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HYPERVELOCITY PROJECTILE

by

John B. Means, Christopher M. Quarles, Miguel E. Sanchez Jr., and Matthew X. Wu

September 2020

Advisor: Paul T. Beery
Co-Advisor: Eugene P. Paulo

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John B. Means, Christopher M. Quarles, Miguel E. Sanchez Jr., and Matthew X. Wu

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Lead Editor: John B. Means

Reviewed by:

Paul T. Beery Advisor	Eugene P. Paulo Co-Advisor

Accepted by:
Ronald E. Giachetti
Chair, Department of Systems Engineering

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This project focuses on the definition and analysis of a concept of operations for hypervelocity projectile (HVP) employment in support of layered defense within an adaptive force package (AFP). The project defines, via development of a systems architecture and mission engineering, the weapon characteristics relevant to HVP utilization. The project presents an initial set of system requirements as well as a definition of the system functionality and potential physical configurations. The project develops a detailed analysis model that analyzes the performance parameters that have the largest impact on the overall effectiveness of the proposed HVP systems. In particular, the project examines the impact of alterations to range-dependent kill criteria and engagement envelopes on the effectiveness of the overall system in complex threat scenarios. That analysis is then fed back into the system architecture to develop recommended system configurations and inform system requirements.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFP	Adaptive Force Package
BLUFOR	Blue Force
CIWS	Close-in Weapon System
CONOPS	Concept of Operations
DOD	Department of Defense
ESSM	Evolved Sea Sparrow Missile
GC	Green Country
HVP	Hypervelocity Projectile
I/O	Input / Output
MBSE	Model-Based Systems Engineering
ME	Mission Engineering
MOE	Measure of Effectiveness
ONR	Office of Naval Research
RC	Red Country
REDFOR	Red Force
SAM	Surface-to-air Missile
SM-2ER	Standard Missile-2 Extended Range
SM-2MR	Standard Missile-2 Medium Range
SM-3	Standard Missile-3
SM-6	Standard Missile-6
TLAM	Tomahawk Land Attack Missile
VLA	Vertical Launch Antisubmarine Missile
VLS	Vertical Launch System

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EXECUTIVE SUMMARY

The hypervelocity projectile (HVP) is a multi-mission projectile currently being developed for use in both electromagnetic and conventional gun-based weapons. This study addresses the use of the HVP and its effects on the capability of ships to defend themselves from enemy missile attacks. Additionally, this study seeks to determine the cost-benefit of including the HVP as part of a multiple-layered defense of ships, analyze feasible engagement envelopes, and define any doctrinal and tactical recommendations to aid the deployment of HVP.

A simulation and associated analysis are conducted to assess the ability of the HVP to augment current or near-future U.S. naval capabilities. The concept of operations (CONOPS) for the simulation of HVP as part of missile defense is based on an adaptive force package (AFP) of two missile destroyers and two missile cruisers defending themselves from a salvo of anti-ship missiles. In addition to the HVP, the ships are armed with a full load of currently deployed anti-missile weapons. The simulation uses analogues of these weapons based on publicly available parameters with notional values to avoid using classified values for these parameters. For the simulation, the ships are armed with analogues for the SM-6, designated in the simulation as “Taller”, the SM-2/SM-2ER (“Lancer”), Enhanced Sea Sparrow (“Robin”), and the Phalanx Close-In-Weapons-System (CIWS) (“Pillbox”). The ships defend against anti-ship missiles consisting of analogues of four types of sub-sonic and super-sonic enemy weapons.

Four detailed sub-scenarios are analyzed to assess the utility of the HVP. The baseline scenario simulates a ship-based defense without use of the HVP. The HVP in-the-loop (HVP ITL) scenario adds the HVP into the baseline defense net. For cost-savings analysis, weapon reduction scenarios, where the magazine capacity of one of the anti-missile missiles is reduced by half, were also performed. For further comparisons, a scenario where the AFP defended itself with only the HVP and CIWS weapons was also evaluated.

The simulation is created using the ExtendSim software suite for discrete system modeling. Parameters of each force's weapons, such as range, velocity, and probabilities of kill were entered into the input database, with a separate database to track weapon probabilities of hit. Based on sponsor and stakeholder feedback, the simulation limited the HVP engagement to subsonic targets only. For the design of experiments, there were six main configurations based on the scenarios: the Baseline, HVP ITL, Taller reduction, Lancer reduction, Robin reduction, and HVP-Only defense scenarios. Each scenario with HVP had additional variables: the enemy missile salvo size of 100, 75, 50, and 25 missiles; the probability of hit of the HVP of 10%, 20%, and 30% chance to hit, and an HVP burst size of three or five-rounds. This defined a total of 144 unique scenario configurations, each of which was replicated 500 times to account for the stochastic nature of the simulation. The simulation output database was compiled and sorted by munitions expended, kills per weapon, and the ships damaged or sunk for each configuration. Output data for the average kills per weapon, the total percentage of the enemy swarm destroyed by the defense net, the average munitions expended in the scenario, and the average AFP survivability were calculated

This project and analysis show that the HVP can increase the combat capability of an AFP by increasing the effectiveness of missile defense. Based on the reduced data from the simulation, the existing defense weapons can adequately defend the AFP for salvos of 50 targets or fewer. However, the inclusion of HVP provides an increased effectiveness of salvo destruction for enemy salvos of 75 and 100 targets. Even at its lowest probability of hit, the HVP ITL scenario provides an improvement in salvo destroyed for the 100-target salvo.

For the parameters of HVP, the five-round burst increases defense effectiveness across all scenarios but changing the probability of hit has less effect. Therefore, if development of the HVP cannot attain higher probabilities of hit, then employing the five-round burst would be the preferred doctrine for HVP deployment.

I. INTRODUCTION AND INITIAL RESEARCH

A. BACKGROUND

In their 2018 study, Gunzinger and Rehberg point out that the Department of Defense (DOD) spends billions of dollars annually on ballistic missile defense. The authors note that the primary focus of a ballistic defense scenario is a “salvo competition” in which the offensive and defensive forces seek to improve strike lethality and magazine capacity. They determine that it is possible for numerical advantages to mitigate technological disadvantages. Given that naval operations are inherently constrained in terms of force size, it is vitally important to improve the defensive salvo size and efficiency.

The basic structure of a ballistic missile defense system relies on a layered defense strategy. The current structure relies heavily on counter ballistic missiles and kinetic interceptors as first and second level defensive capabilities. According to the 2018 Gunzinger and Rehberg study, these options are costly (multi-million dollars per missile) and have a limited magazine for continued engagement (Gunzinger and Rehberg 2018, 1). To combat these issues, the Navy is considering a layered defense system that utilizes rail gun technology, the hypervelocity projectile (HVP), laser- and directed-energy weapons, and electronic warfare systems to combat ballistic missile threats.

The HVP is particularly well suited to expand the capabilities of the current defensive structure. The HVP is capable of supersonic speeds and mid-air course correction to intercept incoming ballistic missiles as well as engaging other targets as an offensive weapon. The HVP is being developed to be fired from the future rail gun system as well as the current Navy five-inch gun systems. For the purpose of this study, the HVP is evaluated as used with the five-inch gun.

B. PROBLEM STATEMENT / STATEMENT OF NEED

The HVP has potential to provide improved missile defense capability as part of a shipboard gun-based defense system. This study seeks to identify the parameters of the HVP that have the largest impact on operational effectiveness in a defensive situation, determine the cost benefit of including the HVP as part of a multi-mission role, determine feasible engagement envelopes, and define doctrinal and tactical changes to aid in the deployment of a HVP.

C. PROJECT APPROACH

The standard systems engineering processes (such as the Vee model) do not fit the approach for this project. Given the heavy reliance on simulation and analysis, a mission engineering approach is utilized which "necessitates a focus on three major areas: System Definition, System Design, and System Analysis" (Van Bossuyt et al. 2019, 4). The tailored systems engineering process identified in (Betancourt et al. 2018, 7–8) was chosen as it fit the needs of a mission engineering program (Figure 1).

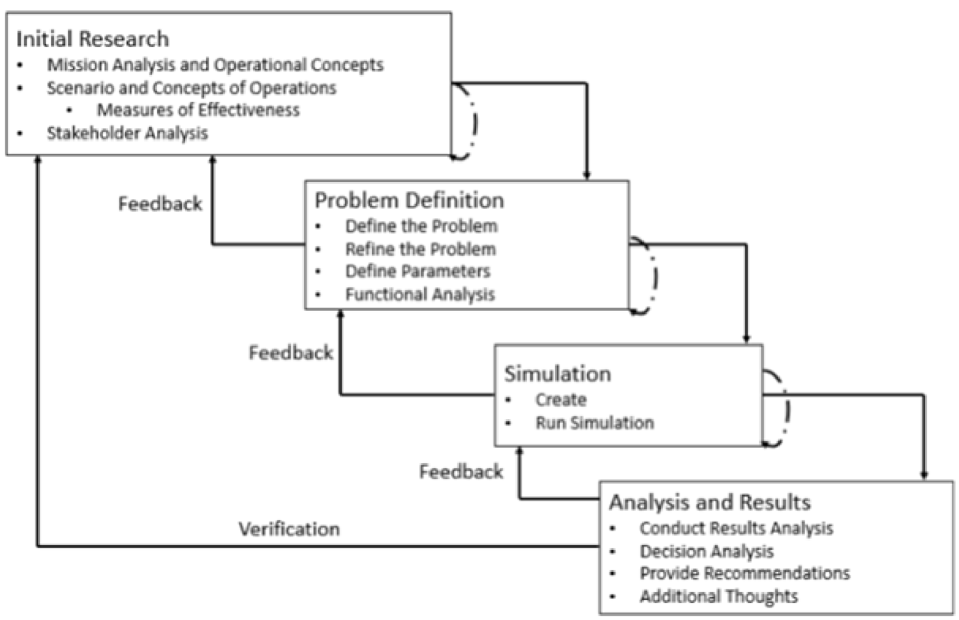

Figure 1. The HVP Systems Engineering Process. Adapted from Betancourt et al. (2018, 8).

1. Initial Research

During the initial research phase, existing information regarding current naval system load outs for ships and to evaluate Navy doctrine for engagements is gathered. Stakeholder analysis is conducted based on the early research to determine those functions and requirements necessary for the HVP to operate in theater. Further research is conducted to evaluate operational scenarios and concepts of operation to determine the best framework within which to evaluate the performance of the HVP.

2. Problem Definition

The problem definition, concept of operations, and operational scenarios are explored and constructed during this phase based on the initial research. Based on the HVP concept of operations, an input / output (I/O) diagram is developed along with a system context diagram. Through examination of these items, a preliminary parameter lists is developed to aid with a simulation development.

3. Simulation

The simulation phase is where the concept of operation and theater scenarios are built within a simulation environment to examine the performance of the HVP. A simulation program is selected based on its ability to conduct both discrete and continuous event modeling as well as its ability to represent the functionality and environment defined in the Problem Definition phase in an appropriate level of detail.

4. Analysis and Results

The analysis and results phase examines the outputs from the scenario simulations. Based on the analysis of the scenario outputs, performance and doctrine recommendations are made. Furthermore, cost benefit analysis is conducted based on the change in load out as the HVP has a potential cost savings associated with its replacement of conventional ballistic weapons.

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II. INITIAL RESEARCH

A. STAKEHOLDER ANALYSIS

1. Preliminary Analysis

Stakeholder analysis was conducted to define the scope of the customer needs. The stakeholder analysis highlights the early constraints, assumptions, objectives, requirements (measures of effectiveness [MOEs]), and prioritization determined for all identified stakeholders. The full list of stakeholders can be seen in Appendix A.

2. Focused Analysis

The primary focus area for requirements was determined based on the highest priority stakeholders: The Office of Naval Research (ONR) Railgun Office, the Battlefield Commander, and Ship Leadership. This priority was established based on the functional aspects of the HVP and its need to perform in theater. The objectives, potential MOEs, and requirements for these stakeholders reflects the operational need (Table 1).

Table 1. Focused Stakeholder Analysis Group

Stakeholder	Objectives	MOEs	Requirements (System Shall)
ONR Railgun Office	Weapon is effective, weapon is operational in mission environment	Depth of Magazine	…have an Ao of [X], be able to sustain [X] raids before rearming, be compatible with current (powder) and next-generation (EMR) weapons (Requirements values derived from conventional defense configuration)
Battle Field Commander	Weapon meets mission goals, weapon is cost effective, weapon defends friendly forces	P(Hit), P(Kill),	…have a P(hit) of [X], have a P(Kill) of [Y]
Ship Leadership	Understand weapon capabilities in mission environment, weapon protects fleet	P(RaidKill)	…have a P(Raidkill) of [Z] - comparable to conventional defense configuration

Based on the focused analysis, it is necessary to review existing Navy ships and capabilities to identify opportunities for HVP integration that are consistent with the MOEs and requirements for each stakeholder.

B. AFP ARMAMENTS

1. Ticonderoga Class Cruiser

The Ticonderoga Class Cruiser is outfitted with two Vertical Launch System (VLS) units that carry an assortment of missiles (Military.com n.d.a). The most current loadout of the Ticonderoga, based on the Bunker Hill, consists of 12 Standard Missile-6 (SM-6), three Standard Missile-2 Extended Range (SM-2ER), 56 Standard Missile-2 Medium Range (SM-2MR), 12 Evolved Sea Sparrow Missile (ESSM), 10 Standard Missile-3 (SM-3), 32 Tomahawk Land Attack Missiles (TLAM), six Vertical Launch Antisubmarine Missile (VLA), and eight Harpoon missiles (The Influence of History, 2018). In addition to VLS cells, the Ticonderoga Class is also outfitted with two Mk 45 five-inch guns (Military.com n.d.a). Each Mk 45 five-inch gun has an individual capacity of 600 rounds, giving a total of 1200 rounds for each Ticonderoga Class Cruiser (DiGuilian 2020). As part of this project, the loadout mix (HVP and conventional munitions) for the Mk 45 will be explored.

2. Arleigh Burke Class Destroyer

The Arleigh Burke Class Destroyer, like the Ticonderoga Class Cruiser, is outfitted with two Vertical Launch System (VLS) units that carry an assortment of missiles (Military.com n.d.b). The most current load out of the Arleigh Burke, based on the John Finn, consists of 12 SM-6, eight SM-3, 16 SM-6, 30 SM-2MR, 16 ESSM, 32 TLAM, and six VLA (The Influence of History, 2018). In additional to VLS cells, the Arleigh Burke Class is also outfitted with one Mk 45 five-inch guns (Military.com n.d.b). The Mk 45 five-inch gun on the destroyer has an individual capacity of 680 rounds (NavWeaps n.d.a).

3. HVP System

As previously stated, for the purpose of this study, the HVP munition will only be utilized in the Mk 45 five-inch gun. Other variants of the HVP are capable of being fired from the Electromagnetic Railgun, Advanced Gun System, and the 155mm tube artillery (BAE 2018, 2). A convenient design aspect of the HVP is that is designed to utilize the conventional Mk 45 propellant charge (The Drive n.d.). This allows for mixed magazines to be utilized without the need for additional propellants or the loss of magazine depth as was the case with the Extended Range Guided Munition (Federation of American Scientists [FAS] n.d.). The HVP also has the ability to alter its flight path through the use of movable fins and an internal guidance system which allows for greater accuracy (Mizokami 2019).

C. SYSTEM INPUT / OUTPUT

The inputs to the system can be separated into two groups: controllable inputs and uncontrollable inputs. The controllable inputs are for both the blue force and red force and represent factors that affect the performance of the system. These inputs are also design characteristics that can be changed as desired to modify the system. The uncontrollable inputs also affect the system but represent characteristics that are based on external inputs. The intended outputs directly correspond to the functions that the system requires to perform in theater and give a basis for simulation parameters and metrics. These outputs are based on the number of targets destroyed, the number of AFP ships hit or sunk, the amount of munitions expended for both offensive and defensive munitions, and the average time to destroy the ground targets (Figure 2).

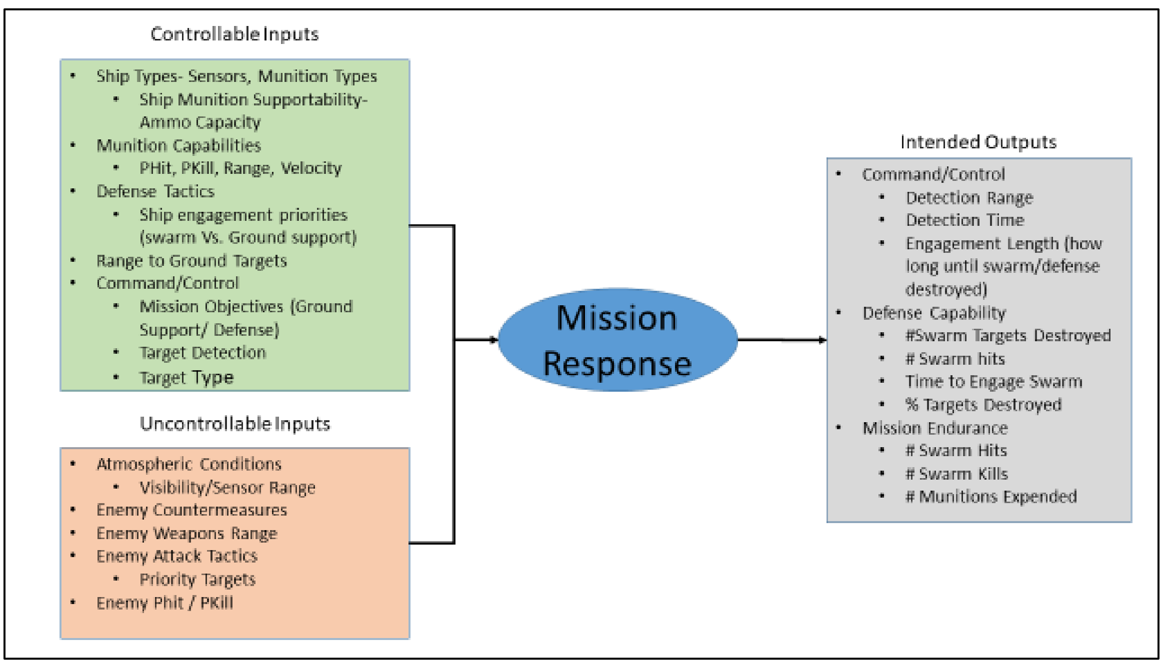

Figure 2. System Input / Output (I/O) Diagram

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III. PROBLEM DEFINITION

A. CONCEPT OF OPERATIONS (CONOPS)

The Concept of Operations for this project is based around an adaptive force package (AFP) consisting of four ships conducting a strike mission. Of these ships, two are Arleigh Burke Class Destroyers and two are Ticonderoga Class Cruisers. The ships come under counterattack and must defend themselves with on-board munitions. The CONOPS has two scenarios: one has the ship defense conducted with conventional munitions (baseline) while the other has the ship defense augmented with the hypervelocity projectiles (HVP).

In 2030, red country (RC) has claimed an area of the Pandora Sea and has annexed the islands and countries within extending its claims of sovereignty. On one of the annexed islands, RC has repurposed an old civilian airfield as a staging area for air maritime patrols, which are disrupting sea traffic with both aircraft and surface-to-air missile (SAM) batteries. The SAM batteries restrict most air attacks. Initial reports showed that RC had deployed mostly subsonic SLAPSTICK anti-ship missiles, reinforced by smaller numbers of ground- and air-launched supersonic anti-warship missiles designated SHARKBITE, SNAKEFANG, and SUNFIRE. While RC had initially deployed a token force on the island, intelligence data indicated that RC intends to reinforce the island's airfield in order to support heavier cargo aircraft, allowing RC to deploy long-range ballistic anti-ship missiles with longer range and heavier payloads. This will allow RC to extend its anti-shipping capabilities into more key areas of the Pandora Sea, causing more severe disruptions in sea shipping and traffic.

Blue force (BLUFOR) is now conducting a mission to destroy the airfield along with its defenses in hope to remove sea traffic disruptions and prevent RC from extending its anti-shipping range. BLUEFOR's AFP, named ABLE, consists of two Ticonderoga-class guided missile cruisers and two Arleigh-Burke guided missile destroyers assigned to conduct ground strikes on the objectives.

ABLE has moved to engagement range from the island and engaged the priority targets with ground-attack cruise-missiles. ABLE's attack is noticed by the island forces, and ABLE is counterattacked by air- and ground-based anti-ship missiles. ABLE is attacked by a salvo of anti-ship missiles comprised of SLAPSTICK, SNAKEFANG, SHARKBITE, and SUNFIRE missiles. Because ABLE has already launched its attack, ABLE's primary objective is to defend the surface group from counterattack.

1. CONOPS Layout

The HVP CONOPS is based on two scenarios. The first scenario has ABLE (the AFP) defending itself with only conventional munitions based on parameterized analogues of loadouts used by U.S. Navy ships: TALLER for the SM-6, LANCER for the SM-2, ROBIN for the Enhanced Sea Sparrow, and PILLBOX for the Phalanx close-in weapons systems (CIWS). This scenario establishes a performance baseline and is also a "control" for the cost-benefit analysis. The second scenario is based on augmenting the ship defense with the HVP, and is divided up based on what the HVP is augmenting- the long-range missiles (2A), medium-range missiles (2B), or all missiles (2C). The CWIS will be used for all defensive scenarios.

The purpose of the analysis is ship-defense and, based on the current HVP performance parameters, maintaining a superior engagement range (Figure 3). For the simulation and analysis, only the munitions for the ship-based defense will be modeled and analyzed.

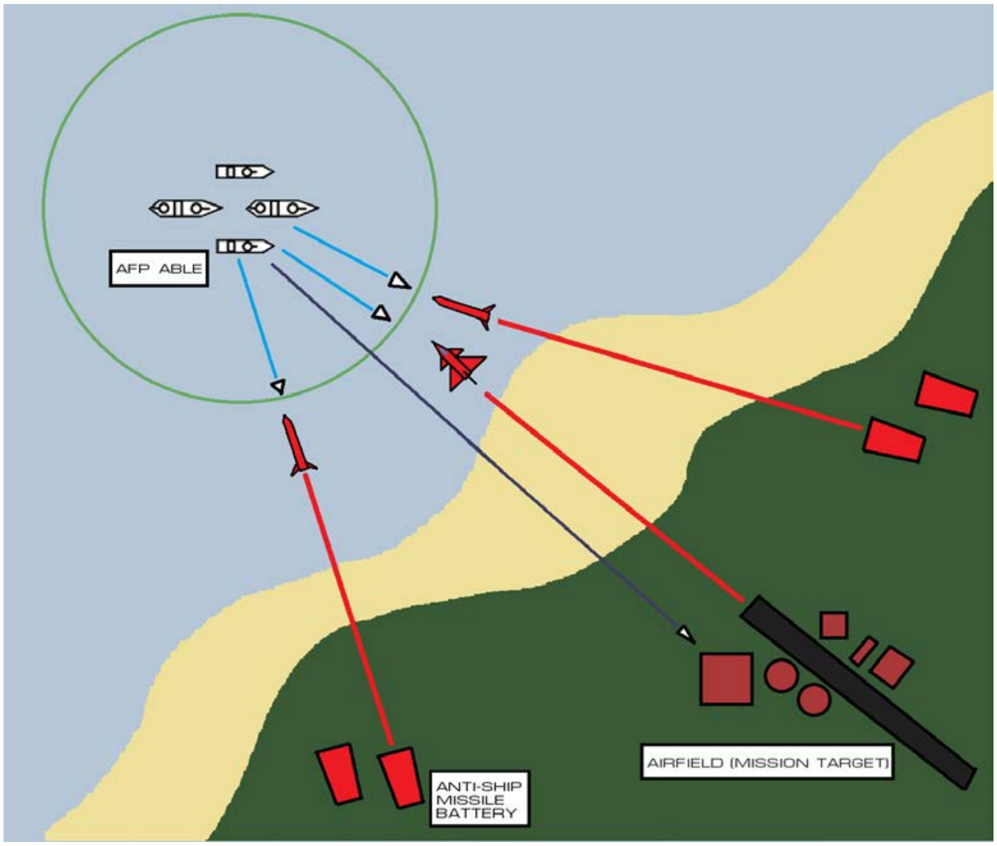

Figure 3. CONOPS Illustration of Engagement Space

2. CONOPS Scenario 1

Scenario 1 has ABLE conduct the mission with only conventional munitions. ABLE will conduct defense with TALLER and LANCER long-range missiles, ROBIN medium-range missiles, and PILLBOX close-in weapons system (CIWS). This scenario establishes a performance baseline and a control scenario for the cost-benefit analysis.

3. CONOPS Scenario 2

Scenario 2 focuses on using HVP to augment ABLE's defensive capabilities. Scenario 2A augments the TALLER and LANCER missiles with HVP by reducing their magazine capacities by 50%; Scenario 2B augments the ROBIN missiles with the same 50% ammunition reduction; Scenario 2C has an "HVP Only" defense, in which ABLE will only use HVP as its anti-missile defense. The PILLBOX CIWS is used for all scenarios. Scenarios 2A and 2B also feature a velocity discrimination parameter, in which the HVP weapon will only engage the subsonic SLAPSTICK missiles. The supersonic SNAKEFANG, SHARKBITE, and SUNFIRE missiles will be engaged by the ship-borne missile weapons.

4. CONOPS Assumptions

The assumptions for the Concept of Operations are split into assumptions for BLUFOR, the HVP, and Red Force (REDFOR). BLUFOR is assumed to be fully combat-capable at the beginning of the fire mission, with no delays in targeting or engaging enemy assets. For target data, ABLE is AEGIS-capable and is linked to a sensor network that can detect and track enemy assets before they enter engagement range. All parameters for the BLUFOR weapon systems, such as fire rate, range, and probabilities of hit and kill, are set at the beginning of the mission and will not change over time. ABLE is situated in calm, open waters during daylight hours, and will not have to consider landmasses, civilian traffic, or weather and lighting conditions for its defense. ABLE's ships are oriented so that all ships can engage enemy assets without needing to turn or move any ships. ABLE ships are assumed to be combat effective until the fire mission ends, and any ships that have been hit by enemy attacks will only be considered "destroyed" at the mission end.

The HVP is assumed to be able to hit and kill targets at maximum range without changes to its probabilities of hit and kill. The parameters for the HVP will be set at the fire mission start and will not change over time. It is assumed that probability of kill is constant against enemy attackers. The HVP for the scenarios will be loaded onto conventional five-inch cannons, with ship configurations based on the Arleigh-Burke and Ticonderoga-class ships.

REDFOR is assumed to start its attack after ABLE has begun its fire mission. Conversely, ABLE is assumed to be unable to pre-emptively attack REDFOR anti-ship missiles and will only engage these assets with defensive munitions. The engagement ranges of the REDFOR weapons against ABLE is based on the maximum engagement ranges of the defensive weapons aboard ABLE. REDFOR's weapons are parameterized analogues of current anti-ship weapons used by the: The SLAPSTICK is based on the C-802, SNAKEFANG is based on the YJ-12, the SUNFIRE is based on the YJ-18, and the

SHARKBITE is based on the YJ-91. These parameterized analogues are based on publicly available information. REDFOR's attack will be a mix of these weapons, with the majority being SLAPSTICK/C-802 missiles and comparatively fewer SNAKEFANG/YJ-12s, SUNFIRE/YJ-18s, and SHARKBITE/YJ-91s. REDFOR is assumed to have no naval assets in the area that can attack ABLE. REDFOR is also assumed to not have long-range ballistic anti-ship missiles that will be able to engage ABLE from outside of the operational area. The REDFOR anti-ship missiles target ABLE ships based on a parameterized radar-cross section and will not focus on a particular ship or ship type. The air-launched anti-ship missiles (SNAKEFANG and SHARKBITE) will be assumed to already be launched when they enter the defensive weapon engagement zone, with constant values of velocity and probabilities of hit and kill.

B. SYSTEM CONTEXT

The information contained in the CONOPS and scenarios assisted in creating a system context diagram. The purpose of the context diagram is to illustrate the boundaries of the system and their associated inputs and outputs. In a traditional context diagram, the system of interest is in the center; however, due to the nature of the HVP and the mission engineering focus, the HVP operates as a sub-system and augments the systems threat response (Figure 4). This concept and approach to the system definition follows a Model-Based Systems Engineering (MBSE) approach to Mission Engineering (ME). As stated in (Beery and Paulo 2019), this approach "establishes a formal linkage between operational need and physical system configurations." Similarly, the ME approach to the system definition allows for the decomposition of system requirements in relation to the specific operational concept.

