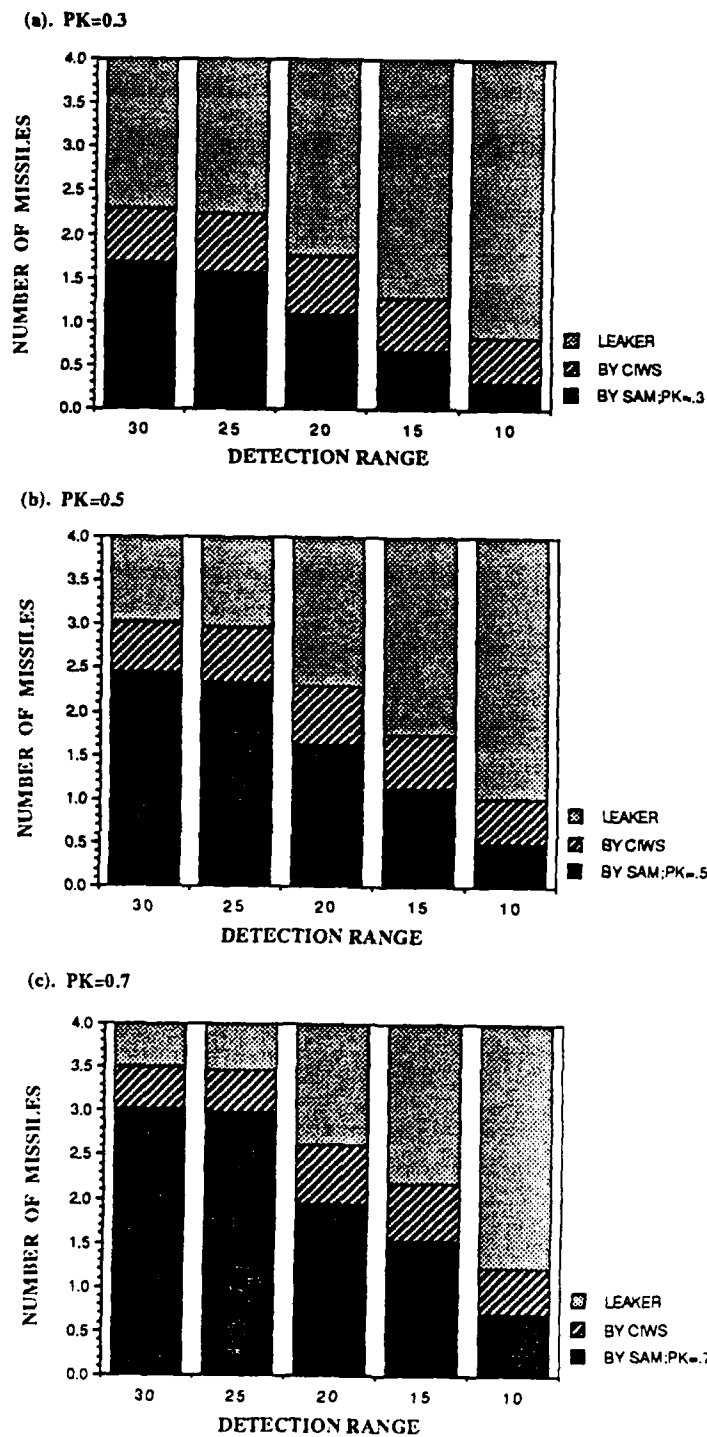
Figure IV-2 Performance of hard-kill systems VS detection
ange SAM RT=30: (a) SAM P_c=0.3   (b) SAM P_c=0.5   (c) SAM
P_k=0.7.
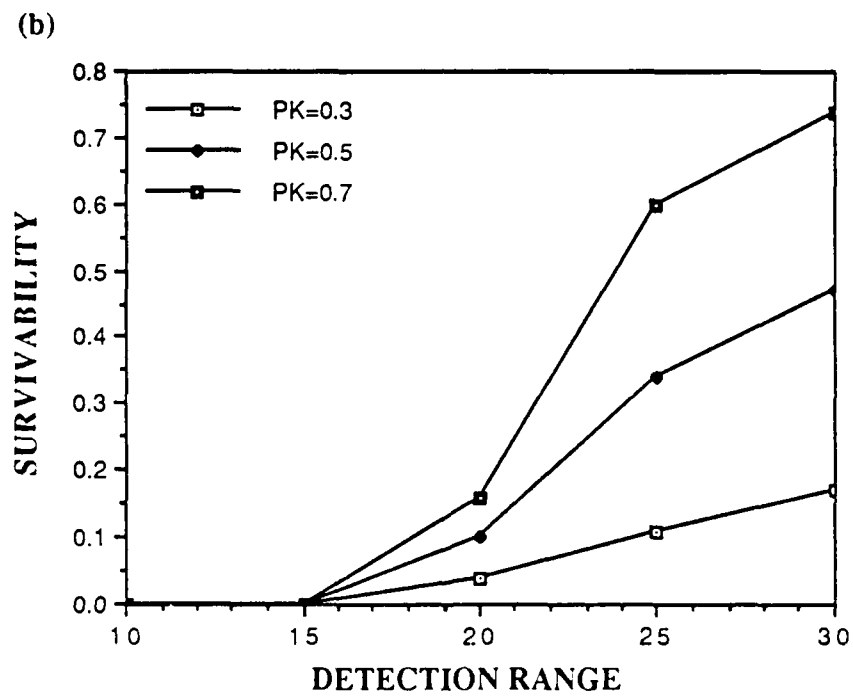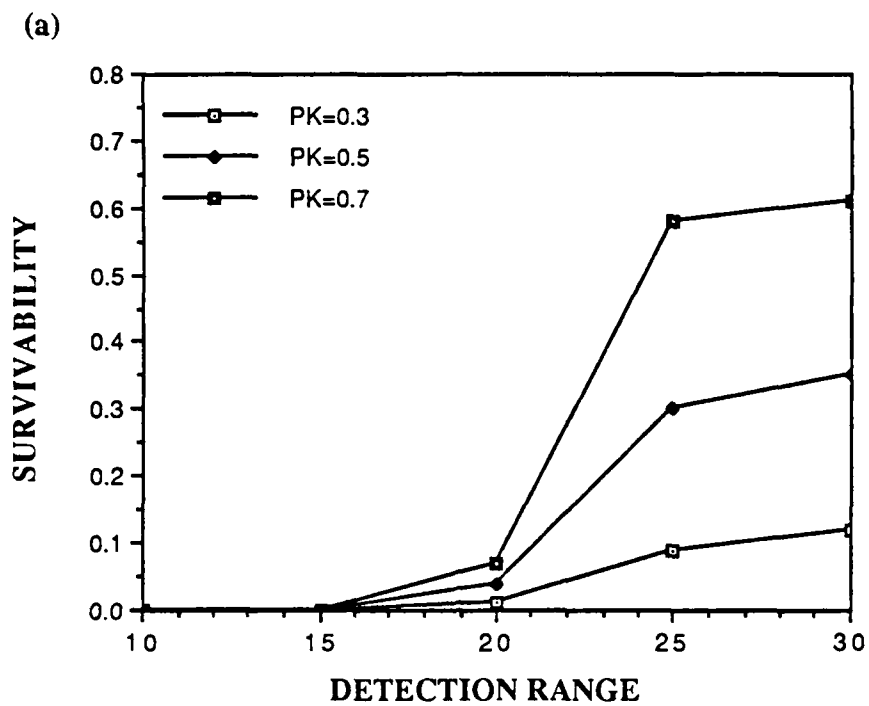
Figure IV-3 Ship survivability vs. detection range (a)
SAM RT=30 (b) SAM RT=20.
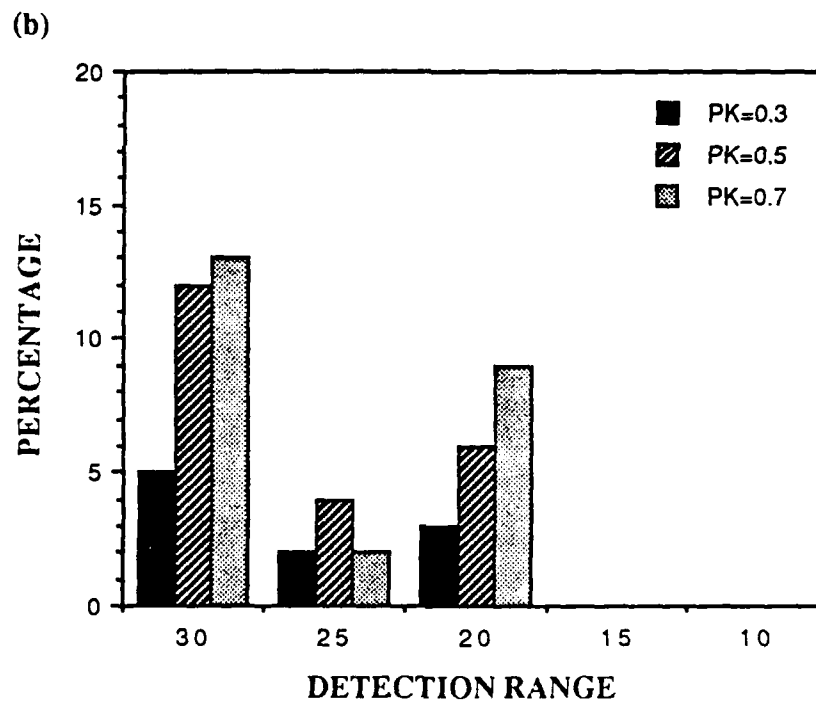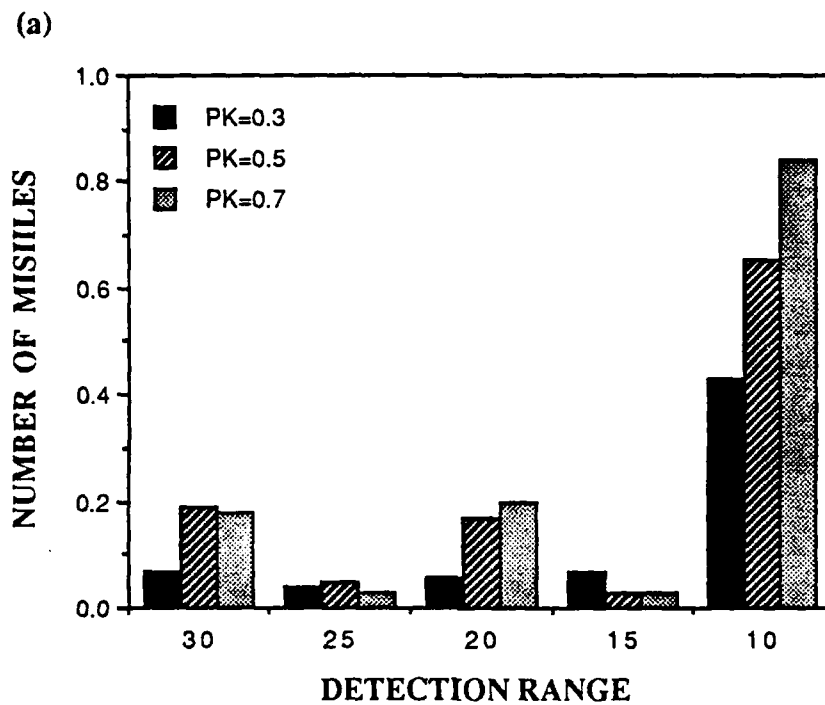
Figure IV-4   (a) Decrement of expected leaking misssiles detection range (from RT=30 to RT=20)   (b) Increment of ship survivability vs. detection range (from RT=30 to RT=20).
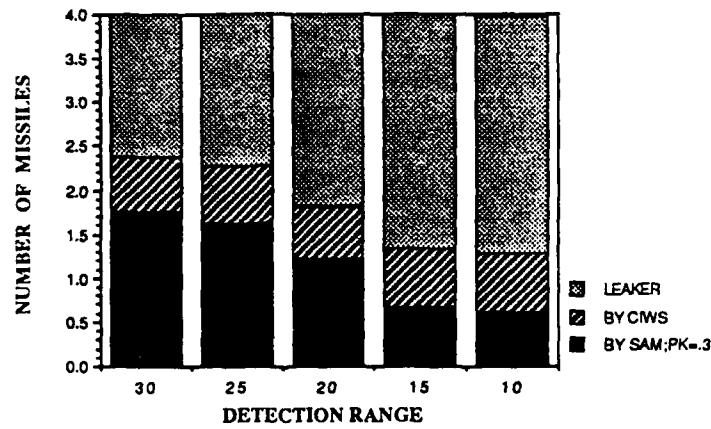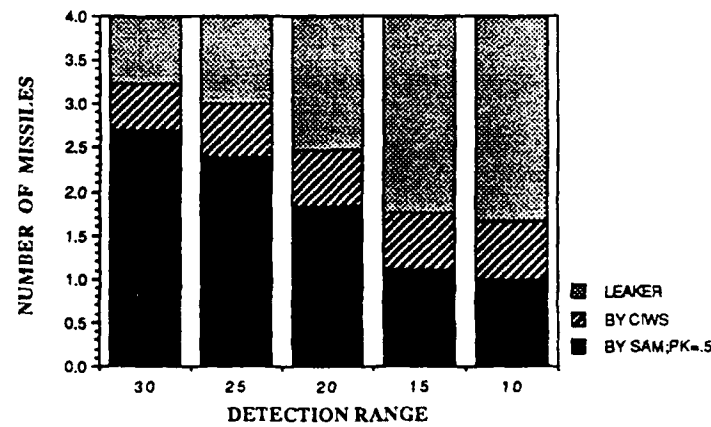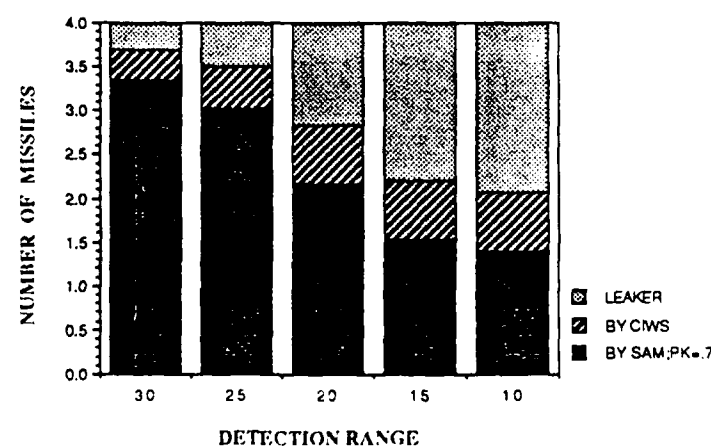
Figure IV-5 Performance of hard-kill systems vs. detection range SAM RT=20: (a) SAM P.=0.3 (b) SAM P.0.5 (c) SAM P.=0.7.

a. Range=30   b. Range=25

c. Range=20   d. Range=15

e. Range=10
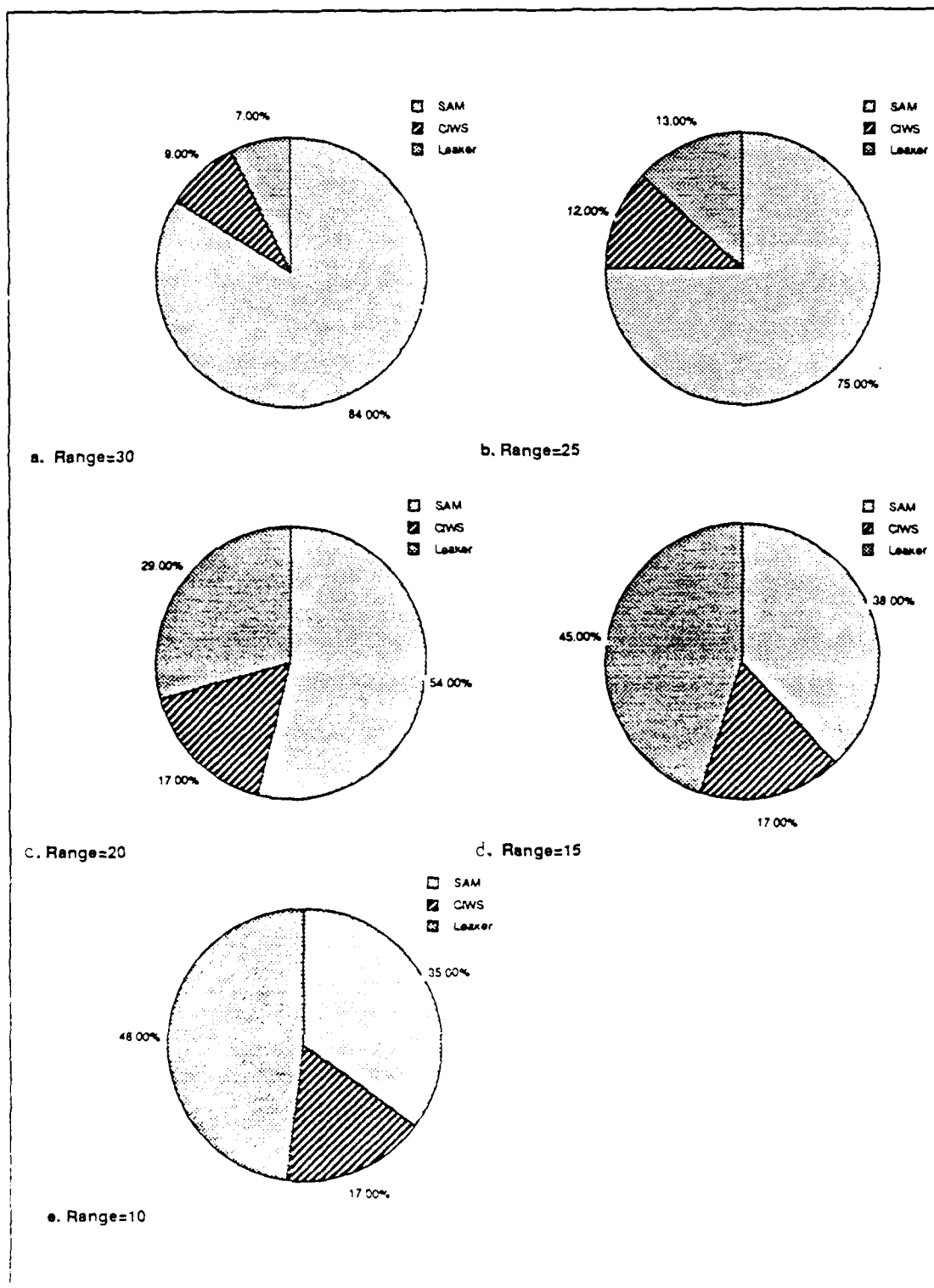
Figure IV-6 The pie-chart of the performance at different
detection range SAM RT=30 P_s=0.7.

pie-chart of the performance at different detection ranges for reaction time equal to 20 seconds and kill probability equal to 0.7.

