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TECHNICAL REPORT

"SEA SWAT"
A Littoral Combat Ship for Sea Base Defense
by:

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13. ABSTRACT (no more than 100 words)

Unlike past conflicts which were characterized by major naval battles in the open ocean, present day threats are mostly associated with rogue nations and terrorist cells. These threats are of a different nature to past threats and may strike at unsuspected times and locations. The United States Navy may operate from a Sea Base which projects power ashore through the use of surface and air assets. These assets must transit from the Sea Base in the blue water through the littoral region in order to reach the objective area. Total ship system designs of a group of high-speed littoral combat ships (LCS) are required which are capable of operating in these regions and defending the Sea Base and the surface and air assets from an asymmetric threat. With the modular design and the ability to carry multiple helicopters and underwater vehicles (UUV), the SEA SWAT LCS concept can be quickly employed as a force multiplier capable of operating as an Air Warfare or Undersea/Mine Warfare mission platform. With the addition of the core and Surface Warfare sensors and weapons to one of these modular mission packages, the SEA SWAT LCS concept for sea base defense will ensure air, surface and subsurface superiority during conflict. An advanced electrical power system in conjunction with an integrated propulsion system and zonal power distribution provides sustained combat capability against multiple asymmetric threats. Its enclosed super-structure allows for high survivability in a CBR environment.

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ABSTRACT

Unlike past conflicts which were characterized by major naval battles in the open ocean, present day threats are mostly associated with rogue nations and terrorist cells. These threats are of a different nature to past threats and may strike at unsuspected times and locations. The United States Navy may operate from a Sea Base which projects power ashore through the use of surface and air assets. These assets must transit from the Sea Base in the blue water through the littoral region in order to reach the objective area. Total ship system designs of a group of high-speed littoral combat ships (LCS) are required which are capable of operating in these regions and defending the Sea Base and the surface and air assets from an asymmetric threat. With the modular design and the ability to carry multiple helicopters and underwater vehicles (UUV), the SEA SWAT LCS concept can be quickly employed as a force multiplier capable of operating as an Air Warfare or Undersea/Mine Warfare mission platform. With the addition of the core and Surface Warfare sensors and weapons to one of these modular mission packages, the SEA SWAT LCS concept for sea base defense will ensure air, surface and subsurface superiority during conflict. An advanced electrical power system in conjunction with an integrated propulsion system and zonal power distribution provides sustained combat capability against multiple asymmetric threats. Its enclosed super-structure allows for high survivability in a CBR environment.

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The 2003 Total Ship Systems Engineering Team would like to thank our families and friends for their understanding and support throughout our time at the Naval Postgraduate School. We also would like to extend our appreciation to Professor Fotis Papoulias and Professor Mike Green for their assistance and support throughout the TSSE curriculum and design project. For Professor David Jenn, a special acknowledgement for his invaluable assistance during the RCS evaluation of our design.

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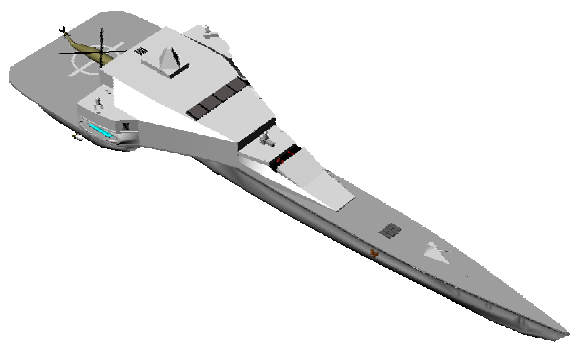
I. EXECUTIVE SUMMARY

The Navy requires a ship designed to provide Sea Base defense, which is highly maneuverable and can establish a secure line of communication between the SEA BASE and the shore while operating in shallow water with minimum manning and multi-mission capable. The resulting design is the trimaran SEA SWAT.



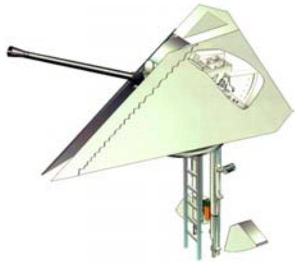
SEA SWAT is a high-speed trimaran designed to operate in very shallow water. It was design to operate singly or in groups to protect the ships of the Sea Base while in theater, including all airborne and surface assets between Sea Base and the objective. The design allows for modular payloads, which can be tailored for a specific mission, including SUW, USW and AAW.

SEA SWAT Characteristics	
Displacement	3120 LT
Length	400 ft
Beam	102 ft
Max Draft	14 ft
Designed Waterline	12 ft

SEA SWAT Operational Requirements	
Range	2500 nm @ 15 kts
Max Speed	42+ knots
Sustained Speed	35 knots (SS3)
Installed HP	64520 hp
Manning	160

A. CORE SYSTEMS

The core vessel is equipped with a Multi Function Radar, 4 HARPOON missiles, 2 Rigid Hull Inflatable Boats (RHIB), Mk 3 BOFORS 57mm gun, SEA RAM, and a Chaff Launch System.

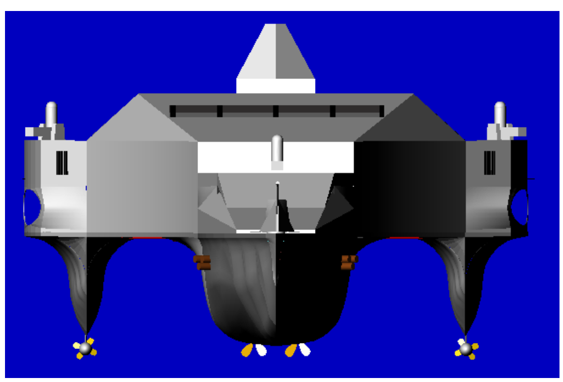


B. USW/MIW MISSION PACKAGE

The USW/MIW Mission Package contains a Mk 32 Mod 15 Torpedo Launcher, 6 Mk 50 Torpedoes, a Low Frequency Active Towed Sonar (LFATS), LAMPS, and the AN/SLQ-32 Nixie. It also features the Advanced Side Looking Sonar (ASLS), the AN/AQS-20X hull mounted sonar for mine detection, and 2 mine hunting UUVs.

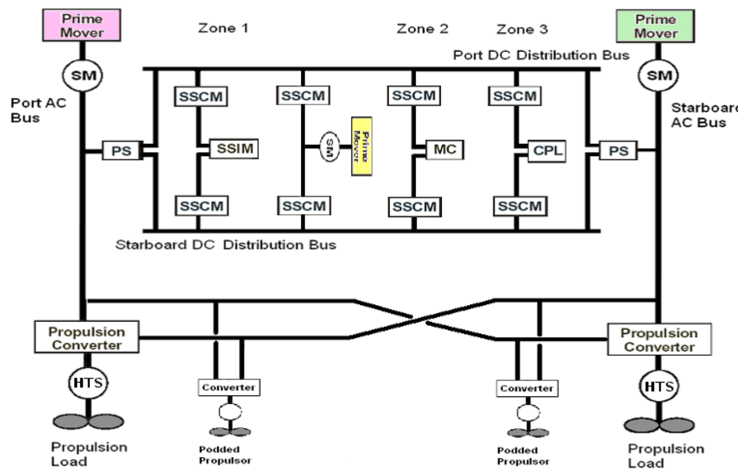
C. AAW MISSION PACKAGE

The AAW Mission Package is equipped with and 8-cell Mk 41 VLS and 32 Evolved Sea Sparrow Missiles, using the Mk 25 Quad-Pack.



D. PROPULSION/ELECTRICAL SYSTEM

An LM2500+, an LM1600 and a 3 MW Allison Generator, for emergency use, power SEA SWAT. Two 25 MW synchronous high temperature superconducting (HTS) motors capable of providing more than 67,000 SHP are available for primary means of propulsion. Two-podded propulsors located on each sidehull provide 500 SHP for low speed maneuverability. Port and starboard AC Buses provide 13.8 KVAC 3-phase power for propulsion and combat systems. Port and starboard DC buses provide 500 VDC power for ships service, combat systems and auxiliaries. The integrated design allows for continuity of power under casualty conditions.



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II. INTRODUCTION

The 2003 Total Ship Systems Engineering (TSSE) design project is intended to support the Wayne Meyer Institute of Systems Engineering in developing a Littoral Combat Ship (LCS) that is capable of defending the ships of a Sea Base while at sea in an operating area. The defense of the sea base includes the airborne assets moving between the sea base and objective and the surface assets moving between the sea base and beach or port during small scale or forcible entry missions of an Expeditionary Force.

The objective of this project is to take the required capabilities needed to defend the Sea Base and integrate them into a platform or group of platforms that could be brought together to successfully defend the Sea Base from attack.

In Sea Power 21, the Chief of Naval Operations has established Sea Basing as the future capability of naval forces. Sea Power 21 describes ships, aircraft, submarines and units connected through a netted and distributed architecture as shown in Figure 1. The pillars of SEA POWER 21 are Sea Shield, Sea Basing, Sea Strike, and FORCEnet. Each pillar is divided into tasks, with each task being further divided into capabilities.

Figure 1. Sea Force 21 Force Structure

The Littoral Combat Ship (LCS), a member of the family of future surface combatants, plays an integral role in the Sea Shield component of Sea Power 21 – that is, the projection of defensive power from the sea. SEA SWAT will contribute to Sea Shield through its unique ability to quickly respond, to operate in a littoral environment, and to conduct focused missions with a variety of networked off board systems. Missions associated with Sea Shield, anti-submarine warfare, surface warfare and mine countermeasure, will be enhanced through the employment of a distributed LCS force. These missions conducted with persistent surveillance and reconnaissance will be the LCS contribution toward assuring access for the Joint force. LCS also will directly support Sea Strike operations by enabling forced entry for Joint power projection forces. This would include support to the Marine Corps and Special Operations Forces. LCS will be an enabler of Sea Basing by providing security for Joint assets and by acting as a logistics element for joint mobility and sustainment. In

Figure 2 below, the capabilities of each task assigned to Sea Shield are listed.

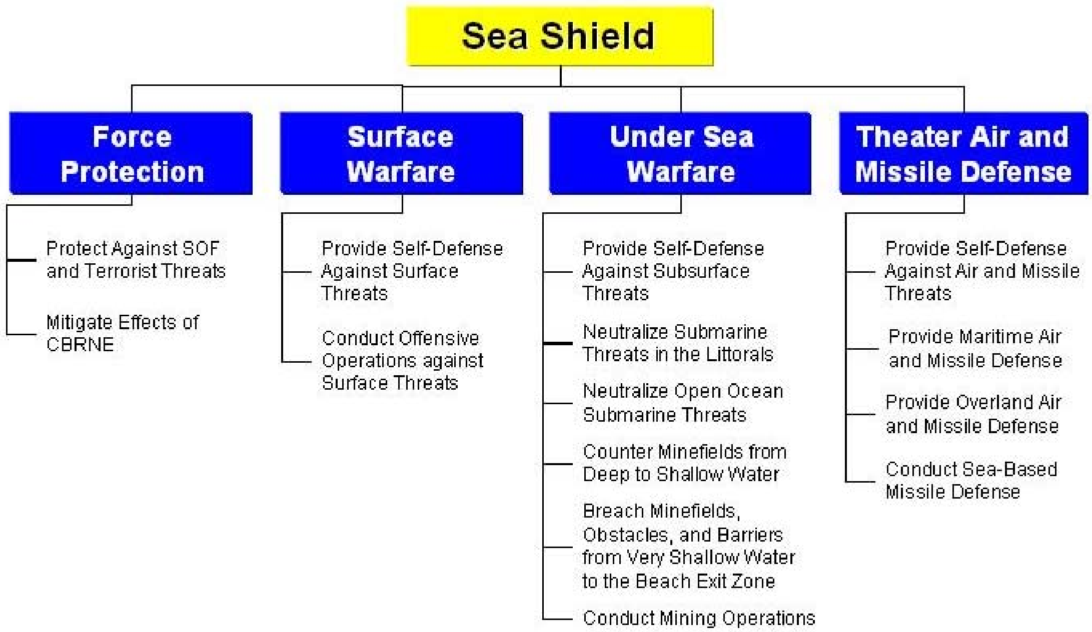

Figure 2. SEA SHIELD Mission Structure

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III. DEFINING THE REQUIREMENTS

In order to define the requirements of defending the Sea Base, it is necessary to understand what the threats are in the areas the LCS will be operating. In this particular case, by defining the threats, the TSSE team became aware of the capabilities required to accomplish the mission. Interaction and iteration with the SEA-4 team ensured that these design-level requirements were compatible with and met the intent of the system-level requirements.

A. THREAT ANALYSIS

The Sea Base extends from twenty-five to two hundred fifty nautical miles from shore as seen in Figure 3. Operating in this vast water space allows a wide variety of platforms and weapon systems to pose a substantial threat to the assets of the sea base. The TSSE team outlined a wide spectrum of threats that the sea base might encounter during operation. It is not intended to be inclusive of all present threats nor does it provide a complete feasibility of future threats. However, it does give a list of threats from a multitude of weapon methods of delivery, platforms, and weapons systems. This threat analysis document may be found in Appendix A.1. Appendix A.2. is the TSSE breakdown of the various threats based on platform threats, weapons threats, and method of weapon delivery.

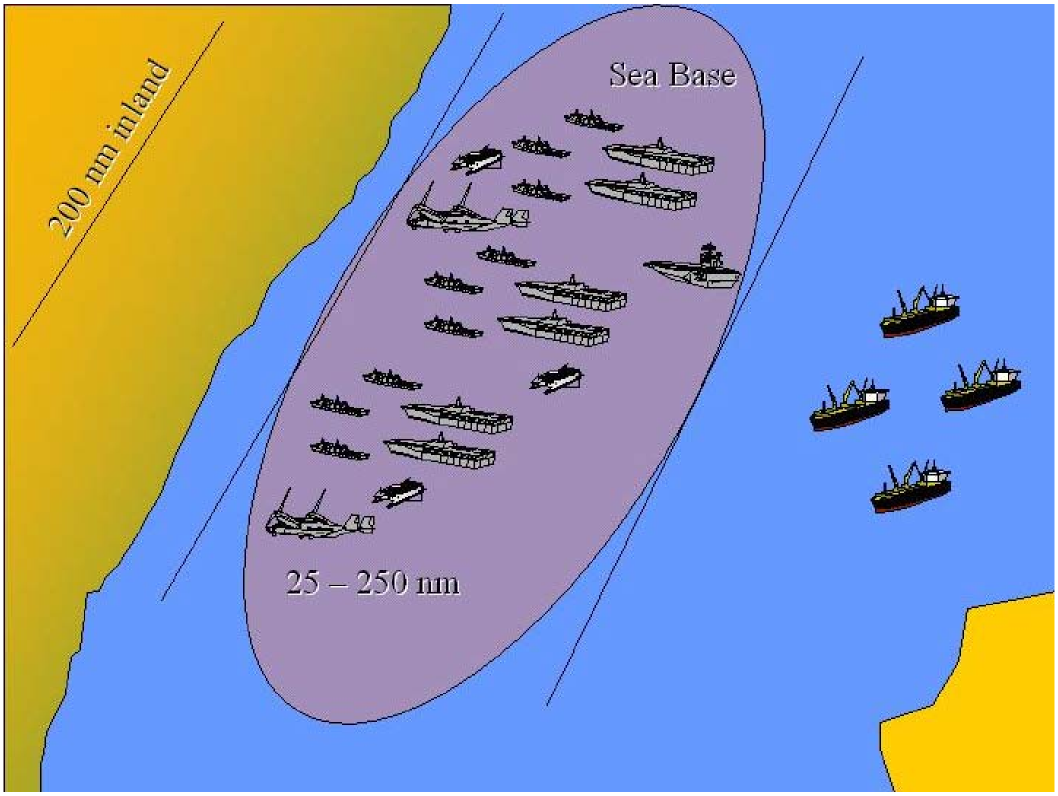

Figure 3. Sea Base Operating Area

B. SEA INITIAL REQUIREMENTS DOCUMENT (IRD) ANALYSIS

The Systems Engineering and Analysis (SEA) Initial Requirements Document (IRD) was the governing document in the analysis and development of the requirements for the TSSE concept design. At this stage of the design process, it was crucial to the TSSE team to have a complete understanding of the SEA-IRD. Accordingly, the team commenced a detailed review of the requirements stated in the Initial SEA-IRD found in Appendix B.1. The Final SEA-IRD located in Appendix B.2 was not completed until early November. The design of SEA SWAT is based on the requirements established in the Initial SEA-IRD.

IV. ANALYSIS OF ALTERNATIVES

A. NEEDS ANALYSIS

Upon completion of defining the requirements, it was necessary to conduct a combat systems needs analysis to determine what major combat systems were necessary to fulfill the requirements outlined in the previous chapter to defend the Sea Base against the threats. The results of the needs analysis may be seen below in Table 1.

Rotary Aircraft	X	X				
UAVs	X	X				
SAMs	X	X				
ASCM	X		X			
USVs	X		X			
Small Boats	X		X			
Recreational Craft	X		X			
Submarines					X	X
UUVs					X	X
Mines				X		
Navigation Obstacle				X	X	
Associated Threat / Combat System	Multi-Function Radar	Air Search Radar	Surface Search Radar	Mine Warfare Package	Variable Depth Sonar	Early Torpedo Warning

Table 1. Combat Systems Needs Analysis based on Threat Document

B. FEASIBILITY STUDY

Upon completion of conducting the needs analysis study, it was necessary to conduct a feasibility study to determine if a single ship or a group of ships would be required to satisfy the requirements outlined above. The team divided into two groups and conducted a feasibility study based on two ship and three ship variants. Reconfigured and optimized FFG-7 or DDG-51 classes of ship for Sea Base defense would represent a single ship design capable of satisfying all the requirements. Because of the rough order of detail that is present in the initial phase of the design process, these two classes of ships that exist in today's fleet can represent the single ship design.

1. TWO SHIP VARIANT

A two ship variant concept was proposed to maximize mission success as well as convenience and simplicity in ship design. The two proposed variants consisted of a Blue Water Mission Ship Design and a Littoral Mission Ship Design. The Blue Water Combatant Ship was designed to carry a modular mission package to support AW, SUW and USW warfare. The Littoral Combatant Ship would carry a MIW, C4I and unconventional modular mission package to support asymmetric threats associated with terrorist organizations and small rogue nations. Both combatant ships would contain a core mission package consisting of navigation, self-defense, Electronic Warfare and propulsion systems. The two-ship approach would allow a more effective defense system for the Sea Base, providing a dedicated ship to effectively defend against threats most common to shallow water operations as well as a dedicated deep-water ship to defend against deep-water threats.

2. THREE SHIP VARIANT

A three ship variant concept was considered as the second of two design concepts for the LCS. It was envisioned that there would be a core vessel that would be designed with three interchangeable modules. These modules, each encompassing a specific warfare area would be adaptable for the given mission. The LCS variant ships would deploy in small packs, not unlike the PT boat squadrons of the South Pacific in World War II, with the premise that if one ship was hit not all of the mission capabilities would be lost.

Designed with a core package that included the basic ship functions such as engineering, navigation and communications, the core vessel would also contain essential combat systems for self-defense. Each core vessel would be supplemented by a specific mission package. The three mission packages originally chosen consisted of the warfare areas of Under Sea Warfare, Mine Warfare and Surface Warfare. A sample iteration of the payload comparison tables for the core vessel and mission packages is found below in Table 2 and Table 3.

Threat	CORE ASSETS	WEIGHT	QNTY	TOTAL WEIGHT
	SYSTEM	MT		
MISSILE – AIR	VLS (SINGLE MODULE-WITH 8 CELL) LOADED W 8 SM-2	25.00	2	50.00
MISSILE – AIR	VLS (SINGLE MODULE-WITH 8 CELL) LOADED W 8 RIM-7	24.00	0.5	12.00
	VLS CONTROL SYSTEMS	1.12	1.5	1.68
ASM, SURFACE CRAFT, HELO, UAV, AIRCRAFT	SEA RAM WITH 11 MISSILE (ABOVE DECK)	7.08	1	7.08
	SEA RAM BELOW DECK	0.72	1	0.72
SURFACE CRAFT, FAST	BOFORS 57MM MK3 NAVAL ALL-TARGET w/	13.00	1	13.00

BOAT, KAMIKAZE,RPG	1000 rounds			
ELECTRONIC ATTACK	SBROC CHAFF AND DLS LAUNCHER	0.21	2	0.41
	SBROC ROUNDS	0.03	24	0.65
TORPEDO	LEADS	0.03	8	0.21
FAST BOAT, JET SKI REC VEHICLE	50 CAL	0.03	4	0.12
WEAPONS SYSTEMS				85.86
	COMBAT SYSTEMS PAYLOAD			
	AN/SYQ-17 RAIDS	1.14	1	1.15
	AN/SLY-2V	2.00	1	2.00
	Tacan	0.23	1	0.23
	UHF/SHF/EHF/VHF Communications	0.16	2	0.33
	Communications Antenna	0.28	2	0.57
	Inmarsat	0.25	1	0.25
	IFF	0.17	1	0.17
	Air Search Radar	7.81	1	7.81
	Surface Search Radar	0.05	1	0.05
	Helo Auxilliaries	5.00	1	5.00
	Helo Fuel	30.00	1	30.00
COMBAT SYSTEMS				47.55
TOTAL CORE WEIGHT				133.41

Table 2. Estimated Core Vessel Payload Weight

	UNDERWATER WARFARE VARIANT			
SUBMARINE	VLS MK15 CANISTER W ASROC	1.46	4	5.84
	DEPTH CHARGE	0.02	1	0.02
	SH-60F (Full load out)	10.66	1	10.66
	LFATS (Towed Sonar)	3.30	1	3.30
UUV	UUV	0.05	2	0.09
	UUV handling equipment & Fuel	5.00	1	5.00
Navigation Hazard	Sensitive Navigation Radar	1.00	1	1.00
ASW Package Weight				25.91
VARIANT WEIGHT				159.32
	MINE WARFARE VARIANT			
	ASLS (Side looking mine detecting sonar)	0.59	1	0.59
	MH-60R (Full load out)	10.66	1	10.66
	LMRS UUV	0.05	2	0.09
	LMRS Handling equipment	5.00	1	5.00
Navigation Hazard	Sensitive Navigation Radar	1.00	1	1.00
MIW Package Weight				17.34
VARIANT WEIGHT				150.75
	SURFACE /BEACH HEAD/EW VARIANT			
	SH-60F (Full loadout)	10.66	1	10.66
Surface ship	Hellfire Missile	0.05	4	0.20
	Harpoon missile	0.69	8	5.52

	Harpoon Launcher	4.02	2	8.04
	Harpoon Console	1.10	1	1.10
EW Attack	SLQ-32	1.18	2	2.36
Intel	Intellligence/Cryptology Suite	5.00	1	5.00
NGFS	57 mm rounds	0.01	2000	12.20
SUW Package Weight				45.08
VARIANT WEIGHT				178.50

Table 3. Estimated Mission Package Payload Weights

The initial analysis showed that the largest variant weight was the surface variant at 45 LT, with the 17 LT for the MIW and USW 26 LT. It was quickly recognized that there needed to be a change in the mission packages. The surface warfare variant was the easiest to overload with all other systems that did not specifically fit into a warfare area such as CBR, the multi-search radar etc.

Since it was found through this initial analysis that a helicopter was required for all three of the variants, it was moved into the core vessel. Also the core vessel came to incorporate SUW in replace of Air Warfare. Air Warfare became a separate mission package. Due to their similarities and smaller payload requirements, Mine Warfare and Under Sea Warfare were also combined as the second mission package. Therefore it was determined that a three ship variant concept would be too extraneous. Combining USW and MIW into one mission package, a single ship or a two ship variant would be best suited for the LCS design.

C. SINGLE SHIP VS TWO-SHIP DESIGN

Based on the information presented in the needs analysis study, it was determined that a two-ship and three-ship variant is capable of satisfying all the requirements. However, due to the estimated cargo payloads of the two-ship and three-ship variant study were able to combine the variants into a single ship and two-ship variant, respectively. The factors considered to determine which design variant was the most effective for defending the Sea Base were operational flexibility, operational capability, operational availability, cost, space availability, and acquisition. These factors were weighted based on the team's opinion of the areas which are the most important for fulfilling our requirements. Operational flexibility, capability and availability were all weighted 20%, cost and space availability were weighted 15%, and a 10% weighting for acquisition. These factors are defined in detail below. The single and two-ship design were then rated either a five for the best or one for the least effective in the respective factor. The product of the priority weight and rate were summed to get a total score. The design with the highest score was taken as the most effective design that will enable the requirements for a Sea Base defense platform to be met.

1. OPERATIONAL FLEXIBILITY

Operational Flexibility was defined as the ability of the LCS design to defend the Sea Base against an asymmetric threat. The single ship variant has the capability to defend against any contact that poses to be a threat against the Sea Base. However, if the intelligence reports that there is not a specific threat in a given operating area, then the warfare sensors and weapons are not being fully utilized on the LCS ship. For the two-ship design, the modularity of the ship allows the ability to tailor the ship for the operating area and to maximize usage of the entire payload it carries onboard. If there is not an air threat, but a significant submarine or mine threat exists then both ships may be tailored to carry the USW/MIW module. If an air threat is later determined to exist by the intelligence community, then one of the two ships may return to the Sea Base to install the AAW modules. This flexibility will maximize the capabilities of the United States Navy and allow for dominance in the operating area of interest.

2. OPERATIONAL CAPABILITY

Operational Capability was defined as the ability of the LCS design to fulfill the operational requirements outlined in the previous chapter. The single ship variant has an advantage over the two-ship variant because it does contain all sensors, weapons and support required by all three warfare areas. The two-ship variant is only able to conduct operations in two of the three warfare areas depending on the modular configuration.

3. OPERATIONAL AVAILABILITY

Operational Availability was defined as the ability of the LCS design to fulfill the operational requirements based on the degradation or loss of an LCS in defense of the Sea Base. The single ship variant is at a disadvantage because if a single ship is rendered out of commission then the ability to conduct defensive operations in all warfare areas for the Sea Base has been degraded. Whereas the two-ship variant, both ships have the capability to conduct surface warfare operations and only one-third of the warfare areas will have been degraded from the Sea Base defense. With the two-ship variant, the defense of the Sea Base does not lie directly on the shoulders of a single platform.

4. COST

Cost was defined as the estimated cost to build the LCS. The estimated cost was based on the cost of the hull plus one-half the hull cost for the combat systems required in order to fulfill the operational requirements. The cost of building and equipping two ships is inherently higher when the size of the two-ship variant differs little from the single ship variant. As shown in Table 4 below, the two-ship variant is almost twice as expensive as the single ship variant. This does make the single ship variant financially more attractive.

Characteristics	Single Ship (SUW, USW/MIW, AW)	Two Ship (SUW, USW/MIW & SUW, AW)
Length	258 ft	249 ft
Beam	52 ft	50 ft
Draft	19.2 ft	18.5 ft
Power	39500 hp	36800 hp
Displacement	1626 LT	1454 LT
Est. Cost of Hull	$450 M	$425 M
Est. Cost of Combat Systems	$225 M	$212.5 M
Total Est. Acquisition Cost	**$675 M**	$637.5 M * 2 = **$1272 M**

Table 4. Total Estimated Acquisition Cost for Single and Two- Ship Variant

5. SPACE AVAILABILITY

Space availability was defined as the ability for the LCS-design to allow for maximized use of space to house all required assets to meet the operational requirements. This space is not only applied to topside main deck space, but also internal and external superstructure and below deck space that can give the ship and watchstander more freedom to conduct operations against the opposing threats. For the single ship variant, a ship roughly of the same size of the two-ship variant as shown above in Table 4, will have a layout that combines the weapons systems of all three warfare areas. Whereas, the layout of the two-ship variant has more space to better equip, monitor, and support only two warfare areas.

6. ACQUISITION

Acquisition was defined as the ability for the LCS-design to be manufactured in the current United States shipyards, the ability for the LCS to transit the Panama Canal, Suez Canal and enter all United States port facilities. Based on the information above in Table 4, it was determined that either the single ship or two-ship variant may meet all the requirements for acquisition and may dock in all port facilities and transit routes which are currently utilized by the United States Navy.

7. RESULTS

Based on the above priorities and their associated weighted value, the single ship and two-ship were ranked by the members of the TSSE team. The concepts were given a score of five or one with five being the best for each priority. The product of each priority weight and score were summed to a total score. The outcome determined that the two-ship design was the best system to satisfy the requirements based on the information and factors considered for defense of the Sea Base. Table 5, Table 6 and Figure 4 show the results of the feasibility study.

Priority	Single Ship Design Votes Received	Two-Ship Design Votes Received
Operational Flexibility	0	8
Operational Capability	6	2
Operational Availability	2	6
Cost	8	0
Space Availability	1	7
Acquisition	4	4

Table 5. TSSE Team Votes for Single and Two-Ship LCS Design

Priority	Single Ship Design	Two Ship Design
Operational Flexibility	.2	1
Operational Capability	1	.2
Operational Availability	.2	1
Cost	.75	.15
Space Availability	.15	.75
Acquisition	.5	.5
Total	2.8	3.6

Table 6. Feasibility Study Results for Single and Two-Ship LCS Design

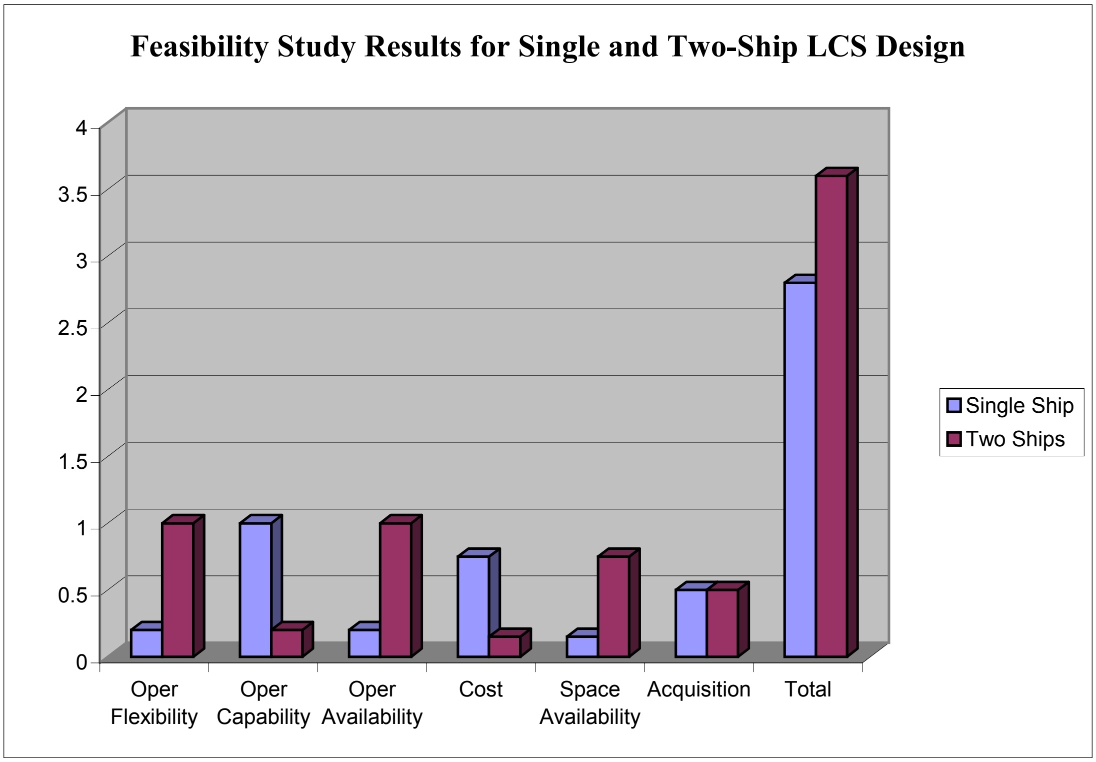

Figure 4. Feasibility Results for Single and Two-Ship LCS Design

D. COMBAT SYSTEM TRADE-OFF ANALYSIS

The focus of the TSSE design team was to design the Combat System Suite prior to any other component of the ship. This would allow the LCS to have maximized combat system capabilities to effectively defend the Sea Base. This is contrary to some designs where the hull is designed first and the combat systems are fit onto the ship. This type of design philosophy degrades the quality of the combat systems on board and can cause possible degradation of the system because systems overlap and blind each other. The two-ship design allows for each ship to contain a common warfare mission area while dividing the other two between them. The team concluded the surface warfare (SUW) mission was an essential mission to combat in order to defend the Sea Base. The presence of small craft exists in almost every operating area, whether they are fishing craft, recreational vessels or vessels of unknown purpose. Therefore the SUW mission will be the common warfare mission to each platform. The other warfare areas will be combined into their respective modular mission package and placed on their respective ships. The two mission packages are the air warfare mission package and the undersea-mine warfare mission package.

1. CORE / SURFACE WARFARE (SUW)

The core package includes the basic capabilities required as a ship and the features and services common to other packages, for example the self-defense equipment and the surface warfare equipment.

The basic package provides the necessary systems in order to perform the basic missions of a ship. The basic package includes navigation radar, log, fathometer, bottom mapping hull mounted sonar, inertial navigation system, satellite navigation system, and communications equipment and other systems.

The main basic system is the combat and control system, which is capable of performing all the missions depending on the corresponding weapon system plugged into it.

In the modern battle space, signature management is a crucial factor to hide or modify the ship’s signatures, including visual, radar, IR and magnetic. Also, signature management reduces the electronic defense and electronic attack signal ratios.

The Chemical, Biological, and Radiological (CBR) sensors and alarms system are also part of the core package.

The self-defense package consists of defense from the threats analyzed in the threat analysis, consisting of anti-ship cruise missiles, torpedoes and unguided munitions.

The self-defense package includes a surface and air radar, EO/IR sensors, electronic support, electronic attack, electronic defense, torpedo warning sonar, obstacle-diver avoidance sonar, high fire rate gun (e.g. Mk 3 BOFORS 57 mm), self defense missile (e.g. SEA RAM). The combination was chosen in order to maximize the probability of kill in the following scenarios:

1. Submarine Launched ASCM during Near Shore Mine Clearing Operations.
2. Four Air Launched slow low flying ASCMs.
3. Single LCS Engaged by Two Attack Helicopters.
4. LCS Engaged by airplane Carrying high speed ASCM.
5. Single LCS Engaged by Aircraft Carrying high diver ASCM.

The probability of raid annihilation obtained is about 0.95. The method of conducting the weapon systems analysis and the output from the raid annihilation simulations are summarized in Appendix H.

The embarked aircraft are also part of the self-defense equipment used for search, reconnaissance and surveillance, and electronic support and electronic defense.

The surface package complements the basic core package. In order to combat with the small, high-speed surface threat the weapons choice is a high rate fire gun (e.g. Mk 3 BOFORS 57 mm) and a small/ medium surface missile (e.g. AGM-119b Anti-Ship Missile). The self-defense missile secondary mode can be used to engage surface targets at reduced distance. The trade-off analysis for the selection for the ship’s gun is listed in Figure 5 and Table 7. The trade-off analysis for the selection of the self-defense system is listed in Figure 6 and Table 8.

Aircraft are also part of the surface package, used in search, reconnaissance and surveillance, electronic support and electronic defense, targeting, damage assessment and weapons delivering. The clear advantages of using helicopters or UAV include speed, extended visual range and better sensor performance.

Gun Trade-off Analysis				
Gun	Firing Rate	Weight	Range	
76mm	1	5	3	
57mm	5	3	1	
5in	3	1	5	
Weighting Factor	0.5	0.25	0.1	
76mm	0.5	1.25	0.3	2.05
57mm	2.5	0.75	0.1	3.35
5in	1.5	0.25	0.5	2.25

Table 7. Gun Trade-off Analysis

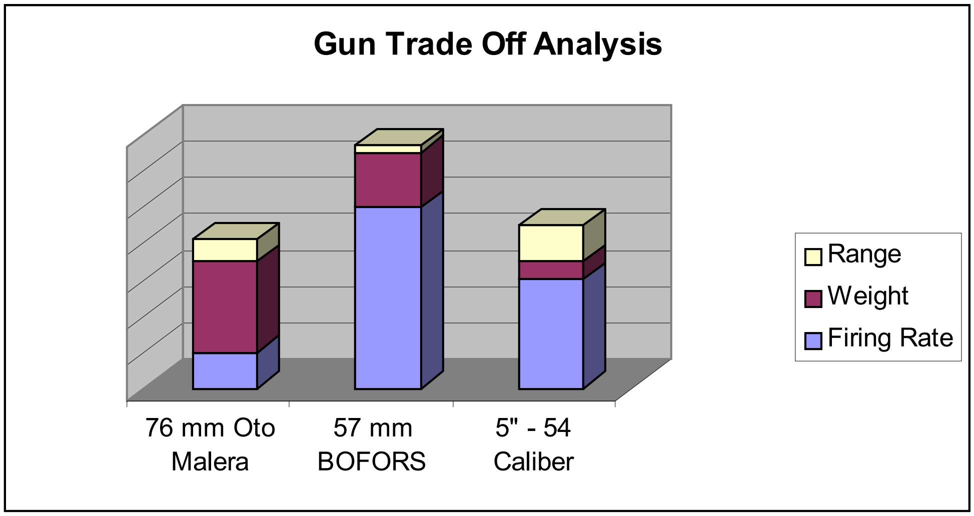

Figure 5. Gun Trade-off Analysis

Self Defense Weapon System Trade-off Analysis		
System	Range	Weight
Phalanx	1	1
SEA RAM	5	5
Weighting Factor	0.75	0.25
Phalanx	0.75	0.25
SEA RAM	3.75	1.25

Table 8. Self Defense Weapon System Trade-off Analysis

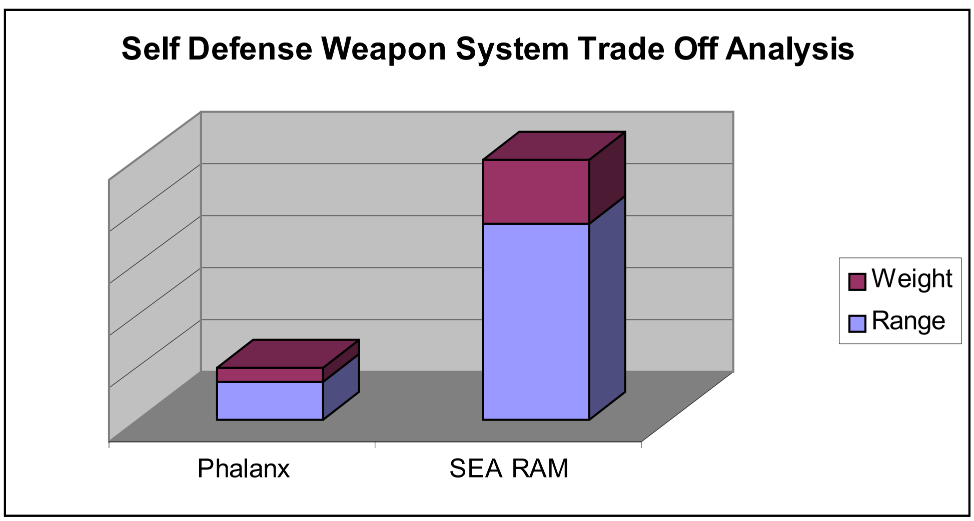

Figure 6. Self Defense Weapon System Trade-off Analysis

2. AIR WARFARE (AW) MISSION PACKAGE

The design process for the anti-air warfare package began with a review of the threats involved and the ship's mission to protect the Sea Base, small boats and aircraft as they transit to and from the beach. The threats considered were primarily missiles and manned/unmanned aircraft.

Next, the weapon systems selection was considered to fulfill the ship's mission and combat potential threats. To ensure full air coverage by the systems selected, the airspace around the ship was divided into three zones: Missile Engagement Zone (MEZ), Close-in Weapons Engagement Zone (CEZ) and Surveillance Zone (SZ). After the theater engagement zones were determined, weapons systems were assigned to each of the engagement zones. The following system requirements were determined necessary for the respective zones:

- MEZ: an effective weapon for soft kill similar to the SM-2 and Evolved Sea Sparrow.
- CEZ: a 57 mm gun with capabilities similar to CIWS or Goalkeeper. SEA RAM and SRBOC chaff were also deemed necessary in order to satisfy the ranges necessary to effectively engage expected air targets and maximizing the probability of kill as well as adding to the ship's self protection capability.
- SZ: a sensor providing the maximum range possible.

After completion of a full list of weapons, the following primary ship constraints were considered: range of 2500 nm, payload weight of 200 tons and speed of 35 kts. The limiting factor was the payload weight restriction of 200 tons and therefore became the primary concern in the final selection process of the weapons systems for the anti-air warfare package. In order to reduce weight and save volume, it was decided that the weapons and sensors systems selected needed to provide not only protection to the Sea Base, but also an offensive capability to combat the threats inland as well.

The combat effectiveness of the weapon and sensor systems working in conjunction with future package designs was considered, with particular interest paid to developments such as multi-functional radar, the Evolved Sea Sparrow Missile (ESSM), and the MK 3 BOFORS 57 mm gun. Multi-Functional Radar (MFR) was selected over the 3-D radar in lieu of its versatility and compatibility with other warfare packages. Because the MFR is in the early stages of development, the system characteristics and capabilities conform to the characteristics of the Dutch APAR radar system. The MK 3 BOFORS 57 mm gun was selected because of its low weight, small volume, and high firing rate. Although the ESSM was selected, a discussion still exists on the launcher. For versatility of a variety of missiles launched, a vertical launch system is desired. However, for weight and volume considerations a more detailed analysis was conducted to determine the size of the launch system utilizing decision matrices and probability of kill (P_k) calculations based upon the same scenarios listed in the above section. The trade-off analysis for the selection of the ship's surface missile is listed in Figure 7 and Table 9. Additional information on systems for the basic core, SUW and AW mission packages can be found in Appendix C.

Surface Missile Trade-off Analysis						
Missile	Quantity	Size	Range	Cost	Maneuverability	Close Proximity Range
ESSM	5	5	1	5	5	5
SM 2	1	1	5	1	1	1
Weighting Factor	0.1	0.05	0.15	0.2	0.2	0.3
	Quantity	Size	Range	Cost	Maneuverability	Close Proximity
ESSM	0.5	0.25	0.15	1	1	1.5
SM 2	0.1	0.05	0.75	0.2	0.2	0.3

Table 9. Surface Missile Trade-off Analysis

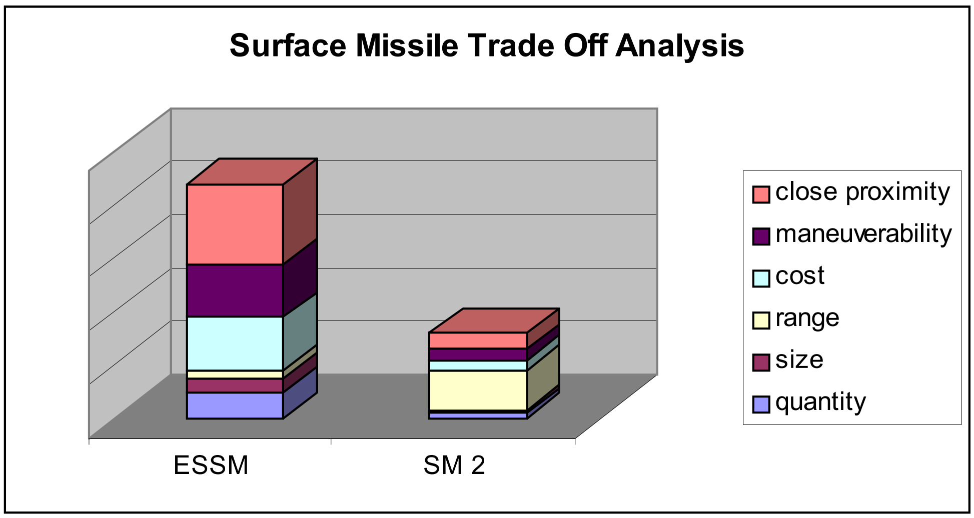

Figure 7. Surface Missile Trade-off Analysis

3. UNDERSEA WARFARE (USW) / MINE WARFARE (MIW) MISSION PACKAGE

The approach to conducting the trade-off analysis for the USW/MIW mission package was combining own ship assets with controlled assets in order to provide the best Sea Base defense against the potential threats determined during the threat analysis.

The trade-off analysis was conducted by combining the collective experience of the group with additional research of current and future systems relating to the USW/MIW mission. Then several systems were researched and evaluated against each potential threat. Also considered in the trade-off analysis were the weight, dimensions, capability, cost and ability to be modularized.

The systems evaluated in support of the USW mission were torpedoes, torpedo launchers, towed array sonar system, helicopters, torpedo countermeasures, and depth charges.

The MK 50 torpedo and MK 32 Mod 15 launcher was selected due to superior capabilities. The launcher is capable of being installed on the weather deck making modularity more feasible. The overall performance of the MK 50 when compared against the other variants outweighs the MK 50 torpedo's additional size and weight. The MK 54 Light Hybrid Torpedo (LHT) that combines MK 50 search and homing with a MK 46 propulsion system, in the name of cost-effectiveness will still be handicapped by shortfalls in some characteristics. For this reason, the Navy's current plan to develop the LHT as a relatively cheap substitute for a MK 50 may not yield an operationally effective weapon in a war-fighting scenario without significant improvements in target locating ability and weapons placement accuracy. The trade-off analysis for the selection of the torpedo launcher is shown in Table 10 and Figure 8. The trade-off analysis for the selection of the ship's torpedo is shown in Table 11 and Figure 9.

The Low Frequency Towed Array Sonar (LFATS) was selected due to high performance to weight ratio. The LFATS is a low frequency sonar system used on ASW surface ships to detect, localize and prosecute a number of quiet, diesel/electric submarines. The LFATS system is designed for high performance at a low operating frequency and easy installation, removal and handling from ships of modest size, including frigates, corvettes and even small patrol craft. For torpedo counter measures, the NIXIE was evaluated as the best torpedo countermeasure system available and also selected were the BDC-204 depth charges due to their ease of operation and low weight. The trade-off analysis for the selection of the ship's towed array sonar is shown in Table 12 and Figure 10.

Initially individual MIW systems were evaluated, however, in depth research lead to the organic MIW concept. Combined in this concept are own ship and controlled assets. The airborne systems in this concept include Airborne Laser Mine Detection System (ALMDS), AN/AQS-20/X Towed Array Sonar, Organic Airborne and Surface Influence Sweep (OASIS), Airborne Mine Neutralization System (AMNS), and Rapid Airborne Mine Clearance System (RAMICS). The airborne systems require a minimum of three helicopters or UAV's. Following the trade-off analysis, the USW/MIW mission package weight totaled to an estimated payload of 37.28 MT not including the required helicopters or UAV's. The shipboard systems in the concept include the Advanced Side Looking Sonar (ASLS), Expendable Mine Destructor (EMD) and Mine-Hunting UUVs. The trade-off analysis for the selection of the air asset for the organic MIW concept is shown in Table 13 and Figure 11. Additional information on systems for the basic core, SUW and AW mission packages can be found in Appendix D.

Torpedo Launching System Trade-off Analysis		
	Weight	# of Torpedoes
Mk 32 Mod 15	5	5
Mk 32 Mod 9	1	1
Weighting Factor	0.4	0.6
	Weight	# of Torpedoes
Mk 32 Mod 15	2	3
Mk 32 Mod 9	0.4	0.6

Table 10. Torpedo Launching System Trade-off Analysis

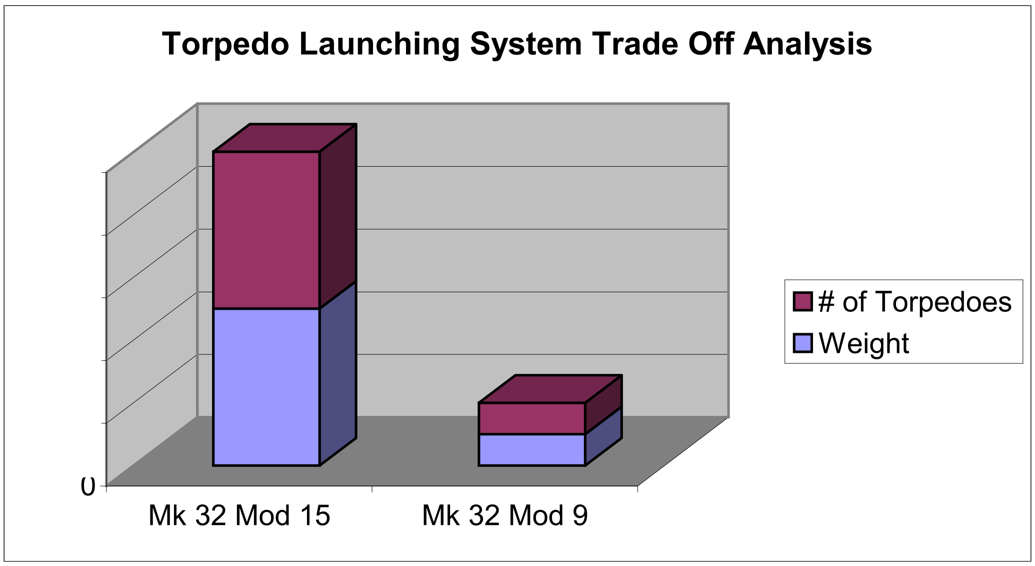

Figure 8. Torpedo Launching System Trade-off Analysis

Torpedo Trade-off Analysis				
Torpedo	Size	Range	Cost	Targeting Capability
MK 46	5	1	5	1
MK 50	1	5	1	5
MK 54	3	3	3	3
Weighting Factor	0.1	0.5	0.2	0.3
Torpedo	Size	Range	Cost	Targeting Capability
MK 46	0.5	0.5	1	0.3
MK 50	0.1	2.5	0.2	1.5
MK 54	0.3	1.5	0.6	0.9

Table 11. Torpedo Trade-off Analysis

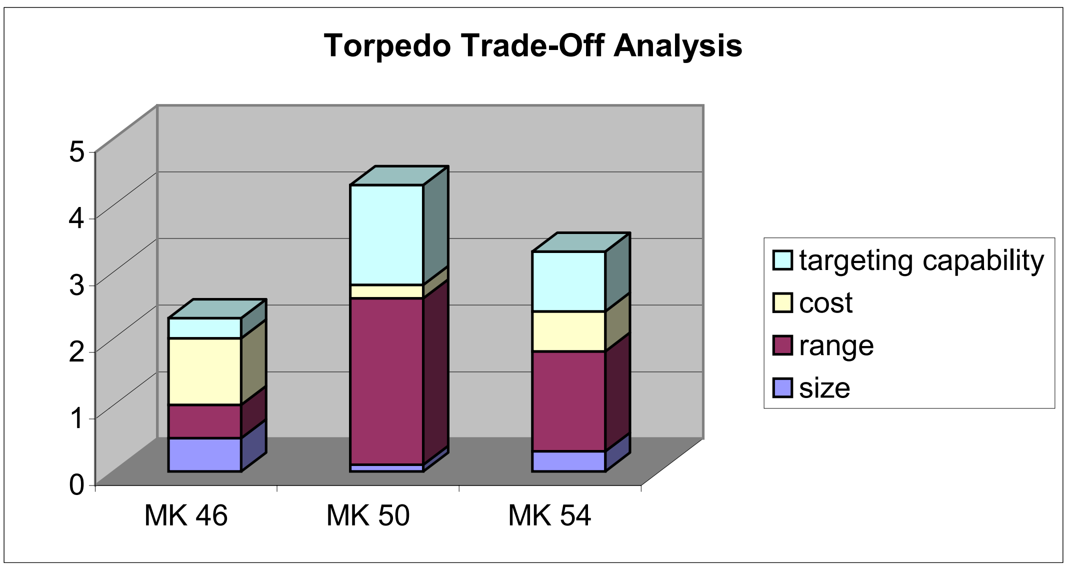

Figure 9. Torpedo Trade-off Analysis

Towed Array Sonar Trade-off Analysis				
	Weight	Volume	Operational Speed	Performance
AN/SQR 19	1	1	5	5
LFATS	5	5	5	5
Weighting Factor	0.2	0.2	0.3	0.3
	Weight	Volume	Operational Speed	Performance
AN/SQR 19	0.2	0.2	1.5	1.5
LFATS	1	1	1.5	1.5

Table 12. Towed Array Sonar Trade-off Analysis

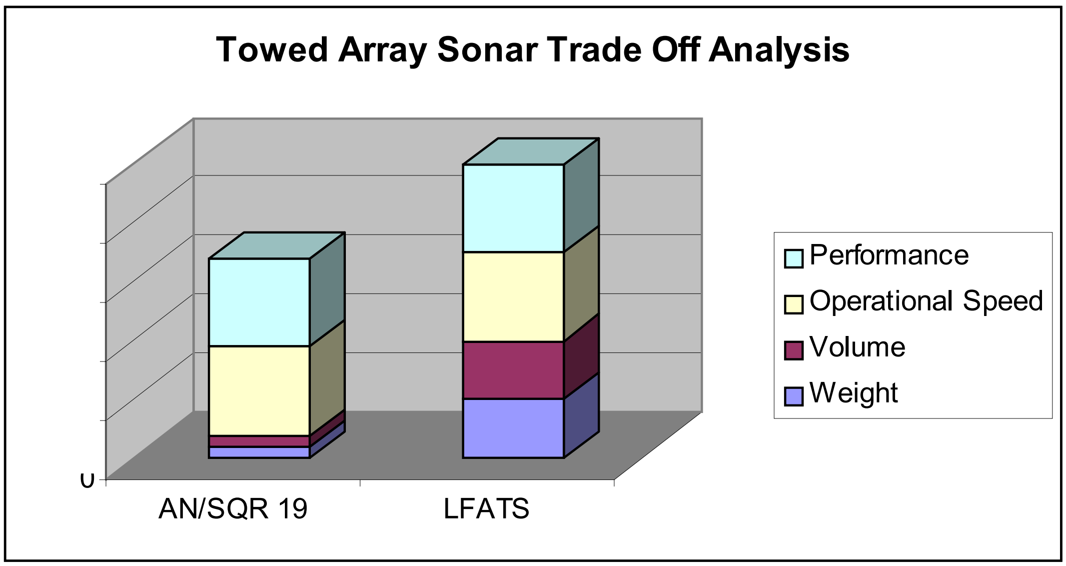

Figure 10. Towed Array Sonar Trade-off Analysis

MIW Airborne Assets Trade-off Analysis					
Airborne Asset	manning	range	payload	speed	weight
LAMPS III	1	1	2	1	1
VTOL HV-911 (UAV)	2	2	1	1	2
Weighting Factor	0.1	0.05	0.75	0.05	0.05
	manning	range	payload	speed	weight
LAMPS III	0.1	0.05	1.5	0.05	0.05
VTOL HV-911 (UAV)	0.2	0.1	0.75	0.05	0.1

Table 13. MIW Airborne Asset Trade-off Analysis

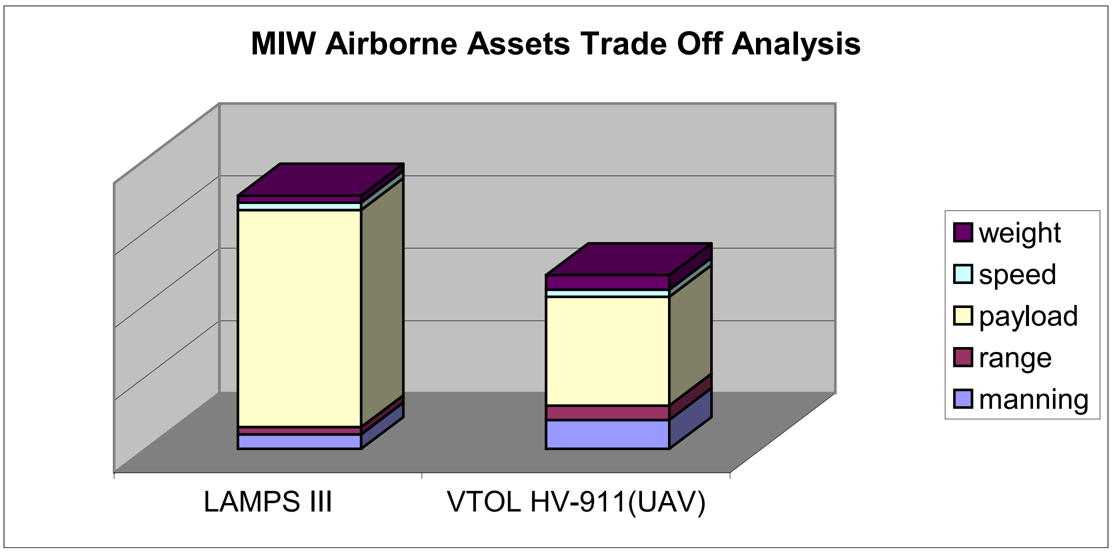

Figure 11. MIW Airborne Assets Trade-off Analysis

E. HULL DESIGN ANALYSIS

There are a variety of hull forms that are capable of fulfilling the requirements to defend the Sea Base. The team was divided into four groups and each group selected a hull form and conducted analyses. The results of the analyses allowed the group to determine the characteristics of the ship based on the desired speed, range and payload weights which were determined in the Combat Systems needs and trade-off analyses.

The Hull Design Analysis was conducted using the Maritime Applied Physics Corporation's spreadsheet tool. [Ref. 1] This spreadsheet tool, commonly known as MAPC, uses parametric models and scaling to create high level designs of various hull types. The inputs are desired speed, range, payload, sea state and maximum displacement; speed, range and payload are given priorities. A sample interface is presented in Figure 16.

MAPC uses a primary basis vessel for each hull type to provide the block coefficient and the ratios of length to beam and beam to draft. Additional basis vessels are used to derive resistance and powering data. Historical parametric data is used to determine speed loss in waves and weight fractions.

First, the team added the capability to perform calculations for a traditional monohull vessel. This was done to ensure that a full range of hull types would be represented in the comparison.

The specific inputs for the team's analysis were 200 LT payload, 2500 NM range, and 35 knots.

1. MONOHULL

When considering the monohull design the first area of interest was the history of the hull form. The monohull has been the accepted hull form for centuries and therefore, a large amount of research data have been collected and the hull perfected and understood in great detail. A new hull type will require more research and development thus increasing its acquisition costs over that of the accepted monohull. Monohull acquisition costs are also lower than other hull types because of the singularity of machinery systems and volume allotted for the installation, multi-hull forms have more cramped spaces, which would increase building costs.

Since monohull design has all the available volume in a single hull, there exists flexibility in the layout of the machinery and living spaces. Flexibility also exists in the choice of propulsion machinery, because of the single hull either a single or multiple propulsion units can be used. The single propulsion unit offers the advantage of less volume, less displacement, lower maintenance costs and acquisition costs.

The monohull design in comparison to multi-hull forms has a relatively narrow beam, large waterplane area and deeper draft. The narrow beam allows for more access to ports and maintenance facilities. However, the monohull design’s deeper draft is a disadvantage for the ship’s mission, operating in littoral waters. The large waterplane area is advantageous in the consideration of weight growth, i.e. the deepening of the draft with additional payload, but is disadvantageous in the area of sea keeping. Hull form research can be simplified to the fact that a vessel will react to dynamic input of swells or waves proportional to the waterplane, i.e. increased area results in increased ship motions. This disadvantage can be amplified by the fact that a warship must have good seakeeping not only for its crew but also for the weapon and sensor systems onboard.

The seakeeping of the monohull can be improved by passive and active systems. Active systems, which include fin stabilizers, can add weight and complexity to the ship also active systems for effective at speed but effectiveness is greatly reduced as speed is reduced. Although the speed of the ship is sustained speed of 35 knots, it is expected that the ship will spend a large portion of the operating time at lower speeds. Passive systems are very simple but on average less effective, include bilge keels and a deep centerline keel. Bilge keels are effective at all speeds, but can create drag, increase roll period while reducing roll amplitude. A deep centerline keel is inexpensive but less effective than a bilge keel, increases draft, enhances course keeping but reduces maneuverability.

Another consideration was the power requirements for increased speed. As the speed increased the power increased greatly, almost tripling from 35 knots to 45 knots. Outputs from the MAPC spreadsheet for the monohull speeds, ranging from 35 to 45 knots, can be found in Appendix E.1.

2. TRIMARAN

Initial requirements for the preliminary hull design were determined based on the threat analysis. One of the candidate hull concepts was a trimaran hull form. The initial constraints were the payload, deck area, and range and speed requirements. The outputs were evaluated for a broad range of speed (35-45 knots). The results of the calculations are tabulated in Appendix C. The following conclusions were drawn depending on the results of the mentioned comparison tool and some research papers about trimaran hull form.

Figure 12. RV Triton Trimaran Hull Design (taken from QinetiQ website)

Many research papers were found that investigated the benefits of large multi-hull configurations for future cargo ships. Most of this research involved tri-hull designs, leading to a focus primarily on the tri-hull concept for the Sea Force ship. There are also several large trimaran designs being investigated, again for future container ships, which claim both high speed and high hull efficiency.

Tri-hull designs have many advantageous characteristics, which may be summarized in four ship design principles: Resistance, Propulsion and Seakeeping, Stability and Maneuverability, Deck Area/Growth Margin, and Signature Reduction.

The trimaran hull design has a twenty percent reduction in hull resistance at high speeds due to the narrow, slender main hull. This reduction in hull resistance will result in less power, weight and fuel consumption and will allow for a wide range of propulsion options. The additional side hulls will improve seakeeping performance at higher speeds and will allow the hull to operate in higher sea states compared to the other hull forms.

The trimaran hull design has a greater stability, allowing heavy equipment, such as a large aerial detection radar system to be installed. With the propulsors fitted on all three hulls, the trimaran is a highly maneuverable vessel and proper side hull placement will allow helicopters to operate under a wide range of sea conditions.

Another advantage of the trimaran hull is the increased deck area; up to 40% more deck space for a given tonnage, offering more space for hangars, helicopter operation and weapons. Some of the greatest advantages for the trimaran come from the improved effectiveness of the whole ship design enabled by this very large deck area. With the significant additional stability, the growth margins are greatly benefited and equipment upgrades during the life of the ship will be easily accommodated.

The signature reduction of the trimaran has increased potential for reductions in radar cross-section and infrared signatures. A reduction in heat signature could be gained by exhausting stack gasses between the side hulls rather than the conventional main structure funneling.

The side hulls of a trimaran provide greater stability, which offers growth potential for ship systems and the ability to mount sensors higher above the water line to improve early-warning missile-defense capabilities. The higher mounted equipment reduces the effect of shock levels, which are one of the main causes of equipment failures. The side hulls can also be utilized for configuring a multi-line towed array sonar system. Outputs from the MAPC spreadsheet for the trimaran hull speeds, ranging from 35 to 45 knots, can be found in Appendix E.2.

In 2000, the HMS TRITON was constructed, the largest tri-hulled ship ever built, Figure 12. With a displacement of approximately 2000 LT, it has undergone testing in the British Navy, and has demonstrated many of the benefits that a tri-hull design has to offer.

3. CATAMARAN

The catamaran's performance, relative to the monohull, trimaran, and SES versions, varied with increasing speed.

At 35 knots, the catamaran hull had the second best characteristics in the categories of length, beam, draft, lift to drag and the third best in the categories of fuel, power, and calm water speed. It also had the fourth best displacement.

At 40 knots, the catamaran, when compared to the other three hull forms, improved in displacement (fourth to third) and power (third to first).

At 45 knots, the catamaran performance improved from third to second in displacement and remained steady in the other areas.

The performance of the catamaran displays an upward trend with increasing speed requirements when compared to the other hull forms. The trimaran performed the best over the entire range. Outputs from the MAPC spreadsheet for the catamaran hull speeds, ranging from 35 to 45 knots, can be found in Appendix E.3.

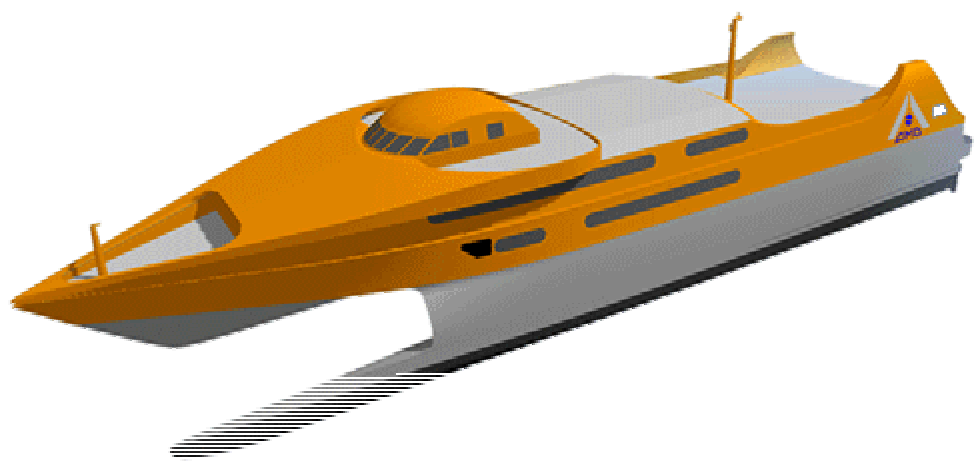

Figure 13. Catamaran (taken from Advance Multihull Designs website)

4. SURFACE EFFECT SHIP (SES)

The Surface Effects Ship (SES) design, first conceived as a naval combatant in the 1970's is to some degree a take off of the basic catamaran shaped hull form that has an air cushion system that closes off the bow and stern, but much thinner side hulls. The lift is generated from air that is forced down into the cavity created by the two thin side hulls and skirts at the bow and stern area. Minimizing the wetted surface area greatly reduces the resistance of the hull. When compared to a typical monohull, the same payload can be carried at a much-reduced displacement.

Though not widely used in a military role, the SES, generally employed as car/passenger ferries overseas, has come into its own with the new emphasis on countering the terrorist threat and defending surface combatant forces from close-in attack. Most recently, a Raytheon-led team (that includes the naval design firm of J.J. McMullen & Assoc., Atlantic Marine, Goodrich and Umoe Mandal) has proposed a SES vessel design based on the Norwegian Skjold, a 154-foot composite ship, as its preliminary bid for the LCS design contract.

Figure 14. SES Craft. (taken from Goodrich Corporation EPP)

SES vessels are typically powered by gas turbine engines and use waterjet propulsion to obtain speeds in excess of 50 knots. However, sustained operations at high speeds limit the range of SES vessels due to the hefty specific fuel consumption because the lift fans must carry the weight of the fuel in addition to the payload. Thus additional fuel loading to extend range of the vessel becomes a self-defeating process.

In addition to its high speed, the main advantages of the SES were found to be its sharp maneuverability, virtually unrestricted draft of four and a half feet in the foil-borne mode, and expansive deck space available topside. Conversely, the disadvantages include a much increased hull resistance, reduction in maneuverability and sea keeping performance while in the waterborne mode. Other disadvantages include limited range; very loud lift fans, box shape design for large radar cross-section, and decreased loitering capability as it is designed for point-to-point transit. Outputs from the MAPC spreadsheet for the SES hull speeds, ranging from 35 to 45 knots, can be found in Appendix E.4.

5. RESULTS

Each hull variant has their advantages and disadvantages to meet the overall requirements. Analyzing the results from each of these hull-designs, the trimaran displayed the best results especially in deck area and draft that will fulfill the requirements in the most effective manner. The trade-off analysis for the design of the ship's hull is shown in Table 14, Figure 15, and Figure 16

Hull Design Analysis Trade-off Analysis							
Priority*	**Deck Area**	**Maneuverability**	**Draft**	**Length**	**Beam**	**Power**	**Displacement**
Monohull	1	4	1	4	4	1	2
Catamaran	3	2	3	3	2	2	1
Trimaran	**4**	**1**	**4**	**1**	**1**	**4**	**4**
SES	2	3	2	2	1	3	3
All Priorities Equally Weighted							

Table 14. Hull Design Trade-off Analysis

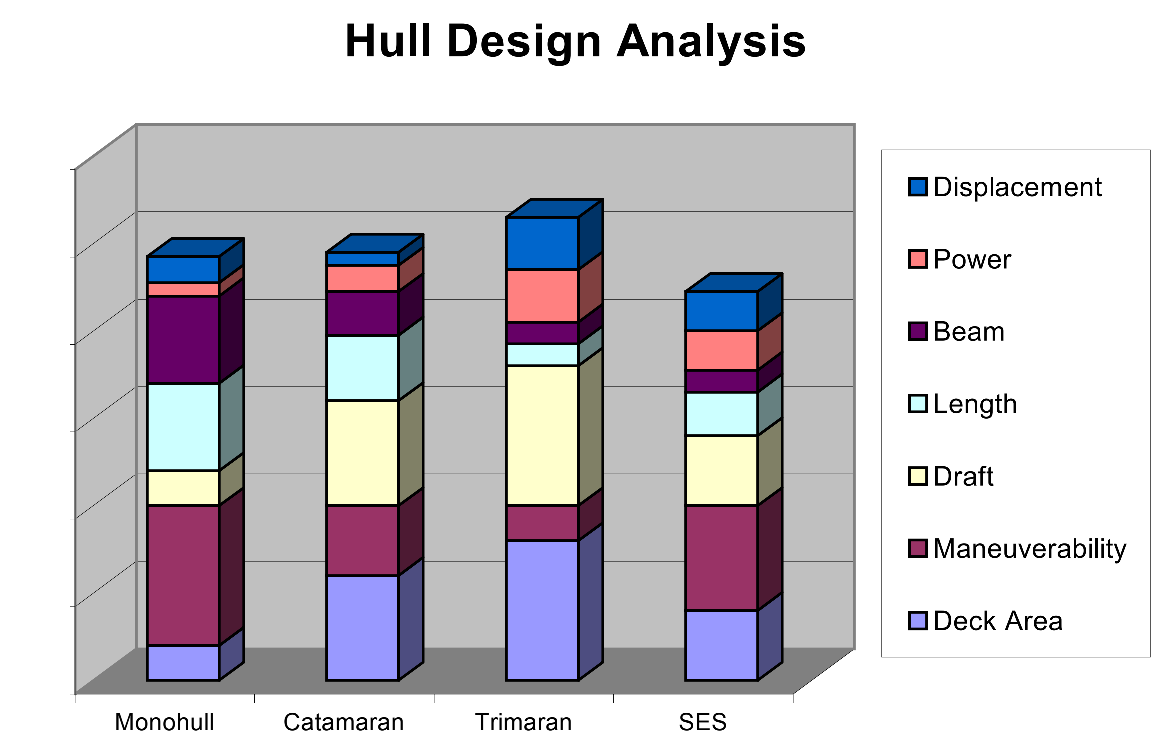

Figure 15. Hull Design Analysis

Maritime Applied Physics Corporation
410-233-4000
Modified at NPS for the TSSE "SEA ARCHER" Project
by LT. A. DALAKOS HN

calculate
view plot
lift to drag
print

Initial Input

Ranking			
1	Desired Speed in Waves	35	knots
2	Desired Payload	200	long tons
3	Desired Range	2,500	nautical miles
	Sea State	3	wave height at top of SS3 = 4.1feet
	Maximum Displacement	2,500	long tons

Results		Hydrofoil	HYSWAS	SES	Semi-Planing Monohull	Catamaran	Trimaran	SWATH
Calm Water Speed [3,12]	knots	35.3	35.2	35.3	35.7	35.4	36.4	35.0
Speed in Waves [1,3,4,8,10,11]	knots	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Payload Weight [2,3,4,8]	long tons	200	200	200	200	200	200	200
Range at Speed in Waves [4,7,8]	nautical miles	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Displacement [3,7]	long tons	1,291	1,114	1,378	1,454	1,567	1,361	2,131
Installed Power [3,8,7]	long tons	27,691	22,640	30,092	36,810	30,543	25,648	43,987
Engines [6]	long tons	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board [3,7,3]	long tons	310	283	330	488	348	299	547
Length	feet	262	194	303	249	274	402	208
Beam	feet	66	56	57	50	88	97	92
Hullborne Draft	feet	36.0	27.1	12.5	18.5	12.5	10.1	19.1
Foilborne / Cushionborne Draft	feet	14.6	14.3	3.5	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$448,200,000	$445,000,000	$449,500,000	$448,600,000	$450,800,000	$449,100,000	$459,300,000
Lift to Drag Ratio		17.3	15.8	15.7	13.0	17.1	18.5	13.7

Figure 16. MAPC Tool Output with Inputs for Hull Design Analysis

F. CONCLUSION

Based on the results of the Analysis of Alternatives, a two-ship, trimaran hull design was determined to be the best suited for defending the Sea Base per the team's assumptions above. The trimaran does have a wide beam due to the side-hulls and can be of great length because of the long slender main hull, but the ability to properly utilize the available space for weapons and sensors make this selection preferable for Sea Base defense.

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V. DESIGN PROCESS

A. DESIGN PHILOSOPHY

A list of priorities shown in Table 15, with a given weighted factor of high, medium, or low, determined the team's design philosophy. These priorities were instrumental when the trade-off analyses were performed. The requirement of SEA SWAT to defend the Sea Base drove the weighting factors of each priority. The team gave high weighting factors to the defensive combat system suite, modularity, speed and an aviation capable ship. In order to successfully defend the Sea Base against an asymmetric threat, it was determined a high speed ship with coordination and control of an aircraft would be able to intercept the threats at further distances from the Sea Base. Modularity played an important role because the ability to tailor the LCS to meet the perceived threat allowed for maximized usage of manpower and ship's payload.

The weighting factors of medium were assigned for the priorities of cost, manning reduction, and maintainability. The cost of the ship is a very important factor, however the team determined the ability to successfully defend the Sea Base to the satisfaction of the given requirements was more important that cost. Cost was never ignored and was considered in most trade-off analyses performed. The team determined that by tailoring the design of the ship to defeat the perceived threat by modularity that the reduction of manning would not only reduce the number of crew, but also would more efficiently utilize their skills and performance.

Low weighting factors were assigned for the offensive combat systems, indefinite sustainment, and the appearance of the ship. The LCS is not a strike platform, that mission will be reserved for the DD(X), CG(X), and other strike capable platforms that exist in the year 2020. Therefore consideration of offensive systems was not given much weight. Because the LCS will be operating in and around the Sea Base, an indefinite sustainment of the LCS will not be necessary as stores and repair parts can easily be transferred by vertical replenishment or underway replenishment. The appearance of the ship will not be weighed heavily in as much as the ability to reduce the radar cross section (RCS) will drive the topside design of the LCS. The radar cross section of the LCS is combined with the defensive combat system priority.

Priority	**Weighting Factor**
Combat System, Defensive	High
Modularity	High
Speed	High
Aviation Capability	High
Cost	Medium
Manning Reduction	Medium
Maintainability	Medium
Combat System Offensive	Low
Indefinite Sustainment	Low
Appearance	Low

Table 15. Design Philosophy Weighing of Priorities

B. DESIGN OBJECTIVES

The design objective was kept simple: design a ship that was capable of high speeds, highly maneuverable and meet all the requirements necessary to conduct Sea Base defense. In order to satisfy these requirements, the combat systems must be designed prior to any other component of the ship.