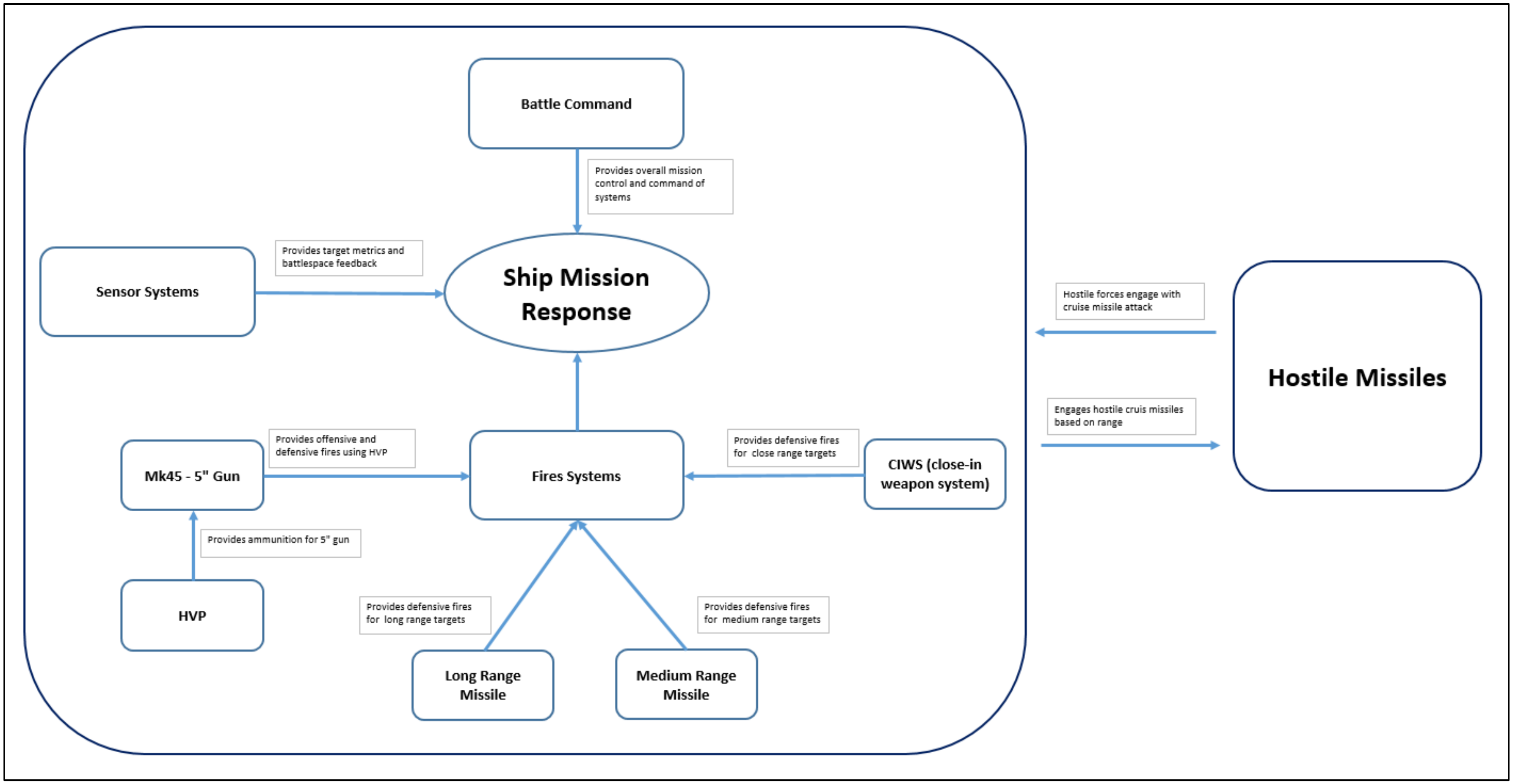

Diagram illustrates HPV as part of the total mission

Figure 4. System Context Diagram

C. FUNCTIONAL ANALYSIS

Using the CONOPS as a guide, the mission requirements were explored. Rather than focus on the HVP as a system, the HVP is considered as a functional element of a larger missile defense system as discussed as part of the system context. As such, the fire mission itself is the system of interest and Figure 5 shows the fire operation proposed by (Davis et al. 2020, 89) to be used as a template for the functional analysis and all subsequent analyses and system simulation.

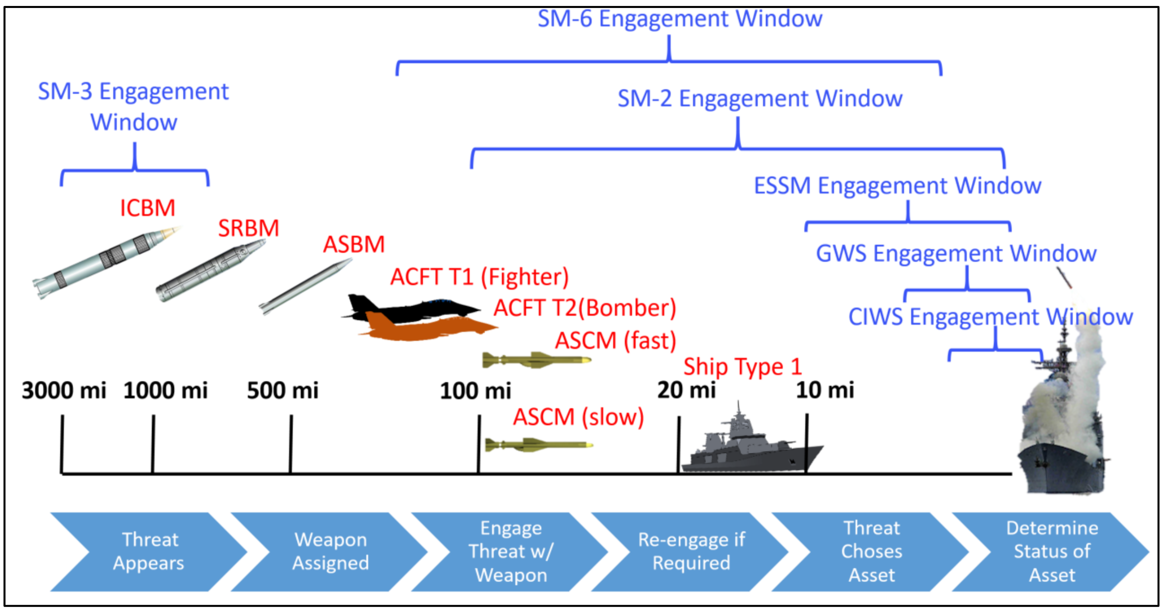

Figure 5. Threat Engagement Window With Order Of Operations. Source: Davis et al. (2020, 89).

Based on the threat engagement window, the basic fire mission functions were created. These primary functions are directly traceable to the fire operation presented in Figure 5. These primary functions were decomposed in the functional hierarchy diagram seen in Figure 6.

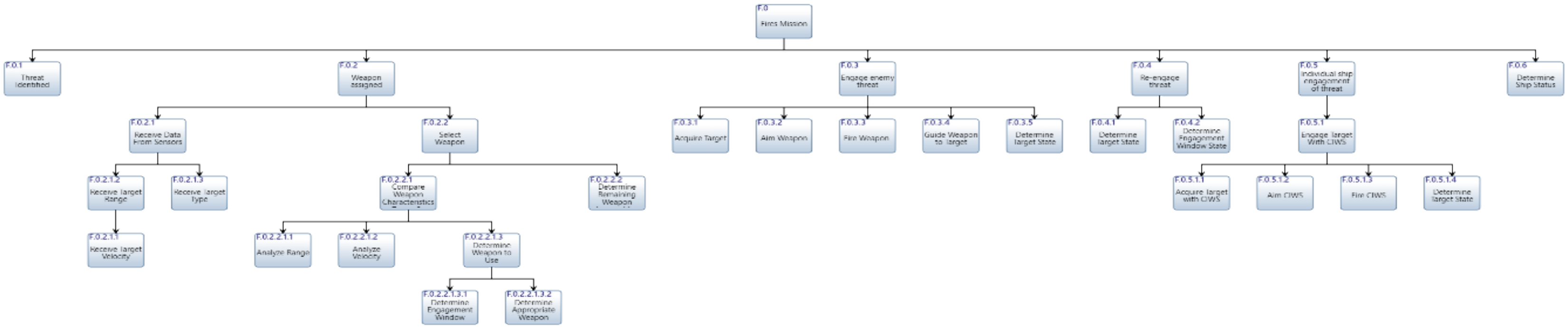

Figure 6. Functional analysis hierarchy

As seen in Figure 6, the "Threat Identified" and "Determine Ship Status" functions have not been decomposed. With the focus of the project on the performance of the HVP, the threat identification will be assumed to remain constant based on the AFP radar capabilities. The final status determination, though not composed, will be part of the simulation as a determination of remaining assets following each hostile engagement.

Figure 7 shows the top-level decomposition of the primary fire mission functions.

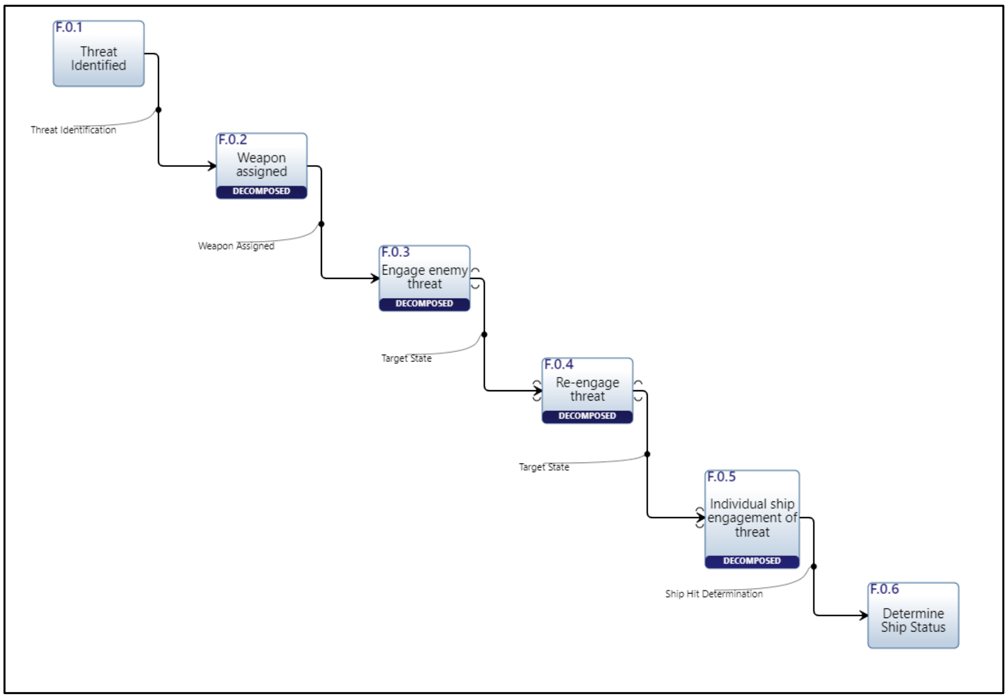

Figure 7. Fire Mission Functional Decomposition

1. Weapon Assignment Functional Decomposition

Figure 8 shows the next level of decomposition for the weapon assignment function. Based on the information received from the threat detection function, threat identification and threat characteristics (i.e., velocity and range), this function determines the engagement envelope and assign the appropriate interceptor.

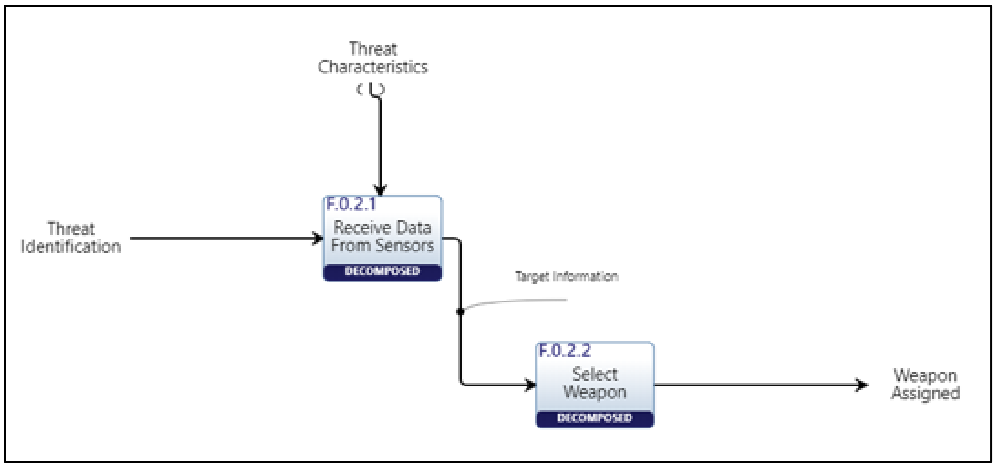

Figure 8. F0.2 Weapon Assignment Functional Decomposition

a. Receive Sensor Data Functional Decomposition

The receive sensor data function decomposes to attain the sensor information for range and velocity. This information is used to determine the threat engagement window and determine the target type based on known missile profiles for the REDFOR in the area of engagement (Figure 9).

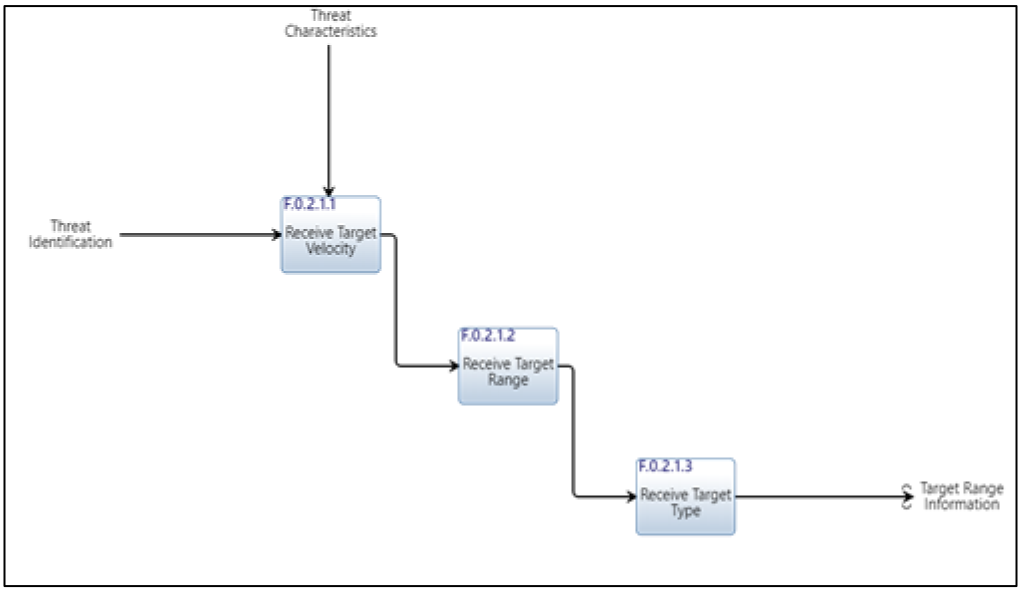

Figure 9. F0.2.1 Receive Sensor Data Functional Decomposition

b. Select Weapon Functional Decomposition

Figure 10 shows how, based on the threat characteristics from the parent function, the select weapon function choses the appropriate weapon to engage the threat with a feedback loop to examine the available magazine.

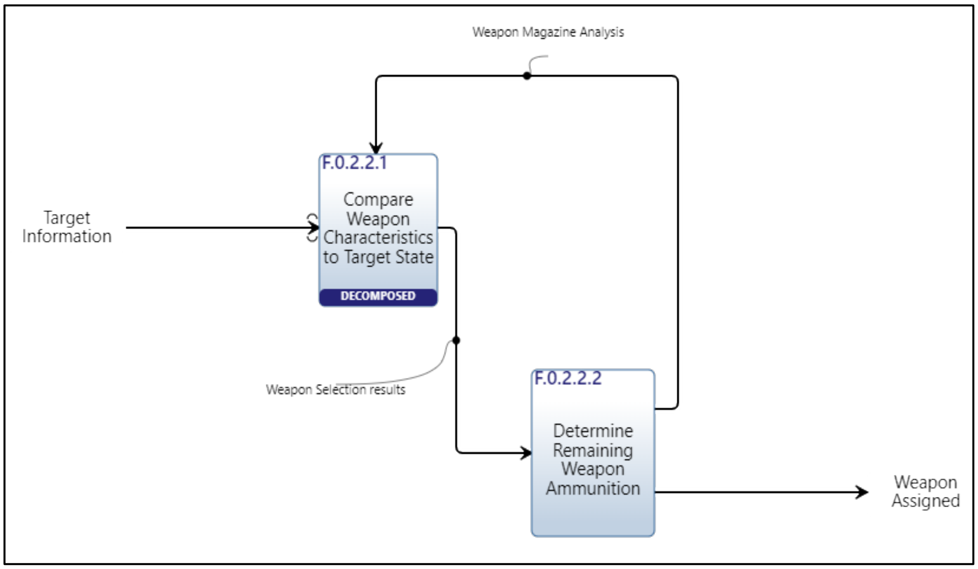

Figure 10. F0.2.2 Select Weapon Functional Decomposition

(1) Compare Weapon Characteristics to Target State Functional Decomposition

Figure 11 shows the decomposition of the Compare Weapon Characteristics to Target State Functional Decomposition. Based on the range and velocity of the incoming threat, the appropriate weapon is selected based on the available magazine. Based on this decision analysis, TALLER, ROBIN, LANCER, or HVP is chosen for engagement.

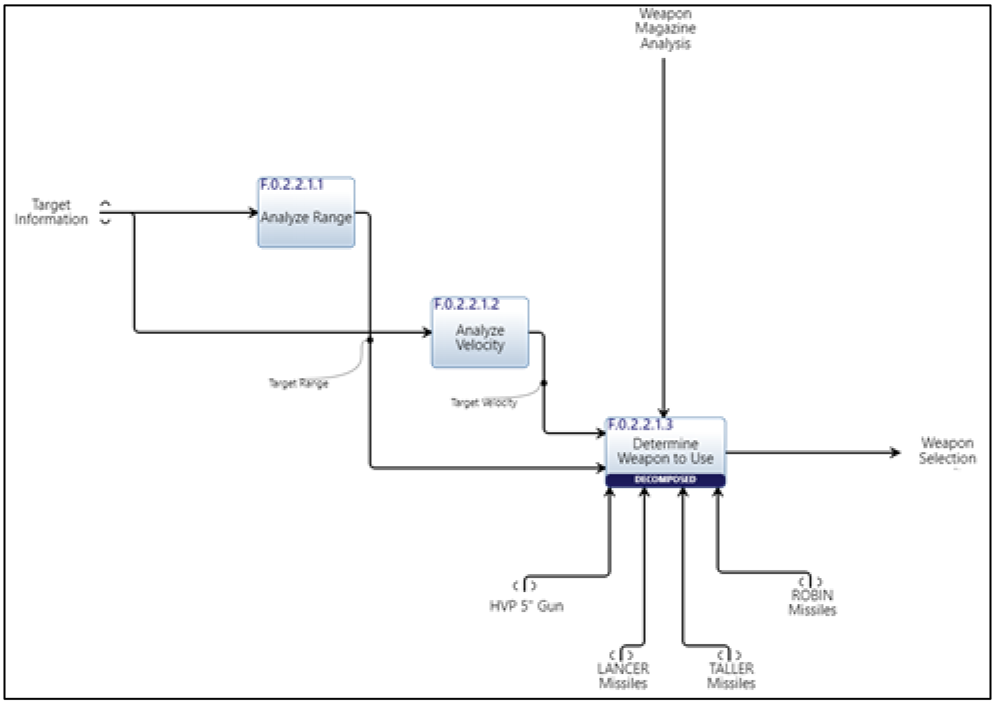

Figure 11. F0.2.2.1 Compare Weapon Characteristics to Target State Functional Decomposition

(2) Determine Weapon to Use Functional Decomposition

Figure 12 shows the function for determining the engagement window from the velocity and range data. This data feeds the final weapon selection function.

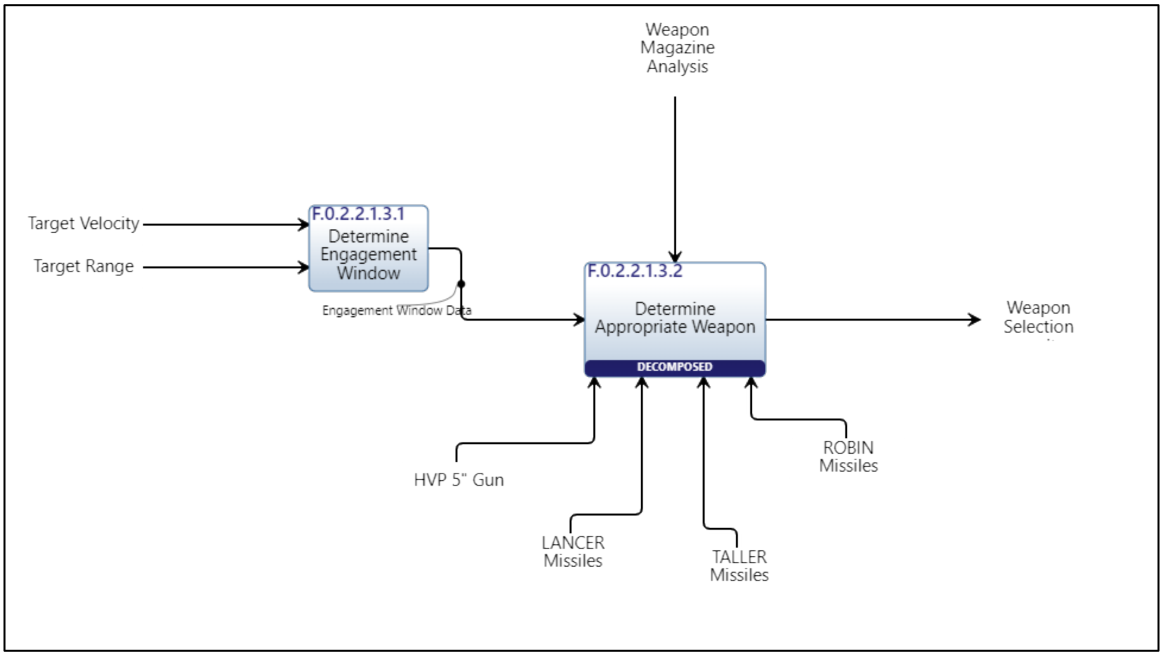

Figure 12. F0.2.2.1.3 Determine Weapon to Use Functional Decomposition

(3) Determine Appropriate Weapon Functional Decomposition

Figure 13 shows the final weapon selection function where the system discriminates between the antiballistic missile battery in the VLS or the HVP with the Mk 45 five-inch gun.

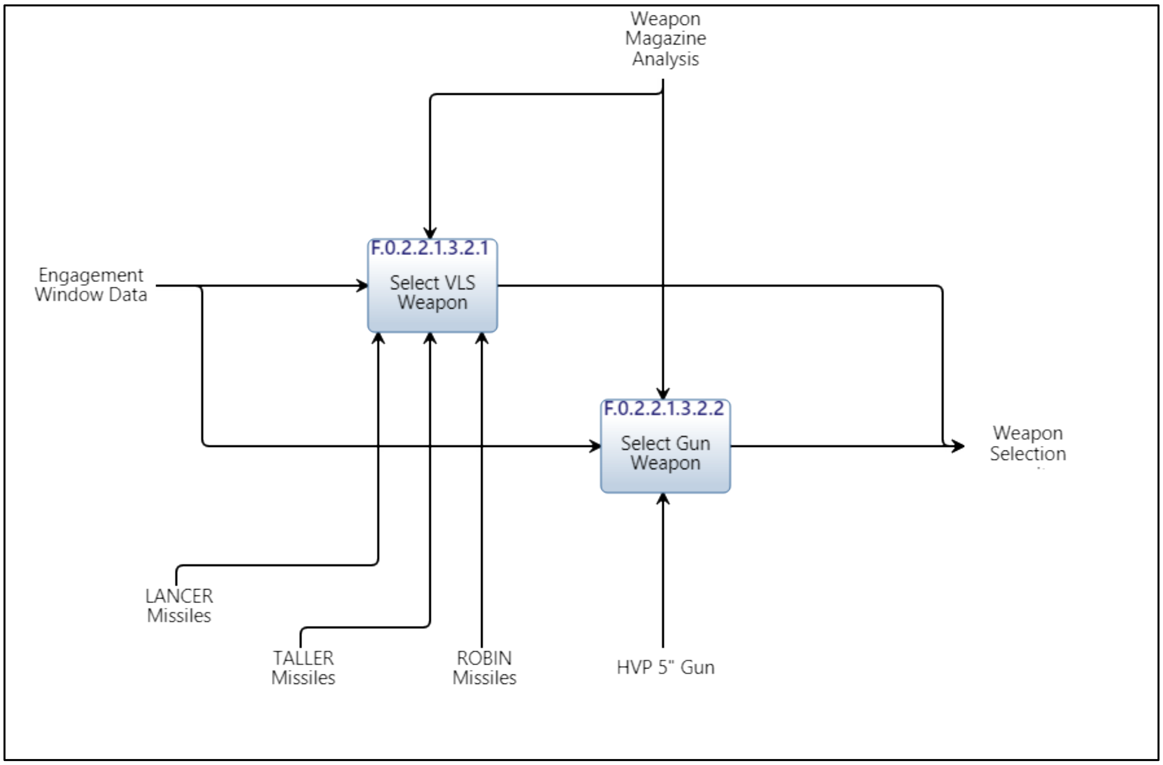

Figure 13. F0.2.2.1.3.2 Determine Appropriate Weapon Functional Decomposition

2. Engage Enemy Threat Functional Decomposition

Figure 14 shows the next level of decomposition for the weapon assignment Function.

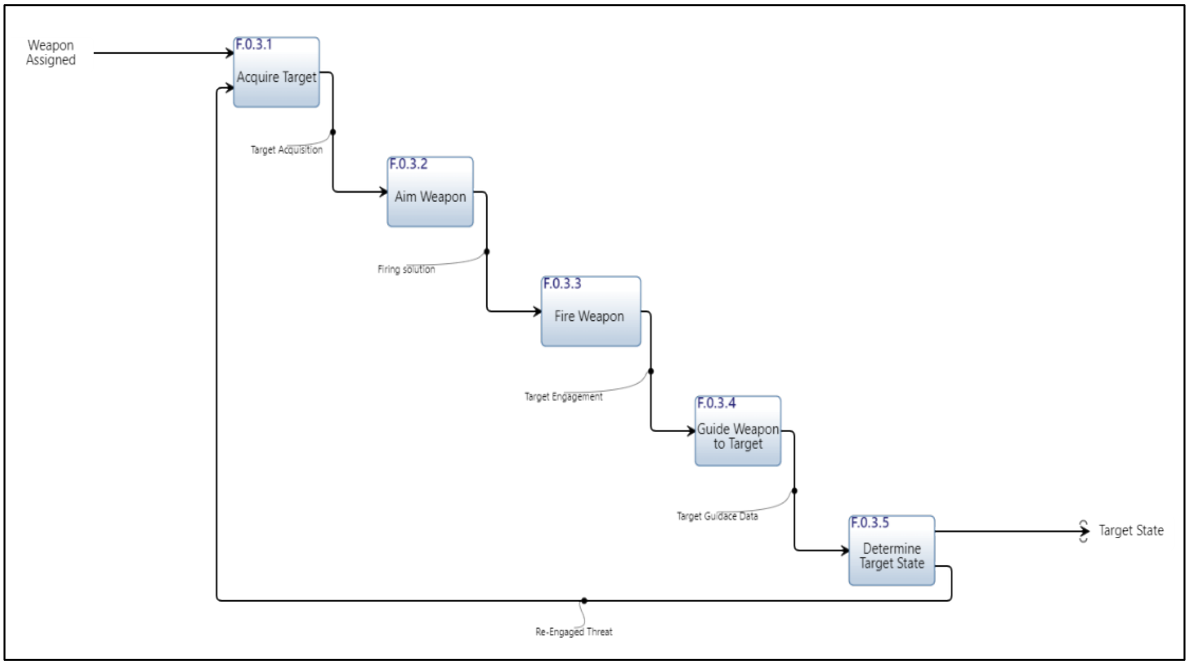

Figure 14. F0.3 Engage Enemy Threat Functional Decomposition

3. Re-engagement of Threat Functional Decomposition

Figure 15 shows the functional decomposition of the threat reengagement function. This function allows for reevaluation of the threat's velocity and range in order to determine the new engagement window. Should the threat not fall within the AFP's engagement window for the VLS and MK 45 five-inch gun, then the target state is forwarded on to the individually targeted ship for CIWS engagement.