B.   INTEGRATED PERFORMANCE OF THE ACTIVE AND EW SYSTEM

From the point of view of a total defense, one must consider not only the hard-kill system but also the soft-kill system. Once the soft-kill system is purchased and installed with the hard-kill system, then the anti-ship missiles would have to engage three defensive layers which provide a better survivability. The point for doing this is because "Offense is the best defense"; the more aggressive defensive system could give more efficient protection.

In this section the EW system will be considered in three categories: ECM, Chaff and ECM & Chaff. The best and normal category is the combination of ECM and chaff. From a tactical point of view, the better the integration (ECM and Chaff) the better the result. In case we have to use chaff or ECM only, we are interested to know how much we can gain from each system. This could aid in supporting the decision to add the EW systems. The following will demonstrate how these three categories effect the defense effectiveness.

There are four conditions which are specified in Table IV-2 that will help us to track the categories. First of all, the base EW system ($P_{k(jamming)}$=0.3, $P_{k(chaff)}$=0.4) is added to the base active system which is condition 3. In this case, Figure IV-7(a) shows the survivability of each condition and the difference is shown in Figure IV-8(a). For instance, condition 1 could increase survivability 9%, condition 2 could increase survivability 12% and condition 3 could increase survivability 18% at detection range 25 NMs.
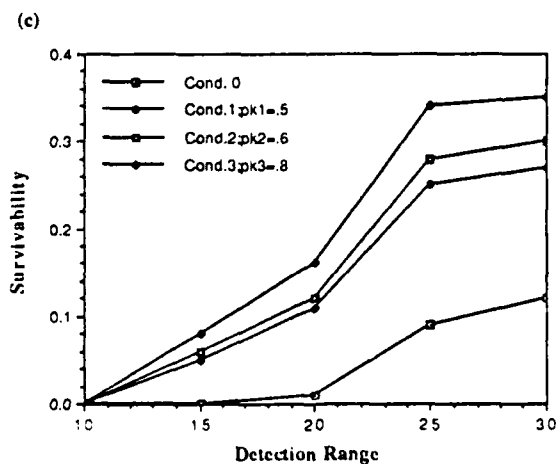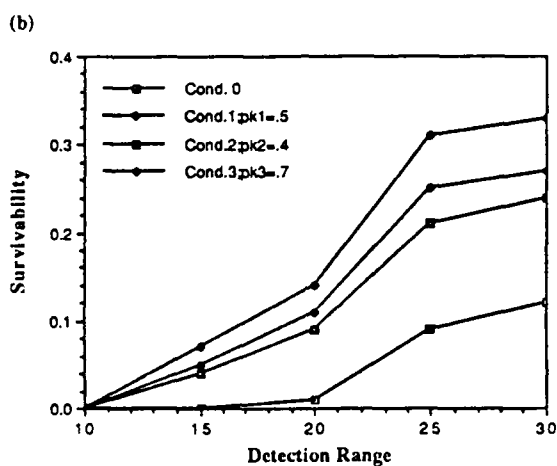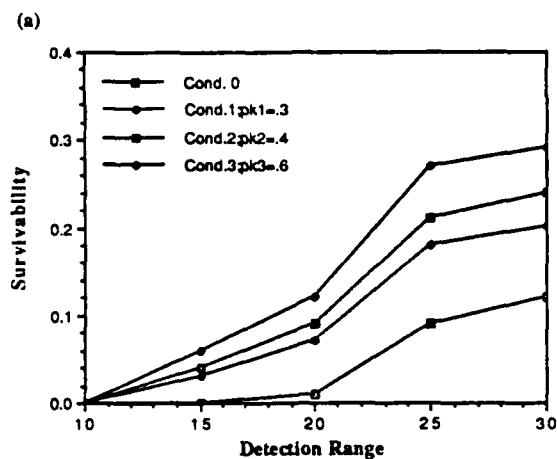
Figure IV-7 Ship survivability VS detection range (SAM
RT=30 P_v=0.3): (a) ECM P_v=0.3;Chaff P_v=0.4 (b) ECM
P_v=0.5;Chaff P_v=0.4 (c) ECM P_v=0.5 Chaff P_v=0.6.
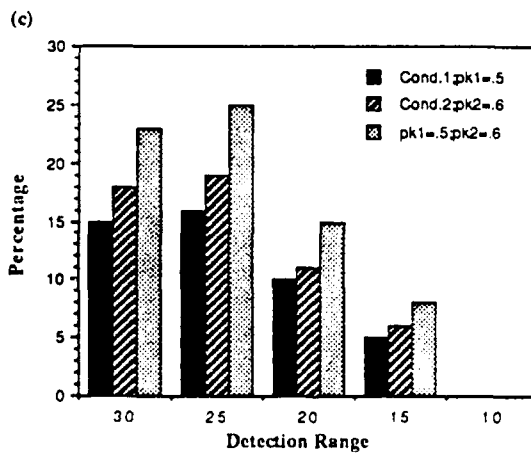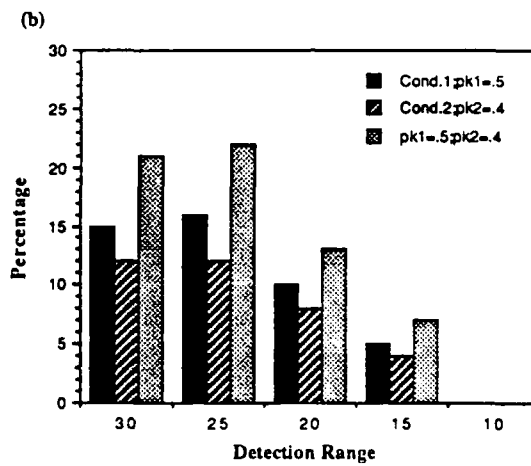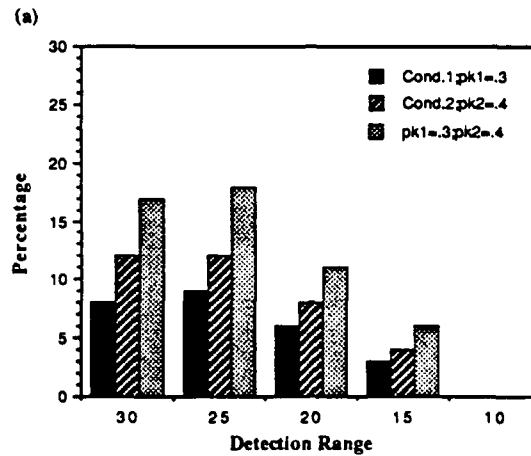
Figure IV-8 The increment of ship survivability corresponding to Fig. IV-7.

TABLE IV-2 Weapon Systems Corresponding to Conditions

Condition	SAM	CIWS	ECM	Chaff
0	X	X		
1	X	X	X	
2	X	X		X
3	X	X	X	X

So far, the result is the kind of reasonable thing which one can predict. The key at this stage is whether this is good enough or whether there is another way which could further increase the survivability. As far as survivability is concerned, it is still not high enough at this stage. In order to achieve the desired results, further action will be required.

1. Improving ECM P_k value from 0.3 to 0.5

The characteristics of the ECM have been mentioned in chapter two. The P_k contains such factors as personnel, operation, maintenance and data upgrade, as well as system reliability. Thus, an ECM system, which when new might have an effective P_k of 0.5, may now have a current P_k of 0.3.

When the P_k of ECM is improved to 0.5, the survivability is illustrated in Figure IV-7(b) and the difference is shown in Figure IV-8(b). At detection range 25 Nm, condition 1 has 7% improvement and condition 3 has 4% improvement. As a result, the higher the P_k, the higher the survivability. The number of expected leaking missiles decreases at each detection range as is demonstrated in Figure IV-9(a)&(b) and Figure IV -10(a)&(b). Condition 1 has 5% decrement and condition 3 has 3% decrement at the same detection range.
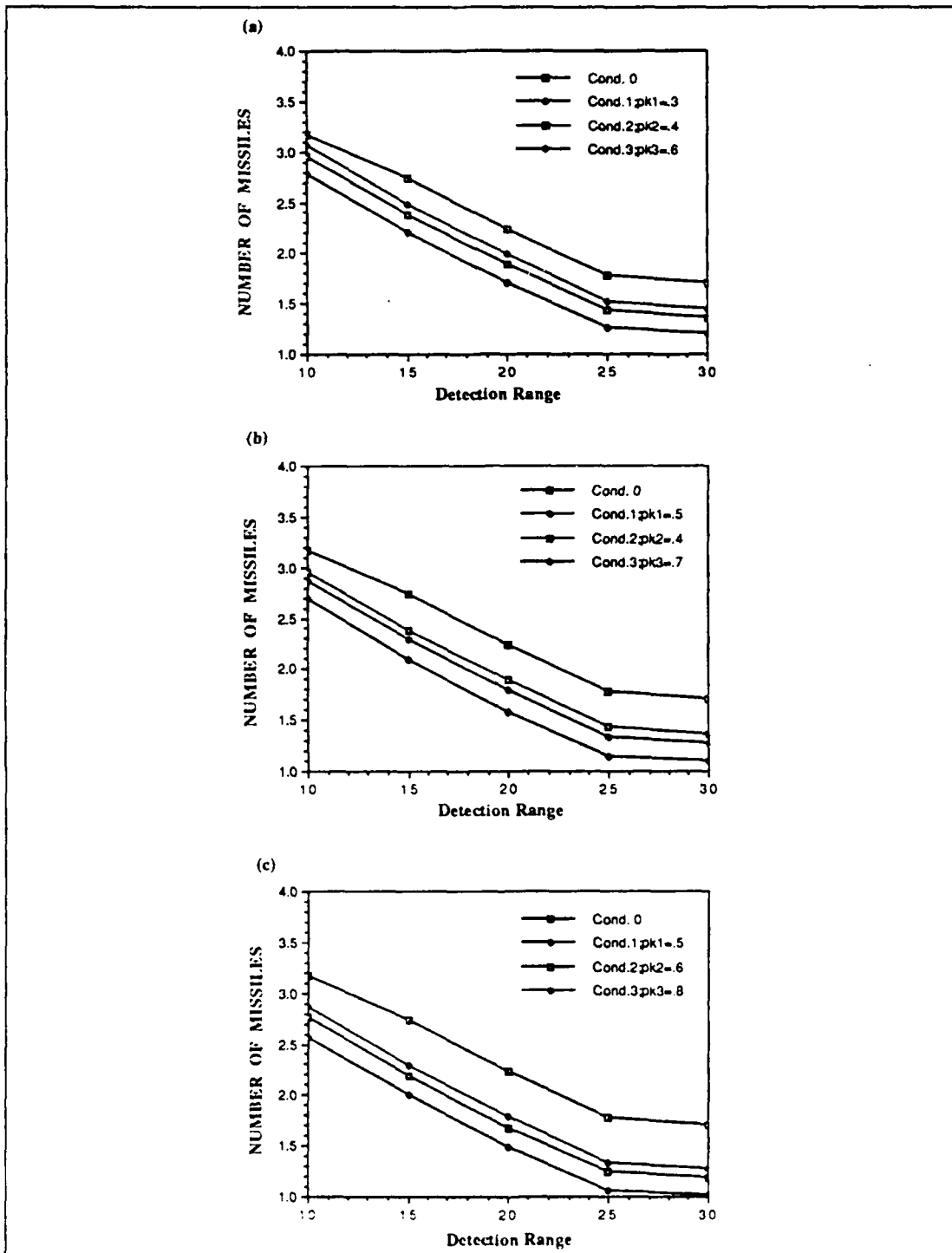
Figure IV-9 Expected leaking missiles vs. detection range
at various conditions (SAM RT=30; P.=0.3): (a) ECM P.=0.3
Chaff P.=0.4 (b) ECM P.=0.5; Chaff P.=0.4 (c) ECM P.=0.5
Chaff P.=0.6.
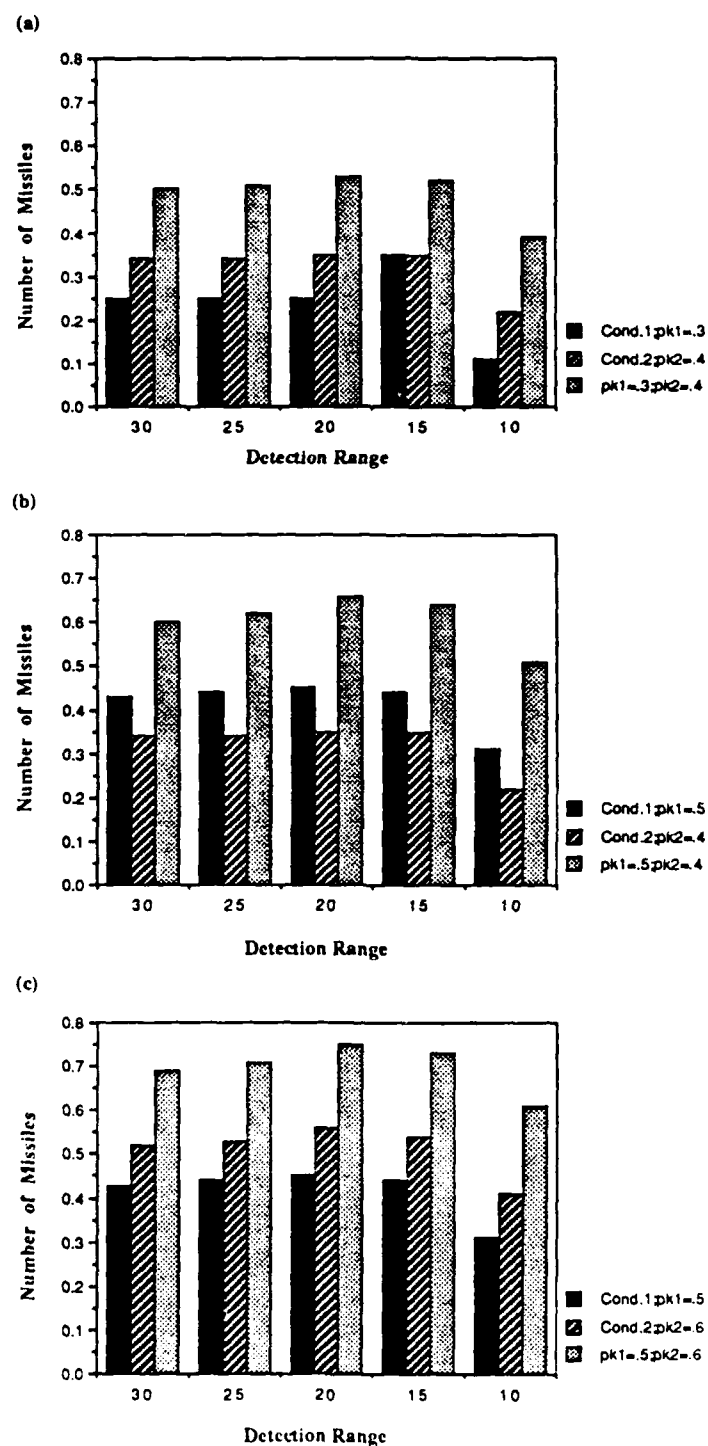
Figure IV-10 Decrement of expected leaking missiles corresponding to Fig. IV-9.