This will allow for a ship with maximum capabilities in order to provide sufficient Sea Base defense.

C. DESIGN CONSTRAINTS

The design constraints were also simple in nature. SEA SWAT must be able to conduct littoral operations in water depths of ten to forty feet while also being able to conduct deep-water operations. The ship must also be able to conduct transoceanic deployments and must be able to access all US ports of interest.

D. SHIP HULL DESIGN

The selection of the hull form has always been a difficult decision to take for all designers. A single form to compensate for all the various conflicting engineering and operational requirements must be found. The choice of the hull form is strongly influenced by the performance (speed, range, seakeeping, maneuverability, and stability), layout (combat system, helicopter facilities, propulsion plant, habitability) and survivability. Our design objective was kept simple: to design a ship that is capable of high speeds, highly maneuverable and meets all the requirements necessary to conduct Sea Base defense.

There were a variety of hull forms to meet the overall requirements for high-speed vessels for different purposes. We were looking for the most feasible hull form that was capable of fulfilling the requirements to defend the Sea Base. The candidate hull forms were monohull, trimaran, catamaran and SES. The team divided into four groups and each group selected a hull form and conducted the Hull

Design Analysis by using the Maritime Applied Physics Corporation's spreadsheet tool. The specific inputs for the team's analysis were a payload of 200 LT, which was determined in the Combat Systems needs and trade-off analyses, 2500 NM range, and 35 knots. The results of the analyses allowed the group to determine the characteristics of the ship based on the desired speed, range and payload weights. Each hull variant has their advantages and disadvantages to meet the overall requirements. Analyzing the results from each of these hull-designs, the trimaran displayed the best results especially in deck area and draft that will fulfill the requirements in the most effective manner.

Based on the MAPC spreadsheet, the trimaran was determined to be 402 feet in length and approximately 7 feet in width. The draft of the ship was approximately twelve feet. These outputs were used as guidelines for the characteristics of SEA SWAT.

The U.S. Navy's DDG-51 destroyer hull form was chosen for the main hull. This hull form was attractive for a number of reasons. The DDG-51 is a modern destroyer with a high length-to-beam ratio (8:1), fine lines, and an appropriate bow and stern. To take the full advantage of the trimaran configuration the main hull length-to-beam ratio stretched to 13:1 by reducing the main hull length from 466 ft to 400 ft, beam from 59 ft to 30 ft and draft from 24 ft to 12 ft in order to make the ship narrow. The shape of the side hull is assumed to be a mathematical hull form of modified Wigley Hull. The seakeeping and resistance calculations determined the side hull position. There were two locations on the x-axis and three locations on the y-axis that were evaluated to determine the optimized location of the side hulls. The separation between the main hull and the side hulls was chosen to reduce the interference effects. The longitudinal position of the side hulls was chosen to maximize the amount of flexibility mission area in the stern. Also, the side hulls positioned at the stern are expected to reduce overall ship resistance when the ship traveling at speeds greater 26 knots. The length of the side hull was chosen to minimize wetted surface drag while still providing the necessary stability, and to have more operational deck area. The depth of the side hulls was chosen to ensure that the draft of the side hulls was sufficient in all conditions of loading and roll. The general characteristics of SEA SWAT, main hull body plan and the side hull body plan are shown in Table 16, Figure 17, Figure 18, and Figure 19 below.

Characteristic	**Main Hull**	**Side Hull**
Length (L_{BP})	400 ft	125 ft
Beam (B)	30.8 ft	7.5 ft
Total Beam for $Y_{out} / L_{pp} = 0.1$	89.5 ft	
Draft (T)	12 ft	10 ft
L/B	13.0	16.7
$L / \nabla^{1/3}$	9.39	7.54
Block Coefficient (C_B)	0.53	0.50

Midship Coefficient (C_M)	0.84	0.68
Waterplane Coefficient (C_W)	0.81	0.79
Volume	77226 ft^3	4558ft^3
Displacement	2206 LT	130 LT
Total Volume	86343 ft^3	
Total Displacement	2466 LT	

Table 16. SEA SWAT Characteristics

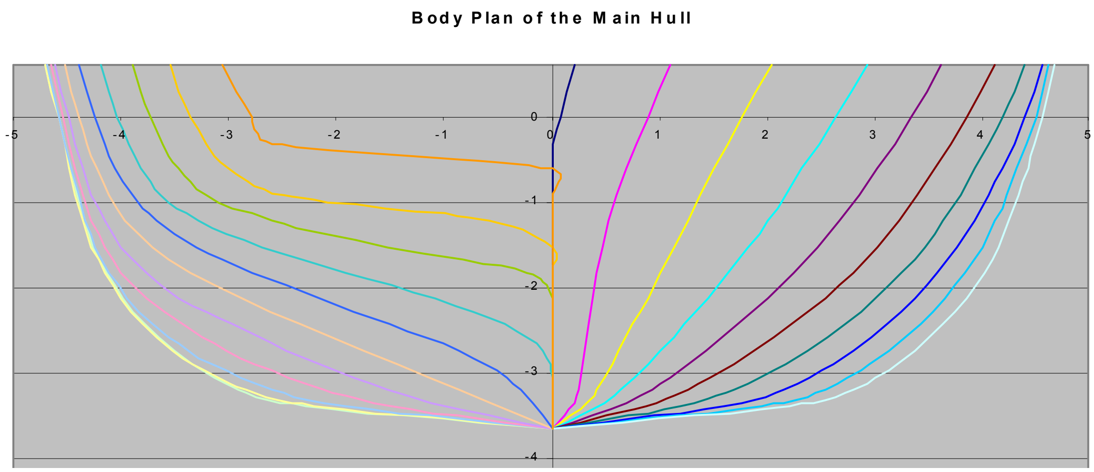


Figure 17. Body Plan of the Main Hull

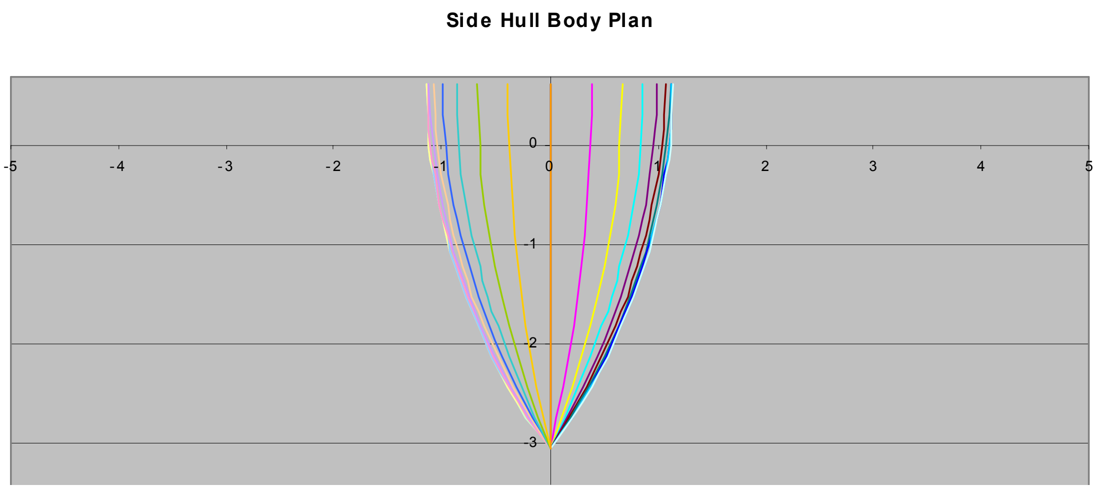


Figure 18. Body Plan of the Side Hull

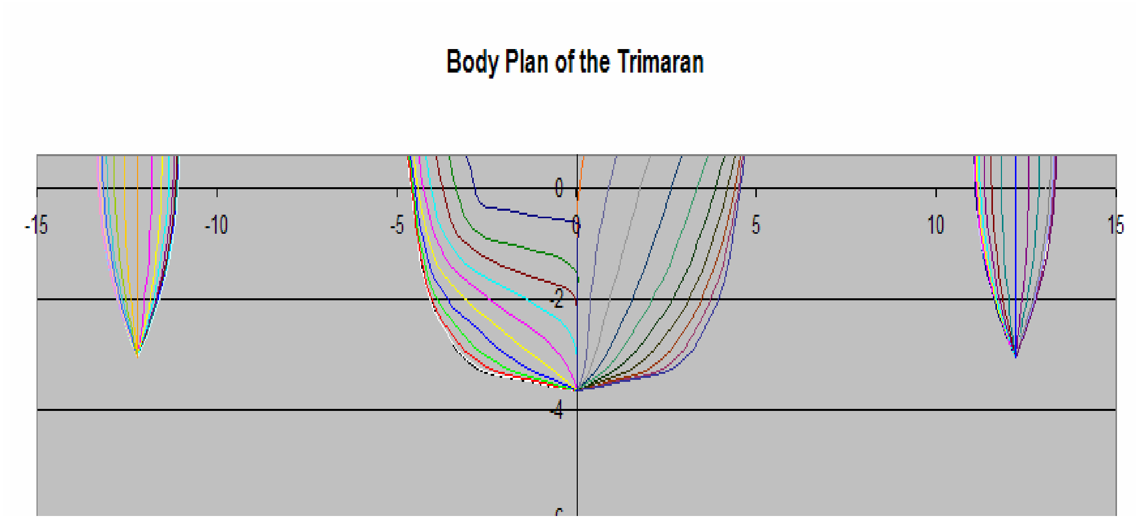


Figure 19. Body Plan of the Trimaran

Many research papers were found that investigated the benefits of tri-hull configurations for future for high-speed vessels both for military and commercial applications. Based on these research papers, a tri-hull design offers advantages in the following ship design considerations, which we tried to take advantage during the hull design process:

- Resistance
- Seakeeping and Motions
- Maneuverability
- Machinery Arrangement
- General Arrangement
- Survivability
- Signature Reduction

The resistance and seakeeping calculations of the SEA SWAT were supported by two-thesis project, which were done by LTJG Zafer Elcin Turkish Navy and LTJG Aziz Alper Kurultay Turkish Navy.

1. RESISTANCE AND SEAKEEPING CALCULATIONS

Based on the results of the resistance and seakeeping calculations for different longitudinal and transverse positions of the side hulls, the best transverse position for the side hulls was determined as inboard of the ship. However, the longitudinal position of the side hulls was selected in conjunction with other design issues, particularly, the layout requirements, because there is no exact optimum position for entire speed range. According to this optimization SEA SWAT has the following features.

2. MANEUVERABILITY

Two retractable-podded propulsors were installed at the side hulls in order to increase ship maneuverability especially at low speeds.

3. MACHINERY ARRANGEMENTS

The trimaran hull form gave us more functional space for machinery. Some machinery was placed at the superstructure.

4. GENERAL ARRANGEMENTS

An undoubted feature of the trimaran form is the additional upper deck and upper ship space that is created. SEA SWAT has significantly more deck space for a given tonnage, offering more space for hangars, helicopter operation and weapons.

With the significant additional transverse stability, the growth margins are greatly benefited and equipment upgrades during the life of the ship will be easily accommodated.

The additional topside space has a number of potential uses. For example the greater length could be used for better separation of upper deck sensors and antennae; thereby alleviating some of the EMC problems and improving survivability.

The side hulls provide greater stability offering growth potential for ship systems and the ability to mount sensors higher above the water line to improve early-warning missile defense capabilities.

Another benefit that is significant for surface combatants is the ability to mount equipment higher on the vessel; this reduces the effect of shock levels, which are one of the main causes of equipment failures in action. The side hulls can also be utilized for configuring a multi-line towed array sonar system.

5. SURVIVABILITY

In SEA SWAT, the side hulls were used as armor for critical machinery and control spaces. This definitely increases the survivability of the ship.

6. SIGNATURE REDUCTION

The trimaran hull form offered a major advantage in signature reduction. Venting exhaust gases down into the space between the main and side hulls can significantly reduce the overhead thermal signature.

E. MODULARITY DESIGN IMPLEMENTATION

As prescribed in the requirements, the design of the LCS is to incorporate modularity. For the LCS design, modularity consists of systems that can be exchanged pier-side with minimal time and effort. The individual modules will be grouped into mission packages that will change the mission capability of the LCS when installed or removed.

The LCS is operable without a mission package installed and its core capabilities include SUW and self-defense. At the discretion of the Sea Base, and in response to threat analysis, the LCS will be outfitted with one of two available mission packages, AW or USW/MIW.

The modular systems that comprise the AW mission package include:

- Mk 41 Vertical Launching System with Mk 25 Quad Pack for Evolved Sea Sparrow Missile (ESSM), Figure 20

Figure 20. ESSM being loaded in to Mk 25 Quad Pack

The modular systems that comprise the USW/MIW mission package include:

- Towed Torpedo Countermeasure
- Towed Array Sonar
- Torpedo and Launcher
- Airborne Underwater and Mine Warfare sensors and weapons
- Unmanned Underwater Vehicles

Systems that comprise the core configuration will be modular to assist in systems upgrade. They include:

- Harpoon Missile (Figure 21)
- SEARAM (Figure 22)
- Guns (e.g. Bofors 57 mm Mk III, Figure 23)

Figure 21. Harpoon Missile

Figure 22. Modular SEA RAM being installed

Figure 23. BOFORS 57mm Mk III

F. AIR WARFARE LCS COMBAT SYSTEMS DESIGN LAYOUT

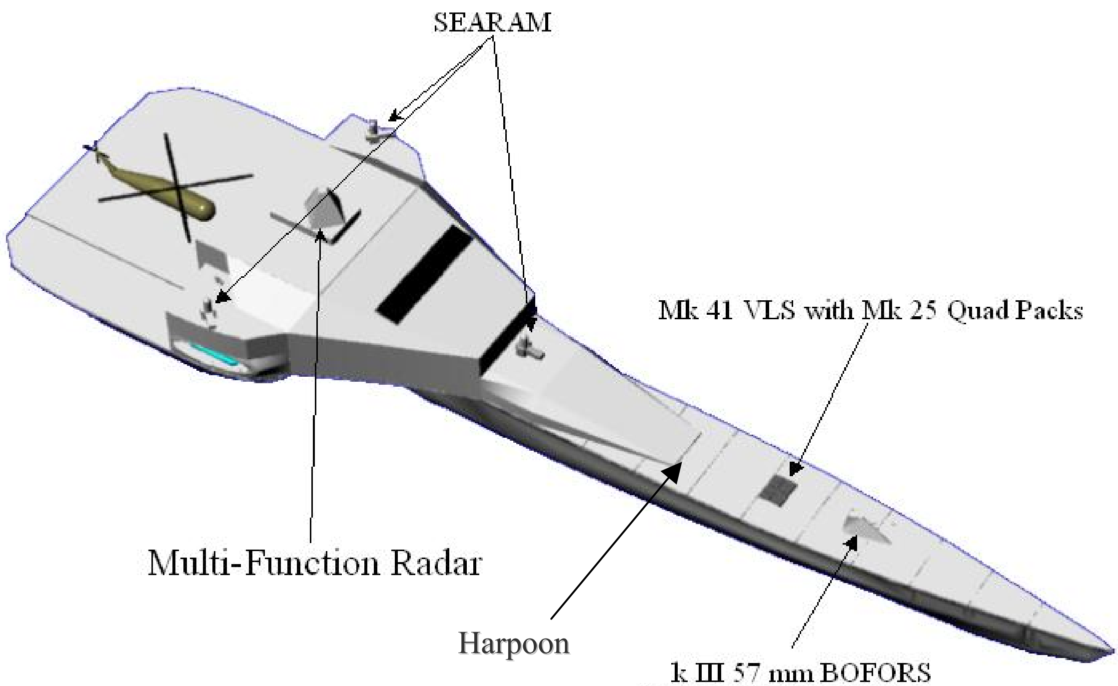


Figure 24. Topside SEA SWAT Combat Systems Layout

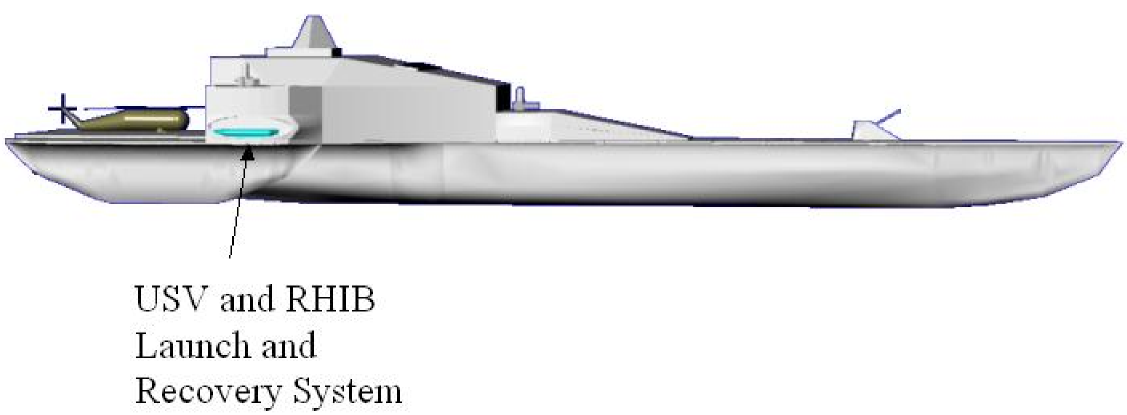


Figure 25. Profile of SEA SWAT

G. UNDERSEA/MINE WARFARE LCS COMBAT SYSTEMS DESIGN LAYOUT

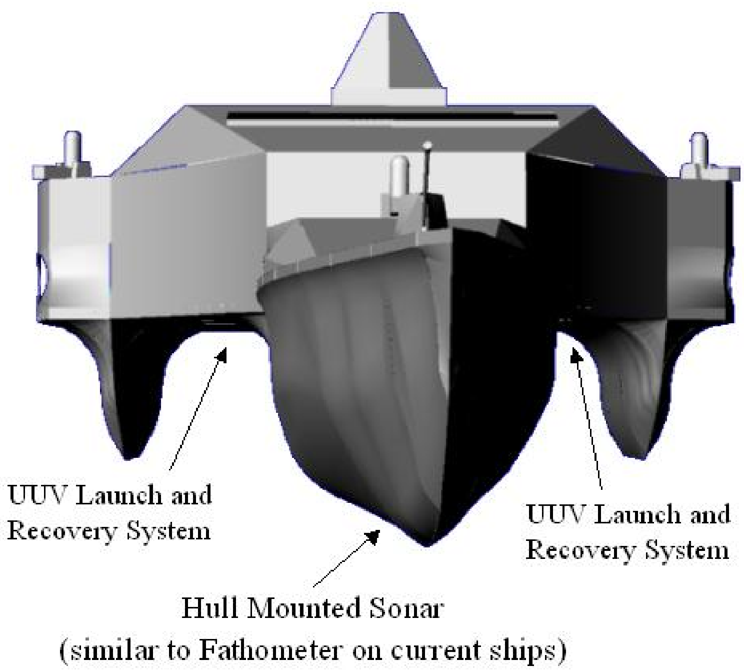


Figure 26. Bow Aspect of SEA SWAT Combat Systems

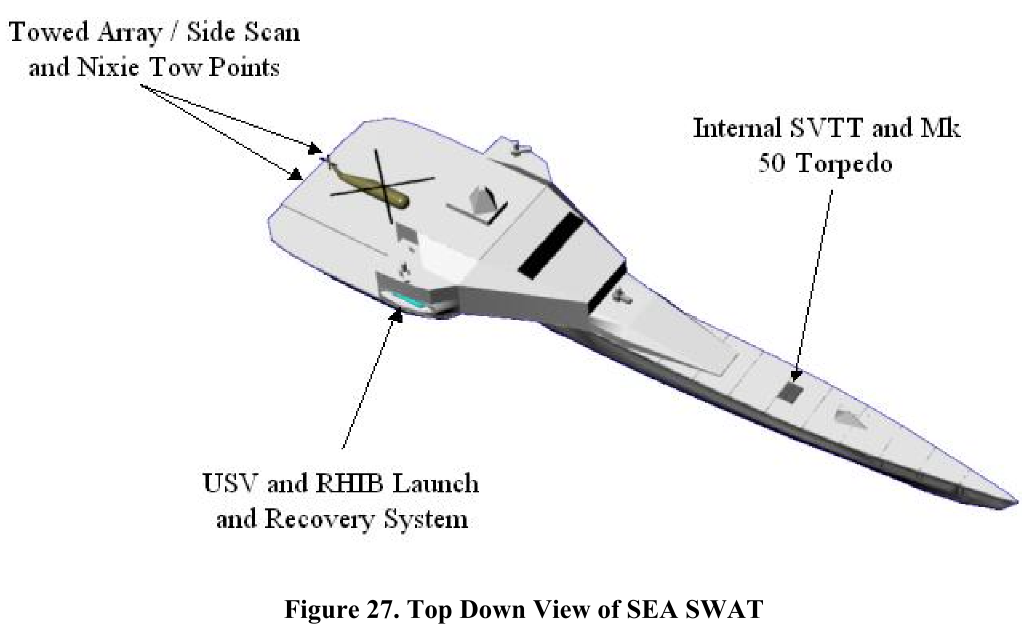


Figure 27. Top Down View of SEA SWAT

H. PROPULSION PLANT ANALYSIS

The basis for the electrical distribution systems stems from the need for a design that will allow the provision of energy to multiple systems through out the ship, in particular, the propulsion system. The current ship design mandates that a large portion of heaviest system components be placed at or forward of the unloaded center of gravity (CG) has lead us to design a distribution system that allows great flexibility in the placement of propulsion and power systems about the ship. For this reason, an integrated propulsion system to the electrical distribution system was chosen.

1. PROPULSION PLANT TRADE-OFF ANALYSIS

The considerations for the propulsion plant are minimizing the weight and the size, cost of the construction and overhaul, fuel efficiency, endurance, maintenance, modularity and location flexibility, manning, resistance to vibration and shock, easy and quick start up times and reliability. Most possible marine propulsion plant types were researched. Focusing on the requirements set out in the Mission Needs Statements (MNS) and the Operational Requirements Documents (ORD) held all the studies.

All marine capable propulsion systems were investigated. These included Diesel and Gas Turbine Engines, Nuclear Steam Plant, Conventional Steam Plant, and Fuel Cells. These systems are compared with respect to the design considerations mentioned above.

a) CONVENTIONAL STEAM PLANT

The conventional steam plant is most efficient for different loading conditions and low speed. High power is also available most of the time. Another advantage is the ability to use the steam for the auxiliary systems. In addition, it is really easy to start up, but requires a high volume and weight. The fuel efficiency is low. So this brings up high volume requirement for the fuel storage. Manning and the maintenance is also a problem, it needs long overhaul time and requires huge amount of manning. According to design considerations the steam propulsion plant was not found to be the appropriate plant for the design.

b) NUCLEAR STEAM PLANT

Nuclear propulsion was not found to be viable option for the following reasons: weight, manning and cost in terms of production and life cycle. This plant requires high manning and personnel training in service and during overhaul period. Another disadvantage of this system is weight because of the shielding. Radiation, long start up time and political problems due to nuclear plant are other disadvantages. The all the information about the nuclear plants is classified, so the design team could not get the satisfactory results from their research. When the advantages and the disadvantages of the nuclear plant are weighed, it was decided that this type of propulsion system is not feasible for the design. Since the previous disadvantages are contrary to the basic design principle of low cost and manning, nuclear power was dropped from consideration.

c) FUEL CELLS

Fuel cells were not found to be a viable option for SEA SWAT propulsion system. Current fuel cell technology can only achieve output power levels at or near 0.12 MW for marine applications, falling well short of the anticipated required output power (50 MW-65 MW). Since fuel cell technology is not mature enough for power levels required for SEA SWAT, it was decided that this type of propulsion system is not feasible for our design.

d) DIESELS

Even though diesel engines are cost efficient and have low specific fuel consumption, because of their high weight, intensive manpower requirements, and high lube oil consumption it was found that they do not constitute an appropriate plant for the design. Diesel systems have space and arrangement problems due to need of several engines per shaft. The number of engines, which will be used to meet the power requirement, will add a lot to volume and weight. Therefore, diesel engines were dropped from the design.

e) GAS TURBINES

Present production and anticipated Marine capable Gas Turbine engines were investigated. The advantages of Gas Turbine engines are as follows: Gas Turbine installations are relatively simple/modular in design and are lightweight ranging from 0.68 kg/HP to 1.81 kg/HP. They possess good high power fuel efficiency and are capable of rapid start up (times of less than 10 seconds are feasible). Typical engines require reduced shipboard maintenance and produce less hull noise than equivalent power diesel installations.

Reliability, low noise signature, location flexibility, modularity are other advantages of Gas Turbines.

Normally Gas Turbines produce a large infrared signature, which can be reduced by appropriate exhaust and stack design, Infrared (IR) suppression systems.

Another advantage of a gas turbine engine is its ability to be removed from the ship for repair in a short period of time (approximately 72 hours). A set of rails is permanently installed in the intakes of each engine and a set of temporarily installed transition rails allow the disconnected engine to transit from its mounting attachments in the module onto the rails in the intakes. Crane service capable of extending over the soft patches in the intakes is required to pull the engine up the rails and out of the ship.

After weighing the advantages and disadvantages for each potential propulsion systems, Gas Turbine engines were found to be the most feasible option for SEA SWAT.

2. GAS TURBINE COMPARISONS

a) ICR WR21

The ICR WR21 (Intercooler Recuperator), Figure 28, incorporates revolutionary advancements in Gas Turbine technology. This Gas Turbine can achieve greater than 14% reduction in specific fuel consumption as compared to the simple cycle Gas Turbine and greatly reduces the ship Infrared signature (IR) by using compressor inter-cooling, exhaust energy recover, and airflow management. The disadvantages of these Gas Turbines are higher weight, higher volume, higher acquisition cost, and higher risk.

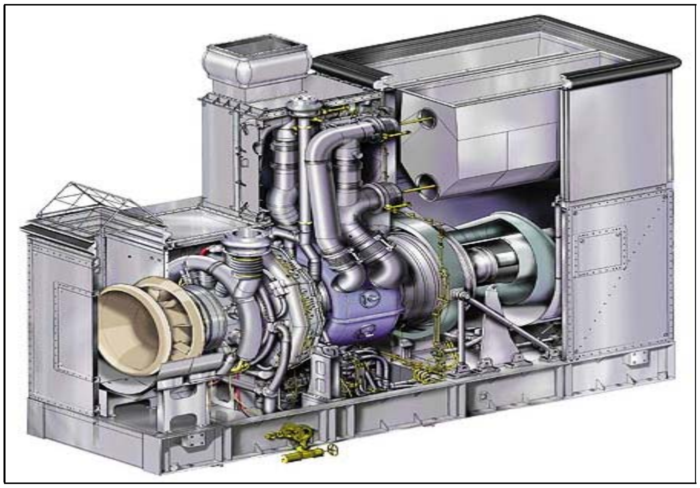


Figure 28. ICR WR21 Gas Turbine

b) MT30

With 36 MW of total power, the MT 30 was another choice for the propulsion plant, Figure 29. It has a thermal efficiency of more than 40 %. The SFC of this engine is even efficient while operating at 70% of full power. In this case volume requirement for the machinery room will increase dramatically therefore this type of engine is not feasible for the design.

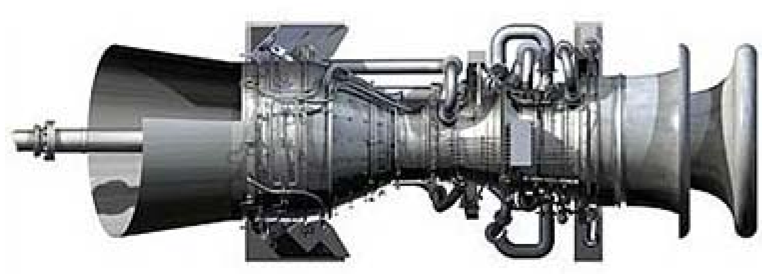


Figure 29. MT 30 Gas Turbine

c) LM 2500

This engine has a variety of uses in marine applications. It uses the latest power plant technology. It gives great flexibility for cogeneration and combined cycle applications. Ability to use the exhaust gas to produce heat increases the overall efficiency. This steam can be used for auxiliary systems like boilers and other equipments. The LM 2500, Figure 30, has an availability rate of 99.6 %. Engines need corrective maintenance of 40 hours in every 10,000 hours. The hot section maintenance is done in every period of 12 000 to 15 000 hours. But, it was decided that; because of its low power with respect to power requirement of the ship and the higher SFC it is not the engine for the design. Compared to its advanced model LM 2500+, even it weighs is 10% less, it has almost 50% more volume due to its height.

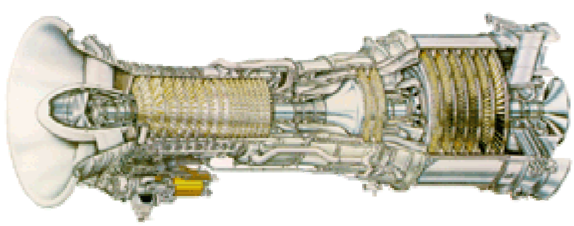


Figure 30. LM2500 Gas Turbine

d) LM 2500+

This engine is the newest technology and newest aero derivative design of the GE Company. The LM2500+, Figure 31, is an upgraded version of LM2500, which provides lower installed dollar per horsepower and life-cycle costs than the LM2500. The 3600-rpm LM2500+ has been designed for 40,000 brake horsepower (bhp) with a simple cycle thermal efficiency of 39% at ISO conditions. It delivers 25 % more power than LM 2500. Availability rate of the LM 2500+ is again 99.6 %. Reliability, high efficiency, low SFC, installation flexibility makes it one of the most demanded engine in the market of marine applications. It has simple cycle thermal efficiency of 39% at ISO conditions. The LM2500+ achieves increased power over the LM2500 primarily by increasing the compressor airflow 23%, with a minimal increase in combustor firing temperature by adding a compression stage (zero stage) to the front of the LM2500 compressor. The temperature capability of the hot section was also increased by adding a thermal barrier coating to the combustor, upgrading turbine airfoil materials and by improving internal cooling designs.

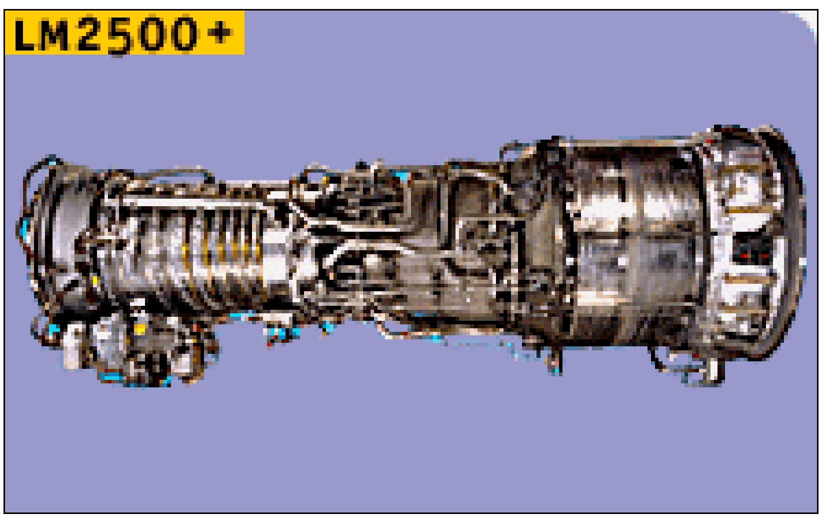


Figure 31. LM2500+ Gas Turbine

e) LM 1600

LM 1600, Figure 32, is another aero derivative engine of the LM series, which is derived from F404 turbofan aircraft engine. It is fairly small engine for the design. The significant factors, which contribute to this high efficiency, are: the high-pressure ratio of the compressors, high turbine inlet temperature, improved component efficiencies, and conservation of cooling air flow. The LM1600 is an excellent power producer for a variety of mechanical drive applications such as driving compressors, electrical generators, and pumps for power generation.

Combining the features of high power-to-weight ratio, compact design, ease of operation and ease of maintenance, this dual-rotor gas generator coupled with a two-stage power turbine is ideally suited for marine applications.

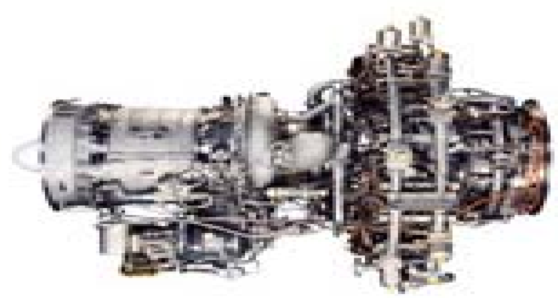


Figure 32. LM 1600 Gas Turbine

f) LM 6000

The LM6000, Figure 33, is the most fuel-efficient, simple-cycle Gas Turbine in the world with an SFC at 0.200 kg/(kW-hr). The LM6000 has a higher thermal efficiency and lower exhaust gas temperature as compare to other General Electric engines. The LM6000 requires 202m^3 of volume and weighs 55 mT (including Gas Turbine, inlet, vents, exhaust, Gas Turbine enclosure, Gas Turbine base, Auxiliary Skids, and Shock mounts). This engine is well suited for high-speed ferries and cargo ships. The LM6000 has a high power to weight ratio (7.85 HP/kg). The disadvantage of employing the LM6000 for SEA SWAT is engine water-cooling. The LM6000 is a water-cooled engine requiring excessive weight and volume requirements not suitable for this design.

Figure 33. LM6000 Gas Turbine

As seen in the Figure 34, ICR WR21 is excluded due to its excessive weight requirements. A trade-off is performed for MT30 and LM2500+ based on the fuel requirements shown in Figure 36. Based on the trade-off studies, presented later in this report, it was determined that LM 1600 and LM2500+ are the optimal prime movers for SEA SWAT.

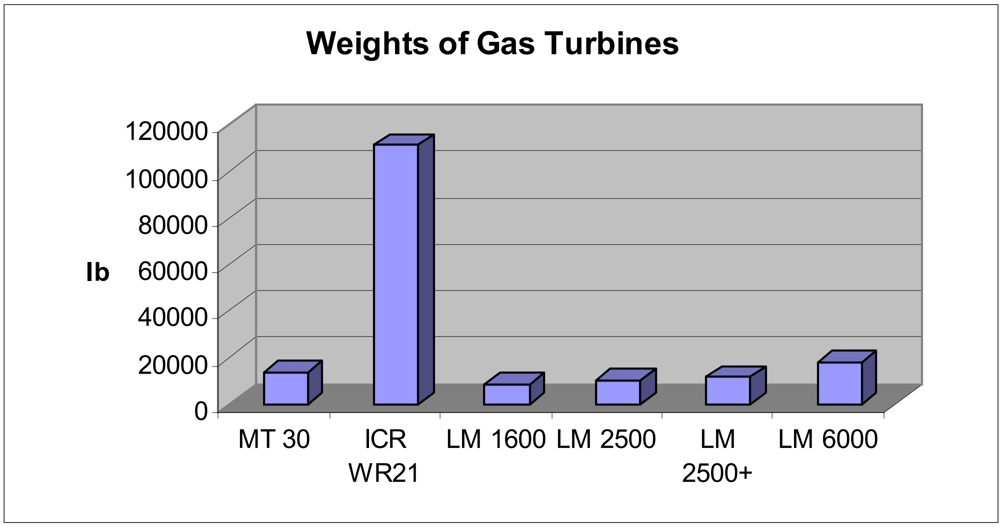


Figure 34. Weight Comparison for Gas Turbines

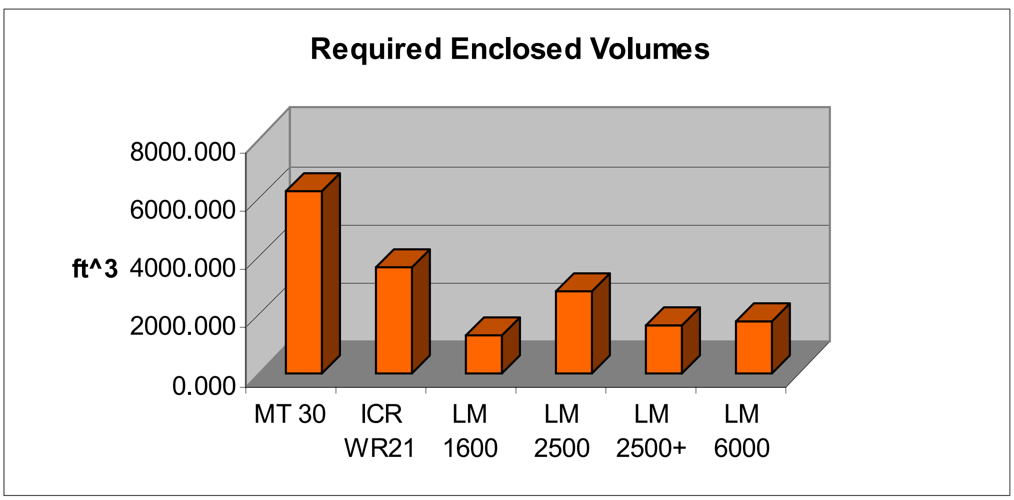


Figure 35. Volume Requirements for Gas Turbines

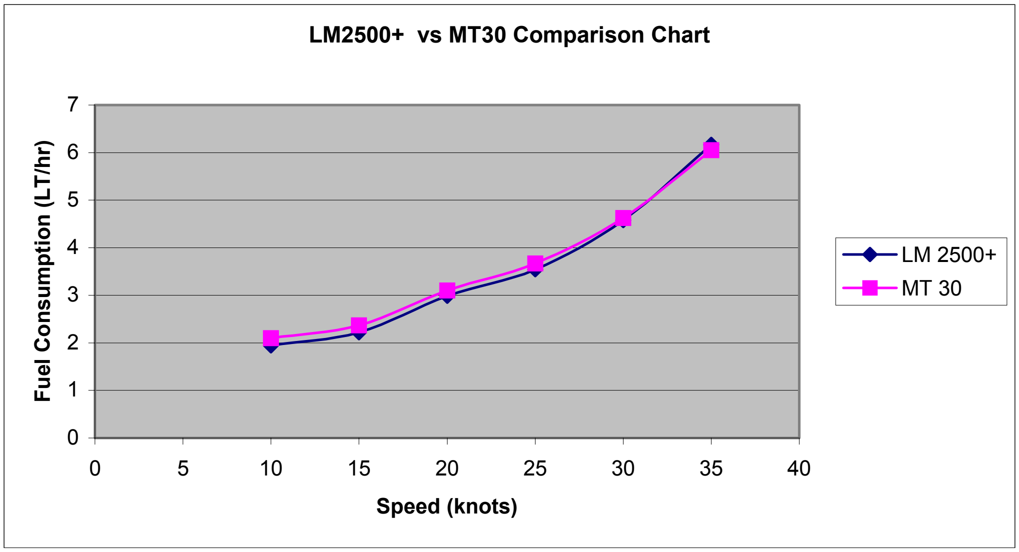


Figure 36. LM 2500+ and MT30 Fuel Consumption Comparison

I. ELECTRICAL DISTRIBUTION

The electrical distribution system proposed is derived from the ONR reference system, which has been developed to support the Naval Survivability Initiative at the University of Missouri and Purdue University. The system has been modified to suit the needs of the SEA SWAT. Figure 37 presents the electrical distribution system developed.

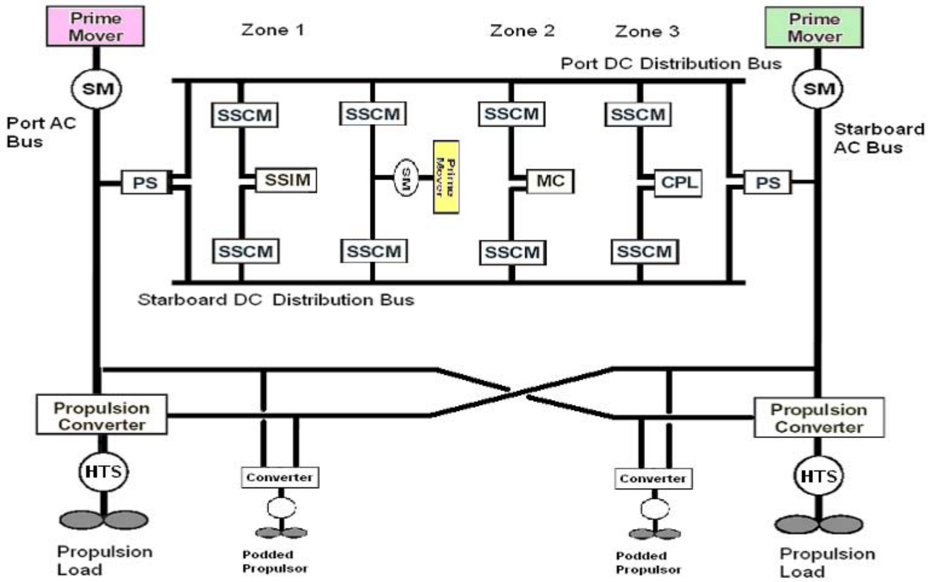


Figure 37. SEA SWAT ELECTRICAL DISTRIBUTION

The system begins with two prime movers corresponding to the LM 2500+ and the LM 1600. These are depicted in red and green. These provide 13.8 KV of 3-phase AC power to port and starboard AC buses via two synchronous machines. These are designed to provide power for propulsion as well as combat systems equipment. The AC buses feed the port and starboard DC buses via a pair of 3-phase AC diode rectifiers bridges feeding a buck converter to produced 500 VDC.

The DC distribution systems consist of 3 zones independently powered from both port and starboard DC buses. Each zone is powered by two ships service converter modules (SSCM), which convert 500 VDC to intra-zone distribution of approximately 400 VDC. This 400 VDC supply is available to feed ships service loads, combat systems and auxiliary loads.

To add redundancy and increased reliability as well as survivability, a 3 MW Allison gas turbine is coupled to port and starboard DC buses via a synchronous motor and two SSCMs. This provides the ability to provide for ship hotel loads in port when no shore power is available as well as an emergency power supply in casualty situations.

Two 21 MW synchronous motors are used for propulsion. These are controlled by two pulse width modulated (PWM) controllers/converters. These are fed from both port and starboard AC buses to maximize continuity of power during casualty situations.

The two synchronous motors are high temperature superconducting (HTS) machines. These were selected due to their high power-to-weight and power-to-volume ratios when compared to currently available conventional systems. Figure 38 shows how HTS machines compare with available conventional machines.

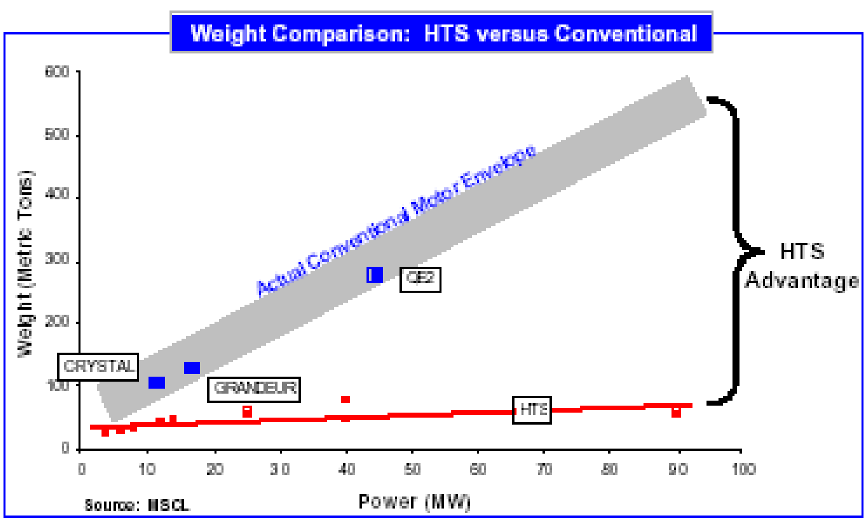


Figure 38. HTS vs. Conventional Weight Comparison

Finally, two-podded propulsors are installed on the side hulls to provide low speed maneuverability. These provided up to 500 SHP from port and starboard AC buses.

VI. SHIP DESCRIPTORS

A. PROPULSION AND ELECTRICAL SYSTEM

1. MAIN ENGINE TRADE-OFF ANALYSIS

To determine the optimal prime mover for SEA SWAT, all requirements were taken into account. The ship was found to require nearly 33,600 SHP to achieve 35 knots. Required power for different speeds up to 55 knots is shown in Table 17. Also, 5,000 HP is the anticipated requirement for continuous ship's service electric load with 25% growth margin.

Each of the engines investigated had certain advantages and disadvantages. The ship will need power about 38,600 HP with 24-hour electrical load. Six types of gas turbine engines were discussed. Each of them was considered with respect to dimensions, weight, volume, fuel efficiency, and maximum power. Based on Figure 39 and Figure 40, it was decided that the combination of LM1600 and LM2500+ is the most feasible prime mover for SEA SWAT. Even though utilizing just one LM2500+ would be enough to achieve 35 knots speed requirements, for redundancy, one LM1600 is combined with LM2500+. Therefore, the most feasible prime movers for propulsion plant is one LM1600 and one LM2500+.

Gas Turbines	Power (MW)	Power (BHP)	SFC	l (ft)	w (ft)	h (ft)	vol (ft^3)	weight (lb)
MT 30	36	48276.8	0.34	30.09	12.59	16.5	6250.746	13596.5
ICR WR21	25.2	33793.8	0.337	26.25	8.67	15.83	3602.710	111150
LM 1600	14.92	20008.0	0.376	18.84	10	6.67	1256.628	8200
LM 2500	25.06	33606.0	0.373	26.96	15.67	6.7	2830.503	10300
LM 2500+	30.11	40378.2	0.354	27.56	8.69	6.7	1604.626	11545
LM 6000	42.75	57328.7	0.329	30.5	7	8.3	1772.050	18010

Table 17. Gas Turbine Comparisons

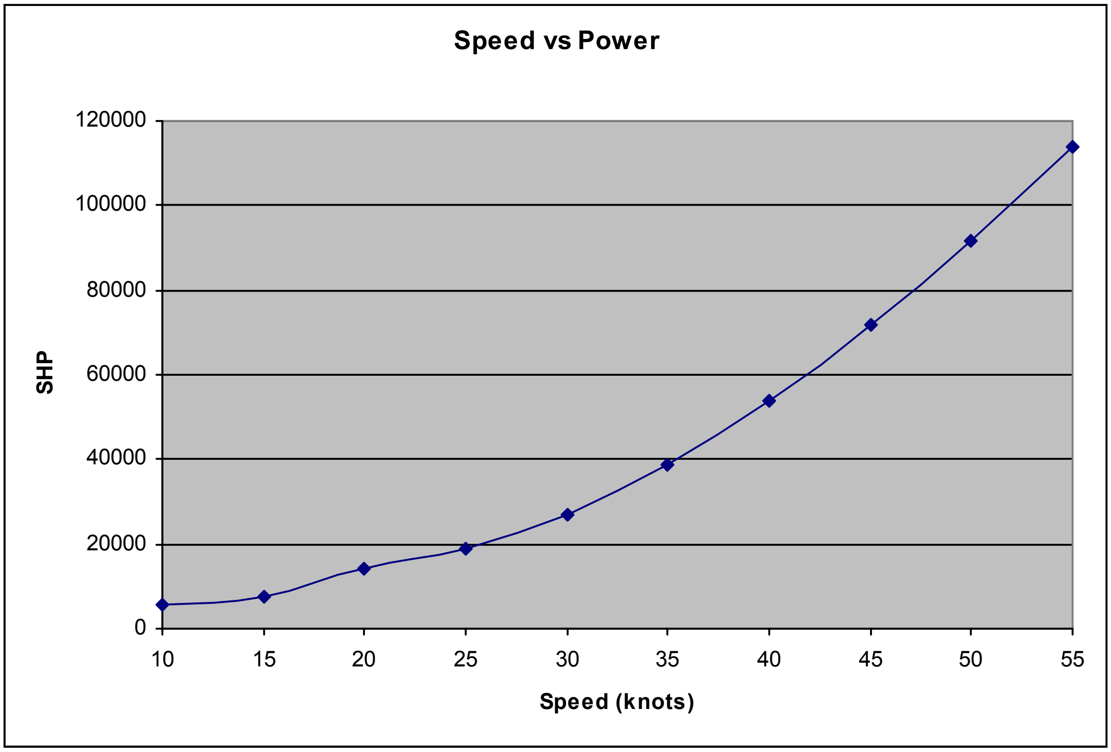


Figure 39. Speed vs Required Power

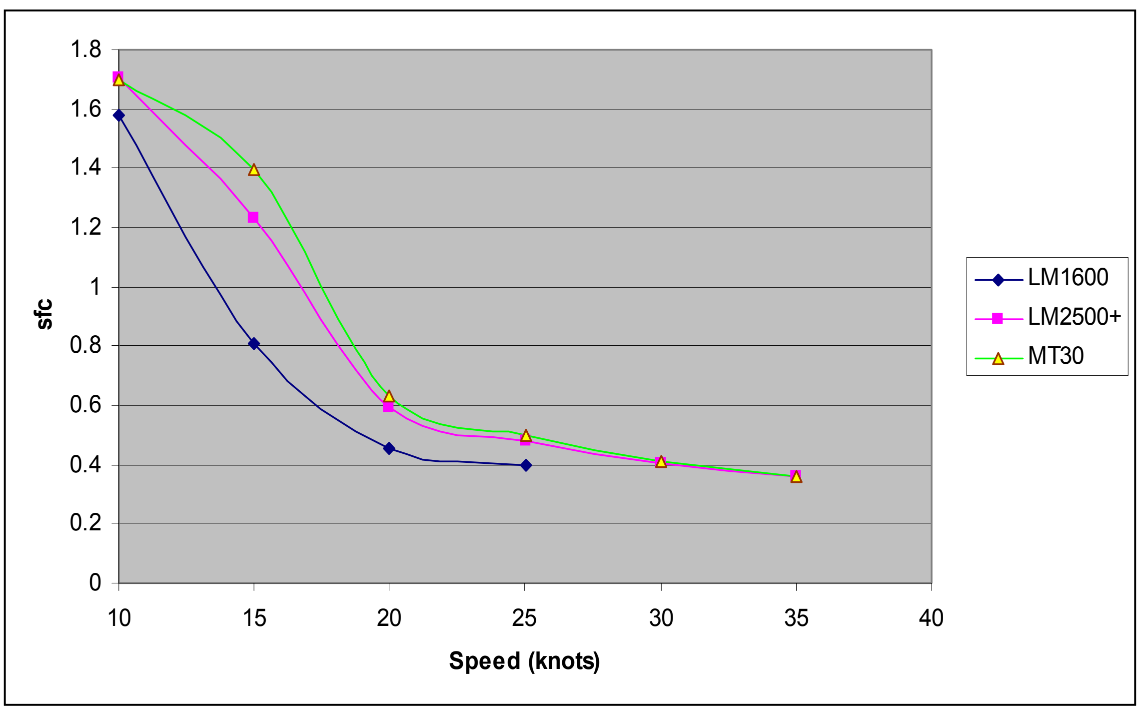


Figure 40. Specific Fuel Consumptions of Gas Turbines

As can be seen from Figure 41, the LM1600 gives better fuel consumption up to 25 knots compared to LM2500+. The LM2500+ performs very inefficiently between 10-25 knots.

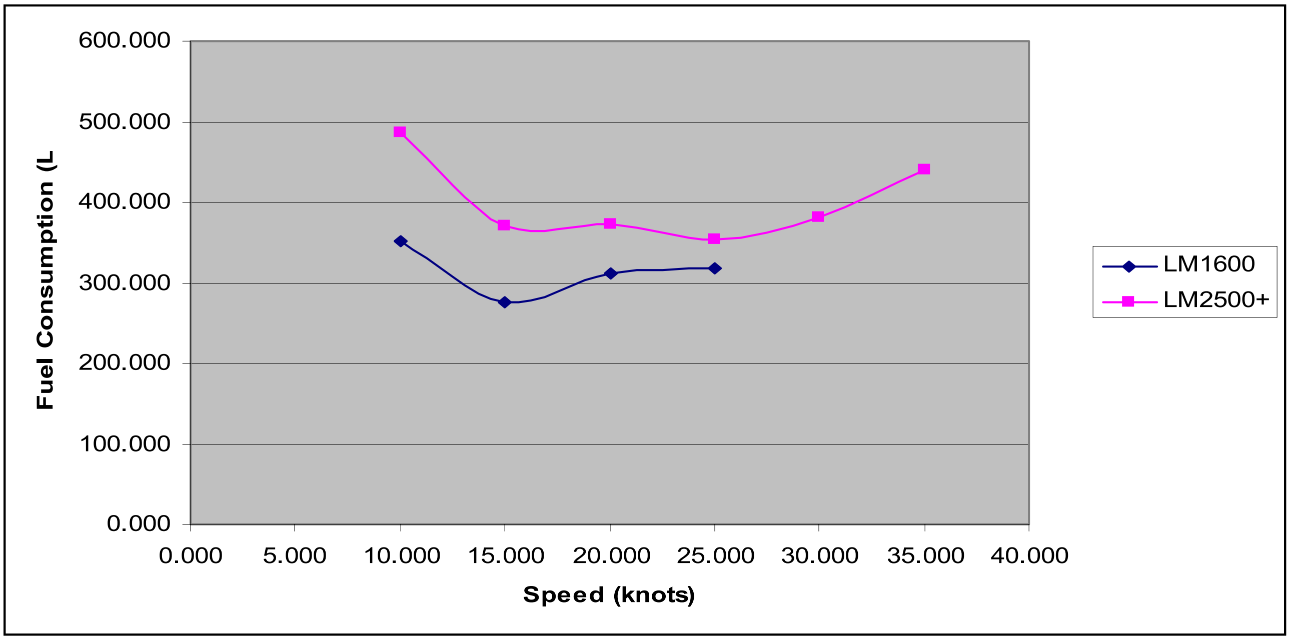


Figure 41. LM 1600 vs LM2500+ Fuel Consumptions

After considering the previous chart, using LM1600 for speeds up to 25 knots is more fuel-efficient. Figure 42 shows the required fuel capacity to achieve 2500 NM endurance range. The endurance speed of 15 knots speed was selected based on this figure.

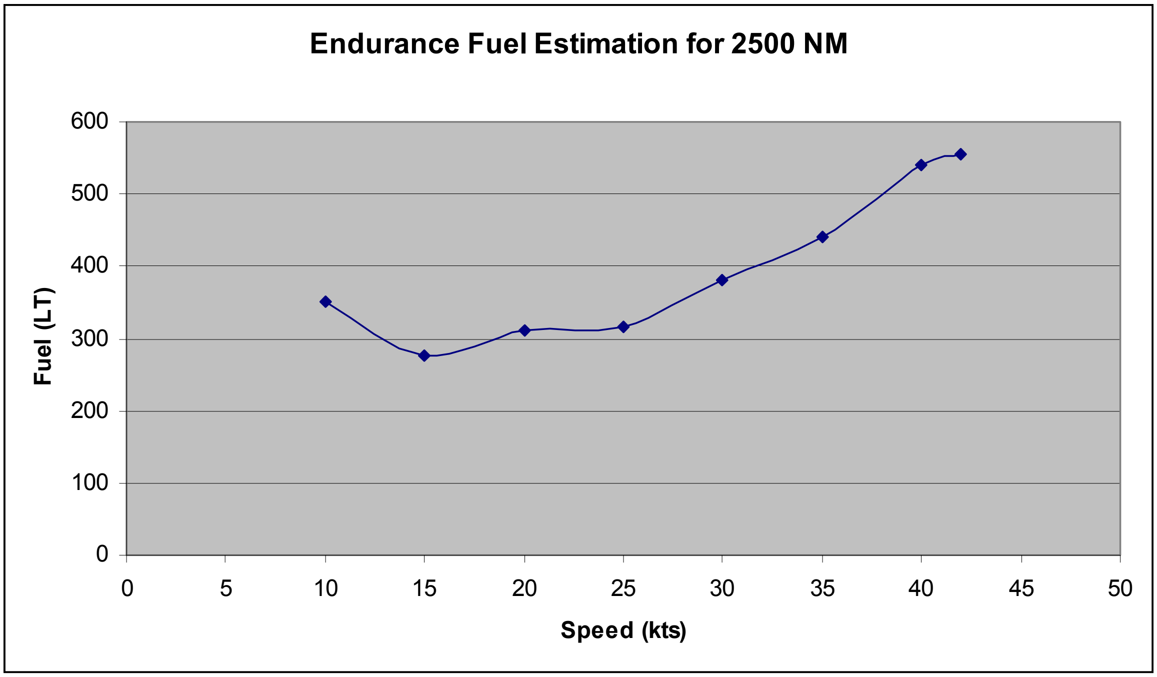


Figure 42. Endurace Fuel Estimation for 2500 NM

For 15 knots endurance speed, Figure 43 shows the required fuel capacities for each of the prime movers. The LM1600 is selected as the only prime mover for this endurance range.

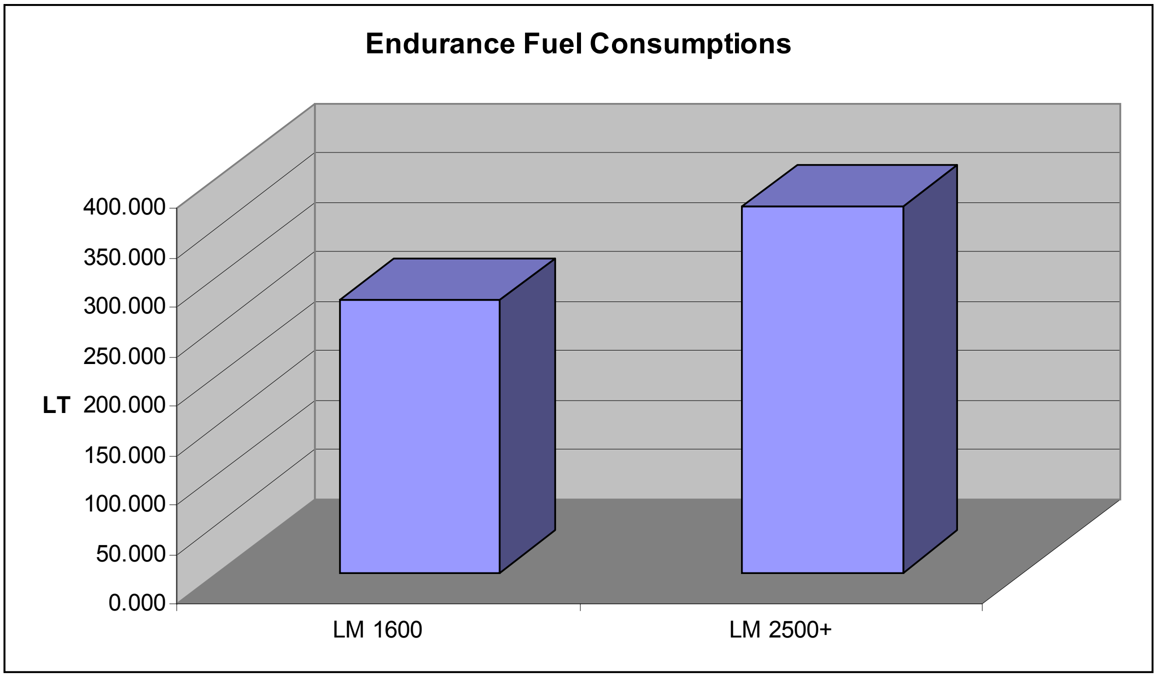


Figure 43. Endurance Fuel Consumption Comparison at 15 knots

Concluding, the propulsion plant of one LM1600 and one LM2500+ will be used in the design. LM1600 will be utilized for loitering speeds up to 25 knots. The LM2500+ will be used for higher speeds up to 42 knots. One Allison AG9140 3 MW Gas Turbine generator set was also added to the propulsion system for Harbor duties and emergency. The engine room layout is shown in Figure 44 below.

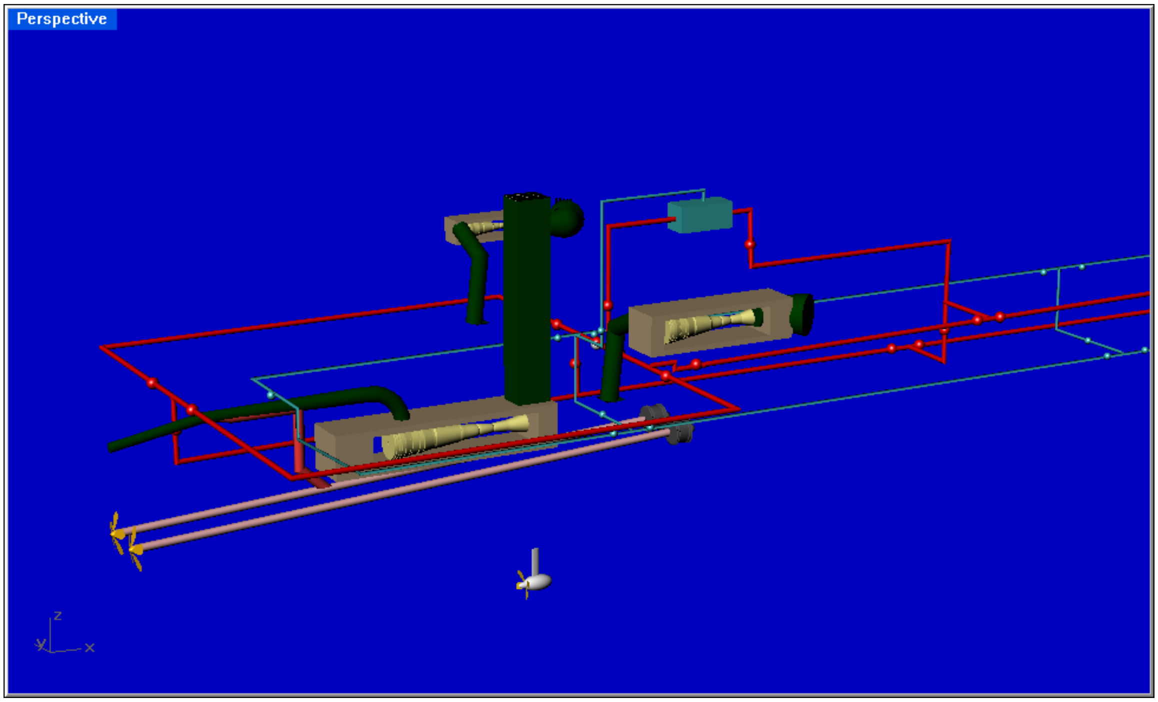


Figure 44. SEA SWAT Engine Layout

2. PROPULSION EXHAUST SYSTEM

Exhaust gas cooling is set up by water injection for uptake of the LM2500+. The exhaust gas systems supplied by Mecmar AS are recognized by the injection of seawater into the exhaust gas. Seawater is used to cool the exhaust gas, to reduce the emission of harmful components in the exhaust gas into the atmosphere and increase safety onboard the vessels.

Furthermore, as a consequence of cooling the exhaust gas, the volume of the exhaust gas to be handled gets considerably reduced, which makes the systems more compact and lighter when compared to conventional exhaust gas systems. Figure 45 and Figure 46 show the gas turbine exhaust system installed on SEA SWAT. The LM2500+ is exhausted out the stern of SEA SWAT, while the LM1600 and

Allison Turbines are exhausted between the side hulls. This exhausting method will reduce the ship’s overall IR signature.

A typical exhaust gas system for gas turbine engine application comprises the following features:

- Inlet pipes.
- Injectors and separator.
- Outlet pipe.
- Drainage system.
- Flexible bulkhead and hull penetrations.
- Compensators.
- Flexible supporting.
- Relief valve.
- Sensors.

The systems are individually placed to meet the various engine manufacturer requirements with respect to permissible back pressure levels in the exhaust gas system, and take into the consideration the lower volume flow and added mass flow due to the seawater injection.

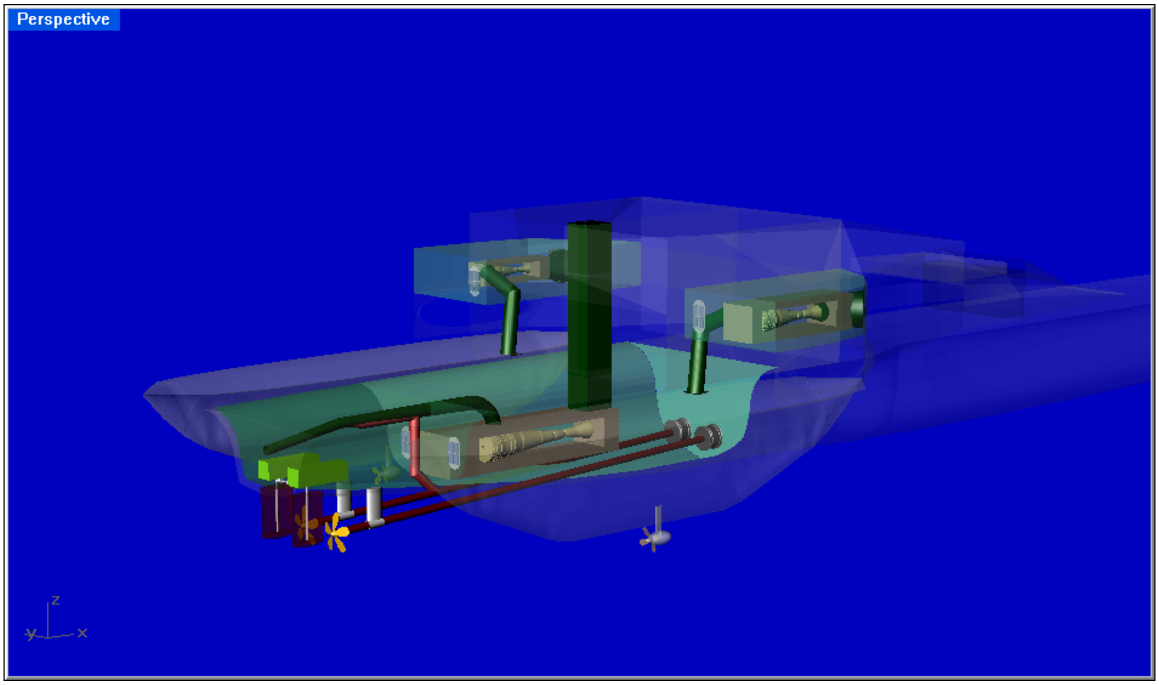


Figure 45. Gas Turbine Exhaust System

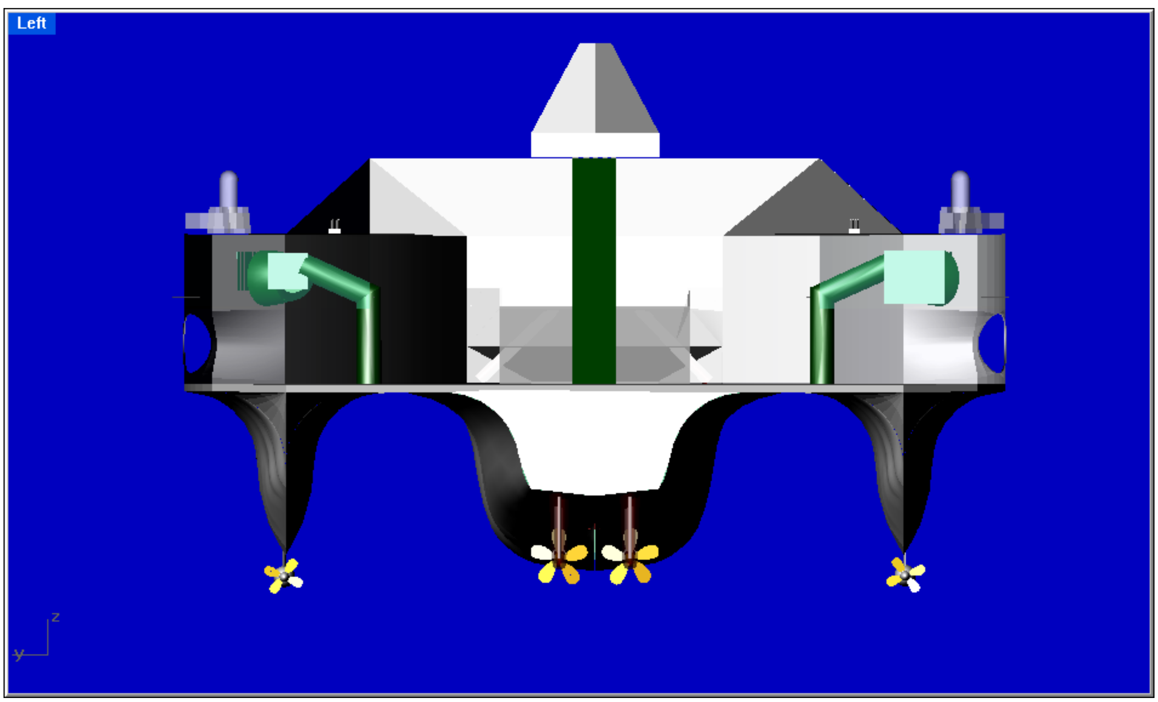


Figure 46. Gas Turbine Exhaust System between Side Hulls

In case of an exhaust gas outlet blockage caused by following seas, the exhaust gas system for gas turbines is equipped with a relief valve arrangement, which prevents excessive pressure peaks in the system.

a) MATERIAL SELECTION

It is obvious that high temperatures of the exhaust gas leaving the engines in direct combination with the injected seawater place high demands on the materials used for construction. In the dry sections of the exhaust gas systems, high temperature resistant stainless steel is used, whilst titanium is preferred in all sections exposed to wet exhaust gas. The following criteria are the basis for selecting titanium:

- Corrosion-resistant to the mixture of sea water and exhaust gas.
- Sufficient strength.
- Low thermal expansion.
- Low modulus elasticity, and hence high degree of flexibility and good ability to withstand shock loading.
- Low weight.
- Good weld-ability.
- Good ductility for the sake of cold forming ability.
- Market availability.

Titanium ASTM Grade 2 meets the above criteria. The characteristics and material properties of Titanium ASTM Grade 2 are listed below in Table 18.

Titanium Grade 2
Commercial Pure Titanium

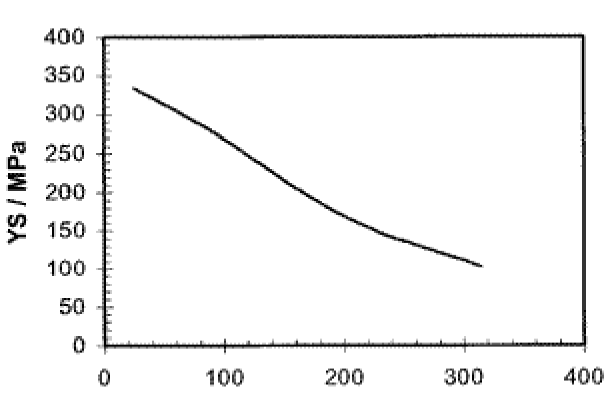
The data given is for information, not for design.

Chemical composition (weight %) (Maximum values unless range is shown)										
O	**N**	**C**	**H**	**Fe**	**A1**	**V**	**Ni**	**Mo**	**Others**	**Residuals**
0.25	0.03	0.08	0.015	0.3						0.4

Grade 2 is the most widely used titanium allow in all product forms for industrial service, offering an excellent balance of moderate strength and reasonable ductility. Highly corrosion-resistant in highly oxidizing and mildly reducing environments, including chlorides.

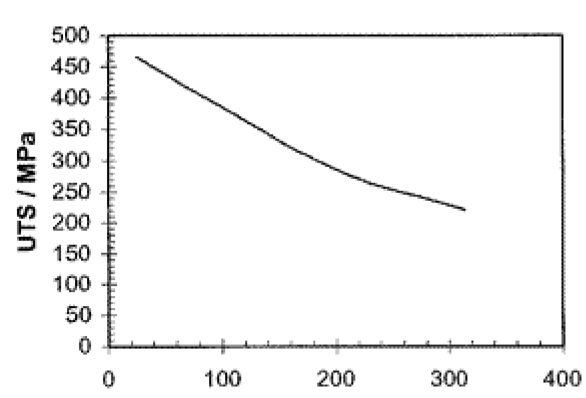
Mechanical properties at room temperature		
	Minimum values	**Typical values**
Yield Strength	275 MPa	350-450 MPa
Ultimate Strength	345 MPa	485 MPa
Elongation in 50 mm, A5	20%	28%
Reduction in Area	30%	55%
Hardness		160-200 HV
Modulus of elasticity		103 GPa
Charpy V-Notch Impact		40-82 J

Yield strength vs. temperature



Temperature / °C

Tensile strength vs. temperature



Temperature / °C

Fatigue properties at room temperature (Stress to cause failure in 10^7 Cycles)

Rotating bend		
Smooth	Kt=1	230 MPa
Notch	Kt=3	155 MPa

Physical Properties	
Melting Point, ± 15 °C	1660 °C
Density	4.51 g/cm3
Beta transus, ± 15 °C	910°C
Thermal Expansion, 20 - 100 °C	$8.6 * 10^{-6} K^{-1}$
Thermal Expansion, 0 - 300 °C	$9.7 * 10^{-6} K^{-1}$
Thermal Conductivity, room temperature	20.8 W/mK
Thermal Conductivity, 400 °C	15 W/mK
Specific heat, room temperature	0.52 J/gK
Specific heat, 400 °C	0.60 J/gK
Electrical Resistively, room temperature	56 µW*cm
Poisson's Ratio	0.34-0.40

Heat Treating			
		Temperature	Time
Annealing	Air-cooled	650-760 °C	6 min - 2 hours
Stress Relieving	Air-cooled	480-595 °C	15 min - 4 hours

Weldability - Excellent
Grade 2 has very good weldability. Being substantially single-phase material, the microstructure of the alpha phase is not affected greatly by thermal treatments of welding temperatures. Therefore, the mechanical properties of a correctly welded joint are equal to, or exceed those of the parent metal and show good ductility.

Available mill products
Bar, billet, ingot, extrusions, plate, sheet, strip, tubing, wire, pipe, forging.

Typical Applications
For corrosion resistance in the chemical and offshore industries; in aircraft construction where certain strength level and ease of formability is desired. Also used in heat exchangers, hypochlorite systems, fire water systems, ballast water systems, risers, fittings, flanges, fasteners, forgings, pumps, and valves.

Table 18. Titanium ASTM Grade 2 Material Properties and Characteristics

b) IR SIGNATURE SUPPRESSION AND SYSTEM OPERATION

The goal is to minimize the overall target contrast and to better the pattern deception characteristics. The most important contribution is to reduce the spectral heat radiance by lowering the temperature with measures to cool the both the exhaust duct and the exhaust gas.