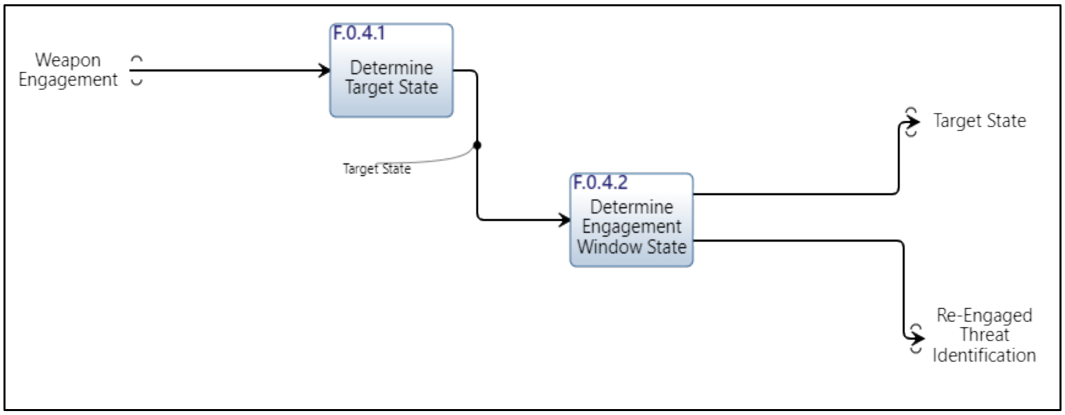

Figure 15. F0.4 Reengagement of Threat Functional Decomposition

4. Individual Ship Engagement of Threat Functional Decomposition

Figure 16 shows the functional decomposition of the individual ship engagement of the incoming threat should all other means have failed to successfully intercept the threat. When this occurs, the ships engage the threat using their CIWS unit(s).

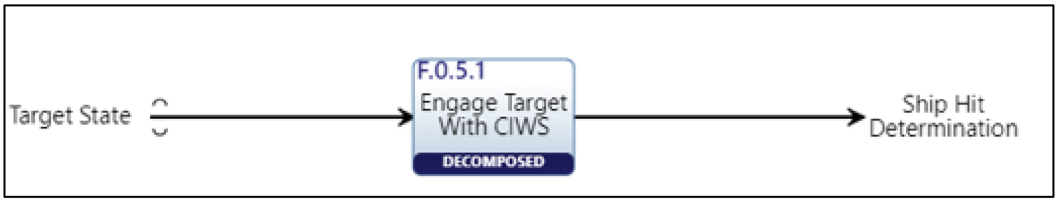

Figure 16. F.0.5 Individual Ship Engagement of Threat Functional Decomposition

a. Engage Target with CIWS Functional Decomposition

Figure 17 shows the decomposition of the Engage Target with CIWS function where the CIWS goes through the target acquisition, aim, and engage functions. In addition, a reengagement loop is included to allow for multiple engagements should there be an opportunity. If the CIWS also fail to intercept the incoming threat, the function output moves on to Ship Hit Determination.

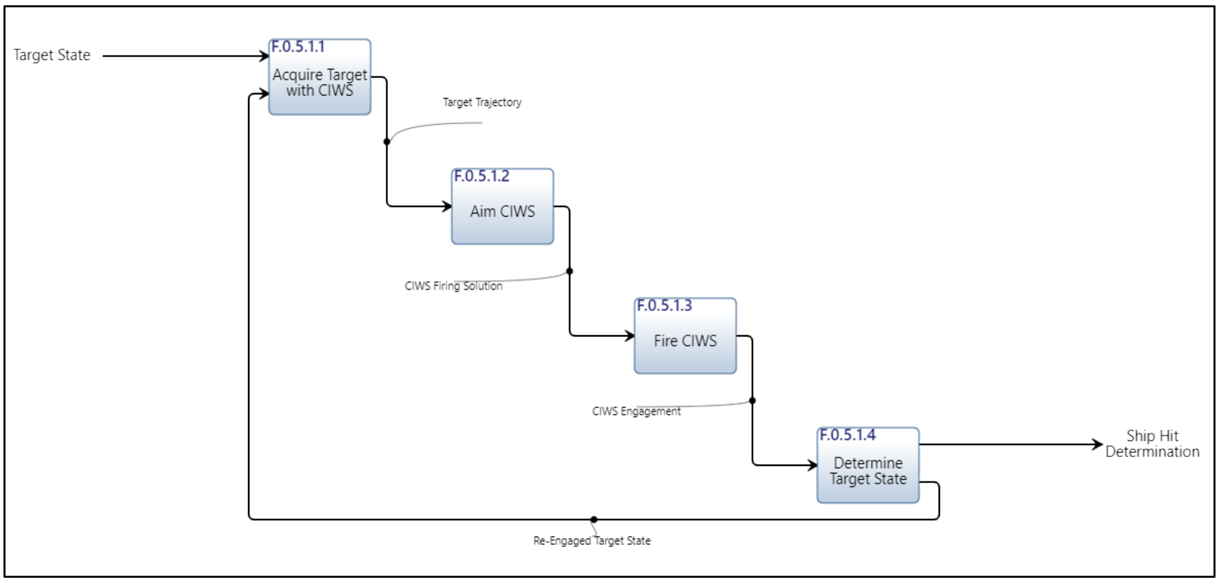

Figure 17. F.0.5.1. Engage Target with CIWS Functional Decomposition

D. REQUIREMENTS ANALYSIS

1. Mission Requirements

Requirements analysis was conducted to determine the requirements needed to satisfy each of the critical functions identified in the functional analysis. Following the project precedent, the system requirements are focused on the overall fires mission. The requirements analysis leads to the critical characteristics of the HVP that will aid in mission satisfaction. Figure 18 shows a tree diagram of the requirements flow.

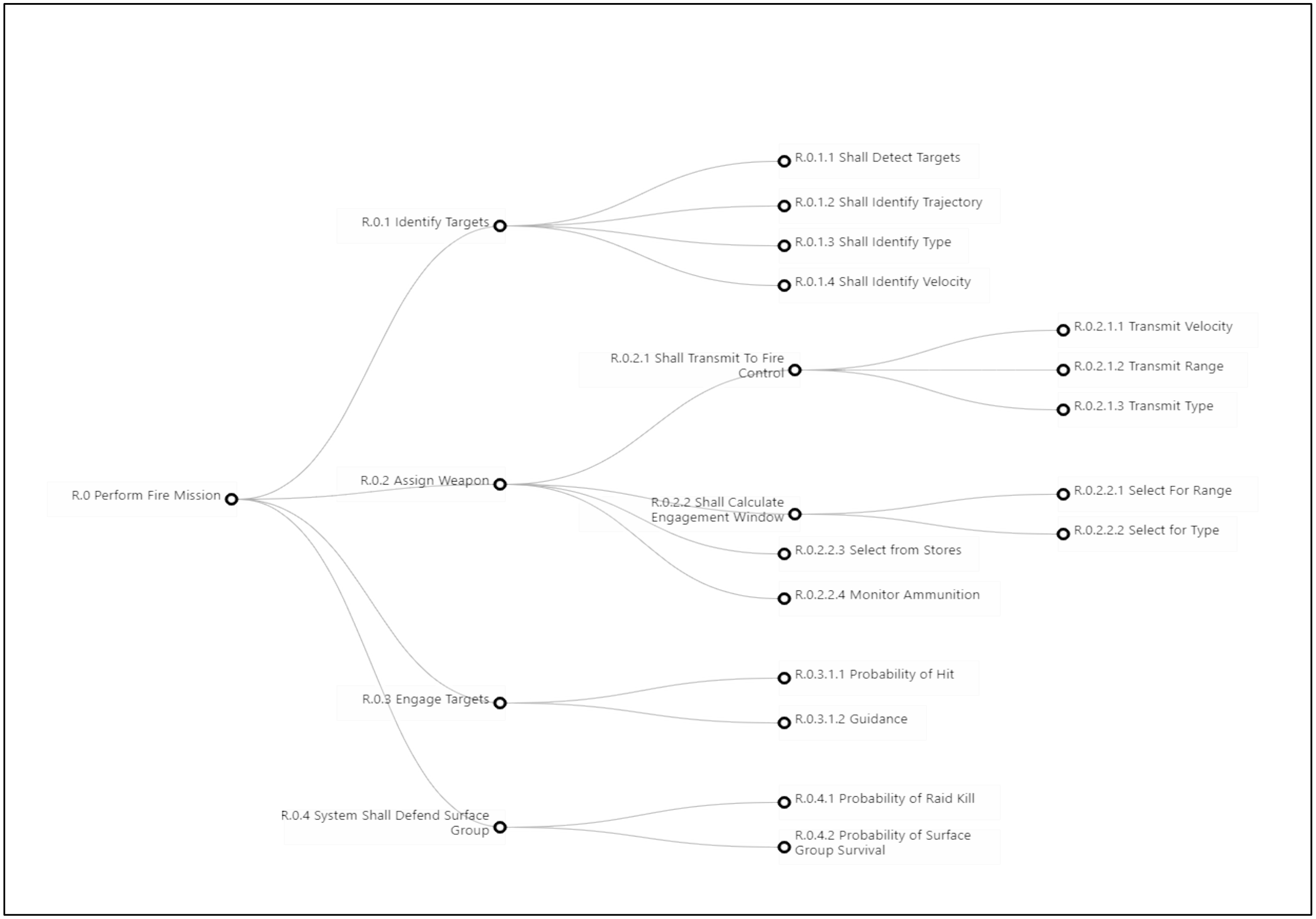

Figure 18. Requirements Tree Diagram for Fires Mission

2. HVP Requirements

As an operational part of a fires mission and the focus of the project, the specific performance requirement thresholds and objectives are unknown and are to be determined through simulation and analysis; however, identification of those requirements is paramount to the building of the simulation. Many of the performance characteristics of the HVP are a function of its employment using the Mk 45 five-inch gun.

a. HVP Accuracy

While the fire rate is governed almost exclusively by the Mk 45, the overall accuracy is a combination of the Mk 45 firing system accuracy and the guidance system accuracy for the HVP. In order to simplify the simulation, the total accuracy will be considered for each firing of the HVP to intercept an incoming threat. In addition, each incoming threat will have its own characteristics that need to be accounted for (i.e., velocity and range). The accuracy of the HVP will need to be determined on a case by case basis such that the HVP will have a greater penalty to accuracy as the velocity of an incoming threat increases.

b. HVP Velocity

The HVP velocity is a crucial performance characteristic because it affects the firing window for the HVP. The faster the interceptor velocity, the more projectiles that can be fired at a threat before it is no longer within firing range. Note that firing rate of the Mk 45 will also impact the number of projectiles that can be fired.

The HVP velocity is only known notionally; however, given that the primary charge for the HVP is the same as the conventional round, there are a number of assumptions that can be made to help determine the velocity of the HVP when fired with the Mk 45.

(1) Energy Balance / Conservation of Energy

Since the HVP and conventional rounds share the same propellant charge, it is assumed that there is a perfect exchange of energy from one round to the other such that the kinetic energy at the muzzle is equal. Under this assumption, the following relationship is assumed to be true:

Kinetic Energy Balance Equation: $(\frac{1}{2}mv^2)_{conventional} = (\frac{1}{2}mv^2)_{HVP}$

To find the velocity of the HVP munition, this equation can be rearranged to produce the following:

HVP Muzzle Velocity Equation: $v_{HVP} = \sqrt{\frac{m_{con}v_c^2}{m_{HVP}}}$; where m_{con} is the mass/weight of the conventional round, v_{con} is the muzzle velocity of the conventional round, and m_{HVP} is the mass/weight of the HVP.

The mass/weight and velocity of the conventional round are given to be 70 lbs. (max) and 2,700 ft/s, respectively (BAE Systems 2015, 18). The mass/weight for the HVP is given to be 28 lbs. (BAE Systems 2018, 2). Entering these values into the muzzle velocity equation yields a resulting HVP muzzle velocity of 4,269 ft/s, approximately Mach 3.8.

(2) Maximum Range / Flight Compensation Velocity

While the muzzle velocity equation gives a reasonable approximation for the velocity of the HVP, it does not compensate for air resistance. Air resistance and friction will create drag on any projectile; however, these values are dependent on the geometry of the projectile, which is unknown. To compensate for this loss of velocity, an additional approach was utilized using the maximum range projectile equation. This equation is derived from the standard distance equation:

Maximum Distance: $d = \frac{v_0^2 sin2\theta}{g}$; where d is the distance, v_0 is the initial velocity, θ is the launch angle, and g is acceleration due to gravity (Lumen n.d.).

By rearranging the maximum distance equation, one can solve for the initial velocity of the projectile. The maximum range for the HVP is given to be greater than 50 nautical miles (BAE Systems 2018, 2). With the true maximum range unknown, the value of 50 nautical miles is assumed to be the maximum. For maximum range, the launch angle is set to 45°. Once rearranged, the velocity for the HVP is determined to be 3,126 ft/s, or approximately Mach 2.78.

(3) HVP Velocity for Simulation and Analysis

From the two previously calculated velocities, the average was taken. This value comes to 3,698 ft/s, or approximately Mach 3.29. This value for the velocity comes close to the notional velocity of Mach 3 (Trevithick 2019).

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IV. SIMULATION

A. INTRODUCTION

Based on the CONOPS and functional architecture presented in Chapter III, a discrete event simulation is built in ExtendSim. To completely represent the sequence of events described in the CONOPS, the simulation model was divided into six major steps: Threat Generation, Weapon Assignment, BLUFOR Engagement, BLUFOR Re-Engagement, Threat Engagement, and Damage Assessment. Figure 19 presents a high-level overview of the model. Note that Figure 19 will be decomposed in subsequent sections to highlight the details associated with each step.

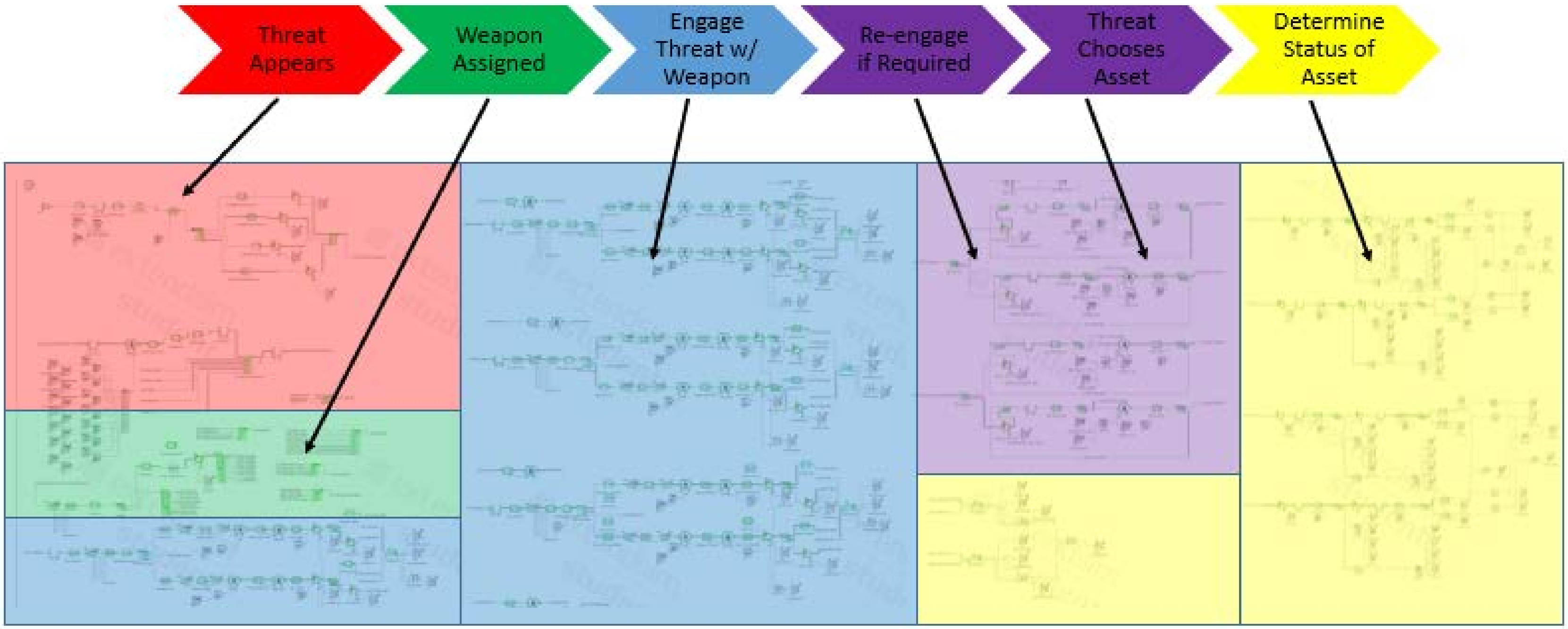

Figure 19. ExtendSim Model Overview

B. MODEL INPUTS

The system inputs fall into two categories: BLUFOR system inputs and REDFOR system inputs. BLUFOR system inputs are defined as those parameters that directly affect the performance of the friendly systems and their ability to accomplish the fires mission. REDFOR system inputs are defined as those parameters required to engage the friendly AFP. In both cases, the central parameters for each armament and interceptor are velocity, range, magazine size / swarm size, probability of hit, and probability of kill. For the BLUFOR system interceptors, the probability of kill is assumed to one with a successful hit. BLUFOR magazine sizes are predetermined based on the system load out and are modified as part of the simulation scenarios. Similarly, the opposition swarm sizes are determined as part of each of the simulation scenarios.

1. BLUFOR and REDFOR System Inputs

Recall that Chapter III presented the systems available to BLUFOR and REDFOR. Given that the goal of the analysis is to approximate the performance of real-world system using an unclassified model, Table 2 presents values for probability of hit, range, and velocity based on information from (Wilkening 1998, 189; Designation-Systems.net. n.d.a; NavWeaps n.d.b; Horitski 2016a; GlobalSecurity.org n.d.a; Horitski 2016b; Thai Military and Asian Region n.d.; GlobalSecurity.org n.d.b).

Table 2. Model Input Values for BLUFOR and REDFOR Munitions.

BLUFOR Munitions			
Munition	Phit	Velocity (Mach)	Range (nmi)
LANCER	0.8	3.5	100
TALLER	0.8	3.5	130
ROBIN	0.8	4	27
PILLBOX	0.5	3.24	27
HVP	-	3.29	0.8
REDFOR Munitions			
Munition	Phit	Velocity (Mach)	Range (nmi)
SNAKEFANG	0.9	3	260
SUNFIRE	0.9	3	292
SHARKBITE	0.9	2.9	59
SLAPSTICK	0.98	0.9	65

C. FIRE MISSION SIMULATION SEQUENCE

1. Threat Identified

During threat identification, the incoming missile swarm is assigned its classification. This classification process identifies each incoming missile as either SNAKEFANG, SUNFIRE, SHARKBITE, or SLAPSTICK. With this classification, all identifying characteristics are also set (velocity, range, and probability of hit and kill). The incoming threats are assigned a type based on the assumption that the opposition force is following a similar salvo mix to the AFP, whereas the more modern and expensive munitions are less likely to be fired and the more common munitions are more likely to fired. Table 3 shows the probability distribution for each swarm in the simulation scenarios and the launch range is determined randomly through a normal distribution within the engagement area and maximum range of the munition. Figure 20 shows the simulation segments and how the threat is modeled.

Table 3. Enemy Munition Distribution

Munition Type	Probability of Launch
SNAKEFANG	0.1
SUNFIRE	0.1
SHARKBITE	0.3
SLAPSTICK	0.5

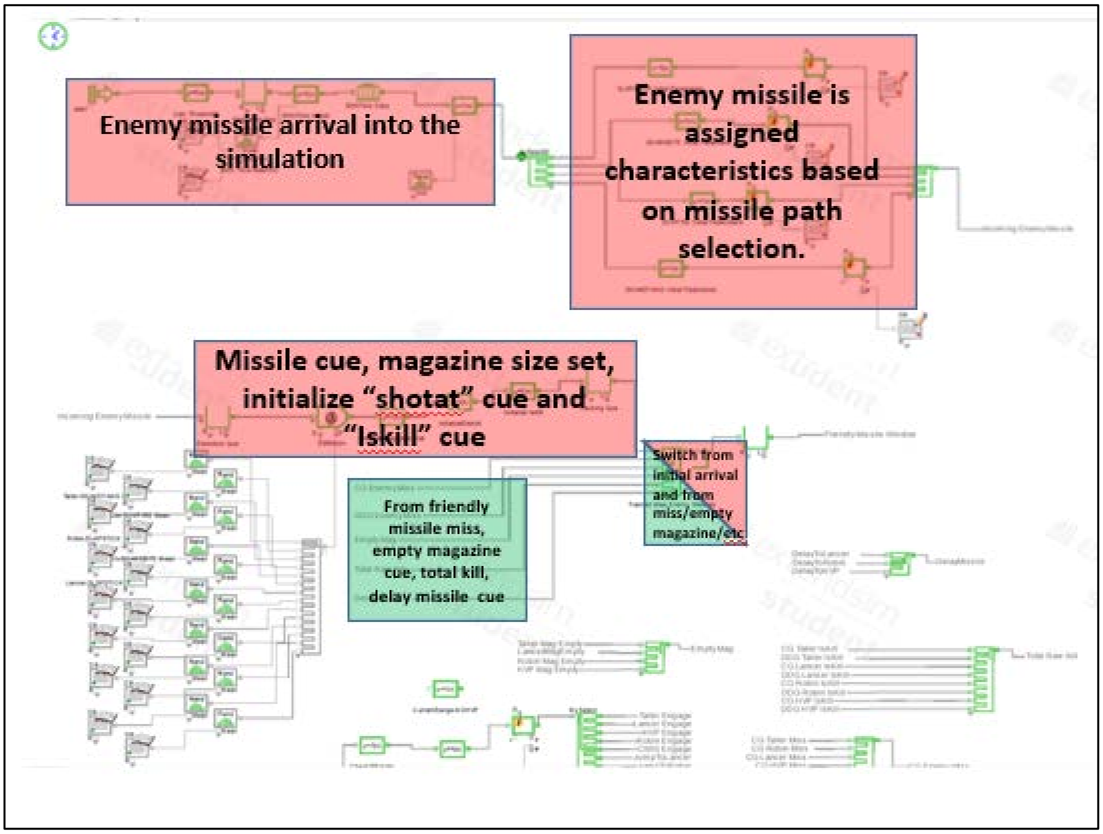

Figure 20. Threat Identification Simulation Segment

2. Weapon Assigned

Weapon assignments are made based on the range and velocity of the incoming munition. Using this information, the firing window is also calculated to determine how many shots may be fired before the firing window closes. Figure 21 shows the simulation segment for the weapon assignment sub function.

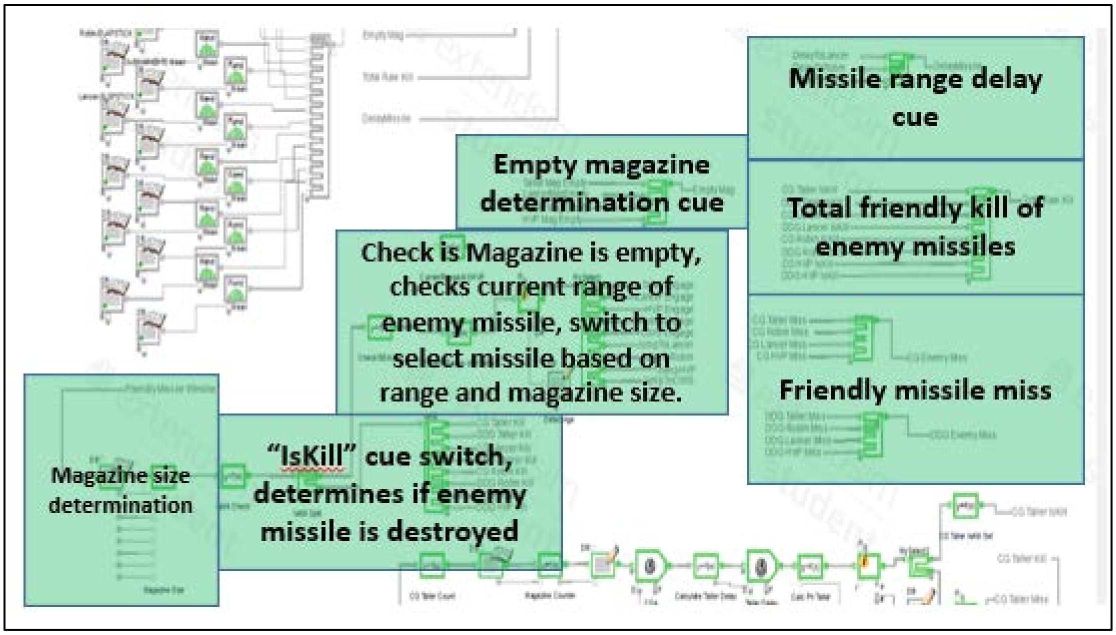

Figure 21. Weapon Assignment Simulation Segment

3. Engage Enemy Threat

With the weapon selected, the threat is forwarded on to the engagement sequence of the simulation. In this segment of the sequence, the enemy munition is assigned to the destroyers or cruisers based on their respective remaining magazine sizes. Firing assignments are prioritized to use up the cruiser magazines prior to utilizing the destroyer magazines. Figure 22 shows the simulation segments for the enemy engagements by weapon type.

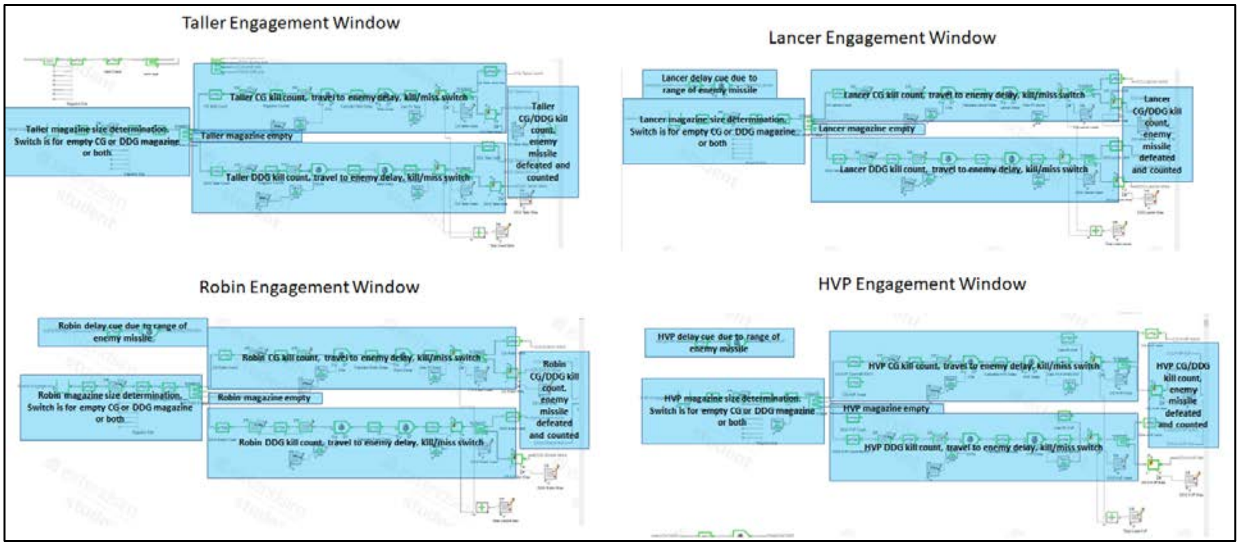

Figure 22. Engage Enemy Threat Simulation Segments For Weapon Types

4. Re-engagement of Enemy Threat

Should the initial engagement of the threat fail to intercept, the enemy munition is routed through a logic loop to reassess the firing window (Weapon Assigned function) and change munitions if necessary. Following this check, the simulation routes the munition for engagement as seen in the Engage Enemy Threat segment.

