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TECHNICAL REPORT

Sea TENTACLE:
Track, Engage, & Neutralize Threats - Asymmetric & Conventional - in the Littoral Environment

by

Student Members

LT Brian C. Black, USN
LCDR Laura H. Bollock, USN
LTjg Sinene Bouabid, Tunisian Navy
LCDR Michael A. Glova, USN
LT Jason S. Hall, USN
LCDR Glynn M. Harden, USN
LCDR Curtis J. Hickle, USN
LTjg Selcuk Hosoglu, Turkish Navy
LT Peter Majewicz, USN
LT Kenneth R. Mullenix, USN
LT Andrew B. Nozik, USN
LCDR Stephen F. Sarar, USN
LTJG Hakan Ucar, Turkish Navy

Faculty Members

Fotis Papoulias
William Solitario
Gregory Miller
J. Michael Green
Robert Ashton

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13. ABSTRACT (maximum 200 words)

Sea TENTACLE is a proposed afloat platform whose primary mission is to utilize the state-of-the-art technology of unmanned vehicles to monitor and neutralize all subsurface enemy threats in the littorals. This mission can be specified further as anti-submarine warfare, mine warfare and maritime surveillance. The design philosophy of Sea TENTACLE embodies the ideal of providing a multi-mission capable sea frame extending network-centric warfare into the littorals.

The design goals of the TSSE team were first to develop a platform to deploy, recover, and maintain unmanned vehicles (e.g. UUVs, USVs, UAVs) and second to enable the ship to act as an afloat network operations center for distributed assets. Allowing all units to work together seamlessly to conduct focused missions in the littorals makes the Sea TENTACLE a critical component within the network-centric environment.
The versatility of its cargo hold and modular design allows Sea TENTACLE to be outfitted dynamically to complete a variety of secondary missions including humanitarian aid, salvage and special operations support.
Sea TENTACLE's combat management and operations system will employ the Enterprise Architecture design enabling C4ISR capabilities that will meet emerging network centric warfare needs.

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The 2005 Total Ship Systems Engineering Team would like to thank our families and friends for their understanding and support throughout the Sea TENTACLE project. We also would like to extend our appreciation to Professor Fotis Papoulias, Professor J. Mike Green, Professor William Solitario, Professor Robert Ashton, and Professor Gregory Miller for their assistance and support throughout the TSSE curriculum and design project.

Several special acknowledgements are due. First, we wish to thank David DeMartino and Steven Albertson of NAVSEA Panama City for providing detailed information for the Sea Predator UUV system, which became the backbone of our payload design. Next we thank Professor David Jenn for his invaluable assistance during the RCS evaluation of our design. We also thank Jeffrey Koleser for providing detailed ships work breakdown structure information. Last, but not least, we thank Ana Tam for designing our logo.

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I. INTRODUCTION

The 2005 Total Ships Systems Engineering (TSSE) Team operated as part of an integrated project with the Systems Engineering Analysis (SEA) Cohort number 8 (SEA-8). Initial overall tasking was generated by faculty members of the Meyers Institute of Systems Engineering at the Naval Postgraduate School in Monterey, CA and concerned littoral anti-submarine warfare (ASW) in the 2025 timeframe. SEA-8 was tasked with designing a system of systems (SoS) architecture that would be capable of using traditional and non-traditional assets to perform battlespace preparation and monitoring, persistent detection and cueing, combined arms prosecution, high volume search and kill rates, in a defense in depth manner. TSSE was tasked to perform an investigation of concepts of ship employment while conducting littoral ASW and to use its newly acquired knowledge to design either a ship or family of ships that could be incorporated into SEA-8's overall SoS architecture. The SEA-8 and TSSE tasking letters are included as Appendices I and II, respectively.

SEA-8 investigated the capabilities of legacy systems and looked at existing programs of record as a means of determining the future capabilities of US forces. Based on their analysis, SEA-8 generated a set of top level requirements for the TSSE design project. The SEA-8 requirements documents are summarized here, and included in their entirety as Appendix III. SEA-8 also provided two specific scenario types and one specific geographic region where the TSSE ship design was to operate. Details of the ASW scenarios are given in Section II.

The TSSE ship design was tasked with having the ability to deploy, retrieve, and regenerate large unmanned undersea vehicles (UUVs) semi-clandestinely. Main UUV parameters were to be in accordance with the Navy's UUV Master Plan. The ship would carry and deploy enough sensors to provide a probability of detection (Pd) of 0.8 across a contested 6,700 nm^2 area of operations (AO) within 10 days. The TSSE ship was also tasked with possessing the ability to provide logistic support necessary to sustain SoS for 30 days, to launch, recover, and control a 7,000 lb UAV, and to employ box-launcher weapons and torpedoes for enemy engagement. Finally, the TSSE ship was tasked to communicate via the following circuits:

High Band Width Air/Space Line of Sight (LOS)
LOS Data
LOS Voice
Over the Horizon (OTH) Voice
OTH Data
SATCOM
Underwater Data

Figure 1 illustrates a simple work breakdown structure of the TSSE design's deployment requirements.

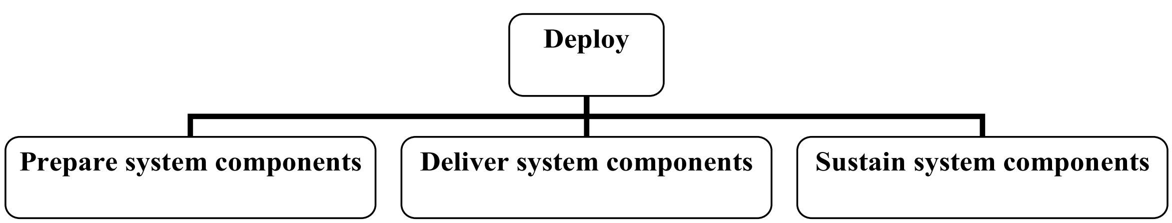

Figure 1. TSSE Design Deployment Requirements

In order to achieve the goals of the project, the TSSE team adopted the Classical Systems Engineering Process as defined in the Naval Sea Systems Command Ship Design Manager Manual as the baseline design model. We then tailored the process to fit our team's unique needs. As can be seen in Figure 2, the Classical Systems Engineering Process consists of three main blocks, namely, Requirements Analysis, Functional Analysis Allocation, and Synthesis, which are then tied together by a fourth block called System Analysis and Control Balance.

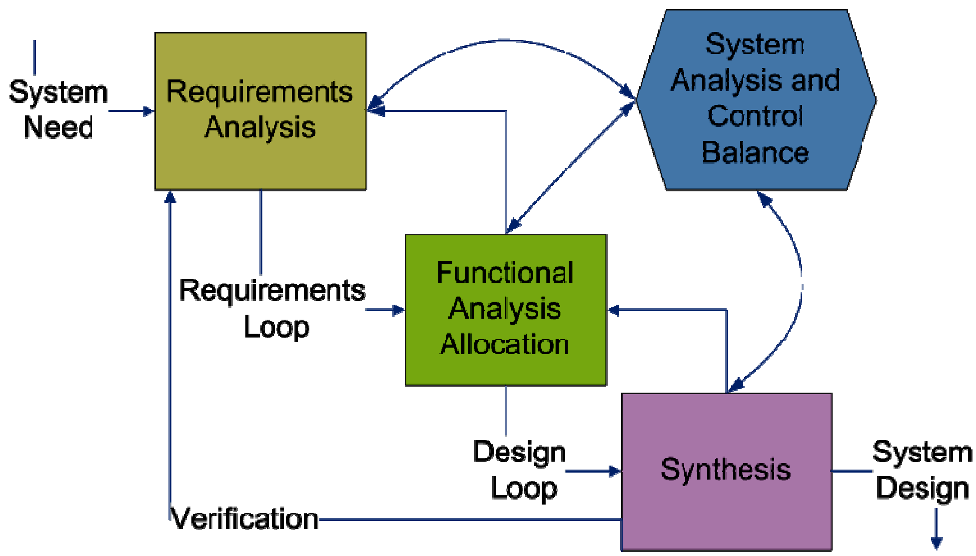

Figure 2. The Classical Systems Engineering Process

With an established process in place, the team then organized the tasking into distinct portions. First, the team studied and discussed littoral ASW techniques and challenges and established our own ideas of future needs. Upon receipt of our requirements from SEA-8, several meetings took place to perform requirements clarification. This phase of the project, conducted in July and August made up the Requirements Analysis Portion of the project.

At this early stage in the process the SEA-8 cohort had not selected a specific set of sensors to be carried on the TSSE ship. Thus, the TSSE team designed a notional payload architecture and presented the concept to SEA-8. The notional payload consisted of a sensor grid of sensors that would be deployed on the sea floor by a large UUV. Both teams accepted the notional payload, and it became the building block for the larger sensors to be carried by the TSSE ship design. This step was a combination of Requirements Analysis and Functional Analysis Allocation. The notional payload is described in detail in Section III.

Armed with top level requirements and a notional payload, the TSSE team then entered the true Functional Analysis portion of the project. We performed an analysis of alternatives (AoA) of three competing systems to prepare, deliver, and sustain the notional payload. The details of the AoA process are covered in detail in Section III of this report.

The TSSE team continued with our Functional Analysis Allocation mission and translated the top level requirements into a set of mission-based requirements. We developed an Interim Requirements Document (IRD) which included a table of Critical Design Parameters (CDPs). The IRD is included as Appendix IV.

At this stage, the Design portion of the project began in early September, and continued through the end of November. In the end, we believe that the TSSE design offers a unique and robust littoral ASW capability as well as a platform that can be used to perform several other primary and secondary missions. The Design Process is discussed in Section IV and the Design Evaluation is covered in Section V. Figure 3 shows a graphical depiction of the tailored systems engineering approach used for our project.

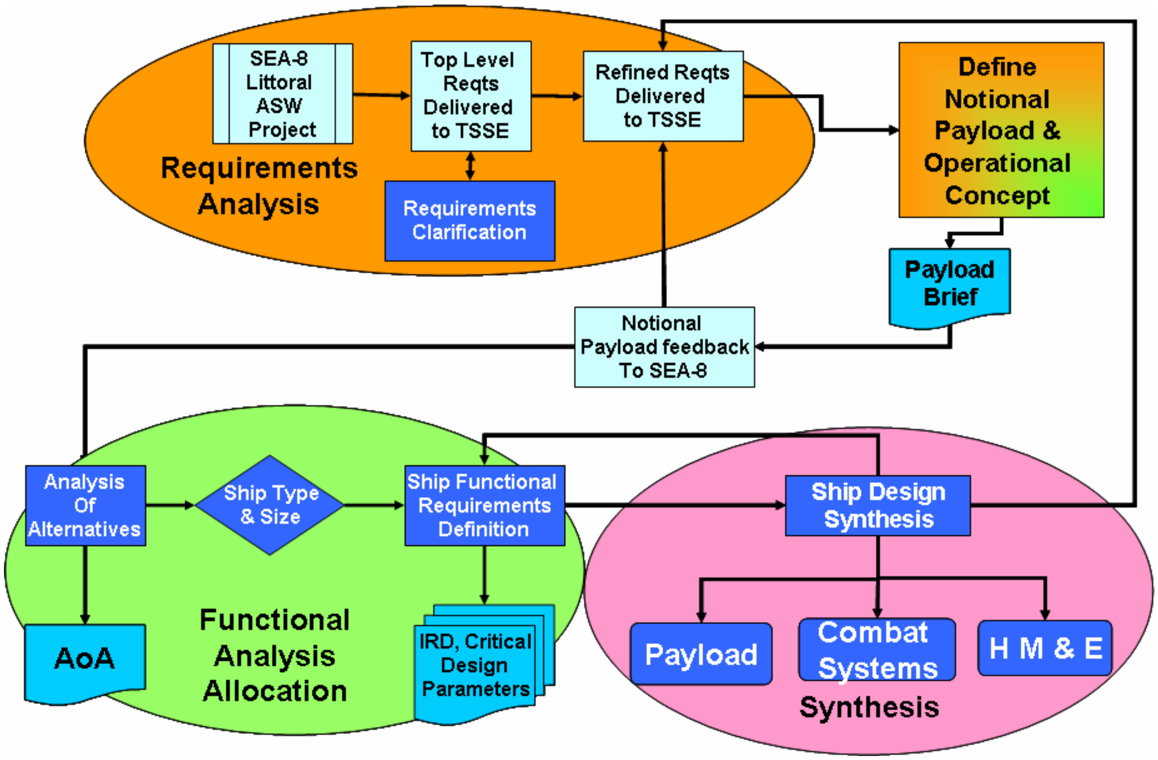

Figure 3. TSSE Tailored Systems Engineering Process

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II. LITTORAL ASW OVERVIEW

A. CONCEPT OF OPERATIONS

The Navy's transformational efforts in ASW are focused on gaining maritime superiority by rapidly finding, destroying or, where necessary, avoiding enemy submarines, thus rendering the submarine irrelevant as an anti-access weapon against friendly naval forces.

Figure 4 shows the underlying Future ASW Warfighting Vision focusing on capabilities in three functional areas: Protected Passage, Maritime Shield, and Hold at Risk [1]. The Protected Passage scenario depicts the ability of performing ASW adequately to allow safe transit through strategic choke points to keep sea lines of communication open. Maritime Shield is an open ocean scenario where ASW forces are deployed to protect a Sea Base. Finally, the Hold at Risk scenario focuses on offensive and defensive ASW in a specific theater near an enemy shoreline.

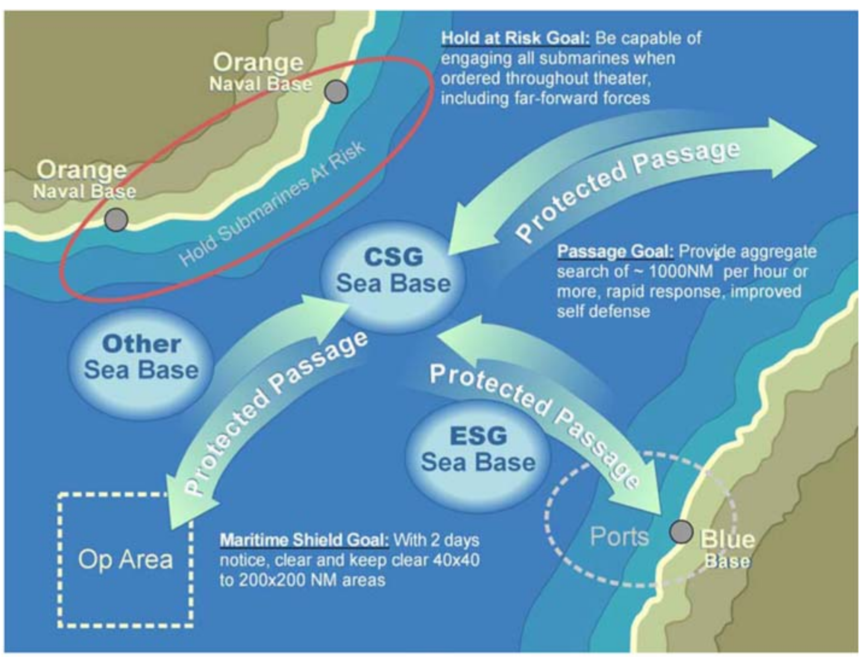

Figure 4. Future ASW Concept of Operations

Due to time constraints, SEA-8, and thus TSSE focused on the Hold at Risk scenario specifically applied to the defense of an island nation in a confined littoral environment. The Office of the Secretary of Defense (OSD) response and time to act strategy of "10-30-30" was applied to the scenario. Thus, ASW forces arrive on station seizing the initiative within 10 days; obtain the capability for a swift defeat within 30 days; and maintain the ability to reset the force for additional action within another 30 days. The specific geography of the Bass Straits was used, as the acoustic environment offers a challenging mix of sound velocity profiles. The Bass Strait is very shallow, but the depth rapidly changes as one heads away from Australia's Continental Shelf. Thus, the region combines both shallow water and blue water ASW challenges.

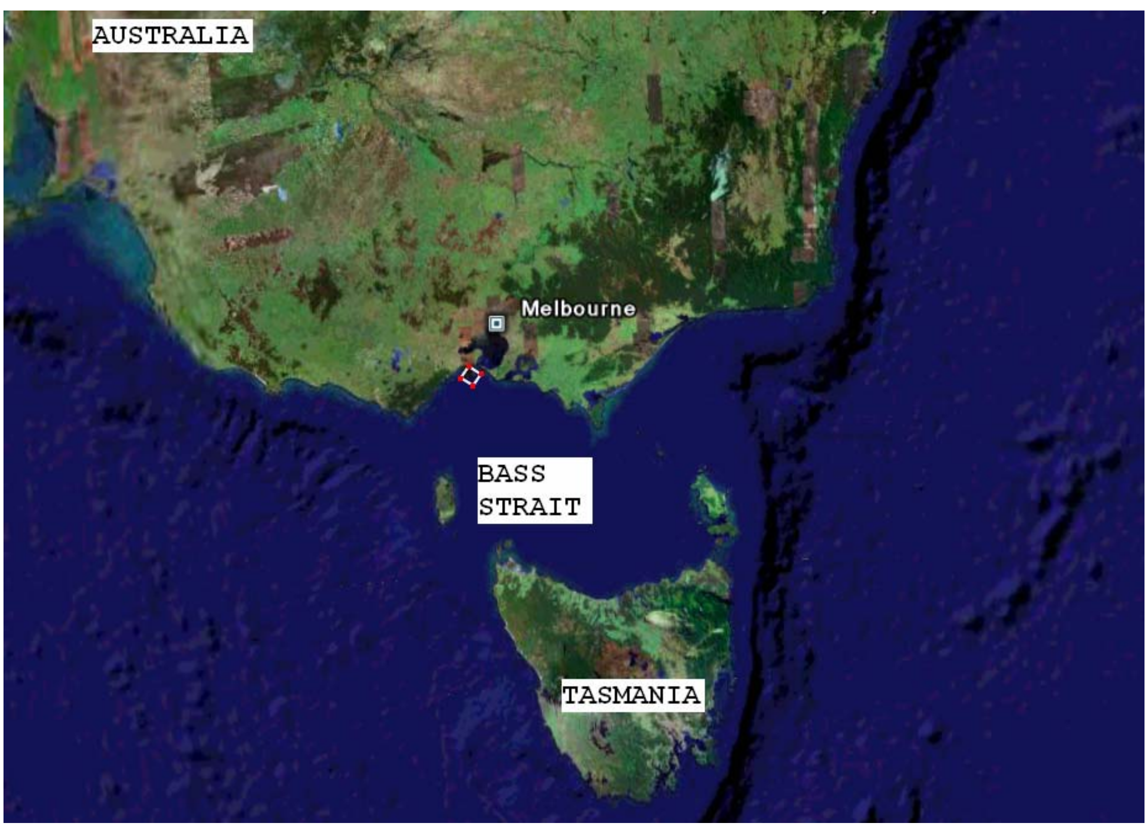

Figure 5. Geography of the Bass Straits

B. SCENARIO DESCRIPTION

1. Harbor Gate "Tripwire"

USW in a littoral environment will require a flexible and scaleable solution to effectively locate, track and prosecute adversaries. In the Harbor Gate scenario the initial network will be focused around a 10x10 nm grid in the water-space surrounding an enemy port facility. The system will not engage the enemy submarine, nor will it attempt to maintain a long duration track. The concept of operations is that a sensor grid will placed rapidly and covertly as a means of informing friendly forces of enemy submarine deployments. The most likely employment for the Harbor Gate in the Bass Strait is given in Figure 6. Due to the limited number of required assets, the Harbor Gate scenario has a 72-hour time limit to be fully deployed and operational.

Figure 6. Very Constrained Scenario Geography

2. Semi Constrained Scenario

The semi-constrained scenario is represented by a strait between an island nation and a significantly larger mainland nation. Factors considered are any large volume of water, limited access, relatively predictable transit/commerce routes, as well as various evasion options available to enemy and friendly forces. The volume of littoral water presents a significant challenge. The relatively short distances (≈ 100 nm) between the two bodies of land translate into a potentially high likelihood of enemy targeting of friendly surface platforms. It is assumed that during the first ten days of operations, the enemy has control of the skies over the strait. In the case of actual combat operations, US forces will attempt to avoid transiting these areas. The time limits call for 0.5 Pd within 72-hours, and 0.8 Pd within 240 hours (10 days).

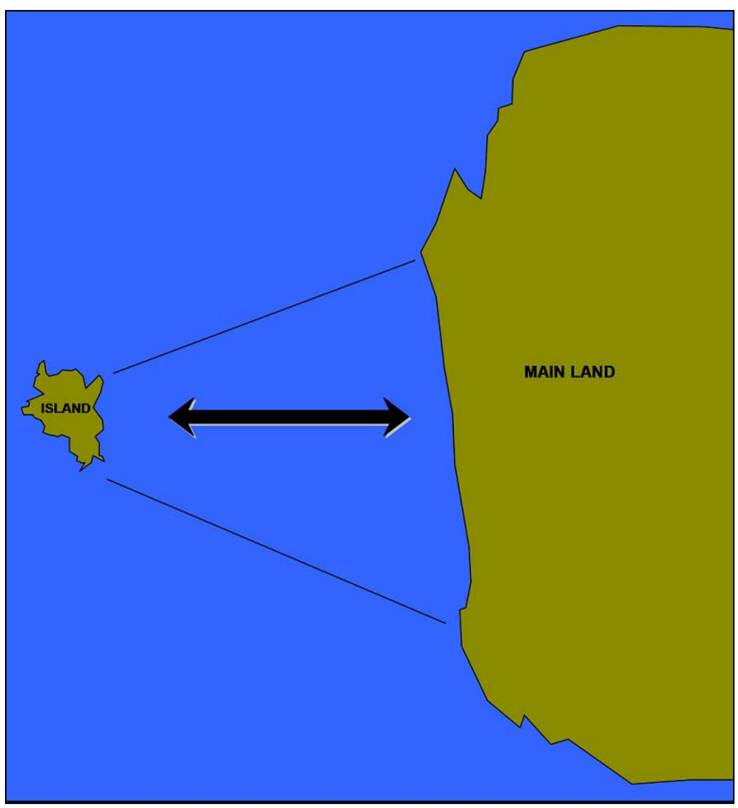

Figure 7. Semi-Constrained Scenario Geography

As previously covered, the TSSE ship or family of ships is to provide sensor coverage for 6700 nm^2. This can be approximated by a 70 x 100 nm grid. To ensure adequate Pd over the area, it is assumed that at least 50% of the AO will need to be covered with our notional architecture. Also, the full first line of defense along the enemy homeport should have full coverage to allow for maximum chance of early detection. Therefore, a minimum of 40 notional architecture building blocks is necessary to provide the 0.8 Probability of Detection for the AO.

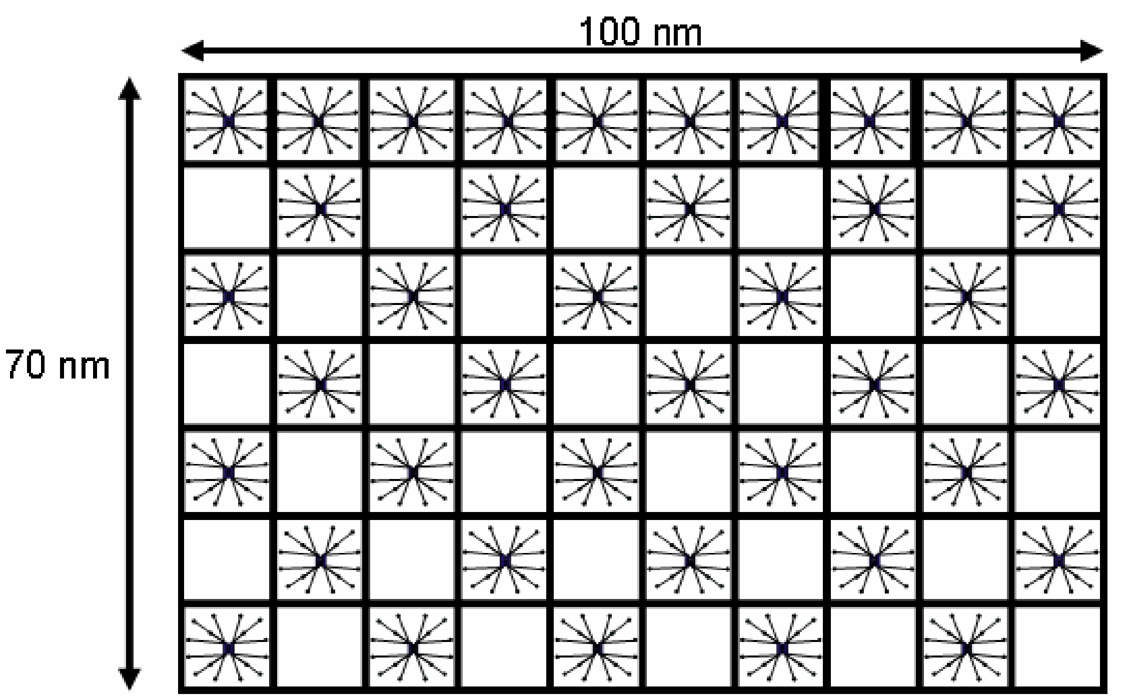

Figure 8. Minimum Sensor Coverage of the AO

3. References

1. Naval Transformational Roadmap, www.chinfo.navy.mil/navpalib/transformation/trans-pg19.htm

2. Naval Postgraduate School Technical Report: Littoral Undersea Warfare in 2025, December 2005.

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III. ANALYSIS OF ALTERNATIVES

A. INTRODUCTION

As discussed in Section I, the TSSE team developed a notional architecture capable of fulfilling the SEA-8 delivered requirements. The notional architecture was designed to perform the Harbor Gate scenario, and was then scaled up to cover the full AO. This Analysis of Alternatives identifies the unit structure and assumptions used to project volume and weight requirements in order to provide a consistent basis for the comparison of delivery platform alternatives. Three distinct alternatives including small (less than 200 long ton (LT) craft, a mid-size vessel, and a Littoral Combat Ship (LCS) modular payload are compared in terms of weighted parameters including: platform capabilities, deployability, survivability, endurance, flexibility, technical risk, and generalized cost assumptions. These alternatives were considered to be representative for the problem at hand and should not be thought of as representing an all-inclusive list. Should additional time and resources were available to the team; more alternative would have been studied.

B. NOTIONAL PAYLOAD DESCRIPTION

Resources required for the 10nm x 10nm Harbor Gate Scenario represent the structural building blocks for the TSSE architecture. In compliance with SEA-8 requirements and its references including the updated UUV Master Plan, the TSSE alternative includes a functional hierarchy of three UUV types and a specially designed connector sled that is carried by the large UUV. The UUVs are as follows: one large Sea Predator mini-sub, six light weight 12.75”

UUV’s, and 16 man-portable sensor deployment UUV’s. The connector sled serves a dual purpose of cargo carrier and central communication hub. It has two 21” x 22’ shapes that house the 16 man-portable UUVs and their necessary communication wires. It also includes a built in acoustic modem, deployable communications buoy, docking transducers, and hydrophones.

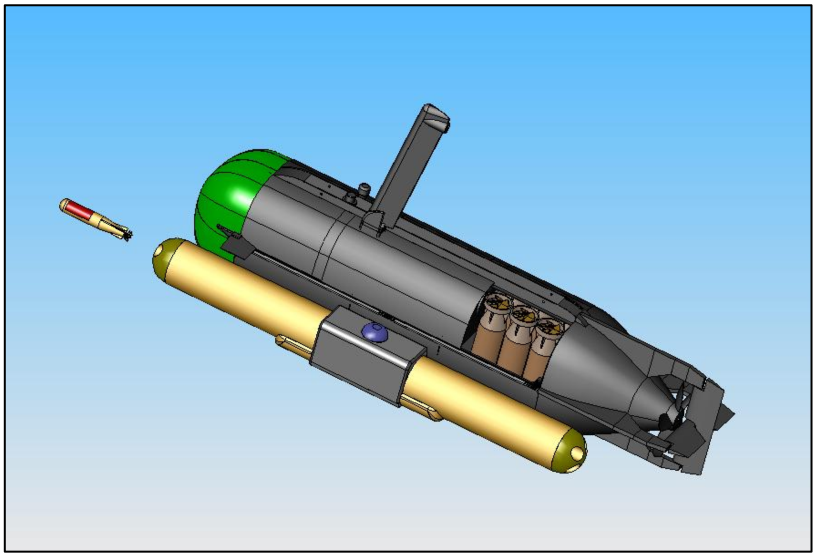

Figure 9. Sea Predator with Sled and 12.75” UUV Payload

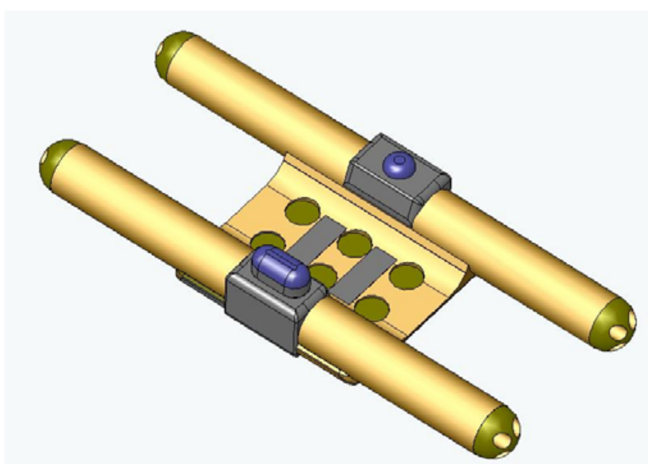

Figure 10. Connector Sled

Upon deployment, the Sea Predator swims to a pre-selected location and bottoms. The sled is detached and rests on the bottom. The Sea Predator then hovers in close proximity to the sled and deploys the six 12.75″ from its internal cargo bay. The 12.75″ UUVs dock with the sled, with four acting as batteries and two acting as computer processors. The 16 man-portable UUVs then swim out from the sled and distribute themselves in a preset pattern as seen in Figure 12. The man-portable UUVs are hardwired to the sled, and each carries an acoustic listening element that is assumed to posses a 0.5 Pd at a range of one nautical mile, giving sensor coverage seen in Figure 13. As can be seen, this architecture provides excellent coverage for a 10 x 10 nm box as described in the Harbor Gate scenario. Sled design calculations are included in Appendix V.

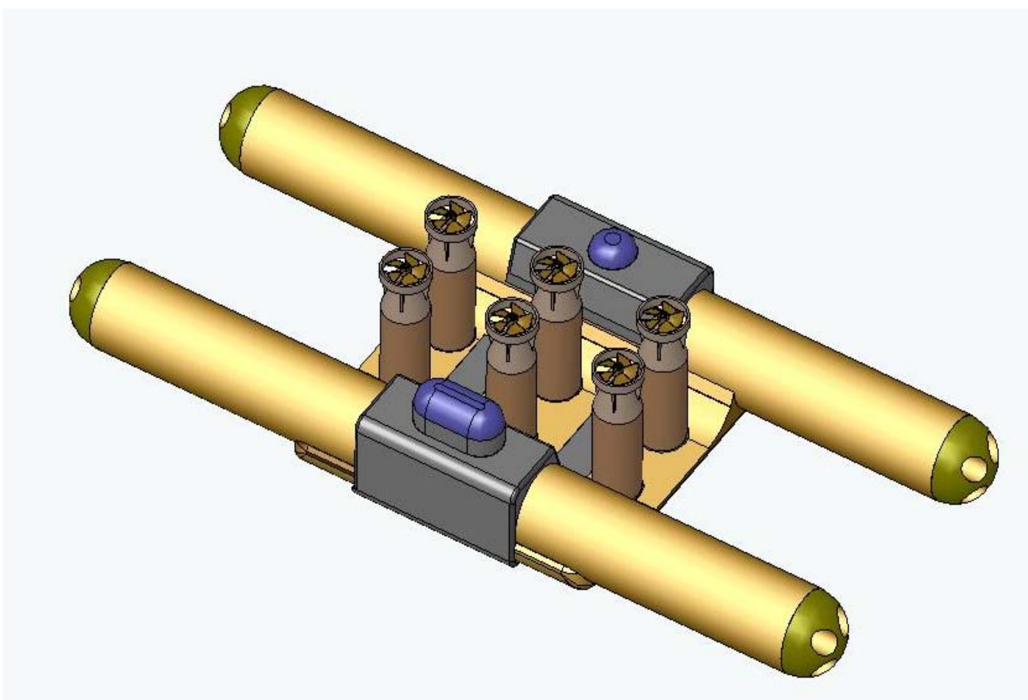

Figure 11. Connector Sled with docked 12.75″ UUVs

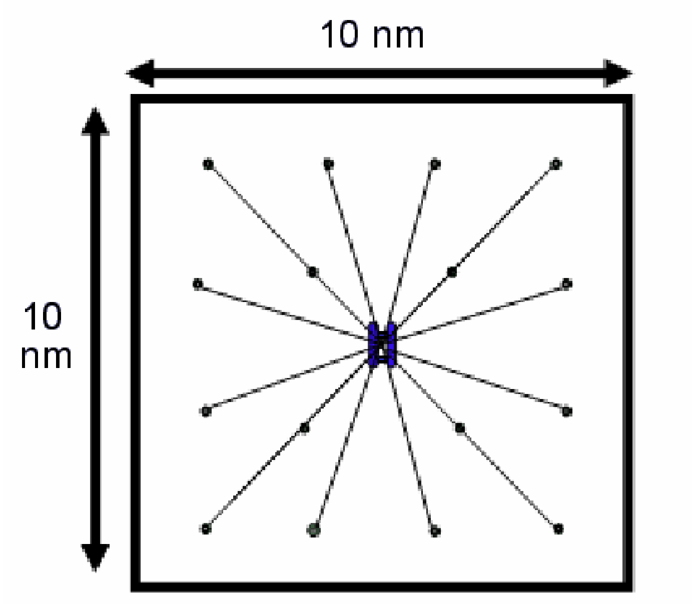

Figure 12. Man-portable UUV deployment: four @5 nm, eight @ 4nm, four @ 2 nm, and one on the sled

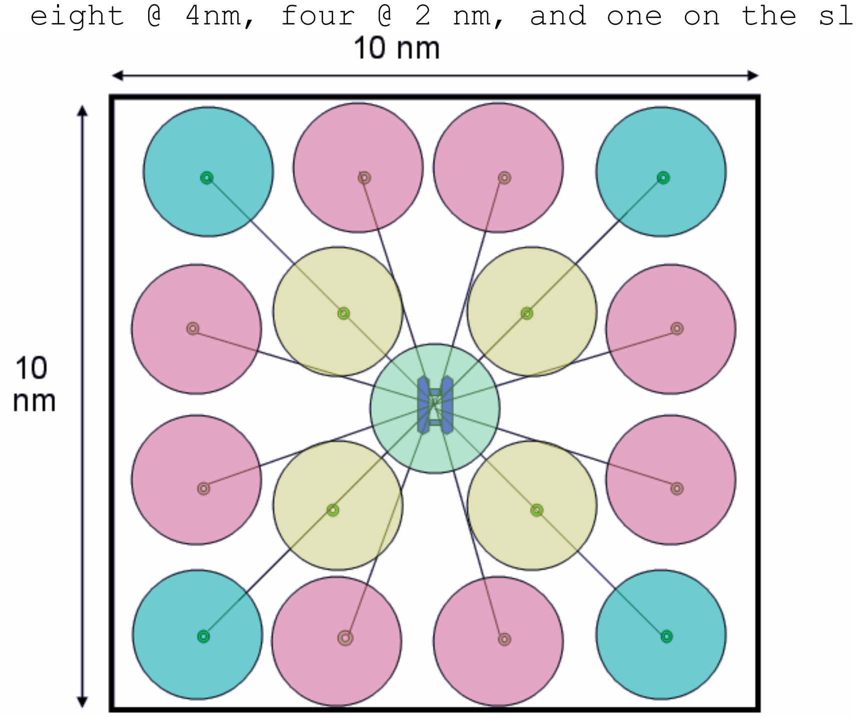

Figure 13. Notional architecture sensor coverage area (assumes 0.5 Pd at one nm range)

After deploying the sled and 12.75" UUVs, the Sea Predator can loiter in the area or return to the ship for recharging and to be outfitted with additional payload options. A full description of Sea Predator capabilities, ranges, and payload options is included as Appendix VI.

C. AOA COMMON TIMELINE ASSUMPTIONS

Given the specific geographic constraint of the Bass Straits, the TSSE team assumed Guam, which is approximately 3,300 nm from the entry point of the strait, as the port of debarkation for all alternatives. The team recognized that Guam does not serve as the homeport for all the alternative options, but that fact was overlooked due to the low probability of actually deploying ASW sensors in the Bass Straits.

Due to the time and distance calculations between Guam and the Bass Strait, the TSSE team quickly concluded that no surface ship solution could deliver assets in time to participate in the Harbor Gate scenario. Similarly, no system could meet the 0.5 Pd within 72-hours. However, it is possible to achieve the 0.8 Pd within 240-hours in the Bass Strait.

The details of time and distance requirements are given in Figure 14. The first 20 hours of the scenario allow for emergency preparations for the deploying ship to get underway. The ship will then transit with a 20 knot speed of advance (SOA) for 160 hours covering a distance of 3,200 nm. Twelve hours are allotted to launch the Sea Predators, at a conservative rate of 4 per hour. The Sea Predators then transit to the AO at a speed of 5 knots, covering a distance of 200 nm in 40 hours. The final 8 hours are used to dock the 12.75" UUVs, for the man-portable UUVs to deploy and to allow for system initialization. Thus, the system is fully operational at a range of 3,400 nm in 240 hours.

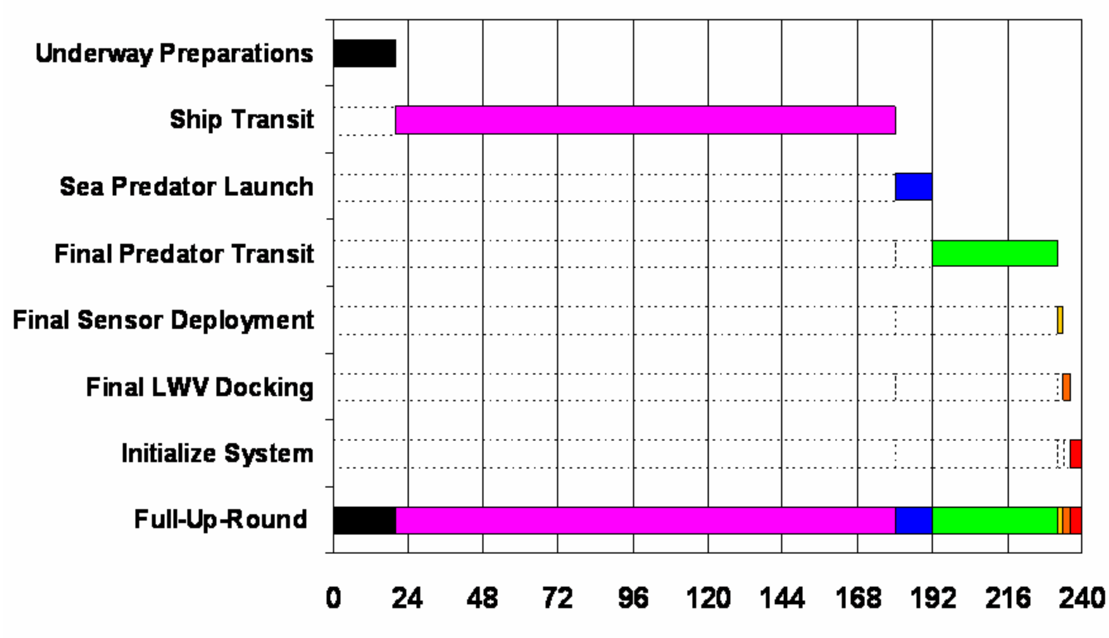

Figure 14. Notional architecture deployment timeline

While the Harbor Gate timeline is not achievable for the Bass Straits, there are several other areas where a surface deployed system could meet operational needs within 72-hours. One first has to assume that the deploying ship is ready to get underway at time t=0. Then using the final 48 hours of the timeline in Figure 14, the ship could transit at top speed for a period of 23 hours, leaving one hour for Sea Predator deployment. If the deploying ship has a top speed of approximately 20 knots, an operational Harbor Gate system could be placed nearly 650 nm from the port of debarkation. For a 30 knot top speed, the range is extended to nearly 800 nm. This notional timeline is shown in Figure 15.

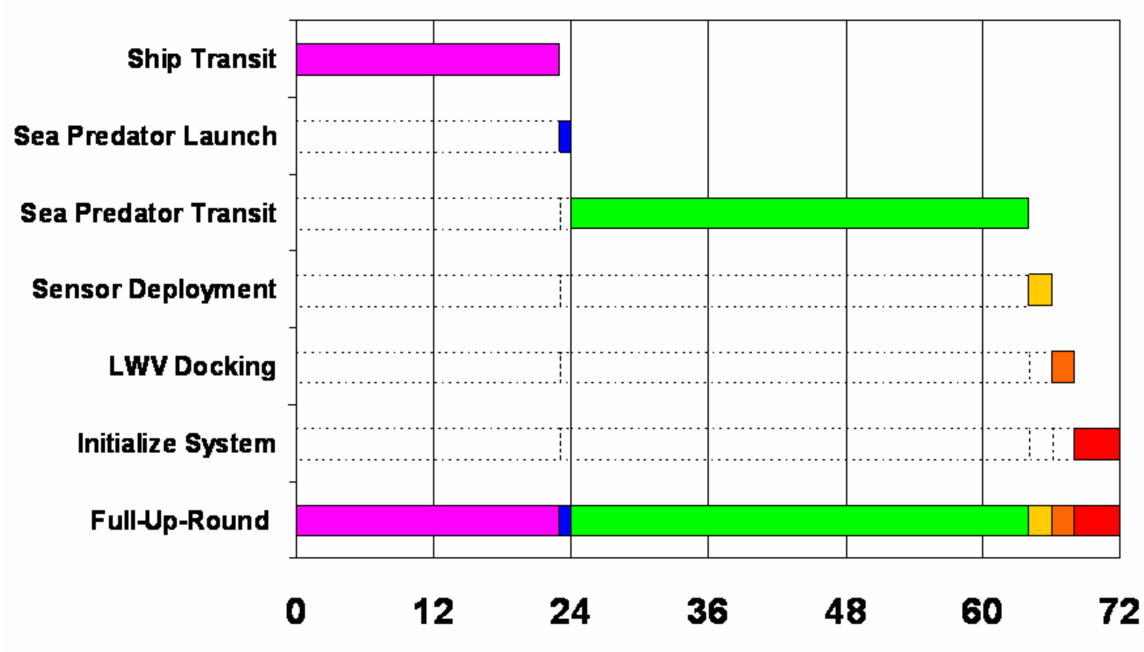

Figure 15. Harbor Gate timeline

An important note is that achieving full AO coverage is not a less challenging task than the Harbor Gate Scenario. Adequate sensor population requires between forty and seventy times the Harbor Gate coverage area while permitting just over three times the deployment time. Even assuming that the multitude of units required to accomplish such a deployment sit poised at maximum underway readiness, capable of an "instant" underway when the countdown metric begins, the most significant portion of the deployment time is consumed simply in transit to a covert UUV deployment point. Therefore, Harbor Gate scenario conditions were not considered as part of the AoA.

D. AOA CATEGORY DEFINITIONS

The purpose of the SEA TENTACLE Analysis of Alternatives (AoA) is to compare various options for shipboard deployment and control of the littoral ASW network needed to fulfill the Semi-constrained scenario previously defined. The TSSE team selected three options as viable means to perform the needed mission. The first option was to use a small ferry platform, using the standard Landing Craft Air Cushion (LCAC) as the model. The second option considered a new class of ship tailored to UUV delivery, maintenance and control. The third option utilized a mission package for the Littoral Combat Ship (LCS). Each alternative was assessed independently in seven categories, and each category was assigned a point total, with a maximum overall score of 100 points. The list of categories and their respective weighting factors is as follows: Capability (30), Deployability (20), Survivability (20), Endurance (10), Flexibility (10), Technical Risk (5), and Cost (5). A brief definition of each category will be discussed here, and the evaluation methodology will be discussed later.

Capability was defined as the ability of the alternative to successfully complete the assigned mission. This category was subdivided into three subcomponents, each with its own contribution to the overall weighting score. The first subdivision is Time to Complete the Mission (TTCM), which represented 15 of the 30 points. An alternative would only receive 15 points if it could meet the 240 hour time requirement.