A horizontal layout for the exhaust ducting is more favorable when cooling exhaust gas through the injection of seawater. Such a configuration delivers low IR signatures for two reasons: One because the exhaust gas gets very efficiently cooled and two, because it leaves the vessel just above the water line. The seawater injection reduces the exhaust gas temperature from a typical 500°C to less than 100°C. Furthermore the pattern deception characteristics increase as the system generates a multi-spectral fog that covers the IR range.

c) WEIGHT OPTIMIZATION

Due to water injection, the exhaust gas volume to be handled gets considerably reduced due to the temperature reduction; hence the systems can be compactly designed. Low temperature levels make insulation and insulation coverage unnecessary which are the major parts of the exhaust gas systems. The combination of compact design and the use of lightweight materials contribute to a considerable weight reduction of the complete system. The systems less weight require smaller dimensioned flexible supporting systems, which again reduce transmission of shock loads and vibration to the vessels structure.

d) SAFETY

Fire hazards are reduced by the low surface temperature of the major pieces of the exhaust gas piping and thus eliminate a possible ignition source in the case of an oil or fuel leakage. In the case of a seawater supply failure, the surface temperature of exhaust gas system will rise and an alarm situation will occur, but the emergency operation of the vessel remains possible as the systems are designs to sustain the thermal loading caused by such temperature rises.

3. DRIVE SYSTEMS TRADE-OFF ANALYSIS

On any naval vessel, the transmission and drive system exhibit the following characteristics:

- Transmits power from the power source to the propulsor.
- Adjusts the speed of the rotating shaft from the power source speed to the desired rotative speed for the propulsor.
- Provides coupling of one or more power sources to each propulsor.
- Cross-connects the power sources so that a minimum number of power sources need be operated to power the vessel’s propulsor shafts.

Two technologies were taken into account for the trade-off studies of drive system. These technologies are mechanical drive and integrated propulsion system (IPS).

By utilizing electric drive and integrating ship’s service and combat system’s power through the use of rapidly developing power electronics, all installed ship power will be available in flexible electric form. With an IPS, naval vessels will be able to apportion power to propulsion, ship’s service, and combat systems, as the situation requires. At present, 70 percent to 90 percent is dedicated to propulsion. The Integrated Propulsion System (IPS) will need fewer prime movers.

Some of an IPS can be attained by this architecture independently of the technology utilized. With fewer prime movers, the IPS saves fuel, reduces maintenance requirements, and improves noise signature. The advantages of an integrated electric warship can be summarized as follows:

- Fuel consumption: Greater than 15-19 percent savings over existing gas-turbine combatants when operating a minimum of two generator sets.
- Engine maintenance: Reduced by nearly 50 percent over existing ships.
- Propulsion shaft: Shortened by more than 50 percent. Short shafts reduce propulsion drive-train construction costs and vulnerability damage.
- Propulsors: Reversible electric motors allow use of fixed pitch, ducted, pre- or post-swirl, or other advanced types for better efficiency and reduced acoustic signature.
- Flexibility/upgradeability: Allows for combat systems upgrades using significantly more electric power. Because the speed-power curve for a ship is a cubic (speed proportional to power cubed), doubling ship service load will cause negligible loss in top speed for a typical destroyer.
- Increased automation requires automated power-managements systems because electrical transients occur too rapidly for the 'man-in-the-loop" control typically used on today's ships. Automated start-up,

reconfiguration, and power management are facilitated by modern solid-state controlled power systems.

- Signatures: Fewer prime movers operating and reduced fuel consumption improve infrared signature. Advanced propulsors and quiet electric machinery improve acoustic signature beyond what is capable with today's mechanical-drive ships.
- Naval architecture: Gives the ship designer flexibility in locating large prime movers and other support systems not possible with traditional systems. This allows the high-value space on the ship to be used by the mission payload of the ship.
- Payload capacity: Reduced machinery compliment and increased fuel efficiency allow the same size the ship to carry more payload, go farther, or stay on station longer.

Based on the previous advantages Integrated Propulsion System was selected. In IPS gearbox is replaced with a generator, motor drive, and propulsion motor. The generator can supply all shipboard power demands, eliminating dedicated turbine generators for conventional electrical loads. The motor drive controls the speed of the propulsion motor, eliminating controllable pitch propellers on gas turbine ships.

4. PROPULSOR TRADE-OFF

Two technologies were taken into account for the trade-off studies of propulsors. These are propellers and electrical pods. Since there is no high-speed requirement for the design water jets and hydro drives are kept out of consideration. Another disadvantage of the water jets is the weight problem. The water entering the duct increases the weight of the ship.

The main comparison and trade-off was made between pods and the conventional propellers. The disadvantages of podded propulsors are added drag resistance and increased navigational draft at lower speeds due to massive dimensions. Considering the small beam of the main hull at the stern and maximum draft, podded propulsors are not applicable to SEA SWAT. Current technologies do not offer 42 MW total propulsive powers at this scale. It should be pointed out, however, that this is a rapidly evolving technology and it is possible that future podded propulsor developments will make them more attractive.

Conventional double propellers are utilized with electric motors for SEA SWAT. Three-meter, three and a half meter, and four-meter propeller diameters are analyzed based on the outputs of Propeller B-Series Optimization MATLAB codes fcn.m and propopt.m. Results are shown in Appendix I. Three-meter diameter propellers are selected due to the limitations of SEA SWAT's beam and draft. Additionally, shafts are shortened by more than 50 percent. Short shafts reduce propulsion drive-train construction costs and vulnerability damage and offers design flexibility of machinery rooms.

5. PROPULSOR MOTOR SELECTION

The propulsor motor selection trade-off studies were conducted among HTS AC synchronous motors, conventional motors and DC Homopolar motors. The AC synchronous motor and the DC Homopolar motor are superconducting motors, which are being demonstrated by ONR. Table 19 below shows the comparison between superconducting technology and conventional systems.

Superconducting Electric Power Applications	System Performance	Reliability & Maintenance	Efficiency	Operating Lifetime	Installed Cost [1]	Competing Technology
AC synchronous generators	Improved steady state and transient	Must be equivalent	Higher by 0.5-1.0%	Longer	Equal or higher	Gaseous and liquid-cooled
AC synchronous motors	No change	Must be equivalent	Higher by 1.0 to 2.0%	Longer	Higher	Induction and addition of VSD
AC underground transmission	Ability to double the rated capacity	Must be equivalent to conven. undrgd.	Slightly higher	Longer	Higher	▪ Cu/Al ▪ "FACTS" ▪ extruded
Fault-Current Limiters for transmission & distribution	Reduces transient currents on system components	Comparable to circuit breakers	More efficient T & D system	Longer than circuit breakers	2 to 10x circuit breaker	▪ Solid State breakers ▪ Reactors ▪ "FACTS"
Transformers for transmission & distribution	No change [2]	Must be equivalent to conven. transf.	Slightly higher by 0.1-0.2% [3]	Longer	Higher	▪ Iron Core
Storage Superconducting Magnetic Energy Storage (SMES)	Improves power quality and conditioning, spinning reserve, VAR & AGC	Comparable to other T&D components	Most efficient storage technology	Longer	Higher	▪ Flywheels ▪ VAR Comp. ▪ Batteries ▪ STATCOM ▪ Capacitors

Table 19. Comparison of Superconducting Electric Power Applications to Conventional Technologies

As seen in the table the superconducting technology increases system performance. There is no loss for reliability and the maintenance and they have longer operating lifetime. Even with these kinds of improvements they do not have a significant change for the efficiency. The only disadvantage from the table is the cost. The size and the power density of the conventional motors are far away from our requirements. Since the pods are chosen for the propulsors, the dimensions of the motors are very important. The ship will need large amounts of power for propulsion. This will increase the number of the pods that will be utilized. This is one of the reasons for the need for small size propulsion motors.

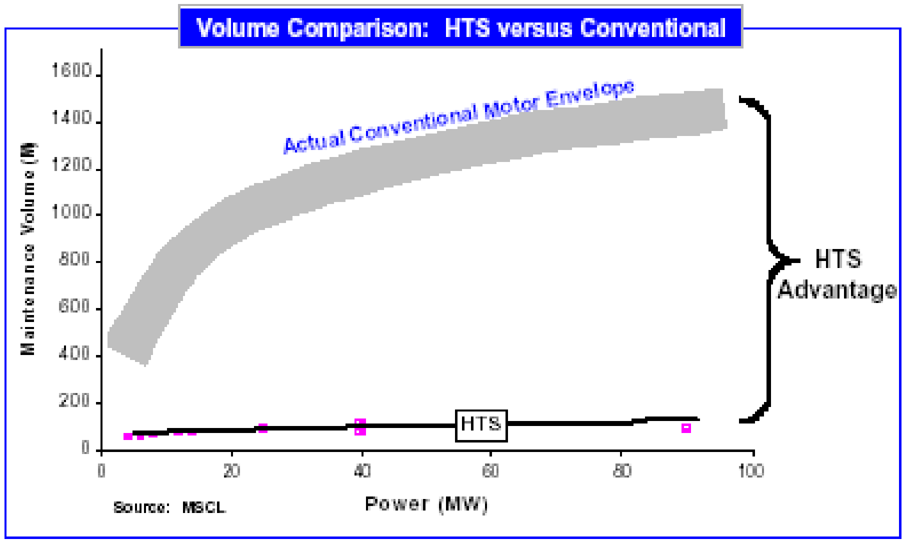


Figure 47. Volume Comparison HTS versus Conventional

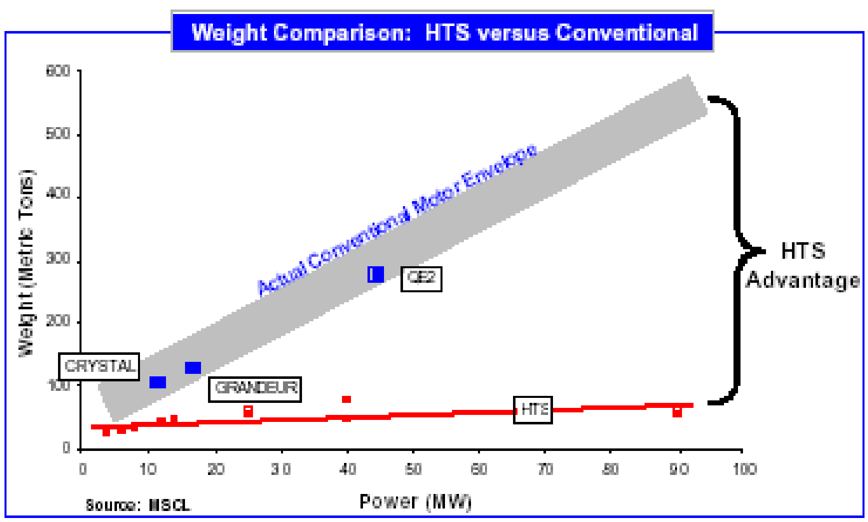


Figure 48. Weight Comparison HTS versus Conventional

Besides the volume advantages; the HTS (High Temperature Superconducting) also gives a huge amount of weight advantage even for power levels up to 90 MW it weighs less than 100 tons. Both weight and volume advantages may be seen in the above figures, Figure 47 and Figure 48

In terms of motor efficiency the HTS again has overwhelming advantages compared to the other type motors shown below in Figure 49.

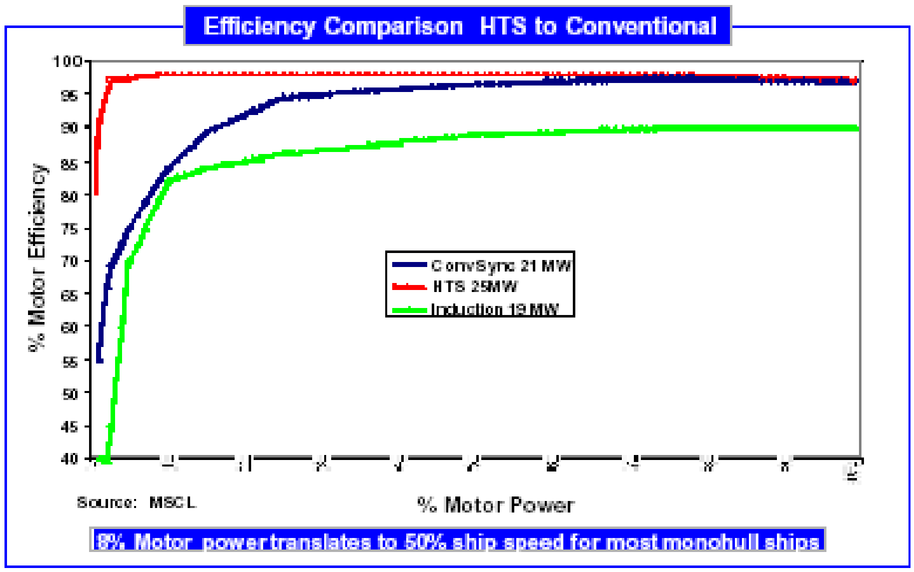


Figure 49. Efficiency Comparison HTS to Conventional

After comparing the conventional motors with the superconducting motors, DC superconducting homopolar and HTS AC Synchronous motor were considered.

a) DC SUPERCONDUCTING HOMOPOLAR MOTOR

For warship propulsion research and development, the Navy built a 25,000 hp multipole induction motor that weights in at 117 tons and occupies 2500 ft^3. In comparison, and yet to be built, a 40,000 hp superconducting DC homopolar (SCDCHP) motor would weigh in at 33 tons and occupy 1250 ft^3. But this motor will need two cryo-coolers. These coolers will weigh less than 200 pounds. Since it creates low noise, it is very stealthy.

b) HIGH TEMPERATURE SUPERCONDUCTING (HTS) AC SYNCHRONOUS MOTOR

American Superconductors Company is working developing a 33,500 hp synchronous motor for the navy. The motor includes all the cooling systems and has one fifth of the size and one third of the weight of a conventional electric motor of the same power rating. It provides great hydrodynamic efficiency for the pods with its dimensions. The Motor can be driven at several times. A comparison of the dimensions of the AC synchronous and DC Homopolar motors are listed in Table 20.

Motor Type	Diameter (m)	Length (m)	Cyro-cooler Volume (m^3)
HTS AC synchronous	2.65	2.08	1.0
DC Homopolar	2.65	3.05	1.4

Table 20. HTS AC Synchronous versus DC Homopolar Motor Dimension Comparison

The rated output for short periods provides the ship with important operational capability. The motor can be turned off in case of a fault in the stator. This ability gives motor field control. They have low noise and no cogging torque. These motors are smaller than the DC Homopolar motors.

Concluding, HTS AC Synchronous motors were chosen for the propulsor motors.

B. HYDROSTATIC CHARACTERISTICS

Figure 50, Figure 51, and Figure 52 show the hydrostatic data for SEA SWAT. These were calculated separately for the main hull and the side hulls, and were appropriately combined for the overall hull. Form coefficients are shown separately for the main hull and the side hulls.

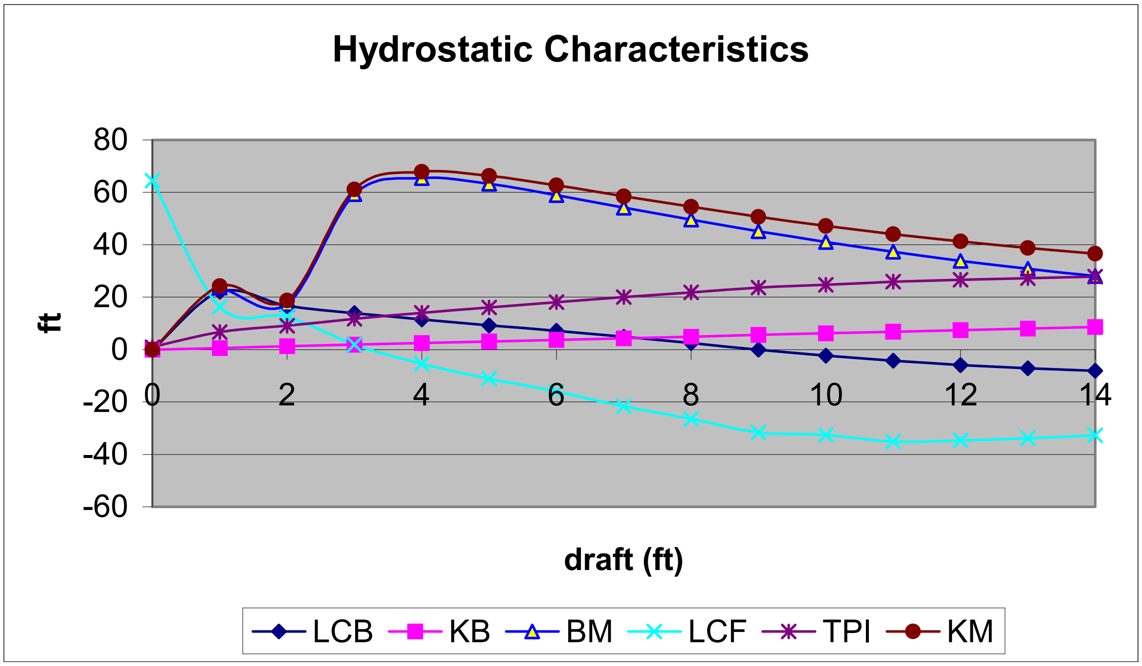


Figure 50. SEA SWAT Hydrostatic Characteristics

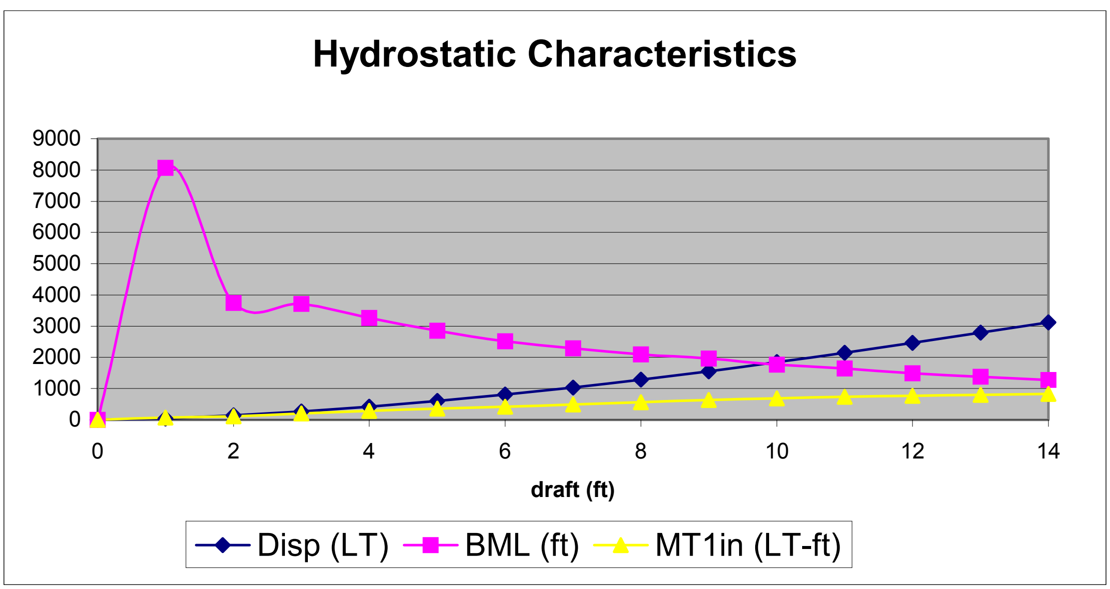


Figure 51. SEA SWAT Hydrostatic Characteristics

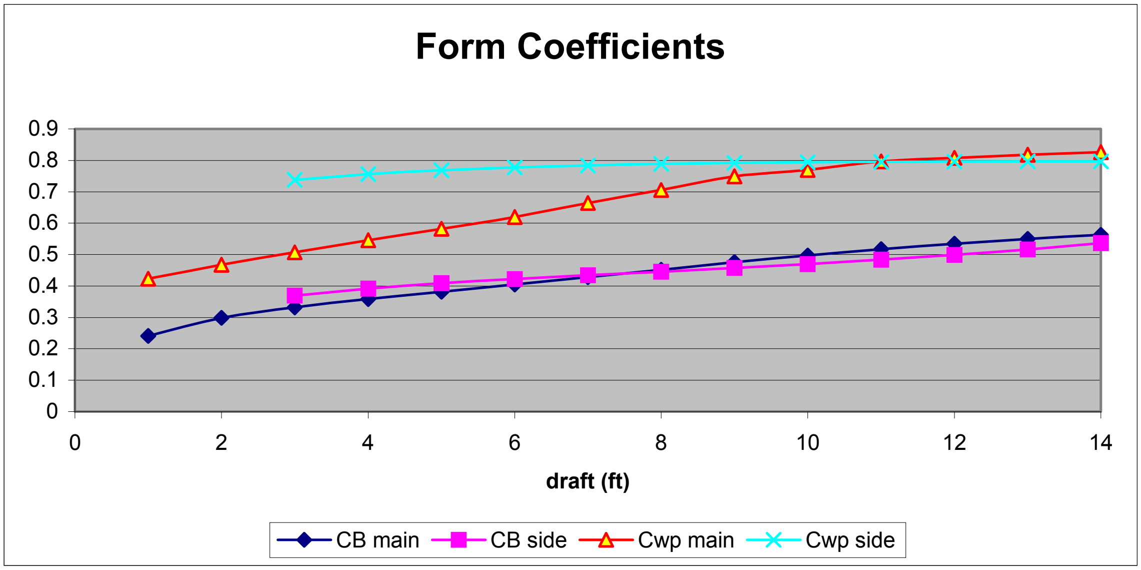


Figure 52. SEA SWAT Form Coefficients

Appendix F contains more hydrostatic data based on the mission package installed on SEA SWAT. The data in Appendix F includes:

- Cross Curves of Stability
- Hull Data with Appendages
- Hydrostatic Properties
- Longitudinal Strength
- Righting Arms versus Heel Angle

For comparison purposes, it should be pointed out that the results of Appendix F are based on calculations for the main hull only due to time constraints.

C. COMBAT SYSTEMS FOR AIR WARFARE CAPABLE SEA SWAT

1. MULTI FUNCTION RADAR

The Multi-Function Radar (MFR) program was selected as the radar of choice for the LCS and is installed on both the AW and USW/MIW LCS platforms. It would be prudent that a future sea combatant utilize common sensor systems and obtain better costs savings and easier integration across all platforms. Sizing was estimated using both the SPY 3 for size and weight estimates and the Dutch APAR I-Band Radar for design and performance criteria. The SPY 3 size and weight estimation is shown in Figure 53. Radar providing the multifunction capabilities required for the modern missile threat. This includes target detection, tracking and multiple missile control based on mid-course guidance and terminal homing. CW generation and illumination is a built-in feature of the APAR system. The 3424 elements in every face provide powerful and redundant system architecture. The complete APAR multifunction radar consists of four faces covering 360 degrees of possible threat.

In order to validate the selection of this radar, a rough order of magnitude calculation was performed to ascertain the approximate detection range of the system.

Assumptions:

- ASCM radar cross section = 0.05 m^2,
- Radar Frequency = 10 GHz (X band radars are between 8-12 GHz)

- Probability of Detection, P_D = 0.9
- Probability of False Detection, P_{fa} = 0.01%
- S_{min} = 1 × 10^{-12}

$$\text{Antenna Gain } G = \frac{4\pi A_e}{\lambda^2} \qquad \left(\text{where } A_e = \text{ Area of Array } \& \ \lambda = \frac{c}{f}\right)$$

$$= \frac{4\pi \times 1.59 \times 0.96}{\left(\frac{3\times 10^8}{10\text{GHz}}\right)^2}$$

$$= 21321.52$$

$$= 10\log(21321.52)$$

$$= 43.29 \text{ dB}$$

Peak Power = 66 dB = 3.981 MW (from SPY 1 data)

$$\text{Maximum Detection Range} = \sqrt[4]{\frac{P_p G \sigma A}{(4\pi)^2 S_{min}}}$$

$$= 71.5 \text{ km}$$

Since the missile range for the Evolved Sea Sparrow Missile (ESSM) is only 30 km, this range for weapon control is sufficient. The extra range will allow for target tracking.

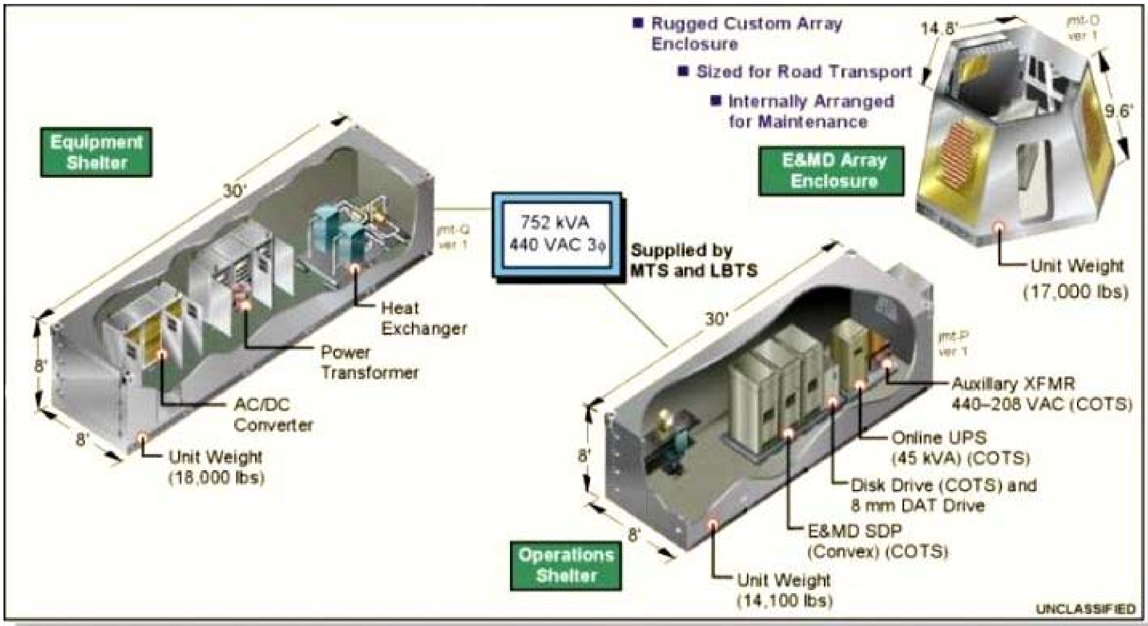


Figure 53. Estimated Size and Weight for MFR based on SPY 3

2. MK III BOFORS 57 MM NAVAL GUN

The 57 mm naval gun has robust capabilities and is installed on both the AW and USW/MIW LCS platforms. With a rate of fire of 220 rounds per minute and short firing sequences gives super accuracy five tactical freedom at all conflict levels. The stealth-designed cupola effectively shields the complete system with only the barrel exposed for the short sequence of firing. The gun is remotely operated with a gyro-stabilized local control back-up and has a maximum range of just over ten miles. The air burst ammunition is a great asset for small boat defense.

3. EVOLVED SEA SPARROW MISSILE (ESSM) AND MK 41 VERTICAL LAUNCH SYSTEM WITH MK 25 QUAD PACK CANISTER

The Evolved Sea Sparrow Missile (ESSM) is a short-range missile to provide self-protection for surface ships. It will provide the LCS with the capability to engage a variety of anti-ship cruise missiles (ASCMs) and aircraft to support self-defense. It will be more capable against low observable highly maneuverable missiles, have longer range, and can make flight corrections via radar and midcourse uplinks.

The ESSM is a coordinated effort with numerous nations in the North Atlantic Treaty Organization (NATO). This coordinated effort allows all NATO countries to have the same self-defense capability and at the same time, reduce the cost to each country associated with developing and testing new systems.

Loaded in an Mk 25 Quad-Pack canister for the MK 41 VLS, this tail-controlled missile, with Thrust Vector Control and quick start guidance section, offers a significant increase in load-out, response time, and firepower. The guidance section, which includes a radome-protected antenna for semi active homing, attaches to a new warhead section. The fore body is attached to a 10-inch diameter rocket motor, which provides higher thrust for longer duration than predecessor Sea Sparrow (RIM-7P) missiles. The ESSM will use tail control steering, whereas earlier Sea Sparrows were wing-controlled. ESSM will retain capability of the RIM-7P missile but will also have capability against maneuvering anti-ship missiles. The kinematics of the ESSM versus an ASCM is shown in Figure 54.

The ESSM takes full advantage of modern missile control technology. Inertial guidance and command mid-course navigation with options for X-band and S-band data links, Home-All-the-Way and Sample Data Homing terminal guidance provides ESSM with a broad spectrum of capabilities to meet the emerging ship defense threat.

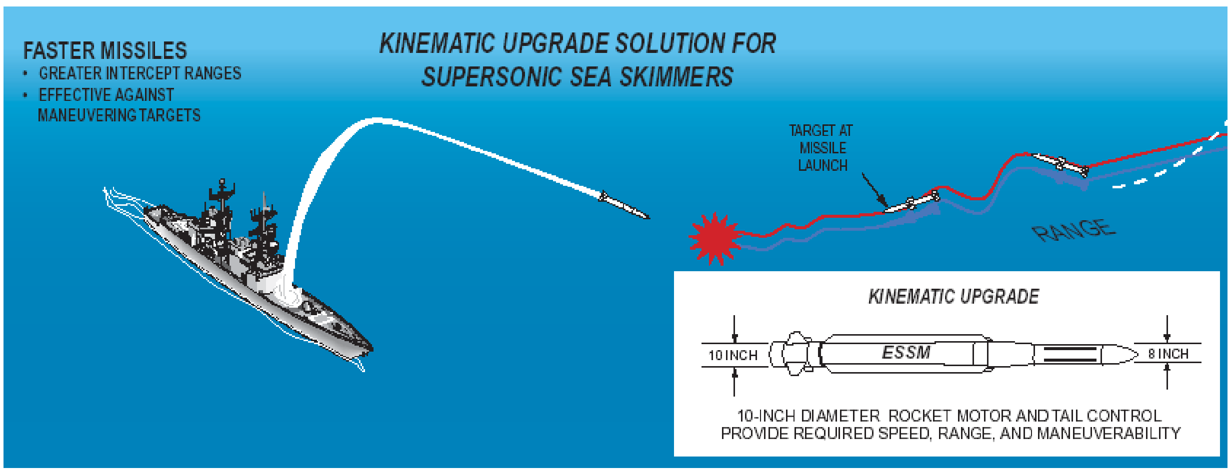


Figure 54. ESSM Kinematics against Anti-Ship Cruise Missile

D. COMBAT SYSTEMS FOR UNDERSEA / MINE WARFARE CAPABLE SEA SWAT

The combats systems associated with the LCS configured with the USW/MIW mission package contains both shipboard and airborne assets. These assets were the driving force as to the selection of the air assets that the ship could embark. There are currently no unmanned aircraft that can carry the payloads required for the Organic Mine Warfare system. As the unmanned aircraft become larger and are capable of carrying equivalent payloads to the SH-60, then the manning will be reduced on the LCS.

1. SHIPBOARD USW / MIW SYSTEMS

a) PETREL HULL MOUNTED SONAR

The hull-mounted sonar is a lightweight forward looking three-dimensional sonar that is operated hands free from the bridge of the ship with automatic monitoring for timely response of the Officer of the Deck (OOD). The hull-mounted sonar is installed on both the AW and USW/MIW LCS platforms. A sample display is shown in Figure 55 below. This high resolution, active sonar is designed for a high probability of detection and a low false-alarm rate. The sonar is available for mine/obstacle avoidance, undersea and mine warfare, navigation and underwater diver detection.

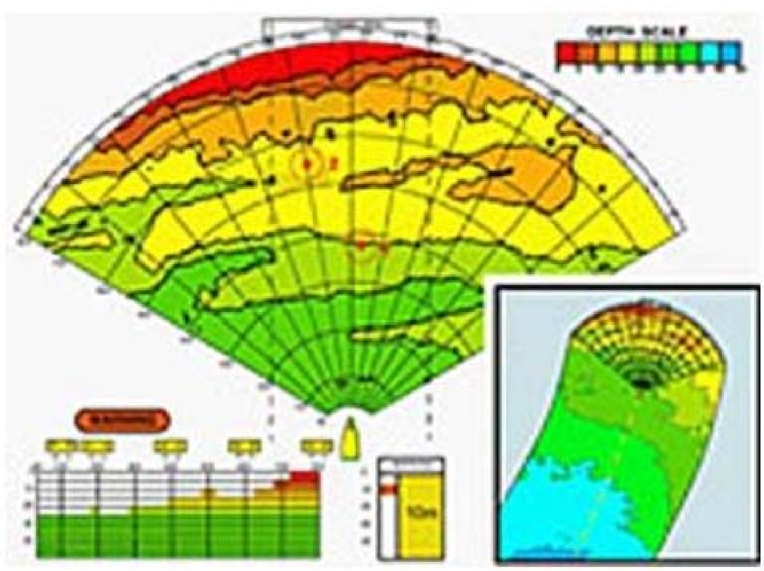


Figure 55. Hull Mounted Sonar Bridge Display

The mine/obstacle avoidance and diver detection programs of the sonar system provide location of mine/obstacle in bearing and depth, shown below in Figure 56. Sonar has a probability of detection greater than 0.99 at a range of 700 m and a probability of false alarm of less than 10^{-8}.

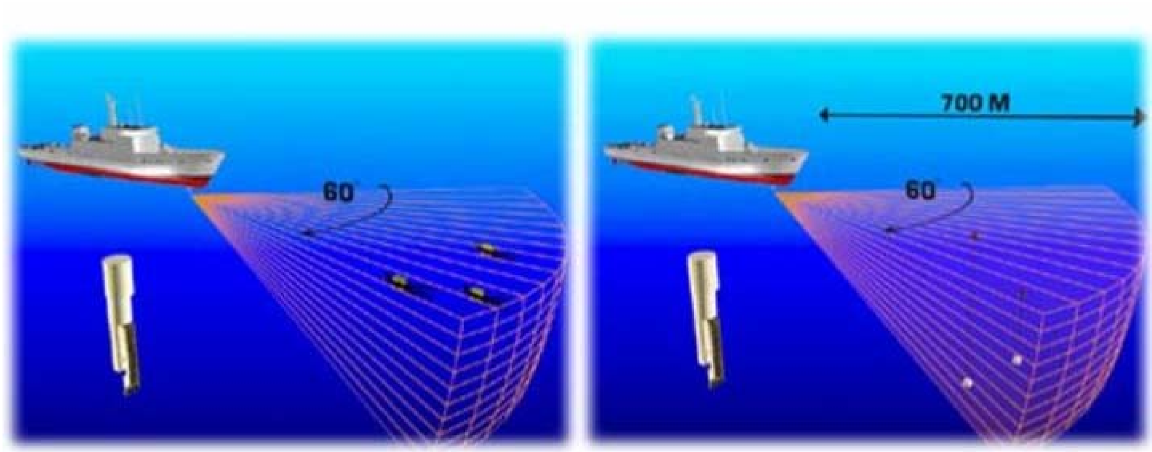


Figure 56. Diver Detection and Mine/Obstacle Avoidance

The undersea and mine warfare programs detect bottom mines and mini subs located on the ocean bottom, shown below in Figure 57. The program has a classification system by using the shadow of the mini sub on the ocean floor.

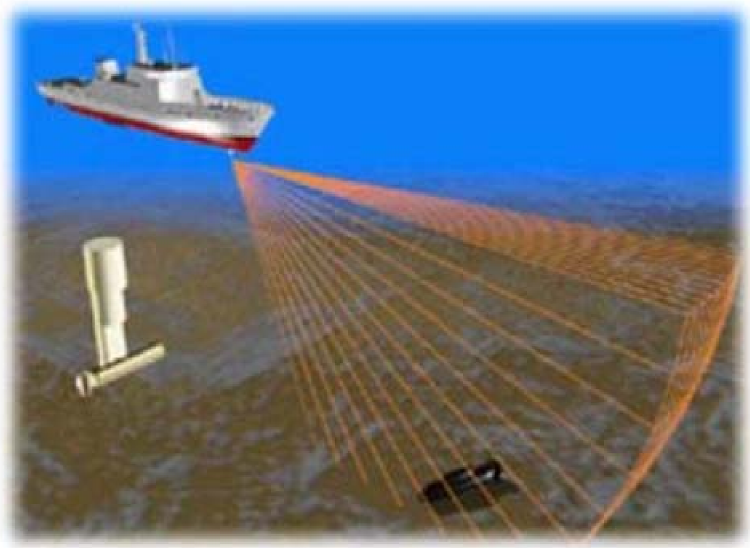


Figure 57. Under Sea Warfare Mini Sub Detection and Seabed Slope Determination

The navigation program allows for three-dimensional contours of the ocean bottom and can determine slope of the seabed as shown above in Figure 57. Due to the LCS operating in the littoral region the benefits to the aid of navigation make this system an invaluable asset to the ship.

b) EXPENDABLE MINE DESTRUCTOR (EMD)

EMD Physical Characteristics	
Size	
Length	41 in
Diameter	8 in
Warhead	Bulk charge Shaped charge Advanced Mortar
Weight	61 lbs

Table 21. EMD Physical Characteristics

The EMD is a fully automatic operating device that is typically hands-free from launch to mine destruction. There are multiple types of warheads available depending on the situation and circumstance. The EMD is rugged and reliable and can transit up to a 12-knot sprint and may operate in a sea current up to five knots. While making the final kill approach, an acoustic homing range is activated typically around 100 feet from the targeted mine.

The operating console may be outfitted for use onboard a ship or helicopter. With four selectable lights and two high-resolution video channels, in-transit video may be relayed via wide bandwidth expendable fiber-optic cables. This allows the operator to view the EMD while transiting to the target and can validate a mission kill. The physical and performance characteristics are shown Table 21 and Table 22, respectively.

EMD Performance Characteristics	
Speed	12 kts
Operational Depths	6.6 – 985 feet
Operational Duration	15 min @ 8 kts 1 hour @ 4 kts
Probability of Kill	Pk – Hard Kill: 0.9 Pk – Soft Kill: 0.95

Table 22. EMD Performance Characteristics

c) ADVANCED SIDE LOOKING SONAR (ASLS)

The Advanced Side Looking Sonar (ASLS) shown in **Error! Reference source not found.** is a high-resolution side scanning sonar that is capable of rapidly surveying large ocean areas and detecting bottom, close-tethered and moored mines. Through the use of several motion compensation systems combined with a processing system, which forms motion compensated beams, create a telephoto lens effect. The features associated with the telephoto lens effect produces real time, photo quality images with very high sharpness even at high tow speeds and heavy sea state conditions.

The ASLS, whose performance characteristics are shown in Table 23, is designed to be quickly installed or removed from the platform and is packaged in a container for ease of transportation. The tow-fish body is made of very high-strength composite material and is a lightweight system suitable for airborne operation if necessary.

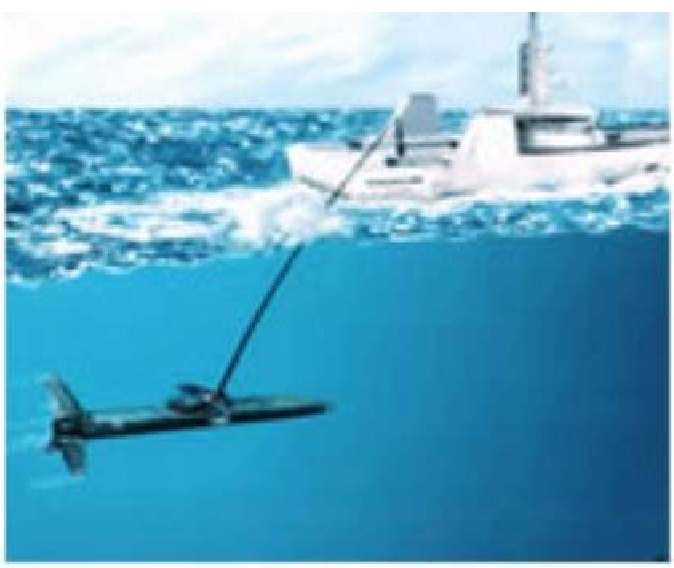


Figure 58. Shipboard Advanced Side Looking Sonar

ASLS Performance Characteristics	
Detection Range	656 feet
Search Rate	~2 nm^2/hr
Installation Time	4 hours
Shadow Contrast Ratio	>15 dB
Key Operational Features	Terrain Following Mode Active Motion Compensation

Table 23. ASLS Performance Characteristics

d) LOW FREQUENCY ACTIVE TOWED SONAR (LFATS)

LFATS Physical Characteristics	
Size	
Array and Handling	8x8x6.6 ft
Shipboard Electronic Operator Console	52x24x68 in
Deck Space Area required	10x10x10 ft
Weight	
Array and Handling	7150 lbs
Shipboard Electronics	1940 lbs

Table 24. LFATS Physical Characteristics

LFATS is a rugged, compact commercial off-the-shelf shipboard towed array sonar package that is modular and expandable due to the open architecture in the design. An effective, state of the art processing system using multiple ping wave trains, multi-dimensional target clustering and averaging allow for target discrimination against high-clutter, shallow water backgrounds. The LFATS also has the ability to cancel own-ship noise and nullify Doppler.

The workstation-based operator-machine interface allows for point and click operator control using a track-ball and push button switches. The functions and parameters may be selected and adjusted, respectfully, by utilizing the pull down menus in the program. Additional operator aids include operating mode and parameter setting recommendations based on operating conditions, automated range of day estimations, and data history recall. The ground stabilized, high-resolution displays allow for effective, flexible search, classification and geographic display formats. LFATS physical and performance characteristics are shown below in Table 24 and Table 25, respectively.

LFATS Performance Characteristics	
Source Level	19 - 222 dB/1 μPa (Omni-Directional)
Operational Frequency	.38 kHz
Operational Speeds	Operational: 3-15 kts Survivable: 30 kts

Operational Depths	15 – 300 m Max depth at 15 kts: 130 m

Table 25. LFATS Performance Characteristics

2. AIRBORNE USW / MIW SYSTEMS

The Naval Sea Systems Command's Airborne Mine Defense Program Office (PMS-210) has been working to provide an organic mine countermeasures operations with forward-deployed naval forces. The system is a suite of organic air, surface and subsurface systems that are utilized by the H-60 Seahawk helicopter. The Seahawk's ability to function as a multi-mission platform allows it the inherent ability to utilize the mine countermeasure systems.

The key components of the system include the Airborne Mine Neutralization System (AMNS), AN/AQS-20/X Mine Hunting Sonar, Organic Airborne and Surface Influence Suite (OASIS), Airborne Laser Mine Detection Systems (ALMDS) and Rapid Airborne Mine Clearance System (RAMICS).

a) AIRBORNE MINE NEUTRALIZATION SYSTEM (AMNS)

The Airborne Mine Neutralization System (AMNS) will be employed by an MH-60S helicopter to explosively neutralize unburied bottom and moored sea mines that are impractical or unsafe to counter using existing minesweeping techniques. AMNS gives operating aircraft a safe standoff range from mine detonation and reduces requirements for explosives ordnance disposal (EOD). The system is intended for use in support of amphibious operations and clearance of port approaches.

Mine destruction is achieved by shaped charges, which are integrated into the Neutralizer shown in Figure 59. Data from previous AMCM missions are used to approximate target position and determine safe helicopter-to-target standoff distance. The Neutralizers on-board camera provides target identification.

The Operator Control Console (OCC) is a modified NDI console and includes two operator seats. The OCC receives, processes, records, and displays data from and issues updated control commands to the Neutralizer.

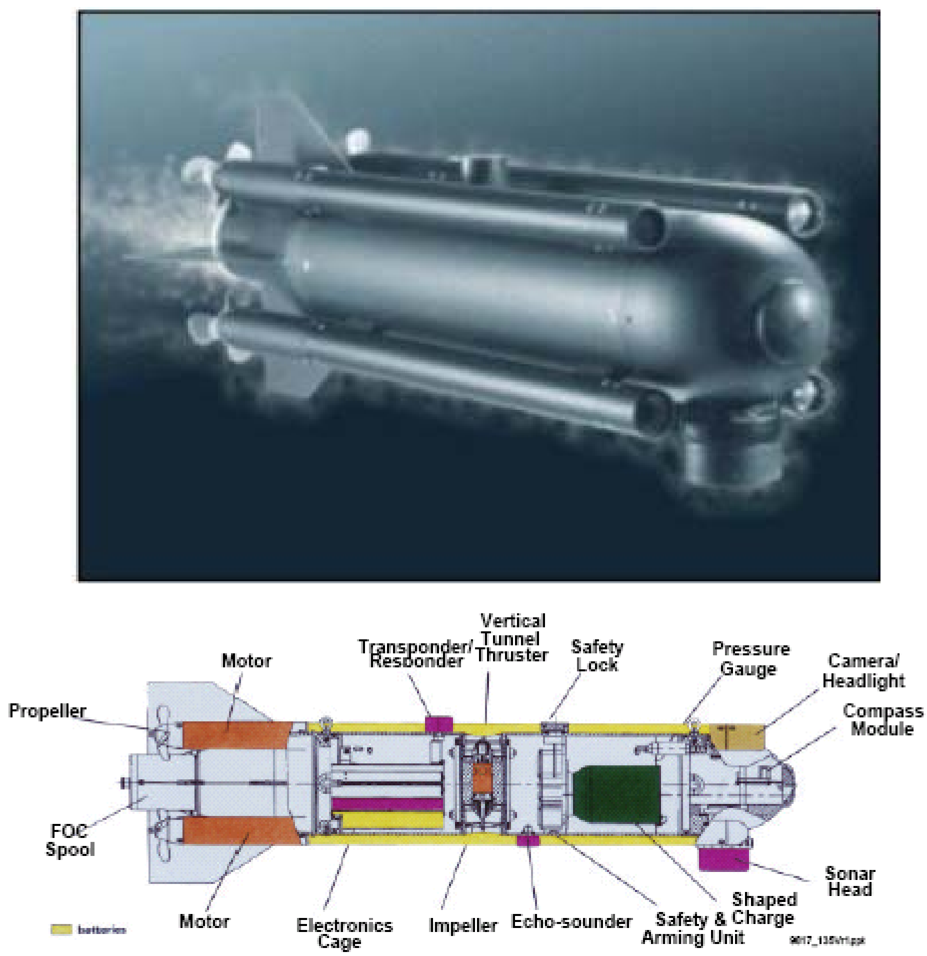


Figure 59. The AMNS Neutralizer

TABLE I-1. PHYSICAL DESCRIPTION OF THE AMNS					
COMPONENTS	DEPTH	WIDTH	HEIGHT	WEIGHT	LOCATION
Operator Control Console (OCC)	47 in	25 in	58 in	654 lbs w/o pallet 720 lbs w/ pallet	Forward Cabin
Single Winch w/Modification Kit (WMK)	NA	*	NA	2000 lbs	Middle Cabin
Davit/Sheave Assembly (DSA)	NA	84 in	22 in	150 lbs	Aft Cabin Station 522
Launch Box Assembly (LBA)	72.5 in	56 in	29 in	687 lbs w/ four neutralizers	Aft Cabin Stations 442-522
In-Water Assembly (IWA)	60 in	21 in	27 in	180 lbs	Installed in IWA Cradle on ramp
Neutralizer	51.57 in	15.35 in	15.35 in	124 lbs	Installed in LBA

* Extension/protrusion from the existing winch envelope will not exceed seven inches.

Figure 60. AMNS Components and Physical Characteristics

b) AQS-20/X MINE HUNTING SONAR

The AN/AQS-20/X is an underwater mine-detection sonar system that employs an Electro-Optic Identification (EOID) sensor. The EOID sensor is capable of locating and identifying bottom, close-tethered, and moored sea mines, and positively identifying bottom mines at tactically significant water depths. The AN/AQS-20/X mine hunting system will be deployed and operated from the MH-60S helicopter. The AQS-20/X system will also serve as the mine detection component of the Remote Mine Hunting System hosted on board Navy surface warships.

c) ORGANIC AIRBORNE AND SURFACE INFLUENCE SUITE (OASIS)

The AN/WSS-1 Organic Airborne and Surface Influence System (OASIS) provides the LCS with an organic, high-speed influence minesweeping capability against magnetic/acoustic combination influence mines. OASIS influences these combination mines by emulating surface ship acoustic and magnetic signatures to influence the mine to detonate. This magnetic/acoustic capability is self-contained and is capable of demagnetizing for carriage on the aircraft.

d) AIRBORNE LASER MINE DETECTION SYSTEM (ALMDS)

The Airborne Lased Mine Detection System (ALMDS), uses Light Detection and Ranging (LIDAR) technology to detect, localize, and classify near-surface moored and floating sea mines. ALMDS will also provide organic self-protection, mine avoidance and reconnaissance in the combat escort role. ALMDS provides a high area search rate and targeting data to the Rapid Airborne Mine Clearance System (RAMICS).

e) RAPID AIRBORNE MINE CLEARANCE SYSTEM (RAMICS)

The concept of mine clearance is to utilize the current developmental concept of Rapid Airborne Mine Clearance System (RAMICS) shown in Figure 61. Uses the LIDAR system located on the helicopter to scan the water for and reacquire shallow and floating mines. Once a mine is located, a stabilized gun mounted on the helicopter will fire 20 mm caliber, super-cavitating, armor piercing rounds optimized for traversing the water with sufficient velocity for mine neutralization. The major advantage of RAMICS is that it will neutralize shallow and floating mines with minimal risk to personnel and equipment.

Figure 61. RAMICS System Concept

E. DAMAGE CONTROL AND CHEMICAL BIOLOGICAL AND RADIATION (CBR) SYSTEMS

1. INTRODUCTION

There is no real way to totally avoid ship system casualties. A surprise attack, unforeseen threat, a missile that made it past the layered defense, or even a careless watchstander’s mistake; all are scenarios that can lead to disaster at sea. The Damage Control Philosophy of the SEA SWAT is summed up by three words --- prevent, combat, restore.

With an ever present emphasis on reduced manning, it is paramount to prevent the initial damage from cascading into much more serious casualties. Mitigation of these effects is dependent on the design of the ship, the abilities of the crew and the timeliness of initial response. The ship and its crew, working as an integrated system need to combat the fire, flooding, Chemical Biological Radiation (CBR) attack, loss of power, whichever casualty may occur, immediately after the event occurs without hesitation or time delay. And once the damage is under control the crew must restore from the casualty as soon as possible through use of sound but it some cases temporary measures. The SEA SWAT needs to be able to combat the damage, restore from the casualty and prevent it from impacting its primary mission of SEA BASE defense.

SEA SWAT will accomplish it damage control tasking through the use of innovative commercial technologies, better human-system interface, and a zonal architecture approach throughout the ships electrical mechanical and damage control systems. In addition, more highly trained personnel combined with zonal compartmentalization and a greater reliance on automated sensing and response systems will enable SEA SWAT to reduce the attendance time, which is defined as the time from when the call taker has sufficient information to mobilize resources to when the resources arrive at the given address.

2. TRAINING

In order to prevent Damage Control casualties from cascading, the crew must train to combat the casualty in a realistic environment and in real time. Waving rags and simulating damage control corrective actions without action-oriented feedback is not sufficient to make this happen. With the limited personnel permanently assigned to the SEA SWAT, the use of current shipboard training teams will not be possible.

Virtual Reality (VR) trainers, such as the one the models and simulates actual smoke and fire casualties on the ex-USS Shadwell, is one option that could break this old paradigm. Using high- speed computer processors and head mounted displays the operator can literally walk through the space and take the necessary actions to fight the fire or ventilate a space within the VR environment. Developed by the Information Technology Division of Navy Research Laboratory, this training tool could greatly help familiarize new crewmembers with both the layout of the ship and its damage control systems.

Figure 62. HMD View of Fire Compartment with Simulation Fire

Such a system would allow for execution of the operators actions in the VR environment without retribution or cause for alarm in the event of a mistake. At a minimum this technology could cut down on the countless hours at General Quarters while the boundary men are looking for zebra fittings, hatches and valves to close. As part of its implementation in SEA SWAT the software would be specifically tailored to each individual ship and have the capacity of being updated as changes and alterations are made throughout the life of the ship.

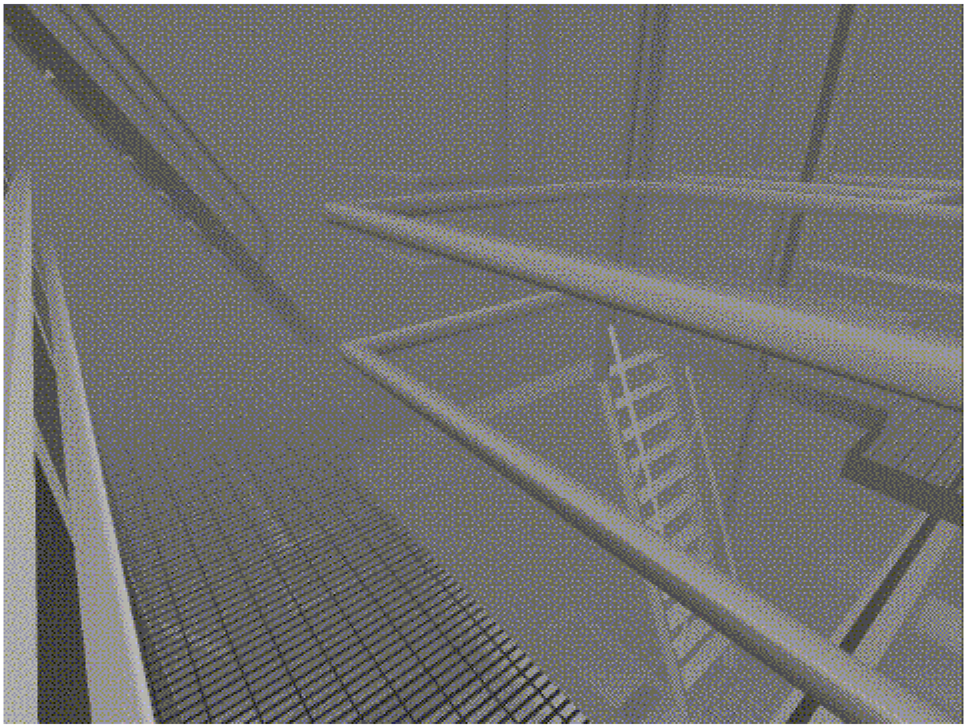


Figure 63. The ex-USS Shadwell Mock Machinery Space VR Model with Simulated Smoke

3. INTEGRATED ZONAL ARCHITECTURE

It is one thing to say that the electrical system is zonal in design, or that the ventilation system is segregated by compartment, but it quite another thing to claim that a ship is truly zonal in nature. It is essential that the ship systems and major components be integrated and arranged such that the ship can be broken up into zones that cross all major systems, including: electrical, mechanical, and damage control. SEA SWAT has been conceived to have sufficient resources available to be segregated and operate each of three zones throughout the ship independently in the event of a casualty, with the additional capability of providing service to another area that may have been damaged.

Electrical disconnects and automated bus segregation will occur instantly without operator interface in the event of a casualty. The electrical system zonal architecture and operation are discussed in greater detail in the Electrical System portion of this paper.

In the case of mechanical isolation the key is in getting it done as quickly as possible, before there is a chance for fire, flooding or contamination to spread. Mechanical isolation involves such systems as chill water, ventilation, and complete compartment closures. There will be an expanded use of automated mechanical closure systems such as the magnetically released non-watertight doors that fail in the closed position. SEA SWAT will be designed with "watertight/airtight" integrity in mind from the start. The number of watertight bulkhead and deck penetrations for stuffing tubes, ventilation ducting and piping runs will be strictly limited to specific areas where the zonal architecture will be able to adequately accommodate such intrusions without compromising the overall integrity of the zone.

Along the same principle as the mechanical and electrical systems, the Collective Protection System (CPS), which is currently in use in many surface combatants, will be designed in SEA SWAT to strategically physically subdivide the ship. Many improvements have been incorporated into the latest version of the CPS which is being employed in the LPD-17 Class currently under construction. This system, in conjunction with the more traditional electrical and mechanical isolation systems will enable a particular zone of the ship to act as a protected “citadel” in the event of a mass conflagration.

The overall concept for the zonal protection plan in SEA SWAT is to allow for an equipment source, for instance a chill water pump, to remain in operation during a casualty, proving chill water to its own zone as well as others without being adversely effected by that casualty. The service that the equipment source provides should be re-routable around not only its own zone but other zones such that if it were subsequently taken out of action its service could be replaced with a physically separate and mechanically, or electrically, isolated similar component.

4. REMOTE SENSING SYSTEMS

There is a lot of work being done in industry in the area of remote sensors. They are getting smarter, more compact, high speed, and even wireless in some cases. SEA SWAT will employ many of these innovative ideas in its ship wide damage control sensing system.

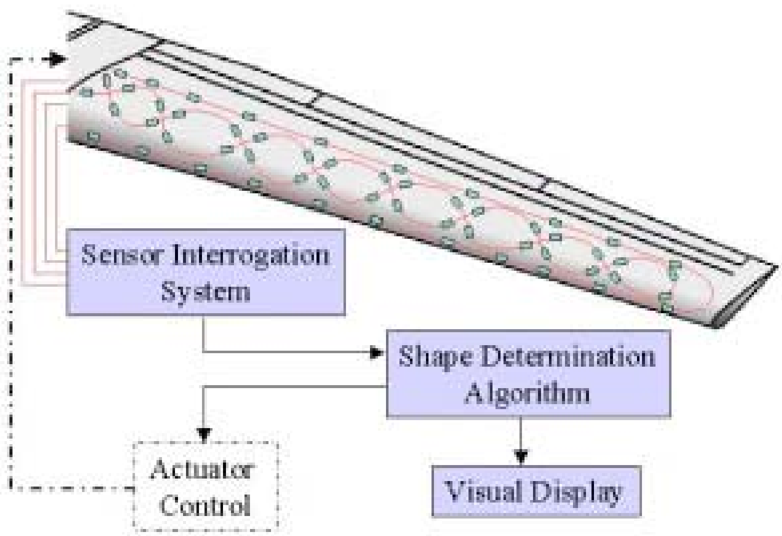


Figure 64. Force Base SPA Fiber Optic Embedded Wing Shape Sensing System

The fiber optic embedded network example shown in Figure 64 is being implemented by the Air Force Research Laboratory at Wright Patterson Air Force Base in automated control systems testing. It uses a fiber optic sensor mesh embedded into the wing surface to gather data, send it through a central processing unit and control flight parameters based on the deformation of the wing surface, all in real-time.

There are other applications of embedded sensors currently in use in industry such as the embedded networks being used to sense and transmit temperature data over long stretches in the northern oil pipelines. The embedded sensors will be found within the skin of the ship, within bulkheads, in the decks, platforms and levels. These types of simple information sensors will be used throughout the ship to create a mesh or grid with layers of sensors, which will be built upon with the addition of infrared smoke/fire detectors, liquid level sensors, humidity sensors and air content detectors. Table 26 is a matrix of sensing systems that will be employed in SEA SWAT and given locations.

Compartment	Infra-red Flame/Smoke Detector	CCTV/ Video Camera	Liquid Level Sensor	Fiber Optics Embedded Sensor	Air Quality Sensor
CIC	X				X
Bridge	X				X
Offices	X				X
Berthing	X		X	X	X
Galley & Messing	X	X			X
Passageways	X			X	X
Electronics spaces	X	X			
Pump rooms	X	X	X	X	
AC&R rooms	X	X	X	X	
Paint lockers	X				X
Engine enclosures	X	X			
Machinery spaces	X	X	X	X	
Magazines	X	X	X		X
Hangar	X	X			
Flight deck		X			

Table 26. Integrated Damage Control Sensor Matrix

Although already in use in a limited capacity, the installation of Closed Circuit Television (CCTV) and video monitoring equipment in machinery and electrical spaces will be greatly expanded in the SEA SWAT. The idea here is based on the premise that if a space is important enough for a roving watch stander to visit it during the sounding and security round, and then it should be outfitted with a camera. Video technology has improved tremendously over the last decade while the costs and physical size of the equipment has shrank inversely proportional to the picture quality. This is an area where Commercial Off the Shelf (COTS) technologies will be of great benefit to the Navy of the future. Relatively inexpensive and expendable video units will be outfitted throughout the ship.

Some locations will have fixed cameras, while others would have zoom and pan control through the watch stander at the Damage Control Central (DCC), Central Control Station (CCS), Pilot House or some other relevant location in the ships command and control system Shipboard Wide Area Network (SWAN).

SWAN is a fiber optic centralized computer network that will encompass many information flow aspects throughout the ship. The ships command and control, communications, combat systems suite, VR training and even Internet access will be handled by this large area computer network having hundreds of drops throughout the ship.

5. AUTOMATED RESPONSE CASUALTY CONTROL

Now we will concentrate on one type of casualty response, it this case the most common and perhaps most threatening, a fire at sea. First we will look at the automated response systems employed in SEA SWAT and the integral role that they will play in combating the damage in the Littoral Combatant Ship of the future. Following is a discussion of various automated response systems that have been chosen for use in SEA SWAT based on current maritime accepted commercial practices. It is suspected that such systems will continue to improve and will remain viable options in fire suppression.

Figure 65. Water Mist System Spray Pattern

The Water Mist System operates at approximately 1000 psi, atomizing fresh water to quickly cool the flames and remove the heat element of the fire triangle as well as depletes the oxygen that fuels the fire. It is a low water consumption system with high efficiency as a result of the dense fog that is created. This in turn results in less damage to equipment, less impact on the environment, use of lightweight piping and reduced space requirements. Spraying smaller than 300-micron water droplets (1 micron = 1/1000 mm), it is good against gaseous fires, liquid pooling fires, and electrical fires. It would be primarily used in the common areas such as passageways, crew living areas, and storage areas with limited application in engineering spaces and weapons magazines.

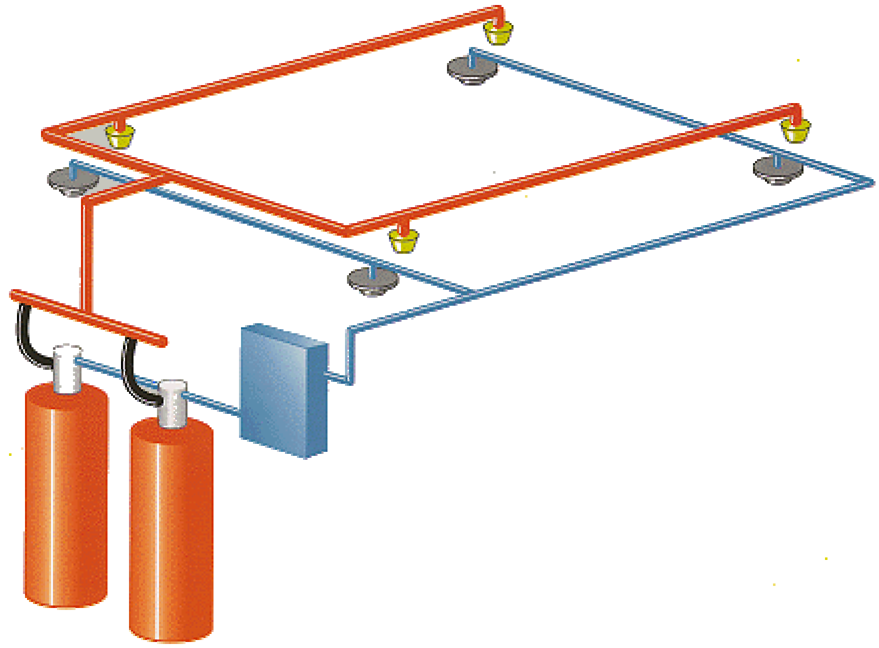


Figure 66. FM-200 (HFC-227) Fire Suppression System

The next system that SEA SWAT will employ in its automated response will be the FM-200 (HFC-227) Fire Suppression System. Chemically known as heptafluoropropane, it is an alternative fire suppression agent to Halon 1301. It is currently manufactured in the United States by Great Lakes Chemical as FM-200 and the DuPont Corporation under the product title of HFC-227. Safe to release in the presence of watchstanders, it is very desirable since there is no time delay involved in getting the watchstanders out of the space, as was true with Halon 1301. Additionally it is environmentally safe and is not an ozone depleting substance. Its application would be primarily in the engineering spaces and those spaces containing a high density of electronics components.

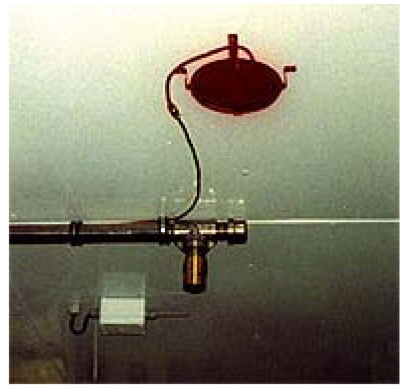
 

Figure 67. Flood System Storage Cylinder, Sensor and Nozzle

CO_2 Flooding, from cylinder bottles, in use on Navy ships since the1940's, will continue to play an important role in putting out fires in enclosed engineering spaces. When discharged into the space, a large portion of the liquid CO_2 flashes to vapor and the rest is converted to fine dry-ice particles. There are associated CO_2 hose reels for manual entry into a space. It is especially beneficial in the electrical/electronics spaces where water damage is costly. The obvious disadvantage to this system is that the space must be evacuated first by all watchstanders prior to release of the agent.

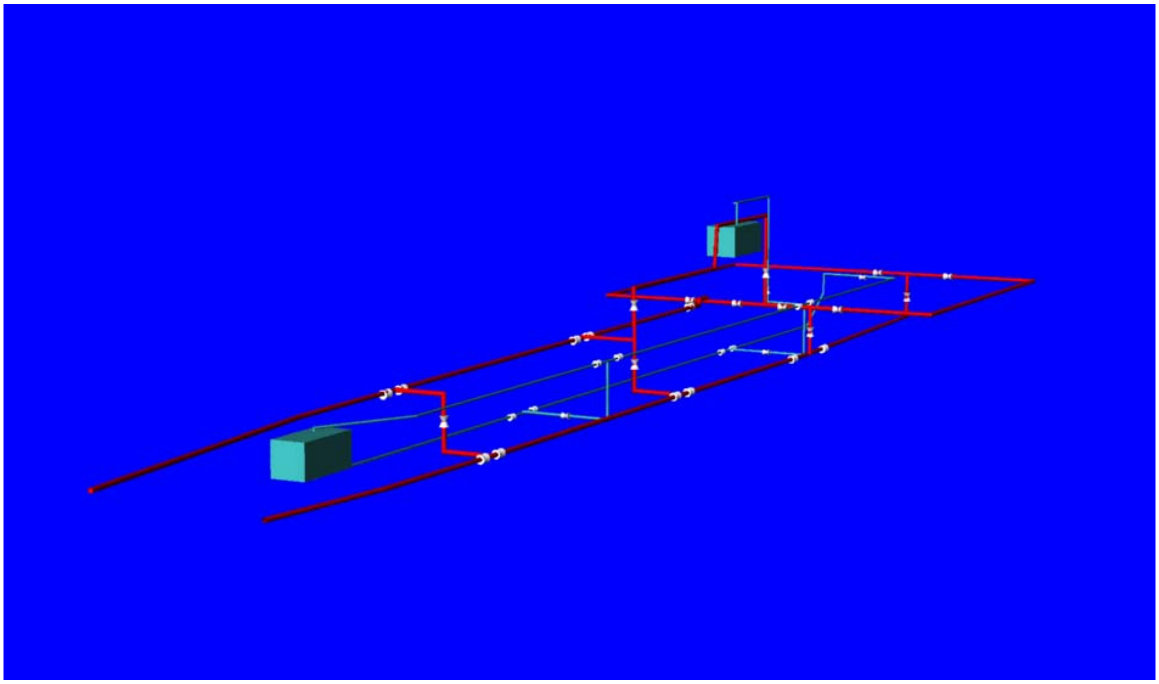


Figure 68. Firemain and AFFF System Loops

Aqueous Film Forming Foam (AFFF), also in use for many years in the Navy, will be used in SEA SWAT. This relatively simple yet effective system that combines seawater fed from the firemain with the AFFF additive at a ratio of 94% to 6%, is still one of the most effective agents for separating the fuel from the fire. The system will be a vertically split loop with two 600 gallon main charging stations, one located forward of the main gun battery and the other suspended in the level above the helicopter hanger. AFFF is primarily used against flammable liquid fires. Both low-capacity and high-capacity AFFF systems will be installed to combat fires in machinery spaces, fueling areas, helicopter hangers and the flightdeck. Figure 68 shows the firemain (red) and AFFF(turquoise) loops while Figure 69 illustrates their notional layout within the ship.

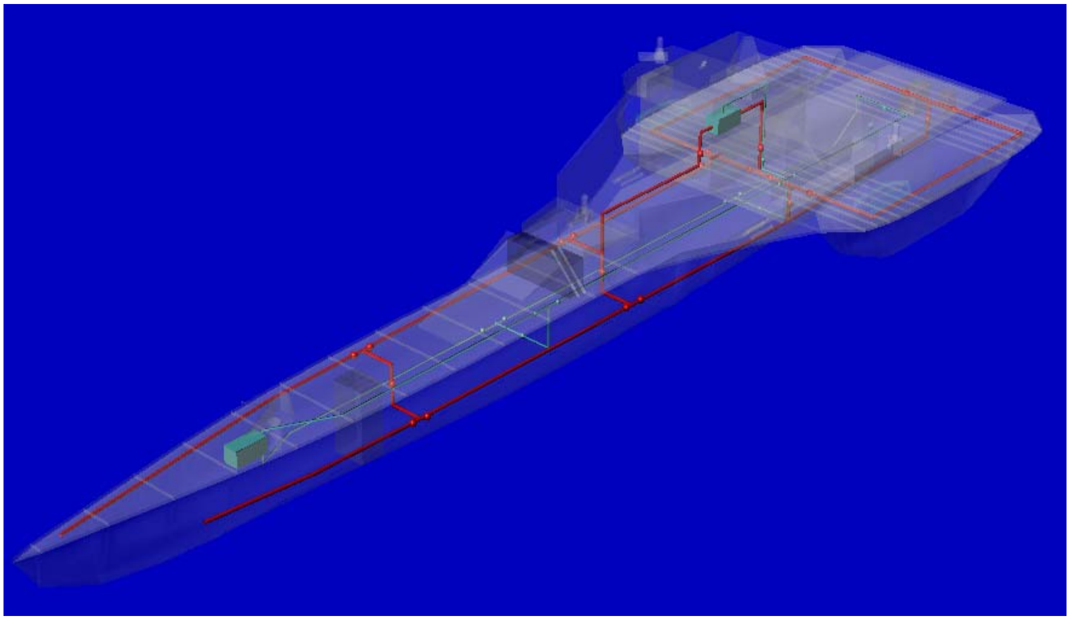


Figure 69. Firemain and AFFF System Notional Layout

SEA SWAT will employ a standard150 psi firemain that is designed as a combination newtwork with a vertically split loop forward and a horizontal loop back aft running just beneath the flightdeck. Both the AFFF and firemain systems will be cross-connected and segregated by zone for maximum efficiency and redundancy. These systems will draw from a common set of seachests as is typical in current surface combatant design practice.

As is apparent from the automated systems listed in Table 27, there is a layered response throughout the ship, with a heavier concentration of systems in the critical areas such as the main engine rooms, electrical spaces and helicopter hanger area. This system redundancy will ensure that SEA SWAT is adequately protected by its automated response system as its first line of defense in casualty control.

Compartment	FM 200	CO_2	Water Mist	AFFF
CIC	X			
Bridge	X			
Offices	X			
Berthing			X	
Galley & Messing			X	
Passageways			X	
Electronics Spaces	X	X		
Pump rooms	X	X		
AC&R rooms	X	X		
Paint lockers	X	X		
Engine enclosures	X	X		
Machinery spaces	X	X	X	X
Magazines			X	X
Hangar			X	X
Flight deck				X

Table 27. Damage Control Automated Response System Matrix

6. HUMAN SYSTEM INTERFACE

The concept that SEA SWAT's crew will use is to fill out two damage control teams that will respond to casualties out of two main repair lockers, one located forward and one aft. Additionally there will be numerous satellite sites throughout the ship containing basic damage control gear and equipment. The teams' response would be coordinated from a centralized location such as DCC or an alternate location accessible through SWAN.

Two important features that the human system interface will provide are first, an accurate personnel identification and tracking system and secondly a universal ability to access to key information necessary to combat the casualties. Envisioned as a computer chip incorporated into a crewmember's dog tags, or as a bracelet or perhaps a tiny transmitting device worn on a belt loop, the personnel identification and tracking system would provide an interlock for automated systems to keep from indivertibly dumping hazardous agents with watchstanders still in the space. Additionally, each crewmember would be provided a Supplemental Emergency Egress Device (SEED) as standard issue while serving in SEA SWAT. The SEED, roughly the size of a one Liter soda bottle, provides 5 minutes of oxygen with which the watchstander can escape from a smoke filled space.

Figure 70. Damage Control Party Accessing a Space

With fewer crewmembers available for damage control duties, the emphasis will be on letting the automated systems, the ship's first response, do their job. Thus the repair locker personnel would serve as secondary defense in combating the damage. This way the damage control command and control team will have time to formulate their response based on software programs that predict progressive fire and flooding effects based on damage control party actions. Software similar to DC-Train 2.0, based on the Minerva-DCA (real-time problem solver capable software), is one such application that would allow for sound guidance from DCC to the on-scene leaders in targeting and effectively containing the casualty at its source. Based on operator training and an extensive database this kind of action response planning tool is vital in future damage control operations.

A reduction in the damage control party will be achieved by use of the integrated sensor system and automated response system. Video monitoring as a means of remote casualty investigation will allow prompt and correct reactions based on information collected and processed through SWAN. Potentially, the scene shown in Figure 71 with an investigator dragging large bag of tools along will be a thing of the past on SEA SWAT.

Figure 71. Investigator Grabs Gear out of Repair Locker

Furthermore cross training of repair locker personnel as utilityman, not in specific positions will enable the first person on the scene, or at the locker to do whatever action is necessary. This will save precious seconds that could make all the difference in effectively controlling the damage. The use of wire-free communications and SWAN drops for data input on-scene will free up phone talkers and messengers from the damage control party manning list.

In short, the primary job of the damage control parties in SEA SWAT will be to make sure that the automated systems did there job as anticipated. Secondly the damage control parties will ensure that the reflash watch is set so as to prevent the progression of any further damage. They will also be charged with restoring the ship's systems so as to put personnel and systems back in an environment in which the SEA SWAT can execute its primary mission of SEA BASE defense.

