A COMPUTER SIMULATION AIDED METHOD FOR PREDICTING EXPENDITURES OF A SHORT RANGE, SEMI-ACTIVE HOMING MISSILE SYSTEM

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THESIS

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ABSTRACT

This thesis presents a computer simulation aided method for predicting expenditures of a short range, semi-active homing missile system engaged in an amphibious assault. The methodology used considers varying threat size, enemy strategy, and expected missile kill probabilities. Only a single-shot firing doctrine is considered. The results obtained, displayed for varying missile kill probabilities, provide the user with expenditure information on which to base missile procurement policy.

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE

This United States Naval Postgraduate School thesis has been prepared to assist planners in predicting missile expenditure requirements of a United States Marine Corps anti-aircraft missile battalion engaged in an amphibious operation.

B. BACKGROUND

Past U. S. Marine Corps efforts to determine surface-to-air missile expenditure requirements used mathematical models that calculated the number of missiles required to completely destroy a scenario-dependent number of aircraft. No statistical analysis of the model parameters or of the resulting expenditures was performed. The method used gave results that were dependent on the assumed kill effectiveness of the missile against the scenario targets and on the chosen number of threat aircraft. While great effort was made to find the best available figures for all model parameters there is reason to doubt their validity in an actual combat situation. Historical combat expenditure data was not available for United States missile units, since these units have not fired against the assumed threat aircraft. Data from extensive practice firings was available and used. However, since realistic maneuvering targets are expensive and difficult to control there was little data available from which to ascertain a reliable effectiveness figure. It is difficult to relate practice firing results to combat conditions. It is all too easy to visualize the Russian planners for the SA-2 missile system

thinking they had a system with a high kill effectiveness while combat data has shown this system to be quite ineffective when correct air tactics are used. Missile kill effectiveness is also dependent on the enemy's electronic counter-measures (ECM) capability. Electronic counter-measure effects are difficult to evaluate even if one has complete knowledge of the type of devices that would be used. Since intelligence information is probably not complete in this field, the evaluation of ECM effects is even more difficult and subject to error in its estimation. Hence, picking a single kill effectiveness figure, or a group of them against a group of various type targets, can lead to incorrect expenditure requirement figures. The variation of expenditures with different kill effectiveness should be analyzed before any conclusions are made.

Choosing the correct threat for the scenario also presents problems. The location of the next amphibious operation and the threat in that location is unknown. Choosing too small a threat for use in the scenario could lead to using planning figures that are too small, with unfavorable tactical consequences. Choosing too large a threat is wasteful and leads to a misuse of limited funds. Thus planners should consider an analysis of the variation of expenditure with the threat. In addition, previous methods of analysis did not consider all enemy tactical options, in particular that of attacking the missile units.

II. NATURE OF THE PROBLEM

A. STATEMENT OF THE PROBLEM

The problem considered in this thesis is to find a method to obtain missile expenditure requirement figures for a U. S. Marine Corps surface-to-air missile battalion engaged in an amphibious operation. An investigation of how the predicted expenditures varied with the missile effectiveness, enemy air threat, and enemy air strategy was conducted in order to ascertain a useful expenditure planning figure when these three quantities can not be accurately predicted. The missile system used in this study is a hypothetical representative of a short range, semi-active homing missile system. It does not knowingly represent any specific system currently employed by U. S. forces. Therefore the figures shown throughout this thesis are not applicable to any specific system. However, the methodology used to obtain these figures is applicable to any system of the type considered.

B. PROBLEM SCENARIO

A United States Marine Corps Amphibious Force (MAF) is engaged in an amphibious landing on a hostile shore. The MAF is composed of a reinforced ground division and an air wing. The landing is supported by elements of the U. S. Navy and by its aircraft carriers during the early stages of the invasion. Within the Marine Wing is the anti-aircraft missile battalion. The missile battalion has three firing batteries. The essential battery components

are shown in Figure 1. Typical parameter values were chosen to display the methodology results, but users must insert the parameter values representative of the specific missile system they are considering to obtain values applicable to their use. System parameters chosen for this model were:

Maximum missile range = 25 miles

Maximum detection range = 100 miles

Minimum intercept range = 5 miles

Average missile velocity = 1200 miles per hour

Probability of detection = 0.95

Probability of track = 0.95

The battery is considered to have a 360-degree capability to detect, track, and fire. No altitude limitations were considered for the missile system.

The missile kill effectiveness was expressed as a Probability of Single Shot Kill (PSSK). This effectiveness figure was varied throughout the study to investigate its effect on expenditures. Note that the Probability of Single Shot Kill (PSSK) parameter used in this study differs from the term Single Shot Kill Probability (SSKP) used in other missile literature. The Probability of Single Shot Kill (PSSK) used herein is an expected value for the effectiveness of the entire system firing one shot at one aircraft. It includes system reliability and operational capability as well as the usual factors implied by SSKP. The PSSK is the same against all aircraft in the assumed threat. Electronic counter-measure effects are included in the PSSK.

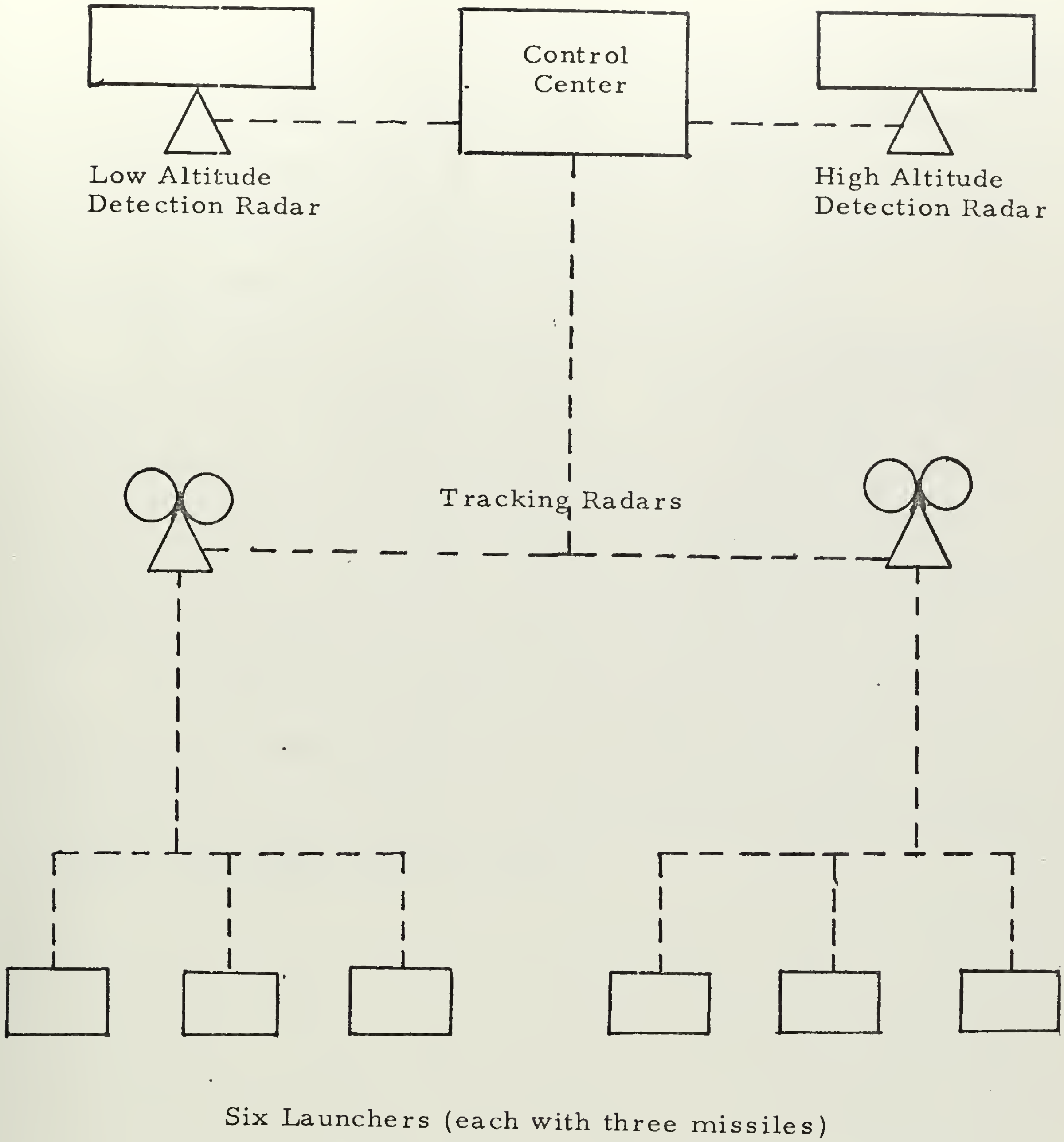

Figure 1. Essential Elements of a Missile Battery

The enemy threat chosen for this scenario was a representative one and not a specific country's force. The enemy inventory of aircraft was varied to study its effects where applicable. The enemy aircraft speeds are uniformly distributed from a minimum of 300 miles per hour to a maximum of 800 miles per hour.

The enemy has been engaged with the MAF for two days prior to the landing of the missile battalion. During this time he has been experiencing losses due to friendly fighters. This study does not include an analysis of a detailed air-to-air battle. The friendly fighter kill rate was chosen as 20 percent of the attempted penetrations by the enemy into the Amphibious Objective Area (AOA).

The Amphibious Objective Area (AOA) is small enough for each missile battery to have coverage of the entire AOA. This is compatible with the division's limited offensive capability and the range of the chosen missile system.

III. EXPERIMENTAL PROCEDURE

A. ASSUMPTIONS

The following assumptions were made and are used throughout all steps in the experimental procedure where applicable.

No degradation to the missile units was considered except complete destruction by enemy air attack.

Five aircraft successfully penetrating the combined fighter-missile air defense system can destroy a missile battery if they choose to attack that battery. Fifteen successful penetrations can destroy the missile battalion (three batteries).

The enemy is intelligent and will know when the missiles are emplaced and become operational by either photo reconnaissance or electronic means.

The enemy can ascertain that the missile system emplaced is a semi-active homing type and its approximate range.

If the enemy decides to attack the battalion he will do so in a saturation type of attack against all three batteries simultaneously. This type of attack can be shown to defeat any semi-active type system though costs in terms of aircraft losses may be high. This attack is assumed to be made at high speed (600 miles per hour) by all attacking aircraft.

No specific terrain was included in the model. However, the radar detection range was made to vary uniformly over the range from maximum to minimum detection range. This, in a random manner, assumes terrain effects are present and are being used by

the enemy to make his attacks without always being detected at maximum range. Since the locale of future amphibious operations is unknown, this method of assuming terrain effects is felt to be more suitable for planning purposes than considering a specific terrain.