5. Individual Ship Engagement

If an enemy munition fails to be intercepted by the layered defense, it is classified as a leaker and its individual target is assigned. The Arleigh Burke destroyer class is identified as having a radar cross section that is one-tenth that of the Ticonderoga class cruiser (Eric Jackson Labs 2003, 6). With two of each class in the AFP, this gives a probability of selection for the Arleigh Burke class destroyers of 0.09 and a probability of selection for the Ticonderoga class cruisers of 0.91. With the target class determined, the probability of either of ships in the selected class being targeted is 0.5.

With the individual ship targeted, that ship then has the ability to mount a final defense using PILLBOX, the ship's CIWS system. As previously done in the weapon selection and engagement segments of the simulation, PILLBOX has its own calculations for its firing window and engages accordingly. Figure 23 shows the simulation segments for the CIWS engagements.

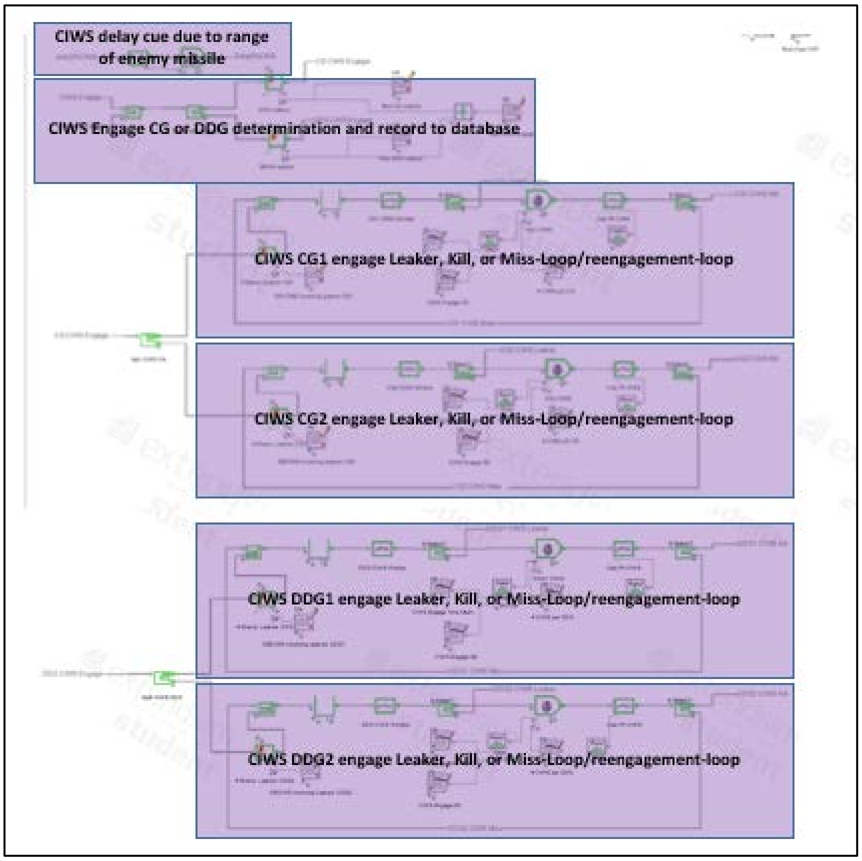

Figure 23. CIWS Engagement Simulation Segments

6. Determine Status of Asset

As each enemy munition completes its path through the simulation, metrics are gathered based on each individual outcome. Furthermore, should a leaker successfully strike a ship in the AFP, information is gathered for the outcome of the ship (i.e., lethal strike vs. damaging strike). Appendix C contains an output table depicting all variables tracked throughout each scenario. Figure 24 shows the simulation segments for asset status determination.

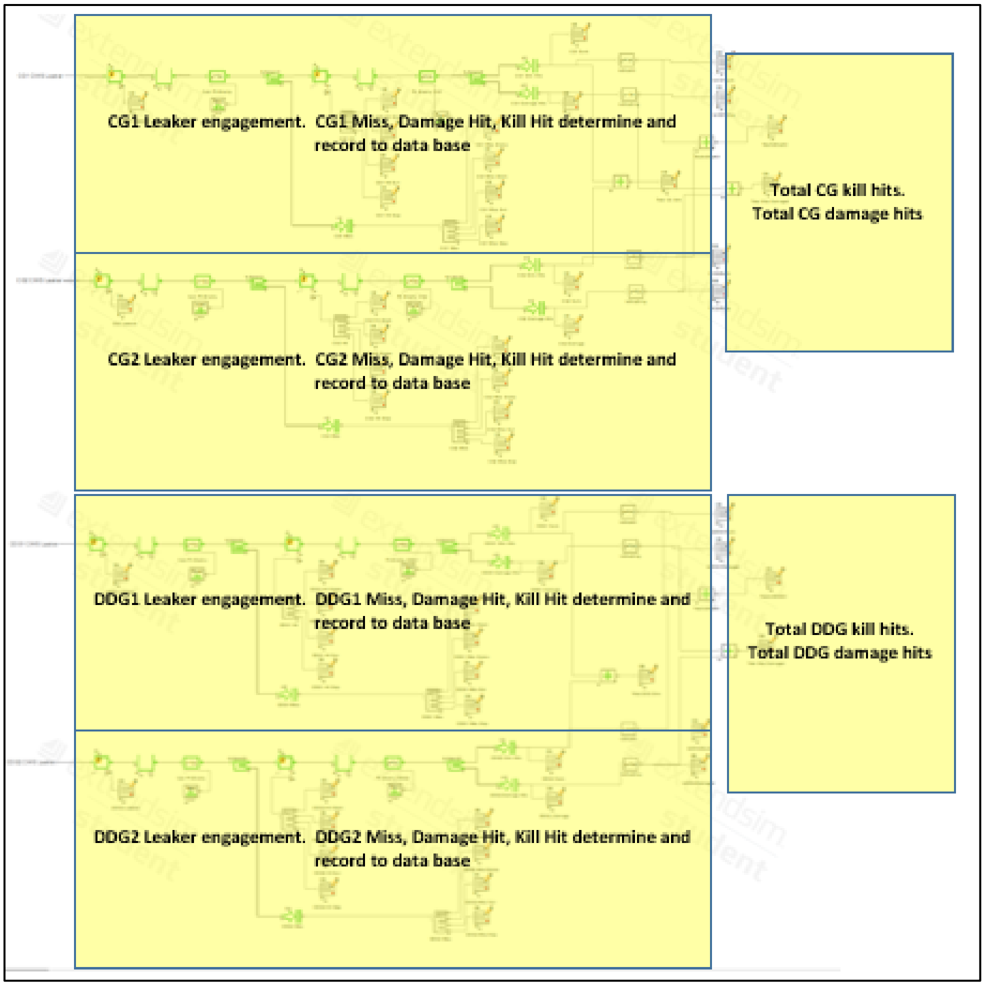

Figure 24. Asset Status Determination Simulation Segments

D. SIMULATION SCENARIOS

The simulation primary scenarios include a baseline scenario using only the AFP's conventional load out, an HVP included scenario, HVP only load out, a TALLER reduction load out, a LANCER reduction load out, and a ROBIN reduction load out. In addition, for each of the primary simulation scenarios, the incoming swarm size was adjusted. Swarm sizes were evaluated at 25, 50, 75, and 100 incoming threats.

1. Baseline Scenario

The baseline scenario illustrates how effectively the AFP performs its defensive operations with only its conventional load out. The baseline acts as a point of comparison for the use of the HVP in a defense net. For this scenario, only the existing defensive munitions are used: TALLER, LANCER, ROBIN, and PILLBOX.

2. HVP Included Scenario

For this scenario, the baseline scenario is augmented to include the HVP. This scenario is intended to evaluate the effectiveness of the HVP when used in conjunction with the current missile defense load out of the AFP. In addition, the engagement window for LANCER is adjusted to minimize weapon system overlap with HVP. With the probability of hit and kill for the HVP unknown, simulation runs were created for an HVP probability of hit of 0.1, 0.2, and 0.3. In addition to varying of probability, burst firing options are explored where the HVP is continuously fired without waiting to verify a kill or miss. Given that high end estimates for the HVP only reach $100,000, the simulation leverages the high firing rate of the MK 45 for intercept missions as an intercept under these conditions would likely be cheaper than using a VLS interceptor (LaGrone 2019). For this, burst simulations contain three and five-round burst firing which increases the overall probability of intercept where: $P_{intercept} = 1 - \left[P_{hit}(1 - P_{hit)}{}^{n-1}\right]$. Figure 25 shows an illustration of the HVP in the loop (ITL) scenarios with sub-scenarios.

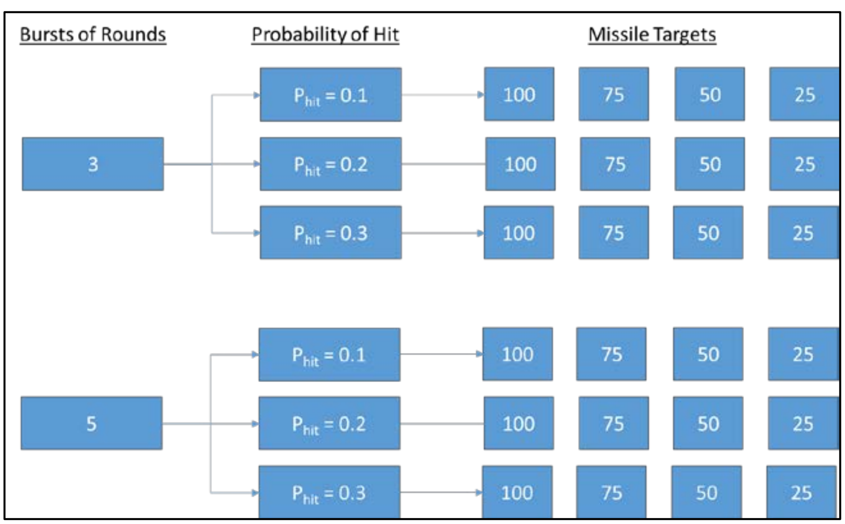

Figure 25. HVP Scenario Schema

3. HVP Only Scenario

The HVP only scenario removes the standard load out munitions. Under this scenario, the HVP is still only used to engage subsonic targets. Additional simulation runs are conducted using HVP burst fire as previously described.

4. Reduction Scenarios

Reduction scenarios are scenarios in which the existing magazines for the VLS system are systematically reduced in order to evaluate the total mission performance and to see if the HVP is capable of maintaining the overall system performance under an increased firing load. To accomplish this, the following scenarios were generated:

- 50% reduction of TALLER magazine
- 50% reduction of LANCER magazine
- 50% reduction of ROBIN magazine

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V. ANALYSIS AND RESULTS

A. INTRODUCTION

The primary focus for the analysis of the simulation data is centered on the performance of the HVP and those factors that affect its efficacy as part of the layered AFP defense. Based on the previously determined MOEs, the probability of hit / kill and magazine depth of the HVP were determined to the primary focus of the stakeholders. As such, the data included focuses on the percentages of the incoming salvos destroyed based on the probability of hit. Though the magazine depth of the HVP was previously determined, the data presented shows a more accurate representation of what should be carried based on the efficiency of the raid defense and the number of rounds expended. All simulation data is included for future examination in Appendix C.

B. SALVO DEFENSE ANALYSIS

Recall that multiple AFP configurations were modeled in ExtendSim: a baseline configuration, an HVP only configuration, an integrated HVP configuration, and multiple reduction scenarios where the quantities of each currently fielded projectile is limited. Each of these configurations is examined across four different enemy salvo sizes, ranging from 25 to 100 targets.

1. Baseline Configuration

The baseline configuration runs off the current VLS load outs of the AFP. Under these conditions, the AFP is able to fend off the swarms of 25 and 50 incoming hostile targets without the loss of any ships. It is not until the swarm reaches seventy-five and one hundred that the ships defenses are overcome. The data collected during these runs is used as the base of comparison in the following analysis. Figure 26 shows the percentages of the swarms that are destroyed by the VLS munitions (CIWS kill information is excluded from reporting since the HVP is a direct compliment to the VLS magazine and the CIWS performance has no impact on the HVP's performance; however, all CIWS data was captured and is included in the data set).

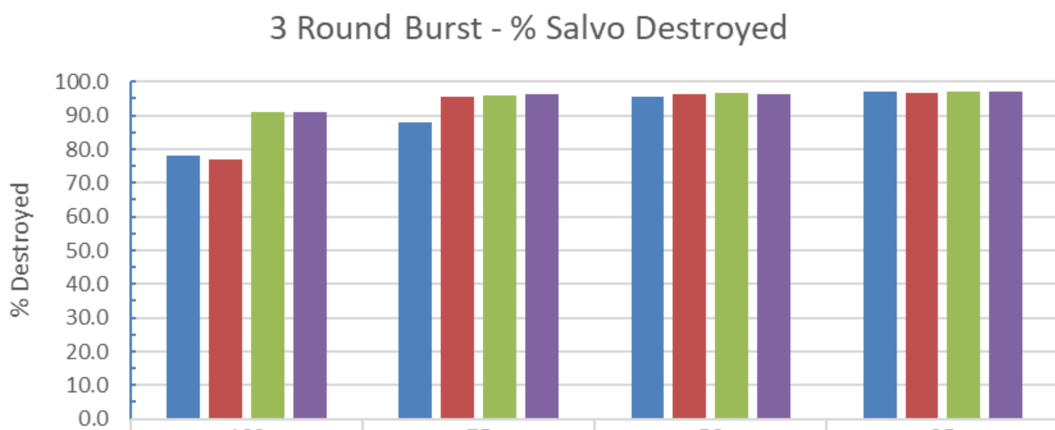
Figure 26. Percentage of Salvo Destroyed by VLS

2. HVP in the loop (ITL)

Recall from Chapter IV that the simulations conducted with the HVP ITL were built using three- and five-round burst configurations. The burst scenarios are examined for all salvo sizes previously used in the baseline configuration for direct comparison.

a. Three-round Burst

With a fire doctrine of three-round burst firing, the HVP does not appreciably affect the percentage of salvo destroyed with a probability of hit of 0.1. When the probability of hit is increased, the effectiveness of the HVP on the total outcome also increases. Figure 27 shows the percentage of salvo destroyed for each probability and includes the baseline output for comparison.



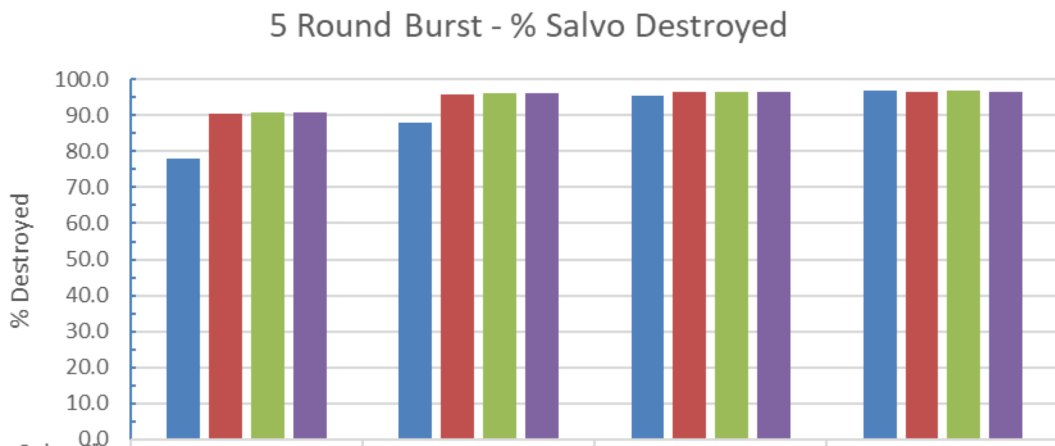
Salvo Size	100	75	50	25
Baseline	78.1	88.1	95.5	97.0
Phit 0.1	77.0	95.7	96.2	96.6
Phit 0.2	90.9	95.9	96.5	97.0
Phit 0.3	90.8	96.2	96.4	96.9

Figure 27. Percentage Of Salvo Destroyed Three-Round Burst Comparison

When the incoming salvo is 50 or fewer, the addition of HVP increases the percentage of salvo destroyed by less than one percent. As the salvo increases to 75 and above, the VLS capabilities begin to be overwhelmed. The inclusion of HVP increases the percentage of salvo destroyed by an average of 7.8 percent across all probabilities. When evaluating the one hundred incoming salvo data, it is important to note that even with a probability of hit of 0.1, the HVP ITL only reduces the effectiveness of the defense by 1.1 percent while increasing the defense effectiveness by 12.8 and 12.7 percent for probabilities of hit of 0.2 and 0.3, respectively. With the HVP being developed as a multi-mission munition, the data demonstrates that its inclusion into a standard load out will be beneficial even if only as an optional munition choice with a probability of hit of 0.1.

b. Five-round Burst

With a fire doctrine of five-round burst firing, the HVP provides nearly identical performance across all probabilities of hit for enemy salvos of 75 and below. Figure 28 shows the effectiveness of the HVP as compared to the baseline data.



Salvo Size	100	75	50	25
Baseline	78.1	88.1	95.5	97.0
Phit 0.1	90.3	95.7	96.4	96.5
Phit 0.2	90.7	96.1	96.6	96.9
Phit 0.3	90.8	96.1	96.7	96.6

Figure 28. Percentage of Salvo Destroyed Five-Round Burst Comparison

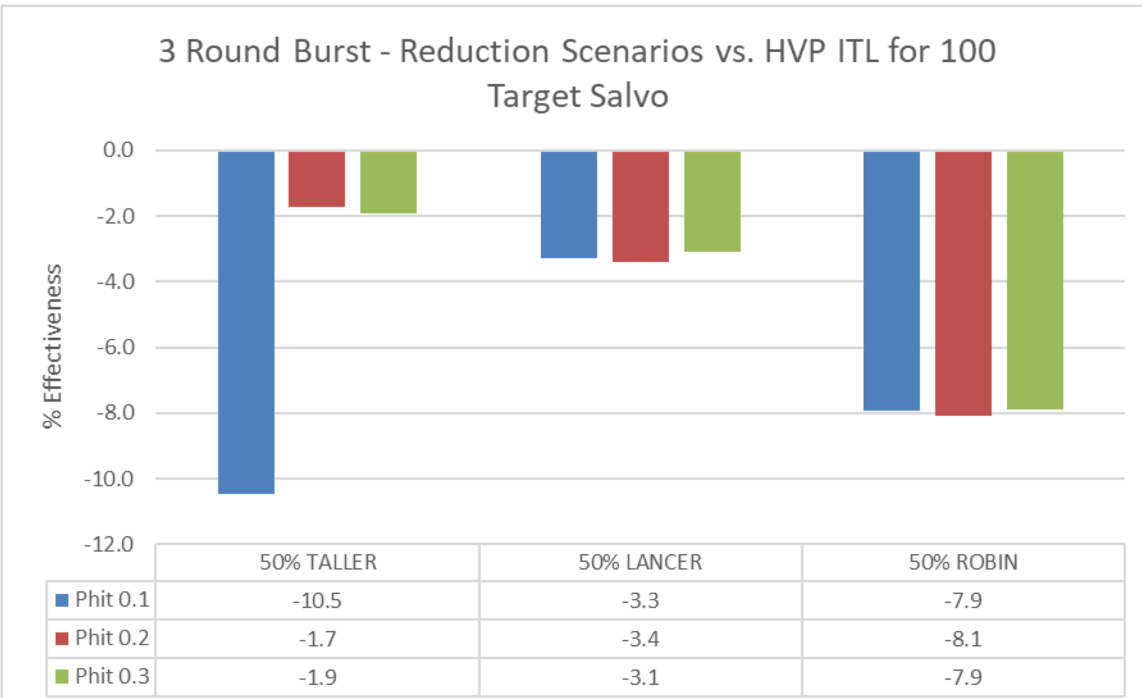
Whereas the three-round burst is only capable of comparable results when the HVP has a probability of hit of 0.1 with an enemy salvo of 100, a five-round burst of the same probability is capable of destroying more targets and comparable to higher probability HVP load outs, increasing the percentage of salvo destroyed by 12.2 percent. Based on this outcome, should the HVP not be able to achieve a higher probability in an early stage of engineering maturity, an increased burst rate can achieve better results when encounter an enemy swarm larger than 75. This is largely attributed to the high fire rate of the MK 45 and the number of available guns in the AFP as the intercept windows are determined by the velocity and range of the incoming projectile.

3. REDUCTION SCENARIOS

Across all reduction scenarios, the inclusion of the HVP offered no appreciable increase in overall salvo defense versus the HVP ITL. In most cases, the overall defense integrity was hindered; once the VLS magazine is depleted against a salvo of 100 targets, the overall defense integrity begins to fall off. Essentially, the layered defense is operating at full capacity for all salvo sizes below 100. The HVP serves well as an augmentation to the baseline system, but it is unable to compensate for the loss of magazine for the other VLS munitions under the current model conditions and assumptions.

a. Three-round Burst

For a salvo size of one hundred, the operational effectiveness of the defense system decreases across all reduction scenarios. Figure 29 shows the results on this analysis.



	50% TALLER	50% LANCER	50% ROBIN
Phit 0.1	-10.5	-3.3	-7.9
Phit 0.2	-1.7	-3.4	-8.1
Phit 0.3	-1.9	-3.1	-7.9

Figure 29. Three-round burst reduction scenario results

a. Five-Round Burst

Under the five-burst firing doctrine for HVP, the reduction scenarios gave similar results to the three-round burst scenarios, with the exception of the TALLER reduction scenario. For this scenario, the effectiveness of the layered defense was reduced by 1.6 percent versus the reduction of effectiveness of 10.5 percent in the three-round burst scenario. Figure 30 shows the results for the five-round burst reduction scenarios.

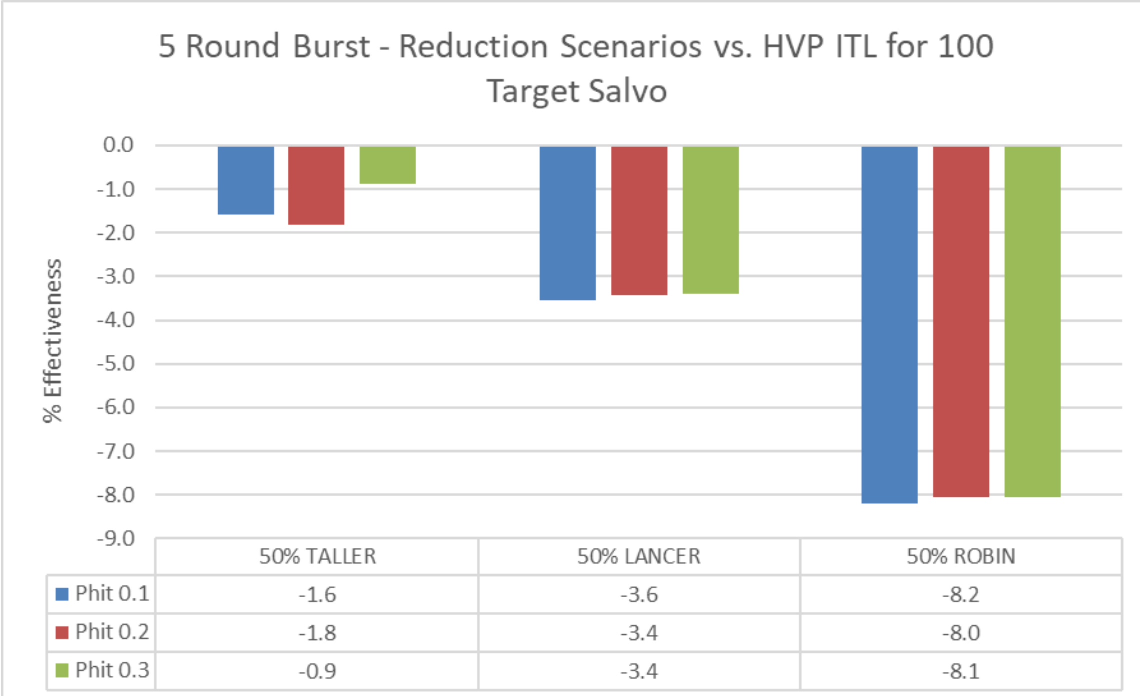


Figure 30. Five-round burst reduction scenario results

C. MUNITION EXPENDITURE AND COST ANALYSIS

1. Baseline Configuration

As before, the baseline configuration expenditure and cost data will be used as a point of comparison for the HVP ITL scenarios. In order to determine the cost associated with each munition, the system analogues were used as models for TALLER, LANCER, and ROBIN. Based on the unitary cost of the SM-6, each TALLER has a cost of $5.6 million dollars (Deagle n.d.a). Based on the unitary cost of the SM-2, each LANCER has a cost of $0.75 million (Deagle n.d.a). Based on the unitary cost of the ESSM, each ROBIN has a cost of $0.64 million (Deagle n.d.b). Table 4 shows the average magazine expenditure and engagement cost for the baseline scenarios.

Table 4. Baseline Scenario Average Magazine Expenditures and Costs

Baseline Scenarios Magazine Expenditures and Costs							
Salvo Size	TALLER Fired	TALLER Cost	LANCER Fired	LANCER Cost	ROBIN Fired	ROBIN Cost	Cost Totals
100	34.1	191.1	171.0	128.3	56.0	35.8	355.2
75	25.7	143.8	140.6	105.4	55.4	35.5	284.7
50	17.2	96.6	96.4	72.3	44.8	28.7	197.6
25	8.6	48.0	48.9	36.6	23.2	14.9	99.5

2. HVP ITL

a. Three-round Burst

When utilizing the three-round burst firing doctrine for the HVP as part of the layered defense, there is an appreciable decrease in the total defense cost across all probabilities of hit apart from the one hundred salvo scenarios. Based on the data, the HVP decreases the dependence on ROBIN for the engagements. Table 5 shows the munition expenditure and cost for the three-round burst scenarios and compares the total cost to the baseline.

Table 5. HVP ITL Three-round Burst Munition Expenditure and Cost

Three Round Burst - HVP ITL											
HVP Probability of Hit	Salvo Size	TALLER Fired	TALLER Cost ($M)	LANCER Fired	LANCER Cost ($M)	ROBIN Fired	ROBIN Cost ($M)	HVP Fired	HVP Cost ($M)	Cost Totals ($M)	Delta Cost from Baseline ($M)
Phit = 0.1	100	33.5	187.7	171.1	128.3	55.2	35.3	331.6	28.2	379.5	24.3
	75	25.3	141.4	139.7	104.8	45.1	28.8	96.3	8.2	283.2	-1.5
	50	17.4	97.4	97.1	72.8	27.4	17.5	64.4	5.5	193.2	-4.4
	25	8.3	46.2	48.5	36.4	13.7	8.8	32.1	2.7	94.1	-5.4
Phit = 0.2	100	34.4	192.8	170.7	128.0	55.2	35.3	79.1	6.7	362.9	7.6
	75	25.8	144.3	140.4	105.3	44.6	28.6	54.6	4.6	282.7	-1.9
	50	17.4	97.2	96.9	72.7	27.6	17.7	37.0	3.1	190.7	-6.9
	25	8.2	46.2	48.9	36.7	12.9	8.3	19.1	1.6	92.8	-6.7
Phit = 0.3	100	33.8	189.3	170.9	128.2	55.2	35.3	59.3	5.0	357.9	2.7
	75	25.4	142.4	140.8	105.6	43.9	28.1	41.9	3.6	279.7	-5.0
	50	16.6	92.9	97.1	72.8	27.9	17.9	27.2	2.3	185.9	-11.7
	25	8.6	47.9	48.6	36.5	13.6	8.7	13.6	1.2	94.2	-5.3

b. Five-round Burst

As with the three-round burst scenarios, utilizing the five-round burst firing doctrine for the HVP shows a general decrease in the total cost of engagements apart from higher incoming salvo numbers. Unlike with the three-round burst scenarios, there is also an increase in cost for the 75 target scenario for the probability of 0.1 scenario. This is due to the higher number of misses and the subsequent reengagement having the larger burst. Table 6 shows the munition expenditure and cost for the five-round burst scenarios and compares the total cost to the baseline.