7. CASUALTY RESTORATION

Even though the SEA SWAT concept was designed with a typical steel superstructure and hull in mind, there is promising work in composite superstructures currently underway; notably the AEM/S masts on the LPD-17 and other smaller surface combatants such as the Swedish Navy's Visby Class. Inasmuch, there are currently items available in industry such as water-activated foam filling compound that can expand to fill up a space that has been hit and has a large hole freely communicating with the sea. Instead of shoring the space, if practical, the space can be sealed and filled with the agent that replaces the lost buoyancy, enabling the ship to recover maneuverability and seakeeping lost in the casualty. Also available are items such as two part epoxy quickset patches that are currently used in a limited manner for pipe patching and other uses, but have the potential to be used as a sort of self-healing ship's skin. The addition of Kevlar cladding to the superstructure, critical piping and cable runs is also a means of allowing for quick return after a casualty. Kevlar is relatively lightweight at 0.8lbs per sq. ft. The added weight for armor plating necessary to withstand up to a 9mm round is 2.0lbs per sq. ft. Much more versatile than steel plate armor, Kevlar would allow for the ship to take fragmentation hits, termed as soft kill devices, thus preserving critical systems functions.

As a final step in the restoration process installed smoke ejectors, drainage and eductors will be located within each of the zones. These simple yet effective devices will aid in freeing up additional personnel from the damage control parties while adding to the depth of protective systems found in SEA SWAT.

8. CBR DEFENSE

A standard suite of chemical biological and radiological defensive protective and sensing systems will be employed in SEA SWAT. Table 28 briefly outlines the threats that SEA SWAT's CBR Defense system will warn and guard against.

Chemical	Nerve, Blister, Blood, Choking Agents
Biological	Toxin, Bacterial, Viral, Fungal Infection
Nuclear	Blast and Level Radiation

Table 28. Common CBR Threats

The Improved [Chemical Agent] Point Detection System (IPDS) is a chemical detection system that automatically detects and alerts to chemical agents vapors present in the air. It will be externally mounted on the superstructure with control and display units on the bridge.

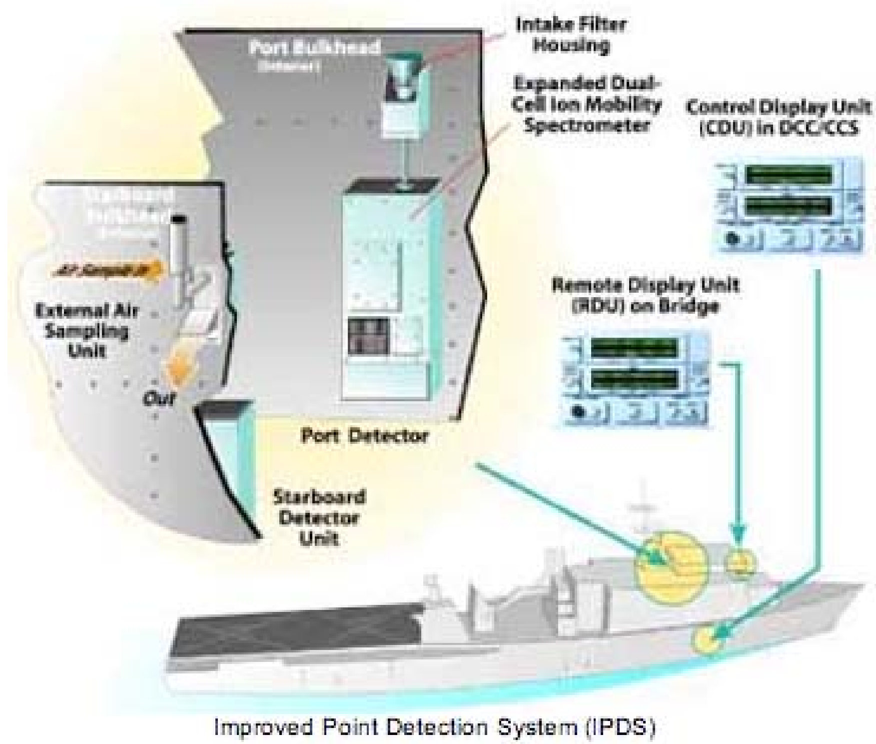
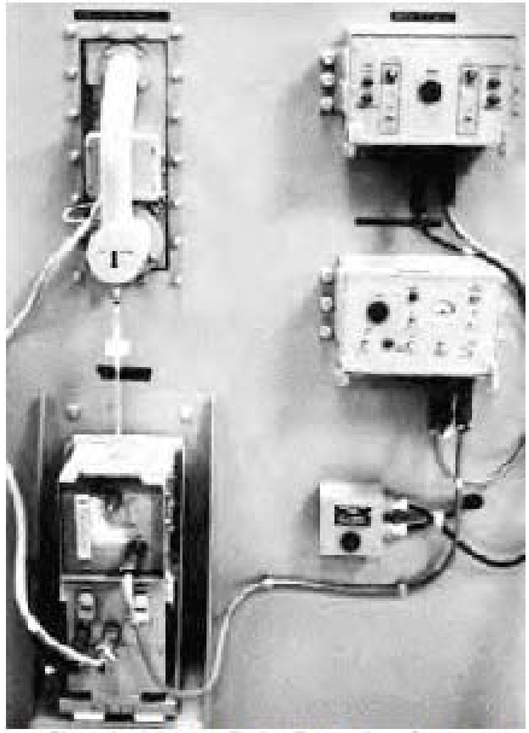


Figure 72. Improved Point Detection System

The next system that SEA SWAT will use is the Shipboard Chemical Agent Point Detection System (CAPDS) is a fixed system capable of detecting selected chemical agents in vapor form using baffle tube ionization. It obtains a sample of the external air, ionizes the airborne vapor molecules and collects them on a charged plate after eliminating lighter molecules via the baffle structure. When sufficient ion mass is collected an alarm is sent to the Bridge. It will be mounted atop the superstructure as well.



Chemical Agent Point Detection System
(CAPDS)

Figure 73. Chemical Agent Point Detection System (CAPDS)

The Interim Biological Agent Detector (IBAD) can detect, identify and warn of the presence of biological agents. The IBAD is composed of a particle sizer/counter, particle wet cyclone sampler, and manual identifier. It will be mounted under the bridgewings and alarm on the bridge upon detection of a hazard.

Figure 74. Interim Biological Agent Detector (IBAD)

Shipboard Collective Protection System (Ship CPS), as previously discussed will provide a contamination-free environment within specified zones. These zones will be pressurized and supplied with filtered air, providing a citadel for crewmembers. CPS is an integral part of the HVAC system onboard SEA SWAT.

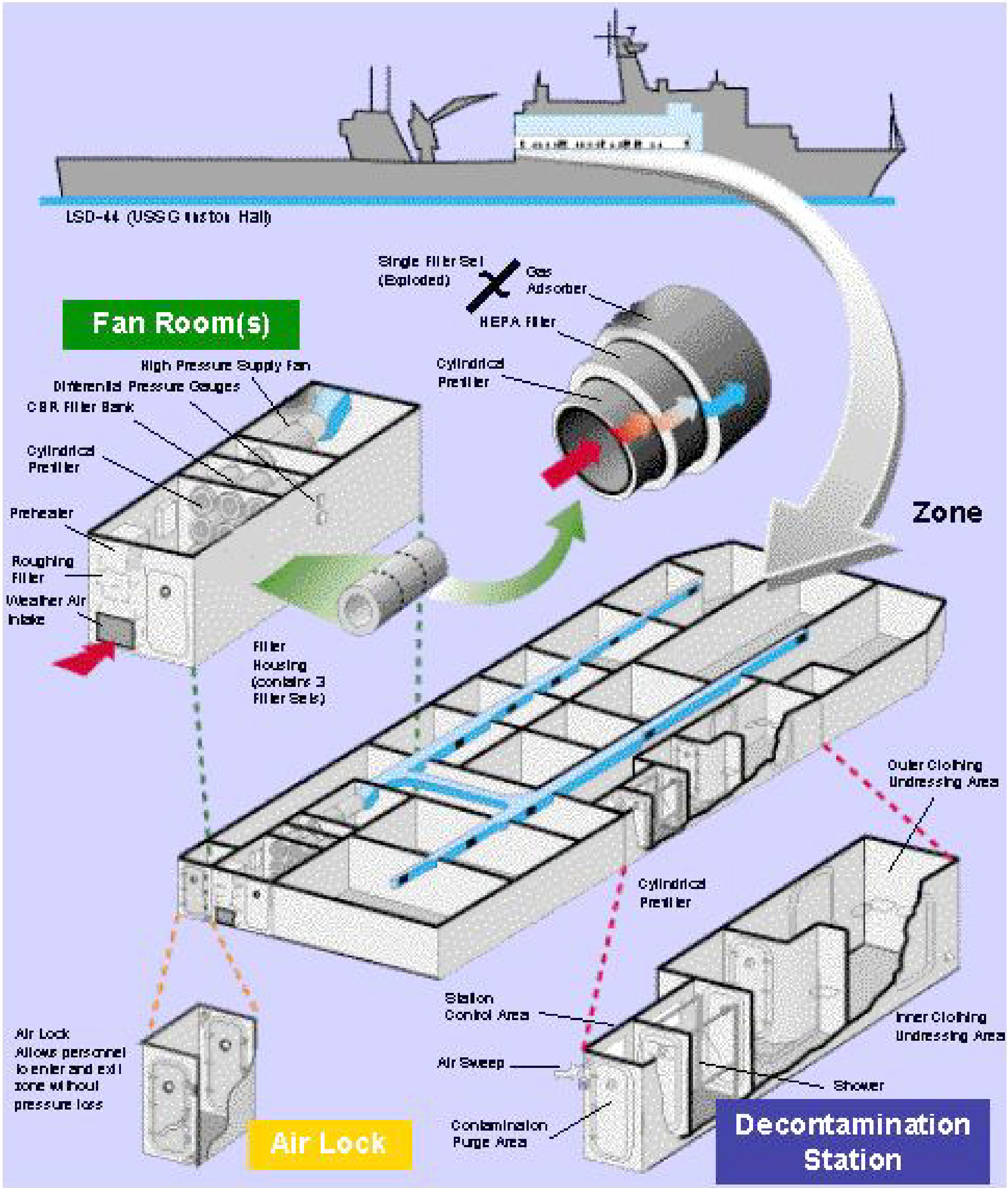


Figure 75. Typical Collective Protection System Installation

The last major system in the CBR layered defense of SEA SWAT is the Ship Countermeasure Wash Down System (CMWDS). It consists of piping and a series of nozzles that spray salt water on weather decks and other surfaces. The film is designed to retard the further accumulation of and facilitate the removal of foreign agents.

Figure 76. AN/KAS-1A

Based on the forward-looking infrared (FLIR) electro-optics sensor technology, the Chemical-Biological threats directional detectors (AN/KAS-1A) detect the presence of chemical agents from a distance. Infrared detectors provide night vision capability for shipboard security. There will be one of these units on either side of the bridge.

9. DAMAGE CONTROL SUMMARY

With and increase reliance on installed damage control sensing systems and automated response systems SEA SWAT possess the ability to better prevent, combat and restore from casualties. The crew will be in a position to gain better situational awareness through use of SWAN. By leveraging on the improvements made in industry through the exclusive use of COTS equipment, SEA SWAT will be to stay current with the latest damage control systems and equipment throughout its ship life, making for a more survivable asset to be used in defense of the SEA BASE.

F. MANNING AND HABITABILITY

1. REDUCED MANNING CONCEPTS

In efforts to reduce manning the team's first step was to identify all required watch stations. The easiest way of accomplishing this was to develop a Condition One watch bill for each weapons package. The watch bills were created with the idea of low maintenance design of equipment and vast use of automation on the ship. The watch bills created included a required repair party of 57 people and resulted in a minimum required manning of 111 –AAW and 115 - USW. These minimum manning would have the ship in one section rotation. Therefore, the following steps were taken to calculate the required manning for three-section rotation, a normal watch rotation for combat vessels. The repair party numbers were subtracted and the remaining required equipment stations were doubled to yield 108 and 116, respectively. Then the repair party quantity of 57 was added back in to yield required manning to be 165-AAW and 173-USW, both required manning is enough for three-section rotation. Since the weapons packages are exchangeable on the same platform the required berthing is based on largest weapons package requirement, USW. Also since the vessels will be required to house up to three helicopter detachments, the required berthing will be 173+15 yielding 188.

To help reduce manning the following concepts were employed: Condition based Maintenance, self-diagnostic and self-healing software, computer automation in Combat Systems and Engineering, and increased level of training thus increase crew skill level resulting in high versatility. Condition base maintenance is a concept, which reduces unnecessary maintenance, by monitoring the systems a regular basis, reading such as voltage and pressure. Once the measured quantity reaches an established limit, maintenance will be conducted instead of the current system of quarterly or annually maintenance. The monitoring and resultant maintenance will b e preformed by ship's crew but since the maintenance is conditional less maintenance is required and thus less people are required. The idea of full automation leads to a heavy use of computers and with computer there comes the software. Self-diagnostic and self-healing software means that if a problem exists in the computer software the computer runs a diagnostic, locates the problem and takes creative measures to fix the problem. The current concept of self-diagnostic and self-healing software will reduce the time the system is down and the people required to diagnostic and repair the program in the computer software. The electrical distribution systems full automation design prevents the need for personnel to switch loads or buses in time of causality. Another effort to reduce manning in engineering is the use of electrical drive. This concept reduces the amount of mechanically linked systems thus reducing the mechanical systems, which are high in maintenance and potential problems, and the crew required to complete such maintenance and casualty control. The use of sensors and computer monitors can send all required data to a central location (CCS) and only one or two people will be required to monitor the output of engineering equipment.

The area of damage control the ship will employ SWAN (Ship Wide Area Network), which is a network of sensors located throughout the ship and will be used to locate problem area and provide information to other computers which will then take corrective action. This automation reduces the need for investigators, the damage caused by the problem, and repair efforts thus reducing the men needed for damage control.

An additional area to reduce manning is in the area of training. There exists a ship virtual reality training program which allows the crew to experience casualties more realistically but in a controlled environment. This program increases the crew knowledge and experience making the crew more versatile and better prepared and thus reduces manning. The additional benefit of the training program is the elimination of Engineering Training Team members. If a combat system virtual reality program can be designed for the future use the respective combat system training team will also be eliminated.

2. HABITABILITY AND BERTHING

Following the determination of the size of the crew, the berthing and galley facilities were designed according to Navy Regulations. The commanding officer sea cabin will require 138 ft^2 in accordance with Figure 77.

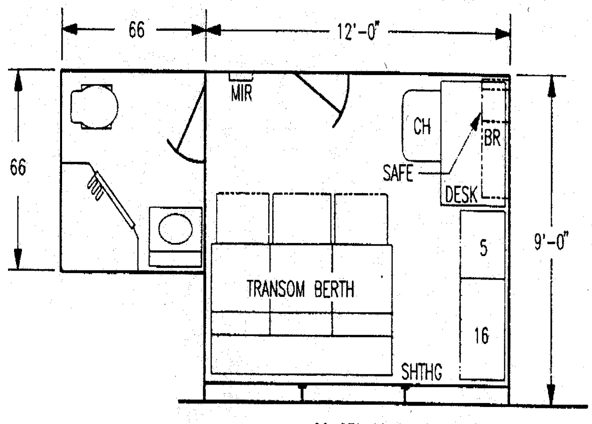


Figure 77. CO Sea Cabin and Bath

The executive officer's stateroom will be located in officer's country and consist of 195 ft^2 in accordance with Figure 78.

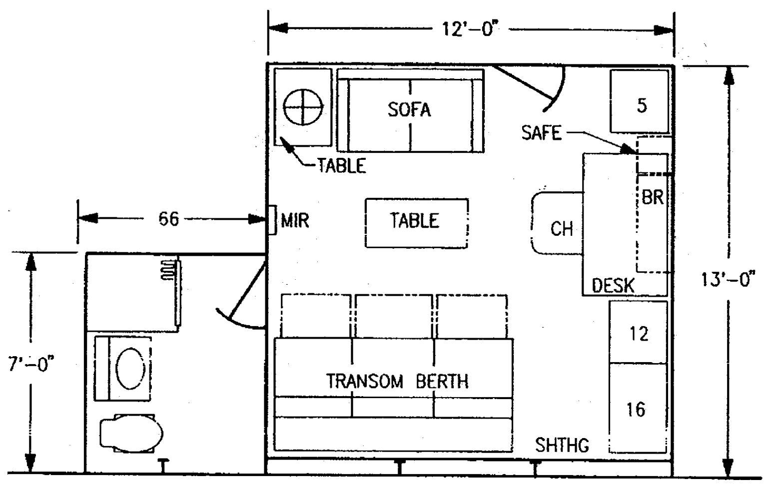


Figure 78. CO / XO Stateroom and Bath

Eighteen officers in addition to the CO and XO will be assigned to the LCS (12 ship's company and 6 from the helicopter detachments). Two officers will be assigned per stateroom with each requiring 108 ft^2 in accordance with Figure 79.

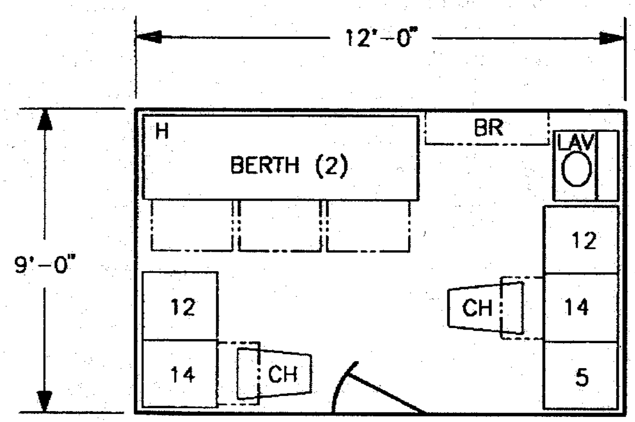


Figure 79. Officer Stateroom

Twelve CPO's will be assigned to the LCS. Twelve CPO's will be assigned per berthing spaces in accordance with Figure 80 requiring approximately 450 ft^2.

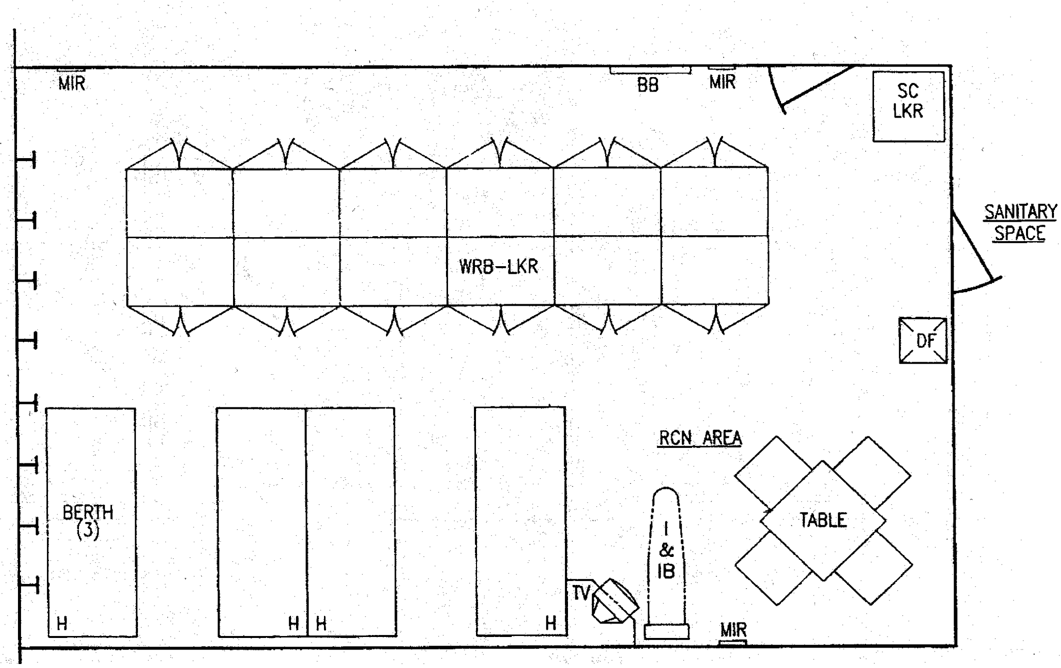


Figure 80. CPO Berthing

156 enlisted personnel, not including CPO's, are assigned (147 ship's company and 9 from the helicopter detachments). This will require four berthing compartments consistent with Figure 81 providing 1350 ft^2 each.

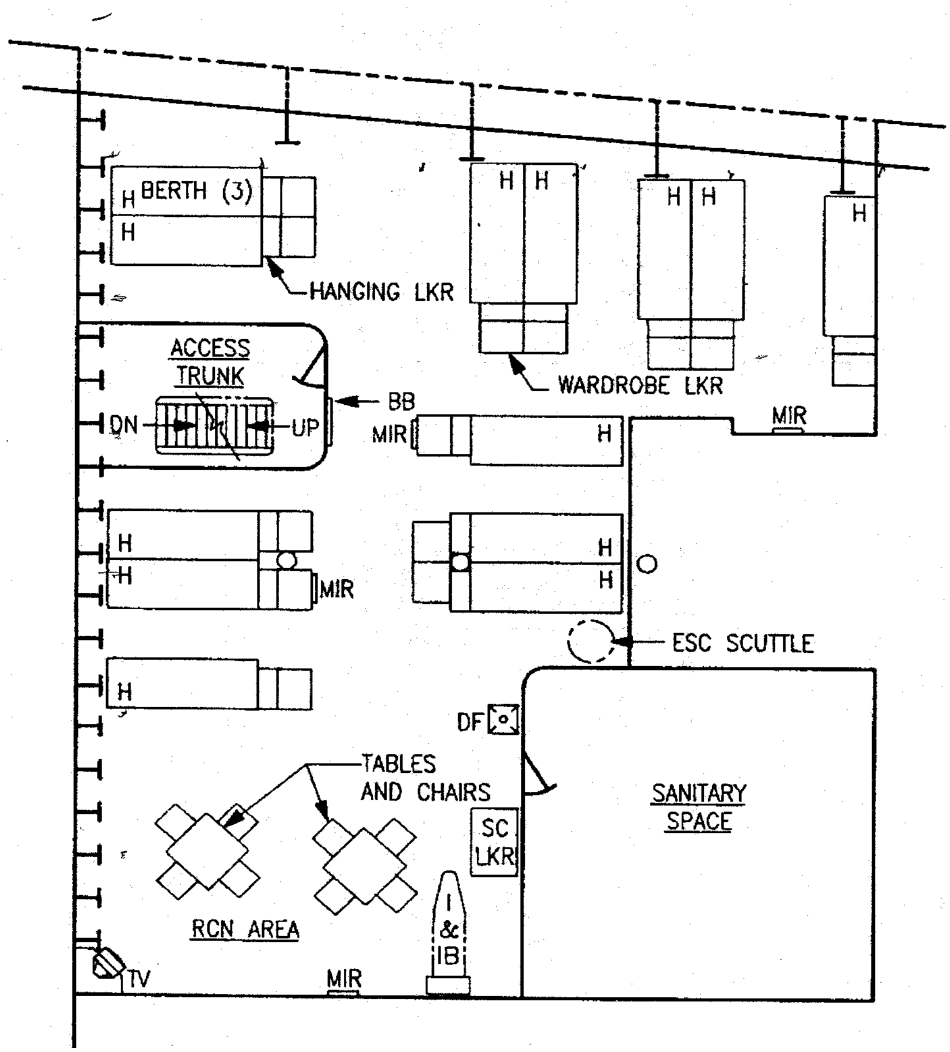


Figure 81 Crew Berthing

A centralized galley concept will be employed aboard the LCS consistent with Figure 82 and Figure 83.

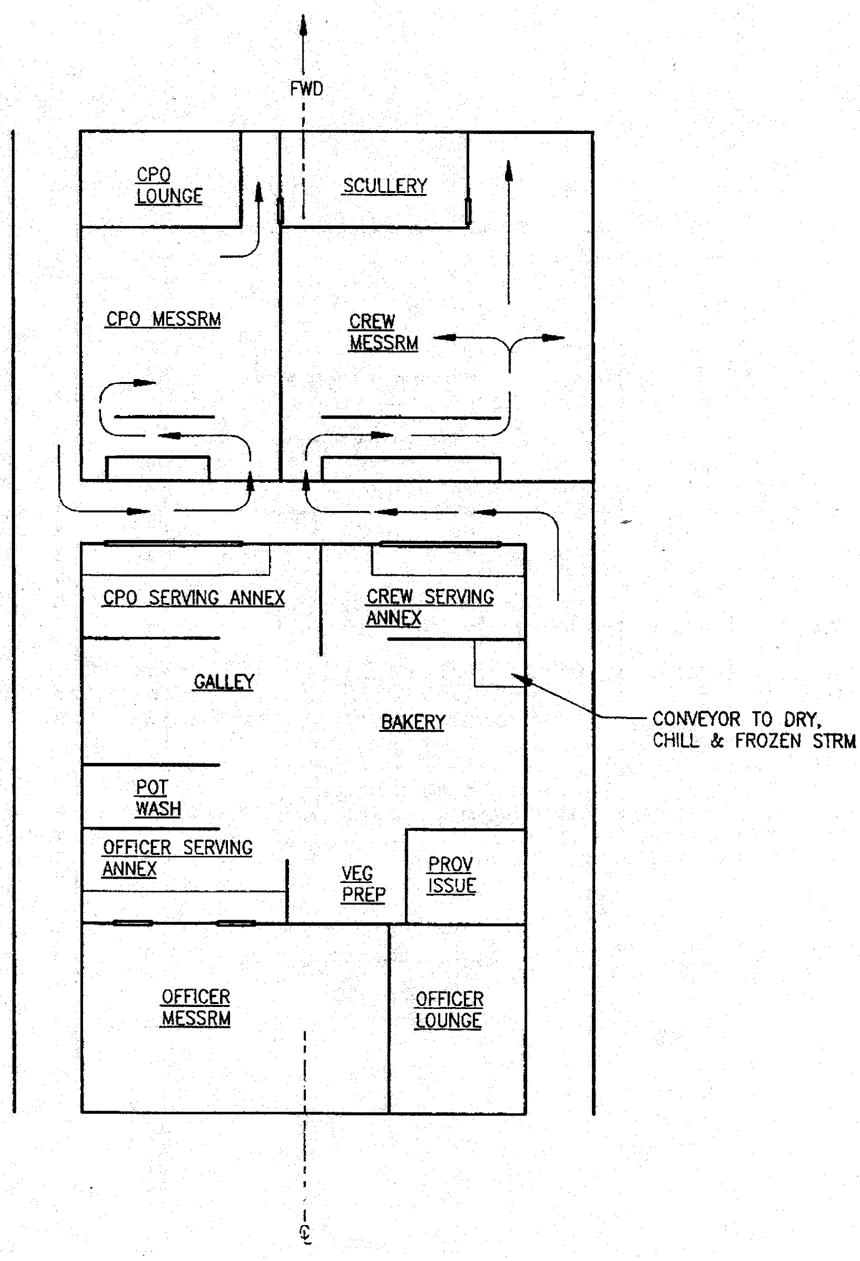


Figure 82 Centralized Galley

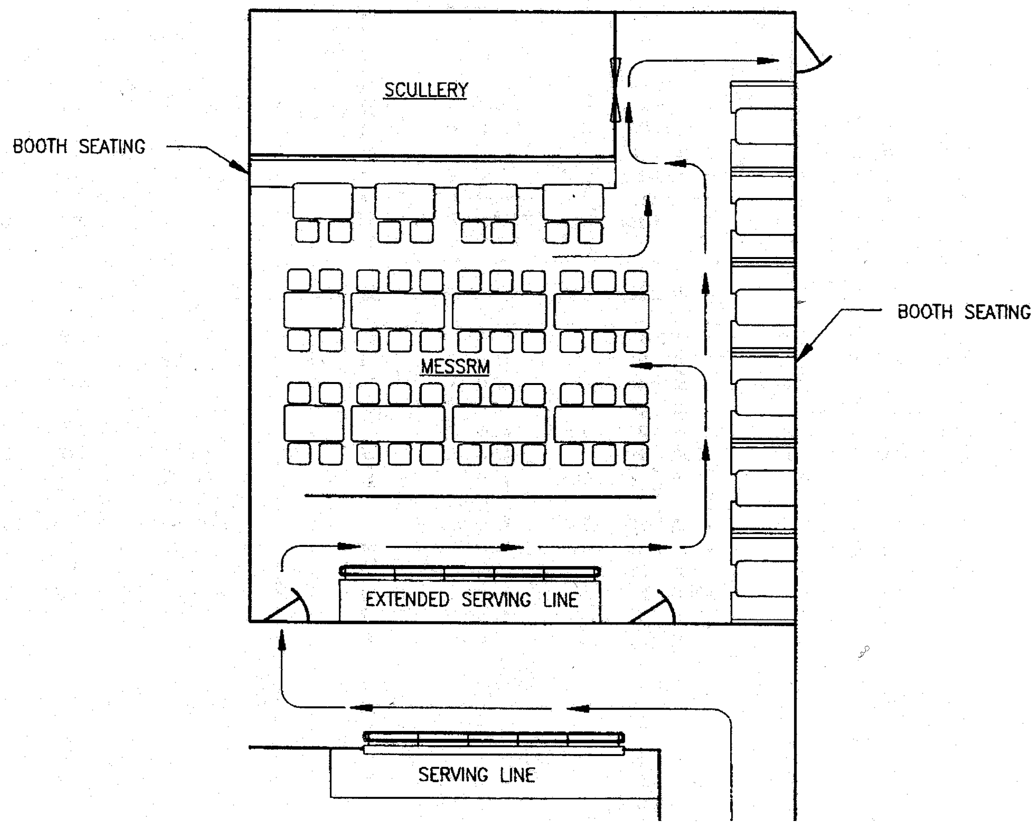


Figure 83 Crew Galley

G. ENVIRONMENTAL CONCERNS

SEA SWAT was designed to operate without disturbing the environment. SEA SWAT complies with all EPA and NAVOSH regulations and has many systems that are environment friendly. Below are descriptions of two major systems that will prevent environmental disaster.

1. CHT SYSTEM

This system is designed to accept soil drains from water closets and urinals and waste drains from showers, laundries, and galleys. As the name of the system implies, sewage collection, holding, and transfer are three functional elements, which constitute the CHT system.

a) COLLECTION ELEMENT

The collection element consists of soil and waste drains with diverter valves. Depending on the position of the diverter valves, the soil or waste can be diverted overboard or into the CHT tank. The basic CHT system concept requires that waste drains be kept separate from soil drains wherever practical until they reach their respective overboard diverter valves. Downstream of the overboard diverter valves both waste drains and soil drains may be combined into a single drain line. All drains above the waterline may be diverted overboard by gravity. Drains located below the waterline cannot be diverted directly overboard and must use the CHT system as an ejection system. In this case, the CHT system must operate continuously in all modes. All drain piping is pitched to insure rapid and complete drainage. The pitch is 1/4-inch per foot whenever possible, but not less than 1/8-inch per foot relative to the operating trim.

Garbage grinder drains connected to the waste drains are installed with a minimum slope of 3 inches/ft. Garbage grinder drains are also pro-vided with a check valve to preclude back-flow from the waste drain and a diverter valve to permit drainage to either the CHT tank or overboard. When the garbage grinder employs seawater for flushing, the waste piping downstream of the garbage grinder is of copper-nickel alloy.

Plumbing drains may penetrate watertight bulkheads. Usually, each bulkhead penetration below flooding water level is provided with a bulkhead stop valve. The stop valve is operable at the valve and the damage control deck. Diverter valves also may be used to prevent progressive flooding throughout the CHT system drains, eliminating the need for the bulkhead stop valves.

b) HOLDING ELEMENT

The CHT tank is usually sized for a 12-hour holding period. Individual ship constraints may affect this design objective. Each tank has inside surfaces, which are usually free of structural members such as stiffeners, headers, and brackets. The tank bottom slopes approximately 1.5 inches per foot toward the pump section. All internal surfaces of the tank are coated in accordance with procedures given in the Naval Ship's Technical Manual chapter 63. Each CHT tank is fitted with a vent to the atmosphere and an overflow to the sea. In addition, a manhole is provided for internal maintenance. Vents should be positioned to avoid intake of CHT gases into the air compressor or ventilation intakes.

c) TRANSFER ELEMENT

Each tank is equipped with two non-clog marine sewage pumps connected in parallel. The pumps may discharge sewage to a tender, barge, shore facility, or directly overboard, depending on the position of the discharge diverter valve. Each pump is equipped with full-port plug or ball suction and discharge valves, and a discharge swing check valve with a hold-open device.

d) SYSTEM TYPES

Two types of CHT systems may be installed. The type selected for a particular ship depends on the holding tank capacity. Systems with tanks with a capacity of more than 2000 gallons use a comminutor and aeration system. Smaller systems with tanks having a capacity of less than 2000 gallons use strainers. A 2000 gallon tank was selected for the LCS due to the fact that the operational areas may prevent it from operating in an At-Sea transfer mode. This will allow the LCS to operate in the littoral for extended periods of time without having to discharge and be in violation of Federal Environmental regulations.

e) COMMINUTOR

In a comminutor-type system, the comminutor located in the soil drain or the combined soil and waste drain serves to macerate solids passing in-to the CHT tank. A bypass is fitted upstream of the comminutor. If the comminutor jams or plugs, the bypass provides drainage around the comminutor and into the tank.

Isolation valves are fitted directly before and after the comminutor to allow for preventative maintenance. Most installations include an access port, or cleanout, to permit removal of foreign objects, which may jam or plug the comminutor. The components of the comminutor-type CHT system are shown in Figure 84 and Figure 85.

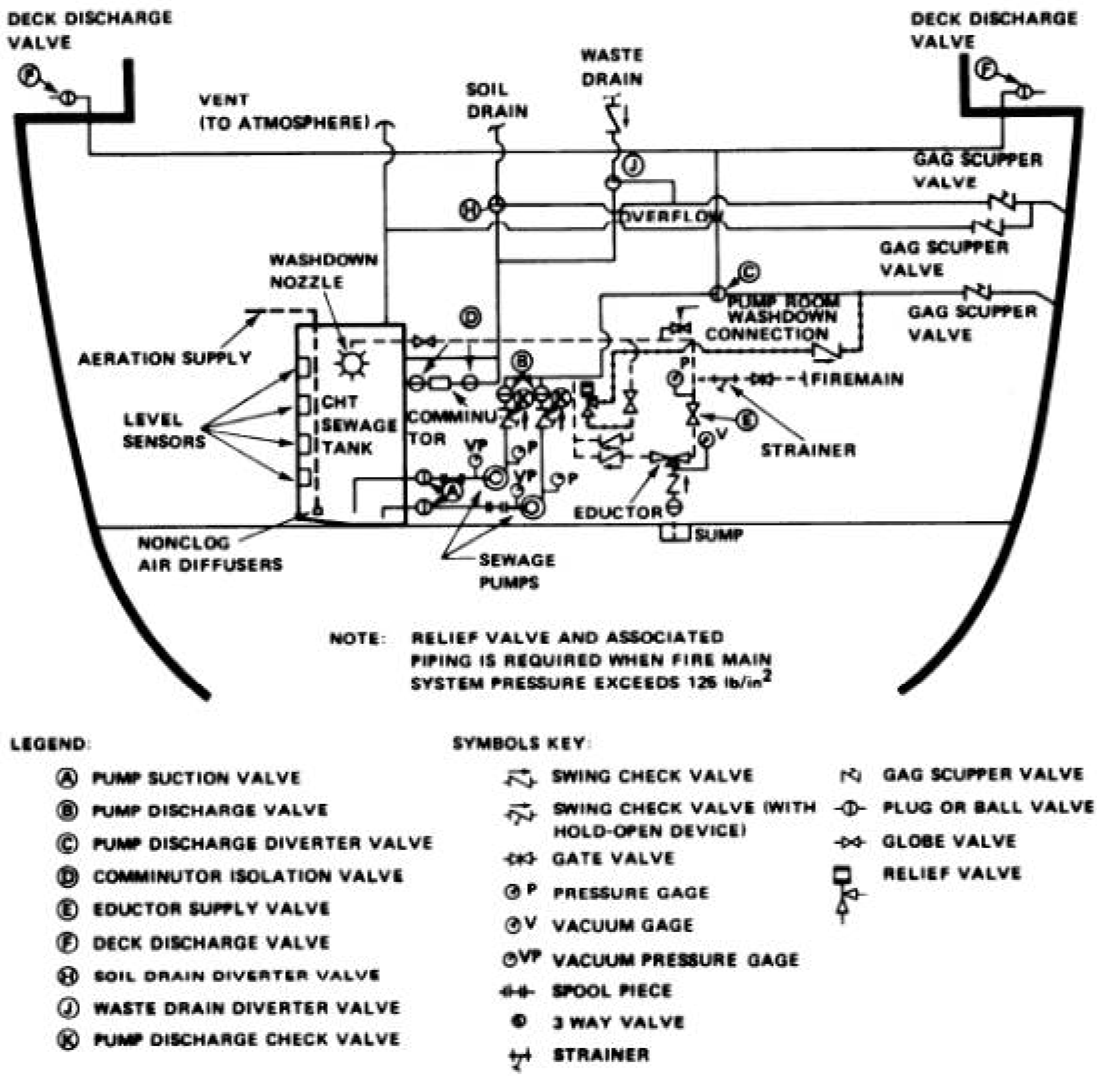


Figure 84. Comminutor-type CHT system.

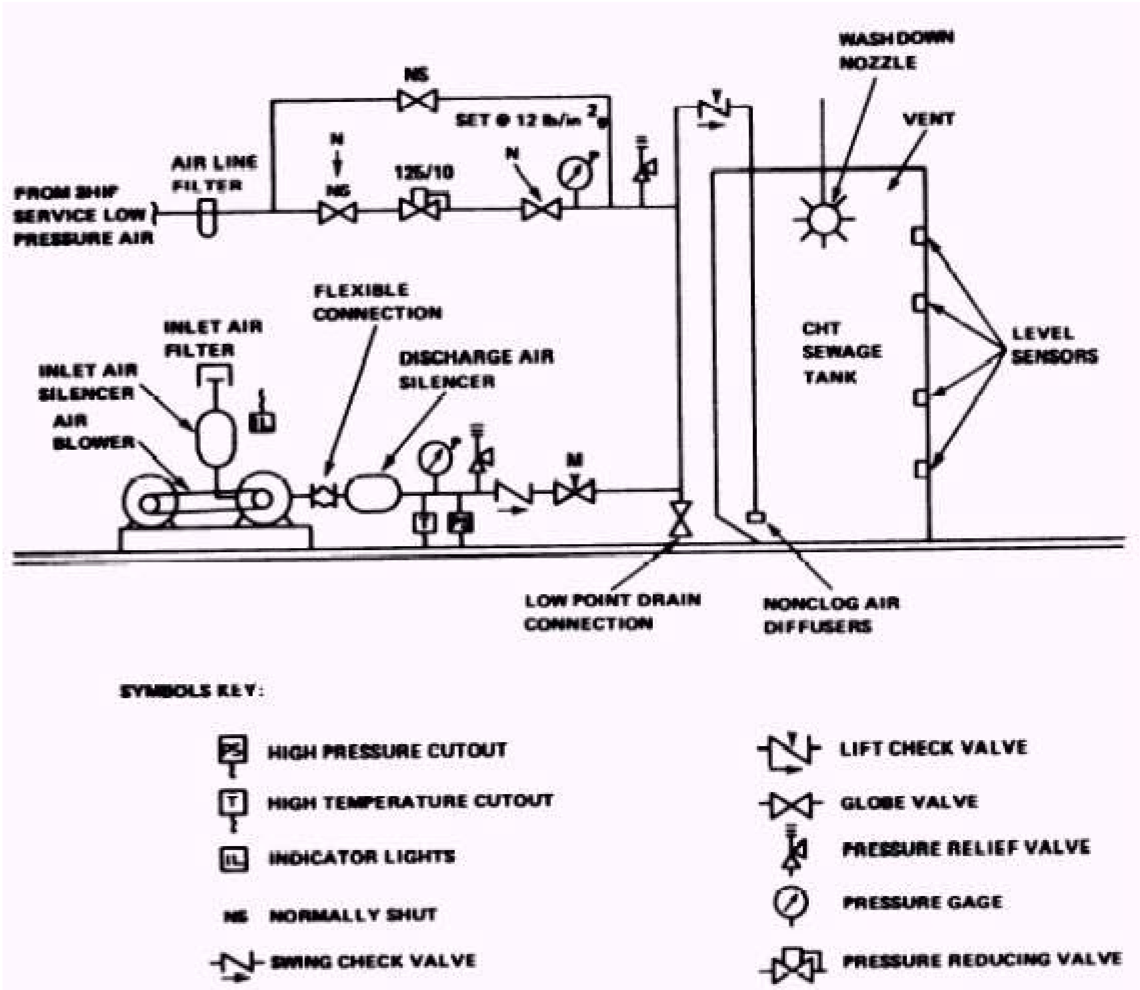


Figure 85. Aeration subsystem

f) CHT OPERATIONAL MODES

The CHT system can be used in any of three district modes of operation in accordance with any one of the following situations:

1. Transiting Restricted Zones. When transiting restricted zones, the CHT system must be set up to collect and hold the discharges from soil drains only.

2. In Port. During in-port periods, the CHT system collects, holds, and transfers to shore sewage facility all discharges from soil and waste drains.

3. At Sea. When operating at sea outside restricted areas, the CHT system is set up to divert discharges from both soil and waste drains overboard.

2. OIL WATER SEPARATOR

Bilge water consists of liquid drainage that collects in the lower spaces of a ship’s hull. The primary sources of bilge water are equipment found within a ship's engine and auxiliary machinery rooms. Drainage to the bilge also comes from equipment associated air conditioning systems. Approximately 90% of the Navy’s surface combatants are currently fitted with oil water separator (OWS) systems to control this discharge. Along with the existing OWS system installed on board, a secondary treatment system downstream from the existing OWS would be the most effective approach for achieving high levels of pollutant removal. NAVSEA has identified a membrane ultra-filtration as the most promising technology for shipboard application. The following are key performance parameters this secondary OWS system will conduct:

- Ability to consistently meet the existing discharge requirement of fifteen-ppm oil,
- Potential capability to meet future discharge restrictions, such as those established by UNDS,
- Compatibility with the Navy’s existing OWS, and
- Adaptability to space, weight, and ship integration constraints

The membrane system works in conjunction with the OWS system, see Figure 86. Bilge water drains to an oily waste holding tank and then flows through the OWS. The OWS produces two discharges: 1) effluent, which flows to the membrane and 2) concentrated waste oil, which is held in a waste oil tank. The ultra-filtration process allows water and dissolved particles from the OWS effluent to pass through a semi-permeable ceramic membrane, see Figure 87. Permeate contains significantly lower levels of contaminants than the incoming wastewater. The oil and other impurities retained by the membrane are carried off in a wastewater concentrate stream. The ultra-filtration membrane system concentrates the influent from the OWS by a factor of 100. For example, an input of 100 gallons from an OWS would generate an output of 99 gallons of permeate for overboard discharge and one gallon of concentrated oily waste to be stored in a waste oil tank for shore disposal.

Information on the system suggests that membrane systems offer the following major benefits such as low maintenance costs, low manpower requirements and automated operation.

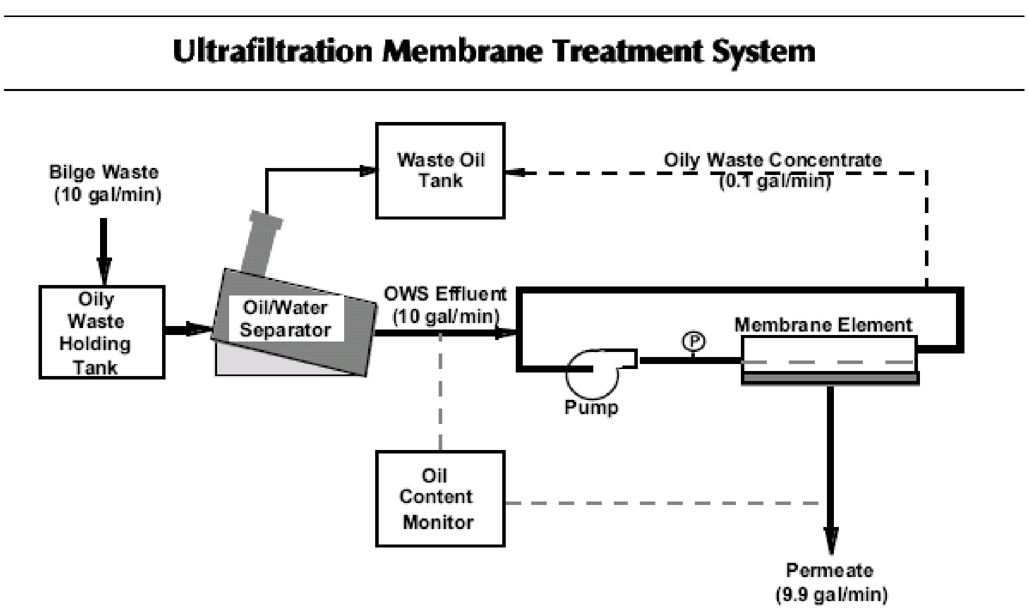


Figure 86. OWS System with Ultra-filtration Membrane

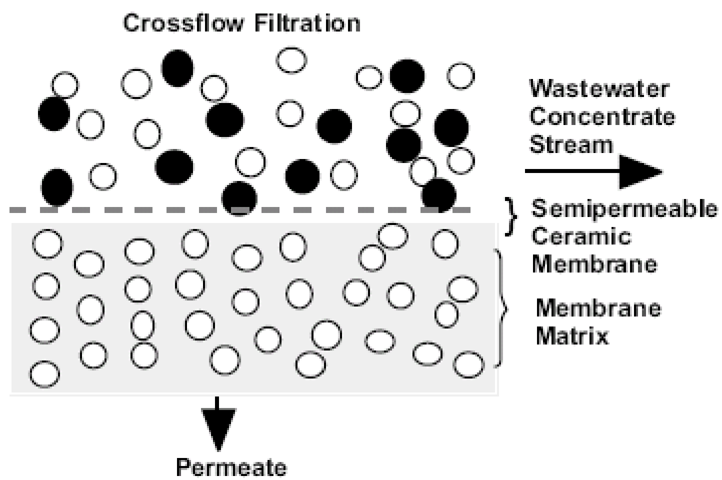


Figure 87. Ultra-filtration Membrane System

VII. OPERATIONAL CONCEPT

A. SIGNATURES ANALYSIS

1. RADAR CROSS SECTION COMPUTATIONAL CALCULATION

The radar cross-section analysis was performed in two stages. The first one using the traditional model calculations based on the ship's geometry, and the second using a computational tool.

The computational tool used to conduct the radar cross-section analysis was Xpatch. Facilitated by the EC department, Xpatch is a classified tool, so only the inputs and outputs are shown in this report.

The first frequency band selected was L-Band, corresponding in general to the search radars onboard ships and coastal stations. The frequency chose was 1 GHz with a 5-degree angle of sight.

The following table is an example of the first output at 1 GHz.

f(GHz)	inc-EL	inc-AZ	E-vert(co)	e-hori	e-vert	E-hori(co)
1.000	5.000	0.000	50.75	-6.02	-6.02	50.37
1.000	5.000	0.994	28.19	15.54	15.54	33.35
1.000	5.000	1.989	37.48	19.82	19.82	37.59
1.000	5.000	2.983	31.82	23.30	23.30	32.54
1.000	5.000	3.978	26.86	22.28	22.28	34.86
1.000	5.000	4.972	23.55	18.15	18.15	22.78
1.000	5.000	5.967	4.82	-0.62	-0.62	23.12
1.000	5.000	0.000	50.75	-6.02	-6.02	50.37

Table 29. 1 GHz Radar Cross-Section Analysis

Figure 88 depicts the radar cross-section prediction in the vertical and horizontal polarizations.

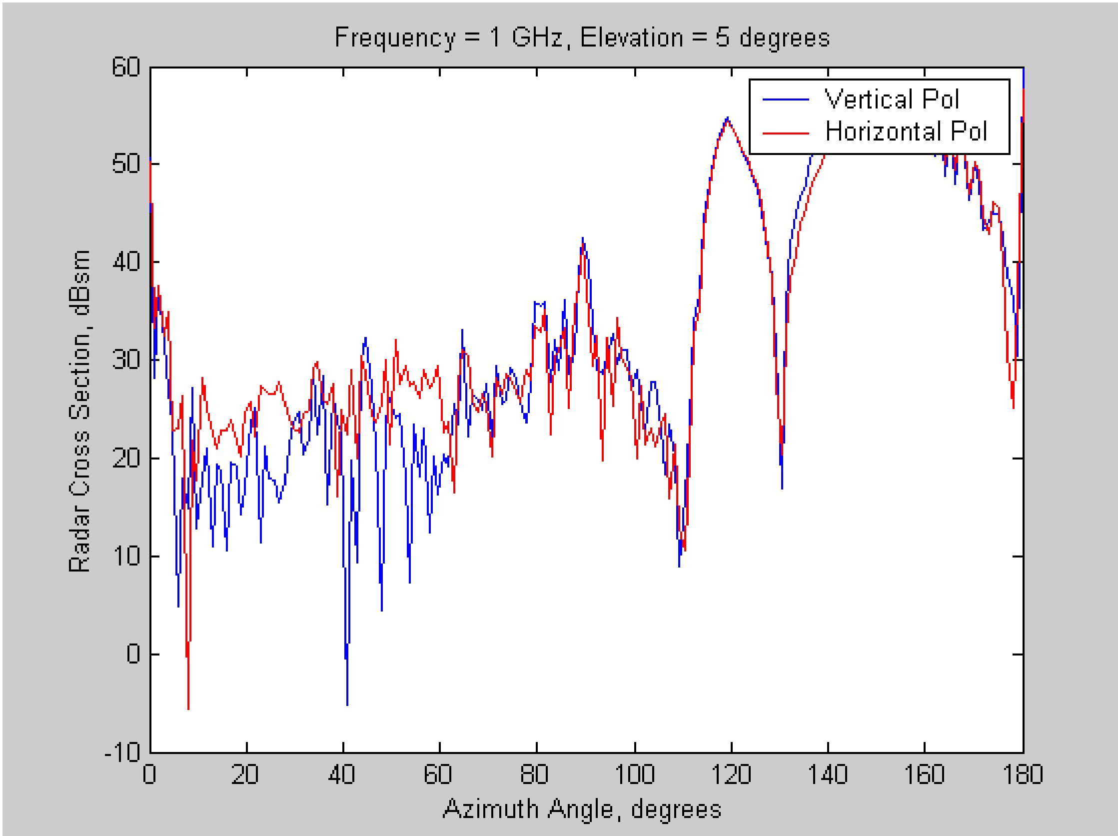


Figure 88. 1 GHz Radar Cross-Section in Vertical and Horizontal Polarizations

The polar representation gives a better estimation of the angles and big contributors to the cross-section. In Figure 89 and Figure 90, the front and side peaks are notorious. However, the bigger ones, the "wings" in the aft section (120 to 180 degrees), correspond to the open hangar that acts as a resonance box for the electromagnetic radiation. The following iterations of SEA SWAT designs include the proper hangar doors.

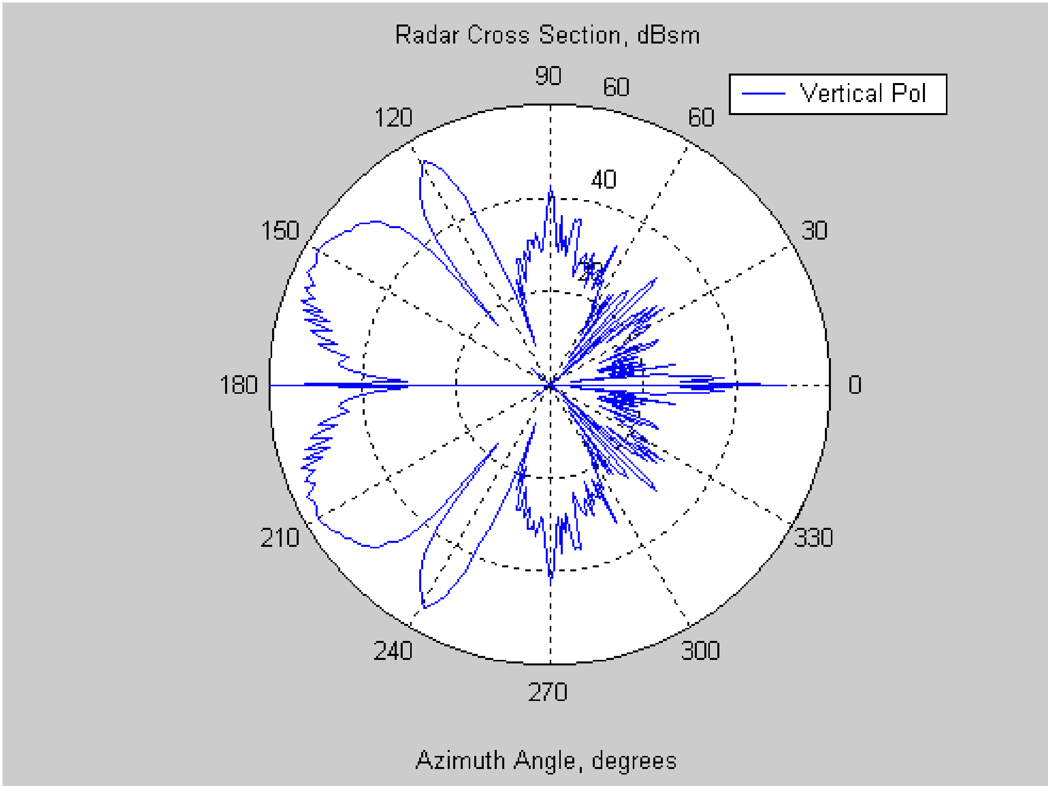


Figure 89. 1 GHz Radar Cross-Section Vertical Polarization

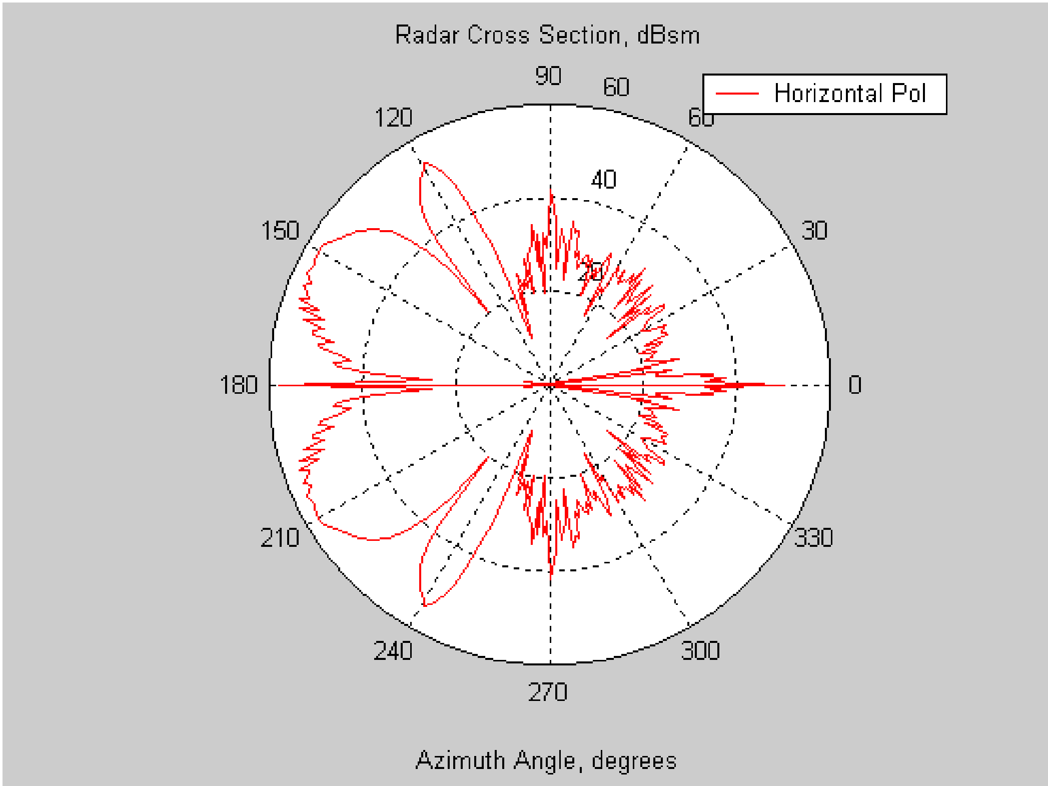


Figure 90. 1 GHz Radar Cross-Section Vertical Polarization

The second frequency band selected for evaluation was X-Band, corresponding in general to the search radars and fire control radars onboard ships and anti-ship cruise missiles. The frequency chose was 10 GHz with a 5-degree angle of sight.

f(GHz)	inc-EL	inc-AZ	E-vert(co)	e-hori	e-vert	E-hori(co)
10.000	5.000	0.000	65.59	17.72	17.72	64.93
10.000	5.000	0.497	31.79	17.93	17.93	35.81
10.000	5.000	0.994	37.95	22.32	22.32	38.11
10.000	5.000	1.492	29.57	18.38	18.38	31.40
10.000	5.000	1.989	21.38	13.07	13.07	28.51
10.000	5.000	2.486	12.00	11.76	11.76	26.75
10.000	5.000	2.983	27.28	10.97	10.97	27.34
10.000	5.000	3.481	34.78	17.44	17.44	29.60

Table 30. 10 GHz Radar Cross-Section Analysis

Figure 91 depicts the radar cross-section prediction in the vertical ad horizontal polarizations, but up to 45-

degrees. This is due to the long simulation times required to perform this actions, estimated in three to four weeks only for this frequency range.

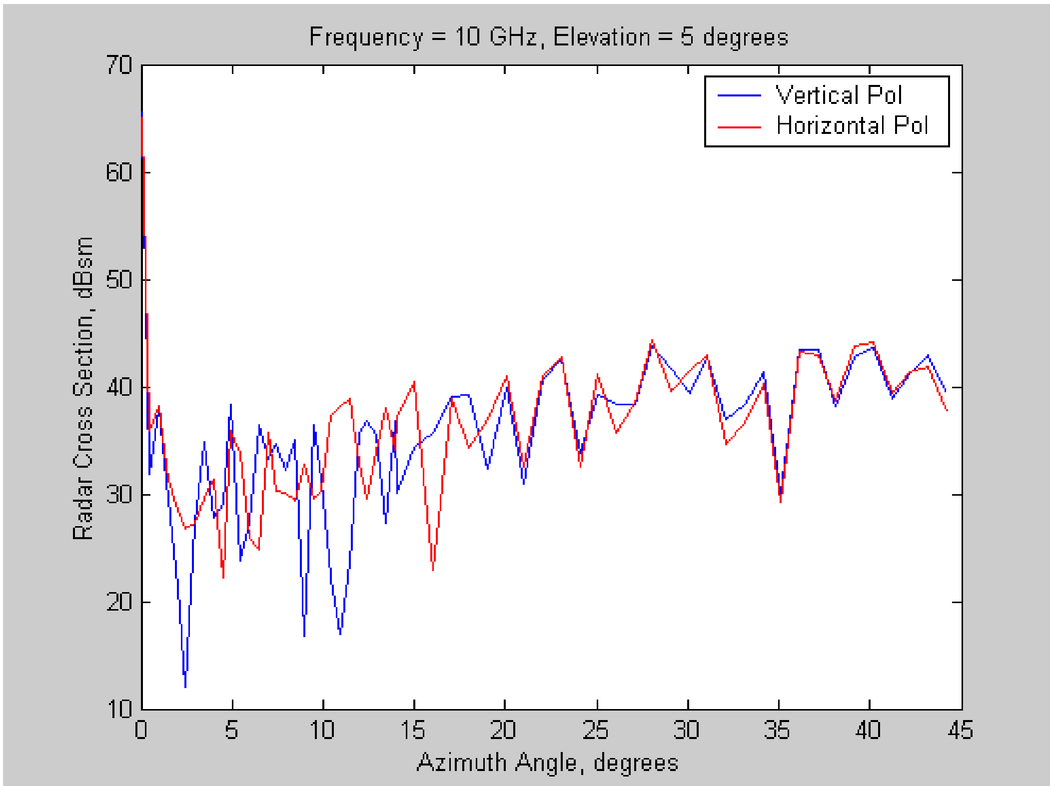


Figure 91. 10 GHz Radar Cross-Section Vertical and Horzonatal Polarizations

Figure 92 and Figure 93 depict the first 45-degrees out of the simulation. Due to the higher frequency, the dispersion between the scattered centers is higher, but the average stays around 40 dB/sm.

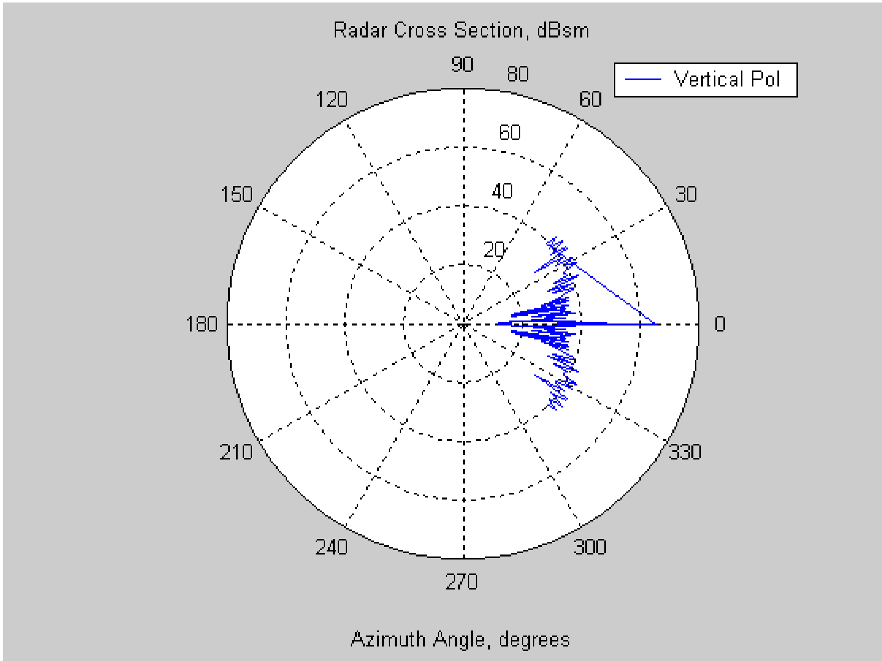


Figure 92. 10 GHz Radar Cross-Section Vertical Polarization

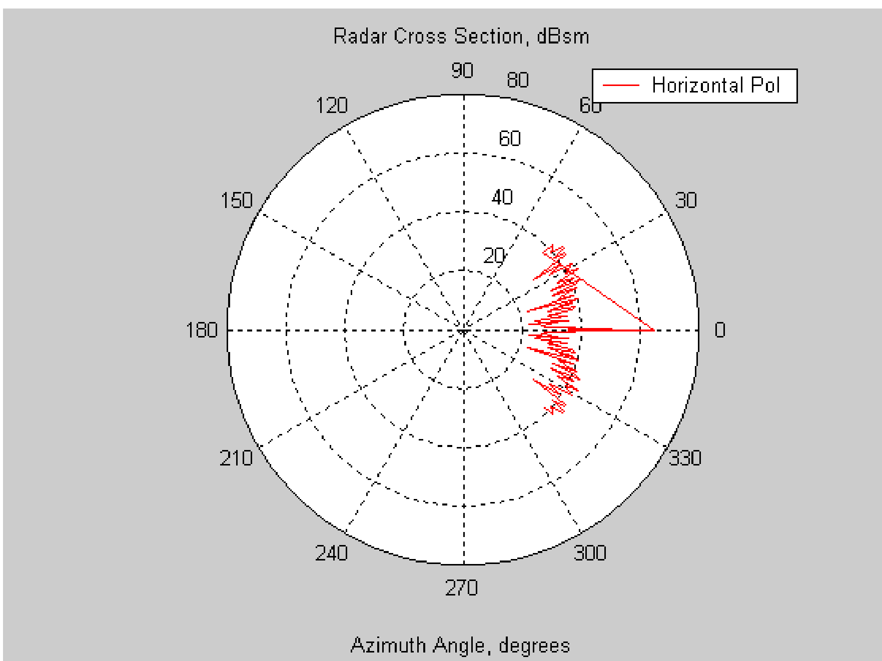


Figure 93. 10 GHz Radar Cross-Section Vertical Polarization

2. INFRA RED SIGNATURE

The Infra Red (IR) characteristics were modeled in the MusesPro tool (by Thermoanalytics), using only environmental factors, such as solar radiance, water reflectance, and sky noise; and hull characteristics, such as material, dimensions and shape.

a) TEMPERATURE MODEL

The Temperature model was simulated using a standard day weather conditions (24 hrs) in the Monterey Bay, (N 36° 35'13.1", W 121° 50' 34"), like the time interval 0610 to 0650 hrs in Table 31.

TIME	AIRT	SOLAR	WIND	HUMID	CLOUD	LWIR	WINDIR
0610	18.8	0	1.299	78.833	5	0	155.808
0615	18.9	2	0.828	78.25	6	0	150.912
0620	18.7	4	0.903	77.667	6	0	151.92
0625	18.6	6	1.532	77.083	6	0	180.216
0630	18.7	10	1.055	76.5	7	0	169.704
0635	18.4	20	1.63	75.917	7	0	162.72
0640	18.4	24	1.016	75.333	7	0	171.936
0645	18.4	34	1.39	74.75	8	0	159.408
0650	18.5	50	1.131	74.167	8	0	149.184

Table 31. Temperature Model Output

The sky and water backgrounds were obtained as modeled and assume a standard day (e.g 15 C of temperature).

The material used in the ship’s hull was standard steel plate, with the following characteristics:

Insulation	Non insulated
Thickness	5 mm
Density	7768.98 Kg/m3
Conductivity	52.019 W/m-K
Specific heat	460.967 J/Kg-K
Emissivity	0.9
Absorptivity	0.7

Table 32. Ship Hull Material Characteristics

It was covered with grey paint, with the following characteristics:

Emissivity	0.9
Absorptivity	0.62

Table 33. Gray Hull Paint Characteristics

In Figure 94, the temperature simulation is presented and areas corresponding to the green and red colors indicate the higher temperatures. These areas are the bow with the gun, and the superstructure, with the hangar. The last one is due to the early model stage, with the hangar opened to the environment. The following designs correct this issue installing doors to it.

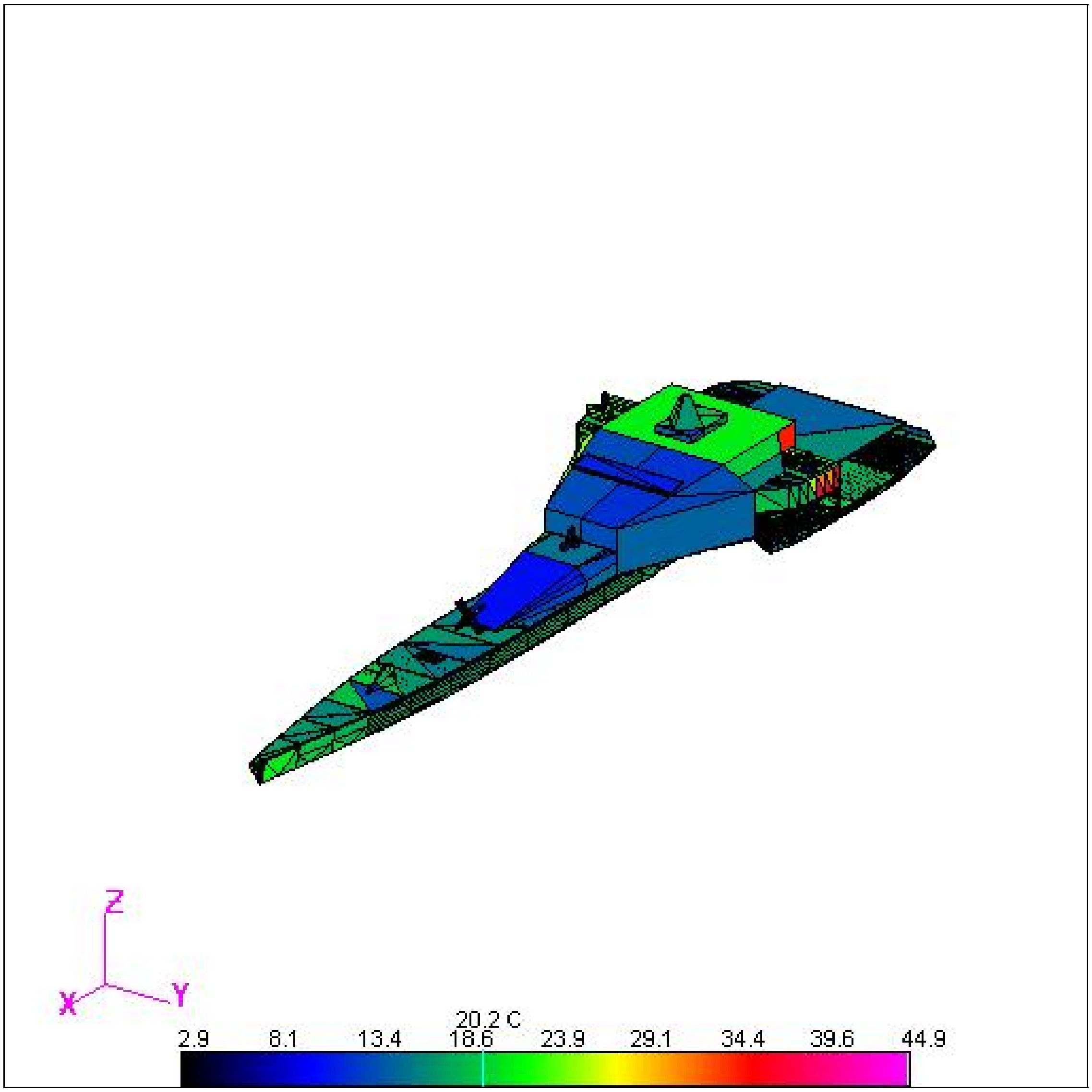


Figure 94. Temperature Model Simulation Output

b) INFRA RED SIGNATURE

The following sensor simulated the Infrared signature:

Frequency	8-12 micron
Field of view	Instantaneous
Range	10 Km
Sensor	Staring
Array	640 x 480 elements
Resolution	0.5 x 0.5 mrad

Table 34. IR Sensor Characteristics

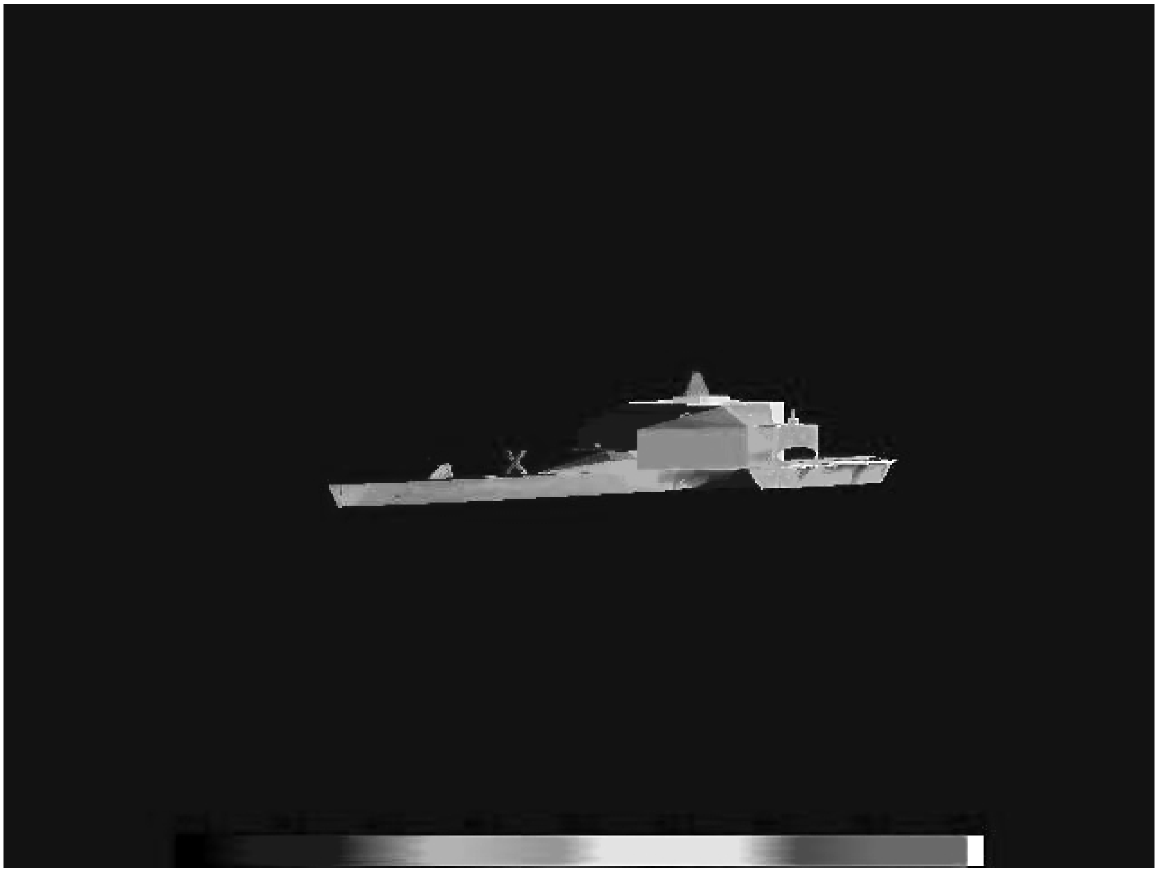


Figure 95. IR Signature Model Output

In Figure 95, the hot spots due to the gun and hangar are very clear. Also, the harpoon canisters appear with less intensity; this led to the relocation of them inside the superstructure. Between the hulls, the cold spot will be the place chosen to discharge the exhaust gases from the gas turbines.