Interoperability, or the ability to work with friendly units, was worth 8 points and was the second component of the Capability score. Finally, the Percent of Mission Completion was assessed, based upon the ability of a system to deploy, retrieve, control and monitor UUVs. If the alternative could perform all of the above functions, it would also need to carry enough payload to fully cover the AO to receive the maximum score possible of 7 points.

Deployability is defined as a measure of the ease of which a given platform could reach the AO and in order to complete the mission. Deployability was assessed in terms of being able to deploy alone, as part of a larger combat force, or if the unit needed to be ferried to the AO.

Survivability is defined in the Glossary of Defense Acquisition Acronyms & Terms, 12th Edition, July 2005 published by the Defense Defense Acquisition University Press, page B-158 as the capability of a system and crew to avoid or withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission. Survivability consists of susceptibility, vulnerability, and recoverability. Survivability is broken into three components of susceptibility, vulnerability, and recoverability, with assigned values of 7, 7, and 6 points respectively. The definitions of the three components of survivability, also from the Glossary of Defense Acquisition Acronyms & Terms, 12th Edition, July 2005 are:

> Susceptibility—The degree to which a weapon system is open to effective attack due to one or more inherent weaknesses. (Susceptibility is a function of operational tactics, countermeasures, probability of enemy fielding a threat, etc.)
>
> Vulnerability—The characteristic of a system that causes it to suffer a definite degradation (loss or reduction of capability to perform its

designated mission) as a result of having been subjected to a certain (defined) level of effects in an unnatural (man-made) hostile environment.

Recoverability—Following combat damage, the ability to take emergency action to prevent loss of the system, to reduce personnel casualties, or to regain weapon system combat mission capabilities.

The final four categories have simple definitions. Endurance was defined as the range of the vessel, and the total provisions that a vessel can carry. Maintenance issues and operational availability was also factored into the Endurance rating. Flexibility was defined as the number of various missions that the vessel could perform, either in conjunction with or in lieu of littoral ASW operations. Technical Risk was defined as the ease of developing and building the specific alternative. Cost considered both acquisition and total lifecycle cost components.

E. SMALL SHIP (≤200 TON) OPTION

1. Description

The first alternative studied as a means of deploying littoral USW sensors and assets is the small ship, ≤ 200 LT. Ships of this weight, such as the Landing Craft Air Cushion (LCAC), can be deployed from the current and future amphibious warfare ships in an Expeditionary Strike Group (ESG). This option does not attempt to establish the actual platform technical specifications, nor does it attempt to promote a selection for the next generation LCAC or LCAC replacement. The goal, rather, is to evaluate the ability of small craft to deploy the systems as defined in Section I in terms of anticipated payload capacity, speed, and range. A basic assumption is that these vessels will perform other cargo missions in support of Amphibious Operations, such as troop and vehicle transport as well as the USW missions. As such, the LCAC will be used as the baseline vessel in this study, as its size and weight are compatible with amphibious warships in the US fleet. The dimensions of the LCAC are included as Table 1.

LCAC SPECIFICATIONS

Hull	
Length	Off-cushion - 81 feet; on-cushion - 87 feet, 11 inches
Beam	Across fenders - 46 feet, 8 inches On-cushion - 47 feet
Height Above Ground	Off-cushion - 19 feet, 6 inches On-cushion - 23 feet, 10 inches; Cushion depth - 5 feet
Deck Area	1,809 square feet

Table 1. LCAC Specifications

The LCAC design payload is 120,000 lb with an overload capacity of 150,000 lb. Typical amphibious vehicle loadouts include either four Light Armored Vehicles (LAV) or two Amphibious Assault Vehicles (AAV). It is worth noting that the loadout of 2 AAVs puts the LCAC at the overload condition. Thus, this alternative assumes overload payload capacity as the standard for USW system deployment. The LCAC deck area is 27' wide by 67' long, for a total of 1,809 ft^2. A bulkhead of 12' gives the maximum overall cargo volume of 21,708 ft^3.

The notional payload is estimated to have a maximum weight of 14,500 lbs and fixed volume of 742.5 ft^3. The weight breakdown necessary to deploy the notional architecture from an LCAC is listed in Table 1. The volume is based on a rectangular box based on a Sea Predator while coupled with a connector sled. The Sea Predator has dimensions of nearly 4'W x4'H x22'L and the sled adds an additional 3.5' in width. The actual volume of the components is smaller than 724.5 ft^3, but while stacked together this figure accurately represents the volume consumed.

Table 2 gives the details of payload calculations. It can clearly be seen that weight, and not volume is the critical payload parameter. Both weight estimates accounts for the UUVs and sensors needed as well as the storage and handling equipment. The total number of grids that can be seeded per sortie was calculated assuming overload conditions for both the maximum and minimum weight per grid. Analysis shows that each LCAC sortie will have the capability of deploying assets to cover between 9 10x10 nm grids, giving a need for a sortie of 5 LCACs to carry the necessary sensors for AO coverage.

UNIT	Dry WT (lbs)	One Grid			Max Option A - 4		
		# Reqd	WT (lbs)	Vol (ft^3)	# Reqd	WT (lbs)	Vol (ft^3)
Sea Predator	7,500	1	7,500	742.5	9	67,500	6682.5
12.75" UUV	500	6	3,000	0	54	27,000	0
Connector Sled	4,000	1	4,000	0	9	36,000	0
Storage Rollers	100	1	100	29	9	900	261
Handling Equip	3,000	1	3,000	1,000	1	3,000	1,000
		TOTAL	17,600	1771.5	TOTAL	134,400	7943.5

Table 2. Weight and Volume Estimates for a Single 10x10 nm Grid, and Max Grid Coverage per Sortie

2. Capability

a) Time to Complete Mission

Using the timelines established in Section III C, only the best-case estimate for grid deployment from the LCAC option will be discussed. Thus, factors such as weather which could affect SOA, will not be considered. We can modify the 240 timeline for the LCAC delivery option. Total Sea Predator deployment time will drop from twelve to nine hours, as the LCACs could likely deploy one per hour. This gives an extra three hours of transit time. Given the 350 nm range and 50 knot top speed of an LCAC, the extra three hours could be used for LCAC transit, effectively extending the range by 175 nm for a total of 3,575 nm. As a typical ESG in the 2025 timeframe will possess at least 7 LCACs, the LCAC option can meet the 240 hour window.

b) Interoperability

LCACs are fully interoperable with the ESG and Marine Expeditionary Unit requirements. They possess joint communications and navigation sensors, and are fully integrated into the ESG force.

e) Percent of Mission Completion

The LCAC option is unlikely to be capable of fulfilling 100% of the ASW mission defined by SEA-8. A single LCAC provides the capability to sustain the Harbor Gate scenario, but cannot fully seed a 6,700 nm grid. As seen from the following payload calculations, a group of 5 LCACs could fully seed the large grid. However, the LCAC fleet could not maintain tactical control of the grid nor provide adequate means for UUV repair. It could best be used as a means of delivery and recovery, but could not perform the sustainment mission requirement. Also, the

LCAC provides no means of offensive ASW engagement of enemy submarines.

3. Deployability

The LCAC requires an amphibious ship for deployment. This is a significant requirement but the ship could serve many other functions in addition to the ASW mission. Different classes of amphibious ships can carry different quantities of LCACs. At most, 4 LCACs can be carried on a single ship. Within an ESG, between 7 and 9 LCACs will be available for the mission.

4. Survivability

In terms of susceptibility, the LCAC sized option has favorable marks due to its low Radar Cross Section (RCS), its high speed, its operating range far from the enemy coast, and its air cushion that provides protection from deep-sea mines. Susceptibility enhancements in the form of countermeasures such as chaff launchers, and shoulder fired anti-air missiles offer valid alternatives. While susceptibility is low, the LCAC sized platform has considerably low marks in vulnerability. The current LCAC configuration has exposed vital systems such as the drive train and the propulsion systems. Also, the small size makes this type of vessel incapable of surviving damage from most anti-ship cruise missiles (ASCMs). The addition of armor in high threat environments would reduce vulnerability to small arms and machine gun fire. Recoverability of LCAC size platforms, like vulnerability, is a function of its small size. The crew of five personnel would not likely be able to effect emergency repairs in order to restore the vessel to a useable condition, despite the relative simplicity of installed systems.

5. Endurance

With a fuel capacity of 5000 gallons and using an average of 1000 gallons per hour, the current LCAC has an endurance of 5 hours. This could be extended by adding fuel tanks. The LCAC has more than enough capacity so the addition of a fuel tank may be worthwhile. Additional fuel would also adversely affect survivability. Another 5000 gallons would reduce the payload by (5000*7.1lbs/gal=35,500 lbs) 18 tons while doubling the endurance to 10 hours. This would leave a payload of 44 and 57 tons which is more than enough for this mission. At a speed of 40 knots this makes the range 400 nm. This could be increased dramatically by enhancing the fuel efficiency which should be possible with a different style craft at the expense of the land-going capability.

Given the LCACs speed and ability to seed multiple grids per sortie, it is not envisioned that the LCAC would loiter on station to perform UUV maintenance and recovery missions. Rather, LCAC sorties would be scheduled routinely or as needed during the 30-day operational timeframe. This approach is beneficial in that LCACs are high maintenance vehicles, and typically are limited to 16 hours of operations per day. Also, after 5 days of continued use, LCAC reliability drops to 75%. Therefore, an approach of maximum sorties on day 1, and limited sorites on day 2-30 will ensure adequate LCAC resources are available for the USW grid reseeding, as well as other operations.

6. Flexibility

LCAC sized platforms are extremely flexible. This option could be used not only for the same missions that current LCAC's provide (amphibious assault, mine warfare, personnel transport, medical evacuation and civil-emergency response) but also for the design requirements at hand that include anti-submarine warfare, anti-surface warfare and minimal anti-air warfare. The limiting factor in this options flexibility is its size. With a its open cargo space, this option would be capable of carrying the proposed payload to support the requirements provided, a modified modular systems. Examples of such systems include "harpoon-in-a-box," and systems similar to the Affordable Weapon concept.

7. Technical Risk

If the standard LCAC type platform is used to perform the UUV deployment mission, there is little to no technical risk. The only technical consideration would be the best means stacking the various components. However, if a small ship option that does not involve the same components as the current LCAC configuration is considered, then the technical risk involved could potentially increase.

8. Cost

The purchase cost of the current LCAC fleet is FY 1990 budget request included $219.3 million for nine craft. This amounts to $24 million for each vessel. Research and development costs can vary widely but a recent study of the arsenal ship concluded the value of the R&D portion of the program to be $520 million with each vessel valued at between $500 and $800 million. The CVN-21 will cost $10.5 billion with an R&D cost of $3.2 billion. Since this vessel may be similar to an LCAC the costs will be smaller, approximately $20 million.

F. MEDIUM SIZE SHIP (2000 – 6000 TON) OPTION

1. Description

The medium sized ship is envisioned as an ASW platform that will utilize a combination of organic sensors and weapons. The ship will serve as the fleet's primary carrier and deployer of UUVs. The ship (or group of ships) will possess the capability to carry the UUVs necessary to provide adequate sensor coverage of a 6,700 nm grid for littoral ASW operations as outlined by the SEA-8 guidance. The large UUV payload could necessitate the medium sized ship option to resemble a scaled down version of a large amphibious ship, such as the San Antonio Class Amphibious Transport Dock (LPD 17) ships.

2. Capability

a) Time to Complete Mission

As the total cargo weight and volume are less than 50% of the LPD 17 class, we can safely assume that the medium sized ship can carry enough UUVs and sensors to fully seed the full AO in a single sortie. Any new ship class design must possess the speed necessary to operate with other friendly forces, which sets the minimum speed requirement of 20+ knots. Given the above conditions, it can safely be deduced that the medium sized ship option can meet the 240-hour requirement.

b) Interoperability

A medium sized ship will carry all sensors needed to maintain full interoperability with US and allied forces. All systems related to littoral ASW can be assumed to be fully integrated with all friendly forces.

c) Percent Mission Completion

The medium sized ship will possess the capability to perform 100% of the mission requirements. The payload will accommodate the sensors and UUVs; the Command and Control (C2) functionality will be present to monitor and control the grid in real or near real-time; maintenance facilities, including UUV recharging systems, will be inherent; the ship will be able to deploy and retrieve all sizes of UUVs. The ship will also carry a robust offensive ASW sensor and weapons suite that will be able to prosecute enemy submarine contacts.

3. Deployability

The mid size vessel is an independently deployable vessel. Depending on mission and crew size requirements, this vessel could be made to withstand 15 to 30 days of continued operations with constant speed of 15-20kts. Replenishment intervals could increase to beyond 30 days, with an increase in overall vessel size.

The size of the vessel will affect the ease of deployment. Mid sized vessels can sustain continued operations in open ocean sea state 4 as well as operate in costal waters with restricted depths. This mid size vessel will be able to get underway and to moor independently thereby eliminating the outside support for these operations.

4. Survivability

The medium sized ship will possess a moderate level of susceptibility when compared to other ships its size. The ship will be required to meet the requirements for Level I in accordance with OPNAVINST 9070.1. If a monohull design is incorporated, the ship may not have enough speed to outrun larger surface combatants. If a catamaran design in selected, high-speed maneuvering is possible. By design, amphibious ships include minimal outfitting of Surface Warfare payloads. However, the CONOPS have the ship operating near friendly forces and several hundred miles from the enemy coast, which will lessen the likelihood that the vessel will come under direct attack from surface vessels while conducting littoral ASW operations. Potential secondary missions, such as Mine Warfare (MIW) missions could require the ship to travel closer to enemy coastlines, but not as close as current minesweeping ships do. The standoff range can be assumed to increase as remote minehunting vehicles increase in autonomy and range.

The option will possess a defense in depth anti-air system that will include medium and short range missile defenses as well as short range and point defense gun systems. Susceptibility to air attack can be minimized with robust RCS and IR signature reduction. RCS signatures can be controlled through the use of composite deckhouses and topside design. IR signature reduction can be achieved through selection of the prime mover and by innovative exhaust systems as seen on ships like Sweden’s VISBY Class corvettes.

The ship will possess a state of the art sonar suite, undersea warfare weapons system, and will carry torpedoes. Noise reduction measures will be employed, such as shock mounting installed machinery. The UUVs, and UAV systems will be able to perform ASW search and attack missions. Thus, the medium sized ship option will have a low susceptibility to ASW threats.

If damage is sustained, the ship will be designed with system redundancy and compartmentalization to maximize ship survivability. Recoverability will be aided through the use of installed fire suppression systems and foam generation systems. The foam generation systems are capable of displacing flood water from a space via automatic activation. The affected space will be unusable until the foam is removed by ship's force or shipyard repair parties, but total damage to the space is greatly reduced when compared to flood damage.

5. Endurance

Endurance depends on the speed, displacement and wave height. The relationship between speed and endurance for a typical combatant ship is shown in Figure 16. With more fuel and a lower burn rate resulting with the decreased displacement, endurance is greatly increased. Therefore, larger ships have the lower endurance due to the weight impacts. They will have low ability to operate autonomously for extended periods and reach the areas where they are needed and to remain in these areas long enough to complete the tasks unless they have enough fuel amount. It is difficult to design a ship with high speed, long endurance, and a large payload.

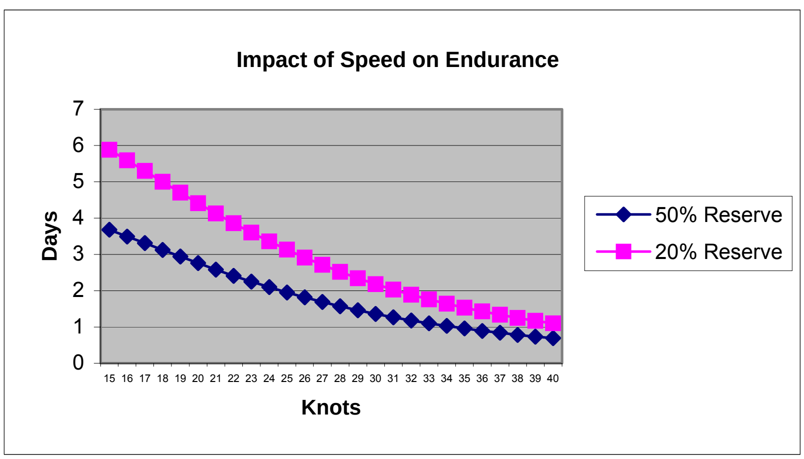

Figure 16. The impact of speed on endurance, full displacement, 6-foot wave height.

6. Flexibility

Flexibility in terms of mission availability is key for a mid size vessel. With the ever changing battle space dynamics this vessel with an outfitted modular core in the combat systems suite and the cargo hold will have the capability to participate in any and all future missions. It will be large enough to independently operate for a predetermined time as well as meld with any scenario to better effect our naval presence. Additionally, it will be small enough to semi-covertly operate in the littoral waters as a key asset in ASW operations such as grid deployment, UUV support, mine sweeping and hunting and utilized as the central source for linking to an underwater sensor grid.

7. Technical Risk

In general, as ship size increases, the complexity increases, making fruition of a completely new design more risky and less feasible. If a catamaran or trimaran hull shape is selected, the risk will increase as few US shipyards have experience in building these platforms.

The ship will rely heavily on manned and unmanned vehicles to execute assigned tasking. In order to conduct successful combat operations in an adverse littoral environment, it will need to employ technologically advanced weapons, sensors, data fusion, C4ISR, hullform, propulsion, optimal manning concepts, smart control systems and self-defense systems. As the ship’s ability to contain these systems increases, more and more new technology will be included in the design, and the technical risk of implementation will increase.

8. Cost

The overall cost of the medium sized ship option is likely to be quite high in comparison to the other options. Research and development and detailed design costs of a major ship class would tally into the hundreds of millions of dollars. For example, the FFG(X) ship, as proposed in the Congressional Budget Office (CBO) report in 2004, is estimated to cost nearly $800 million to design and build. A ship capable of carrying over 40 Sea Predators would likely be on the same size scale as the FFG(X).

G. LITTORAL COMBAT SHIP (LCS) MODULE OPTION

1. Description

Option III entailed the design of a combat package for use in conjunction with the Littoral Combat Ship. LCS is not just a ship; rather it is a SoS approach to naval warfare in the 21st century. It is designed around a common seaframe whereby a variety of combat systems are installed to form a coherent package. This package can be tailored as necessary to provide the required mission capabilities dictated by the situation. Each package has a total of five types of zones. These are: the sensor zone, the aviation zone, the support zone, the sea zone, and the weapons zone.

The sensor module exists at the after portion of the seaframe. It is primarily designed to carry a towed array sonar. For our option, the LCS will contain the same towed array as that installed in the LCS ASW option.

The aviation modules reside in the hanger portion of the LCS. Two aviation modules exist, one being slightly larger than the other. Each aviation module can accept a weight of 10,500 kgs. Both a wide variety of helicopter and VTUAV assets are capable of being deployed by the LCS. These include an MH60R helo equipped with a standard ASW loadout and 3 vertical take-off unmanned aerial vehicles

(VTUAVs) used for data networking and general reconnaissance.

The support module resides in the near amidships portion of the seaframe. This module carries the various equipment and stowage space needed to support the primary mission. It consists of nine type one support containers and one type two support module. Both types of support modules are of the same width and height. The type one module is 6.1 m long; the type two is 3.05 m long. Module parameters are summarized in Table 3.

Mission Module	Length (ft)	Width (ft)	Height (ft)	Unit Mass (LT)	Other/ Special
Aviation Module Type1	49.02	15.32	13.45	10.33	One required
Aviation Module Type2	42.98	11.15	13.45	10.33	One required
Sea Type 1 Module	40.03	11.48	10.83	10.09	Two required
Sea Type 2 Module	23.29	8.53	13.78	6.79	Two required, the mass of the module in the Normal recovery condition is 8.74 LT
Ship-based Sensors Module	7.22	7.22	8.20	2.95	Towed array
Weapon Type 1 Module	*	*	*	7.38	Three required *See Table2.4 of LCS CDD for dimensions.
Support Type 1 Module	20.01	8.01	8.53	6.89	Nine required

Table 3. A listing of LCS module parameters.

The sea zone is at the after end of the ship, at the water line. It consists of two type one sea modules and two type two sea modules. The type one sea modules will be used in our design to accommodate the largest UUV's such as the Sea Predator and our connector sled. The type two sea modules will be used to accommodate the Heavyweight and other UUVS as well as additional Sea Predator payload.

The weapons zone is installed on the forward end of the ship. LCS includes several self defense weapons such as guns, missiles, and an anti-torpedo defense. The weapons zone does not include these core weapons. Rather it includes mounts for three additional weapons systems (such as guns or launchers) and the associated magazines below it. The weapons zone loadout is not specified for this configuration, but will be determined as required by the tactical situation.

The LCS Module option has three different configurations that are possible for performing our intended mission. The first configuration still carries all aviation components. The second option allows for the carrying of one additional Sea Predator and connector sled unit, at the cost of half of the onboard aviation unit. The third option forgoes all aviation assets for two additional Sea Predators. Table 4 summarizes the covert ASW options.

Module Station Type	No.	Configuration 1	Configuration 2	Configuration 3
Aviation Type 1	1	MH 60R	MH 60R*	1 Sea Predator + 14 LW UUV
Aviation Type 2	2	VTUAV (3)	1 Sea Predator + 14 LW UUV	1 Sea Predator + 14 LW UUV
Support Type 1	3	MH 60R PUK	MH 60R PUK	5 Heavy Weight
Support Type 1	4	MH 60R PUK	MH 60R PUK	5 Heavy Weight
Support Type 1	5	VTUAV PUK	5 Heavy Weight	40 Man Portable
Support Type 1	6	Sonobuoys	Sonobuoys	Sonobuoys
Support Type 1	7	Battle Preparation	Battle Preparation	Battle Preparation
Support Type 1	8	-	40 Man Portable UUV	-
Sea Type 1	9	1 Sea Predator + 14 LW UUV	1 Sea Predator + 14 LW UUV	1 Sea Predator + 14 LW UUV
Sea Type 1	10	1 Sea Predator + 14 LW UUV	1 Sea Predator + 14 LW UUV	1 Sea Predator + 14 LW UUV
Sea Type 2	11	5 Heavy weight	5 Heavy Weight	5 Heavy weight
Sea Type 2	12	5 Heavy weight	5 Heavy Weight	5 Heavy weight
Support Type 1	13	60 Man Portable UUV (20 Spare)	60 Man Portable UUV	60 Man Portable UUV (20 Spare)
Support Type 1	14	RMS PUK	RMS PUK	RMS PUK
Support Type 1	15	ACES (EER) (1/2 TEU)	ACES (EER) (1/2 TEU)	ACES (EER) (1/2 TEU)
Support Type 2	16	16 LW UUV (Spare)	16 LW UUV (Spare)	16 LW UUV (Spare)
Weapon Type 1	17	-	-	-
Weapon Type 1	18	-	-	-
Weapon Type 1	19	-	-	-
Sensor *	20	OOV Towed Arrays	OOV Towed Arrays	OOV Towed Arrays

Table 4. Comparison of ASW Configurations

2. Capability

a) Time to Complete Mission

As stated earlier, a total of at least 40 Sea Predator/connector sled units are required to perform our tasked mission. Each LCS is capable of carrying at most three Sea Predators. SEA-8 analysis of US Navy projected force structures estimates that a Littoral Action Group (LAG) will likely possess no more than three LCS units. Hence, a LAG will only be able to support a total of nine copies of our notional architecture building blocks. This means that a LAG will not be able to complete the assigned mission within the 240-hour requirement. Fourteen LCS units fully loaded with Sea Predators are required, and it is unlikely that sufficient units will be available in a specific theater.

b) Interoperability

The LCS seaframe is designed to be fully interoperable with US and friendly forces in a joint environment.

c) Percent Mission Completion

The LCS has the ability to deploy, retrieve, and control the Sea Predators and its associated network of sensors. It will possess the ability to recharge and reload the Sea Predators with additional payloads. However, due to the limited carrying capacity, one LCS will be able to perform less than 10% of the assigned mission, whereas a LAG can perform on the order of 25-30% of the mission.

3. Deployability

The executive summary of the LCS Capabilities Development Document (CDD) released in April 2004, develops the concept of operations for the future of littoral operations in the 21st century. Our evaluation of the deployability of the LCS platform, in the early stages of its Flight 0 design, assumes that the CDD objectives are realized. As the specialized mission requirements include modular SUW, MIW, and ASW packages, our TSSE design objective is to provide a distinct alternative covert ASW module which can be deployed to meet the requirements set by SEA-8. Given the 40-50 kt speed capacity, a draft of less than 20 feet, and a 3,500 nm transit capacity, the LCS will satisfy the requirement to accompany battle group deployment elements such as the Expeditionary or Carrier Strike Groups. Three module options iterate aviation and internal storage configurations to provide a range of LCS unit commitment to the covert ASW mission. A single highly deployable LCS unit is capable of exceeding the Harbor Gate scenario coverage requirements while preserving aviation capabilities and interface control requirements. For the full operating coverage scenario of 6,700 nm, the LCS module option requires multiple units and significant sea-basing support. As a result, the more the LCS units are specialized, the less deployable they become.

4. Survivability

The LCS incorporates a total ship approach to survivability that addresses susceptibility, vulnerability, and recoverability, with crew survival as the primary objective. The principal means to be employed is to minimize susceptibility through speed, agility, signature management and the core self-defense weapon suite. The LCS' capability to reduce vulnerability by absorbing a weapon impact and retain seaworthiness and weapons system capability is commensurate with ship's size and hull displacement and emphasizes crew survival and automated damage control and firefighting applications. The LCS meets the requirements for Level I in accordance with OPNAVINST 9070.1.

LCS incorporates automated damage control technology. For example, automatic detection, location, classification and management of fire, heat, toxic gases and flooding, structural damage and hull breaching throughout the ship using a ship's damage control management system,

- Economically maximize personnel protection, prevention of ship loss, and retention of self-defenses capability with fragmentation protection,

- Employ an appropriate level of collective protection against chemical, biological, and radiological threats,

- Incorporate signature management to deny and disrupt the enemy's detect-to-engage sequence to reduce the probability that the ship will be hit by a threat,

- Monitor and control own ship emissions (EMCON) and apply tactical signature control through rapid control of electronic, infrared, optical and acoustic signatures in anti-surveillance, anti-targeting, and self defense roles,

- And Monitor own ship magnetic and acoustic signature to maximize ship survivability when operating in the vicinity of a minefield.

The LCS has core systems that provide the capability detect, identify, track, and protect itself against anti-ship cruise missiles (ASCMs) and threat aircraft. Specifically, the LCS;

- Employs signature management, hard kill and soft kill systems to counter and disrupt the threats detect-to-engage sequence in the littoral environment, and has networked capabilities to improve situational awareness to complement hard kill, soft kill and signature management systems,

- Has the capability to provide point defense against ASCMs and threat aircraft through the use of hard-kill and soft-kill systems, counter-targeting, speed, and maneuverability. LCS will be Link16 and CEC (receive only) capable. For Flight 0 LCS, the capabilities provided by CIWS Mk 15 Blk lB. RAM, and NULKA should be considered,

- Has the capability to operate in clear and severe natural and electronic countermeasures environments inherent in littoral operating areas,
- Finally, it has the capability to evaluate engagements against air targets.

5. Endurance

The agility and quick reaction capabilities of the LCS platform result in significant payload limitations. Although capable of significant transit distances, with a provision capacity of only 14 to 21 days, the LCS has a poor endurance. This is offset somewhat by its capacity for underway replenishment. For both the Harbor Gate and full operating area coverage scenarios, the LCS is uniquely capable of rapid ASW system deployment, but limited in its ability to service the network independently in other than a standoff capacity. Where multiple LCS units can be employed, an LCS unit rotation scheme may be required to provide practical mission endurance lengths.

6. Flexibility

The modular Mission Packages are the central feature of the LCS design and provide the main war fighting capability and functionality for specific mission areas. A Mission Package may consist of a combination of modules, manned and unmanned off-board vehicles, deployable sensors, and mission manning detachments. The modules are integrated in the ships' module stations or zones. The ship's module stations have defined volumes, structures, and support service connections. LCS is a modular ship. The platform supports mine warfare, anti-submarine warfare and anti-surface boat modules. The LCS concept is presently being defined and is envisioned to be an advanced hull form (sea frame) employing open systems architecture modules to undertake a number of missions and to reconfigure in response to changes in mission, threat, and technology. LCS has a stern ramp and side doors for multiple launch and recovery options near waterline, and it has large reconfigurable interior volume for mission modules. The threshold level for required time for mission package change-out to full operational capability is 4 days.

The modular capabilities of LCS include;

- Open architecture,
- Modular, "plug-in" on board sensing, C4, weapons systems and displays,
- Modular, "plug-in" off board systems (including arrays, undersea/surface/air UVs and payloads, weapons),
- Rapid modular reconfiguration capability,
- Manning by system specific-trained personnel,
- Mission packages that are scalable and transportable by air and sea,
- And Adequate stowage and easy handling systems.

Since our mission is covert ASW, our mission module would consist of large, heavy and light weight underwater unmanned vehicles, maintenance and spare part containers, and additional underwater weapons according to the mission needs. We can assume that the LCS has built-in handling systems for launching and recovering UUVs and built-in communication devices to communicate with the UUVs.

7. Technical Risk

Option 3 is based on the assumption that the LCS seaframe is operational. The only technical risk in option 3 is the additional modifications required to be made to the sea module and support module stations. These modifications, which include building a framework for the UUV's in the sea module station, and modifying containers in the support module stations, involve no real research and development, and thus have very little technical risk.

8. Cost

Option 3 has the potential for significant cost savings. Since option 3 uses the LCS seaframe as the basis for its design, no new hull costs are created. The only additional costs involved with option 3 are those modifications to allow the UUV system to deploy on the LCS seaframe. Specifically, two module stations will require modifications, the sea module station and the support module station. These modifications will require little acquisition costs, a minimum per unit cost, and a low life cycle cost (mostly due to quality assurance).

The sea module station will be required to be modified in order to support the storing, launching, and recovery of the Sea Predator and heavyweight UUV's. In addition, the sea module station must be capable of launching and recovering the lightweight UUV's. In order to support the Sea Predator and heavyweight UUV's an additional temporary frame will have to be installed in the sea module to provide support for these UUV's. Such a manifold will also have to support the necessary cable attachments required for power and information transfer. The lightweight UUV’s will be transferred to the sea module station via the LCS’s crane system; therefore they do not contribute to the additional cost of the sea module station.

The support module station will not have been modified per se, rather, the containers in the support module will have to be modified. These modifications include containers specifically suited for storage of the lightweight UUV’s, as well as the containers required for maintenance, repair parts, and support of all of the UUV’s. The cost of these container modifications coupled with the sea module modifications, mean an overall low cost option when compared with the construction of a new hull.

E. AOA METHODOLOGY

The seven categories that were chosen for the AoA were capability, deployability, survivability, endurance, flexibility, technical risk, and cost. They were chosen because each plays a key role in determining which option is would be best, and from the experience and knowledge gained from class. Each category was given a weighting factor, and the sum of the weighting factors was 100. This was done to make sure that the points for individual categories for each option could be determined separately and then to each other in order to find the highest ranked and therefore best option to choose.

Each category will now be discussed in order from the most number of points assigned to least. Capability was given 30 points because it is the most important category because the best option chosen depends heavily on how well it can get the job done. Capability includes speed, payload, number of sorties, time to complete mission, interoperability, and percent mission completion. Of these the most important were time to complete mission, percent mission completion, and interoperability. Those three categories were what were scored for each option and will be further discussed.

Deployability was given 20 points because traveling to the area of operations is essential for effective involvement and coordination in the actual operations. This also includes speed in terms of how long it takes to get to the area of operations, and independence from other assets once there.

Survivability was given 20 points and includes susceptibility, vulnerability, and recoverability. Susceptibility depends on detect ability, and what happens after the option is acquired, targeted, and hit. Vulnerability answers the whether the option will be killed after receiving a hit, and recoverability is how well and how fast the option can fix itself after being hit.

Endurance and flexibility were each given 10 points. Endurance includes time on station and ability to accomplish an underway replenishment (UNREP). Flexibility includes the number of missions each option is capable, and other missions it is capable of completing. The last two categories were technical risk and cost. Each of these were given 5 points. Technical risk included research and development and cost was simply how much the design and acquisition of each unit would be.

	Option #1 - Small Ship		Option #2- Medium Ship	Option #3 - LCS Module	
	1 Unit	7 Units	1 Unit	1 Unit	3 Units
Capability (30)	11	23	29	8	10
a) Time to Deploy Sensor Grid (15)	7	15	15	0	0
b) Interoperability (8)	3	3	7	7	7
c) Percent Mission Completion (7)	1	5	7	1	3
Deployability (20)	15	15	20	17	17
Survivability (20)	8	8	15	14	14
a) Susceptibility (7)	6	6	5	5	5
b) Vulnerability (7)	1	1	6	5	5
c) Recoverability (6)	1	1	4	4	4
Endurance (10)	5	7	10	10	10
Flexibility (10)	5	6	8	8	10
Technical Risk (5)	5	5	4	5	5
Cost (5)	3	3	1	5	5
Total Points (100)	**52**	**67**	**87**	**67**	**71**

Table 5. AoA Results Table

F. LCAC OPTION

1. Capability

The 30 points available in the capability category are divided into three subcategories: time to complete mission (15), percent mission completion (8), and interoperability (7). The LCAC option was given a score 7 if only one vessel is available because it cannot complete the mission in the allowed time. However, a single LCAC is capable of making two sorties and deploying eighteen Sea Predators, which is nearly 50% of the necessary units. If seven vessels are available the option was judged 15 out of 15, as a single wave of seven units can deploy as many as 63 Sea Predators. In interoperability the single vessel option was given a 3 due to its lack of a robust communications and C2 functionality. Likewise, the seven ship option was also given a score of 3 for interoperability. In the percent mission completion subcategory the option was given a 1 (single vessel assumption) due to the vessels inability to monitor the system, inability to perform command and control functions and the lack of offensive ASW weapons. With the seven ships from an ESG the option is judged 3 since it can fully seed and refurbish the grid. In total, for a single LCAC performing this mission the option received 11 out of 30 points and an ESG with 7 vessels received 23 of 30 points.

2. Deployability

This option was judged 15 out of 20 for the deployability category. The LCAC must be carried to the fight on an amphibious ship, which detracted from its score. It is not a large penalty since it is reasonable to expect an ESG to be present during this operational scenario.

3. Survivability

The 20 points available in the survivability category are divided into three subcategories: susceptibility (7), vulnerability (7) and recoverability (6). Susceptibility is the chance of a vessel being hit by an adversary's weapon. The LCAC earned 6 out of 7 points in susceptibility because of its small size, high speed and distance from the coast that it will operate at. The LCAC was given 1 out of 7 because it was judged likely to be destroyed by any weapon of significant size. The LCAC was given 1 out of 6 because of its small crew size and limited damage control facilities. When totaled, this option received 8 of the available 20 points. The same score applied to a single vessel or the wave of seven units.

4. Endurance

This option was scored a 5 out of the 10 points available in the endurance category for a single LCAC. The LCAC's limited sortie time detracted from the score. It was also hurt by its inability for underway replenishment. The vessel must return to an amphibious ship to refuel. After five consecutive days of use it is estimated that 25% of these vehicles will be unavailable due to preventative or corrective maintenance. This lack of reliability also contributed to the slightly reduced endurance score. A wave of seven LCACs earned a grade of 7 out of 10 points, as the increased number of units increases the likelihood of having enough serviceable craft to continue grid sustainment operations.

5. Flexibility

The LCAC option was given 5 out of 10 available points for flexibility for a single craft. The vessel has many uses and any replacement would be at least as capable. LCAC's are used in amphibious assaults carrying troops and equipment from ship to shore, certain mine warfare applications and other uses shown in section IV. A wave of seven was scored slightly higher, at 6 out of 10. This is because as only 5 LCACs are needed to seed the first wave, the other two LCACs could be loaded with other equipment such as mobile air defense batteries, or a "Harpoon-in-a-box" type weapon.

6. Technical Risk

The LCAC was scored as 5 out of 5 due to the low technical risk involved in this option. The vessel uses proven technology that would also be required in the replacement. Gas turbines and fans have been studied extensively and many manufacturers are available for a project of this type. Given this information a maximum score was assigned to both the single ship and wave of seven.

7. Cost

This option was given a score of 3 of 5 for the cost category. This option involves designing the next generation LCAC which implies some cost. The technology is mature and the cost is limited. With this in mind, a medium score was given for both configurations.

G. MID-SIZE SHIP OPTION

1. Capability

For the time to complete mission subcategory the mid-size ship was given the maximum score. Since the vessel will be designed from the ground up for this mission, it is assumed that it will be able to perform its function. It was also given the maximum score in the percent mission completion subcategory for the same reason. This option scored 7 of 8 in interoperability due to the complexity of the systems involved. Overall, this option received 29 of the 30 points.

2. Deployability

The mid size ship was given the maximum score in deployability. The vessel deploys itself and is large enough to sustain itself while traveling to the operation area. This option could also be forward deployed and respond more quickly.

3. Survivability

In the susceptibility subcategory, the mid size option received 4 of 7 points. It is larger and slower than the LCS but could contain some level of offensive capability to destroy the threat before the enemy could find and hit it. It may also have some self defense capability that may contribute to its score. The mid size ship received 6 of 7 points for vulnerability because it is larger and more able to sustain a blow than any of the other options. As the largest option with the largest crew and most damage control ability the mid size option scored the highest in recoverability, 5 of 6. In total, the mid size ship was judged a 15 of 20 in survivability.

4. Endurance

The mid size ship was given all of the available points in endurance because the ship can UNREP and stay on station indefinitely.

5. Flexibility

The mid size ship was judged to be able to be designed with significant flexibility. This accounted for the high score of 8 out of 10. Clearly, the vessel will have ASW and C2 inherent capabilities. The large UUV payload also makes this an ideal for conducting MIW, battlespace reconnaissance, and hydrographic research missions.

6. Technical Risk

This option faired will in terms of technical risk, and was rated as 4 out of 5. It is assumed that the ship will borrow heavily on proven technology minimizing the risk.

7. Cost

The mid size ship requires a complete design and manufacture. This makes the option the most expensive and justifies the score of 1 of 5. The more similar to other existing vessels the ship is, the lower the cost will be.

H. LCS OPTION

1. Capability

In the time to complete mission subcategory the LCS module option received 0 points regardless if only one vessel or a LAG with three vessels was considered. This is because neither configuration can meet the 240-hour time limit. This option scored 7 of 8 in interoperability for both configurations. As in the Mid-size ship option, it is assumed that perfect interoperability is not possible, but the LCS is designed to operate in the joint environment. If one vessel is available, this option received 1 of 8 points in the percent mission completion. With three vessels operating a score of 3 of 8 was awarded. The LCS design was simply not made to carry the large number of UUVs needed in our scenario. As stated earlier, fourteen units are needed to meet our timeline. In total, the LCS option received 8 of 30 for 1 vessel and only slightly better at 10 of 30 if 3 ships are in theater.

2. Deployability

The LCS module was judged 17 of 20 points in deployability. The vessel can deploy as part of a larger force or independently, which accounts for the high score. However, as noted, as the payload becomes more specialized, deployability goes down. The Sea Predator payload is highly specialized, and resulted in a 3 point deduction from the maximum possible score.

3. Survivability

In the susceptibility subcategory, the LCS option received 5 of 7 points. It is larger and slower than the LCAC but could contain some level of offensive capability to destroy the threat before the enemy could find and hit it. The LCS scored a 5 of 7 in vulnerability. It is certainly much less vulnerable than an LCAC type vessel but its smaller size makes it more vulnerable than the mid size ship. The small crew size and possibility of fewer damage control systems than a mid size ship contribute to the lower score in recoverability of 4 of 6. Together, the LCS received 14 of the 20 points available in survivability for both the single ship and the LAG of three units.

4. Endurance

The LCS was given all of the available points (10) in endurance because the ship can UNREP and stay on station indefinitely.

5. Flexibility

The LCS received a score of 9 of 10 in flexibility for the single ship case. The LCS design is highly flexible, and accounts for the high score. However, as in the case of deployability, the specialized Sea Predator payload limits the amount of flexibility for a single ship. The LAG was given a score of 10, as each of the three ships could be given a slightly different C2 and weapons loadout, thereby regaining some of the flexibility lost due to the specialized payload.

6. Technical Risk

The LCS received all of the points (5) in technical risk category. The vessel is already designed and this option entails only the design of the storage and deployment system for the Sea Predator and its related equipment.

7. Cost

This option receives the maximum score (5) in cost. The only cost is involved in the design and manufacturing of the storage rack system for the cargo.

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IV. DEFINING THE REQUIREMENTS

A. INITIAL REQUIREMENTS

SEA-8 mandated that the Total Ships Systems Engineering team design a system capable of detection, tracking, classification, and prosecution of the four identified 2025 ASW threats (diesel, AIP, nuclear submarine, or UUV). The system must also be capable of reduction of enemy threat performance, able to transmit and receive communications, data and ISR information across a secure and survivable distributed control network. From the SEA-8 employment perspective this meant:

- The system must have sensor assets capable of providing a P_d of 0.5 across one harbor waterway (6,700 nm^2) within 72 hours of initiation
- The system must have sensor assets capable of providing a P_d of 0.8 across a contested operating area (1000 nm^2) within 10 days
- The system must provide the logistic support necessary to sustain the system of systems for 10 days.

With these preliminary top level requirements as a basis, the TSSE team then derived more specific functional and operational requirements that would determine the TENTACLE design. These requirements are delineated in Appendix III.

B. REQUIREMENT DEVELOPMENT

The TSSE design team first designated a sub-group consisting of one member each from the HM&E, Payload, and Combat Systems teams to develop a preliminary list of requirements. This sub-group reviewed the initial requirements provided by SEA-8 and examined the guidance set forth in the 2005 TSSE project document (Appendix I).

In order to gain an understanding of the design problem and possible solutions, the team also reviewed the UUV Master Plan.

1. The Threat and the Operating Environment

Unclassified details of technologically feasible threats in 2025 are listed in Appendix VII.

The Operating Environment is expected to encompass both blue water and littoral areas. A typical Harbor Gate scenario has the TENTACLE starting in a friendly port with a full load-out, pending assignment. Once tasked, the vessel will commence a fast transit for up to 2400 nm, via any navigable seas, to a stand-off point that is 200 nm away from the area of operation. Therefore, in the Harbor Gate scenario, the TENTACLE will always be at least 200 nm from the hostile coast. The TENTACLE will then deploy UUVs that independently swim the final 200 nm to the area of operation. The UUVs deploy a sensor and communications network meeting the probability of detection requirements of the mission. The TENTACLE will maintain this 200nm stand-off distance throughout the monitoring and persecution of the threat – the UUVs will transit back to the TENTACLE "mother ship" for recovery, recharging, and maintenance.

The TENTACLE is anticipated to be a flexible, versatile platform, and other types of missions such as mine warfare, maritime interdiction, home land defense, or anti-submarine warfare without the extensive use of UUVs may require operation in the littorals.

2. Detailed Requirement Development

To begin this requirement development process, the team was divided into three sub-groups; HM&E, combat systems, and payload. Each sub-group then generated a list of specific requirements that the TENTACLE must satisfy to effectively meet both the initial requirements set forth by SEA-8 and the more specific and extensive self-imposed requirements.

a) Ship Capabilities and Characteristics

It was determined that while the primary mission of the TENTACLE is to deploy, retrieve, and regenerate large-size UUVs in the "harbor gate" scenario, it also makes sense to design a flexible vessel that will be a competent participant in other warfare areas, such as Anti-Submarine Warfare, Mine Warfare, Maritime Surveillance, and Home Land Defense. The TSSE team decided the ship must be capable of independent, trans-oceanic voyages in order to be a self-sustaining, deployable warship.

b) Combat System Capabilities

The primary combat system is the "system of systems" in which the ship plays a central role in the transportation, deployment, maintenance, and recovery of the UUVs that actually do the detection, tracking, classification, and prosecution of enemy submarines.

A key concept was that the TENTACLE must be a warship capable of participating in its own self-defense. The self-defense capabilities of the TENTACLE would be short-range systems, relying on other friendly forces in company for protection from long-range threats.

c) Payload Interfacing

This team was tasked with developing notional requirements that define the amount and type of cargo that the TENTACLE will be required to carry (tons and volume at a minimum). The number and size of UUVs was the main concern.