Table 6. HVP ITL Five-round Burst Munition Expenditure and Cost

Five Round Burst - HVP ITL											
HVP Probability of Hit	Salvo Size	TALLER Fired	TALLER Cost ($M)	LANCER Fired	LANCER Cost ($M)	ROBIN Fired	ROBIN Cost ($M)	HVP Fired	HVP Cost ($M)	Cost Totals ($M)	Delta Cost from Baseline ($M)
Phit = 0.1	100	33.9	189.6	170.9	128.2	55.2	35.4	232.9	19.8	372.9	17.7
	75	25.5	142.7	139.4	104.6	44.3	28.4	158.9	13.5	289.1	4.5
	50	16.7	93.5	97.1	72.8	26.5	17.0	108.2	9.2	192.5	-5.1
	25	8.5	47.7	48.6	36.4	13.7	8.8	55.6	4.7	97.6	-1.9
Phit = 0.2	100	34.1	190.8	170.9	128.2	55.3	35.4	133.2	11.3	365.7	10.4
	75	25.2	141.1	140.4	105.3	43.9	28.1	92.5	7.9	282.4	-2.3
	50	17.2	96.4	96.8	72.6	27.1	17.4	62.5	5.3	191.6	-6.0
	25	8.6	47.9	48.5	36.4	13.6	8.7	30.1	2.6	95.6	-3.9
Phit = 0.3	100	33.7	188.6	170.9	128.2	55.2	35.3	98.7	8.4	360.5	5.2
	75	25.4	142.5	140.7	105.6	44.2	28.3	67.6	5.7	282.1	-2.6
	50	16.8	94.1	97.9	73.4	27.4	17.5	47.9	4.1	189.1	-8.5
	25	8.5	47.6	48.2	36.2	13.5	8.7	22.0	1.9	94.3	-5.2

VI. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

The HVP has potential to provide improved missile defense capability as part of a shipboard gun-based defense system. This study seeks to identify the parameters of the HVP that have the largest impact on operational effectiveness in a defensive situation, determine the cost benefit of including the HVP as part of a multi-mission role, determine feasible engagement envelopes, and define doctrinal and tactical changes to aid in the deployment of a HVP.

This project utilizes a modified system engineering process tailored to a mission engineering approach, consisting of an initial research, problem definition, simulation, and analysis phases. The initial research phase gathers existing information for the HVP and current naval weapon systems. The problem definition phase defines the concept of operations, stakeholder needs, and necessary functional requirements of the HVP by examining theater deployment and establishes the desired MOEs. The simulation phase demonstrates a mathematical model for the performance of the missile defense system augmented by the use of the HVP. The analysis of results phase evaluates the data from the simulation to determine the effectiveness of the system and the HVP's ability to satisfy those requirements established during the problem definition phase.

The concept of operations for the model centers on an AFP fire mission. During the mission, the AFP comes under attack by anti-ship missiles and deploys the necessary countermeasures to defend the incoming attack. Analogues were created for the BLUFOR to mimic current naval defense weapons based on the current VLS loadouts of the Arleigh Burke and Ticonderoga class ships (TALLER, LANCER, ROBIN, and PILLBOX). Similarly, enemy analogues were created to mimic munition for the REDFOR (SNAKEFANG, SHARKBITE, SLAPSTICK, and SUNFIRE). The CONOPS presents two primary scenarios for consideration: baseline scenario featuring current system analogues and HVP ITL scenarios where the HVP augments the current load out. The HVP

ITL scenario includes sub-scenarios that feature munition reductions for the baseline munitions.

The simulation is built based on the CONOPS and creates realistic engagements to collect data on the performance of the HVP. This establishes measurable data points from which to analyze the overall performance of the AFP in a missile defense scenario.

B. ANALYSIS FINDINGS

This project and analysis show that the HVP can increase the combat capability of an AFP by increasing the effectiveness of missile defense. Based on the reduced data from the simulation, the existing defense weapons are able to adequately defend the AFP for salvos of 50 targets or fewer. However, the inclusion of HVP provides an increased effectiveness of salvo destruction for enemy salvos of 75 and 100 targets. Even at its lowest probability of hit, the HVP ITL scenario provides an improvement in salvo destroyed for the one-hundred target salvo.

For cost-effectiveness, inclusion of the HVP into the system load out shows a net decrease in defense cost against an enemy salvo. It is only when the salvo size reaches one hundred that the total system defense cost increases. Based on the Weapon Reduction scenarios, the reduction of the Taller munitions (SM-6) had the least negative effect on the effectiveness of the ship defense in terms of salvo destroyed. Reducing the Lancer (SM-2) and Robin (ESSM) had a more negative impact on the number of targets destroyed.

Since the inclusion of HVP had shown an increase in effectiveness for salvos above 75, the inclusion of HVP as part of anti-missile defense against high-density swarms is worth further investigation. Due to the inability for the HVP to engage supersonic targets, an HVP-only configuration for anti-missile defense is not recommended. If upfront cost-reduction is to be considered, the reduction of use of the TALLER/SM-6 for a swarm-attack scenario seems to be the most promising lead, as long as the enemy salvo remains below 75 targets. However, in terms of defense capability, any reduction in VLS weapons is not recommended due to the decreased values of salvo destroyed.

Regarding the specific parameters of the HVP, the analysis showed that utilizing a five-round burst, rather than a three-round burst, increased defense effectiveness across all scenarios. Varying the probability of hit of individual HVP rounds between 10% and 30% had comparatively less impact than changing the burst size. Therefore, should the system not be capable of higher probabilities of hit, the simulation shows that leveraging the high fire rate of the MK 45 can mitigate any decrease to operational effectiveness that may be expected with a reduction to probability of hit by utilize five-round bursts.

C. RECOMMENDATIONS

1. Further Research

The simulation and analysis for the evaluation of the HVP was purposely created using a modular approach. Further investigation into the performance of the HVP as part of a layered missile defense system can be accomplished by entering more exact probabilities for all munitions. In addition, opposition munitions can be adapted for any given foe or scenario.

2. Expansion of Research

With the HVP developed as a multi-mission munition, this study can be expanded on to include offensive fires as part of the total mission as is envisioned in the concept of operations. Expansion on the study of system load outs will provide the opportunity to evaluate the full logistics life cycle of the HVP, providing additional lifecycle cost information. The Navy is also developing the HVP for use with the railgun. This creates more opportunities to evaluate the future of the HVP and modern naval weapons in complete scenarios.

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APPENDIX A. STAKEHOLDER ANALYSIS

Table 7. HVP Stakeholder List

Stakeholder	Notes (Facts Assumptions)	Constraints	Objectives	Requirements (Needs/ Wants/Desires)	Priority
ONR Railgun Office	Capstone project	Ship environment. Ship power. Enemy countermeasures.	Weapon operates in the mission environment that is required, both offensive and defensive.	Effectiveness of weapon system when use is required.	High
Battle Field Commander	Responsible for all blue forces in the battle space. Overall mission planning.	Enemy movements and positions, defensive systems of the enemy	Ensure mission success and friendly force survival	Meet mission goals; minimum expense of munitions; survival of friendly force	High
Ship Leadership	Responsible for battle space management and strategy.	Changing battlefield environment; making on the spot mission decisions.	Protect the fleet at all cost to ensure mission success	Understand how effective the munition is, what are the limits, and how efficient the lethality of the munition	High
HVP Project Manager	Responsible for project management for the HVP	Only can control what is in the view of the PM	Deliver the system to meet user needs and requirements.	Get the HVP fielded for Solider use.	Medium

Stakeholder	Notes (Facts Assumptions)	Constraints	Objectives	Requirements (Needs/ Wants/Desires)	Priority
SE group	Responsible for requirements management	Must maintain requirements, given a fluid user environment	Control the requirements and verify completion.	Ensure that the current program objectives meet user needs	Medium
SW group	Management of system SW	Ship software interface and other information assurance policies developed by the military.	Ensure that the software for firing and accuracy is correct and delivers the munition on target and on time.	Understand of the system to write code	Medium
Contractor	Paid to produce the product	Can only build what they are paid to construct. Limited by funding	Deliver a HVP that meets the requirements developed by the user and by the program management office	Produce the HVP for the user; ensures that the HVP will be able to be fired from a cannon	Medium
Cannon Project Office	HVP may require cannon software to be adapted and or upgraded to use the HVP; will require working across multiple project offices and primes.	Other munitions that are utilized in the cannon	Ensure that the cannon barrel meets the diameter requirements of the required munitions	Ensure that the HVP is usable by the cannon, give specs on cannon to ensure compatible design	Medium

Stakeholder	Notes (Facts Assumptions)	Constraints	Objectives	Requirements (Needs/ Wants/Desires)	Priority
Gunner team / User	Handles loading and firing of projectile	Availability of munitions at the pace required for the mission.	Mission success on the battlefield	Use the HVP in combat	Low
Radar group	Must interface with SE and SW to interface radar target acquisition with fire support.	Close-to-ship accuracy of the radar is limited.	Ensures that the munition is fired in a timely manner to meet and threat defensive or offensive.	Proper battlespace awareness	Low
Ship personnel	Rely on their safety through accurate interception	Munition size, delivery to cannon	Ensure proper storage of the munition	Deliver the munition as required by the mission requirements in a timely fashion	Low
Ammo / Munitions control	Responsible for stowing, transport, and staging to gunner team.	Size of munition	Provide the munition when tasked by the battlefield commander	Ensure that each munition works as planned, and is available for use when required.	Low
Tax Payer	Provide military funding	Limited view of what the money is spent on	Ensure that the funding is delivered as required to build the product as required for the mission	Ensure that the money given through taxes goes to what is required and not what over reach for its own sake.	Low

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APPENDIX B. SIMULATION INSTRUCTIONS

Before running the simulation, ensure that the following parameters are set.

A. SIMULATION INITIALIZATION

1) Open the simulation setup (Figure 31).

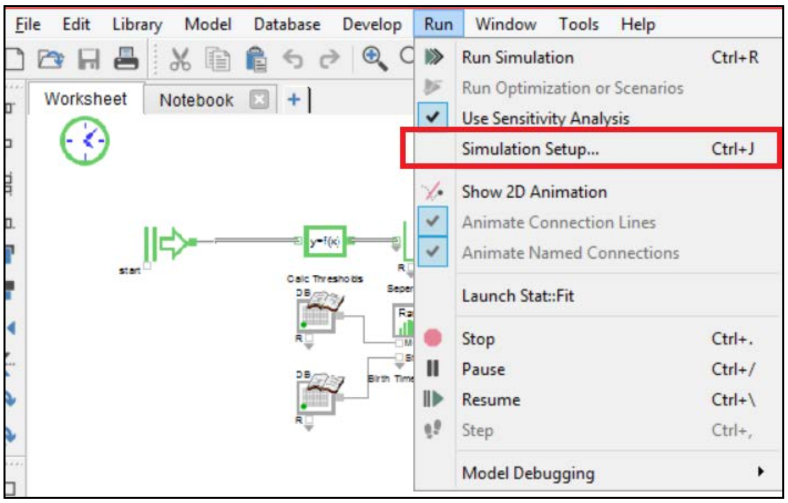


Figure 31. Open Simulation Setup

a. Set the simulation time to 1000 seconds (Figure 32).

b. The simulation is set to 500 runs be default. Note that this can be changed, but it would require expanding the input database and the missile count database (Figure 32).

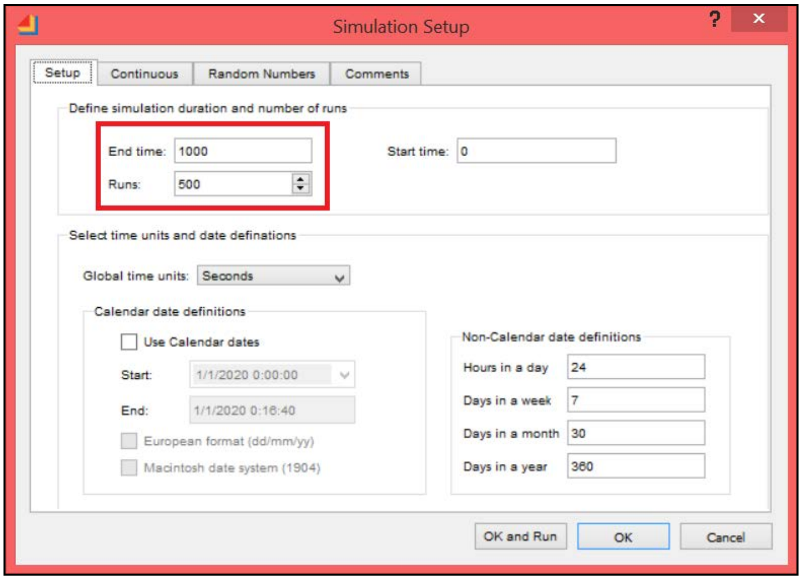


Figure 32. Simulation Setup

2) Set ship ammunition to desired amounts in input database.

   a. Open the project database under the tab Database—it is the first selection in the Database dropdown (Figure 33).

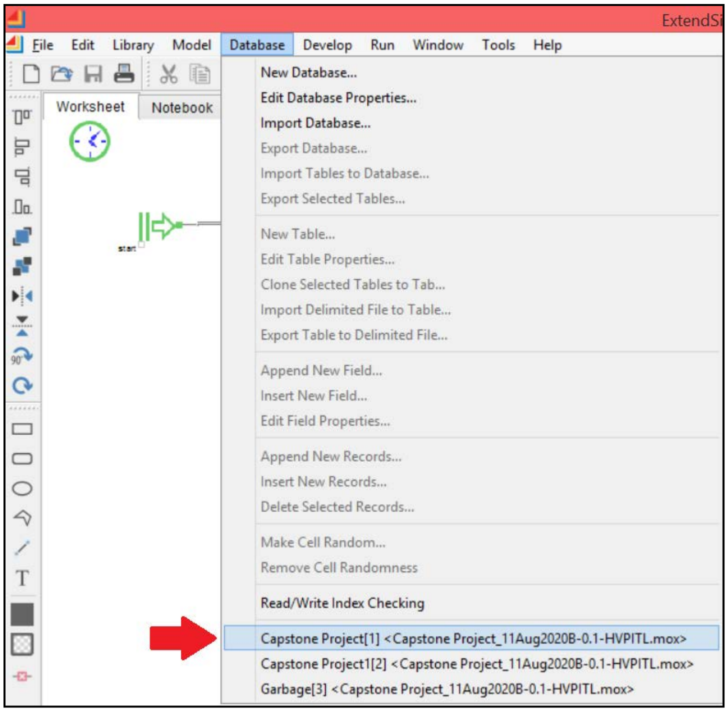
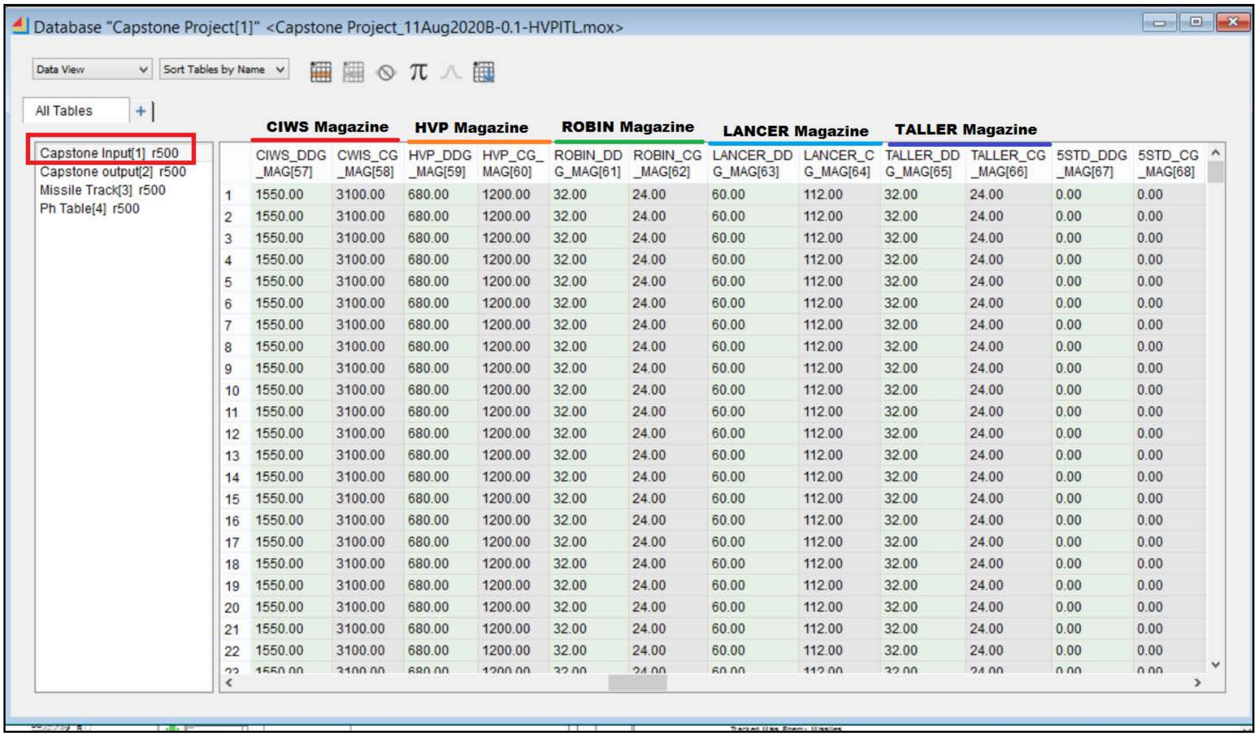


Figure 33. Database Dropdown

b. Select “Capstone Input[1] r500” and find Column 57. Columns 57-66 control the magazine amounts of the ships (Figure 34). Modify ammunition as required.



	CIWS Magazine		HVP Magazine		ROBIN Magazine		LANCER Magazine		TALLER Magazine			
	CIWS_DDG _MAG[57]	CWIS_CG _MAG[58]	HVP_DDG _MAG[59]	HVP_CG_ MAG[60]	ROBIN_DD G_MAG[61]	ROBIN_CG _MAG[62]	LANCER_DD G_MAG[63]	LANCER_C G_MAG[64]	TALLER_DD G_MAG[65]	TALLER_CG _MAG[66]	5STD_DDG _MAG[67]	5STD_CG _MAG[68]
1	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
2	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
3	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
4	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
5	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
6	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
7	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
8	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
9	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
10	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
11	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
12	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
13	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
14	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
15	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
16	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
17	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
18	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
19	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
20	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
21	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
22	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00
23	1550.00	3100.00	680.00	1200.00	32.00	24.00	60.00	112.00	32.00	24.00	0.00	0.00

Figure 34. Project Database Magazine Count

c. Note that for the baseline configuration, it is a full load out of both ships (i.e., twice the amount than a single ship carries). For example, a single CG carries 56 LANCER missiles, so the database entry for column 64 is 112 for two CGs.

d. For easier modification, you can create and copy over values from an Excel spreadsheet with 500 (by default) rows.

3) Set entire missile tracking database to “0”.

a. In the same database window as before, select “Missile Track[3] r500” (Figure 35).

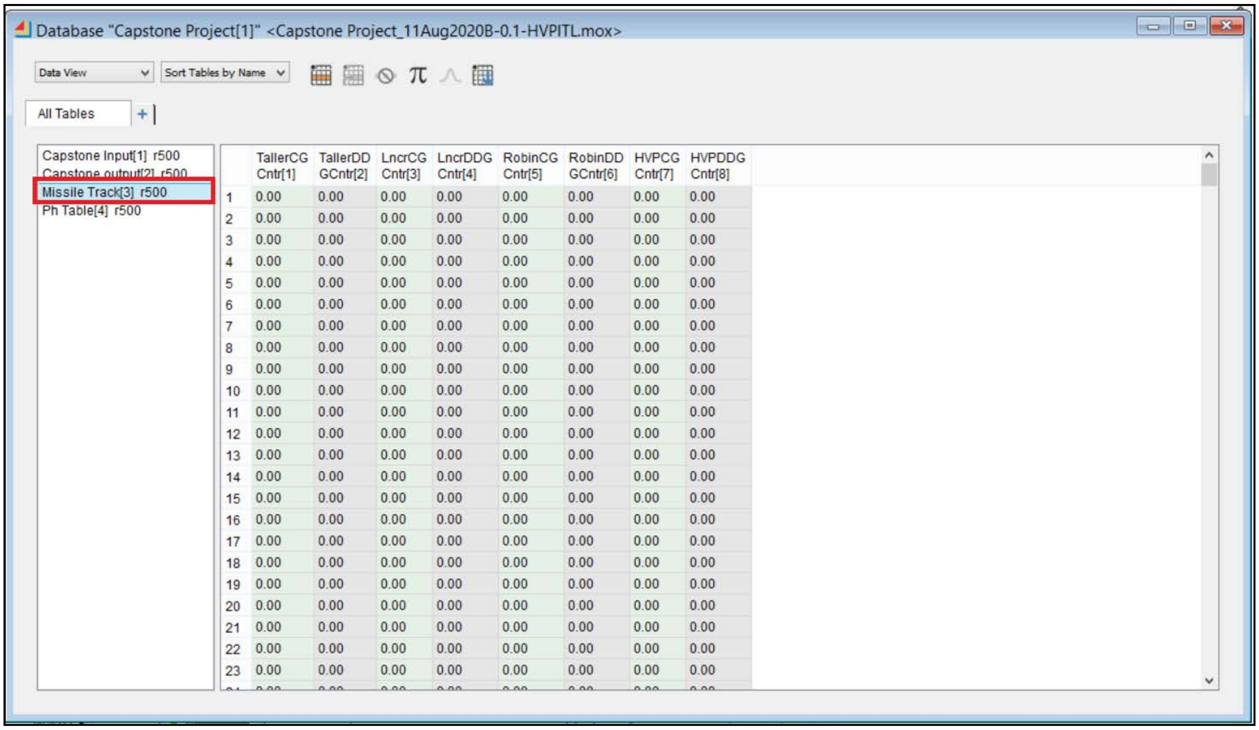


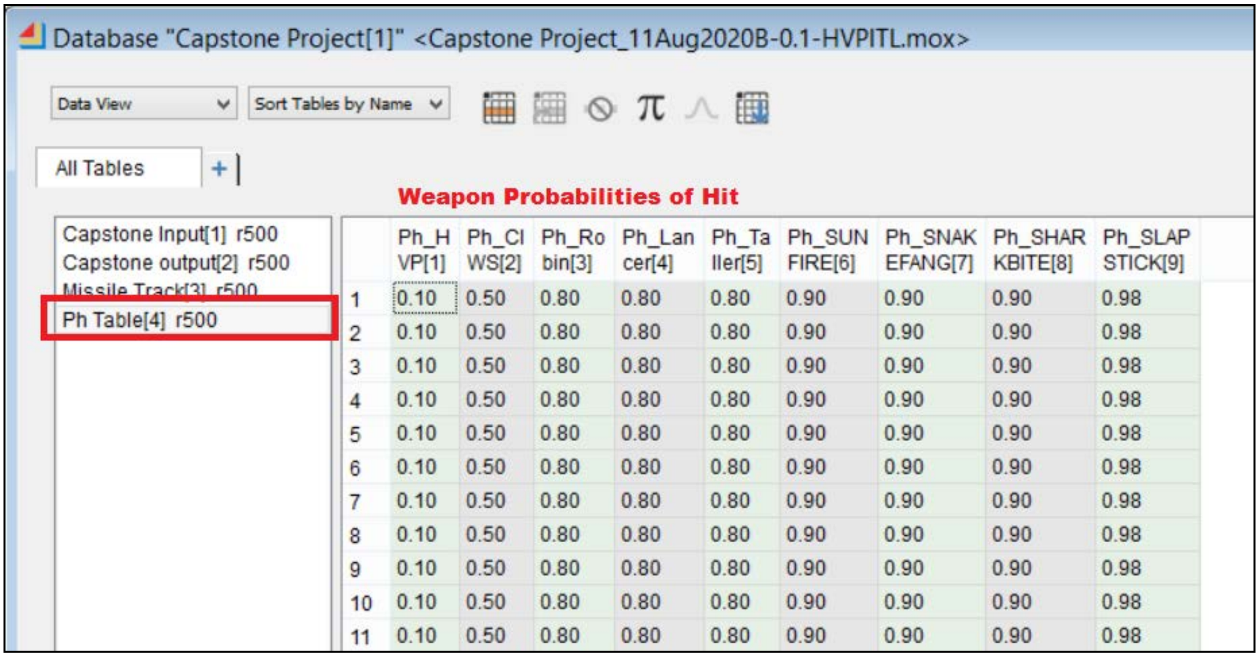
Figure 35. Missile Tracking Database

b. Before running a simulation, ensure that the entire missile track database is set to "0". This database counts the weapons used in each run, and must be manually reset for each simulation run (Figure 35).

c. For simplified operation, create an Excel spreadsheet with 9 columns and 500 (by default) rows populated with "0". After each run, copy and paste the Excel sheet into the missile track database.

4) Set desired weapon probabilities of hit (Phit) for both Ship-borne and enemy.

a. In the same database window as before, select "Ph Table[4] r500" (Figure 36).



	Ph_HVP[1]	Ph_CIWS[2]	Ph_Robin[3]	Ph_Lancer[4]	Ph_Taller[5]	Ph_SUNFIRE[6]	Ph_SNAKEFANG[7]	Ph_SHARKBITE[8]	Ph_SLAPSTICK[9]
1	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
2	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
3	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
4	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
5	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
6	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
7	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
8	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
9	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
10	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98
11	0.10	0.50	0.80	0.80	0.80	0.90	0.90	0.90	0.98

Figure 36. Weapon Probabilities of Hit Database

b. This database controls each weapon's Phit. Modify these values as required. Note that an assumption of Phit for each weapon is equal to probability of kill was made.

5) Set desired HVP burst for the simulation.

a. Return to the simulation window and locate the HVP burst count equation blocks (Figure 37).

b. Modify equation to the desired HVP burst amount (Figure 37). The CG and DDG blocks are calculated separately. Ensure both ships are configured to the same burst amount.

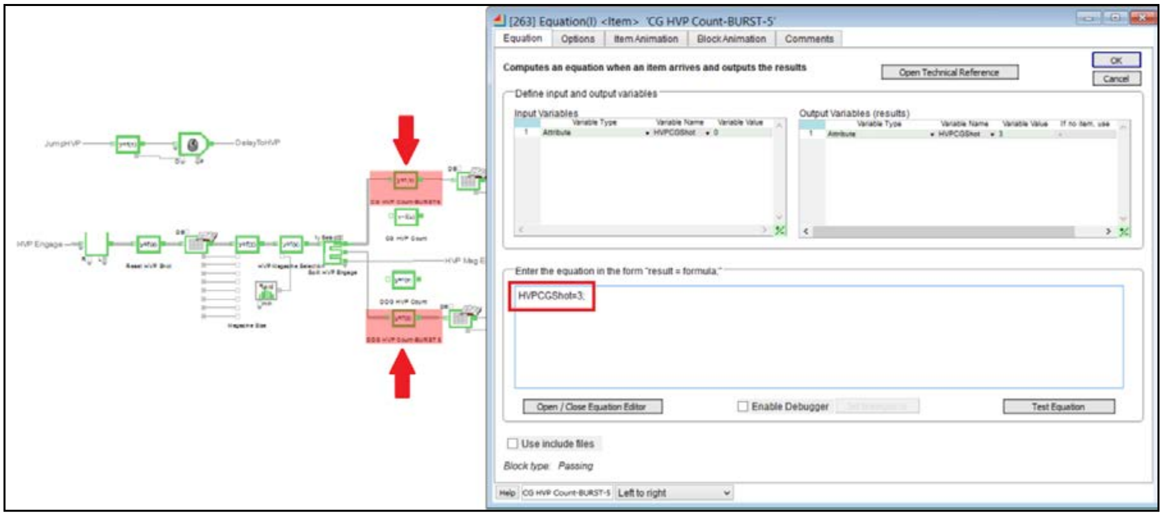


Figure 37. HVP Burst Count Blocks Modification

B. SCENARIO DEFINITION

1) Start block—This is where the number of incoming enemy missiles is inputted (Figure 38). Open start block and modify number of enemies as required (Figure 39).

2) Calc Thresholds—This is where engagement windows are established for enemy missiles. It reads from the database and creates the windows as needed (Figure 38).

3) Birthtime Adjust—This block sets the birthtime of the incoming missiles. By default, all missile birth times are set to 0 (Figure 38).

4) Random %—Determines which Myselect28 value is chosen for the selected enemy missile. This is based off of a probability distribution set within the equation block that fits the assumption of how the enemy weapons are distributed (Figure 38).

