(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SPECIFICATION OF DIFFICULT TO TEST
RADAR
PERFORMANCE

by

Yu, Chen-Kuo

September, 1990

Thesis Advisor: Hung-Mou Lee

Approved for public release; distribution is unlimited.

Unclassified

security classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified	1b Restrictive Markings
2a Security Classification Authority	3 Distribution/Availability of Report
2b Declassification/Downgrading Schedule	Approved for public release; distribution is unlimited.
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School / 6b Office Symbol (if applicable) 3A	7a Name of Monitoring Organization Naval Postgraduate School
6c Address (city, state, and ZIP code) Monterey, CA 93943-5000	7b Address (city, state, and ZIP code) Monterey, CA 93943-5000
8a Name of Funding/Sponsoring Organization / 8b Office Symbol (if applicable)	9 Procurement Instrument Identification Number
8c Address (city, state, and ZIP code)	10 Source of Funding Numbers: Program Element No / Project No / Task No / Work Unit Accession No

11 Title (Include security classification) SPECIFICATION OF DIFFICULT TO TEST RADAR PERFORMANCE

12 Personal Author(s) Yu, Chen-Kuo

13a Type of Report	13b Time Covered	14 Date of Report (year, month, day)	15 Page Count
Master's Thesis	From To	SEPTEMBER 1990	87

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms (continue on reverse if necessary and identify by block number)
Field	Group	Subgroup	operational requirement, specification of radar performance

19 Abstract (continue on reverse if necessary and identify by block number)

In order to obtain detection range requirement of a new radar system, a computer simulation model is develpoed to evaluate the capability of the radar in an anti-air defense operation. Since the anti-ship missile is not available for test and evaluation, a technique to specify the performance requirement and design the test and evaluation plane using an airplane is developed. The effects of the propagation environment are also discussed.

20 Distribution/Availability of Abstract ☒ unclassified/unlimited ☐ same as report ☐ DTIC users	21 Abstract Security Classification Unclassified

22a Name of Responsible Individual	22b Telephone (Include Area code)	22c Office Symbol
Hung-Mou LEE	(408) 646-2846	62Lh

DD FORM 1473,84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete

security classification of this page

Unclassified

Approved for public release; distribution is unlimited.

SPECIFICATION OF DIFFICULT TO TEST RADAR PERFORMANCE

by

Yu, Chen-Kuo
Commander, Republic of China Navy
B.S., Naval Academy of Republic of China, 1976

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING
(ELECTRONIC WARFARE)

from the

NAVAL POSTGRADUATE SCHOOL
September 1990

Author: Yu, Chen-Kuo

Yu, Chen-Kuo

Approved by: Hung-Mou Lee

Hung-Mou Lee, Thesis Advisor

Joseph Sternberg

Joseph Sternberg, Second Reader

Joseph Sternberg

Joseph Sternberg, Chairman
Electronic Warfare Academic Group

ABSTRACT

In order to obtain detection range requirement of a new radar system, a computer simulation model is developed to evaluate the capability of the radar in an anti-air defense operation. Since the anti-ship missile is not available for test and evaluation, a technique to specify the performance requirement and design the test and evaluation plane using an airplane is developed. The effects of the propagation environment are also discussed.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not be applicable to all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they can not be considered validated. Any use of these programs is at the risk of the user.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENT

I wish to express my sincere gratitude to Professor Hung-Mou Lee for his professional guidance, invaluable advice and moral support throughout the thesis preparation period. Thanks to Professor Joseph Sternberg for his review and suggestions to the thesis work. I am also thankful for the help and concern of my friends, and for the inspiration provided by my family.

I. INTRODUCTION

Radar systems play a key role in most modern shipboard combat systems. Their all-weather functioning capability at long ranges is unmatched by that of other sensors. They are also among the few sensors capable of providing accurate range information. Their shipboard applications include air surveillance and traffic control, surface search and navigation, target acquisition and close-in weapon systems control, and target illumination for semi-active missile homing.

Radar system development involves a wide variety of technologies and consumes the navy budget heavily. Typically, a radar design cycle takes five to ten years to complete. It approaches technical obsolescence and requires upgrade within two years of initial deployment. Therefore, to avoid being driven to obsolescence due to increased threat upon its deployment, a new radar system has to be designed to meet a threat environment anticipated by the fleet in ten years. How to specify the operational requirements of a radar for a still non-existent threat and how to test the radar system when such a threat is not available are two important questions to be answered.

The operational requirements define the basic performance characteristics of the radar system to be acquired. Usually, it is prepared by the system user and approved by an authorization committee. It is the basis for system development. If the operational requirements are prudentially and accurately determined, the new radar should meet what the fleet desires.

Exact system performance specification is the rule for every military system acquisition program. Through a clear understanding of the operational requirements, it is possible to specify system performance exactly. The required performance determines the critical issues of the system. To ensure that the new radar meets the requirements, all critical issues have to be included in the test and evaluation master plan (TEMP). It is clear that a critical issue which cannot be tested should never be specified. How, then, can one specify the performance requirements and design test plans against a non-existent or unavailable threat? In this thesis, the problem of developing a surveillance radar to counter an unavailable threat is considered. The use of an alternative, readily available threat target for radar performance specification and test and evaluation is studied.

In what follows, some operational requirements of a new shipboard surveillance radar to detect incoming low flying missiles will be determined through threat scenario simulation. Its performance parameter will then be specified in terms of the detection of a high flying aircraft. Performance evaluation of the radar can be carried out against the aircraft. The effectiveness of the radar against the anticipated threat will be deduced from its performance against the aircraft.

This work attempts to demonstrate the methodology of utilizing currently available technical tools to assist in radar system acquisition. The threat scenario, the anti-air warfare (AAW) capability and the surveillance and tracking radar reaction times are all flexible: they are different for different navies of the world. Therefore, the system characteristics adopted in this thesis are chosen to describe reasonable scenarios only. They do not correspond to any current weapons and radar systems, nor are they expectations of any in the future.

II. OPERATIONAL REQUIREMENTS

Operational requirements define the basic performance required of a new radar. Before a new radar is designed, the following items are considered to generate the threat environment and determine the operational requirements of the radar:

(1) The results of previous operational exercises or warfare.

(2) The system developments of enemy (or potential enemy).

(3) The tactical thought invented by tacticians.

(4) The development tendency of future naval weapons and warfare.

Once the threat environment is determined, it should be straight forward to find the performance requirements of the new radar if an exercise of practicing forces can be arranged according to the threat scenario. There are several difficulties need to considered:

(1) This requires a lot of personnel and equipment which may not be economical.

(2) Some desired situations are difficult to model.

(3) Threat systems are not easily obtained or simulated.

(4) The new radar has not been produced, and its actual performance can not be ascertained.

(5) The effects of combining with other systems are not easily predictable.

Therefore, to obtain an operational requirement, practicing forces are seldom employed to model a situation. So far war games or computer simulations are often used. Although they are not real world situations, they allow even the most stressful situation to be attempted and evaluated. In addition, they are economical and not requiring real threat forces or systems.

Computer simulation is utilized in this thesis. A threat scenario is set. A FORTRAN simulation program is used which runs on the IBM/370 mainframe computer at the Naval Postgraduate School. Through analyzing the results, the desired operational requirements are established.

A. SCENARIO AND OUTLINE

A scenario is defined as, "an outline of the plot of dramatic work, giving particulars as to the scenes, characters, situations, etc." A scenario is a description of an imaginary situation that will be used to simulate real system operation during a test. Therefore, a scenario is prepared to provide all detailed descriptive materials necessary to determine the operational requirements to accomplish the following mission:

(1) Developing and exercising of realistic models and/or simulations of systems to obtain required information about system characteristics and operational performance.

(2) Permit conducting of realistic two-sided exercises to determine the ability of systems to achieve operational missions [Ref. 1].

The following is an example of determining the operational requirements through computer simulation of a scenario.

******* Scenario -- Anti-Ship Missile Defense Operation *******

1. Red Force:

The SSN-X anti-surface missiles of Red force are launched from either a ship, a submarine or an aircraft beyond the radar horizon of ships of the Blue force in a wave of missiles (TM) with a time lapse (TL) in seconds between each missile launched.

2. Blue Force:

(a) A ship of the Blue force is fitted with a modern surface surveillance radar, which provides initial target information on the attack. The time delay between an incoming missile crossing the radar detection range and being detected by the radar system have been assumed to be normally distributed, with a mean delay time (MM) in seconds and a standard deviation (DM) in seconds.

(b) The air defense of the ship relies on two short-range surface-to-air weapon systems. Each weapon system has an associated single-channel tracking radar. The tracking radar establishes a track after an incoming missile has been detected by the modern surface surveillance radar, assuming that the tracking radar is free to be assigned. For this model, the availability of each tracking radar is assumed to be uniformly distributed in time, with a mean delay time (MT) in seconds and a standard deviation (DT) in seconds.

(c) The ship has two close-in weapon systems (CIWS) also. Each close-in weapon system has its own radar to provide gun tracking information. When a target crosses the maximum firing range of a gun, the gun will start firing automatically to attack the target. This firing continues until the target crosses the minimum firing range of the gun.

(d) The first short-range surface-to-air weapon system (FCS #1) will automatically engage a target which enters its engagement envelope. If more than one target are present or if the first system is busy, then CIWS #1 will automatically engage the target except when CIWS #1 is busy or when the target is outside its engagement envelope.

(e) If the target is outside the engagement envelope of both CIWS, then FCS #2 will immediately engage this target except when FCS #2 is busy also.

(f) When both CIWS and FCS are busy, or two FCS are busy and the target is outside the engagement envelope of the close-in weapon systems (CIWS), the target will be put in a waiting queue until one of the systems is free or until the target crosses the maximum engagement range of one of the two CIWS.

3. **Performance Data:**

(a) The anti-ship missiles of Red force:

- Radar cross section each of the missiles = 0.1 $meter^2$
- Missile velocity = SPM meter/second

- Combined in flight reliability and hit probability for each missile is PM

(b) The short-range surface-to-air missiles of Blue force:

- Minimum launch range = RMI meters
- Maximum launch range = RMA meters
- Average missile velocity = SPA meter/second
- Reliability (at intercept) and Hit / Kill probability = PA

(c) The close-in weapon systems of Blue force:

- Minimum fire range = RMIC meters
- Maximum fire range = RMAC meters
- Kill probability = 0.2/second * total available engage time

4. Scenario Simulation

The computer program developed can be used to simulate this scenario and to determine the defense capability of a blue force ship at 40 different detection ranges. The results are plotted. The program will find the required detection range of the surface surveillance radar with a success confidence interval of 95%.

B. DISCRETE-EVENT SIMULATION

Discrete-event simulation concerns the modeling of a system as it evolves over time. The state variables will change only at a countable or discrete times. These points in time are determined by the instant an event occurs. An event is defined to be an instantaneous occurrence which may change the state of a system [Ref. 2].

Since this scenario simulates the engagement of several weapon systems which will pass via different routines and different time periods determined by a random number generator, the state variables may change randomly at a countable number of times. The discrete-event simulation model thus adequately describes the required situation.

1. Time-Advance Mechanism

Because of the dynamic nature of discrete-event simulation models, the current value of the simulated time has to be tracked as the simulation proceeds. A mechanism is also required to advance the simulated time from one value to another. In this simulation "the next-event time-advance" is used. The simulation clock is first initialized to zero. The simulation clock is then advanced to the time of the most imminent (first occurring) of the future events. At this point, the state of the system is updated to account for the fact that an event has occurred. The time of the occurrence of this event is also updated. This process of advancing the simulation clock from one event time to another is continued until eventually some prescribed stopping condition is satisfied. In the "next-event time-advance" mechanism, all state changes occur only at event times for a discrete-event simulation model. Periods of inactivity in a system are skipped over by jumping the clock from event time to event time [Ref. 2].

2. Components

Discrete-event simulation models always have a number of common components. In this simulation, the next-event time-advance mechanism is used which includes the following components.

a. Input Parameters

This scenario does not use a lot of pre-set parameters. The user will input parameters suitable for a desired situation, so parameters like SR, IR, SPM, SPA, PM, PA, ... etc.

b. System State

The collection of state variables of the systems, STATUS(1), STATUS(2), STATUS(3), and STATUS(4) stand for the states of the FCS #1 and #2, CIWS #1 and #2. STATUS(I) = 1 if the system is busy, STATUS(I) = 0 if the system is idle.

c. Simulation Clock

In this simulation, the variable TIME gives the current value of simulation time in seconds. It is updated by the next-event time-advance mechanism.

d. Statistical Counters

Variables (such as NH, NIQ, NM, NR, ..) used for storing the desired information or statistical quantities about system performance.

e. Initialization Routine

The subroutine INIT initialize the variables TIME, STATUS(I), NM, NIQ, TNE(J) at simulation time zero.

f. Timing Routine

The subroutine TIM determines the next event from the event list and then advances the simulation clock to the time when the event is to occur.

g. Event Routine

The subroutine ENG (and INIT, DEP1, DEP2, DEP3, DEP4), initialize and updates the system state when a particular type of event occurs.

h. Report Generator

The subroutine REPT, computes estimates of the desired measures of performance and prints a report after each run.

i. Main Program

The MAIN program handles all the simulations as it proceeds.

3. Organization

The logical relationships among the above components for each simulation run are shown in Fig. 1. The simulation begins at time zero when the main program calls the initialization routine. The simulation clock is set to zero. The system state and the statistical counters are initialized. The event list is also initialized. After control has been returned to the main program, it calls the timing routine to determine which event type is most imminent. If an event of type I is the next to

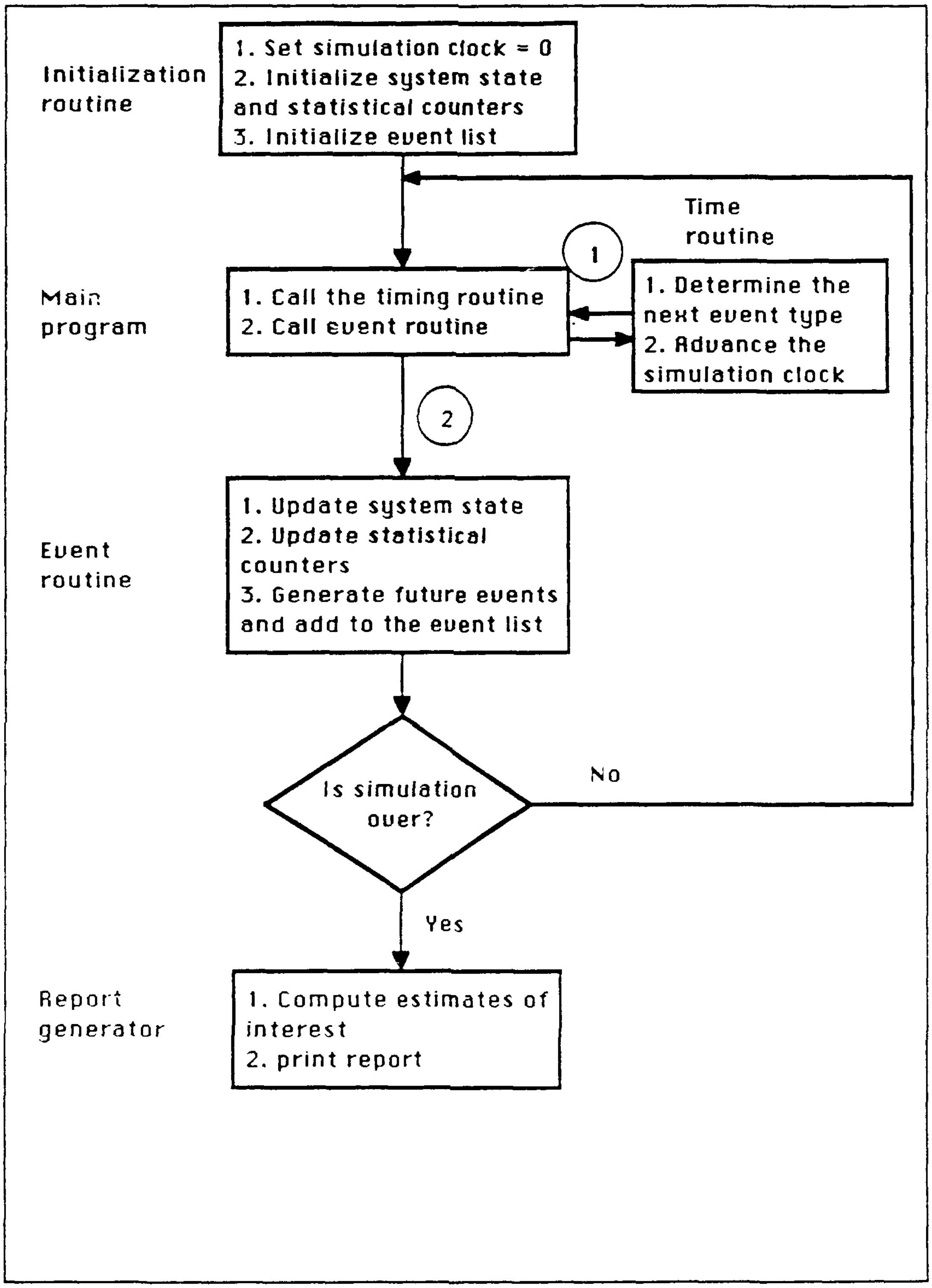


Figure 1 The relationships between the components in the simulation. After Ref. 2

occur, the simulation clock is advanced to the time of this event of type I. Then control is returned to the main program. Next the main program calls the event routine I. Three types of activities occur:

(1) update the system state to account for the fact that an event of type I has occurred.