B. COST AND WEIGHT ANALYSIS

The MAPC spreadsheet tool initially estimated the LCS weight when the hull design trade-off analysis was conducted. Using parametric weight design estimation equations, a first order light ship weight, total deadweight, and total ship weight was calculated and shown in Table 35 below. The light ship weight calculations estimate the weight of the ship's structural components, machinery, outfit and hull engineering weight, and a weight margin. The total deadweight of the ship estimates the ship's cargo weight, fuel oil weight, lube oil weight, freshwater weight, the weight of the crew and their effects, and the weight of the provisions.

$$W_S = K * E^{1.36}(1 + 0.5(C_B^{'} - 0.70))$$
$$C_B^{'} = C_B + (1 - C_B)\left(\frac{0.8D - T}{3T}\right)$$
$$E = E_{hull} + E_{ss} + E_{dh} = L(B+T) + 0.85 * L(D-T) + 0.85\sum_i l_i h_i + 0.75\sum_j l_j h_j$$
$$W_{dh} = W_s(E_{hull} + E_{ss} + E_{dh}) - W_s(E_{hull} + E_{ss})$$
$$W_{ss} = W_s(E_{hull} + E_{ss}) - W_s(E_{hull})$$
$$W_M = W_{ME} + W_{rem}$$
$$W_{ME} = 12.0\left[\frac{MCR}{Ne_i}\right]^{0.84}$$
$$W_{rem} = C_m(MCR)^{0.70}$$
$$W_o = C_o LB$$

Equation 1. Lightship Weight Parameterization Equations

$$DWT_T = DWT_C + W_{FO} + W_{LO} + W_{FW} + W_{C\&E} + W_{PR}$$

$$W_{FO} = SFR * MCR * \left[\frac{range}{speed}\right] * margin$$

$$W_{LO} = 20 * t$$

$$W_{FW} = 0.17 * \frac{t}{person * day}$$

$$W_{C\&E} = 0.17 * \frac{t}{person}$$

$$W_{PR} = 0.01 * \frac{t}{person * day}$$

Equation 2. Deadweight Parameterization Equations

Weight Parameterization						
Light Ship Weight:						
Structural Weight:						
Ehullfwd	1161.62		Lfwd	83.33		
Ehullaft	1331.50		Laft	37.88		
Ehull	2493.11		Ltot	121.21		
Ess	374.66		D	7.88		
Edh1	233.85		T	4.24		
Edh2	6.98		Bfwd	9.70		
Edh	240.82		Baft	30.91		
E	3108.59		K:	0.02	for Frigates/Corvettes	
Cb	0.60					
Cb'	0.64					
Ws	1254.12	LT				
Wdh	134.83	LT				
Wss	209.76	LT				
Machinery Weight:						
Wme	3.10		MCR	1000.00	kW	initial guess
Wrem	23.92		N	5000.00	RPM	initial guess
Wm	27.02	LT	# engines	3.00		
			Cm	0.19	for Frigates/Corvettes	
Outfit Weight:						
Wo	989.44	LT	Co	0.50		

Light Ship Weight Total:						
Wls	2497.64	LT	Margin	10.0%	227.06	LT
Total Deadweight:						
Dead Weight Cargo:	250.00	LT	Initial Payload Estimate			
Fuel Oil Weight:			Spec Fuel Rate	0.00021500	t/kWhr	
Wfo	1.54	LT	range	2500.00	nm	300 LT correcttin
			speed	35.00	kts	
Lube Oil Weight:						
Wlo	3.00	LT	t	0.15		
Fresh Water Weight:						
Wfw	7.65	LT	t/person*day	45.00		
Crew and Effects Weight:						
Wce	0.03	LT	t/person	0.18	Naval Standard	
Provisions Weight:						
Wpr	0.00004	LT	t/person*day	0.0036	Naval Standard	
Dead Weight Total:						
Wdw	262.22	LT				
Total Ship Weight:						
3059.85 LT						

Table 35. SEA SWAT Weight Parameterization

Based on the ship's first order weight estimation, the acquisition cost of SEA SWAT could be determined using a weight scaled model similar to that employed in the 2002 TSSE SEA FORCE and 2001 TSSE SEA ARCHER studies. This model used CER's from the S-CVX study conducted in 1998.

The SEA SWAT model incorporates non-traditional weight fractions, high cost for specialized equipment required to meet the ship's missions, and one time costs for Government Furnished Equipment (GFE) that is presently under development. Cost estimates for SEA SWAT, SEA SWAT's estimated labor cost, and SEA SWAT's specialized equipment included in the cost model are summarized in the tables below. Table 36, Table 37, Table 38, and Table 39 shows the total cost of the fourth ship of production.

SEA SWAT TOTAL COST ESTIMATE								
	Lightship Weight	Total Shipweight						
Ref Tot.	2500	3100						
					SEA SWAT	SEA SWAT	SEA SWAT	SEA SWAT
		WT	Wt/Tot		MAT	MATERIAL	Labor	Labor
Description		(LT)		Other	CER	COSTS	CER	Hours
SHELL + SUPPORTS		220.1	0.08804		1181	$259,938	316	69552
HULL STRUCTURAL BULKHEADS		291.4	0.11656		1181	$344,143	316	92082
HULL DECKS		300.7	0.12028		1181	$355,127	316	95021
HULL PLATFORMS/FLATS		40.3	0.01612		1181	$47,594	316	12735
DECK HOUSE STRUCTURE		105.4	0.04216		1028	$108,351	692	72937
SPECIAL STRUCTURES		368.9	0.14756		1632	$602,045	251	92594
MASTS+KINGPOSTS+SERV PLATFORM		14.849	0.00594		6183	$91,811	164	2435
FOUNDATIONS		52.7	0.02108		1028	$54,176	359	18919
SPECIAL PURPOSE SYSTEMS		55.8	0.02232	75000000	4758	$75,265,496	404	22543
Structure Sum		1450.1	0.58006			$77,128,682		478818
PROPULSION UNITS		37.2	0.01488		144	$5,357	209	7775
TRANSMISSION+PROPULSIOR SYSTEMS		7.223	0.00289		63	$455	162	1170
SUPPORT SYSTEMS		18.91	0.00756		288	$5,446	412	7791
PROPUL SUP SYS -FUEL,LUBE OIL		2.79	0.00112		36916	$102,996	1412	3939
SPECIAL PURPOSE SYSTEMS		1.984	0.00079		288	$571	0	0
Propulsion Sum		68.1	0.02724			$114,825		20675
ELECTRIC POWER GENERATION		15.5	0.00620		650	$10,075	4	62
POWER DIST. SYSTEM		53.971	0.02159		98329	$5,306,914	1294	69838
LIGHTING SYSTEM		13.082	0.00523		5450	$71,297	1329	17386
POWER GEN SUPPT. SYSTEM		6.665	0.00267		14545	$96,942	1882	12544
SPECIAL PURPOSE SYSTEMS		2.201	0.00088		788	$1,734	471	1037
Electrical Sum		91.4	0.03657			$5,486,963		100867
COMMAND+CONTROL SYS		2.945	0.00118		150000	$441,750	235	692
NAVIGATION SYS		1.86	0.00074		150000	$279,000	235	437
INTERIOR COMMS		5.425	0.00217		150000	$813,750	235	1275

EXTERIOR COMMS		4.464	0.00179		150000	$669,600	235	1049
SURF SURV SYS (RADAR)		7.75	0.00310		150000	$1,162,500	235	1821
COUNTERMEASURES		0.3937	0.00016		150000	$59,055	235	93
FIRE CONTROL SYS		2.48	0.00099		150000	$372,000	235	583
SPECIAL PURPOSE SYS		1.302	0.00052		150000	$195,300	235	306
Command/Cont Sum		26.6	0.01065			$3,992,955		6256
CLIMATE CONTROL		40.579	0.01623		32868	$1,333,751	494	20046
SEA WATER SYSTEMS		24.8	0.00992		50705	$1,257,484	679	16839
FRESH WATER SYSTEMS		7.5	0.00300		34033	$255,248	529	3968
FUELS/LUBRICANTS, HANDLING+STORAGE		60.605	0.02424		42125	$2,552,986	271	16424
AIR, GAS+MISC FLUID SYSTEM		7.533	0.00301		70265	$529,306	647	4874
SHIP CONTL SYS		0	0.00000		14025	$0	353	0
UNDERWAY REPLENISHMENT SYSTMES		65.131	0.02605		8035	$523,328	176	11463
MECHANICAL HANDLING SYSTEMS		93.744	0.03750		16853	$1,579,868	259	24280
SPECIAL PURPOSE SYSTEMS		29.078	0.01163		1888	$54,899	282	8200
Auxiliary Sum		329.0	0.13159			$8,086,868		106093
SHIP FITTINGS		0.31	0.00012		55033	$17,060	882	273
HULL COMPARTMENTATION		18.6	0.00744		11160	$207,576	741	13783
PRESERVATIVES+COVERINGS		55.8	0.02232		10789	$602,026	494	27565
LIVING SPACES		15.5	0.00620		29677	$459,994	1235	19143
SERVICE SPACES		6.2	0.00248		26174	$162,279	135	837
WORKING SPACES		15.5	0.00620		27376	$424,328	292	4526
STOWAGE SPACES		34.1	0.01364		86901	$2,963,324	12	409
SPECIAL PURPOSE SYSTEMS		0.837	0.00033		35511	$29,723	694	581
Habitability Sum		146.8	0.05874			$4,866,310		67117
GUNS + AMMUNITION		36.2	0.01448		100000	$3,620,000	235	8507
MISSILES+ROCKETS		35.34	0.01414		100000	$3,534,000	235	8305
SMALL ARMS+PYROTECHNICS		4.3	0.00172		100000	$430,000	235	1011
MINES		0	0.00000		100000	$0	235	0
DEPTH CHARGES		0	0.00000		100000	$0	235	0
TORPEDOES		2.5	0.00100		100000	$250,000	235	588
AIRCRAFT RELATED WEAPONS		0.589	0.00024		100000	$58,900	235	138
SPECIAL PURPOSE SYSTEMS		5.828	0.00233		100000	$582,800	235	1370
Armament Sum		50.5	0.02021			$4,855,700		11411
MATERIAL / LABOR SUMMATIONS		2162.6	0.86506	1991 Material Cost	$104,532,303		791237	
	2003 Material Cost	$149,038,069						

SHIPS FORCE	12.958	
MISSION RELATED EXPENDABLES	69.626	
STORES	29.264	
LIQUIDS, PETROLEUM BASED	840.1	
LIQUIDS, NON-PETROLEUM BASED	28.241	
FUTURE GROWTH MARGIN	19.685	
Total Payload weight:	999.874	
Total Ship Weight	**3182.5**	**LT**

Table 36. SEA SWAT Total Cost and Weight Estimates

			Multi-Hull Adj	unit cost with basic	**With Multi-Hull**
	Hours	**Labor Cost**	**.30*Labor**	Shipyard Overhead	**Labor Overhead**
Total 1997 1st Ship Labor	1628940.032	$48,868,201	$14,660,460	$240,456,118	$255,116,578
Total 1997 2nd Ship Labor	1547493.03	$46,424,791	$13,927,437	$237,487,375	$251,414,812
Total 1997 3rd Ship Labor	1501750.71	$45,052,521	$13,515,756	$235,820,067	$249,335,824
Total 1997 4th Ship Labor	**1470118.379**	**$44,103,551**	**$13,231,065**	$234,667,069	**$247,898,134**
Total 1997 5th Ship Labor	1446042.008	$43,381,260	$13,014,378	$233,789,485	$246,803,863
Total 1997 6th Ship Labor	1426663.175	$42,799,895	$12,839,969	$233,083,127	$245,923,095
Total 1997 7th Ship Labor	1410481.356	$42,314,441	$12,694,332	$232,493,299	$245,187,631
Total 1997 8th Ship Labor	1396612.46	$41,898,374	$12,569,512	$231,987,778	$244,557,290
Total 1997 9th Ship Labor	1384492.463	$41,534,774	$12,460,432	$231,546,004	$244,006,436
Total 1997 10th Ship Labor	1373739.908	$41,212,197	$12,363,659	$231,154,073	$243,517,733

Table 37. Estimated Labor Cost of SEA SWAT

SEA SWAT Specialized Equipment used for ship cost estimate							
Costs are reflected back to 1991 at 3% inflation rate to align with CER's in given model.							
Later, total is reflected to 2001 with same inflation rate.							
One Time Installs	Costs in 2003		Costs in 1991		What to add		
Engines/Pods	$100,000,000		$70,137,988		$70,137,988		Propulsion
Electric Plant	$60,000,000		$42,082,793		$18,482,793		Electric
Steel Hull Form	$50,000,000		$35,068,994				
EW Suite	$30,000,000		$21,041,396				
Multi Function Radar	$50,000,000		$35,068,994		$54,110,390		Radar
Other Weps/Sensor Systems	$20,000,000		$14,027,598				Harpoon, BOFORS
SEA RAM	$30,000,000		$21,041,396		$21,041,396		
Automated DC systs.	$35,000,000		$24,548,296				
DC Automation IP (.75*gear)	$26,250,000		$18,411,222		$42,959,518		Automation (Hab/DC)
SUMS	$401,250,000		$281,428,677		$206,732,085		

Table 38. SEA SWAT Specialized Equipment

Fourth Ship		
Estimated System Cost (w/o Manning):		
Ship	**$253,491,929**	
One Time Installs	$401,250,000	
Payload	$499,937	
Total System Cost		$655,241,866

Table 39. SEA SWAT Total System Cost of the Fourth Ship of Production

C. ELECTRICAL DISTRIBUTION EVALUATION

The electrical distribution system for SEA SWAT was designed to maintain continuity of power under casualty conditions. In this section, we will describe in detail the system operation and evaluate its operation under minor and major casualty situations.

Figure 96 presents SEA SWAT electrical system design. The integrated propulsion system, consisting of two 21 MW HTS synchronous motors powered from port and starboard AC buses providing 13.8 KV AC power. The AC buses also provide power to a three-zone DC distribution system that provides power to electrical auxiliaries, ships services and combat systems.

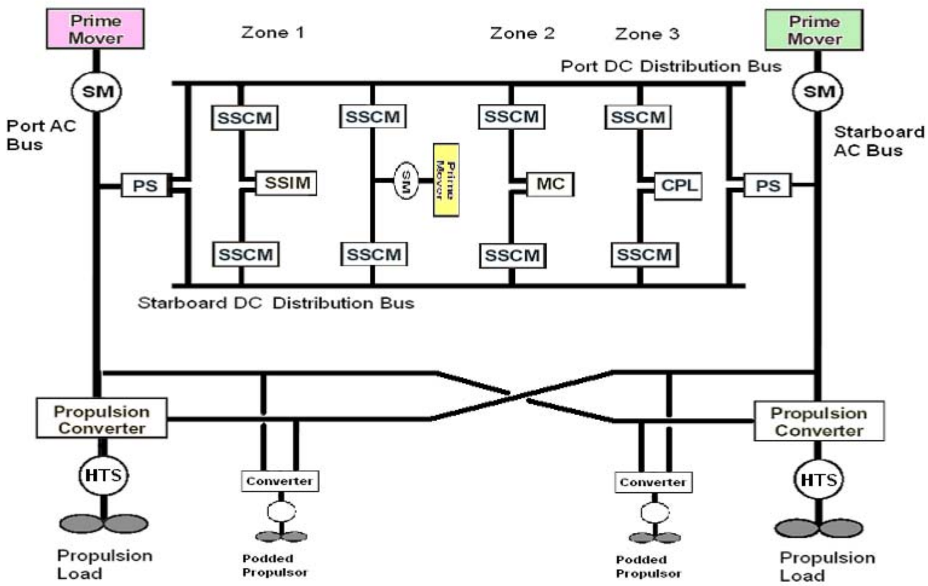


Figure 96. SEA SWAT Electrical Distribution

System operation under an intra-zone casualty is shown in Figure 97.

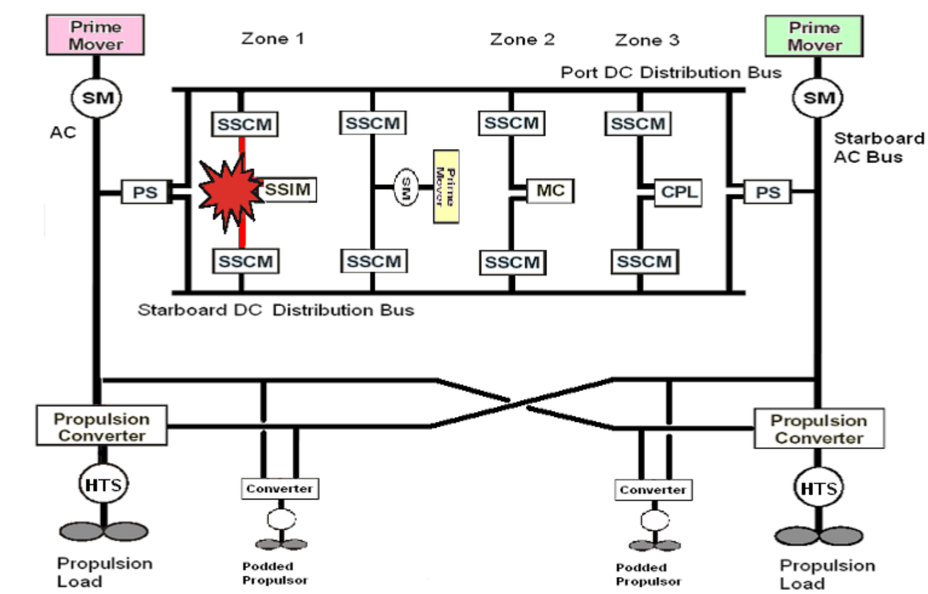


Figure 97. Intra-zone Casualty Operation

For the scenario where a minor casualty occurs in one of the DC zones, the automatic protection system (APS) will immediately isolate the zone via the ship service converter modules (SSCM). Power still remains available through the port and starboard DC buses to the remainder of the zones. Port and starboard AC buses remain unaffected, and full propulsion capability remains available.

System operation under a DC bus casualty is shown in Figure 98.

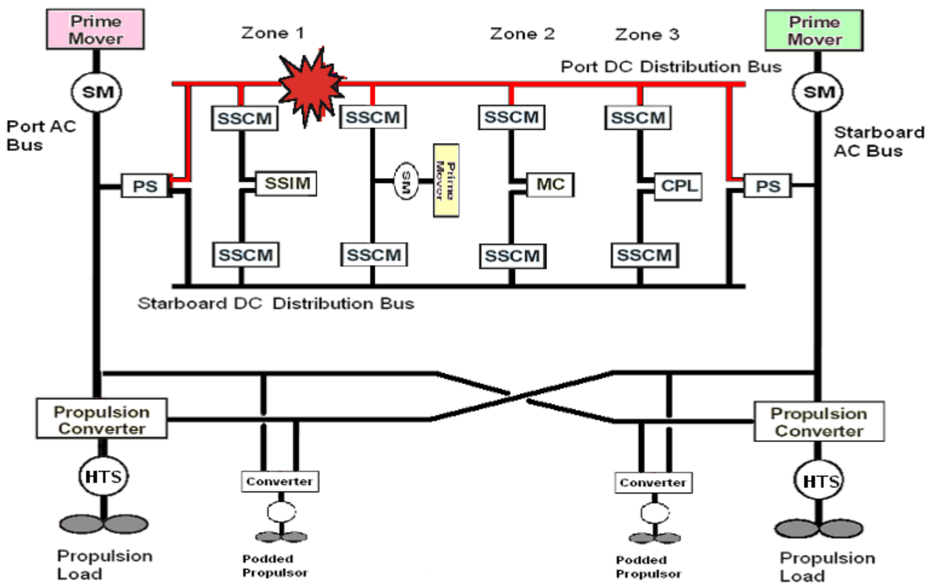


Figure 98. DC Bus Casualty Operation

When a casualty is sustained causing damage to a DC bus, APS will immediately isolate the affected DC bus from the AC buses via the ship service power supplies (PS). The bus will also be isolated from the rest of the DC distribution system via the SSCMs. Full system operation continues to all DC zones via the unaffected DC bus. Port and starboard AC buses remain unaffected.

System operation under and AC bus casualty is shown in Figure 99.

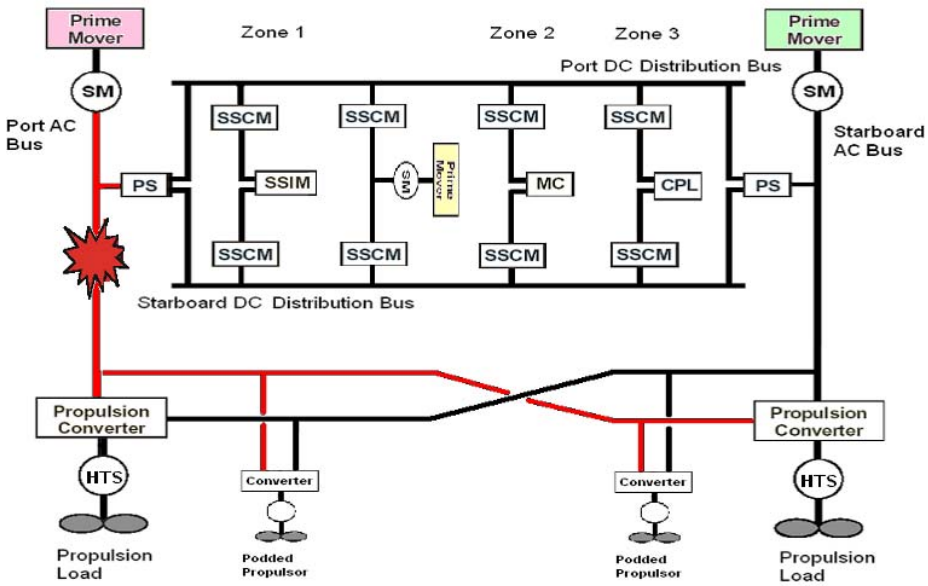


Figure 99. AC Bus Casualty Operation

When a major casualty is sustained causing damage to one of the AC buses, power is immediately secured to the affected AC bus by APS. Power is secured to the affected DC side via the ship service power supply as well as to the main engine and podded propulsors via the affected propulsion converters. All engines however will still have backup power from the unaffected AC bus, which will be routed via the converter modules. Therefore, all main engines and podded propulsors are still capable of being powered from the unaffected AC bus. Furthermore, emergency power from the 3-MW Allison turbine can be routed to the unaffected ac bus via the port or starboard DC bus for maximum propulsion.

In summary, the electrical distribution design provides maximum propulsion capability under various casualty conditions, making SEA SWAT an extremely tough and versatile warship.

VIII. REQUIREMENT SATISFACTION

In order to ensure that all requirements had been satisfied in the design of SEA SWAT, this family of tables was created. The system or group of systems was listed next to the requirement that it would satisfy. In some cases the system is capable of satisfying more than one requirement. Some systems are not listed because they are either part of a larger systems suite or the design simply meets the requirement based on the geometry or design of the ship.

DESCRIPTION OF SYSTEM	
Platform or family of platforms that encapsulates all mission capabilities and system level requirements	Family of Two LCS Platforms
Full use of Vertical Take-Off, Landing UAV, USW, UUV, future force protection and Battle Management C4I	Helo capable, UUV capable, USV capable, UAV capable
Accommodates growth trends and new technologies	10% Design Margin

AIR WARFARE	
Detect, identify and defeat air targets	AIR WARFARE (AW) MISSION PACKAGE MULTI FUNCTION RADAR EVOLVED SEA SPARROW MISSILE (ESSM) AND MK 41 VERTICAL LAUNCH SYSTEM WITH MK 25 QUAD PACK CANISTER MK III BOFORS 57 MM NAVAL GUN SEA RAM

SURFACE WARFARE	
Detect, identify, track and defeat surface craft	CORE / SURFACE WARFARE (SUW) MULTI FUNCTION RADAR
Detect surface threats with ownship and networked sensors	MULTI FUNCTION RADAR SLQ-32
Deconflict potentially hostile craft from friendly or neutral shipping	MULTI FUNCTION RADAR SLQ-32

Direct, support and/or embark aircraft conducting SUW	Helo/UAV Capable
Engage surface threats to the ExWar force	EVOLVED SEA SPARROW MISSILE (ESSM) AND MK 41 VERTICAL LAUNCH SYSTEM WITH MK 25 QUAD PACK CANISTER MK III BOFORS 57 MM NAVAL GUN SEA RAM

UNDERSEA WARFARE / MINE WARFARE	
Support both USW and MCM	UNDERSEA WARFARE (USW) / MINE WARFARE (MIW) MISSION PACKAGE
Detect, identify, track and defeat UUVs and no warning torpedo attacks	LOW FREQUENCY ACTIVE TOWED SONAR (LFATS), PETREL HULL MOUNTED SONAR
Must provide for the control and support of USW helos / UAVs and control of UUVs	Helo/UAV Capable, UUV Capable
Direct, support and/or embark aircraft conducting USW	Helo/UAV Capable
Hosting of remote mine search capability from deep water to surf zone	ADVANCED SIDE LOOKING SONAR (ASLS) AIRBORNE MINE NEUTRALIZATION SYSTEM (AMNS) AQS-20/X MINE HUNTING SONARORGANIC AIRBORNE AND SURFACE INFLUENCE SUITE (OASIS) AIRBORNE LASER MINE DETECTION SYSTEM (ALMDS) RAPID AIRBORNE MINE CLEARANCE SYSTEM (RAMICS) EXPENDABLE MINE DESTRUCTOR (EMD)
Possess ownship capabilities to conduct MCM from deep water to VSW	PETREL HULL MOUNTED SONAR
Possess an offensive mining capability	Capable of carrying Depth Charges and Mines

ADDITIONAL REQUIREMENTS	
Operate in deep water to very shallow water (10-40 feet)	Shallow Draft, UUV, USV, and RHIB capable
Operate as far as 200 nm offshore	Yes
Operate at sustained speeds of 35 kts	>40 kts
Trans-oceanic capable	Yes
Full operation in Sea State 5	Yes

Full capabilities in CBR environment	DAMAGE CONTROL AND CHEMICAL BIOLOGICAL AND RADIATION (CBR) SYSTEMS
Full capabilities in all thermal environments	Yes
Comply with Federal EPA and NAVOSH regulation and international law where applicable	ENVIRONMENTAL CONCERNS
Reduced manning concepts employed	MANNING AND HABITABILITY
Ensure crew comfort / QOL	MANNING AND HABITABILITY

INFORMATION OPERATION AND INFORMATION WARFARE	
Interoperability with joint, combined and interagency force	Combat Suite
Comm suite with fully networked assets	Combat Suite
Deployable acoustic and RF arrays to act as early warning threat tripwire	Combat Suite
Extend horizon with systems such as aerostats and robotic airships	Combat Suite
Capable of conducting EA, EP, ES	SLQ-32 Suite
Command and control architecture must support planning, gaining and maintaining situational awareness, decision making, order generation, weapons direction and ship system monitoring and control with uninterrupted voice, video and data connectivity	Combat Suite
Collect, process, exploit and disseminate an uninterrupted flow of information in support of operations	Combat Suite

Table 40. Requirement Satisfaction Check Off List

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APPENDIX A.1. THREAT DOCUMENT

A. BELOW THE WATERLINE

1. MINES

a) DEFINITION

This study defines a naval mine as an explosive device laid in the water with the intention of damaging or sinking ships or surface transport assets such as the HLCAC, LCU(R), and AAAV. The term does not include devices attached to the bottoms of ships or to harbor installations by personnel operating underwater, nor does it include depth-charge type devices.

b) THREAT TO SEA BASE

Mines can be employed by hostile forces to disrupt Sea Base operations in littoral regions. Not only capable of damaging and sinking Sea Base assets, but mines can interfere with operations by channeling, blocking, or delaying ships and landing craft. The mere uncertainty of their presence may slow operations, limit mobility, and/or cause planners to redefine operating areas to avoid the mine threat. Due to their relatively low cost and ease of use, mines may play a prominent role in an adversary's sea denial arsenal.

c) HISTORY

The ideas and use of mine warfare have been around since the Revolutionary War when David Bushnell floated contact mines using barrels of gunpowder to attack British warships. During World War I (WWI) and World War II

(WWII), simple mines were used to interdict shipping and to close vital ports. In WW I, a total of 966 ships and submarines were sunk or damaged by mines. In WW II, a total of 3,200 ships and submarines were sunk or damaged by mines. During the Korean War, an amphibious landing at Wonsan was delayed for eight days while United Nations mine countermeasure forces struggled to clear a channel. The commander of the amphibious task force at Wonsan, Rear Admiral Allan E. Smith stated, "We have lost control of the seas to a nation without a navy, using pre-World War I weapons, laid by vessels that were utilized at the time of the birth of Christ." In the Gulf War (Operation Desert Storm), USS Tripoli (LPH 10) and USS Princeton (CG 59) were damaged by mines off the coast of Kuwait. Amphibious forces threatened Iraq with a possible landing in Kuwait. This diversion greatly contributed to the ground war's success. Intelligence reports after the war revealed Iraqi minefields were larger and denser than anticipated, and could potentially have caused a disaster for U.S. amphibious forces.

As shown in Figure 100, since 1950, mines have caused damage to 15 U.S. warships. This is significantly more than the damage caused by terrorist, missile, torpedo, and aerial attacks combined.

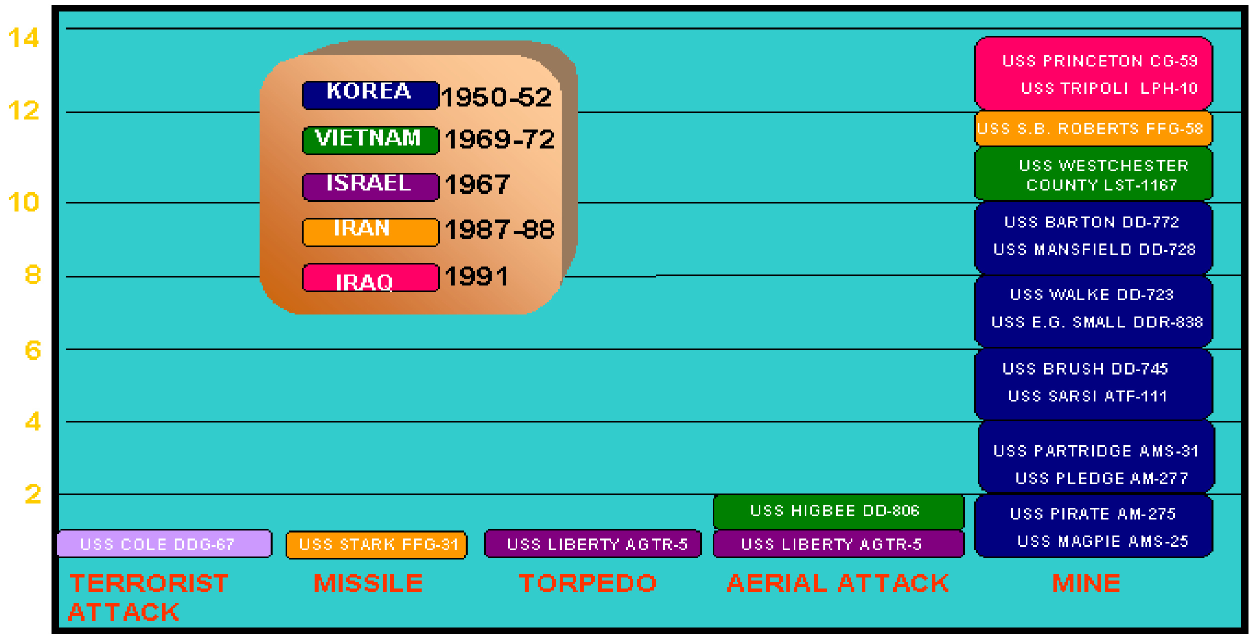

Figure 100. Damage to U.S. Warships Since 1950

Mines are widely proliferated. More than 50 countries have mining capabilities with more than 300 types of mines. One appealing aspect of mines is their cost effectiveness. Table 41 shows the costs to transport and repair U.S. ships that were struck by mines and the cost of the mines themselves.

Ship	Damage Cost	Mine Cost
Samuel B. Roberts	$52.1mil	<$1,500
Princeton	$24mil	$3,000
Tripoli	$3.5mil	$1,500

Table 41. Cost of mine damage compared to cost of mine.

d) FUTURE

	MINE-1 Surf Zone & CLZ 0 – 10 ft	MINE-2 Very Shallow Water (VSW) 10 – 40 ft	MINE-3 Shallow Water (SW) 40 – 200 ft	MINE-4 Deep Water (DW) 200 ft
Type	Bottom	Bottom	Bottom / Moored	Moored
Actuation	Contact / Influence	Contact / Influence	Contact / Influence	Influence
Delivery	Personnel / Ship / Aircraft	Ship / Aircraft / Sub	Ship / Aircraft / Sub	Ship / Aircraft / Sub
Warhead (lbs)	700	1000	700	800

Table 42. Mine Threat Representative Characteristics.

Improvements in technology are further complicating the mine threat. Mines are being developed with active burial systems and non-metallic parts to reduce their target signature. Mines are becoming more robust with hardened casings and resistant fuses. Mines are also becoming more resistant to mine countermeasures through the use of ship counters. Although advances in technology are improving mines, vintage mines from WW II still pose a threat to U.S. forces. Table 42 shows characteristics of mines the Sea Base assets may encounter in various water regions.

2. TORPEDOES

a) DEFINITION

This study defines a torpedo as a steerable self-propelled underwater projectile filled with an explosive charge used for destroying ships or submarines.

b) THREAT TO SEA BASE

The torpedo poses a threat to the Sea Base for numerous reasons. A single torpedo is capable of seriously damaging or destroying Sea Base ships and/or any escorts. Torpedoes can be employed from air, surface, or subsurface platforms. Torpedoes are difficult to locate visually and may be difficult to detect. Furthermore, they are highly maneuverable and travel at speeds faster than Sea Base shipping.

c) HISTORY

The torpedo has evolved from a floating mine used in the Revolutionary War to the fast moving, self-guided, homing torpedoes used today. WWI and WWII torpedoes traveled in a straight line on a pre-set course. The homing torpedo is fired in the direction of the target and automatically changes its course to seek out the target.

d) FUTURE

Torpedo technology is proliferating and advancing throughout the world. There are more than 30 different torpedo models with varying capabilities that include: silent, wake free propulsion; high speed capability; multiple, selectable attack geometries; long range; at least twelve different guidance, homing or fusing techniques; decoy rejection; state of the art signal processing to improve the chance for target acquisition; multiple re-attack logic; and use of a wide band of the acoustic spectrum (less than 10 kHz to nearly 100kHz); adaptive, countermeasure-resistant homing.

Representative torpedo threats the Sea Base may encounter will likely have the characteristics listed in Table 43.

	TORP-1 (sub launched)	**TORP-2** (sub launched)	**TORP-3** (air or surf launched)
Length (ft)	26	26	8
Diameter (in)	21	21	13
Warhead (lbs)	600	600	100
Speed (kts)	50	200	40
Range (nm)	10	4	4
Depth (ft)	700	700	1200
Guidance	passive /active acoustic Wake homing	passive / active acoustic homing	passive / active acoustic homing

Table 43. Torpedo Threat Representative Characteristics

3. SUBMARINES

a) DEFINITION

This study defines a submarine as a warship that can operate on the surface or underwater. For purposes of the study, the submarine will be focused primarily on anti-surface and anti-submarine mission areas.

b) THREAT TO SEA BASE

The submarine poses a versatile threat capable of both direct and indirect actions towards the Sea Base. Indirectly, the submarine can act as an intelligence platform intercepting valuable communications and/or providing targeting data to other assets. Conversely, a potential adversary could easily deny access to a region by advertising its presence. In a more direct sense, a submarine threatens the Sea Base by possessing the capability to seriously damage or sink Sea Base shipping through the use of torpedoes or mines.

c) HISTORY

Submarines have proven their destructive potential throughout history. During WWI, German U-boats exacted a huge toll on merchant shipping while practicing unrestricted submarine warfare. In order to mitigate this problem, a new warfare area was created, anti-submarine warfare (ASW). ASW included the use of depth charges and maneuvering surface assets in convoys. During WWII, U.S. submarines played an important role against Japan's surface assets. By 1945, about 1/3 of all Japanese warships were destroyed and over half of Japan's merchant vessels were destroyed by U.S. submarines. During the Cold War, nuclear attack submarines were developed to protect carrier battle groups against Soviet submarines. After the end of the Cold War, the focus of the submarine threat moved to the littorals.

Although the overall number of submarines in the world has decreased, their quality and versatility have improved. Forty-five countries around the world have submarines in their inventory. Due to affordability, nations that are unable to produce their own submarines are able to purchase submarines from other countries. Nations are also obtaining the submarine's threat capability by purchasing cheaper "midget" submarines. Midget submarines can deploy as diver vehicles to attack larger ships using mines or torpedoes.

d) FUTURE

Sea Base assets may encounter two types of attack submarines listed in Table 44.

	SUB-1	SUB-2
Length (ft)	240	360
Beam (ft)	30	36
Displacement (tons) (surfaced / submerged)	2325 / 3076	6000 / 7000
Speed (kts) (surfaced / submerged)	10 / 19	15 / 30
Armament	6 – 21 in torpedo tubes (18 torpedoes) 24 – Mines (replaces torpedoes) 8 – SAMs	6 – 21 in torpedo tubes (18 torpedoes) 24 – Mines (replaces torpedoes) 8 – SAMs
Propulsion	Diesel electric (AIP)	Nuclear / Pressurized Water Reactors
Endurance (days)	45	45
Diving depth (ft)	1000	1000

Table 44. Submarine Threat Representative Characteristics.

B. ON THE WATERLINE

1. SMALL BOATS

a) DEFINITION

This study defines small boats as an extensive range of craft designed to operate in shallow coastal water such as patrol boats, patrol gunboats, torpedo boats, missile boats, fast-attack-craft, drones, suicide craft and motorboats. The armament mounted or carried on small boats range from miscellaneous side and shoulder-fired weapons to large caliber machine guns, cannons, mortars, rockets, and torpedoes. These small craft are inherently constrained in range, endurance, and capability due to their size, seaworthiness, and reliance on non-organic platforms for over-the-horizon targeting information and support.

b) THREAT TO SEA BASE

Small boats are a considerable challenge to Sea Base assets operating in the littoral environment. The small radar cross section of vessels in this class make them particularly difficult to detect and target. Their speed (up to 50 knots in some cases) and maneuverability complicate the difficulty of targeting them with current weapons systems. Furthermore, the current means of addressing the small boat threat are not cost effective. In mass, small boats could attrite the weapons inventory as Sea Base assets use costly means to defend themselves.

c) HISTORY

"When John Paul Jones pleaded for a fast-sailing ship because he intended 'to go in harm's way,' he set the tone for the first hundred years of American naval history." The United State's Navy was "built around fast ships skippered by bold captains, officered by ambitious lieutenants, and manned by individualistic seamen." The Navy employed "hit and run" tactics in order to disrupt enemy merchant traffic and engage smaller enemy combatants. Though the Navy's roots stemmed from using fast, small "boats" as an effective platform from which to conduct warfare at sea, it was not until those same tactics were used against the U.S. Navy that small boats were viewed as a viable threat.

The Tanker War, from 1984-1987, would bring to light the large combatant's inherent vulnerability when challenged by fast, small boats. The Iranians conducted 43 small boat attacks against merchant shipping during this conflict. Their swarming tactics proved to be quite successful and though they rarely sank a ship, they were effective at inflicting serious damage on the tankers and their crews. These small boats harassed U.S. ships as well, but luckily, the Iranians made no significant efforts to go toe-to-toe with the Americans. The U.S. Navy, whose assets were not designed or equipped to deal with the small boat threat, countered the Iranians with Special Operations Forces and helicopter gun-ships.

The Liberation of Tamil Elam (LTTE), a.k.a. the Tamil Tigers, an ethnic insurgence group fighting for independence in Sri Lanka, India, have notably been the most successful group to employ small boat swarm tactics against larger naval forces. This group generally employs 10 to 15 craft, armed with machineguns, and will overwhelm their enemy by attacking from many different directions. "Sri Lanka has lost at least a dozen naval vessels, both in harbor and at sea, as a result of LTTE attacks." The Tamil Tigers have also successfully employed "kamikaze" style attacks against their targets.

d) FUTURE

As foreign militaries concentrate on coastal defense because they cannot afford a blue water naval capability, small boats will likely play a larger role in future enemy strategies to deny access to, or disrupt, U.S. naval and amphibious operations in the littorals. Small boats require smaller crews to operate, thereby reducing manning, training, and operating costs. Furthermore, small boats are cheaper to acquire and replace, and are easier to hide or disguise. For terrorists, non-state actors, or rogue governments seeking high payoff targets, small boats are likely to become a viable asymmetric option to counter U.S. supremacy of the sea. The ExWar ships and the Sea Base transport assets may be particularly vulnerable to small boat attacks while attempting to project power to an objective during the assault phase of the amphibious operation.

Sea Base assets may encounter small boat threats with the following characteristics highlighted in Table 45.

Threat		SB-1	SB-2	SB-3
Dimension (ft)	Length	10	82	190
	Beam	4	18	26
	Height	2	20	33
Displacement (lton)		0.34	46.5	280
Speed (kts)		40	50	40
Range (nm)		125	500	1500
Engine Type		1.2L Turbo	3 Diesel	4 Diesel
Engine Power (MW)			1.54	7.94
Hull		Fiberglass	Steel / Aluminum	Steel / Aluminum
Armament Type		Machine gun / RPG / Explosives	Machine gun / Rocket / Torpedo / Missile	Machine gun / Rocket / Torpedo / Missile

Table 45. Various Small Boat Characteristics

2. UNCONVENTIONAL VESSELS

a) DEFINITION

This study defines unconventional vessels as innocent craft such as, sailboats, junks, dhows, small merchants, large merchants, container ships, cargo vessels, Petroleum Oil Lubrication or natural gas container ships used with the intent of causing harm or providing targeting information against friendly forces. These vessels require an increased level of identification to discern their disposition. Unconventional vessels cover an extensive range of surface craft.

b) THREAT TO SEA BASE

Unconventional vessels are a potentially devastating threat to the Sea Base operating in the littoral environment for numerous reasons. These vessels can cause harm to the Sea Base both directly and indirectly. Direct action means gaining access to the Sea Base by closing distances due to an unsuspecting nature, and conducting direct action missions employing various types of conventional or unconventional weapons. Indirect attack includes actions such as: saturating the operating area to make maneuver difficult; laying mines; clandestine movement of enemy assets; intelligence gathering operations; or providing targeting information to fixed or mobile enemy weapons systems. If an organized effort was made either directly and indirectly to inhibit the movement of Sea Base assets, disrupt operations, or target friendly assets, the Sea Base may be unable to execute certain critical missions, thus making the overall mission a failure.

c) HISTORY

Deception and military operations go hand in hand. The Greeks successfully conquered Troy after their "gift" to the Trojans was moved inside the city. Though not a sea-going vessel, the Trojan horse can easily be used as an example of the devastation that may befall friendly forces if an unconventional vessel is allowed within weapons range or successfully accomplishes its mission. The USS Cole (DDG 67) was severely damaged in October 2000 by an unsuspecting surface craft that was "helping" it moor to an offshore fuel point.

d) FUTURE

Foreign militaries, terrorists, non-state actors, and rogue nations will continue their efforts to counter the U.S. using asymmetric means. Unconventional vessels allow America's enemies a new platform from which to implement their weapons systems. A Sea Base attempting to conduct a forced entry mission and sustainment of forces ashore would be extremely vulnerable to these types of vessels. For example, a large merchant vessel could transit close to the Sea Base using a standard shipping lane and quickly unleash a barrage of anti-ship cruise missiles from its containers.

C. ABOVE THE WATERLINE

1. ANTI-SHIP CRUISE MISSILE (ASCM)

a) DEFINITION

This study defines cruise missiles as unmanned, self-propelled vehicles that sustain flight through the use of aerodynamic lift. ASCMs are cruise missiles capable of engaging ships or other surface vessels. Because of the maneuverability inherent in ships and surface craft, ASCMs are typically guided by one or more means and possess flight controls that allow them to maneuver in order to hit their designated target(s).

b) THREAT TO SEA BASE

ASCMs present a significant threat to the Sea Base. ASCMs are widely proliferated and increasingly able to travel further and faster while enjoying greatly reduced signatures through the use low observable technologies. They are capable of being employed on a variety of platforms including surface craft, aircraft, submarines, and coastal batteries. Due to an advantage in accuracy, ASCMs, in the littoral, are regarded as a far more dangerous threat than that posed by other threats such as ballistic missiles. Many ballistic missile systems use inherently inaccurate inertial guidance systems and do not possess a means of guiding onto maneuvering targets such as ships. The typical ASCM however, is able to use many forms of guidance both internally and externally. Modern ASCMs are capable of using inertial navigation augmented by inputs from the Global Positioning System (GPS) or other remote sensors, such as digital scene mapping and/or radar altimeters. Target designation and terminal guidance may be provided through a variety of means including infrared (IR), electro-optical (EO), and/or radar. These enhanced guidance packages greatly reduce the typical ASCM's circular error probable (CEP) as compared to the CEP of a typical ballistic missile.

c) HISTORY

For several decades, warfare at sea has concentrated on the threat posed by ASCMs. Indeed, many countermeasures and weapon systems have been developed specifically to address this ever-increasing threat. The growing trend in ASCM proliferation demands that modern navies develop and deploy effective means of dealing with ASCMs. Two notable examples in recent history demonstrate the effectiveness of modern ASCMs: during the 1983 Falkland Islands conflict, three Exocet ASCMs were used to sink or damage three British ships and killed 45 sailors; and in 1987, two

Exocets severely damaged the USS Stark (FFG 31) killing 37 sailors.

d) FUTURE

Many students of the Revolution in Military Affairs (RMA) have pointed to the emergence of high speed, long distance, and highly accurate weapons as a key technological development for future warfare. Several countries have recognized these observations. Recently, the United States, Russia, China, Japan, India, and several European countries have shown great interest in hypersonic technology. Advances in ramjets and scramjets have produced vehicles with ranges greater than 700 km and sustained speeds in excess of Mach 5. These technologies will undoubtedly make their way into future ASCMs.

Two current threat representative ASCMs and one potential future ASCM, with corresponding characteristics and flight profiles, are presented as likely future threats. The information for these ASCMs was obtained or derived using open source material. The three phases of an ASCM's flight, generally referred to as boost, midcourse, and terminal, are assumed for the three missiles. The missile characteristics and associated flight profiles are listed below. (See Table 46 and Figure 101.)

Threat	Speed (kts)	Max Range (nm)	Cruise Altitude (ft)	Terminal Altitude (ft)	Seeker Type
ASCM-1	583	81	16	10	Radar, EO, IR
ASCM-2	1602	162	33	16	Radar, EO, IR
ASCM-3	3208	540	79000	79000 (30 degree dive)	Radar, EO, IR

Table 46. ASCM Threat Representative Characteristics

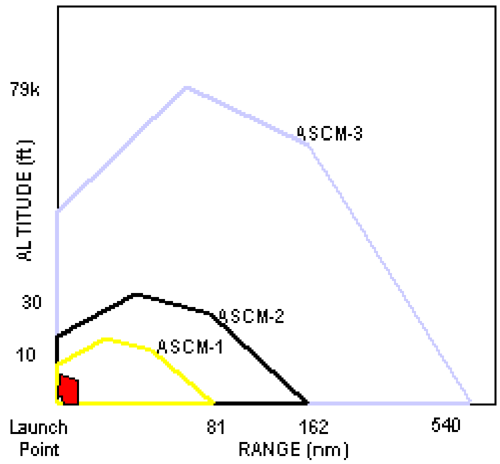

Figure 101. ASCM Threat Representative Flight Profiles

2. ROTARY WING AIRCRAFT/FIXED WING AIRCRAFT/UNMANNED AERIAL VEHICLE (UAV)

a) DEFINITION

For this study's purpose, aircraft include both manned rotary wing and manned fixed wing platforms, although each will be treated separately. Rotary wing aircraft require the generation of lift largely from overhead spinning rotors and are regarded as manned helicopters. Fixed wing aircraft require the generation of lift by the rapid flow of air over a surface, or wing, that for the most part does not move, and is firmly attached to or is a part of the aircraft’s main body. While the wings of a fixed wing aircraft may be variable geometry, the motion of the wings themselves does not contribute directly to the generation of airflow.

An Unmanned Aerial Vehicle (UAV) may either be fixed wing or rotary wing, but it differs from the term aircraft as used here in that it is unmanned and can fly autonomously or be piloted remotely. A UAV can be expendable or recoverable and can carry a lethal or non-lethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.

b) THREAT TO SEA BASE

Rotary wing aircraft, fixed wing aircraft, and UAVs present a significant threat to the Sea Base and the associated delivery vehicles. Large variety of attack aircraft is produced in many countries around the world. Many of these aircraft are widely proliferated and are increasingly able to travel large distances at relatively high speeds while carrying greater payloads and enjoying greatly reduced signatures through the use stealth and other low observable technologies. These aircraft are typically capable of conducting air superiority, surveillance, and reconnaissance in addition to their attack roles. Attack aircraft, in the littoral, are regarded as dangerous threats because of their versatility and ever-increasing capabilities.

c) HISTORY

Since World War I, aircraft have played ever-increasing roles in warfare at sea, on land, and in the air. The military uses of aircraft have evolved from scouting to air defense, air superiority, and strike/attack. The means of conducting these missions have involved an increasing variety of both hard and soft kill armament.

The ability to achieve air superiority has proven decisive in many of the conflicts in modern history. The ability to strike an opponent's forces while denying him the ability to do the same is of great importance to military planners. While augmented by surface-to-air missiles, anti-air artillery, cruise missiles, or ballistic missiles, these missions rest primarily with manned aircraft.

UAVs do not have as long a history as manned aircraft, yet several variants have enjoyed great success in recent conflicts. UAVs have proven invaluable because of their relatively long endurances, low observable features, and tactical flexibility. In Bosnia, Afghanistan, and Iraq, UAVs proved extremely reliable and capable in performing surveillance, reconnaissance, and attack missions.

d) FUTURE

Because of the significant investment in equipment and training required to obtain modern fighter-attack aircraft and the pilots to man them, many countries may turn instead to the relative affordability offered by UAVs. The development of UAVs, such as the Unmanned Combat Air Vehicle (UCAV), promise an affordable weapon system capable of performing a wide variety of tactical missions, either autonomously or remotely, as early as 2010.

The use of both rotary wing and fixed wing manned aircraft cannot be discounted for future warfare. The proliferation and continued development of manned aircraft ensure that these platforms will remain in the arsenals of many countries for the foreseeable future.

Two current threat representative manned aircraft, one potential future manned aircraft, and one potential future multi-role UAV with corresponding characteristics are determined to present likely future threats. The information for these aircraft and the UAV was obtained or derived using open source material. The aircraft and UAV characteristics are listed in Table 47.

Threat	Max Speed (kts)	Max Range (nm)	Service Ceiling (ft)	Max Payload (lbs)	Sensors
ACFT-1 (rotary wing)	184	248	18,045	5512	EO, IR, FLIR, Laser, Radar, Visual
ACFT-2 (fixed wing)	1602	905	60,368	8818	EO, IR, FLIR, Laser, Radar, Visual
ACFT-3 (fixed wing, low observable)	583	1080	61,024	4409	EO, IR, FLIR, Laser, Radar, Visual
UAV-1 (UAV, low observable)	551	999	39,370	2998	EO, IR, FLIR, Laser, Radar

Table 47. Aircraft and UAV Threat Representative Characteristics

3. SURFACE-TO-AIR MISSILES (SAMS)

a) DEFINITION

For the purposes of this study, SAMs are defined as surface-launched missiles that are used against airborne targets.

b) THREAT TO SEA BASE

SAMs will present a significant threat to the Sea Base's airborne assets. SAMs are widely proliferated throughout the world in a variety of forms and are typically fast and very accurate. Many SAMs are capable of using a variety of both passive and active methods for guidance and homing. These methods include radar, laser, electro-optical (EO), infrared (IR), and ultraviolet (UV). Furthermore, many SAM systems are highly mobile and do not rely on fixed site emplacement. These SAMs are normally man-portable or are employed on tracked or wheeled vehicles or onboard surface craft. The ability of these systems to shoot and move greatly complicates counter-targeting by enemy forces.

c) HISTORY

SAMs have enjoyed great success in several conflicts in recent history. They have been widely used in many areas and at various times with devastating results. While not able to gain air superiority themselves, SAMs have acted as effective barriers to the attainment of air superiority by opponents.

d) FUTURE

SAMs will continue to be used in future conflicts. Their affordability and lethality are attractive alternatives to the establishment of an expensive air defense composed of high-cost air-defense fighters. SAMs furthermore provide an effective deterrent against many modern air forces.

SAMs will most likely continue to increase in speed, range, and accuracy. Many experts attribute the success of the U.S. in recent conflicts to the attainment of air superiority. Future enemies will most likely focus on the denial of air superiority through increases in the performance capabilities of their air defense systems.

Two current threats representative SAMs with corresponding characteristics are likely to present future threats. The information for these SAMs was obtained or derived using open source material. The SAMs' characteristics are listed in Table 48.

Threat	Max Speed (kts)	Max Range (nm)	Max Altitude (ft)	Launch Platform	Sensors
SAM-1	3600	108	98,425	Mobile/Semi-Mobile (TEL, ship)	EO, IR, Radar
SAM-2	1602	5.4	19,685	MANPAD	EO, IR, UV, Laser, Visual

Table 48. SAM Threat Representative Characteristics

4. UNGUIDED WEAPONS

a) DEFINITION

For the purposes of this study, unguided weapons are defined as projectiles that follow a ballistic trajectory with no in-flight control. Unguided weapons encompass small arms, artillery, and ballistic rocket systems.

b) THREAT TO SEA BASE

Unguided weapons present a significant threat to the Sea Base and its associated delivery assets. Unguided weapons are relatively cheap and widely proliferated throughout the world in a variety of forms.

c) HISTORY

Unguided weapons have been used in almost every conflict since man first picked up a rock. They have evolved from simple slings and spears to catapults and crossbows to modern day machine guns and long-range howitzers.

d) FUTURE

Unguided weapons will continue to be heavily used in future conflicts. Their affordability, lethality, and ease of use ensure their continued existence in every arsenal. Unguided weapons will most likely continue to increase in range, accuracy, and firepower.

The Sea Base may encounter three representative unguided weapons listed in Table 49. The information for these unguided weapons was obtained or derived using open source material.

Threat	Projectile	Effective Range	Max RPM	Armor Penetration (RHA)	Portability
DW-1 (MLRS-type)	227mm	16 nm	6 rockets per launcher (644 submunitions per rocket)	4 in (per submunition)	Truck w/ 13 ft bed
DW-2 (crew-served)	40mm	1695 yds	60	2 in	3 man
DW-3 (assault rifle)	7.62mm	328 yds	600	N/A	1 man

Table 49. Unguided Weapons Threat Representative Characteristics

APPENDIX A.2. PLATFORM THREATS

- **AIR**
  - **UAV**
  - **ROTARY WING**
- **SURFACE**
  - **USV**
  - **SMALL BOAT**
  - **REC CRAFT**
- **SUB SURFACE**
  - **SUB**
  - **AUV**
  - **MINES**
  - **NAVIGATION OBSTACLE**

APPENDIX A.3. METHOD OF DELIVERY

- **AIR**
  - **MISSILES**
  - **HELO**
  - **UNMANNED AIR VEHICLE (UAV)**

- **SURFACE**
  - **ANTISHIP CRUISE MISSILE (AIR, LAND, SEA)**
  - **SMALL BOAT/WAVE RUNNER (RPG/50 CAL/ C-4)**
  - **UNMANNED SURFACE VEHICLE (USV)**
  - **FLOATING MINE**

- **SUB SURFACE**
  - **DIESEL SUBS**
  - **AUTONOMOUS / MANNED UNDERWATER VEHICLE / DIVERS/MIDGET SUB**
  - **SEA MINES (ALL TYPES)**
  - **NAVIGATION OBSTACLE**

- **MISC.**
  - **NBC / CBR**
  - **EW / JAMMING**
  - **DIRECT ENERGY WEAPON**
  - **EMP**
  - **C4ISR**

APPENDIX A.4. WEAPONS THREATS

- **AIR-AIR**
  - **GUNS**
  - **MISSLES**
  - **TORPEDOS**
  - **KAMIKAZI**
  - **EW**
- **AIR-SURFACE**
  - **GUNS**
  - **MISSILES**
  - **TORPEDOS**
  - **CRUISE MISSLE**
  - **KAMIKAZI**
  - **EW**
- **AIR-SUBSURFACE**
  - **TORPEDOS**
  - **KAMIKAZI**
- **DIRECTED ENERGY**
- **ARTILLARY MUNITIONS**

- **GUIDED**
- **UNGUIDED**

- **SMALL ARMS**
- **MINES**
  - **MOORED**
  - **BOTTOM**
  - **FLOATING**
- **EXPLOSIVES / C-4**
- **RPG/MOBILE MISSLE SYSTEM**
- **EMP / NBC / CBR**
- **C4ISR**

- **NAVIGATION**
- **IMAGING**
- **COMMUNICATIONS**

APPENDIX B.1. INITIAL REQUIREMENTS DOCUMENT

FOR

TSSE Design Project
Summer and Fall Quarter 2003

17 July 2003

1. GENERAL DESCRIPTION OF OPERATIONAL CAPABILITY.

a. Mission Need Statement: The top-level mission need is stated in the Project Guidance Memorandum from Professor Calvano (22 May 2003) stored on the SEA Share Drive. This need is to "address protection of the ships of the Sea Base while at sea in the operating area as well as the protection of the airborne transport assets moving between the Sea Base and the objective and the surface assets moving between the Sea Base and the beach or a port." The integrated teams are specifically not required to address protection of the Sea Base assets while in port. Furthermore, the tasking does not include addressing the protection of the land force itself or land transport from the beach to the objective.

(The SEI-3 Study paints a broad picture of Expeditionary Warfare (ExWar) as it might look like by the year 2020. The SEI-3 Study embodies the capabilities of pertinent documents germane to ExWar.)

b. Overall Mission Area: Expeditionary Force Protection (EFP).

SEA-4 has defined Expeditionary Force Protection (EFP) as actions taken to prevent or mitigate hostile action against the Sea Base to include resources, facilities, and critical information. These actions conserve the force's fighting potential so it can be applied at the decisive time and place and incorporate the coordinated and synchronized offensive and defensive measures to enable the effective employment of the joint force while degrading opportunities for the enemy. Force protection does not include actions to defeat the enemy or protect against accidents, weather, or disease. (Adapted from DOD Dictionary definition of Force Protection.)

c. Description of Proposed System: This system is intended to be a platform, or family of platforms, that encapsulates all mission capabilities and meets system level requirements contained in this document. The system will support the operational flexibility and rapid operational tempo (OPTEMPO) required for the protection of the ExWar force (SEI-3 conceptual architecture). It will support littoral operations across the spectrum of conflict — from small-scale contingency missions as part of a forward-deployed Amphibious Ready Group (ARG), to forcible entry missions in a major theater war (MTW) as part of a large naval expeditionary force. It must be able to enhance the protection of the ExWar ships and associated delivery vehicles.

This system must be capable of integration with current and future joint, combined, or interagency systems. This system must allow the Navy to fully use the capabilities of future systems such as Vertical Take-Off and Landing

Unmanned Aerial Vehicles (UAV), Unmanned Surface Vehicles (USV), or Unmanned Underwater Vehicles (UUV) as well as future force protection and Battle Management C4I (BMC4I) capabilities. The system will need to be designed to accommodate growth trends and the insertion of new technologies throughout its service life to avoid built-in obsolescence.

2. SYSTEM STATES AND ASSOCIATED THREATS

Three system states have been identified for the ExWar force. The following are SEA-4 determined system states and their associated primary threats:

a. State I – Staging/Buildup (Operating Area)

- Anti-ship cruise missile (ASCM)
- Swarming small boats
- Unconventional ships/boats
- Submarines/UUVs
- Mines

b. State II – Ship-to-Shore / Ship-to-Objective Movement

- Swarming small boats
- Mines
- Surface-to-air missiles (SAMs)
- Unguided munitions
- Aircraft/UAVs

c. State III – Sustainment

- ASCM

- Mines
- Unconventional ships/boats
- SAMs
- Aircraft/UAVs

3. WARFARE AREAS

The Sea Base will operate as an amphibious strike group. For a MEB sized force, a Carrier Strike Group (CSG) will be operating in the vicinity of the Sea Base.

Air Warfare (AW): The system must detect, identify, track, and defeat air targets that have been launched without warning or have eluded AW defenses provided by other fleet units (i.e., "leakers"). The employment of these threats may vary from low density to saturation attack.

- Anti-ship cruise missile (ASCM)
- Attack aircraft
- UAV
- Low slow flyer

Surface Warfare (SUW): The system must detect, identify, track, and defeat a variety of surface craft. The surface craft themselves may vary from asymmetric/unconventional boats to patrol craft. The employment of these threats may vary from low density to saturation. In the dense, cluttered, and environmentally complex littoral regions, the system must be able to:

- Detect surface threats with ownship and networked sensors

- Deconflict potentially hostile craft from friendly and neutral shipping
- Direct, support, and/or embark aircraft conducting SUW.
- Engage surface threats to the ExWar force

Under-Sea Warfare (USW): The system must support both anti-submarines operations and Mine Countermeasures (MCM). Furthermore, the system must be able to detect, identify, track, and defeat UUVs and no-warning torpedo attacks. The design must provide for the control and support of USW helicopters/UAVs, and the control of UUVs. The ship must also support Mine Warfare (MIW) assets. This includes:

- Direct, support, and/or embark aircraft conducting USW.
- Hosting of remote mine search capability (i.e., unmanned surface/subsurface vehicles and/or Very Shallow Water (VSW) Detachment operated from the ship) from deep water to surf zone.
- Possess ownship capabilities to conduct MCM from deep water to VSW.
- Possess an offensive mining capability.

Information Operation / Information Warfare (IO/IW): The Command and Control (C2) architecture must support planning, gaining, and maintaining situational awareness, decision-making, order generation, weapons direction, and ship system monitoring and control with uninterrupted voice, video, and data connectivity. The system must be able to collect, process, exploit, and disseminate an uninterrupted flow of information in support of operations. Interoperability, not just compatibility, of C2 systems across the joint/combined/interagency force is required. The system must be capable of deploying an expeditionary sensor grid with the following characteristics:

- Communication suite allowing fully networked assets (helos, UAVs, USVs, UUVs).
- Deployable surface and bottom acoustic and RF arrays to act as tripwire and early warning of threats.
- Deployment of systems such as aerostats and robotic airships to extend the horizon and provide a stable sensor array versus low observable targets such as small, fast movers.

The system must be capable of conducting electronic attack (EA), electronic protection (EP), and/or electronic support (ES).

4. ADDITIONAL REQUIREMENTS.

a. Operational Requirements:

- Operate in deep water to very shallow water.
- Operate as far as 200nm offshore.
- Capability to operate at a sustained speed of 35kts.
- Trans-oceanic crossing capability.
- Employ full capabilities in a sea state of five.
- Employ full capabilities in a Chemical-Biological-Radiological (CBR) environment

- Employ full capabilities in temperatures ranging from -18 C to 40 C (Outside Dry Bulb).

b. Environmental, Safety and Occupational Health (ESOH) and Other System Characteristics:

- Must comply with Federal EPA and NAVOSH regulations and international law as applicable.

c. Supportability Requirements: The system must be capable of sustainment from legacy and future CLF ships as well as from ExWar ships. Prolonged expeditionary operations will demand that the Sea Base FP assets be able to remain on-station for the duration of the campaign. This capability will facilitate the elimination of an operational pause and permit the ExWar force to conduct Ship to Objective Maneuver (STOM) and Operational Maneuver From the Sea (OMFTS). By gaining and maintaining access throughout the littorals, the U.S. Navy will become the chain link that will provide the capability to conduct joint, combined, and interagency expeditionary operations. The system must have Intermediate Level (I-Level) Maintenance for platforms in company and ownself.

d. Human Systems Integration:

- Reduced manning concepts must be employed.
- Ensure crew comfort/QOL.

5. REFERENCES.

a. SEI-3 ExWar Study

b. Project Guidance for AY 2003 SEA-4 Team (Prof Calvano memo dtd 22 May 2003)

c. Littoral Combat Ship Concept of Operations (NWDC website http://www.nwdc.navy.mil/Concepts/LCSCONOPS.asp)

d. The Maritime Vision

e. The Naval Operational Concept

f. The Maritime Concept

g. Expeditionary Maneuver Warfare

h. Seabased Logistics, May 1998

i. MPF 2010 and Beyond

j. STOM CONOPS

Note: All documents are located in the SEA lab or on the SEA Share Drive.

6. POINTS OF CONTACT.

a. LT Chris Wells (ckwells@nps.navy.mil, (831) 656-7880)

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APPENDIX B.2. FINAL REQUIREMENTS DOCUMENT

FOR

TSSE Design Project
Summer and Fall Quarter 2002

05 November, 2002

1. GENERAL DESCRIPTION OF OPERATIONAL CAPABILITY

Mission Need Statement: The top-level mission need is implied in the OPNAV Tasker (Ser N7/U655631, 12 April 02) stored on the SEI Share Drive. The SEI CONOPS paints a broad picture of Expeditionary Warfare (ExWar) as it might look like by the year 2020. The SEI CONOPS embodies the capabilities of pertinent documents germane to ExWar as outlined by the OPNAV Tasker.

Overall Mission Area: Expeditionary Warfare.

Description of Proposed System: This system is intended to be a platform, or family of platforms, that encapsulates all mission capabilities and meets system level requirements contained in this document.

2. DEFINITION OF PROPOSED MISSION CAPABILITIES:

Amphibious Warfare (AMW)

The system will be used in amphibious operations to transport, land, and support the landing force. The system will support the operational flexibility and rapid operational tempo (OPTEMPO) required by the ExWar force.

It will support littoral operations across the spectrum of conflict — from small-scale contingency missions as part of a forward-deployed Amphibious Ready Group (ARG), to forcible entry missions in a major theater war (MTW) as part of a large naval expeditionary force.

This system must allow the Marine Corps to fully use the capabilities of future systems such as the Advanced Amphibious Assault Vehicle (AAAV), MV-22, Short Take-Off Vertical Landing Joint Strike Fighter (STOVL JSF), CH-53E or replacement, AH-1Z, UH-1Y and Unmanned Aerial Vehicles (UAV), as well as future amphibious assault command and control capabilities. The system will need to be designed to accommodate growth trends and the insertion of new technologies — such as intermodal transfer and improved underway replenishment capabilities — throughout its service life to avoid built-in obsolescence.

Sea Based Logistics

The system must provide for the option of indefinite sustainment, by serving as a conduit for logistics support from military/commercial suppliers. The prolonged operations will demand that the Sea Bbase be able to store and maintain the lighterage and cargo transfer platforms. This capability will reduce the ExWar force’s footprint on land, eliminate operational pause, and enable the ExWar force to conduct Ship to Objective Maneuver (STOM) and Operational Maneuver From the Sea (OMFTS). By providing a mobile sea base, the U.S. Navy will become the chain link that will provide the capability to conduct joint, coalition, and interagency expeditionary operations.

Should shore basing be required, the Sea-base will possess the flexibility to support the logistics and maintenance efforts ashore. It will be able to safely navigate and access a wide range of ports worldwide. This will include the ability to conduct Roll On/Roll Off and Lift On/Lift Off cargo operations in the majority of worldwide commercial marine cargo terminals as well as over-the-horizon and in-stream cargo operations in unimproved ports

Other Warfare Areas The platform/s of the Sea Base will operate as amphibious strike groups. For a MEB sized force, an escort package of 3 CG, 3 DDG, 3 FFG/DD, 3 SSN, and a squadron of P-3C Update III AIP aircraft will be tasked to support the Sea Base. Additionally, a CVBG will be associated with the Sea Base, although not necessarily under their direct control; however, the platform/s of the Sea Base must retain a self-defense capability for threats that elude these escorts as described below.

Air Warfare (AW)

The system must detect, identify, track, and defeat air targets that have been launched without warning or have eluded AW defenses provided by other fleet units (i.e., "leakers").

Surface Warfare (SUW)

The system must include the capability of detecting, tracking, and destroying multiple small, high-speed surface craft. In the dense, cluttered, and environmentally complex littoral regions, the system must be also be able to:

Detect surface threats to the horizon with its own sensors

Deconflict potentially hostile craft from friendly and neutral shipping

Direct aircraft conducting SUW

Engage surface threats to the ExWar force within the horizon

Under-Sea Warfare (USW)

The system must support both anti-submarine operations and MCM. The design must provide for the control and support of USW helicopters, and the control of unmanned underwater vehicles (UUV). The ship must support MIW assets. This includes:

“Lily-pad” support for airborne mine countermeasures helicopters

Short-term hosting of remote mine search capability (i.e., unmanned surface/subsurface vehicles operated from the ship) is needed.

Transporting, directing, supplying, and maintaining of shallow water and very shallow water clearance activities from the landing craft that will be embarked on the ship

Strike Warfare (STW)

The system must allow coordinating, tasking and supporting strike missions.

Support Naval Special Warfare (NSW)

The system must have C3 functions that can support any embarked command, but with special requirements in the areas of secure communications, storage of non-standard ordnance, and support for craft and SEAL Delivery Vehicles (SDV) and Explosive Ordinance Disposal (EOD) Units.

C4ISR Operational Concept and Requirements

The Command and Control (C2) architecture must support planning, gaining, and maintaining situational awareness, decision-making, order generation, weapons direction, and ship system monitoring and control with uninterrupted voice, video, and data connectivity. Interoperability, not just compatibility, of C2 systems across the joint/combined/interagency force is required.

Sea Based C2 must afford commanders the capability to transition to command ashore. Embarked tactical units need large staging areas to brief units of up to 250 personnel. The conduct of STOM by the landing force demands a ship-to-objective architecture, allowing receipt and rapid response to requests for intelligence, operations, or logistic support at distances approximating 200 nautical miles inland. The design should allow for commercial-off-the-shelf (COTS) equipment replacement without major impact or modification.

The C4ISR architecture must address Naval Surface Fire Support (NSFS) by having the communications facilities required for coordinating the employment of mortars, rockets, artillery, air and naval surface fires. The architecture must have the capability to communicate in a network-centric environment with the force fires coordination center, the fire support coordination center, fire support elements, joint fires elements, or another surface combatant operating in a land attack controlling unit role, from the SACC. All NSFS capabilities must be fully integrated into joint land attack command, control, communications, computers, intelligence, surveillance, reconnaissance, and targeting (C4ISRT) networks.

Information Warfare (IW), Information Operations (IO), Information Dominance (ID), and Command and Control Warfare (C2W) are capabilities that the C4ISR infrastructure must be able to support. The system must be able to collect, process, exploit, and disseminate an uninterrupted flow of information in support of such operations. It must be able to conduct offensive information operations, and the design should incorporate highly integrated sensor assets to exploit the entire spectrum.

3. THREAT.

The capabilities of this system must be based on existing and potential threat environments in which the future ExWar force might be employed. The future ExWar force will be forward deployed and rapidly deployable in a chaotic international environment. Belligerents, enemies and potential enemies will range from modern well-equipped forces to individual fanatics. The ExWar force may face military forces, para-military forces, terrorists, criminal organizations, drug and contraband traffickers, gangs, and/or mobs. Additionally, there may well be more than one belligerent faction involved in the conflict, compounding the difficulty for the ExWar force.

Many of the scenarios and adversaries could involve large segments of civilian and non-combatant population. Weapons may range from very primitive to highly sophisticated. The ability of almost every potential adversary to obtain and employ modern weapons has greatly increased. The lethality of the weapons has increased while reaction time in which to defend against them has been drastically reduced. The proliferation of weapons of mass destruction and the probability of their employment will add new and critical aspects to the situation facing the future ExWar force. While preparing to meet the various threats posed by governments and individuals, the ExWar force must also be prepared, when directed by the chain-of-command, to react to a full array of natural disasters and human suffering. (Source: SEI CONOPS)

4. SHORTCOMINGS OF EXISTING SYSTEMS AND C4ISR ARCHITECTURES

- Insufficient interoperability of C2 systems across the joint/combined/interagency force.
- Inability to provide indefinite, continuous C4ISR and logistics support to expeditionary forces.

- Cannot rely on foreign governments to provide bases and facilities for U.S./coalition forces in case of regional contingency.
- Aging amphibious assault platforms.
- The lack of a Seabased Logistic C2.
- Inadequate life to execute OMFTS and STOM.
- Inadequate indefinite sustainment capability.

5. SYSTEM LEVEL REQUIREMENTS

Baseline AMW Requirements.

System lift capacity of 1.0 Marine Expeditionary Brigade (MEB). A MEB is a reinforced brigade Marine Air Ground Task Force (MAGTF) made up of three Marine Expeditionary Units (MEU), a reinforced battalion sized MAGTF. A MEU consists of 1200 combat troops and their combat support elements for a total complement of 2200 personnel. A MEB can be formed in two ways: an amphibious MEB roughly consists of the combat load onboard the ships of the three MEU sized Amphibious Readiness Groups (ARG) for a total of 14,000 personnel; however, a maritime pre-positioning squadron (MPRON) can deliver additional vehicles, equipment, materials, and supplies to increase the size and firepower of the MEB (an MPF MEB) to 17,000 total personnel, if required. Starting with the merger of at least two MEU sized ARGs, the Expeditionary Warfare system must be capable of delivering an MPF MEB size force directly to the objective via the Sea Base. Baseline equipment load and supply requirements for an MPF MEB sized force are contained in a spreadsheet found on the SEI share drive in the folder marked "Configuration Control."

Operate at sea 25 to 250 NM from the beach.

Employ all capabilities in a sea state of at least three (seas 3.5 - 4 ft, period 2 - 7 sec, average length between swells 52 ft, wind to 15 kts).

The system must be capable of transoceanic transportation. From a pre- positioning location, and under the conditions stated in the standard Indonesian and Burmese scenarios, the system must be able to arrive on station in no less time than the present day forces (threshold) and preferably in one half the transit time required by present day forces (objective).

Accommodate both current and future aviation and surface assault assets — including helicopters, MV-22, STOVL JSF, AAAV, LCAC, LCU(R), and MCM assets — under improved day or night, adverse weather conditions. The platforms must be compatible with operations of existing and future surface ships such as the LHD and LPD-17. The Sea Base platforms must operate with the long range, heavy lift aircraft conceptual design under development by the Aeronautical Engineering curriculum. The heavy lift design will have a spot factor no greater then twice that of a CH-53E, spread and folded. The design goal is a spot factor 1.5 times that of a CH-53E, spread and folded. The aircraft maximum gross weight is projected to be as high as 110,000 - 140,000 lbs for the quad tilt rotor concept.

Sea Base platforms required to carry both troops and support materials must be capable of simultaneously spotting, starting, loading, and launching troop transport and heavy lift aircraft. These simultaneous operations must be capable of moving troops and supplies at as least the same rate as individual troop and cargo operations from current platforms. The ability to concurrently operate STOVL fixed wing attack aircraft and troop/material transport aircraft from individual ships of the Sea Base is desired, but not required.

The platforms must be able to operate unmanned vehicles including Unmanned Aerial Vehicles (UAV), Unmanned Surface Vehicles (USV), and Unmanned Underwater Vehicles (UUV).

Support training for the crew and embarked units.

Provide organic battle group and JTF-level scenario development and simulation-based rehearsal capability.

Support Tactical Recovery of Aircraft and Personnel (TRAP) missions.

Direct the surface and air assaults; provide surface craft control, including serving as the primary control station; and exercise air control and coordination.

Interoperability capability in all aspects, including logistics, combat systems, C4ISR etc with other services as well as allied forces.

Seabasing and Logistics Requirements.

The system must act as an integrated OTH, floating distribution center and workshop providing sustainment to a MEB for 30 days, with a throughput ability to sustain the MEB ashore for an indefinite time.

Provide command and control of logistics operations within the seabase and ashore.

The system must be able to receive supplies and materials via 8′ x 8′ x 20′ and 8′ x 8′ x 40′ shipping containers as well as 8′ x 8′ x 5′ “quadcons.” The system must be capable of moving these stores and supplies within the sea base as well as reconfiguring them onto 48″ x 40″ wooden pallets for transfer ashore, if required.