5) Select Item out (4 count) block—Divides the simulation to establish the individual missile selection (Figure 38).

6) “Missile Name” Initial Parameters—Sets up the individual missile velocity, initial range, PHit for the CG and DDG, and PKill for the CG and DDG for each missile. These parameters are also read from the input database (Figure 38).

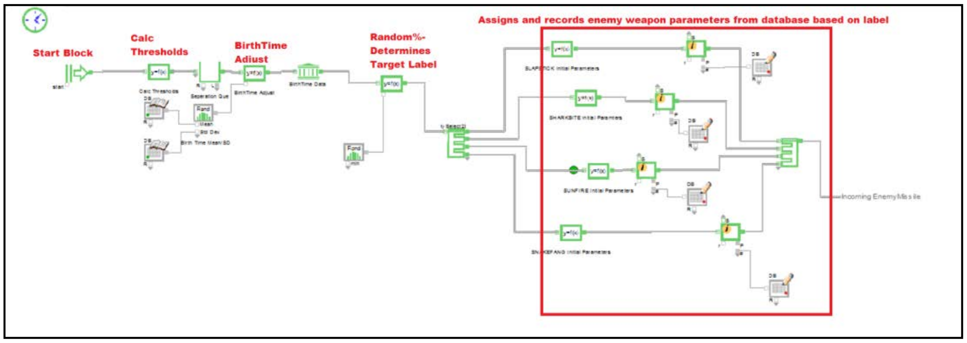


Figure 38. Initial Setup Blocks

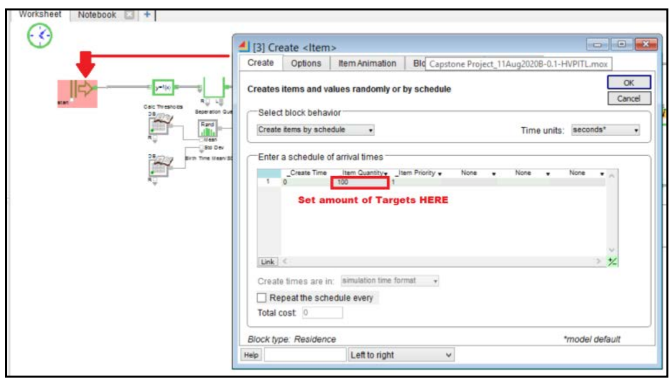


Figure 39. Start Block Modification

7) Detection Que—This queue is based off of the initial time that the missile is detected (Figure 40).

8) Initial Magazine size—This is the first setup of friendly magazine size. The simulation reads the magazine sizes from the input database (Figure 40).

9) Initial ShotAt—This block initializes the variable ShotAt. It sets all shot cues to zero for tracking purposes (Figure 40).

10) Initialize IsKill—Sets the initial IsKill value to 0, meaning the missile has not been shot down. This variable is assigned to each missile and will be used to track whether the missile is shot down (Figure 40).

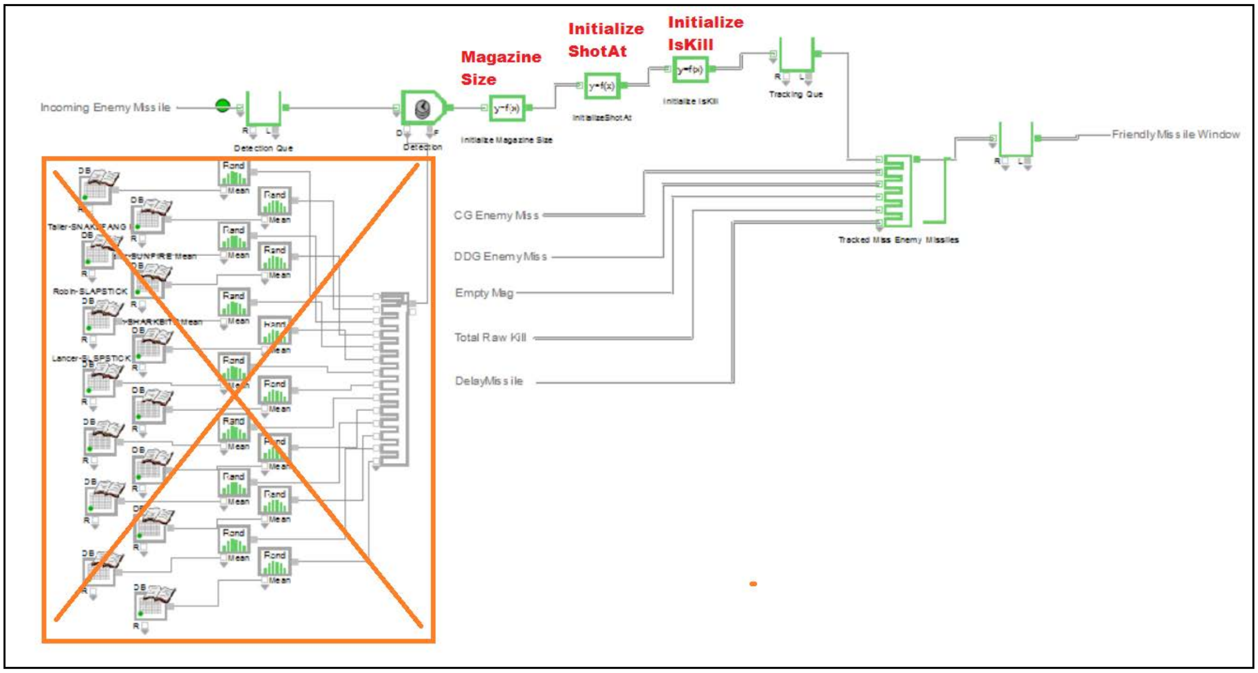


Figure 40. Initial Setup Blocks (continued)

11) Magazine size—Reads the magazine size and the shot counter from the missile tracking database and denotes how many rounds of a specific type were expended. This amount is initialized above, and is updated in each specific missile engagement (Figure 41).

12) IsKill Check—Checks to see if the missile in question is defeated or not based on the IsKill variable from the friendly missile engagement window (Figure 41).

13) IsKill Split—If the IsKill Check value is 1, the missile kill is selected based on which missile cycle the IsKill value was assigned. The IsKill variable itself has a different number based on which weapon destroyed the incoming missile (Figure 41).

14) CheckISEmpty—if previous value was 0, then this is selected to determine size of the weapon magazines, and if munitions are available. Munitions are selected based on range, velocity, and availability (Figure 41).

15) Current Range of Enemy—determines current range based on time alive and velocity to determine which MySelect value is assigned (Figure 41). This block is the basis of the weapon selection. It checks the current range of the incoming missile. It then checks the magazine of the intended weapon in that range, and if it is not empty, it selects that weapon to engage the missile. If the intended weapon is empty, then it sets it to delay to the next weapon range, elaborated in Figure 42.

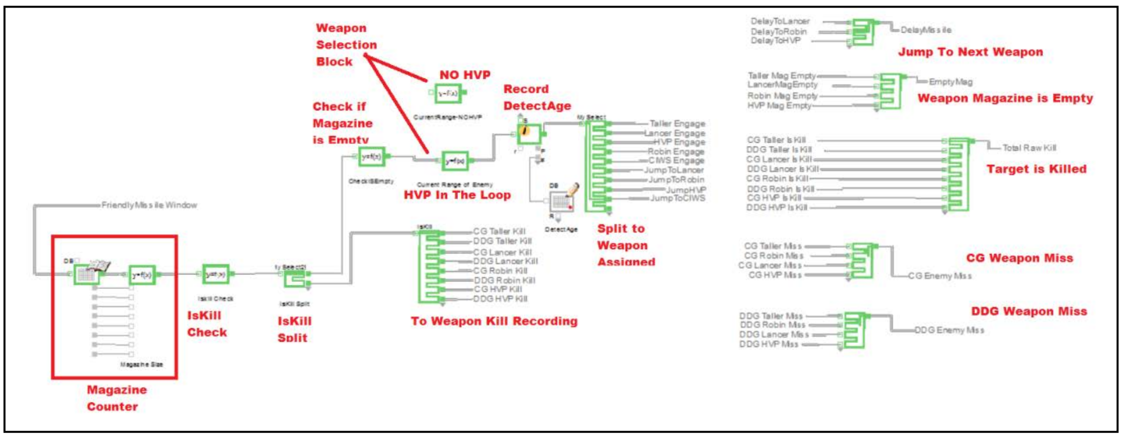


Figure 41. Friendly Missile Window

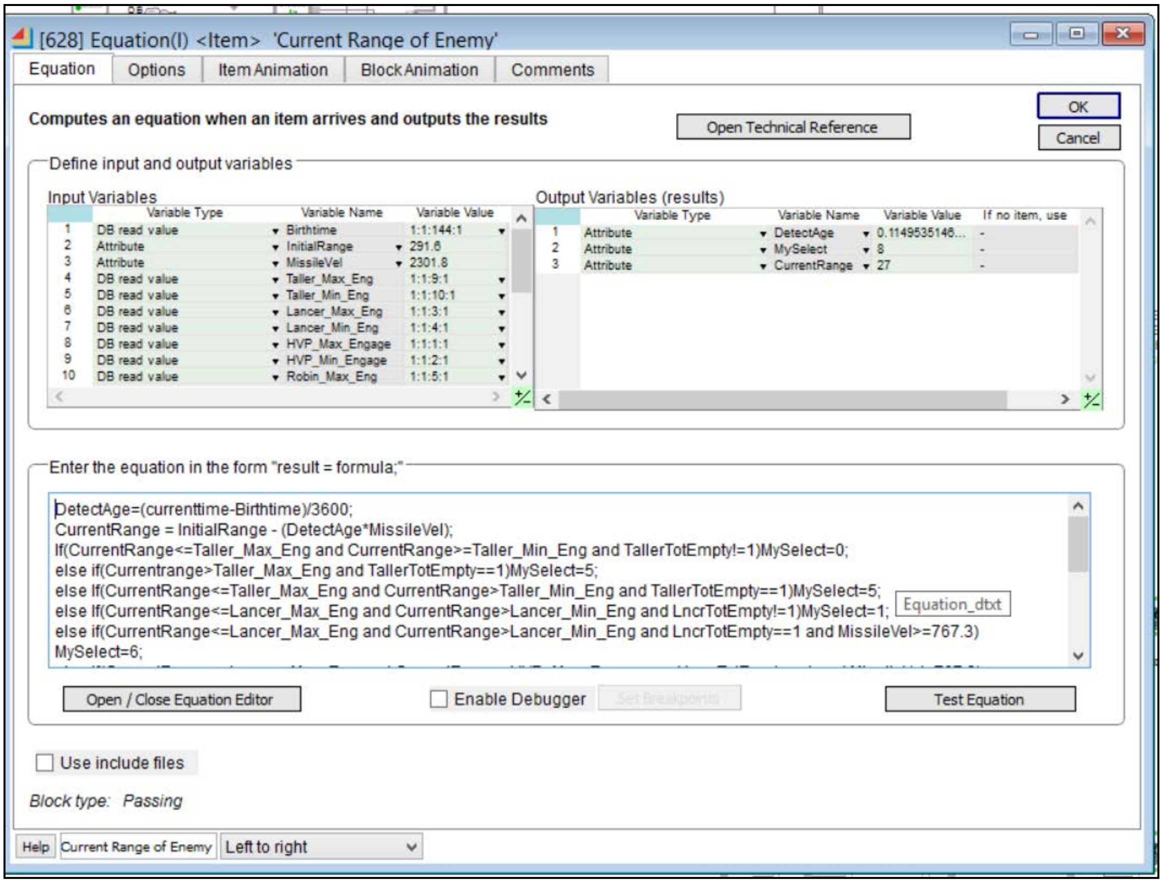


Figure 42. Current Range of Enemy Block

C. MISSILE ENGAGEMENT SPECIFICS

The following description is for Taller Engage, but is applicable to Lancer, Robin, and HVP.

1) Taller Engage—This engagement window is first selected based on the proper range and velocity, and the taller shot count is reset to 0 within the "Reset Taller Shot" equation block (Figure 43).

2) The Magazine size is once again checked, this time for Taller missiles, and if munitions remain, the CG Taller Count block is assigned first, then the DDG Taller Count block path. If the selection is 0 remaining in the magazine for Taller for both CGs and DDGs, then the selection proceeds to the Taller Mag Empty (Figure 43).

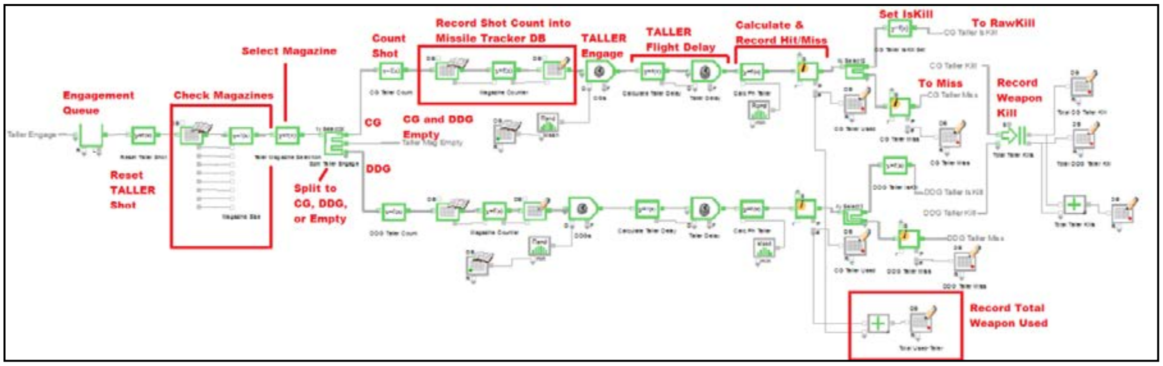


Figure 43. Missile Engagement Specifics (Taller Engage)

D. CG AND DDG SPECIFICS

The following description is for Taller Engage, but is applicable to Lancer, Robin, and HVP. The CG and DDG paths are the same logic, but have different magazine sizes, as discussed below.

1) CG Taller Count—This changes the Taller Shot (the ShotAt variable initialized above, this time set to Taller Specific) value from 0 to 1 for counting purposes (Figure 43).

2) Magazine Counter—Pulls the magazine size for Taller CG into the equation block, adds 1 count, then writes to the missile tracking database (Figure 43).

3) CG Action Block—Activates the act of firing a Taller missile (Figure 43).

4) Taller Delay Block equation and action blocks—The math for the delay in time of impact of the Taller missile based on speed (of the friendly missile) and distance (of the ship from the enemy missile) is determined for accurate time keeping (Figure 43).

5) Ph Taller calc block—Based on a random number generator, with a uniform real distribution, compared to the Ph value of the Taller missile, then a MySelect 2 value is set with 0 determining a kill shot, and 1 determining a miss shot (Figure 43).

6) If the weapon kills the missile, then the IsKill variable is changed accordingly. For Taller, IsKill is set to 1. Each defensive weapon has a different IsKill variable to sort the missile after it is pushed through the engagement window again.

7) CG Taller IsKill option is pushed back through the initial engagement window to add the use through the magazine size. If the IsKill value is assigned, then that missile is counted as killed and pushed back to CG Taller Kill block, and counted as defeated and recorded to the database.

8) If CG Taller Miss option is pushed back through the initial engagement again, to update the magazine count and if not IsKill, then pushed through the range assessment to determine if Taller will be used, or another munition selected.

9) This is the same option used for each missile type until defeated or magazine is depleted until the range is less than the Robin engagement window, and now in the CIWS window.

E. HVP SPECIFICS

1) HVP is set up to have a burst-fire capability. This means that the HVP shot counter is set to the amount of rounds in a burst, and the probability of hit calculation has a sub-equation in the block that is then compared to the randomized number generated. HVP is currently the only weapon in the defense net that has this setup (Figure 44 and 45).

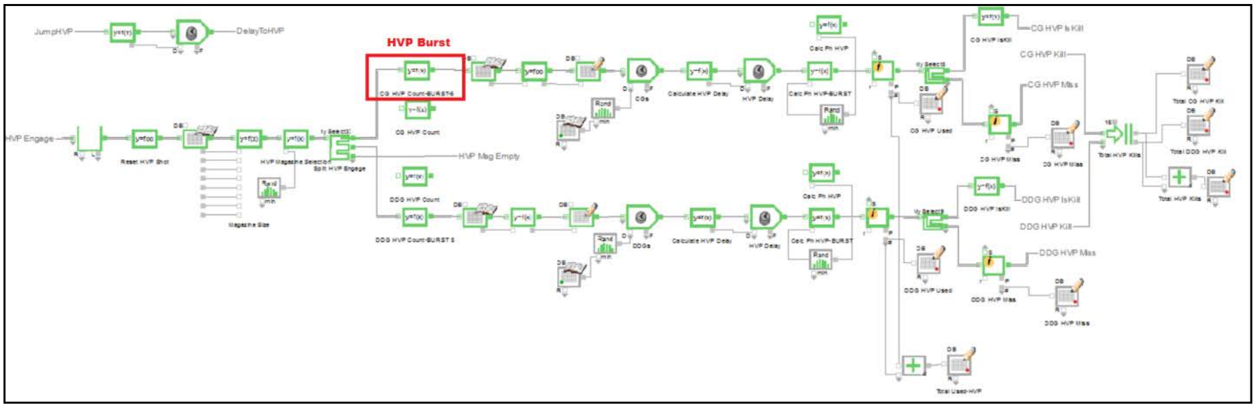


Figure 44. HVP Burst Count

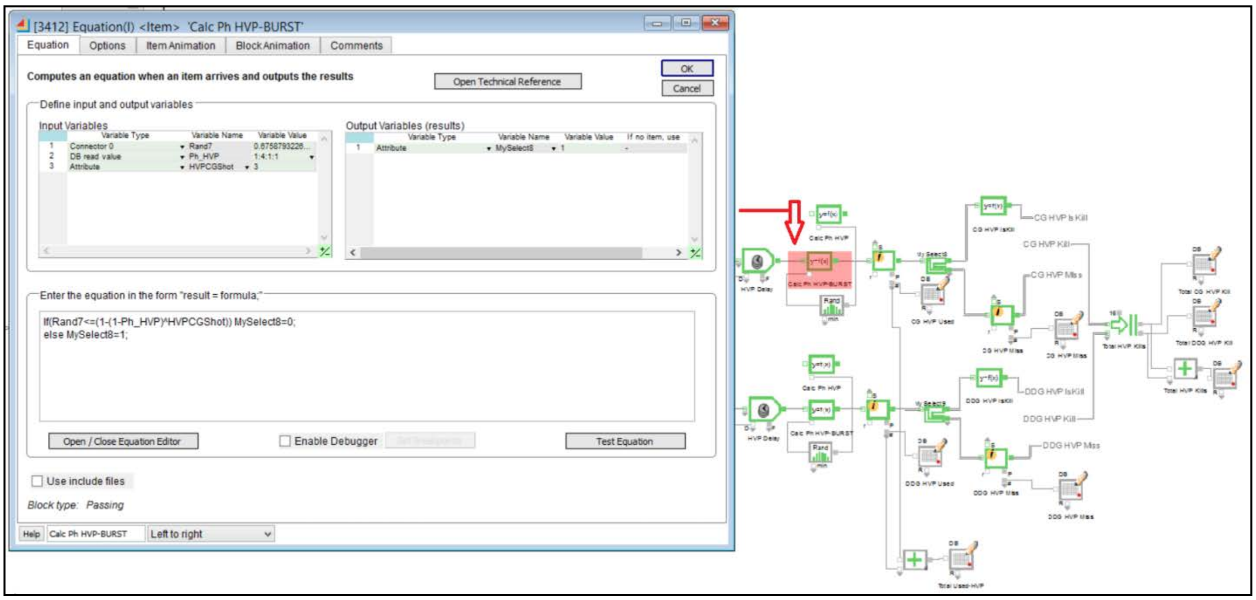


Figure 45. HVP Burst Phit Calculation

2) If the current missile engaged is not within range of a missile, and that missile magazine is empty, a "Jumpto[Weapon]" (where [Weapon] is Lancer, Robin, HVP, or CIWS) is selected based on range and velocity. This block provides a wait time until the missile is within range of the Lancer (or Robin or HVP of CIWS) (Figure 46).

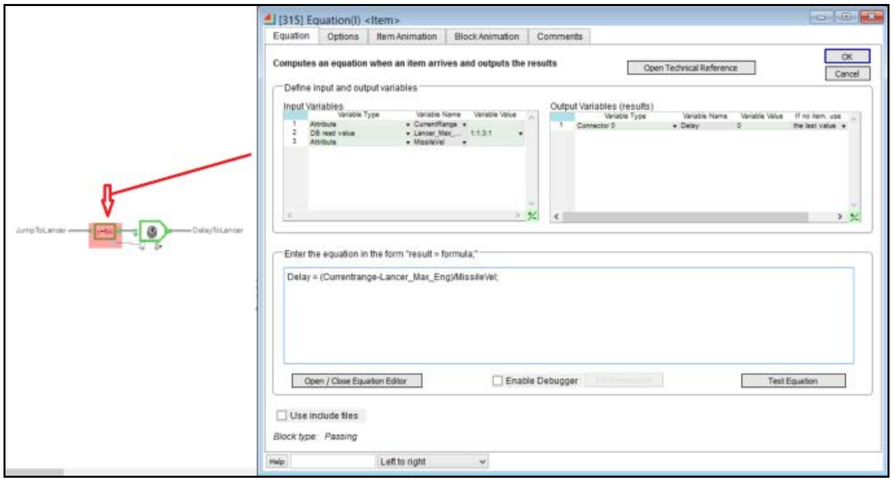


Figure 46. Jumpto Weapon Select

3) HVP is selected based on range and velocity (specifically less than 1.0 Mach). The engagement loop is the same for that munition as Taller, Lancer, and Robin. If the incoming missile has not been shot down, and range is less than Robin engagement window, then CIWS is selected. Also, the CG and DDG engagement is divided 40% to CG and 60% to DDG, based on parameterized radar profiles.

F. CIWS SPECIFICS

The CIWS engagement window is divided into CG and DDG. Only the CG path is listed below.

1) First block is a recording of the Enemy leakers through the missile defense net into the database (Figure 47).
2) CG1 CIWS Window—This block determines if the CIWS is in range of the missile, or if it is out of range and will either impact or miss the ship through MySelect11 (Figure 47).
3) CG CIWS action window—This simulates the engagement of the CIWS, limited by the number of CIWS per CG (i.e. the ship will be able to simultaneously engage as many missiles as there are mounts). The amount of mounts is read from the input database (Figure 47).

4) Ph CIWS Calc—gives the MySelect12 value based on defeat probability and either goes to CIWS Kills or CIWS Miss. CIWS miss goes back through the loop (Figure 47).

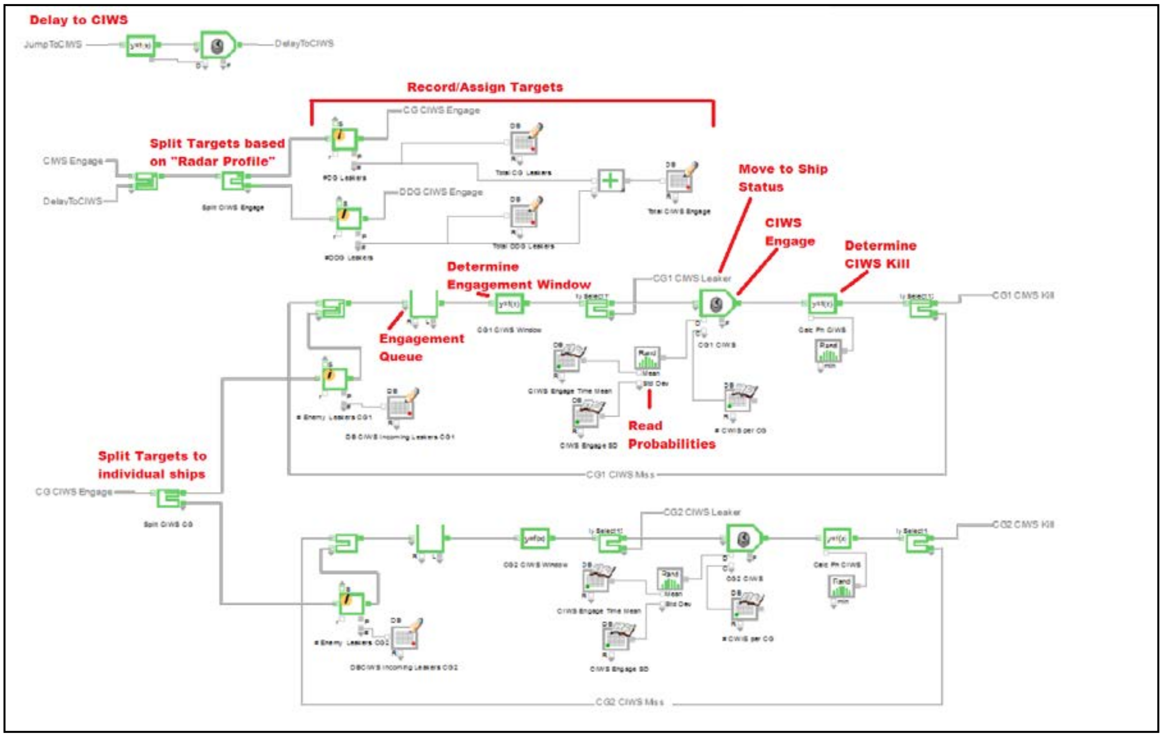


Figure 47. CIWS Engagement Blocks

5) CG1 CIWS Kill—Goes to sequence to record the kill to the database (Figure 48).

6) CG1 CIWS Leaker goes to a CG1 CIWS Leaker sequence (Same sequence for CG2, DDG1, and DDG2) (Figure 48).

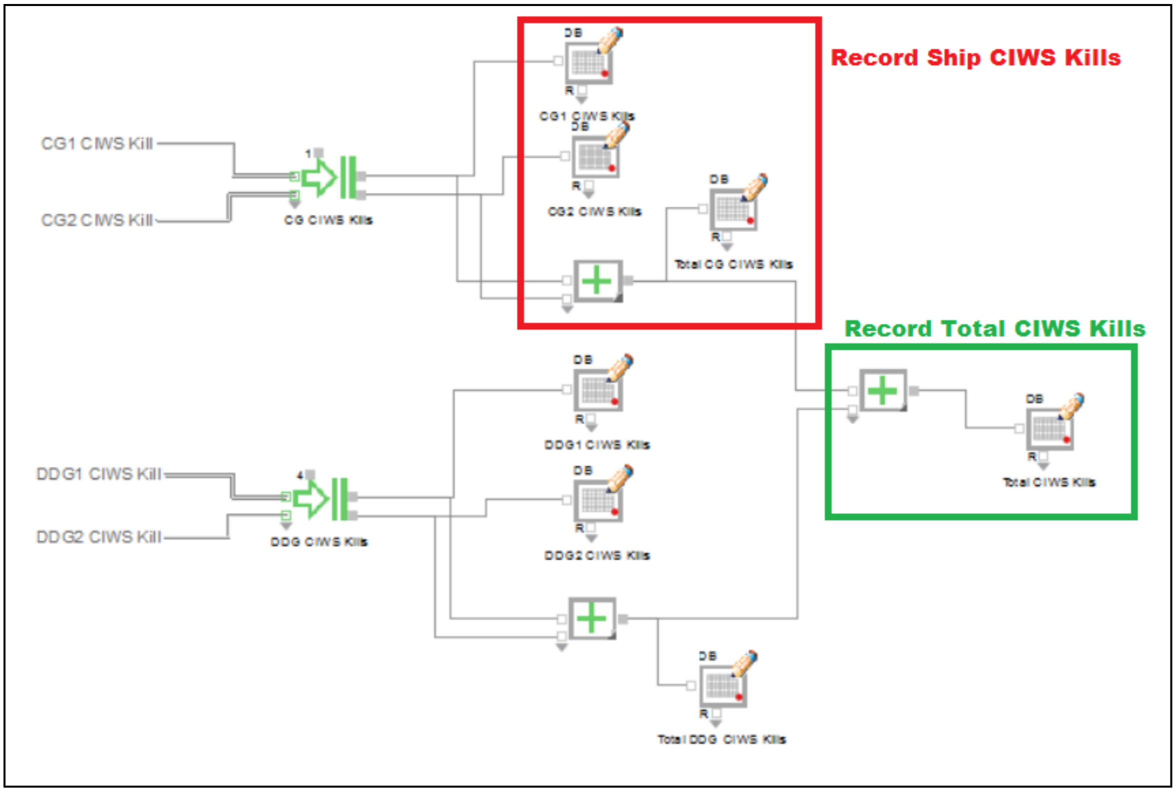


Figure 48. CIWS Engagement Blocks (continued)

7) CG1 Leakers are recorded in the first block (Figure 49).
8) Ph Enemy Calc—Block brings in the Ph of the enemy missile against hitting or missing the ship. MySelect19 is either a Miss (and recorded in the database) or a hit (Figure 49).
9) Pk Enemy CG1—Blocks determines if it is a damage hit, or a fatal (sink) hit. Both are then recorded in the database (Figure 49).

