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THESIS

VERTICAL LAUNCH SYSTEM LOADOUT MODEL

by

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September, 1994

Thesis Advisor: Wayne P. Hughes, Jr.

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VERTICAL LAUNCH SYSTEM LOADOUT MODEL

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This thesis develops a model to assist in determining the surface-to-air missile (SAM) requirement for defensive firepower in a specific theater. Through the vehicles of simulation, combat and mathematical modeling we determine (1) SAM requirement for theater Air Warfare (AAW) defensive firepower, (2) Aegis equipped Vertical Launch System (VLS) battle force structure for anti-ship cruise missile (ASCM) defense, (3) Aegis equipped VLS ship loadout for AAW defense in a specific theater of operation. The model was used against a mock threat potential consisting of 60 attack aircraft, 150 air launched ASCM'S, 100 land launched ASCM'S, and 40 surface launched in the original inventory. Two cases were considered: (1) Combat Air Patrol (CAP) available to the battle force and (2) no CAP available to the battle force. In the first case, the battle force required 196 long-range SAM and five Aegis equipped VLS ships with 40 SAM each. In the second case, the battle force required 352 long-range SAM, ten Aegis equipped VLS ships with 36 SAM each.

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EXECUTIVE SUMMARY

The vertical launch system (VLS) currently employed on CG-47, DD-963, and DDG-51 class ships provides a versatile means of transporting and delivering firepower. VLS provides air warfare (AAW) defensive power through surface-to-air missiles (SAM) engaging anti-ship cruise missiles (ASCM'S). VLS provides offensive firepower through strike missiles, anti-surface (ASUW) missiles, anti-submarine vertical launched ASROC (VLA), and SAM's engaging attack aircraft.

Therefore, the tactical question is posed: Given a particular theater of operation, what is the optimal VLS load of SAM, strike, ASUW, and VLA missiles?

Theater AAW is the basis for our study. We determine the number of SAM's required in theater to provide defensive firepower for a battle force. The remaining VLS cells are available for use as offensive firepower.

First, through simulation we estimate the expected number of attack aircraft to survive a combat air patrol (CAP) engagement.

Second, we use an ordnance expenditure model programmed on a spreadsheet to determine the number of long and short-range SAM'S required in theater to provide defensive firepower for the battle force against air, surface and land launched ASCM'S. The model is based on a shoot-shoot-look engagement doctrine for the SAM'S. We also make assumptions on the single shot probability of kill (P_k) of a SAM and the point defense probability of a hard kill and probability of a soft kill.

The ordnance expenditure model is run for two cases. Case One uses the input of the CAP engagement simulation results. Case Two does not use the CAP engagement simulation results as its input. All of the attack aircraft in the wave deliver ASCM'S toward the battle force in Case Two. This gives the user a low-end and high-end surface-to-air missile requirement for theater AAW defensive firepower. The results assist the battle force commander in determining the appropriate Aegis equipped VLS battle force for the theater of operation.

Third, we use the data generated by the two cases of the ordnance expenditure model to compute the minimum number of Aegis equipped VLS ships needed in theater for each case. The minimum load of SAM'S needed for defensive firepower from each of these ships is also determined. The remaining VLS cells are available for other tasking.

The model was demonstrated against a mock threat potential consisting of 60 attack aircraft, 150 air launch ASCM'S, 100 land launched ASCM'S, and 40 surface launched ASCM'S. We assumed that the attacks would come in waves of twelve attack aircraft carrying four ASCM'S each, four land launched ASCM'S, and fdour surface launched ASCM'S as long as the threat had sufficient aircraft and missiles in inventory. We assumed that we could eliminate 50% of enemy land and surface launch ASCM inventory after each wave of attacks through various friendly forces, but the attack aircraft could only be destroyed by CAP.

In Case One of this scenario, we used simulation to determine we could eliminate 5.51 attack aircraft each wave. In this case we needed 196 long-range SAM'S throughout the campaign. The largest wave of ASCM'S encountered was 30. The Aegis equipped VLS force for this case was determined to consist of five ships carrying 40 SAM'S for AAW defense.

In Case Two, all twelve of the attack aircraft launched ASCM'S at the battle force until the inventory of 150 ASCM'S was consumed. In this case we needed 352 long-range SAM'S throughout the campaign. The largest wave of ASCM'S encountered was 56. The Aegis equipped VLS force for this case was determined to consist of ten ships carrying 36 SAM'S for AAW defense.

These results give the battle force commander a high and low-end requirement for Aegis equipped VLS ships for the theater of operation. The appropriate force can then be chosen.

I. INTRODUCTION

A. BACKGROUND

The Vertical Launch System (VLS) is currently employed on Ticonderoga class cruisers CG-52 through CG-73. There are 122 VLS cells on this class of cruiser and they are used to carry strike, air warfare (AAW), anti-submarine warfare (ASW), and anti-surface warfare (ASUW) missiles [Ref. 1, p. 786]. VLS is currently scheduled for employment on 24 of 31 Spruance class destroyers. There are 61 VLS cells available on this class of destroyer, primarily to carry strike, ASW and ASUW missiles [Ref. 1, p. 792]. The Arleigh Burke class destroyer is scheduled to have 26 ships commissioned in the class by October, 1998. All 26 ships of the class are scheduled to have 90 VLS cells for strike, AAW, ASW, and ASUW missiles [Ref. 1, p. 790]. The VLS missile delivery system presents a unique problem to load planners and battle group commanders because of the different combinations of missile types that can be loaded on any given ship. The pre-deployment problem used to be simply finding enough missiles to fill the surface-to-air missile (SAM) magazine for AAW, armored box launcher (ABL) for strike missiles, and anti-submarine rocket (ASROC) launcher for ASW missiles. Each magazine filled a specific warfare need. Now we have an opportunity to find the best mix of missiles for the VLS vessels prior to entering a specific theater of operation.

B. THESIS APPROACH

This thesis examines the VLS SAM requirement for AAW defense. Two cases of air warfare in a theater campaign are examined in an ordnance expenditure model. Case One assumes that the battle force has Combat Air Patrol (CAP) available to engage enemy aircraft attack waves. Only the attack aircraft that survive the CAP engagement launch anti-ship cruise missiles (ASCM'S) at the battle force. Case One provides a low-end number of SAM'S required in theater for a campaign. Case Two assumes no CAP is available to the battle force. All of the attack aircraft in the wave launch ASCM'S at the battle force. Case Two provides a high-end number of SAM'S required in theater for a campaign. The ordnance expenditure model determines the number SAM'S required in theater for AAW defense in Case One and Case Two providing a range of SAM requirements for the campaign. The VLS ship requirement and AAW defense SAM load for each of these ships is then mathematically determined from the results of the ordnance expenditure model.

C. RELATED RESEARCH

Two other studies of VLS loadout have been conducted. First, the Johns Hopkins University Applied Physics Laboratory conducted an analysis to determine the notional peacetime VLS loadout. The study was done to determine the VLS loadout of standard missiles, upper tier theater ballistic defense missiles, and strike missiles based on the possibility of fighting two concurrent Major Regional Conflicts (MRC'S) starting from a peacetime posture [Ref. 2]. Second, Carderock Division, Naval Surface Warfare Center, conducted an analysis to determine the optimal VLS mix of standard missile block 3B, 4, and 4A. The study was done using simulation scenarios approved by the Ballistic Missile Defense Office (BMDO) and Defense Intelligence Agency (DIA). In the scenarios, the VLS ships carried 60 SAM'S each. Different combinations of standard missile block 3B, 4, and 4A to fill these 60 cells were used in the scenarios to determine the optimal mix of these standard missiles. The results are contained in a forthcoming report [Ref. 3].