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2. **Improving Chaff P_k value from 0.4 to 0.6**

After the improvement of ECM, the deserved performance of the system and the survivability of the warship still can not be satisfied. Therefore, the process of improving the chaff's P_k value has to be continued at this stage.

When chaff's P_k value is upgraded to 0.6, the performance of the soft-kill system is more remarkable than before. As demonstrated in Figure IV-9(b)&(d) and Figure IV-10(b)&(d), the number of expected leaking missiles is reduced from 1.43 to 1.24 for condition 2 and from 1.15.to 1.06 for condition 3 at detection range 25 Nm. The degree of decrement in expected leaking missiles is 5% for condition 2 and 2.3% for condition 3. As shown in Figure IV-7(b)&(d) and Figure IV-8(b)&(d), the value of ship survivability is increased from 0.21 to 0.28 for condition 2 and from 0.31 to 0.34 for condition 3 at detection range 25 Nm. The degree of increment in survivability is 7% for condition 2 and 3% for condition 3.

So far, we have done case 3 and a part of case 4, as described in Table-IV-1, in which P_k values are 0.3 for SAM, 0.3 to 0.5 for ECM, 0.4 to 0.6 for Chaff, and reaction time is 30 seconds. In order to complete the improvement plan, the P_k value of SAM has to be upgraded 0.7 and the reaction time has to be reduced to 20 seconds. Then, the result of increasing the P_k values of ECM and Chaff must be estimated again.

Figure IV-11 shows the ship survivabilities corresponding to the different defense configurations and the comparisons are demonstrated in Figure IV-12. For example, when the P_k values are 0.7 for SAM, 0.5 for ECM, and 0.4 for Chaff, and the reaction time is 20 seconds, the ship survivabilities are 0.16 for condition 0, 0.41 for condition 1, 0.36 for condition 2, and 0.51 for condition 3 at detection range 20
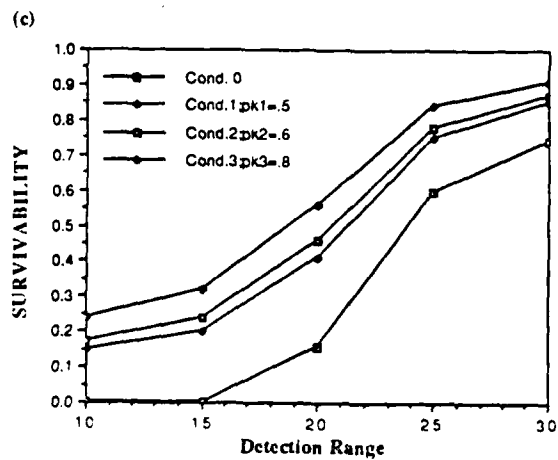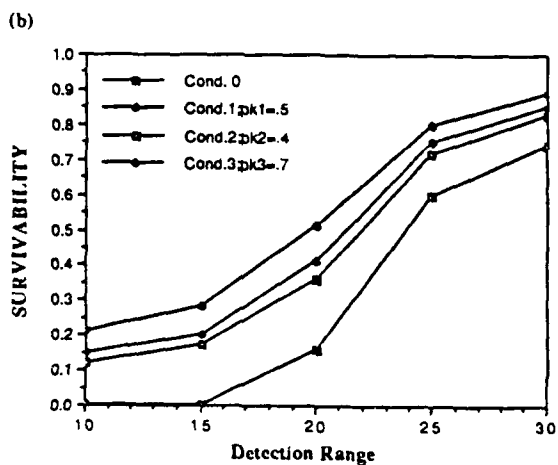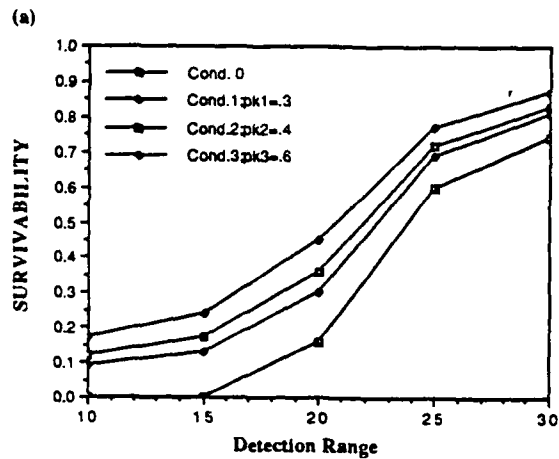
Figure IV-1i Ship survivability vs. detection range at various conditions (SAM PT=20; P_k=0.7): (a) ECM P_k=0.3; Chaff P_k=0.4 (b) ECM Pk=0.5; Chaff P=0.4 (c) ECM P=0.5; Chaff P_k=0.6.

(a)

(b)

(c)
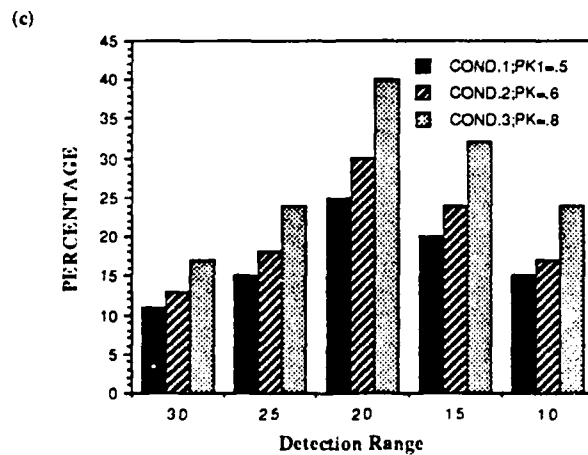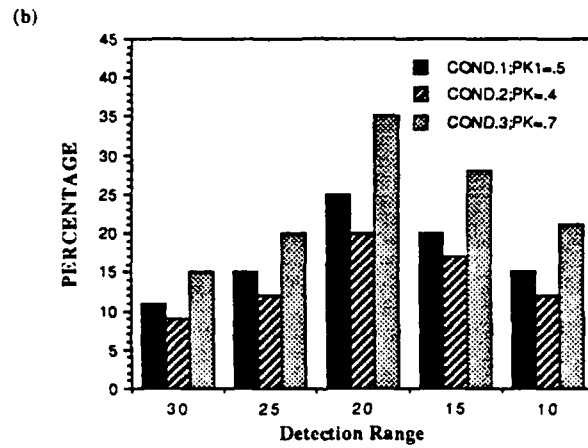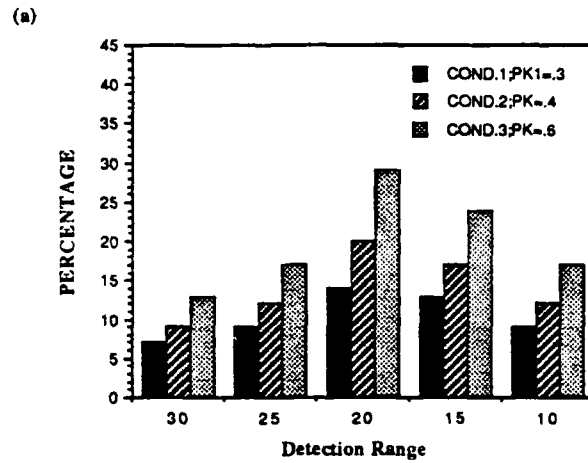
Figure IV-12   Increment of ship survivability at various
conditions corresponding to Fig. IV-11.

Nm. The improvement percentages, when compare with condition 0, are 25 % for Condition 1, 20 % for condition 2, and 35 % for condition 3 at the same detection range. All these things are illustrated in Figure IV-11(b) and Figure Iv-12(b) individual.

There are six options, created from the above discussions. These are shown in Table IV-3. The $P_{k(SAM)}$ value is 0.3 and reaction time is 30 for option 1, 2, &3; the P_k value is 0.7 and reaction time is 20 for option 4, 5, &6. The P_k(ECM) value is 0.3 and P_k(Chaff) value is 0.4 for base EW; the P_k(ECM) value is 0.5 and P_k(Chaff) is 0.6 for improved EW. The ship survivability at different options and different detection ranges are summarized in Figure IV-13, and the comparisons corresponding to the various decisions are exhibited in Figure IV-14. These provide further information helping the decision maker to find the trade-off between systems costs and measures of effectiveness.

TABLE IV-3 Weapon Systems Corresponding to Decisions

OPTIONS	SAM&CIWS	Improved SAM&CIWS	EW	Improved EW
1	X			
2	X		X	
3	X			X
4		X		
5		X	X	
6		X		X

Of course, there are some other factors that will bear on the decision to implement a particular option. These includes system reliability, maintainability, storage space, balance of the warship, capability of support, and training requirements. Therefore, one could make a better decision. Some further criteria will be discussed in next section.
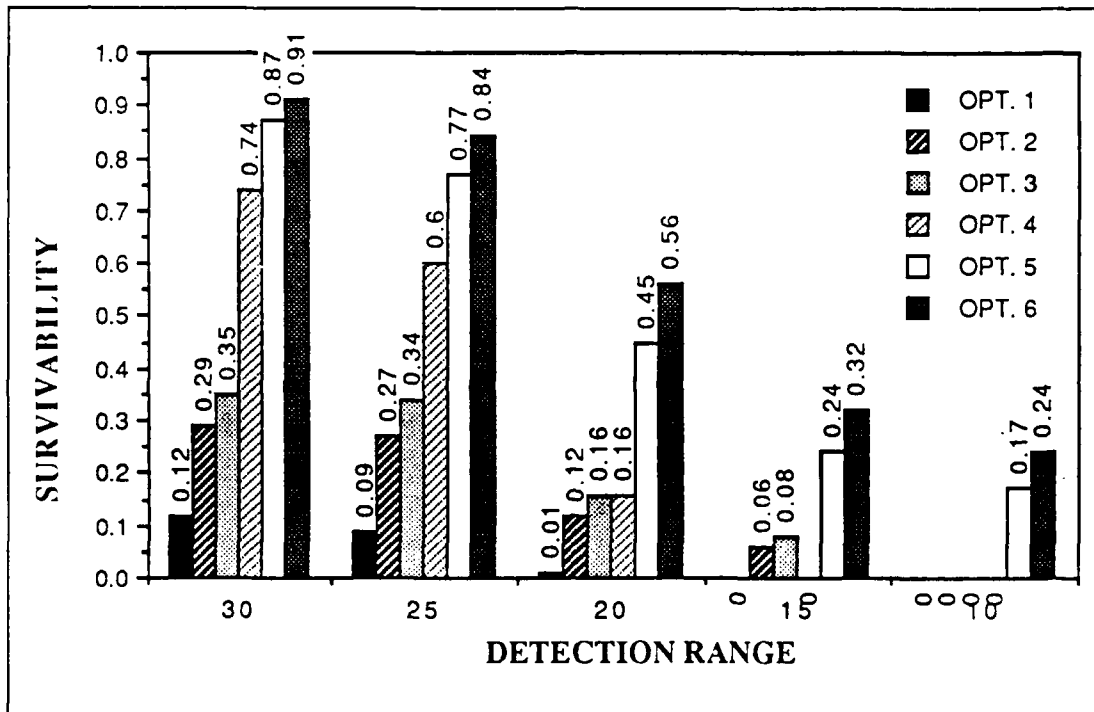
Figure IV-13   The ship survivability VS detection range at various options.
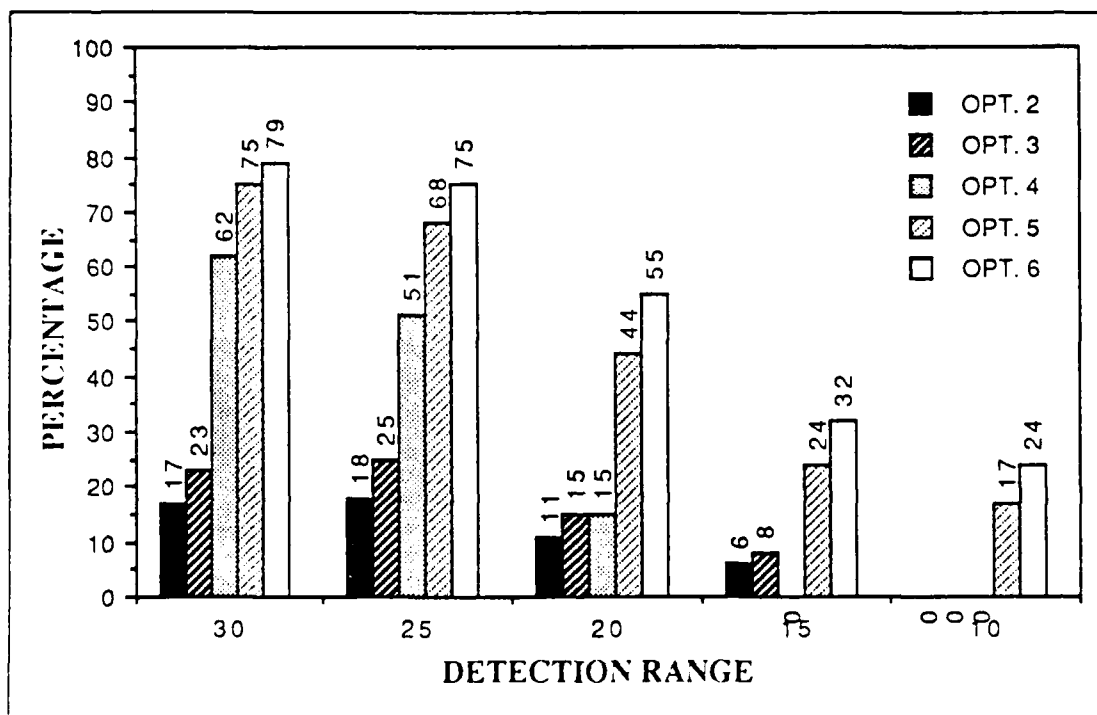
Figure IV-14   Increment of ship survivability corresponding to Fig. IV-13.

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C. UNDER JAMMING CONDITIONS

A more complete description of the enemy threat to target ship survivability would include enemy jamming of the ship's defensive systems. The jamming threat can be estimated in several ways, ranging from using intelligence on an enemy's present capabilities and design practices to an assessment of technological trends in this threat. The latter method estimates the theoretical characteristics possible for the kind of threat systems under evaluation. Examples of the above described threat estimation methods in this section are constrained by the fact that much of the detailed information on enemy threats is by nature classified. However, an assumption is available in the unclassified literature and will be used to illustrate the various threat estimation approaches. The reader is cautioned that the use of such assumption is for parametric study purposes only, and does not imply the authenticity of the assumption utilized.

In general, the countermeasures used against the defensive systems will be directed against the detection and missile guidance systems. In the design of radars, it is a complex project to counter ECM, and depends on the sort of ECM involved and the mission of the special radar under consideration. From the viewpoint of an ECM-ECCM duel, any radar can be jammed and any ECM can be countered depending on those resources which either side is willing to commit. From the enemy point of view, three possible actions could be taken against radar, such as using radiation energy to confuse the radar, injecting spurious targets into the radar's surveillance volume, and destruction of the radar. The first two are kinds of soft-kill and the last is referred to as hard-kill. There are five major ECM threats to a surveillance radar as followings[3]

- Noise jamming
- Deception jamming
- Chaff
- Decoys and expendables
- Anti-radiation missiles.

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[3]Ref. 6, p. 109

The range at which the defending radar can detect an attacking ASM is a fundamental attribute of either a search or tracking radar. It is obvious that this depends on the parameters of the radar and the reflection characteristics of the target, such as average transmitter power, effective antenna aperture, average target radar cross section, etc. Nevertheless, a basic limitation is that the target usually has to be detected against an interference background which includes at least the ever-present receiver thermal noise. Since it is a random process, the noise has to be specified in terms of its statistical properties. As a result, radar detection has to be described in a statistical manner in order to be meaningful, using such parameters as threshold signal strength, probability of detection, and probability of false alarm. Estimates of the detection performance of a practical radar in a noise background can be calculated from the Marcum-Swerling theory but this is beyond the scope of this study. In fact, good detection performance in both clear and ECM environments requires a balance betweenaverage transmitter power and antenna aperture. The rest of this section will focus on the analysis of the simulation results and the estimations of the various threat environments.