(2) gather information about system performance by updating the statistical counters.

(3) generate the time of occurrences of future events and add these information to the event list.

After all processing of an event routine has been completed, either in the event routine or in the main program, a check is made to determine whether the simulation should be terminated. If it is time to terminate the simulation, the report generator is called from main program to compute estimates (from the statistical counters) of the desired performance measures and to print a report. If it is not time to terminate, control is passed back to the main program and the main program routine check cycle is continued until the stopping condition is eventually satisfied.

C. PROGRAM DESCRIPTION

The computer program to simulate this scenario is listed in Appendix A. In addition to the main program, there are subroutines and functions called by the main program. Table 1 shows the subroutines, functions and variables the program uses:

Name	Purpose
INIT	Initialization routine
TIM	Timing routine
ENG	Event routine which processes the engagement of the four weapon systems and the time the next missile is detected
DEP	Event routine which processes the departure time of each system
REPT	Generates report
LNORM	A normal distribution random number generator
LRND	A uniform distribution random number generator

Table 1. Subroutines, functions, and variables for the program

1. Main Program

The flowchart for the MAIN program is shown in Fig. 2. The MAIN program begins with the MODEL common block. The variables in MODEL are the ones required to be global variables. They also specify the positive seeds for the normal distribution random number generator (LNORM) and the uniform distribution random number generator (LRND). The reason for using 1103205531 as the seed for both generators is that it is not easy to repeat. The program also

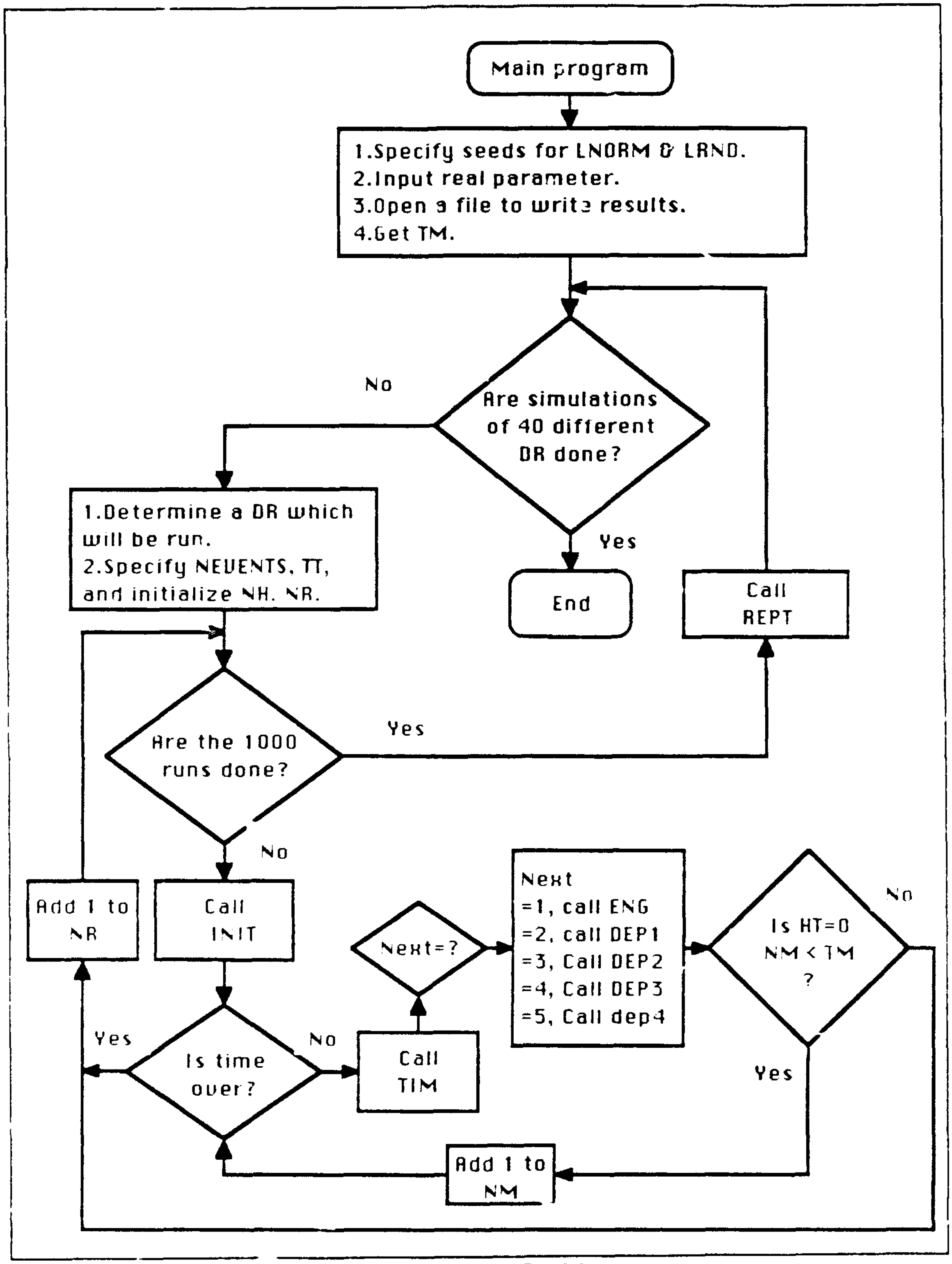


Figure 2 The flowchart of the MAIN PROGRAM

opens a file to write results.

The common declaration statement is followed by the specification of the number of runs for the simulation. In order to get an accurate simulated result, the scenario is set to run for 1000 times.

The main purpose of this program is to simulate the scenario stated above. It is run for forty different radar detection ranges. From among these forty ranges, the minimum at which the ship successfully defeats the missile attack at the 95% confidence level is considered as the operational requirement.

The scenario simulation is started by calling subroutine INIT to initialize the simulation at TIME = 0. The timing routine, subroutine TIM, is called to determine the event type, NEXT. This will determine the next event to occur and to advance the simulation clock (TIME) to the time of occurrence of the next event. Then a computed go to statement based on NEXT is used to pass control to the appropriate event routine. If NEXT = 1, the event routine ENG is called to process the engagement and determine the time when the next missile is detected. If NEXT = 2 (or 3, 4, 5), event routine DEP 1 (or 2, 3, 4) is called to process the departure of a missile after completing the engagement. This is the next-event time-advance approach. After control is returned to the main program from ENG or DEP, a check is made to see if the ship is hit by the last missile or the wave of missile attack is over. The program also checks if the total run time for a wave of attack exceed the prescribed limit. If this limit is exceeded, the wave of attack is also considered as over. If the ship is hit by the last missile or the wave of missile attack is over, INIT is called and the simulation is repeated until 1000 runs are done. The simulation of missile attack for a given radar detection range is then considered to be completed. REPT will then be called to compute and file the result, and the simulation for the next radar detection range begins. After simulated results at 40 different detection ranges are obtained, the program will be terminated.

The program as described above can be nested in one more layer of do-loop in which the total number of incoming missiles can be varied.

2. Subroutine INIT

Flowchart of this subroutine is shown in Fig. 3. The program is quite straightforward. It initialize the simulation clock, the statistical counter, the variables of states and the event list. The time the first missile is detected by the surveillance radar, TNE(1), is determined by calling a normal distribution random number generator (LNORM) with a mean delay time (MM) and a standard deviation (DM) in seconds. Since no other missile is present at TIME = 0, the time of the next event, TNE(2), TNE(3), TNE(4), and TNE(5), are set to 1.E+30. This will guarantee that the first event will be ENG.

3. Subroutine TIM

Flowchart of this subroutine is given in Fig. 4. At TIME = 0 the program sets NEXT to 1. After the first run, the program compares TNE(2), TNE(3), ... TNE(NEVENTS) and sets NEXT equal to the event type whose time of occurrence is the earliest. The simulation clock is advanced to the time of occurrence of the

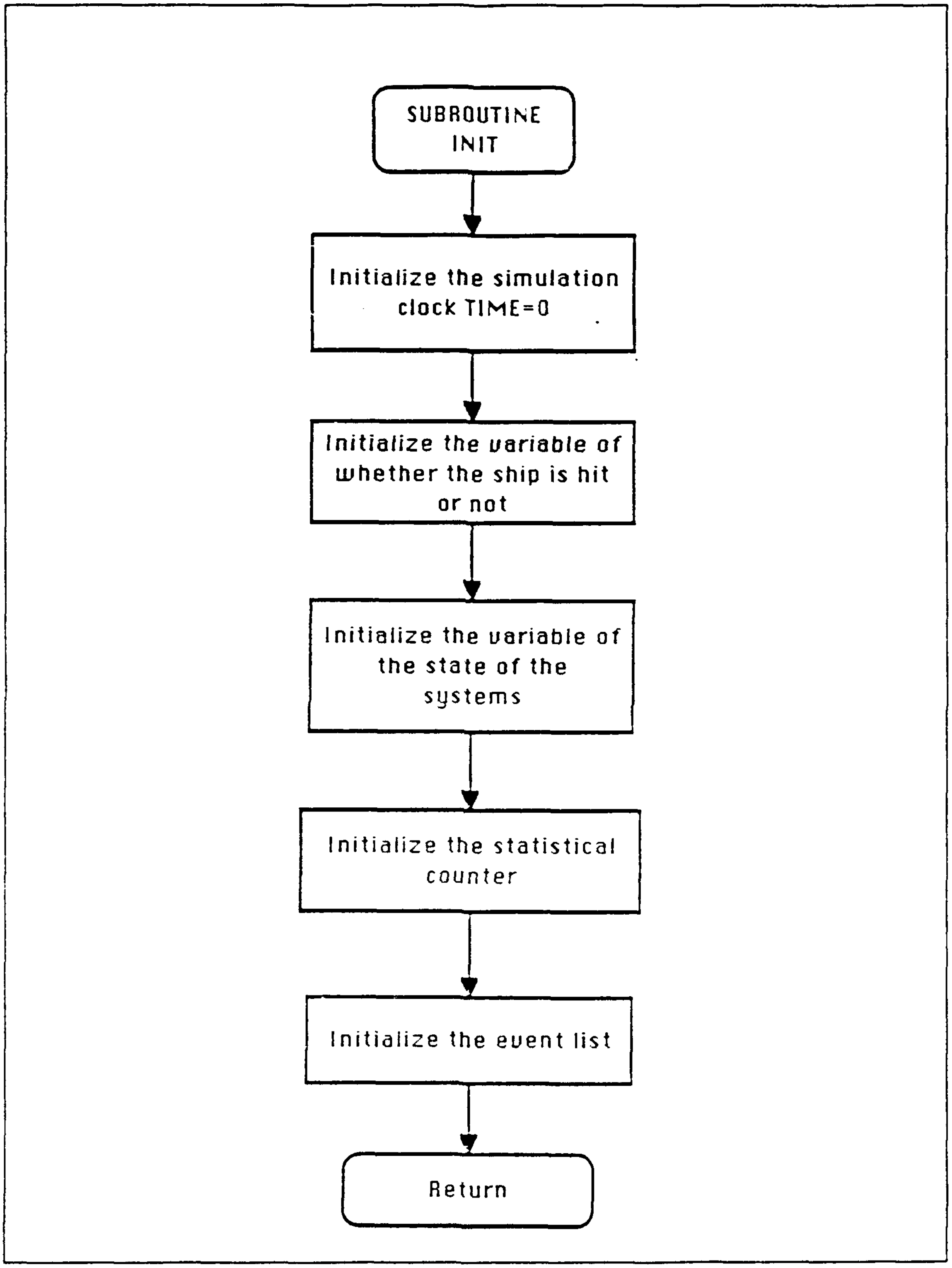


Figure 3 The flowchart of subroutine INIT

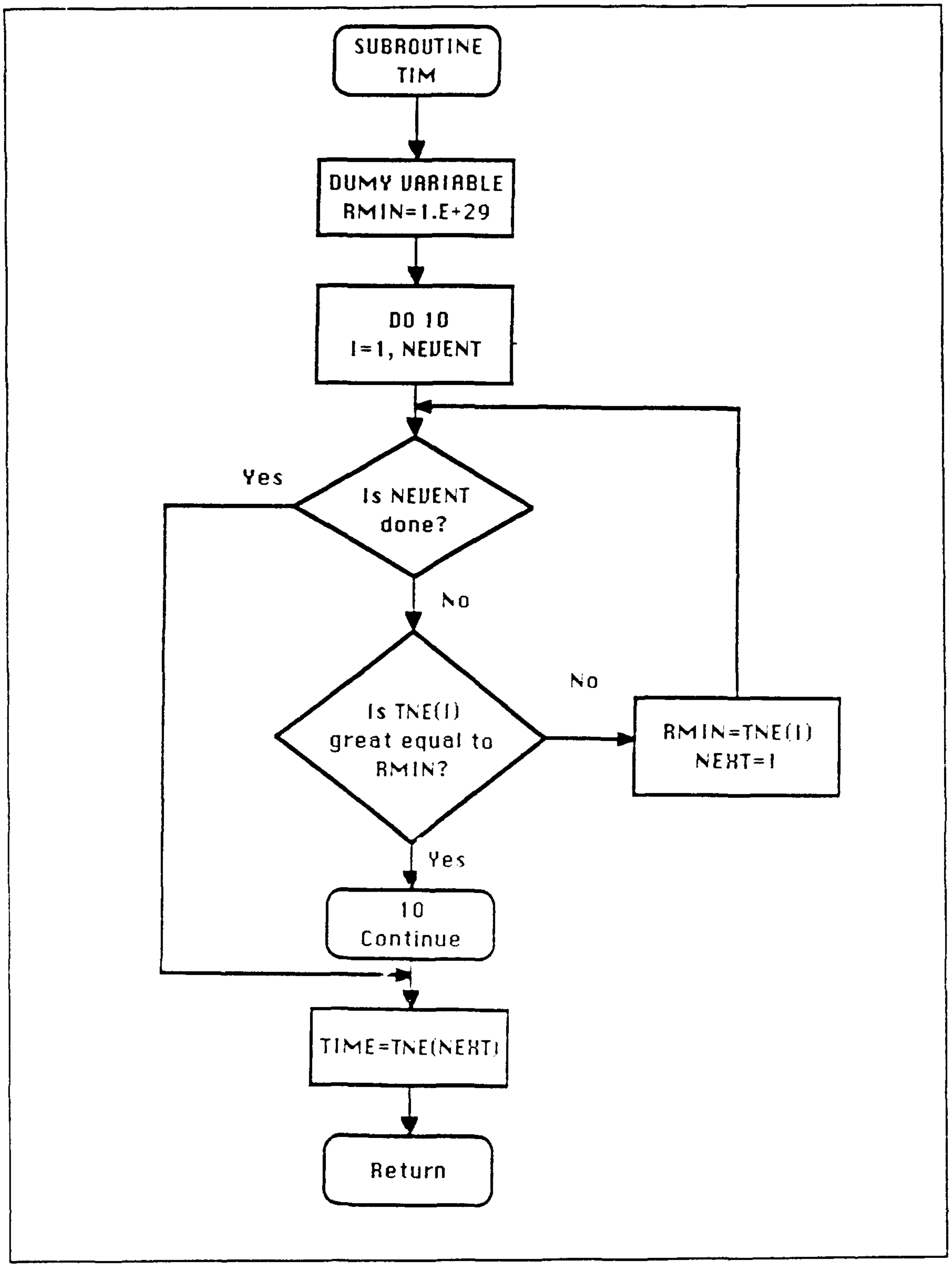


Figure 4 The flowchart of subroutine TIM

chosen event type, namely TNE(NEXT).

4. Subroutine ENG

Subroutine ENG is a major subroutine of this simulation. A flowchart of this subroutine is shown in Fig. 5. The purpose of this subroutine is to simulate the engagement scenario. The subroutine begins by scheduling the detection time of the next arriving missile. Then a check is made to determine whether FCS #1 is busy, i.e., if STATUS(1) = 1. If FCS #1 is idle, then the program uses *Routine A* to process the simulation. Fig. 6 shows the flowchart of *Routine A*. *Routine A* processes the simulation according to the following procedures:

(1) Schedules the time for FCS #1 to establish track.