The approach taken in this thesis is unique because (1) it is a wartime decision aid that provides a specific theater SAM VLS load for AAW defense; (2) it allows the user to change parameters while stepping through the ordnance expenditure model, or to reflect up-to-date tactical or intelligence inputs.

D. THESIS GOALS AND OUTLINE

The goals of this thesis are: (1) develop a model that determines the SAM resources necessary to provide adequate theater AAW defensive firepower, (2) provides a guide to choosing an adequate VLS ship force for theater AAW defensive firepower, and, (3) guides in distributing the VLS SAM requirement among the VLS ships in the battle force.

Chapter II contains the general methodology used to determine the SAM requirement for VLS ships providing AAW defense. This is intended to help the reader better understand the concepts that follow.

Chapter III details the ordnance expenditure model. This is done to show the sequence of the AAW layered defense engagements against air, land, and surface launched ASCM'S. This allows the reader to visualize the sequence of SAM and point defense engagements against ASCM'S.

Chapter IV shows the four different windows of the spreadsheet program developed from the ordnance expenditure model defined in Chapter III. This is done to show the reader the interaction between the four program windows and define what input is required when using the spreadsheet program.

Chapter V applies the model in a mock theater of operation. This is done to show the reader how to use the model to determine the required Aegis equipped VLS ship force and load for a specific theater.

Chapter VI summarizes the results of Chapter V and makes recommendations for future work on VLS loadout.

Appendix A defines the variables, formulas, and equations used in the spreadsheet program. This shows the reader how the results of Tables 2 through 9 were obtained and acts as a user guide to the spreadsheet program.

Finally, Appendix B defines the RESA simulation tool used in the experiment of Chapter V.

II. METHODOLOGY

A. INTRODUCTION

This chapter is devoted to an overview of the techniques used in the development of the Vertical Launch System loadout model. The ideas are presented so that the user has a general understanding of the techniques used in the model. Later chapters expand the ideas presented.

B. SIMULATION OF THE AIR-TO-AIR ENGAGEMENT

Simulation is used to estimate the number of attack aircraft that can penetrate the battle force with air launched anti-ship cruise missiles (ASCM'S) when CAP is on station. Simulation provides a means of dividing the model-building task into smaller component parts that can be formulated readily and then combined in their natural order [Ref. 4, p. 857]. The CAP engagement scenario is illustrated in Figure 1. The enemy attack aircraft escorted by fighter aircraft are engaged by CAP. The surviving attack aircraft expend their air launched ASCM'S at the battle force out of SAM range, return to home base (RTHB), rearm, and attack again in another wave. This cycle continues until either (1) the inventory of enemy attack planes is depleted by CAP or (2) the enemy expends its inventory of air launched ASCM'S.

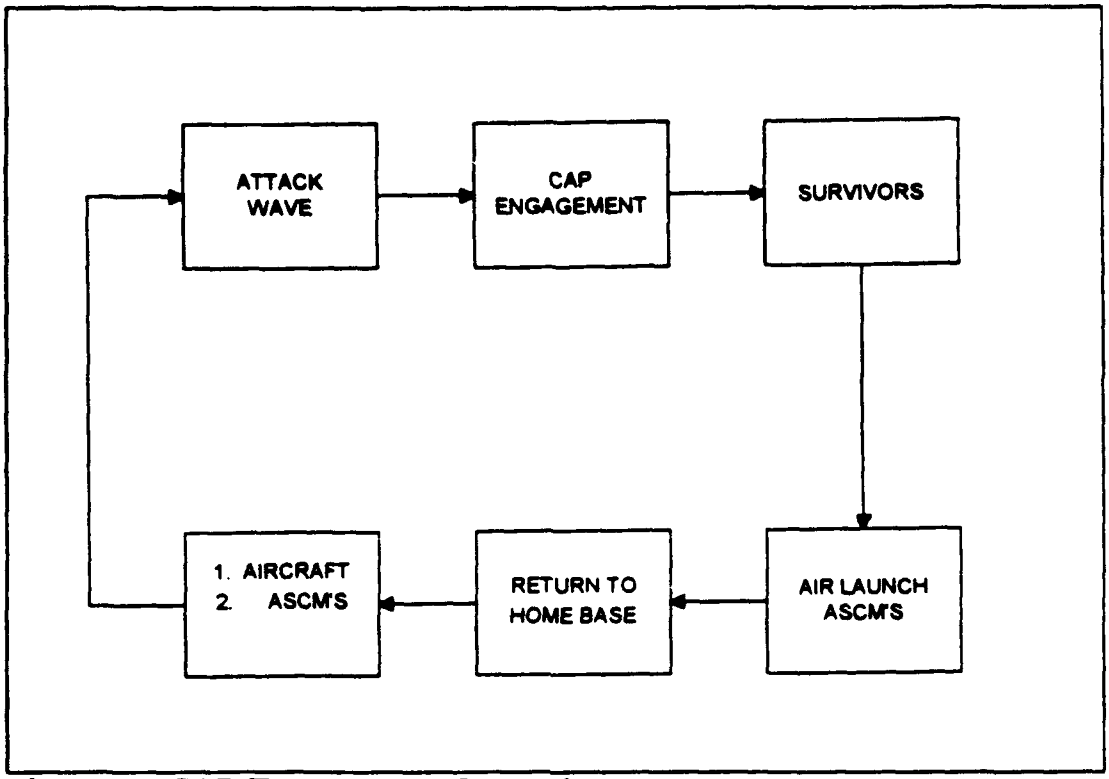

Figure 1. CAP Engagement Scenario.

To produce the best results in the analysis, a simulation scenario must be designed which resembles the CAP tactics to be employed and the potential enemy air order of battle for the theater of operation. After a realistic scenario has been developed for the expected air battle, several replications must be run to determine the long-run average number of attack aircraft to survive a CAP engagement. From the simulation replications, the expected number of enemy strike aircraft that can penetrate the battle force with air launched ASCM'S is calculated. This number will be used in Case One of the ordnance expenditure model.

C. LAYERED AAW DEFENSE MODEL TO RECORD ORDNANCE EXPENDITURE

A model is a simplified representation of the entity it imitates or simulates [Ref. 5, p. 1]. A mathematical model is a mathematical construct designed to study a particular real-world system of phenomenon. We use formulas, equations, and systems of equations to describe how the underlying factors of the model are interrelated [Ref. 6, p. 32].

A combat model has two general purposes. First, to provide a decision-aid tool to help the decision maker. Second, to aid in the study of historical battles. Experience, knowledge of subject matter, technique, and creativity are prerequisites in the formulation of combat models [Ref. 5, p. xiv]. This thesis uses mathematical tools and a layered AAW defense model to estimate ordnance expenditure against a given threat. The ordnance expenditure model, defined in Chapter III, is used as a decision tool for load and battle force planners to ensure a battle force has a sufficient number of SAM'S in theater to provide required defensive firepower. From the ordnance expenditure model programmed on spreadsheet, defined in Chapter IV, the user has the following information: (1) total number of long and short-range missiles needed in theater throughout the campaign; (2) largest wave of ASCM'S needed to be engaged by long and short-range missiles. From this information the user determines (1) an adequate VLS ship force for theater AAW defense; (2) SAM distribution among the VLS force.

D. DETERMINING VLS SHIP REQUIREMENTS

The number of VLS ships required in theater is determined by (1) dividing the number of long-range missiles needed in theater (A) by the total number of VLS cells available (B) and (2) dividing the largest wave of ASCM'S (C) by the number of ASCM'S an Aegis ship can simultaneously engage using a shoot-shoot-look engagement doctrine (D) which requires two SAM'S engaging each ASCM. The larger of these two numbers, $MAX\{\lceil A/B \rceil, \lceil C/D \rceil\}$, is the number of Aegis equipped VLS ships required for the campaign. The SAM'S are equally distributed among these ships.