B. METHODOLOGY

As previously mentioned in the introduction, it is difficult to ascertain the correct value for the Probability of Single Shot Kill (PSSK) and the enemy threat. Therefore these items are varied in computing missile requirements in order to provide the planner with information on how expenditures vary as these factors vary. Two Monte Carlo computer simulations were devised for this study. While the simplified models used in this study are tractable to conventional mathematical formula and analysis, the simulation was chosen to allow for further extensions and adaptability to various missile systems. The computer program is easily modified to allow for inclusion of different firing doctrines, weapon characteristics, and enemy tactics that could lead to a level of complexity that prohibits solution by mathematical equations.

The simulations used are one-dimensional. Due to the 360-degree coverage and range of the system, the relatively small objective area, and overlapping coverage of the missile batteries there was no need to consider the bearing of the incoming aircraft. One rate of aircraft attack (one aircraft every six minutes) was used. Due to the high missile firing rate it makes no difference in total expenditures whether this rate is decreased by any amount or is increased until the missile system is saturated. The battalion

is capable of engaging six incoming aircraft simultaneously. It was considered improbable that the enemy would coordinate his strike aircraft through the friendly fighter defense in raids greater than six unless he were making a well-planned, highly coordinated attack on the battalion itself. This type of attack is considered separately.

One firing doctrine was investigated, and that is the doctrine of firing one missile per target without reengagement except in the case of a saturation attack on the battalion. In the event of a saturation type attack the battalion was allowed to expend the maximum number of missiles mechanically possible during the attack.

1. Computation of the Mean Missile Expenditures if the Enemy Does Not Attack the Missile Battalion

One of the Monte Carlo computer simulations previously discussed was devised to compute, as a function of PSSK, the number of missiles that would be expended if the battalion were not attacked by the enemy aircraft. The PSSK was varied from 0.1 to 1.0 in increments of 0.1. Threats of 100 and 200 enemy aircraft were used in computing results. One hundred runs for the threat of 100 aircraft and 20 runs for the threat of 200 aircraft were made for each value of PSSK. From these runs the mean number of expenditures was computed. Figures 2 and 3 show the plot of the mean number of missiles expended versus the PSSK. The curve fitted to the data points was done by the freehand method, as are all curves displayed in this thesis. The computer program used to obtain these results is the first computer program at the end of this thesis.

The results of this program, while obtained from simulation as opposed to mathematical formula, are very similar to those obtained

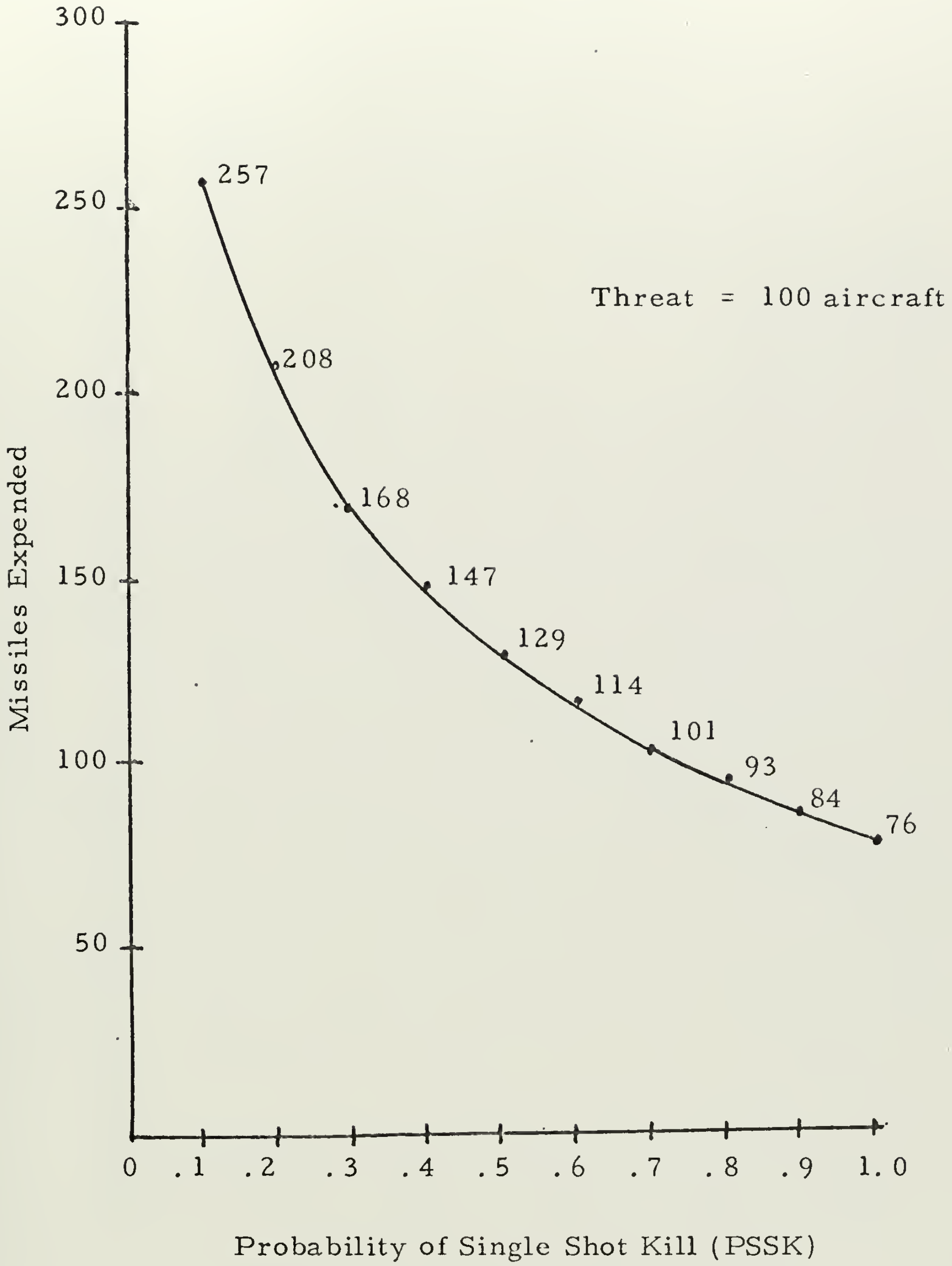

Figure 2. Mean Missile Expenditures Versus PSSK if the Enemy Does Not Attack the Missile Battalion.

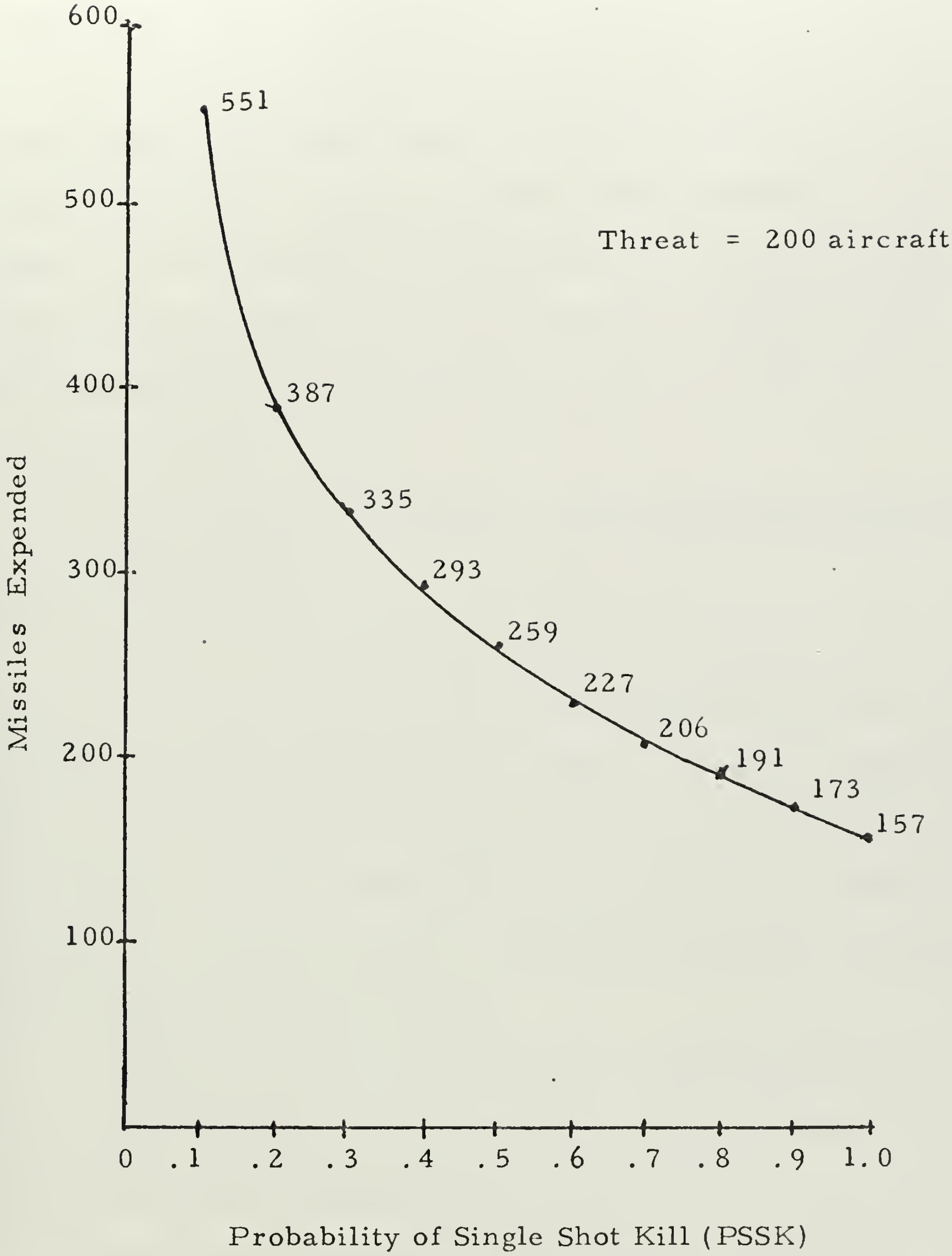

Figure 3. Mean Missile Expenditures Versus PSSK if the Enemy Does Not Attack the Missile Battalion.

by past methods. They are computed here only for illustrative and comparative purposes. Appendix B shows an analytic method for computing the missile expenditures under the same assumptions as were used in the simulation. The analytic method is more efficient providing the mathematics remain tractable. The almost identical results obtained by using either method lends credence to each method. It is not necessary for the planner to use this program in computing his planning figures. The results obtained from this program, which does not consider enemy tactics, will be referred to as "past method" results.