But technical complexities and classification problems aside, the major impact of countermeasures is to reduce the detection range. The fact that this significantly increases the severity of the threat is illustrated in Figure IV-15(a) which shows that, for a hard-kill defense, when detection range is 17 Nm, about 49 % of the ASM could be destroyed by SAM, 17 % could be destroyed by CIWS, and 34 % would be leaking through the defense. If detection range is cut to 7 Nm, the SAM is unable to destroy the target because the interception range is within the 3 Nm from the warship. In this case, the defense can only be done by CIWS. The number of anti-ship missiles leaking through the defense at different detection ranges and different SAMs P_k value are demonstrated in Figure IV-16. Figure IV-17 illustrates the ship survivability under the same conditions.

The summary from the above discussion is that the SAM defense is vulnerable to EW, although CIWS could improve the close-in defense. But, from the overall defense viewpoint, the ship survivability is not sufficient for real war. However an EW system introduced into the defense tends overcome this vulnerability. Figure IV-18 shows the performance for condition 1 and 2 at different P_k values, and condition

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(a). RANGE=17

By SAM
BY CIWS
Leaker

34.00%

49.00%

17.00%

(b). RANGE=12

By SAM
BY CIWS
Leaker

35.00%

48.00%

17.00%

(c). RANGE=7

0%

15.00%

By SAM
BY CIWS
Leaker

85.00%
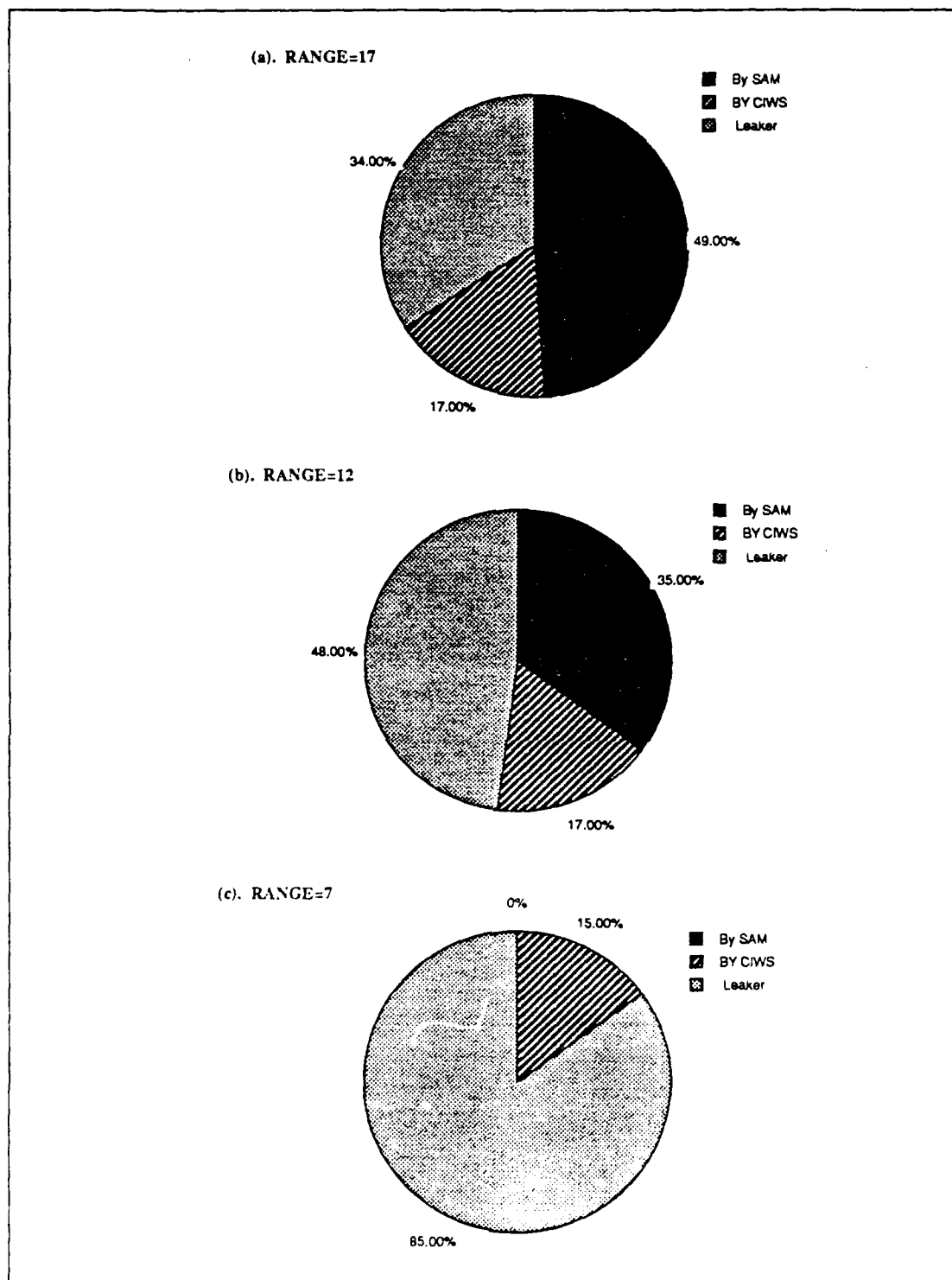
Figure IV-15 The performance of hard-kill system at
different detection range (SAM PT=20;P =0.7): (a) 17 NMs
(b) 12 NMs (c) 7 NMs.

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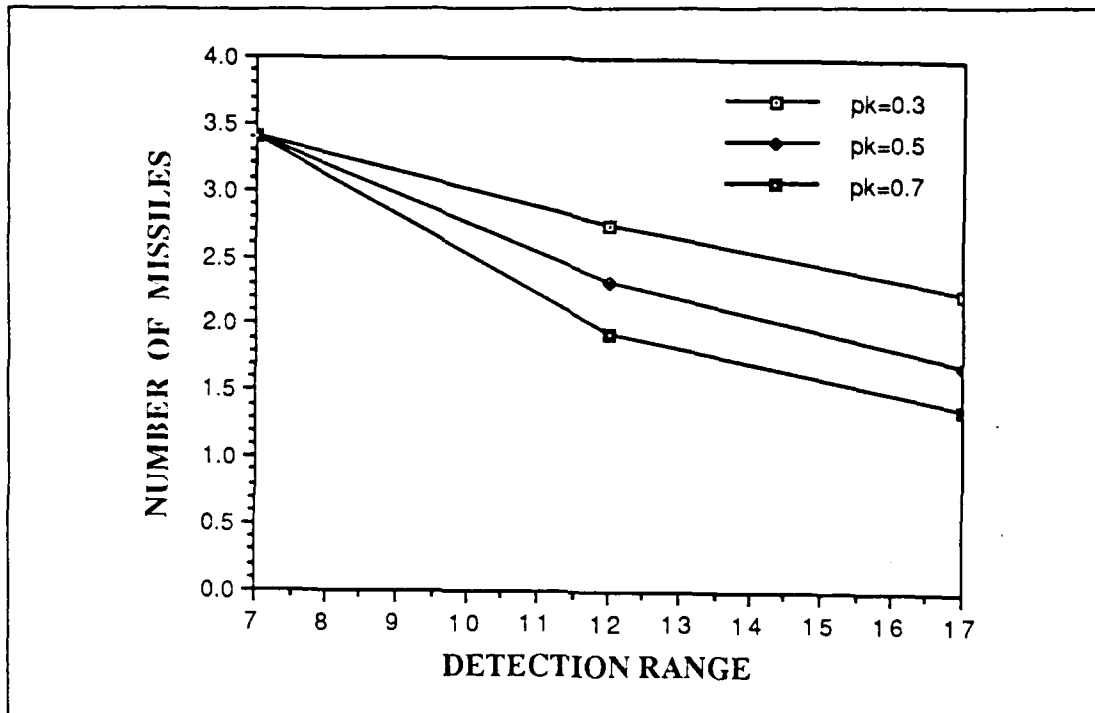
Figure IV-16 Expected leaking missiles vs. detection range (SAM RT=20).
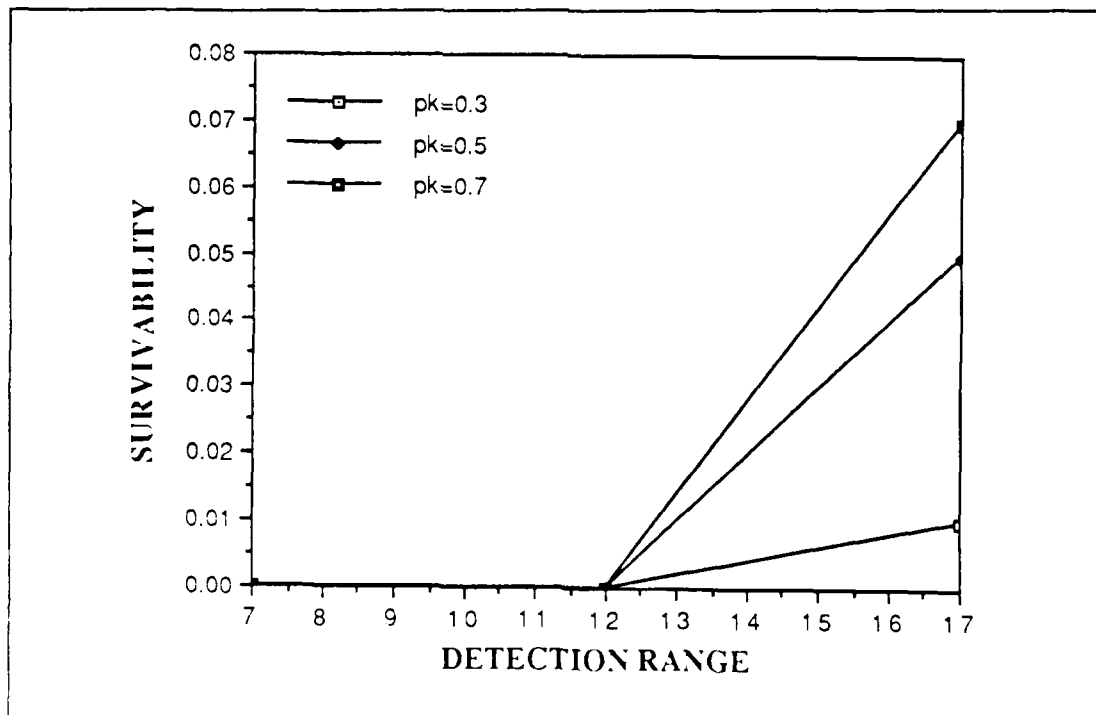
Figure IV-17 Ship survivability vs. detection range (SAM RT=20).
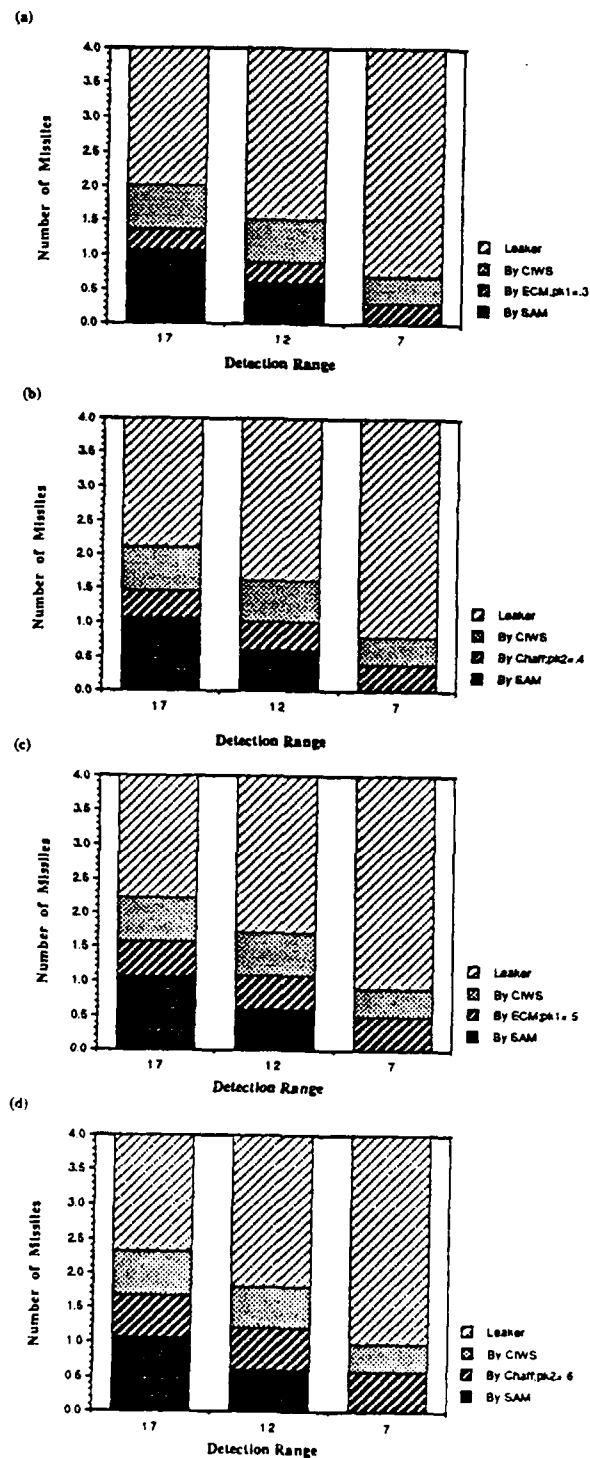
Figure IV-18 Performance of condition 1 & 2 (SAM
RT=30;P$_r$=0.3): (a) ECM P$_r$=0.3 (b) Chaff P$_r$=0.4 (c) ECM
P$_r$=0.5 (d) Chaff P$_r$=0.6

3 is demonstrated in Figure IV-19. Figures IV-19(a) to (c) illustrate the range from base EW system performance to improved EW system performance. In a sense, the performance at higher P_t value provides more effectiveness than others. The ship survivabilities from base EW system to improved EW system are summarized in Figure IV-20. For instance, the survivabilities are 0.07 for condition 0, 0.22 for condition 1, 0.27 for condition 2, and 0.36 for condition 3 at detection range equals 17 Nm, as shown in Figure IV-20(a). The degrees of increment of the shipsurvivabilities at various conditions are illustrated in Figure IV-21. Figure IV-21(a) shows that condition 1 could increase survivability 15%, condition 2 could increase survivability 20%, and condition 3 could increase survivability 29% at the same detection range.

The ship survivabilities for various options and different detection ranges are exhibited in Figure IV-13, and the comparisons corresponding to the different decisions are illustrated in Figure IV-14. These data provide the information which under jamming condition. For instance, at detection range 15 NMs, decision 5 has increment about 24 % compare to decision 1 and 2, decision 6 has 32 % increment at the same condition, the difference between these two is 8 %. It is very useful and helpful for making the decision on the final modification plan.

D. SERIAL ASM THREAT CONSIDERATION

The sequential threat will be illustrated in this section. The ASM were launched following one after another in an orderly pattern. The AAW operation was shown in Figure IV-22. The four lines represent the different flight routes of the engaged ASM. The starting points of these lines represent the time and range at which the warship detects each attacking ASM. The ends of these lines represent the times of ASM impact on the warship. The intercept points are different from those which are illustrated in Example 3.1 and Table III-2 due to the fact that the spacing is different. Figure IV-22-(a) shows the SAM can exactly hit the engaged ASM and destroy it. Figure IV-22-(b) illustrates one SAM missing the engaged ASM. Of course, this simulation program can generate more complicated situations and provide the response results. In addition, it also include the EW and CIWS defensive scenario.