III. ORDNANCE EXPENDITURE MODEL DESCRIPTION

A. INTRODUCTION

The purpose of this Chapter is to describe the ordnance expenditure model used in the development of vertical launch system loadout tool. This is done so the reader can follow the flow of ASCM'S as they penetrate the battle force layered AAW defense.

B. ORDNANCE EXPENDITURE MODEL

As illustrated in Figure 2, There are three launch sources of ASCM'S in the ordnance expenditure model: (1) Air launch from attack aircraft (2) Land launch from land based delivery systems (3) Surface launched from surface combatants. The combination of these three sources compose one batch of ASCM'S. A batch of ASCM'S constitutes a strike wave.
The wave of ASCM'S first enters the long-range missile engagement zone. Long-range SAM'S launched from Aegis equipped VLS ships engage the wave in the long-range missile engagement zone. The total number of long-range SAM'S expended throughout each of the waves is recorded. The total number of long-range SAM'S launched at the completion of the campaign constitutes the AAW defensive firepower required by the Aegis equipped VLS ships.

The ASCM'S in the wave that are not destroyed in the long-range missile engagement zone continue towards the battle force and enter the short-range missile engagement zone. Short-range SAM'S launched from the non-Aegis ships in the battle force engage the remaining ASCM'S in the short-range missile engagement zone. The total number of short-range SAM'S expended throughout each of the waves is recorded. The total number of short-range SAM'S launched at the completion of the campaign constitutes the AAW defensive firepower required by the non-Aegis ships.

The ASCM'S that survive short-range missile engagement zone close the battle force so that a ship in the battle force can engage the ASCM with point defense. Point defense is broken into the probability of a hard kill (P_h) and the probability of a soft kill (P_s).

1. Probability of a Hard Kill (P_h)

Hard kill implies that the incoming ASCM is destroyed prior to hitting a ship.

2. Probability of a Soft Kill (P_s)

Soft kill implies that the incoming ASCM may not necessarily be destroyed, but diverted harmlessly from the battle force through the use of chaff, jamming, or maneuvering tactics.

We model the defensive power of hard and soft kill point defense weapons simultaneously. Therefore, we compute the number of ASCM'S that will penetrate the battle force as follows. The probability that an ASCM will not be destroyed by a hard kill weapon is $(1-P_h)$. The probability that an ASCM will not be destroyed by a soft kill weapon is $(1-P_s)$. So the probability that the ship being homed in on by the ASCM does not destroy the ASCM is $(1-P_h)(1-P_s)$ [Ref. 7, p. 30]. The number of ASCM'S that enter the point defense zone multiplied by the survival probability, $(1-P_h)(1-P_s)$, gives the expected number of hits to the battle force in each wave. The total number of expected hits is recorded throughout the campaign.

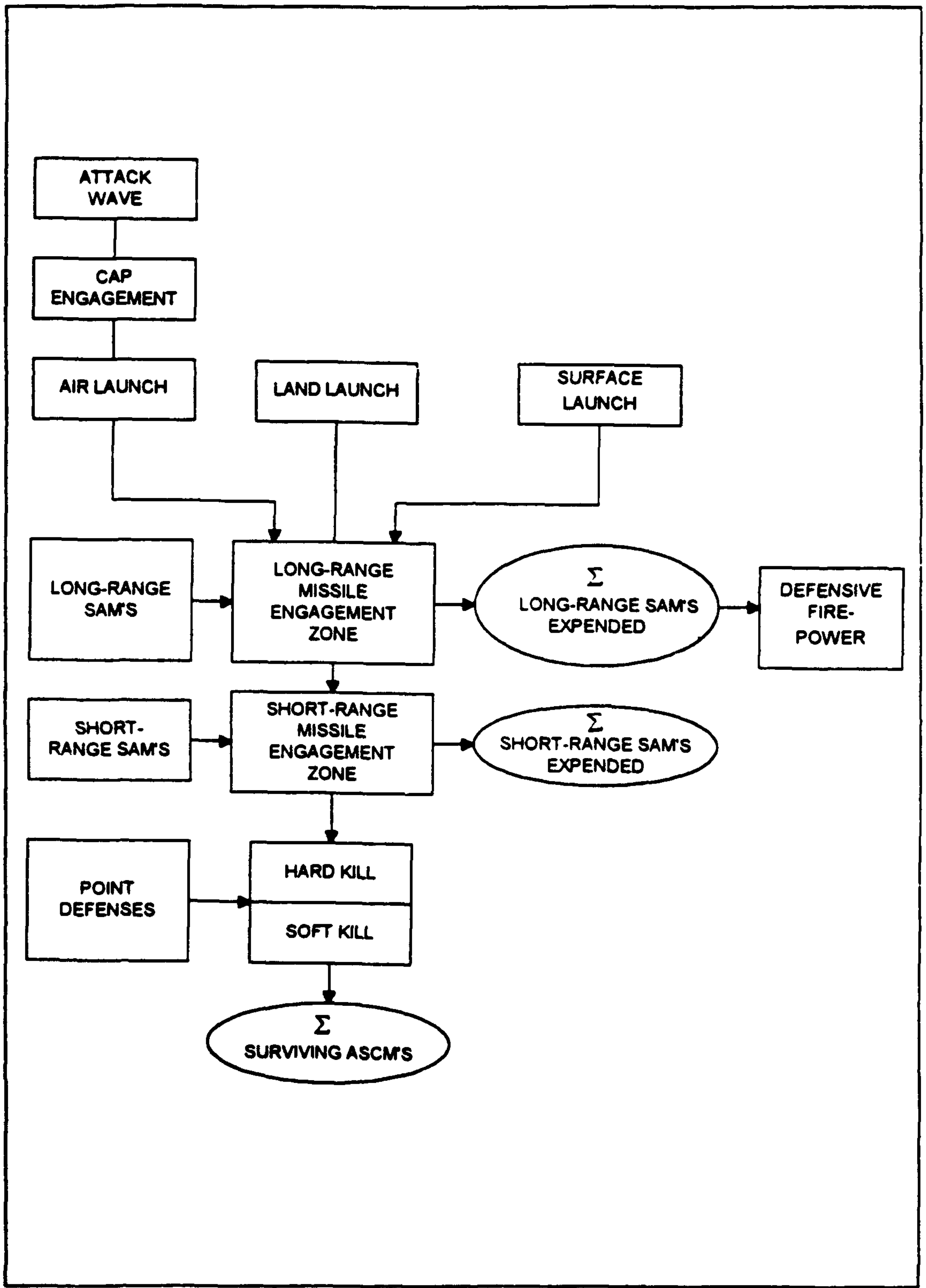

Figure 2. Layered Air Defense Model

IV. SPREADSHEET PROGRAM DESCRIPTION

A. INTRODUCTION

The purpose of this Chapter is to describe the spreadsheet program adapted from the ordnance expenditure model defined in Chapter III.

B. SPREADSHEET PROGRAM DESCRIPTION

The ordnance expenditure model is programmed on Borland Quattro Pro for Windows version 5.0 [Ref. 8]. The primary purpose of the program is to allow the user to step through an anticipated theater AAW campaign to determine the required battle force AAW defensive firepower. The program is based on the CAP engagement scenario, Figure 1, and the ordnance expenditure model, Figure 2. There are four windows in the program (1) CAP engagement scenario (CAP), (2) long-range missile engagement zone (LONG), (3) short-range missile engagement zone (SHORT), and (4) point defense (POINT). Program variable definitions and equations are defined in Appendix A.