2. Determination of the Missile Expenditures During an Enemy Attack on the Battalion

Because of the assumed knowledge on the part of the enemy that he is encountering a semi-active homing missile system and the assumption that five penetrating aircraft can destroy a missile battery, it is shown later in this report that he can attack and destroy the missile units. Since the enemy has the option of attacking, it was necessary to determine how many missiles would be expended during this attack if it were made.

Consider one battery. The battery will see a large number of high speed attacking aircraft on its detection radar's screen (under the assumed saturation type attack at 600 miles per hour). Each firing radar (tracking radar) can track and fire at only one aircraft at a time with a semi-active type missile system. The first missile intercept can occur at the missile's maximum range of 25 miles. The tracking radar operator must then evaluate the intercept and shift to another target or fire again at the same target

if the intercept was unsuccessful. An alternate target will be quite close due to the assumed large number of attacking aircraft. Assuming the operator is alert, the time to shift targets or to refire at the same target was taken as a constant of ten seconds during the attack. Appendix A shows the calculations for the second and succeeding intercepts. Note that the fifth possible intercept occurs at a range less than the minimum intercept range for this system and hence cannot be made. Therefore, each tracking radar can engage four targets during the attack. The battery can make eight separate engagements and the battalion can make 24.

However, if the battalion saw itself under this type of attack it is probable that more than one missile would be launched at a time against each incoming aircraft. The number of missiles expended would then not be equal to the number of separate engagements the battalion could make but would be greater. The number fired was taken to be all the missiles loaded on the launchers plus those that could be loaded during the attack. Due to the aircraft speed and the fact that no launcher can be loaded until the first one is empty, only one launcher per firing section can be reloaded during the attack. This means each battery can fire its 18 pre-loaded missiles plus the six it could load during the attack. The battalion could fire a total of 72 missiles during this type of attack.

3. Determination of If and When the Enemy Would Attack the Missile Battalion

As shown above, the missile battalion can engage a maximum of 24 separate aircraft during an attack. The missile systems currently in use are highly complex, vulnerable systems and no

satisfactory method of protecting them during their operational time has been found to date. Therefore it was assumed that if fifteen aircraft successfully penetrated the fighter and missile defenses with the purpose of attacking the battalion they would destroy the battalion.

Since the enemy is intelligent he can calculate approximately how many aircraft to send in to destroy the battalion and can calculate his approximate expected losses as shown below.

Let

MMK = Maximum Missile Kills = Maximum number of separate engagements made by the battalion = 24 kills.

EFK = Expected fighter kills

PFK = Probability of fighter kill (assumed = 0.20)

TA = Total attackers necessary to destroy the battalion

NTD = Number of aircraft to destroy the battalion, (after successful penetration through the fighters and missiles), and is assumed to be 15 aircraft

ETL = Expected total enemy losses

Then,

EFK = (PFK)X(TA)

= 0.20(TA)

TA = MMK+EFK+NTD

TA = 24+0.20(TA)+15

TA = 39/0.80 = 48.75 aircraft (Total aircraft necessary to attack and destroy the battalion)

To compute the enemy's expected losses take

ETL = MMK+EFK

ETL = 24+0.20(48.75)

ETL = 33.8 aircraft

Note that this figure can be taken as a maximum expected loss since the missile engagements are all taken to be successful. Hence, the expected losses do not exceed 34 and will be lower for any missile PSSK less than 1.0. If the enemy does not attack the batteries but does conduct strikes in the Amphibious Objective Area he can again calculate his expected losses. Consider a threat of 100 aircraft each making one raid into the AOA. The first run (first raid) losses can be calculated as below:

$$\begin{aligned} \text{Expected First Run Losses} &= \text{Expected Fighter Kills} + \\ &\quad\ \text{Expected Missile Kills} \\ &= \text{EFK} + \text{PSSK}(100-\text{EFK}) \\ &= 20 + \text{PSSK}(80) \end{aligned}$$

Table 1 shows the expected first run losses (total) and first run missile losses for each chosen value of PSSK.

PSSK	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Expected First Run Losses (Total)	28	36	44	52	60	68	76	84	92	100
Expected First Run Losses due to Missiles	8	16	24	32	40	48	56	64	72	80

Table 1. Expected First Run Aircraft Losses Due to Missiles and Total First Run Aircraft Losses.

With a PSSK of 0.5 or above the enemy losses exceed the number that would be lost by attacking the battalion which is 34. If the enemy desired to make a second raid with the surviving aircraft his losses would increase. Using a PSSK of 0.3, for example, and formula

similar to those above the second run losses due to missiles are 13 aircraft. This gives a total loss for the two runs of approximately 37 aircraft, which again exceeds the losses sustained if he were to attack and destroy the batteries. If the threat were greater than 100 aircraft the enemy losses, for the first and subsequent runs, would be even higher.

The enemy can easily make these calculations in an approximate form and it is concluded that the enemy will attack the battalion once he learns the missiles are effective. If the missiles are ineffective there is no need to attack the batteries and this case is not considered here. The enemy was not considered to attack the battalion immediately. The enemy was assumed not to know the missile effectiveness at the beginning of the battle. The enemy has many high priority targets in the AOA and would rather apply his strike force against those targets aiding the invasion offensively if he does not lose that strike force due to missiles. It was considered that the enemy uses his aircraft against these other targets until he learns if the missiles are effective. This necessitated the determination of how fast an enemy would learn the missiles are effective.

A learning function was subjectively devised to represent the enemy's learning process. This function is used in later calculations. This function, while subjectively estimated, is considered to be realistic judging from the experience of the writer. It simply represents the fact that the more aircraft out of those entering the AOA that are killed by missiles the faster the enemy will learn of the missile effectiveness. A "time period" is defined to be the time to make ten possible missile engagements (i.e., ten aircraft penetrating the

fighter defense). Through the use of radar and radio communications the enemy can ascertain how many aircraft successfully penetrate the fighter defense, since this battle takes place over terrain that the enemy controls. When these penetrating aircraft enter the AOA and drop to lower altitudes to make attacks he can not see what happens to them. However, if an aircraft does not return he can assume it was lost due to missiles since no other air defense weapons are present and small arms fire and accidental losses are negligible over short time periods. The learning function for a single "time period" is shown here:

Aircraft Losses Due to Missiles	Probability the Enemy Learns
0.0	0.0
1.0	0.05
2.0	0.10
3.0	0.20
4.0	0.40
5.0	0.60
6.0	0.80
7.0	0.90
8.0	0.95
9.0	0.99
10.0	0.999

This function gives the probability the enemy learns in one time period as a function of his losses. For example, if the enemy has ten penetrating aircraft and nine or ten of them are shot down (killed by missiles) his probability of learning that the missiles are effective

is very high. On the other hand, if only one or two aircraft are lost out of the first ten penetrating aircraft the enemy has a low probability of learning the missiles are effective. The loss figures and their respective probabilities represent more than just the fact that the enemy is unsure of the missile's effectiveness. If the enemy lost five out of ten aircraft he would be quite sure the missiles are effective, but he may also desire to try slightly different flight profiles or other means of reducing his losses before coming to the conclusion that the missiles are indeed effective.

For the second and succeeding "time periods" the probability the enemy learns was calculated by the following formula:

$$PLEARN = PL_S + [\, 1 - PL_S \,]\, P_{TP}$$

where

$PLEARN$ = Probability of learning by this time period

PL_S = Probability of learning by succeeding time period

$[1 - PL_S)$ = Probability of not learning by succeeding time period

P_{TP} = Additional probability factor for learning in this time period obtained by entering the learning function with the losses sustained in this time period.

and $0 \quad PLEARN \quad 1$

The probability of learning is a non-decreasing function of time. Therefore the enemy has the knowledge from all past periods plus the knowledge gained in the current time period. This cumulative learning formula allows the enemy to eventually learn, even for small PSSK's, that the missiles are effective. For example, consider a steady loss rate of two aircraft out of each ten (two in each "time

period"). In the first "time period" the probability the enemy learns is found by entering the learn function with the two losses to find a probability the enemy has learned equal to 0.10. Using the previously stated cumulative learn formula the probability the enemy learns is shown for the first through the seventh "time periods."

Time period	1	2	3	4	5	6	7
Cumulative probability of learning	.1	.19	.28	.35	.41	.47	.53

This shows that while the one time loss of two out of ten aircraft is not very indicative of the enemy learning, that the continued loss of two out of ten will lead the enemy to having a much higher probability of being able to evaluate the system's effectiveness.

This learning function and cumulative learning formula represents probabilistically when the enemy learns the missiles are effective and when he will launch an attack on the battalion since it was shown he would attack the battalion once he learned the missiles were effective. This function represents the time of learning as a function of the enemy attack rate rather than in standard time units. This method of representation accounts for variances that could occur in the enemy launch rate. For instance, if the enemy only launches one aircraft per day he isn't going to gain much information for a long time (and none for ten days by this function). If the enemy launches one aircraft per minute he is going to learn in a very short time span that the missiles are effective if he is sustaining losses from them.

4. Computation of Missile Expenditures Prior to the Enemy Learning the Missiles are Effective

A Monte Carlo computer simulation, similar to that described in paragraph III. B. 1, was used to compute the number of missiles the battalion would expend prior to the enemy learning the missiles are effective. This program makes use of the learning function and cumulative learning formula described in the previous section to ascertain, using the Monte Carlo technique, when the enemy actually learns the missiles are effective. To illustrate this technique, consider that ten aircraft successfully penetrate the fighter defense and become possible missile targets. After the first ten aircraft have either been engaged by the missiles or not engaged due to not being detected or tracked by the missiles the losses out of these ten aircraft due to the missiles are calculated. With these losses the learn function is entered to obtain the enemy's probability of learning. A random number is then drawn by the computer from a random number generator and compared to the probability the enemy learned. If the random number drawn is greater than the probability that the enemy learned the enemy is considered not to have learned. If the random number is less than or equal to the probability the enemy learned the enemy is considered to have learned. This is done for the first and succeeding time periods using the cumulative learn formula for the second and succeeding time periods in place of the learn function to obtain the enemy's probability of having learned. The total missiles expended is printed, along with other information, whenever the enemy learns the missiles are effective or whenever the threat is completely destroyed.

This program also prints the number of enemy aircraft destroyed by friendly aircraft, the number of aircraft destroyed by missiles, the number of aircraft not tracked, the number of aircraft not detected, and the time period during which the enemy learned the missiles were effective as well as the number of missiles expended.