The system must be capable of conducting vertical replenishment operations with UH-1Y, MV-22A, CH-53E, and the Aero-conceptual design aircraft to support the logistics requirement of the landing force without interrupting aircraft troop transport and surface craft operations.

Provide increased aviation ordnance stowage, handling facilities, and equipment to accommodate the wide variety and quantity of air-delivered ordnance associated with the missions and aircraft mix of the ACE.

The system design must support reconstitution and redeployment of the ExWar force entirely through the Sea Base.

Design must possess selective offload capabilities to reinforce the assault echelon of an ExWar force.

Spaces (especially cargo spaces) should allow flexibility for easy reconfiguration for multi-mission purposes between stores, facilities, and personnel.

The primary role of the Sea Base is the support of operations by expeditionary forces ashore. While the platforms of the Sea Base must be compatible with current and future fleet oilers and supply ships, a secondary role of supporting escort and Sea Base assets with similar services will be considered prior to the FRD.

Information Exchange Requirements.

The C4ISR system must have defense-in-depth. To prevent intrusion, the information system and TSCE must be physically protected, firewalled, and redundant.

Communications and computers must support secure, reliable, network-centric communications and data exchange, not only with the warfare mission commanders, but also with other surface ships, submarines, and manned and unmanned aircraft.

The system must facilitate reachback to the theater and CONUS facilities for ISR products.

Provide the embarked staff a C4ISR capability that supports decentralized, naval, network-centric, and joint/combined/interagency operations.

Environmental, Safety and Occupational Health (ESOH) and Other System Characteristics.

Must comply with Federal EPA and NAVOSH regulations and international law as applicable.

6. PROGRAM SUPPORT.

a. Maintenance Planning.

- The system must have Intermediate Level (I-Level) Maintenance for aircraft, landing craft, other platforms in company and ownself.

b. Human Systems Integration.

- Reduced manning concepts must be employed.
- Ensure crew comfort/QOL.
- Design the system to accommodate mixed genders.

c. Other Logistics and Facilities Considerations.

- The system must support medical evacuation evolutions, whether from combatant operations or in support of MOOTW and NEO operations. This includes patient regulation, transport/evacuation, receipt, and stabilization in preparation for transport.
- The system must be capable of receiving casualties from air and waterborne craft.
- The system must include adequate treatment facilities for critical patients and decompression facilities for EOD personnel.

7. PROGRAM AFFORDABILITY.

- TBD

8. REFERENCES.

For more information read the following:

- OPNAV Tasker (Ser N7/U655631, 12 April 02)
- SEI CONOPS
- The Maritime Vision
- The Naval Operational Concept
- The Maritime Concept
- Expeditionary Maneuver Warfare
- Seabased Logistics, May 1998
- MPF 2010 and Beyond
- STOM CONOPS

APPENDIX C.1. AAW / SUW / CORE TRADE-OFF ANALYSIS SUMMARY

CORE ASSETS	WEIGHT		TOTAL WEIGHT	DIMENSIONS (IN)					Volume (ft3)	Range(nm)	FREQ(Hz)	Volt	Power (kW)		
SYSTEM	Metric Ton	QNTY		Length	Width	Height	Dia	Working Circle					Peak	average	phase
VLS (SINGLE MODULE-WITH 8 CELL) LOADED W 8 SM-2 Block II	25.00	1.00	25.00	103.00	135.00	266.00			2140.47	50.00	60.00	440		29.00	3.00
LAUNCH CONTROL SYSTEM															
Status Panel	0.0456	1	0.0456	11.5	18	24			2.88						
Remote launch enable panel	0.01368	1	0.01368	8	10	13			0.60						
Launch Control Unit	0.6156	1	0.6156	34	44	80			69.26						
Power Requirements by 1 Module															
Lighting											60	115		2	1
Backup power for 440 VAC											60	115		4	3
Launch Control Unit											60	115		6	1
400 Hz Voltage											400	440		10	3
Standard Missile SM2	0.71	8.00	5.66	186.00	39.60		13.20	$421,000		50.00					
Evolved Sea Sparrow Missile	0.31	32	9.92	144.00			10.00			27+					
SPS-49(2D) (above decks)	1.43	1.00	1.43					340.80		250.00	850-942M	360	13.00		
(below decks)	6.33	1.00	6.33												
SPS-52C (Antenna)	1.4592	1.00	1.46							280			1000		
(below decks)	6.40224	1.00	6.40												
SMART-L (Antenna)	7.35	1	7.35		10	5				230			130		
(below decks)	4.438	1	4.44										10.5		
Helo	11.34	1	11.34												

Aviation Fuel (JP-5)		1	0
Helo in-flight refuel system	7.72196	1	7.72196
Helo securing system	3.65777	1	3.65777
Helo rearm+ magazine	2.76365	1	2.76365

AAW mission package	37.46	VLS w/ 8 SM-2+Launch Control System+SMART L Radar

APPENDIX C.2. RADAR TRADE-OFF ANALYSIS

AIR SEARCH RADARS

2-D		WEIGHT	DIMENSIONS (m)				MTBF (hrs)	Range(nm)	FREQ(Hz)	Power (kW)			Band
	SYSTEM	Metric Ton	Length	Width	Height	Dia				Peak	average	phase	
	SPS-49(2D) (above decks)	1.43				340.80	>600	250.00	850-942M	360.00	13		
	(below decks)	6.33											
	SPS-65 (Antenna)	0.2					350	100	1.2-1.35G	25	1.2		
	(below decks)	0.727											
	SPS-40E (Antenna)	0.788					252	200		130			
	(below decks)	1.584											
	Multi-Function Radar	Future Development											X
	VARIANT (Antenna)	0.45		2.4	1.3			40		8.5		3	I and G
	(below decks)	0.375								0.5		1	
3-D	SPS-48E (Antenna)	2.591904					268-586	220		2200			
	(below decks)	10.95221											
	SPS-52C (Antenna)	1.4592					216	280		1000			
	(below decks)	6.40224											
	FAST (Antenna)	3.182							5.4-5.9G	1000	10		
	(below decks)	6.045											
	SMART-S (Antenna)	1.5		5.3	2.05			50		45		3	F
	(below decks)	1.543								7.5		1	
	SMART-L (Antenna)	7.35		10	5			230		130		3	D
	(below decks)	4.438								10.5		1	

APPENDIX C.3. AAW TRADE-OFF ANALYSIS

Threat	CORE ASSETS	WEIGHT		TOTAL WEIGHT	DIMENSIONS (IN)		Range(nm)			
	SYSTEM	Metric Ton	QNTY		Length	Width	Height	Dia	Working Circle	
MISSILE	VLS (SINGLE MODULE-WITH 8 CELL) EMPTY	14.00	0.00	0.00	103.00	135.00	266.00			
AIR	VLS (SINGLE MODULE-WITH 8 CELL) LOADED W 8 SM-2	25.00	2	50.00	103.00	135.00	266.00			
AIR	VLS (SINGLE MODULE-WITH 8 CELL) LOADED W 8 RIM-7	24.00	0.50	12.00	103.00	135.00	266.00			
	VLS MK13 CANISTER W SM-2	1.39	0.00	0.00						
	VLS MK22 CANISTER W RIM-7	1.23	0.00	0.00						
ASW	VLS MK15 CANISTER W ASROC	1.46	0.00	0.00						
	VLS CONTROL SYSTEMS	1.12	1.50	1.68						
CIWS	Goal Keeper (above deck)	9.90	2.00	19.80			146.14			1.61
	(below deck)				100.00		98.43			
	Phalanx	6.71	2.00	13.41						
GUNS	Oto Melara 3 in (76/62 mm) (SR)	7.50	1.00	7.50						11.88
	Bofors 57 mm (Mk 3)	13.00	1.00	13.00						9.18
	5" / 54 in	22.00	1.00	22.00						12.42
COUNTERMEASURES										
SRBOC	Mk-36 w/4 launchers	1.07	1.00	1.07						
	Canisters 100 rounds	2.24	1.00	2.24						
Breda Sclar	each module (22 tubes)	1.75	1.00	1.75						
Barricade	Barricade Mk III(CU + Launcher)	0.11	1.00	0.11						

	SuperBarricade	0.16	1.00	0.16						
	Ultra Barricade (in development)		1.00	0.00						
	(w/o rockents)	0.45	1.00	0.45						
	(payload)	0.60	1.00	0.60						
RADARS										
Air search	SPS-49(2D) (above decks)	1.43	1.00	1.43					340.80	250.00
	(below decks)	6.33	1.00	6.33						
Surface Search	SPS-67(2D)		1.00	0.00						192.63
IR Search	Mk 46 Electro-Optical detector									
COMMAND&CONTROL	SSDS (AN/SYQ-17 RAIDS)									
	AN/SYQ-20 ACDS									
	AN/SYQ-XX (V) FUTURE									
Communications	Link 11	0.03	1.00	0.03	0.47	0.44	0.18			
	MK91 G/M Fire Cont. Sys									
	AN/SRN-25(V) 1 Radio Nav. Set									
	AN/URN-25 TACAN									
	CIC Displays (AN/SPQ-14(V)) ASDS									
	CEC GCCS-M (AN/USG2(V))									
	Amp Asst Dir Sys (AN/KSQ-1)									
DDG-79 (ASSET)	DDG 51 EXTERNAL COMMUNICATIONS	38.5183								
	DDG 51 NAVIGATION SYSTEM ..DDG79 CDWE	7.40698								
	MK XII AIMS IFF...DDG79 CDWE	2.34707								
	COMBAT DF ... DDG79 CDWE	4.53157								
	CEC	3.40376								
	MK3 INTEGRATED FCS...DDG79 CDWE	5.95404								

	SHIPBOARD NON-TACTICAL AUTO PROCESS - AREA REQ										
Frigate (ASSET)	DATA DISPLAY GROUP	5.83211									
	DATA PROCESSING GROUP	1.49359									
	INTERFACE EQUIPMENT	0.304814									
	SPS-55 SURFACE SEARCH RADAR	0.772196									
	SPS-49 2-D AIR SEARCH RADAR	7.02088									
	WMEC901 CIC.......WMEC901 CDWE 6-78	7.21393									
Variant Weight				63.68							

APPENDIX D.1. USW/MIW SUMMARY

MK 32 Mod5/7 Unloaded Torpedo Launching System	1.01
MK 50 Torpedo	0.34
LFATS(Low Frequency Active Towed Sonar by L3)	4.00
LAMPS	11.34
Aviation Fuel (JP-5)	65.4335
Helo in-flight refuel system	7.72196
Helo securing system	3.65777
Helo rearm+ magazine	2.76365
AN/SLQ-25 Nixie	
Remote-control unit	0.01
Electronic console	0.40
Winch (RL-272)	1.43
Coaxial switching	0.03
Unit	
Dummy loads (x 3)	0.01
RL-272A	1.20
RL-272B	1.54
LEAD MK13 (Anti-Torpedo Countermeasure Effector)	0.22
ASLS(Advanced Side Looking Sonar by L3)	14.36
EMD(Expendable Mine Destructor by L3)	0.03
LMRS AN/BLQ-11 for MCM	1.28
ALMDS (AN/AES-1) Airborne Laser Mine Det. Sys.	
RAMICS	
OASIS	
AMNS	
RMS(compare with EMD)	0.03
BDC 204 Depth Charge	0.06

Aviation Fuel (JP-5)	65.43
Helo in-flight refuel system	7.722
Helo securing system	3.658
Helo rearm+ magazine	2.764
	79.58

Total minus helo	37.28
Total Package Weight	116.86

APPENDIX D.2. USW / MIW TRADE-OFF ANALYSIS

	UNDER SEA/ MINE WARFARE TRADEOFF ANALYSIS	WEIGHT		TOTAL WEIGHT	DIMENSIONS (M)				Volume (ft3)
Threat	**SYSTEM**	**Metric Ton**	**QNTY**		**Length**	**Width**	**Height**	**Dia**	
USW Torpedo Launching System									
	MK 32 Mod 15 Unloaded Torpedo Launching System	**1.01**	**2.00**	**2.02**	**3.43**	**0.94**	**1.26**		
	MK 32 Mod 9 Unloaded Torpedo Launching System	2.01	2.00	4.02	3.56	0.70	1.31		
USW Torpedoes									
	MK 46 Mod 2/5 Torpedo	0.23		0.00	2.59			0.32	
	MK 50 Torpedo	**0.34**		**0.00**	**2.88**			**0.32**	
	MK 54 Torpedo (ship)	0.28		0.00	2.72			0.32	
	MK 54 Torpedo (helicopter)	0.29		0.00	2.79			0.32	
USW Sonar									
	AN/SQR-19 T. Array	23.67	1.00	23.67	4.89	4.89	4.89		116.93
	LFATS(Low Frequency Active Towed Sonar by L3)	**4.00**	**1.00**	**4.00**	**3.00**	**3.00**	**2.30**		**20.70**
USW/MIW Helo Support									
	LAMPS	**11.34**	**1**	**11.34**	**19.76**	**2.36**	**5.18**		**241.56**
	Aviation Fuel (JP-5)	**65.4335**	**1**	**65.43**					
	Helo in-flight refuel system	**7.72196**	**1**	**7.72**					
	Helo securing system	**3.65777**	**1**	**3.66**					
	Helo rearm+ magazine	**2.76365**	**1**	**2.76**					
USW Torpedo CM System									
	AN/SLQ-25 Nixie								

	Remote-control unit	**0.01**	**1.00**	**0.01**	**0.38**	**0.44**	**0.16**		
	Electronic console	**0.40**	**1.00**	**0.40**	**1.23**	**0.64**	**0.60**		
	Winch (RL-272)	**1.43**	**1.00**	**1.43**	**1.21**	**1.78**	**1.75**		
	Coaxial switching	**0.03**	**1.00**	**0.03**	**0.69**	**0.51**	**0.08**		
	Unit								
	Dummy loads (x 3)	**0.01**	**3.00**	**0.02**	**0.21**	**0.15**	**0.36**		
	RL-272A	**1.20**	**1.00**	**1.20**	**1.24**	**1.54**	**1.72**		
	RL-272B	**1.54**	**1.00**	**1.54**	**1.23**	**1.53**	**174.10**		
USW Torpedo CM									
	LEAD MK12 (Anti-Torpedo Countermeasure Effector)	0.25		0.00	1.23			0.13	
	LEAD MK13 (Anti-Torpedo Countermeasure Effector)	**0.22**		**0.00**	**1.19**			**0.13**	
MIW Sonar									
	ASLS(Advanced Side Looking Sonar by L3)	**14.36**	**1.00**	**14.36**	**2.40**	**2.40**	**6.10**		**35.14**
MIW UUVs									
	EMD(Expendable Mine Destructor by L3)	**0.03**	**1.00**	**0.03**	**1.05**			**0.20**	**0.03**
	AN/SLQ-48 Mine Neutralization Vehicle	1.25	1.00	1.25	3.80	0.90	1.20		
	MANTA Multimission UUV	7.00	1.00	7.00	10.50	2.40	0.90		
	BPAUV for MCM	0.33	1.00	0.33	3.30			0.53	
	LDUUV	2.36	1.00	2.36	7.60			0.67	
	21UUV for MCM	1.27	1.00	1.27	6.35			0.53	
	SAHRV	0.04	1.00	0.04	1.60			0.19	
	Morpheus for MCM			1.20					
Airborne MIW									
	LMRS AN/BLQ-11 for MCM	**1.28**	**1.00**		**6.10**			**0.53**	
1 helo	**ALMDS (AN/AES-1) Airborne Laser Mine Det. Sys.**								
	RAMICS								
1 helo	**OASIS**								
1 helo	**AMNS**								

	AQS-20/X								
	RMS(compare with EMD)	**0.03**			**1.05**			**0.20**	
MIW	MK11 Depth Charge	0.15			1.39			0.28	
	BDC 204 Depth Charge	0.06			0.99			0.24	
				157.10					

APPENDIX D.3. MIW AIRBORNE ASSETS TRADE-OFF ANALYSIS

UNDER SEA/ MINE WARFARE TRADEOFF ANALYSIS	MANNING	RANGE	PAYLOAD (MT)	SPEED(KTS)	SEA STATE	WEIGHT		TOTAL WEIGHT	DIMENSIONS (M)				
SYSTEM						Metric Ton	QNTY		Length	Width	Height		
LAMPS	18det / 30 (including ship's company)	4hrs (endurance) / 100NM	3.551	180	5	11.34	1	11.34	19.76	16.40	5.18		
Aviation Fuel (JP-5)						65.4335	1	65.43					
Helo in-flight refuel system						7.72196	1	7.72					
Helo securing system						3.65777	1	3.66					
Helo rearm+ magazine						2.76365	1	2.76					
VTOL HV-911(UAV)	6 (control 4 uavs)	8hrs (endurance) / 110 NM	0.09	200	5	0.59	4	2.36	5.46	4.63	1.73		6.56

SCALED DATA

VTOL HV-911 scaled 2	6 (control 4 uavs)	8hrs (endurance) / 110 NM	0.18	200	5	1.18	4	4.72	6.88	5.83	2.18	2.00	6.56
VTOL HV-911 scaled 2.7	6 (control 4 uavs)	8hrs (endurance) / 110 NM	0.243	200	5	1.593	4	6.37	9.58	8.12	3.04	2.70	6.56

Aviation Fuel (JP-5)						**65.4335**	**1**	**65.43**					
A/S Torpedo (MK 46)						**0.24**							
AntiShip miss(Sea Skua)		**11 nm**				**0.15**							
Dip Sonar (L3 ASQ18)						**0.23**							
Anti Surf miss (hellfire)						**0.1**							

APPENDIX E.1. MONOHULL DESIGN ANALYSIS

MONOHULL

Calm Water Speed	**knots**	35.7	36.7	37.7	38.7	39.7	40.7	41.7	42.7	43.7	44.7	45.7
Speed in Waves	**knots**	35	36	37	38	39	40	41	42	43	44	45
Payload Weight	**long tons**	200	200	200	200	200	200	200	200	200	200	200
Range at Speed in Waves	**nautical miles**	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Displacement	**ylong tons**	1455	1519	1589	1665	1748	1836	1931	2033	2141	2257	2381
Installed Power	**ylong tons**	36813	40104	43723	47693	52039	56790	61975	67623	73767	80439	87673
Engines [5]	**ylong tons**	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board	**ylong tons**	488	518	551	586	625	666	710	757	808	861	919
L - Length	**feet**	249	252	256	260	264	269	273	278	283	288	293
B - Beam	**feet**	50	50	51	52	53	54	55	56	57	58	59
T - Hullborne Draft	**feet**	18.5	18.7	19	19.3	19.6	20	20.3	20.7	21	21.4	21.8
Foilborne / Cushionborne Draft	**feet**	na	N/A									
Rough Order of Magnitude Cost		448600000	449600000	450700000	452000000	453300000	454700000	456300000	458000000	459800000	461800000	464000000
Lift to Drag Ratio		13	12.8	12.7	12.5	12.3	12.2	12	11.9	11.8	11.6	11.5

APPENDIX E.2. TRIMARAN HULL DESIGN ANALYSIS

TRIMARAN

Calm Water Speed	**knots**	36.39327371	37.4177604	38.4414442	39.4643416	40.4864752	41.5078577	42.5285156	43.5484651	44.56773051	45.5863841	46.6043446
Speed in Waves	**knots**	35	36	37	38	39	40	41	42	43	44	45
Payload Weight	**long tons**	200	200	200	200	200	200	200	200	200	200	200
Range at Speed in Waves	**nautical miles**	2500.246	2500.246	2500.244	2500.246	2500.247	2500.247	2500.247	2500.247	2500.247	2500	2500
Displacement	**ylong tons**	1361.37	1415.38	1471.82	1530.77	1592.29	1656.48	1723.39	1793.11	1865.7	1941.01	2019.55
Installed Power	**ylong tons**	25648	28157	30850	33736	36824	40126	43652	47412	51419	55680	60214
Engines [5]	**ylong tons**	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board	**ylong tons**	299.416859	318.803915	339.028279	360.115007	382.08538	404.965637	428.777022	453.543597	479.2871551	505.949784	533.70696
L - Length	**feet**	401.8675974	407.113293	412.454296	417.888974	423.41378	429.028685	434.729176	440.514197	446.380145	452.307223	458.327379
B - Beam	**feet**	97.11647178	98.3841616	99.6748837	100.988243	102.323384	103.680298	105.057895	106.455919	107.8735012	109.305856	110.760704
T - Hullborne Draft	**feet**	10.06161645	10.1929537	10.3266771	10.4627459	10.6010713	10.7416525	10.8843765	11.0292169	11.17608346	11.3244805	11.4752081
Foilborne / Cushionborne Draft	**feet**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		449100000	450000000	451000000	452000000	453100000	454300000	455500000	456900000	458200000	459700000	461300000
Lift to Drag Ratio		18.50970067	18.0300884	17.5877359	17.1794253	16.8021359	16.4523901	16.1276823	15.8261992	15.54516447	15.2823416	15.037593

APPENDIX E.3. CATAMARAN HULL DESIGN ANALYSIS

CATAMARAN

Calm Water Speed	**knots**	35.39526388	36.40052	37.40528	38.4095659	39.41336	40.41667	41.41948	42.4218	43.42363	44.42497	45.42581
Speed in Waves	**knots**	35	36	37	38	39	40	41	42	43	44	45
Payload Weight	**long tons**	200	200	200	200	200	200	200	200	200	200	200
Range at Speed in Waves	**nautical miles**	2500.245	2500.247	2500.244	2500.246	2500.246	2500.247	2500.248	2500.246	2500.247	2500.247	2500.247
Displacement	**ylong tons**	1566.76	1596.16	1626.91	1659.02	1692.51	1727.41	1763.73	1801.51	1840.77	1881.54	1923.86
Installed Power	**ylong tons**	30543	32215	33969	35808	37735	39754	41868	44080	46395	48815	51346
Engines [5]	**ylong tons**	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board	**ylong tons**	347.8699754	356.509	365.5294	374.931147	384.714	394.8812	405.433	416.3738	427.7081	439.4385	451.5721
L - Length	**feet**	273.8424026	275.5447	277.3029	279.115365	280.981	282.8992	284.8682	286.8878	288.9569	291.0746	293.2408
B - Beam	**feet**	87.53260962	88.07673	88.63874	89.2180907	89.81443	90.42757	91.05695	91.70252	92.36389	93.04082	93.73322
T - Hullborne Draft	**feet**	12.45656368	12.534	12.61397	12.6964206	12.78128	12.86854	12.9581	13.04997	13.14409	13.24042	13.33896
Foilborne / Cushionborne Draft	**feet**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		450800000	4.51E+08	4.52E+08	452600000	4.53E+08	4.54E+08	4.55E+08	4.55E+08	4.56E+08	4.57E+08	4.58E+08
Lift to Drag Ratio		17.14289252	17.03123	16.92029	16.8104921	16.70232	16.59586	16.49146	16.38965	16.29004	16.1934	16.09921

APPENDIX E.4. SURFACE EFFECT SHIP (SES) HULL DESIGN ANALYSIS

SURFACE EFFECT SHIP (SES)

Calm Water Speed	**knots**	35.2619443	36.26559	37.26898	38.27212	39.275	40.27765	41.28007	42.28227	43.28425	44.28602	45.28759
Speed in Waves	**knots**	35	36	37	38	39	40	41	42	43	44	45
Payload Weight	**long tons**	200	200	200	200	200	200	200	200	200	200	200
Range at Speed in Waves	**nautical miles**	2500.245	2500.247	2500.245	2500.246	2500.246	2500.246	2500.246	2500.246	2500.247	2500.247	2500.247
Displacement	**ylong tons**	1377.55	1403.67	1430.99	1459.51	1489.22	1520.12	1552.21	1585.51	1620.02	1655.75	1692.71
Installed Power	**ylong tons**	30092	31896	33797	35800	37907	40123	42451	44895	47459	50148	52965
Engines [5]	**ylong tons**	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board	**ylong tons**	330.224535	339.7085	349.6192	359.9534	370.7059	381.8745	393.4578	405.4571	417.8724	430.7047	443.9556
L - Length	**feet**	302.922931	304.8256	306.7905	308.8152	310.8966	313.0322	315.2196	317.4578	319.7446	322.0782	324.457
B - Beam	**feet**	56.7980496	57.15479	57.52322	57.90286	58.29311	58.69353	59.10367	59.52334	59.9521	60.38966	60.8357
T - Hullborne Draft	**feet**	12.5246981	12.60336	12.68461	12.76832	12.85438	12.94268	13.03312	13.12566	13.22021	13.31669	13.41505
Foilborne / Cushionborne Draft	**feet**	3.49526459	3.517218	3.53989	3.563253	3.587269	3.61191	3.637149	3.662975	3.68936	3.716287	3.743735
Rough Order of Magnitude Cost		449500000	4.5E+08	4.51E+08	4.51E+08	4.52E+08	4.53E+08	4.53E+08	4.54E+08	4.55E+08	4.56E+08	4.57E+08
Lift to Drag Ratio		15.7356285	15.55933	15.38579	15.21484	15.04748	14.88347	14.72333	14.56733	14.41551	14.26769	14.12426

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APPENDIX F. SEA SWAT HYDROSTATICS

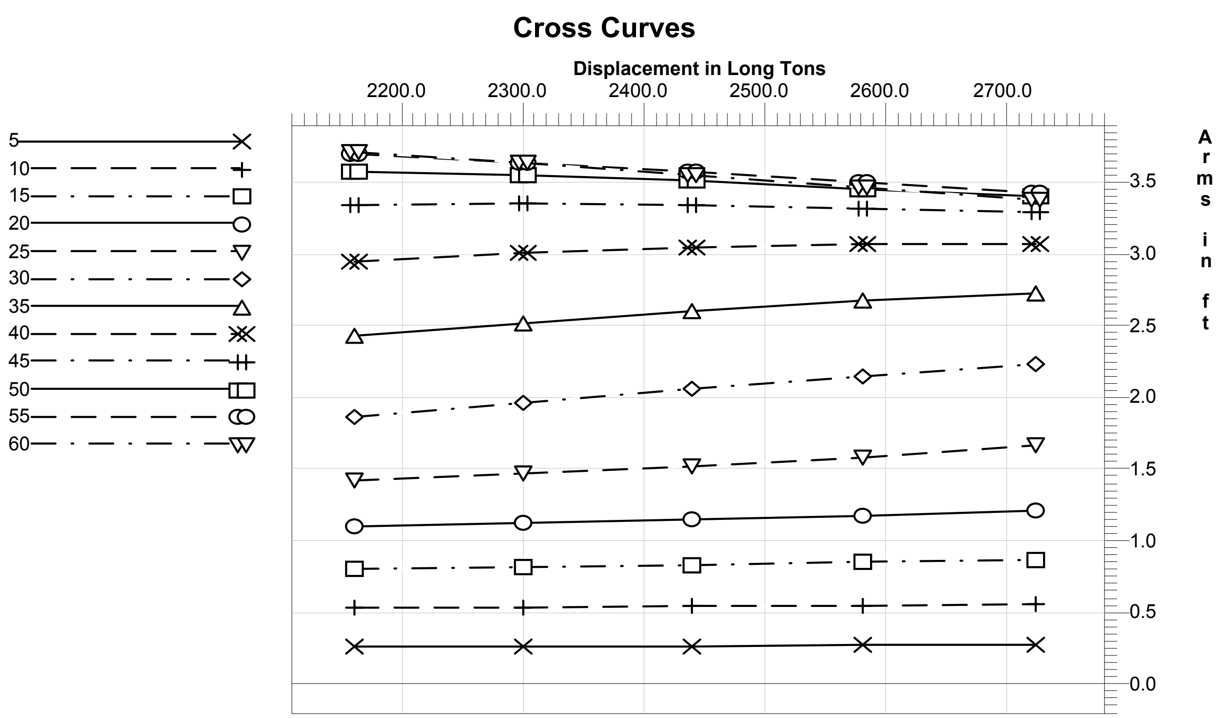
D. AAW MISSION PACKAGE

1. CROSS CURVES OF STABILITY

Righting Arms(heel) for VCG = 12.04
Trim aft 0.07 deg. at heel = 0 (RA Trim = 0)

Displ (LT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s
2161.137	0.267s	0.537s	0.815s	1.110s	1.431s	1.870s
2299.540	0.268s	0.542s	0.826s	1.128s	1.471s	1.968s
2439.265	0.271s	0.549s	0.838s	1.151s	1.520s	2.062s
2580.239	0.274s	0.557s	0.854s	1.180s	1.589s	2.152s
2722.373	0.279s	0.567s	0.872s	1.214s	1.675s	2.234s
Displ (LT)	**35.000s**	**40.000s**	**45.000s**	**50.000s**	**55.000s**	**60.000s**
2161.137	2.429s	2.954s	3.343s	3.583s	3.702s	3.719s
2299.540	2.523s	3.012s	3.352s	3.553s	3.641s	3.636s
2439.265	2.609s	3.051s	3.346s	3.512s	3.576s	3.553s
2580.239	2.678s	3.071s	3.325s	3.463s	3.504s	3.468s
2722.373	2.727s	3.075s	3.292s	3.406s	3.430s	3.381s

Water Specific Gravity = 1.025.



2. HULL DATA (WITH APPENDAGES)

Baseline Draft: 14.267 at Origin
Trim: aft 0.07 deg.
Heel: zero

DIMENSIONS
Length Overall: 407.893 ft LWL: 399.518 ft Beam: 50.095 ft BWL: 31.563 ft
Volume: 98193.160 ft^3 Displacement: 2804.958 LT

COEFFICIENTS
Prismatic: 0.671 Block: 0.542 Midship: 0.807 Waterplane: 0.795

RATIOS
Length/Beam: 8.142 Displacement/length: 43.986 Beam/Depth: 3.485
LT/inch Immersion: 23.863

AREAS
Waterplane: 10024.410 ft^2 Wetted Surface: 14686.810 ft^2
Under Water Lateral Plane: 5034.939 ft^2 Above Water Lateral Plane: 3816.795 ft^2

CENTROIDS (Feet)
Buoyancy: LCB = 11.222 aft TCB =0.001 stbd VCB = 8.680
Flotation: LCF = 17.818 aft
Under Water LP: 3.937 fwd of Origin, 6.604 below waterline.
Above Water LP: 2.493 fwd of Origin, 4.769 above waterline.

Note: Coefficients calculated based on waterline length at given draft

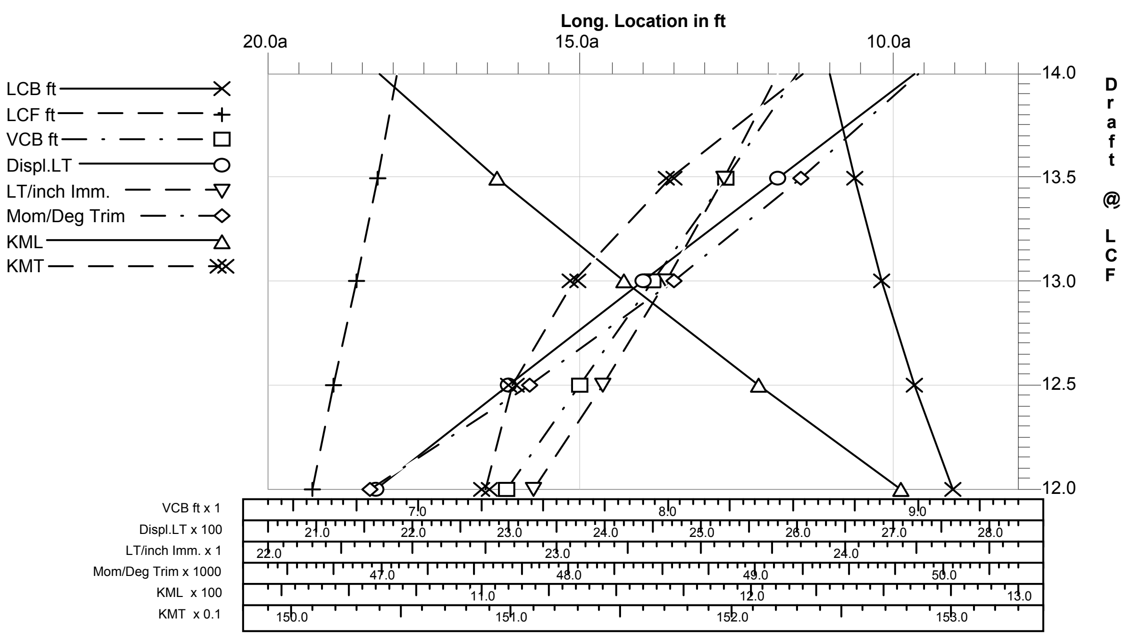
3. HYDROSTATIC PROPERTIES

Draft is from Baseline.
Trim: aft 0.07 deg., No heel, VCG = 12.04

LCF Draft (ft)	Displ (LT)	LCB (ft)	VCB (ft)	LCF (ft)	TPI (LT/inch)	MTI (LT-ft /deg)	KML (ft)	KMT (ft)
12.000	2161.138	9.056a	7.347	19.307a	22.92	46941.30	1,256.416	15.088
12.500	2299.540	9.657a	7.642	18.960a	23.16	47784.62	1,202.531	15.100
13.000	2439.265	10.179a	7.935	18.602a	23.38	48560.54	1,152.562	15.128
13.500	2580.239	10.630a	8.226	18.260a	23.58	49239.07	1,105.314	15.172
14.000	2722.374	11.020a	8.514	17.956a	23.76	49863.73	1,061.380	15.232

Water Specific Gravity = 1.025.

Hydrostatic Properties at Trim = 0.07a, Heel = 0.00



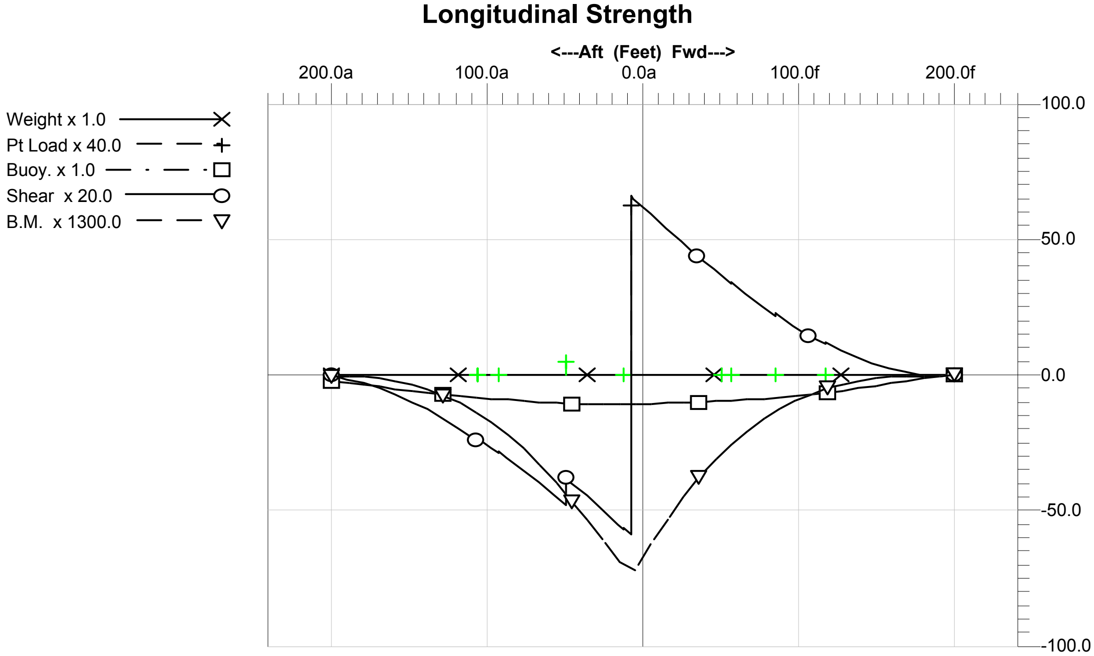
4. LONGITUDINAL STRENGTH (ZERO)

Location (ft)	Weight (LT)	Buoyancy (LT/ft)	Shear (LT)	Bending (LT-ft)
199.552f	0.000	0.000	0.00	0
197.759f	0.000	0.041	0.04	0
187.560f	0.000	0.448	2.53	-10
177.362f	0.000	1.259	11.23	-73
167.163f	0.000	2.127	28.50	-269
156.964f	0.000	3.038	54.84	-686
146.765f	0.000	3.947	90.46	-1419
136.566f	0.000	4.810	135.12	-2563
126.367f	0.000	5.572	188.06	-4204
116.168f	0.000	6.300	248.60	-6425
116.000f	19.200*	6.312	230.46	-6467
105.969f	0.000	7.007	297.26	-9108
95.770f	0.000	7.582	371.65	-12515
85.571f	0.000	8.131	451.78	-16709
84.000f	24.000*	8.198	440.61	-17429
75.372f	0.000	8.563	512.91	-21540
65.173f	0.000	8.972	602.33	-27224
56.000f	2.700*	9.274	683.32	-33132
54.974f	0.000	9.308	692.85	-33838
50.000f	1.300*	9.452	738.21	-37400
44.775f	0.000	9.602	787.98	-41387
34.576f	0.000	9.856	887.21	-49927
24.377f	0.000	10.051	988.73	-59492
14.178f	0.000	10.226	1092.13	-70102
3.979f	0.000	10.325	1196.93	-81775
6.220a	0.000	10.403	1302.63	-94521
8.500a	2499.998*	10.406	-1173.64	-97518
13.000a	7.600*	10.410	-1134.40	-92342
16.419a	0.000	10.413	-1098.81	-88525
26.618a	0.000	10.376	-992.80	-77859
36.817a	0.000	10.284	-887.44	-68272
47.016a	0.000	10.460	-781.66	-59760
50.000a	209.000*	10.214	-959.81	-57473
57.215a	0.000	9.620	-888.26	-50809
67.414a	0.000	9.620	-790.15	-42251
77.613a	0.000	9.295	-693.69	-34687
87.812a	0.000	8.954	-600.63	-28090
93.000a	20.000*	8.728	-574.76	-25093
98.010a	0.000	8.509	-531.58	-22322
106.000a	3.000*	8.093	-468.26	-18342
107.000a	18.300*	8.040	-478.49	-17878
108.209a	0.000	7.977	-468.81	-17305
118.408a	0.000	7.389	-390.45	-12929
128.607a	0.000	6.788	-318.15	-9321
138.806a	0.000	6.152	-252.16	-6418

149.005a	0.000	5.513	-192.68	-4156
159.204a	0.000	4.881	-139.67	-2467
169.403a	0.000	3.991	-94.43	-1281
179.602a	0.000	3.553	-55.96	-518
189.801a	0.000	2.681	-24.17	-117
199.967a	0.000	1.037	0.00	0

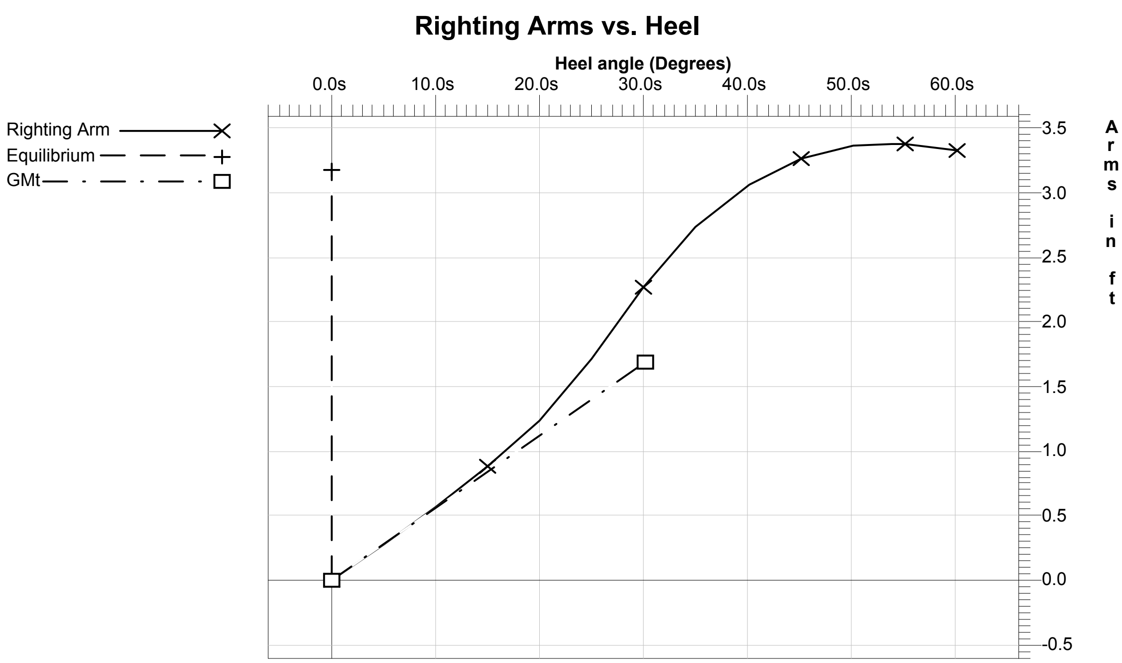
* Point weight in Long Tons

Max. Shear 1326.36 LT at 8.500a
Max. Bending Moment -97518 LT-ft at 8.500a (Sagging)



5. RIGHTING ARMS VS HEEL ANGLE

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Righting Arm (ft)
0.00	0.07a	14.27	0.00
5.00s	0.07a	14.21	0.28
10.00s	0.07a	14.02	0.57
15.00s	0.06a	13.70	0.88
20.00s	0.04a	13.24	1.24
25.00s	0.00f	12.61	1.73
30.00s	0.07f	11.83	2.28
35.00s	0.11f	10.97	2.75
40.00s	0.15f	10.07	3.07
45.00s	0.18f	9.15	3.27
50.00s	0.21f	8.18	3.37
53.75s	0.23f	7.44	3.39
55.00s	0.24f	7.19	3.38
60.00s	0.26f	6.16	3.33



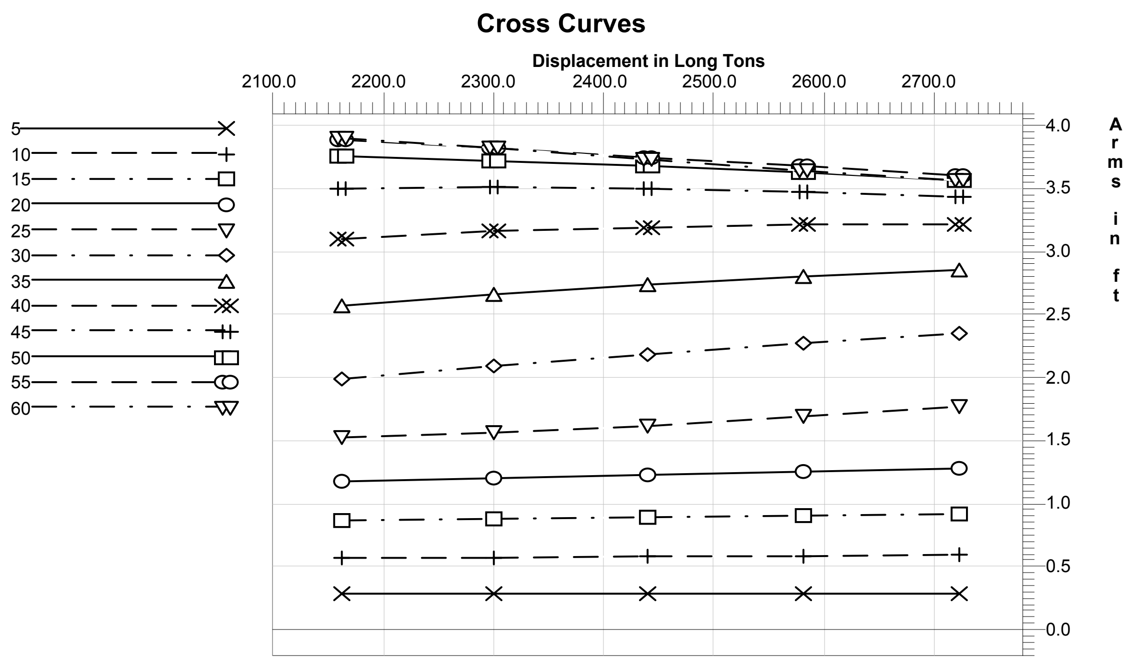
E. USW MISSION PACKAGE

1. CROSS CURVES OF STABILITY

Righting Arms(heel) for VCG = 11.84
Trim aft 0.14 deg. at heel = 0 (RA Trim = 0)

Displ (LT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s
2160.860	0.285s	0.574s	0.871s	1.186s	1.529s	1.999s
2299.339	0.286s	0.579s	0.881s	1.204s	1.569s	2.096s
2439.099	0.288s	0.585s	0.894s	1.227s	1.619s	2.189s
2580.088	0.292s	0.593s	0.909s	1.256s	1.693s	2.275s
2722.234	0.297s	0.603s	0.928s	1.291s	1.780s	2.354s
Displ (LT)	**35.000s**	**40.000s**	**45.000s**	**50.000s**	**55.000s**	**60.000s**
2160.860	2.575s	3.110s	3.509s	3.759s	3.887s	3.912s
2299.339	2.665s	3.164s	3.515s	3.725s	3.824s	3.827s
2439.099	2.746s	3.200s	3.505s	3.683s	3.755s	3.740s
2580.088	2.812s	3.217s	3.482s	3.631s	3.682s	3.654s
2722.234	2.857s	3.218s	3.447s	3.571s	3.605s	3.566s

Water Specific Gravity = 1.025.



2. HULL DATA (WITH APPENDAGES)

Baseline Draft: 14.200 at Origin
Trim: aft 0.14 deg.
Heel: zero

DIMENSIONS
Length Overall: 407.893 ft LWL: 399.231 ft Beam: 50.095 ft BWL: 31.561 ft
Volume: 97754.880 ft^3 Displacement: 2792.439 LT

COEFFICIENTS
Prismatic: 0.669 Block: 0.538 Midship: 0.804 Waterplane: 0.795

RATIOS
Length/Beam: 8.142 Displacement/length: 43.884 Beam/Depth: 3.474
LT/inch Immersion: 23.834

AREAS
Waterplane: 10012.110 ft^2 Wetted Surface: 14639.990 ft^2
Under Water Lateral Plane: 5007.006 ft^2 Above Water Lateral Plane: 3844.727 ft^2

CENTROIDS (Feet)
Buoyancy: LCB = 12.550 aft TCB =0.001 stbd VCB = 8.658
Flotation: LCF = 18.139 aft
Under Water LP: 2.507 fwd of Origin, 6.569 below waterline.
Above Water LP: 4.327 fwd of Origin, 4.808 above waterline.

Note: Coefficients calculated based on waterline length at given draft

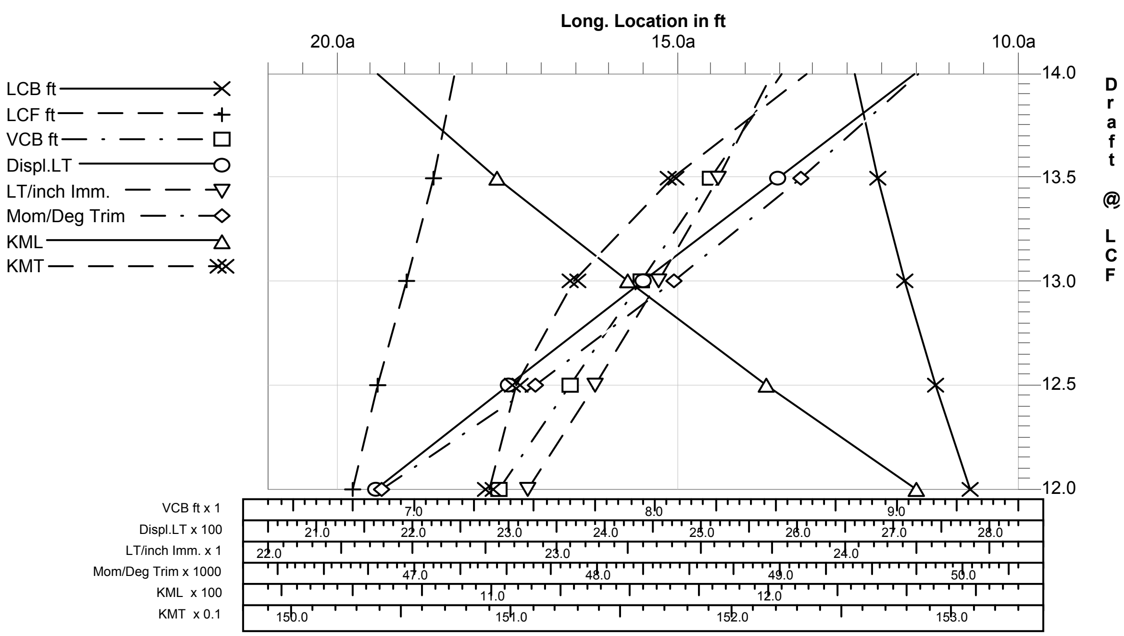
3. HYDROSTATIC PROPERTIES

Draft is from Baseline.
Trim: aft 0.14 deg., No heel, VCG = 11.84

LCF Draft (ft)	Displ (LT)	LCB (ft)	VCB (ft)	LCF (ft)	TPI (LT/inch)	MTI (LT-ft /deg)	KML (ft)	KMT (ft)
12.000	2160.860	10.703a	7.349	19.785a	22.89	46813.89	1,252.990	15.090
12.500	2299.339	11.226a	7.645	19.401a	23.13	47652.61	1,199.137	15.102
13.000	2439.099	11.683a	7.937	18.988a	23.35	48409.86	1,148.892	15.128
13.500	2580.088	12.071a	8.228	18.605a	23.56	49109.34	1,102.289	15.173
14.000	2722.234	12.404a	8.517	18.273a	23.75	49753.89	1,058.914	15.234

Water Specific Gravity = 1.025.

Hydrostatic Properties at Trim = 0.14a, Heel = 0.00



4. LONGITUDINAL STRENGTH (ZERO)

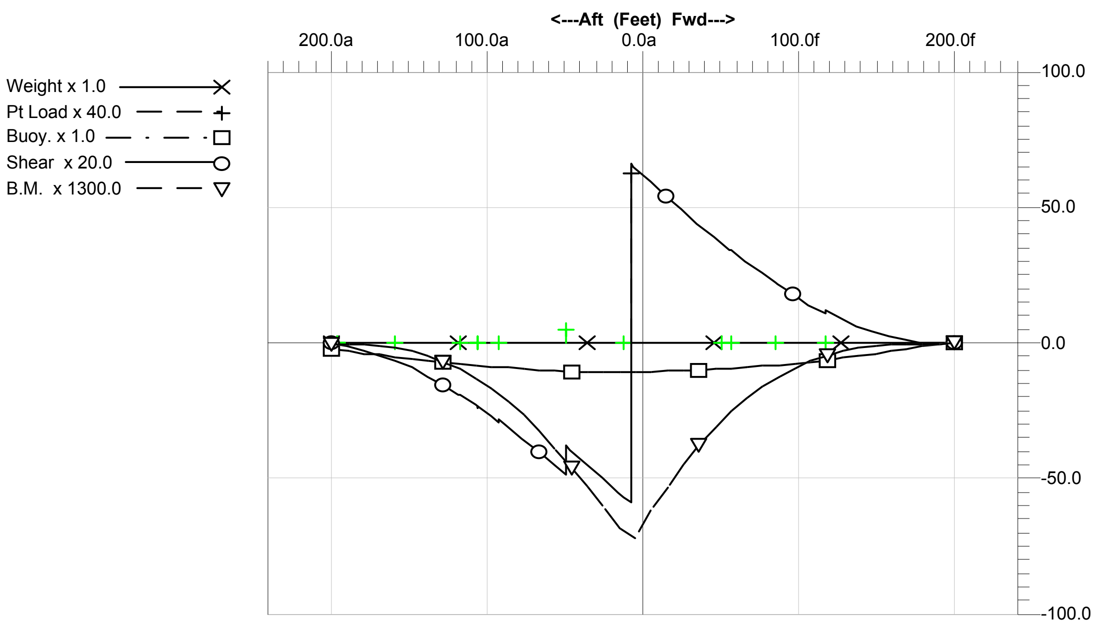
Location (ft)	Weight (LT)	Buoyancy (LT/ft)	Shear (LT)	Bending (LT-ft)
199.265f	0.000	0.000	0.00	0
197.759f	0.000	0.029	0.02	0
187.560f	0.000	0.412	2.27	-9
177.362f	0.000	1.195	10.47	-68
167.163f	0.000	2.040	26.97	-253
156.964f	0.000	2.931	52.32	-650
146.765f	0.000	3.824	86.77	-1352
136.566f	0.000	4.675	130.11	-2452
126.367f	0.000	5.427	181.62	-4035
116.168f	0.000	6.150	240.65	-6183
116.000f	19.200*	6.161	222.48	-6224
105.969f	0.000	6.854	287.76	-8778
95.770f	0.000	7.432	360.61	-12080
85.571f	0.000	7.986	439.24	-16155
84.000f	5.000*	8.054	446.83	-16855
75.372f	0.000	8.425	517.92	-21015
65.173f	0.000	8.842	605.98	-26744
56.000f	2.700*	9.154	685.82	-32679
54.974f	0.000	9.188	695.23	-33388
50.000f	1.300*	9.337	740.00	-36961
44.775f	0.000	9.493	789.19	-40955
34.576f	0.000	9.757	887.36	-49503
24.377f	0.000	9.963	987.92	-59065
14.178f	0.000	10.150	1090.49	-69663
3.979f	0.000	10.261	1194.58	-81316
6.220a	0.000	10.351	1299.69	-94035
8.500a	2499.992*	10.355	-1176.70	-97026
13.000a	7.600*	10.365	-1137.68	-91836
16.419a	0.000	10.372	-1102.23	-88007
26.618a	0.000	10.347	-996.57	-77306
36.817a	0.000	10.266	-891.45	-67679
47.016a	0.000	10.454	-785.79	-59125
50.000a	208.999*	10.212	-963.96	-56826
57.215a	0.000	9.626	-892.40	-50133
67.414a	0.000	9.637	-794.17	-41533
77.613a	0.000	9.324	-697.47	-33930
87.812a	0.000	8.994	-604.06	-27297
93.000a	20.000*	8.774	-577.97	-24283
98.010a	0.000	8.561	-534.54	-21497
106.000a	3.000*	8.152	-470.78	-17495
107.000a	3.000*	8.101	-465.65	-17029
108.209a	0.000	8.039	-455.89	-16472
118.000a	3.500*	7.484	-383.40	-12385
118.408a	0.000	7.461	-380.35	-12229
128.607a	0.000	6.869	-307.27	-8729

138.806a	0.000	6.242	-240.41	-5942
149.005a	0.000	5.610	-179.97	-3805
159.204a	0.000	4.985	-125.95	-2251
160.000a	10.000*	4.915	-132.01	-2152
169.403a	0.000	4.089	-89.67	-1117
179.602a	0.000	3.664	-50.13	-408
189.801a	0.000	2.784	-17.25	-73
196.000a	8.000*	2.418	-9.13	-18
199.967a	0.000	1.092	0.00	0

* Point weight in Long Tons

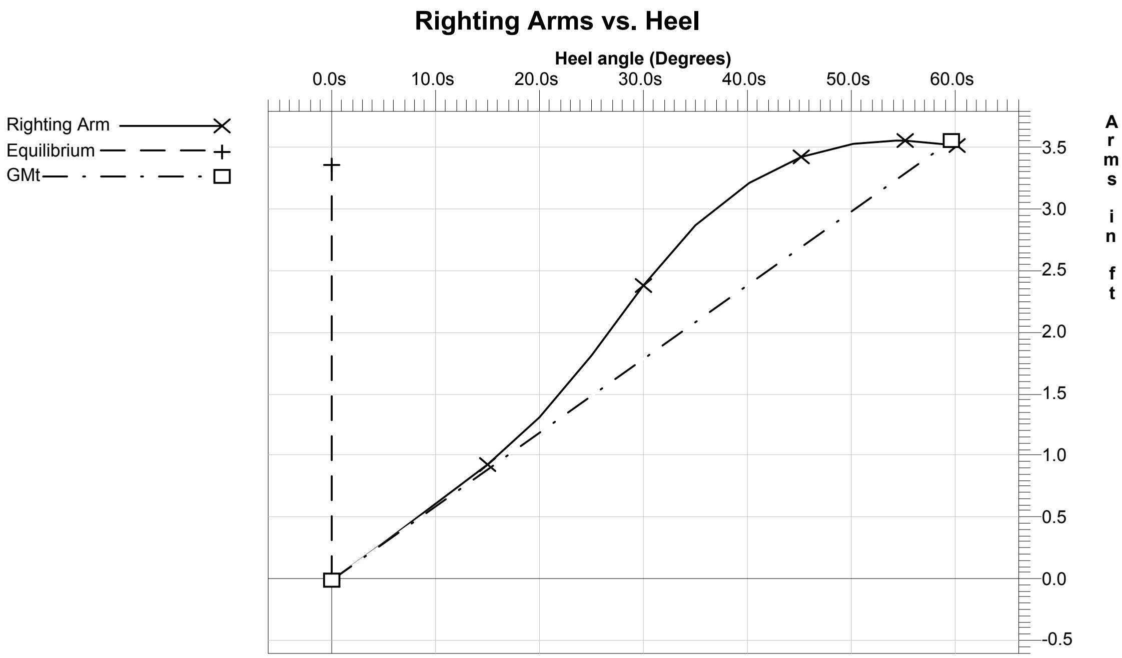
Max. Shear	1323.29 LT	at	8.500a	
Max. Bending Moment	-97026 LT-ft	at	8.500a	(Sagging)

Longitudinal Strength



5. RIGHTING ARMS VS HEEL ANGLE

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Righting Arm (ft)
0.00	0.14a	14.20	0.00
5.00s	0.14a	14.14	0.30
10.00s	0.14a	13.95	0.61
15.00s	0.13a	13.63	0.94
20.00s	0.11a	13.18	1.31
25.00s	0.07a	12.54	1.82
30.00s	0.00	11.77	2.39
35.00s	0.05f	10.91	2.87
40.00s	0.08f	10.01	3.21
45.00s	0.11f	9.09	3.43
50.00s	0.14f	8.13	3.54
54.24s	0.16f	7.29	3.57
55.00s	0.16f	7.13	3.57
60.00s	0.19f	6.11	3.52



APPENDIX G. SEA SWAT MANNING

SHIP CONTROL	DIV		AAW	USW
PILOT HOUSE			2	2
OFFICER OF THE DECK (OOD)	WR			
TALKER/PLOTTER	NX			
CO/XO	WR		2	2
SIGNAL BRIDGE				
SIGNAL BRIDGE / SRBOC SUPERVISOR	NX/OW		1	1
AFT STEERING			1	1
HELMSMAN (N53)/REPAIRMAN				

Table 50. Ship Control Manning

COMMAND AND CONTROL	DIV		AAW	USW
TACTICAL ACTION OFFICER	WR		1	1
TACTICAL INFORMATION				
TACTICAL INFORMATION COORDINATOR/JMCIS OPERATOR	OI		1	1
IDENTIFICATION SUPERVISOR/ SURFACE TRACKER	OI		1	1
EW SUPERVISOR	OW		1	1
AIR WARFARE				
ANTI -AIR WARFARE COORDINATOR	WR		1	1
AIC (controls aircraft -AAW package)	OI		1	0
ASTAC (controls helos -both package)	OI		1	1
SURFACE WARFARE				
Anti- Surface WARFARE COORDINATOR	CG		1	1
THERMAL IMAGINING OPERATOR (LOOKOUT)	CG		1	1
SEARAM Operator/HARPOON OPERATOR/BOFORS OPERATOR	CG		1	1
SUBSURFACE WARFARE				
ANTI-SUBMARINE WARFARE COORDINATOR	WR		0	1
ASWCSO	CA		0	1
UUV	CA		0	1

Table 51. Command and Control Manning

RADIO CENTRAL	**DIV**		**AAW**	**USW**
MSG PROCESSOR/MESSENGER	OC		1	1
TECH CONTROL	OC		1	1

Table 52. Radio Central Manning

COMBAT SYSTEMS CASUALTY CONTROL	**DIV**		**AAW**	**USW**
COMBAT SYS MAINTENANCE CENTRAL				
CSOOW /PLOTTER	CS		1	1
ELECTRONIC REPAIRMAN	CE		1	1
IC/GYRO ROOM (FWD/AFT)				
IVCS REPAIRMAN (N26)/WSN-5 OPERATOR	CE		2	2

Table 53. Combat Systems Casualty Control Manning

WEAPONS CONTROL	DIV		AAW	USW
BOFORS LOADER DRUM ROOM				
MOUNT CAPTAIN/LOCAL OPERATOR	CG		1	1
REPAIRMAN	CG		1	1
BOFORS HANDLING ROOM				
AMMO PASSER	CS		1	1
AMMO PASSER	CS		1	1
SEARAM MOUNT #1				
LOCAL CONTROL PANEL OPER (N65)	CG		1	1
SEARAM MOUNT #2/3				
LOCAL CONTROL PANEL OPER (N65)	CG		1	0
VERTICAL LAUNCHING SYS / HARPOON				
VLS MONITOR FWD/HARPOON REPAIRMAN/TORPEDO	CG		1	1
SONAR SYSTEMS				
SONAR SUPERVISOR/OPERATOR/NIXIE OPERATOR	CA		0	1
TOWED ARRAY ROOM				
TOWED ARRAY SUPERVISOR/WINCH OPERATOR	CA		0	1
TOWED ARRAY HANDLER	CA		0	1

Table 54. Weapons Control Manning

ENGINEERING CONTROL	DIV		AAW	USW
CENTRAL CONTROL STATION				
EOOW / PROP/AUX CTL CONSOLE OPER	WR		1	1
ELEC PLANT CTL CONSOLE OPER (N85)	EE		1	1
AUXILIARY MACHINERY ROOM #1				
AMR SUPERVISOR/EQUIP MONITOR/SWITCHBOARD OPERATOR	EA		1	1
LOWER ENGINE ROOM				
EQUIPMENT MONITOR/PSM	EM		1	1

OD BOX OPERATOR/ROVER (one per shaft)	EM		1	1
OD BOX OPERATOR/ROVER (one per shaft)	EM		1	1
AUXILIARY MACHINERY ROOM #2/PUMP ROOM				
EQUIPMENT MONITOR /JP-5	EM		1	1
UPPER ENGINE ROOM (PORT)				
EQUIPMENT MONITOR/ SWITCHBOARD OPERATOR	EA		1	1
UPPER ENGINE ROOM (STBD)				
EQUIPMENT MONITOR/ SWITCHBOARD OPERATOR	EA		1	1
OIL LABORATORY				
OIL WATER TESTER/FCCO	EM		1	1

Table 55. Engineering Control Manning

DAMAGE CONTROL	DIV		AAW	USW
DAMAGE CONTROL CENTRAL				
DAMAGE CONTROL ASSISTANT (DCA)	WR		1	1
TALKER /PLOTTER	ER		1	1
REPAIR 2			21	21
REPAIR LOCKER OFFICER	ER			
MESSENGER	ER			
LKR PHONE TALKER (NET 80)	ER			
ON-SCENE LEADER	ER			
#1 NOZZLEMAN				
#1 HOSEMAN				
#1 HOSEMAN				
#1 PLUGMAN				
#2 NOZZLEMAN				
#2 HOSEMAN				
#2 HOSEMAN				
#2 PLUGMAN				
ELECTRICIAN				
MECHANICAL ISOLATION				
AFFF OPERATOR				
#1 UTILITY MAN (Desmoking.Dewatering,Shoring, Patching)				
#2 UTILITY MAN				
#3 UTILITY MAN				
#4 UTILITY MAN				
BOUNDARYMAN				
BOUNDARYMAN				
REPAIR 5			21	21
REPAIR LOCKER OFFICER	ER			
MESSENGER	ER			
LKR PHONE TALKER (NET 80)	ER			
ON-SCENE LEADER	ER			
#1 NOZZLEMAN				
#1 HOSEMAN				
#1 HOSEMAN				
#1 PLUGMAN				
#2 NOZZLEMAN				

#2 HOSEMAN				
#2 HOSEMAN				
#2 PLUGMAN				
ELECTRICIAN				
MECHANICAL ISOLATION				
AFFF OPERATOR				
#1 UTILITY MAN (Desmoking.Dewatering,Shoring, Patching)				
#2 UTILITY MAN				
#3 UTILITY MAN				
#4 UTILITY MAN				
BOUNDARYMAN				
BOUNDARYMAN				

Table 56. Damage Control Manning

HELO CONTROL				
FLIGHT CONTROL			5	5
HELO SAFETY OFFICER	OD			
HCO	SUP			
LSE	OD			
CHOCK AND CHAIN #1	OD			
CHOCK AND CHAIN #2	OD			
HELO FIRE FIGHTING TEAM			11	11
ON SCENE LEADER (OSL)	ER			
HOT SUITMAN #1	ER			
HOT SUITMAN #2	ER			
NOZZLE				
HOSE				
HOSE				
PLUGMAN				
NOZZLE				
HOSE				
HOSE				
PLUGMAN				

Table 57. Helo Control Manning

BATTLE SUPPORT	DIV		AAW	USW
BATTLE DRESSING STATIONS			6	6
CORPSMAN (FWD)	NH			
STRETCHER BEARER				
STRETCHER BEARER				
CORPSMAN [IDC] (AFT)	NH			
STRETCHER BEARER				
STRETCHER BEARER				
BATTLE MESSING			3	3
MESS SPECIALIST				
MESS SPECIALIST				
MESS SPECIALIST				
SUPPLY SUPPORT			3	3
STOCK CONTROL SUPERVISOR	SUP			
LOCATE/ISSUE CLERK	SUP			
LOCATE/ISSUE CLERK	SUP			
Total			111	115

Table 58. Battle Support Manning

TOTAL MANNING			AAW	USW
Repair Parties			57	57
Watch bill without Repair Parties			54	58
2 Section Rotation			108	116
Required Manning (2 Section + Repair Parties)			165	173
Required Berthing (Largest Package + 3 Helo Detachments*)				188
* 5 Persons per Helo Detachment				

Table 59. Total Required Manning

DEPARTMENTS	AAW	USW
COMBAT SYSTEMS	46	54
ENGINEERING	50	50
OPERATIONS	33	33
SUPPLY	10	10
NAV/EXEC	12	12
OFFICERS	14	14
HELO DET(S)	5	15
TOTAL:	170	188

Table 60. Departmental Manning

APPENDIX H. COMBAT SYSTEMS ENGAGEMENT SIMULATIONS

A. WEAPONS ANALYSIS

Threats:

M1 ASCM Low slow, 3 mts, Mach1, RCS 0.2-0.8
M2 ASCM Low fast, 3 mts, Mach 2

Threat	Scenario	Title	Mission	System Stringencies
M1 Low & Slow ASCM	1	Submarine Launched M1 ASCM	Two LCS undergoing ASW operations close to SeaBase	Submarine launched Low flier
M1 Low & Slow ASCM	2	Four Surface/Air M1 ASCMs	LCS defending against airplanes	Low flier
M1 Low & Slow ASCM	3	LCS Engaged by M1 Coastal batteries	Two LCS will undertake a 20 hrs. operation of mine sweeping to clear a passage from SeaBase to shore. Positioned 8 miles from shore	Very short reaction time Firing into an urban littoral setting
M2 Low & Fast ASCM	4	LCS Engaged by MIG-29 Carrying T2 ASCM	Two LCS are escorting an ExWar ship,	Low flier Stresses kinematics of missiles and guns

Threat	Scenario	Title	Description
M1 Low & Slow ASCM	1	Submarine Launched M1 ASCM	Two LCS undergoing ASW operations close to SeaBase
M1 Low & Slow ASCM	2	Four Surface/Air M1 ASCMs	LCS defending against airplanes attacking SeaBase
M1 Low & Slow ASCM	3	LCS Engaged by M1 Coastal batteries	Two LCS undertaking mine sweeping to clear a passage from SeaBase to shore. Positioned 8 miles from shore
M2 Low & Fast ASCM	4	LCS Engaged by MIG-29 Carrying T2 ASCM	Two LCS are escorting an ExWar ship,

Combat System Element	Parameters
Phased array horizon search radar	3D X band Variable power aperture
Scanning IR	2D 3-5 microns Camera
Pointing IR	3D 3-5 microns 0.46 m camera
EO system	3D 650-950 nanometers Camera
Commercial Navigation radar	X or S-Band
C^2	Open architecture Fiber optic cabling UYQ-70 consoles 4800 hour MTBF 100 Mbps data transfer rate
EW	2-18 GHz frequency coverage 81 dBm EA power, monopulse DF arrays 24 track capacity Automatic 16 target simultaneous engagement capacity 370km Maximum range
Seduction	210 round chaff magazine 2 rounds of active decoys
Active stealth	Water Camouflage Automatically controlled salt water spray of superstructure
Gun	35 mm revolving cannon 0.2-3 km range 1000 rounds/minute 500 round magazine Airburst with sub-munitions 2 mounts required for 360° coverage
Missile	RF/IR guidance 1-9.4 km range Velocity of 2 Mach Trainable launcher

Combat System Element	Parameters
	21 round magazine

Table 61. Combat Systems Parameters

This section describes the sensor suite design solutions and identifies subsystems to satisfy the requirements of the LCS functional architecture. Sensor IPT translated the functional architecture into a sensor design architecture that provided a workable arrangement of sensor system elements and interfaces.

As with any system analysis, numerous system parameters were used to assess the overall contribution of the sensor subsystem to the ship combat system. The following parameters were used for sensor analysis.

Performance: Involves the functional performance of the system. This includes factors such as detection capability, volume of coverage, accuracy, flexibility, power output, along with other technical and physical characteristics the system must exhibit to accomplish its intended mission. This functional performance capability was the primary concern when considering candidate sensor subsystems.

Weight/Size: What impact will the proposed sensor subsystem have on the overall weight and size budget limits for this combat system? A sensor system that performs flawlessly in every environment but will not fit within the superstructure of the ship or will cause the center of gravity of the ship to rise unacceptably will not contribute to the success of the ship’s mission and therefore must be eliminated from consideration.

Cost: Not only the initial procurement cost, but also the life cycle cost projection is important in the analysis of various sensor suites. A detailed life cycle cost projection was not available for the sensor subsystems considered, but initial procurement cost was a factor in considering the desirability of a sensor subsystem.

Interoperability: Does the proposed sensor system operate correctly in the proposed naval and littoral environment and does it operate properly within the electromagnetic spectrum that will be required for the ship’s mission? The system and its subsystems must integrate correctly with other elements of the combat system as well as off board sensors.

Reliability: Defined as the probability that a system or product will accomplish its mission in a satisfactory manner for a given period of time when used under realistic operating conditions.

Maintainability: The ease, accuracy, safety, and economy of performing maintenance activities. Maintenance may be measured in a number of ways, including mean corrective maintenance time, mean preventive maintenance time, and maintenance frequency.

Ship Integration Impact: Will the proposed sensor suite fit within the physical ship structure allocation and will it require massive or expensive ship modifications to incorporate the sensor into the ship’s physical structure? What are the power and cooling requirements of the sensor subsystem and will the ship’s power plant and chilled water plant accommodate the sensor’s requirements? Sensors were evaluated according to whether the increased performance available also required expensive infrastructure upgrades.

1. EO, IR, EW CONTRIBUTION TO SCENARIOS AND TIMELINES

Making some key assumptions and analyzing the notional scenarios and threats, EO/IR sensors probably would not contribute to self-defense compared with an active radar suite. The first assumption, which came from open source literature, was that the three threat active seekers notionally turned on at 22 km range. This was important for the EW system because it would detect the seeker. The second assumption was that the threat IR signature [or Incidence (E)] was great enough for the IR systems to detect it at the EO/IR horizon. The given threats had three IR signatures associated with them (Surface, Engine, and Plume) as shown in Table 62.

Threat	Terminal Altitude	Speed	IR W/cm^2
Threat 1	3m	300m/s	Surface 0.107 Engine 13.5 Plume 17.5
Threat 2	15.24m	730m/s	Surface 2.6 Engine 32.5 Plume 54
Threat 3	24km, 30° dive	1220m/s	Surface 4 Engine 120 Plume 162

Table 62. LCS Threat IR Signatures

This was probably a safe assumption for scenarios 1 and 2 since the targets were launched close to own ship, within the horizon, where the plume contribution of IR signature should be readily exposed to the IR sensors. The targets in scenarios 3 to 6 were fired from long range, so the engine and plume IR signatures would probably not be sensed from the EO/IR sensors due to range. By the time the targets got within detector range, the engine and plume would probably be off. For those scenarios, the IR sensor would have to detect the Surface IR signatures. The worst case was scenario 4 which had the low/slow target, Threat 1, fired from 150 km. Threat 1 had the smallest surface IR signature, 0.107 W/cm^2. IR sensors would have to be able to detect this IR signature at the horizon, in this case 20 km. Another concern regarding the given scenarios was that the IR sensors would have to discriminate the four targets in a raid on the same bearing. This would be a challenge for IR sensors. The last assumption for this analysis was that the weather was good and had minimal effect on the EO/IR sensor detections.

Given the above assumptions, the best case EO/IR sensor would probably not detect and go to firm track before the radar sensors. The team examined several critical parameters to determine this, which are summarized in Table 63for Threats 1 and 2.

Parameter	Threat 1 (m)	Threat 2 (m)
EO/IR Horizon	20047	28426
Radar Horizon	21428	30385
Seeker Turn-on Range	22000	22000
EO/IR Firm Bearing Track Range	19147	26236
EO/IR Firm Track Range	15100	13810
Radar Firm Track Range	20529	28195
EW Firm Bearing Range	19147	19810

Parameter	Threat 1 (m)	Threat 2 (m)
EW Firm Track Range	15100	13810

Table 63. Passive Sensor Parameters for Threats 1 and 2

The data is shown graphically in Figure 102 and Figure 103. This analysis assumed that the EO/IR and radars would detect the targets right when they broke the horizon. The radars transitioned to a firm track and the EO/IR sensors transitioned to a firm bearing track very quickly, in this case notionally 1-3 seconds. Firm track was defined to occur when the system developed accurate bearing and range, which was required to support the majority of missile and gun engagements. Most of the EO/IR systems could not resolve range without a laser rangefinder. Laser rangefinders have a shorter range than the EO/IR horizon. For this analysis, it was assumed that the maximum laser rangefinder range was 16 km and that it took from 1-3 seconds to determine the target range.