1. Cap Scenario (CAP)

The CAP window provides the number of expected air launched ASCM'S that the battle force needs to defend against. Entering the CAP window the user must have a good estimate of the number of enemy attack aircraft in inventory, the number of air launch ASCM'S the enemy has in inventory, the expected size of enemy attack waves, and the number of air launched ASCM'S each attack aircraft carries.

The two cases of air warfare are encountered in the CAP window. In Case One, simulation (or any other means available to the force planner) is used to find the expected number of attack aircraft to survive each wave of anticipated CAP engagements. The aircraft that do not survive the CAP engagement are deleted from the red inventory. The aircraft that survive the CAP engagement launch their ASCM'S and return to home base, rearm, and attack in another wave. Case One is run until either (1) the red inventory of attack aircraft is exhausted or (2) the red inventory of air launched ASCM'S is exhausted. Case one provides a low-end estimate of the AAW defensive firepower required from SAM'S. In case two there is no CAP present. All of the attack aircraft in the attack wave launch their ASCM's. Case two is run until the red inventory of air launched ASCM'S is exhausted. Case Two provides a high-end estimate of the AAW defensive firepower required from SAM'S.

Multiplying the number of air launched ASCM'S each attack aircraft carries by the number of aircraft that survive the CAP engagement, Case One, or the number of attack aircraft in the wave, Case Two, we have the expected number of air launched ASCM'S the battle force will face each wave. These air launched ASCM'S contribute part of the wave that enter the long-range missile engagement zone as seen in Figure 2. The program transfers the number of air launched ASCM'S to the long-range missile engagement zone window (LONG) each wave.

2. Long-Range Missile Engagement Zone (Long)

Long-range missile engagements are conducted by Aegis equipped VLS ships. The long-range missile engagement zone window (LONG) of the program determines the defensive firepower required from Aegis equipped VLS ships in the battle force. There are three launch sources of ASCM'S that enter the long-range missile engagement zone each wave air, land, and surface launched, as shown in Figure 2.

a. Air Launched ASCM'S

Launched from attack aircraft. Computed in the CAP window and imported into the long-range missile engagement window (LONG).

b. Land Launched ASCM'S

Launched from land based launch systems. The user must have an estimate of red inventory and deployment tactics for land launched ASCM'S prior to entering the window. The user inputs the number of land launched ASCM'S that red is expected to launch each wave. The user also inputs the percent of the red land launch ASCM'S inventory blue forces expect to eliminate each wave. The red land launched ASCM inventory is updated each wave by first subtracting the number launched in the wave then multiplying the remaining inventory by the percent eliminated by blue forces. Land based ASCM'S are launched in each wave until the inventory is exhausted.

c. *Surface Launched ASCM'S*

Launched from surface vessels. The user must have an estimate of red inventory and deployment tactics for surface launched ASCM'S prior to entering the window. The user inputs the surface launched ASCM'S that red is expected to launch each wave. The user also inputs the percent of the red surface launched ASCM'S that blue forces expect to eliminate each wave. The red inventory is updated each wave by first subtracting the number launched in the wave then multiplying the remaining inventory by the percent eliminated by blue forces. Surface launched ASCM'S are launched in each wave until the inventory is exhausted.

Adding the contribution that these three launch sources provide each wave gives the number of ASCM'S entering the long-range missile engagement zone (long) for each wave throughout the campaign.

The program for surface-to-air missile expenditure was developed with a shoot-shoot-look engagement doctrine. This doctrine requires two SAM'S shot at each incoming ASCM. Multiplying the number of ASCM'S entering the long-range missile engagement zone each wave by two gives the number of long-range SAM'S expended in the wave. The total number of long-range SAM'S expended throughout the campaign constitutes the Aegis equipped VLS ship defensive firepower requirement.

From unclassified sources, we assume a single shot probability of kill for each SAM of approximately 0.7. Therefore, the probability of hitting any incoming ASCM is about 0.91 [Ref. 7, p. 35]. Multiplying the number of ASCM'S that enter the long-range missile engagement zone each wave and throughout the campaign by 0.09 gives the expected number of ASCM'S to survive the long-range missile engagements and pass into the short-range missile engagement zone.

d. Short-Range Missile Engagement Zone (Short)

The same shoot-shoot-look engagement doctrine and probability of kill assumptions are made when entering the short-range missile engagement zone window (SHORT). The number of ASCM'S entering the short-range engagement zone is multiplied by two to get the required defensive firepower for non-Aegis ships for the wave and throughout the campaign. The number of ASCM'S entering the short-range missile engagement zone is multiplied by 0.09 to compute the expected number of ASCM'S to enter the point defense region in a wave and throughout the campaign. No user input is required in this window of the program.

e. Point Defense (Point)

This window computes the number of ASCM'S expected to penetrate the battle force. The user must approximate the probability of hard kill (P_h) and the probability of soft kill (P_s) for the battle force and enter these approximations into the program. Multiplying the number of missiles entering the point defense per wave and throughout the campaign by $(1-P_h)(1-P_s)$ the program estimates the expected number of leakers the battle force encounters in a wave and throughout the campaign. This number of leakers encountered throughout the campaign directly reflects the capability of the layered AAW defense.

V. MODEL IMPLEMENTATION

A. INTRODUCTION

The purpose of this Chapter is to step through an experiment using the vertical launch system loadout model. This allows the user to see how the tool is implemented and the assumptions needed prior to using the model.

B. ESTIMATION OF RED FORCES

For this experiment, the following red force estimations were made when entering the CAP engagement window (CAP) and the long-range missile engagement window (LONG).

1. Cap Engagement Estimations

We begin the scenario by estimating the number of attack aircraft in the red inventory to be 60. The number of ASCM'S each of the red attack aircraft can carry is four. The number of red attack aircraft in an attack wave is twelve. The number of red force ASCM'S at the beginning of the campaign is 150.

2. Long-Range Missile Engagement Zone (Long) Estimations

The red force begins the campaign with 40 surface launched ASCM'S and 100 land launched ASCM'S in inventory. The red force launches four land and four surface ASCM'S each wave. We begin the scenario by estimating the percent of red surface and land launched ASCM'S that can be eliminated by blue force to be fifty percent per wave after red launches land and surface ASCM'S.

3. Point Defense (Point) Estimations

We estimate P_h to be 0.07 an P_s to be 0.06.

C. CAP CASE SCENARIOS

With extensive help from Gordon Nakagawa, CAPT, USN (Ret.), two different red attack force strike packages were developed. These two strike packages were simulated to engage the CAP using the RESA simulation described in Appendix B. Each strike package scenario was run 30 times on RESA. Captain Nakagawa's extensive knowledge and professional experience lends authority to the scenarios developed.

1. Strike Package Scenario Number One

Strike package scenario number one employs the use of three stations of two F-14 aircraft 150 miles from the carrier. There is forty-five degrees of separation between each F-14 CAP station. The second layer of CAP defense is two stations of two F/A-18 aircraft 100 miles from the carrier. There is thirty degrees of separation between each F/A-18 CAP station. The CAP aircraft are stationed at 20,000 feet and there is an E-2 on station to control CAP aircraft. The attacking force is composed of twenty Mig-29 fighter aircraft attacking directly down the threat axis 260 miles from the carrier at 16,000 feet. After the red fighter aircraft engage the CAP, eight Backfire attack aircraft at 100 feet and four May attack aircraft at 500 feet pop-up fifteen degrees off the center of the threat axis at 180 miles from the carrier. There is also a Bear-D in theater to jam the CAP aircraft radars. This scenario is illustrated in Figure 3.