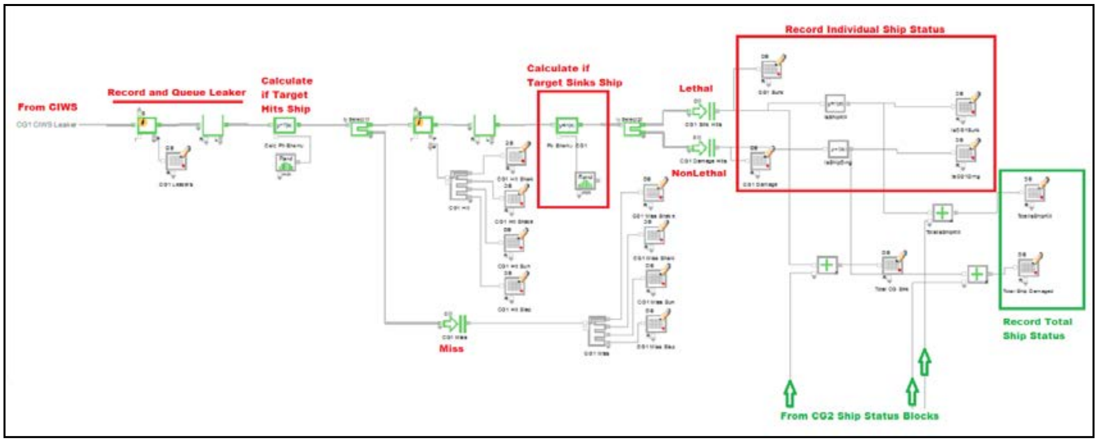


Figure 49. CIWS Leaker Blocks

G. DATA OUTPUT

1) Open the project database under the tab Database—it is the first selection in the Database dropdown (Figure 33).
2) Select “Capstone output[2] r500” (Figure 50).
3) Select all data and right click. Select “Copy Data with Headings” (Figure 50).
4) Paste output data into an Excel spreadsheet for further analysis.

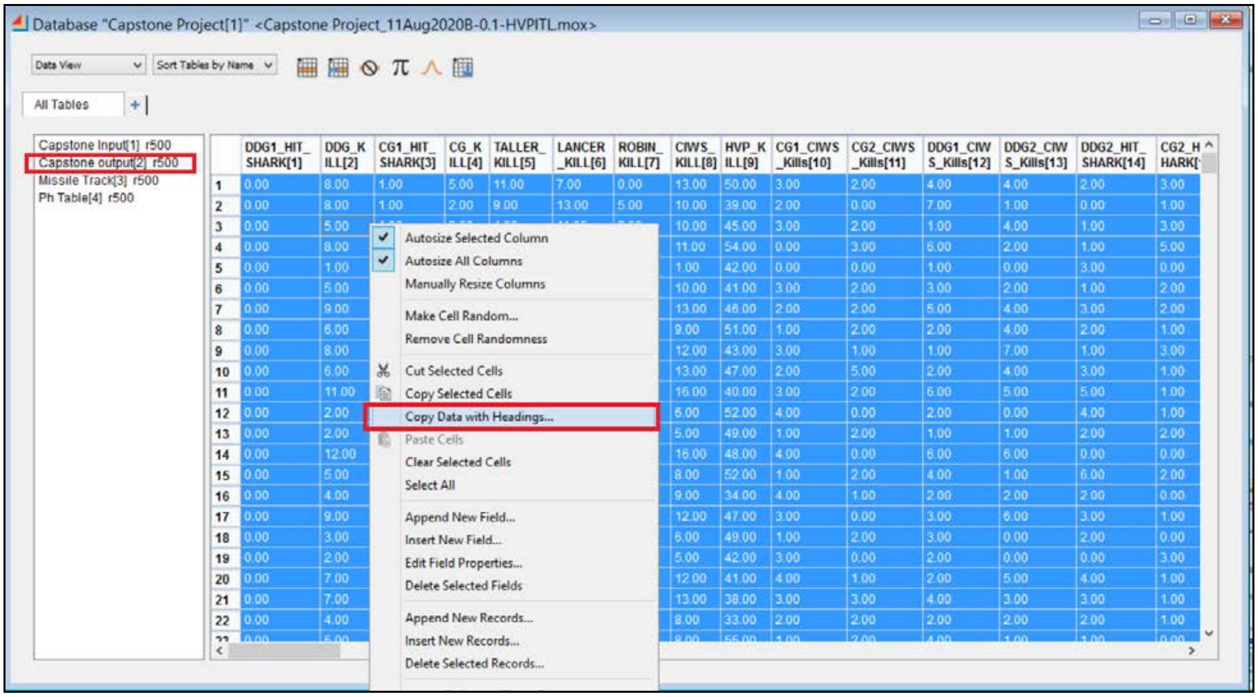
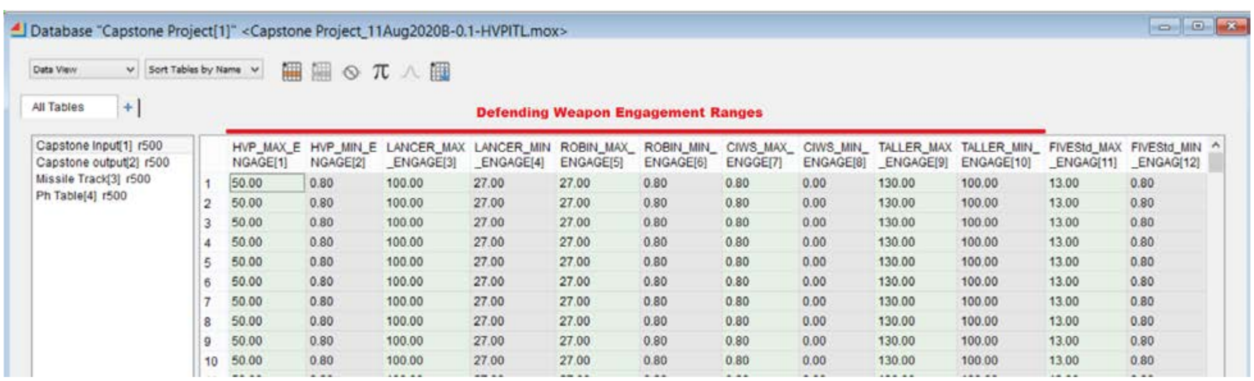


Figure 50. Output Data



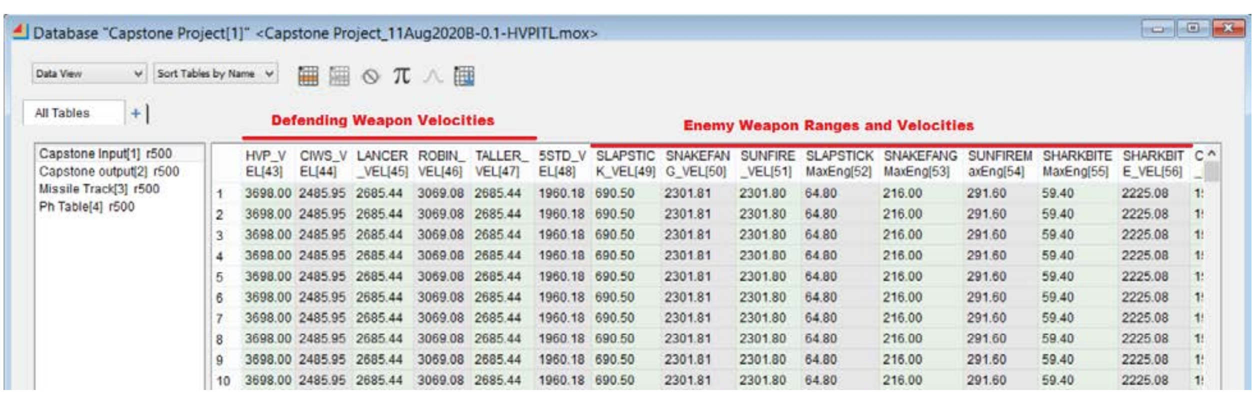


Figure 51. Parameters to Know in Input Database

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APPENDIX C. DATA ANALYSIS

Table 8. Baseline Scenario—Weapon Data (3 Round Bursts).

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.13	34.13	3.37	10.13	51.16	171.05	3.34	51.16	16.77
	75	7.72	25.67	3.33	10.29	41.82	140.59	3.36	55.76	16.55
	50	5.25	17.25	3.29	10.50	29.03	96.45	3.32	58.07	13.48
	25	2.56	8.57	3.35	10.24	14.50	48.86	3.37	58.01	7.18
Phit = 0.2										
	100	10.11	33.59	3.32	10.11	51.26	170.63	3.33	51.26	16.70
	75	7.51	25.17	3.35	10.02	41.91	140.92	3.36	55.88	16.65
	50	4.99	16.65	3.34	9.97	29.05	97.44	3.35	58.10	13.65
	25	2.53	8.46	3.35	10.10	14.63	48.92	3.34	58.54	7.04
Phit = 0.3										
	100	10.11	34.40	3.40	10.11	51.60	170.58	3.31	51.60	16.83
	75	7.58	24.94	3.29	10.10	42.22	140.57	3.33	56.30	16.53
	50	5.09	16.82	3.31	10.18	29.04	97.28	3.35	58.09	13.51
	25	2.66	8.85	3.33	10.63	14.60	48.43	3.32	58.40	6.92

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	56.00	3.34	16.77	0	0	0	0	0	78.07
	75	55.44	3.35	22.07	0	0	0	0	0	88.12
	50	44.83	3.32	26.97	0	0	0	0	0	95.53
	25	23.24	3.24	28.73	0	0	0	0	0	96.98
Phit = 0.2										
	100	56.00	3.35	16.70	0	0	0	0	0	78.07
	75	55.62	3.34	22.19	0	0	0	0	0	88.10
	50	45.29	3.32	27.30	0	0	0	0	0	95.37
	25	23.51	3.34	28.17	0	0	0	0	0	96.81
Phit = 0.3										
	100	56.00	3.33	16.83	0	0	0	0	0	78.54
	75	55.26	3.34	22.04	0	0	0	0	0	88.44
	50	45.05	3.33	27.02	0	0	0	0	0	95.29
	25	23.04	3.33	27.66	0	0	0	0	0	96.70

Table 9. Baseline Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	21.93	0.61	46.00	212.00	242.00	0.81	88.00	229.00	183.00	0.57	0.78	1.80	19.60	5.00
	75	11.88	0.31	16.00	123.00	361.00	0.36	21.00	140.00	339.00	0.29	0.39	0.00	51.00	28.60
	50	4.47	0.10	1.00	50.00	449.00	0.14	2.00	68.00	430.00	0.06	0.16	0.00	78.00	63.00
	25	3.02	0.04	0.00	18.00	482.00	0.05	0.00	25.00	475.00	0.05	0.05	0.00	91.60	82.00
Phit = 0.2															
	100	21.93	0.58	43.00	203.00	254.00	0.76	72.00	236.00	192.00	0.60	0.81	1.40	22.80	4.80
	75	11.90	0.27	13.00	108.00	379.00	0.43	27.00	163.00	310.00	0.25	0.38	0.00	48.40	26.40
	50	4.63	0.10	3.00	45.00	452.00	0.14	2.00	66.00	432.00	0.07	0.11	0.00	78.20	66.00
	25	3.19	0.03	0.00	16.00	484.00	0.05	0.00	26.00	474.00	0.03	0.06	0.00	91.60	83.80
Phit = 0.3															
	100	21.46	0.51	31.00	192.00	277.00	0.80	79.00	241.00	180.00	0.60	0.80	0.60	20.00	4.60
	75	11.56	0.30	14.00	120.00	366.00	0.38	17.00	155.00	328.00	0.26	0.40	0.20	48.80	26.60
	50	4.71	0.08	0.00	41.00	459.00	0.12	1.00	60.00	439.00	0.11	0.13	0.00	80.80	65.20
	25	3.30	0.05	0.00	24.00	476.00	0.06	0.00	28.00	472.00	0.02	0.05	0.00	89.80	83.80

Table 10. Baseline Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.23	34.43	3.36	10.23	51.18	170.86	3.34	51.18	16.68
	75	7.60	25.49	3.35	10.14	41.90	140.66	3.36	55.87	16.38
	50	5.08	17.00	3.35	10.16	29.24	96.66	3.31	58.48	13.26
	25	2.44	8.39	3.44	9.77	14.54	48.84	3.36	58.16	7.12
Phit = 0.2										
	100	10.28	34.39	3.35	10.28	51.63	170.75	3.31	51.63	17.00
	75	7.55	25.53	3.38	10.07	42.10	140.40	3.33	56.14	16.81
	50	5.07	17.11	3.37	10.14	29.19	97.11	3.33	58.38	13.38
	25	2.61	8.59	3.29	10.45	14.62	48.21	3.30	58.49	6.98
Phit = 0.3										
	100	10.16	34.62	3.41	10.16	51.22	170.80	3.33	51.22	16.67
	75	7.72	25.76	3.34	10.29	42.25	140.35	3.32	56.33	16.38
	50	5.18	17.33	3.34	10.36	28.99	96.23	3.32	57.99	13.52
	25	2.56	8.44	3.30	10.23	14.58	48.83	3.35	58.33	7.05

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	56.00	3.36	16.68	0	0	0	0	0	78.10
	75	55.14	3.37	21.84	0	0	0	0	0	87.85
	50	44.75	3.37	26.53	0	0	0	0	0	95.17
	25	23.54	3.31	28.49	0	0	0	0	0	96.42
Phit = 0.2										
	100	55.98	3.29	17.00	0	0	0	0	0	78.91
	75	55.26	3.29	22.41	0	0	0	0	0	88.61
	50	44.79	3.35	26.75	0	0	0	0	0	95.27
	25	23.08	3.31	27.93	0	0	0	0	0	96.86
Phit = 0.3										
	100	55.97	3.36	16.67	0	0	0	0	0	78.05
	75	55.21	3.37	21.85	0	0	0	0	0	88.47
	50	45.02	3.33	27.05	0	0	0	0	0	95.40
	25	24.04	3.41	28.22	0	0	0	0	0	96.78

Table 11. Baseline Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	21.90	0.59	52.00	191.00	257.00	0.75	64.00	248.00	188.00	0.53	0.85	1.20	20.00	4.40
	75	12.15	0.27	10.00	115.00	375.00	0.46	27.00	177.00	296.00	0.25	0.38	0.00	46.20	27.40
	50	4.83	0.09	1.00	41.00	458.00	0.15	4.00	68.00	428.00	0.09	0.16	0.00	78.60	62.20
	25	3.58	0.03	0.00	16.00	484.00	0.06	0.00	31.00	469.00	0.03	0.04	0.00	90.60	84.80
Phit = 0.2															
	100	21.09	0.57	45.00	196.00	259.00	0.74	67.00	235.00	198.00	0.56	0.81	0.80	24.00	5.60
	75	11.39	0.22	7.00	95.00	398.00	0.35	20.00	134.00	346.00	0.28	0.38	0.20	54.60	28.20
	50	4.73	0.07	1.00	34.00	465.00	0.14	2.00	64.00	434.00	0.09	0.18	0.00	81.20	61.80
	25	3.14	0.05	0.00	25.00	475.00	0.05	0.00	27.00	473.00	0.03	0.05	0.00	90.00	83.00
Phit = 0.3															
	100	21.95	0.57	43.00	200.00	257.00	0.75	64.00	249.00	187.00	0.56	0.82	1.00	19.60	3.80
	75	11.53	0.26	13.00	103.00	384.00	0.40	27.00	144.00	329.00	0.26	0.43	0.80	51.20	28.20
	50	4.60	0.09	2.00	40.00	458.00	0.11	0.00	57.00	443.00	0.07	0.15	0.00	81.60	65.80
	25	3.22	0.03	0.00	17.00	483.00	0.05	0.00	27.00	473.00	0.03	0.05	0.00	91.40	84.80

Table 12. HVP ITL Scenario—Weapon Data (3 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	9.76	31.90	3.27	9.76	28.14	94.07	3.34	28.14	9.30
	75	7.61	25.25	3.32	10.15	42.17	139.68	3.31	56.23	13.29
	50	5.09	17.39	3.42	10.17	29.09	97.07	3.34	58.18	8.14
	25	2.51	8.26	3.30	10.02	14.55	48.52	3.33	58.20	4.14
Phit = 0.2										
	100	10.45	34.43	3.29	10.45	51.02	170.67	3.35	51.02	16.57
	75	7.70	25.76	3.34	10.27	41.84	140.38	3.36	55.79	13.42
	50	5.14	17.36	3.37	10.29	28.94	96.92	3.35	57.88	8.19
	25	2.55	8.25	3.24	10.18	14.70	48.94	3.33	58.82	3.96
Phit = 0.3										
	100	10.15	33.81	3.33	10.15	50.86	170.94	3.36	50.86	16.63
	75	7.66	25.43	3.32	10.21	41.99	140.79	3.35	55.99	13.36
	50	5.10	16.58	3.25	10.20	28.89	97.10	3.36	57.77	8.28
	25	2.55	8.56	3.36	10.18	14.49	48.61	3.35	57.96	4.19

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	31.47	3.39	9.30	29.85	110.53	3.70	11.11	29.85	77.04
	75	45.05	3.39	17.72	8.71	32.11	3.69	11.06	11.62	95.71
	50	27.38	3.36	16.29	5.80	21.45	3.70	11.10	11.59	96.23
	25	13.70	3.31	16.57	2.95	10.69	3.62	10.87	11.81	96.60
Phit = 0.2										
	100	55.23	3.33	16.57	12.82	26.38	2.06	6.17	12.82	90.85
	75	44.62	3.33	17.89	8.97	18.19	2.03	6.08	11.96	95.91
	50	27.59	3.37	16.39	5.98	12.32	2.06	6.18	11.96	96.52
	25	12.94	3.27	15.82	3.04	6.37	2.09	6.28	12.18	97.00
Phit = 0.3										
	100	55.22	3.32	16.63	13.18	19.78	1.50	4.50	13.18	90.82
	75	43.90	3.29	17.82	9.11	13.98	1.54	4.61	12.14	96.15
	50	27.90	3.37	16.56	5.94	9.07	1.53	4.59	11.87	96.40
	25	13.56	3.24	16.74	3.00	4.54	1.51	4.54	11.99	96.88

Table 13. HVP ITL Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	22.96	0.75	85.00	206.00	209.00	0.93	127.00	212.00	161.00	0.69	0.94	7.40	20.80	10.60
	75	4.29	0.10	1.00	50.00	449.00	0.22	8.00	93.00	399.00	0.14	0.20	0.00	71.40	51.80
	50	3.77	0.07	1.00	35.00	464.00	0.12	3.00	52.00	445.00	0.09	0.12	0.00	82.40	68.80
	25	3.40	0.02	0.00	11.00	489.00	0.05	0.00	27.00	473.00	0.03	0.06	0.00	92.40	85.00
Phit = 0.2															
	100	9.15	0.34	21.00	127.00	352.00	0.47	31.00	171.00	298.00	0.34	0.52	1.40	44.80	22.60
	75	4.09	0.12	3.00	52.00	445.00	0.21	8.00	90.00	402.00	0.12	0.19	0.00	72.40	52.00
	50	3.48	0.08	0.00	40.00	460.00	0.12	1.00	59.00	440.00	0.06	0.12	0.00	80.60	67.40
	25	3.00	0.04	0.00	20.00	480.00	0.04	0.00	20.00	480.00	0.02	0.04	0.00	92.80	86.80
Phit = 0.3															
	100	9.18	0.33	16.00	134.00	350.00	0.49	32.00	181.00	287.00	0.30	0.48	0.20	40.20	20.00
	75	3.85	0.11	3.00	50.00	447.00	0.17	3.00	81.00	416.00	0.08	0.19	0.00	74.80	58.40
	50	3.60	0.08	2.00	36.00	462.00	0.11	1.00	55.00	444.00	0.06	0.11	0.00	81.60	68.20
	25	3.12	0.01	0.00	6.00	494.00	0.05	0.00	27.00	473.00	0.04	0.05	0.00	93.40	85.40

Table 14. HVP ITL Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.06	33.86	3.36	10.06	51.19	170.87	3.34	51.19	16.49
	75	7.73	25.48	3.30	10.30	41.95	139.42	3.32	55.94	13.36
	50	5.01	16.70	3.33	10.03	29.52	97.06	3.29	59.04	7.85
	25	2.56	8.52	3.33	10.23	14.47	48.58	3.36	57.90	4.15
Phit = 0.2										
	100	10.25	34.07	3.32	10.25	51.19	170.92	3.34	51.19	16.39
	75	7.69	25.20	3.28	10.26	42.02	140.41	3.34	56.03	13.33
	50	5.11	17.21	3.37	10.22	28.99	96.81	3.34	57.98	8.19
	25	2.60	8.56	3.29	10.39	14.49	48.54	3.35	57.98	4.09
Phit = 0.3										
	100	10.11	33.68	3.33	10.11	51.17	170.88	3.34	51.17	16.63
	75	7.48	25.44	3.40	9.98	42.04	140.74	3.35	56.06	13.54
	50	4.99	16.81	3.37	9.98	28.80	97.87	3.40	57.60	8.29
	25	2.56	8.50	3.32	10.23	14.71	48.24	3.28	58.86	4.02

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	55.24	3.35	16.49	12.57	46.58	3.71	11.12	12.57	90.31
	75	44.33	3.32	17.81	8.72	31.79	3.64	18.22	11.63	95.69
	50	26.51	3.38	15.70	5.84	21.64	3.71	18.53	11.68	96.45
	25	13.74	3.32	16.58	2.94	11.12	3.78	18.90	11.76	96.47
Phit = 0.2										
	100	55.30	3.37	16.39	12.91	26.64	2.06	6.19	12.91	90.74
	75	43.95	3.30	17.78	9.06	18.49	2.04	10.21	12.08	96.15
	50	27.12	3.31	16.38	6.00	12.50	2.08	10.41	12.01	96.59
	25	13.63	3.33	16.35	3.04	6.01	1.98	9.88	12.17	96.89
Phit = 0.3										
	100	55.23	3.32	16.63	12.88	19.74	1.53	4.60	12.88	90.79
	75	44.20	3.27	18.05	9.05	13.52	1.49	7.47	12.07	96.15
	50	27.40	3.30	16.58	6.27	9.58	1.53	7.64	12.55	96.71
	25	13.54	3.37	16.09	2.85	4.39	1.54	7.70	11.41	96.58

Table 15. HVP ITL Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	9.69	0.32	17.00	125.00	358.00	0.53	41.00	185.00	274.00	0.37	0.54	0.40	40.60	18.60
	75	4.31	0.15	4.00	66.00	430.00	0.20	3.00	92.00	405.00	0.13	0.20	0.00	70.60	49.80
	50	3.55	0.05	0.00	26.00	474.00	0.11	1.00	51.00	448.00	0.08	0.11	0.00	84.60	70.20
	25	3.53	0.04	1.00	18.00	481.00	0.05	0.00	25.00	475.00	0.05	0.04	0.00	91.20	83.60
Phit = 0.2															
	100	9.26	0.36	15.00	151.00	334.00	0.48	33.00	176.00	291.00	0.37	0.50	0.20	40.40	20.00
	75	3.85	0.13	2.00	63.00	435.00	0.18	6.00	79.00	415.00	0.15	0.17	0.00	72.00	54.20
	50	3.41	0.09	1.00	41.00	458.00	0.11	2.00	51.00	447.00	0.08	0.10	0.00	82.20	68.00
	25	3.11	0.03	0.00	17.00	483.00	0.06	0.00	28.00	472.00	0.03	0.05	0.00	91.20	84.80
Phit = 0.3															
	100	9.21	0.36	12.00	154.00	334.00	0.47	36.00	162.00	302.00	0.33	0.50	0.40	40.60	21.40
	75	3.85	0.10	1.00	46.00	453.00	0.16	4.00	74.00	422.00	0.12	0.18	0.00	77.00	57.80
	50	3.29	0.07	1.00	32.00	467.00	0.10	1.00	49.00	450.00	0.06	0.11	0.00	84.00	69.60
	25	3.42	0.02	0.00	12.00	488.00	0.07	1.00	32.00	467.00	0.04	0.05	0.00	91.20	82.60

Table 16. 50% TALLER Scenario—Weapon Data (3 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	5.98	19.99	3.34	5.98	37.22	123.48	3.32	37.22	12.52
	75	7.21	23.98	3.32	9.62	42.72	141.05	3.30	56.95	13.11
	50	5.20	17.12	3.29	10.40	29.13	96.80	3.32	58.26	8.00
	25	2.49	8.40	3.37	9.98	14.44	48.75	3.38	57.77	4.19
Phit = 0.2										
	100	8.15	27.28	0.00	8.15	51.62	171.73	3.33	51.62	16.59
	75	7.16	23.97	3.35	9.54	42.74	141.24	3.30	56.99	13.13
	50	4.87	16.88	3.46	9.75	29.00	97.91	3.38	58.00	8.19
	25	2.54	8.65	3.41	10.16	14.52	48.56	3.34	58.07	4.07
Phit = 0.3										
	100	8.19	27.30	0.00	8.19	51.63	171.64	3.32	51.63	16.44
	75	7.01	24.04	3.43	9.35	42.32	141.99	3.36	56.42	13.61
	50	5.14	17.09	3.33	10.27	28.94	97.27	3.36	57.88	8.11
	25	2.60	8.44	3.25	10.39	14.54	48.37	3.33	58.14	3.98

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	42.29	3.38	12.52	24.50	90.70	3.70	11.11	24.50	80.21
	75	44.40	3.39	17.48	8.65	32.34	3.74	11.21	11.54	95.59
	50	26.71	3.34	16.00	5.87	22.03	3.75	11.26	11.73	96.39
	25	14.44	3.45	16.77	2.91	11.06	3.80	11.40	11.64	96.15
Phit = 0.2										
	100	55.43	3.34	16.59	12.77	26.68	2.09	6.27	12.77	89.12
	75	43.64	3.32	17.51	8.93	17.94	2.01	6.03	11.90	95.94
	50	27.71	3.38	16.39	6.12	12.82	2.09	6.28	12.25	96.39
	25	14.13	3.47	16.28	2.99	6.02	2.01	6.03	11.97	96.48
Phit = 0.3										
	100	55.47	3.37	16.44	12.64	19.36	1.53	4.60	12.64	88.90
	75	45.20	3.32	18.15	8.97	13.68	1.53	4.58	11.95	95.88
	50	27.04	3.33	16.22	6.10	9.26	1.52	4.56	12.19	96.56
	25	13.18	3.31	15.94	3.07	4.67	1.52	4.56	12.28	96.75

Table 17. 50% TALLER Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	19.79	0.60	48.00	204.00	248.00	0.87	95.00	244.00	161.00	0.64	0.89	2.00	15.80	3.60
	75	4.41	0.13	1.00	61.00	438.00	0.23	11.00	92.00	397.00	0.11	0.17	0.00	70.60	55.00
	50	3.61	0.07	1.00	32.00	467.00	0.12	4.00	50.00	446.00	0.08	0.09	0.00	83.60	69.80
	25	3.85	0.04	0.00	20.00	480.00	0.07	2.00	31.00	467.00	0.04	0.05	0.00	89.60	82.00
Phit = 0.2															
	100	10.88	0.42	33.00	143.00	324.00	0.56	36.00	206.00	258.00	0.36	0.55	1.00	35.80	18.00
	75	4.06	0.12	2.00	55.00	443.00	0.17	8.00	70.00	422.00	0.15	0.18	0.00	74.40	53.60
	50	3.61	0.06	0.00	30.00	470.00	0.12	5.00	51.00	444.00	0.07	0.11	0.00	83.80	69.20
	25	3.52	0.04	0.00	22.00	478.00	0.06	0.00	28.00	472.00	0.03	0.05	0.00	90.20	82.80
Phit = 0.3															
	100	11.10	0.40	19.00	162.00	319.00	0.57	48.00	189.00	263.00	0.42	0.57	0.60	36.20	15.60
	75	4.12	0.10	1.00	46.00	453.00	0.20	4.00	94.00	402.00	0.10	0.19	0.00	73.20	54.60
	50	3.44	0.08	0.00	39.00	461.00	0.10	0.00	49.00	451.00	0.07	0.12	0.00	83.40	69.00
	25	3.25	0.03	0.00	16.00	484.00	0.05	0.00	24.00	476.00	0.04	0.05	0.00	92.20	84.20