(2) Calculates the distance between the missile and FCS #1.

(3) Checks whether the distance of the missile is greater than the effective range of FCS #1. If the missile is outside the range of FCS #1, the program schedules the time the missile comes inside the maximum effective range. It then updates the simulation clock and checks the missile location again. If the missile distance is shorter than the minimum effective range of FCS #1, the program calls *Routine B*. If the missile falls within the effective range of FCS #1, *Routine A* simulates the engagement of FCS #1 with this missile until the missile leaves its effective range, being destroyed, or the defense by FCS #1 is deemed unsuccessful. Therefore, changing the state of FCS #1, scheduling the engagement time, and checking whether the defense is successful are required. If it is not a successful defense, then FCS #1 engages the missile again. Otherwise, an intercept time,

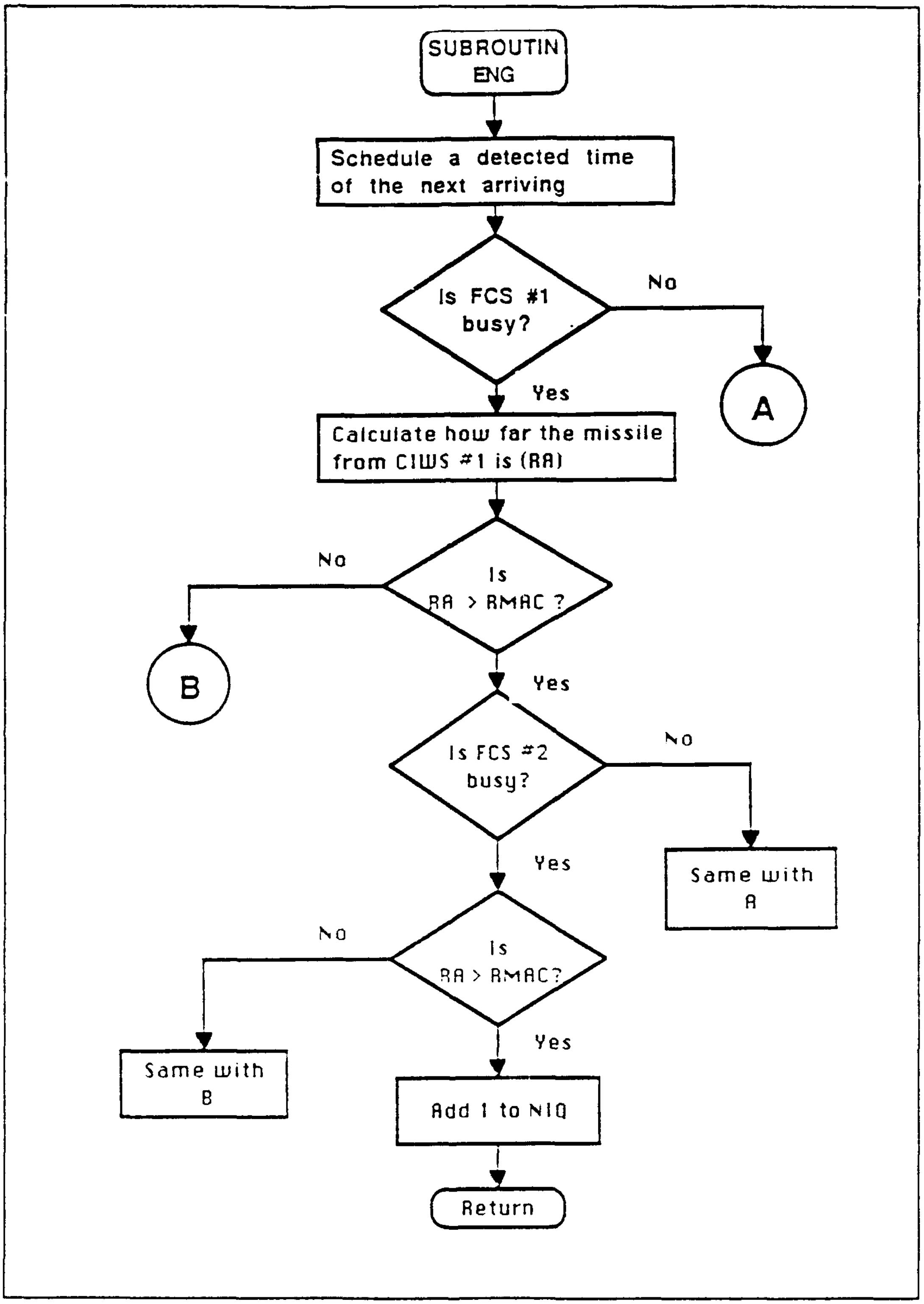


Figure 5 The flowchart of subroutine ENG

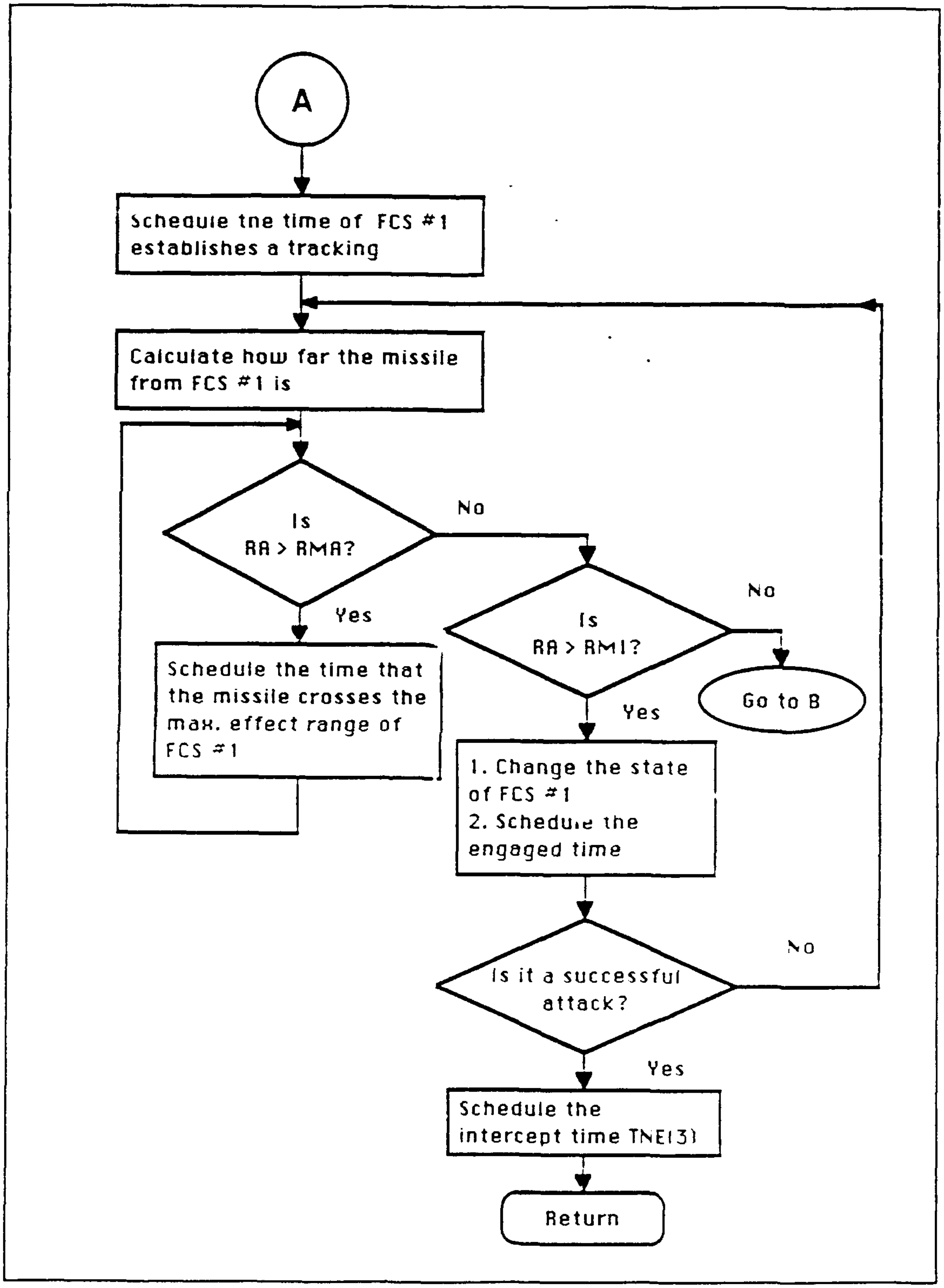


Figure 6 The flowchart of subroutine ENG - A

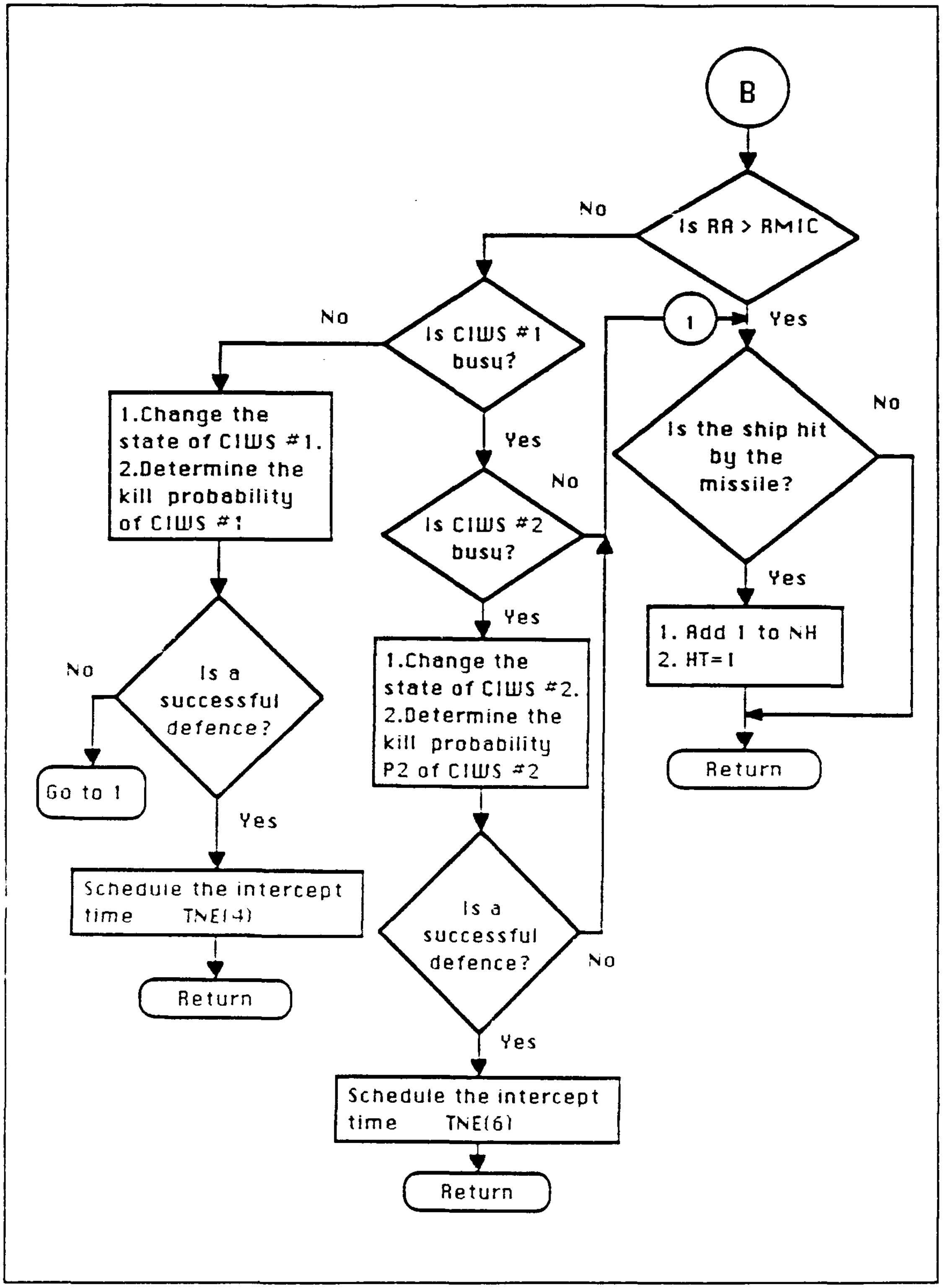


Figure 7 The flowchart of subroutine ENG - B

TNE(3) is scheduled.

On the other hand, if FCS #1 is busy, CIWS #1 will automatically engage the missile. If the missile is within the maximum effective range of CIWS #1, *Routine B* is called to simulate the engagement. Figure 7 shows the flowchart of *Routine B*. *Routine B* processes the simulation according to the following procedures:

(1) Checks whether the distance of the missile is smaller than the minimum range of CIWS #1. If the distance is smaller, it uses routine 1 to check whether the ship is hit by the missile or not. If the answer is positive, it adds 1 to the NH counter, set HT=1. Otherwise the missile is within the effective range of CIWS #1.

(2) Checks whether CIWS #1 is busy. If CIWS #1 is idle, then the program:

- changes the state of CIWS #1;
- determines the kill probability of CIWS #1;
- determines whether the defense is successful. If it is a successful defense, then schedules a intercept time, TNE(3) and return to the main program. Otherwise, since there is no time to engage again, routine 1 is used to check whether the ship is hit.

(3) If CIWS #1 is busy, the program checks whether CIWS #2 is busy. If CIWS #2 is also busy, routine 1 is employed. If it is idle, follow the procedure (2) except that the intercept time is stored in TNE(5).

When the distance between the missile and the CIWS is greater than the maximum effective range of CIWS, the program checks if FCS #2 is busy. If it is idle. the *Routine A* is followed. If it is busy, the program checks if the distance between target and the ship, RA, is greater than the maximum effective range of the CIWS.

If the RA is greater than the maximum effective range of the CIWS, 1 is added to NIQ and the control is returned to the main program. Otherwise, *Routine B* is followed.

5. Subroutine DEP

Subroutines DEP1 through DEP4 share the same flowchart, Fig. 8. Each of these subroutines corresponds to an individual weapon system, DEP1 for FCS #1, DEP2 for CIWS #1, DEP3 for FCS #2, DEP4 for CIWS #2.

These subroutines schedule the departure of the anti-ship missile after an engagement by resetting the systems to idle, and setting TNE(I+1) to 'infinity'. When the number in queue, NIQ, is greater than 1, these subroutines reduce 1 from NIQ. set TNE(I+1) to 'infinity', let TNE(1) equal to TIME (this procedure allow the next-event time-advance mechanism to select the ENG route) and make the system busy again.

D. RESULTS OF SIMULATION

There are several parameters which can be varied in the simulation program: the characteristics of the incoming anti-ship missiles, the capability of the AAW

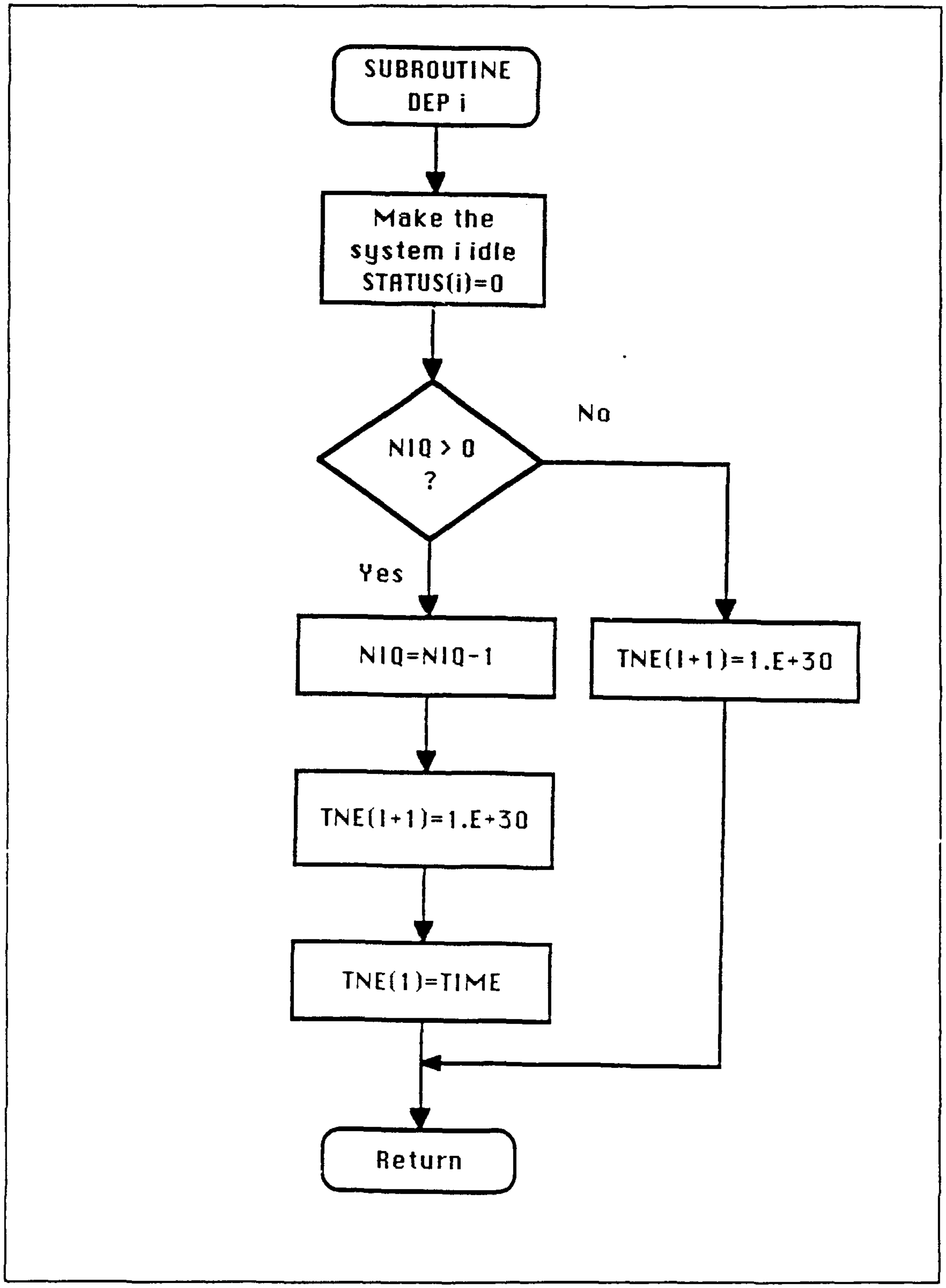


Figure 8 The flowchart of subroutine DEP

missiles and CIWS of the defending ship, the time delay in detection after an anti-ship missile comes within detection range of the search radar and the time delay for the tracking radar to acquire the target after the target information is handed over from the search radar. In what follows, radar detection range requirements as determined from simulations using two different sets of parameters are presented.