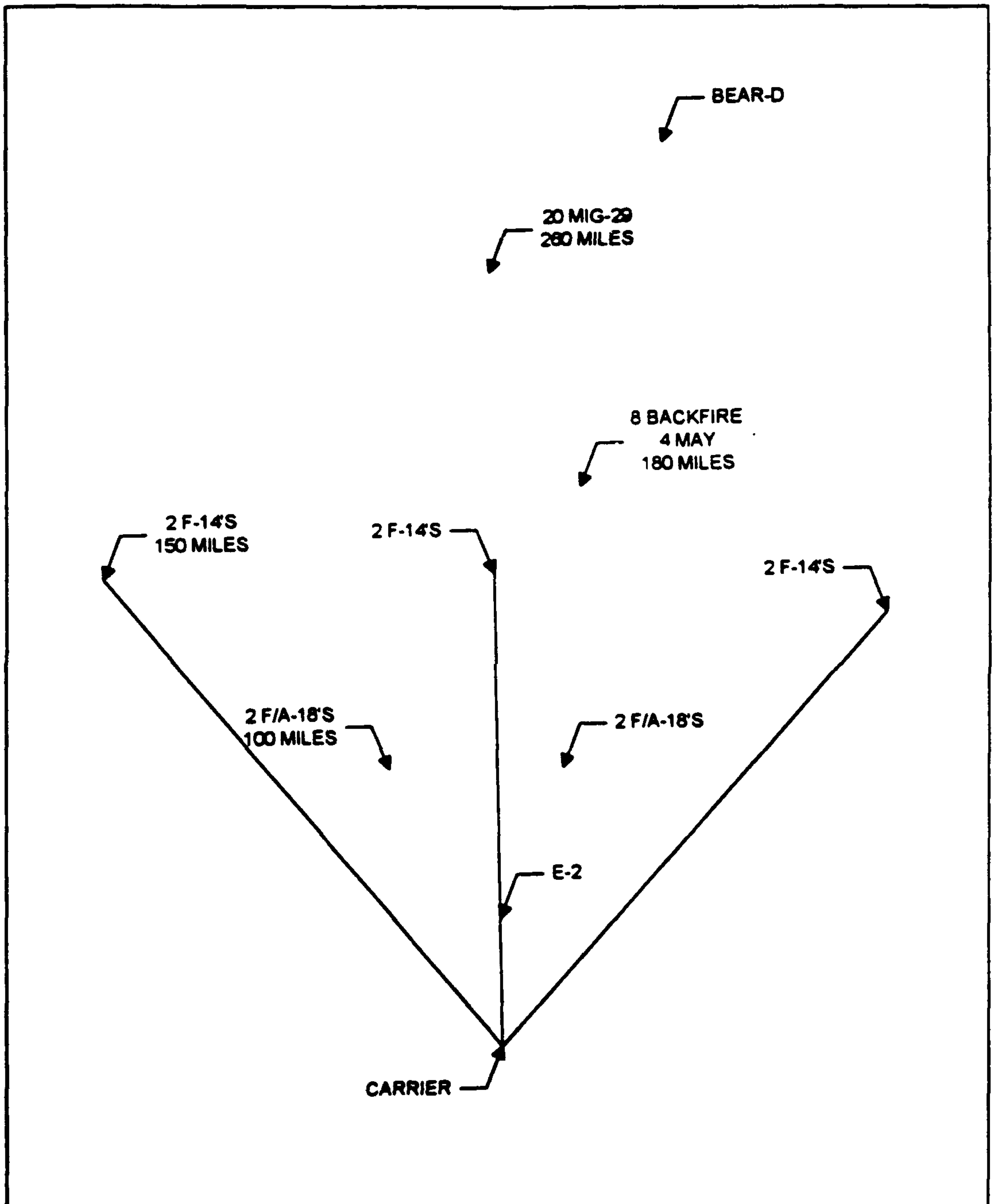

Figure 3. Strike Package Scenario Number One.

2. Strike Package Scenario Number Two

Strike package scenario Number Two uses the same CAP formation, but changes the red attack profile. Fifteen Mig-29 fighter aircraft attack directly down the threat axis 260 miles from the carrier at 16,000 feet. After the red fighter aircraft engage the CAP, eight Backfire attack aircraft at 100 feet and four May attack aircraft at 500 feet escorted by five Mig-29 fighter aircraft at 16,000 feet pop-up fifteen degrees off the center of the threat axis 125 miles from the carrier. This scenario is depicted in Figure 4.

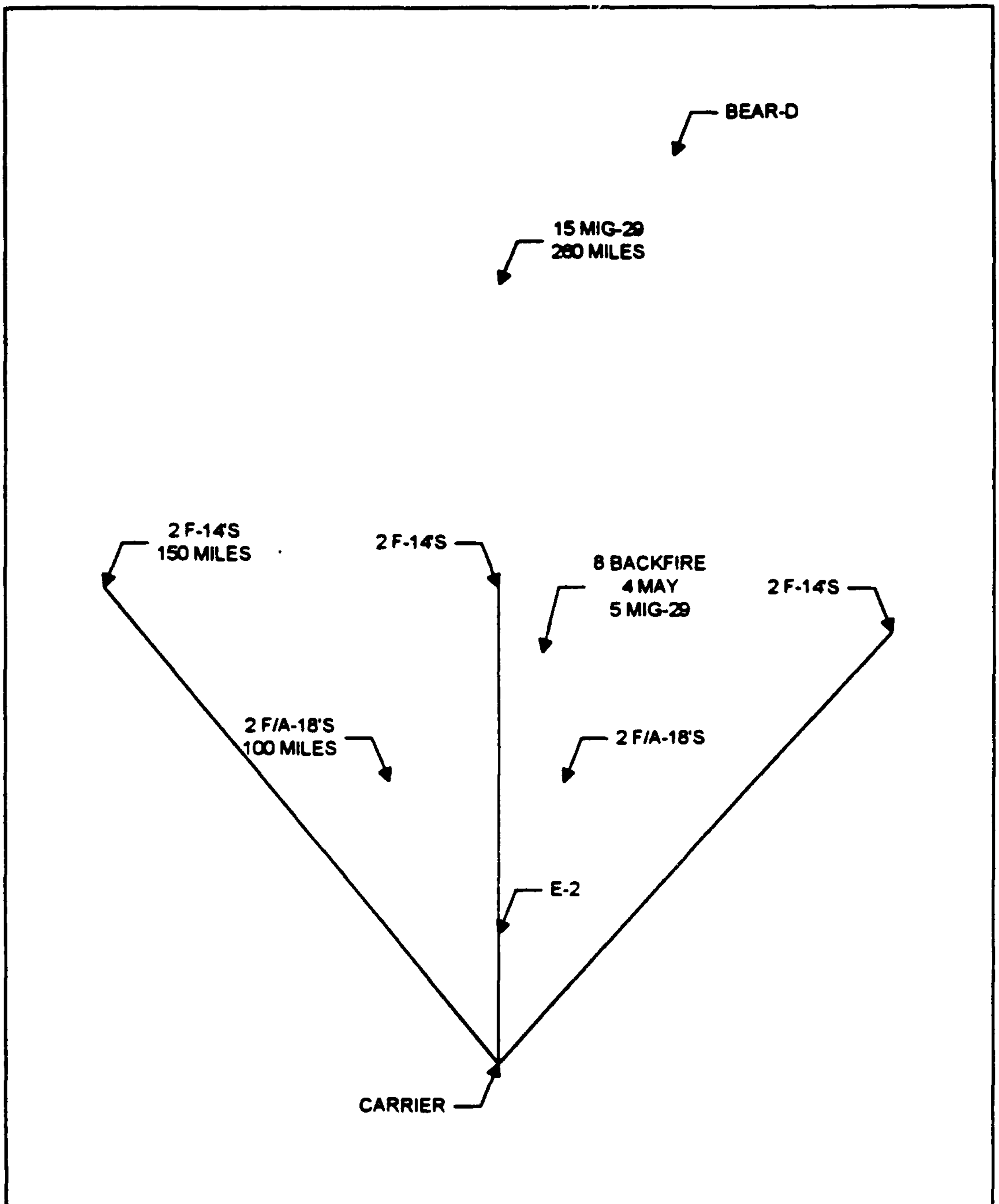

Figure 4. Strike Package Scenario Number Two.