3. Final Development

All of the sub team requirements were thoroughly analyzed by the entire TSSE team before selecting the final list of requirements for which the TENTACLE would be designed to meet. In some cases the same requirement was developed by more than one group, and in other cases the team decided that a requirement was not realistic or necessary. Two weeks of class time was spent by the TSSE team reviewing and analyzing each requirement in order to develop the final list. The output of this final requirements development included a table of critical design parameters, which is included here as Table 6

Category	Threshold	Objective
Operational Availability	0.85	0.95
Hull Service Life	20 years	30 years
Draft @ Full Load	8 m	5 m
Max Speed	30 + kts	40 + kts
Range @ Max Speed	1000 nm	1500 nm
Range @ Cruise Speed	3500 nm	4500 nm
Large UUV Capacity	40	50+
Hvy Wt UUV capacity	80	100+
Cargo Weight	400 MT	800 MT
Cargo Volume	5000 m^3	6000 m^3
Small Boat (7 m RHIB)	1	2
USV (11 m RHIB)	1	2
UUV/USV/UAV Launch Recover	Sea State 3	Sea State 4
Aviation Support	One 7000 lb VTUAV	VTUAV (2)/ SH-60R
Aircraft Launch / Recover	VTUAV	VTUAV/SH-60R
UNREP Modes	RAS, CONREP, VERTREP	RAS, CONREP, VERTREP
Core Crew Size	≤130	≤ 100
Crew Accommodations	130	130
Provisions	30 days	45 days

Table 6. Critical Design Parameters

V. DESIGN PROCESS

A. PAYLOAD DESIGN

1. Stowage Spaces

a) UUV Cargo Area

The layout of the Main deck is shown in Figure 19. There are 4 points of access for launching or retrieving of the waterborne vehicles the SEA TENTACLE can carry. There are two ramps located on the ships' centerline between the hulls. One is in the aft compartment and another two compartments forward. Surface vehicles will be launched and retrieved from the aft ramp, as there is insufficient clearance under the hull for the forward ramp. There are two side doors in the third compartment forward for launching and retrieval of large UUVs. These doors are the primary method of retrieval, while the ramps are preferred for launch. Launching large UUVs from the ramps ensures a level of covertness that cannot be matched with the side doors.

The aftermost compartment of the main deck contains one rigid hull inflatable boat (RHIB), one unmanned surface vehicle (USV), and two small boats. The RHIB and USV are stored on either side of the aft ramp and one small boat is outboard on each side. A forklift type device is stored forward of the starboard small boat to be used for moving spare equipment for installation to the UUVs. All of these surface vehicles are handled with the Overhead Hoist Array System (OHAS), to be discussed below, and secured to the deck with the Deck Latch mounting system.

Forward of the small boat on the port side lays a UUV workshop. This is utilized for non-routine maintenance, repair and refitting. Large UUVs have multiple payloads and they will be reconfigured in this space as well. In the same area on the starboard side is the helicopter deck access hatch which is typically kept clear.

In the next compartment forward 12 large UUVs are stored stacked 2 high roughly along the centerline. Two WLD-1s are stored outboard the second row, and a ladder well is outboard of that on each side. Outboard of the first row of UUVs in this section is an intake for the engines below. On each intake wall 5 battlespace preparation UUVs are stored. Just forward lay 8 spare battery units and 8 processing modules. These 12.75” UUV like devices are used inside large UUVs.

Just forward on centerline is the second ramp. Outboard of this ramp on each side are 6 large UUVs arranged in two rows of three, stacked two high, for a total of 24. Two side doors are in the forward corner of this compartment on each side.

The next forward compartment contains 12 more large UUVs, centerline in two rows of three, stacked two high. In the aft port corner five columns of torpedoes are stored five high. Just forward on the port side missiles are stored in two groups, each five wide and seven high for a total of 70. Missiles and torpedoes are alternative payloads for the large UUVs. In the forward corner on the port side is another engine intake. Along the wall of the intake, Semi Autonomous Hydrographic Reconnaissance Vehicles (SAHRV) are stored. On the starboard side, the aft corner is filled with extra Ranger type units to be installed or interchanged. Just forward lay extra sled subassemblies, also used as spares. In the forward starboard corner is the final engine intake with sidescan sonar units installed in racks along the wall. These units are another alternative payload for the large UUVs.

The next forward compartment is dedicated to habitability. There are two ladder wells in the aft corner of the compartment, port and starboard. Inside on this area is a large recreation facility and gymnasium. Forward of this is overflow berthing and the study area. This compartment is vital to some of the secondary missions of the SEA TENTACLE. The ship may perform a number of missions requiring extra personnel, and while all military personnel need to stay in good physical condition, it is more important for the crew of this ship. It is anticipated that long strenuous hours would be spent launching and retrieving UUVs near hostile coasts and the crew would need the time in the gym to wind down.

The forwardmost compartment on the main deck is an equipment space with VLS tubes and support.

There are several key parts of the payload bay design. One is the UUV handling system. This system allows for greater space efficiency and flexibility. Another is the system of access points with two ramps and two doors built into the hull. This design feature allows for covertness and increased reliability. A final critical point in the design is the layout of the bay itself. This layout allows for fast deployment, ease of maintenance, and a low, central center of gravity for better ship handling characteristics. While these three central points of the design must work closely together for the best possible cargo bay, each was selected separately on its own merits.

The UUV architecture is the central component of the ASW system, and the SEA TENTACLE is built around this system. With the large number of vehicles required for an effective ASW capability over a large area, the handling system inside the ship is absolutely critical. Different alternatives considered for the handling system were grouped into deck mounted systems, and overhead systems. Deck mounted systems envisioned ranged from a simple forklift to an omni-directional vehicle. Overhead systems evaluated were a crane and the Overhead Hoist Array System (OHAS).

An analysis of alternatives was conducted for the handling system between the OHAS, floor rails, a conveyor, an omni-directional vehicle, and a forklift. Several attributes were weighted based on relative importance with a weight from 0 – 1 summing to 1. The alternatives were then given a score from 0 – 10 on each attribute and the scores summed to determine the best alternative.

The Overhead Hoist Array System is an X – Y – Z-axis transport system consisting of guide rails mounted in the overhead and a number of electric hoists. The hoists move along the guide rail system in an X – Y plane with the ability to raise and lower objects accounting for the Z direction. Each UUV, when supported by hoist, is attached at 8 points by individual arms that operate in unison. Two arms are attached to a rail motor forming an upside down V shape. Four rail motor assemblies and the associated V arms support each UUV. Each assembly consists of an electric motor used for moving the UUV along the rail system, or raising and lowering the UUV, and two hollow telescoping arms with cable running through them and the connection point to the UUV. The forward portion of the UUV is supported by two rail motor assemblies, port and starboard, as is the aft portion. When the cables are fully withdrawn, the rigid telescoping arms contact the UUV and hold it firmly in place in all directions. The UUVs are stored and moved in this condition. All of the second level UUVs are stored on the hoist system while the first level units are firmly attached to the deck. The rail motors operate in unison when moving a UUV transversely or longitudinally, or when raising or lowering a unit. The rail motors turn a pinion on a rack mounted inside the rail system to move the UUVs along the rails. Since the motors operate in unison a constant spacing is maintained. When switching between the lateral rails and the central longitudinal rail the rail motor and pinion rotate 90° and lower slightly to mesh with the next rail's rack. The UUV can be transported to either ramp or door for launch.

The floor rail system is similar to that used in a submarine torpedo room. A train track like system of rails is mounted in the floor. Electric motors drive the UUVs and sled subassemblies to the desired location. The grooves in the floor mirror the guide rail system in OHAS. The conveyor system is a similar deck mounted system in which side conveyors feed a main longitudinal conveyor centerline. In the chosen launching system this central conveyor leads to the ramps. An omni directional vehicle is a wheeled unmanned cart that carries UUVs throughout the bay, from storage to launch point. A forklift was considered for completeness. A bridge crane was considered but eventually discounted because of the extreme danger of a single point of failure losing the full capability of the system and the slow operation related to moving only one vehicle at a time.

The analysis of alternatives was conducted by the SEA TENTACLE payload team of experts. The relevant attributes were space efficiency, reliability, speed, flexibility, security, and cost. Space efficiency, weighted at 35%, is the ability of the handling system to store and move UUVs utilizing the available space to the maximum extent possible. Space efficiency is the most important attribute because the SEA TENTACLE is designed around the UUV subsystem and should be only as large as necessary to support this subsystem. The handling system affects the size of the ship through it’s ability to move and store UUVs efficiently. The OHAS received the maximum score in this attribute because it utilizes a complete second level for UUV storage, allowing 48 large UUVs to be stored on a single deck. It is easily the most space efficient alternative among those considered. Floor rails and the conveyor system received a score of 5 as they allow close spacing and movement but they are not suitable for a 2 level storage system. The omni directional vehicle was given a similar score but requires slightly more space thus lowering the overall space efficiency. The forklift received a somewhat higher score due to its ability to utilize at least a portion of a second level with a rack storage system in place. This ensures a higher spatial efficiency than the other deck-mounted systems. Clearly the OHAS is the best candidate in terms of the most important attribute, space efficiency.

Reliability was regarded as the next most important attribute and weighted at 25%. Reliability was defined as the systems durability and ability to continue to function in the presence of failures. It is important to recall that the handling systems work closely with launching systems in these attributes, but each alternative was judged in terms of a common environment. Reliability of the handling system is important to the SEA TENTACLE because the handling system is vital to the launch and retrieval of the UUVs, which are the central part of the vessels mission. The OHAS was given a score of 6 for this attribute because of the complicated nature of the system. This was mitigated by the many alternate means to operate with a single or combination of failed hoists. Floor rails and the conveyor were given higher scores because of their relative simplicity and mature technology. The omni directional vehicle suffered because it is based on a new technology susceptible to a single point of failure. The forklift is also susceptible to a failure but is proven in such applications.

Speed was weighted at 20%. This is important to the ships mission as the requirements state the need to deliver a sensor system to a critical area quickly. Therefore it is vital for the handling system to move the UUVs to a launch point quickly. The OHAS received the highest score for this attribute because multiple UUVs can be moved simultaneously and quickly anywhere in the cargo bay to any number of launch points. Floor rails and the conveyor are considerably slower but multiple vehicles are moved simultaneously, mitigating the score. The omni directional vehicle and the forklift were judged to be much slower, moving one UUV at a time. Even teams of vehicles or forklifts would still be slower, each moving a single UUV.

Security was judged to be the next most important factor. Security to the ability of the handling system to store the cargo safely and rigidly, preventing damage in rough seas or during attacks by hostile forces. The OHAS was scored as 6 out of 10 because the large UUVs suspended by hoist system may be somewhat vulnerable in violent motions. Floor rails received the highest score because of the firm attachment to the deck at all times and the conveyor was only slightly worse. The omni directional vehicle and the forklift were considerably worse as neither is secured to the vessel during motion and the attachment of the UUV to the transport is a weak link.

Flexibility is the next most important factor when choosing between the alternatives. Flexibility was weighted at 5% and defined as the ability of the system to handle various types of cargo. UUV technology is advancing rapidly and one can be certain new vessels will be designed during the lifetime of the SEA TENTACLE. The ship is also required to carry a number of different vehicles including Rigid Hull Inflatable Boats (RHIBs), Unmanned Surface Vehicles (USVs), WLD-1 minehunting vehicles, and small boats. The OHAS was highly rated in flexibility, receiving a score of 10. The variable attachment points and options make this system very attractive for any type of cargo. While rail spacing is constant, the rail motor assemblies can be spaced as necessary with any number of attachment points. Floor rails received a similar score, lowered slightly for the number of attachment options available.

The conveyor system received a 5 because of the constant belt. If the system is designed for a 10 foot long UUV it is difficult to work with a 30 foot long RHIB. The omni directional vehicle suffers from similar effects to a greater extent, and received a lower score. The forklift was judged to be even more limited.

Cost was the last attribute making up the final 5%. While cost is important in any military vessel, the cost of the handling system for this vessel is less important. This vessel must carry a large number of UUVs to the battlefield safely and efficiently. As mentioned earlier, the ability of the handling system to use space efficiently has an effect on the size of the ship, which is a huge cost driver. A cheaper handling system may only utilize a single level of UUV storage requiring a larger ship and the overall product would be more expensive. Cost is only important to a point. The OHAS was given the lowest score in this group of alternatives due to the costly overhead rail system and the many hoisting mechanisms required. Floor rails and conveyors were given intermediate scores due to their simplicity and few required modifications to the basic cargo bay. The omni directional vehicle scored higher still and the forklift was given a higher score simply because the vehicle itself is cheaper.

The results of the analysis of alternatives are presented below in the table. The OHAS was the chosen alternative by a wide margin because it does the important things well. While it is the most complicated system, it is a necessary choice for the SEA TENTACLE. This ship will be the Navy’s premiere UUV mother ship and must be able to handle large numbers of UUVs quickly, easily, and efficiently. The Overhead Hoist Array System is the best way to accomplish this requirement.

Handling Systems						
Attribute	**Weight**	**OHAS**	**Floor Rails**	**Conveyor**	**Omni Dir Vehicle**	**Forklift**
Space Efficiency	0.35	9	5	5	4	6
Reliability	0.25	6	8	8	5	6
Speed	0.2	10	5	6	4	3
Security	0.1	6	8	7	4	3
Flexibility	0.05	10	7	4	6	5
Cost	0.05	3	6	5	7	8
Total		**7.9**	**6.2**	**6.1**	**4.5**	**5.15**

Table 7. Handling Systems AoA

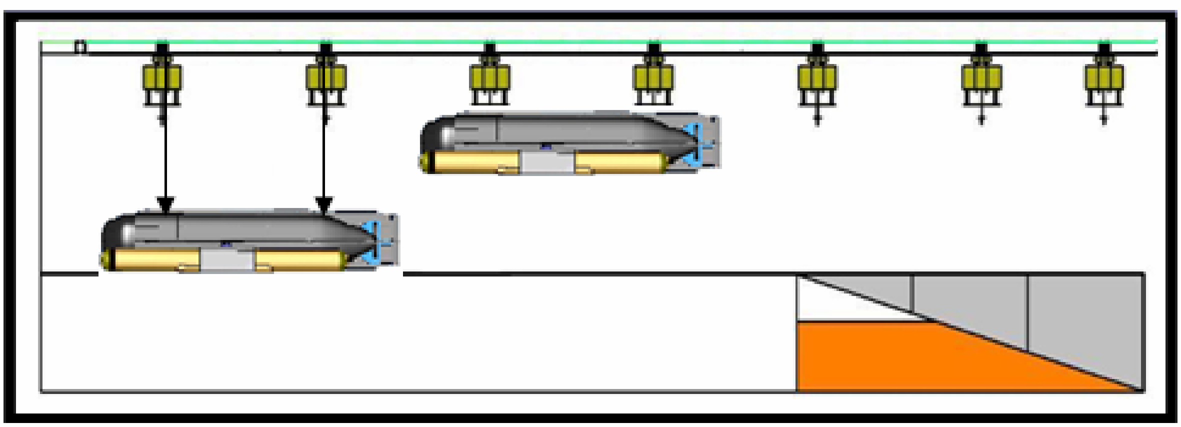


Figure 17. Overhead Hoist Array System

The launching/retrieval system is also vital to the ship's mission since the large number of UUVs play a central role. Several alternative were considered and an in depth analysis was undertaken. Doors and ramps were considered in various combinations, and a bridge crane was added for completeness. The most aggressive alternative consisted of 2 doors and 2 ramps (2D2R). This alternative places a door on each side of the ship with folding extensions of the overhead rail system to extend the rails outside the hull. The OHAS can then move the large UUV through the open door and lower it into the water. The ramps in all alternatives are centerline for access to the water between the hulls. In all alternatives the aft ramp utilizes a variable cradle. This allows a variety of vehicles to be retrieved quickly and safely. All USVs and RHIBs would be retrieved with this ramp. With this in mind, the 2D2R option contains a door on each side and a ramp centerline about amidships and a second ramp in the stern. The 1 door 1 ramp (1D1R) version places the ramp at the stern and a single door in the third forward compartment. The 2 ramp (2R) alternative consists of centerline ramps fore and aft and the 2 door (2D) option is a door on each side of the ship.

The analysis of alternatives was conducted for the launching system between these alternatives by the payload team. Several attributes were weighted based on relative importance with a weight from 0 – 1 summing to 1. The alternatives were then given a score from 0 – 10 on each attribute and the scores summed to determine the best alternative.

The relevant attributes were covertness, reliability, integrity, speed, flexibility, security, technical risk and cost. Covertness was considered to be the most important characteristic and weighted at 30%. Even though the ship will generally launch UUVs 200nm from an enemy point of interest, it would severely degrade the ships mission if that enemy knew the ship was deploying UUVs. If a country felt threatened they would be watching the coast and far out into the ocean. If they were alerted to the presence of the UUVs and they would actively seek them out. If the UUVs are launched covertly there is little of no risk of enemy intervention. Reliability was judged the next most important factor and weighted 20%. It was defined as the ability of the system to operate durably and continue to operate in the presence of one or more failures. If a ramp becomes stuck or a power source in the ramp fails and that is the sole launch access point, the system is not reliable. If there are multiple access points the probability of them all failing is low and the reliability is higher. Integrity was the next considered. Integrity was weighted 15% and defined in terms of the hull strength when the access point is installed. More access points tends to weaken the structure and lowers the score for integrity. Speed was judged to be equally important. The ship is required to launch UUVs quickly to perform its mission. The faster the ship can launch the UUVs the less time it must spend loitering near the area to be monitored. If the launching system could launch from 1 point it would be slower than a multiple access point system. The next attribute is flexibility. It was weighted 10% and defined as the ability of the system to handle different types of vehicles and to operate in different modes. Currently, the ship must launch and recover boats of various sizes, large UUVs, and the WLD-1 mine hunter. Over the lifetime of the ship one could expect other payloads to be developed as well. The launching system must be flexible enough to function with a large variety of vehicles. As defined, flexibility is also concerned with the ability of the system to operate in multiple modes. This implies a system that can utilize multiple access points simultaneously scores higher in flexibility. Technical risk was the next factor considered and weighted at 5%. As the complexity of the system increases the technical risk score decreases. Cost was the final attribute considered and weighted at 5%. Again, complex systems will cost more and receive a lower score.

Any system with a ramp included received the maximum score for covertness. While the interior ramp is the most covert, even a stern ramp launch leaves the large UUV at the waterline and the ramp itself is undetectable from a distance. The 2D system received a 3 as it was determined that the launching process out a door in the side of the hull is not only detectable but may actually draw attention.

Reliability was considered next. The 2D2R system received the maximum score. With multiple access points of two different types this system is clearly the most reliable. The durability difference between door operation and ramp operation was not known and not considered in the analysis. The 1D1R system received a 7 because it still retains two types of access points. A fault that causes all doors to fail will not disable this system. The other systems received a 5 for this reason. These systems fail completely in the presence of a fault common to a particular type of launch access point.

Integrity considerations caused the 2D2R system to be judged a 5. This system has twice as many hull openings as the other systems. This weakens the hull and lowers the score. The other systems were given a score of 7. It was difficult to determine whether a door or ramp would have a larger effect on the catamaran so they were considered equal. The other systems have fewer openings and generated a higher score.

The 2D2R system received a score of 10 for the speed attribute. The system could launch from 3 points at the same time and the aft ramp could be raised and lowered in turn raising the launch rate even more. The 1D1R option was the next fastest but graded significantly lower with only half the launching points. 2R and 2D systems were rated slightly lower with a single type of launch point. The 2R system cannot launch UUVs simultaneously and thus would be slower than 1D1R. In general, one would not launch from two open doors simultaneously accounting for the lower 2D score.

The 2D2R option was given the highest score for flexibility. With two of each type of access this system is conceptualized with the future in mind. New UUV payloads may only fit through one type of access point, or may only be stored in a certain location, so the most flexible configuration combines these attributes. 1D1R was the next most flexible, offering both types of launching points. The 2D and 2R systems were rated slightly lower.

The 2D system received the highest ranking in technical risk. Since doors are already available in ship construction, the doors required for the SEA TENTACLE are the least risky. Ramps entail more risk, especially for a catamaran, because this is a new idea requiring special structural support. The 2D2R and the 2R systems were rated the lowest and the 1D1R system received an intermediate score.

The final attribute considered was cost. The scoring was similar to that for technical risk. The 2D system was given the highest score as the technology exists and has been demonstrated. The 1D1R system was ranked next with only 1 of the more expensive ramps. The 2R system was next and the 2D2R was last with the most openings.

The 2D2R system emerged as the clear winner, as shown in the graphic below. While there is a penalty in risk, cost, and integrity, this system is clearly the most forward looking and capable.

Launching Systems					
Attribute	**Weight**	**2 Doors 2 Ramps**	**1 Door 1 Ramp**	**2 Ramps**	**2 Doors**
Covertness	0.3	10	10	10	3
Reliability	0.2	10	7	5	5
Integrity	0.15	5	7	7	7
Speed	0.15	10	6	5	5
Flexibility	0.1	10	8	6	6
Tech risk	0.05	5	6	5	7
Cost	0.05	3	7	6	8
Total		**8.15**	**7.4**	**6.65**	**4.75**

Table 8. Launching System AoA

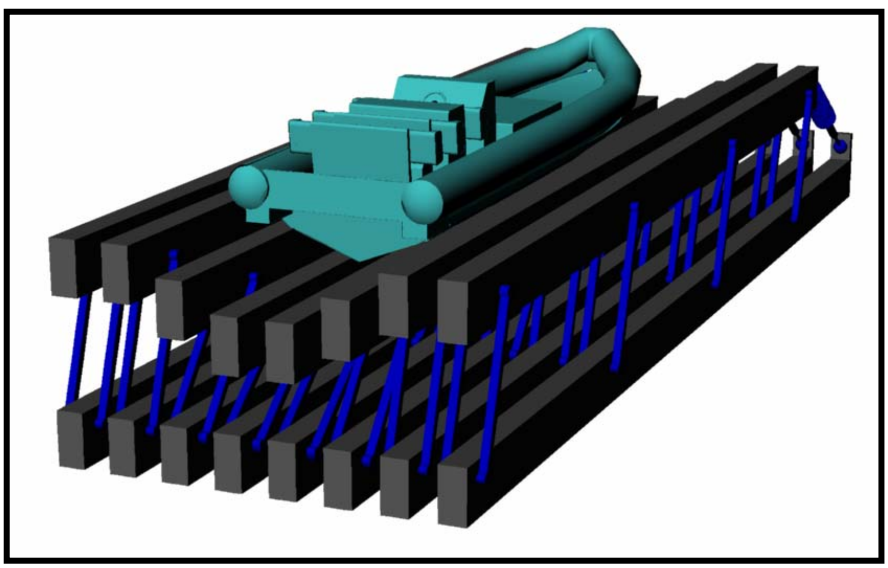


Figure 18. Variable Geometry Ramp

With a handling system and launching system in mind, the overall layout of the payload bay was considered next. While a strict analysis of alternatives was not conducted for this choice, care was taken to design the best possible arrangement. The myriad of choices made in this design made an analysis of alternatives prohibitively difficult. Weight distribution was considered. It is important to keep as much weight low in the vessel as possible for better handling and stability. Unfortunately, due to the large number of UUVs required for the ships mission, UUVs were stacked in two levels. This is more efficient use of the space thereby keeping the overall size of the ship as small as possible. It is just as important to keep the weight as close to the centerline as possible. As many of the large UUVs as possible were placed along the centerline as possible, given the ramp type access points that had to be placed between the hulls. The engine intakes, which are very light, are placed outboard, increasing stability. Due to the requirement for quick deployment of UUVs, care was taken to store them as close to the access points at possible. Figure 20 shows the large UUVs immediately adjacent to three of the access points and very close to the second ramp. This allows for the fastest possible UUV deployment. RHIBs and USVs are also placed close to the second ramp for easy deployment, retrieval and storage. The spare equipment is stored both close to the UUVs, and in pockets of otherwise unusable space. The spare equipment is light compared to the UUVs and all spares are placed outboard. Not only is this positioning positive for stability considerations, it provides for faster, easier maintenance with no UUV relocation necessary and efficient use of space. There is sufficient space around the UUVs for the crew to perform maintenance and each vessel has a battery charging connection at its storage location.

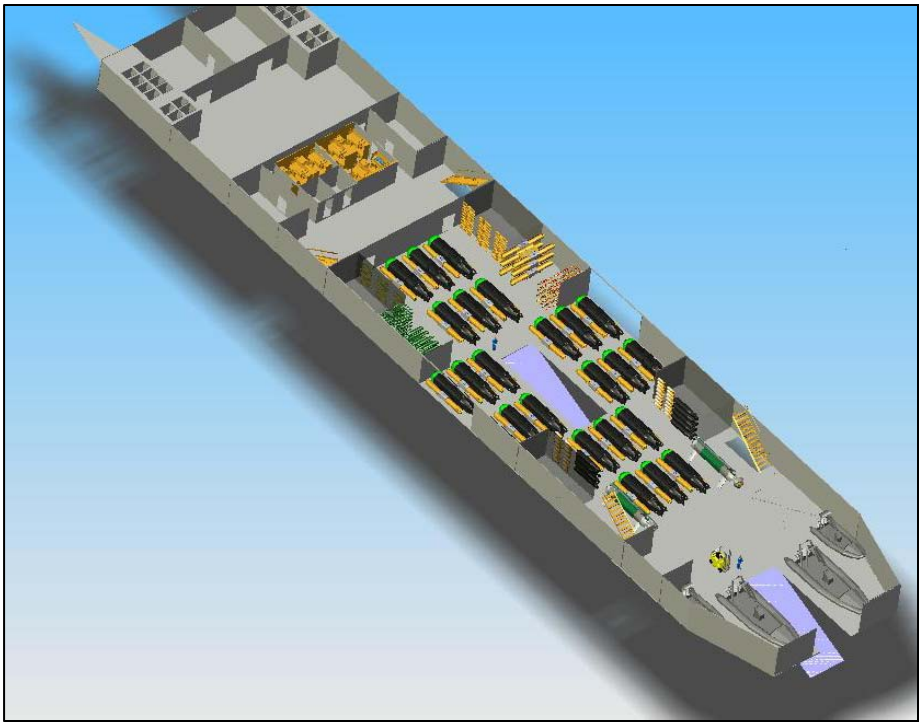


Figure 19. Cargo Deck Layout

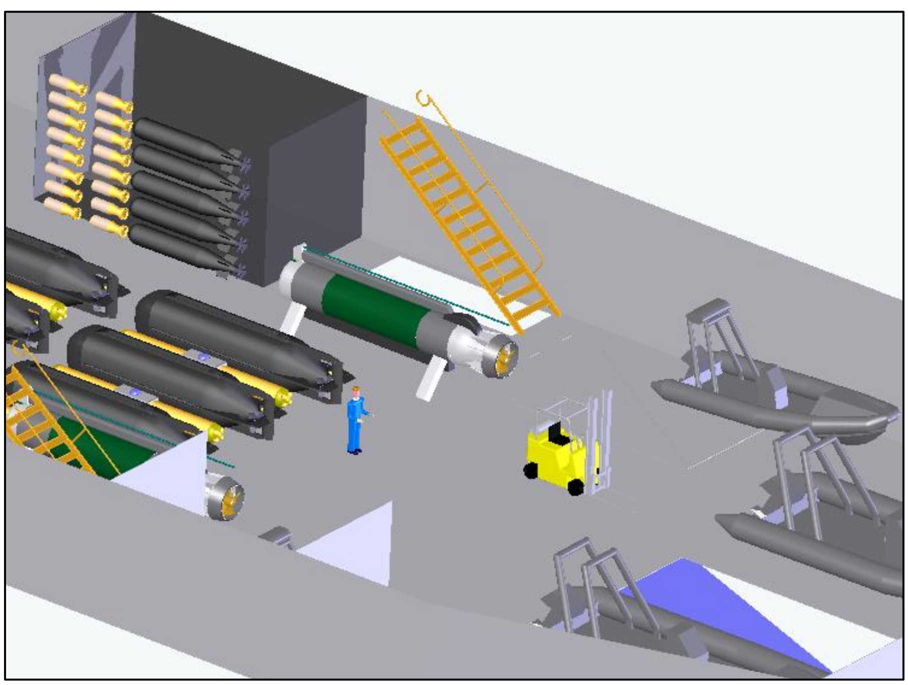


Figure 20. Close up view of Cargo Bay

b) Aviation

The SEA TENTACLE is equipped with two SH-60R helicopters. This aircraft contributes to the ASW mission, is reconfigurable for minehunting, and will be very significant in search and rescue, maritime surveillance, special operations, and humanitarian missions.

The SEA TENTACLE has a 20m x 25m landing deck aft of the superstructure. The deck is equipped with a Recovery Assist, Secure and Transverse (RAST) system used in landing and on deck mobility. The hangar is directly forward of the landing deck in the center section of the after main deck. It measures 7m x 15m and contains 2 SH-60Rs and 2 Firescout VTUAVs. The SH-60Rs are stored side by side and take 12.5 m of the length and each Firescout takes up 7 meters. Each of the VTUAVs will be modified to use wheels instead of skids, which unlock only when attached to the RAST handling system. The handling system is also used for moving the vehicles to and from the hangar, adjacent to the landing deck. Along the walls of the hangar, rack storage systems contain the equipment for converting the helicopters for other missions.

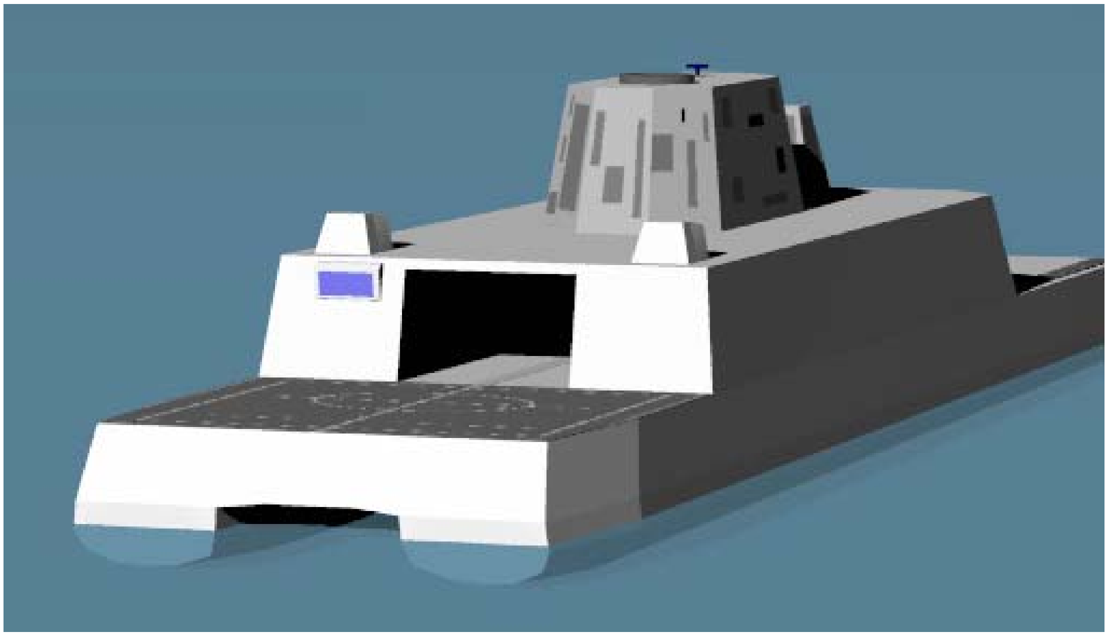


Figure 21. Helo Bay

2. Living Spaces

The living spaces aboard Sea TENTACLE are designed in accordance with governing U.S. Navy Regulations concerning habitability (Refs. OPNAVINST 9640.1A and the Shipboard Habitability Design Criteria Manual). These accommodations provide for significant recreational areas complete with several lounges, a fully-equipped gym with nautilus, free-weight and aerobic equipment, and a separate berthing area that can support twenty additional crewmembers when needed. In order to allow for modularity and to reduce wasted space, all the berthing spaces are designed in standard modules. Although the specific size and layout of the modules are based on rank, each module does have its own associated sanitary space and allocated leisure and commissary spaces. The specifics of each ranks quarter is detailed as follows:

a) Officer Quarters

In the case of the Officer Quarters, there are a total of eight staterooms. Two of these staterooms are reserved for the CO and XO and each have individual sanitary spaces and lounges. Three of the staterooms are designed for the Department Head level officers with berthing and dedicated office space for one officer each. One of these staterooms has its own sanitary space while the other two share a sanitary space. This same arrangement is repeated for the Division Officer level officer staterooms with the difference that each of these is designed with double bunks vice single. The design of the sanitary spaces is unique in that by being attached to the staterooms with access to them gained through the staterooms and not directly from the passageways, it allows the crewmember to use the sanitary space without exiting his or her stateroom. Additionally, by designing two of each level of the junior officer staterooms with their own sanitary space, the gender requirements for ship's manning are essentially eliminated. The total areas of the CO's and XO's living spaces are each 140 sq. ft. with the junior officer staterooms each at 90 sq. ft. These areas include the sanitary spaces and the lounges in the case of the CO and XO. The Wardroom is designed with an accordion style bulkhead that can be opened for large briefings or closed to separate a leisure/recreation space from the messing space.

b) CPO Quarters

The CPO Quarters are modeled very similarly to the officer berthing described above with separate sanitary spaces and a shared messing space except that there are a total of 2 modules with each module designed to accommodate

5 crewmembers. The total area allotted for the CPO quarters to include the sanitary spaces and shared messing area is 700 sq. ft.

c) Enlisted Quarters

The Enlisted Quarters are designed in modules accommodating 15 crewmembers each with a total of 5 modules plus one extra on the UUV storage deck which can be used to for flex manning scenarios. Each module has its own dedicated sanitary space and lounge area. The total area allotted for the Enlisted Quarters, including the sanitary spaces and lounge areas is 2500 sq. ft.

d) Medical Spaces

The medical space in Sea TENTACLE is designed to be staffed by one to two Hospital Corpsmen with one of them being an Independent Duty Corpsman. With this in mind the medical space consists of two separate rooms, one equipped with an operating table and associated medical equipment and another that consists of two bunks joined by a fully equipped sanitary space.

e) Commissary Spaces –

The commissary spaces that provide for the Wardroom, CPO mess and Enlisted mess are designed to be serviced by an elevator system which significantly reduces the amount of manpower required to load and transfer stores. Additionally, the dry, frozen and chilled storerooms are located the main deck and thus also reduce the amount of work required for stores transfer.

B. COMBAT SYSTEM DESIGN

Design and selection of the combat system suite for the SEA TENTACLE was an integral part of the overall design process. Details of the combat system design are presented in Appendix XII, while a detailed description of the Radar Cross Section calculations is found in Appendix XIII.

C. HULL DESIGN

Designing a ship much more than just choosing or designing specific equipment to support functionality. It is, rather, the integration of systems and equipment to optimize the balance of maximum performance with minimum cost. The process is inherently multi-disciplinary and decidedly iterative.

The design process for a naval warship must follow very specific steps and comply with several fundamental physical laws in order to achieve a balanced design. Many of these laws are very basic, such as hydrostatic balance, resistance-to-powering balance, and structural stress-to-integrity balance. These properties must be satisfied just to provide the most essential qualities such as ensuring the ship will float, move, and is able to be steered. Mastery of much more complex physical laws is required for increased effectiveness and decreased cost, demanding considerations for matters such as passive versus active-defense tradeoff and hullform versus producible design.

This is both a management and an engineering-mathematical challenge. The management portion consists of extracting feasible requirements and meaningful boundaries and constraints from the customers. The engineering-mathematical aspect is developing a physical solution to the given system variables that is a robust and accurate optimization of the requirements. As stated previously, the process is highly iterative in nature. Decisions may be made sequentially or in parallel. However, premature parallel development of "downstream" events may be superseded by changes made to earlier stages. This necessitates rework due to the coupling of many events. Iteration is necessary by the degree of imbalance among stages. Specifically, effort is expended to optimize system objectives based on the needs of the customer, the constraints of the environment and the feasible solution space [Ref. 1]. The naval ship design process is an example of a system engineering process with the following elements:

- Establishing the military objective
- Defining this need in terms of military requirements and constraints
- Performing a set of design tasks to generate solutions
- Validating the solution obtained versus the requirements
- Translating the solution into a usable form for production and ship support

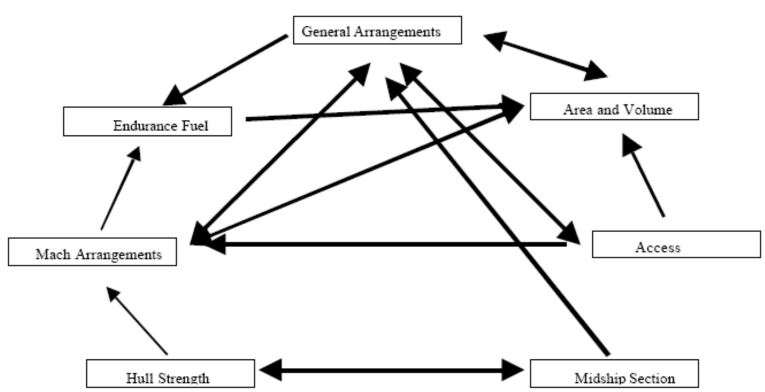


Figure 22. The iterative process of HM&E design

The Sea TENTACLE project used the waterfall process model, shown below in Figure 23, as the system process model. The waterfall process model was chosen because in this model type:

- Requirements are known and well defined from the beginning
- Project activity flows from top to bottom in discrete, sequential, linear phases
- Later modifications incorporate feedback loops
- Delivery is of one single product at one time
- System is simplified with a smaller number of alternatives

We were well aware that a ship is not by any means a simple system, but for the scope of this project, the focus was on the initial design stages. Therefore, only the first three stages of the process model were explored [Ref. 2].

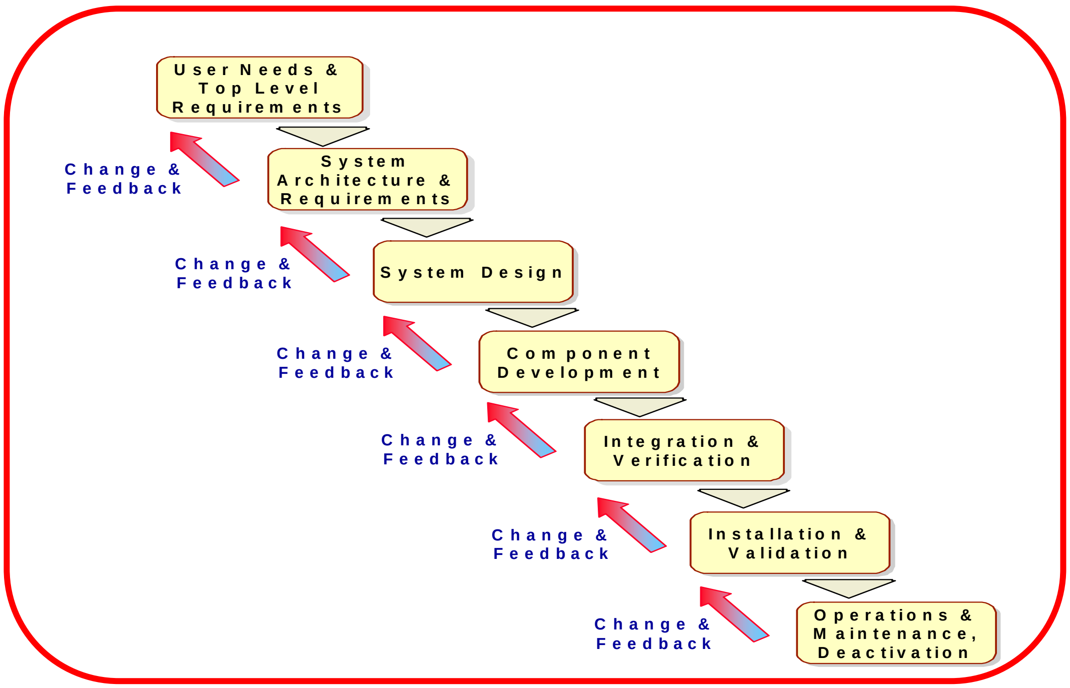


Figure 23. Waterfall Process Model

After examining the requirements document, each subgroup started to search for alternatives that would meet these requirements. At this point an analysis of alternatives (AoA) was done for three rough solutions and the conclusion was that a midsize ship best meets the requirements.

In the early design stage, with the inputs from the payload and combat systems subgroups, the first estimate was that the displacement of the ship would be somewhere between 8,000 to 9,000 tons. We conducted extensive research on current and future technology in the shipbuilding industry as well as current cutting-edge designs.

The goals of this preliminary design were [Ref. 3]:

- Attain feasible design that can be reasonably built with 2025 technology
- Analyze the space available for cargo and mission payload
- Analyze the different ways that payload can be launched/recovered at sea
- Conduct a preliminary structure analysis to determine the expected hull weight and possible interferences with payload movement on board
- Determine the space available for propulsion engines
- Examine different types of propulsions

Hull type selection was our first major decision. After conducting an AoA to determine which hull type to be used, we decided to use a catamaran hull form (The AoA is in Section 3). Referring to the current catamaran ship designs and literature, it was noted that there are very few catamarans of approximately 8,000 tons displacement. Most catamarans of that size are the wave-piercing type, which would not be structurally compatible with our application, because we were planning to use the space between the two hulls as launching / recovering stations for UUVs. Also, according to current designs and tradition, we knew that a ship of this size probably would have a displacement or a semi-displacement hull type. The displacement used for the first design iteration was 9,000 tons.

Concurrent with our work on the first design, the other subgroups were making refinements and changes to their areas of concentration, and deciding which systems (UUV payload, combat systems, guns, propulsion components, propulsion plants etc.) to put into the ship. We started to assemble the components of the ship and generated an overall weight breakdown structure. Ship Weight Breakdown Structure (SWBS) tables showed that in the initial design the weight, and therefore the displacement, was overestimated. Therefore, the first design was modified and refined to reflect these changes. The second design had a displacement of 7,000 tons. Of course, when the displacement was changed, all the calculations were performed again, and ultimately resulted in a lower resistance. This led to a change in the propulsion plant configuration and hence fuel consumption levels, which in turn changed the displacement yet again. After multiple iterations, the final design is ready for analysis in the following sections.

1. TYPE

Monohulls have long dominated the maritime world from shipping to military combat.[Ref. 4, 5]. There are multiple alternatives available for high speed vessels for a variety of purposes. The Navy is looking beyond monohulls to meet the requirements of 21st century warfare- with faster, more stable, and shallower draft ships- to increasingly operate in the world's littoral regions. Classifying these choices based on hull form gives categories including: catamarans, small waterplane twin hull (SWATH), SLICE, Air Cushion Vehicle (ACV), surface effects ship (SES), hydrofoils, hybrids and trimarans.

a) Monohull

From a customer's point of view, the most important ship performance measures are payload/weight ratio and speed. These requirements are unfortunately coupled to one another, and an improvement in one is achieved at a detriment to the other. Higher speeds generally demand higher power, which results in higher fuel consumption, and results, in turn, in less relative payload. The following attributes make monohulls the most widely used displacement hull forms:

- Small propulsion power requirements and long endurance at low speeds
- Moderate propulsion power at moderate speeds
- Ruggedness, simplicity, and durability
- Tolerance to growth in weight and displacement
- Existing infrastructure of yards, docks, and support facilities designed for monohulls, and
- Low cost

Together, these characteristics make for cost-effective ships that can carry large payloads of any composition over great distances at low to moderate speed, and with good mission endurance. Monohull ships have shortcomings that mariners and industry have learned to live with. In high seas, most ships must sacrifice either speed or seakeeping ability. To survive in high sea states and maintain speed, conventional displacement ships must be very large. The increasing demand for fast sea transportation of maximum cargo has boosted the interest in advanced hull forms, which could potentially reduce the high fuel consumption linked to the higher speeds of conventional ships.