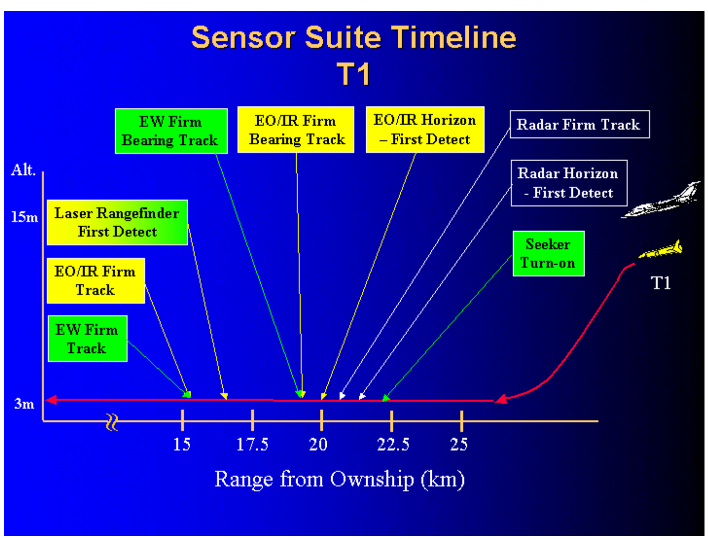


Figure 102. Sensors Suite Timeline for Threat 1

Assumptions: EO/IR Firm Bearing Track takes 3 sec, EO/IR Firm Track requires Laser Rangefinder (16 km max range and 3 sec)

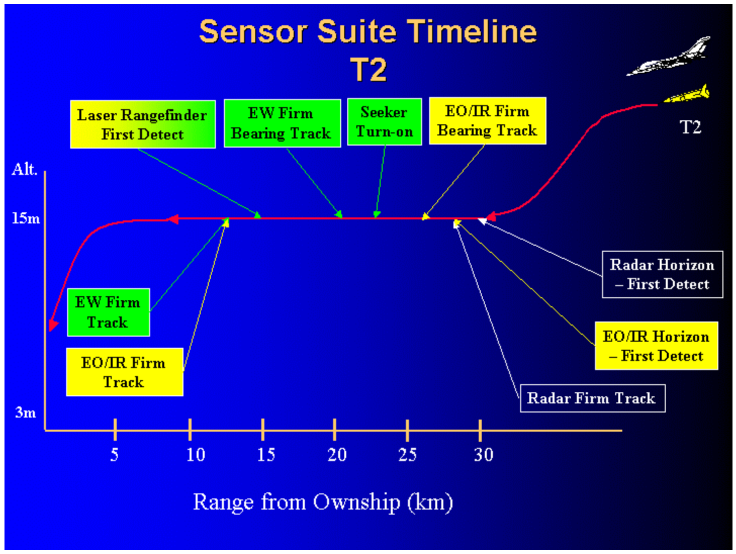


Figure 103. Sensor Suite Timeline for Threat 2

Assumptions: EO/IR Firm Bearing Track takes 3 sec, EO/IR Firm Track requires Laser Rangefinder (16 km max range and 3 sec)

These sets of assumptions depended on the type of EO/IR, EW, and radar sensors. Just as there are phased array search type radars that have fast detections and firm track transitions, there are also distributed aperture IR systems that also have fast detect and firm track times. However, many IR systems are "director", or turret type, systems that use mechanical scan patterns. These systems can have long detect times, between 6 and 12 seconds. The other limitation to a dedicated staring-type IR sensor is that it can only track one target at a time. For LCS to detect the scenario 2 targets, it would have to have four laser rangefinders.

2. MULTI-SENSOR FUSION TRACKING

The analysis described above was a comparison of EO/IR and radar systems acting as independent systems. For the LCS sensor suite, the radars and EO/IR sensors would interface with a Multi-Sensor Fusion Tracker (MSFT) system. This system would combine the best attributes of each sensor and fuse their data into a coherent track. For example, radar systems can have a hard time detecting fast, low altitude, small RCS targets. EO/IR sensors are good at detecting these types of targets and can often detect them before a radar system. The ability to fuse sensor tracks and perform sensor cueing is dependent on complex algorithms. The algorithms must take into account sensor characteristics and accuracies, the environment, system latency, system and sensor resources, and other parameters.

One advantage of an MSFT is that it would allow for sensor cueing, where a track initiated with one sensor would be used to cue another sensor. For example, a radar that could not find a track using its normal search waveform could use a high-energy waveform to find it if cued by an accurate IR sensor bearing track. This would allow a radar to provide range information long before a laser rangefinder could, thereby increasing the firm track range. This was one way LCS could take advantage of MSFT, especially if the EO/IR sensors could be put at a height of 16 m, 4 m higher than the radar sensors, to overcome horizon limitations. This might be possible due to the low height of EO/IR sensors. The Systems and Sensors IPTs derived the antenna height of 12 m, from estimates of LCS mast height.

3. EO, IR, AND EW OPTIONS

The Sensor IPT looked at three different IR sensors, two EO sensors, three EW receivers, one laser warning sensor, a laser rangefinder, and a Ladar sensor to determine a mix of required sensors. In addition, an Identification Friend or Foe (IFF) system, MSFT, IR/EO fusion processor, radar/EW master scheduler, and a smart blanker were added to the mix to round out the notional system. Data sheets on these systems are in Appendix F. Table 64 lists passive sensors and their antenna type, slew rate, and notional firm track transition times. The following is a brief synopsis of the passive sensors:

IR Scanning Sensor 1—This was a turret type of IR sensor. It could slew at a rate of 60°/sec, so if it were in a horizon search mode, it would take 6 sec to complete a scan. It could transition to track in 5 seconds. This was a mid-range sensitivity IR sensor and might not have been able to detect all targets at their maximum horizon range.

IR Scanning Sensor 2—This was a high sensitivity turret IR sensor. It could detect targets out to the visible horizon.

IR Distributed Aperture System (DAS)—This was a new type of IR sensor that had characteristics like a phased array radar. It had a distributed set of staring EO/IR apertures that covered 30-40° that when combined could provide full 360° coverage. This system could detect and transition to track within 1 second on multiple threats and calculate range by passive-angle ranging. This was an expensive system and was modeled on IR apertures used on modern fighter aircraft, like the F-22. Development costs would be associated with the technology transfer too, so cost and schedule risks were assessed as high in the time frame required for LCS.

Passive EW 1, EW Receiver—This sensor detected, analyzed, and identified radar systems and associated threat emitters. It had a multi-element planar array that could report the bearing of the emitter. It had a frequency range of 6-12 GHz. EW systems for LCS were based on modern small patrol boat (foreign systems) or US EW systems adapted from combat helicopter systems. The Sensor IPT looked at legacy systems like the SLQ-32, but high life cycle costs, high signature properties, and size eliminated them early in the EW trade analysis.

Passive EW 2, Emitter Location Sensor System—This was also a multi-element planar array antenna but covered a frequency range of 0.5-18 GHz. It could also identify the emitter bearing with less than 1° error. While somewhat redundant to the EW receiver, the Emitter Locator system would find an engagement quality bearing after the earlier warning of the EW receiver.

Passive EW 3, Missile Warning System—This system was proposed to be an imaging, Ultraviolet (UV) sensor system that passively detected UV energy, tracked multiple sources, and quickly identified each source as ASM missile, non-missile, or clutter. The UV capability was required for LCS in the littoral and could provide early warning of a shore missile launch as well as useful intelligence in locating enemy ground forces. It had a notional detect and transition to track within 4 seconds.

Passive EW 4, Laser Warning System (LWS)—This sensor detected laser emissions (0.5-1.8 μm) for up to 8 threats. It had 360° coverage and could transition to firm track within 2 seconds. With LCS in the Littoral, the probability of laser-guided missiles launched from shore vehicles increased. Laser warning system was designed to provide LCS crews with vitally important situational awareness of laser emissions. By using synthetic intelligence and threat library mapping, the LWS for LCS C^2 would process raw threat energy data detected by the onboard sensors.

Laser Rangefinder—This system could track, range targets with LPI characteristics for many types of weapons, and achieve very long range information for LCS' tracking system. This is very important if the ship does not have, or cannot use, active radar sensors. This was a "director" type of system, so it could only track or point at one target at a time.

Ladar Sensor—This system, Laser Radar or Ladar, had a very small beam width compared with conventional radar. It could obtain very precise angular range and had very good Doppler sensitivity. It could receive track information by illuminating a target for 1-2 milliseconds and be virtually undetectable by the target. Ladar sensing was ideally suited to the LCS application because the sensor provided an ability to "poke through" holes in the littoral environment. Other applications for LCS could include constructing a 3-D understanding of an environment from a limited range of viewing directions, as might be the case when viewing coastal defenses. While there has not been any open-source activity on the surface naval Ladar, the Army's

Jigsaw Program and airborne DASSL technologies were used to develop a notional Ladar for LCS.

Sensor Controller 1, Radar/EW Master Scheduler—Optimum blanking between active sensor and passive EW systems was achieved when PULSE DELAY and PULSE WIDTH controls were set to the minimum values needed to provide consistent blanking, while limiting the impact on EW receiver "OFF" time. Insufficient blanking would cause ownship emitters to be processed and displayed, while excessive blanking reduces EW receiver "look-time." Blanking procedures should be performed in a normal sea state environment to minimize the effects of weather conditions on the EW receivers. Blanking pulses could be increased to compensate for reflection of ownship emitters when high seas existed and sea return presented a problem. For a future ship like LCS, the *old* SLA-10 blanker would not be able to handle the complex signals of many emitters and changing LCS mission configurations. This unique process in the combat system must be "invented" for LCS to control emission, active radiation timing, as well as sector (bearing) EMCON control to prevent interference with offboard systems such as decoys. Items, including beam descriptions, pulse patterns, scan patterns, scan definitions, and frequency agility patterns, would be stored in a central sensor data base. These definitions would be available to the user to build the scenarios and test sequences that were required for the different LCS mission packages.

EO Sensor Low Light TV—This system would not contribute to the LCS AAW self-defense function except for confirmation of target kill assessment, but it was important for other LCS functions, such as surface target identification.

EO Ultraviolet Camera—This was a solar-blind detector to overcome the problem of high intensity solar background radiation. Like the Low Light TV, this sensor would not contribute to the LCS AAW self-defense function. It would be used for missile plume detection, biological and chemical agent detection, and short-range, covert communication.

<table>
<tr><th colspan="2">Sensor</th><th>Aperture Type</th><th>Slew Rate</th><th>Notional Firm Track Transition Time</th></tr>
<tr><td rowspan="3">IR</td><td>IR Scanning Sensor 1</td><td>Turret</td><td>60°/sec</td><td>5 sec</td></tr>
<tr><td>IR Scanning Sensor 2</td><td>Turret</td><td>Unknown</td><td>3 sec</td></tr>
<tr><td>Distributed IR Aperture System</td><td>Distributed Aperture</td><td>N/A</td><td>1 sec</td></tr>
<tr><td rowspan="4">EW</td><td>Passive EW 1</td><td>Scanning beam</td><td>N/A</td><td>2 sec</td></tr>
<tr><td>Passive EW 2</td><td>Scanning beam</td><td>N/A</td><td>2 sec</td></tr>
<tr><td>Passive EW 3 Missile Early Warning</td><td>Planar Array</td><td>N/A</td><td>4 sec</td></tr>
<tr><td>Passive EW 4 Laser Warning System</td><td>Planar Array</td><td>N/A</td><td>2 sec</td></tr>
<tr><td rowspan="2">EO</td><td>Low Light TV</td><td>Turret</td><td>Unknown</td><td>N/A</td></tr>
<tr><td>EO UV Camera</td><td>Turret</td><td>Unknown</td><td>Unknown</td></tr>
<tr><td rowspan="3">Other</td><td>Laser Range Finder</td><td>Turret</td><td>Unknown</td><td>3 sec</td></tr>
<tr><td>Ladar</td><td>Turret</td><td>Unknown</td><td>1 sec</td></tr>
<tr><td>Radar/EW Master Scheduler</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

Table 64. Passive Sensor Parameters

Criterion/MOP	Radar 1 (Phased Array Horiz. Search)	Radar 2 (Rotating Volume Search)
Probability of Sensor Availability (RM&A)	0.95	0.85
Probability of Availability (2007 IOC) – Yes or No	Yes	Yes
Size/Weight Estimate	2500lbs	3000lbs
Probability of First Detection		
Probability of Firm Track		
*Transition to Track Time	1 sec	4-12 sec
Passive/Active/LPI	Active	Active
*Transmission Method (RF/EO/IR)	RF	RF
Coverage (2D/3D)	3D	3D
Frequency/Band	X Band	C or S
Antenna/Aperture Size	4x4 / 3Arrays	
Antenna/Aperture Type	Active Phased	Passive
Power Aperture	Variable	650 Kw
Weather/Clutter/Littoral performance (Radar vs. IR)	A+	A
*Minimum Range (needs to match weapon)	50m	250m
*# of Operators	1	1
*# of Maintainers	1	1
*Special Rqmts (e.g., chilled water)	Chilled H_20 & Air	Chilled H_20 & Air
Electrical Power Rqmts		
Signature (RCS/IR) contribution	Small	Med

Table 65. Radar Sensor Parameters

B. WEAPON ENGAGE MODEL

1. INTRODUCTION

The weapon-engage model is an event based Monte Carlo simulation designed to estimate the Probability of Raid Annihilation (P_{RA}) of a combat system in a given threat scenario. Random numbers are used to vary time delays in the engagement sequence and to determine whether a weapon killed or missed a target based on the weapon's probability of kill (P_k). It was written in MATLAB to take advantage of the vector and matrix manipulation features that are available in MATLAB. As a result, it was very easy add and modify weapon parameters in a series of vectors at the start of the model. Encapsulating the model within a MATLAB function also provided a means of running over 100 production runs with different input permutations automatically from a master script.

The model is event driven, and events are scheduled by queuing event times in a common vector and sorting them in ascending order. For the purposes of these simulations, the launch times and the arrival times were fixed for each of the targets and are preloaded in the time queue at the start of each iteration. The remaining events in the engagement sequence are only loaded into the scheduling queue when the previous event for that specific target is executed. That way each of the targets are processed in the correct order and executing the event earliest in the engagement sequence first breaks any ties in event times. If a target is "killed" the target arrival event is removed from the time queue. Otherwise, if there was sufficient time to deploy decoys/chaff, a random number was drawn at the target arrival time to determine if the seduction is effective before scoring a hit on the ship. After all the iterations of a simulation run are executed, the model outputs P_{RA} and weapon round usage. Table 1 describes each of the events in greater detail.

Event	Description	Predecessor
Target Launched	Generated when the target is instantiated in the model (an input parameter). Schedules the target detection event based on the appropriate detection range parameter.	N/A
Target Detected	Scheduled when target reaches detection range. Schedules the firm track event using a random number based on a probability distribution. Also schedules the soft kill events at same time as the firm track event.	Target Launched
Firm Track	Scheduled for when the firm track delay expires. Schedules the recommend fire event based on a random number time delay for Threat Evaluation and Weapon Assessment (TEWA).	Target Detected
Electronic Attack Started	Denotes the start of the EA period. Schedules the EA Evaluation event using a fixed time period (early target arrival may shorten the time period).	Target Detected
Decoys Enabled	Denotes the start of the decoy launch period.	Target Detected
Recommend Fire	Scheduled when TEWA has expired. Gun systems go straight into an engagement order with no delay. Engagement orders for missile systems are scheduled with a random number delay for operator reaction time in a semi-automatic engagement.	Firm Track
Engagement Order	Scheduled when the TEWA delay has expired for gun systems or when the operator delay has expired for missile systems. Schedules weapon firing based on a fixed launch delay.	Recommend Fire
Weapon Fired	Scheduled when launch delay has expired. Schedules intercept event based on weapon and target range-time profiles.	Engagement Order
Intercept	Scheduled for when the target range-time profile and the weapon range-time profile cross each other in range. Calculates missile "kill" or "miss" (based on a random number and weapon P_k) and schedules kill evaluation event. Calculates gun rounds based on a ramped cumulative P_k function up to minimum range (no kill evaluation).	Weapon Fired
Kill Evaluation	Scheduled only for missile systems when the random	Intercept

	number kill evaluation delay has expired. Does not schedule any other events but does remove the Target Arrival event from the queue if intercept registered a kill. Event can be bumped forward in time by early target arrival.	
EA Evaluation	Scheduled for when the EA evaluation period is completed. Determines EA effectiveness (either "kill" or "not effective"). Does not schedule any other events but does remove the Target Arrival event from the queue if EA is registered effective. Event can be bumped forward in time by early target arrival.	Electronic Attack Started
Target Arrival	Scheduled for when the target range reaches zero based on the target profile parameters. The event is scheduled prior to target launch and removed from the time queue after a "kill" by the Kill Evaluation event. If the fixed decoy delay has expired, the event handler calculates the effectiveness of seduction and related soft kill (based on a random number and weapon P_k). If the soft kill is effective it is registered as a "kill." Otherwise a hit on the ship is recorded.	N/A

Table 66. Discrete Events in Weapon Engage Model

The weapon-engage model has the ability to simulate hard kill weapons that can fire more than one round in a missile salvo. The hard kill weapons can also reengage if the predicted intercept range is outside the minimum range. The weapons can engage separately and can be bearing limited. Electronic attack (EA) was modeled by a random number test that was scheduled a fixed time after the firm track time of each target.

2. ASSUMPTIONS

The following assumptions were made in the weapon-engage model:

- Electronic Attack can affect hard kill decisions after 10 seconds if judged effective

- Seduction is effective at target arrival only if at least 6 seconds has transpired from the first firm track
- Decoys and chaff do not prevent hard kill engagements
- Weapons incorporate fratricide delays between successive launches but not between weapons
- Weapons fire as soon as the launch sequence ends and are not interdependent
- Targets fly radial profiles (and are fully reliable)
- Hard kill weapons can be modeled by linear profiles with an acceleration delay
- Hard kill weapons have a fixed launch delay and a fixed time spacing between multiple round salvos
- Weapons execute one launch sequence at a time
- Weapon P_k does not depend on target type
- Missile salvo size is two missiles (both initial and reengagement)
- Gun rounds become more effective at shorter ranges (a cumulative P_k ramp function was used to calculate the number of rounds fired until kill with maximum cumulative P_k at gun minimum intercept range).
- Guns fire rounds from initial engagement time until target reaches minimum range

3. PARAMETER DESCRIPTIONS

To set up the simulation, the main simulation parameters have to be loaded into the corresponding variable vectors at the start of the weapon engage function. To facilitate multiple scenarios and combat systems, the parameters are selected at run time by the scenario, sensor suite, missile, and gun parameters. The first vectors in the program are the target parameters for each scenario that are selected by embedded cases within a "switch" statement. The key parameters are launch time, launch range and target speed for each of the targets in the scenario. MATLAB makes it easy to implicitly define the length of a vector simply by specifying all of the elements within brackets as shown below for the parameters in our scenario number 1 (with four targets).

```
Case 1
    target_type=  1;                          % Target type (not used)
    launch_time=  [0 5 10 15];                % Launch Times (seconds)
    launch_range= [18000 18000 18000 18000]; % Launch Ranges (meters)
    launch_alt=   [    3     3     3     3]; % Launch Altitude (m, not
used)
    tgt_speed=    [300 300 300 300];          % Target Speed (m/sec)
    tgt_azimuth=  [0 0 0 0];                  % Target Azimuth (degrees)
```

Although the weapons engage model accepts simple radial target profiles, it does not model the sensor performance against the targets beyond target detection and firm track events. It is assumed that other models will be used to calculate target detection range and to estimate the firm track delay from target detection. In our case we modeled three sensor suites with the first two sensor suites being radar based and the third sensor suite combining IR with a laser range finder. The firm track delays for the first two were modeled with triangle distribution functions and the delays for the third suite was modeled with a uniform distribution function. The event handler for the target detection event can be modified as necessary to change these firm track options. The sensor parameters were also scenario dependent and specified inside a "switch" statement. Table 67 summarizes the sensor vectors that were used.

```
Case 1
    detection_range=  21400;          % Detection range (meters)
    firm_track_delay= [1 1 1; 2 2 6]; % Time from detection to FT
(seconds)
    laser_range=      16000;          % Laser rangefinder max range
(meters)
    laser_FT_delay=   [ 2  6];        % Time to firm track inside
```

Parameter	Definition
Target Detection Range	The maximum range at which the target can be detected by the sensor suite. The model schedules a "Target Detected" event at the time the target profile crosses this range. In some scenarios the targets are launched inside the detection range, in which case the model assumes the detection time is equal to the launch time.
Firm Track Delay	The amount of time after the "Target Detected" event when the "Firm Track" event is scheduled. Provides the inputs to a triangle distribution function random number generator.
Laser Detection Range	This parameter is for Sensor Suite 3 only. It is used instead of Target Detection Range to generate the "Target Detected" event and is the maximum detection range of the laser rangefinder.
Laser FT Delay	This parameter is for Sensor Suite 3 only. It is used instead of Firm Track Delay to schedule a "Firm Track" event. Provides the inputs to a uniform distribution function random number generator.

Table 67. Sensor Parameters

Once a target is in firm track there are additional delays before a target can be engaged. Threat evaluation and weapon assignment (TEWA) is the first phase and we assumed that an automated system (such as a Bayesian Belief Network) would be used to minimize system reaction time. We assumed that any missile system would be operating in semi-automatic mode where the combat system issues a recommend fire alert to an operator and the operator has to push a button before a missile can be fired against a target. For the gun systems we assumed that they would be operating in automatic mode and this operator delay was bypassed (determined by the setting of the Auto Engage parameter described in Table 68). After a missile reaches an intercept point a kill evaluation delay is applied before the weapon can reengage the same target. The kill evaluation does not apply to the gun systems since they are modeled to fire from first engagement all the way to where the predicted intercept is equal to the minimum range of the gun. Table 69 describes each of these parameters in greater detail.

```
% C2 Parameters (minimum, mode, maximum)
TEWA_delay=       [0.25 0.5 0.75];  % Firm Track time to BBN decision
(seconds)
operator_delay=   [5  7  10];  % Semi-Auto delay to engage order
(seconds)
KE_delay=         [2  3   4];  % Kill evaluation delay before reenagage
(sec)
```

Parameter	Definition
TEWA Delay	The amount of time between the “Firm Track” event and the “Recommend Fire” event. It is assumed that a Bayesian Belief Network (BBN) or similar automated system will respond in less than one second.
Semi-Auto Operator Delay (missile)	The amount of time between the “Recommend Fire” event and the “Engagement Order” event for missiles. It is estimated that a trained operator can surface an alert in less than 10 seconds based on informal laboratory tests. This delay was not applied to the gun systems. They were modeled operating in automatic mode.
Kill Evaluation Delay (missile)	The amount of time between the “Target Intercept” event and the “Kill Evaluation” event for missiles. Although the random number is drawn in the intercept event, the target is not removed from the queue or re-engaged until this delay has expired. Gun systems are tied up for the entire engagement so this only applies to missile systems.

Table 68. Command and Control Parameters

Most of the input parameters fall in the hard kill section. Launch delay is used to time the first shot in a salvo and launch spacing is used to time subsequent shots based on the salvo size value for the weapon. A salvo size of zero is used for a gun to indicate that the gun fires continuously (all of the missiles were simulated with a salvo size of two). Magazine size indicates the number of missiles or bullets per mount. If there is more than one mount, the magazine size is multiplied by the number of mounts to get the total capacity. For guns, the firing time is calculated using a cumulative ramped P_k function (but the mount is seized for the entire engagement window) and is multiplied by the rate of fire to get a bullets expended count for the end statistics. Instead of using a quadratic equation for missile range versus time, a fixed acceleration time delay offset was applied to the linear range-time profiles calculated from weapon speed. P_k values are input per missile or per gun engagement (salvo size is zero). The auto-engage flag determines whether the semi-auto operator delay is applied after TEWA (set to zero for guns). The number of mounts parameter determines the weapon firing capacity and can also be used to disable a weapon if it is set to zero. (The missile number and the gun number inputs to the weapon-engage function are fed into a mask vector to zero any weapons not desired in a run). Table 4 describes each of the hard kill parameters in greater detail.

```
% Hard Kill Weapon Parameters [w1 w2 w3 w4 w5]
launch_delay=   [ 2 2 3 1.1 1.1];  % Min time from eng order to launch
(sec)
launch_spacing= [ 3 3 3 0 0];      % Min round separation in a salvo
(sec)
salvo_size=     [ 2 2 2 0 0];      % Max rounds fired per engagement
(0=gun)
mag_size=       [32 8 21 500 1550];       % Magazine size (rounds)
rate_of_fire=   [0 0 0 16.667 75];        % Gun rate of fire
(rounds/second)
wpn_acc_delay=  [2.19 3.28 0.91 0 0];     % Acceleration delay
(seconds)
wpn_speed=      [1360 1224 680 1000 1100];    % Weapon Speed (m/sec)
```

```
max_range=      [55560 22200 9400 3000 1500]; % Maximum intercept range
(m)
min_range=      [ 1500  1500 1000  200  200]; % Minimum intercept range
(m)
min_bearing=    [   0    0    0    0    0];   % Minimum launch bearing
(degrees)
max_bearing=    [ 360  360  360  360  360];   % Maximum launch bearing
(degrees)
pk_ss=          [0.85 0.5 0.9 0.8 0.75];   % Single Shot/Engage Prob of
Kill
auto_engage=    [   0    0    0    1    1];   % Auto engagement flag (1 for
gun)
wpn_mounts=     [   1    1    1    2    2];   % Number of mounts
```

Parameter	Definition
Launch_delay	The amount of time between the "Engagement Order" event and the "Weapon Fired" event. It is assume that the launch sequence takes a fixed amount of time once the engagement order is processed (and the weapon is freed from any earlier engagement).
Launch_spacing	The amount of time between missile launches in a multiple missile salvo. It is assumed to be a fixed amount of time based on fratricide rules.
Salvo_size	The number of missiles fired in each salvo. A salvo size of 0 is used for guns since they are modeled as firing continuously throughout the engagement window.
Mag_size	The number of rounds stored in a single instance of the weapon. This parameter is multiplied but the number of mounts parameter to get the total magazine capacity.
Rate_of_Fire	The firing rate of the gun systems in rounds per second.
Wpn_acc_delay	The time offset applied to the weapon range-time profile to account for initial weapon acceleration. Instead of applying a quadratic equation, the following formula is used: Range = Wpn_speed (clock_time – firing_time – Wpn_acc-delay)
Wpn_speed	The linear speed of the weapon in meters per second. (see Wpn_acc_delay for the range formula)
Max_range	The maximum intercept range of the weapon in meters.
Min_range	The minimum intercept range of the weapon in meters.
Min_bearing	The minimum firing bearing of the weapon in degrees. This cutout feature was not used to model our scenarios.
Max_bearing	The maximum firing bearing of the weapon in degrees. This cutout feature was not used to model our scenarios.
Pk_ss	The single shot probability of kill for a single missile firing. For the gun systems this is the probability of target kill in a single engagement (when the salvo size is zero).
Auto_engage	A flag to bypass the Semi-Auto Operator Delay. This flag is set to one for guns and zero for missiles.
Wpn_mounts	The total number of instances of this weapon in the simulation. A value

	of zero disables the weapon from the simulation (and was used to enable automated runs with different weapon permutations). Two or more mounts permit simultaneous engagement of more than one target.

Table 69. Hard Kill Weapon Parameters

Soft kill was originally added to the model without any time constraints and was checked at target arrival to see if any of the components were effective before declaring a hit on the ship. Since then a few time constraints have been added to allow EA kill of a target early in the engagement cycle and inhibit decoys if the target is not in track long enough to be effective. The EA evaluation time sets how long after a target are in firm track that an EA evaluation is made for target kill. The decoy delay sets how long after a target is in firm track before seduction and water camouflage will have a P_k value. The three P_k values for soft kill are tested against separate random numbers. The decoy P_k value is for both chaff and active decoys combined. Table 70 describes the soft kill parameters in greater detail.

```
% Soft Kill Weapon Parameters
pk_ea=          0.4;  % Electronic Attack Probability of Kill
pk_decoy=       0.7;  % Seduction/Decoy Probability of Kill
pk_wc=          0.1;  % Water Camouflage Probability of Kill
ea_eval_time=  10;    % The time window before EA Pk is evaluated
(seconds)
decoy_delay=    6;    % The time window before seduction is evaluated
(seconds)
```

Parameter	Definition
Pk_EA	The probability that Electronic Attack is effective. The "Electronic Attack Started" event is scheduled concurrent with the "Firm Track" event and a fixed evaluation time is applied before the random number is drawn in the "EA Evaluation" event. If the target is scheduled to arrive before the evaluation is scheduled, the EA is evaluated to be "Not Effective."
Pk_Seduction	The probability that seduction (decoys or chaff) is effective. Seduction is not considered to be effective until after the decoy delay has expired.

Pk_WC	The probability that the water camouflage is effective.
EA_evaluation_time	The amount of time between the "Electronic Attack Started" event and the "EA Evaluation" event. If the target is scheduled to arrive before the evaluation is scheduled, the EA is evaluated just before arrival to be "Not Effective."
Decoy_delay	The amount of time after the first firm track before the seduction is considered to be in place.

Table 70. Soft Kill Weapon Parameters

4. MODEL OUTPUTS

To facilitate data analysis, the outputs of the weapon engage function are stored in a comma separated variable (*.csv) data file that can be easily input into an Excel spreadsheet. The input parameters are stored first, followed by the engagement timelines for each of the iterations. When all of the iterations are run, several run statistics are also output at the end of the file. The file is named automatically based on the scenario number, the sensor suite number, the missile number, and the gun number (e.g. Scenario1S1M1G1) so that it can be spotted later if multiple permutations are being run. There is also a separate file (named Pra_outputs.csv) that stores just the P_{RA} values and the weapon firing statistics to collect data from multiple permutations of the scenario, sensor suite, missile, and gun parameters. Table 6 summarizes the fields that are output for each event in the engagement timeline (see Table 71 for the event descriptions).

Column	Description
Time(s)	The clock time since the launch of the first target (in seconds)
Range(km)	The range of the target at that time (in km)
Target	The index number of the target in the simulation
Event	See Table 1
Next Time(s)	The time of the next scheduled event for that target

Delay	The time delay incorporated in calculating the next time
Shells	The number of gun rounds fired
Random Num	The random number used in the gun ramp function

Table 71. Timeline Columns

P_{RA} and weapon firing statistics are calculated at the end of a run. First the hit counts for the ship are normalized into hit probability estimates one target at a time. The hit probabilities are fed into a state transition probability matrix and multiplied by the current state probability vector in a Markov process to estimate the distribution of hits between states (zero hits, one hit, two hits, etc.) starting with the first target. The last line of the Markov process should come close to the actual distribution of the hit counts (normalized to the number of iterations) output on the following line. The probability of zero hits equates to P_{RA}. After P_{RA} is output the weapon firing statistics are output giving the average number of rounds fired, the standard deviation, the 99% upper confidence limit on the mean, the minimum fired, the median fired, the 99th percentile fired, and the maximum fired. The iteration number for the minimum and maximum values is also output. Table 72 shows the end statistics from a sample run.

End of run Hit Statistics for 1000 iterations							
Tgt	Hits	P(hit)	0	1	2	3	4
1	16	0.016	0.984	0.016	0	0	0
2	9	0.009	0.975	0.025	0	0	0
3	9	0.009	0.966	0.033	0	0	0
4	6	0.006	0.961	0.039	0.001	0	0
Actual Hits			0.961	0.038	0.001	0	0
P(ra)			0.961				
Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired

1	0	0	0	0	0	0	0
2	7.96	0.266	7.98	6	8	8	8
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	183.56	228.17	200.35	0	0	824	1207
Min Fired:	6	Iteration	39				
Max Fired:	1215	Iteration	959				

Table 72. Sample End Statistics

Note: The statistics are listed by the weapon index in the input parameter list and not the missile or gun number used to name the file (i.e. weapon 4 was equivalent to gun number 1 in our runs).

5. CONCLUSION

MATLAB provided an excellent development framework for the weapon-engage model. Although a high fidelity weapon engagement model was beyond the scope of the capstone design project, we were able to develop a robust model that could be easily modified as needed to add additional capability using an event-based simulation. MATLAB allowed us to customize our outputs into comma separated variable files that could be easily imported into Excel for data analysis. As a result we did not have to add any special analysis features to the model itself. We also were able to make production runs with over 100 permutations automatically under script control. Certainly the model could have been developed with special purpose tools such as Arena, but there would have been less flexibility to change inputs as the parameters provided by the various teams kept changing.

C. PROBABILITY OF RAID ANNIHALATION

Scenario	Suite	Missile	Gun	Pra
1	3	0	2D	0.833
1	2	0	2D	0.841
1	1	0	1D	0.855
1	1	0	2D	0.859
1	2	0	1D	0.873
1	3	0	1D	0.874
1	3	2	2D	0.958
1	1	2	2D	0.959
1	2	2	2D	0.961
1	1	2	1D	0.967
1	3	2	1D	0.967
1	2	2	1D	0.970
1	1	1	1D	1.000
1	1	3	1D	1.000
1	2	1	1D	1.000
1	2	3	1D	1.000
1	3	1	1D	1.000
1	3	3	1D	1.000
1	1	1	2D	1.000
1	1	3	2D	1.000
1	2	1	2D	1.000
1	2	3	2D	1.000
1	3	1	2D	1.000
1	3	3	2D	1.000
2	3	2	2D	0.020
2	3	0	2D	0.025
2	3	3	2D	0.027
2	3	1	1D	0.029
2	3	0	1D	0.031
2	3	2	1D	0.032
2	3	3	1D	0.033
2	3	1	2D	0.033
2	2	0	2D	0.084
2	2	2	2D	0.086
2	2	2	1D	0.094
2	2	3	2D	0.095
2	2	1	1D	0.102
2	2	3	1D	0.102
2	2	1	2D	0.102
2	2	0	1D	0.115
2	1	2	2D	0.481
2	1	3	2D	0.489
2	1	0	2D	0.502

2	1	1	2D	0.508
2	1	1	1D	0.577
2	1	0	1D	0.580
2	1	3	1D	0.581
2	1	2	1D	0.592
3	1	0	2D	0.822
3	2	0	2D	0.839
3	1	0	1D	0.872
3	2	0	1D	0.886
3	1	2	2D	0.953
3	2	2	2D	0.953
3	2	2	1D	0.966
3	1	2	1D	0.969
3	2	3	2D	0.993
3	1	1	2D	0.996
3	1	3	2D	0.996
3	2	1	2D	0.996
3	1	1	1D	0.997
3	1	3	1D	0.998
3	2	1	1D	0.999
3	2	3	1D	0.999
4	3	0	2D	0.848
4	2	0	2D	0.851
4	1	0	2D	0.857
4	3	0	1D	0.882
4	2	0	1D	0.884
4	1	0	1D	0.885
4	1	2	2D	0.960
4	2	2	2D	0.962
4	3	2	2D	0.963
4	1	2	1D	0.973
4	2	2	1D	0.975
4	3	2	1D	0.977
4	1	1	1D	1.000
4	1	3	1D	1.000
4	2	1	1D	1.000
4	2	3	1D	1.000
4	3	1	1D	1.000
4	3	3	1D	1.000
4	1	1	2D	1.000
4	1	3	2D	1.000
4	2	1	2D	1.000
4	2	3	2D	1.000
4	3	1	2D	1.000
4	3	3	2D	1.000
5	1	0	2D	0.841
5	2	0	2D	0.847

5	3	2	2D	0.847
5	3	0	2D	0.873
5	3	0	1D	0.886
5	2	0	1D	0.887
5	1	0	1D	0.888
5	3	3	1D	0.900
5	3	1	2D	0.901
5	3	3	2D	0.902
5	3	2	1D	0.904
5	3	1	1D	0.919
5	2	2	2D	0.957
5	1	2	1D	0.961
5	1	2	2D	0.964
5	2	2	1D	0.968
5	1	3	2D	0.996
5	1	1	1D	0.998
5	2	1	1D	0.998
5	1	3	1D	0.999
5	2	3	1D	0.999
5	2	3	2D	0.999
5	1	1	2D	1.000
5	2	1	2D	1.000
6	1	0	2D	0.842
6	1	0	1D	0.858
6	2	0	2D	0.863
6	2	0	1D	0.867
6	2	2	2D	0.957
6	1	2	1D	0.961
6	2	2	1D	0.965
6	1	2	2D	0.969
6	2	1	1D	0.997
6	1	3	2D	0.997
6	1	1	1D	0.998
6	1	3	1D	0.998
6	2	1	2D	0.998
6	2	3	1D	1.000
6	1	1	2D	1.000
6	2	3	2D	1.000

D. PROBABILITY OF RAID ANNIHALATION SIMULATION OUTPUT

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	0	1D	0.855								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	335.38	149.169	346.35	0	341	651	738
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	0	2D	0.859								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	695.86	332.738	720.34	0	697	1421	1649
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	1	1D	1.000								
					1	8.07	0.612	8.12	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0.29	6.588	0.77	0	0	0	179
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	1	2D	1.000								
					1	8.02	0.536	8.06	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	2	1D	0.967								
					1	0	0	0	0	0	0	0
					2	7.96	0.28	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	84.25	109.879	92.33	0	0	403	520
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	2	2D	0.959								
					1	0	0	0	0	0	0	0
					2	7.97	0.274	7.99	4	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	179.25	226.168	195.88	0	0	825	1122
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	8	0.438	8.03	6	8	10	10
					4	3.21	22.192	4.85	0	0	154	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	1	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.98	0.499	8.02	6	8	10	12
					4	0	0	0	0	0	0	0
					5	0.21	6.764	0.71	0	0	0	214
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	0	1D	0.873								
					1	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	326.39	144.945	337.05	0	332	645	710
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	0	2D	0.841								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	727.89	340.614	752.94	0	728	1469	1649
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	1	1D	1.000								
					1	8.09	0.61	8.13	4	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0.17	3.742	0.44	0	0	0	97
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	1	2D	1.000								
					1	8.05	0.598	8.1	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	0.41	13.022	1.37	0	0	0	412
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	2	1D	0.970								
					1	0	0	0	0	0	0	0
					2	7.97	0.259	7.99	4	8	8	8
					3	0	0	0	0	0	0	0
					4	86.95	104.707	94.66	0	50.5	368	561

					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	2	2D	0.961								
					1	0	0	0	0	0	0	0
					2	7.96	0.266	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	183.56	228.17	200.35	0	0	824	1207
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.98	0.433	8.01	6	8	10	10
					4	2.76	20.346	4.26	0	0	130	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	2	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.98	0.481	8.02	6	8	10	10
					4	0	0	0	0	0	0	0
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	0	1D	0.874								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	328.37	142.173	338.83	0	330	619	717
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	0	2D	0.833								

					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	729.89	332.636	754.35	0	716	1513	1649
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	1	1D	1.000								
					1	8.06	0.541	8.1	4	8	10	11
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	7.08	33.44	9.54	0	0	202	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	1	2D	1.000								
					1	8.06	0.511	8.1	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	0.75	16.755	1.98	0	0	0	412
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	2	1D	0.967								
					1	0	0	0	0	0	0	0
					2	7.95	0.3	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	86.26	106.468	94.09	0	0	404	492
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	2	2D	0.958								
					1	0	0	0	0	0	0	0
					2	7.95	0.324	7.97	6	8	8	8
					3	0	0	0	0	0	0	0

					4	0	0	0	0	0	0	0
					5	172.62	231.971	189.68	0	0	870	1536
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	8	0.438	8.03	6	8	10	12
					4	3.44	24.745	5.26	0	0	172	331
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
1	3	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.98	0.447	8.01	6	8	10	10
					4	0	0	0	0	0	0	0
					5	3.27	30.223	5.5	0	0	147	398
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	0	1D	0.580								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	174.03	20.521	175.53	120	175	214	221
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	0	2D	0.502								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	604.66	68.205	609.67	388	609	739	757
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired

2	1	1	1D	0.577								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	174.07	20.648	175.59	118	174	217	224
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	1	2D	0.508								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	604.66	67.05	609.59	402	605	742	772
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	2	1D	0.592								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	174.67	21.201	176.23	116	175	217	226
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	2	2D	0.481								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	601.87	67.275	606.81	397	603	745	767
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	3	1D	0.581								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0

					3	0	0	0	0	0	0	0
					4	173.57	20.822	175.1	115	173	216	222
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	1	3	2D	0.489								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	603.27	67.568	608.24	391	604	742	764
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	0	1D	0.115								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	68.32	20.032	69.8	9	68	112	125
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	0	2D	0.084								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	293.27	86.56	299.64	49	294	478	519
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	1	1D	0.102								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	67.47	20.309	68.96	14	67	116	131
					5	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	1	2D	0.102								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	293.94	85.766	300.24	37	296	475	540
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	2	1D	0.094								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	69.07	19.909	70.53	10	68	114	125
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	2	2D	0.086								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	294.57	84.283	300.77	46	295	471	540
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	3	1D	0.102								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	68.66	20.838	70.19	12	69	117	124
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	2	3	2D	0.095								
					1	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	290.91	86.318	297.26	22	289	482	533
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	0	1D	0.031								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	48.01	22.297	49.65	0	47	102	108
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	0	2D	0.025								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	205.68	96.342	212.77	0	197	438	499
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	1	1D	0.029								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	48.47	22.288	50.11	0	47	103	118
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	1	2D	0.033								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0

					5	208.46	99.82	215.8	0	203	448	490
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	2	1D	0.032								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	46.58	22.325	48.22	0	46	101	117
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	2	2D	0.020								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	211.38	96.179	218.46	0	209	450	513
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	3	1D	0.033								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	48.33	22.983	50.02	0	47	103	125
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
2	3	3	2D	0.027								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	210.83	100.702	218.23	0	211	466	510
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	0	1D	0.872								

					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	171.2	72.598	176.54	0	166	318	340
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	0	2D	0.822								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	342.52	141.74	352.95	0	330	632	660
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	1	1D	0.997								
					1	7.85	0.47	7.89	5	8	8	9
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	104.96	66.934	109.88	0	85	254	330
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	1	2D	0.996								
					1	7.88	0.454	7.92	5	8	8	9
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	97.38	107.797	105.31	0	110	379	464
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	2	1D	0.969								
					1	0	0	0	0	0	0	0
					2	7.8	0.566	7.84	4	8	8	8
					3	0	0	0	0	0	0	0

					4	142.25	72.263	147.57	0	141	303	340
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	2	2D	0.953								
					1	0	0	0	0	0	0	0
					2	7.75	0.599	7.8	5	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	192.95	132.303	202.68	0	165	512	636
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	3	1D	0.998								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.36	1.018	7.44	2	8	8	8
					4	171.37	72.538	176.71	0	170	318	334
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	1	3	2D	0.996								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.29	1.051	7.37	2	8	8	8
					4	0	0	0	0	0	0	0
					5	237.78	141.782	248.2	0	253	588	660
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	0	1D	0.886								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	165.63	71.138	170.87	0	160	314	334
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired

3	2	0	2D	0.839								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	336.04	143.116	346.57	0	320	621	651
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	1	1D	0.999								
					1	7.88	0.466	7.92	5	8	9	9
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	106.99	68.576	112.04	0	85	259	331
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	1	2D	0.996								
					1	7.86	0.484	7.89	4	8	8	9
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	98.83	110.761	106.98	0	110	415	531
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	2	1D	0.966								
					1	0	0	0	0	0	0	0
					2	7.81	0.538	7.85	5	8	8	8
					3	0	0	0	0	0	0	0
					4	145.01	72.475	150.34	0	146	309	340
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	2	2D	0.953								
					1	0	0	0	0	0	0	0
					2	7.83	0.517	7.86	5	8	8	8

					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	182.31	131.944	192.02	0	165	489	613
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	3	1D	0.999								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.34	1.027	7.41	2	8	8	8
					4	171.5	71.621	176.76	0	170	317	330
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
3	2	3	2D	0.993								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.41	0.991	7.48	2	8	8	8
					4	0	0	0	0	0	0	0
					5	241.61	133.073	251.4	0	265	569	633
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	0	1D	0.885								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	321.06	149.89	332.08	0	322	624	694
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	0	2D	0.857								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	709.21	327.386	733.29	0	706	1422	1646

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	1	1D	1.000								
					1	8.05	0.614	8.1	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0.08	2.402	0.25	0	0	0	76
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	1	2D	1.000								
					1	8.07	0.528	8.11	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	2	1D	0.973								
					1	0	0	0	0	0	0	0
					2	7.95	0.342	7.97	4	8	8	8
					3	0	0	0	0	0	0	0
					4	78.67	102.477	86.2	0	0	398	555
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	2	2D	0.960								
					1	0	0	0	0	0	0	0
					2	7.96	0.273	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	182.79	230.518	199.74	0	0	856	1239
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	3	1D	1.000								
					1	0	0	0	0	0	0	0

					2	0	0	0	0	0	0	0
					3	4.82	2.094	4.97	0	4	10	10
					4	4.61	26.175	6.54	0	0	187	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	1	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	4.75	2.018	4.9	0	4	8	10
					4	0	0	0	0	0	0	0
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	0	1D	0.884								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	330.46	149.67	341.47	0	334	647	720
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	0	2D	0.851								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	708.09	325.632	732.04	0	693	1500	1611
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	1	1D	1.000								
					1	8.03	0.616	8.08	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0.37	8.32	0.98	0	0	0	202

					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	1	2D	1.000								
					1	8.07	0.605	8.12	4	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	2	1D	0.975								
					1	0	0	0	0	0	0	0
					2	7.97	0.235	7.99	6	8	8	8
					3	0	0	0	0	0	0	0
					4	81.82	106.897	89.68	0	0	396	605
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	2	2D	0.962								
					1	0	0	0	0	0	0	0
					2	7.97	0.274	7.99	4	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	168.9	218.423	184.97	0	0	810	1185
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	4.69	1.936	4.84	0	4	8	10
					4	2.27	18.179	3.61	0	0	120	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	2	3	2D	1.000								

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	4.86	2.038	5.01	0	4	8	11
					4	0	0	0	0	0	0	0
					5	0.53	13.16	1.49	0	0	0	396
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	0	1D	0.882								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	321.33	143.49	331.88	0	319	619	678
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	0	2D	0.848								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	716.16	335.992	740.87	0	717	1483	1652
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	1	1D	1.000								
					1	8.07	0.557	8.11	4	8	10	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	6.52	30.868	8.79	0	0	190	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	1	2D	1.000								
					1	8.1	0.589	8.14	6	8	10	12
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					4	0	0	0	0	0	0	0
					5	0.83	18.451	2.18	0	0	0	413
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	2	1D	0.977								
					1	0	0	0	0	0	0	0
					2	7.95	0.306	7.97	6	8	8	8
					3	0	0	0	0	0	0	0
					4	80.72	108.909	88.73	0	0	404	526
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	2	2D	0.963								
					1	0	0	0	0	0	0	0
					2	7.96	0.293	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	173.93	229.924	190.84	0	0	826	1239
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.97	0.517	8	4	8	10	10
					4	3.88	25.067	5.72	0	0	180	202
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
4	3	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.99	0.443	8.02	6	8	10	10
					4	0	0	0	0	0	0	0
					5	5.27	42.534	8.39	0	0	289	413
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired

5	1	0	1D	0.888								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	175.67	65.151	180.46	0	187	299	311
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	0	2D	0.841								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	440.85	186.911	454.59	0	444	855	900
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	1	1D	0.998								
					1	7.99	0.545	8.03	4	8	10	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	33.4	46.969	36.85	0	0	168	220
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	1	2D	1.000								
					1	8.01	0.481	8.04	4	8	10	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	9.56	42.662	12.7	0	0	225	341
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	2	1D	0.961								
					1	0	0	0	0	0	0	0
					2	7.96	0.292	7.98	6	8	8	8

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					3	0	0	0	0	0	0	0
					4	95.57	70.212	100.74	0	95	253	312
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	2	2D	0.964								
					1	0	0	0	0	0	0	0
					2	7.94	0.34	7.96	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	104.7	128.105	114.12	0	0	462	681
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	3	1D	0.999								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.94	0.336	7.97	6	8	8	8
					4	145.17	66.46	150.06	0	162	255	310
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	1	3	2D	0.996								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.95	0.324	7.97	6	8	8	8
					4	0	0	0	0	0	0	0
					5	121.31	100.83	128.73	0	146	368	450
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	0	1D	0.887								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	180.82	60.827	185.3	0	190	288	318
					5	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	0	2D	0.847								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	427.85	189.486	441.78	0	420	849	884
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	1	1D	0.998								
					1	8	0.449	8.03	6	8	10	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	64.47	56.827	68.65	0	71	214	220
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	1	2D	1.000								
					1	7.97	0.451	8	6	8	9	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	14.71	51.613	18.51	0	0	225	355
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	2	1D	0.968								
					1	0	0	0	0	0	0	0
					2	7.94	0.339	7.97	4	8	8	8
					3	0	0	0	0	0	0	0
					4	112.77	70.449	117.95	0	110	252	277
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	2	2D	0.957								
					1	0	0	0	0	0	0	0

					2	7.96	0.286	7.98	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	136.05	146.251	146.81	0	130	546	625
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	3	1D	0.999								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.94	0.337	7.97	6	8	8	8
					4	145.91	66.259	150.78	0	160	269	285
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	2	3	2D	0.999								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	7.93	0.37	7.96	4	8	8	8
					4	0	0	0	0	0	0	0
					5	117.63	109.957	125.72	0	132	430	597
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	0	1D	0.886								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	223.37	42.728	226.51	53	226	307	320
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	0	2D	0.873								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0

					5	425.23	182.673	438.66	0	429	817	891
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	1	1D	0.919								
					1	2.12	0.735	2.17	1	2	4	4
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	223	43.964	226.23	0	226	307	320
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	1	2D	0.901								
					1	2.1	0.695	2.16	1	2	4	4
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	430.37	189.293	444.29	0	428	833	900
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	2	1D	0.904								
					1	0	0	0	0	0	0	0
					2	1.56	0.666	1.61	1	1	3	4
					3	0	0	0	0	0	0	0
					4	223.15	45.162	226.47	0	227	306	320
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	2	2D	0.847								
					1	0	0	0	0	0	0	0
					2	1.53	0.67	1.58	0	1	3	3
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	437.87	178.175	450.98	0	441	802	899
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	3	1D	0.900								

					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	2.11	0.617	2.16	1	2	3	4
					4	226.18	44.171	229.43	55	230	308	320
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
5	3	3	2D	0.902								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	2.09	0.605	2.13	1	2	3	4
					4	0	0	0	0	0	0	0
					5	436.72	187.978	450.55	0	434	840	900
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	0	1D	0.858								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	171.66	71.391	176.91	0	166	315	340
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	0	2D	0.842								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	356.12	145.947	366.86	0	344	641	688
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	1	1D	0.998								
					1	7.96	0.386	7.99	6	8	9	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					4	64.46	58.866	68.79	0	65	226	260
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	1	2D	1.000								
					1	7.97	0.354	8	6	8	9	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	43.31	77.547	49.01	0	0	306	479
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	2	1D	0.961								
					1	0	0	0	0	0	0	0
					2	7.92	0.389	7.95	4	8	8	8
					3	0	0	0	0	0	0	0
					4	112.34	68.179	117.35	0	114	277	332
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	2	2D	0.969								
					1	0	0	0	0	0	0	0
					2	7.92	0.375	7.95	4	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	141.33	129.437	150.85	0	138	496	623
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	1	3	1D	0.998								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	6.34	1.589	6.45	0	6	8	8
					4	170.06	72.278	175.38	0	166	318	327
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired

6	1	3	2D	0.997								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	6.34	1.535	6.45	2	6	8	8
					4	0	0	0	0	0	0	0
					5	210.8	148.407	221.71	0	172	539	649
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	0	1D	0.867								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	170.98	72.555	176.32	0	169	319	340
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	0	2D	0.863								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	348.93	144.069	359.52	0	332	652	684
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	1	1D	0.997								
					1	7.95	0.421	7.98	2	8	9	10
					2	0	0	0	0	0	0	0
					3	0	0	0	0	0	0	0
					4	61.59	58.123	65.86	0	64	224	253
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	1	2D	0.998								
					1	7.96	0.411	7.99	4	8	9	10
					2	0	0	0	0	0	0	0

Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	41.49	74.974	47.01	0	0	302	428
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	2	1D	0.965								
					1	0	0	0	0	0	0	0
					2	7.94	0.308	7.97	6	8	8	8
					3	0	0	0	0	0	0	0
					4	110.24	70.525	115.43	0	108	280	327
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	2	2D	0.957								
					1	0	0	0	0	0	0	0
					2	7.94	0.326	7.96	6	8	8	8
					3	0	0	0	0	0	0	0
					4	0	0	0	0	0	0	0
					5	133.93	123.536	143.02	0	137	483	648
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	3	1D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	6.25	1.616	6.36	0	6	8	8
					4	174.21	68.794	179.27	0	166	318	339
					5	0	0	0	0	0	0	0
Scenario	Suite	Missile	Gun	Pra	Weapon	Ave Fired	S.D. Fired	99% UCL	Min Fired	Median	99%-tile	Max Fired
6	2	3	2D	1.000								
					1	0	0	0	0	0	0	0
					2	0	0	0	0	0	0	0
					3	6.29	1.668	6.41	0	6	8	8
					4	0	0	0	0	0	0	0
					5	204.23	149.014	215.19	0	172	590	688

E. WEAPONS FIRED

Suite	Missile	Gun	Scenario	Pra	Weapon	99%-tile
1	0	1D	1	0.855	4	651
1	0	1D	2	0.580	4	214
1	0	1D	3	0.872	4	318
1	0	1D	4	0.885	4	624
1	0	1D	5	0.888	4	299
1	0	1D	6	0.858	4	315
1	0	2D	1	0.859	5	1421
1	0	2D	2	0.502	5	739
1	0	2D	3	0.822	5	632
1	0	2D	4	0.857	5	1422
1	0	2D	5	0.841	5	855
1	0	2D	6	0.842	5	641
1	1	1D	1	>0.999	1	10
1	1	1D	2	0.577	4	217
1	1	1D	3	0.997	1	8
1	1	1D	3	0.997	4	254
1	1	1D	4	>0.999	1	10
1	1	1D	5	0.998	1	10
1	1	1D	5	0.998	4	168
1	1	1D	6	0.998	1	9
1	1	1D	6	0.998	4	226
1	1	2D	1	>0.999	1	10
1	1	2D	2	0.508	5	742
1	1	2D	3	0.996	1	8
1	1	2D	3	0.996	5	379
1	1	2D	4	>0.999	1	10
1	1	2D	5	>0.999	1	10
1	1	2D	5	>0.999	5	225
1	1	2D	6	>0.999	1	9
1	1	2D	6	>0.999	5	306
1	2	1D	1	0.967	2	8
1	2	1D	1	0.967	4	403
1	2	1D	2	0.592	4	217
1	2	1D	3	0.969	2	8
1	2	1D	3	0.969	4	303
1	2	1D	4	0.973	2	8
1	2	1D	4	0.973	4	398
1	2	1D	5	0.961	2	8
1	2	1D	5	0.961	4	253
1	2	1D	6	0.961	2	8
1	2	1D	6	0.961	4	277
1	2	2D	1	0.959	2	8
1	2	2D	1	0.959	5	825

1	2	2D	2	0.481	5	745
1	2	2D	3	0.953	2	8
1	2	2D	3	0.953	5	512
1	2	2D	4	0.960	2	8
1	2	2D	4	0.960	5	856
1	2	2D	5	0.964	2	8
1	2	2D	5	0.964	5	462
1	2	2D	6	0.969	2	8
1	2	2D	6	0.969	5	496
1	3	1D	1	>0.999	3	10
1	3	1D	1	>0.999	4	154
1	3	1D	2	0.581	4	216
1	3	1D	3	0.998	3	8
1	3	1D	3	0.998	4	318
1	3	1D	4	>0.999	3	10
1	3	1D	4	>0.999	4	187
1	3	1D	5	0.999	3	8
1	3	1D	5	0.999	4	255
1	3	1D	6	0.998	3	8
1	3	1D	6	0.998	4	318
1	3	2D	1	>0.999	3	10
1	3	2D	2	0.489	5	742
1	3	2D	3	0.996	3	8
1	3	2D	3	0.996	5	588
1	3	2D	4	>0.999	3	8
1	3	2D	5	0.996	3	8
1	3	2D	5	0.996	5	368
1	3	2D	6	0.997	3	8
1	3	2D	6	0.997	5	539
2	0	1D	1	0.873	4	645
2	0	1D	2	0.115	4	112
2	0	1D	3	0.886	4	314
2	0	1D	4	0.884	4	647
2	0	1D	5	0.887	4	288
2	0	1D	6	0.867	4	319
2	0	2D	1	0.841	5	1469
2	0	2D	2	0.084	5	478
2	0	2D	3	0.839	5	621
2	0	2D	4	0.851	5	1500
2	0	2D	5	0.847	5	849
2	0	2D	6	0.863	5	652
2	1	1D	1	>0.999	1	10
2	1	1D	2	0.102	4	116
2	1	1D	3	0.999	1	9
2	1	1D	3	0.999	4	259
2	1	1D	4	>0.999	1	10
2	1	1D	5	0.998	1	10

2	1	1D	5	0.998	4	214
2	1	1D	6	0.997	1	9
2	1	1D	6	0.997	4	224
2	1	2D	1	>0.999	1	10
2	1	2D	2	0.102	5	475
2	1	2D	3	0.996	1	8
2	1	2D	3	0.996	5	415
2	1	2D	4	>0.999	1	10
2	1	2D	5	>0.999	1	9
2	1	2D	5	>0.999	5	225
2	1	2D	6	0.998	1	9
2	1	2D	6	0.998	5	302
2	2	1D	1	0.970	2	8
2	2	1D	1	0.970	4	368
2	2	1D	2	0.094	4	114
2	2	1D	3	0.966	2	8
2	2	1D	3	0.966	4	309
2	2	1D	4	0.975	2	8
2	2	1D	4	0.975	4	396
2	2	1D	5	0.968	2	8
2	2	1D	5	0.968	4	252
2	2	1D	6	0.965	2	8
2	2	1D	6	0.965	4	280
2	2	2D	1	0.961	2	8
2	2	2D	1	0.961	5	824
2	2	2D	2	0.086	5	471
2	2	2D	3	0.953	2	8
2	2	2D	3	0.953	5	489
2	2	2D	4	0.962	2	8
2	2	2D	4	0.962	5	810
2	2	2D	5	0.957	2	8
2	2	2D	5	0.957	5	546
2	2	2D	6	0.957	2	8
2	2	2D	6	0.957	5	483
2	3	1D	1	>0.999	3	10
2	3	1D	1	>0.999	4	130
2	3	1D	2	0.102	4	117
2	3	1D	3	0.999	3	8
2	3	1D	3	0.999	4	317
2	3	1D	4	>0.999	3	8
2	3	1D	4	>0.999	4	120
2	3	1D	5	0.999	3	8
2	3	1D	5	0.999	4	269
2	3	1D	6	>0.999	3	8
2	3	1D	6	>0.999	4	318
2	3	2D	1	>0.999	3	10
2	3	2D	2	0.095	5	482

2	3	2D	3	0.993	3	8
2	3	2D	3	0.993	5	569
2	3	2D	4	>0.999	3	8
2	3	2D	5	0.999	3	8
2	3	2D	5	0.999	5	430
2	3	2D	6	>0.999	3	8
2	3	2D	6	>0.999	5	590
3	0	1D	1	0.874	4	619
3	0	1D	2	0.031	4	102
3	0	1D	4	0.882	4	619
3	0	1D	5	0.886	4	307
3	0	2D	1	0.833	5	1513
3	0	2D	2	0.025	5	438
3	0	2D	4	0.848	5	1483
3	0	2D	5	0.873	5	817
3	1	1D	1	>0.999	1	10
3	1	1D	1	>0.999	4	202
3	1	1D	2	0.029	4	103
3	1	1D	4	>0.999	1	10
3	1	1D	4	>0.999	4	190
3	1	1D	5	0.919	1	4
3	1	1D	5	0.919	4	307
3	1	2D	1	>0.999	1	10
3	1	2D	2	0.033	5	448
3	1	2D	4	>0.999	1	10
3	1	2D	5	0.901	1	4
3	1	2D	5	0.901	5	833
3	2	1D	1	0.967	2	8
3	2	1D	1	0.967	4	404
3	2	1D	2	0.032	4	101
3	2	1D	4	0.977	2	8
3	2	1D	4	0.977	4	404
3	2	1D	5	0.904	2	3
3	2	1D	5	0.904	4	306
3	2	2D	1	0.958	2	8
3	2	2D	1	0.958	5	870
3	2	2D	2	0.020	5	450
3	2	2D	4	0.963	2	8
3	2	2D	4	0.963	5	826
3	2	2D	5	0.847	2	3
3	2	2D	5	0.847	5	802
3	3	1D	1	>0.999	3	10
3	3	1D	1	>0.999	4	172
3	3	1D	2	0.033	4	103
3	3	1D	4	>0.999	3	10
3	3	1D	4	>0.999	4	180
3	3	1D	5	0.900	3	3

3	3	1D	5	0.900	4	308
3	3	2D	1	>0.999	3	10
3	3	2D	1	>0.999	5	147
3	3	2D	2	0.027	5	466
3	3	2D	4	>0.999	3	10
3	3	2D	4	>0.999	5	289
3	3	2D	5	0.902	3	3
3	3	2D	5	0.902	5	840

F. SCENARIO FIRED

Scenario	Suite	Missile	Gun	Pra	Weapon	99%-tile
1	1	0	1	0.855	G1	651
1	1	0	2	0.859	G2	1421
1	1	1	1	>.999	M1	10
1	1	1	2	>.999	M1	10
1	1	2	1	0.967	M2	8
					G1	403
1	1	2	2	0.959	M2	8
					G2	825
1	1	3	1	>.999	M3	10
					G1	154
1	1	3	2	>.999	M3	10
1	2	0	1	0.873	G1	645
1	2	0	2	0.841	G2	1469
1	2	1	1	>.999	M1	10
1	2	1	2	>.999	M1	10
1	2	2	1	0.970	M2	8
					G1	368
1	2	2	2	0.961	M2	8
					G2	824
1	2	3	1	>.999	M3	10
					G1	130
1	2	3	2	>.999	M3	10
1	3	0	1	0.874	G1	619
1	3	0	2	0.833	G2	1513
1	3	1	1	>.999	M1	10
					G1	202
1	3	1	2	>.999	M1	10
1	3	2	1	0.967	M2	8
					G1	404
1	3	2	2	0.958	M2	8
					G2	870
1	3	3	1	>.999	M3	10
					G1	172
1	3	3	2	>.999	M3	10

					G2	147
2	1	0	1	0.580	G1	214
2	1	0	2	0.502	G2	739
2	1	1	1	0.577	G1	217
2	1	1	2	0.508	G2	742
2	1	2	1	0.592	G1	217
2	1	2	2	0.481	G2	745
2	1	3	1	0.581	G1	216
2	1	3	2	0.489	G2	742
2	2	0	1	0.115	G1	112
2	2	0	2	0.084	G2	478
2	2	1	1	0.102	G1	116
2	2	1	2	0.102	G2	475
2	2	2	1	0.094	G1	114
2	2	2	2	0.086	G2	471
2	2	3	1	0.102	G1	117
2	2	3	2	0.095	G2	482
2	3	0	1	0.031	G1	102
2	3	0	2	0.025	G2	438
2	3	1	1	0.029	G1	103
2	3	1	2	0.033	G2	448
2	3	2	1	0.032	G1	101
2	3	2	2	0.020	G2	450
2	3	3	1	0.033	G1	103
2	3	3	2	0.027	G2	466
3	1	0	1	0.872	G1	318
3	1	0	2	0.822	G2	632
3	1	1	1	0.997	M1	8
					G1	254
3	1	1	2	0.996	M1	8
					G2	379
3	1	2	1	0.969	M2	8
					G1	303
3	1	2	2	0.953	M2	8
					G2	512
3	1	3	1	0.998	M3	8
					G1	318
3	1	3	2	0.996	M3	8
					G2	588
3	2	0	1	0.886	G1	314
3	2	0	2	0.839	G2	621
3	2	1	1	0.999	M1	9
					G1	259
3	2	1	2	0.996	M1	8
					G2	415
3	2	2	1	0.966	M2	8
					G1	309

3	2	2	2	0.953	M2	8
					G2	489
3	2	3	1	0.999	M3	8
					G1	317
3	2	3	2	0.993	M3	8
					G2	569
4	1	0	1	0.885	G1	624
4	1	0	2	0.857	G2	1422
4	1	1	1	>.999	M1	10
4	1	1	2	>.999	M1	10
4	1	2	1	0.973	M2	8
					G1	398
4	1	2	2	0.960	M2	8
					G2	856
4	1	3	1	>.999	M3	10
					G1	187
4	1	3	2	>.999	M3	8
4	2	0	1	0.884	G1	647
4	2	0	2	0.851	G2	1500
4	2	1	1	>.999	M1	10
4	2	1	2	>.999	M1	10
4	2	2	1	0.975	M2	8
					G1	396
4	2	2	2	0.962	M2	8
					G2	810
4	2	3	1	>.999	M3	8
					G1	120
4	2	3	2	>.999	M3	8
4	3	0	1	0.882	G1	619
4	3	0	2	0.848	G2	1483
4	3	1	1	>.999	M1	10
					G1	190
4	3	1	2	>.999	M1	10
4	3	2	1	0.977	M2	8
					G1	404
4	3	2	2	0.963	M2	8
					G2	826
4	3	3	1	>.999	M3	10
					G1	180
4	3	3	2	>.999	M3	10
					G2	289
5	1	0	1	0.888	G1	299
5	1	0	2	0.841	G2	855
5	1	1	1	0.998	M1	10
					G1	168
5	1	1	2	>.999	M1	10
					G2	225

5	1	2	1	0.961	M2	8
					G1	253
5	1	2	2	0.964	M2	8
					G2	462
5	1	3	1	0.999	M3	8
					G1	255
5	1	3	2	0.996	M3	8
					G2	368
5	2	0	1	0.887	G1	288
5	2	0	2	0.847	G2	849
5	2	1	1	0.998	M1	10
					G1	214
5	2	1	2	>.999	M1	9
					G2	225
5	2	2	1	0.968	M2	8
					G1	252
5	2	2	2	0.957	M2	8
					G2	546
5	2	3	1	0.999	M3	8
					G1	269
5	2	3	2	0.999	M3	8
					G2	430
5	3	0	1	0.886	G1	307
5	3	0	2	0.873	G2	817
5	3	1	1	0.919	M1	4
					G1	307
5	3	1	2	0.901	M1	4
					G2	833
5	3	2	1	0.904	M2	3
					G1	306
5	3	2	2	0.847	M2	3
					G2	802
5	3	3	1	0.900	M3	3
					G1	308
5	3	3	2	0.902	M3	3
					G2	840
6	1	0	1	0.858	G1	315
6	1	0	2	0.842	G2	641
6	1	1	1	0.998	M1	9
					G1	226
6	1	1	2	>.999	M1	9
					G2	306
6	1	2	1	0.961	M2	8
					G1	277
6	1	2	2	0.969	M2	8
					G2	496
6	1	3	1	0.998	M3	8

					G1	318
6	1	3	2	0.997	M3	8
					G2	539
6	2	0	1	0.867	G1	319
6	2	0	2	0.863	G2	652
6	2	1	1	0.997	M1	9
					G1	224
6	2	1	2	0.998	M1	9
					G2	302
6	2	2	1	0.965	M2	8
					G1	280
6	2	2	2	0.957	M2	8
					G2	483
6	2	3	1	>.999	M3	8
					G1	318
6	2	3	2	>.999	M3	8
					G2	590

APPENDIX I. PROPULSION SPREADSHEETS

A. SIDE HULL POSITIONING RESISTANCE CALCULATIONS

SPEED(M/S)	SPEED(KTS)	Xout/Lpp	Yout/Lpp	LWL (m)	B (m)	TMAX (m)	Pw(hp)	Pform (hp)	Pf (hp)	Ptotal (hp)
6.9132221	13.4393898	0.1563	0.1	122.2	27	3.658	222.131	331.7927	663.59	1217.509
10.369833	20.1590847	0.1563	0.1	122.2	27	3.658	2881.59	1064.388	2128.8	6074.754
13.826444	26.8787796	0.1563	0.1	122.2	27	3.658	3523.33	2435.625	4871.3	10830.21
17.283055	33.5984745	0.1563	0.1	122.2	27	3.658	5889.21	4630.751	9261.5	19781.47
20.739666	40.3181694	0.1563	0.1	122.2	27	3.658	10172.4	7829.968	15660	33662.35
24.196277	47.0378643	0.1563	0.1	122.2	27	3.658	13826.9	12209.62	24419	50455.77
27.652888	53.7575592	0.1563	0.1	122.2	27	3.658	16365.6	17942.95	35886	70194.47
6.9132221	13.4393898	0.2	0.1	122.2	27	3.658	185.619	331.7927	663.59	1180.997
10.369833	20.1590847	0.2	0.1	122.2	27	3.658	3231.89	1064.388	2128.8	6425.049
13.826444	26.8787796	0.2	0.1	122.2	27	3.658	4166.47	2435.625	4871.3	11473.34
17.283055	33.5984745	0.2	0.1	122.2	27	3.658	6479.99	4630.751	9261.5	20372.24
20.739666	40.3181694	0.2	0.1	122.2	27	3.658	10489.4	7829.968	15660	33979.28
24.196277	47.0378643	0.2	0.1	122.2	27	3.658	14517.8	12209.62	24419	51146.63
27.652888	53.7575592	0.2	0.1	122.2	27	3.658	18541.5	17942.95	35886	72370.38
6.9132221	13.4393898	0.1563	0.2	122.2	39	3.658	204.987	331.7927	663.59	1200.365
10.369833	20.1590847	0.1563	0.2	122.2	39	3.658	2272.74	1064.388	2128.8	5465.909
13.826444	26.8787796	0.1563	0.2	122.2	39	3.658	2759.73	2435.625	4871.3	10066.6
17.283055	33.5984745	0.1563	0.2	122.2	39	3.658	6352.57	4630.751	9261.5	20244.82
20.739666	40.3181694	0.1563	0.2	122.2	39	3.658	10517.2	7829.968	15660	34007.08
24.196277	47.0378643	0.1563	0.2	122.2	39	3.658	13937.2	12209.62	24419	50566.05
27.652888	53.7575592	0.1563	0.2	122.2	39	3.658	16903.1	17942.95	35886	70731.96
6.9132221	13.4393898	0.2	0.2	122.2	39	3.658	187.751	331.7927	663.59	1183.129
10.369833	20.1590847	0.2	0.2	122.2	39	3.658	2667.52	1064.388	2128.8	5860.685

For Yout=0.1; Xout=0.15625 vs 0.2

SPEED(KTS)	P 0.15625	P 0.2	Diff (hp)	Diff%
13.43939	1217.509	1180.997	-36.5122	-3.09164
20.159085	6074.754	6425.049	350.2946	5.452015
26.87878	10830.21	11473.34	643.1335	5.605459
33.598475	19781.47	20372.24	590.7747	2.8999
40.318169	33662.35	33979.28	316.9332	0.932725
47.037864	50455.77	51146.63	690.8589	1.350742
53.757559	70194.47	72370.38	2175.904	3.006623

For Yout=0.15; Xout=0.15625 vs 0.2

SPEED(KTS)	P 0.15625	P 0.2	Diff(hp)	Diff%
13.43939	1200.365	1183.129	-17.2367	-1.45688
20.159085	5465.909	5860.685	394.7765	6.736013
26.87878	10066.6	10157.42	90.81713	0.894096
33.598475	20244.82	20629.4	384.5827	1.864246
40.318169	34007.08	34154.43	147.3462	0.431412
47.037864	50566.05	51169.33	603.2852	1.178998
53.757559	70731.96	70887.65	155.6865	0.219624

For Xout=0.15625

SPEED(KTS)	P 0.1	P 0.15	Diff(hp)	Diff%
13.43939	**1217.509**	1200.365	-17.144	-1.40812
20.159085	**6074.754**	5465.909	-608.845	-10.0226

13.826444	26.8787796	0.2	0.2	122.2	39	3.658	2850.55	2435.625	4871.3	10157.42	26.87878	**10830.21**	10066.6	-763.605	-7.0507
17.283055	33.5984745	0.2	0.2	122.2	39	3.658	6737.15	4630.751	9261.5	20629.4	33.598475	**19781.47**	20244.82	463.3527	2.342358
20.739666	40.3181694	0.2	0.2	122.2	39	3.658	10664.5	7829.968	15660	34154.43	40.318169	**33662.35**	34007.08	344.7344	1.024095
24.196277	47.0378643	0.2	0.2	122.2	39	3.658	14540.5	12209.62	24419	51169.33	47.037864	**50455.77**	50566.05	110.2779	0.218564
27.652888	53.7575592	0.2	0.2	122.2	39	3.658	17058.8	17942.95	35886	70887.65	53.757559	**70194.47**	70731.96	537.4891	0.765714

B. GAS TURBINE TRADE OFF

D5=4 m.			Single Propeller	Electrical Drive		max RPM		
						SFC	SFC	
						LM1600	LM2500+	MT 30
V (kts)	**V (m/s)**	Resistance (N)	Thrust (N)	PS (kW)	SHP (HP)			
10	5.144	71961	84231.11498	554.603533	743.7355	1.55	1.7082	1.6872
15	7.716	178400	208819.0952	2098.316452	2813.888	0.8	1.18625	1.368
20	10.288	419624.7	491175.1693	6921.631115	9282.059	0.45	0.589329	0.62016
25	12.86	529373.2	619636.9544	10480.05294	14053.98	0.396	0.469755	0.39216
30	15.432	712728.5	834256.281	16773.26687	22493.32		0.39858	0.37392
35	18.004	935636.4	1095172.346	25490.28918	34183.03		0.361569	0.361152
40	20.576	1192624	1395979.062	37042.6515	49675.01			
45	23.148	1458076	1706693.448	50557.73219	67799.02			
50	25.72	1719120	2012248.223	65897.9625	88370.61			
55	28.292	1975317	2312129.533	82592.53794	110758.4			

D4=1 m.			Twin Propeller	Electrical Drive				
						LM1600	LM2500+	MT 30
V (kts)	**V (m/s)**	Resistance (N)	Thrust (N)	PS (kW)	SHP (HP)			
10	5.144	71961	84231.11498	963.1977526	1291.669	1.35	1.6133	1.5504
15	7.716	178400	208819.0952	3713.105168	4979.355	0.6	0.84461	0.88464
20	10.288	419624.7	491175.1693	12926.80375	17335.13	0.378	0.441285	0.44688
25	12.86	529373.2	619636.9544	18813.56439	25229.4		0.38909	0.39216
30	15.432	712728.5	834256.281	29675.00722	39794.83		0.36062	0.34656
35	18.004	935636.4	1095172.346	44791.50079	60066.38			
40	20.576	1192624	1395979.062	64723.21124	86795.24			
45	23.148	1458076	1706693.448	87856.25314	117817.2			

50	25.72	1719120	2012248.223	113328.619	151976.2
55	28.292	1975317	2312129.533	140375.8472	188247.1

D4=3 m.