One hundred runs for each value of PSSK, which was varied from 0. 1 to 1. 0 in increments of 0. 1, was run for a threat of 100 aircraft. The results of this program were used to compute the mean number of missiles expended prior to the enemy learning. In no case were all 100 aircraft destroyed prior to the enemy learning the missiles were effective, so no greater threat was considered and the same results hold for any threat greater than 100. The mean number of missiles expended prior to the enemy learning they are effective versus the PSSK is shown in Figure 4. The second computer program was used to obtain these results.

5. Calculation of Total Missile Expenditures When the Enemy Attacks the Battalion After Learning the Missiles Are Effective

Using the information determined in paragraph III. B. 4 on expenditures made prior to the enemy learning and from paragraph III. B. 2 on expenditures made during the attack until the missile battalion is destroyed, the total expenditures required are simply an addition of these two previously computed values for each PSSK. This addition was performed and Figure 5 graphically depicts these results.

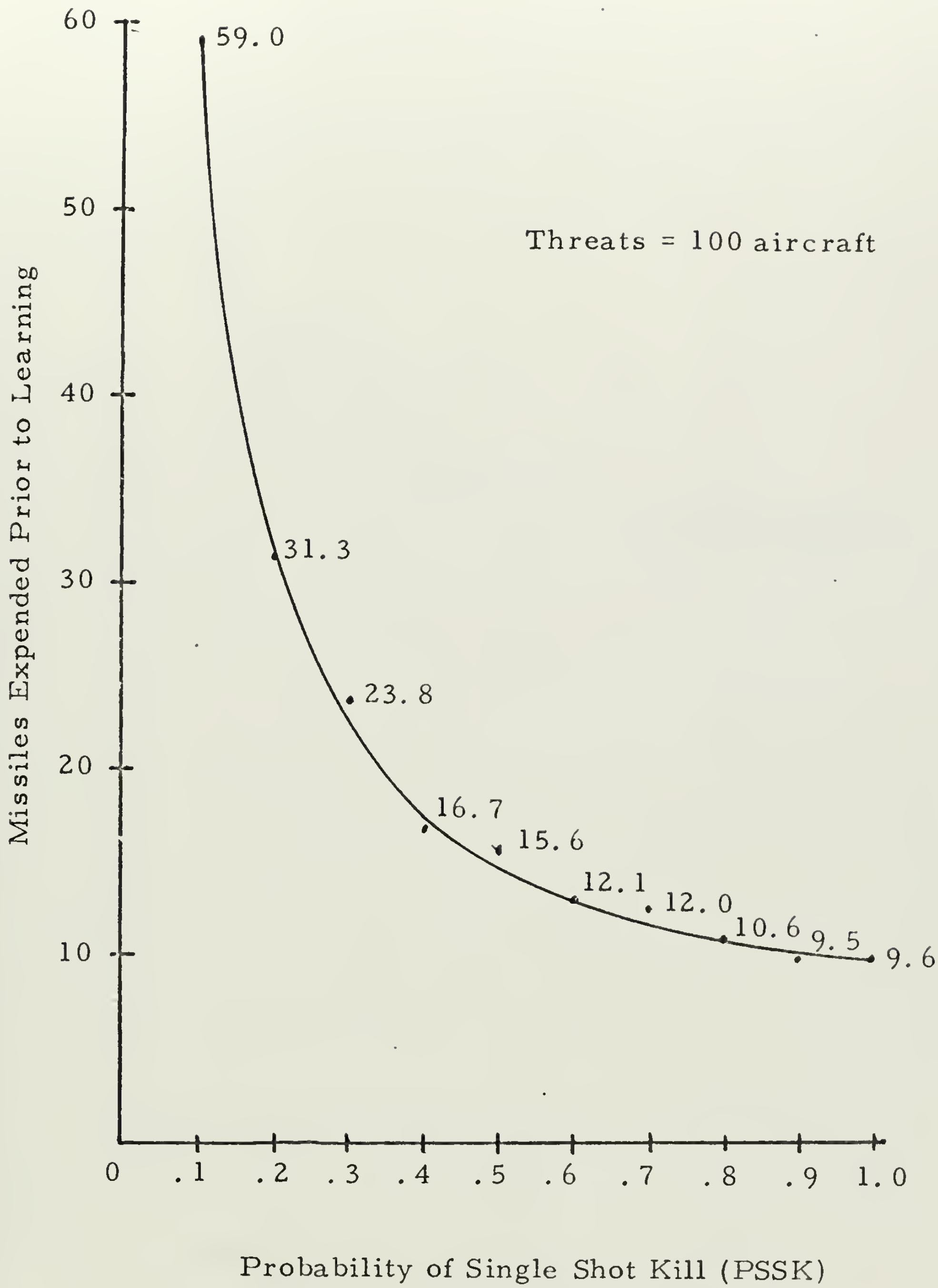

Figure 4. Mean Missile Expenditures Versus PSSK Prior to Enemy Learning Missiles are Effective.

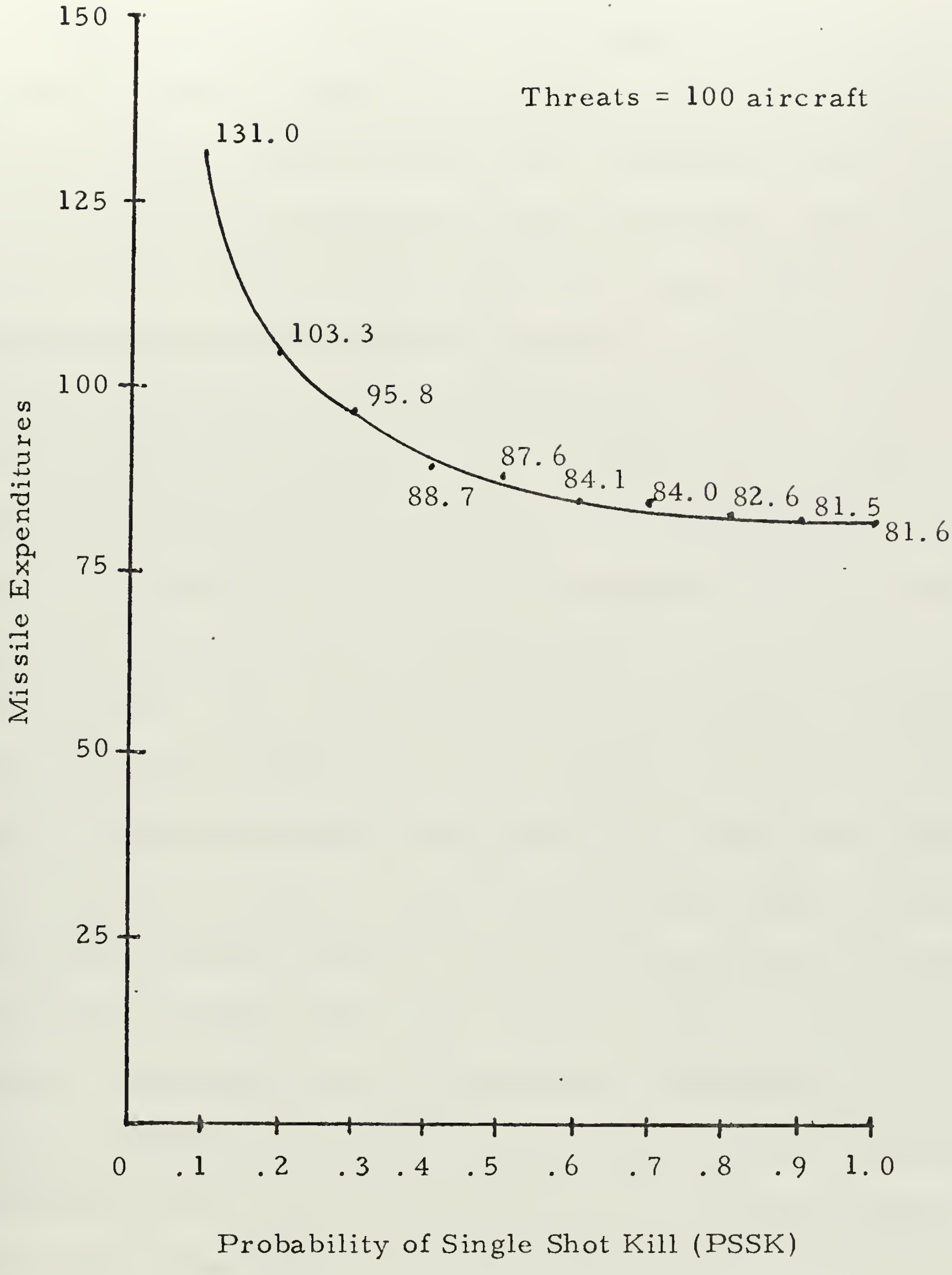

Figure 5. Mean Missile Expenditures Versus PSSK When Enemy Attacks the Battalion After Learning the Missiles are Effective.

IV. RESULTS

Figure 6 shows the results of paragraphs III. B. 1 and III. B. 5 on the same graph for comparison purposes. The top line may be considered an upper limit on mean missile expenditures since missiles are fired until all the enemy aircraft are destroyed. The graph is for the threat of 100 aircraft and this mean upper limit will increase as the threat increases and would decrease as the threat decreases. A lower bound, under the assumed vulnerability of the missile units, is the number of missiles that could be fired if the enemy were to immediately attack the battalion prior to any other targets. This figure was found to be 72 missiles. This lower bound does not vary with the threat unless the enemy does not have the resources to mount such an attack. This case was not considered since it is doubtful missiles would be deployed in such a situation. Opposing a rational, intelligent enemy the actual requirements are within these bounds. The lower line in Figure 6 represents the mean missiles expended under the assumptions that the enemy started with no previous knowledge of the systems effectiveness and learned in accordance with his losses. This mean does not increase for a threat greater than 100 aircraft. While this line represents the mean number of missiles expended it does not give the figure to use for planning purposes. Since it is a mean, there is a 50 percent chance that more missiles will be required in a given battle than this plotted figure. The planner must therefore establish a goal of what he desires the probability of having enough missiles to be set at. Economical, logistical, and tactical consequences must be considered when establishing this goal.