1. Situation 1:

The situation is set as the following:

Red Force:

Anti-ship missile:

speed: 500 meters/second

kill probability (include reliability): 0.72

time laps between each missile launched: 5.0 seconds

Blue Force:

Short range surface-to-air missile:

speed: 1000 meters/second

kill probability: 0.81

effective range: 2000 to 10000 meters

Close-in weapon system:

effective range: 200 to 2000 meters

Surveillance radar delay time in detection: (gaussian distribution)

mean: 10.0 seconds

deviation: 2.0 seconds

Tracking radar acquisition time: (gaussian distribution)

mean: 2.0 seconds

deviation: 1.0 second

The kill probabilities, effective ranges and speeds of the attacking and defending missiles under this situation are close to the capabilities of existing ones. The delay times of both the surveillance radar and the tracking radar are on the long side. This situation can be considered as a test of the capability of radars currently in service.

The percentage of successful defense as a function of the detection range of the surveillance radar is given in Fig. 9. The total number of anti-ship missiles is varied from 4 to 10. It can be seen from this figure that the 95% successful defense against the missiles requires a radar detection range of about 11000 meters. It appears that the total number of attacking missiles does not strongly influence the percentage of successful defense when the radar detection range is large. It is conjectured that, if the radar detection range is far enough, the weapons systems of the defending ship engages a fixed number of the attacking missiles in an almost periodic manner, hence the probability of successful defense is independent of the number of incoming missiles. On the other hand, to achieve a fixed percentage of successful defense, the difference between two required radar ranges for two different numbers of incoming missiles appears to be fluctuating about a constant. These interesting phenomena warrants further study.

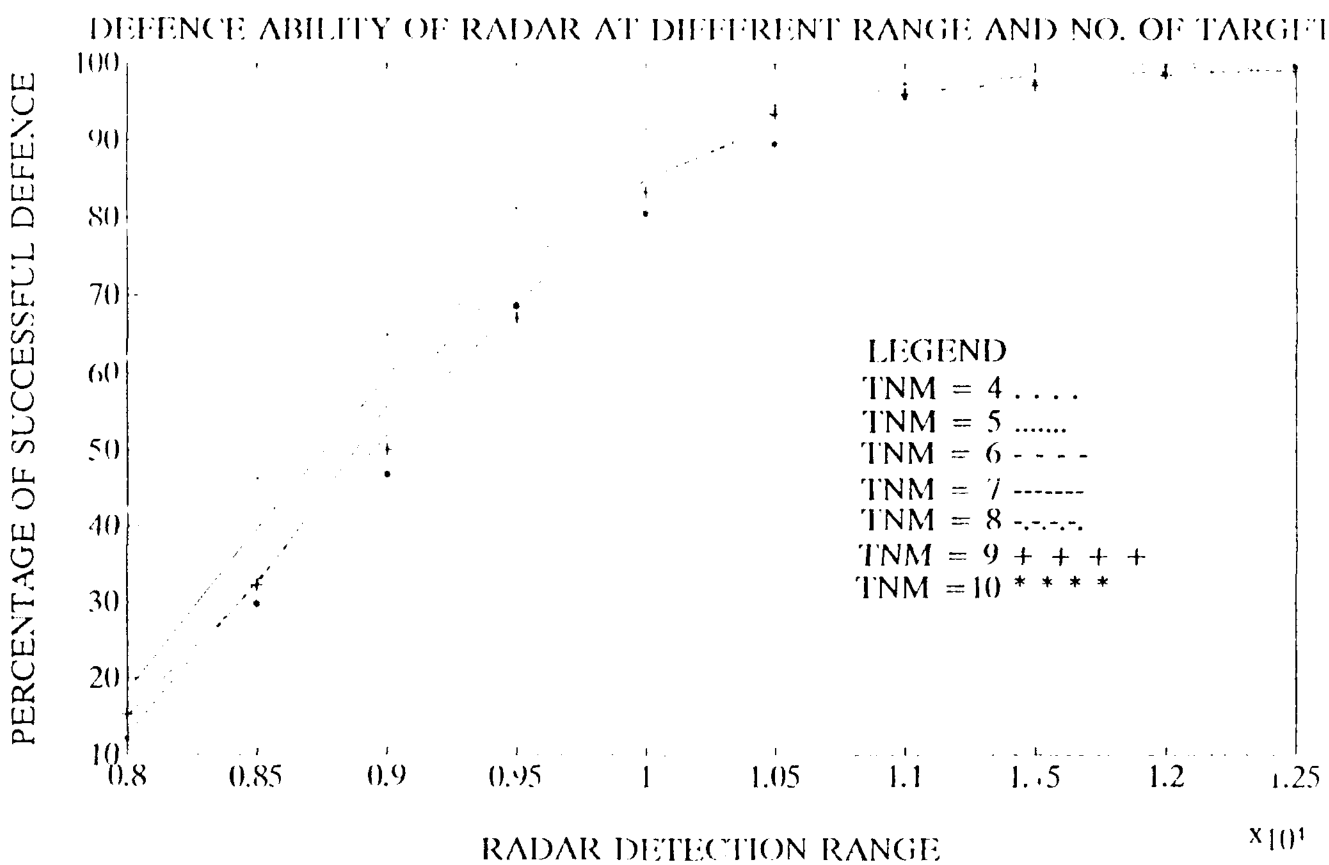


Figure 9 Defence ability of the situation 1

2. **Situation 2:**

This situation is set as the following:

Red Force:

Anti-ship missile:

speed: 700 meters/second

kill probability (include reliability): 0.95

time laps between each missile launched: 3.0 seconds

Blue Force:

Short range surface-to-air missile:

speed: 1000 meters/second

kill probability: 0.9

effective range: 2000 to 15000 meters

Close-in weapon system:

effective range: 200 to 2000 meters

Surveillance radar delay time in detection: (gaussian distribution)

mean: 6.0 seconds

deviation: 2.0 seconds

Tracking radar acquisition time: (gaussian distribution)

mean: 1.0 seconds

deviation: 0.5 second

In anticipation of the presence of faster and better missiles in the future, the speed of the attacking missiles is increased to 700 meters per second

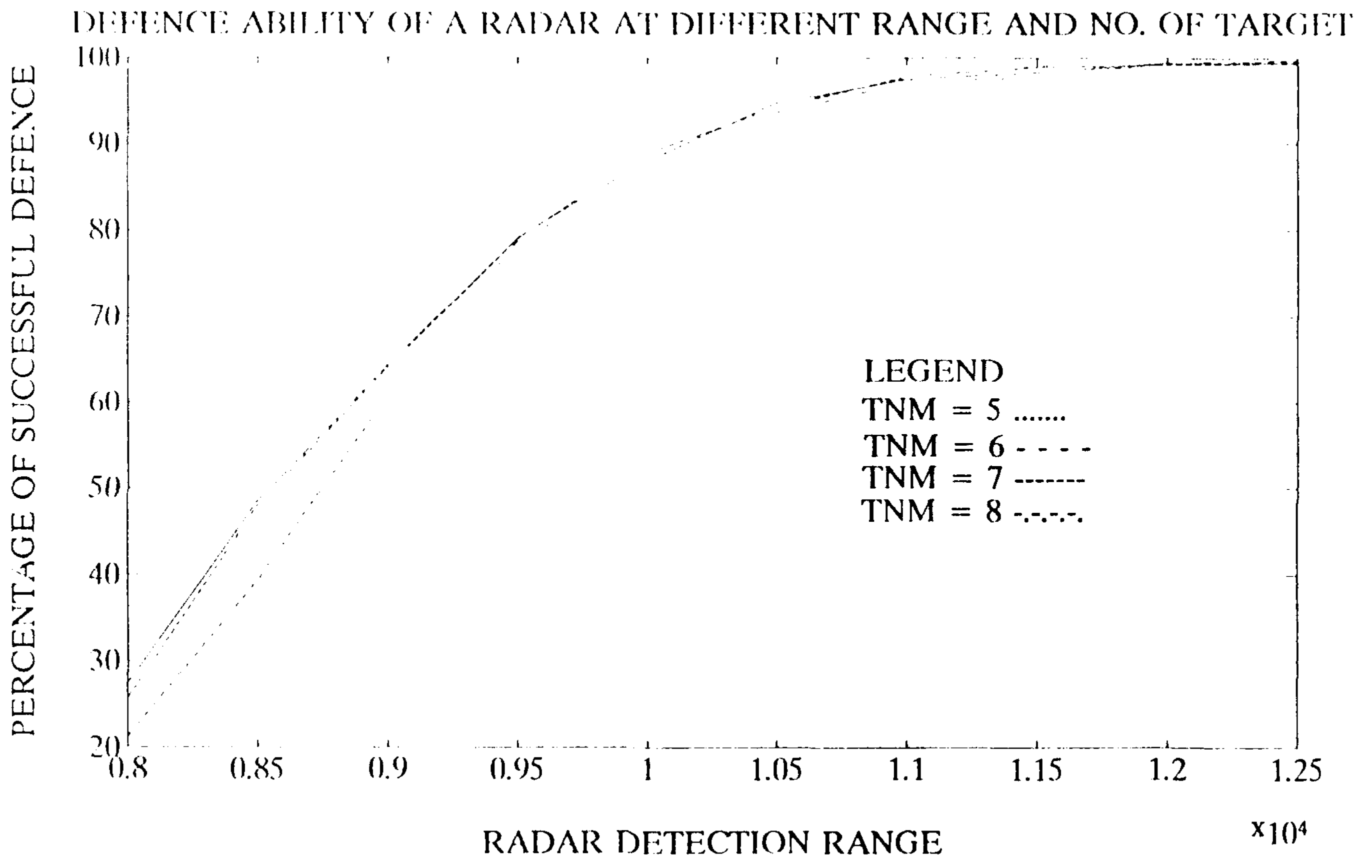


Figure 10 Defence ability of the situation 2

(approximate Mach 2), with the probability of kill improved to 0.95 to simulate a more realistic threat. The anti-air missiles have the same speed of 1000 meters per second (approximate Mach 3) with an increased range of 15000 meters and an improved probability of kill of 0.9. (Note that the probability of kill usually depends upon the height, range and speed of the target which can be incorporated into the simulation program. It is treated as a constant in this thesis for simplicity.) Assume that this situation represents the expected environment, the result of the simulation will provide the desired operational requirement of the new surveillance radar.

Figure 10 shows the percentage of successful defense as a function of the detection range of the surveillance radar. The total number of anti-ship missiles is varied from 5 to 8. The criterium of 95% successful defense against the incoming missiles is met if the radar detection range is about 10500 meters. This detection range of 10500 meters will be used as the operational requirement for the new surveillance radar in the next chapter.

III. SPECIFY DIFFICULT TO TEST PERFORMANCE REQUIREMENTS

Every military system acquisition program must accurately specify its system performance requirements. These requirements must be tested and evaluated. A performance specification which cannot be tested will create problems. The added cost to meet such a specification will only be wasted. When an operational requirement is based on an anticipated but unavailable threat, it is quite probable that the corresponding performance specification cannot be tested directly due to the lack in the actual targets or models. An alternative, easy to test performance specification should be used to replace the actual one.

Assume that situation 2 of Chapter II is the scenario under which a new surveillance radar is expected to function. Assume that the missile used in that threat scenario is not expected to be available to the navy at the time when the radar is to be tested. An alternative target, may be an airplane or an RPV of a different radar cross section but of a similar speed, flown at a safer height, will be used as the substitute for planning the test and evaluation of the detection range of the radar. In this chapter, the way an alternative target can be used for the specification and testing of radar range performance will be demonstrated.

A. RADAR RANGE EQUATION

The radar range equation relates the detection range of a radar to the characteristics of its antenna, transmitter, receiver, and its anticipated target. Not only is it useful for determining the maximum distance from the radar to the target at which detection can be made but it also serves as a basis for radar design and as a tool for understanding radar operations.

The new radar under consideration is assumed to be a monostatic pulse radar. Its receiving antenna, if not also used for transmission on a time-sharing basis, is located near its transmitting antenna so that the distances from the antennas to the target are essentially the same. It transmits pulses of durations very short compared to the pulse repetition time, with a peak power P_t. Hence only the radar equation for a monostatic pulse radar will be considered.

1. Simple Form

The simple form of the radar range equation is as the following:

$$R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4}$$

This is the fundamental form of the radar range equation. The maximum radar range, R_{max}, is the distance within which a target of the specified radar cross section, σ, can be detected for a specified probability of detection, P_d, and a specified probability of false alarm, P_{fa}. The radar fails to detect the target when the target echo signal power obtained by the receiving antenna falls below the minimum detectable signal, S_{min}. The transmitting gain, G_t, and the receiving gain, G_r, are assumed to be the same, G. Note that the radar cross section is the ratio of the estimated total radiated power of the target, computed by assuming that the target radiates evenly in all directions as it does in the direction toward the receiving antenna, to the total power intercepted by the target [Ref 3]. Also note that, to apply the concept of radar cross section, the target must be in the far field of the radar antennas, and vice versa. For an unambiguous definition of the radar cross section, a single pulse must extend over the whole target.

This simple form of the radar range equation does not consider the propagation environment of the radar. Therefore it does not adequately describe the performance of a radar. To improve the radar range equation so that its predictions will correlate better with the actual performance of a radar, the pattern-propagation factor [Ref. 4], or simply the propagation factor, *F*, has to be introduced.

2. Pattern-Propagation Factor

Including the propagation factor, the radar range equation is [Ref 4]:

$$R = \left[\frac{P_t \, G_t \, G_r \, \sigma \, \lambda^2 \, F_t^2 \, F_r^2}{(4\pi)^3 \, P_r \, L} \right]^{1/4}$$

Where

P_t = transmitted peak power (at antenna terminals)

P_r = received power (at antenna terminals)

G_t = transmitting antenna power gain

G_r = receiving antenna power gain

σ = radar target cross section

λ = radar wavelength

F_t = transmitting antenna to target pattern-propagation factor

F_r = target to receiving antenna pattern-propagation factor

L = system loss factor

R = radar to target distance

It is assumed that $G_t = G_r = G$. For a monostatic radar, this assumption leads to the conclusion that $F_t = F_r = F$. The factor F is defined as the ratio of the actual electric field strength E at the target location, to that which would exist at the same distance from the radar in free space and in the antenna beam maximum-gain direction, E_0. Symbolically this is

$$F = \frac{|E|}{|E_0|}$$

The propagation factor is a desirable quantity. It accounts for the possibility that the target is not located in the beam maximum and for any path related propagation gain or loss that would not occur in free space. The most common of such effects are atmospheric absorption, earth diffraction and shadowing, various types of refraction effects, and multipath interference. To compute the propagation factor, the program EREPS will be utilized [Ref. 5].