The survivability of the warship versus different sequential threats was demonstrated in Figure IV-23. The spacings of the sequential threats are assumed to
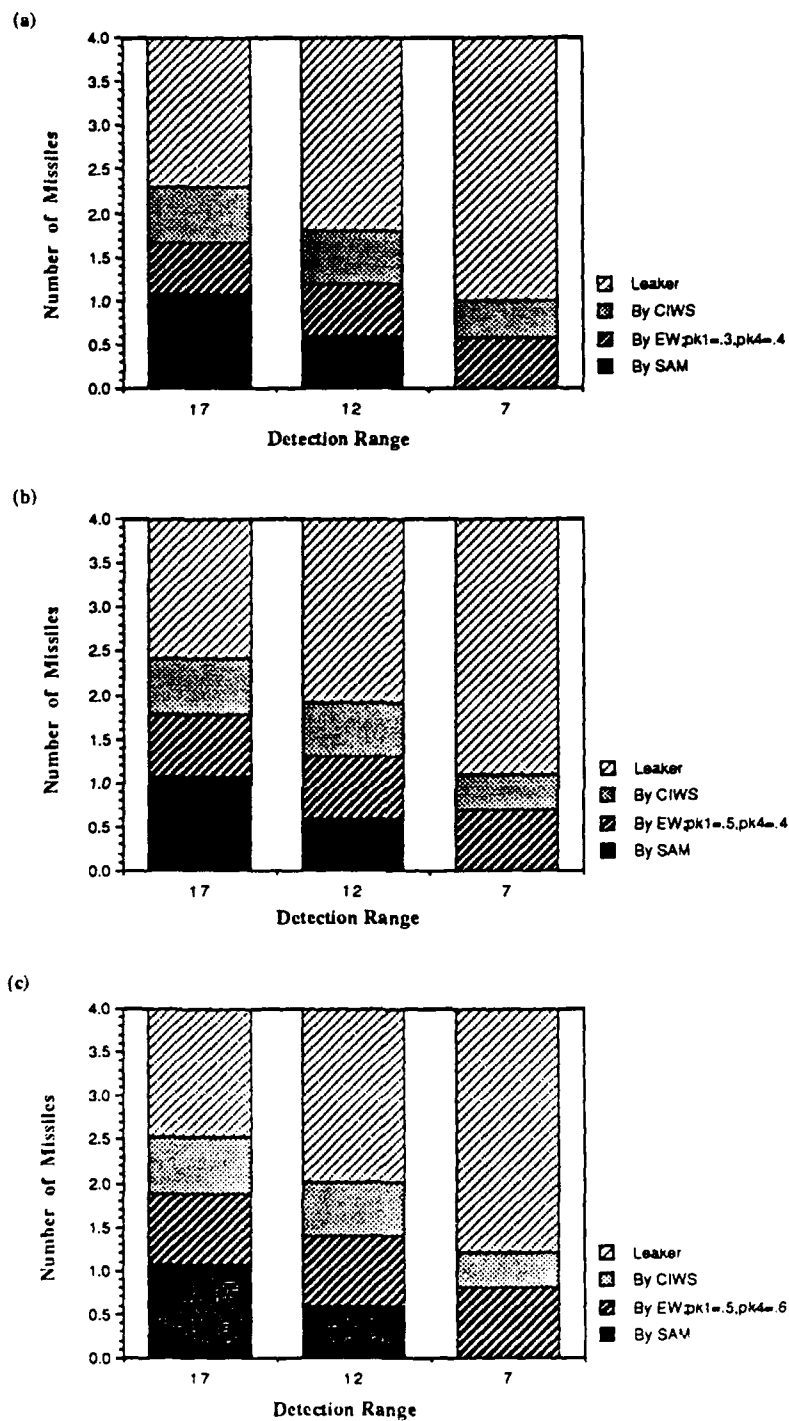
Figure IV-1: The performance of various conditions.
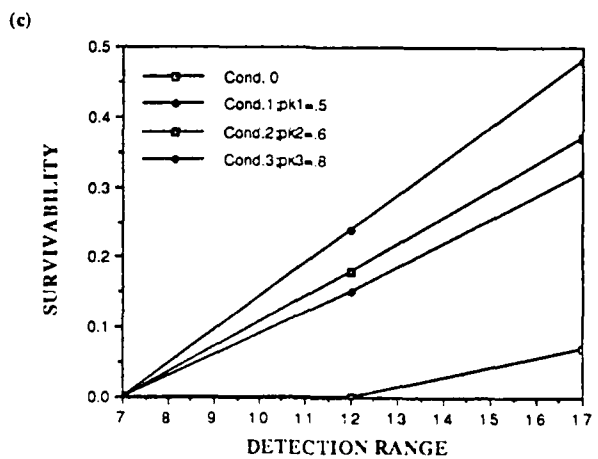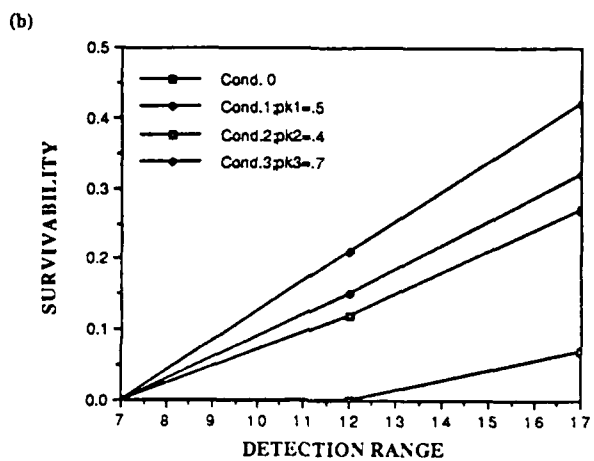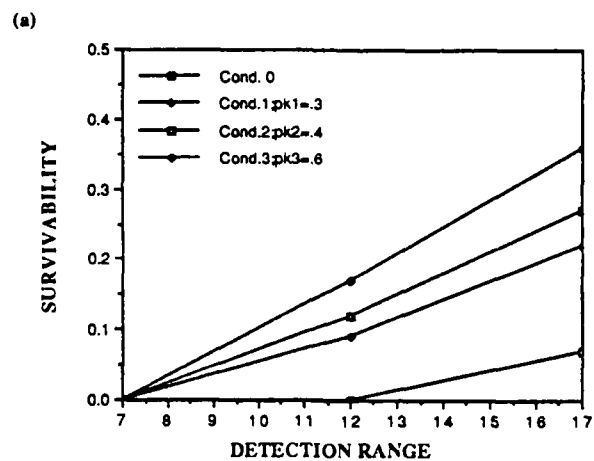
Figure IV-20 Ship survivability vs. detection range at various conditions.
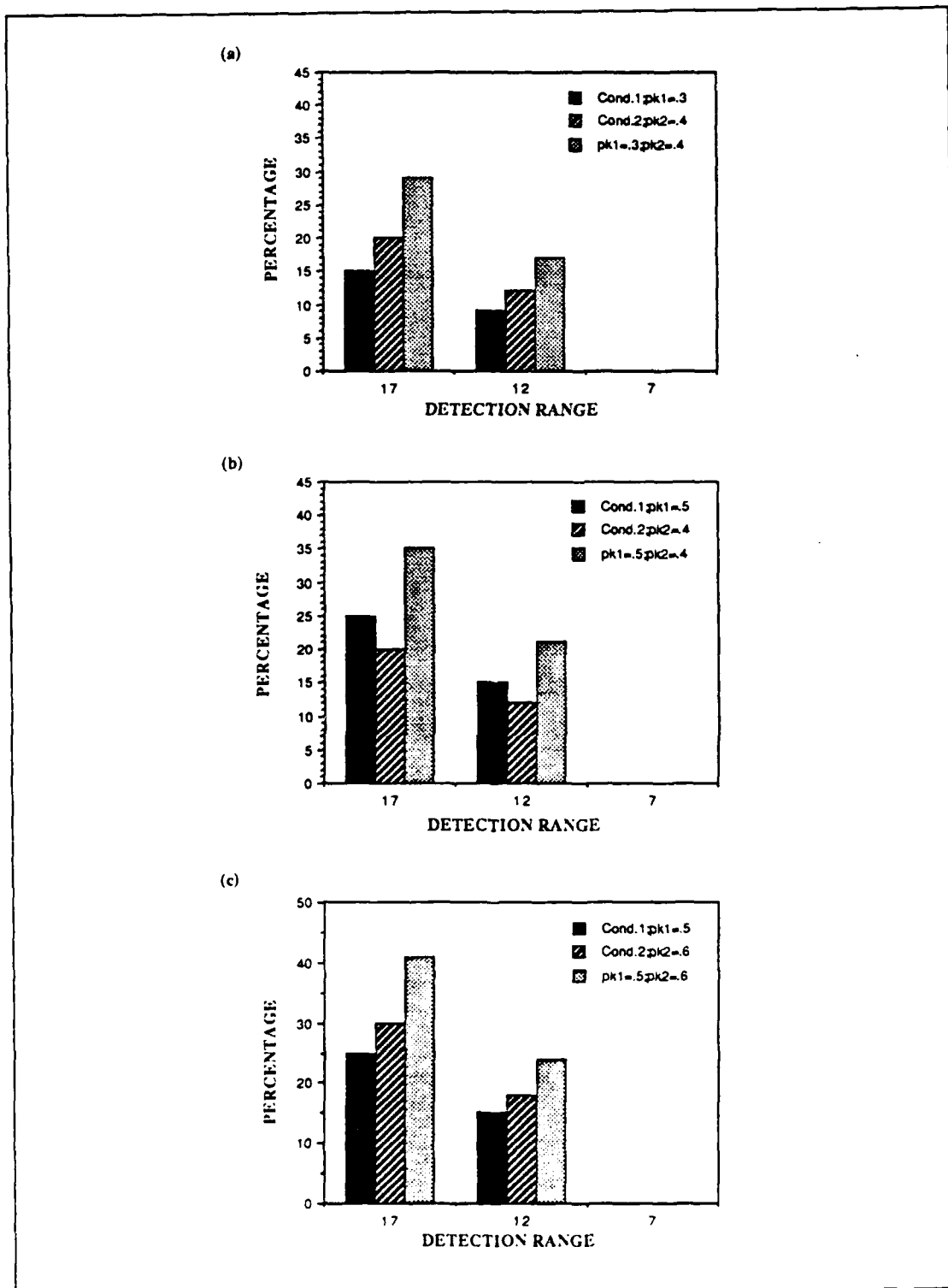
Figure IV-21 The increment of ship survivability corresponding to Fig. IV-20.
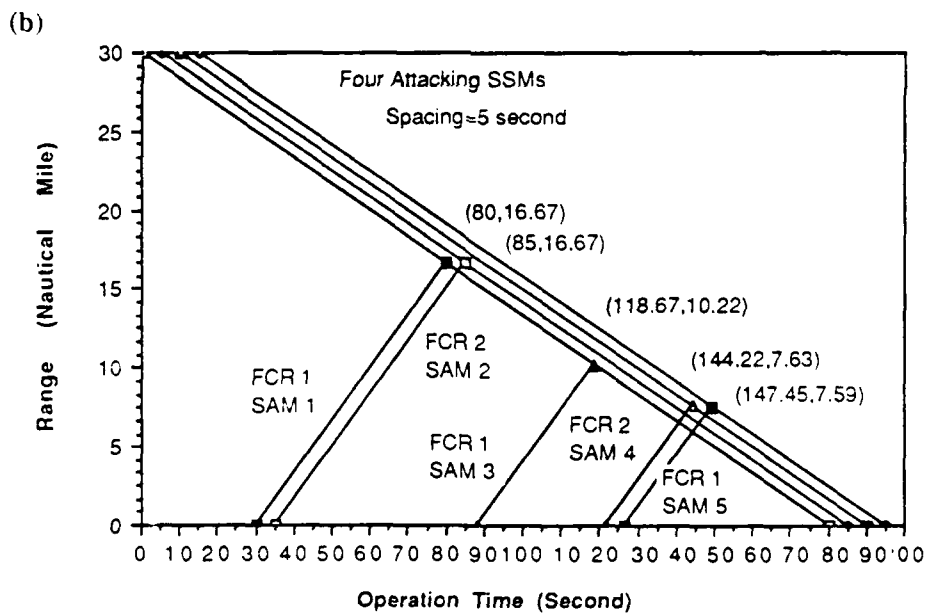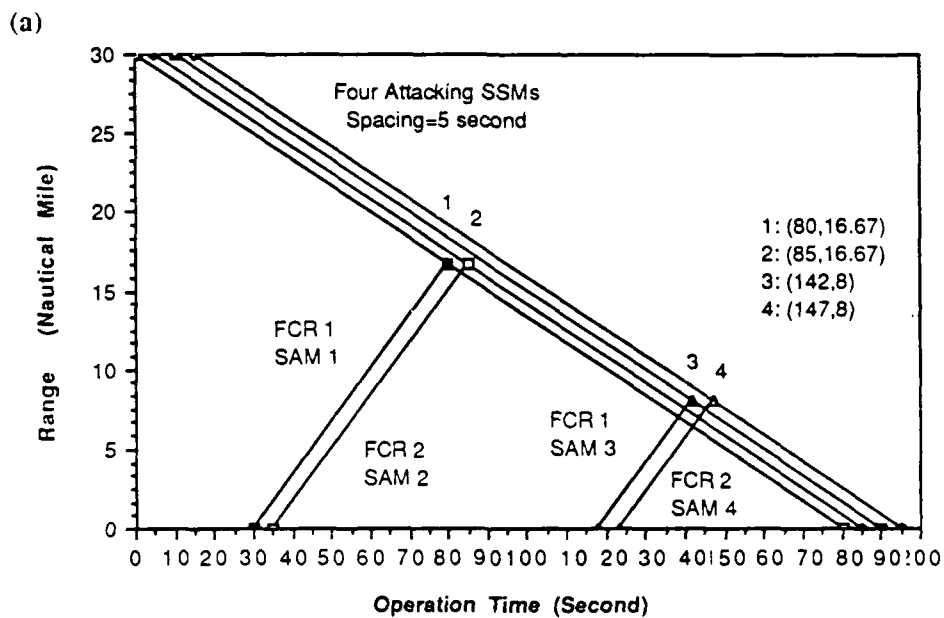
Figure IV-22 The AAW operation corresponding to serial ASM threat (a) SAM exactly hit the engaged ASM (b) one SAM missing the engaged target.

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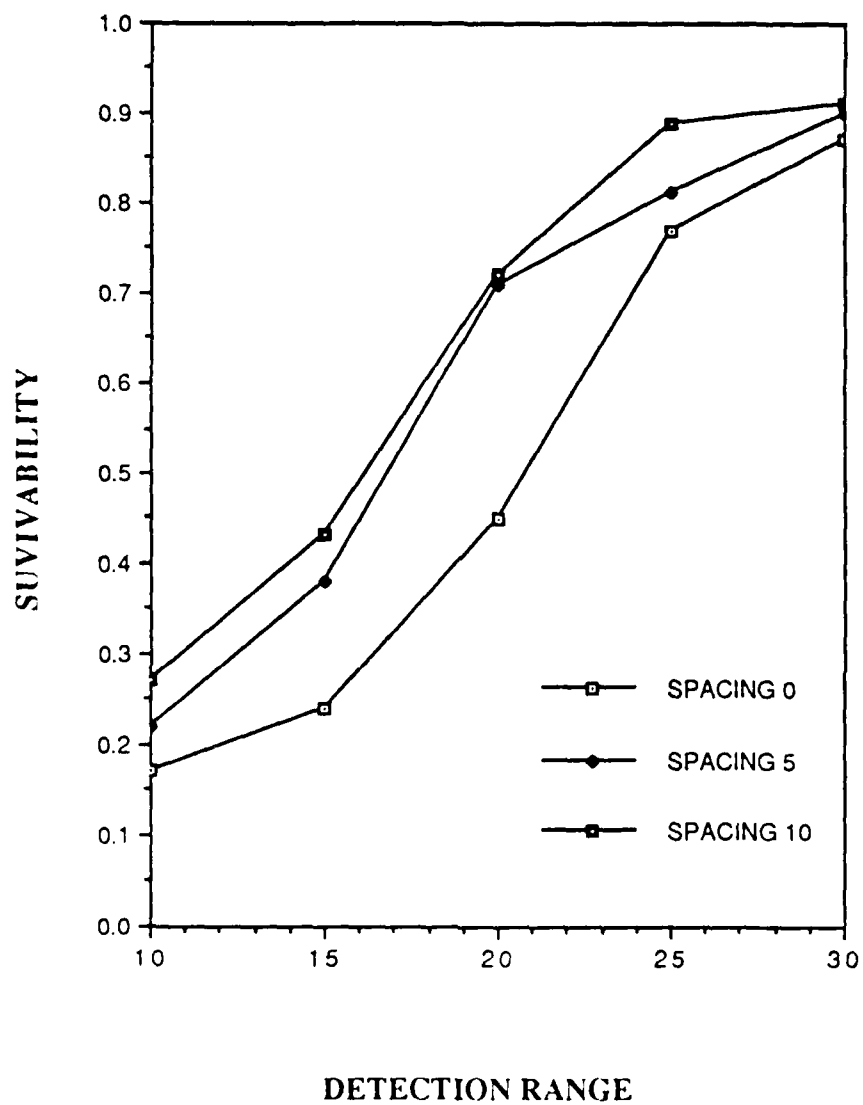
Figure IV-2? The ship survivability vs. three different
sequential attacking ASMs.

be zero, five, and ten respectively. The detection range is 30 NMs for this example, the reaction time of SAM is 20 seconds, and the P_k values are 0.7, 0.3, and 0.4 for SAM, ECM, and Chaff. As one can predict, the wider the spacing, the higher the ship survivability.

V. CONCLUSION

A computer program simulating an anti-air warfare operation conducted by the various weapon systems of a warship was written in the TURBO BASIC language to run on a PC-DOS personal computer. This program simulates the integrated performance of hard-kill and soft-kill systems against a four anti-ship missile attack, predicts the expected number and percentage of anti-ship missiles destroyed by various weapon modules, and the corresponding ship survivabilities. In addition, it provides the analysis and comparison of the results which came from the different P_k values and the various weapon modules.