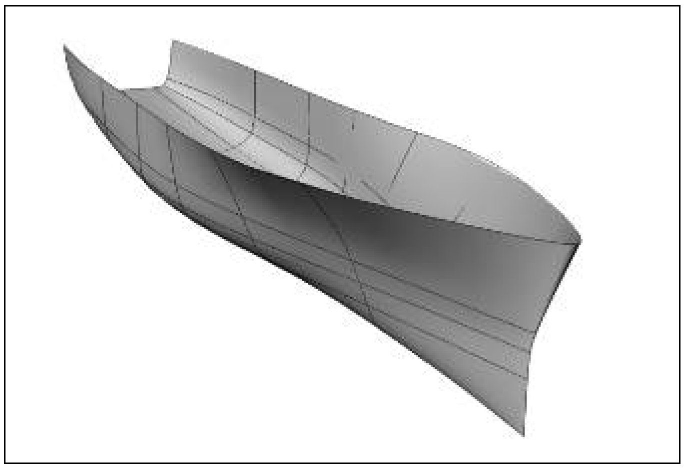


Figure 24. Typical Monohull

b) Catamarans

The catamaran is a vessel with two hulls-normally arranged parallel and abreast, with the wetted areas separated from each other but attached at the top by a common deck. Catamarans outperform monohulls at minimizing wave resistance because the distribution of displacement between the two hulls allows each individual hull to operate with fewer waves making resistance at higher speed-length ratios. This is offset somewhat by increased wetted surface area and increased frictional resistance. There is also the possibility for numerous wave interactions between the hulls. Catamarans are stable in the ship's roll response, however they are susceptible to pitch and heave responses.

Another distinct advantage to catamarans, especially for the littoral mission, is a shallow draft. A catamaran will have a lower draft than a monohull of equivalent displacement. High-speed catamarans are widely used as vehicle and passenger ferries. Many designs are in service with displacement up to about 3,850 tonnes with speeds of 35-40 knots. Some small ferries have pushed the speed envelop above 50 knots, although generally only in sheltered water. Range of even the largest high-performance ferries is generally a few (200-400) hundred miles [Ref. 4, 5].

Although catamarans are increasingly popular for applications in restricted or coastal waters, their seakeeping ability in open ocean operations is inferior to that of the SES and the SWATH.

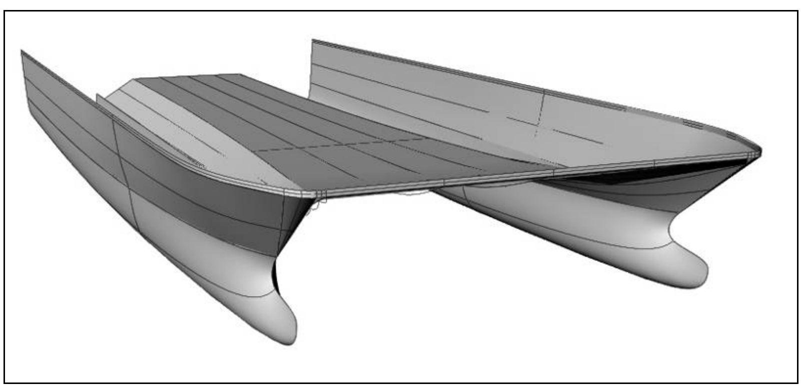


Figure 25. Typical Catamaran

c) SWATH (Small Waterplane Area Twin Hulls)

The development of the SWATH hullform was motivated by the quest for improved seakeeping. SWATH-type vessels generate lift from both their hydrodynamic shape and from buoyancy. The SWATH, as shown below in Figure 5, generally has a pair of fully submerged hulls above which slender struts are mounted to support the cross structure. The struts present minimal underwater volume so that deeper submersion of the hulls results in a very small increase in buoyancy. Better seakeeping is achieved by designing the struts with appropriate water plane properties. In addition to better seakeeping than comparable monohull vessels, a SWATH also exhibits less falloff in speed with increasing sea state.

One disadvantage of the SWATH hullform is the high concentration of stresses on the hull as opposed to a more even distribution of stresses on a more conventional design. The SWATH hull form can achieve speeds greater than 25 knots but at the cost of much higher power consumption than other hull forms for the same speeds. This lack of speed limits the applicability of SWATH vessels and ship designers and operators are faced with the dilemma of choosing either speed or stability. An attempt by Lockheed Martin to increase the speed of the stable SWATH design resulted in the SLICE hull form, which is described below [Ref. 4].

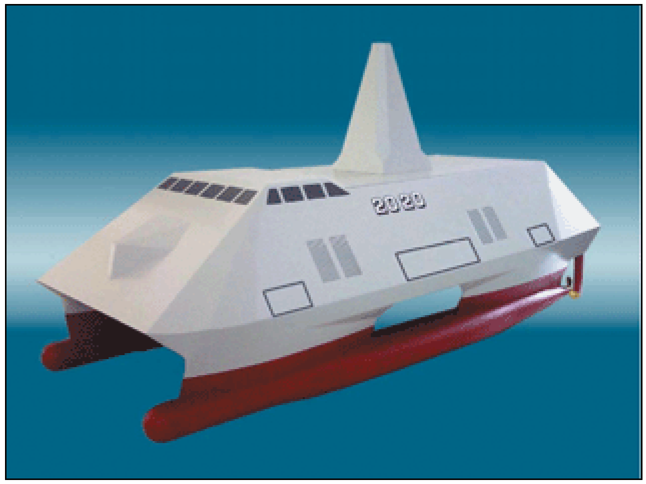


Figure 26. SWATH

d) SLICE

SLICE, a SWATH variant with four short hulls, called pods, is a recently developed hullform. A depiction is shown in Figure 27. The four-pod design offers significant reduction in wave making resistance. Data release by Lockheed Martin Marine Systems suggests that SLICE achieves power efficiencies 20-35% greater than those with conventional SWATH designs at speeds in excess of 18 knots. Lockheed Martin's SLICE prototype is 104 feet in length with a 55-foot beam that can maintain 30 knots in waves up to 12 feet in height. Claimed advantages over a conventional monohull are higher speed for the same power; lower installed power and fuel consumption for the same speed; more flexibility in strut/hulls arrangements; and lower wake signature at high speed [Ref. 4]. However, the SLICE concept is too new for the various merits and pitfalls to have been proven.

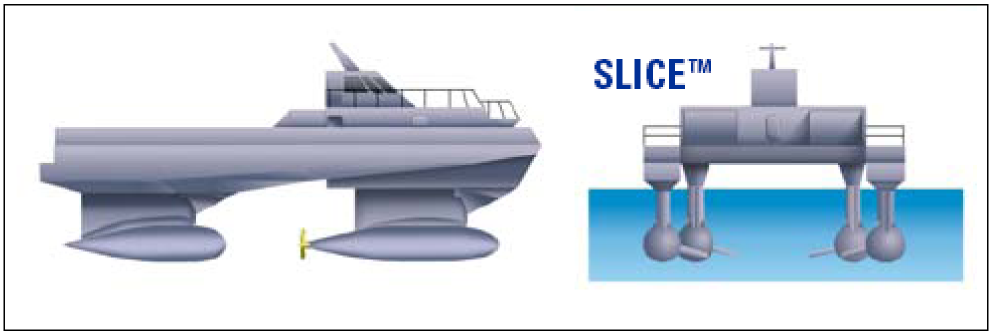


Figure 27. SLICE

e) ACV (Air Cushion Vehicle)

The ACV rides on cushion of low-pressure air, which is held in by a flexible fabric skirt attached around the perimeter of the underside of the craft’s hard structure. Air must be supplied continuously by using fans or blowers housed within the hard structure to maintain the supporting pressure over the broad base of the craft as air escapes. The hard structure can ride well above the surface of the sea or even the beach, as the flexible skirt offers very little resistance to forward motion. Calm-water speeds in excess of 80 knots have been possible since early 1960’s. The ACV is useful for a fast-attack mission, and its amphibious nature gives it a beach assault capability. Since the hull is not in contact with the water, it is less susceptible to mine explosion. The ACV performs as well as monohulls in moderate sea states [Ref. 4].

Despite these advantages, the ACV has significant flaws that make is unsuitable for the Sea TENTACLE mission. The ACV has very poor seakeeping in heavy seas and would not be able to make an independent ocean crossing. Also, the supporting air pressure can only be maintained for a relatively small vessel, and this size limitation eliminated the ACV from further consideration as a viable option.

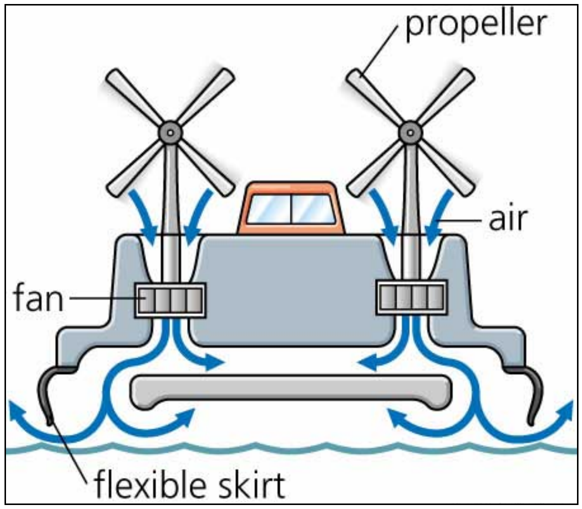


Figure 28. Air Cushion Vehicle

f) *Surface Effects Ship (SES)*

The SES boasts approximately 40 years of development and operational experience, both in the U.S. and abroad. The SES, similar to the principles of operation of a ACV, uses a pressured air cushion to reduce the drag significantly over that which conventional ships experience. However, the SES has rigid catamaran-style side hulls as opposed to a flexible skirt around the entire perimeter. As air cushion pressure elevates the vessel, the hulls remain partially immersed to contain the air cushion. Flexible skirts forward and aft allow waves to pass through the cushion area. The side hulls improve underway stability and maneuverability, resulting in high speed and improved seakeeping that make the SES a candidate for the fast attack mission. Though not widely used in military applications, the SES, widely utilized 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.

A disadvantage of the SES hullform is that the air cushion causes a destabilizing effect on the roll restoring moment due to the water level inside the air cushion being lower than the vessel's waterline. SES-type vessels require less power and generally maintain higher speeds than a catamaran, but the speed loss in waves is more significant than catamarans [Ref. 4, 5].

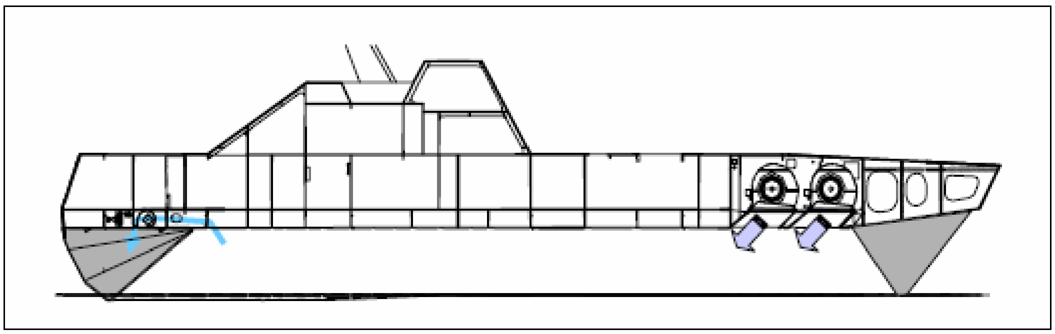


Figure 29. Surface Effect Ship

g) Hydrofoils

Hydrofoils are essentially monohulls with additional structural attachments that behave like aircraft wings to lift the main hull out of the water. Two basic foil system types are used for hydrofoil crafts: surface-piercing V-shaped or U-shaped foils and fully submerged foils. At proper speeds, these foils create sufficient lift to raise the hull completely of the craft out of the water. Lift can be adjusted by controlling the speed (higher speed gives greater lift) or by changing the foils' angle of attack. As the hydrofoil slows below take-off speed, the foils fail to provide adequate lift, and craft sinks onto the sea surface and stays afloat as with the conventional displacement method. High speed and the ability to operate in rough water make the hydrofoil an ideal candidate for the fast-attack mission.

The size of the foils required to achieve foil borne operation at feasible speeds puts a practical limitation on the overall size of hydrofoil vessels. The required size and weight of the foils grows disproportionately with increases in the hydrofoil vessel's displacement. Consequently, hydrofoil vessels have been effectively limited to about 500 tonnes in displacement [Ref. 4].

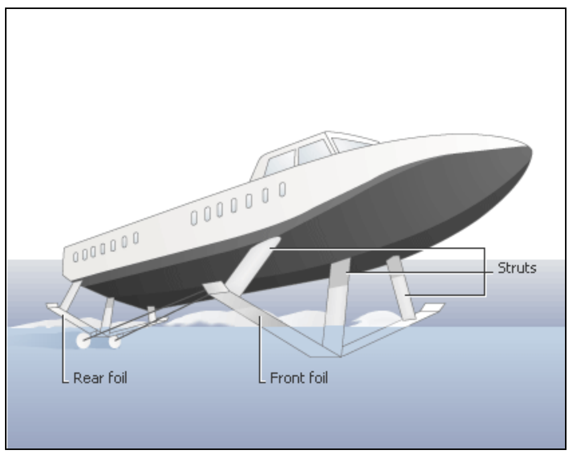


Figure 30. Hydrofoil

h) Trimaran

Trimarans pose an intriguing possibility for minimizing the constraints associated with the high fuel consumption coupled with the higher speeds of conventional ship. Trimarans attempt to combine the best features of monohulls and catamarans. A very slender main hull keeps the increase in wave resistance at higher speeds within reasonable limits. Increased stability can be gained from the side hulls, which can be relatively small and thin, thus producing little resistance. Some increase in total wetted surface is unavoidable and this causes less favorable fuel economy at lower speeds, where frictional resistance dominates, but at sufficiently high speeds considerable gains are possible. At higher speeds, residuary resistance, which is composed primarily of wave making resistance, dominates. As a vessel becomes more slender, or fine, both wave making and form resistance decrease. Also, a point of interest is the interference effect between the main and side hulls. By appropriate positioning of the side hulls a considerable wave reduction may be possible, reducing wave resistance. Compared to monohull performance, the reduction in residuary resistance greatly outweighs the penalty for increased wetted surface at higher speeds.

However, fuel consumption depends on the speed profile, and also on the power weighted proportion of time spent above or below the crossover speed. It is therefore, unfortunately, possible with a trimaran for overall fuel consumption to be increased despite a reduction in installed power, if a lot of time is spent at low to medium speeds [Ref. 4, 5].

Figure 31. Trimaran

2. SELECTION

From the hull types mentioned above, the most appropriate and feasible hull types for the Sea TENTACLE project were monohulls, catamarans and trimarans. The other hull types have not been proven to be useful in a ship of displacing approximately 7,000 tonnes. Making this broad scope judgment call simplified the hull type analysis of alternatives. More refined and in-depth comparisons were performed to select the best from these three hull types. The weighting table and the results are as shown below.

		Monohull		Catamaran		Trimaran	
Requirement	**Weight**		**Weighted**		**Weighted**		**Weighted**
Endurance at low speed	0.06	5.00	0.30	4.00	0.24	3.50	0.21
Endurance at high speed	0.07	3.00	0.21	4.50	0.32	5.00	0.35
Risk	0.08	5.00	0.40	4.00	0.32	3.00	0.24
Cost	0.10	5.00	0.50	4.00	0.40	3.50	0.35
Draft	0.10	3.50	0.35	4.50	0.45	5.00	0.50
Deck Area	0.16	3.00	0.48	5.00	0.80	4.00	0.64
Growth Margin	0.08	4.00	0.32	5.00	0.40	5.00	0.40
Sea Keeping	0.10	4.00	0.40	5.00	0.50	5.00	0.50
Stability	0.15	4.00	0.60	4.50	0.68	5.00	0.75
Footprint (RCS)	0.10	4.00	0.40	5.00	0.50	4.00	0.40
Total	1.00		**0.79**		**0.92**		**0.87**

Table 9. Hull Selection AoA

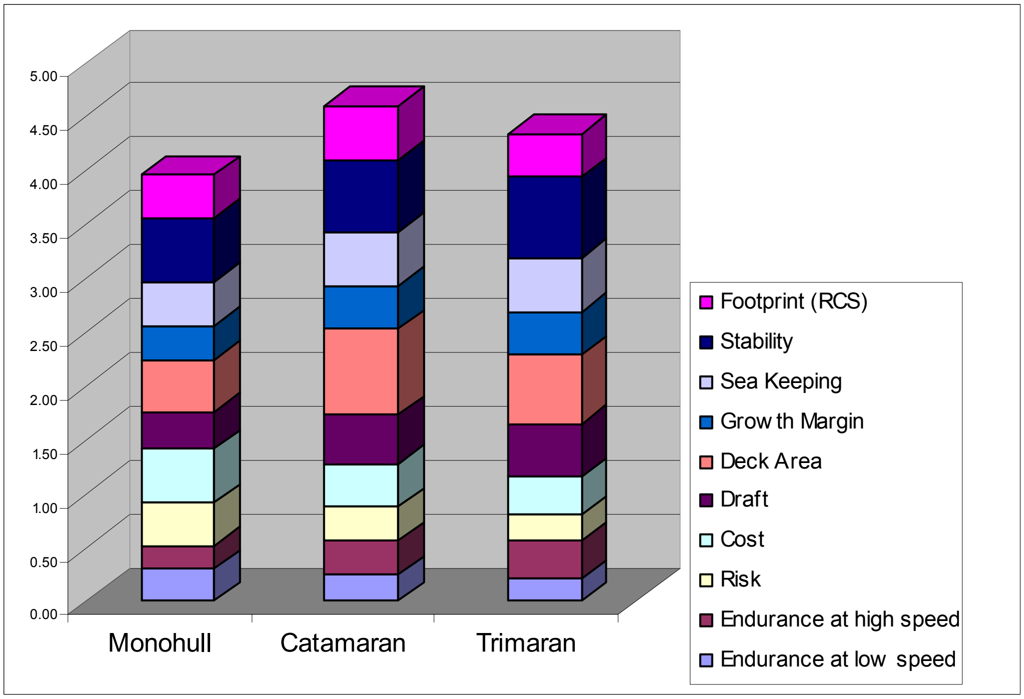


Figure 32. Hull Type Comparison

Note that while grading the hull types the footprint was considered as not only the RCS and IR signature but also the level of covertness of the operation. RCS and IR signatures are mostly design dependant, but since the space between demi hulls can be used for launching/recovering stations (semi-covert operation), catamaran was graded as the best option for footprint. The catamaran was selected as the best hull type for Sea TENTACLE.

3. SHIP CHARACTERISTICS

The final design was achieved after going through the iterative design process for refinement of details and specifics pertaining to the ship structure and form. The main characteristics of the Sea TENTACLE with full mission payload are delineated below in Table 10.

Draft Amidship. m	5.198
Displacement tonnes	7023
Heel to Starboard degrees	-0.51

Draft at FP m	5.251
Draft at AP m	5.144
Draft at LCF m	5.197
Trim (+ve by stern) m	-0.107
WL Length m	117.442
WL Beam m	24.553
Wetted Area m^2	3268.975
Waterpl. Area m^2	1664.682
Prismatic Coeff.	0.925
Block Coeff.	0.746
Midship Area Coeff.	0.806
Waterpl. Area Coeff.	0.964
LCB from Amidsh. (+ve fwd) m	-0.888
LCF from Amidsh. (+ve fwd) m	-0.816
KB m	2.965
KG fluid m	5.925
BMt m	19.005
BML m	260.973
GMt m	16.046
GML m	258.014
KMt m	21.969
KML m	263.937
Immersion (TPc) tonne/cm	17.066
MTc tonne.m	154.523
RM at 1deg = GMt.Disp.sin(1) tonne.m	1966.81
Max deck inclination deg	0.5
Trim angle (+ve by stern) deg	-0.1

Table 10. Sea TENTACLE Characteristics

Note that there is a 0.51 degree design heel to port and 0.1 degree design trim to bow, which can be compensated by filling the CB4 (3-67-1) ballast tank to 95% level.

4. HULL FORM

As mentioned above, the catamaran hull type was selected. Due to the 7,000 tonnes displacement of the ship it was decided that a semi-displacement type hull form would be ideal. Since the first platform was set aside for the UUV hangar space and we envisioned launching and recovering the UUVs between the demi-hulls, determination of the spacing between the demi-hulls was an early design step. The SWAN software was utilized to test and visualize the wave generation between demi-hulls for different spacing at a variety of speeds. After the tests, the results showed that the optimum spacing is 8 meters from centerline. Another point of concern was the vertical distance between design waterline and launching ramps and side doors. The results of the SWAN program and a seakeeping analysis described in Appendix VIII showed that the distance must be at least 2 meters to be able to operate in sea states up to 4.

The main dimensions are illustrated in Figures 33 and 34.

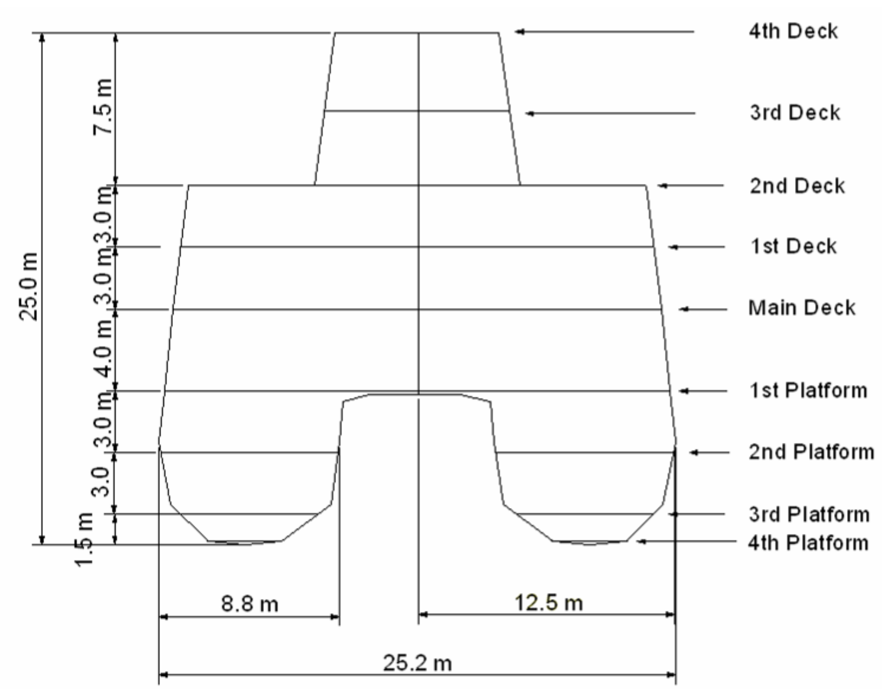


Figure 33. Transverse View

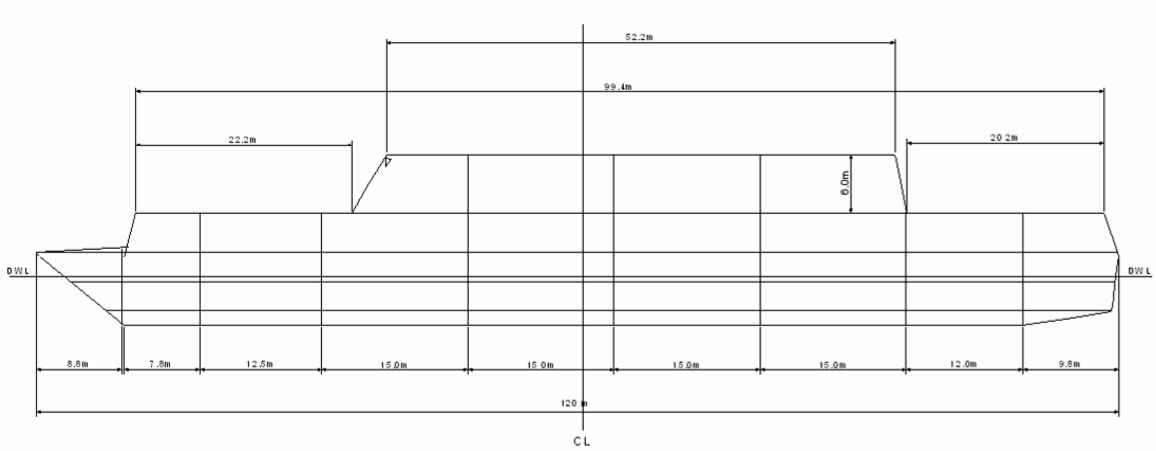


Figure 34. Longitudinal View

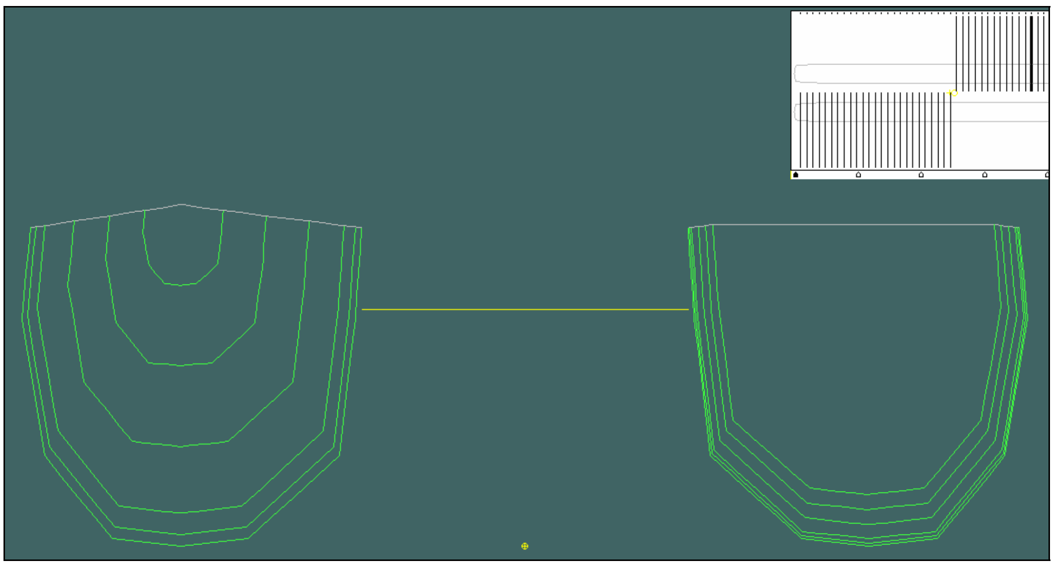


Figure 35. Body Plan

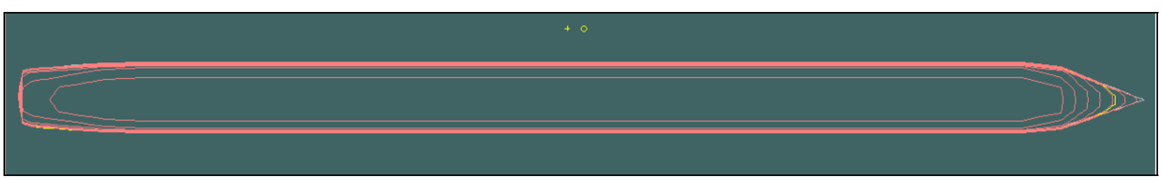


Figure 36. Plan View

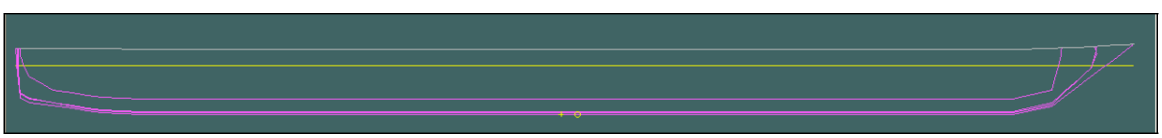


Figure 37. Profile

		Height (m)						
		1 m	2 m	3 m	4 m	5 m	6 m	6.9 m
St.Pos.(m)		WL1	WL2	WL3	WL4	WL5	WL6	WL7
0	St 1	0	0	0	0	0	0	0.539
4.8	St 2	0	0	0	0.837	1.664	1.855	1.844
9.6	St 3	2.167	3.104	3.445	3.636	3.827	3.743	3.642
14.4	St 4	2.482	3.418	3.609	3.8	3.915	3.879	3.779
19.2	St 5	2.482	3.418	3.609	3.8	3.915	3.879	3.779
24	St 6	2.482	3.418	3.609	3.8	3.915	3.879	3.779
28.8	St 7	2.482	3.418	3.609	3.8	3.915	3.879	3.779
33.6	St 8	2.482	3.418	3.609	3.8	3.915	3.879	3.779
38.4	St 9	2.482	3.418	3.609	3.8	3.915	3.879	3.779
43.2	St 10	2.482	3.418	3.609	3.8	3.915	3.879	3.779
48	St 11	2.482	3.418	3.609	3.8	3.915	3.879	3.779
52.8	St 12	2.482	3.418	3.609	3.8	3.915	3.879	3.779
57.6	St 13	2.482	3.418	3.609	3.8	3.915	3.879	3.779
62.4	St 14	2.482	3.418	3.609	3.8	3.915	3.879	3.779
67.2	St 15	2.482	3.418	3.609	3.8	3.915	3.879	3.779
72	St 16	2.482	3.418	3.609	3.8	3.915	3.879	3.779
76.8	St 17	2.482	3.418	3.609	3.8	3.915	3.879	3.779
81.6	St 18	2.482	3.418	3.609	3.8	3.915	3.879	3.779
86.4	St 19	2.482	3.418	3.609	3.8	3.915	3.879	3.779
91.2	St 20	2.482	3.418	3.609	3.8	3.915	3.879	3.779
96	St 21	2.482	3.418	3.609	3.8	3.915	3.879	3.779
100.8	St 22	2.482	3.418	3.609	3.8	3.915	3.879	3.779
105.6	St 23	2.482	3.418	3.609	3.8	3.915	3.879	3.779
110.4	St 24	2.338	3.277	3.53	3.722	3.915	3.813	3.713
115.2	St 25	1.519	2.477	3.086	3.286	3.486	3.437	3.344
120	St 26	0	1.773	2.7	2.908	3.117	3.114	3.026

Table 11. Offset Table of One Demi-hull

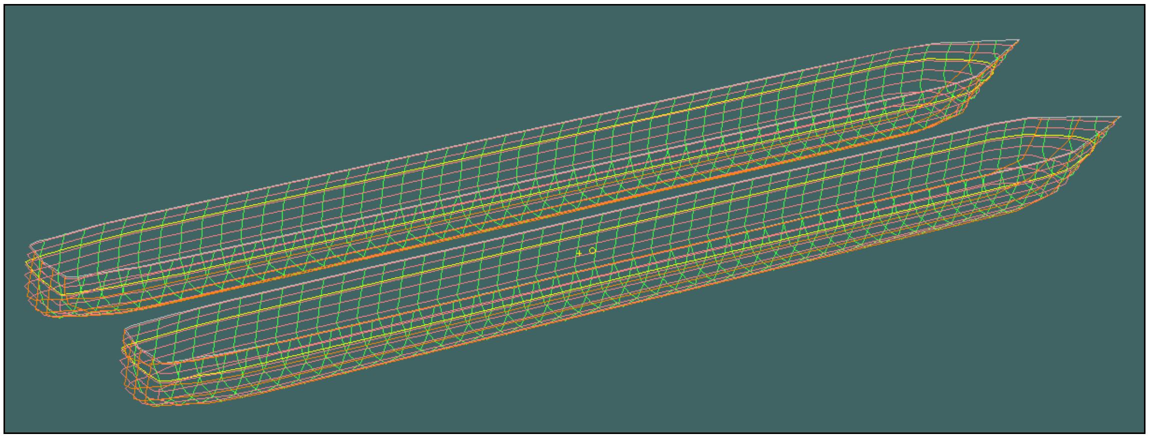


Figure 38. Perspective View

5. RESISTANCE

The resistance calculations were performed using resistance prediction algorithms of Navcad 4.0 and AutoPower 3.0.5 software. The resistance values provided by these programs were averaged to estimate the resistance and powering requirements of Sea Tentacle. The resistance predictions are tabulated below in Table 4 and the corresponding ship speeds for a given shaft power, in kilowatts and horsepower, are depicted in the following figures and tables.

NAVCAD RESISTANCE PREDICTION								
Speed	**Fn**	**Rn**	**Cf**	**Cr**	**Ct**	**Resistance (kN)**	**Shaft Power (kW)**	**Shaft Power (HP)**
0	0					0	0	0
5	7.60E-02	2.53E+08	0.001829	0.001033	0.003182	34.7	89.2	119.5
10	1.52E-01	5.07E+08	0.001668	0.002009	0.003997	174.34	896.9	1201.8
15	2.28E-01	7.60E+08	0.001584	0.00287	0.004774	468.52	3615.4	4844.6
20	3.04E-01	1.01E+09	0.001528	0.003559	0.005408	943.44	9706.9	13007.2
25	3.80E-01	1.27E+09	0.001487	0.00402	0.005827	1588.35	20428	27373.5
30	4.56E-01	1.52E+09	0.001454	0.004194	0.005968	2342.8	36157.3	48450.8
35	5.32E-01	1.77E+09	0.001427	0.004025	0.005772	3084.04	55529.9	74410.1
40	6.07E-01	2.03E+09	0.001405	0.003455	0.00518	3614.6	74380.5	99669.9
45	6.83E-01	2.28E+09	0.001385	0.002624	0.004329	3823.39	88511.6	118605.5

AUTOPOWER PREDICTION			
Speed	**Fn**	**Shaft Power (kW)**	**Shaft Power (HP)**

AVERAGE		
Speed	**Shaft Power (kW)**	**Shaft Power (HP)**

0	0	0	0
5	7.60E-02	716.84	960.6
10	1.52E-01	4394.78	5889.0
15	2.28E-01	11441.9	15332.1
20	3.04E-01	21132.88	28318.1
25	3.80E-01	32592.86	43674.4
30	4.56E-01	45098.58	60432.1
35	5.32E-01	57894.38	77578.5
40	6.07E-01	69929.74	93705.9
45	6.83E-01	93915.08	125846.2

0	0.0	0.0
5	403.0	540.0
10	2645.8	3545.4
15	7528.7	10088.4
20	15419.9	20662.7
25	26510.4	35524.0
30	40627.9	54441.4
35	56712.1	75994.3
40	72155.1	96687.9
45	91213.3	122225.9

Table 12. Resistance Predictions

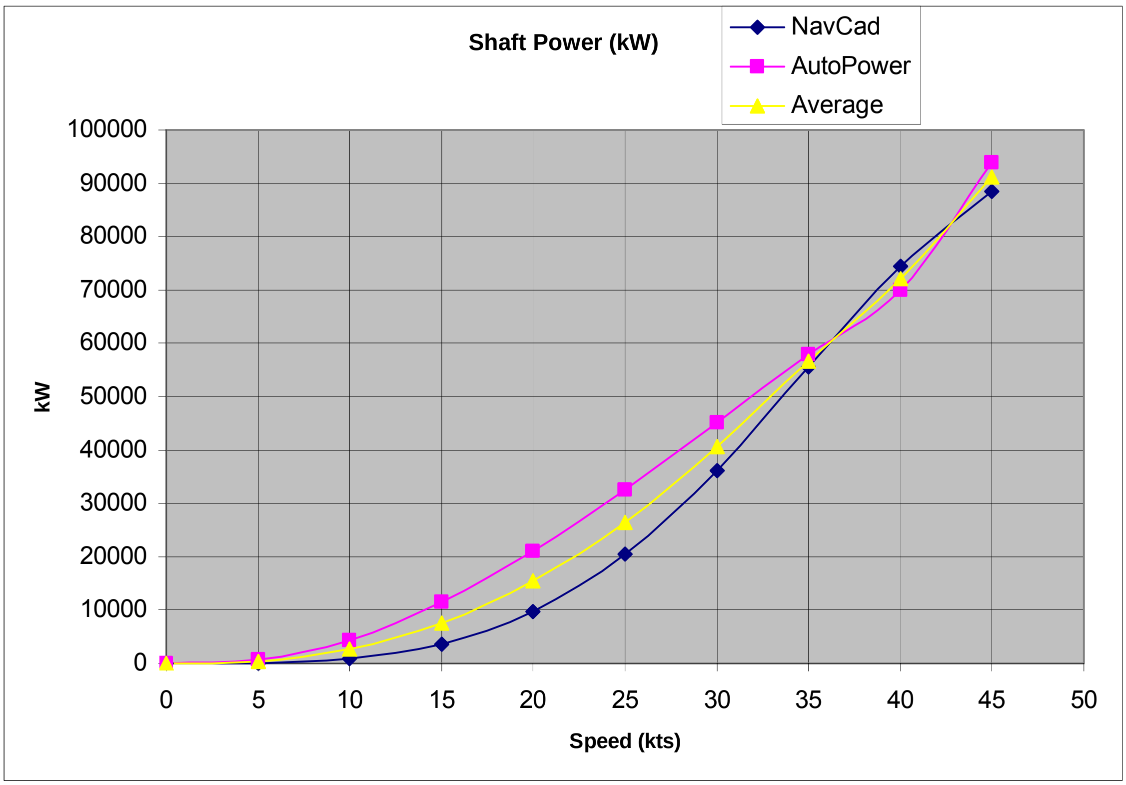


Figure 39. Shaft Power (kW)

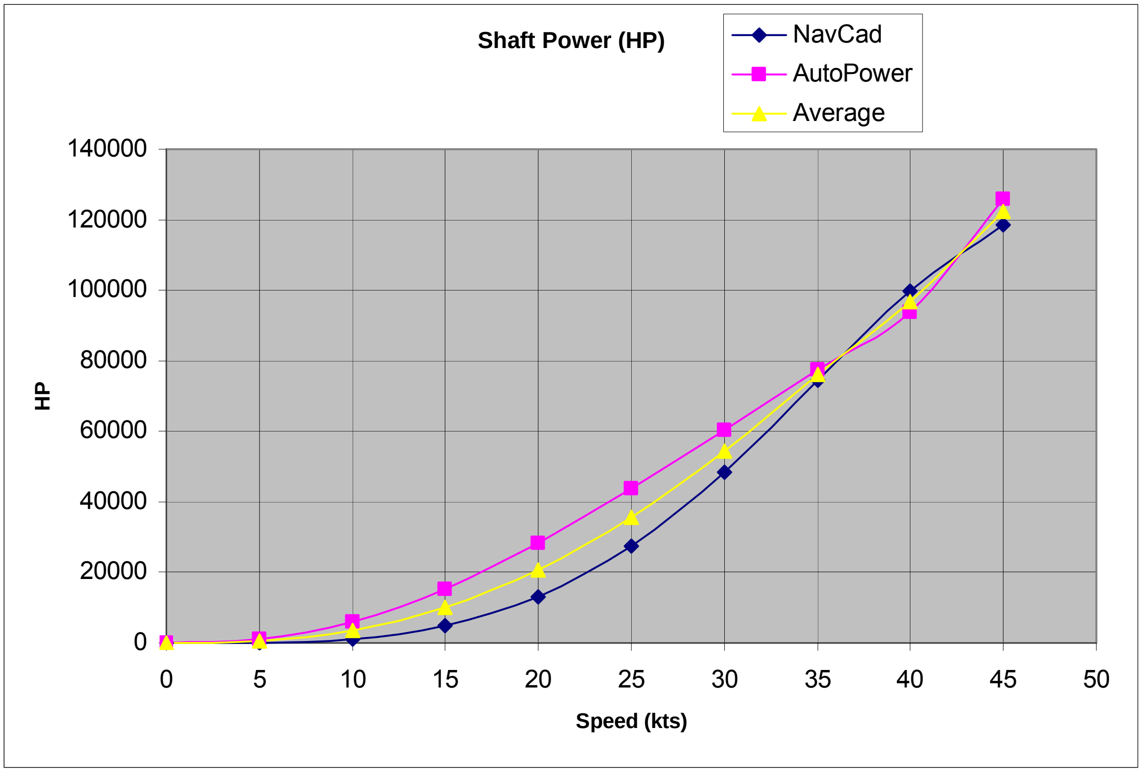


Figure 40. Shaft Power (HP)

6. DECKS LAYOUT AND ARRANGEMENT

The deck spacing is modeled after current DDX design. The height of the double bottom is 1.5 meters and the height of first platform is 4 meters to facilitate storage of two stacked Sea Predators on the deck. All other decks are 3 meters high. Engine rooms occupy two decks to accommodate the large volume of gas turbine modules and their associated exhaust system.