B. EREPS OVERVIEW

The Engineer's Refractive Effects Prediction System, or EREPS, is a set of stand-alone IBM/PC-compatible programs which are designed to assist an engineer in properly assessing electromagnetic (EM) propagation effects of the lower atmosphere on proposed radar, electronic warfare, or communication systems. The EREPS models account for effects of optical interference, diffraction, tropospheric scattering, refraction, evaporation and surface-based ducting, and water-vapor absorption under horizontally stratified atmospheric conditions.

EREPS revision 2.0 consists of five executable programs and a program source code listing in BASIC [Ref. 5]:

1. PROPR

PROPR generates a graphic display of propagation-loss, propagation-factor, or radar signal-to-noise ratio versus range under a variety of environmental conditions from which signal levels relative to a specified threshold or maximum free-space range can be determined.

2. PROPH

PROPH provides a graphic display similar to that given by PROPR except the signal strength or the propagation factor, etc., is plotted against the target height instead of the target range.

3. COVER

COVER provides a height-versus-range graphic display showing the area where signal level meets or exceeds a specified threshold.

4. RAYS

RAYS displays the altitude-versus-range trajectories of a series of rays for the specified refractive-index profile.

5. SDS

SDS displays an annual climatological summary of the evaporation duct height and the surface-based duct height over each Marsden square on the earth's surface. SDS may be used as a source of environmental data for the programs PROPR, PROPH, and COVER.

6. FFACTR

FFACTR is not an executable program but rather a program source code. It may be compiled external to the EREPS system to produce a stand-alone program or may be incorporated into a user program as a subroutine. FFACTR is structured as a subroutine that returns the one-way propagation factor in dB for specified environmental and EM system parameters.

C. TARGET DESCRIPTION

When an anticipated threat missile is not available or not desirable to be used for testing the performance requirements of a radar, a substitute target has to be employed. The test and evaluation plans should be developed using an available test target. The pertinent performance requirements of the radar should also be specified in terms of the test target according to the test plan. Nothing about the threat missile need to be mentioned. In what follows, the characteristics of the anticipated threat missile and the available test target are described.

1. Threat Missile

The missiles considered in the threat scenario used for establishing the operational requirements of the surveillance radar is a sophisticated air-, surface- and subsurface-launched anti-ship, RF-guided missile that incorporates a digital processor for progaming the missile functions. It can be launched from a platform far beyond the horizon of the new surveillance radar. Its trajectory is essentially platform independent during the midcourse and the terminal phases.

a. Threat Missile Trajectory

The midcourse and terminal trajectory of the anti-ship missile is shown in Fig. 11. For example, the missile can be dropped by an aircraft at an altitude of about a thousand meters at a distance about 80 km from the ship. It then descends to an altitude of about 30 meters in the first 20 km and cruises at that altitude at 700 m/sec (about Mach 2). At about 4 km from the ship, the missile descends further to an altitude of 10 meters and flies straight to the ship.

b. Threat Missile Characteristics

The relevant characteristics of the anti-ship missile are as the following:

radar cross section (head-on): 0.1 m^2

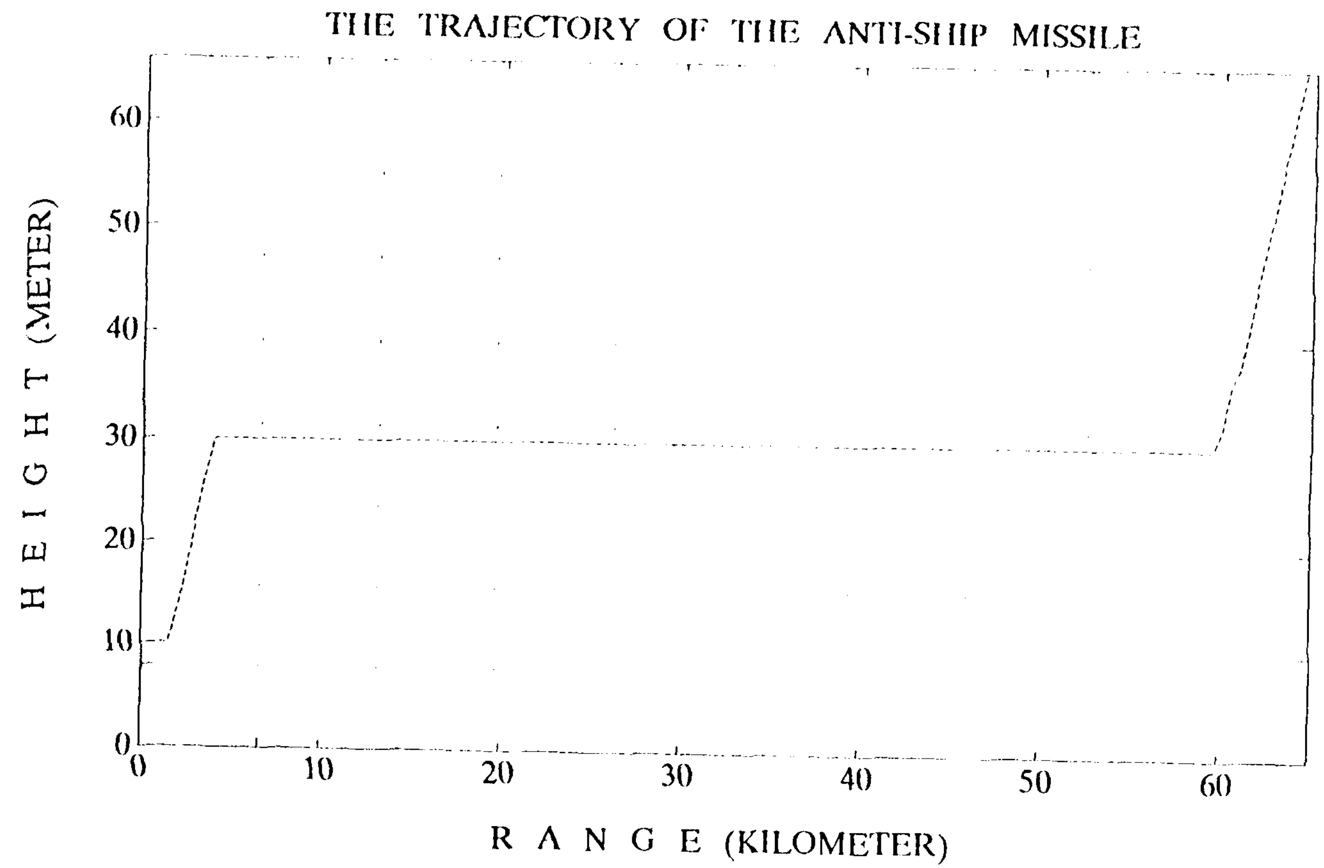


Figure 11 The trajectory of the anti-ship missile

speed: 700 m/sec (about Mach 2)

range: greater than 80 km (32.4 nmi)

probability of kill: 0.95

2. **Test Target**

A fighter jet can be made available for the test and evaluation of the range performance of the new radar. The speed of the plane should be the same as that of the threat missile so that there will be no question about the integration gain due to doppler or moving target indicator (MTI) processing of the radar. Since a fighter has a radar cross section of about 10 square meters, the radar should be able to detect it at a greater range than that required to detect the threat missile. For safety, the airplane is to be flown at no lower than 100 meters above sea level, preferable in the 1000 to 3000 meters range. These are factors to be considered when a test and evaluation plan is designed and when the range performance of the radar is to be specified.

The clutter environments are different at different ranges and at different heights. Great care has to be exercised in specifying the clutter suppression capability of the radar. At the range and height where the anticipated threat missile need to be detected, the radar should be required to reduce the clutter to the system thermal noise level or below. Then the detection probabilities of the radar for both the threat missile and the test plane is clutter independent. Note that due to the presence of the sea spikes, the false alarm rate is higher for the detection of the threat missile. But the false alarm rate is a separate measurement which requires no involvement of a test target. The characteristics of the test target is given below:

radar cross section (head-on): 10 m^2

cruise speed: at least 700 m/sec at the required altitude

D. RADAR PERFORMANCE SPECIFICATION

According to Scenario 2 of Chapter II, the radar is required to detect, at a range of 10500 meters, a target of 0.1 m^2 radar cross section flying at a height of 30 m and a speed of 700 m/sec. Since a target of 10 m^2 radar cross section flying at no lower than 100 meters will be used for test and evaluation, the radar range requirement should be specified in terms of the detection of a 10 m^2 test target at a height of 100 meters. This specified range for the radar to detect the test target should be chosen so that the detection of the smaller, lower flying threat missile at 10500 meters can be guaranteed. (Note that a different height can be used. The choice here of 100 meters for the altitude of the test target is completely arbitrary.)

To guaranteed the successful detection of the threat missile, the propagation environment of the transmitted radar pulses has to be taken into account. In what follows, EREPS will be utilized to compute the radar received echo power as the cross section, height and range of a target is varied.

1. Sample Radar Parameters

It is meaningful, and may even be preferred, to specifying the delay time in detection of a search radar as one of its performance parameters, because the delay time is used directly in simulating the threat scenarios in Chapter II. On the other hand, a surveillance radar is customarily characterized in terms of its probability of detection and false alarm rate. In deed, the delay time in radar detection can be deduced from the probability of detection and other physical parameters of the radar, as the false alarm probability can usually be made so small that it seldom affects the detection capability of a radar. For example, consider a typical radar scanning at the rate of 15 rotations per minute (rpm), or 4 seconds per scan. Since a target may appear in a completely arbitrary direction, the mean delay time for detecting the target right after it enters the detection range is 2 seconds. If the protocol requires a confirmation during the second visit of the radar, the mean delay time for detection of the radar is 6 seconds. To actually achieve this 6-second mean delay time at the 15 rpm scan rate, this radar must have an almost certain probability of detection for each visit. Hence if a vendor proposes a 15 rpm scan rate, the radar must be designed to have a probability of detection of at least 90%. Thus it may be desirable to leave the particular choice of the probability of detection and other mix of technical features to the radar supplier, so long as the vender claimed probability of detection and the delay time in radar detection can be tested and verified.

Parameters of a typical radar which can achieve a 6-second mean delay time in radar detection is given in Table II. These parameters are used to establish the detection threshold of the radar and are used as input to EREPS. To establish

Table II Radar Parameters

Antenna

Feed: rectangular horn

Capability: Transm' /receive both radar and IFF energy

Operation Temperature: -70C (94F) to +70C (158C)

Wind: Operating - 80 knots, Survival - 100 knots

Antenna Gain: 23 dBi

Polarization: Vertical

Transmit Power Rating: 20 kw peak (minimum)

Rotating Rate: 15 .pm

Radar Characteristics:

a. Operating Frequency: 1200 to 1300 MHZ

b. Horizontal Beamwidth (3 dB): 5.7 degrees (nominal)

c. Vertical Beamwidth (3dB): 16 degrees (minimum)

Transmitter

Power Output:

a. Peak: 12 kw minimum,b. Average: 260 w

Duty Cycle:

a. Low prf - 0.01527 b. high prf- 0.02081

Prf: on scan-to-scan basis between 2500 pps and 3500pps

Pulse Length: 6.5 microseconds

Receiver-Processor

IF Bandwidth (3dB): 130 KHZ

Velocity Coverage:

Two Scan: 80 to 2000 knots

One Scan: 80% of two scan coverage

Range Cell: 4.4 microseconds over 25 nmi

minimum Range: 1 nmi

Noise Figure: 5.5 dB maximum

Clutter Cancellation Ratio: 57 dB minimum

Sub Clutter Visibility: 54 dB minimum

Minimum Discernible Signal: -110 dBm (maximum)

False Alarm Rate: One false alarm per 21 hours (maximum) the deviation and the probability distribution of the delay time, a more detailed study is required which is beyond the scope of this thesis.

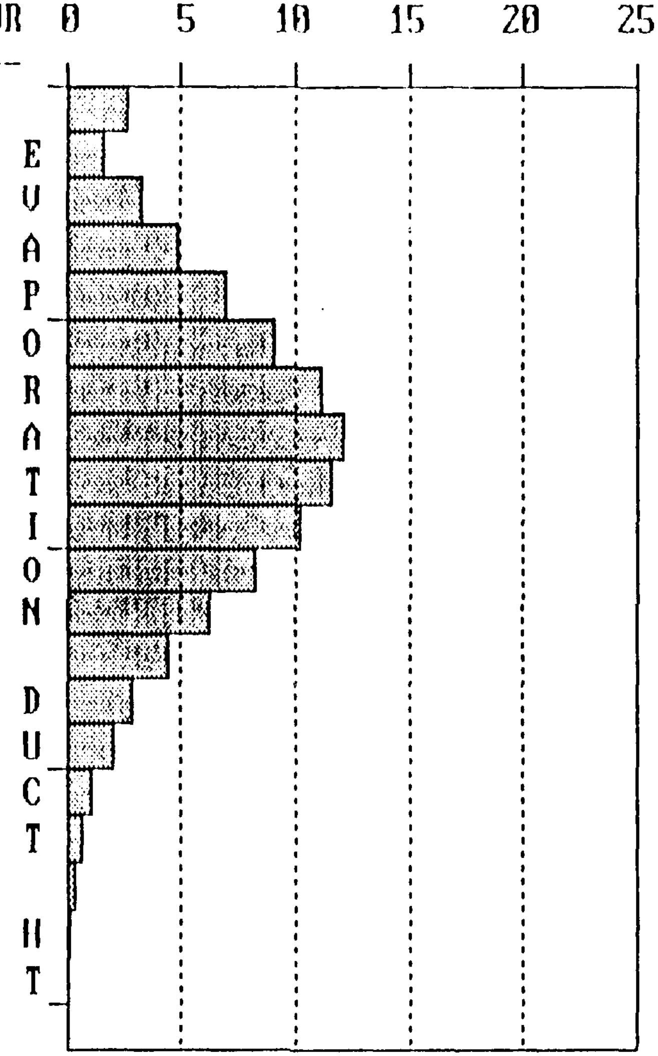
The detection threshold can be expressed in terms of the detector threshold voltage, the minimum required signal, the propagation loss threshold, or the propagation factor threshold. In this thesis the propagation factor threshold is adopted because it turns out to be the most convenient. Note that the particular threshold value is irrelevant: if two different targets at two different locations provide a radar with equal amount of power, they should still return equal amount of power if the radar is replaced with a different radar of the same frequency. For any radar, the necessary amount of power arriving at the receiver required for detection by this radar is fixed. Thus if this radar can detect one of the two targets, it should be able to detect the other.

The operating frequency listed in Table II requires special attention. The ratio between the propagation factors at two locations changes when the frequency is changed. The radar detection range has to be specified as a quantity dependent on the operating frequency. For this thesis, the operating frequency of 1200 to 1300 MHz is used.