These scenarios were chosen because of their relationship to modern littoral warfare threats. Having the attack aircraft pop-up was used to simulate an attack wave coming in low and fast off land as would be expected in many littoral terrains. The CAP stations were chosen because of the capabilities of the aircraft used and their on-station time due to fuel requirements. The results of the 60 runs are in Table 1 and the average number of attack aircraft to survive these CAP engagement is 5.51.

RUN NUMBER	SCENARIO 1	SCENARIO 2	
1	12	9	
2	4	4	
3	4	4	
4	4	6	
5	4	4	
6	4	5	
7	3	4	
8	4	4	
9	4	4	
10	12	4	
11	4	8	
12	12	8	
13	4	4	
14	4	7	
15	4	4	
16	4	4	
17	12	4	
18	4	4	
19	5	12	
20	8	4	
21	4	8	
22	4	4	
23	4	4	
24	8	8	
25	7	5	
26	4	4	
27	4	4	
28	4	4	
29	4	4	
30	12	8	TOTAL BOTH RUNS
SUM	171	160	331
AVERAGE SURVIVORS	5.7	5.33	5.51

Table 1. Simulation Results.

D. CASE ONE EXAMPLE

Case One is the scenario with CAP on station. Case One gives the user the low-end SAM requirement for the battle force. Using the spreadsheet program defined in Chapter IV, the following results were produced:

1. CAP Engagement Window

Table 2 shows the results of the CAP engagement and the number of air launched ASCM'S the battle force would expect to defend against per wave. The limiting factor in this scenario is the number of air launched ASCM'S in the red inventory. After wave three, the red attack force does not have enough ASCM'S to conduct another air strike. The number of attack aircraft remaining in the red inventory at the end of wave three is 40.50. The number of air launched ASCM'S the battle force expects to see per wave is 22. The total number of air launched ASCM'S the battle force expects to defend against in this scenario is 66.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4
A = total attack a/c in inventory	60	53.5	47	40.5
m = number of ASCM'S per attack a/c	4	4	4	4
R = size of attack waves	12	12	12	12
Es = expected number of attack a/c to survive CAP	5.5	5.5	5.5	5.5
Mr = number of ASCM'S in inventory	150	102	54	6
T = # of air launched ASCM'S shot per wave	22	22	22	0

Table 2. Case One CAP Window.

2. Long-Range Missile Engagement Window (Long)

Table 3 shows the results of the long-range missile engagement zone. By the end of wave three no more air launched ASCM'S enter the long-range missile engagement zone. By the end of wave four no more surface launched ASCM'S enter the long-range missile engagement zone. By the end of wave five no more land launched ASCM'S enter the long-range missile engagement zone. By the end of the campaign there are 66 air launched, 13.50 surface launched, and 18.50 land launched ASCM'S entering the long-range missile engagement zone for a total of 98 ASCM'S. Therefore a total of 196 long range SAM'S are shot throughout the campaign. The largest wave of ASCM'S expected by the battle force is 30. A total of 8.82 ASCM'S escape long-range SAM coverage and enter the short-range missile engagement zone.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
T = air launched ASCM'S penetrating per wave	22	22	22	0	0
# of surface ASCM'S launched per wave	4	4	4	1.5	0
# of land launched ASCM'S per wave	4	4	4	4	2.5
ATTsurf = % surface ASCM'S eliminated per wave	0.5	0.5	0.5	0.5	0
ATTland = % land ASCM'S eliminated per wave	0.5	0.5	0.5	0.5	0.5
surf = # of suface ASCM'S begin wave	40	18	7	1.5	0
land = # of land ASCM'S at begin wave	100	48	22	9	2.5
surf' = # of surface ASCM'S at end wave	18	7	1.5	0	0
land' = # of land ASCM'S at end wave	48	22	9	2.5	0
Total ASCM'S penetrating in wave	30	30	30	5.5	2.5
Total ASCM'S penetrating in campaign	30	60	90	95.5	98
Long-range missiles expended in wave	60	60	60	11	5
Total long-range missiles expended	60	120	180	191	196
T' = # of ASCM'S escaping long per wave	2.7	2.7	2.7	0.49	0.23
T" = total number of ASCM'S escaping long	2.7	5.4	8.1	8.59	8.82

Table 3. Case One Long Window.

3. Short-Range Missile Engagement Zone Window (Short)

Table 4 shows the results of the short-range missile engagement zone. The largest wave of ASCM'S entering the short-range missile engagement zone is 2.70. The total number of short-range SAMS shot in the campaign is 17.64. The total number of ASCM'S that escape short-range missile coverage in the campaign to enter the point defense region is 0.79.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
T = # of ASCM'S penetrating per wave	2.7	2.7	2.7	0.49	0.22
T' = # of ASCM'S penetrating total	2.7	5.4	8.1	8.59	8.82
Number of short-range missiles per wave	5.4	5.4	5.4	0.99	0.45
Number of short-range missiles total	5.4	10.8	16.2	17.19	17.64
Number of ASCM'S escaping short per wave	0.24	0.24	0.24	0.04	0.02
Number of ASCM'S escaping short total	0.24	0.48	0.72	0.77	0.79

Table 4. Case One Short Window.

4. Point Defense (Point) Window

Table 5 shows the results of the point defense engagement. The largest wave of ASCM'S to enter the point defense region is 0.24. The total number of ASCM'S expected to penetrate the battle force and possibly hit a ship in the battle force is 0.69.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
Number of ASCM'S penetrating point per wave	0.24	0.24	0.24	0.04	0.02
Number of ASCM'S penetrating point total	0.24	0.48	0.72	0.77	0.79
Probability of hard kill	0.07	0.07	0.07	0.07	0.07
Probability of soft kill	0.06	0.06	0.06	0.06	0.06
Number of leakers per wave	0.21	0.21	0.21	0.03	0.01
Number of leakers total	0.21	0.42	0.63	0.67	0.69

Table 5. Case One Point Window.

5. Missile Loadout

Using the data generated by the spreadsheet program we use the procedure defined in Chapter II to determine the required number of Aegis equipped VLS ships. Since the largest wave the battle force will face is 30 ASCM'S, a total of 60 long-range SAM'S must be shot against that wave, based on our shoot-shoot-look engagement doctrine. We assume that an Aegis platform can engage six ASCM'S simultaneously using this doctrine; therefore, we need five Aegis ships in theater (30 ASCM'S/six ASCM'S engaged per Aegis ship) to engage the maximum wave of 30 ASCM'S. Dividing equally the 196 total SAM'S needed in theater among these five ships gives a total of approximately 40 SAM'S per ship. This is the total defensive firepower required per Aegis ship in the battle force. Subtracting 196 from the total number of Aegis VLS cells in theater gives the available offensive firepower for the Aegis VLS ships in the battle force. The same process can be used to ensure that sufficient non-Aegis ships are in theater for short-range SAM coverage.