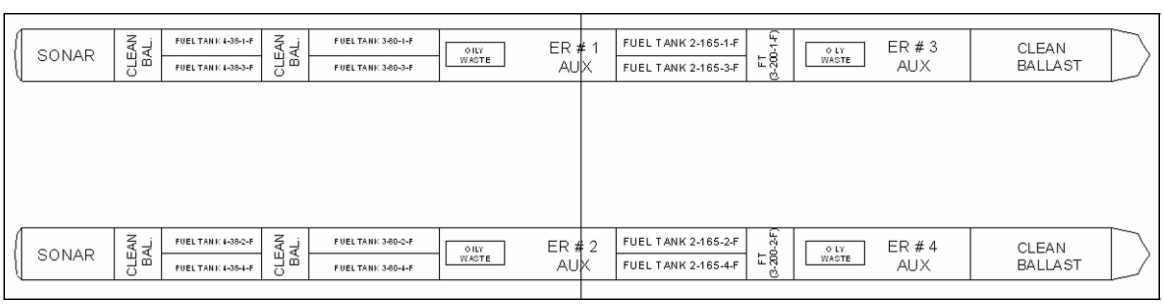


Figure 41. Fourth Platform

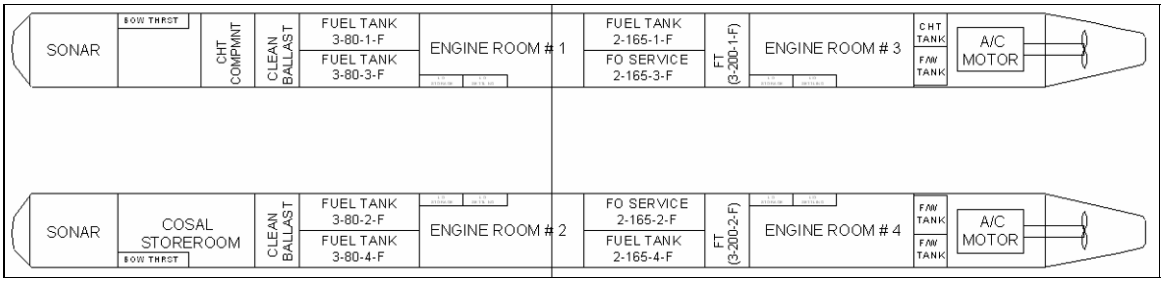


Figure 42. Third Platform

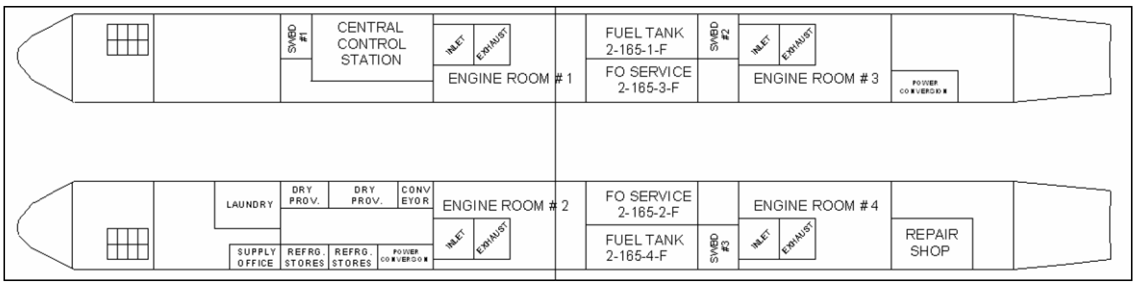


Figure 43. Second Platform

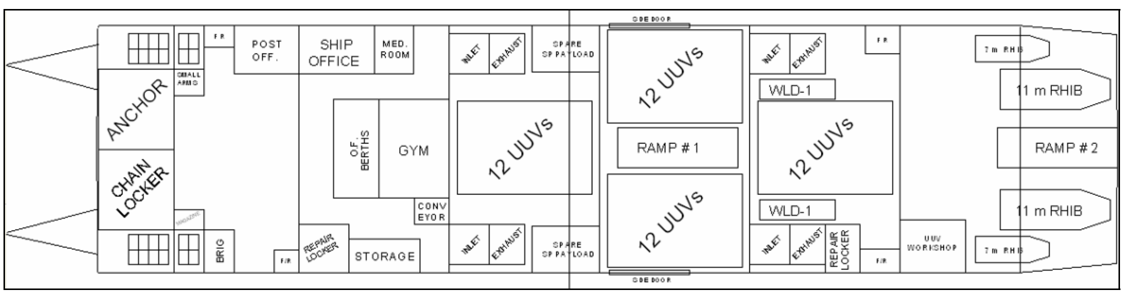


Figure 44. First Platform

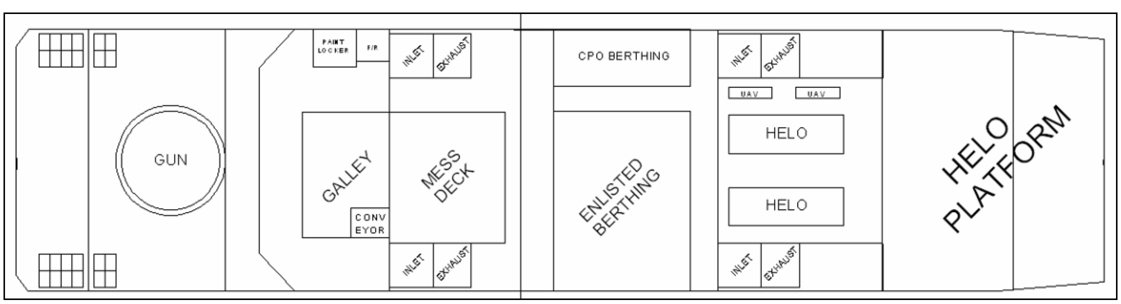


Figure 45. Main Deck

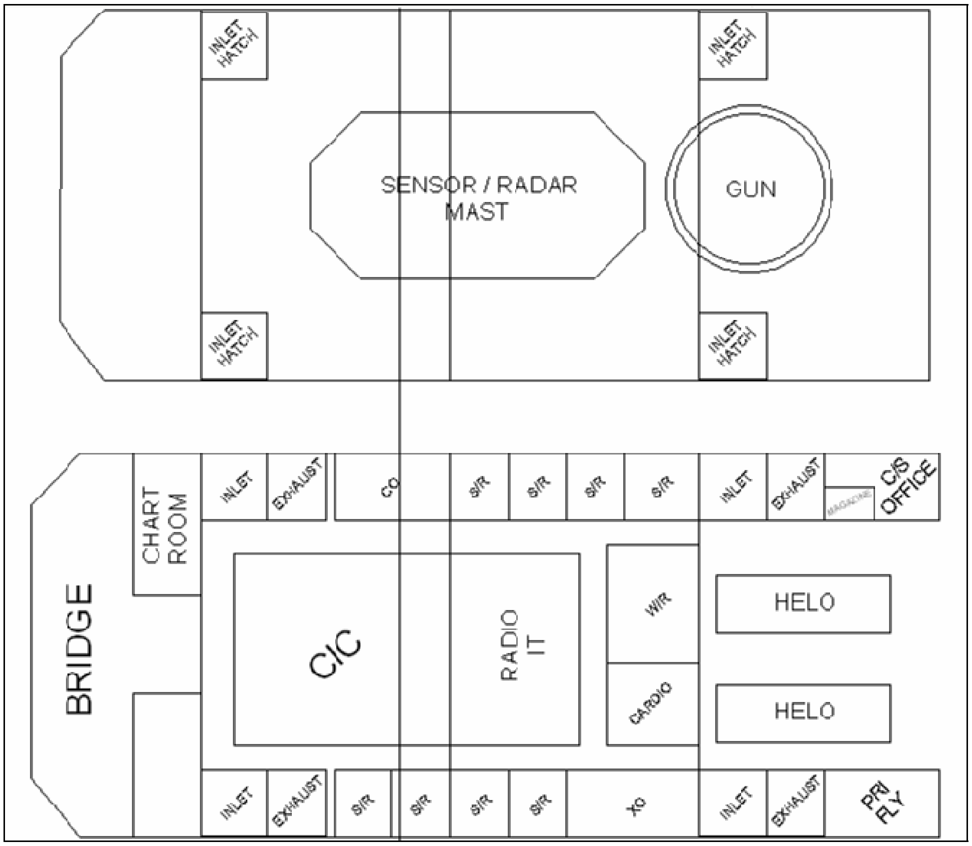


Figure 46. 1^{st} and 2^{nd} Decks

7. TANKAGE

Tank status is as shown below:

FUEL OIL					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
FT1 (4-38-1-F)	98.50%	12.06	31.35	0.92	6.893
FT2 (4-38-2-F)	98.50%	12.06	31.35	0.92	-6.893
FT3 (4-38-3-F)	98.50%	34.29	31.35	0.834	9.056
FT4 (4-38-4-F)	98.50%	34.29	31.35	0.834	-9.056
FT5 (3-80-1-F)	98.50%	196.1	18.1	2.462	9.571
FT6 (3-80-2-F)	98.5 %	196.1	18.1	2.462	-9.571
FT7 (3-80-3-F)	99%	90.9	18.1	2.643	6.472
FT8 (3-80-4-F)	98.50%	90.9	18.1	2.643	-6.472
FT9 (2-165-1-F)	98.50%	350.3	-8.9	3.974	9.722
FT10 (2-165-2-F)	98.50%	350.3	-8.9	3.974	-9.722
FT11 (2-165-3-F)	98.50%	179.8	-8.9	4.311	6.263
FT12 (2-165-4-F)	98.50%	179.8	-8.9	4.311	-6.263
FT13 (3-200-1)	98.50%	71.8	-16.4	2.519	8.591

FT14 (3-200-2)	98.50%	71.8	-16.4	2.519	-8.591
FUEL OIL =		**1870.5**	**MT**		

FRESH WATER					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
FW1	99%	19.75	-34.4	3.058	6.373
FW2	99%	19.75	-34.4	3.058	-6.373
FW3	99%	39.51	-34.4	3.017	-9.742
FRESH WATER =		**79.01**	**MT**		

LUBE OIL					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
LO STORG (3-116-1-F)	1	11.5	10.1	3	5.4
LO STORG (3-116-2-F)	1	11.5	10.1	3	-5.4
LO SETTLE (3-130-1-F)	1	11.5	6.1	3	5.4
LO SETTLE (3-130-2-F)	1	11.5	6.1	3	-5.4
LO STORG (3-214-1-F)	1	11.5	-19.9	3	5.4
LO STORG (3-214-2-F)	1	11.5	-19.9	3	-5.4
LO SETTLE (3-227-1-F)	1	11.5	-23.9	3	5.4
LO SETTLE (3-227-2-F)	1	11.5	-23.9	3	-5.4
LUBE OIL =		**92**	**MT**		

OILY WASTE

ITEM	QUANTITY	WEIGHT [mT]	LCG [m] From Amidships	VCG [m] From Keel	TCG [m]
OW1	50.00%	5.05	9.05	0.544	7.305
OW2	50%	5.05	9.05	0.544	-7.305
OW3	50%	5.05	-21.45	0.544	7.305
OW4	50%	5.05	-21.45	0.544	-7.305
BALLAST					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
CB1 (4-26-1)	99.00%	23.8	37.6	0.86	8.495
CB2 (4-26-2)	99%	23.8	37.6	0.86	-8.495
CB3 (3-67-1)	99%	78.3	25.6	2.529	8.591
CB4 (3-67-2)	99%	78.3	25.6	2.529	-8.591
CB5 (4-264-1)	99%	70.8	-38.85	0.86	8.495
CB6 (4-264-2)	99%	70.8	-38.85	0.86	-8.495

Tank arrangement:

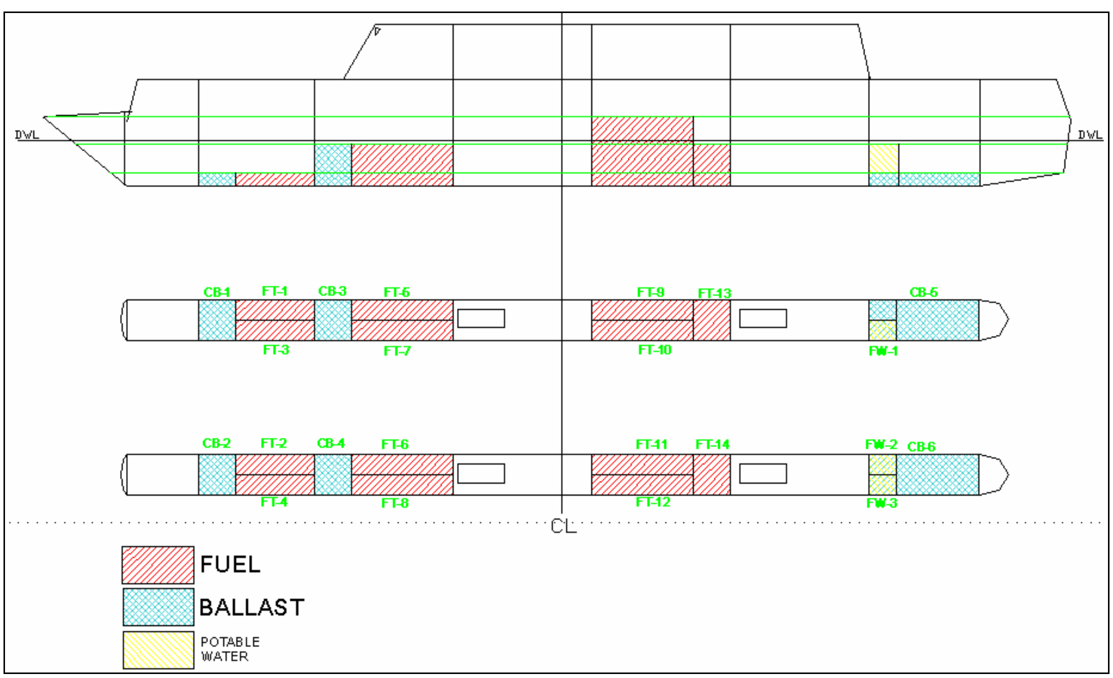


Figure 47. Tank arrangement

Summary of the fluids:

Fluid	Load %	Weight (MT)
Fuel Oil	98.5	1674.4
Fresh Water	99	79.01
Ballast	99	345.8
Lube. Oil	100	92

Table 13. Fluid Summary

8. STRUCTURE

A preliminary structural design and structural strength analysis was made to estimate structure weight and bending stresses at the midship section of the ship. Longitudinal bending moments were calculated by Hydromax software. Transverse structure calculations were performed using FEMLAB software and are included as Appendix IX.

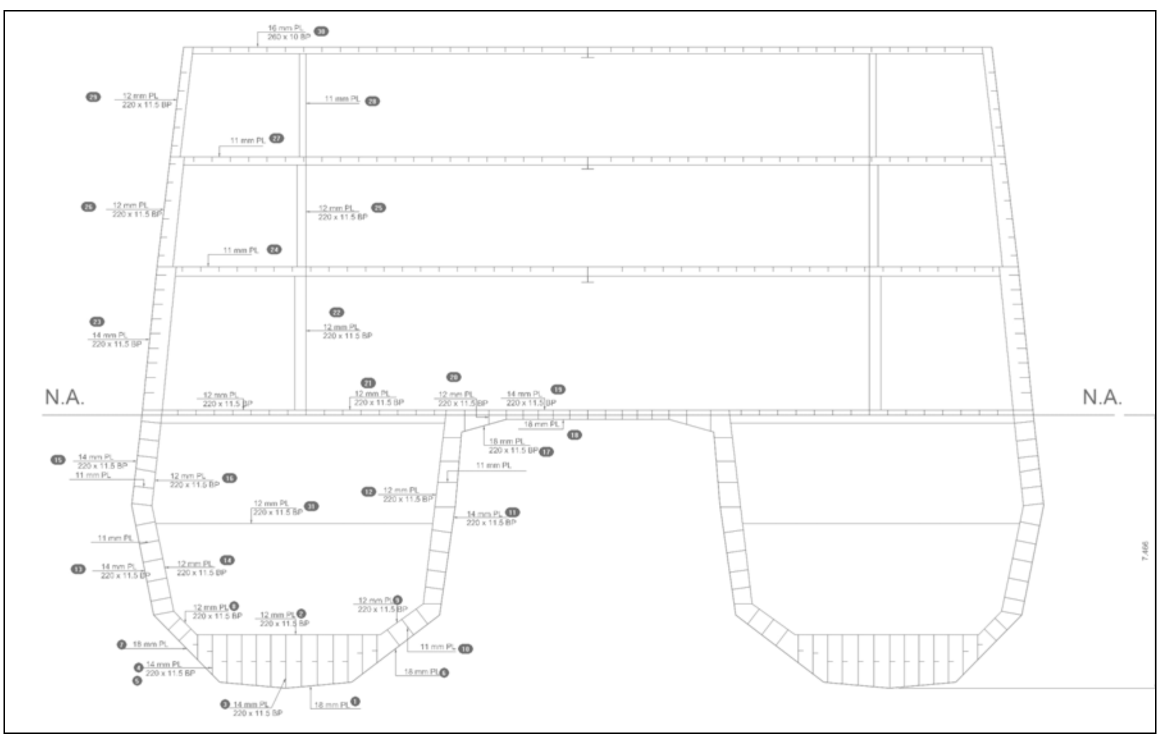


Figure 48. Structural Arrangement

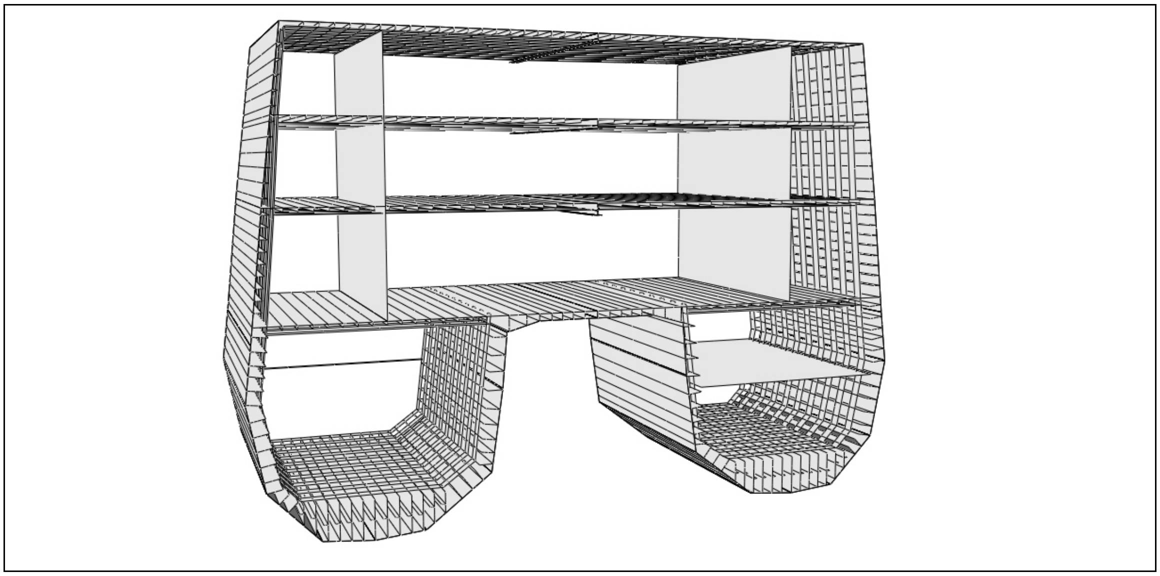


Figure 49. Midship Section Structure

a) Structural Strength

STRUCTURAL ELEMENTS									
			a_n (cm^2)	d_n (m)	h (m)	i_n (cm^2m^2)	a_nd_n	$a_nd_n^2$	$i_n+a_nd_n^2$
Alignment	Item No	Scantlings (cm)	Area	Distance	Height	Moment of Inertia	(cm^2m)	(cm^2m^2)	(cm^2m^2)
Horizontal	1	2x180.8x1.8	1301.760	0.083	0.000	0.000	108.046	8.968	8.968
Horizontal	2	498x1.2	1195.200	1.459	0.000	0.000	1743.797	2544.200	2544.200
Vertical	3	9x145.9x1.4	3676.680	0.730	1.459	652.207	2683.976	1959.303	2611.509
Vertical	4	2x109x1.4	610.400	0.914	1.090	60.435	557.906	509.926	570.360
Vertical	5	2x68.3x1.4	382.480	1.118	0.683	14.869	427.613	478.071	492.939
Horizontal	6	302x1.8	1087.200	1.083	0.000	0.000	1177.438	1275.165	1275.165
Vertical	7	257x1.8	925.200	1.083	2.570	509.238	1001.992	1085.157	1594.395
Vertical	8	91.5x1.2	219.600	1.781	0.915	15.321	391.108	696.563	711.884
Horizontal	9	144.9x1.2	347.760	1.883	0.000	0.000	654.832	1233.049	1233.049
Horizontal	10	5x53.4x1.1	587.400	1.671	0.000	0.000	981.545	1640.162	1640.162
Vertical	11	503.6x1.4	1410.080	4.961	5.036	2980.121	6995.407	34704.214	37684.335
Vertical	12	533.1x1.2	1279.440	4.953	5.331	3030.094	6337.066	31387.489	34417.583
Vertical	13	305.9x1.4	856.520	3.500	3.059	667.906	2997.820	10492.370	11160.276
Vertical	14	294.6x1.2	707.040	3.545	2.946	511.362	2506.457	8885.389	9396.751
Vertical	15	261.7x1.4	732.760	6.545	2.617	418.204	4795.914	31389.258	31807.462
Vertical	16	262.7x1.2	630.480	6.500	2.627	362.585	4098.120	26637.780	27000.365
Horizontal	17	126.8x1.8	456.480	7.173	0.000	0.000	3274.331	23486.777	23486.777

Horizontal	18	221.9x1.8	798.840	7.346	0.000	0.000	5868.279	43108.375	43108.375
Horizontal	19	385.7x1.4	1079.960	7.600	0.000	0.000	8207.696	62378.490	62378.490
Vertical	20	8x25.4x1.2	487.680	7.473	0.254	2.622	3644.433	27234.845	27237.467
Horizontal	21	828.3x1.2	1987.920	7.600	0.000	0.000	15108.192	114822.259	114822.259
Vertical	22	364x1.2	873.600	9.420	3.640	964.571	8229.312	77520.119	78484.690
Vertical	23	392x1.4	1097.600	9.420	3.920	1405.513	10339.392	97397.073	98802.586
Horizontal	24	1174.6x1.1	2584.120	11.500	0.000	0.000	29717.380	341749.870	341749.870
Vertical	25	300x1.2	720.000	12.890	3.000	540.000	9280.800	119629.512	120169.512
Vertical	26	302.2x1.2	725.280	12.890	3.022	551.967	9348.859	120506.795	121058.762
Horizontal	27	1138.5x1.1	2504.700	14.500	0.000	0.000	36318.150	526613.175	526613.175
Vertical	28	300x1.1	660.000	15.910	3.000	495.000	10500.600	167064.546	167559.546
Vertical	29	302.2x1.2	725.280	15.910	3.022	551.967	11539.205	183588.748	184140.716
Horizontal	30	1102.3x1.6	3527.360	17.500	0.000	0.000	61728.800	1080254.000	1080254
Horizontal	31	756.1x1.2	1814.640	4.500	0.000	0.000	8165.880	36746.460	36746.460

Location of Neutral Axis

Total Section Area = 35993.460 cm^2

Dg = 7.466 m (From Keel)

Section Modulus

I_n = 3190762.088 cm^2m^2

I_o = 1184397.655 cm^2m^2

z_{top} = 10.03 m

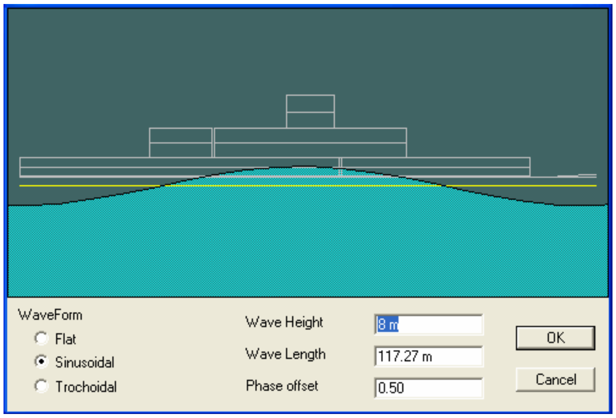
z_{bot} = 7.47 m

$S.M._{top}$ = 118039.4715 cm^2m

$S.M._{bot}$ = 158636.9776 cm^2m

All bending stresses were calculated assuming a safety factor of two.

Maximum bending stresses on waves:

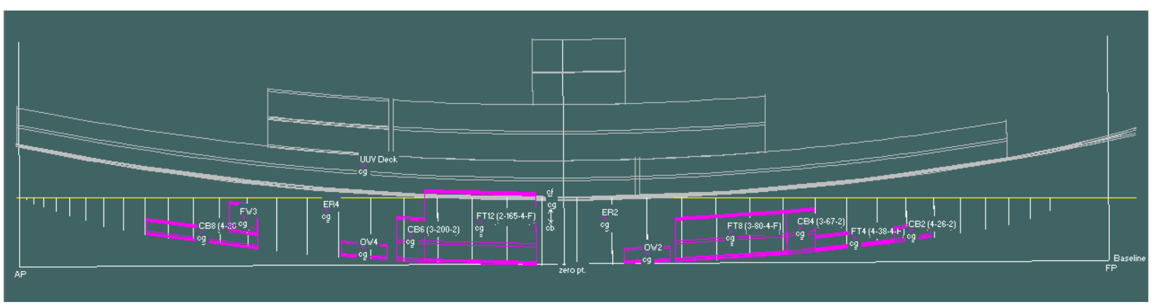


Max.Bending
Moment = 33113 T·m

σ_{top} = **55.039MPa**

σ_{bot} = **40.954MPa**

Max bending stresses at sagging condition:

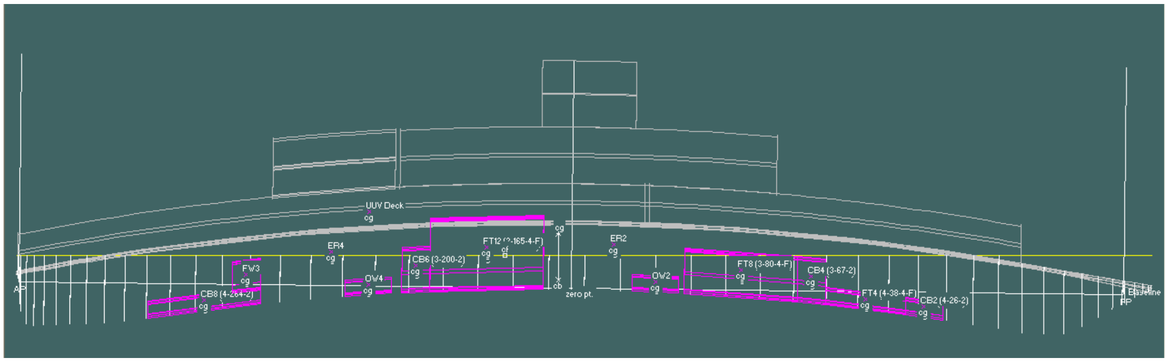


Max.Bending
Moment = 50910 T·m

σ_{top} = **84.620MPa**

σ_{bot} = **62.965MPa**

Max bending stresses at hogging condition:



Max.Bending
Moment = 92900 T·m

σ_{top} = 154.414 MPa

σ_{bot} = 114.897 MPa

b) Structural Weight Estimation

LONGITUDINAL COMPONENTS						
Alignment	**Item No**	**Scantlings (cm)**	**Area (cm^2)**	**Area (m^2)**	**Length (m)**	**Volume (m^3)**
Horizontal	1	2x180.8x1.8	1301.760	0.130	110.000	14.319
Horizontal	2	498x1.2	1195.200	0.120	WEB	WEB
Vertical	3	9x145.9x1.4	3676.680	0.368	110.000	40.443
Vertical	4	2x109x1.4	610.400	0.061	110.000	6.714
Vertical	5	2x68.3x1.4	382.480	0.038	110.000	4.207
Horizontal	6	302x1.8	1087.200	0.109	110.000	11.959
Vertical	7	257x1.8	925.200	0.093	110.000	10.177
Vertical	8	91.5x1.2	219.600	0.022	WEB	WEB
Horizontal	9	144.9x1.2	347.760	0.035	WEB	WEB
Horizontal	10	5x53.4x1.1	587.400	0.059	110.000	6.461
Vertical	11	503.6x1.4	1410.080	0.141	110.000	15.511
Vertical	12	533.1x1.2	1279.440	0.128	WEB	WEB
Vertical	13	305.9x1.4	856.520	0.086	110.000	9.422
Vertical	14	294.6x1.2	707.040	0.071	WEB	WEB

Vertical	15	261.7x1.4	732.760	0.073	110.000	8.060
Vertical	16	262.7x1.2	630.480	0.063	WEB	WEB
Horizontal	17	126.8x1.8	456.480	0.046	110.000	5.021
Horizontal	18	221.9x1.8	798.840	0.080	110.000	8.787
Horizontal	19	385.7x1.4	1079.960	0.108	110.000	11.880
Vertical	20	8x25.4x1.2	487.680	0.049	110.000	5.364
Horizontal	21	828.3x1.2	1987.920	0.199	110.000	21.867
Vertical	22	364x1.2	873.600	0.087	110.000	9.610
Vertical	23	392x1.4	1097.600	0.110	110.000	12.074
Horizontal	24	1174.6x1.1	2584.120	0.258	110.000	28.425
Vertical	25	300x1.2	720.000	0.072	52.000	3.744
Vertical	26	302.2x1.2	725.280	0.073	52.000	3.771
Horizontal	27	1138.5x1.1	2504.700	0.250	52.000	13.024
Vertical	28	300x1.1	660.000	0.066	52.000	3.432
Vertical	29	302.2x1.2	725.280	0.073	52.000	3.771
Horizontal	30	1102.3x1.6	3527.360	0.353	52.000	18.342
Horizontal	31	756.1x1.2	1814.640	0.181	50.000	9.073
			Side and Deck Longitudinals =	0.638	110.000	70.180
					Total =	**355.642**

WEB COMPONENTS

Deep Frames		
Thickness (mm)	**Area (m^2)**	**Volume (m^3)**
8	47.98	0.3904

Deep Frames at every 3 m : Number of Deep Frames =37

Total Deep Frame Volume = 14.445m^3

Ordinary Frames		
Thickness (mm)	**Area (m^2)**	**Volume (m^3)**
6	47.98	0.2944

Ordinary Frames at every 1 m : Number of Deep Frames =73

Total Deep Frame Volume = 21.495m^3
Total Structure Volume =391.582m^3

Steel Structure		
Specific Weight =	76000	N/m3
Approximate Weight =	**3033.66**	**MT**

Alluminum Structure		
Specific Weight =	27000	N/m3
Approximate Weight =	**1077.75**	**MT**

c) Longitudinal Strength

The loads that are considered in longitudinal strength analysis are as below.

LIGHTSHIP LOADS					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
HULL STRUCTURE	1	3034	- 0.1	7	0
COMB.AIR SYSTEM	1	50	-7.9	10	0
UPTAKES	1	40	-8.9	10	0
PROP.SEA WATER COOLING	1	40	-7.9	3	0
POWER CONVERSION EQ 1	1	10	14.9	6	-11.2
POWER CONVERSION EQ 2	1	10	-36.2	6	5.4
SS POWER CABLE	1	100	0.1	6	0
LIGHTING SYSTEMS	1	40	0.1	6	0
VENTILATION SYSTEMS	1	100	0.1	5	0

FIREMAIN AND FLUSHING	1	60	0.1	5	0
COMPRESSED AIR SYSTEMS	1	60	0.1	5	0
FIRE EXTINGUISHING SYS.	1	50	0.1	5	0
AUX.SYS.OP.FLUIDS	1	80	0.1	5	0
SEA WATER	1	80	0.1	5	0
SONAR 1	1	10	43.5	3	8.3
SONAR 2	1	10	43.5	3	-8.3
BOW THRUSTER 1	1	2	36.4	3	10.8
BOW THRUSTER 2	1	2	36.4	3	-10.8
COSAL SR	1	25	32.8	3	-8.25
CHT CMPT	1	14	29.6	3	8.25
AFT CHT TANK	1	15	-34.4	3	10
AC MOTOR 1	1	30	-39.9	3	8.2
AC MOTOR 2	1	30	-39.9	3	-8.2
WATERJET 1	1	4	-48.9	-0.5	8.2
WATERJET 2	1	4	-48.9	-0.5	-8.2
VLS 1	1	13	42.1	8	10
VLS 2	1	13	42.1	8	-10
SRBOC 1	1	1	38.1	10	10
SRBOC 2	1	1	38.1	10	-10
LAUNDRY	1	10	30.4	6	-6
SUPPLY OFFICE	1	4	29.9	6	-10
DRY PROV	1	2	21.35	6	-5.2
REFRG.STR.	1	2	22.4	6	-11.3
CONVEYOR	1	4	13.9	13	-5.2
SWBD 1	1	3	25.6	6	10.5
CCS	1	10	18.1	6	9.3
ENG.ROOM 1	1	70	3.7	4	9.2
ENG.ROOM 2	1	120	3.7	4	-9.2
SWBD 2	1	3	-15.9	6	10.1
SWBD 3	1	3	-15.9	6	-10.1
ENG.ROOM 3	1	70	-25.3	4	9.2
ENG.ROOM 4	1	50	-25.3	4	-9.2
REPAIR SHOP	1	8	-36.9	5	-10
ANCHOR	1	20	43.4	7.5	3.9
CHAIN LOCKER	1	10	43.4	8.5	-3.9
SMALL ARMS	1	1	38.1	9.5	6.6
FWD MAGAZINE	1	1	38.1	9.5	-6.7
FAN ROOM 1	1	1	35.1	9	11.1
POST OFFICE	1	1	30.3	9	8.7
FAN ROOM 2	1	1	28.4	9	-11.3
SHIP OFFICE	1	2	22.8	9	9.8
MED.ROOM	1	2	17.1	9	9.8
O.F.BERTH.	1	5	21.1	9	0
GYM	1	8	15.4	9	0
REPAIR LOCKER 1	1	5	24.6	9.5	-9.9
STORAGE	1	4	15.6	9.5	-9.9
REPAIR LOCKER 2	1	5	-27.2	9.5	-10

FAN ROOM 3	1	1	-31.1	9	10.8
FAN ROOM 4	1	1	-31.1	9	-10.8
UUV WORKSHOP	1	3	-36.1	9	-9.8
UUV HOISTS AND UTILS	1	5	-15.2	10.5	0
RHIB 1	1	3	-48.4	9.5	6
RHIB 2	1	3	-48.4	9.5	-6
SMALL RHIB 1	1	1.5	-44.9	9.5	10.1
SMALL RHIB 2	1	1.5	-44.9	9.5	-10.1
GUN 1	1	4	32.1	12.5	0
GALLEY	1	5	16.1	12.5	-1.3
PAINT LOCKER	1	2	17.1	13	10.2
FAN ROOM 5	1	1	13.6	13	10.5
MESS DECK	1	6	6.8	12	-1.5
ENLISTED BERTH.	1	10	-9.1	13	-3.7
CPO BERTHING	1	5	-9.1	13	10.5
BRIDGE	1	3	18.7	16	0
CHARTROOM	1	1	14.1	16	7.2
CO SR	1	2	0.3	16	9.5
CIC	1	10	3.6	15	0
RADIO IT	1	5	-6.8	16	0
S/R GROUP	1	4	-7.4	16	0
W/R	1	2	-15.2	16	2.4
CARDIO	1	2	-15.2	15	-3.8
AFT MAGAZINE	1	1	-19.4	16	5.5
C/S OFFICE	1	6	-28.7	16	10
PRI FLY	1	6	-28.7	16	-10
RADAR/SENSOR	1	38	-2.9	21	0
MAST	1	15	-2.9	21	0
GUN 2	1	4	-21.1	18.5	0

LIGHTSHIP WEIGHT = 4504 MT

PAYLOAD					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
UUV GROUP 1	1	84	4.6	9.5	0
UV SPARE GROUP 1	1	10	0.1	9.5	9.9
UV SPARE GROUP 2	1	10	0.1	9.5	-9.9
UUV GROUP 2	1	84	-10.4	9.5	7.1
UUV GROUP 3	1	84	-10.4	9.5	-7.1
UUV GROUP 4	1	84	-25.4	9.5	0
WLD-1	1	5	-22.6	8.5	5.9
WLD-1	1	5	-22.6	8.5	-5.9
HELO	2	20	-42.1	13	0
UAV	1	3	-35.9	12.5	0
VLS 1	1	20	42.1	8	10
VLS 2	1	20	42.1	8	-10

SRBOC 1	1	2	38.1	10	10
SRBOC 2	1	2	38.1	10	-10
DRY PROV	1	10	21.35	6	-5.2
REFRG.STR.	1	15	22.4	6	-11.3
PAYLOAD WEIGHT = 458 MT					

FUEL OIL					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
FT1 (4-38-1-F)	98.50%	12.06	31.35	0.92	6.893
FT2 (4-38-2-F)	98.50%	12.06	31.35	0.92	-6.893
FT3 (4-38-3-F)	98.50%	34.29	31.35	0.834	9.056
FT4 (4-38-4-F)	98.50%	34.29	31.35	0.834	-9.056
FT5 (3-80-1-F)	98.50%	196.1	18.1	2.462	9.571
FT6 (3-80-2-F)	98.5 %	196.1	18.1	2.462	-9.571
FT7 (3-80-3-F)	99%	90.9	18.1	2.643	6.472
FT8 (3-80-4-F)	98.50%	90.9	18.1	2.643	-6.472
FT9 (2-165-1-F)	98.50%	350.3	-8.9	3.974	9.722
FT10 (2-165-2-F)	98.50%	350.3	-8.9	3.974	-9.722
FT11 (2-165-3-F)	98.50%	179.8	-8.9	4.311	6.263
FT12 (2-165-4-F)	98.50%	179.8	-8.9	4.311	-6.263
FT13 (3-200-1)	98.50%	71.8	-16.4	2.519	8.591
FT14 (3-200-2)	98.50%	71.8	-16.4	2.519	-8.591
FUEL OIL = 1870.5 MT					

FRESH WATER					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
FW1	99%	19.75	-34.4	3.058	6.373
FW2	99%	19.75	-34.4	3.058	-6.373
FW3	99%	39.51	-34.4	3.017	-9.742
FRESH WATER = 79.01 MT					

LUBE OIL					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
LO STORG (3-116-1-F)	1	11.5	10.1	3	5.4
LO STORG (3-116-2-F)	1	11.5	10.1	3	-5.4
LO SETTLE (3-130-1-F)	1	11.5	6.1	3	5.4
LO SETTLE (3-130-2-F)	1	11.5	6.1	3	-5.4
LO STORG (3-214-1-F)	1	11.5	-19.9	3	5.4

LO STORG (3-214-2-F)	1	11.5	-19.9	3	-5.4
LO SETTLE (3-227-1-F)	1	11.5	-23.9	3	5.4
LO SETTLE (3-227-2-F)	1	11.5	-23.9	3	-5.4

LUBE OIL = 92 MT

OILY WASTE					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
OW1	50.00%	5.05	9.05	0.544	7.305
OW2	50%	5.05	9.05	0.544	-7.305
OW3	50%	5.05	-21.45	0.544	7.305
OW4	50%	5.05	-21.45	0.544	-7.305

BALLAST					
ITEM	**QUANTITY**	**WEIGHT [mT]**	**LCG [m] From Amidships**	**VCG [m] From Keel**	**TCG [m]**
CB1 (4-26-1)	99.00%	23.8	37.6	0.86	8.495
CB2 (4-26-2)	99%	23.8	37.6	0.86	-8.495
CB3 (3-67-1)	99%	78.3	25.6	2.529	8.591
CB4 (3-67-2)	99%	78.3	25.6	2.529	-8.591
CB5 (4-264-1)	99%	70.8	-38.85	0.86	8.495
CB6 (4-264-2)	99%	70.8	-38.85	0.86	-8.495

TOTAL DISPLACEMENT = 7023 MT

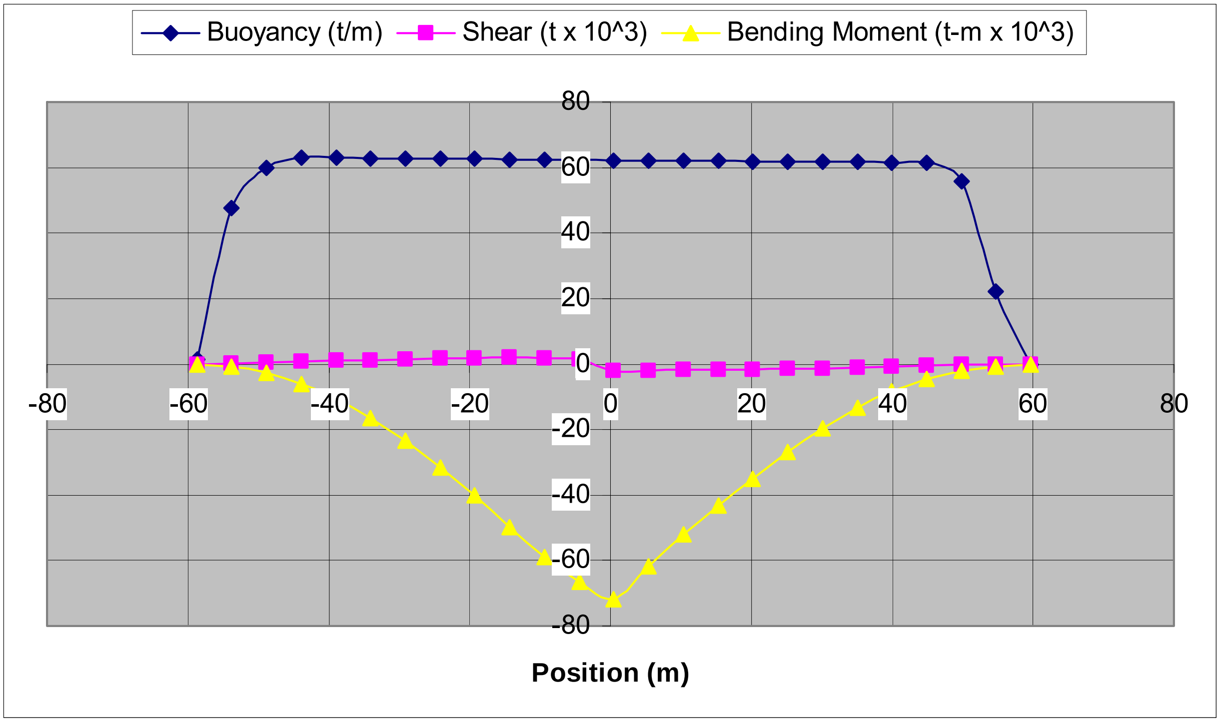


Figure 50. Loading and Bending Moments

Condition	Position	Value
Max. Shear (tonnes)	0.498 m	-2089
Max. Bending Moment (t-m)	0.498 m	-71772

9. Hull calculations

Hydromax has been used for Naval Architecture calculations. These calculations are shown in Appendix X and include:

- Hydrostatics
- Cross Curves of Stability
- Tank Calibrations
- Intact Stability
- Damaged Stability.

10. REFERENCES

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3. "Joint ACCESS:High-Speed Assault Connector (HSAC) for Amphibious Seabasing Operations and Joint Expeditionary Logistics", Technical Report, Naval Post Graduate School, Monterey, California, December 2004.

4. "Wave Making Resistance Characteristics of Trimaran Hulls", Zafer Elcin, Master's Thesis, Naval Post Graduate School, Monterey, California, 2003

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D. PROPULSION DESIGN

1. POWER TRANSMISSION ANALYSIS

An analysis was conducted to determine the type of propulsion plant required for the SEA TENTACLE. The first step in this process involved the selection of the power transmission "scheme". Two main options were initially considered by the group: a segregated propulsion and electric power system involving reduction gears, or an Integrated Power System (IPS) involving electric drive.

a) Segregated Power Systems/ Reduction Gears

Most warships in service in the U.S. Navy have a segregated power system utilizing reduction gears in the propulsion train. The term segregated refers to the fact the ship has separate prime movers for propulsion and electrical power. These prime movers generally have to run at very high speeds to be efficient; however, these speeds are too fast to power the propulsion unit. In order to achieve the desired speed necessary to propel the ship, a series of gears that reduce the number of revolutions per minute (RPM) are utilized. These gears are referred to as reduction gears.

Segregated power systems have many disadvantages. They require separate prime movers for both propulsion and electrical purposes. They require lengthy propulsion "trains" that are limited in the positions they may be located in the ship. The use of reduction gears involves costly maintenance and upkeep. Possibly the biggest disadvantage is that the trend in the U.S. Navy (and in civilian shipbuilding as well) is away from segregated power plants and towards an IPS. For these reasons, the Sea TENTACLE team did not choose a segregated power system.

b) Integrated Power System

An IPS refers to an engineering design whereby both electrical and propulsion power are supplied from a set of common prime movers. Power is supplied along a common set of busses before being split off for propulsion and ship service use. Propulsion power is utilized by some version of an electric motor which in turn drives the propulsion unit.

IPS's have several advantages over segregated power systems. IPS's require less maintenance than reduction gear designs. Propulsion machinery may be located in a variety of areas due to the lack of reduction gear. A variety of motors which take up far less space than that used by reduction gears may be utilized. With regards to cost, the economical improvements in semiconductors now mean that that the IPS costs less than the segregated power system. An IPS has the unique advantage of being able to utilize unneeded propulsion power for high energy weapons, such as an electromagnetic rail gun. Although SEA TENTACLE does not envision utilizing any high energy weapon systems, an IPS was still selected due to the numerous other advantages.

c) Propulsion Motors

As stated above, an IPS allows for a variety of different electric motors to power the ship. An early choice was to utilize Superconducting motors instead of Commercial off the Shelf (COTS motors). Superconducting motors offer advantages in that they are more efficient and smaller than COTS motors. Although they cost more than COTS motors, superconducting motors have a longer lifespan than COTS motors, thereby offsetting the cost. The SEA

TENTACLE team looked at two types of superconducting motors, the High Temperature Superconducting Synchronous motor, and the DC Superconducting Homo-Polar Motor.

i. DC Superconducting Homo-Polar Motor

A Homo-Polar motor is the basic DC electrical motor first discovered by Michael Faraday. In this design, the stationary part of the motor, called the stator utilizes a single magnetic field. This field may be generated by a permanent magnet, or by a DC current. The rotating part of the machine, or rotor, is supplied with a DC current. The magnetic field produced by the rotor interacts with the field associated with the stator, causing a torque on the device. In a superconducting Homo-Polar motor, the use of superconducting technologies allows for a very high current to flow in this stator. This high current translates into a high stator magnetic field, and hence, a high torque produced for this design.

ii. HTS AC Synchronous Motor

A Synchronous Motor is an AC motor that rotates at the same speed as the rotating electrical field. Many such motors use multiple phases (commonly three) to create this effect. AC current is supplied to coils on the stator, which cause a magnetic field. A similar current is applied to coils on the rotor, also causing a magnetic field. The resulting interaction between these two fields applies a torque to the shaft, causing it to rotate. High Temperature Superconducting (HTS) technology can be applied to the stator. This allows for a greater current to flow in the stator, allowing for a larger torque to be produced.

The HTS AC Synchronous motor has one main advantage over the DC superconducting Homopolar Motor.

That is, the HTS AC Synchronous Motor is powered by AC power, instead of DC. Currently most generators in use by the Navy generate 3 phase, AC power. In order to utilize a DC superconducting Homopolar Motor, a large amount of additional AC-DC power converters would be required. Besides the cost involved, utilizing AC-DC power converters on this scale results in a prohibitive use of volume. The SEA TENTACLE design therefore utilizes the HTS AC Synchronous Motor.

2. Propulsion Plant Analysis

The team conducted a detailed investigation of possible propulsion schemes. Given that electric drive power transmission has been selected, multiple alternatives for the other key elements of the propulsion train – the propulsion plant or, "prime mover" and the propulsor - were considered in various possible combinations. The "prime mover" is the portion of the propulsion plant that extracts energy from some source, whether it is nuclear, chemical, or fossil fuel, and converts it into a useful form to generate electrical power and controlled ship motion. Types of propulsors considered were: propellers, podded propulsors, and water jets.

a) Propulsion Plant Trade Off Analysis

Many attributes were taken into consideration when choosing a propulsion plant. The factors deemed of most importance were: weight and volume, efficiency, reliability, power provided, and acceleration ability. The options considered were steam plants (conventional and nuclear), fuel cells, diesel engines, and gas turbine engines. Each type of propulsion plant was researched and considered on the basis of its ability to best meet the needs and requirements set forth in the Appendix IV.

b) Fuel Cells

A fuel cell is an electrochemical energy conversion device that converts hydrogen and oxygen into water, and in the process produces electricity. It offers a means of making usable power very efficiently and with low pollution of the environment. Some fuel-cell technologies are thought to have the potential to be able to generate electricity more efficiently than today's power plants. The fuel-cell technologies being developed for these power plants will generate electricity directly from hydrogen in the fuel cell, but will also use the heat and water produced in the cell to power steam turbines and generate even more electricity. [Ref 1] For a naval application, the electricity generated by fuel cells would be used to power electric-drive propulsion motors, as well as support the other electrical needs of the ship. The reaction in a single fuel cell produces only about 0.7 volts. To raise the voltage to a useful level, many separate fuel cells must be combined to form a fuel-cell stack.