Table 18. 50% TALLER Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	8.18	27.18	0.00	8.18	50.97	171.74	3.37	50.97	16.80
	75	7.28	24.24	3.33	9.70	42.13	142.03	3.37	56.17	13.36
	50	5.16	16.94	3.28	10.32	28.86	96.88	3.36	57.71	8.13
	25	2.62	8.40	3.21	10.46	14.57	48.54	3.33	58.27	4.04
Phit = 0.2										
	100	7.92	27.35	0.00	7.92	51.00	171.76	3.37	51.00	16.66
	75	7.10	24.18	3.41	9.46	43.01	141.77	3.30	57.34	13.14
	50	5.15	16.96	3.29	10.31	28.89	97.13	3.36	57.77	8.11
	25	2.52	8.30	3.29	10.09	14.47	48.98	3.38	57.90	4.06
Phit = 0.3										
	100	8.40	27.18	0.00	8.40	52.10	171.67	3.30	52.10	16.69
	75	7.28	23.77	3.26	9.71	42.26	141.69	3.35	56.34	13.19
	50	4.88	16.59	3.40	9.76	29.10	97.57	3.35	58.19	8.25
	25	2.40	8.20	3.42	9.60	14.51	48.81	3.36	58.03	4.23

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	55.65	3.31	16.80	12.77	47.25	3.70	11.10	12.77	88.71
	75	44.86	3.36	17.81	8.90	32.70	3.67	18.36	11.87	95.55
	50	27.14	3.34	16.26	5.98	22.08	3.69	18.45	11.96	96.26
	25	13.53	3.35	16.17	2.91	10.73	3.69	18.43	11.64	96.54
Phit = 0.2										
	100	55.66	3.34	16.66	13.35	20.06	1.50	4.51	13.35	88.92
	75	43.89	3.34	17.51	8.82	17.86	2.02	10.12	11.77	96.09
	50	27.44	3.39	16.21	6.03	12.25	2.03	10.16	12.06	96.35
	25	13.35	3.29	16.25	3.14	6.40	2.04	10.19	12.56	96.79
Phit = 0.3										
	100	55.27	3.31	16.69	12.72	19.37	1.52	4.57	12.72	89.90
	75	44.33	3.36	17.59	9.20	14.01	1.52	7.62	12.26	95.90
	50	27.78	3.37	16.50	6.00	9.14	1.52	7.62	11.99	96.45
	25	13.85	3.27	16.93	3.05	4.62	1.52	7.58	12.18	96.74

Table 19. 50% TALLER Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	11.29	0.38	17.00	155.00	328.00	0.54	50.00	170.00	280.00	0.46	0.57	0.40	38.00	14.00
	75	4.45	0.13	3.00	61.00	436.00	0.18	4.00	83.00	413.00	0.16	0.21	0.00	72.60	50.80
	50	3.74	0.08	0.00	38.00	462.00	0.09	0.00	43.00	457.00	0.06	0.10	0.00	84.20	72.40
	25	3.46	0.03	0.00	14.00	486.00	0.06	0.00	28.00	472.00	0.04	0.04	0.00	91.80	84.60
Phit = 0.2															
	100	11.08	0.39	23.00	150.00	327.00	0.58	42.00	204.00	254.00	0.42	0.56	0.00	31.00	13.20
	75	3.91	0.10	2.00	46.00	452.00	0.20	6.00	90.00	404.00	0.12	0.17	0.00	73.00	55.60
	50	3.65	0.08	0.00	40.00	460.00	0.10	0.00	50.00	450.00	0.07	0.12	0.00	82.80	68.40
	25	3.21	0.04	0.00	21.00	479.00	0.05	0.00	27.00	473.00	0.04	0.05	0.00	90.60	82.60
Phit = 0.3															
	100	10.10	0.36	18.00	143.00	339.00	0.53	40.00	184.00	276.00	0.35	0.49	0.20	37.60	19.60
	75	4.10	0.16	3.00	73.00	424.00	0.19	7.00	82.00	411.00	0.12	0.18	0.00	70.80	53.00
	50	3.55	0.10	1.00	50.00	449.00	0.11	3.00	50.00	447.00	0.07	0.08	0.00	80.40	69.60
	25	3.26	0.04	0.00	21.00	479.00	0.05	0.00	26.00	474.00	0.04	0.05	0.00	90.80	83.60

Table 20. 50% LANCER Scenario—Weapon Data (3 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.22	33.92	3.32	10.22	25.47	86.00	3.38	25.47	16.85
	75	7.61	25.85	3.39	10.15	25.89	86.00	3.32	34.51	15.40
	50	5.07	16.86	3.32	10.15	25.75	85.67	3.33	51.51	9.76
	25	2.44	8.43	3.45	9.76	14.64	49.03	3.35	58.56	4.05
Phit = 0.2										
	100	10.29	33.96	3.30	10.29	25.78	86.00	3.34	25.78	16.58
	75	7.54	25.44	3.37	10.06	25.77	86.00	3.34	34.36	15.65
	50	5.18	17.00	3.28	10.35	25.64	85.68	3.34	51.29	9.72
	25	2.50	8.43	3.37	9.99	14.46	48.78	3.37	57.82	4.11
Phit = 0.3										
	100	10.35	34.03	3.29	10.35	26.06	86.00	3.30	26.06	16.76
	75	7.58	25.54	3.37	10.11	25.69	86.00	3.35	34.26	15.60
	50	4.92	16.91	3.43	9.84	25.65	85.71	3.34	51.30	10.02
	25	2.48	8.72	3.51	9.93	14.58	48.27	3.31	58.31	4.24

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	55.89	3.32	16.85	34.85	128.36	3.68	11.05	34.85	87.39
	75	51.63	3.35	20.54	21.24	78.58	3.70	11.10	28.31	93.52
	50	33.01	3.38	19.52	7.37	26.55	3.60	10.80	14.74	95.92
	25	13.58	3.35	16.20	3.01	11.36	3.78	11.33	12.02	96.54
Phit = 0.2										
	100	55.83	3.37	16.58	34.80	72.18	2.07	6.22	34.80	87.45
	75	51.23	3.27	20.87	21.50	44.33	2.06	6.19	28.66	93.94
	50	33.36	3.43	19.45	7.42	15.06	2.03	6.09	14.84	95.93
	25	13.91	3.39	16.43	3.09	6.45	2.09	6.26	12.36	96.61
Phit = 0.3										
	100	55.74	3.33	16.76	34.55	52.73	1.53	4.58	34.55	87.73
	75	51.54	3.30	20.80	21.41	32.44	1.52	4.55	28.54	93.71
	50	33.25	3.32	20.04	7.45	11.36	1.53	4.58	14.89	96.07
	25	13.84	3.26	16.97	2.91	4.49	1.54	4.63	11.65	96.86

Table 21. 50% LANCER Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	12.61	0.48	32.00	177.00	291.00	0.62	52.00	206.00	242.00	0.45	0.68	0.60	28.80	11.40
	75	6.48	0.17	3.00	80.00	417.00	0.27	13.00	109.00	378.00	0.18	0.28	0.00	64.00	42.60
	50	4.08	0.08	2.00	36.00	462.00	0.12	4.00	54.00	442.00	0.09	0.13	0.00	81.20	64.20
	25	3.46	0.03	0.00	15.00	485.00	0.05	0.00	27.00	473.00	0.04	0.06	0.00	91.80	82.40
Phit = 0.2															
	100	12.55	0.47	31.00	172.00	297.00	0.62	57.00	198.00	245.00	0.47	0.69	0.40	30.60	11.20
	75	6.06	0.17	5.00	75.00	420.00	0.27	17.00	103.00	380.00	0.18	0.31	0.00	65.60	41.20
	50	4.07	0.08	1.00	40.00	459.00	0.12	4.00	54.00	442.00	0.09	0.11	0.00	80.80	65.80
	25	3.39	0.03	0.00	15.00	485.00	0.06	0.00	30.00	470.00	0.03	0.06	0.00	91.00	84.00
Phit = 0.3															
	100	12.27	0.44	24.00	173.00	303.00	0.67	66.00	204.00	230.00	0.42	0.59	0.60	29.00	11.60
	75	6.29	0.21	4.00	95.00	401.00	0.32	11.00	136.00	353.00	0.20	0.30	0.00	58.60	38.20
	50	3.93	0.09	1.00	45.00	454.00	0.09	0.00	47.00	453.00	0.09	0.11	0.00	82.60	66.60
	25	3.14	0.03	0.00	16.00	484.00	0.05	0.00	25.00	475.00	0.04	0.05	0.00	92.00	83.80

Table 22. 50% LANCER Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.01	34.00	3.40	10.01	26.03	86.00	3.30	26.03	16.58
	75	7.55	25.39	3.36	10.07	25.80	86.00	3.33	34.41	15.50
	50	5.13	16.98	3.31	10.25	25.56	85.66	3.35	51.12	9.80
	25	2.57	8.51	3.31	10.30	14.70	48.29	3.29	58.78	3.96
Phit = 0.2										
	100	10.13	33.86	3.34	10.13	25.47	86.00	3.38	25.47	16.58
	75	7.40	25.38	3.43	9.87	25.66	86.00	3.35	34.22	15.29
	50	5.13	17.28	3.37	10.26	25.64	85.62	3.34	51.29	9.81
	25	2.50	8.46	3.39	10.00	14.54	48.51	3.34	58.18	4.15
Phit = 0.3										
	100	10.10	34.38	3.40	10.10	26.07	86.00	3.30	26.07	16.63
	75	7.76	25.91	3.34	10.34	25.85	86.00	3.33	34.46	15.37
	50	5.05	17.11	3.39	10.10	26.04	85.61	3.29	52.08	9.68
	25	2.49	8.39	3.37	9.94	14.56	48.87	3.36	58.23	4.13

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	55.82	3.37	16.58	34.13	125.90	3.69	11.07	34.13	86.75
	75	50.92	3.28	20.67	21.39	79.39	3.71	18.56	28.51	93.66
	50	32.52	3.32	19.60	7.50	27.33	3.64	18.21	15.01	95.98
	25	13.33	3.36	15.85	2.88	10.91	3.79	18.94	11.52	96.45
Phit = 0.2										
	100	55.81	3.37	16.58	35.14	72.48	2.06	6.19	35.14	87.32
	75	51.87	3.39	20.39	21.61	44.81	2.07	10.37	28.81	93.29
	50	32.71	3.34	19.61	7.46	15.78	2.11	10.57	14.93	96.09
	25	14.14	3.41	16.58	2.95	6.25	2.12	10.59	11.80	96.56
Phit = 0.3										
	100	55.90	3.36	16.63	34.60	52.48	1.52	4.55	34.60	87.40
	75	50.96	3.31	20.50	21.47	32.58	1.52	7.59	28.62	93.92
	50	32.40	3.35	19.36	7.30	11.02	1.51	7.55	14.60	96.14
	25	13.49	3.27	16.51	3.05	4.73	1.55	7.75	12.20	96.89

Table 23. 50% LANCER Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	13.25	0.54	35.00	201.00	264.00	0.67	56.00	224.00	220.00	0.45	0.72	1.00	25.60	9.20
	75	6.34	0.19	5.00	85.00	410.00	0.28	17.00	106.00	377.00	0.21	0.23	0.20	62.80	44.60
	50	4.02	0.08	0.00	41.00	459.00	0.11	3.00	50.00	447.00	0.09	0.11	0.00	81.40	67.00
	25	3.55	0.03	0.00	17.00	483.00	0.05	0.00	27.00	473.00	0.03	0.05	0.00	91.40	84.80
Phit = 0.2															
	100	12.68	0.41	23.00	161.00	316.00	0.69	59.00	225.00	216.00	0.49	0.65	0.60	31.00	12.40
	75	6.71	0.20	14.00	70.00	416.00	0.29	13.00	119.00	368.00	0.19	0.29	0.20	62.20	40.60
	50	3.91	0.06	2.00	28.00	470.00	0.10	3.00	42.00	455.00	0.08	0.11	0.00	85.80	71.40
	25	3.44	0.05	0.00	23.00	477.00	0.07	1.00	35.00	464.00	0.03	0.06	0.00	88.40	80.80
Phit = 0.3															
	100	12.60	0.50	32.00	184.00	284.00	0.57	34.00	216.00	250.00	0.48	0.66	0.80	29.60	11.20
	75	6.08	0.19	5.00	85.00	410.00	0.28	11.00	119.00	370.00	0.20	0.29	0.00	62.60	41.80
	50	3.86	0.09	0.00	44.00	456.00	0.11	0.00	54.00	446.00	0.08	0.14	0.00	81.80	65.20
	25	3.11	0.02	0.00	8.00	492.00	0.05	0.00	26.00	474.00	0.04	0.06	0.00	93.20	84.20

Table 24. 50% ROBIN Scenario—Weapon Data (3 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.49	34.52	3.29	10.49	51.35	170.79	3.33	51.35	8.49
	75	7.75	25.60	3.30	10.34	41.97	139.81	3.33	55.96	8.49
	50	5.03	16.92	3.36	10.07	29.34	96.61	3.29	58.67	7.23
	25	2.63	8.17	3.10	10.52	14.50	48.82	3.37	58.00	3.96
Phit = 0.2										
	100	10.45	34.45	3.30	10.45	51.50	170.45	3.31	51.50	8.24
	75	7.47	25.74	3.45	9.96	42.23	140.67	3.33	56.31	8.24
	50	5.08	17.17	3.38	10.16	29.14	96.91	3.33	58.29	7.20
	25	2.66	8.62	3.24	10.63	14.34	48.27	3.37	57.34	4.08
Phit = 0.3										
	100	10.17	33.75	3.32	10.17	51.40	170.73	3.32	51.40	8.59
	75	7.67	25.70	3.35	10.23	41.99	140.56	3.35	55.99	8.39
	50	4.96	16.67	3.36	9.92	29.16	97.74	3.35	58.32	7.07
	25	2.64	8.53	3.23	10.57	14.66	48.36	3.30	58.64	3.96

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	28.00	3.30	8.49	12.40	45.73	3.69	11.06	12.40	82.73
	75	27.81	3.27	11.33	8.83	32.73	3.70	11.11	11.78	89.40
	50	24.13	3.34	14.46	5.67	20.71	3.65	10.95	11.35	94.55
	25	12.91	3.26	15.82	3.08	11.08	3.59	10.78	12.34	96.68
Phit = 0.2										
	100	28.00	3.40	8.24	12.57	25.97	2.07	6.20	12.57	82.77
	75	27.65	3.35	10.99	9.07	18.57	2.05	6.14	12.09	89.35
	50	23.68	3.29	14.40	5.97	12.35	2.07	6.20	11.94	94.79
	25	13.81	3.38	16.34	3.04	6.52	2.15	6.44	12.15	96.46
Phit = 0.3										
	100	28.00	3.26	8.59	12.79	19.64	1.54	4.61	12.79	82.94
	75	27.76	3.31	11.19	8.95	13.57	1.52	4.55	11.93	89.34
	50	24.05	3.40	14.13	6.16	9.43	1.53	4.59	12.32	94.69
	25	13.22	3.34	15.83	2.95	4.41	1.49	4.48	11.80	96.84

Table 25. 50% ROBIN Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	17.27	0.61	44.00	215.00	241.00	0.86	93.00	245.00	162.00	0.58	0.80	1.40	16.60	2.80
	75	10.60	0.29	16.00	111.00	373.00	0.42	25.00	159.00	316.00	0.30	0.41	0.20	46.60	23.40
	50	5.45	0.12	2.00	58.00	440.00	0.14	2.00	66.00	432.00	0.13	0.15	0.00	76.40	60.20
	25	3.32	0.03	0.00	13.00	487.00	0.04	1.00	19.00	480.00	0.03	0.08	0.00	93.40	83.60
Phit = 0.2															
	100	17.23	0.64	55.00	212.00	233.00	0.86	90.00	251.00	159.00	0.61	0.84	1.80	15.60	2.60
	75	10.65	0.29	12.00	120.00	368.00	0.42	25.00	161.00	314.00	0.30	0.43	0.00	47.40	23.20
	50	5.21	0.10	0.00	49.00	451.00	0.15	4.00	67.00	429.00	0.12	0.18	0.00	78.00	59.00
	25	3.54	0.05	0.00	24.00	476.00	0.04	0.00	21.00	479.00	0.04	0.06	0.00	91.00	82.40
Phit = 0.3															
	100	17.06	0.62	52.00	208.00	240.00	0.85	97.00	230.00	173.00	0.59	0.85	1.80	16.20	3.80
	75	10.66	0.34	23.00	122.00	355.00	0.40	27.00	148.00	325.00	0.32	0.42	0.00	46.40	25.00
	50	5.31	0.09	1.00	43.00	456.00	0.19	6.00	82.00	412.00	0.12	0.13	0.00	75.00	60.20
	25	3.16	0.02	0.00	11.00	489.00	0.06	1.00	26.00	473.00	0.04	0.04	0.00	92.60	84.80

Table 26. 50% ROBIN Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	10.07	33.66	3.34	10.07	51.10	171.07	3.35	51.10	8.34
	75	7.74	25.71	3.32	10.32	42.08	139.55	3.32	56.10	8.35
	50	4.95	16.84	3.40	9.90	29.32	97.13	3.31	58.65	7.11
	25	2.61	8.62	3.30	10.46	14.41	48.32	3.35	57.65	4.03
Phit = 0.2										
	100	10.00	33.39	3.34	10.00	51.32	170.92	3.33	51.32	8.32
	75	7.65	25.53	3.34	10.20	41.99	139.88	3.33	55.98	8.42
	50	5.13	16.79	3.27	10.26	29.19	96.89	3.32	58.38	7.16
	25	2.59	8.32	3.21	10.35	14.37	48.84	3.40	57.48	4.01
Phit = 0.3										
	100	10.30	34.45	3.34	10.30	51.22	171.11	3.34	51.22	8.35
	75	7.74	25.39	3.28	10.32	41.84	140.12	3.35	55.78	8.18
	50	4.96	16.95	3.42	9.92	29.21	96.49	3.30	58.42	7.21
	25	2.59	8.55	3.31	10.34	14.52	48.48	3.34	58.08	4.06

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	28.00	3.36	8.34	12.61	47.25	3.75	11.24	12.61	82.12
	75	27.79	3.33	11.13	8.64	31.46	3.64	18.21	11.52	89.07
	50	23.68	3.33	14.23	5.79	21.46	3.70	18.52	11.58	94.36
	25	13.70	3.40	16.12	3.01	11.36	3.77	18.86	12.05	96.27
Phit = 0.2										
	100	28.00	3.37	8.32	13.06	26.59	2.04	6.11	13.06	82.70
	75	27.76	3.30	11.23	9.00	18.47	2.05	10.26	12.00	89.41
	50	23.84	3.33	14.32	6.05	12.60	2.08	10.42	12.09	95.06
	25	13.50	3.37	16.03	3.19	6.54	2.05	10.24	12.78	96.64
Phit = 0.3										
	100	28.00	3.35	8.35	12.87	19.48	1.51	4.54	12.87	82.73
	75	27.77	3.40	10.91	8.95	13.47	1.50	7.52	11.93	88.94
	50	24.20	3.36	14.42	5.88	8.92	1.52	7.59	11.76	94.52
	25	13.38	3.30	16.24	3.04	4.71	1.55	7.75	12.15	96.82

Table 27. 50% ROBIN Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	17.88	0.62	42.00	224.00	234.00	0.84	87.00	248.00	165.00	0.59	0.84	2.20	16.60	4.80
	75	10.93	0.34	18.00	133.00	349.00	0.44	28.00	164.00	308.00	0.31	0.48	0.60	42.60	20.80
	50	5.64	0.09	2.00	41.00	457.00	0.19	9.00	79.00	412.00	0.11	0.19	0.00	75.80	58.00
	25	3.73	0.04	0.00	18.00	482.00	0.04	1.00	20.00	479.00	0.04	0.04	0.00	92.40	84.60
Phit = 0.2															
	100	17.30	0.63	52.00	213.00	235.00	0.84	90.00	238.00	172.00	0.65	0.85	1.80	16.20	3.60
	75	10.59	0.30	17.00	114.00	369.00	0.42	31.00	150.00	319.00	0.32	0.43	0.60	48.20	25.80
	50	4.94	0.13	3.00	57.00	440.00	0.12	3.00	56.00	441.00	0.12	0.12	0.00	77.60	65.00
	25	3.36	0.03	0.00	15.00	485.00	0.07	0.00	34.00	466.00	0.03	0.05	0.00	90.20	82.60
Phit = 0.3															
	100	17.27	0.58	50.00	188.00	262.00	0.86	97.00	237.00	166.00	0.58	0.82	1.80	17.40	3.80
	75	11.06	0.31	15.00	124.00	361.00	0.44	23.00	174.00	303.00	0.32	0.43	0.00	45.40	22.80
	50	5.48	0.14	3.00	63.00	434.00	0.15	5.00	64.00	431.00	0.09	0.17	0.00	76.20	61.80
	25	3.18	0.03	0.00	14.00	486.00	0.04	1.00	19.00	480.00	0.04	0.07	0.00	93.40	82.60

Table 28. HVP Only Scenario—Weapon Data (3 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
Phit = 0.2										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
Phit = 0.3										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	0	0	0	49.68	182.56	3.67	11.02	49.68	49.68
	75	0	0	0	37.04	136.36	3.68	11.04	49.38	49.38
	50	0	0	0	24.77	91.58	3.70	11.09	49.53	49.53
	25	0	0	0	12.34	45.36	3.68	11.03	49.34	49.34
Phit = 0.2										
	100	0	0	0	50.77	104.08	2.05	6.15	50.77	50.77
	75	0	0	0	37.48	76.67	2.05	6.14	49.98	49.98
	50	0	0	0	25.17	51.82	2.06	6.18	50.34	50.34
	25	0	0	0	12.51	25.99	2.08	6.23	50.02	50.02
Phit = 0.3										
	100	0	0	0	50.28	76.37	1.52	4.56	50.28	50.28
	75	0	0	0	38.08	58.20	1.53	4.59	50.77	50.77
	50	0	0	0	24.87	38.06	1.53	4.59	49.74	49.74
	25	0	0	0	12.73	19.20	1.51	4.52	50.91	50.91

Table 29. HVP Only Scenario—Survivability (3 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	50.32	1.29	206.00	234.00	60.00	1.59	311.00	171.00	18.00	1.36	1.58	24.80	0.40	0.00
	75	50.62	1.05	147.00	232.00	121.00	1.38	231.00	228.00	41.00	1.15	1.41	14.60	1.80	0.00
	50	50.47	0.82	85.00	238.00	177.00	1.09	152.00	242.00	106.00	0.79	1.13	5.60	7.80	0.60
	25	50.66	0.46	34.00	163.00	303.00	0.65	58.00	211.00	231.00	0.46	0.69	0.20	28.80	9.20
Phit = 0.2															
	100	49.23	1.31	225.00	205.00	70.00	1.58	312.00	167.00	21.00	1.32	1.53	29.00	1.20	0.00
	75	50.02	1.08	152.00	238.00	110.00	1.40	247.00	205.00	48.00	1.10	1.36	14.40	2.80	0.00
	50	49.66	0.86	90.00	252.00	158.00	1.11	151.00	254.00	95.00	0.87	1.04	4.60	4.80	0.80
	25	49.98	0.48	30.00	179.00	291.00	0.61	58.00	190.00	252.00	0.45	0.69	0.40	29.40	6.60
Phit = 0.3															
	100	49.72	1.33	217.00	233.00	50.00	1.56	308.00	164.00	28.00	1.32	1.59	28.80	1.40	0.00
	75	49.23	1.09	153.00	237.00	110.00	1.41	256.00	194.00	50.00	1.03	1.39	14.80	2.20	0.00
	50	50.26	0.85	96.00	235.00	169.00	1.12	153.00	254.00	93.00	0.81	1.09	6.60	6.40	0.20
	25	49.09	0.46	25.00	178.00	297.00	0.64	53.00	212.00	235.00	0.51	0.72	0.40	28.80	5.60

Table 30. HVP Only Scenario—Weapon Data (5 Round Bursts)

	Salvo Size	Taller Kills	Taller Used	Taller Shots/Kills	Taller %	Lancer Kills	Lancer Used	Lancer Shots/Kills	Lancer%	Robin Kills
Phit = 0.1										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
Phit = 0.2										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
Phit = 0.3										
	100	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0

	Salvo Size	Robin Used	Robin Shots/Kills	Robin %	HVP Kills	HVP Bursts Used	HVP Bursts/Kills	HVP Shots/Kills	% HVP	Total % Destroyed
Phit = 0.1										
	100	0	0	0	49.79	183.12	3.68	11.03	49.79	49.79
	75	0	0	0	37.02	135.91	3.67	18.36	49.35	49.35
	50	0	0	0	25.14	92.94	3.70	18.48	50.29	50.29
	25	0	0	0	12.33	46.09	3.74	18.69	49.31	49.31
Phit = 0.2										
	100	0	0	0	50.14	103.06	2.06	6.17	50.14	50.14
	75	0	0	0	37.60	76.44	2.03	10.17	50.13	50.13
	50	0	0	0	25.03	51.12	2.04	10.21	50.06	50.06
	25	0	0	0	12.65	25.97	2.05	10.27	50.58	50.58
Phit = 0.3										
	100	0	0	0	49.80	76.29	1.53	4.60	49.80	49.80
	75	0	0	0	37.52	57.23	1.53	7.63	50.02	50.02
	50	0	0	0	24.80	38.01	1.53	7.66	49.59	49.59
	25	0	0	0	12.73	19.37	1.52	7.61	50.90	50.90

Table 31. HVP Only Scenario—Survivability (5 Round Bursts)

	Salvo Size	% Engaged by CIWS	Average CG Sunk	2 CG Sunk	1 CG Sunk	0 CG Sunk	Average DDG Sunk	2 DDG Sunk	1 DDG Sunk	0 DDG Sunk	Average CG Damaged	Average DDG Damaged	All AFP Sunk (%)	All AFP Afloat (%)	All AFP Unharmed (%)
Phit = 0.1															
	100	50.21	1.33	220.00	223.00	57.00	1.60	326.00	150.00	24.00	1.34	1.55	29.00	0.20	0.00
	75	50.65	1.07	146.00	243.00	111.00	1.40	245.00	208.00	47.00	1.05	1.36	14.20	0.80	0.00
	50	49.71	0.78	72.00	246.00	182.00	1.09	157.00	233.00	110.00	0.80	1.06	3.40	6.60	1.00
	25	50.69	0.47	31.00	174.00	295.00	0.69	54.00	238.00	208.00	0.44	0.65	0.40	24.40	7.80
Phit = 0.2															
	100	49.86	1.28	214.00	213.00	73.00	1.57	309.00	165.00	26.00	1.29	1.58	26.80	0.60	0.00
	75	49.87	1.09	142.00	261.00	97.00	1.38	244.00	203.00	53.00	1.11	1.42	14.80	1.60	0.00
	50	49.94	0.79	78.00	241.00	181.00	1.11	151.00	254.00	95.00	0.87	1.07	4.00	7.20	0.00
	25	49.42	0.45	27.00	169.00	304.00	0.65	53.00	219.00	228.00	0.44	0.64	0.00	28.00	6.60
Phit = 0.3															
	100	50.20	1.32	209.00	240.00	51.00	1.61	327.00	152.00	21.00	1.29	1.63	24.60	0.80	0.00
	75	49.98	1.11	157.00	241.00	102.00	1.39	241.00	214.00	45.00	1.09	1.34	14.80	1.40	0.00
	50	50.41	0.82	85.00	240.00	175.00	1.12	143.00	272.00	85.00	0.87	1.14	4.60	6.20	0.20
	25	49.10	0.44	23.00	173.00	304.00	0.70	70.00	209.00	221.00	0.52	0.66	0.80	25.80	6.20

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