Twin Propeller Electrical Drive

V (kts)	**V (m/s)**	Resistance (N)	Thrust (N)	PS (kW)	SHP (HP)	LM1600	LM2500+	MT 30
10	5.144	71961	84231.11498	545.6968326	731.7914	1.58	1.7082	1.69632
15	7.716	178400	208819.0952	2055.761986	2756.822	0.81	1.2337	1.39536
20	10.288	419624.7	491175.1693	6780.388464	9092.649	0.455	0.593125	0.62928
25	12.86	529373.2	619636.9544	10280.05203	13785.77	0.398	0.479245	0.49704
30	15.432	712728.5	834256.281	16433.49191	22037.67		0.401427	0.4104
35	18.004	935636.4	1095172.346	25053.72329	33597.59		0.362518	0.362976
40	20.576	1192624	1395979.062	36331.63493	48721.52			
45	23.148	1458076	1706693.448	49744.08815	66707.91			
50	25.72	1719120	2012248.223	64724.66917	86797.2			
55	28.292	1975317	2312129.533	81220.92931	108919			

D=3.0 m.

										Option 1			
							LT/ hr	LT/ hr	LT/ hr	up to 25 kts	25 to 35	35 to 42	45+
V (kts)	PS (kW)	SHP (HP)	total power	LM 1600	LM2500+	MT 30	LM 1600	LM2500+	MT 30	1 LM 1600	1 LM 2500+	1 LM1600 + LM2500	2 LM1600 + LM2500+
10	545.6968326	731.7913807	5731.791381	0.55	0.7592	0.8208	1.407359	1.942668	2.100292	1.40735949	1.94266786	1.942667864	1.942667864
15	2055.761986	2756.82176	7756.82176	0.478	0.640575	0.684	1.65525	2.218226	2.368601	1.65525036	2.21822594	2.218225937	2.218225937
20	6780.388464	9092.64914	14092.64914	0.396	0.4745	0.49248	2.491379	2.985251	3.09837	2.49137904	2.9852509	2.9852509	2.9852509
25	10280.05203	13785.77448	18785.77448	0.378	0.422305	0.43776	3.170099	3.541664	3.671277	3.17009944	3.54166361	3.541663612	3.541663612
30	16433.49191	22037.67187	27037.67187		0.3796	0.38304		4.58192	4.623442		4.58191975	4.58191975	4.58191975
35	25053.72329	33597.59057	38597.59057		0.357773	0.35112		6.164811	6.050172		6.16481061	6.164810612	6.164810612
40	36331.63493	48721.51661	53721.51661									8.656189657	8.656189657
45	49744.08815	66707.90954	71707.90954									9.334910056	11.8262891
50	64724.66917	86797.19615	91797.19615										12.5050095
55	81220.92931	108919.0416	113919.0416										

Option 2		
up to 25 kts	25 to 35	35 to 45+
1 LM 1600	2 LM 1600	2 LM1600 + LM2500+
1.40735949	1.40735949	1.407359491
1.65525036	1.65525036	1.655250358

2.49137904	2.49137904	2.491379044
3.17009944	3.17009944	3.170099443
	4.8253498	4.825349801
	6.34019889	6.340198887
		9.325449787
		11.34019889
		12.5050095

Required Fuel for 2500 NM Endurance

	Option 1 up to 25 kts	25 to 35	35 to 42	45+	
	1 LM 1600	1 LM 2500+	1 LM1600 + LM2500	2 LM1600 + LM2500+	LT
10	1.407359491	1.942667864	1.942667864	1.942667864	351.8399
15	1.655250358	2.218225937	2.218225937	2.218225937	275.8751
20	2.491379044	2.9852509	2.9852509	2.9852509	311.4224
25	3.170099443	3.541663612	3.541663612	3.541663612	317.0099
30		4.58191975	4.58191975	4.58191975	381.8266
35		6.164810612	6.164810612	6.164810612	440.3436
40			8.656189657	8.656189657	541.0119
42			9.334910056		555.6494
45				11.8262891	657.0161
47.2				12.5050095	694.7227

	Option 2 up to 25 kts	25 to 35	35 to 45+
	1 LM 1600	2 LM 1600	2 LM1600 + LM2500+
10	1.407359491	1.407359491	1.407359491
15	1.655250358	1.655250358	1.655250358
20	2.491379044	2.491379044	2.491379044
25	3.170099443	3.170099443	3.170099443
30		4.825349801	4.825349801
35		6.340198887	6.340198887
40			9.325449787
45			11.34019889
47.2			12.5050095

C. PROPELLER OPTIMIZATION

D1=3.0 m

2-propellers

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	**KT/J^2**	**etao**	**P/D**	**J**	**KT**	**KQ**	**n (rpm)**	**T (N) ***	**Q (Nm)**	**PD (kW)**	**PS (kW)**	**SHP (HP)**	**PS (kW)**	**SHP (HP)**

10	71961	84231.11	3.895088	0.3009134	0.6763	1.2	0.8544	0.2197	0.0442	91.1772	42121.96	25422.7	242.8351	495.58182	664.58604	545.6968	731.79138
15	178400	208819.1	5.842632	0.3315559	0.6667	1.1	0.7825	0.203	0.0379	149.332	104402.5	58475.7	914.8141	1866.9675	2503.6442	2055.762	2756.8217
20	419624.7	491175.2	7.790176	0.4386776	0.6347	1.1	0.7259	0.2311	0.0421	214.635	245531.6	134187	3017.273	6157.6997	8257.6099	6780.388	9092.649
25	529373.2	619637	9.737721	0.3541819	0.6597	1.1	0.7693	0.2096	0.0389	253.158	309799.6	172489	4574.623	9335.9656	12519.733	10280.05	13785.774
30	712728.5	834256.3	11.68526	0.3311509	0.6668	1.1	0.7827	0.2029	0.0379	298.589	417190.9	233783	7312.904	14924.294	20013.804	16433.49	22037.671
35	935636.4	1095172	13.63281	0.3193857	0.6704	1.1	0.7899	0.1993	0.0374	345.178	547646.3	308309	11148.91	22752.871	30512.097	25053.72	33597.590
40	1192624	1395979	15.58035	0.3116936	0.6728	1.1	0.7947	0.1968	0.037	392.107	697813.9	393584	16167.58	32995.056	44247.091	36331.63	48721.516
45	1458076	1706693	17.5279	0.3010922	0.6762	1.2	0.8543	0.2197	0.0442	410.345	853169.4	514931	22136.12	45175.754	60581.672	49744.09	66707.909
50	1719120	2012248	19.47544	0.2875481	0.681	1.2	0.8642	0.2147	0.0434	450.716	1005876	609991	28802.48	58780.567	78826.025	64724.67	86797.196
55	1975317	2312130	21.42299	0.2730586	0.6862	1.2	0.8752	0.2092	0.0425	489.556	1156308	704729	36143.31	73761.864	98916.272	81220.93	108919.04

D2=3.5 m.

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	**KT/J^2**	**etao**	**P/D**	**J**	**KT**	**KQ**	**n (rpm)**	**T (N) ***	**Q (Nm)**	**PD (kW)**	**PS (kW)**	**SHP (HP)**	**PS (kW)**	**SHP (HP)**
10	71961	84231.11	3.895088	0.2210793	0.705	1.3	0.9762	0.2107	0.0464	68.4009	42119.33	32464.1	232.6312	474.75764	636.66037	522.7668	701.04176
15	178400	208819.1	5.842632	0.2435921	0.6967	1.2	0.8992	0.197	0.0405	111.387	104431.3	75142.8	876.8522	1789.4942	2399.7508	1970.454	2642.4222
20	419624.7	491175.2	7.790176	0.3222937	0.6695	1.1	0.7881	0.2002	0.0375	169.453	245615.6	161024	2858.537	5833.748	7823.1835	6423.678	8614.2920
25	529373.2	619637	9.737721	0.2602152	0.6908	1.2	0.8854	0.204	0.0416	188.539	309831.6	221135	4367.785	8913.8474	11953.664	9815.248	13162.461
30	712728.5	834256.3	11.68526	0.2432946	0.6968	1.2	0.8995	0.1968	0.0404	222.7	417022.8	299629	6990.498	14266.322	19131.449	15708.98	21066.090
35	935636.4	1095172	13.63281	0.2346507	0.6998	1.2	0.907	0.193	0.0398	257.668	547486.5	395155	10666.74	21768.863	29192.520	23970.21	32144.573
40	1192624	1395979	15.58035	0.2289994	0.7018	1.3	0.9683	0.2147	0.0471	275.836	697953.9	535900	15485.94	31603.958	42381.598	34799.86	46667.378
45	1458076	1706693	17.5279	0.2212106	0.705	1.3	0.9761	0.2108	0.0464	307.836	853496.1	657532	21205.04	43275.588	58033.509	47651.77	63902.066
50	1719120	2012248	19.47544	0.2112599	0.709	1.3	0.9864	0.2055	0.0455	338.468	1005866	779485	27639.41	56406.949	75642.951	62111.02	83292.239
55	1975317	2312130	21.42299	0.2006145	0.7136	1.4	1.055	0.2233	0.0525	348.105	1156122	951354	34694.17	70804.423	94950.278	77964.42	104551.99

D3=4 m.

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	**KT/J^2**	**etao**	**P/D**	**J**	**KT**	**KQ**	**n (rpm)**	**T (N) ***	**Q (Nm)**	**PD (kW)**	**PS (kW)**	**SHP (HP)**	**PS (kW)**	**SHP (HP)**

10	71961	84231.11	3.895088	0.1692638	0.7279	1.4	1.0954	0.2031	0.0486	53.3379	42115.59	40311.5	225.2519	***459.69772***	616.46468	506.184	678.80381
15	178400	208819.1	5.842632	0.1865002	0.7201	1.4	1.0725	0.2145	0.0509	81.7151	104398.4	99093.3	848.3011	***1731.2267***	2321.6128	1906.295	2556.8269
20	419624.7	491175.2	7.790176	0.2467561	0.6956	1.2	0.8966	0.1983	0.0407	130.329	245506.9	201556	2751.937	***5616.1989***	7531.4454	6184.129	8293.0523
25	529373.2	619637	9.737721	0.1992273	0.7142	1.4	1.0567	0.2225	0.0524	138.228	309873.9	291908	4227.139	***8626.8149***	11568.747	9499.189	12738.620
30	712728.5	834256.3	11.68526	0.1862724	0.7202	1.4	1.0728	0.2144	0.0508	163.385	417165.3	395373	6767.395	***13811.011***	18520.867	15207.63	20393.764
35	935636.4	1095172	13.63281	0.1796544	0.7233	1.4	1.0814	0.2101	0.05	189.099	547605.6	521281	10326.79	***21075.085***	28262.149	23206.27	31120.119
40	1192624	1395979	15.58035	0.1753277	0.7252	1.4	1.0871	0.2072	0.0494	214.98	697990	665651	14991.63	***30595.16***	41028.777	33689.05	45177.755
45	1458076	1706693	17.5279	0.1693644	0.7279	1.4	1.0952	0.2032	0.0487	240.064	853572.3	818287	20579.58	***41999.148***	56321.775	46246.25	62017.236
50	1719120	2012248	19.47544	0.1617458	0.7313	1.4	1.1059	0.1978	0.0476	264.157	1006035	968398	26799.07	***54691.984***	73343.146	60222.63	80759.868
55	1975317	2312130	21.42299	0.1535954	0.7347	1.4	1.1177	0.1919	0.0465	287.505	1156188	1120640	33753.25	***68884.19***	92375.204	75850.01	101716.51

D4=2 m.

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	**KT/J^2**	**etao**	**P/D**	**J**	**KT**	**KQ**	**n (rpm)**	**T (N) ***	**Q (Nm)**	**PD (kW)**	**PS (kW)**	**SHP (HP)**	**PS (kW)**	**SHP (HP)**
10	71961	84231.11	3.895088	0.6770552	0.5794	1	0.5966	0.241	0.0395	195.864	42118.12	13806.4	283.2942	***578.15148***	775.31377	636.6162	853.71629
15	178400	208819.1	5.842632	0.7460007	0.5662	0.9	0.5377	0.2157	0.0326	325.979	104417	31562.3	1077.858	***2199.7107***	2949.8601	2422.153	3248.1605
20	419624.7	491175.2	7.790176	0.9870246	0.5273	0.9	0.4904	0.2373	0.0351	476.561	245513.4	72629.8	3626.069	***7400.1413***	9923.7512	8148.47	10927.276
25	529373.2	619637	9.737721	0.7969092	0.5573	0.9	0.5265	0.2209	0.0332	554.856	309811.4	93125.8	5413.191	***11047.329***	14814.709	12164.47	16312.826
30	712728.5	834256.3	11.68526	0.7450896	0.5663	0.9	0.5379	0.2156	0.0326	651.716	417163.8	126155	8613.251	***17578.063***	23572.567	19355.62	25956.310
35	935636.4	1095172	13.63281	0.7186177	0.5711	0.9	0.544	0.2127	0.0322	751.809	547676.7	165822	13060.32	***26653.706***	35743.202	29349.02	39357.683
40	1192624	1395979	15.58035	0.7013107	0.5744	1	0.59	0.2441	0.0399	792.221	697914.5	228159	18935.95	***38644.806***	51823.529	42552.71	57064.111
45	1458076	1706693	17.5279	0.6774575	0.5793	1	0.5965	0.241	0.0395	881.537	853178	279672	25828.17	***52710.555***	70686.006	58040.84	77834.029
50	1719120	2012248	19.47544	0.6469833	0.5857	1	0.6052	0.2369	0.039	965.405	1005833	331173	33494.09	***68355.294***	91665.943	75267.63	100935.53
55	1975317	2312130	21.42299	0.6143818	0.5927	1	0.6149	0.2323	0.0384	1045.19	1156070	382205	41850.07	***85408.306***	114534.40	94045.1	126116.53

D5=4 m. Single

Propeller

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	KT/J^2	etao	P/D	J	KT	KQ	n (rpm)	T (N) *	Q (Nm)	PD (kW)	PS (kW)	SHP (HP)	PS (kW)	SHP (HP)
10	71961	84231.11	3.895088	0.3385276	0.6645	1.1	0.7783	0.2051	0.0382	75.0692	84246.15	62763.6	493.5971	***503.67056***	675.43322	554.6035	743.73546
15	178400	208819.1	5.842632	0.3730004	0.654	1.1	0.7589	0.2148	0.0397	115.482	208797.9	154363	1867.502	***1905.6139***	2555.4699	2098.316	2813.8882
20	419624.7	491175.2	7.790176	0.4935123	0.6208	1	0.6561	0.2124	0.0357	178.102	491080.7	330162	6160.252	***6285.9711***	8429.6246	6921.631	9282.0586
25	529373.2	619637	9.737721	0.3984546	0.6464	1.1	0.7455	0.2214	0.0406	195.93	619499.3	454411	9327.247	***9517.5991***	12763.308	10480.05	14053.980
30	712728.5	834256.3	11.68526	0.3725448	0.6541	1.1	0.7591	0.2147	0.0397	230.904	834363	617125	14928.21	***15232.865***	20427.604	16773.27	22493.317
35	935636.4	1095172	13.63281	0.3593089	0.6582	1.1	0.7664	0.211	0.0391	266.822	1094929	811597	22686.36	***23149.344***	31043.776	25490.29	34183.034
40	1192624	1395979	15.58035	0.3506554	0.6608	1.1	0.7713	0.2086	0.0388	303.002	1395938	1038588	32967.96	***33640.775***	45113.015	37042.65	49675.005
45	1458076	1706693	17.5279	0.3387287	0.6645	1.1	0.7782	0.2051	0.0382	337.855	1706423	1271289	44996.38	***45914.675***	61572.501	50557.73	67799.023
50	1719120	2012248	19.47544	0.3234917	0.6692	1.1	0.7874	0.2005	0.0376	371.008	2011602	1508952	58649.19	***59846.109***	80254.940	65897.96	88370.608
55	1975317	2312130	21.42299	0.3071909	0.6742	1.1	0.7976	0.1954	0.0368	402.89	2311842	1741572	73507.36	***75007.509***	100586.70	82592.54	110758.39

D4=1 m.

														Mechanical Drive		Electrical Drive	
V (kts)	Resistance (N)	Thrust (N)	Va (m/s)	KT/J^2	etao	P/D	J	KT	KQ	n (rpm)	T (N) *	Q (Nm)	PD (kW)	PS (kW)	SHP (HP)	PS (kW)	SHP (HP)
10	71961	84231.11	3.895088	2.7082209	0.3827	0.8	0.3105	0.2611	0.0337	752.674	42115.52	5435.82	428.623	***874.74082***	1173.0465	963.1978	1291.6692
15	178400	208819.1	5.842632	2.9840028	0.3694	0.8	0.2985	0.2658	0.0342	1174.4	104377.6	13430.1	1652.332	***3372.1057***	4522.0674	3713.105	4979.3551
20	419624.7	491175.2	7.790176	3.9480982	0.3328	0.7	0.2436	0.2342	0.0273	1918.76	245499.6	28617.2	5752.428	***11739.648***	15743.124	12926.8	17335.126
25	529373.2	619637	9.737721	3.1876368	0.3604	0.8	0.2905	0.2689	0.0345	2011.23	309697	39734.3	8372.036	***17085.788***	22912.415	18813.56	25229.401
30	712728.5	834256.3	11.68526	2.9803585	0.3695	0.8	0.2986	0.2658	0.0342	2348.01	417230.8	53684.3	13205.38	***26949.751***	36140.205	29675.01	39794.833
35	935636.4	1095172	13.63281	2.8744709	0.3745	0.8	0.3031	0.264	0.034	2698.68	547427.5	70502	19932.22	***40677.996***	54550.081	44791.5	60066.381
40	1192624	1395979	15.58035	2.8052428	0.3779	0.8	0.3061	0.2628	0.0339	3053.97	697874.2	90022.6	28801.83	***58779.243***	78824.249	64723.21	86795.241
45	1458076	1706693	17.5279	2.7098299	0.3827	0.8	0.3104	0.2611	0.0337	3388.12	853388.8	110146	39096.03	***79787.822***	106997.21	87856.25	117817.15
50	1719120	2012248	19.47544	2.5879333	0.3891	0.8	0.3162	0.2588	0.0335	3695.53	1006327	130263	50431.24	***102920.89***	138019.16	113328.6	151976.15
55	1975317	2312130	21.42299	2.4575271	0.3963	0.8	0.3229	0.2562	0.0332	3980.73	1155918	149791	62467.25	***127484.19***	170959.08	140375.8	188247.07

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APPENDIX J. RCS AND IR RESULTS

A. RCS CODE

```
% plot TSSE ship RCS
% Created by Prof. David Jenn
% Modified by Lt Rodrigo Cabezas
clear
load tsse1.m   % at 1 GHz
 %load tsse10.m   % at 10 GHz
A=tsse1;
fghz=A(1,1);
El=A(:,2);
Az=A(:,3);
Sigvv=A(:,4);
Sigvh=A(:,5);
Sighv=A(:,6);
Sighh=A(:,7);
figure(1)
plot(Az,Sigvv,'b-',Az,Sighh,'r-')
legend('Vertical Pol','Horizontal Pol')
xlabel('Azimuth Angle, degrees')
ylabel('Radar Cross Section, dBsm')
title(['Frequency = ',num2str(fghz),' GHz, Elevation = ',...
       num2str(El(1)),' degrees'])
pause
Azdeg=Az*pi/180;
Azfulldeg=[Azdeg;-Azdeg];
Sigvvfull=[Sigvv;Sigvv];
polar(Azfulldeg,Sigvvfull);
legend('Vertical Pol')
xlabel('Azimuth Angle, degrees')
%ylabel('Radar Cross Section, dBsm')
%title(['Frequency = ',num2str(fghz),' GHz, Elevation = ',...
%       num2str(El(1)),' degrees'])
title('Radar Cross Section, dBsm');

pause
%Azdeg=Az*pi/180;
%Azfulldeg=[Azdeg;-Azdeg];
Sighhfull=[Sighh;Sighh];
polar(Azfulldeg,Sighhfull,'r-');
legend('Horizontal Pol')
xlabel('Azimuth Angle, degrees')
%ylabel('Radar Cross Section, dBsm')
%title(['Frequency = ',num2str(fghz),' GHz, Elevation = ',...
%       num2str(El(1)),' degrees'])
title('Radar Cross Section, dBsm');
```

B. RCS OUTPUT 1

```
Runname: tsse1
   Target facet file = trimaranIN.facet
   Target is pec
   Length unit is inch
   Target total facet surface area =  2.1825872E+07
   Facets: good=   7835  bad(thrown out)=   5349  absorb=
0
   Target geometry: facet
   [3] 1st bounce:z-buffer(FD)   Higher bounce:SBR   Edge
diffrac:none
   Ray divergence factor is set to 1
   All mono-static rcs are in dBsm & angles in deg
```

f(GHz)	inc-EL	inc-AZ	E-vert(co)	e-hori	e-vert	E-hori(co)
1.000	5.000	0.000	50.75	-6.02	-6.02	50.37
1.000	5.000	0.994	28.19	15.54	15.54	33.35
1.000	5.000	1.989	37.48	19.82	19.82	37.59
1.000	5.000	2.983	31.82	23.30	23.30	32.54
1.000	5.000	3.978	26.86	22.28	22.28	34.86
1.000	5.000	4.972	23.55	18.15	18.15	22.78
1.000	5.000	5.967	4.82	-0.62	-0.62	23.12
1.000	5.000	6.961	17.92	11.59	11.59	26.38
1.000	5.000	7.956	14.85	8.56	8.56	-5.55
1.000	5.000	8.950	27.13	9.68	9.68	21.80
1.000	5.000	9.945	12.78	13.80	13.80	17.74
1.000	5.000	10.939	17.96	11.07	11.07	28.26
1.000	5.000	11.934	20.94	10.54	10.54	25.08
1.000	5.000	12.928	11.01	10.31	10.31	22.37
1.000	5.000	13.923	19.44	10.92	10.92	21.08
1.000	5.000	14.917	18.72	13.54	13.54	22.76
1.000	5.000	15.912	10.58	0.48	0.48	22.84
1.000	5.000	16.906	19.58	10.33	10.33	23.79
1.000	5.000	17.901	19.25	7.95	7.95	21.73
1.000	5.000	18.895	14.35	6.10	6.10	20.11
1.000	5.000	19.890	16.86	4.27	4.27	24.62
1.000	5.000	20.884	23.60	4.03	4.03	25.74
1.000	5.000	21.878	25.05	4.37	4.37	22.16
1.000	5.000	22.873	11.49	5.83	5.83	27.38
1.000	5.000	23.867	21.27	17.03	17.03	27.02

1.000	5.000	24.862	17.92	4.69	4.69	26.45
1.000	5.000	25.856	17.68	-0.03	-0.03	26.60
1.000	5.000	26.851	15.51	3.60	3.60	27.77
1.000	5.000	27.845	17.56	9.38	9.38	25.41
1.000	5.000	28.840	21.22	2.03	2.03	24.12
1.000	5.000	29.834	23.77	2.13	2.13	23.11
1.000	5.000	30.829	24.76	-11.45	-11.45	22.70
1.000	5.000	31.823	20.34	-7.13	-7.13	24.51
1.000	5.000	32.818	22.01	4.25	4.25	24.81
1.000	5.000	33.812	29.19	-5.52	-5.52	29.17
1.000	5.000	34.807	22.39	1.75	1.75	29.72
1.000	5.000	35.801	28.35	2.00	2.00	25.90
1.000	5.000	36.796	15.33	-2.21	-2.21	25.51
1.000	5.000	37.790	26.40	-24.30	-24.30	27.55
1.000	5.000	38.785	23.71	-15.42	-15.42	16.00
1.000	5.000	39.779	22.92	-3.06	-3.06	24.97
1.000	5.000	40.773	-5.15	6.09	6.09	22.37
1.000	5.000	41.768	19.68	-0.64	-0.64	28.90
1.000	5.000	42.762	9.34	-5.85	-5.85	19.90
1.000	5.000	43.757	30.03	-8.60	-8.60	30.48
1.000	5.000	44.751	32.19	5.14	5.14	28.53
1.000	5.000	45.746	27.06	2.57	2.57	24.23
1.000	5.000	46.740	21.47	-0.52	-0.52	23.61
1.000	5.000	47.735	4.41	11.88	11.88	25.55
1.000	5.000	48.729	23.66	6.78	6.78	29.95
1.000	5.000	49.724	26.08	4.24	4.24	21.52
1.000	5.000	50.718	24.17	7.33	7.33	32.04
1.000	5.000	51.713	24.47	-4.15	-4.15	27.57
1.000	5.000	52.707	17.96	5.77	5.77	29.42
1.000	5.000	53.702	7.38	3.75	3.75	27.44
1.000	5.000	54.696	23.54	-7.37	-7.37	27.67
1.000	5.000	55.691	18.12	7.52	7.52	26.18
1.000	5.000	56.685	23.07	6.99	6.99	29.00
1.000	5.000	57.680	12.49	3.61	3.61	27.20
1.000	5.000	58.674	20.16	8.86	8.86	27.68
1.000	5.000	59.669	16.22	7.95	7.95	29.33
1.000	5.000	60.663	20.42	6.41	6.41	22.56
1.000	5.000	61.657	19.07	-12.03	-12.03	23.62
1.000	5.000	62.652	25.41	11.23	11.23	16.51
1.000	5.000	63.646	23.43	-6.74	-6.74	27.54
1.000	5.000	64.641	33.02	10.36	10.36	30.94
1.000	5.000	65.635	22.27	7.84	7.84	30.35
1.000	5.000	66.630	26.52	-0.96	-0.96	25.99
1.000	5.000	67.624	25.99	11.05	11.05	24.74

1.000	5.000	68.619	24.99	7.78	7.78	26.62
1.000	5.000	69.613	27.46	1.72	1.72	25.57
1.000	5.000	70.608	21.97	2.37	2.37	20.25
1.000	5.000	71.602	29.43	10.42	10.42	28.24
1.000	5.000	72.597	25.58	2.76	2.76	26.44
1.000	5.000	73.591	25.84	0.40	0.40	28.62
1.000	5.000	74.586	29.21	6.08	6.08	28.21
1.000	5.000	75.580	28.22	11.22	11.22	26.76
1.000	5.000	76.575	25.77	7.29	7.29	25.70
1.000	5.000	77.569	23.65	8.95	8.95	29.04
1.000	5.000	78.564	27.62	2.14	2.14	27.94
1.000	5.000	79.558	35.91	11.39	11.39	33.54
1.000	5.000	80.552	35.57	6.11	6.11	32.89
1.000	5.000	81.547	35.89	14.59	14.59	35.09
1.000	5.000	82.541	27.80	17.01	17.01	22.52
1.000	5.000	83.536	32.03	17.36	17.36	30.34
1.000	5.000	84.530	29.01	9.33	9.33	30.75
1.000	5.000	85.525	36.14	7.83	7.83	33.32
1.000	5.000	86.519	28.68	16.73	16.73	25.03
1.000	5.000	87.514	30.76	8.33	8.33	35.28
1.000	5.000	88.508	38.83	18.70	18.70	37.60
1.000	5.000	89.503	42.52	2.83	2.83	41.95
1.000	5.000	90.497	39.93	12.47	12.47	34.72
1.000	5.000	91.492	33.67	13.23	13.23	29.37
1.000	5.000	92.486	28.99	9.93	9.93	32.38
1.000	5.000	93.481	28.59	16.15	16.15	19.78
1.000	5.000	94.475	30.27	5.21	5.21	32.31
1.000	5.000	95.470	32.73	18.13	18.13	25.33
1.000	5.000	96.464	29.58	8.50	8.50	34.36
1.000	5.000	97.459	31.07	12.75	12.75	30.45
1.000	5.000	98.453	31.08	11.27	11.27	29.25
1.000	5.000	99.448	26.97	7.58	7.58	28.21
1.000	5.000	100.442	29.09	7.83	7.83	20.01
1.000	5.000	101.436	25.42	10.47	10.47	27.42
1.000	5.000	102.431	22.66	11.32	11.32	21.38
1.000	5.000	103.425	27.74	5.31	5.31	22.96
1.000	5.000	104.420	27.74	2.35	2.35	21.15
1.000	5.000	105.414	23.13	7.71	7.71	23.43
1.000	5.000	106.409	18.31	9.87	9.87	24.44
1.000	5.000	107.403	23.47	3.49	3.49	15.94
1.000	5.000	108.398	20.19	-0.92	-0.92	21.45
1.000	5.000	109.392	8.86	2.20	2.20	13.05
1.000	5.000	110.387	16.17	-5.04	-5.04	10.52
1.000	5.000	111.381	23.24	0.44	0.44	20.32

1.000	5.000	112.376	34.00	-6.22	-6.22	32.43
1.000	5.000	113.370	36.87	-2.91	-2.91	35.32
1.000	5.000	114.365	44.42	6.33	6.33	43.40
1.000	5.000	115.359	48.15	-1.66	-1.66	47.62
1.000	5.000	116.354	50.52	7.46	7.46	50.16
1.000	5.000	117.348	52.36	-7.51	-7.51	52.04
1.000	5.000	118.343	54.00	2.37	2.37	53.48
1.000	5.000	119.337	54.73	4.08	4.08	54.47
1.000	5.000	120.331	53.65	1.43	1.43	53.49
1.000	5.000	121.326	52.58	1.30	1.30	52.74
1.000	5.000	122.320	51.45	4.70	4.70	51.58
1.000	5.000	123.315	50.27	2.56	2.56	50.60
1.000	5.000	124.309	48.98	1.79	1.79	49.26
1.000	5.000	125.304	47.42	7.89	7.89	47.98
1.000	5.000	126.298	45.22	-1.04	-1.04	46.08
1.000	5.000	127.293	42.48	7.38	7.38	42.87
1.000	5.000	128.287	38.42	-0.73	-0.73	38.28
1.000	5.000	129.282	31.13	6.71	6.71	27.68
1.000	5.000	130.276	16.91	-3.51	-3.51	20.44
1.000	5.000	131.271	35.52	7.17	7.17	32.23
1.000	5.000	132.265	41.79	-4.77	-4.77	38.40
1.000	5.000	133.260	44.91	1.92	1.92	40.91
1.000	5.000	134.254	46.78	4.33	4.33	43.93
1.000	5.000	135.249	48.06	10.69	10.69	45.63
1.000	5.000	136.243	50.67	-1.62	-1.62	47.36
1.000	5.000	137.238	51.53	8.11	8.11	48.60
1.000	5.000	138.232	52.03	13.63	13.63	49.71
1.000	5.000	139.227	52.85	8.75	8.75	50.86
1.000	5.000	140.221	53.32	7.64	7.64	51.69
1.000	5.000	141.215	53.52	12.57	12.57	52.53
1.000	5.000	142.210	53.85	7.61	7.61	53.04
1.000	5.000	143.204	54.59	6.56	6.56	53.45
1.000	5.000	144.199	55.08	11.11	11.11	53.95
1.000	5.000	145.193	55.40	14.23	14.23	54.73
1.000	5.000	146.188	56.10	9.79	9.79	55.32
1.000	5.000	147.182	56.58	9.25	9.25	56.12
1.000	5.000	148.177	56.80	4.40	4.40	56.73
1.000	5.000	149.171	57.29	14.33	14.33	57.16
1.000	5.000	150.166	57.15	14.80	14.80	57.14
1.000	5.000	151.160	56.98	9.05	9.05	57.11
1.000	5.000	152.155	56.55	12.94	12.94	56.64
1.000	5.000	153.149	56.16	11.94	11.94	56.37
1.000	5.000	154.144	56.51	11.95	11.95	56.80
1.000	5.000	155.138	56.97	11.18	11.18	57.22

1.000	5.000	156.133	56.01	9.32	9.32	56.19
1.000	5.000	157.127	54.74	3.56	3.56	55.25
1.000	5.000	158.122	56.25	13.86	13.86	56.76
1.000	5.000	159.116	55.19	13.13	13.13	55.64
1.000	5.000	160.110	53.61	9.83	9.83	54.52
1.000	5.000	161.105	55.94	13.60	13.60	56.32
1.000	5.000	162.099	50.95	7.14	7.14	51.90
1.000	5.000	163.094	55.21	14.89	14.89	56.00
1.000	5.000	164.088	48.87	9.68	9.68	50.06
1.000	5.000	165.083	54.15	14.79	14.79	54.70
1.000	5.000	166.077	48.07	11.79	11.79	49.52
1.000	5.000	167.072	52.21	17.07	17.07	52.12
1.000	5.000	168.066	50.60	17.43	17.43	51.58
1.000	5.000	169.061	46.41	15.47	15.47	47.03
1.000	5.000	170.055	50.17	6.56	6.56	50.29
1.000	5.000	171.050	48.09	7.59	7.59	49.47
1.000	5.000	172.044	43.23	17.00	17.00	44.84
1.000	5.000	173.039	44.04	11.78	11.78	42.88
1.000	5.000	174.033	45.22	7.49	7.49	46.27
1.000	5.000	175.028	44.70	18.13	18.13	45.52
1.000	5.000	176.022	42.64	11.87	11.87	39.87
1.000	5.000	177.017	38.71	12.80	12.80	30.70
1.000	5.000	178.011	36.29	19.88	19.88	25.13
1.000	5.000	179.006	30.45	13.00	13.00	36.28
1.000	5.000	180.000	59.92	3.59	3.59	57.83

C. RCS OUTPUT 2

```
---Target geometry: ACAD facet
 ---Read target facet file.....
 -----WARNING--------
 The model has more than 80 bad(thin) facets which are
 not used in computation. RCS results may be affected.
 List of bad facets are given in RUNNAME.badfct .
 Use cifer convert[1b] to filter out and identify bad
facets.
      Total # of nodes       =        26368
      Total # of good facets =         7835
      Bad (tiny) facets      =         5349
 ---Build BSP tree.....
 ---Done building BSP tree.....
 ---First bounce by z-buffer & higher bounce by SBR.....

             *** RCS by xpatchf  v2.4d July 1996 ***

   Runname: tsse10
   Output:runname.rcs    = RCS values just as below
          runname.rcsave = Average RCS over the freq band
          runname.field  = Scattered complex field
          runname.ray    = Number of rays that hit target
          runname.cp     = RCS due to circular pol
          runname.cadwarn= Possible warning messages about
CAD
          runname.badfct = List of bad facets (not used)
          runname.bound  = Target bounding box
          runname.monitor= % of completion
   Target facet file = trimaranIN.facet
   Target is pec
   Length unit is inch
   Target total facet surface area =  2.1825872E+07
   Facets: good=   7835  bad(thrown out)=   5349  absorb=
0
   Target geometry: facet
   [3] 1st bounce:z-buffer(FD)   Higher bounce:SBR   Edge
diffrac:none
   Ray divergence factor is set to 1
   All mono-static rcs are in dBsm & angles in deg

                          E-                    E-
     f(GHz) inc-EL inc-AZ vert(co) e-hori e-vert hori(co)
     10.000 5.000  0.000  65.59    17.72  17.72  64.93
```

10.000	5.000	0.497	31.79	17.93	17.93	35.81
10.000	5.000	0.994	37.95	22.32	22.32	38.11
10.000	5.000	1.492	29.57	18.38	18.38	31.40
10.000	5.000	1.989	21.38	13.07	13.07	28.51
10.000	5.000	2.486	12.00	11.76	11.76	26.75
10.000	5.000	2.983	27.28	10.97	10.97	27.34
10.000	5.000	3.481	34.78	17.44	17.44	29.60
10.000	5.000	3.978	27.72	14.58	14.58	31.25
10.000	5.000	4.475	29.00	25.62	25.62	22.13
10.000	5.000	4.972	38.33	18.82	18.82	35.92
10.000	5.000	5.470	23.70	19.32	19.32	33.75
10.000	5.000	5.967	27.36	18.86	18.86	25.86
10.000	5.000	6.464	36.39	20.57	20.57	24.77
10.000	5.000	6.961	33.26	20.20	20.20	35.69
10.000	5.000	7.459	34.70	21.58	21.58	30.19
10.000	5.000	7.956	32.18	20.24	20.24	30.11
10.000	5.000	8.453	34.98	19.92	19.92	29.35
10.000	5.000	8.950	16.81	17.16	17.16	32.64
10.000	5.000	9.448	36.46	23.09	23.09	29.58
10.000	5.000	9.945	31.23	19.44	19.44	30.27
10.000	5.000	10.442	22.28	18.50	18.50	37.25
10.000	5.000	10.939	16.87	6.48	6.48	38.17
10.000	5.000	11.436	23.60	14.52	14.52	38.79
10.000	5.000	11.934	35.67	14.12	14.12	32.81
10.000	5.000	12.431	36.73	20.34	20.34	29.52
10.000	5.000	12.928	35.55	15.62	15.62	34.02
10.000	5.000	13.425	27.28	11.97	11.97	37.95
10.000	5.000	13.923	36.78	19.01	19.01	34.12
10.000	5.000	14.000	30.05	20.43	20.43	37.13
10.000	5.000	15.006	34.26	-0.75	-0.75	40.52
10.000	5.000	16.012	35.68	14.87	14.87	22.82
10.000	5.000	17.018	39.04	11.99	11.99	38.87
10.000	5.000	18.024	39.25	5.47	5.47	34.26
10.000	5.000	19.030	32.33	7.62	7.62	36.91
10.000	5.000	20.036	39.92	-12.71	-12.71	40.91
10.000	5.000	21.042	31.02	-5.47	-5.47	32.52
10.000	5.000	22.048	40.63	0.80	0.80	40.93
10.000	5.000	23.055	42.48	6.23	6.23	42.70
10.000	5.000	24.061	33.81	7.89	7.89	32.61
10.000	5.000	25.067	39.16	5.88	5.88	41.18
10.000	5.000	26.073	38.27	-3.02	-3.02	35.78
10.000	5.000	27.079	38.38	6.42	6.42	38.54
10.000	5.000	28.085	43.72	-10.62	-10.62	44.37
10.000	5.000	29.091	41.67	10.31	10.31	39.54

10.000	5.000	30.097	39.37	12.31	12.31	41.52
10.000	5.000	31.103	42.78	10.36	10.36	42.84
10.000	5.000	32.109	36.90	6.30	6.30	34.64
10.000	5.000	33.115	38.36	13.32	13.32	36.63
10.000	5.000	34.121	41.23	7.50	7.50	40.18
10.000	5.000	35.127	30.04	3.25	3.25	29.25
10.000	5.000	36.133	43.40	-1.44	-1.44	43.25
10.000	5.000	37.139	43.44	-1.12	-1.12	42.84
10.000	5.000	38.145	38.18	-6.01	-6.01	38.62
10.000	5.000	39.152	42.76	-4.38	-4.38	43.83
10.000	5.000	40.158	43.66	0.59	0.59	44.11
10.000	5.000	41.164	38.88	3.24	3.24	39.42
10.000	5.000	42.170	41.11	10.33	10.33	41.34
10.000	5.000	43.176	42.94	10.29	10.29	41.85
10.000	5.000	44.182	39.30	12.98	12.98	37.66

D. IR WEATHER FILE

TIME	AIRT	SOLAR	WIND	HUMID	CLOUD	LWIR	WINDIR
0610	18.800	0.000	1.299	78.833	5.000	0.000	155.808
0615	18.900	2.000	0.828	78.250	6.000	0.000	150.912
0620	18.700	4.000	0.903	77.667	6.000	0.000	151.920
0625	18.600	6.000	1.532	77.083	6.000	0.000	180.216
0630	18.700	10.000	1.055	76.500	7.000	0.000	169.704
0635	18.400	20.000	1.630	75.917	7.000	0.000	162.720
0640	18.400	24.000	1.016	75.333	7.000	0.000	171.936
0645	18.400	34.000	1.390	74.750	8.000	0.000	159.408
0650	18.500	50.000	1.131	74.167	8.000	0.000	149.184
0655	19.700	116.000	2.397	73.583	8.000	0.000	137.088
0700	18.800	94.000	1.633	73.000	7.000	0.000	163.512
0705	18.500	34.000	0.467	72.583	7.000	0.000	182.232
0710	18.400	26.000	1.758	72.167	7.000	0.000	147.456
0715	18.000	14.000	2.811	71.750	6.000	0.000	161.280
0720	17.800	16.000	1.647	71.333	6.000	0.000	142.056
0725	17.800	14.000	0.659	70.917	6.000	0.000	170.928
0730	17.900	12.000	3.116	70.500	5.000	0.000	157.248
0735	17.800	10.000	1.309	70.083	5.000	0.000	214.848
0740	18.000	10.000	1.679	69.667	4.000	0.000	148.464
0745	18.200	28.000	2.012	69.250	4.000	0.000	166.320
0750	18.500	70.000	2.727	68.833	4.000	0.000	152.496
0755	18.800	160.000	2.131	68.417	4.000	0.000	168.480
0800	19.500	282.000	2.072	68.000	4.000	0.000	156.528
0805	20.000	306.000	2.419	67.917	3.000	0.000	153.792
0810	19.700	260.000	1.402	67.833	3.000	0.000	144.432
0815	20.000	294.000	1.209	67.750	3.000	0.000	176.544
0820	19.900	308.000	2.516	67.667	3.000	0.000	172.368
0825	19.900	310.000	1.515	67.583	3.000	0.000	182.232
0830	19.800	292.000	1.483	67.500	3.000	0.000	147.528
0835	19.900	286.000	2.031	67.417	3.000	0.000	151.776
0840	20.200	354.000	1.293	67.333	2.000	0.000	237.168
0845	20.300	352.000	1.631	67.250	2.000	0.000	173.448
0850	20.100	368.000	1.807	67.167	2.000	0.000	159.480
0855	20.100	384.000	1.446	67.083	2.000	0.000	140.472
0900	20.300	400.000	1.967	67.000	2.000	0.000	148.464
0905	20.100	398.000	1.504	66.917	2.000	0.000	164.160
0910	20.100	414.000	1.030	66.833	2.000	0.000	160.416
0915	20.100	430.000	2.862	66.750	2.000	0.000	189.936
0920	20.100	440.000	1.435	66.667	2.000	0.000	159.048

0925	20.100	450.000	1.752	66.583	1.000	0.000	132.552
0930	20.400	462.000	2.231	66.500	1.000	0.000	125.352
0935	20.300	480.000	0.707	66.417	1.000	0.000	172.008
0940	20.400	510.000	2.117	66.333	1.000	0.000	160.344
0945	20.300	520.000	1.520	66.250	1.000	0.000	163.368
0950	20.400	526.000	2.134	66.167	1.000	0.000	169.992
0955	20.200	542.000	1.522	66.083	1.000	0.000	169.272
1000	20.300	554.000	3.271	66.000	1.000	0.000	167.328
1005	20.800	564.000	1.010	66.083	1.000	0.000	159.984
1010	20.600	578.000	1.016	66.167	1.000	0.000	124.344
1015	20.800	590.000	1.779	66.250	1.000	0.000	170.208
1020	20.400	600.000	2.040	66.333	1.000	0.000	154.944
1025	20.600	606.000	1.791	66.417	0.000	0.000	168.264
1030	20.400	624.000	3.125	66.500	0.000	0.000	169.920
1035	20.600	632.000	1.561	66.583	0.000	0.000	175.824
1040	20.600	644.000	2.837	66.667	0.000	0.000	174.888
1045	21.200	650.000	0.753	66.750	0.000	0.000	186.840
1050	20.700	658.000	0.916	66.833	0.000	0.000	192.816
1055	21.200	672.000	1.224	66.917	0.000	0.000	163.440
1100	20.400	690.000	1.726	67.000	0.000	0.000	158.688
1105	21.100	700.000	1.956	66.917	0.000	0.000	171.936
1110	21.100	708.000	1.387	66.833	0.000	0.000	198.792
1115	21.600	710.000	0.884	66.750	0.000	0.000	192.672
1120	21.400	722.000	1.577	66.667	0.000	0.000	159.552
1125	21.800	734.000	1.431	66.583	0.000	0.000	211.824
1130	21.200	740.000	2.232	66.500	0.000	0.000	170.352
1135	20.700	748.000	2.599	66.417	0.000	0.000	188.856
1140	21.400	762.000	0.714	66.333	0.000	0.000	203.760
1145	21.300	770.000	2.549	66.250	0.000	0.000	186.912
1150	21.500	772.000	0.992	66.167	0.000	0.000	155.232
1155	21.100	782.000	1.933	66.083	0.000	0.000	207.144
1200	21.500	790.000	1.344	66.000	0.000	0.000	201.384
1205	21.000	798.000	2.328	65.750	0.000	0.000	176.976
1210	21.700	802.000	1.727	65.500	0.000	0.000	189.216
1215	21.200	810.000	2.532	65.250	0.000	0.000	176.472
1220	21.300	820.000	1.106	65.000	0.000	0.000	152.496
1225	22.400	824.000	1.661	64.750	0.000	0.000	210.888
1230	21.500	830.000	2.452	64.500	0.000	0.000	190.584
1235	21.600	834.000	1.366	64.250	0.000	0.000	188.280
1240	21.900	840.000	1.851	64.000	0.000	0.000	219.600
1245	22.100	844.000	1.342	63.750	0.000	0.000	192.960
1250	21.800	848.000	2.102	63.500	0.000	0.000	153.576
1255	22.200	850.000	3.257	63.250	0.000	0.000	157.536
1300	22.200	850.000	1.933	63.000	0.000	0.000	161.136

1305	21.900	856.000	1.944	63.167	0.000	0.000	148.248
1310	21.800	862.000	2.694	63.333	0.000	0.000	184.176
1315	21.700	868.000	1.807	63.500	0.000	0.000	167.544
1320	21.800	872.000	1.839	63.667	0.000	0.000	172.584
1325	22.200	874.000	1.284	63.833	0.000	0.000	163.656
1330	21.900	876.000	2.331	64.000	0.000	0.000	189.936
1335	22.300	880.000	1.232	64.167	0.000	0.000	168.408
1340	22.400	880.000	1.541	64.333	0.000	0.000	163.728
1345	23.100	880.000	1.550	64.500	0.000	0.000	198.936
1350	22.800	880.000	1.375	64.667	0.000	0.000	170.928
1355	22.500	880.000	2.155	64.833	0.000	0.000	167.544
1400	22.700	880.000	1.243	65.000	0.000	0.000	171.072
1405	23.100	880.000	1.073	65.833	0.000	0.000	186.192
1410	22.800	880.000	1.734	66.667	0.000	0.000	153.792
1415	23.300	880.000	3.066	67.500	0.000	0.000	198.288
1420	22.900	880.000	2.306	68.333	0.000	0.000	147.168
1425	22.900	878.000	1.891	69.167	0.000	0.000	143.136
1430	23.900	874.000	0.649	70.000	0.000	0.000	139.464
1435	23.800	866.000	1.251	70.833	0.000	0.000	151.920
1440	23.600	860.000	1.179	71.667	0.000	0.000	201.744
1445	23.500	860.000	1.489	72.500	0.000	0.000	166.104
1450	23.400	860.000	1.439	73.333	0.000	0.000	189.072
1455	23.000	852.000	2.124	74.167	0.000	0.000	191.520
1500	23.300	850.000	1.720	75.000	0.000	0.000	196.344
1505	23.600	850.000	1.198	73.833	0.000	0.000	157.032
1510	23.800	842.000	1.814	72.667	0.000	0.000	227.088
1515	22.900	838.000	3.068	71.500	0.000	0.000	163.800
1520	23.300	832.000	0.935	70.333	0.000	0.000	188.784
1525	23.300	828.000	2.096	69.167	0.000	0.000	144.936
1530	23.700	820.000	0.808	68.000	0.000	0.000	166.032
1535	23.200	814.000	1.257	66.833	0.000	0.000	175.896
1540	23.300	808.000	1.646	65.667	0.000	0.000	162.648
1545	23.800	802.000	1.209	64.500	0.000	0.000	199.008
1550	23.700	798.000	0.746	63.333	0.000	0.000	190.584
1555	23.900	788.000	3.028	62.167	0.000	0.000	190.368
1600	23.700	780.000	2.494	61.000	0.000	0.000	164.880
1605	24.000	772.000	1.487	59.000	0.000	0.000	186.984
1610	23.800	766.000	1.950	57.000	0.000	0.000	176.328
1615	24.100	758.000	2.375	55.000	0.000	0.000	176.472
1620	24.200	750.000	0.931	53.000	0.000	0.000	156.672
1625	24.200	744.000	1.568	51.000	0.000	0.000	187.560
1630	24.300	738.000	1.750	49.000	0.000	0.000	218.592
1635	24.700	714.000	1.078	47.000	0.000	0.000	154.944
1640	24.400	708.000	1.027	45.000	0.000	0.000	158.256

1645	24.400	700.000	1.411	43.000	0.000	0.000	151.488
1650	24.600	692.000	0.788	41.000	0.000	0.000	192.240
1655	24.800	684.000	1.224	39.000	0.000	0.000	220.176
1700	25.000	674.000	1.247	37.000	0.000	0.000	156.744
1705	24.400	662.000	1.431	37.083	0.000	0.000	193.032
1710	24.000	650.000	2.481	37.167	0.000	0.000	183.456
1715	24.000	640.000	1.322	37.250	0.000	0.000	163.080
1720	24.600	626.000	2.553	37.333	0.000	0.000	164.232
1725	24.300	618.000	1.084	37.417	0.000	0.000	177.480
1730	24.400	604.000	0.714	37.500	0.000	0.000	173.592
1735	24.200	594.000	1.370	37.583	0.000	0.000	215.928
1740	24.700	582.000	0.757	37.667	0.000	0.000	139.176
1745	24.700	568.000	0.693	37.750	0.000	0.000	184.608
1750	24.800	552.000	1.349	37.833	0.000	0.000	180.360
1755	24.600	542.000	1.225	37.917	0.000	0.000	194.112
1800	24.400	530.000	0.968	38.000	0.000	0.000	196.344
1805	24.200	516.000	1.418	38.417	0.000	0.000	194.256
1810	25.100	502.000	0.554	38.833	0.000	0.000	179.784
1815	24.300	488.000	0.860	39.250	0.000	0.000	176.976
1820	24.300	474.000	0.981	39.667	0.000	0.000	168.840
1825	24.700	460.000	0.941	40.083	0.000	0.000	204.768
1830	24.400	444.000	0.824	40.500	0.000	0.000	201.168
1835	24.100	434.000	1.095	40.917	0.000	0.000	223.200
1840	23.900	418.000	0.870	41.333	0.000	0.000	185.760
1845	23.800	400.000	0.973	41.750	0.000	0.000	201.528
1850	23.700	386.000	1.339	42.167	0.000	0.000	178.632
1855	23.900	374.000	1.111	42.583	0.000	0.000	190.152
1900	23.900	358.000	1.211	43.000	0.000	0.000	209.448
1905	23.900	344.000	1.674	43.000	0.000	0.000	164.952
1910	23.900	328.000	0.624	43.000	0.000	0.000	178.200
1915	23.700	316.000	1.223	43.000	0.000	0.000	212.472
1920	23.300	300.000	0.753	43.000	0.000	0.000	199.440
1925	23.600	286.000	0.791	43.000	0.000	0.000	181.080
1930	23.400	272.000	0.482	43.000	0.000	0.000	183.960
1935	23.300	260.000	0.622	43.000	0.000	0.000	140.904
1940	23.700	240.000	0.626	43.000	0.000	0.000	181.224
1945	23.400	230.000	0.505	43.000	0.000	0.000	167.544
1950	23.400	216.000	0.303	43.000	0.000	0.000	204.912
1955	23.000	202.000	0.783	43.000	0.000	0.000	186.768
2000	22.400	184.000	0.200	43.000	0.000	0.000	198.648
2005	22.000	176.000	0.337	44.167	0.000	0.000	216.360
2010	21.900	168.000	0.200	45.333	0.000	0.000	141.912
2015	21.800	154.000	0.202	46.500	0.000	0.000	186.768
2020	21.600	144.000	0.388	47.667	0.000	0.000	207.288

2025	21.500	126.000	0.290	48.833	1.000	0.000	236.736
2030	21.400	120.000	0.201	50.000	1.000	0.000	174.024
2035	21.400	104.000	0.238	51.167	1.000	0.000	190.728
2040	21.300	84.000	0.201	52.333	1.000	0.000	191.016
2045	20.900	78.000	0.200	53.500	1.000	0.000	176.472
2050	20.700	66.000	0.200	54.667	1.000	0.000	180.432
2055	20.100	54.000	0.256	55.833	1.000	0.000	185.184
2100	19.800	46.000	0.225	57.000	1.000	0.000	186.768
2105	19.100	36.000	0.200	57.259	1.000	0.000	183.816
2110	18.400	24.000	0.200	57.519	1.000	0.000	186.768
2115	17.200	20.000	0.201	57.778	1.000	0.000	166.464
2120	16.400	18.000	0.200	58.037	1.000	0.000	178.056
2125	16.000	16.000	0.200	58.296	1.000	0.000	182.880
2130	15.500	10.000	0.200	58.556	1.000	0.000	174.024
2135	15.000	10.000	0.200	58.815	1.000	0.000	167.832
2140	14.800	10.000	0.200	59.074	1.000	0.000	167.328
2145	14.600	6.000	0.200	59.333	1.000	0.000	161.352
2150	14.400	6.000	0.200	59.593	1.000	0.000	134.568
2155	14.300	8.000	0.200	59.852	1.000	0.000	119.088
2200	13.900	0.000	0.200	60.111	1.000	0.000	119.088
2205	13.900	2.000	0.201	60.370	1.000	0.000	119.880
2210	13.800	0.000	0.200	60.630	1.000	0.000	119.664
2215	13.500	0.000	0.200	60.889	1.000	0.000	135.576
2220	13.400	0.000	0.200	61.148	1.000	0.000	122.616
2225	13.500	2.000	0.199	61.407	1.000	0.000	123.624
2230	13.600	2.000	0.200	61.667	1.000	0.000	123.624
2235	13.400	2.000	0.201	61.926	1.000	0.000	123.192
2240	13.400	0.000	0.201	62.185	1.000	0.000	122.616
2245	13.400	0.000	0.200	62.444	1.000	0.000	122.832
2250	13.500	4.000	0.200	62.704	1.000	0.000	129.024
2255	13.500	2.000	0.200	62.963	1.000	0.000	120.888
2300	13.400	0.000	0.200	63.222	1.000	0.000	120.888
2305	13.500	0.000	0.200	63.481	1.000	0.000	138.888
2310	13.400	0.000	0.200	63.741	1.000	0.000	138.456
2315	13.400	4.000	0.200	64.000	1.000	0.000	139.752
2320	13.300	0.000	0.200	64.259	1.000	0.000	139.968
2325	13.200	2.000	0.200	64.519	1.000	0.000	138.960
2330	13.300	0.000	0.200	64.778	1.000	0.000	141.696
2335	13.200	2.000	0.200	65.037	1.000	0.000	121.608
2340	13.200	0.000	0.200	65.296	1.000	0.000	126.000
2345	13.000	0.000	0.200	65.556	1.000	0.000	146.880
2350	13.100	0.000	0.250	65.815	1.000	0.000	146.016
2355	13.000	0.000	0.200	66.074	1.000	0.000	146.880
0000	13.100	0.000	0.200	66.333	1.000	0.000	155.448

0004	13.100	2.000	0.200	66.541	1.000	0.000	149.616
0009	13.300	0.000	0.264	66.800	1.000	0.000	158.472
0014	13.200	0.000	0.200	67.059	1.000	0.000	154.512
0019	13.300	0.000	0.200	67.319	1.000	0.000	176.760
0024	13.700	0.000	0.200	67.578	1.000	0.000	166.968
0029	14.300	0.000	0.200	67.837	1.000	0.000	172.584
0034	14.400	4.000	0.704	68.096	1.000	0.000	175.752
0039	14.600	0.000	0.200	68.356	1.000	0.000	180.648
0044	14.600	0.000	0.336	68.615	1.000	0.000	176.976
0049	14.700	0.000	0.227	68.874	1.000	0.000	184.248
0054	14.600	0.000	0.302	69.133	1.000	0.000	180.144
0059	14.800	0.000	0.218	69.393	0.000	0.000	183.600
0104	14.500	0.000	0.252	69.652	0.000	0.000	177.192
0109	14.500	0.000	0.205	69.911	0.000	0.000	170.208
0114	14.200	2.000	0.200	70.170	0.000	0.000	187.488
0119	14.600	2.000	0.421	70.430	0.000	0.000	191.664
0124	14.500	0.000	0.290	70.689	0.000	0.000	225.792
0129	14.400	0.000	0.369	70.948	0.000	0.000	214.848
0134	13.900	0.000	0.199	71.207	0.000	0.000	187.704
0139	14.600	0.000	0.266	71.467	0.000	0.000	188.208
0144	14.600	0.000	0.291	71.726	0.000	0.000	182.808
0149	14.600	0.000	0.531	71.985	0.000	0.000	182.880
0154	14.800	0.000	0.887	72.244	0.000	0.000	190.080
0159	14.800	0.000	0.415	72.504	0.000	0.000	206.424
0204	14.900	0.000	0.498	72.763	0.000	0.000	187.200
0209	14.800	0.000	0.304	73.022	0.000	0.000	206.784
0214	14.800	4.000	0.514	73.281	0.000	0.000	195.336
0219	14.600	0.000	0.855	73.541	0.000	0.000	193.248
0224	14.200	0.000	0.344	73.800	0.000	0.000	193.896
0229	13.800	0.000	0.747	74.059	0.000	0.000	159.768
0234	13.300	2.000	0.213	74.319	0.000	0.000	167.760
0239	13.300	0.000	0.200	74.578	0.000	0.000	178.128
0244	13.200	2.000	0.529	74.837	0.000	0.000	168.768
0249	13.300	0.000	0.938	75.096	0.000	0.000	173.160
0254	13.600	4.000	0.423	75.356	0.000	0.000	165.024
0259	13.800	0.000	0.572	75.615	0.000	0.000	175.752
0304	13.900	0.000	0.599	75.874	0.000	0.000	188.640
0309	13.300	0.000	0.280	76.133	0.000	0.000	201.168
0314	13.300	0.000	0.352	76.393	0.000	0.000	179.136
0319	13.300	0.000	0.640	76.652	0.000	0.000	179.784
0324	13.000	4.000	1.227	76.911	0.000	0.000	162.072
0329	13.300	0.000	0.761	77.170	0.000	0.000	175.248
0334	13.300	0.000	0.627	77.430	0.000	0.000	187.272
0339	13.200	0.000	0.689	77.689	0.000	0.000	169.632

0344	13.300	0.000	1.235	77.948	0.000	0.000	191.304
0349	13.900	0.000	0.551	78.207	0.000	0.000	193.392
0354	13.900	0.000	1.011	78.467	0.000	0.000	194.688
0359	14.100	0.000	0.877	78.726	0.000	0.000	207.648
0404	13.800	0.000	1.102	78.985	0.000	0.000	191.880
0409	13.200	2.000	0.341	79.244	0.000	0.000	182.304
0414	12.600	0.000	0.397	79.504	0.000	0.000	192.168
0419	12.600	0.000	0.595	79.763	0.000	0.000	194.040
0424	12.400	0.000	0.432	80.022	0.000	0.000	180.144
0429	12.300	0.000	0.911	80.281	0.000	0.000	181.728
0434	12.200	0.000	0.573	80.541	0.000	0.000	170.928
0439	12.100	4.000	0.283	80.800	0.000	0.000	190.728
0444	12.100	0.000	0.259	81.059	0.000	0.000	191.016
0449	12.400	0.000	0.323	81.318	0.000	0.000	189.360
0454	12.300	0.000	0.904	81.578	0.000	0.000	183.384
0459	11.700	0.000	0.980	81.837	0.000	0.000	187.560
0504	11.700	0.000	0.464	82.096	0.000	0.000	183.816
0509	12.000	0.000	0.601	82.356	0.000	0.000	184.464
0514	12.400	0.000	0.474	82.615	0.000	0.000	179.352
0519	12.300	0.000	0.640	82.874	0.000	0.000	190.800
0524	11.800	0.000	0.254	83.133	0.000	0.000	179.856
0529	11.900	0.000	0.553	83.393	0.000	0.000	180.576
0534	12.100	0.000	0.984	83.652	0.000	0.000	169.632
0539	12.000	0.000	1.041	83.911	0.000	0.000	168.984
0544	11.900	4.000	0.271	84.170	0.000	0.000	174.024
0549	11.900	2.000	0.938	84.430	0.000	0.000	166.752
0554	12.200	4.000	0.423	84.689	0.000	0.000	163.656
0559	12.300	2.000	0.812	84.948	0.000	0.000	164.016
0604	12.300	0.000	0.556	85.207	0.000	0.000	165.384
0609	12.300	10.000	0.699	85.467	0.000	0.000	166.392
0614	12.200	10.000	0.492	85.726	0.000	0.000	169.272

E. TEMPERATURE CALCULATIONS SAMPLE

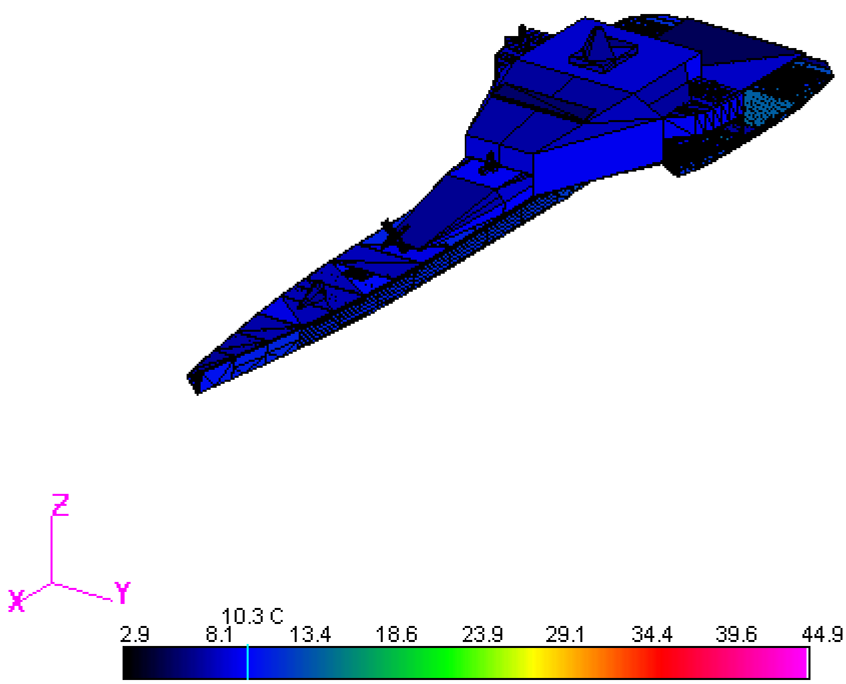

Figure 104. Temperature Model Simulation Output

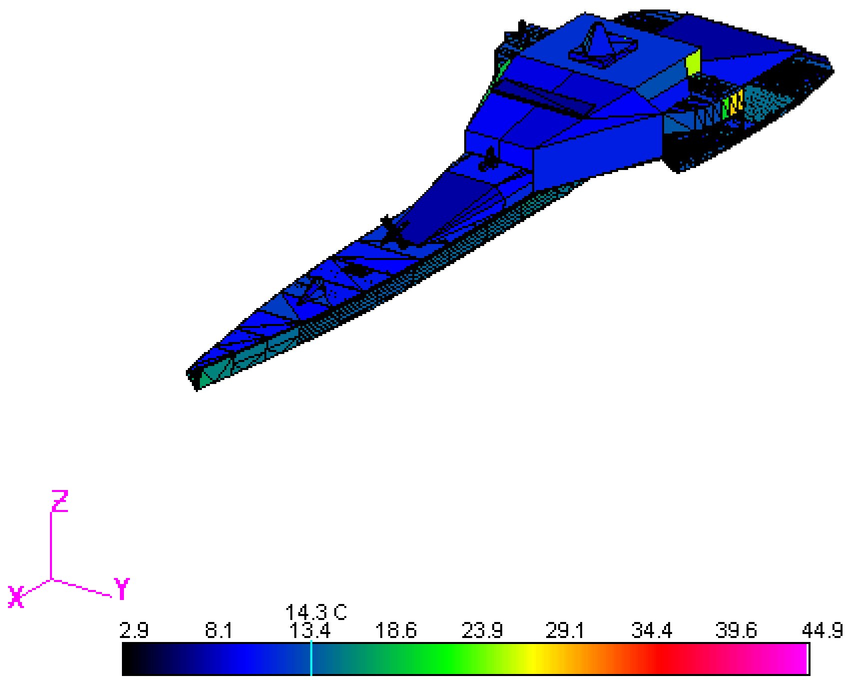

Figure 105. Temperature Model Simulation Output

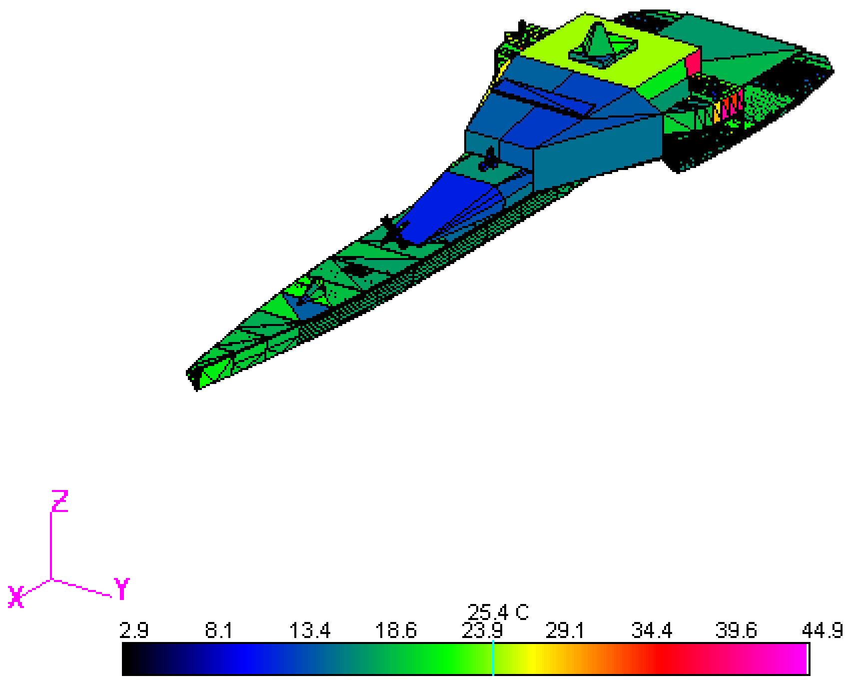

Figure 106. Temperature Model Simulation Output

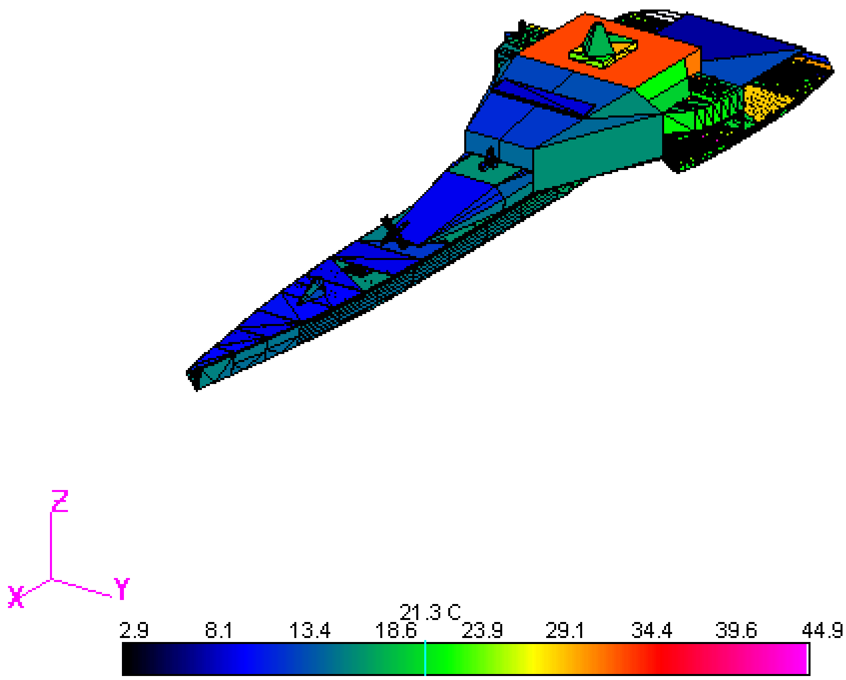

Figure 107. Temperature Model Simulation Output

F. SIGNATURE PREDICTION EXAMPLE

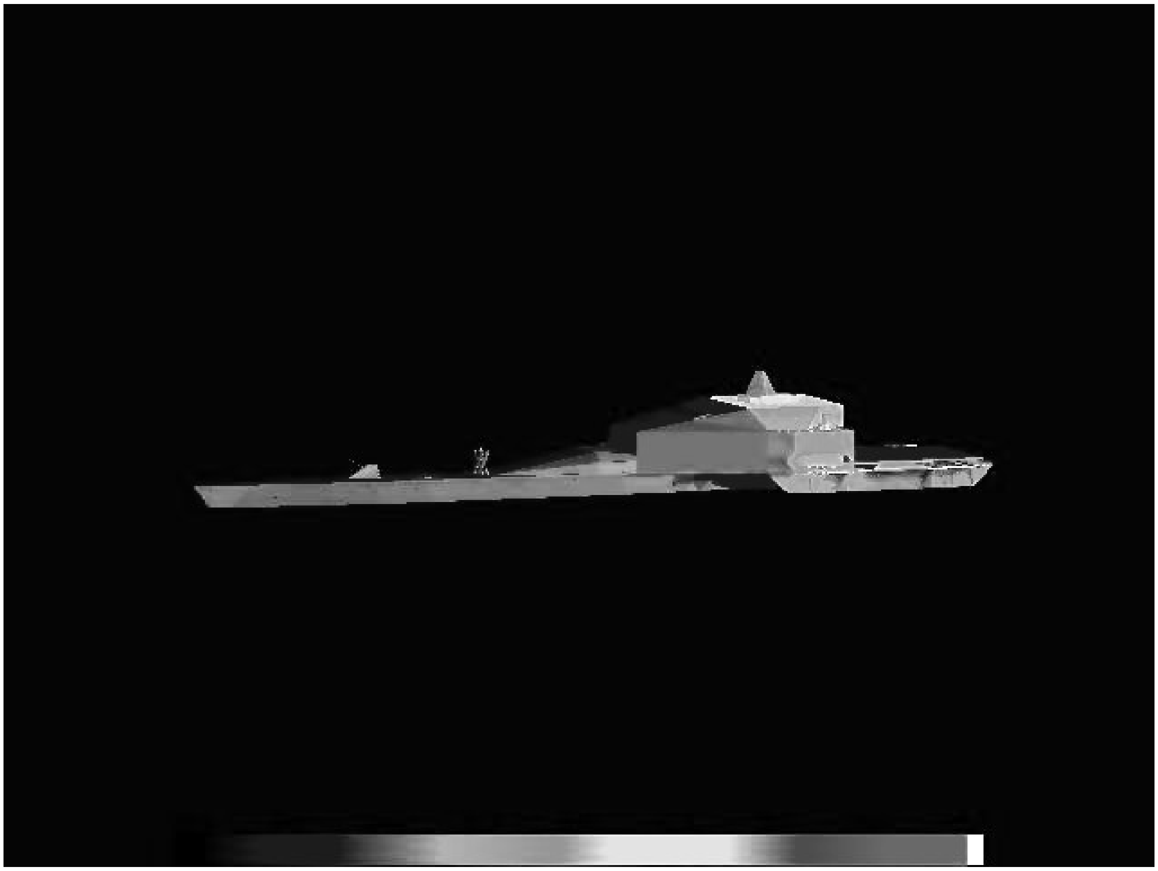

Figure 108. IR Signature Model Output

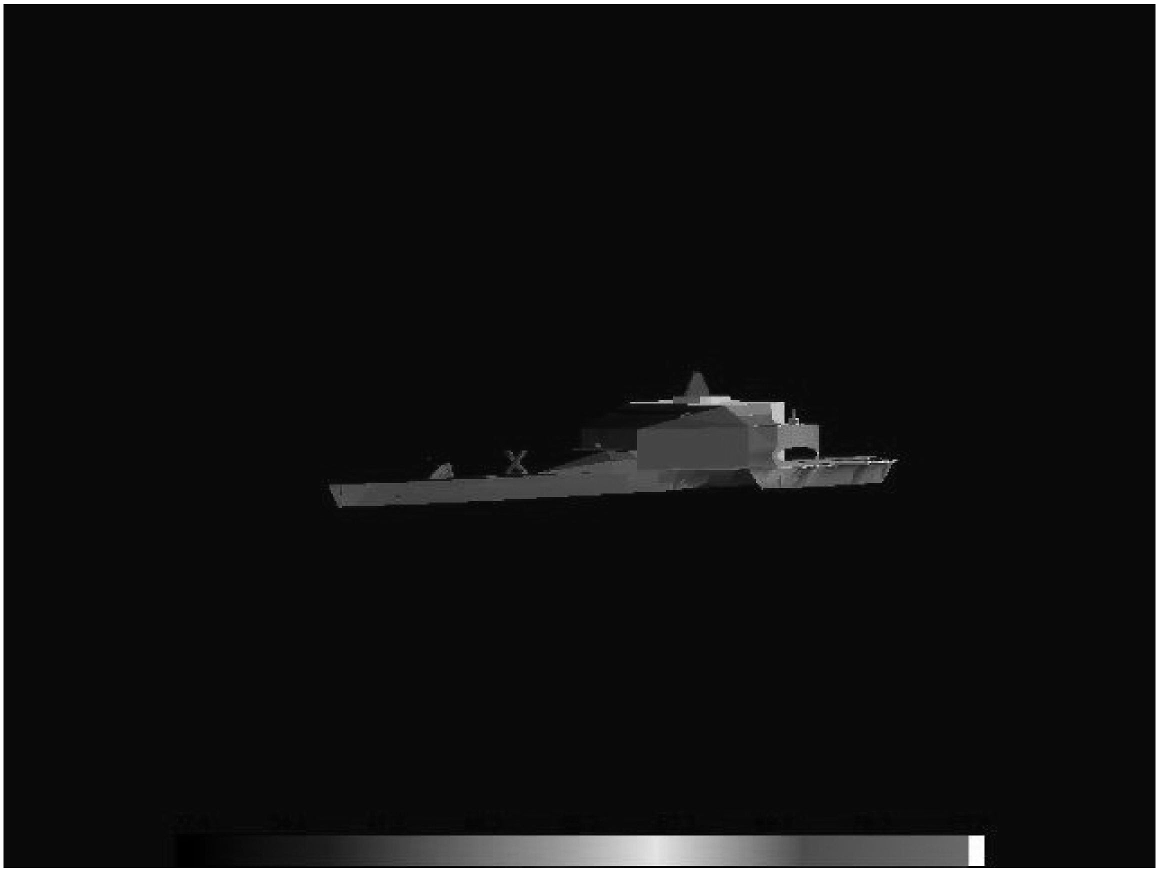

Figure 109. IR Signature Model Output

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