There are several different types of fuel cells, each using a different chemistry. Fuel cells are usually classified by the type of electrolyte they use. The proton exchange membrane fuel cell (PEMFC) is one of the most promising types. Pressurized hydrogen gas (H_2) enters the fuel cell at the anode and is forced through the catalyst. When an H_2 molecule comes in contact with the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode, where they make their way through an external circuit (doing useful work such as turning a motor) and return to the cathode of the fuel cell. Steady improvements in the engineering and materials used in these cells have achieved increasingly greater power densities.

The primary advantage to using fuel cells is pollution reduction, as they are a very clean and efficient source of power. Fuel cells, unlike batteries, have chemicals constantly flow into the cell so they never go dead - as long as flow of chemicals into the cell is maintained, electricity flows out of the cell. Although fuel cells do generate heat as a by-product, they do not produce the distinct heat signature associated with the exhaust gases from a fossil fuel-burning propulsion plant. The absence of hot gases and large stacks would help the ship achieve a lower infrared signature, and possibly a smaller radar cross-section as compared to a conventionally-powered ship.

Despite the promising technological advances in the field of fuel cell development, current capabilities are still well below those required to power a naval warship. At present, the achievable power density is only sufficient to power a car, a bus, or serve as a backup power source to a stationery facility, such as a hospital. This is significantly less power than the SEA TENTACLE will require, and this broad technology gap is unlikely to be bridged by 2025. Also, although the oxygen required for a fuel cell comes from the air, the hydrogen is not so readily available. Hydrogen is flammable and explosive, which makes it difficult to store and distribute. For these reasons, fuel cells were removed from the list of feasible means of propulsion.

c) Conventional Steam Plant

In conventional steam plant propulsion, boilers produce steam that is used by various components. The main engines, which efficiently convert the thermal energy of steam into useful mechanical energy to propel the ship through the water, and consist of high and low pressure turbines that drive the propellers (usually with reduction gearing to allow both the engine and the propellers to operate at their own optimal speed), ship's service turbine generators to provide electrical power, and many other auxiliary systems.

Steam generation begins with the boiler. Typical boilers operate at either 600 psi or 1200 psi. Fuel oil burners are located on the boiler front and extend into the furnace to provide heat to generate steam. A fuel oil service system provides the proper amount of fuel oil to the boiler for operation. Air is drawn in from the outside atmosphere and directed to the boiler to facilitate combustion. The proper air-to-fuel ratio is critical for complete combustion of the fuel Modern surface ships use Automatic Boiler Control (ABC) are to run the operation of the boiler and auxiliaries under all load conditions from minimum to 120 percent [1].

Conventional steam plants have high endurance, until the ship must slow for refueling. They are also very efficient at low speeds. Conventional steam plants use superheated steam, which results in smaller turbine size and greater specific energy content of the steam, as compared to nuclear powered steam plants. This allows the use of smaller turbines to attain the same power levels, and also eliminates much of the "carry over" of contaminants that can erode turbine blades. Limitations on power production by a steam system are tied to the design and construction of the reduction gears, shafting, thrust bearings, and supporting structure, rather than in the turbines or steam generators themselves.

One of the biggest disadvantages of team plants is the low fuel efficiency, necessitating significant volume and weight allotments for fuel storage. Manning and maintenance demands are extensive. Steam plants take a relatively long time to start up, due to the inherent complexity of multiple integral systems, and the limitations imposed by steam system piping heat-up-rates to minimize thermal stresses. Finally, steam plants use seawater passing through the tubes of a main condenser to return the used steam to a liquid state so that it can be recycled to the steam generator, therefore seawater surface temperature in certain operating environments can impose a limitation on the maximum sustained performance of a steam plant.

Based on the requirement of needing a vessel to transit at high speeds, but also have large amounts of weight and volume dedicated to cargo, the conventional steam plant was eliminated as a viable option.

d) Nuclear Steam Plant

The nuclear power plant consists of a high-strength steel reactor vessel, numerous heat exchangers, and associated piping, pumps, and valves. Each reactor plant also contains over 100 tons of lead shielding.

Naval nuclear propulsion plants use a pressurized water reactor design which has two basic systems - a primary system and a secondary system. The primary system circulates pressurized water through the reactor, where heat from fission is transferred to the water, to the steam generators where heat is transferred to create steam in the secondary system, and back through the reactor in a closed-loop system. The secondary system is isolated from the primary system so that the water in the two systems does not mix.

In the secondary system, which is much like a conventional steam system, the steam from the steam generators is used to drive turbine generators to supply electrical power, and to the main propulsion turbines, which spin the propeller. The system uses condensers and pumps to recirculate the secondary water.

Since there is no requirement for either air or oxygen, this enables the ship to operate completely independent from the atmosphere for extended periods of time, making nuclear propulsion ideal for submarines. This advantage, or necessity, does not extend to surface ships.

For surface ships, a nuclear steam plant does provide some advantages. Nuclear power plants are highly efficient at all speeds and powers. A nuclear reactor can provide the ship with power for several years without refueling, eliminating the need to dedicate large storage volumes for fuel, alleviating the operational hindrance of stopping to refuel, and easing dependence on limited natural resources for fossil fuels. The lack of hot exhaust gases and stacks themselves also gives a nuclear-powered vessel a lower infrared signature, and possibly a smaller radar cross-section than a conventionally-powered ship.

There are however, many disadvantages to a nuclear powered steam plant. Radiological shielding is extremely heavy, rigorous training and maintenance requirements are imposed, and manning requirements are more extensive than for other plant types. Political issues are also significant concerns – some countries do not permit nuclear- powered ships to pull into their ports, which could be a significant problem after a ship has sustained battle damage. Finally, removal, containment and disposal of spent nuclear fuel are highly complex and expensive processes, and it is difficult to ensure there will no deleterious effects on the environment over the centuries for which the fuel and reactor components will remain radiologically active.

Specific information pertaining to naval nuclear power is classified; therefore it would be difficult to obtain pertinent data for a meaningful comparison study with other propulsion types. Based on the stated disadvantages and practical difficulties, the option of a nuclear steam plant design was eliminated.

e) Diesel Engines

The diesel engine involves the combustion of a fossil fuel inside a cylinder containing a piston, whose motion results from the transformation of thermal energy into mechanical work. Combustion forces the piston down or outward (power stroke) from rapid expansion of the gases. The moving parts of the diesel engine provide for controlling the elements necessary for combustion and the transformation of combustion to mechanical shaft energy. The major moving components are the crankshaft, piston assembly, connecting rod, camshaft, valves, operating gear, flywheel, vibration dampener and various gears. Diesel engines are used extensively in naval applications, serving as propulsion units for small boats, ships and land vehicles, and as prime movers in auxiliary machinery, such as diesel generators, pumps and compressors.

Medium-sized combatant ships and many auxiliary vessels are powered by large single-unit diesel engines or, for more economy and operational flexibility, by combinations of several smaller engines. In general, the use of diesels on intermediate sized combatants and larger requires that several smaller units be combined to drive a common shaft, which can result in severe space and arrangement problems.

Diesel engines have relatively high efficiency at partial load, and much higher efficiency at very low partial load when compared to steam turbines. They also have greater efficiency at high speeds than any of the other fossil-fueled plants. Hence, they require the least amount of fuel weight and volume for a given endurance. Other advantages include low initial cost and relatively low RPM, which results in smaller and lighter reduction gears. Also, diesel engines can be brought on-line from cold conditions much more rapidly than steam plants. Diesels are reliable and simple to operate and maintain, having a long history of active development for marine use.

Among the disadvantages of diesel propulsion is the fact that periodic engine overhaul and progressive maintenance are required, resulting in frequent down periods, which decrease the amount of time the ship has full power available while at sea. Also, the marine diesel has a high rate of lube oil consumption, which may approach

5% of the fuel consumption; thus large quantities of lube oil must be carried. Finally, the aforementioned space and arrangement problems caused by the necessity of multiple engines per shaft on a vessel as large as TENTACLE will be prohibitive. Therefore, the diesel option was ruled out.

f) Gas Turbines

A gas turbine is a rotary engine that extracts energy from a flow of combustion gas. It has an upstream compressor mechanically coupled by a shaft to a downstream turbine, with a combustion chamber in-between. Energy is added to the gas stream in the combustor, by mixing and ignition of air and fuel. Combustion increases the temperature, velocity and volume of the gas flow, which is directed through the turbine blades, which spins the turbine and powers the compressor. Useful energy is extracted in the form of shaft power, compressed air and thrust.

Gas turbines are described thermodynamically by the Brayton cycle. As with all cyclic heat engines, higher combustion temperature means greater efficiency. The ability of the steel, ceramic, or other materials that make up the engine to withstand heat and pressure is a limiting factor in efficiency. Significant engineering effort goes into cooling the turbine parts. Most turbines also try to recover exhaust heat, which is otherwise wasted energy. Recuperators are heat exchangers that pass exhaust heat to preheat the compressed air, prior to combustion. Combined heat and power (co-generation) uses waste heat to produce hot water for other uses such as hotel loads.

Gas turbines can be much less complex than internal combustion piston engines. Simple turbines might have one moving part: the shaft/compressor/turbine assembly. More sophisticated turbines may have multiple shafts, hundreds of turbine blades, movable stator blades, and a complex system of piping, combustors and heat exchangers. Thrust bearings and journal bearings are a critical part of design. Traditionally, they have been hydrodynamic oil bearings, or oil-cooled ball bearings.

Gas turbines are used in many naval applications, due to their high power-to-weight ratio, relatively good fuel efficiency at high powers, and ability to accelerate the ship rapidly. Gas turbines are modular, meaning one can be removed for maintenance be repaired, replaced with a identical gas turbine, or swapped out with a new, more advanced gas turbine. Gas turbine propulsion plants also have minimal startup time, enabling the ship to get underway quickly from cold-iron. Gas turbine technology, especially computer design and material advances, have allowed higher compression ratios and temperatures, more efficient combustion, better cooling of engine parts and reduced emissions. Also, compliant foil bearings were commercially introduced to gas turbines in the 1990s. They can withstand over a hundred thousand start/stop cycles and eliminated the need for an oil system. [Ref 3] Other advantages include a low noise signature and reliability.

Gas turbines have a few disadvantages. They typically give a ship high infrared signature due to emission of very hot exhaust gases. They are less fuel-efficient than diesel engines. They rely on a non-renewable source of energy, of which the United States has a finite supply.

Despite the disadvantages, gas turbines have many redeeming qualities that make them an attractive option for warship propulsion. Based on their proven capability, reliability, and efficiency on many current naval combatants, gas turbines were chosen as the power plant for the Sea TENTACLE.

3. Gas Turbine Analysis

There are numerous specific types of gas turbines available, with varying design parameters to suit the myriad of possible particular applications. Next, an analysis was performed to choose which type and how many gas turbines would be used for Sea TENTACLE. Performance parameters of interest were: weight, volume, power output and efficiency.

a) ICR WR21

The WR21 is an intercooled recuperated (ICR) gas turbine engine currently being developed by Rolls-Royce. The WR21 ICR engine offers improved Specific Fuel Consumption (SFC) and an overall cycle efficiency gain when compared to simple cycle gas turbine engines. A reduction in fuel burn of 27% is achieved. It also offers reduced signature, increased reliability and ease of maintenance as well as operational advantages in ship range, speed and time on station. The disadvantages of this gas turbine are its high weight, volume and cost when compared to other single cycle gas turbines.

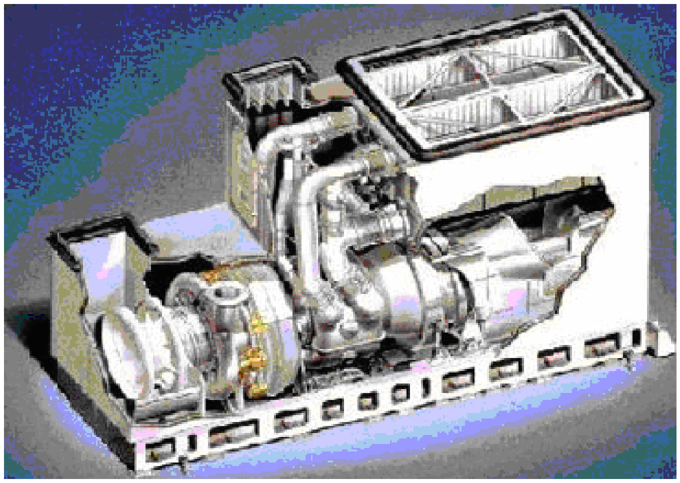


Figure 51. ICR WR1 Gas Turbine

b) MT30 TRENT

MT30 is a highly competitive gas turbine which is based on the Trent 800 aero engine which powers the Boeing 777 aircraft. It is capable of producing over 36 MW of power and offers high efficiency which is 40%. Designed with 50% to 60% fewer parts than other gas turbines in its class, the MT30 maintains its competitive efficiency down to 25 MW, a rare quality in gas turbines. One of the principal advantages of MT30 is that, with a very high power, a wider range of dedicated cruise engines can be used in combination with it, providing an optimized solution to achieve lower fuel burn. The MT30 also maintains efficient fuel consumption (SFC=0.21 kg/kWhr) compared to other gas turbines and high speed diesels.

Figure 52. MT30 TRENT Gas Turbine

c) LM2500

The LM2500 is a well-proven, very successful aero-derivative gas turbine that is made up of a single-rotor gas turbine coupled aerodynamically to a power turbine. It has been deployed in a wide range of naval ships and was designed to be a highly efficient, easily repaired and maintained, and corrosion-resistant marine gas turbine. It is capable of producing 22 MW of power with a thermal efficiency of 37% and provides one horse power for every 1.5 pounds with the weight 34000 pounds. LM2500 requires just 40 hours of major maintenance for each 10,000 operating hours and maintains specific fuel consumption at 0.216 kg/kWhr. The efficiency of this gas turbine can be greatly increased by using the exhaust for other applications such as boilers and other auxiliary systems.

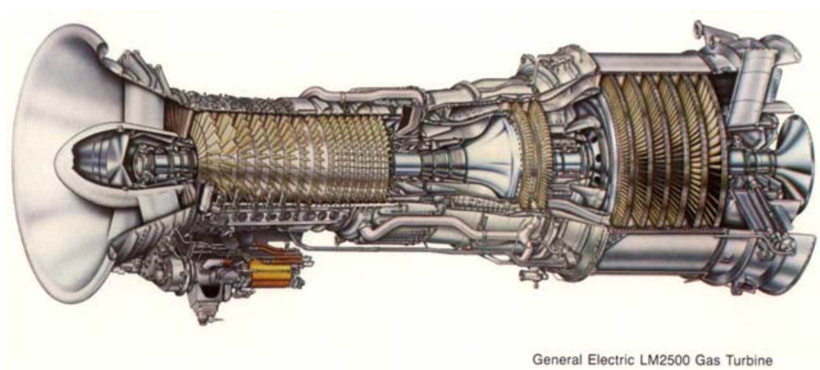


Figure 53. LM2500 Gas Turbine

d) LM2500+

The LM2500 Plus is a high-performance version of the LM2500 with an additional compressor stage, providing higher flow, improved efficiency, technically advanced materials and coatings in the high pressure turbine and a redesigned power turbine. It is designed to achieve the precedent-setting reliability, 99.6%, of the LM2500 and rated up to 28.6 megawatts, 40,500 shaft horsepower at a thermal efficiency of 39%. Its high efficiency, reliability, modularity, and installation flexibility make it ideal for a wide variety of marine power generation and mechanical drive applications. The specific fuel consumption of the LM2500+ is 0.354 lb/SHP-hr.

Although the LM2500+ has less volume than LM2500, it gives more output power than the LM2500 with essentially the same combustion air requirements due to the greatly improved efficiency of the compressor.

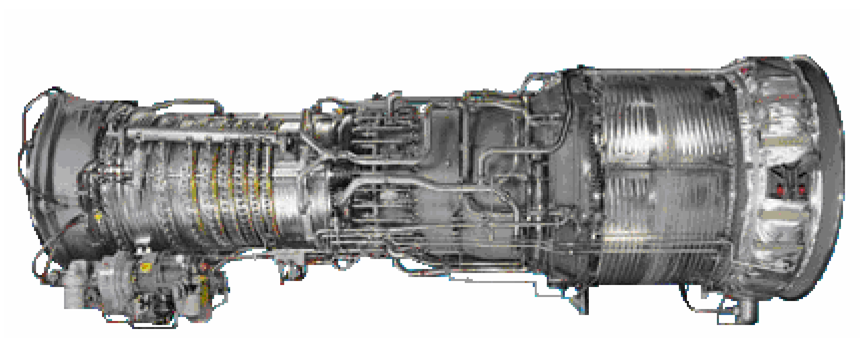
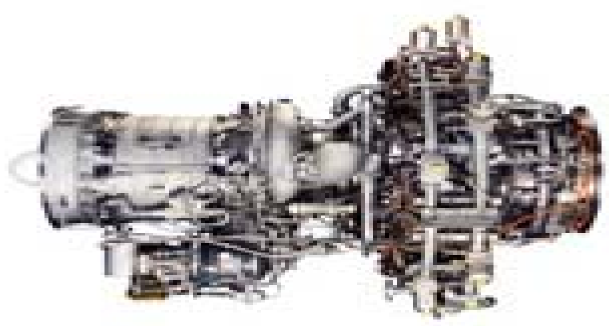


Figure 54. LM 2500+ Gas Turbine

e) LM1600

The LM1600 is the most fuel efficient, simple cycle, gas turbine engine available in its power class with 0.376 lb/SHP-hr SFC. It is capable of producing 20,000 shaft horse power with a thermal efficiency of 37%. 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. Additional features of the LM1600 are: high power to weight ratio, compact design, ease of operation and ease of maintenance. It is much smaller than LM2500 and LM2500+ with a weight of 8,200 lb.



LM 1600 Gas Turbine

f) LM6000

The LM6000 is a derivative of the CF6-80C2 high bypass aircraft engine and, due to its advanced design and materials, is the most fuel-efficient simple cycle gas turbine in its class with a thermal efficiency of over 40%. Power output can be augmented up to 47.5+ MW (57,330 hp). It provides the power and unprecedented efficiency needed by users at an installed cost that is competitive with any gas turbine. Although the LM6000 has high thermal efficiency and high power-weight ratio, it has higher volume and weight than LM2500 and LM2500+, and also requires a large and heavy cooling system.

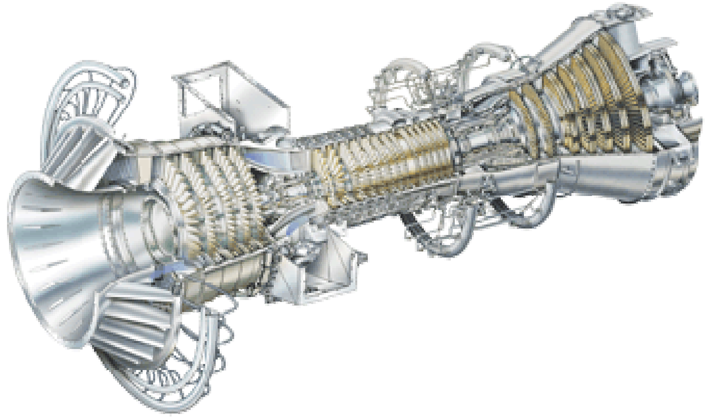


Figure 55. LM6000 Gas Turbine

4. Gas Turbine Comparison and Conclusions

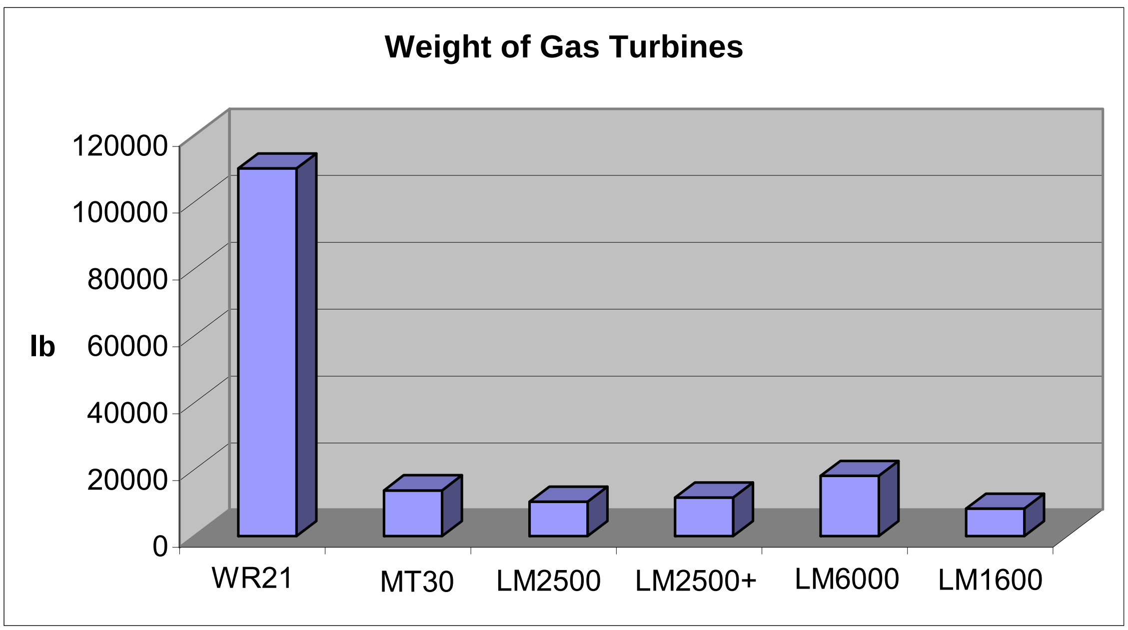


Figure 56. Weight Comparison of Gas Turbines

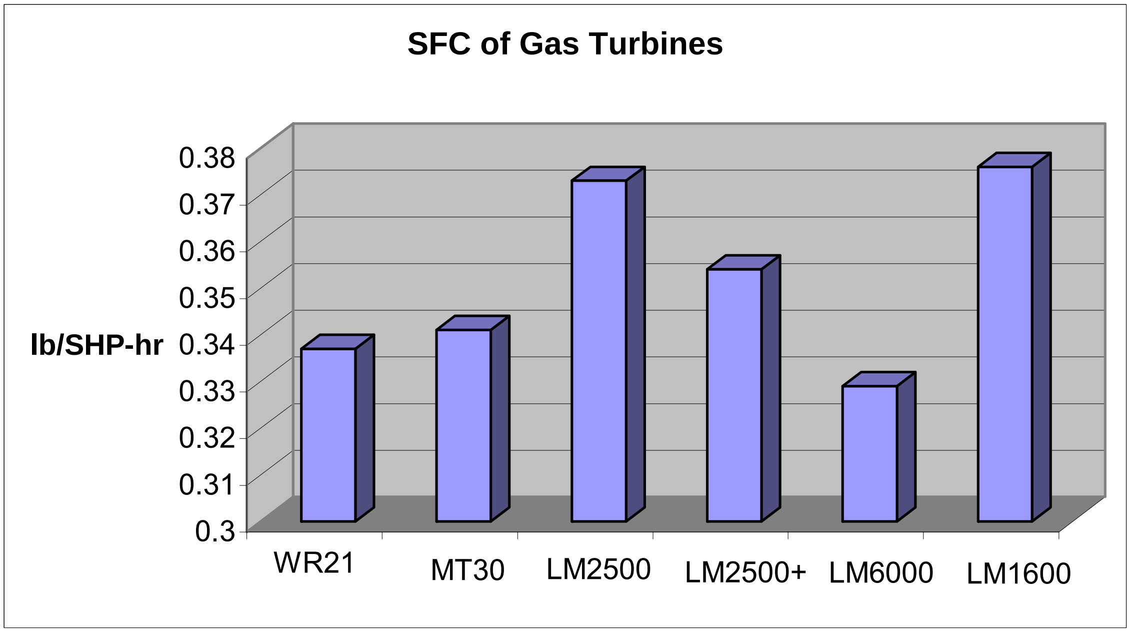


Figure 57. Specific Fuel Consumption (SFC) of Gas Turbines

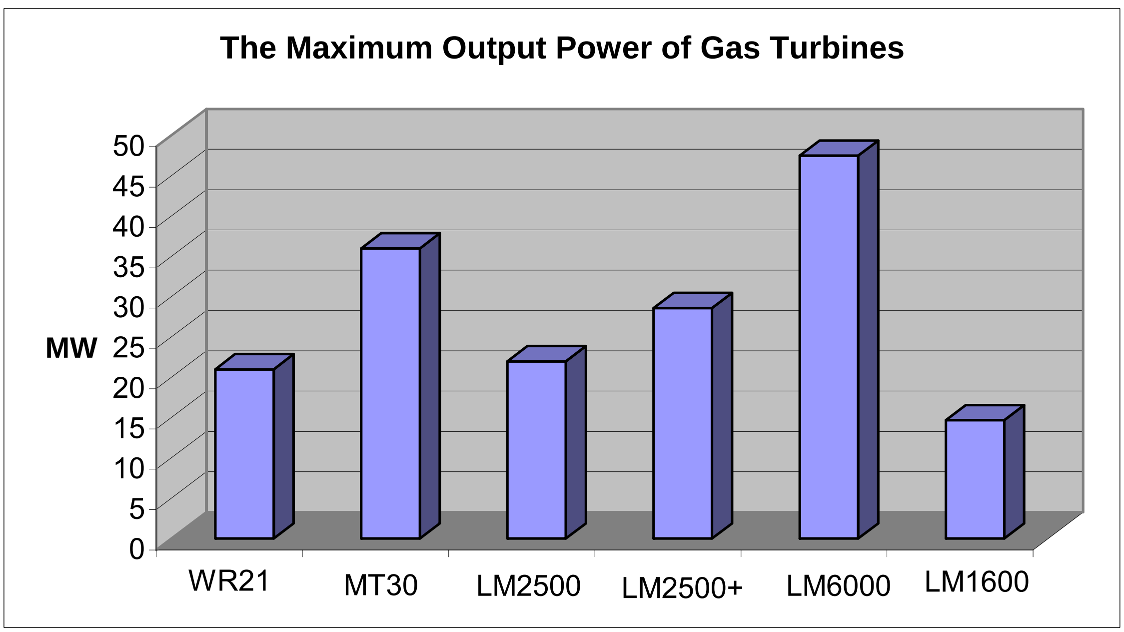


Figure 58. Maximum Output Power of Gas Turbines

GAS TURBINES	SFC (lb/SHP-hr)	WEIGHT (lb)	POWER (MW)
ICR WR21	0.337	110,00	21
MT30 TRENT	0.341	48,01	36
LM2500	0.373	10,00	22
LM2500+	0.354	11,45	28.6
LM6000	0.329	18010	47.5
LM1600	0.376	8200	14.7

Table 14. Properties of Individual Gas Turbines

Since the Sea TENTACLE requires approximately 73.5 MW, the ICR WR21 gas turbine is not a good option due to the large weight and low power compared to the other gas turbines. Although MT30 seems to be a good option due to its high efficiency and high output power, the Sea TENTACLE would need three MT30 gas turbines in order to achieve full power, resulting in an extreme increase in the weight of the ship. Therefore, MT30 is not feasible for our design.

LM2500 is a well-proven gas turbine already deployed successfully in several naval ships, but compared to the advanced model LM2500+, it produces lower power and has higher fuel burn rate. Although LM2500 weighs approximately 11% less than LM2500+, its volume is approximately 90% higher due to its geometry. LM1600 is also not a feasible option for our design. The Sea TENTACLE would need five LM1600 gas turbines, contributing a total of 41,000 pounds to the ship weight. It seems feasible according to the weight, but this gas turbine has the least desirable specific fuel consumption rate at low speeds.

After elimination of the other gas turbines for the reasons explained, the optimal prime movers for the Sea TENTACLE are the LM2500+ or LM6000. LM6000 is capable of producing more power than LM2500+ and also gives higher thermal efficiency. LM6000 is more efficient, especially for high speeds, giving less SFC at speeds higher than 10 knots. The LM2500+ is more efficient at lower ship speeds.

In order to determine whether to use LM2500+ or LM6000, or one of them in some combination with another type of gas turbine, and how many of the turbine chosen, two plausible alternatives were proposed. The analysis of the alternatives is as follows:

According to the resistance calculations, 40 knots was decided to be the maximum speed of Sea TENTACLE and the analysis of engine configuration was based on this. Sea TENTACLE's maximum required EHP for 40 knots is 72.15 MW. The propulsive efficiency is assumed to be 0.79.

For maximum speed, 40 knots,

$$SHP = \frac{EHP}{\eta_P} = 91.335MW = 122,890SHP$$

In order to obtain 40 knots, we need 3 gas turbines.

ALTERNATIVE 1 (one LM6000 and two LM2500+):

1 LM6000 + 2 LM2500+ = 57,330 + 81,000 = 138,330 SHP

ALTERNATIVE 2 (one LM2500+ and two MT30):

2 MT30 + 1 LM2500+ = 97,893 + 40,500 = 138,393 SHP

We referred to the SFC chart of LM2500 as a reference for the other gas turbines and in order to calculate SFC at various speeds. We calculated two SFC values. One of them is for 20 knots, which is our estimated cruising speed and the other is the maximum speed of 40 knots.

LT	Total Power (SHP)	Shipboard Power	SFC @ 15 knots	SFC @ 35 knots	Weight (lb)	Volume (ft^3)
1	138,330	11.572 MW	0.392	1.077	41,100	3,956.212
2	138,393	11.615 MW	0.392	1.075	38,881	11,864.906

Table 15. Comparison of Gas Turbine Alternatives

As shown in Table 3, both options gave similar values for shipboard power, specific fuel consumption, and weight. The primary difference was in volume, and Alternative 2 occupies three times the space that Alternative 1 occupies. The final decision was made to use Alternative 1, consisting of one LM6000 and two LM2500+ gas turbines.

5. Propulsor Trade Off Analysis

a) Propeller

Propellers were one alternative. Since the wave-piercing catamaran is a planing hull form, propellers would have to be placed lower to ensure submersion even at high speed. A reasonable expectation finds that propellers increase our navigational draft significantly further restricting operations in littoral waters. In addition, propellers would require a reduction gear regardless of the engine type chosen. Because of the weight and space requirements that are required when using a reduction gear, we have chosen to avoid reduction gear and propeller systems.

b) Podded Propulsors

Podded propulsion systems can demonstrate several advantages over conventional propeller in terms of maneuverability, weight, arrangements, build schedule and cost. These systems are being adopted as the principle means of propulsion for many large cruise ships, as well as for several warships in the foreign navies. Podded propulsors are being considered for the US Navy’s future electric warship programs.

According to Alstom, podded propulsors are 14% more efficient compared to conventional propulsion: 6-8 % from a more efficient hull, 4-6 % due to reduced appendages, and 1-2% by tilting the propeller into the flow. Additionally, the azimuthing pods can turn 35° at full speed, and a full 180° at slow speed or stop. This contributes to unsurpassed maneuverability in littoral waters [4].

Podded propulsion systems can offer advantages in outfitting and fuel costs compared with conventional systems, but military requirements such as shock must be met before they can be considered for warships. Additionally, podded propulsion will increase the draft requirements over a water jet because they require nearly the same area as an open propeller system. For these reasons the podded propulsion system was avoided.

c) Water Jets

i. General description

Water jets are a more efficient propulsor than controllable pitch propeller, quieter than propellers, and typically will not increase navigational draft. Additionally, they promise to be more maneuverable and will not require reversing the engines in order to drive backwards.

ii. Bird-Johnson AWJ-21

The US Navy is currently funding the development of the AWJ-21, a propulsor designed to be an integral part of a more efficient hull form without rudders and other underwater appendages. Its key features are the patented underwater discharge configuration and advanced mixed flow pump design, which is the most efficient today. These features lead to improved cavitation performance and reduced jet-related wake disturbance giving greater stealth allowing any vessel to reduce noise at higher speeds, potentially 4-6knots quicker [5].

The reduced diameter of the AWJ-21 in comparison to a conventional propeller has two advantages. First, in combination with increased rotational speed, for a given power the torque requirements are reduced supporting a smaller drive-train, less expensive and lighter, which is very significant for overall ship weight. Secondly, in most applications the water jets are situated completely above the hull baseline combined with the integrated steering and reversing system that utilizes vectored thrust through a single hull penetration, providing unsurpassed maneuverability at low speeds and a much reduced draft [5].

6. References

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4. Naval Architecture & Ship Systems Newsletter # 11, PODDED PROPUSLOR DEVELOPMENTS IN FRANCE, Mr. Larrie Ferreiro, Date: 11 July 2003.

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E. INTEGRATED POWER SYSTEM

In order to meet the requirements of SEA TENTACLE'S integrated power system, we employed an AC/DC zonal hybrid. This was deemed to be the most flexible, robust, reliable, and compact system available. The gas turbines produce 3 phase, 13.8 kV AC, which is made immediately available to the ship's main busses. Transformers connect to these busses and supply power to SEA TENTACLE's HTS motors. Since ship's service loads are not connected directly to these busses, the bus frequency can be set to what is best required by either the gas turbines or the HTS motors themselves. A diagram of this plant is shown below.

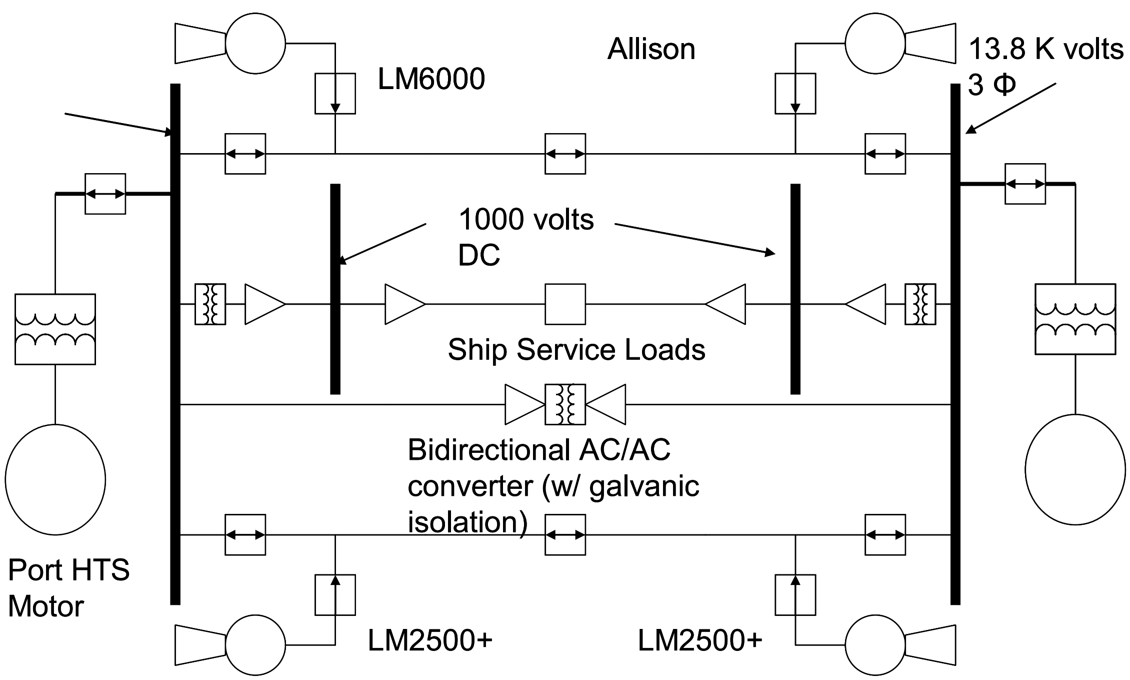

Figure 59. SEA TENTACLE'S Integrated Power System

The 13.8 kV AC produced by the gas turbines is rectified down into 1000 Volts DC for use by the ship's service buses. This rectification will most likely be accomplished by Ship Service Converter Modules. All ship service loads are connected to both ship service buses by either diodes, DC-DC converters, or DC-AC converters. The advantage of this is that if 1 AC (or one DC) bus is lost; all ship service loads will immediately receive DC power from the other bus.

The overall layout of the plant was chosen to accommodate the use of three main gas turbines. (The Allison was primarily selected as a backup). This allows for the use of only 1 gas turbine at lower speeds, resulting in higher efficiencies. At the highest power setting, the two LM 2500+'s would be aligned to one bus, with the LM 6000 bus to the other side. This results in a 17.65 MW unbalance between the power available to both AC busses. To compensate for this, we employed an AC-AC converter capable of approximately 10 MW.

As earlier mentioned, we employed a zonal architecture in our IPS. Most current power systems are "radial". The terms radial and zonal refer to the actual physical layout of the wiring scheme. Both radial and zonal schemes could be used to power the IPS described above. Radial systems consist of hundreds (or thousands) of different wirings that penetrate bulkhead compartments. In a zonal distribution, only the actual "busses" penetrate a watertight bulkhead. All loads in that compartment then connect to that zone. The lower bulkhead penetrations directly contribute to the survivability of the ship, as does the ability to locate and isolate faults more quickly in a zonal system. The following figure shows the zonal distribution of the SEA TENTACLE.

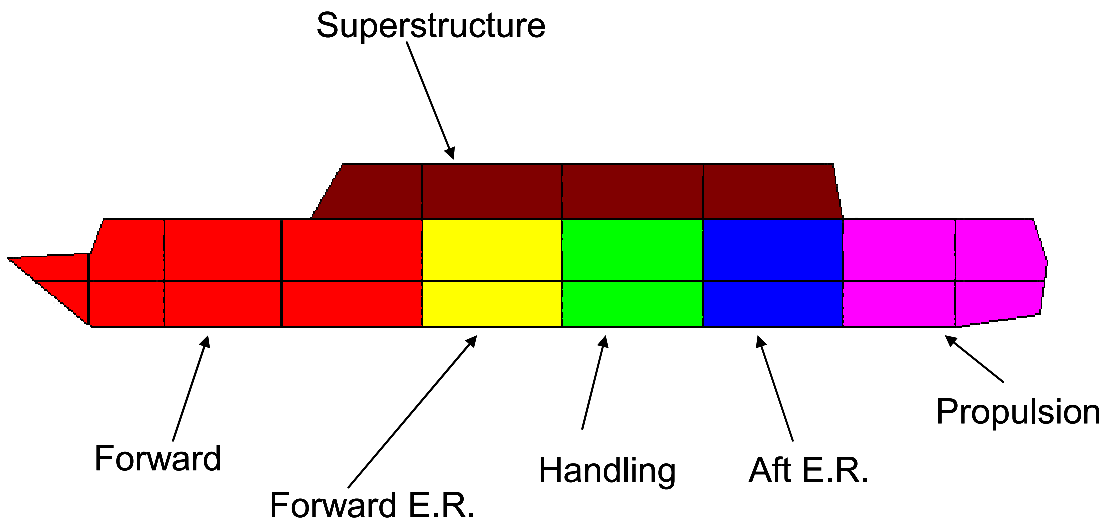

Figure 60. Zonal Distribution System

The zone denoted as Superstructure is primarily concerned with CIC and combat system loads. The Forward Zone is very large in this picture because much of its volume is dedicated to tanks and stores with very few electrical loads. Each Engine Room was allocated a zone, while the spaces dedicated to the propulsion machinery received a zone as well. Finally, the UUV handling space, (which allows the ship to carry out its primary mission) was assigned a zone.

F. DAMAGE CONTROL

The Damage Control – Automation for Reduced Manning (DC-ARM) program is an on-going program with a goal of developing the technologies necessary to achieve major reductions in DC manning. The DC-ARM program has focused on developing the technologies for automating shipboard damage assessment and casualty responses to shipboard fire and fluid system damage conditions. The program consists of four elements: reflexive fluid system technologies (smart valves), advanced fire detection technology, a zonal water mist/ smoke control system and intelligent Supervisory Control System (SCS) technologies. The DC-ARM program has demonstrated that the DC manning requirements on a modern destroyer-type ship could be significantly reduced from its present level of 105 to 45 people, with proper integration of DC System Automation and improved DC Doctrine (organization and procedures) [Ref.1].

1. Detectors

Advance fire detection technology enables reliable, fast automated response by installed systems, and facilitates a rapid crew response. The detection system will consist of a combination of the following types of sensors, for fire and other casualties: smoke detectors, carbon monoxide detectors, fire and flame detectors, a closed circuit television (CCTV) system, heat detectors, smart micro sensors, humidity monitors, and liquid level sensors. Automatic initiation of key fire suppression systems can be achieved through preprogrammed system logic, for example, any two sensors (not both smoke detectors) over a predetermined threshold in the same space or adjacent spaces can initiate automatic action. These sensors will also provide input to a wireless smart shipboard sensor network. The sensor information can be seen using a web page and/or ICAS (Integrated Condition Assessment System). Additionally, the sensors will be made "smart" by storing calibration information on a Ipsil chip and server computer that can be accessed by a HTML based program. By taking pre-computed calibration constants that minimize the measurements errors, and writing them through the web page stored in the Ipsil chip, the calibrated sensor reading can be calculated. [Ref. 2]

The ship-wide array of sensors will allow continuous monitoring of multiple parameters that pose a threat to ship's integrity and safety of the crew. The detection system and associated wireless network will immediately indicate the precise location of any damage, enabling rapid response by damage control parties. Progressive damage or changes in damage will be updated in real time. Response time will be reduced by eliminating the need for investigators to search for the damage.

Multiple interconnected data networks will be strategically routed throughout the ship with redundancy to increase system survivability. Control centers will be able to evaluate the information, and may also select the mode to initiate automatic response as appropriate. Control stations will be located in critical watch station areas, such as the Bridge, CIC, Damage Control Lockers, and Engineering Control Center. Watch standers will be able to monitor the alarms and also verify indications of automatic actions and the actions of the damage control organizations as they occur. Actions performed by damage control personnel may be added manually to the display by a control station operator. On-scene personnel would have wireless hand-held input/output for direction and information update as needed.

Fire is perhaps the most plausible casualty that may occur on a ship, due to the large amount of gas turbine fuel, lube oil, explosives, and other materials onboard that may fuel a fire, even in peace-time steaming. Due to the very real danger, multi-sensor fire detectors will monitor each compartment. Fiber optical or electrostatic smoke detectors, triple wavelength infrared flame, carbon monoxide, CCTV, and high performance optical, or fiber optical heat sensors will detect smoke and fires. Since the detectors will be sending their information via a wireless signal, fire progression can be monitored from the first sign of smoke through the initiation of a conflagration, until the physical limits of the detectors are reached.

Shipboard flooding is a serious casualty that can reduce seakeeping and stability, deny access to needed compartments and the systems they contain, and may ultimately result in the sinking of the ship. Therefore, compartments located below the damage control deck will be continuously monitored for flooding by liquid level detectors. Flooding detectors will consist of sensors arrayed from the bilge level to the overhead. The detectors will be located to indicate the presence of liquid at 2 and 6 inches, and at heights corresponding to flooding levels of 10%, 25%, 50%, 75%, and 100%. This information will also aid in the calculation of changes in ship’s stability due to flooding. In addition, all remotely operated valves and compartment accesses will also be monitored for their material condition status.

In addition to the dangers of fire and flooding, in a shipboard environment it is also possible for dangerous, poisonous gases to collect in enclosed spaces, or for oxygen levels to be depleted, producing a very real threat to human health and safety. Paint lockers and pump rooms will be monitored for atmospheric content that may be unsafe for crew members to enter, or poses an explosion hazard. Sewage spaces will be monitored for hydrogen sulfide gas and air conditioning and refrigeration rooms will be monitored for refrigerants and low oxygen levels. Immediate notification to control stations via the wireless network will facilitate timely corrective action and prevent crew members from entering compartments with potentially deadly atmospheres.