2. Environmental Condition

EREPS accepts refractive index profile for its computation. If the profile is measured locally, timely assessment of propagation effects on a radar system or a communication link can be performed. On the other hand, worldwide annual averages of climatological conditions are available from the SDS program. Figure 12

EVD HT	% OCCUR
0 TO 2 m	2.7
2 TO 4 m	1.6
4 TO 6 m	3.3
6 TO 8 m	4.9
8 TO 10 m	7.0
10 TO 12 m	9.1
12 TO 14 m	11.2
14 TO 16 m	12.1
16 TO 18 m	11.6
18 TO 20 m	10.2
20 TO 22 m	8.2
22 TO 24 m	6.2
24 TO 26 m	4.4
26 TO 28 m	2.9
28 TO 30 m	2.0
30 TO 32 m	1.1
32 TO 34 m	0.7
34 TO 36 m	0.4
36 TO 38 m	0.2
38 TO 40 m	0.1
> 40 m	0.1



ANNUAL
SURFACE DUCT SUMMARY

SURFACE OBS: MS 96

LATITUDE: 20 TO 30 N
LONGITUDE: 120 TO 130 E
AVG EVD HT: 15.9 m
AVG WIND SP: 15.4 KTS
SAMPLE SIZE: 161840 OBS

UPPER AIR OBS: RS 46747

TUNG KONG, CHINA (TAIWAN)

LATITUDE: 22.47 N
LONGITUDE: 120.43 E
SBD OCCURRENCE: 9.0 %
AVG SBD HT: 125 m
AVG NSUBS: 380
AVG K: 1.64
SAMPLE SIZE: 1965

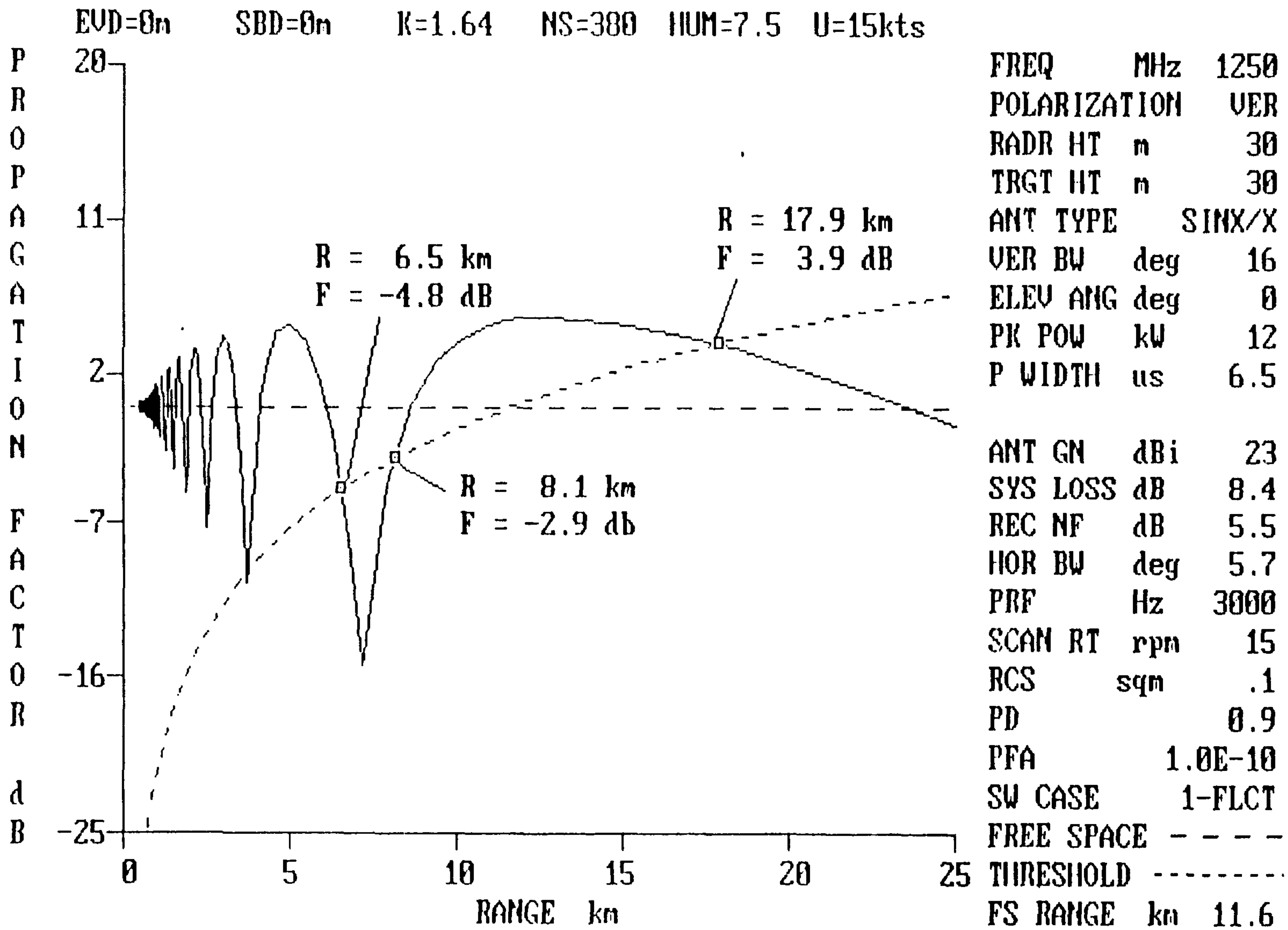
Figure 12 The annual averages of climatological conditions of TUNG KONG displays the data from a permanent oceanographic observation station located at TUNG KONG, CHINA (TAIWAN) (Latitude : 22.47 N, Longitude : 120.43 E) as found in SDS at Marsden squares 96. This set of data is used as the environmental parameters for this thesis.

3. Range Specification

Given the radar listed in Table II and the desired probability of detection against a target of a particular radar cross section, EREPS can compute the detection threshold over different ranges in terms of the minimum required power at the receiving antenna. This detection threshold, presented as the required propagation factor at each range cell for the detection of the target in that cell, overlaid on the computed propagation factor between the radar and the target flying at some specified height, shows at a glance the regions in which the target can be detected.

The propagation factor for the threat missile is given in Fig. 13. It shows that the radar first detects the missile at a range of 17.9 km. At 8.1 km, the missile disappears from the screen and is re-acquired at 6.5 km. Note that the one-way propagation factor is displayed. For radar applications, the round-trip dB value should be twice as large.

The test target, having a cross section of 10 m^2 and to fly at a height of 100 m, can be detected by the same radar at a distance of 43.3 km as can be seen from Fig. 14. Hence the detection range of the new radar should be specified as 43.3 km against a 10 m^2 target flying at 700 km/sec at a height of 100 m. The test and evaluation plan should be designed according to this specification.



Figu.'e 13 The propagation factor for the threat missile

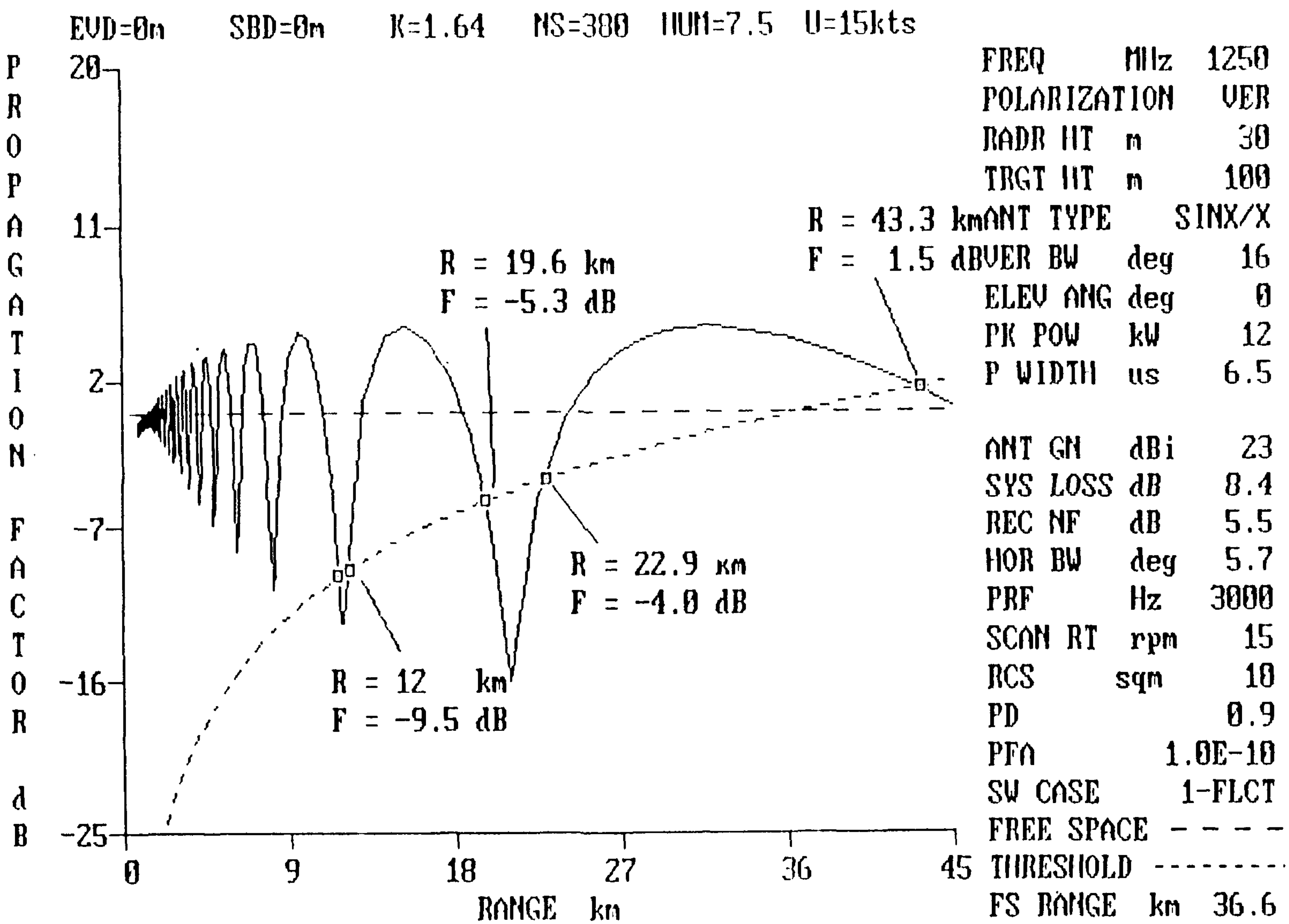


Figure 14 The propagation factor of the test target

4. Further Considerations

It is obvious that, as the propagation environment changes, the propagation factor changes. For example, Fig. 15 shows an increase in detection range when there is a 40 m evaporation duct and a 10 knot wind. The radar detection range should not be determined based only on one set of propagation condition. The information about all possible propagation environments under which the radar will be operating should be reviewed. A reasonable value for the range specification, not necessarily corresponding to the most stressful condition, can then be specified.

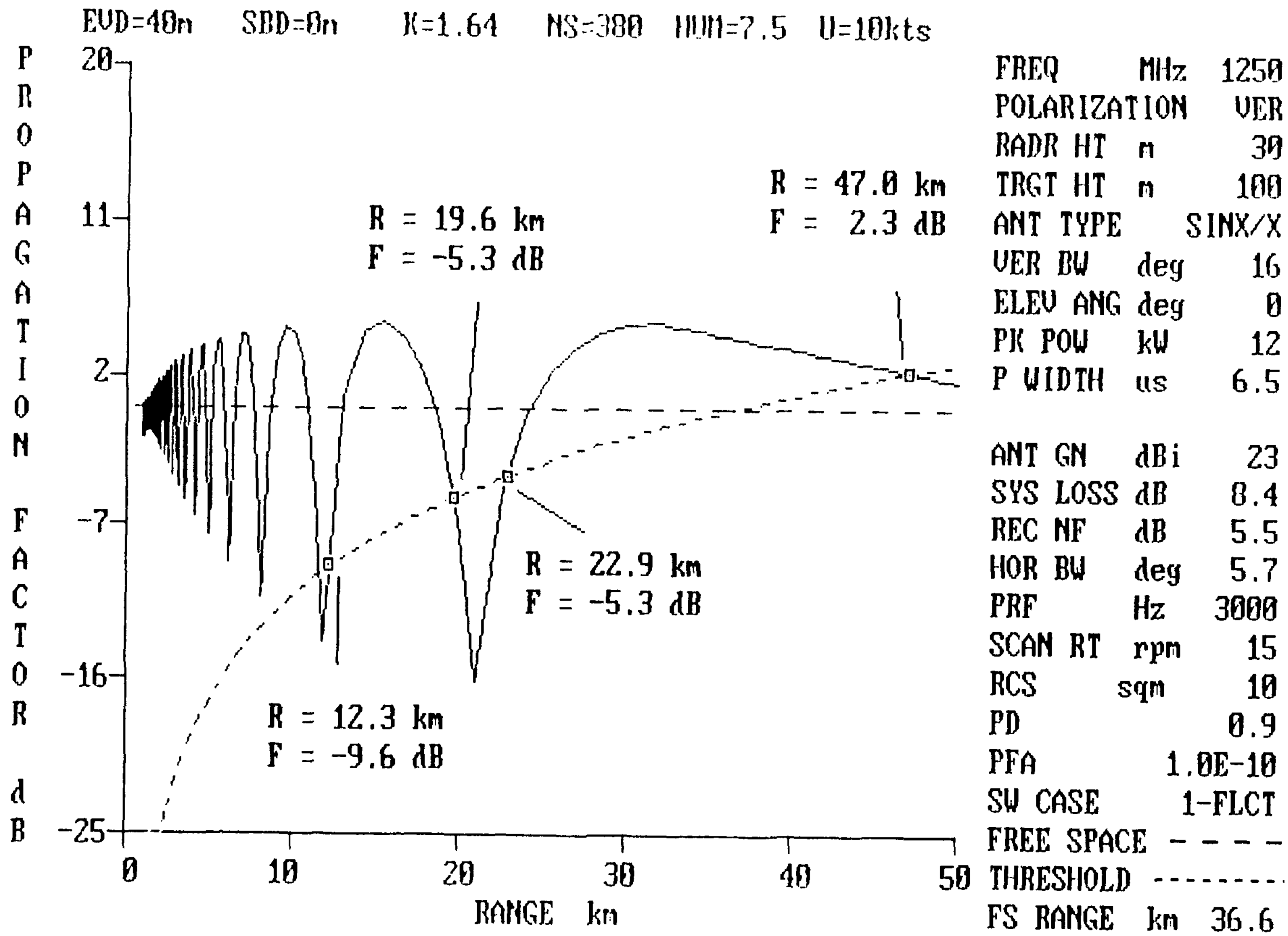


Figure 15 The propagation factor in an evaporation ducting condition

IV CONCLUSION

In this thesis, the problem of specifying system performance requirements which cannot be tested directly is considered. For the acquisition of a radar system to meet an anticipated missile threat, the Discrete-Event Simulation Model using the next-event time-advance mechanism is utilized to generate the detection range requirement of the surveillance radar.

Defending a ship against the anticipated threat is one performance requirement that has to be tested. The missile of the threat scenario is not available for the test and evaluation of the performance of the radar. Through the use of EREPS, the concept of converting the impossible-to-test specification into one which can be easily tested is demonstrated.

The effect of propagation environment on search radar performance is also demonstrated. If the radar has to perform under very different propagation conditions, the performance of the radar under all these conditions should be considered before the detection range requirement can be determined. On the other hand, once the radar is deployed, test of the radar performance against a readily available target can be carried out regularly. EREPS can then be used to infer from the test result the detection range of the radar against a target at a different height.

APPENDIX A: Computer Program To Simulate Anti-Ship Defense

```
*****************************************************************
*
* TITLE    : ANTI-SHIP MISSILE Defense SIMULATION
* DATE     : 25 AUGUST 1990
* AUTHOR   : YU CHEN-KUO
* SYSTEM   : IBM 370
* COMPILER : WATFOR-77
* DESCRIPTION :
*         THE PROGRAM WAS DESIGNED TO SIMULATE AN ANTI-SHIP MISSILE
*         Defense OPERATION.  THE SCENARIO IS SET AS THE FOLLOWING:
*         1.  RED FORCE:
*           ANTI-SHIP MISSILES OF RED FORCE ARE LAUNCHED FROM EITHER
*           A SHIP, A SUBMARINE OR AN AIRCRAFT BEYOND THE RADAR
*           HORIZON OF A BLUE FORCE SHIP IN A WAVE OF MISSILES (TM)
*           WITH A TIME LAPSE (TL) IN SECONDS BETWEEN EACH MISSILE
*           LAUNCHED.
*         2.  BLUE FORCE:
*          (1) A BLUE FORCE SHIP IS FITTED WITH A MODERN SURFACE
*            SURVEILLANCE RADAR, WHICH PROVIDES INITIAL TARGET
*            INFORMATION ON THE ATTACK.  THE TIME DELAY BETWEEN AN
*            INCOMING MISSILE CROSSING THE RADAR DETECTION RANGE AND
*            BEING DETECTED BY THE RADAR SYSTEM HAVE BEEN ASSUMED TO
*            BE APPROXIMATELY NORMALLY DISTRIBUTED, WITH A MEAN DELAY
*            TIME (MM) AND A STANDARD DEVIATION (DM) IN  SECOND.
*          (2) THE AIR Defense CAPABILITY OF THE SHIP IS FITTED WITH
*            TWO SHORT-RANGE SURFACE-TO-AIR MISSILE SYSTEMS.  EACH
*            SYSTEM HAS AN ASSOCIATED SINGLE-CHANNEL TRACKING RADAR.
*            THE TRACKING RADARS ESTABLISH A TRACKING, AFTER AN
*            INCOMING MISSILE HAS BEEN DETECTED BY THE MODERN SURFACE
*            SURVEILLANCE RADAR AND THE TRACKING RADAR IS FREE TO BE
```