Two major AAW improvement plans were considered in this study. One is focused on the hard-kill weapon systems, the other is focused on the soft-kill weapon systems. The ship survivability was estimated with the various improvement plans. Based on these plans, six options of decision were created. The increased ship survivability and the improvements in ASM kills were assessed for each option in a way that would support the making of choices between them. This would be a significant contribution to the resource allocation questions typically faced in selecting a suite of air defense weaponry for a modern warship.

APPENDIX A

Assumptions of the ISSP

* Four low altitude incoming targets.

* The target spacing is 0, 5, 10.

* The radar detection ranges are 30, 25, 20, 15, 10NMs, and the ranges are 17, 12, 7 in jamming condition.

* The reaction time from target detection to SAM launch is assumed to be 20 and 30 seconds.

* The maximum and minimum intercept range of SAM is 30 and 3 NMs, respectively.

* The kill probabilities of a single SAM are assumed to be 0.3, 0.5, 0.7.

* The engagement doctrine is shoot-look-shoot and the SAM is home-all-the-way.

* The SAM launch cycle time is 5 seconds and the assessment time which determines whether the target is destroyed or not is 8 seconds.

* The velocity is 20 NMs/Min for SAM, and 10 NMs/Min for the target.

* The range of target seeker turn on is assumed to be 6 NMs.

* The reaction time of defensive jammer (ECM) is 15 seconds.

* The reaction time from chaff assigned to launch is assumed to be 10 seconds.

* The reaction time from chaff launched to bloom is assumed to be 10 seconds.

* The chaff cloud is able to stay in the sky about 45 seconds.

* The minimum intercept range for CIWS is assumed to be 0.1 NMs, and the maximum intercept range is 2 NMs.

* The reaction time of CIWS is assumed to be 5 seconds, and the assessment time is 2 seconds.

* The fire rate of CIWS is assumed to be 30 rounds per second, and the total ammunition is 1200 rounds.

* The maximum continuous firing time is 8 seconds.

APPENDIX B

```
'**************************    PURPOSE    ***********************************
'*                                                                          *
'*   Interactive Simulation of The Integrated Hard-kill and Soft-kill Weapon *
'*   Systems Performance (ISSP)                                             *
'*                                                                          *
'***************************************************************************

'********************* VARIABLE DECLARATIONS ********************************
'SHIP IS 'HIT' WHEN ANY TGT OVER THE CRITICAL TIME WITHOUT BEING KILLED
'S1: VELOCITY OF SAM
'S2: VELOCITY OF TGT
'LEAKING:TGTS GOT THROUGH THE SHIP'S DEFINSE.
'TGT1SUC:THIS TGT IS SUCCESSULLY LEAKING THRU THE DEFENSE
'SZG: SAMPLE SIZE
'SPG: SPACING TIME
'ENFT: ENVIROMENTAL FACTOR
'MODE: TYPE OF MODE
'MARK:=1, ONE OF THE TWO MISSILES IS NOT ABLE TO INTERCEPTED.

'******************    INITIATION    ***************************************
    OPTION BASE 1
    DIM SS(5,10,30),EK(5,10,30),NS(5,10,30),RA(1000),SA(5,10,30),BYCOMB(5,10,30)
    DIM LEAKTHRU(5,10,30),ESI(5,10,30),ESA(5,10,30),RM(10,50),GOODMIX(5,10,30)
    DIM BG(5,10,30),BYECM(5,10,30),BYCHAFF(5,10,30),BYCIWS(5,10,30),TM(5,10,30)

'****************    INPUT SIMULATION PARAMETER    *************************
    INPUT "SEED =";SEED
    PRINT"SEED=";SEED
    PRINT "INPUT SAMPLE SIZE"
    INPUT "SZG=";SZG
    PRINT "INPUT SPACING TIME"
    INPUT "SPG=";SPG
    IF SEED > 0 THEN SEED=-SEED
    X=RND(SEED)
    TIME$="00:00:00"
    PRINT "ENVIROMENTAL FACTOR"
    PRINT "0 : NO JAMMING"
    PRINT "1 : UNDER JAMMING"
    INPUT "ENFT =";ENFT
    IF ENFT = 0 THEN
        LPRINT "NO JAMMING CONDITION"
        RAEG = 30 : ERAE = 10
    ELSE
        LPRINT "UNDER JAMMING CONDITION"
        PRINT "ENTER DETECTION RANGE (NM)"
        INPUT "RAEG =";RAEG : ERAE = RAEG - 10
    END IF
    PRINT "TYPE OF MODE"
    PRINT "0 : NO EW SYSTEM"
    PRINT "1 : ECM ONLY"
    PRINT "2 : CHAFF ONLY"
    PRINT "3 : COMBINE CHAFF & ECM"
    INPUT "MODE =";MODE
    PRINT "MODE =";MODE
    IF MODE = 0 THEN
        LPRINT"THIS TRIAL RUN IS BASE ON THE ACTIVE SYSTEM ONLY, NO EW SYSTEM INV
OLVED"
    ELSEIF MODE = 1 THEN
        LPRINT"THIS TRIAL RUN IS BASE ON THE ACTIVE SYSTEM & ECM ONLY"
        PRINT "INPUT ECM PK :" : INPUT "ECMPK=";ECMPK
    ELSEIF MODE = 2 THEN
        LPRINT"THIS TRIAL RUN IS BASE ON THE ACTIVE SYSTEM & CHAFF ONLY"
        PRINT "INPUT CHAFF PK :" : INPUT "CAFPK=";CAFPK
    ELSE
        LPRINT"THIS TRIAL RUN IS BASE ON THE COMBINED ACTIVE & EW SYSTEM"
        PRINT "INPUT ECM PK :" : INPUT "ECMPK=";ECMPK
        PRINT "INPUT CHAFF PK :" : INPUT "CAFPK=";CAFPK
        COMPK = 1 - (1-ECMPK)*(1-CAFPK)
    END IF

'********************    MAIN PROGRAM    ***********************************
    S1=1/3 ' S1: speed of SAM
```

70

```
        S2=1/6 ' S2: speed of TGT
        SZ=SZG
        LPRINT"SAMPLE SIZE =";SZ '  SZ:sample size
        SPACING=SPG ' THE SPACING TIME BETWEEN THE TGTs
        LPRINT "SPACING TIME=";SPACING
        LPRINT " "
        SEQ=SPACING ' SAME AS SPACING FOR SUBSTITUTION.
        CIWSRT=5 'CIWS REACTION TIME IS 5 SEC.
        MI=2      'MI IS THE MAXIMUM INTERCEPT RANGE OF THE CIWS
PRINT "THIS PROGRAM IS RUNNING ......., PLEASE DO NOT TURN THESE MACHINES OFF."
PRINT " " : PRINT " "


'******************    SAM MODULE    ***************
        I=0:PK=.70
100     IF PK<.30 THEN GOTO 220
        I=I+1:J=0
        QQ(I)=PK
        RT=30
110          IF RT<20 THEN GOTO 200
             J=J+1:K=0:RM(I,J)=RT
             RT1=RT:RANGE=RAEG
120            IF RANGE<ERAE THEN GOTO 180
               K=K+1:TOTALT=RANGE×6
               RA(K)=RANGE
               HIT=0:SUCCESS=0:LEAKING=0:TLEAK=0:NOLEAK=0
               SAMPTGT1=0
               SAMPTGT2=0
               SAMPTGT3=0
               SAMPTGT4=0
               TGTKILLED=0
               ECMKILL=0
               CHAFFKILL=0
               COMBKILL=0
               CIWSKILL=0
               N=1
130:           IF N>SZ THEN GOTO 160            'N IS SAMPLE SIZE
               T=0:TP=0:TGTK=0:M=0:L=0:MARK=0:OK=4:TGT1SUC=0:TGT2SUC=0:AR=0
               ARC=0:OKC=0
                    RL=1            'RL IS RELOAD NUMBER
                    TT=6×RANGE      'TT IS TOTAL TIME
                    TC=6×(RANGE-3) 'TC IS CRITICAL TIME
                    TGT1SAM=0: TGT2SAM=0: TGT3SAM=0: TGT4SAM=0
                    TGT1=1:TGT2=1:TGT3=1:TGT4=1
                    GOSUB 560
                    SAMPTGT1=SAMPTGT1+TGT1SAM
                    SAMPTGT2=SAMPTGT2+TGT2SAM
                    SAMPTGT3=SAMPTGT3+TGT3SAM
                    SAMPTGT4=SAMPTGT4+TGT4SAM
                NNSAM=TGT1SAM+TGT2SAM+TGT3SAM+TGT4SAM
                IF TGT1=0 THEN TGTK=TGTK+1: OK=OK-1
                IF TGT2=0 THEN TGTK=TGTK+1: OK=OK-1
                IF TGT3=0 THEN TGTK=TGTK+1: OK=OK-1
                IF TGT4=0 THEN TGTK=TGTK+1: OK=OK-1
                TLEAK=TLEAK+OK
                IF OK=0 THEN SUCCESS=SUCCESS+1: NOLEAK=NOLEAK+1
                OKC = OK
                TGTKILLED=TGTKILLED+TGTK
                IF FLAG=1 AND MODE=0 THEN GOTO 140

'*************    ECM MODULE    **********************
                IF FLAG=1 AND MODE=1 THEN
                    GOSUB ECM
                    IF (OKC-ARC) = 0 THEN FLAG=0
                    GOTO 140
                END IF

'*************    CHAFF MODULE    *******************
                IF FLAG=1 AND MODE=2 THEN
                    GOSUB CHAFF
                    IF (OKC-ARC) = 0 THEN FLAG=0
                    GOTO 140
                END IF
```

```
'************    COMBINED ECM $ CHAFF MODULE    *****
                IF FLAG=1 AND MODE=3 THEN
                    GOSUB COMB
                    IF (OKC-ARC) = 0 THEN FLAG=0
                    GOTO 140
                END IF

'************    CIWS MODULE    *********************
140             IF FLAG=1 THEN
                    GOSUB CIWS
                    CIWSKILL=CIWSKILL+ARC
                ELSE
                    CIWSKILL=CIWSKILL+0
                END IF
150             OK=OK-AR
                IF OK > 0 THEN HIT =HIT+1
                IF OK = 0 THEN SUCCESS=SUCCESS+1
            N=N+1: RT=RT1
            GOTO 130
160         N=SZ
            SA(I,J,K)=NOLEAK
            GOSUB 1570
170         RANGE=RANGE-5:GOTO 120
180
190     RT=RT-10:GOTO 110
200
210 PK=PK-.2:GOTO 100
220

'*********************    OUTPUT RESULTS    *********************************************
PRINT " THANKS FOR YOUR PATIENCE, IT'S DONE."
LPRINT"RT          : REACTION TIME."
LPRINT"RANGE       : DETECTION RANGE."
LPRINT"NSAM        : THE # OF THE SAM FIRED."
LPRINT"E(NS)       : THE EXPECTED # OF THE SAM FIRED."
LPRINT"V           : THE # OF SUCCESSFUL DEFENSE OF THE SHIP IN SAM MODE."
LPRINT"E(V)        : EXPECTED VALUE OF V, WHICH IS THE SURVIVALBILITY OF THE "
LPRINT"               SHIP IN SAM MODE."
LPRINT"BINGO       : THE   # OF THE TGTS ARE DISTROYED BY SAM."
LPRINT"EK(SAM)     : EXPECTED # OF THE TGTS ARE DESTROYED BY SAM. "
LPRINT"HIT         : THE EXPECTED # OF THE SHIP IS HIT BY AT LEAST 1 INBOUND TGTS
"
LPRINT"LEAK        : THE # OF THE TGTS LEAKING THROUGHT THE SAM DEFENSE."
LPRINT"E(L)        : EXPECPTED VALUE OF THE LEAKING TGTS."
LPRINT"CIWS        : # OF TGTS KILLED BY CIWS"
LPRINT"EK(S&C:EW): EXSPECTED # OF THE TGTs DESTROYED BY SAM AND CIWS +/- EW."
LPRINT"PENETRATOR: THE EXPECTED # OF TGTS HIT THE SHIP SUCCESSFULLY"
LPRINT"SS          : SHIP SURVIVALBILITY."
LPRINT"PK0,1,2,3 : SAM PK, ECM PK, CHAFF PK, ECM&CHAFF PK
LPRINT"EK (ECM)  : THE EXPECTED # OF DESTROYED TGTS BY ECM"
LPRINT"EK (CHAFF): THE EXPECTED # OF DESTROYED TGTS BY CHAFF"
LPRINT"EK (COMB) : THE EXPECTED # OF DESTROYED TGTS BY ECM & CHAFF"
LPRINT"% (BG)    : THE    OF THE DESTROYED TGTS BY SAM"
LPRINT"% (ECM)   : THE % OF THE DESTROYED TGTS BY ECM"
LPRINT"% (CHAFF) : THE % OF THE DESTROYED TGTS BY CHAFF"
LPRINT"% (COMB)  : THE % OF THE DESTROYED TGTS BY ECM & CHAFF"
LPRINT"% (CIWS)  : THE % OF THE DESTROYED TGTS BY CIWS"
LPRINT" " : LPRINT" " : LPRINT" "
LPRINT"RT RANGE NSAM  E(NS)  V  E(V) BINGO EK   HIT  LEAK  E(L) EK    EK   PENET-
SS"
LPRINT"                          SAM    SAM       (L)         CIWS S&C RATOR
"
LPRINT"                                                            :EW"
LPRINT"__ ____  _____ ____ ____ _____ ____ ____ _____ ____ ____ ____ ____ ____
"
A$= "## ##    ##### #.## #### #.## ##### #.## #.## ##### #.## #.## #.## #.## #.
##"
B$= "PK0= #.#   PK1= #.#   PK2= #.#   PK3= #.#"
C$= "## ##   #.##  #.##  #.##  #.##  #.##  #.##  #.##  #.##"
 FOR I=1 TO 3
     LPRINT USING B$;QQ(I),ECMPK,CAFPK,COMPK
```

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      FOR J=1 TO 2
        FOR K=1 TO 5
          AA=RM(I,J)      'REACTION TIME
          BB=RA(K)        'RANGE
          CC=TM(I,J,K)    'TOTAL SAM THE SHIP HAS FIRED
          DD=NS(I,J,K)    'EXPECTED # OF THE SAM HAVE BEEN FIRED
          EE=SA(I,J,K)    'THE # OF SUCCESSFUL DEFENSE OF THE SHIP IN SAM MODE
          FF=ESA(I,J,K)   'THE EXPECTED # OF SUCCESSFUL DEFENSE OF THE SHIP IN SAM
MODE
          GG=BG(I,J,K)    'THE # OF THE DESTROYED TGTs BY SAM
          HH=EK(I,J,K)    'THE EXPECTED # OF THE DESTROYED TGTs BY SAM
          LL=DEFFAIL(I,J,K)/N 'EXPECTED # OF AT LEAST ONE TGTs IMPACT THE SHIP
          MM=LEAKTHRU(I,J,K)  'THE # OF THE TGTs GET THRU THE SAM'S DEFENSE
          NN=ESI(I,J,K)        'THE EXPECTED # OF THE TGTs GET THRU THE SAM's
                               '            DEFENSE

          OO=ECK(I,J,K)   'THE # OF THE TGTs ARE KILLED BY THE CIWS
          PP=TOTALEK(I,J,K)    'THE FINAL EK (TGTs ARE DEFENDED BY SAM AND CIWS +/
- EW)
          QQ=(MM-GOODMIX(I,J,K))/N 'THE TGTs IMPACT THE SHIP SUCCESSFULLY
          RR=SS(I,J,K)             'THE SHIP's SURVIVALBILITY
   'SA(I,J,K): SUCCESS. ESI(I,J,K):EXPECT # TGT GETTING THRU.
          LPRINT USING A$;AA,BB,CC,DD,EE,FF,GG,HH,LL,MM,NN,OO,PP,QQ,RR
        NEXT K
      NEXT J
 NEXT I
LPRINT" "  : LPRINT" "  : LPRINT" "
LPRINT"RT RANGE EK    EK    EK     %     %     %     %     %   "
LPRINT"          ECM   CHAFF COMB  BG    ECM   CHAF  COMB  CIWS"
LPRINT"__  ____  ____  ____  ____  ____  ____  ____  ____  ____ "