E. CASE TWO EXAMPLE

Case Two is the scenario with no CAP on station. Case Two gives the user a high-end estimate of the required defensive firepower needed for the battle force. Using the spreadsheet program defined in Chapter IV, the following results were produced:

1. CAP Engagement Window

Table 6 shows the results of the CAP engagement and air launched ASCM'S the battle force would expect to defend against per wave. Obviously, in case two the limiting factor will be the number of ASCM'S in the red inventory since no planes are shot down. After wave three the red force does not have enough ASCM'S to conduct another air strike. In case two all twelve of the attacking aircraft launch four ASCM'S each wave, so that the number of air launched ASCM's the battle force expects to see in each wave is 48. The total number of air launched ASCM'S the battle force expects to defend against in this scenario is 144.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4
A total attack a/c in inventory	60	60	60	60
m number of ASCM'S per attack a/c	4	4	4	4
R size of attack waves	12	12	12	12
Es expected number of attack a/c to survive CAP	12	12	12	12
Mr number of ASCM'S in theater	150	102	54	6
T = number of air launched ASCM'S shot per wave	48	48	48	0

Table 6. Case 2 CAP Window.

2. Long-Range Missile Engagement Window (Long)

Table 7 shows the results of the long-range missile engagement zone. By the end of wave three no more air launched ASCM'S enter the long-range missile engagement zone. By the end of wave four no more surface launched ASCM'S enter the long-range missile engagement zone. By the end of wave five no more land launched ASCM'S enter the long-range missile engagement zone. By the end of the campaign there are 144 air launched, 13.50 surface launched, and 18.50 land launched ASCM'S entering the long-range missile engagement zone for a total of 176 ASCM'S. There is a total of 352 long-range SAM'S shot throughout the campaign and the largest expected wave of ASCM'S faced by the battle force is 56. A total of 15.84 ASCM'S escape long-range SAM coverage and enter the short-range missile engagement zone.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
T = air launched ASCM'S penetrating per wave	48	48	48	0	0
# of surface ASCM'S launched per wave	4	4	4	1.5	0
# of land launched ASCM'S per wave	4	4	4	4	2.5
ATTsurf = % surface ASCM'S eliminated per wave	0.5	0.5	0.5	0.5	0
ATTland = % land ASCM'S eliminated per wave	0.5	0.5	0.5	0.5	0.5
surf = # of suface ASCM'S begin wave	40	18	7	1.5	0
land = # of land ASCM'S at begin wave	100	48	22	9	2.5
surf' = # of surface ASCM'S at end wave	18	7	1.5	0	0
land' = # of land ASCM'S at end wave	48	22	9	2.5	0
Total ASCM'S penetrating in wave	56	56	56	5.5	2.5
Total ASCM'S penetrating in campaign	56	112	168	173.5	176
Long-range missiles expended in wave	112	112	112	11	5
Total long-range missiles expended	112	224	336	347	352
T' = # of ASCM'S escaping long per wave	5.04	5.04	5.04	0.49	0.23
T' = total number of ASCM'S escaping long	5.04	10.08	15.12	15.61	15.84

Table 7. Case Two Long Window.

3. Short-Range Missile Engagement Zone Window (Short)

Table 8 shows the results of the short-range missile engagement zone. The largest wave of ASCM'S entering the short-range missile engagement zone is 5.04. The total number of short-range SAM'S shot in the campaign is 31.68. The total number of ASCM'S that escape short-range missile coverage in the campaign and enter the point defense region is 1.42.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
T' = # of ASCM'S penetrating per wave	5.04	5.04	5.04	0.49	0.22
T'' = # of ASCM'S penetrating total	5.04	10.08	15.12	15.61	15.84
Number of short-range missiles per wave	10.08	10.08	10.08	0.99	0.45
Number of short-range missiles total	10.08	20.16	30.24	31.23	31.68
Number of ASCM'S escaping short per wave	0.45	0.45	0.45	0.04	0.02
Number of ASCM'S escaping short total	0.45	0.90	1.36	1.40	1.42

Table 8. Case Two Short Window.

4. Point Defense Window (Point)

Table 9 shows the results of the point defense engagement. The largest wave of ASCM'S to enter the point defense region is 0.45. The total number of ASCM'S expected to penetrate the battle force and possibly hit a ship in the battle force is 1.24.

	WAVE 1	WAVE 2	WAVE 3	WAVE 4	WAVE 5
Number of ASCM'S penetrating point per wave	0.45	0.45	0.45	0.44	0.02
Number of ASCM'S penetrating total	0.45	0.90	1.36	1.40	1.42
Probability of hard kil	0.07	0.07	0.07	0.07	0.07
Probability of soft kill	0.06	0.06	0.06	0.06	0.06
Number of leakers per wave	0.39	0.39	0.39	0.03	0.01
Number of leakers total	0.39	0.79	1.18	1.22	1.24

Table 9. Case Two Point Window.

5. Missile Loadout

Using the data generated by the spreadsheet program we use the procedure outlined in Chapter II to determine the required number of Aegis equipped VLS ships. Since the largest wave the battle force will face is 56 ASCM'S, there is a total of 112 long range SAM'S required to be controlled in that wave. This is based on the shoot-shoot-look engagement doctrine. We assume that an Aegis platform can engage six ASCM'S simultaneously using this doctrine; therefore, we need approximately ten Aegis ships in theater (56 ASCM'S/six ASCM'S engaged per Aegis ship) to engage the maximum wave of 56 ASCM'S. Dividing equally the 352 total SAM'S needed in theater among these ten ships gives a total of approximately 36 SAM'S per ship. This gives the total defensive firepower required per Aegis ship in the battle force. Subtracting 352 from the total number of Aegis VLS cells in theater gives the available offensive firepower for the Aegis VLS ships in the battle force.

F. FORCE AND LOAD DECISION

After stepping through Case One and Case Two to determine the force and load required for each case, the ordnance load planner and battle force commander should then decide on the case which most resembles their specific theater of operation. This helps determine the required force for the mission or determine if the existing force can fulfill the mission.

VI. CONCLUSIONS AND RECOMMENDATIONS

The principal aim of this thesis was to develop a model to assist battle force commanders and ordnance loadout planners when deciding on the SAM load for Aegis equipped VLS ships to provide the AAW defensive firepower required for a specific theater of operation. The model gives the user a high-end and low-end SAM and force requirement based on user predictions and assumptions. "We prefer the risks of decisions based on predictions, including predictions that admit to uncertainties, to decisions made by default." [Ref. 9, p. 8].

A. CONCLUSIONS

As seen from the results of Chapter V and Tables 2 through 9, having CAP in theater (1) reduces the number of Aegis equipped VLS ships needed in theater (2) reduces the number of SAM'S required for <u>defensive firepower</u>, and (3) reduces the number of ASCM'S that will penetrate the battle force. However, the advantage CAP provides by eliminating the attack aircraft before they launch ASCM'S is the "privilege of the rich" [Ref. 10, p. 701] and may not always be available to a battle force. Therefore, the use of this model assists the battle force commander and ordnance load planner decide on the battle force and ordnance load required to provide <u>defensive firepower</u> in a specific theater.

B. RECOMMENDATIONS

It is recommended that the user of the model experiment with different CAP scenarios and enemy order of battle before deciding on the final battle force. This will produce some sensitivity analysis for the user by showing the effects different combat situations have on the VLS AAW defensive load. The VLS loadout model is based strictly on defensive firepower. Because of this, the model produces conservative estimates on the number of SAM'S required for defensive firepower. The offensive firepower provided from the remaining VLS cells needs to explored as well. It is recommended that future work evaluate the effect of SAM'S being used offensively to eliminate attack aircraft before they strike. A study of the effects of strike missile attacks to reduce attack aircraft on the ground and reduce attack sorties by striking airfields, radars, and fuel depots is also recommended. This work will give a better balance between the offensive and defensive requirements for the battle force.