2. Detector Descriptions

The following is a general description of the various installed Damage Control detectors:

a) Smoke Detectors

There are four main categories of smoke detectors: photoelectric, optical, ionization and electrostatic. Photoelectric smoke sensors operate by projecting a beam of light across a sensing chamber. Smoke particles in the chamber would interfere with the light, causing changes in the projected pattern. These changes can be sensed by a photosensitive. These detectors will provide a satisfactory response as long as the smoke contains large enough particles. A disadvantage of photoelectric detectors is that they are susceptible to false alarms from airborne particulates. Optical detectors are similar to the photoelectric principle, except the beam is projected across open areas vice confined to a small sensing chamber. These detectors can monitor areas as large as 25 meters across. An ionization detector uses a minute quantity of a radioactive isotope to ionize the air in the detector chamber so that the air conducts electricity. Smoke from a fire interferes with the electrical current and triggers the alarm. The ionization detector has an advantage over the photoelectric detector in that smaller particles are recognized, providing higher sensitivity. However, the ionization detectors can also be prone to false alarms from airborne particulate matter. Electrostatic detectors function by detecting naturally occurring charged particles across a set of electrodes. The principle of operation is the same as the ionization detectors without requiring a radiation source. These detectors are not as sensitive as ionization detectors, and generally require smoke from a well developed fire to trigger an alarm.

b) Carbon Monoxide Detectors

Carbon monoxide detectors may be, in some situations, able to recognize a fire and generate an alarm well before a smoke detector. Smoke may not be given off for many minutes, or even hours, after ignition of a slow smoldering fire, but colorless, odorless carbon monoxide is given off whenever fuel is burned incompletely. Also, if the protected volume is large and open or the source of the fire is in a hidden area it is unlikely a smoke detector will give timely warning. Carbon monoxide fire detectors are well-suited to berthing areas, where there is a risk of slow smoldering fires impairing the ability of occupants to evacuate, and ultimately causing their death. While a fire is smoldering, carbon monoxide gas can build up to a level sufficiently high so that, on awakening, sleeping persons are too disoriented to evacuate the area. Carbon monoxide fire detectors react well to smoldering carbon-based (Class

A) fires, such as burning wood or paper. Burning plastics, such as polyurethane, and liquid fuel fires (Class B) do not produce sufficient carbon monoxide gas to trigger an alarm.

c) Fire/Flame Detectors

Flame detectors use optical sensors working at specific spectral ranges to monitor the incoming radiation at selected wavelengths. Approximately 30 to 40% of the energy radiated from a fire is electromagnetic radiation that can be read at various spectral ranges, such as ultraviolet (UV), visible (VIS) and infrared (IR). The signals from the detector are analyzed using a predetermined data analysis technique such as: flickering frequency, threshold energy signal comparison, mathematical correlation between several signals, or correlation to a preprogrammed spectral analysis. These optical sensors are capable of monitoring large open areas by a single sensor.

Flame detectors are classified by their sensor types. Some of the most common sensor types include UV detectors, IR detectors, UV/IR detectors, IR/IR detectors, IR^3 (triple IR) detectors, and triple IR spectral band detectors. UV flame detectors (ultraviolet spectral band detection) work with wavelengths shorter than 300 nm. They detect flames at high speed (3-4 milliseconds) due to the UV high-energy radiation emitted by fires and explosions at the instant of their ignition. These devices are very accurate, although they are subject to false alarms due to interference from random UV sources such as lightning, arc welding, radiation, and solar radiation. IR only detectors work within the infrared spectral band. The mass of hot gases emits a specific spectral pattern in the infrared spectral region. They are susceptible to false alarms due to interference by any other "hot" surface in the area.

UV and IR spectral band detectors compare the threshold signal in two spectral ranges and their ratio to each other to confirm the reliability of the signal. This scheme minimizes false alarms. Dual IR (IR/IR) band spectral band flame detectors have similar operation.

IR^3 triple IR spectral band detectors compare three specific wavelength bands within the IR spectral region. Mathematical techniques are used to correlate the three bands to discriminate between a fire condition and a false alarm.

Flame detectors may have a number of features to help them better perform their tasks, and for better survivability in flame laden or explosive environments. These features include adjustable time delays and automatic self-tests, explosion-proof enclosures, and integrated air conditioning systems.

There are also external influences that can have a deleterious effect on the ability of the detector to recognize flame radiation. The main inhibitors of UV propagation are oil mists or films, heavy smoke or hydrocarbon vapor and water films. These are commonly present in machinery spaces and can significantly reduce the intensity of the UV signal. The shortcoming of UV detectors for machinery space applications has resulted in a preference for the triple IR flame detectors in marine applications.

d) Closed Circuit Smoke and Flame Detection System

The system uses standard closed circuit television (CCTV) cameras. The system functions by comparing successive frames, so that any change can be automatically evaluated. The total attenuation of light from the camera to the furthest point in the field of view can be analyzed. The system can also be used to detect visible oil mist, high-pressure oil leakage from pipes, and steam leaks the moment they occur. Human operators can also monitor the cameras in real-time to verify conditions.

e) Heat Detectors

Heat detectors can be either electrical or mechanical. The most common type are thermocouples that sense ambient temperature and provide an alarm signal if the ambient temperature rises above some preset alarm threshold. Heat detectors are broken down into two main classifications, "rate-of-rise" detectors, and "fixed" or "rate compensated."

Rate-of-rise heat detectors react to the sudden change or rise in ambient temperature from a normal baseline condition. Any sudden temperature increase that matches the predetermined alarm criteria will cause an alarm. This type of heat detector can react to a lower threshold condition than would be possible if the threshold were fixed. A typical alarm may sound when the rate of temperature rise exceeds 12° to 15°F per minute.

Fixed threshold or rate compensated heat detectors react to a preset threshold and will not activate until the preset threshold is crossed, regardless of the rate of temperature increase. If there is too much thermal lag in the design, the alarm threshold can be exceeded before an alarm condition is indicated. Fixed temperature heat detectors are optimal for installation where high heat output fires are expected or in areas where ambient conditions will not allow use of other detection methods. It is common to have fixed rate sensors in combination with rate-of-rise sensors, providing good all-round heat protection for a variety of plausible situations.

Heat detectors may be physically implemented in different ways, mainly spot detectors and line detectors. Spot detectors operate at a specific location, or spot. Line detectors consist of a run of cable where temperatures can be detected at a point along the cable, within some distance, typically 1.5 meters.

Thermoelectric effect sensors detect a change in electric resistance in response to an increase in temperature. Fiber optical heat detectors monitor the scattering of light, which is proportional to the temperature, down the fiber. These signals are not susceptible to electromagnetic interference which ensures the integrity of readings in electrically noisy areas, for example around power cables and transformers. The optical fiber temperature sensing system is well-suited for applications such detecting overheating sensitive equipment, and rising temperatures in magazine areas.

f) Humidity Detectors

There a many types of humidity sensors, including capacitive, resistive, and thermal conductivity humidity detectors.

Capacitive relative humidity sensors are widely used in industrial, commercial, and weather telemetry applications. They consist of a substrate, typically glass, ceramic, or silicon, on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated with a porous metal electrode to protect it from contamination and exposure to condensation. The incremental change in the dielectric constant of a capacitive humidity sensor is nearly directly proportional to the relative humidity of the surrounding environment. Capacitive sensors are characterized by low temperature coefficient, ability to function at high temperatures (up to 200°C), full recovery from condensation, and reasonable resistance to chemical vapors. The response time ranges from 30 to 60 seconds for a 63% relative humidity step change.

Resistive humidity sensors measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt, or treated substrate. Resistive sensors usually consist of noble metal electrodes either deposited on the substrate or wire-wound electrodes on a plastic or glass cylinder. The substrate is evenly coated with a salt or conductive polymer. When the sensor absorbs water vapor from the air, ionic functional groups are dissociated, resulting in an increase in electrical conductivity. The response time for most resistive sensors ranges from 10 to 30 seconds for a 63% step change. Nominal operating temperature of resistive sensors ranges from -40°C to 100°C.

Thermal conductivity humidity sensors measure the absolute humidity by quantifying the difference between the thermal conductivity of dry air and that of air containing water vapor. When air or gas is dry, it has a greater capacity as a heat sink. Thermal conductivity humidity sensors consist of two matched negative temperature coefficient thermistor elements in a bridge circuit; one is hermetically encapsulated in dry nitrogen and the other is exposed to the environment. When current is passed through the thermistors, resistive heating increases their temperature to >200°C. The heat dissipated from the sealed thermistor is greater than the exposed thermistor due to the difference in the thermal conductively of the water vapor as compared to dry nitrogen. Since the heat dissipated yields different operating temperatures, the difference in resistance of the thermistors is proportional to the absolute humidity.

These humidity sensors are very durable, operate at temperatures up to 575°F (300°C) and are resistant to chemical vapors by virtue of the inert materials used for their construction. In general, thermal conductivity humidity sensors provide greater resolution at temperatures >200°F than do capacitive and resistive sensors, and may be used in applications where these sensors would not survive.

Rapid advancements in semiconductor technology, such as thin film deposition, ion sputtering, and ceramic/silicon coatings, have made possible highly accurate humidity sensors with resistance to chemicals and physical contaminants—at economical prices. However, no single sensor can satisfy every application. Resistive, capacitive, and thermal conductivity sensing technologies each offer distinct advantages. Resistive sensors are interchangeable, usable for remote locations, and cost effective. Capacitive sensors provide wide relative humidity range and condensation tolerance, and, if laser trimmed, are also interchangeable. Thermal conductivity sensors perform well in corrosive environments and at high temperatures.

g) Liquid Level Detectors

Liquid level detectors designed for use in tanks may employ very sophisticated sensing systems such as infrared, fiber optics, ultrasonic transmissions and vented air pressure. However, typical flooding detectors consist of simple, economical contact-type switches actuated by a float mechanism. This may not give a completely accurate level reading at any given time, but it will provide enough information to determine whether a space is flooded and whether water level is rising or falling. Various sensors can be mounted at set heights within a tank or compartment to determine the liquid level; the level of accuracy dictates the number of sensors that must be used. These switches have only two positions - either "on" or "off" and are called "dry-type" because the circuitry is not immersed in water to make the sensor work. "Wet-type" contact switches may also be used: they operate on the principle of utilizing the fluid level to complete an electrical circuit and provide the alarm. The dry contact switches are most desirable.

h) Conclusions

Compartments will be monitored not only for fire, but also for humidity and temperature, to calculate heat stress. Paint lockers will be monitored for explosive gases and oxygen depletion. Collection, holding, and transfer (sewage) system spaces will be monitored for poisonous hydrogen sulfide gas. Air conditioning and refrigeration spaces will be monitored for refrigerants and low oxygen levels. Monitoring confined areas subject to toxic gas or oxygen deficiency will prevent unwanted exposures of the crew to these hazards. Immediate notification to control stations will prevent crewmembers from entering the compartments, and will facilitate corrective action.

3. Installed Firefighting Systems

The following is a description of the systems that will be installed in the compartments throughout the ship. The Halon Replacement Program is an on-going program aimed at developing replacement agents and alternatives to Halon. Sea TENTACLE will use a combination of firefighting systems that do not utilize Halon, some that are a direct result of the Halon Replacement Program research and development, and some that are technology used aboard naval warships for decades.

a) Water Mist Fire Suppression System

Testing sponsored by the Navy has shown that properly designed water mist systems can effectively extinguish a wide variety of exposed and shielded Class B hydrocarbon pool, spray, and cascading pool fires. Water mist systems extinguish fires primarily by removing heat from the combustion process. A fire is made up of three principal constituents: fuel, heat and oxygen. The water mist system eliminates two of the three factors, heat and oxygen. The system uses either potable water or seawater. Water is applied to the fire in a dense fog of very fine droplets 5-200 μm in size. The water droplets are sprayed into the fire where they are transformed into vapor - a process that consumes great amounts of energy due to the latent heat of vaporization associated with the change of state - thereby reducing the heat of the fire. The heat reduction occurs more than 100 times faster than when traditional sprinklers/nozzles are used, despite the fact that they dump 10-20 times as much water on the fire [Ref. 4]. When the droplets of water transform to steam, they expand in volume by 1700 times, which has the added benefit of displacing the oxygen from the vicinity of combustion. A minimum pressure of 1000 psi is required to supply the small drops of water and simultaneously ensure adequate dispersion. Initiation of the water mist suppression system allows firefighters to enter the space and extinguish fire. Due to its cooling effect and room flooding ability, water mist systems prevent re-ignition.

The water mist system may consist of zones or sectional loops with nozzles in the overhead and in other key areas to be protected. The system may be controlled from a console in the control room or from local control consoles. The pump system has the ability to adjust continuously to meet a range of flow demands. The pump unit supplies water to the mains that in turn feed branches of nozzles. An electrically actuated solenoid valve that is connected to a computer interface controls each branch group of nozzles.

Water mist systems are safe for people as well as environmentally innocuous. The lower flow rates result in less water damage to adjacent equipment, a reduced danger of flooding, and quicker cleanup and recovery than traditional water sprinkler systems. There is a general reluctance to provide water for the purpose of extinguishing electrical fires because of fears of potential equipment damage and shock hazard to personnel. However, after much testing, the summary conclusion relative to LPD-17 is that the probability of a shock hazard is low and that personnel in the space would not have to evacuate prior to water mist activation even if all equipment is energized. The probability is decreased if the water being sprayed is potable and salt-free and if equipment is clean and properly grounded before mist flow is initiated.

Disadvantages of the system include: relative ineffectiveness with small fires that do not create enough steam to displace the oxygen, more complicated and expensive components and maintenance than conventional sprinkler systems, and more demanding water pressure requirements than conventional sprinklers.

b) Carbon Dioxide Fire Suppression Systems

Carbon dioxide systems are an industry standard and work on the principle of displacing atmospheric from the site of the fire so that oxygen can not reach the fuel and sustain the combustion reaction. It is the preferred agent in many applications. Carbon dioxide flooding will be used in specialized spaces such as the paint locker and in selected areas of the machinery rooms, such as in the gas turbine modules

c) Aqueous Film Forming Foam (AFFF) Systems

Aqueous Film Forming Foams (AFFF) is based on combinations of fluoro-chemical surfactants, hydrocarbon surfactants, and solvents. These agents very easily produce high quality foam. AFFF suppresses combustion by separating the fuel from the oxygen in the atmosphere. This is accomplished in several ways: foam blankets the fuel surface and forms a barrier that smothers the fire, the fuel is cooled by the high water content of the foam, or the foam blanket suppresses the release of flammable vapors that can mix with the atmosphere. AFFF can be applied with a variety of foam delivery systems, such as sprinklers or hose reels. This versatility makes AFFF an obvious choice for applications with many flammable liquids present, such as on a warship. AFFF sprinkler systems will be installed in the helicopter hangar bay and in the gas turbine generator spaces. AFFF hose reels will be provided on the flight deck and in all engineering spaces that have significant quantities of fuel or lube oil.

d) FM-200 Fire Suppression Systems

FM-200, which uses the chemical agent heptafluoropropane, is a Halon alternative agent now in use to protect essential applications previously protected by Halon 1301. This agent has similar characteristics to Halon 1301, however is has the additional advantage of being safe in areas normally occupied by personnel.

e) Summary of Systems Used

The installed fire systems protecting a variety of spaces on Sea TENTACLE are summarized in the following table, as shown below:

Table 16. Types of Installed DC Systems for Specific Spaces

Compartment	FM200	CO_2	Water	AFFF
AC /		X		
Berthing	X			
Bridge	X			
CIC	X			
Electrical	X			
Flight Deck				X
Galley	X			X
Gas turbine		X		

Hanger			X	X
Machinery			X	X
Magazine				
Paint		X		
Payload Deck				X
Pump rooms		X		

4. Chemical, Biological and Radiation (CBR) System

SEA TENTACLE must be capable of the prescribed mission in all types of CBR contaminated environments. The first line of defense will be the proper setting of material condition of readiness to isolate the internal portions of the ship from the weather deck environment. Secondly, the countermeasure washdown system will use a water spray to wash off contamination. Each crew member will be issued a gas mask that they must carry or wear when a CBR attack is deemed likely. Portable chemical and biological mass spectrometers, joint chemical agent detectors, radiac equipment, and CBR protective suits, boots, gloves, and hoods will be available at each damage control locker, and in the hangar bay. Helicopters and the VTUAV will be decontaminated in the hangar bay, if necessary.

5. Crew Egression

Should dire circumstances require abandoning the ship, life rafts will be provided for personnel. Three rafts will be installed on each side of the ship, for a total of six. Each of these throw over board life rafts have a twenty-five person capacity, allowing for a total capacity of 150, which twenty percent greater than the crew size. They will be evenly distributed and will be shielded to reduce their contribution to radar cross section.

6. Ship Numbering System

The survivability of the ship depends on positive action by the crew to ensure the compartmentalization as designed to prevent spread of fire or flooding. Automatic closure of key fittings and operation of critical DC equipment is possible, but it is not feasible to completely automate every fitting. Each crew member must be able to take personal responsibility for the operation of necessary DC equipment and fittings in order to effectively control/stop damage. Therefore, it is essential that personnel proficiency be maintained through initial qualification and orientation to the ship, continuing training programs, and drills. All compartments and fittings on the SEA TENTACLE will be numbered according to standard Navy convention, in order to ensure all personnel can quickly locate and operate DC fittings.

7. Battle Stations

For maximum survivability under battle conditions, a ship must be able to rapidly man battle stations and set material condition "Zebra" and also to be able to continue operation under these conditions for an extended period. All shipboard naval personnel must be trained in manning battle stations and making initial preparations for action. Appropriate damage control exercises must be performed periodically, such as manning battle stations, fire and flooding scenario drills, mass conflagration on the flight deck, abandon ship drills, and CBR attack drill to evaluate personnel performance and maintain proficiency and familiarity with appropriate procedures for different emergencies.

8. Conditions of Readiness

The setting of a particular material condition is the process of securing all appropriate damage control fittings to increase compartmentalization at designated times. In general, a material condition is set in anticipation of possible or likely damage due to the tactical situation or operational considerations, although it is also established in response to a casualty in progress. Increasing the compartmentalization of the ship assists in mitigating the spread of fire, smoke, and floodwaters. The proper setting of material condition will enhance the Damage Control organization's ability to control damage and prevent it from spreading.

9. Damage Control Total Ship Survivability

The Sea TENTACLE must be able to combat casualties either inflicted by hostile weapons or by internal casualties such as fuel fires or flooding and maintain mission integrity.

The casualty response plan is designed to give priority to restoration of vital systems as well as fighting fires and flooding. Vital systems include electrical power, firemain, and chilled water.

a) Ship's Priorities in Peacetime

i.. Return to port

ii. Safety of the crew

b) Ship’s Priorities in Wartime

i. Fight: Maintain/Restore Combat Systems to prevent further damage by being able to detect and neutralize any additional threats

ii. Move: If the ship loses the ability to fight, then at least it must make all efforts to retain the ability to maneuver. If the ship maintains the ability to maneuver, then it may be able to evade further damage and also deceive the enemy by mimicking a fighting.

iii. Float: If the ship is unable to maintain the ability to maneuver, then the crew's only hope is to maintain the ship floating until rescue can be affected.

10. Introduction to Firefighting

Fireproofing an entire ship would be prohibitively expensive, if not impossible. Warships contain a number of high risk compartments such as magazines, machinery spaces and fuel tanks. By definition, warships operate in hostile environments where a hit by a missile, torpedo or CBR attack is possible or even likely. A hit could seriously affect the ship's ability to maneuver or fight to defend itself from further damage. A fire on a ship must be controlled and extinguished by shipboard personnel, using only the equipment already onboard. The objectives of the Damage Control Organization are to take preliminary action to prevent damage, minimize and localize damage if it occurs, and finally to restore the space or equipment to maximum functionality.

Firefighting perspective that needs to be understood is that preliminary actions are most important. Prevention is the preferred scenario. Prevention or at least minimizing the risk of a fire includes such tenets as:

- Good housekeeping
- Proper stowage of flammables/explosives
- Fire Marshall program
- General maintenance
- Crew training

- Embarked troop training

11. References

[1] “Current Areas of Research”, Navy Technology Center for Safety & Survivability, http://chemistry.nrl.navy.mil/6180/6186/researchareas.php.v

[2] “Smart Shipboard Sensor Network”, LT Andrew Nozik, Naval Postgraduate School Masters Thesis, December 2005.

[3] “Damage Control Systems”, Navy Technology Center for Safety & Survivability, http://chemistry.nrl.navy.mil/6180/6186/damagecontrol.php.

[4] The Development of Water Mist Fire Protection Systems for U.S. Navy Ships, Robert L. Darwin, Dr. Frederick W. Williams, Naval Engineers Journal, Vol.112 No.6.

G. MANNING

Ship Manning was critical to our design, as the team recognizes the US Navy's need to reduce manning in future ship classes, and thus reduce the total life-cycle cost of the ship. We took a human centered approach to our design, and we were able to leverage from studies conducted in other programs, such as the DD(X) and T-AKE. Such concepts as reliability and condition based maintenance, automated damage control, and reduced watch stations, can be utilized to drive down the anticipated crew size. Manning estimate details are presented in Appendix XIV. It should be mentioned that the accuracy of these estimates is dependent on the success of these reduced manning concepts, when they become fully functional and field-tested.

H. COST ANALYSIS

In order to estimate the acquisition cost of Sea TENTACLE, both top-down and bottom-up methods are used. For the top-down method, a comparison of current and proposed U.S. naval ships to include the DD(X), DDG-51, FFG-7 and an envisioned FFG(X) is made with the Sea TENTACLE. This comparison is based on both the Congressional Budget Office's (CBO) and the Congressional Research Service's (CRS) work in developing each of their analysis of alternatives in response to the call for a transformation of the Navy's Surface Force. In these comparisons, the historical procurement costs are taken for the ships already in the nation's inventory and the procurement cost for the proposed ships are extrapolated assuming that a cost estimating relationship (CER) exists between the procurement cost and the light-ship displacements.

As an example, when estimating the cost of the DD(X), which is envisioned to have a 16,000 ton displacement, the CRS uses the Navy's statement that a single DDG-51 (8,400 ton displacement) will cost about $1.4 billion in FY06 and extrapolates that a follow on DD(X) will cost about $3.2 billion to procure in the same year's dollars adding that taking into account recent Office of the Secretary of Defense (OSD) analyses this number could be as high as $4.7 billion for the first copy [1]. Table 17 lists data for ship characteristics and cost comparisons.

Ship Class	Type	Displacement (tons)	Crew Size	Armament	Missions	Follow ship procurement cost (FY05 $M)	O&S (FY05 $M)
DD(X)	General-Purpose Destroyer	16,000	130	2 Helo, 2 155-mm AGS, 128 VLS	Land attack, ASW	* 3,200	40.8
DDG-51 (II)	Guided-Missile Destroyer	9,200	340	AEGIS, 2 Helo, 1 5-inch, 96 VLS	Long-range air and missile defense, land attack, open-ocean ASW	1,800	31.2
Sea TENTACLE	Focused-Mission Combatant	7,000	100	2 Helo, 2 Millenium gun, 16 VLS, AMRFS, UUV, USV, UAV launch/recover and support	Littoral and open-ocean ASW, maritime interception	* 900	15.9
FFG(X)	Guided-Missile Frigate	6,000	120	2 Helo, 5-inch gun, 48 VLS	Convoy escort, maritime interception, open-ocean ASW	* 700	UNK
FFG-7	Guided-Missile Frigate	4,100	221	2 Helo, 1 76-mm gun, 6 Torpedo Tube	Convoy escort, maritime interception, open-ocean ASW	300	26.1

Table 17. Ship Class Cost Comparison Data

When compared to the Sea TENTACLE, the DD(X) provides an excellent upper bound for interpolation due to its similarity in crew size but significant differences in displacement, VLS cell size and combat suite to include its advanced AEGIS weapon system. Similarly, a lower bound for interpolation can be found by examining the cost analysis for an envisioned FFG(X). According to Reference 2, this ship could be modeled after Spain's F-100 guided missile frigate or Germany's Sachsen class (Type 124) guided-missile frigate. The FFG(X) would have many of the same components as the F-100 to include its 5-inch, 54-caliber gun and 48 VLS cells and support for two embarked helicopters. The F-100 has a range of 5,000 nautical miles at 18 knots and is capable of speeds as high as 27 knots. A few major differences between the FFG(X) and the F-100 are that the FFG(X) would not be Aegis-capable and, through this cost savings, it would have an all-electric propulsion system, reduced ship's signature, decreased crew size through improved automation and have a littoral antisubmarine warfare suite.

These characteristics further defend the use of the FFG(X) as an excellent comparison for the Sea TENTACLE. The estimated procurement cost to include research and development and ship construction for the first ship in a new class of FFG(X) by the CBO is approximately $1.1 billion with an average over 40 total ships of $700 million which is comparable to the established follow-ship costs for the F-100 of $600 million [2]. The initial procurement cost per CBO includes the historical cost of procurement for the first FFG-7 class ship of $600 million translated to FY03 dollars and adds an additional $250 million to account for the difference in displacement, $50 million to cover the added VLS cells, and $200 million for the detailed design [2].

Although, the envisioned FFG(X) for which the CBO study was conducted is very similar to the Sea TENTACLE, a few notable differences do exist. First, the FFG(X) would be a 6,000 ton mono-hull platform compared to the Sea TENTACLE with its 7,000 ton catamaran configuration. Additionally, it is doubtful that the full production run for the SEA TENTACLE would be much more than 10 ships. Furthermore, although it is not explicit in the CBO report, the FFG(X) is assumed to have an advanced combat suite much like the Sea TENTACLE's Integrated Combat Management System with its Advanced Multifunction Radio Frequency System (AMFRS). Due to these minor differences, the FFG(X) cost analysis is extremely useful in establishing an estimated baseline cost figure for further analysis along with provide relatively firm scaling values when accounting for the VLS cells, design costs, and added displacement.

With these lower and upper bounds established on the envisioned cost of the SEA TENTACLE, an interpolation is made to place the estimated cost of the first ship in the class at around $1.75 billion in FY05 dollars to procure with an average over the 10 ships at around $900 million in FY05 dollars. This interpolation is based significantly on a comparison between the Sea TENTACLE with the component cost breakdown for the procurement of the first FFG(X) as outlined above. Similar to the CBO's cost estimate for the FFG(X), the cost of the initial Sea TENTACLE is estimated by starting with the actual cost to build the first FFG-7 in FY05 dollars (around $600 million) and adding $1 million per VLS cell or a total of $16 million, $132.5 million per 1,000 tons of displacement over the FFG-7 displacement (4,100 tons) or a total of $400 million, $200 million for the AMFRS, $100 million for catamaran hull construction, $200 million for detailed design costs of work not included in the cost of the first FFG-7, and an additional $250 million to begin to upgrade existing shipyards to accommodate the construction of a catamaran hull of this size [2]. Table 18 depicts the Sea TENTACLES top down cost estimate described above for the lead ship.

(in millions of 2005 dollars)	Estimated Cost	Primary Basis of Estimate
Detail Design	200	FFG(X) Analogy
Infrastructure Upgrade	250	Catamaran Hull Construction
Production Costs:		
Basic Construction	990	FFG(X) Analogy
VLS	16	FFG(X) Analogy
Advanced Combat Systems Suite	200	AMFRS
Catamaran Construction	100	
Total Lead Ship Cost	~1,750	

Table 18. Sea TENTACLE Top Down Cost Estimate

The figure for detailed design work is based on the CBO's analysis for the LCS which took the detail design costs for the FFG-7 in FY05 dollars to be $100 million and compared this to the predicted value for the DD(X) of $500 million. The CBO assumed that the cost to design the LCS and, similarly, the TSSE team assumes that the Sea TENTACLE design cost will lie between the cost to design the FFG-7 and the DD(X). Much of the design work for the Sea TENTACLE can be borrowed from currently funded projects like the LCS with its deployment systems and the Office of Naval Research's feasibility studies on the AMRFS but there would be significant additional work needed in terms of hull design and pure electric drive. By eliminating the cost of the detailed design for the second in the class as done by CRS for the cost estimate of the DD(X) but leaving the cost for continued infrastructure upgrades, the second ship in the class could be around $1.5 billion with a graduated decrease on a 90 percent curve with an average cost of around $900 million.

For the bottom-up method, a weight scaled model was created to approximate the acquisition cost and was based on the ship's first order weight estimation. Similarly to previous TSSE final designs, Cost Estimating Relationships (CERs) were taken from the CVN-X program study of 1998 and modified as required to take into account the differing features such as propulsion and combat system suites. These modifications were taken into account in the final cost through the addition of one-time install costs. This model resulted in a total cost that was within 15% of the top-method with a cost for the first ship of $1.5 billion and a cost of $900 million for the 10th ship in the class. With these similarities using two separate methods, the TSSE team is confident that the first Sea TENTACLE can be procured for around $1.7 billion with significant savings over 10 ship class. Appendix XV shows the details of the bottom-up cost estimate for the Sea TENTACLE.

1. References

1. Congressional Research Service Report, *Navy DD(X), CG(X), and LCS Ship Acquisition Programs: Oversight Issues and Options for Congress,* July 2005. pp. 26-27.

2. Congressional Budget Office Study, *Transforming the Navy's Surface Combatant Force*, March 2003, pp. 60.

VI. DESIGN EVALUATION

As discussed in Section IV, the Sea TENTACLE was assigned nineteen critical design parameters (CDP). Table 20 gives a complete listing of the CDPs with Threshold, Objective, and Actual values. The Sea TENTALCE met or exceeded eleven Objective values, and met or exceeded five of the remaining eight Threshold values. The Operational Availability and Hull Service Life CDPs were not able to be evaluated at this preliminary stage of design. The only CDP not met was Range at Max Speed. Each of the evaluated CPDs will be discussed separately.

A. DRAFT AT FULL LOAD

This CDP was resolved as SATISFACTORY. The Threshold value was 8 meters, the Objective value was 5 meters, and the Actual value was 5.1 meters. This shallow maximum draft makes the Sea TENTACLE able to navigate safely in most littoral waters.

B. MAX SPEED

This CDP was resolved as SATISFACTORY. The Threshold value was 30 knots, the Objective value was 40 knots, and the Actual value was 40 knots. The high speed available on the Sea TENTACLE is essential if the platform is to be utilized to perform missions such as the Harbor Gate scenario in a 72-hour timeframe. Also, the vessel will have high maneuverability and increased survivability as a result of the top speed.

C. RANGE AT MAX SPEED

This CDP was resolved as UNSATISFACTORY. The Threshold value was 1,000 nm, the Objective value was 1,500 nm, and the Actual value was 920 nm. While not achieved,

Critical Design Parameters			
Category	**Threshold**	**Objective**	**Actual**
Operational Availability	0.85	0.95	N/A
Hull Service Life	20 years	30 years	N/A
Draft @ Full Load	8 m	5 m	5.1 m
Max Speed	30 + kts	40 + kts	40 kts
Range @ Max Speed	1000 nm	1500 nm	920 nm (1045 nm @ 35 kts)
Range @ Cruise Speed	3500 nm	4500 nm	5400 nm (20 kts)
Large UUV Capacity	40	50+	50 (48 SP, 2 WLD-1)
Hvy Wt UUV capacity	80	100+	110
Cargo Weight	400 MT	800 MT	570 MT
Cargo Volume	5000 m^3	6000 m^3	5500 m^3
Small Boat (7 m RHIB)	1	2	2
USV (11 m RHIB)	1	2	2
UUV/USV/UAV Launch Recover	Sea State 3	Sea State 4	Sea State 4
Aviation Support	One 7000 lb VTUAV	VTUAV (2)/ SH-60R	VTUAV (2)/ SH-60R(2)
Aircraft Launch / Recover	VTUAV	VTUAV/SH-60R	VTUAV/SH-60R
UNREP MODES	RAS, CONREP, VERTREP	RAS, CONREP, VERTREP	RAS, CONREP, VERTREP
Core Crew Size	$\leq$130	$\leq$ 100	Approx 110
Crew Accommodations	130	130	130
Provisions	30 days	45 days	30 days

Table 19. Critical Design Parameter Evaluation

This CDP does not have a large negative impact to the overall design. The Actual value is within 8% of the Threshold value, which is itself a subjective and not a technical requirement. The design team felt that the Threshold could be met through a change of a single design parameter or series of changes such as hull shape refinement or modified tank configuration. The team felt that at this time such changes were not necessary, as the range requirement is met at a speed of 35 knots, giving the Sea TENTACLE a 1,000 nm striking distance within 72-hours.

C. RANGE AT CRUISE SPEED

This CDP was resolved as SATISFACTORY. The Threshold value was 3,500 nm, the Objective value was 4,500 nm, and the Actual value was 5,400 nm. The fact that the Actual value greatly surpassed its Objective value makes it possible for the Sea TENTALCE to reach from Guam to the Bass Straits without the need to refuel. Thus, the ship may deploy independently to deliver its payload at great range.

D. LARGE UUV CAPACITY

This CDP was resolved as SATISFACTORY. The Threshold value was 40 UUVs, the Objective value was 50 UUVs, and the Actual value was 50 UUVs. As seen, at least 40 large Sea Predator type (or similar) UUVs are necessary to provide adequate sensor coverage in the AO. The Sea TENTACLE can carry the needed 40 large UUVs, and 8 spare units that can be used to supplement or replace the original 40. Also, it can carry two WLD-1 remote mine hunting UUVs making the ship able to perform simultaneous missions.

E. HEAVY WEIGH UUV CAPACITY

This CDP was resolved as SATISFACTORY. The Threshold value was 80 UUVs, the Objective value was 100+ UUVs, and the Actual value was 110 UUVs. The 21" shapes designed as part of the sled in the Notional Payload are representative of heavy weight UUVs in both size, shape and weight. Thus, the Notional Payload can be considered to carry 96 heavy weight UUVs. Additional storage in the main payload hangar brings the total number of heavy weight UUVs to the value of 110.

F. CARGO WEIGHT

This CDP was resolved as SATISFACTORY. The Threshold value was 400 MT, the Objective value was 800 MT, and the Actual value was 570 MT. The cargo weight requirement was derived from a combination of the Notional Payload and the requirement to carry a single 7,000 lb VTUAV. The weight accounted for vehicles, fuel, and spare parts. Handling equipment and storage systems were considered part of the ship and not cargo. The Actual weight accounts for the UUV payload as well as 2 VTUAVs, 2 SH-60R helicopters, 2 7 meter rigid hull inflatable boats (RHIB) and 2 11 meter USVs, plus fuel and spare parts. The cargo gives the Sea TENTACLE a robust set of assets to perform simultaneous missions in multiple warfare areas, such as ASW, MIW, SUW, and Maritime Surveillance.

G. CARGO VOLUME

This CDP was resolved as SATISFACTORY. The Threshold value was 5,000 m^3, the Objective value was 6,000 m^3 and the Actual value was 5,500m^3. As in cargo weight, the Threshold volume was derived from the extrapolation of the Notional Payload. Requirements for the VTUAV requirements are not included in these calculations. The cargo volume accounts solely for the primary UUV hangar on the Main Deck as well additional storage area for UUV spare parts. The aviation Hangar located on the 01 Level, as well as the tankage required for RHIB, USV, VTUAV, and general purpose aviation fuel are not considered cargo spaces.

H. SMALL BOAT (7M RHIB)

This CDP was resolved as SATISFACTORY. The Threshold value was 1 seven meter RHIB, the Objective value was 2 seven meter RHIBs, and the Actual value was 2 seven meter RHIBs. The RHIBs of this size are primarily for core crew usage in Force Protection, Man-overboard recovery, personnel transfer and other such general purposes. The RHIBs are stored in the main UUV hangar, and can be deployed via a variable geometry ramp or side door.

I. USV CAPACITY (11M RHIB)

This CDP was resolved as SATISFACTORY. The Threshold value was 1 eleven meter RHIB, the Objective value was 2 eleven meter RHIBs, and the Actual value was 2 eleven meter RHIBs. The large USVs are seen as being outfitted with a vast array of sensors and weapons for use as SUW and Maritime Surveillance assets. These craft would be controlled by core crew watchstanders.

J. UUV/USV/UAV LAUNCH AND RECOVER

This CDP was resolved as SATISFACTORY. The Threshold value was to launch and recover in Sea State 3 or lower, the Objective value was to launch and recover in Sea Stare 4 or less, and the Actual value was that the Sea TENTALCE has the ability to launch or recover all assets in Sea State 4 or less. Seakeeping analysis described in Appendix VIII show that ramp and door placement is adequate for sustaining operations at Sea State 4. Similarly, flight deck motion supports launch and recovery in Sea State 4, however, wind conditions were not modeled, and there could be cases where aviation launch and recovery could be limited to less than Sea State 4.

K. AVIATION SUPPORT

This CDP was resolved as SATISFACTORY. The Threshold value was the ability to carry a single 7,000 lb VTUAV, the Objective value to carry 2 VTUAVs and 2 SH-60R helicopters, was 5 meters, and the Actual value is 2 VTUAVs and 2 SH-60Rs can be carried. Sea TENTACLE also has the ability to control the VTUAV remotely. Adequate storerooms were given for aviation maintenance, and extra berthing is available to accommodate additional aircrew and aviation maintenance personnel. Adequate fuel storage is provided for sustained flight operations. The aviation control room is located at the aft end of the port side 01 Level, overlooking the flight deck.

L. AIRCRAFT LAUNCH AND RECOVERY

This CDP was resolved as SATISFACTORY. The Threshold value was the ability to launch and recover a single 7,000 lb VTUAV, the Objective value to launch and recover either a VTUAVs or an SH-60R, and the Actual value is that either VTUAVs or SH-60R assets can be launched or recovered. The flight deck does not allow for simultaneous launching or recovery of assets.

M. UNREP MODES

This CDP was resolved as SATISFACTORY. The Threshold, Objective and Actual values were to be able to conduct refueling at sea (RAS), connected replenishment (CONREP), and vertical replenishment (VERTREP). Two RAS and CONREP probes and rigs are integrated into the mast structure, with one rig on each of the port and starboard sides. The integrated design protects equipment the environment and minimizes the RCS of the ship. The large flight deck and aviation control systems provide the necessary features for conducting VERTREP operations.

N. CORE CREW SIZE

This CDP was resolved as SATISFACTORY. The Threshold value was ≤130 personnel, the Objective value was ≤100 personnel the Actual value was 110 personnel.

O. CREW ACCOMODATIONS

This CDP was resolved as SATISFACTORY. The Threshold, Objective, and Actual values were accommodations to support 130 personnel. This provides a berth for every crewmember, as well as provides an additional 20 berths to support aviation detachments or other personnel as required.

P. PROVISIONS

This CDP was resolved as SATISFACTORY. The Threshold value was to carry 30 days of provisions, the Objective value was to carry 45 days of provisions, and the Actual value was 30 days of provisions are carried.

APPENDICES

APPENDIX I: TSSE PROJECT GUIDANCE MEMO

TSSE Total Ship Systems Engineering

June, 2005

TS4002/TS4003
2005 Capstone Design Project

Platforms in Support of Littoral ASW

1. **TASK**. Your TSSE capstone design project is to examine the concepts associated with the use of ship platforms in support of littoral ASW. From this examination you will produce a design for a ship or a family of ships to enable the neutralization of subsurface threats as outlined in the SEA8 tasking document.

2. **OBJECTIVES**. The objectives for this project include:
   - A. Applying to this project all you have learned in all your previous education.
   - B. Performing the analysis necessary to define the concept of employment needed to meet a broadly-defined need.
   - C. Learning first-hand the ship-impact of requirements, cost and performance tradeoffs within technical and acquisition constraints.
   - D. Increasing your familiarity with the process of evaluating a military need and determining how best to meet it.
   - E. Obtaining experience in the process of translating broad military requirements to mission-based ship requirements and to specific design tasks resulting from those requirements.
   - F. Practicing technical teamwork in an interdisciplinary design effort where the quality of the product is greatly affected by team dynamics.
   - G. Internalizing the systems approach to a Naval ship as a single engineering system satisfying mission requirements.
   - H. Exploring innovative ideas which may prove useful to those working on similar projects, both inside and outside NPS.

3. **TEAMS**. It is expected that you will function as a team in all aspects of this project. As is the case in all team efforts of this nature, you will need to have a leader and you will have to assign the lead on various subtasks to individual team members. However, to be successful (both as a design team and in the academic sense) it will be necessary for you to <u>coordinate</u> your efforts closely. The faculty will expect <u>all</u> team members to be familiar with the major design decisions made by the team, and the reasons therefore. We will expect each team member to be cognizant of the results and major features

of subtasks performed by other team members as well, of course, as being fully familiar with the subtasks he had the lead on.

4. **BACKGROUND**. All background information and documents are located in the \\kiska\tsse\2005\ folder. Your first task is to familiarize yourselves with those documents.

5. **APPROACH**.

A. Phase I-a (July). You are the "combined requirements and analysis team". Your first task is to understand the concepts associated with littoral ASW. Review and understand the requirements from the SEA team. The goal is to determine a set of requirements including but nor necessarily limited to payload, range, threat analysis, and required combat capabilities for your ASW platforms. As you develop your concept of operations, consider additional roles that your platforms might be able to perform. This period should also be used for the necessary team-building.

B. Phase I-b (August). By the end of July you should have developed an initial concept of operations and have finalized desired payload, interfaces, and other requirements from the SEA team. You should also have a general idea of the desired combat system capabilities based on your threat analysis. You will then start exploring concepts for meeting the basic requirements. By the end of this phase you will have reconciled in more detail the requirements for the basic platforms. It is expected that such platforms will include both surfaced and submerged options; therefore, it is possible that the team may be split in two. For each team, ensure that your overall measure of effectiveness is computable and the SEA team is aware of your choice. Perform an analysis of alternatives to evaluate the optimum basic characteristics (including payload, speed, rough size) of your ship. The faculty members will verify (or change) your intended approach to the basic design and its variants.

C. Phase I-c (September). Refine the operational concept and conclude your analysis of alternatives. Identify a basic hull type and its rough dimensions and geometry.

D. Phase III (September/October/November). During phase III you will perform a more complete design of the basic concept and variants resulting from Phase II. You will prepare a design report suitable for publication as part of an NPS technical report and you will make a formal presentation of your design to members of the NPS community and invited visitors. At or before the beginning of Phase III you will receive from the faculty a list of required "deliverables" which must be included in your report or presentation or both. Past TSSE reports will provide you of a glimpse of what is expected; however, this list is always subject to change in light of the unique requirements and expectations of each design effort. Your design report will become part of the overall SEI report of the integrated campus project. Do not underestimate the time needed for final report write-up and formatting and preparation of the presentation; this will occupy you most of the month of December. Project presentation usually occurs around December 7th.

6. **FACULTY ROLE**. This is to be YOUR design. Do not feel that you are competing with previous teams or designs. Normally, the faculty will avoid having undue influence. The design will NOT give preference to faculty ideas at the expense of the team's ideas merely because of their faculty source. On the other hand, the faculty will participate in discussions and try to assist you in reaching conclusions, consensus and feasible solutions. In general, we will act like "coaches", though to some degree we will also be team members. We will, of course, act to avoid letting you call for the impossible or unreasonable. After Phase I, the faculty will play two roles – members and coaches of the design team, as discussed above, but we will also, when the occasion calls for it, become the "seniors" of the design team, acting as the decision makers to consider changes to requirements if the design team should propose them. Of course, our main objective is to maximize the utility of the project as a learning experience and we will always retain the right to change the rules as we think it necessary to achieve that objective. The faculty will contribute to the process and will author some sections of the final report.

7. **ADMINISTRATIVE**. Some administrative items:

A. The six scheduled hours each week are considered mandatory class hours and you will be expected to be present for all of them. We will occasionally use the scheduled time for lectures or presentations by visitors or the faculty. We do not consider the scheduled six hours per week to be sufficient for you to accomplish the necessary tasks to produce a quality design. As in any other course, you are expected to devote between 1 and 2 additional hours for every scheduled hour on the project. You should largely try to use the scheduled hours for coordination and group work and do much of your individual effort outside scheduled times.

B. We will use both the assigned classroom and the Bullard workspace. The latter will be shared by other students, so please be courteous. The TSSE room will be used exclusively by you. You have admin access to all computers in the room, please be careful with them, save your work often, and create restore points prior to any major software configuration change. Make sure that you post all your files in the shared \\kiska\tsse drive so that others can see them.

C. You will be expected to do library and other research; to make phone calls and contacts and request information from individuals outside NPS. Doing this is always a part of this kind of project in the "real world". The faculty can be of assistance in finding individuals and organizations that can help. (While others will generally be glad to send information, answer questions, etc., don't expect your request to go immediately to the top of their priority list – so timeliness in such efforts is extremely important.)

8. **GRADES**. As is the case with other courses, the faculty must assign you a grade for this project. Frankly, we are strongly of the opinion that it is the team output that is most important and are inclined

to give the project a grade and assign the same grade to all the team members. We fully recognize that individuals contribute to different degrees; that some work harder than others; that some facilitate progress while others may actually hinder it. But, as is true in life, the result is what counts and if the result is good, all associated with it bask in the glow – and vice versa. (And learning to cope with the differing contribution levels of team members is one of the "real life" experiences we expect you to reap from this project.) We are inclined to continue to give a single grade for the project to all participants. However, we wish to be able to have greater insight into the individual contributions you are making and may, from time to time, request that you provide a summary of your personal, recent activities.