FOR I=1 TO 3
      LPRINT USING B$;QQ(I),ECMPK,CAFPK,COMPK
      FOR J=1 TO 2
        FOR K=1 TO 5
          AA=RM(I,J)                 'REACTION TIME
          BB=RA(K)                   'RANGE
          BECME=BYECM(I,J,K)/N       'THE EXPECTED # OF DESTROYED TGTS BY ECM
          BCAFE=BYCHAFF(I,J,K)/N     'THE EXPECTED # OF DESTROYED TGTS BY CHAFF
          BCOMB=BYCOMB(I,J,K)/N      'THE EXPECTED # OF DESTROYED TGTS BY ECM & CH
AFF
          BGP=BG(I,J,K)/(4*N)        'THE % OF THE DESTROYED TGTS BY SAM
          ECMP=BYECM(I,J,K)/(4*N)    'THE % OF THE DESTROYED TGTS BY ECM
          CAFP=BYCHAFF(I,J,K)/(4*N)  'THE % OF THE DESTROYED TGTS BY CHAFF
          COMP=BYCOMB(I,J,K)/(4*N)   'THE % OF THE DESTROYED TGTS BY ECM & CHAFF
          CIWP=BYCIWS(I,J,K)/(4*N)   'THE % OF THE DESTROYED TGTS BY CIWS
          LPRINT USING C$;AA,BB,BECME,BCAFE,BCOMB,BGP,ECMP,CAFP,COMP,CIWP
        NEXT K
      NEXT J
 NEXT I
LPRINT"RUNNING TIME=";TIME$
 STOP

'**********************       SUBROUTINES      **********************************
230 'RELOAD: 'SUBROUTINE
            IF NFROM=1234 AND WHERE=1234 THEN
               IF TP-T<1 THEN TP=T+1
               GOTO 240
            END IF
            IF NFROM=1234 AND WHERE=34 THEN
               ' TP=T-4 THE EXACT TIME FOLLOWING TGT3 FOR SPACING 4 SEC WHEN FCR1
                       'FIRES SAM AT TGT3. SAM START RELOADING RIGHT AFTER THIS
                       'INCIDENT AT TP.
               IF TP-T<1 THEN TP=T+1 ELSE TP=TP+0
               GOTO 240
            END IF
            IF NFROM=234 AND WHERE=34 THEN
               IF TP-T>1 THEN TP=TP+0:T=T+0
               GOTO 240
            END IF
            IF NFROM=134 AND WHERE=34 THEN
               IF TP-T<1 THEN T=TP+1
```

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                    GOTO 240
              END IF
              IF NFROM=234 AND (WHERE=24 OR WHERE=4) THEN GOTO 240
              IF NFROM=34 AND (WHERE=3 OR WHERE=4) THEN GOTO 240
              IF NFROM=34 AND NFROM=34 THEN
                  IF TP-T<1 THEN TP=T+1
                  GOTO 240
              END IF
              IF NFROM=134 AND (WHERE=14 OR WHERE=4) THEN GOTO 240
              IF NFROM=234 AND WHERE=234 THEN GOTO 240
              IF NFROM=134 AND WHERE=134 THEN GOTO 240
240
250 RETURN

260 'MEET2:
270        'FIRST BLOCK IS ENGAGING THE 1ST TGT
280        'SECOND    "    "          "   2ND  "
300        DTGT=RANGE-(T/6)
310        T=T+(DTGT/(S1+S2))
320        DTGT=RANGE-(T/6)
330        DTGTP=RANGE-(TP/6)
340        TP=TP+(DTGTP/(S1+S2))
350        DTGTP=RANGE-(TP/6)
370     IF DTGT <= 3 AND DTGTP <= 3 THEN
380        FLAG=1:NSAM1=NSAM1-1:NSAM2=NSAM2-1:RETURN
390     END IF
400 IF DTGT <= 3 AND DTGTP >  3 THEN NSAM1=NSAM1-1:TGT1SUC=1
410 IF DTGT >  3 AND DTGTP <= 3 THEN NSAM2=NSAM2-1:TGT2SUC=1
430 RETURN

440 'MEET1:
450        DTGT=RANGE-(T/6)
460        T=T+DTGT/(S1+S2)
470        DTGT=RANGE-(T/6)
490        IF DTGT <= 3 THEN FLAG=1: NSAM1=NSAM1-1:LEAKING=LEAKING+1
500 RETURN

510 'ASSESSMENT2:
              R1=RND
              R2=RND
              TGTA=1
              TGTB=1
              T=T+8:DTGT=RANGE-(T/6)
              TP=TP+8:DTGTP=RANGE-(TP/6)
              CIWSDTGT=DTGT:CIWSDTGTP=DTGTP
              CIWST=T:CIWSTP=TP 'CIWST AND CIWSTP ARE THE CIWS MODE
              IF DTGT <= 3 AND DTGTP <= 3 THEN FLAG=1:GOTO 520
              IF TGT1SUC=1 AND DTGTP <= 3 THEN FLAG=1:GOTO 520
              IF TGT2SUC=1 AND DTGT  <= 3 THEN FLAG=1:GOTO 520
              IF R1 =< PK THEN TGTA=0
              IF R2 =< PK THEN TGTB=0
520 RETURN

530 'ASSESSMENT1:
              R=RND
              TGT=1
              T=T+8:DTGT=RANGE-(T/6):CIWST=T:CIWSDTGT=DTGT
              IF R =< PK THEN TGT=0
          IF DTGT <= 3 THEN FLAG=1
540
550 RETURN

560 'S1234: FCR1 ON TGT1, FCR2 ON TGT2. NEED REACTION TIME.
          FLAG=0      'IF FLAG=1 THEN SAM'S DEFENSE IS ENDED
          CIWSFLAG=0 'IF CIWSFLAG=1 THEN CIWS MODE IS ON, WHICH IMPLY THERE
                      'ARE TGTs LEAKING THRU THE SAM's DEFENSE
          MARK=0
          NFROM=1234:KUM=0 'KUM IS THE CODE FOR 1234-134-34-3 USE ONLY
          WHERE=1234 'WHERE IS USED IN RELOAD FOR THIS PLACE
          T= T+RT
          TP=TP-SPACING+RT
          CONST1=0
```

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                CONST2=SPACING
                CINST=T:CINSTP=TP
570             GOSUB 230
                TGT1SAM=TGT1SAM+1
                TGT2SAM=TGT2SAM+1
                NSAM1=TGT1SAM:NSAM2=TGT2SAM
                GOSUB 260:TGT1SAM=NSAM1:TGT2SAM=NSAM2:IF FLAG=1 THEN RETURN
                IF TGT2SUC=1 THEN
                    MARK=1:GOSUB 530:TGT1=TGT: GOSUB 1480:RETURN
                END IF
                GOSUB 510: IF FLAG=1 THEN RETURN
                TGT1=TGTA:TGT2=TGTB
                IF TGT1=1 AND TGT2=1 THEN GOTO 570
                IF TGT1=0 AND TGT2=0 THEN GOSUB 590
                IF TGT1=0 AND TGT2=1 THEN GOSUB 610
                IF TGT1=1 AND TGT2=0 THEN GOSUB 650
580 RETURN

590 'S34: 'SUBROUTINE FOR TGT1 AND TGT2 HAVE BEEN KILLED BUT NOT TGT3 AND TGT4
                FLAG=0: WHERE=34
                IF NFROM=1234 THEN
                    T=T-2*SPACING
                    TP=TP-2*SPACING
                    CONST1=2*SPACING
                    CONST2=2*SPACING
                ELSEIF NFROM=234 THEN
                    TP= TP-2*SPACING
                ELSEIF NFROM=134 THEN
                    T=T-3*SPACING
                    CONST1=3*SPACING
                    CONST2=0
                END IF
        IF NFROM=1234 THEN T=T+RT:TP=TP+RT:GOSUB 230
        IF NFROM=234 THEN TP=TP+RT:GOSUB 230
        IF NFROM=134 THEN T=T+RT: GOSUB 230
600         TGT3SAM=TGT3SAM+1
                TGT4SAM=TGT4SAM+1
                NSAM1=TGT3SAM:NSAM2=TGT4SAM
                NFROM=34
                GOSUB 260:TGT3SAM=NSAM1:TGT4SAM=NSAM2:IF FLAG=1 THEN RETURN
                IF TGT2SUC=1 THEN
                    MARK=1:GOSUB 530:TGT3=TGT: GOSUB 1270:RETURN
                END IF
                GOSUB 510: IF FLAG=1 THEN RETURN
                IF TGT2SUC=1 AND TGT1SUC=0 THEN TGT3=TGTA:GOSUB 1270:RETURN
                IF TGT1SUC=1 AND TGT2SUC=0 THEN TGT4=TGTB:GOSUB 1170:RETURN
                TGT3=TGTA:TGT4=TGTB
                IF TGT3=1 AND TGT4=1 THEN GOSUB 230:GOTO 600
                IF TGT3=0 AND TGT4=0 THEN RETURN
                IF TGT3=0 AND TGT4=0 THEN RETURN
                IF TGT3=0 AND TGT4=1 THEN GOSUB 1170
                IF TGT3=1 AND TGT4=0 THEN GOSUB 1270
            RETURN

610 'S234:
620 'SUBROUTINE FOR TGT1 HAS BEEN KILLED BUT NOT TGT2,TGT3 AND TGT4
                FLAG=0:WHERE=234
                'FCR1:TGT1-TGT3. FCR2:TGT2-TGT2.
                TP=TP+0
                T=T-(2*SPACING)+RT
                CONST1=2*SPACING
                CONST2=0
630         GOSUB 230
                TGT2SAM=TGT2SAM+1
                TGT3SAM=TGT3SAM+1
                NSAM1=TGT2SAM:NSAM2=TGT3SAM
                GOSUB 260:TGT2SAM=NSAM1:TGT3SAM=NSAM2: IF FLAG=1 THEN RETURN
                NFROM=234
                IF TGT2SUC=1 THEN
                    MARK=1:GOSUB 530:TGT2=TGT: GOSUB 1340:RETURN
                END IF
                GOSUB 510: IF FLAG=1 THEN RETURN
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                      TGT2=TGTA:TGT3=TGTB
                      IF TGT2=1 AND TGT3=1 THEN   GOTO 630
                      IF TGT2=0 AND TGT3=0 THEN   GOSUB 1170
                      IF TGT2=0 AND TGT3=1 THEN   GOSUB 590
                      IF TGT2=1 AND TGT3=0 THEN   GOSUB 790
     640 RETURN

     650 'S134:
             'SUBROUTINE FOR TGT2 HAS BEEN KILLED BUT NOT TGT1, AND TGT3,TGT4 ARE
             'STILL EXISTING
                      FLAG=0:  WHERE=134:KUM=1
                      'FCR1:TGT1-TGT1.  FCR2:TGT2-TGT3.
                      T=T+0
                      TP=TP-SPACING+RT
                      CONST1=0
                      CONST2=SPACING
     660           GOSUB 230
                      TGT1SAM=TGT1SAM+1
                      TGT3SAM=TGT3SAM+1
                      NSAM1=TGT1SAM:NSAM2=TGT3SAM:NFROM=134
     670           GOSUB 260:TGT1SAM=NSAM1:TGT3SAM=NSAM2:IF FLAG=1 THEN RETURN
     680           IF TGT2SUC=1 THEN
     690              MARK=1:GOSUB 530:TGT1=TGT:GOSUB 1170:RETURN
     700           END IF
     710           NFROM=134:GOSUB 510:  IF FLAG=1 THEN RETURN
     720           TGT1=TGTA:TGT3=TGTB
     730           IF TGT1=1 AND TGT3=1 THEN   GOTO 660
     740           IF TGT1=0 AND TGT3=0 THEN   GOSUB 1170
     750           IF TGT1=0 AND TGT3=1 THEN   GOSUB 590
     760           IF TGT1=1 AND TGT3=0 THEN   GOSUB 980
     770 RETURN

     780 'S24:
     790 'TGT2 AND TGT4 LEFT, BUT FCR1 SHIFTS FROM TGT3 TO TGT4, SO FCR1 NEEDS THE
     800 'REACTION TIME TO LOCK ON TGT4.
     820           FLAG=0:WHERE=24
                      'FCR1:TGT1-TGT3-TGT4.  FCR2:TGT2
                      IF MARK=1 THEN TP=TP+0:GOTO 830
                      T=T-SPACING+RT:TP=TP+0
                      CONST1=SPACING
                      CONST2=0
     830           GOSUB 230
                      TGT2SAM=TGT2SAM+1
                      TGT4SAM=TGT4SAM+1
     840           NSAM1=TGT2SAM:NSAM2=TGT4SAM
     850           NFROM=24
     860           GOSUB 260:TGT2SAM=NSAM1:TGT4SAM=NSAM2:IF FLAG=1 THEN RETURN
     870           IF TGT2SUC=1 THEN
     880              MARK=1:GOSUB 530:TGT1=TGT:GOSUB 1340:RETURN
     890           END IF
     900           GOSUB 510:  IF FLAG=1 THEN RETURN
     910           TGT2=TGTA:TGT4=TGTB
     920           IF TGT2=1 AND TGT4=1 THEN   GOTO 830
     930           IF TGT2=1 AND TGT4=0 THEN   GOSUB 1340
     940           IF TGT2=0 AND TGT4=1 THEN   GOSUB 1170
     950           IF TGT2=0 AND TGT4=0 THEN   RETURN
     960           IF TGT2=0 AND TGT4=0 THEN   RETURN
     970 RETURN

     980 'S14: 'FCR2 KILLED TGT2 AND TGT3 ,AND NOW SHIFTS TO TGT4, WHICH NEED
     990       'REACTION TIME.
    1010           FLAG=0:  WHERE=14:
                      'FCR1:TGT1-TGT1-TGT1.  FCR2:TGT2-TGT3-TG4.
                      T=T+0
                      TP=TP-SPACING+RT
                      CONST1=0
                      CONST2=SPACING
    1020           GOSUB 230
                      TGT1SAM=TGT1SAM+1
                      TGT4SAM=TGT4SAM+1
    1030           NSAM1=TGT1SAM:NSAM2=TGT4SAM
    1040           GOSUB 260:TGT1SAM=NSAM1:TGT4SAM=NSAM2:IF FLAG=1 THEN RETURN
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1050      IF TGT2SUC=1 THEN
1060         MARK=1:GOSUB 530:TGT1=TGT:GOSUB 1480:RETURN
1070      END IF
1080      NFROM=14:GOSUB 510: IF FLAG=1 THEN RETURN
1090      TGT1=TGTA
1100      TGT2=TGTB
1110      IF TGT1=1 AND TGT4=1 THEN   GOTO 1020
1120      IF TGT1=1 AND TGT4=0 THEN   GOSUB 1480
1130      IF TGT1=0 AND TGT4=1 THEN   GOSUB 1170
1140      IF TGT1=0 AND TGT4=0 THEN   RETURN
1150      IF TGT1=0 AND TGT4=0 THEN   RETURN
1160 RETURN

1170 'S4: 'WHEN TGT1,TGT2 AND TGT3 HAVE BEEN KILLED, THERE IS ONLY TGT4 LEFT
         FLAG=0: WHERE=4:'PRINT "IN 4"
         IF NFROM=34 THEN T=TP: GOTO 1180
         IF T >= TP THEN T=TP
1180         IF NFROM=234 THEN T=T-2*SPACING+RT
         IF NFROM=134 THEN T=T-3*SPACING+RT
1190      TGT4SAM=TGT4SAM+1
         NSAM1=TGT4SAM
         GOSUB 440:TGT4SAM=NSAM1:IF FLAG=1 THEN RETURN
1200      NFROM=4:GOSUB 530:IF FLAG=1 THEN RETURN
1210      TGT4=TGT: IF MARK = 1 THEN RETURN
1220      IF TGT4=0 THEN RETURN
1230      IF TGT4=1 THEN GOTO 1190
1240
1250 RETURN

1270 ' S3: 'WHEN ALL THE OTHER THREE TGTS WERE KILLED, TGT3 LEFT
         FLAG=0:WHERE=3
         IF KUM=1 AND NFROM=34 THEN:T=TP:GOTO 1280
         IF T >= TP THEN T=TP
1280      TGT3SAM=TGT3SAM+1
         NSAM1=TGT3SAM
         GOSUB 440:TGT3SAM=NSAM1: IF FLAG=1 THEN RETURN
1290      NFROM=3:GOSUB 530:IF FLAG=1 THEN RETURN
1300      TGT3=TGT:IF MARK=1 THEN RETURN
1310      IF TGT3=0 THEN RETURN
1320      IF TGT3=1 THEN GOTO 1280
1330 RETURN

1340 'S2: 'TGT2 LEFT ONLY.
1350      'THIS CASE WOULD HAPPEN ONLY FROM NODE 24. NO REACTION TIME NECESSARY.
1370      FLAG=0: WHERE=2
1380      IF NFROM=234 AND MARK=1 THEN
1390         IF TGT2=1 THEN T=TP:GOTO 1420
1400         IF TGT2=0 THEN GOSUB 1170:RETURN
1410      END IF
         IF NFROM=24 AND MARK=1 THEN T=TP
         IF T >= TP THEN T=TP
1420      TGT2SAM=TGT2SAM+1
         NSAM1=TGT2SAM
         GOSUB 440:TGT2SAM=NSAM1:IF FLAG=1 THEN RETURN
1430      NFROM=2:GOSUB 530:IF FLAG=1 THEN RETURN
1440      TGT2=TGT:IF MARK=1 THEN RETURN
1450      IF TGT2= 0 THEN   RETURN
1460      IF TGT2=1 THEN GOTO 1420
1470 RETURN