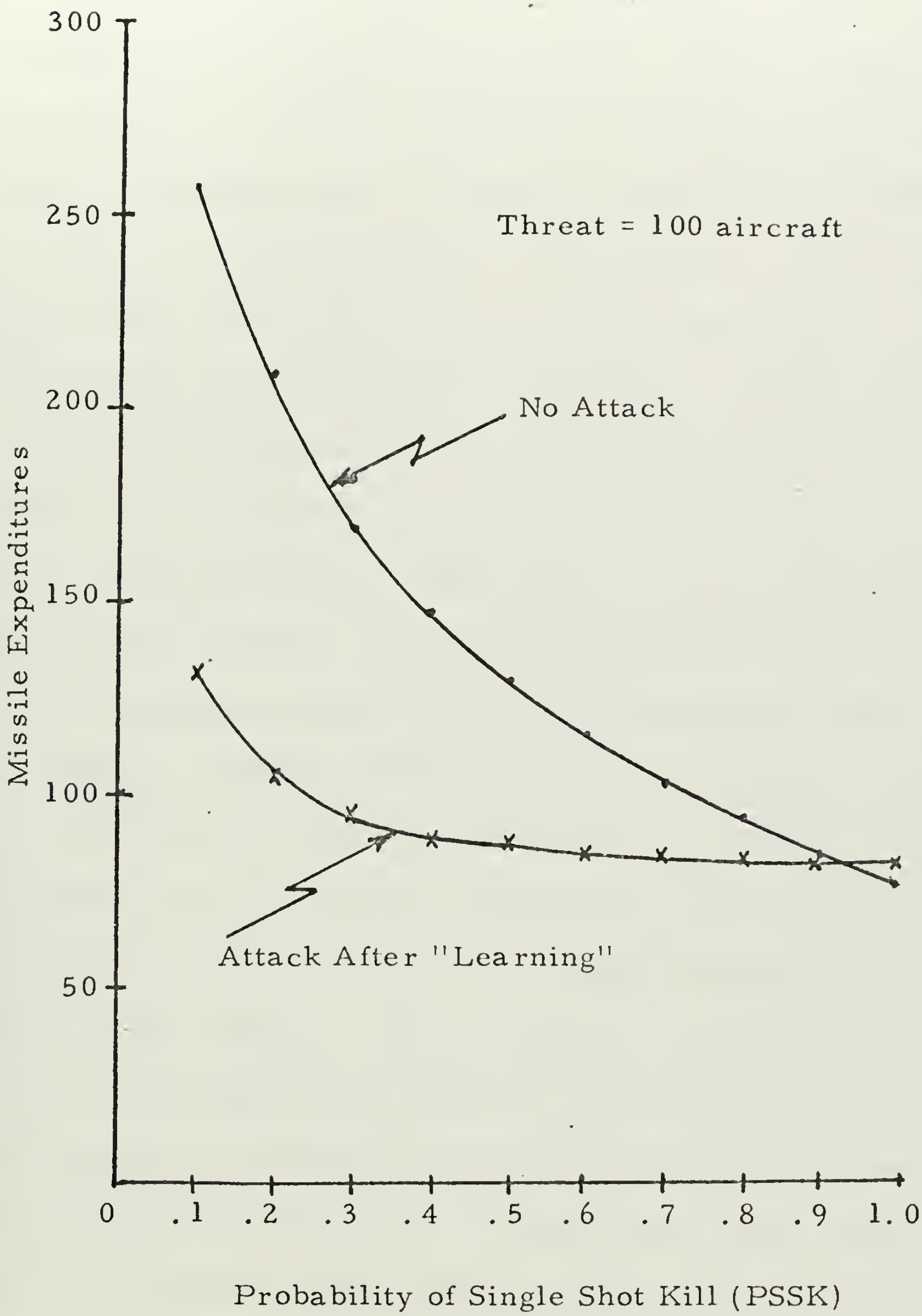

Figure 6. Mean Missile Expenditures Versus PSSK for No Attack and Attack After Learning Cases.

No attempt was made in this paper to establish this goal. However, by appealing to the Central Limit Theorem and assuming each computer run independent, computations were made to obtain missile expenditure figures for two chosen goals. Figure 7 displays the mean expenditures and the expenditure requirements such that the probability that the number of missiles plotted will be adequate for goal figures of 80 and 95 percent. For example, with a PSSK of 0.5 the probability that 101 missiles are adequate is equal to 0.95 and the probability that 95 missiles are adequate is equal to 0.80.

Even after this goal is established the planner must still choose a value of PSSK with which to enter the graph to obtain one figure to use for planning purposes. The problem of determining this figure has not been simplified. But note that the expenditures computed using the supplied program with its corresponding rationale are not as sensitive to changing PSSKs as were past methods and do not vary at all for threat increases over 100 aircraft. Therefore the planner is not likely to be as far off in his predicted requirements as he previously would be for the same mistake in determining an incorrect PSSK. Figure 8 shows missile expenditures for values of PSSK of 0.3 to 0.7 (considered the most likely values for this parameter) under the assumption of no attack as in past methods, and by the new method with a probability goal of 0.95. If the planner chose a value of PSSK equal to 0.7 and the actual results in combat were 0.3 his computed requirements would have been understated by 67 missiles by past methods and only by 28 missiles the new way. This may also be viewed in the opposite way of planning on a PSSK of 0.3 and having 0.7 in combat. The difference in costs of 67 missiles versus 28

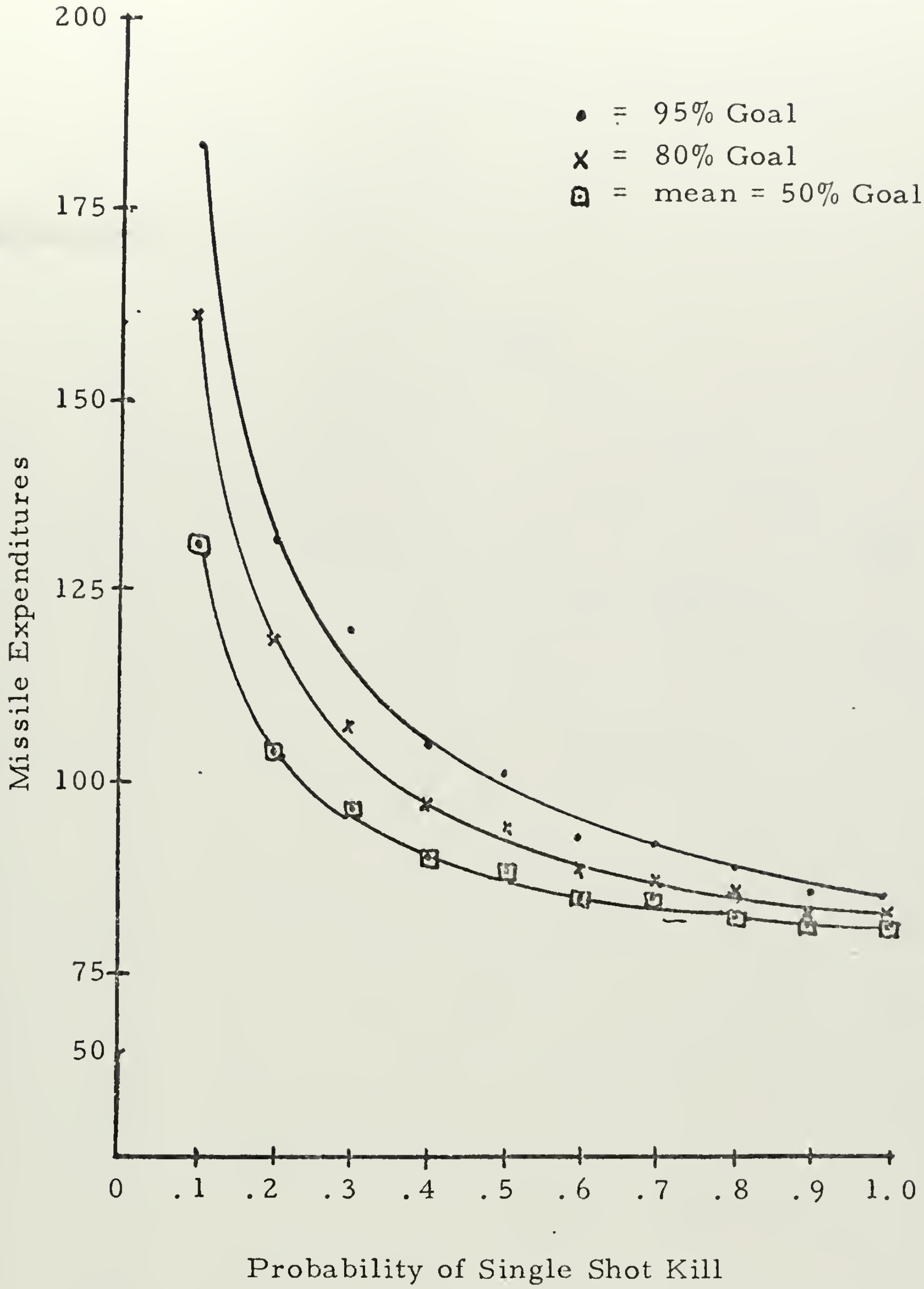

Figure 7. Missile Expenditure Versus PSSK for Planning Adequacy Goals of 50, 80, and 95 percent.