* ASSIGNED, HAS BEEN ASSUMED TO BE APPROXIMATELY UNIFORMLY
* DISTRIBUTED, WITH A MEAN DELAY TIME (MT) IN SECONDS AND
* STANDARD DEVIATION (DT) IN SECONDS.
* (3) THE SHIP HAS APPROPRIATELY INSTALLED TWO CLOSE-IN WEAPON
* SYSTEM (CIWS). EACH CIWS HAS ITS OWN RADAR TO PROVIDE
* THE GUN TRACKING INFORMATION. WHEN A TARGET ENTER ITS
* ENGAGEMENT ENVELOPE, THE GUNS ARE AUTOMATICALLY ATTACKING
* THIS TARGET AND BEGIN TO FIRE. THE FIRING CONTINUES UNTIL
* THE TARGET CROSSES THE MINIMUM FIRING RANGE.
* (4) THE SHORT-RANGE SURFACE-TO-AIR WEAPON SYSTEM FCS #1 WILL
* AUTOMATICALLY ENGAGE A TARGET WHICH ENTER ITS ENGAGEMENT
* ENVELOPE. IF MORE THAN ONE ARE AVAILABLE OR THE FIRST
* SYSTEM IS BUSY, THEN THE CIWS #1 WILL AUTOMATICALLY ENGAGE
* EXCEPT IN THE CASE WHERE THE CIWS #1 IS BUSY OR THE
* TARGET IS OUTSIDE ITS ENGAGEMENT ENVELOPE.
* (5) IF THE TARGET IS AT OUTSIDE THE CIWS' ENGAGEMENT
* ENVELOPE, THE FCS #2 WILL IMMEDIATELY ENGAGE THIS TARGET
* EXCEPT THE FCS #2 IS BUSY ALSO.
* (6) WHEN BOTH CIWS & FCS ARE BUSY, OR TWO FCS ARE BUSY AND
* THE TARGET IS OUTSIDE THE ENGAGEMENT ENVELOP OF CIWS, THE
* TARGETS ARRIVED WILL BE PUT IN A WAITING POSITION UNTIL
* ONE FCS IS FREE OR IT ENTERS THE ENGAGEMENT ENVELOPE OF
* CIWS.
* 3. PERFORMANCE DATA:
* (1).THE ANTI-SHIP MISSILES OF RED FORCE:
* -- MISSILE RADAR CROSS SECTION = 0.1 SQ. METER
* -- VELOCITY : SPM METER/SECOND
* -- COMBINED IN-FLIGHT RELIABILITY AND HIT PROBABILITY
* FOR EACH MISSILE IS PM
* (2).THE SHORT-RANGE SURFACE-TO-AIR MISSILE OF BLUE FORCE:
* -- MINIMUM LAUNCH RANGE = RMI METERS
* -- MAXIMUM LAUNCH RANGE = RMA METERS
* -- AVERAGE MISSILE VELOCITY = SPA METER/SECOND
* -- RELIABILITY (AT INTERCEPT) = PA1

```
*              -- HIT/KILL PROBABILITY = PA2
*         (3).THE CLOSE-IN WEAPON SYSTEMS OF BLUE FORCE:
*              -- MINIMUM FIRE RANGE = RMIC METERS
*              -- MAXIMUM FIRE RANGE = RMAC METERS
*              -- KILL PROBABILITY = 0.2/SECOND * ENGAGE TIME
*    THIS PROGRAM IS USED TO FIND THE Defense CAPABILITY OF THE BLUE
*   FORCE SHIP AT DIFFERENT RADAR DETECTION RANGES.  THROUGH RESULTS
*   OF THIS SIMULATION WE CAN EASILY DETERMINE WHICH DETECTION RANGE
*    IS REQUIRED FOR OUR NEW SURVEILLANCE RADAR.
*
********************************************************************
**
** LIST OF VARIABLES, PARAMETERS, AND FUNCTIONS
** DM      : DEVIATION OF DELAY TIME BY USING SURVEILLANCE RADAR TO
**           DETECT AN ANTI-SHIP MISSILES
** DR      : THE DETECTION RANGE OF BLUE FORCE SURVEILLANCE RADAR
** DT      : DEVIATION OF DELAY TIME BY USING TRACKING RADAR TO
**           ESTABLISH A TRACKING
** HT      : A VARIABLE OF WHETHER THE SHIP IS HIT(=1) OR NO(=0)
** IR      : INCREMENT OF DETECTION RANGE
** IX(1)   : SEED USED IN NORMAL DISTRIBUTION RANDOM NUMBER
**           GENERATOR
** IX(2&3) : SEEDS USED IN UNIFORM DISTRIBUTION RANDOM NUMBER
**           GENERATOR
** LNORM   : NORMAL DISTRIBUTION RANDOM NUMBER GENERATION
** LRND    : UNIFORM DISTRIBUTION RANDOM NUMBER GENERATOR
** MM      : MEAN DELAY TIME BY USING SURVEILLANCE RADAR TO DETECT
**           ANTI-SHIP MISSILE
** MT      : MEAN DELAY TIME BY USING TRACKING RADAR TO ESTABLISH
**           A TRACK
** NEVENTS : NUMBER OF EVENTS
** NEXT    : SCHEDULE THE NEXT ROUTE
** NH      : NUMBER OF THE MISSILES HIT OF BLUE FORCE
** NIQ     : NUMBER OF MISSILE IN WAITING POSITION
```

```
** NM       : NUMBER OF MISSILES RED FORCE LUNCHED
** NR       : NUMBER OF RUN
** P1(OR 2): KILL PROBABILITY OF CIWS #1(OR 2), WHICH IS A PRODUCT
**            OF THE ENGAGEMENT PERIOD AND 0.2/SECOND
** PA       : KILL PROBABILITY OF THE SHORT RANGE AIR-TO-AIR
**            MISSILES
** PM       : RELIABILITY AND KILL PROBABILITY OF THE ANTI-SHIP
**            MISSILES
** RMA      : MAX.  EFFECT RANGE OF THE ANTI-SHIP MISSILES
** RMAC     : MAX.  EFFECT RANGE OF THE SHORT RANGE SURFACE-TO-AIR
**            MISSILES
** RMI      : MIN.  EFFECT RANGE OF THE ANTI-SHIP MISSILES
** RMIC     : MIN.  EFFECT RANGE OF THE SHORT RANGE AIR-TO-AIR
**            MISSILES
** SPA      : SPEED OF THE SHORT RANGE AIR-TO-AIR MISSILES
** SPM      : SPEED OF THE ANTI-SHIP MISSILES
** SR       : START DETECTION RANGE
** STATUS   : THE STATES OF A WEAPON SYSTEM.  THE SYSTEM IS BUSY(=1)
**            OR IDLE(=0)
** TIME     : CLOCK OF THIS SIMULATION
** TL       : TIME LAPSE BETWEEN EACH ANTI-SHIP MISSILE LAUNCHED
** TM       : NUMBER OF TOTAL MISSILE LUNCHED BY RED FORCE
** TNE      : THE TIME OF THE NEXT EVENT.
** TNE(1)- THE TIME OF THE FIRST AND NEXT MISSILE IS DETECTED
** TNE(2)- THE TIME OF THE FCS #1 FINISHES ENGAGEMENT
** TNE(3)- THE TIME OF THE CIWS #1 FINISHES ENGAGEMENT
** TNE(4)- THE TIME OF THE FCS #2 FINISHES ENGAGEMENT
** TNE(5)- THE TIME OF THE CIWS #2 FINISHES ENGAGEMENT
** TT       : THE MAXIMUM RUNNING TIME
**
*****************************************************************
C
C     MAIN PROGRAM
```

```
      INTEGER NEVENTS, NEXT, NIQ, NM, STATUS(4), IX(3), TM, NR, NH,
     &HT
      REAL SR, IR, SPM, SPA, PM, PA, TL, MM, DM, MT, DT, RMA, RMI,
     &RMAC, RMIC, RA, DR, TT, TIME, TNE(5)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
*** SPECIFY POSITIVE SEEDS FOR NORMAL DISTRIBUTION RANDOM NUMBER
*** GENERATOR AND UNIFORM DISTRIBUTION RANDOM NUMBER GENERATOR.
      DO 01 I=1, 3
      IX(I)=1103205531
   01 CONTINUE
C
*** REQUEST TO INPUT PARAMETERS
      PRINT*, 'INPUT REAL PARAMETERS, THE ORDERS ARE AS THE FOLLOW
      &ING:'
      PRINT*
      PRINT*, 'START DETECTION RANGE, DETECTION RANGE INCREMENT(ME
     &TER)'
      PRINT*
      PRINT*, 'SPEED OF ANTI-SHIP MISSILES, AND SHORT RANGE AAMS
      &(M/SEC)'
      PRINT*
      PRINT*, 'THE RELIABILITY AND KILL PROBABILITY OF ANTI-SHIP
      &MISSILE'
      PRINT*
      PRINT*, 'THE KILL PROBABILITY OF THE SHORT RANGE AAMS'
      PRINT*
      PRINT*, 'TIME LAPS BETWEEN EACH ANTI-SHIP MISSILE LAUNCHED'
      PRINT*
      PRINT*, 'MEAN DELAY TIME AND DEVIATION OF AN ANTI-SHIP MISSILE
     &DETECTED BY SURVEILLANCE  RADAR (SECOND)'
      PRINT*
```

```
      PRINT*, 'MEAN DELAY TIME AND DEVIATION OF COMBAT SYSTEM
     &ESTABLISHES A TRACK (SECOND)'
      PRINT*
      PRINT*, 'MAX.  AND MIN.  EFFECT RANGE OF THE SHORT RANGE
     &SURFACE-TO-AIR MISSILE (METERS)'
      PRINT*
      PRINT*, 'MAX.  AND MIN.  EFFECT RANGE OF CIWS (METERS).'
      PRINT*
      PRINT*, 'PUT A SPACE BETWEEN EACH ONE.'
      READ(*, *)SR, IR, SPM, SPA, PM, PA, TL, MM, DM, MT, DT, RMA,
     &RMI, RMAC, RMIC
C
*** OPEN A FILE TO WRITE RESULTS.
      OPEN( UNIT=6, STATUS='OLD', FILE='TH RESULT')
C
*** RUN FOR THE RESULTS AT DIFFERENT NUMBER OF THE TOTAL MISSILE
      DO 300 I=5, 8
      TM=I

      WRITE (6, 02)
   02 FORMAT('INPUT REAL PARAMETERS FOR THIS RUN ARE AS THE FOLLOW
     &ING:')
      WRITE (6, 03)TM
   03 FORMAT('THE ANTI-SHIP MISSILE: (TOTAL NUMBER OF THE MISSILES
     &IS ', I2, ' )')
      WRITE (6, 04)SPM
   04 FORMAT(8X, 'SPEED', 17X, F7.2, 1X' M/SEC')
      WRITE (6, 05)PM
   05 FORMAT(8X, 'RELIABILITY AND KILL PROBABILITY', 5X, F4.3)
      WRITE(6, 06)TL
   06 FORMAT(8X, 'TIME LAPS BETWEEN EACH MISSILE LAUNCHED', 1X,
     &F4.2, 1X, 'SECOND')
      WRITE (6, *)'THE SHORT RANGE AIR-TO-AIR MISSILE:'
      WRITE (6, 08)SPA
```

```
08 FORMAT(8X, 'SPEED', 17X, F7.2, 2X, ' M/SEC')
   WRITE (6, 09)PA
09 FORMAT(8X, 'KILL PROBABILITY', 10X, F3.2)
   WRITE (6, 10)RMA
10 FORMAT(8X, 'MAX.  EFFECT RANGE', 5X, F8.2, 2X, 'METERS')
   WRITE (6, 11)RMI
11 FORMAT(8X, 'MIN.  EFFECT RANGE', 5X, F8.2, 2X, 'METERS')
   WRITE (6, *)'CLOSE-IN WEAPON SYSTEM:'
   WRITE (6, 12)RMAC
12 FORMAT(8X, 'MAX.  EFFECT RANGE', 5X, F8.2, 2X, 'METERS')
   WRITE (6, 13)RMIC
13 FORMAT(8X, 'MIN.  EFFECT RANGE', 5X, F8.2, 2X, 'METERS')
   WRITE (6, *)'USING SURVEILLANCE RADAR TO DETECT ANTI-SHIP MISS
  &ILE:'
   WRITE (6, 14)MM
14 FORMAT(8X, 'MEAN DELAY TIME', 10X, F5.2, 2X, 'SECOND')
   WRITE (6, 15)DM
15 FORMAT(8X, 'WITH DEVIATION', 11X, F5.2, 2X, 'SECOND')
   WRITE(6, *)'USING TRACKING RADAR TO ESTABLISH A TRACK:'
   WRITE (6, 16)MT
16 FORMAT(8X, 'MEAN DELAY TIME', 10X, F5.2, 2X, 'SECOND')
   WRITE (6, 17)DT
17 FORMAT(8X, 'WITH DEVIATION', 11X, F5.2, 2X, 'SECOND')
   WRITE (6, *)
   WRITE (6, *)
   WRITE (6, *)
C
*** RUN FOR FOURTY DIFFERENT DETECTION RANGE IN ORDER TO FIND A
*** MIN.RANGE WHICH SATISFIES WITH SUCCESSFULLY TO COMPLETE THE
*** OPERATIONAL 95% CONFIDENCE INTERVAL.
   DO 200 J=1, 40
C
*** DETECTION RANGES START AT 7500 METERS AND INCREASE 500 METERS.
*** RUN UNTIL FINISH 40 RUNS.
```

```
      DR=SR+J*IR
C
*** SPECIFY THE NUMBER OF EVENTS (NEVENTS) FOR TIMING ROUTINE.
      NEVENTS=5
C
*** GIVE INITIAL VALUE OF PARAMETERS FOR EVERY DETECTION RANGE.
      NH=0
      NR=0
C
*** DETERMINE THE MAXIMUM RUNNING TIME
      TT=(DR/SPM)+TL*(TM-1)
C
*** COLLECT THE DATA OF RUNNING 1000 TIMES.
      DO 100 K=1, 1000
C
*** CALL SUBROUTINE INIT TO INITIALIZE THE VARIABLES OF EACH RUN.
      CALL INIT(MM, DM, TL)
C
*** CHECK WHETHER TIME IS OVER.
   18 IF(TIME.LT.TT) GO TO 20
      GO TO 90
C
*** DETERMINE NEXT EVENT WHICH WILL BE CALLED BY USING SUBROUTINE
*** TIM, AND GO TO AN APPROPRIATE SITUATION ROUTINE.
   20 CALL TIM
      GO TO (30, 40, 50, 60, 70), NEXT
C
*** CALL SUBROUTINE ENG TO SCHEDULE NEXT EVENT AND TO SIMULATE AN
*** ENGAGEMENT.
   30 CALL ENG(NH, RA, SPM, SPA, PM, PA, TL, MM, DM, MT, DT, RMA,
     &RMI, RMAC,RMIC)
C
*** IF THE SHIP OF BLUE FORCE IS HIT BY ANTI-SHIP MISSILE, THEN END
*** THE RUN, OTHERWISE COUNT ONE MORE MISSILE DETECTED BY
```

```
*** SURVEILLANCE RADAR OF BLUE FORCE AND GO ON RUNNING.
      IF (HT.EQ.1) GO TO 90
      NM= NM+1
      GO TO 80
C
*** AFTER ENGAGEMENT CALL AN APPROPRIATE SUBROUTINE DEP TO CHECK
*** WHETHER THE QUEUE IS EMPTY AND TO SCHEDULE A DEPARTURE.
   40 CALL DEP1
      GO TO 80
   50 CALL DEP2
      GO TO 80
   60 CALL DEP3
      GO TO 80
   70 CALL DEP4
C
*** CHECK IF THE NUMBER OF MISSILE ARRIVED IS LESS/EQUAL TO THE
*** NUMBER OF TOTAL MISSILES.
   80 IF (NM.LE.TM) GO TO 18
   90 NR=NR+1
  100 CONTINUE
C
*** SINCE THE SIMULATION OF ONE DETECTION RANGE HAS FINISHED, CALL
*** SUBROUTINE REPT TO GENERATE A REPORT.
      CALL REPT(DR, NR, NH)
  200 CONTINUE
  300 CONTINUE
      STOP
      END
C
*****************************************************************
C
      SUBROUTINE INIT(MM, DM, TL)
      INTEGER NEVENTS, NEXT, NIQ, NM, STATUS(4), IX(3), HT
      REAL TT, TIME, DR, TNE(5), A(1), MM, DM, TL
```

```
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
*** INITIALIZE THE SIMULATION CLOCK
      TIME = 0.
C
*** INITIALIZE THE VARIABLE OF WHETHER THE SHIP IS HIT OR NOT
      HT=0
C
*** INITIALIZE THE VARIABLES OF THE STATE OF THE WEAPON SYSTEMS
      STATUS(1)=0
      STATUS(2)=0
      STATUS(3)=0
      STATUS(4)=0
C
*** INITIALIZE THE STATISTICAL COUNTERS
      NM=0
      NIQ=0
C
*** INITIALIZE THE EVENT LIST.  SINCE NO MISSILE ARE PRESENT,
*** SCHEDULE THE TIME OF THE FIRST MISSILE IS DETECTED, AND THE
*** TIME OF THE NEXT DEPARTURE IS SET TO "INFINITY".
      CALL LNORM(IX(1), A, 1, 1, 0)
      TNE(1)=MM+DM*A(1)+TL*NM
      TNE(2)=1.E+30
      TNE(3)=1.E+30
      TNE(4)=1.E+30
      TNE(5)=1.E+30
      RETURN
      END
C
*****************************************************************
C
      SUBROUTINE TIM
```

```
      INTEGER NEVENTS, NEXT, NIQ, NM, STATUS(4), IX(3)
      REAL TT, TIME, DR, TNE(5), RMIN
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
*** SET A DUMMY VARIABLE
      RMIN=1.E+29
C
*** DETERMINE THE EVENT TYPE OF THE NEXT EVENT TO OCCUR.
         DO 10 I=1, NEVENTS
         IF (TNE(I).GE.RMIN) GO TO 10
         RMIN=TNE(I)
         NEXT=I
   10    CONTINUE
      TIME=TNE(NEXT)
      RETURN
      END
C
*****************************************************************
C
      SUBROUTINE ENG(NH, RA, SPM, SPA, PM, PA, TL, MM, DM, MT, DT,
     &RMA, RMI, RMAC, RMIC)
C
      INTEGER NEVENTS, NEXT, NIQ, NM, STATUS(4), IX(3), HT
      REAL SPM, SPA, PM, PA, TL, MM, DM, MT, DT, RMA, RMI, RMAC,
     &RMIC, TT, TIME, DR, TNE(5), RA, A(1)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
*** SCHEDULE A DETECTED TIME OF THE NEXT ARRIVING MISSILE
      CALL LNORM(IX(1), A, 1, 1, 0)
      TNE(1)=MM+DM*A(1)+TL*(NM+1)
C
```

```
*** IF THE FCS #1 IS BUSY (STATUS=1), AUTOMATICALLY LET CIWS#1
*** HANDLE THE ARRIVING MISSILE.  IF THE FCS #1 IS IDLE (STATUS=0),
*** START THE ENGAGEMENT ROUTE OF FCS #1.
      IF(STATUS(1).EQ.1) GO TO 20
C
*** DETERMINE THE TIME OF THE FCS #1 ESTABLISHES A TRACKING
      CALL LRND(IX(2), A, 1, 1, 0)
      TIME=TIME+DT*A(1)+MT
C
*** CALCULATE THE DISTANCE BETWEEN THE TRACKED MISSILE AND THE SHIP
*** WHEN THE MISSILE IS TRACKED BY FCS #1.
   10 RA=DR-SPM*(TIME-TL*NM)
C
*** CHECK WHETHER THE MISSILE IS AT OUTSIDE OF THE ENGAGEMENT
*** ENVELOPE OF FCS #1.  IF THE DISTANCE IS LARGER THAN THE MAX.
*** ATTACKING RANGE OF FCS #1, THEN SCHEDULE THE TIME OF THE
*** MISSILE CROSSING THE RANGE.  IF THE DISTANCE IS SMALLER THAN THE
*** MIN.  ATTACKING RANGE OF FCS #1, THEN LET CIWS #1 AUTOMATICALLY
*** ENGAGE THE MISSILE.
      IF(RA.GT.RMA) GO TO 11
        IF(RA.LT.RMI) GO TO 20
C
*** THE MISSILE IS WITHIN THE ENGAGEMENT ENVELOPE OF FCS #1, UPDATE
*** THE STATE OF FCS #1.
      STATUS(1)=1
*** DETERMINE THE ENGAGEMENT TIME
      TIME=RA/(SPM+SPA)+TIME
C
*** DETERMINE WHETHER THE FCS #1 SUCCESSFULLY INTERCEPTS THE
*** MISSILE BY RUNNING A UNIFORM DISTRBUTION RANDOM NUMBER
*** GENERATOR WITH SEED IX3.  IF IT IS NOT, THEN DO THE ABOVE ROUTE
*** AGAIN.  IF IT IS, THEN SCHEDULE THE INTERCEPTION TIME.
      CALL LRND(IX(3), A, 1, 1, 0)
      IF(A(1).GT.PA) GO TO 10
```

```
          TNE(2)=TIME
       RETURN
C
*** CALCULATE THE DISTANCE BETWEEN THE MISSILE AND THE SHIP WHEN
*** THE MISSILE IS GOING TO BE TRACKED BY CIWS #1.
    20 RA=DR-SPM*(TIME-TL*NM)
C
*** CHECK WHETHER THE MISSILE IS AT OUTSIDE THE ENGAGEMENT ENVELOPE
*** OF CIWS#1.  IF THE DISTANCE IS LARGER THAN THE MAX.  ATTACKING
*** RANGE OF CIWS#1, THEN LET FCS #2 AUTOMATICALLY ENGAGE THE
*** MISSILE.  IF THE DISTANCE IS SMALLER THAN THE MINIMUM ATTACKING
*** RANGE OF CIWS #1, THEN GO TO THE ROUTE OF DECISION WHETHER THE
*** SHIP IS HIT.  IF CIWS #1 IS BUSY, THEN LET CIWS #2 AUTOMATICALLY
*** ENGAGE THE MISSILE EXCEPT IT IS BUSY ALSO.
       IF(RA.GT.RMAC) GO TO 30
         IF(RA.LT.RMIC) GO TO 13
           IF(STATUS(2).EQ.1) GO TO 25
C
*** THE MISSILE IS WITHIN THE ENGAGEMENT ENVELOPE OF CIWS #1,
*** UPDATE THE STATE OF CIWS #1.
       STATUS(2)=1
C
*** CALCULATE THE KILL PROBABILITY OF CIWS #1
       P1=(RA/SPM)*0.2
C
*** DECIDE WHETHER CIWS #1 KILLS THE ENGAGED MISSILE.
       CALL LRND(IX(3), A, 1, 1, 0)
       IF(A(1).GT.P1) GO TO 13
C
*** SCHEDULE A INTERCEPTION TIME, AND UPDATE SIMULATION CLOCK
         TNE(3)=TIME+(RA-RMIC)/SPM
         TIME=TNE(3)
       RETURN
C
```

```
*** CHECK WHETHER THE CIWS #2 IS BUSY.  IF IT IS, GO TO THE FINAL
*** HIT ROUTE.  IF IT IS NOT, LET CIWS #2 ENGAGE THIS TARGET.
   25 IF(STATUS(4).EQ.1) GO TO 13
        STATUS(4)=1
C
*** CALCULATE THE KILL PROBABILITY OF CIWS #2
        P2=(RA/SPM)*0.2
C
*** DECIDE WHETHER CIWS #2 KILLS THE ENGAGED MISSILE.
        CALL LRND(IX(3), A, 1, 1, 0)
        IF(A(1).GT.P2) GO TO 13
C
*** SCHEDULE A INTERCEPTION TIME, AND UPDATE SIMULATION CLOCK
        TNE(5)=TIME+(RA-RMIC)/SPM
        TIME=TNE(5)
      RETURN
C
*** FINAL HIT ROUTE: DECIDE IF THE SHIP IS HIT BY A MISSILE
   13 CALL LRND(IX(3), A, 1, 1, 0)
      IF (A(1).GT.PM) GO TO 14
        NH= NH+1
        HT=1
   14 RETURN
C
*** SCHEDULE THE TIME THAT THE MISSILE CROSSES THE MAX.  RANGE OF
 *** CIWS #2
   11 TIME=(DR-RMA+1.)/SPM+TL*NM
      GO TO 10
C*****************************************************************
*** IF THE FCS #2 IS BUSY (STATUS=1), AUTOMATICALLY LET CIWS#2
*** HANDLE THE ARRIVING MISSILE.  IF THE FCS #2 IS IDLE (STATUS=0),
*** START THE ENGAGEMENT ROUTE OF FCS #2.
   30 IF(STATUS(3).EQ.1) GO TO 50
C
```

```
*** DETERMINE THE TIME OF THE FCS #2 ESTABLISHES A TRACKING
      CALL LRND(IX(2), A, 1, 1, 0)
      TIME=TIME+DT*A(1)+MT
C
*** CALCULATE THE DISTANCE BETWEEN THE TRACKED MISSILE AND THE SHIP
*** WHEN THE MISSILE IS TRACKED BY FCS #2.
   40 RA=DR-SPM*(TIME-TL*NM)
C
*** CHECK WHETHER THE MISSILE IS AT OUTSIDE THE ENGAGEMENT ENVELOPE
*** OF FCS #2.  IF THE DISTANCE IS LARGER THAN THE MAX.  ATTACKING
*** RANGE OF FCS #2, THEN SCHEDULE THE TIME OF THE MISSILE CROSSING
*** THE RANGE.  IF THE DISTANCE IS SMALLER THAN THE MIN.  ATTACKING
*** RANGE OF FCS #2, THEN LET CIWS #2 AUTOMATICALLY ENGAGE THE
*** MISSILE.
      IF(RA.GT.RMA) GO TO 31
        IF(RA.LT.RMI) GO TO 50
C
*** THE MISSILE IS WITHIN THE ENGAGEMENT ENVELOPE OF FCS #2, UPDATE
*** THE STATE OF FCS #2.
      STATUS(3)=1
C
*** DETERMINE THE ENGAGEMENT TIME
      TIME=RA/(SPM+SPA)+TIME
C
*** DETERMINE WHETHER THE FCS #2 SUCCESSFULLY INTERCEPTS THE
*** MISSILE BY RUNNING A UNIFORM DISTRBUTION RANDOM NUMBER
*** GENERATOR WITH SEED IX3.  IF IT IS NOT, THEN DO THE ABOVE ROUTE
*** AGAIN.  IF IT IS, THEN SCHEDULE THE INTERCEPTION TIME.
      CALL LRND(IX(3), A, 1, 1, 0)
      IF(A(1).GT.PA) GO TO 40
         TNE(4)=TIME
      RETURN
C
*** CALCULATE THE DISTANCE BETWEEN THE MISSILE AND THE SHIP WHEN
```

```
*** THE MISSILE IS GOING TO BE TRACKED BY CIWS #2.
   50 RA=DR-SPM*(TIME-TL*NM)
C
*** CHECK WHETHER THE MISSILE IS AT OUTSIDE OF THE ENGAGEMENT
*** ENVELOPE OF CIWS#2.  IF THE DISTANCE IS LARGER THAN THE MAX.
*** ATTACKING RANGE OF CIWS#2, THEN PUT IT IN QUEUE.  IF THE
*** DISTANCE IS SMALLER THAN THE MIN.  ATTACKING RANGE OF CIWS #2,
*** THEN GO TO FINAL HIT ROUTE, AND DECIDE WHETHER THE SHIP IS HIT.
*** IF CIWS #2 IS BUSY, THEN LET CIWS #1 AUTOMATICALLY ENGAGE THE
*** MISSILE EXCEPT IT IS BUSY ALSO.
      IF(RA.GT.RMIC) GO TO 60
        IF(RA.LT.RMAC) GO TO 33
          IF(STATUS(4).EQ.1) GO TO 35
C
*** THE MISSILE IS WITHIN THE ENGAGEMENT ENVELOPE OF CIWS #2,
*** UPDATE THE STATE OF CIWS #2.
      STATUS(4)=1
C
*** CALCULATE THE KILL PROBABILITY OF CIWS #2
      P2=(RA/SPM)*0.2
C
*** DECIDE WHETHER CIWS #2 KILLS THE ENGAGED MISSILE.
      CALL LRND(IX(3), A, 1, 1, 0)
      IF(A(1).GT.P1) GO TO 33
C
*** SCHEDULE A INTERCEPTION TIME, AND UPDATE SIMULATION CLOCK
        TNE(5)=TIME+(RA-RMIC)/500.
      TIME=TNE(5)
      RETURN
C
*** CHECK WHETHER THE CIWS #1 IS BUSY.  IF IT IS, GO TO THE FINAL
*** HIT
*** ROUTE.  IF IT IS NOT, LET CIWS #1 ENGAGE THIS TARGET.
   35 IF(STATUS(2).EQ.1) GO TO 33
```

```
        STATUS(2)=1
C
*** CALCULATE THE KILL PROBABILITY OF CIWS #1
        P1=(RA/SPM)*0.2
C
*** DECIDE WHETHER CIWS #2 KILLS THE ENGAGED MISSILE.
        CALL LRND(IX(3), A, 1, 1, 0)
        IF(A(1).GT.P1) GO TO 33
C
*** SCHEDULE A INTERCEPTION TIME, AND UPDATE SIMULATION CLOCK
        TNE(3)=TIME+(RA-RMIC)/SPM
        TIME=TNE(5)
      RETURN
C
*** FINAL HIT ROUTE: DECIDE IF THE SHIP IS HIT BY A MISSILE
   33 CALL LRND(IX(3), A, 1, 1, 0)
      IF (A(1).GT.PM) GO TO 34
        NH= NH+1
        HT=1
   34 RETURN
C
*** SCHEDULE THE TIME THAT THE MISSILE CROSSES THE MAX.  RANGE OF
*** CIWS #2
   31 TIME=(DR-RMA+1.)/SPM+TL*NM
      GO TO 30
C
*** IF ALL OF THE FOUR SYSTEMS ARE BUSY, OR FCSS' ARE BUSY AND THE
*** TARGET IS OUTSIDE THE ENGAGEMENT ENVELOPE OF CIWSS, THEN PUT
*** THE TARGET IN QUEUE
   60 NIQ=NIQ+1
      RETURN
      END
*******************************************************************
C
```

```
      SUBROUTINE DEP1
      INTEGER NIQ, STATUS(4), IX(3)
      REAL TNE(5)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
*** MAKE FCS #1 TO IDLE
      STATUS(1)=0
C
*** CHECK NUMBER IN QUEUE
      IF (NIQ.GT.0) GO TO 50
      TNE(2)=1.E+30
      RETURN
   50 NIQ=NIQ-1
      TNE(2)=1.E+30
      TNE(1)=TIME
      RETURN
      END
*****************************************************************
C
      SUBROUTINE DEP2
      INTEGER NIQ, STATUS(4), IX(3)
      REAL TNE(5)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
      STATUS(2)=0
      IF (NIQ.GT.0) GO TO 50
      TNE(3)=1.E+30
      RETURN
   50 NIQ=NIQ-1
      TNE(3)=1.E+30
      TNE(1)=TIME
      RETURN
```

```
      END
*******************************************************************
C
      SUBROUTINE DEP3
      INTEGER NIQ, STATUS(4), IX(3)
      REAL TNE(5)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX

      STATUS(3)=0
      IF (NIQ.GT.0) GO TO 50
      TNE(4)=1.E+30
      RETURN
   50 NIQ=NIQ-1
      TNE(4)=1.E+30
      TNE(1)=TIME
      RETURN
      END

*******************************************************************
C
      SUBROUTINE DEP4
      INTEGER NIQ, STATUS(4), IX(3)
      REAL TNE(5)
      COMMON /MODEL/NEVENTS, NEXT, NIQ, NM, STATUS, TT, HT, TNE,
     &TIME, DR, IX
C
      STATUS(4)=0
      IF (NIQ.GT.0) GO TO 50
      TNE(5)=1.E+30
      RETURN
   50 NIQ=NIQ-1
      TNE(5)=1.E+30
      TNE(1)=TIME
```

```
      RETURN
      END
******************************************************************
C
      SUBROUTINE REPT(DR, NR, NH)
      REAL PS
      INTEGER NR, NH
C
      WRITE(6, 10)DR
   10 FORMAT('DR = ', F8.2, 2X, 'METERS')
      WRITE(6, 20)NR
   20 FORMAT(5X, 'NUMBER OF RUNS', 3X, I4)
      WRITE(6, 30)NH
   30 FORMAT(5X, 'NUMBER OF HITS', 4X, I4)
      PS=((NR-NH)*100./NR)
      WRITE(6, 40)PS
   40 FORMAT(5X, 'PERCENTAGE OF SUCCESSFUL DEFENSE', 2X, F5.1, 1X,
     &'%')
      RETURN
      END
```