1480 'S1:    'TGT1 LEFT ONLY
1490      'NO REACTION TIME NECESSARY
         FLAG=0: WHERE=1
         IF T >= TP THEN T=TP
1510      TGT1SAM=TGT1SAM+1
         NSAM1=TGT1SAM
         GOSUB 440:TGT1SAM=NSAM1:IF FLAG=1 THEN RETURN
1520      NFROM=1:GOSUB 530:IF FLAG=1 THEN RETURN
1530      TGT1=TGT:IF MARK=1 THEN RETURN
1540      IF TGT1=0 THEN RETURN
1550      IF TGT1=1 THEN GOTO 1510
1560 RETURN
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'****************** NUMERICAL STATISTIC  *********
1570 'STATISTIC:
     'TOTALSAM: TOTAL SAMS HAVE BEEN FIRED FROM THE N SAMP'E SIZE
     'EK: EXPECTED NUMBER OF TARGETS BEING KILLED.
     'SS: SHIP SURVIVABILITY AGAINST 4 TARGETS.
     'ESA: EXPECTED # OF DEFENSE SUCCESSFULLY.
     BG(I,J,K)=TGTKILLED      'TGTs ARE KILLED BY SAM
     LEAKTHRU(I,J,K)=TLEAK 'TGTs GET THRU THE SAM DEFENSE
     DEFFAIL(I,J,K)=HIT     'AT LEAST ONE TGT IMPACTS SHIP
     BYECM(I,J,K)=ECMKILL
     BYCHAFF(I,J,K)=CHAFFKILL
     BYCOMB(I,J,K)=COMBKILL
     BYCIWS(I,J,K)=CIWSKILL
     TOTALSAM=SAMPTGT1+SAMPTGT2+SAMPTGT3+SAMPTGT4
     TM(I,J,K)=TOTALSAM
     'TOTALSAM: TOTAL SAM THE SHIP HAS FIRED AT THE INBOUND TGTs
     LEAKTHRU(I,J,K)=TLEAK
     ESI(I,J,K)=LEAKTHRU(I,J,K)/N
     NS(I,J,K)=TOTALSAM/N
     EK(I,J,K)=TGTKILLED/N
     SS(I,J,K)=1-(HIT/N)
     ESA(I,J,K)=SA(I,J,K)/N
     ECK(I,J,K)=BYCIWS(I,J,K)/N
     IF MODE=1 THEN
         GOODMIX(I,J,K)=BYECM(I,J,K)+BYCIWS(I,J,K)
     ELSEIF MODE=2 THEN
         GOODMIX(I,J,K)=BYCHAFF(I,J,K)+BYCIWS(I,J,K)
     ELSEIF MODE=3 THEN
         GOODMIX(I,J,K)=BYCOMB(I,J,K)+BYCIWS(I,J,K)
     ELSE
         GOODMIX(I,J,K)=BYCIWS(I,J,K)
     END IF
     TOTALEK(I,J,K)=(BG(I,J,K)+GOODMIX(I,J,K))/N
1580 RETURN

     ECM: 'IN ECM MODE, ECM SOUBROUTINE
     ARC = 0
     AAPK=ECMPK
     GOSUB AA
     ECMKILL=ECMKILL+ARC
     RETURN

     CHAFF: 'IN CHAFF MODE, CHAFF SUBROUTINE
     ARC = 0
     AAPK=CAFPK
     GOSUB AA
     CHAFFKILL=CHAFFKILL+ARC
     RETURN

     COMB: 'IN ECM & CHAFF COMBINED MODE, COMBINED ECM & CHAFF SUBROUTINE
     ARC =  0
     AAPK=COMPK
     GOSUB AA
     COMBKILL=COMBKILL+ARC
     RETURN

     CIWS: 'IN CIWS MODE, CIWS SUBROUTINE
     C' ISFLAG=1
        ALMAG=1200 ' TOTAL MAGAZINES
      .RERATE=30
     OUCH=0
     TGT=1
     IF CIWSDTGT < CIWSDTGTP THEN  CIWSDTGT=CIWSDTGTP: CIWST=CIWSTP
     CIWSSTARTT=(CIWSDTGT-MI)*6+CIWST 'CIWSSTARTT: THE TIME THE CIWS MODE STARTE
D
     IF CIWSDTGT >= 3 THEN              '3 NM=(5 SEC)*(1/6)(NM/SEC)+2NM
      CIWST=(CIWSDTGT-3)*6+CIWST        '5 SEC IS THE CIWS REACTION TIME
     END IF
     'REACTION AND START FIRING THE CIWS:
     CIWST=CIWST+CIWSRT 'THE TIME CIWS FIRE BY ADDING THE REACTION TIME
     CIWSDTGT=RANGE-CIWST/6  'THE TGT RANGE WHEN THE CIWS START FIRING
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1590 DIFF=TOTALT-CIWST
     IF CIWSDTGT <= 0.1 OR DIFF <= .6 THEN OUCH=1: GOTO 1600
     'FIRING:
     GOSUB SEEKPK
     CIWST=CIWST+CONTFIRET              'THE CIWST HERE IS THE TIME TO CHECK PK
     CIWSDTGT=RANGE-CIWST/6
     GOSUB AA
     IF CIWSDTGT <= 0.1 THEN OUCH=1: GOTO 1600
     IF TGT=1 THEN GOTO 1590
1600 IF NFROM=1234 OR NFROM=134 OR NFROM=234  THEN OUCH=1
     RETURN

'****************  DETERMINATION  ****************
     AA:
     ARC=0
     IF RANGE <= 10 AND NFROM=1234 THEN
     TGTT$="TGT2": 'PRINT"TGT=";TGTT$:'PRINT"C1234 AT DETECTION RANGE 10 NM"
     TGT=TGT2
     END IF :GOTO 1610
     IF NFROM=1234 THEN TGT=TGT1: TGTT$="TGT1":
     IF NFROM=134  THEN TGT=TGT1: TGTT$="TGT1":
     IF NFROM=234  THEN TGT=TGT2: TGTT$="TGT2":
     IF NFROM=34   THEN TGT=TGT3: TGTT$="TGT3":
     IF NFROM=14   THEN TGT=TGT1: TGTT$="TGT1":
     IF NFROM=24   THEN TGT=TGT2: TGTT$="TGT2":
     IF NFROM=1    THEN TGT=TGT1: TGTT$="TGT1":
     IF NFROM=2    THEN TGT=TGT2: TGTT$="TGT2":
     IF NFROM=3    THEN TGT=TGT3: TGTT$="TGT3":
     IF NFROM=4    THEN TGT=TGT4: TGTT$="TGT4":
1610:
     R=RND
     IF R <= AAPK THEN TGT=0:AR=AR+1:ARC=1
     IF RANGE <= 10 AND NFROM=1234 THEN TGT2=TGT: GOTO 1620
     IF NFROM=1234 THEN TGT1=TGT: GOTO 1620
     IF NFROM=134  THEN TGT1=TGT: GOTO 1620
     IF NFROM=234  THEN TGT2=TGT: GOTO 1620
     IF NFROM=34   THEN TGT3=TGT: GOTO 1620
     IF NFROM=14   THEN TGT1=TGT: GOTO 1620
     IF NFROM=24   THEN TGT2=TGT: GOTO 1620
     IF NFROM=1    THEN TGT1=TGT: GOTO 1620
     IF NFROM=2    THEN TGT2=TGT: GOTO 1620
     IF NFROM=3    THEN TGT3=TGT: GOTO 1620
     IF NFROM=4    THEN TGT4=TGT: GOTO 1620

1620 'ASSESSING:
         CIWST=CIWST+2
     RETURN

     SEEKPK:
     CONTFIRET=DIFF-.6
     IF DIFF > 8.6 THEN AAPK=0.6 :CONTFIRET=8
     IF DIFF > 6.6 AND DIFF <= 8.6 THEN AAPK=.05*CONTFIRET+.2
     IF DIFF > 4.6 AND DIFF <= 6.6 THEN AAPK=.1*CONTFIRET-.1
     IF DIFF >0.6 AND DIFF <= 4.6 THEN AAPK=.075*CONTFIRET
     RETURN
1630 END
```

APPENDIX C

Simulation Data

Simultaneous ASMs Attack

Option 1 SAM & CIWS

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=0.7		PK(ECM)=0.0		PK(CHAFF)=0.0			
30	30	3.03	0.48	0.00	3.51	0.49	0.61
30	25	2.98	0.49	0.00	3.48	0.52	0.58
30	20	1.96	0.67	0.00	2.63	1.37	0.07
30	15	1.54	0.64	0.00	2.18	1.82	0.00
30	10	0.70	0.53	0.00	1.23	2.77	0.00
PK(SAM)=0.5		PK(ECM)=0.0		PK(CHAFF)=0.0			
30	30	2.45	0.58	0.00	3.03	0.97	0.35
30	25	2.34	0.62	0.00	2.96	1.04	0.30
30	20	1.62	0.67	0.00	2.29	1.71	0.04
30	15	1.12	0.62	0.00	1.74	2.26	0.00
30	10	0.50	0.52	0.00	1.02	2.98	0.00
PK(SAM)=0.3		PK(ECM)=0.0		PK(CHAFF)=0.0			
30	30	1.69	0.61	0.00	2.30	1.70	0.12
30	35	1.57	0.67	0.00	2.23	1.77	0.09
30	20	1.09	0.67	0.00	1.76	2.24	0.01
30	15	0.67	0.61	0.00	1.27	2.73	0.00
30	10	0.30	0.53	0.00	0.83	3.14	0.00

Option 2 SAM & CIWS & EW

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=0.7		PK(ECM)=0.3		PK(CHAFF)=0.4			
30	30	3.02	0.28	0.44	3.73	0.27	0.78
30	25	2.98	0.29	0.43	3.70	0.30	0.75
30	20	1.96	0.59	0.58	3.13	0.87	0.36
30	15	1.55	0.60	0.58	2.72	1.28	0.23
30	10	0.70	0.34	0.58	1.62	2.38	0.00
PK(SAM)=0.5		PK(ECM)=0.3		PK(CHAFF)=0.4			
30	30	2.42	0.42	0.54	3.38	0.62	0.56
30	25	2.33	0.48	0.53	3.34	0.66	0.53
30	20	1.62	0.62	0.59	2.83	1.17	0.26
30	15	1.12	0.58	0.58	2.27	1.73	0.14
30	10	0.50	0.34	0.58	1.42	2.58	0.00
PK(SAM)=0.3		PK(F)=0.3		PK(CHAFF)=0.4			
30	30	1.69	0.53	0.57	2.80	1.20	0.29
30	35	1.57	0.60	0.58	2.74	1.26	0.27
30	20	1.08	0.63	0.58	2.29	1.71	0.12
30	15	0.66	0.55	0.58	1.79	2.21	0.06
30	10	0.30	0.34	0.58	1.22	2.78	0.00

Option 3 SAM & CIWS & Improved EW

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=0.7		PK(ECM)=0.5		PK(CHAFF)=0.6			
30	30	3.02	0.20	0.60	3.82	0.18	0.84
30	25	2.99	0.22	0.59	3.80	0.20	0.82
30	20	1.96	0.57	0.80	3.34	0.66	0.48
30	15	1.55	0.60	0.80	2.95	1.05	0.32
30	10	0.70	0.34	0.80	1.84	2.18	0.00
PK(SAM)=0.5		PK(ECM)=0.5		PK(CHAFF)=0.6			
30	30	2.43	0.36	0.74	3.53	0.47	0.64
30	25	2.34	0.43	0.74	3.50	0.50	0.62
30	20	1.62	0.61	0.80	3.04	0.96	0.34
30	15	1.12	0.58	0.79	2.49	1.51	0.19
30	10	0.50	0.34	0.80	1.64	2.36	0.00
PK(SAM)=0.3		PK(ECM)=0.5		PK(CHAFF)=0.6			
30	30	1.69	0.51	0.79	2.99	1.01	0.35
30	35	1.57	0.58	0.79	2.94	1.06	0.34
30	20	1.07	0.63	0.81	2.51	1.49	0.16
30	15	0.66	0.54	0.80	2.00	2.00	0.08
30	10	0.30	0.33	0.80	1.44	2.58	0.00

Option 4 Improved SAM & CIWS

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=0.7		PK(ECM)=0.0		PK(CHAFF)=0.0			
20	30	3.34	0.35	0.00	3.69	0.31	0.74
20	25	3.02	0.49	0.00	3.51	0.49	0.60
20	20	2.17	0.66	0.00	2.83	1.17	0.16
20	15	1.54	0.67	0.00	2.21	1.79	0.00
20	10	1.40	0.67	0.00	2.07	1.93	0.00
PK(SAM)=0.5		PK(ECM)=0.0		PK(CHAFF)=0.0			
20	30	2.70	0.53	0.00	3.22	0.78	0.47
20	25	2.40	0.61	0.00	3.01	0.99	0.34
20	20	1.83	0.63	0.00	2.46	1.54	0.10
20	15	1.11	0.66	0.00	1.77	2.23	0.00
20	10	1.00	0.67	0.00	1.67	2.33	0.00
PK(SAM)=0.3		PK(ECM)=0.0		PK(CHAFF)=0.0			
20	30	1.77	0.60	0.00	2.37	1.63	0.17
20	25	1.62	0.65	0.00	2.27	1.73	0.11
20	20	1.22	0.60	0.00	1.82	2.18	0.04
20	15	0.67	0.67	0.00	1.34	2.66	0.00
20	10	0.61	0.67	0.00	1.29	2.71	0.00

Option 5 Improved SAM & CIWS & EW

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=O.7		PK(ECM)=0.3		PK(CHAFF)=0.4			
20	30	3.35	0.19	0.30	3.84	0.16	0.87
20	25	3.03	0.27	0.43	3.72	0.28	0.77
20	20	2.17	0.52	0.57	3.27	0.73	0.45
20	15	1.55	0.63	0.59	2.77	1.23	0.24
20	10	1.40	0.61	0.58	2.59	1.41	0.17
PK(SAM)=O.5		PK(ECM)=0.3		PK(CHAFF)=0.4			
20	30	2.68	0.35	0.47	3.51	0.49	0.65
20	25	2.40	0.44	0.53	3.37	0.63	0.55
20	20	1.85	0.55	0.57	2.97	1.03	0.35
20	15	1.12	0.64	0.58	2.34	1.66	0.14
20	10	0.99	0.61	0.58	2.17	1.83	0.09
PK(SAM)=O.3		PK(ECM)=0.3		PK(CHAFF)=0.4			
20	30	1.79	0.48	0.56	2.83	1.17	0.35
20	25	1.61	0.57	0.57	2.75	1.25	0.28
20	20	1.23	0.54	0.58	2.35	1.65	0.17
20	15	0.66	0.63	0.58	1.87	2.13	0.05
20	10	0.62	0.61	0.58	1.80	2.20	0.03

Option 6 Improved SAM & CIWS & Improved EW

RT	RANGE	EK(SAM)	EK(CIWS)	EK(COMB)	EK[S&C(+/-)EW]	PENETRATOR	SS
PK(SAM)=O.7		PK(ECM)=0.5		PK(CHAFF)=0.6			
20	30	3.34	0.13	0.42	3.89	0.11	0.91
20	25	3.03	0.19	0.59	3.81	0.19	0.84
20	20	2.16	0.50	0.80	3.47	0.53	0.56
20	15	1.55	0.63	0.80	2.98	1.02	0.32
20	10	1.40	0.60	0.81	2.82	1.18	0.24
PK(SAM)=O.5		PK(ECM)=0.5		PK(CHAFF)=0.6			
20	30	2.69	0.29	0.65	3.63	0.37	0.73
20	25	2.40	0.38	0.73	3.51	0.49	0.63
20	20	1.84	0.53	0.80	3.17	0.83	0.44
20	15	1.13	0.63	0.80	2.56	1.44	0.19
20	10	1.00	0.60	0.80	2.39	1.61	0.12
PK(SAM)=O.3		PK(ECM)=0.5		PK(CHAFF)=0.6			
20	30	1.78	0.47	0.77	3.02	0.98	0.42
20	25	1.61	0.55	0.79	2.95	1.05	0.35
20	20	1.22	0.53	0.80	2.56	1.44	0.22
20	15	0.66	0.63	0.79	2.08	1.92	0.07
20	10	0.60	0.60	0.80	2.01	1.99	0.05

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