Another area of concern not addressed is the loss of ships in the battle force and the remaining firepower in their lost VLS cells. The model and data inputs are based on normal battle force operations in which defense in depth is employed to exploit the layered defenses of the U.S. fleet against enemy ASCM'S. As a result, the number of ASCM'S that penetrate the defenses is negligible. Therefore, the losses of SAM'S in particular and defenses in general need not be a concern of the battle force planner. This is the preferred U.S. Navy tactic against ASCM'S. In littoral warfare a layered defense may not always be feasible when task forces are required to operate close to the enemy coast. If littoral operations in close proximity to enemy launch sites are anticipated by the user then a margin for error is appropriate to allow for the possibility of too few SAM'S or too few Aegis ships to survive a series of enemy strikes. Indeed, a future study of the effects of significant leakage and damage could be warranted.

APPENDIX A. VARIABLE DEFINITIONS AND EQUATIONS

A. INTRODUCTION

The purpose of this Appendix is to establish the terminology, calculations, and procedures used in conjunction with the ordnance expenditure model spreadsheet program.

B. COMBAT AIR PATROL ENGAGEMENT

When CAP is present we use the expected number of attack aircraft to survive the CAP engagement when determining the size of the air launched portion of the ASCM batch and there is attrition of red attack aircraft in this case. We call this case one. When there is no CAP present we use the size of the enemy attack wave when computing the size of the air launched ASCM portion of the batch and there is no attrition of red attack aircraft. We call this Case Two. The CAP window variables are computed in the following manner:

- A=Total attack a/c in inventory. Wave one input is supplied from intelligence sources.
- **Case 1:** CAP is present and A is updated upon the completion of each attack wave from the formula $A=A-[R-E_s]$. This is the total inventory minus the quantity of the attack wave size minus the NUMBER of the attack wave survivors. This is equivalent to subtracting the planes lost in the CAP engagement from the red inventory.

- **Case 2:** No CAP present and A remains constant throughout the campaign.
- m=number of ASCM'S per attack a/c. This number will be an estimate obtained from intelligence sources.
- R=size of attack waves. Obtained through intelligence sources.
- Es=expected number of attack a/c to survive CAP.
- **Case 1:** This number is obtained from the use of simulation of the expected air-to-air battle engagement.
- **Case 2:** Since no CAP eliminates the strike wave, Es = R.
- Mr=number of ASCM'S in inventory. Wave one input obtained through intelligence sources. Updated each wave through the spreadsheet by the formula Mr=Mr-Rm.
- T=number of air launched ASCM'S shot per wave. Computed through the spreadsheet as T=Es*m.

C. LONG-RANGE MISSILE ENGAGEMENT (LONG)

This stage of the process is where the AAW defensive firepower requirement for Aegis equipped VLS ships is estimated. Long-range window variables are computed as follows:

- T=number of air launched ASCM'S that are shot by attacking force that enter the long-range missile engagement zone. imported from CAP window.
- ATTsurf=% surface ASCM'S eliminated by blue forces each wave. Entered by the user in each of the wave calculations.
- ATTland=% land ASCM'S eliminated blue forces each wave. Entered by the user in each of the wave calculations.

- surf=number of surface ASCM'S beginning of the wave. number of surface ASCM'S launched per wave=number of red ASCM'S launched by surface vessels in a wave.

- land=number of land ASCM'S beginning of the wave. number of land launched ASCM'S per wave=number of red ASCM'S launched by land platforms in a wave.

- surf'=number of ASCM'S in red inventory at completion of the wave. Computed as red inventory - number launched - number attrited by friendly forces.

- land'=number of ASCM'S in red inventory at completion of the wave. Computed as red inventory - number launched - number attrited by friendly forces.

- total ASCM'S penetrating in wave=total number of ASCM'S that penetrate the long-range missile engagement zone in the wave. Equal to the sum of land, surface, and air launched ASCM'S that penetrate the long-range missile engagement zone in a wave.

- *total ASCM'S penetrating in* campaign=summation of the number of ASCM'S that penetrate the long-range missile engagement zone throughout the campaign.

- long-range missiles expended wave=number of long-range missiles expended in each wave. Computed as 2*total missiles penetrating long in a wave.

- total long-range missiles expended=summation of number of long-range missiles expended throughout the campaign. Computed as 2*total ASCM'S penetrating long.

- T=number of ASCM'S that escape the long-range missile envelope In a wave. Computed as 0.09*total missiles penetrating long in wave.

- T'=number of ASCM'S that escape the long-range missile envelope throughout the campaign. Computed as 0.09*total ASCM'S penetrating in campaign.

D. SHORT-RANGE MISSILE ENGAGEMENT (SHORT)

This stage of the process models the short-range missile shooters engagement of the threat. The total number of red ASCM'S that escape the long-range missile engagement zone enter the short-range missile zone. This region is defended by the non-VLS ships, primarily FFG-7 and DD-963 class ships. Short-range window variables are computed as follows:

- T=number of ASCM'S that penetrate to the short-range envelope in a wave, imported from the long range window.
- T'=summation of the ASCM'S that penetrate the short-range envelope throughout the campaign. Imported from the long-range window.
- number of short-range missiles per wave=number of short-range missiles expended in a wave. Computed as 2*T.
- number of short-range missiles total=number of short-range missiles expended throughout the campaign. Computed as 2*T'.
- number of ASCM'S escaping short per wave=number of ASCM'S that escape the coverage of the short-range missile envelope. Computed as 0.09*T.
- number of ASCM'S escaping short total=total number of ASCM'S that escape the short-range missile envelope throughout the campaign. Computed as 0.09*T'.

E. POINT DEFENSE (POINT)

This is the final stage in the air battle. It is the model of the hard kill (P_h) and soft kill (P_s) capability of the battle group. The variables for the point defense are computed as follows:

- number of ASCM'S penetrating the point per wave=the number of ASCM's that penetrate the point defense each wave. This number is imported from the short range missile window.
- number of ASCM'S penetrating point total=the summation of ASCM'S that penetrate the point defense throughout the campaign. Imported from the short-range missile window.
- probability of hard kill(P_h)=probability the ASCM is eliminated through the use of hard kill. The input is entered by the user.
- probability of soft kill(P_s)=probability the ASCM is eliminated through the use of soft kill tactics. The input is entered by the user.
- number of leakers per wave=number of hits the battle group expects in a wave. Computed as $(1-P_h)(1-P_s)$*number of ASCM'S penetrating point defense per wave.
- number of leakers total=summation of the number of hits the battle group expects to take during the campaign. Computed as $(1-P_h)(1-P_s)$*number of ASCM'S penetrating point defense total.

APPENDIX B. RESA DESCRIPTION

A. RESEARCH, EVALUATION AND SYSTEM TRAINING ANALYSIS (RESA)

RESA has been used for fleet training since the early 1980's and is installed in the Naval Postgraduate School wargaming lab. RESA is a very flexible simulation tool with capabilities ranging from joint theater level operations to single platform operations. The system is designed for interactive control of simulated forces with man in the loop. However, for our purposes a scenario was developed and repeatedly played using the auto-RESA mode in order to obtain statistical data on air-to-air engagements [Ref. 11, p. 1].

The most attractive aspect of RESA is the fact that it can quickly conduct a series of detailed simulations in an expeditious manner. Detailed results of battle engagements are stored in a file and can be analyzed upon completion of the simulation runs.

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