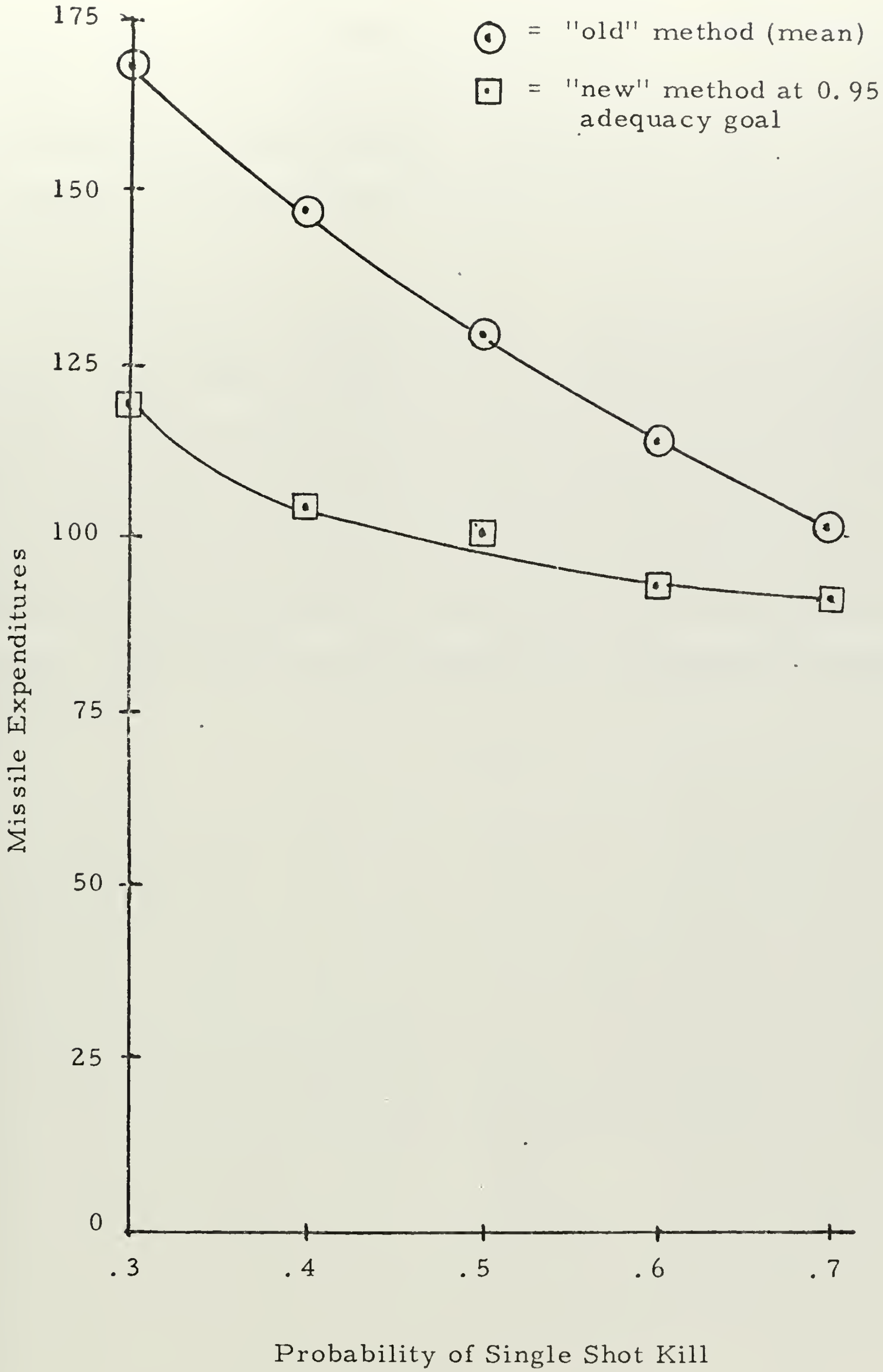

Figure 8. Missile Expenditures Versus PSSK by "New" and "Old" Methods.

missiles is the cost of being conservative in his planning figures. Conservative here refers to the planner's attitude in assuring himself that he has enough missiles by being conservative in his choice of PSSK. Therefore a planner can be more conservative at a much lower cost.

No threats under 100 aircraft were considered in this study. A lower limit threat to which the new methodology can be applied and be an improvement over past methods was not investigated. When the threat gets small it becomes debatable whether missiles will be employed at all since current doctrine states that the amphibious assault must have air superiority prior to being conducted. Hence, small threats can be satisfactorily confronted by fighter aircraft.

V. CONCLUSIONS

This thesis has developed a methodology for predicting the surface-to-air missile expenditure requirements for a United States Marine Corps missile battalion. By insertion of the correct parameter values, representative of a current or future semi-active, short range missile system, into the supplied computer program the planner is provided missile expenditure figures as a function of the Probability of Single Shot Kill (PSSK). Through analysis of the data supplied from the program the planner has available the necessary information to make a sound decision on what figure to use for planning purposes. This model does not provide a single figure result, as logistic and economic considerations that may have a bearing on the actual figure chosen were not considered in the data presented. These considerations are to be used in conjunction with the computer results to obtain the one necessary planning figure.

A. ADVANTAGES OF NEW METHOD

The model presented in this paper has the following advantages when compared with previous methods used in predicting missile expenditures.

It is flexible in that it can easily be modified to include changes in weapon characteristics, firing doctrines, and enemy tactics by modifying the computer program.

It is economical to use. The model presented only requires the insertion of correct parameter values and some minor calculations to provide the planner with the necessary information. Because of

its simplicity the modifications to achieve the flexibility mentioned above are easily made by any programmer familiar with Fortran and the model.

The results of the model are not as sensitive to the threat nor the precise PSSK figure that the planner chooses to use. In most cases the results will not vary at all with the threat. This is a distinct advantage due to the difficulty of predicting correct values for these parameters.

This model considers the enemy's capability to attack and destroy the missile units. It is a waste of scarce resources to buy missiles for a unit above its foreseeable lifetime requirements. This is a serious consideration and will be a factor in determining requirements until missile units can be made invulnerable to attack.

B. DISADVANTAGES

The model presented has the following disadvantage. It requires the user to predict how fast the enemy will learn the missiles are effective and thereby when he will attack the battalion. It was not necessary to do this in past methodologies since the enemy tactics were not considered. No apparent method except subjective reasoning is known to devise this learning rate. If the devised function represents too slow a learning rate the requirements will be overstated and if it represents too fast a learning rate the requirements will be understated. Note, however, that even a very slow learning rate will be better than previous methods that did not consider the enemy's learning at all.

C. RECOMMENDATIONS

It is recommended that the appropriate United States Marine Corps planning agency evaluate this new proposed methodology for predicting missile expenditures for possible adoption. A comparison of results from this method and from existing methods now in use will give the decision maker more information with which to carry out intelligent planning.

APPENDIX A

CALCULATION OF MAXIMUM NUMBER OF SEPARATE ENGAGEMENTS BY ONE TRACKING RADAR DURING ATTACK

Let

TOF = Time of Flight of Missile

MSLVEL = Average Missile Velocity
(Assumed constant at 1200 mph or 1/3 mile/second)

LIR = Last Intercept Range

NIR = Next Intercept Range

ACVEL = Attacking Aircraft Velocity
(Assumed constant = 600 mph or 1/6 mile/second)

TMST = Time to Switch Targets or Refire at same target

Then

1st Intercept = 25 miles (maximum intercept range of system)

NIR = TOF X MSLVEL

and

TOF (MSLVEL + ACVEL) = LIR - ACVEL (TMST)

or substituting constants and simplifying

TOF (1/3 + 1/6) = LIR - 10/6

TOF = 2 (LIR - 5/3)

NIR = 2/3 (LIR - 5/3)

hence

2nd Intercept Range = 2/3(25-5/3) = 15.56 miles

3rd Intercept Range = 2/3(15.56-5/3) = 9.26 miles

4th Intercept Range = 2/3(9.26 - 5/3) = 5.26 miles

5th Intercept Range $= 2/3\,(5.26 - 5/3) = 2.37$ miles

NOTE: Fifth Intercept range is less than the minimum intercept range of the missile system and can't take place.

APPENDIX B

ANALYTIC CALCULATION OF THE MISSILES EXPENDED WHEN ENEMY DOES NOT ATTACK THE BATTALION

This analytic model calculates missile expenditures under the same assumptions as used in the computer simulation when the enemy does not attack the missile battalion.

Each aircraft entering the AOA is first engaged by fighters. If the aircraft survives the fighters it becomes a possible missile target. The missiles then engage the target with a single missile if the target is detected and tracked. Assuming independence between weapon systems and each aircraft run the following formula gives the probability of aircraft kill on each run.

$$PK = PFK + (1-PFK)(PDET)(PTRK)\,PSSK$$

where

PK	=	Probability aircraft killed on any one flight
PFK	=	Probability aircraft killed by fighters
(1-PFK)	=	Probability aircraft survives fighters
PDET	=	Probability aircraft is detected
PTRK	=	Probability aircraft is tracked
PSSK	=	Probability of missile kill for one missile

Then the number of flights until a kill is achieved may be viewed as the observed value of a geometric random variable with parameter PK (probability of kill on a given flight). Of interest is the quantity $\frac{1}{PK}$ which is the mean or expected number of flights until the aircraft is killed.

Then

$$ETF = \frac{1}{PK} N$$

when

ETF = Expected total flights by enemy

N = Number of enemy threat aircraft

and

EFK = PFK [ETF]

where EFK = Expected fighter kills

Then

PMT = ETP - EFK

where

PMT = Possible missile targets

and missile expenditures (ME) may be calculated as follows:

$$ME = PMT \times PDET \times PTRK \qquad (1)$$

since missiles will not be fired at aircraft that are not detected or are not tracked.

Rewriting (1) and substituting one obtains

$$ME = \frac{1}{PK} N (1-PFK) \times PDET \times PTRK \qquad (2)$$

Using (2) and the same values as in simulation scenario for PFK, PDET, PTRK and a threat of 100 aircraft the missile expenditures in table 2 are obtained. Also shown in table 2 are the expenditures obtained from the simulation under the same conditions.

PSSK	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Analytic Expenditures	266	210	173	148	128	114	102	93	85	78
Simulation Expenditures	257	208	168	147	129	114	101	93	84	76