LIST OF REFERENCES

1. R.T. Stevens, *Operational Test & Evaluation*, A Systems Engineering Process, Robert E. Krieger Publishing, Malabar, FL 32950, 1979.
2. A. M. Law and W.D. Kelton, "Basic Simulation Modeling, " in *Simulation Modeling And Analysis*, pp. 4-58, McGraw-Hill, New York, 1982.
3. M. I. Skolnik, *Radar Handbook*, McGraw-Hill, New York, 1990.
4. L. V. Blake, *Radar Range-Performance Analysis*, Artech House, Norwood, MA 02062, 1986.
5. W. L. Patterson, C. P. Hattan, H. V. Hitney, R. A. Paulus, A. E. Barrios, G. E. Lindem, and K. D. Anderson, "Engineer's Refractive Effects Prediction System (EREPS), revision 2.0, " Technical Document 1342, Naval Ocean Systems Center, San Diego, CA 92152, February 1990.
6. E. J. Eichblatt Jr., *Test and Evaluation of the Tactical Missile*, American Institute of Aeronautics and Astronautics, Inc., Washington, DC 20024, 1989.
7. M. I. Skolnik, *Introduction Radar Systems*, McGraw-Hill, New York, 1980.
8. J. L. Eaves and E.K. Reedy, *Principles of Modern Radar*, Van Norstrand Reinhold Company, New York, NY 10003, 1987.