Table 2. Comparison of Expenditure Results From Analytic and Simulation Methods.

```
COMPUTER PROGRAM ONE
THIS PROGRAM COMPUTES MISSILE EXPENDITURES WHEN
THE ENEMY AIRCRAFT DO NOT ATTACK THE MISSILE BATTALION
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      NAMELIST/VARBLE/NTRKRF,PSSK,ENINV
      RNINT=URN(0)
      DO 9999 J=1,100
      N=0
      MAXEV=100
      FTRKIL=0
      ACNDET=0
      SUCPEN=0
      NACTRK=0
      MSLFIR=0
      MSLMIS=0
      MINVEL=300
      MAXVEL=800
      MAXDRG=100
      MINDRG=5
      MSLRG=25
      MSLVEL=1200
      PFK=0.20
      PDET=0.95
      PTRK=0.95
      NREAD=5
      NWRITE=6
      DO 100 I=1,100
  100 ECAL(I,1)=999999999
      CALL SNE(1,1,1,200,500,1,0,0)
      READ (NREAD,VARBLE)
      WRITE (NWRITE,2001) NTRKRF
 2001 FORMAT (' NUMBER OF TRACKING RADARS USED=',I12)
      WRITE (NWRITE,2002) PSSK
 2002 FORMAT (' SINGLE SHOT KILL PROBABILITY=',F15.4)
      WRITE (NWRITE,2003) ENINV
 2003 FORMAT (' INITIALL ENEMY INVENTORY=',I12)
 1000 CALL TNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO (1001,1002,1003,1004,1005,1006),EN
 1001 CALL EVENT1(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1002 CALL EVENT2(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1003 CALL EVENT3(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1004 CALL EVENT4(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1005 CALL EVENT5(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1006 CALL EVENT6(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1111 IF(ENINV.GT.0) GO TO 1000
      WRITE (NWRITE,3001) FTRKIL
 3001 FORMAT (' NUMBER OF ENEMY KILLED BY FIGHTERS=',I12)
      WRITE (NWRITE,3002) ACNDET
 3002 FORMAT (' NUMBER OF AIRCRAFT NOT DETECTED=',I12)
      WRITE (NWRITE,3003) SUCPEN
 3003 FORMAT (' NUMBER OF SUCCESSFUL PENETRATIONS=',I12)
      WRITE (NWRITE,3004) NACTRK
 3004 FORMAT (' NUMBER OF AIRCRAFT NOT TRACKED=',I12)
      WRITE (NWRITE,3005) MSLMIS
 3005 FORMAT (' NUMBER OF MISSILES THAT MISSED=',I12)
      WRITE (NWRITE,3006) MSLFIR
 3006 FORMAT (' TOTAL NUMBER OF MISSILES EXPENDED=',I12)
```

```
9999 CONTINUE
     END

     SUBROUTINE SNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
     IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
     COMMON/ECAL/ECAL(100,8)
     COMMON/SIM/N,MAXEV
     COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
    CMSLMIS
     COMMON/ACDATA/MINVEL,MAXVEL,ENINV
     COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
     COMMON/MSLDAT/MSLRG,MSLVEL
     COMMON/PROB/PFK,PDET,PTRK,PSSK
     COMMON/IOUNIT/NREAD,NWRITE
     IF(N.EQ.MAXEV) GO TO 1
     I=1
   4 IF(ECAL(I,1)-999999999)2,3,2
   3 ECAL(I,1)=ET
     ECAL(I,2)=EN
     ECAL(I,3)=ACN
     ECAL(I,4)=IRG
     ECAL(I,5)=VEL
     ECAL(I,6)=VEL
     ECAL(I,7)=DET
     ECAL(I,8)=TRACK
     N=N+1
     RETURN
   2 I=I+1
     GO TO 4
   1 WRITE (NWRITE,2000)
2000 FORMAT (' WARNING...THE EVENT CALENDAR IS FILLED UP.')
     STOP
     END

     SUBROUTINE TNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
     IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
     COMMON/ECAL/ECAL(100,8)
     COMMON/SIM/N,MAXEV
     COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
    CMSLMIS
     COMMON/ACDATA/MINVEL,MAXVEL,ENINV
     COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
     COMMON/MSLDAT/MSLRG,MSLVEL
     COMMON/PROB/PFK,PDET,PTRK,PSSK
     COMMON/IOUNIT/NREAD,NWRITE
     IF(N.EQ.0) GO TO 100
     M=N
     I=1
     TEST=999999999
   1 IF(ECAL(I,1).GE.TEST) GO TO 2
     TEST=ECAL(I,1)
     MARK=I
   2 IF(ECAL(I,1).EQ.999999999) GO TO 3
     M=M-1
   3 IF(M.EQ.0) GO TO 4
     I=I+1
     GO TO 1
   4 ET=ECAL(MARK,1)
     EN=ECAL(MARK,2)
     ACN=ECAL(MARK,3)
     IRG=ECAL(MARK,4)
     VEL=ECAL(MARK,5)
     ALIVE=ECAL(MARK,6)
     DET=ECAL(MARK,7)
     TRACK=ECAL(MARK,8)
     N=N-1
     ECAL(MARK,1)=999999999
     RETURN
 100 WRITE (NWRITE,2000)
2000 FORMAT (' EVENT CALENDAR EMPTTY')
```

```
      STOP
      END


      SUBROUTINE EVENT1(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      NET=ET+5
      NRG=200
      RNVEL=MINVEL+URN(1)*(MAXVEL-MINVEL)
      NVEL=IFIX(RNVEL)
      CALL SNE(NET,1,ACN+1,NRG,NVEL,1,0,0)
      RNFK=URN(1)
      IF (RNFK.LE.PFK) GO TO 1000
      RET=ET+(200-MAXDRG)/(VEL/60)
      TMXDET=IFIX(RET)
      CALL SNE(TMXDET,2,ACN,IRG,VEL,ALIVE,DET,TRACK)
      RETURN
 1000 FTRKIL=FTRKIL+1
      ENINV=ENINV-1
      RETURN
      END


      SUBROUTINE EVENT2(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      RNDET=URN(1)
      IF (RNDET.GE.PDET) GO TO 1000
      RGDET=MINDRG+URN(1)*(MAXDRG-MINDRG)
      RTDET=ET+(MAXDRG-RGDET)/(VEL/60)
      DETRG=IFIX(RGDET)
      TDET=IFIX(RTDET)
      CALL SNE(TDET,3,ACN,DETRG,VEL,1,1,0)
      RETURN
 1000 ACNDET=ACNDET+1
      SUCPEN=SUCPEN+1
      RETURN
      END


      SUBROUTINE EVENT3(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      RNTRK=URN(1)
      IF (RNTRK.GE.PTRK) GO TO 1000
      RGTRK=IRG-(VEL/60)*URN(1)
      RTTRK=ET+(IRG-RGTRK)/(VEL/60)
```

```
      TRKRG=IFIX(RGTRK)
      TTRK=IFIX(RTTRK)
      CALL SNE(TTRK,4,ACN,TRKRG,VEL,1,1,0)
      RETURN
 1000 NACTRK=NACTRK+1
      SUCPEN=SUCPEN+1
      RETURN
      END


      SUBROUTINE EVENT4(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      IF (NTRKRF.LE.0) GO TO 1000
      NTRFRF=NTRFRF-1
      RGFIRE=MSLRG+(MSLRG/MSLVEL)*VEL
      IRGFIR=IFIX(RGFIRE)
      ARGFIR=MINO(IRGFIR,IRG)
      RTFIR=ET+(IRG-ARGFIR)/(VEL/60)
      TFIR=IFIX(RTFIR)
      CALL SNE(TFIR,5,ACN,ARGFIR,VEL,1,1,1)
      RETURN
 1000 CALL SNE(ET+1,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      RETURN
      END


      SUBROUTINE EVENT5(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      MSLFIR=MSLFIR+1
      RGINT=IRG/(MSLVEL+VEL)*MSLVEL
      IRGINT=IFIX(RGINT)
      RTINT=ET+(IRG-IRGINT)/(VEL/60)
      TINT=IFIX(RTINT)
      CALL SNE(TINT,6,ACN,IRGINT,VEL,1,1,1)
      RETURN
      END


      SUBROUTINE EVENT6(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/FTRKIL,ACNDET,SUCPEN,NACTRK,MSLFIR,
     CMSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK
      COMMON/IOUNIT/NREAD,NWRITE
      RNK=URN(1)
      IF (RNK.GT.PSSK) GO TO 1000
      ENINV=ENINV-1
      NTRKRF=NTRKRF+1
      RETURN
```

```
1000 SUCPEN=SUCPEN+1
     MSLMIS=MSLMIS+1
     NTRKRF=NTRKRF+1
     RETURN
     END
```

COMPUTER PROGRAM NUMBER TWO
THIS PROGRAM COMPUTES MISSILES EXPENDED, BY TIME PERIOD AND UNTIL THE ENEMY LEARNS THE MISSILES ARE EFFECTIVE.
MAIN PROGRAM

```
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      COMMON/PERD/TIMPER,START
      COMMON/ENG/NPENG
      NAMELIST/VARBLE/NTRKRF,PSSK,ENINV
      RNINT=URN(0)
      DO 9000 J=1,100
      N=0
      MAXEV=100
      TOTMK=0
      TOTFK=0
      ACNDET=0
      SUCPEN=0
      NACTRK=0
      MSLFIR=0
      MSLMIS=0
      MINVEL=300
      MAXVEL=800
      MAXDRG=100
      MINDRG=5
      MSLRG=25
      MSLVEL=1200
      FTRKIL=0
      MSLKIL=0
      PFK=0.20
      PDET=0.95
      PTRK=0.95
      PLEARN=0.0
      NREAD=5
      NWRITE=6
      TIMPER=0
      START=0
      NPENG=0
      READ (NREAD,VARBLE)
      DO 100 I=1,100
  100 ECAL(I,1)=999999999
      CALL SNE(1,1,1,200,500,1,0,0)
      WRITE (NWRITE,2001) NTRKRF
 2001 FORMAT (' NUMBER OF TRACKING RADARS USED=',I12)
      WRITE (NWRITE,2002) PSSK
 2002 FORMAT (' SINGLE SHOT KILL PROBABILITY=',F15.4)
      WRITE (NWRITE,2003) ENINV
 2003 FORMAT (' INITIALL ENEMY INVENTORY=',I12)
 1000 CALL TNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO (1001,1002,1003,1004,1005,1006),EN
 1001 CALL EVENT1(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1002 CALL EVENT2(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IF (START.EQ.1) GO TO 4000
      GO TO 1111
 1003 CALL EVENT3(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IF (START.EQ.1) GO TO 4000
      GO TO 1111
 1004 CALL EVENT4(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1005 CALL EVENT5(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      GO TO 1111
 1006 CALL EVENT6(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IF (START.EQ.1) GO TO 4000
```

```
      GO TO 1111
4000  TIMPER=TIMPER+1
      WRITE (NWRITE,4020) TIMPER
4020  FORMAT (' TIME PERIOD=',I12)
      WRITE (NWRITE,4030) FTRKIL
4030  FORMAT (' FIGHTER KILLS FOR THIS PERIOD =',I12)
      WRITE (NWRITE,4040) MSLKIL
4040  FORMAT (' MISSILE KILLS FOR THIS PERIOD =',I12)
      TOTFK=TOTFK+FTRKIL
      TOTMK=TOTMK+MSLKIL
      IF (TIMPER.GT.1) GO TO 4050
      IF (MSLKIL.EQ.0) GO TO 4045
      PLEARN=PLPER(MSLKIL)
      GO TO 4060
4045  PLEARN=0.0
      GO TO 4060
4050  IF (MSLKIL.EQ.0) GO TO 4060
      PLEARN=PLEARN+PLPER(MSLKIL)*(1-PLEARN)
4060  FTRKIL=0
      MSLKIL=0
      WRITE (NWRITE,4070) PLEARN
4070  FORMAT (' PROBABILITY THE ENEMY LEARNED BY THIS TIME
     C=',G12.4)
      RNLEAR=URN(1)
      IF (RNLEAR.GE.PLEARN) GO TO 4170
      WRITE (NWRITE,4080) TIMPER
4080  FORMAT (' ENEMY LEARNED MISSILES EFFECTIVE IN PERIOD
     C=',I12)
      WRITE (NWRITE,4090) TOTFK
4090  FORMAT (' TOTAL FIGHTER KILLS=',I12)
      WRITE (NWRITE,4100) ACNDET
4100  FORMAT (' NUMBER OF AIRCRAFT NOT DETECTED=',I12)
      WRITE (NWRITE,4110) SUCPEN
4110  FORMAT (' NUMBER OF SUCCESSFUL PENETRATIONS =',I12)
      WRITE (NWRITE,4120) NACTRK
4120  FORMAT (' NUMBER OF AIRCRAFT NOT TRACKED=',I12)
      WRITE (NWRITE,4130) MSLMIS
4130  FORMAT (' NUMBER OF MISSILES THAT MISSED =',I12)
      WRITE (NWRITE,4140) MSLFIR
4140  FORMAT (' TOTAL NUMBER OF MISSILES EXPENDED=',I12)
      WRITE (NWRITE,4150) TOTMK
4150  FORMAT (' TOTAL MISSILES THAT KILLED=',I12)
      WRITE (NWRITE,4160) TIMPER
4160  FORMAT (' PROGRAM ENDS BECAUSE ENEMY LEARNED
     CIN TIME PERIOD=',I12)
      GO TO 9000
4170  WRITE (NWRITE,4180) TIMPER
4180  FORMAT (' ENEMY DID NOT LEARN IN TIME PERIOD=',I12)
      START=0
      NPENG=0
      GO TO 1111
1111  IF(ENINV.GT.0) GO TO 1000
      WRITE (NWRITE,3000) ENINV
3000  FORMAT (' PROGRAM STOPS BECAUSE ENEMY INVENTORY=',I12)
      WRITE (NWRITE,3001) TOTFK
3001  FORMAT (' TOTAL FIGHTER KILLS=',I12)
      WRITE (NWRITE,3002) ACNDET
3002  FORMAT (' NUMBER OF AIRCRAFT NOT DETECTED=',I12)
      WRITE (NWRITE,3003) SUCPEN
3003  FORMAT (' NUMBER OF SUCCESSFUL PENETRATIONS=',I12)
      WRITE (NWRITE,3004) NACTRK
3004  FORMAT (' NUMBER OF AIRCRAFT NOT TRACKED=',I12)
      WRITE (NWRITE,3005) MSLMIS
3005  FORMAT (' NUMBER OF MISSILES THAT MISSED=',I12)
      WRITE (NWRITE,3006) MSLFIR
3006  FORMAT (' TOTAL NUMBER OF MISSILES EXPENDED=',I12)
      WRITE (NWRITE,3007) TOTMK
3007  FORMAT (' TOTAL MISSILE  KILLS=',I12)
9000  CONTINUE
      END
```

```
      SUBROUTINE SNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      IF(N.EQ.MAXEV) GO TO 1
      I=1
    4 IF(ECAL(I,1)-999999999)2,3,2
    3 ECAL(I,1)=ET
      ECAL(I,2)=EN
      ECAL(I,3)=ACN
      ECAL(I,4)=IRG
      ECAL(I,5)=VEL
      ECAL(I,6)=VEL
      ECAL(I,7)=DET
      ECAL(I,8)=TRACK
      N=N+1
      RETURN
    2 I=I+1
      GO TO 4
    1 WRITE (NWRITE,2000)
 2000 FORMAT (' WARNING...THE EVENT CALENDAR IS FILLED UP.')
      STOP
      END

      SUBROUTINE TNE(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      IF(N.EQ.0) GO TO 100
      M=N
      I=1
      TEST=999999999
    1 IF(ECAL(I,1).GE.TEST) GO TO 2
      TEST=ECAL(I,1)
      MARK=I
    2 IF(ECAL(I,1).EQ.999999999) GO TO 3
      M=M-1
    3 IF(M.EQ.0) GO TO 4
      I=I+1
      GO TO 1
    4 ET=ECAL(MARK,1)
      EN=ECAL(MARK,2)
      ACN=ECAL(MARK,3)
      IRG=ECAL(MARK,4)
      VEL=ECAL(MARK,5)
      ALIVE=ECAL(MARK,6)
      DET=ECAL(MARK,7)
      TRACK=ECAL(MARK,8)
      N=N-1
      ECAL(MARK,1)=999999999
      RETURN
```

```
 100 WRITE (NWRITE,2000)
2000 FORMAT (' EVENT CALENDAR EMPTTY')
     STOP
     END


     SUBROUTINE EVENT1(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
     IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
     COMMON/ECAL/ECAL(100,8)
     COMMON/SIM/N,MAXEV
     COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
    CMSLFIR,MSLMIS
     COMMON/ACDATA/MINVEL,MAXVEL,ENINV
     COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
     COMMON/MSLDAT/MSLRG,MSLVEL
     COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
     COMMON/TIME/MSLKIL,FTRKIL
     COMMON/IOUNIT/NREAD,NWRITE
     NET=ET+5
     NRG=200
     RNVEL=MINVEL+URN(1)*(MAXVEL-MINVEL)
     NVEL=IFIX(RNVEL)
     CALL SNE(NET,1,ACN+1,NRG,NVEL,1,0,0)
3200 RNFK=URN(1)
     IF (RNFK.LE.PFK) GO TO 1000
     RET=ET+(200-MAXDRG)/(VEL/60)
     TMXDET=IFIX(RET)
     CALL SNE(TMXDET,2,ACN,IRG,VEL,ALIVE,DET,TRACK)
     RETURN
1000 FTRKIL=FTRKIL+1
     ENINV=ENINV-1
     RETURN
     END


     SUBROUTINE EVENT2(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
     IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
     COMMON/ECAL/ECAL(100,8)
     COMMON/SIM/N,MAXEV
     COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
    CMSLFIR,MSLMIS
     COMMON/ACDATA/MINVEL,MAXVEL,ENINV
     COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
     COMMON/MSLDAT/MSLRG,MSLVEL
     COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
     COMMON/TIME/MSLKIL,FTRKIL
     COMMON/IOUNIT/NREAD,NWRITE
     COMMON/PERD/TIMPER,START
     COMMON/ENG/NPENG
     RNDET=URN(1)
     IF (RNDET.GE.PDET) GO TO 1000
2000 RGDET=MINDRG+URN(1)*(MAXDRG-MINDRG)
     RTDET=ET+(MAXDRG-RGDET)/(VEL/60)
     DETRG=IFIX(RGDET)
     TDET=IFIX(RTDET)
     CALL SNE(TDET,3,ACN,DETRG,VEL,1,1,0)
     RETURN
1000 ACNDET=ACNDET+1
     SUCPEN=SUCPEN+1
     NPENG=NPENG+1
     IF (NPENG.EQ.10) GO TO 1100
     RETURN
1100 START=1
     RETURN
     END
```

```
      SUBROUTINE EVENT3(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      CCMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      CCMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      CCMMON/MSLDAT/MSLRG,MSLVEL
      CCMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      COMMON/PERD/TIMPER,START
      CCMMON/ENG/NPENG
      RNTRK=URN(1)
      IF (RNTRK.GE.PTRK) GO TO 1000
 2000 RGTRK=IRG-(VEL/60)*URN(1)
      RTTRK=ET+(IRG-RGTRK)/(VEL/60)
      TRKRG=IFIX(RGTRK)
      TTRK=IFIX(RTTRK)
      CALL SNE(TTRK,4,ACN,TRKRG,VEL,1,1,0)
      RETURN
 1000 NACTRK=NACTRK+1
      SUCPEN=SUCPEN+1
      NPENG=NPENG+1
      IF (NPENG.EQ.10) GO TO 1100
      RETURN
 1100 START=1
      RETURN
      END

      SUBROUTINE EVENT4(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      CCMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      CCMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      CCMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      CCMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      IF (NTRKRF.LE.0) GO TO 1000
      NTRFRF=NTRFRF-1
      RGFIRE=MSLRG+(MSLRG/MSLVEL)*VEL
      IRGFIR=IFIX(RGFIRE)
      ARGFIR=MINO(IRGFIR,IRG)
      RTFIR=ET+(IRG-ARGFIR)/(VEL/60)
      TFIR=IFIX(RTFIR)
      CALL SNE(TFIR,5,ACN,ARGFIR,VEL,1,1,1)
      RETURN
 1000 CALL SNE(ET+1,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      RETURN
      END

      SUBROUTINE EVENT5(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      CCMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      CCMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      CCMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
```

```
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      MSLFIR=MSLFIR+1
      RGINT=IRG/(MSLVEL+VEL)*MSLVEL
      IRGINT=IFIX(RGINT)
      RTINT=ET+(IRG-IRGINT)/(VEL/60)
      TINT=IFIX(RTINT)
      CALL SNE(TINT,6,ACN,IRGINT,VEL,1,1,1)
      RETURN
      END


      SUBROUTINE EVENT6(ET,EN,ACN,IRG,VEL,ALIVE,DET,TRACK)
      IMPLICIT INTEGER(A-O,S,T,V-Z), REAL*4(P-R,U)
      COMMON/ECAL/ECAL(100,8)
      COMMON/SIM/N,MAXEV
      COMMON/MSLSIM/TOTFK,TOTMK,ACNDET,SUCPEN,NACTRK,
     CMSLFIR,MSLMIS
      COMMON/ACDATA/MINVEL,MAXVEL,ENINV
      COMMON/RADDAT/MAXDRG,MINDRG,NTRKRF
      COMMON/MSLDAT/MSLRG,MSLVEL
      COMMON/PROB/PFK,PDET,PTRK,PSSK,PLEARN
      COMMON/TIME/MSLKIL,FTRKIL
      COMMON/IOUNIT/NREAD,NWRITE
      COMMON/PERD/TIMPER,START
      COMMON/ENG/NPENG
      RNK=URN(1)
      IF (RNK.GT.PSSK) GO TO 1000
      MSLKIL=MSLKIL+1
      ENINV=ENINV-1
      GO TO 1100
 1000 SUCPEN=SUCPEN+1
      MSLMIS=MSLMIS+1
 1100 NPENG=NPENG+1
      NTRKRF=NTRKRF+1
      IF (NPENG.EQ.10) GO TO 1200
      RETURN
 1200 START=1
      RETURN
      END


      FUNCTION PLPER(I)
      GO TO (1001,1002,1003,1004,1005,1006,1007,1008,1009,
     C1009,1010),I
 1001 PLPER=0.05
      GO TO 1111
 1002 PLPER=0.10
      GO TO 1111
 1003 PLPER=0.20
      GO TO 1111
 1004 PLPER=0.40
      GO TO 1111
 1005 PLPER=0.60
      GO TO 1111
 1006 PLPER=0.80
      GO TO 1111
 1007 PLPER=0.90
      GO TO 1111
 1008 PLPER=0.95
      GO TO 1111
 1009 PLPER=0.99
      GO TO 1111
 1010 PLPER=0.999
 1111 RETURN
      END
```

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13. ABSTRACT

This thesis presents a computer simulation aided method for predicting expenditures of a short range, semi-active homing missile system engaged in an amphibious assault. The methodology used considers varying threat size, enemy strategy, and expected missile kill probabilities. Only a single-shot firing doctrine is considered. The results obtained, displayed for varying missile kill probabilities, provide the user with expenditure information on which to base missile procurement policy.

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