9. **AND, FINALLY**. As in any real design effort, this project is open-ended. There is no pre-existing "right" answer. Numerous designs could "work". We could spend a significant fraction of a career on this project, carrying it to increasing levels of completeness and sophistication. However, this is an academic exercise and we are limited by outside time constraints. Our expectation is that you will work hard, strive for creativity and innovation, work cooperatively, honor commitments to team members and produce work which you are honestly proud of. If you do that, we'll take care of the rest.

APPENDIX II: SEA-8 TASKING MEMO

NAVAL POSTGRADUATE SCHOOL

Meyer Institute of Systems Engineering
777 Dyer Road
Monterey, CA 93943

January 23, 2006

Memorandum for SEA8 Students

Subject: Integrated Project Tasking Letter

1. This tasking letter provides a framework of guidance for the performance of the April-to-June planning process leading to your July-to-December integrated project.

2. Anti-Submarine Warfare in the Littorals in 2025 will present a major challenge for the United States. Quieter and more capable submarines operating in the littoral environments will continue to challenge the Navy as it assures access. The Navy is developing programs to assure the continued capability to establish undersea superiority.

3. The Navy published "Anti-Submarine Warfare, Concept of Operations for the 21st Century" on 20 Dec 2004. That CONOPS states that the Navy will meet the 21st Century ASW challenge through an integrated combat systems approach that can fully exploit all joint mobility, sensors, and weapons capabilities. This will require new systems that provide pervasive awareness, speed, persistence, and technological agility to eliminate or neutralize subsurface threats. There are numerous systems engineering issues about the development of such new systems. These issues include system architecture, system integration, risk (technical, schedule, cost, performance), and technological challenges.

4. Your task is to develop a system-of-systems (SoS) architecture for the conduct of undersea warfare in the littorals in the 2025 timeframe. The Navy will focus on developing the following operations and associated capabilities (from the CONOPS document) to bring 21st Century ASW to fruition. Working with your project advisors (Project lead advisor: Dr. Shoup, Technical advisor: VADM(ret) Bacon, SEA team advisor: Dr. Vaidyanathan), you will select some or all of these capabilities for your system requirements.
    a. Battlespace preparation and monitoring
    b. Persistent detection and cueing
    c. Combined arms prosecution
    d. High volume search and kill rates

e. Non-traditional methods
f. Defense in-depth

5. You should consider both existing and proposed systems, and you should be prepared to design others to fill any capability gaps you discover.

6. Your role in the July-to-December project will be to serve as the lead systems engineering team, supported by other collaborative teams. You should employ the systems engineering methodology you have studied in your NPS course work. You should commence a Needs Analysis in the spring quarter to determine operational requirements for the system of systems; you should define the functions your SoS will perform and establish boundaries for it. (Some of this activity may extend into the summer quarter.)

7. You will have to define the selected concepts for supporting systems (which may be thought of as “components” in your SoS) and partition the overall SoS requirements to be addressed by collaborating teams. By the end of the spring quarter, you should develop a Problem Statement, Mission Statement and associated guidance documents. You should have a draft Project Management Plan by that time as well.

8. It will be your responsibility to identify supporting “teams” whose work you can integrate with yours in the performance of the project – you should be laying this groundwork during the planning phase ending in June. (Some collaborating “teams” may be individual researchers or thesis authors.) Information concerning some potential collaborating teams is provided in Appendix A to this memorandum. Your project advisors will assist you in coordinating with other student teams. <u>Ultimately, it will be your responsibility to integrate the work of supporting teams.</u>

9. You are expected to treat this project as your own. You will, to a large degree, need to identify for yourselves the tasks necessary to produce an excellent study. Your faculty advisors will, of course, participate in discussions with you, as appropriate, during this process. You are required to seek out other groups of students and/or faculty who can contribute to and support your work. (The study director will provide significant help in the areas addressed in Appendix A.) Your success will partly be determined by the breadth of the interdisciplinary team you assemble to work on this problem. You should be familiar with the integrated projects done by SEA classes who preceded you, particularly those portions of SEA 4 and SEA 5 reports dealing with anti-submarine and undersea warfare. In addition, you should familiarize yourself with Joint Task Force ASW initiatives and establish working ties with Fleet ASW Command.

10. Deliverables. For the planning phase (April-to-June) you should plan on delivering:
    a) An informal IPR no later than 2 June 2005 at which you present your restated problem, your project management plan, and your across campus partners; coordinate with your Project Management course instructor.
    b) A written Project Management Plan draft (by the end of the Spring quarter) which will be your guiding document (subject always to change when appropriate) for the performance of the project in the July-to-December timeframe.
    c) The ultimate deliverable (at the end of the project in December) will be a quality technical report and a formal briefing of the entire project, suitable for presentation to senior Navy and other visitors.

David H. Olwell, PhD
Associate Director for Education

Appendix A: Other curricula on campus that may participate

a. The Total Ship System Engineering curriculum
b. The Undersea Warfare curriculum
c. The Combat Systems curricula
d. The Electrical and Computer Engineering curricula
e. The Oceanography curriculum
f. The Operations Analysis curricula
g. The Space Systems curricula
h. The Information Systems curricula
i. The Electronic Warfare curricula
j. The Business Management curricula

Appendix B: Terms of Reference (JP 1-02 as amended Nov 2004)

Undersea Warfare – Operations conducted to establish battlespace dominance in the underwater environment, which permits friendly forces to accomplish the full range of potential missions and denies an opposing force the effective use of underwater systems and weapons. It includes offensive and defensive submarine, antisubmarine, and mine warfare operations.

Antisubmarine Warfare – Operations conducted with the intention of denying the enemy the effective use of submarines. Also called ASW

Mine Warfare – The strategic, operational, and tactical use of mines and mine countermeasures. Mine warfare is divided into two basic subdivisions: the laying of mines to degrade the enemy's capabilities to wage land, air, and maritime warfare; and the countering of enemy laid mines to permit friendly maneuver or use of selected land or sea areas. Also called MIW

APPENDIX III: TSSE ALTERNATIVE REQUIREMENTS

1. INTRODUCTION

This alternative is provided to TSSE for the purpose of permitting initial design considerations. TSSE will be designing a surface and sub-surface platform capable of retrieving, deploying, and maintaining UUVs. This “TSSE alternative” focuses on using these assets throughout mission completion.

Changes to this alternative may be made during the alternative generation phase of SEA-8’s engineering design process. However, the changes will be minimal and should not greatly affect TSSE’s design assumptions.

As with each of the alternatives SEA-8 will generate, this SoS must be capable of performing the following (in one of three OAs);

- Sensor assets required to provide Pd 0.5 across one harbor waterway (1000 NM^2) within 72 hours of initiation
- Sensor assets required to provide Pd 0.8 across contested OA (6,700 NM^2) within 10 days
- Provide logistic support necessary to sustain SoS for 30 days

Both the TSSE surface and sub-surface vessels must be able to communicate via the following.

- High Band Width Air/Space Line of Sight (LOS)
- LOS Data
- LOS Voice
- OTH Data
- OTH Voice
- SATCOM
- Underwater Data

2. HARBOR GATE

Due to the extremely short timeline required to receive a Pd of 0.5 around the harbor of interest, it is unlikely that TSSE platforms will be able to play a role in deploying these vehicles. Instead, high-altitude platforms will deliver these assets directly to harbors of interest.

The “harbor gate” must be capable of detecting an enemy submarine getting underway from the port of interest. Once detected, the system must be capable of informing the C2 structure and receiving commands. The system must then be capable of engaging the enemy submarine, if necessary. It is envisioned that these assets (sensors and weapons) will remain “anchored” on station and have a minimum life span of 90 days, therefore requiring no regeneration during the 30 day operation. Upon mission completion these assets will be capable of remotely initiated self-destruction.

3. OA COVERAGE

The OA (6,700 NM^2) must have a Pd of 0.8 within 10 days. The TSSE ship and submarine will be an integral part of this requirement.

The TSSE surface asset will be capable of deploying, retrieving, and regenerating (i.e. recharging, performing minor maintenance, etc.) Large size (36 in. diameter, 20,000 lbs.) UUVs semi-clandestinely. Large UUVs will be used to perform sensing and tracking of enemy assets. They will be capable of traveling at 8-10 knots with bursts to 20 knots for short periods (hours). Upon detecting enemy submarine assets they will track and perform an acoustic signal response detected by mobile C3 UUVs (discussed in next paragraph). Large UUVs will be capable of detecting enemy AIP submarines at a range of 5kyds (assumed 50% of the time). Large UUVs will be capable of 200 hours of operation. They must be regenerated by TSSE-designed surface assets.

Both surface and sub-surface assets will be capable of deploying, retrieving, and regenerating (i.e. recharging, performing minor maintenance, etc.) Light Weight Vehicle (LWV) size (12.75in. diameter, 500 lbs.) UUVs to act as mobile C3 nodes. These UUVs will possess a range of 100 NM per day. The surface asset will be capable of semi-clandestine deployment and retrieval while the sub-surface asset will be capable of clandestine deployment and retrieval. These glider UUVs will be capable of communicating with acoustic signals from Large UUVs and relaying data above surface to the command structure via EHF. LWV mobile C3 UUVs will be capable of deploying for 100 hours of operation.

Upon detection of an enemy asset, the Large UUV will initiate track and commence signaling with an acoustic pulse. Upon detection of the pulse by LWV mobile C3 UUVs (detectable at a range of 6kyds), the C3 UUV will glide to the surface and initiate informing the command structure of the presence of the enemy submarine. As the Large UUVs signal is detected by C3 UUVs and the command element informed, they will be able to track the general movement of the enemy submarine.

4. OFFENSIVE ENGAGEMENT

If desired, the command element will be able to offensively engage the enemy submarine via a pre-deployed UAV (7,000 lbs). This UAV will be capable of carrying a small torpedo (700 lbs). When desired or upon receiving signaling of an enemy submarine detection, the command element may deploy this armed UAV to circle the OA at high altitude. When the enemy submarine location is signaled the command element may choose to deploy the torpedo from the UAV. The torpedo will fall from high altitude into the water and commence a general search for the enemy submarine, homing on the tracking Large UUV's signal, if possible. The UAV is capable of remaining in the air for 48 hours before returning to the surface asset. TSSE's surface asset must be capable of deploying, retrieving, and maintaining this UAV as well as its torpedo cargo.

In addition, the TSSE surface asset must be capable of deploying box-launcher weapons and torpedoes for enemy engagement.

The TSSE sub-surface asset must be capable of deploying torpedoes for offensive action as a method of self-defense.

Deployment Team Requirements Document

Introduction

The SEA-8 cohort intends to leverage current and future technology to develop a SoS architecture that enables the US Navy to operate in a distributed manner throughout the future battle space. This distributed manner will require a variety of systems which can be deployed effectively through numerous platforms and methods, under a myriad of conditions within time and cost constraints.

SEA-8 believes effective and efficient deployment of this system to be a key component in maintaining dominance in the littoral domain. Three top level operational functions have been identified as being critical in achieving successful and effective deployment of the SoS, these functions are prepare, sustain and deliver.

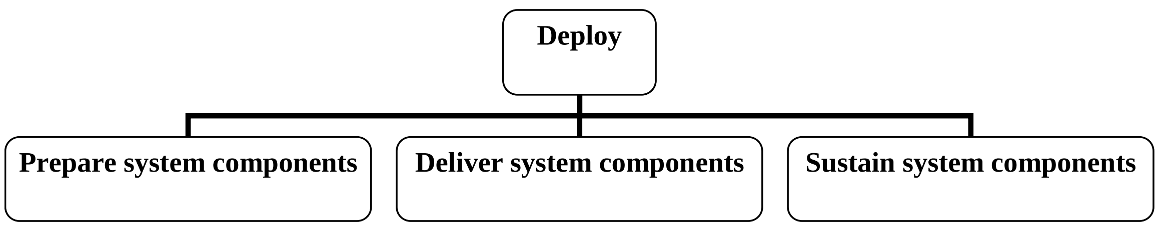

Figure 1: Deployment requirements breakdown

Requirements Generation

Generation of requirements for deployment of the littoral ASW SOS involves evaluation of legacy systems which are projected to be operational in 2025, supplemented with a further study of programs of record in FY2005. Data points will be analyzed providing resulting performance gaps which will guide further study into potential new systems. The use of functional analysis and system decomposition will aid in identifying the capabilities and limitations of platforms in meeting the top-level functions.

Overarching Requirements

<u>Prepare</u>: The preparation and pre-positioning of sensors will be instrumental in rapidly and successfully deploying system components throughout the battle-space. The Deployment team requires two broad categories of platforms:

1. *Self Deploying Platforms*: Platforms which are able to supply and/or deploy and organically support sensor components such as ASW capable surface and subsurface assets.
2. *Deployment Platforms:* Platforms which only deploy SOS components, i.e. aircraft equipped to deploy Heavy Weight (HWV) 21 inch diameter, 3000 lbs or less, UUV and/or Sea web sensor components.

By embracing programs such as SEA Power 21, Sea basing concept and minimizing operational reliance on shore infrastructure, platforms will be further enabled to minimize preparation time to deliver the right sensor to the right location at the right time.

Requirements are:

- Platforms must interoperate with Sea base.
- Sensors must be self initiating and ready for operations upon deployment.
- Durability to be stored in theater for rapid deployment.

<u>Deliver</u>: The nature of conflict in 2025 will require rapid delivery of blue force ASW capabilities, which will set the pace and tone of conflict or even deter conflict from occurring. The need for the SoS to rapidly deliver to any corner of the world is essential to the US Navy succeeding in the "global commons" of the littorals. Successful delivery of the SOS will provide the combatant commanders (COCOM) with more viable courses of action (COA) not previously attainable given current legacy delivery methods.

Requirements are:

- Maintainable
- Interoperable
- Possess extended reach
- Speed
- Limited assets in theater within 72hrs ISO sensor coverage goal of .5 Pd
- Full operational capability within 10 days ISO sensor coverage goal of .8 Pd

Utilization of a balanced mixture of in theater and out of theater assets will serve to provide the combatant commander with the right assets at the right time. Careful distribution of these assets across the AO coupled with readily deployable assets from exterior to the theater will be pivotal to high performance while maximizing optimal deployment levels.

Platforms: Multiple legacy systems and platforms will be utilized when considering deployment of a future system-of-systems concept. Specific consideration will be given to the effective transportation and deployment of sensor component assets in theater. Platforms considered viable delivery options are; space based, air, surface, subsurface and UUV assets. Each of these platforms possesses a valuable delivery attribute such as transit speed, payload capacity, stealth, efficiency etc. Antisubmarine warfare in the littoral region in 2025 will require platforms which excel in one or more attributes.

The ability to deploy an effective system rapidly to achieve sensor coverage is essential. For the purposes of this study target timelines are defined as 72 hours for 5% coverage of the AO and 10 days for 80% coverage of the AO. Trade-off analysis must be conducted to derive a balance of rapidly deployable- small payload, long term response- greater payload assets.

The SEA-8 cohort will evaluate current deployment capable platforms and determine transit capabilities and limitations in an effort to identify platform performance gaps. These performance gaps will provide valuable data for determining how to best distribute platforms within the AO to further mitigate deployment lag times. All current surface, sub-surface and air capable assets will be evaluated utilizing a metric of mean speed over ground (SOG). A second study of platforms to include programs of record for the 2025 timeframe will be conducted to supplement previous data. Analysis of this data will provide hard estimates of platforms required both within and external to the AO.

UUV Assets: The Navy Unmanned Undersea Vehicle (UUV) Master Plan of November 9, 2004 illustrates four basic UUV categories which must be considered when utilizing these assets in the littoral environment. SEA-8 considered theses classes and has chosen to evaluate the Heavy Weight (HWV) 21 inch diameter, 3000 lbs or less, UUV as a standard for this study.

Sustain: The ability for the SoS to remain on station for prolonged periods of time is critical to mission success. The uncertain nature of warfare requires an SoS that is logistically agile and operationally modular. Logistical infrastructure will require initial support capability for SOS for 30 days once the SoS reaches Initial Operational Capability (IOC) in the AO.

"The concept of operation for payload delivery depends on the particular mission being supported. Since a payload delivery UUV would be large and would include fairly robust autonomy, navigation, energy, and propulsion, in most cases vehicle recovery would be desired following delivery of payloads."[1]

Requirements are:

- Logistics sustainment for 30 days of continuous operations.

[1] The Navy Unmanned Undersea Vehicle (UUV) Master Plan of November 9, 2004

Sensors Team Requirements Document

"Advanced technologies employed in support of friendly forces will include exploiting the rapidly increasing computing power of sensors and networks. When coupled to the operational persistence afforded by Sea Basing, such systems will provide pervasive awareness by way of hundreds, even thousands of small sensing and computing devices that permeate the operating environment, yielding unprecedented situational awareness and highly detailed pictures of the battlespace."[2]

The Sensors Team has divided Prosecution into six categories as listed below:

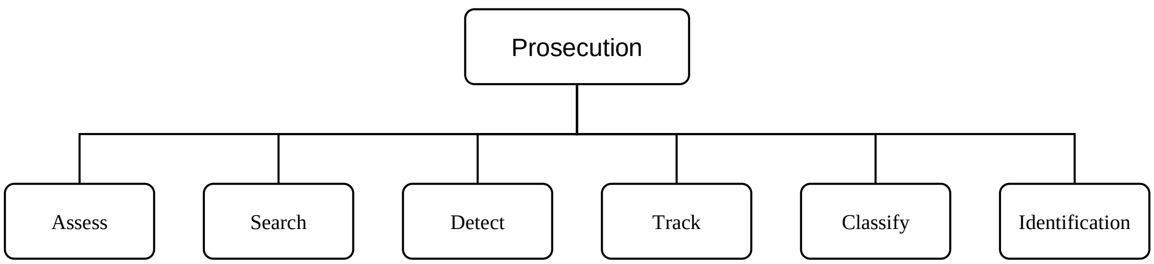

Figure 1: Breakdown of "Sensors" Overall Structure

Assess and Search

Environmental Assessment: Successful ASW in the Littorals depends on a System of System with the ability to exploit and/or adapt plans based on the oceanographic and atmospheric environmental conditions.

- The assessment for water and bathymetric conditions should include but is not limited to both vertical and horizontal variability in a variety of physical parameters including sound velocity profiles (SVPs), sea surface temperature, ocean fronts and eddies, bathymetric and topographic conditions, anomalies, ambient noise, and ocean currents.

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[2] Program Executive Office Integrated Warfare Strategies 5 (PEO IWS 5), *21st Century ASW MASTER PLAN*, 21 December 2004 (the overall classification of this document is SECRET, however, the portions that appear in this paper are Unclassified), pp. 14.

- The assessment for atmospheric conditions should include but is not limited to providing analyzed and forecast air temperature, wind speed and direction, sea and swell height, direction, and period, sky conditions, precipitation, icing for ASW aircraft operation; and the location, movement, and intensity of frontal activity are required.[3]

Littoral ASW Search: The Littoral ASW System of System should be capable of conducting clandestine search operations that consist of a systematic investigation of a particular area, barrier, or datum to establish within a high degree of certainty the presence and/or absence of submarines.[4] This System of Systems should utilize innovative technologies both of the acoustic and non-acoustic nature.

Detect and Localize

From *Anti-Submarine Warfare* "detection can happen in many ways and submarines by their nature, construction and modes of operation offer different opportunities to different systems."[5] Likewise, once detected, the system of systems will be required to localize. From Captain John Morgan of OPNAV N84, "The near-shore regional/littoral operating environment poses a very challenging ASW problem. We will need enhanced capabilities to root modern diesel, air-independent, and nuclear submarines out of the "mud" of noisy, contact-dense environments typical of the littoral, and be ready as well to detect, localize, and engage submarines in deep water and Arctic environments."[6] In conjunction with this recognized capability need, Admiral Natter goes further to require the need to "Develop an undersea network and non-acoustic detection methods to enable a sensor-rich antisubmarine warfare

[3] Antisubmarine Warfare Commander's (ASWC) Manual (NTTP 3-21.1) p. 3-1 – 3-2
[4] Antisubmarine Warfare Commander's (ASWC) Manual (NTTP 3-21.1) p. 4-1
[5] W J R Gardner, Anti-Submarine Warfare, Brassey's, London, 1996, pp 60
[6] http://www.chinfo.navy.mil/navpalib/cno/n87/usw/autumn98/anti.htm, accessed 22 July 2005

environment and advanced weapon technology to counter littoral threats."[7] For the purposes of our system of systems, the requirements for detection and localization shall be:

- The system of systems is required to be able to indicate a perception of contact that may be a submarine, using available sensors.
- The system of systems is required to arrive at an accurate position for a submarine contact, using available sensors.

Track and Targeting

Shifting from the requirements of detection and localization, the follow-on requirements of track and targeting is the next step in the littoral operating environment *Submarine Warfare* has the following to say about the littoral operating environment of the future: "In military technology no advantage can be guaranteed for very long, and as submarines become quieter, so the effectiveness of purely passive sensors diminishes. The hope expressed a few years ago that ASW forces had seen the last active sonar has proved to be absurdly optimistic. Not only are submarines quieter, they have moved into shallow waters. As the SSK proliferates and the confrontation between the Soviet Union and the United States recedes into history, so the new vogue for littoral warfare creates a fresh series of problems."[8] These fresh series of problems are the reason why our system of systems is focused on the littorals of 2025.

To define what the track and targeting requirements are, it may prove useful to remove any misconceptions. In this regard, it is important to note that tracking is not required to be defined as trailing. From *Anti-Submarine Warfare and Superpower Strategic Stability*, "Far fewer sensors and platform combinations have been judged suitable for trailing because this task is, for the most part, restricted to instruments carried both on surface ships and submarines of

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[7] http://www.usni.org/proceedings/articles03/pronatter11-2.htm, accessed 22 July 2005.
[8] Anthony Preston, Submarine Warfare, An Illustrated History, Thunder Bay Press, 1999, pp.139-140.

which there are both acoustic and non-acoustic candidates. Tracking becomes less demanding that trailing, it is potentially open to air- and water-borne acoustic and non-acoustic systems."[9] For the purposes of our system of systems, the requirement for tracking and targeting will be:

- The contact of interest's bearing, range, course and speed are known with sufficient accuracy to record and indicate its history of movement.
- The system of systems will therefore be able to generate an estimate of past and future movement to enable a fire control solution.

Classification and Identification

The most important requirement is "automation". Every classification and identification step in today's ASW environment has an operator in the loop. Being able to classify and identify a contact automatically reduces manning requirements and, depending on the stability of the technological tools, may be able to do so accurately. With that said, another requirement in the "Classify and ID" roles is a reduction in false alarm rates without a reduction in equipment sensitivity.[10]

A second set of requirements can be extracted from the UUV Master Plan. With the goal of a "higher Technology Readiness Level (TRL)" in mind, the requirement would be to "transmit RF data reliably in operational states," whether it is in real or non-real time. The graph below explains what technological concepts will generate these requirements in the future. These same technological concepts should be considered as requirements that are required to meet today's needs, and are listed as:

- Improved Classification
- Low power and automatic classification/ID

[9] Donald C. Daniel, Anti-Submarine Warfare and Superpower Strategic Stability, University of Illinois Press, 1986, pp. 89.
[10] Hill, J. R., Read Admiral, USN, Anti-Submarine Warfare, Naval Institute Press, Maryland, 1985, pp. 46-47.

- Multi-threat Chemical, Biological, Nuclear, Radiological, and Explosives (CBNRE)
- Intelligence, Surveillance, Reconnaissance (ISR) Specific Emitter (SEID)/Visual ID (VID)
- Non-Traditional Tracking (NTT) ASW
- Buried ID

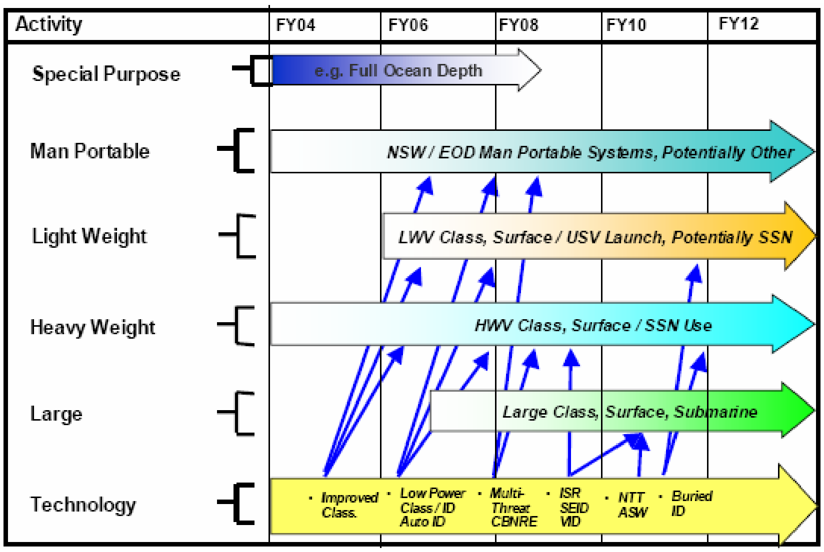

Figure 2: Technology Roadmap for Sensors

Platform Development Team Requirements Document

Introduction

In order to fully address the stakeholders' needs the Platform Design team has researched what requirements are to be applied during the design of the SoS for littoral ASW in 2025. Emphasis has been given to those functions of the Functional Hierarchy for which Platform Design is responsible, shown below;

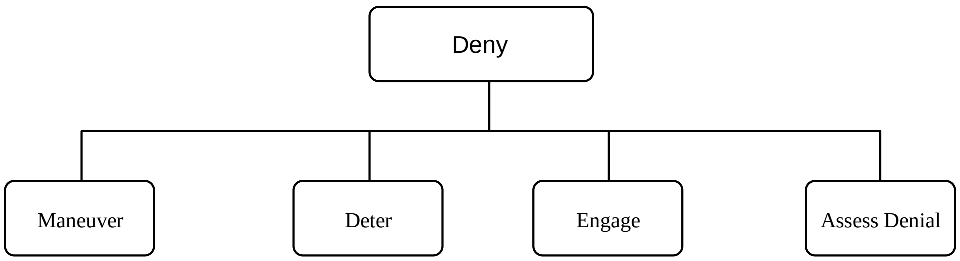

Figure 3: Breakdown of Platform Design Team's Overall Functional Structure

- Maneuver
  - Collaborate with friendly assets for complimentary effect. Use environment and topography for our advantage.
- Deter
  - Show of force or presence to dissuade enemy opposition or movement. Overt actions taken to force, or control, enemy maneuvers. Establish tripwires and follow-on consequential actions that control enemy assets at a safe distance from allied forces.
- Engage
  - Neutralize or disrupt the enemy's ability to perform desired mission.
- Assess Denial
  - Evaluate the effectiveness of action taken to deny the enemy's mission and determine the need for a follow-on response.

Stakeholder Requirements

Our SoS architecture must be capable of performing both overt and clandestine operations in areas inaccessible to conventional naval and maritime forces. The system should be capable of arriving on station with minimal chance of detection and operating without a need for detectable communication. In order to maneuver for advantage the system must be capable of sensing the ocean environment’s critical data, as well as assess the data, decide and act based on received information, often without higher level input or feedback.

In order to deter hostile enemy action, the SoS must be capable of telegraphing escalation of tensions to the enemy. This deterrence may be used to prohibit enemy assets from leaving port, from approaching friendly High Value Units (HVU) within a given range, or from conducting operations within a given area of concern. For example, overt trailing may be performed to inform the enemy of successful tracking by our forces, thereby forcing them to evade to another operating area. ASW traps may be overtly established at the exits of primary ports to deter the enemy from getting underway.

Deterrence also refers to the CONOPS that must be established to respond to enemy action. Tripwires (events that require friendly force response, such as an enemy submarine approaching within a given distance from U.S. maritime assets or loss of contact with a submerged threat) must be established and appropriate action assigned to ensure that our advantage is reestablished and maintained if tripwires are violated.

The system must have the ability to respond offensively, if necessary. This may be manifested in the system’s ability to damage or kill the enemy assets. However, other options may be pursued. Weapons used may disrupt the environment to such an extent that continued operation by the enemy becomes impossible. Another possibility may be to use a weapon that would prevent the enemy from prosecuting (detecting, tracking or firing on) friendly assets. The system does not need to be capable of physically damaging enemy undersea forces.

Upon completing offensive action, battle damage assessment must be performed to determine the enemy's ability to operate and information must be relayed to the decision makers. In the event of enemy deterrence, the system must be capable of recording and transmitting enemy action data as required for the given mission.

The SoS should be capable of accomplishing missions in any littoral region without the assistance or support of local nation States. The system must be sustainable for at least 30 days in the mission sea space while maintaining area prosecution and performing ASW barriers for 3 ports.

As the development of unmanned technology evolves, systems should be considered to improve existing ASW performance. These unmanned systems may be required to avoid detection and be resist attack and countermeasures which will allow penetration of denied areas for sustained independent operations.[11]

In order to provide cost-effective and flexible capabilities, any UUV system alternative should strive to maximize modularity for the vehicles within given classes to facilitate industry standards and open architecture. Modularity will be a key aspect of the SoS to ensure its long term functionality and operability with legacy platforms. In order to ensure modularity, the following standardized sizes must be used, as defined in the UUV Master Plan[12].

- Man-Portable: approximately 25-100+ lbs displacement
- Light Weight Vehicle (LWV): approximately 500 lbs displacement

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[11] USA Department of the Navy, *The Navy Unmanned Undersea Vehicle (UUV) Master Plan*, November 9, 2004, pp.2

[12] USA Department of the Navy, *The Navy Unmanned Undersea Vehicle (UUV) Master Plan*, November 9, 2004, pp. xvi.

- HWV: approximately 3000 lbs displacement
- Large Class: approximately 20,000 lbs displacement sanitize purify

C4ISR Requirements Document

C4ISR System of Systems Requirements

1.0 Introduction

The following C4ISR requirements for the SoS support specific functions needed for overall operation and coordination as we approach littoral ASW in 2025. The figure below illustrates supporting C4ISR functions for Command, and their associated sub-functions; Communicate, Network Data, and Exchange Intelligence, Surveillance, and Reconaisance (ISR).

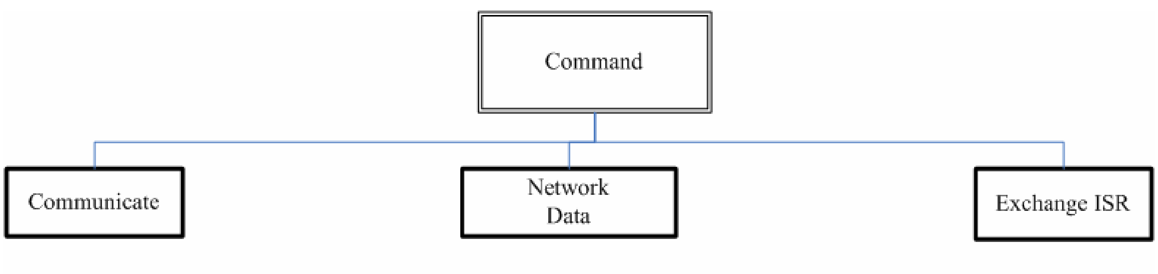


Figure () Future SoS undersea warfare C4ISR system top level hierarchy

2.0 Command Requirements

A survivable real-time C4ISR system architecture is central to successful ASW. These systems must be capable of sharing and providing a clear and complete picture of the undersea environment and allow operators to assimilate tactical information rapidly and efficiently. These systems must also be a part of Joint and Service information networks, to include sensors and networks deployed from aircraft, ships, submarines and off-board vehicles. Through FORCEnet, effective integration into these networks allows the ASW system of systems to share situational awareness, plan collaboratively and fight synergistically with other Joint Forces. Key amongst these requirements is connectivity between systems, including the ability to communicate from below the surface, at tactically useful speeds to facilitate exchange of time-critical information for situational awareness and enemy engagement.

2.1 Communications Systems

2.1.1 Communicate

Effective command and control is impossible without timely and accurate communications. Commanders must be able to receive information and convey orders efficiently and seamlessly to all units engaged in an operation, nowhere is this more important than in the execution of an ASW mission. All platforms, sensors and weapons systems must be reliably linked to facilitate efficient secure command and control. To this end, external ASW communication systems shall transmit and receive communications data by exploiting the full range of the electromagnetic spectrum. Units engaged in ASW must also have the ability to communicate efficiently within their platform. Much like external communications, internal circuits shall have the ability to transmit and receive information for distributed awareness. Processing Voice over Internet Protocol (VoIP) data shall be required, where necessary, for the use of external and internal voice communications.

2.1.2 External Communication and Data Requirements

External command and control communications networks shall be conducted through traditional “above water” methods of radio broadcast via terrestrial and satellite based communications, however tomorrow’s ASW battlefield includes a much greater reliance on unmanned underwater vehicles, to serve the latter, future communications networks must also have the ability to work at tactically significant ranges underwater. To serve this end, future systems must find ways to exploit the EM spectrum and other possible mediums to enable "underwater" communications networks. Due to the unique challenges inherent in underwater operations, communication systems must be robust and redundant enough to operate anywhere in the world, connecting all joint forces as well as many of our allies. For this reason communication systems shall support transmissions and reception for the following communication requirements.

- High Band Width Air/Space Line of Sight (LOS)
- LOS Data
- LOS Voice
- OTH Data
- OTH Voice
- SATCOM
- Underwater Data

2.1.3 Internal Communication Networks

Within manned systems, units shall support communication between personnel within the same unit and facilitate improved man-machine interfaces. The internal communication system shall:

- Transmit and receive directed information
- Utilize the unit's internal access network
- Interface with wireless network system
- Have redundant hardwired alternate communication networks

2.2 Network Data

The SoS will participate in the FORCEnet concept. To support network centric operation, the future system shall utilize unit's distributed internal access networks and external communication capabilities to capture, process, interface, and secure information assurance. An increasing amount of networked tactical data is expected to be in the form of text, voice over IP, recorded data, sensor targeting, fire control data, text command instructions, and images. To support a robust data exchange within the system of systems, this system shall be equipped with a distributed internal access network of computing systems and integrated operator displays that interface with external wide area battlespace networks. Battlespace networks are projected to exist on many levels above and below the sea. The following requirements serve support overall network information data functions.

- Capture requested unit specific information for external air and underwater battlespace networks
- Process shared network information to promote C2 information fusion and C2 directed orders
- Interface unit's internal access network with external battlespace networks.
- Secure network information data through multi-layered information assurance

2.2.1 Distributed internal access network

Each system shall operate a distributed internal access network for onboard command, control, communication, and collaboration.

The internal access network shall be:

- Composable and secure

- Distributed throughout the unit and on operators
- Support unclassified and classified information
- Interface with the SoS undersea warfare C4I Wide Area Network
- Support Audio Video Tele-Conference data exchanges

2.2.2 Tactical Data

The data exchanged as battlespace information to all SoS shall include the following requirements. Additionally it is important to note that although "Exchanging ISR" has been identified as a sub-function for the SoS C4ISR, ISR is listed below as information used by and modified by operators. Exchanging ISR sub-function requirements are addressed in a later section.

- Unit Status
- AVTC
- Weapons Control Doctrine
- Remote Weapons Systems Control
- Sensor detection and tracking data
- legacy link information
- Positional and navigation data
- Targeting and fire control data
- Remote unmanned vehicle control
- Information Assurance Doctrine
- ISR

2.2.3 Command and Control Fusion System

In order to manage the large amounts of battlespace information received and transmitted by the system, each system unit shall have robust controllable computing systems to filter non-collaborated warfare information. The C2 Fusion System shall:

- Interface with a unit's internal access network and distributed control system
- Operate with automaticity unless overridden by operators
- Collaborate battlespace information within the wide area network
- Filter non-collaborated battlespace information
- Control organic and inorganic units and weapons systems
- Interface with distributed sensor fields
- Interface with Joint C2 fusion systems
- Unite unit sensor, fire control, and positional data from organic and inorganic systems for a cooperative battlespace environment
- Be information assured and secure
- Utilize and control legacy link information

2.3 Exchange Intelligence, Surveillance and Reconnaissance (ISR)

Accurate and timely intelligence, surveillance and reconaisance are critical force multipliers for ASW. Exchanging ISR information is designated as a separate function due to its importance and time critical nature. It is imperative that a future SoS undersea warfare system is able to transfer intelligence data, surveillance data, and reconaisance data. To support an exchange ISR function, the SoS shall:

- Operate with an autonomous ISR sharing system
- Automatically transfer raw electronic sensor data to a designated battlespace network for collaboration
- Automatically inject collaborated ISR information to the battlespace common operational/undersea picture
- Accept and process human intelligence input

Glossary of Acronyms

AEHF	Advanced Extra High Frequency
AO	Area of Operations
AOR	Area of Responsibility
ASW	Anti-Submarine Warfare
AVTC	Advanced Video Tele-Conferencing
C2	Command and Control
CBNRE	Chemical, Biological, Nuclear, Radiological, Explosives
COA	Course of Action
COCOM	Combatant Commanders
CONOPS	Concept of Operations
EHF	Extra High Frequency
ELF	Extra Low Frequency
HF	High Frequency
HVU	High Value Unit
HWV	High Weight Vehicle
IOC	Initial Operational Capability
ISR	Intelligence, Surveillance, Reconnaissance
LF	Low Frequency
LOS	Line of Sight
LWV	Light Weight Vehicle
MF	Medium Frequency
NTT	Non-Traditional Tracking
SEID	Specific Emitter Identification
SHF	Super High Frequency
SOG	Speed over Ground
SoS	System of Systems
SSK	Diesel Submarine
SVP	Sound Velocity Profiles
TRL	Technology Readiness Level
UHF	Ultra High Frequency

UUV	Unmanned Underwater Vehicle
VHF	Very High Frequency
VID	Visual Identification
VLF	Very Low Frequency
VoIP	Voice over Internet Protocol

Appendix A: Classification of Submarines

The following was downloaded from the http://www.battlebelow.com/destroyer.htm website:

CONTACT CLASSIFICATIONS

"...in addition to a visual sighting, contacts [are] made with enemy submarines by either Sonar or radar. The likelihood that any of the three methods had been able to accurately identify or detect the presence of an enemy submarine in the area requires that the contact be initially categorized into one of four possible classifications. As the investigation proceeds, the contact classifications can be either upgraded or degraded as necessary.

- CERTSUB - (*certain submarine*) A contact has been sighted and positively identified as a submarine.
- PROBSUB - (*probable submarine*) A contact that displays strong evidence of being a submarine.
  This classification is normally based on the information gathered by either sonar or radar.
- POSSUB - The classification (*possible submarine*) is given to a contact on which available information indicates the likely presence of a submarine, however there is insufficient evidence to justify a higher classification. POSSUB is always followed by an assessment of the confidence level:

A. LOW CONFIDENCE: A contact that cannot be regarded as a non-submarine and which requires further investigation

B. HIGH CONFIDENCE: A contact which, from evidence available, is firmly believed to be a submarine but does not meet the criteria for PROBSUB.

- NONSUB - This condition is indicated when a visual sighting or the sound/radar evaluation is satisfied that the contact is NOT a submarine."

APPENDIX IV: SEA TENTACLE PRELIMINARY DESIGN INTERIM REQUIREMENTS DOCUMENT

1.0 PURPOSE

This document is an Interim Requirements Document (IRD) generated for the design and procurement of the SEA TENTACLE Flight 0 ships and integration of mission systems into the total ship design. This IRD will serve as the basis for developing future SEA TENTACLE requirements. The data gained from ongoing studies and analysis will be incorporated into the requirements of this IRD to develop and IRD for a Final Design IRD and eventually a Capabilities Development Document for Flight 1 SEA TENTACLE.

1.1 Background

The SEA TENTACLE will be a mission-focused ship capable of defeating the conventional, nuclear and asymmetric submarine threat in the littoral. The SEA TENTACLE design primarily focuses on anti-submarine warfare capability in the littorals through the extensive use of unmanned undersea vehicle (UUV) technology, however modularity will enable change-out of mission packages so SEA TENTACLE can be optimized to fight in the littoral. The SEA TENTACLE will be a dominant and tenacious platform that enables sea based friendly forces to operate in the littorals without regard to the presence of enemy submarines.

2.0 THREAT

Further details on existing, projected, and technology feasible threats are contained in the Classified “Major Surface Ship Threat Assessment”, ONI-TA-018-02, July 2002.

3.0 SEA TENTACLE Requirements

This section describes the SEA TENTACLE requirements to perform the missions as envisioned in the concept of operations. Critical Design Parameters are listed for the SEA TENTACLE Flight 0 ships. The SEA TENTACLE shall be configured with core systems and the capability of being modified with specific mission packages that will enable the ship to perform all core ship responsibilities. A core system is a system that is resident in the SEA TENTACLE with the purpose of carrying out core ship functions such as self-defense, navigation, and C4I, or other capabilities common to all mission areas. A mission package is defined as a functional grouping of systems that may be integrated into SEA TENTACLE to give it the capability to execute an emerging mission beyond the current focused missions.

3.0.1 SEA TENTACLE Missions

SEA TENTACLE will conduct missions in support of Sea Power 21 and Naval Power 21. The SEA TENTACLE will deliver focused mission capabilities to enable joint and friendly forces to operate effectively in the littoral. These primary mission capabilities are shallow-water ASW dominance, an enhanced mine warfare capability, and effective maritime surveillance. There are other capabilities inherent in the SEA TENTACLE that support other missions such as Battlespace Preparation, Home Land Defense, Anti-Terrorism/Force Protection, (AT/FP), Maritime Interdiction Operations (MIO) and Intelligence, Surveillance, and Reconnaissance (ISR). As a mission focused ship, the SEA TENTACLE will enable unfettered access to the littorals to allow unimpeded pursuance of other missions by multi-mission surface combatants.

3.0.2 Modularity

The SEA TENTACLE will have extensive volume and weight allocations devoted to storage and handling of numerous deployable systems that will provide the main war fighting capability and functionality for specific mission areas. This also provides the opportunity to bring on modular-type packages in support of alternative missions. A mission package may consist of a combination of modules, manned and unmanned off-board vehicles, deployable sensors, and mission manning detachments. Mission packages, to the greatest extent possible, should integrate into the ships installed core command and control architecture to minimize the use of unique equipment.

3.1 Critical Design Parameters

Category	Threshold	Objective
Operational Availability	0.85	0.95
Hull Service Life	20 years	30 years
Draft @ Full Load	8 m	5 m
Max Speed	30 + kts	40 + kts
Range @ Max Speed	1000 nm	1500 nm
Range @ Cruise Speed	3500 nm	4500 nm
Large UUV Capacity	40	50+

Hvy Wt UUV capacity	80	100+
Cargo Weight	400 MT	800 MT
Cargo Volume	5000 m^3	6000 m^3
Small Boat (7 m RHIB)	1	2
USV (11 m RHIB)	1	2
UUV/USV/UAV Launch Recover	Sea State 3	Sea State 4
Aviation Support	One 7000 lb VTUAV	VTUAV (2)/ SH-60R
Aircraft Launch / Recover	VTUAV	VTUAV/SH-60R
UNREP Modes	RAS, CONREP, VERTREP	RAS, CONREP, VERTREP
Core Crew Size	$\leq$130	$\leq$ 100
Crew Accommodations	130	130
Provisions	30 days	45 days

3.2 Mission Package Performance Requirements

The following sections provide specific performance requirements for the SEA TENTACLE, when outfitted with core systems.

3.2.1 Primary Mission Capabilities

a. Littoral Anti-Submarine Warfare (ASW)
b. Mine Warfare (MIW)
c. Maritime Surveillance (MARSURV)

3.2.1.1 Littoral Anti-Submarine Warfare (ASW)

The SEA TENTACLE, in conjunction with the systems delivered by the platform, will conduct integrated, multi-sensor ASW detection, classification, localization, tracking, and engagement of submarines throughout the water column in the littoral operation environment by employing on-board and off-board systems. This will primarily be accomplished through the use of UUVs, Undersea Surveillance Systems, environmental models and databases. The SEA TENTACLE shall have core systems that provide the capability to detect threat torpedoes at sufficient range to permit initiation of effective countermeasure and or maneuver action to evade or defeat the threat. The SEA TENTACLE will have the capability to embark ASW/multi-mission helicopters and unmanned aerial vehicles. Specifically, SEA TENTACLE and the deployed systems will be able to:

a. Conduct offensive and defensive ASW operations that deny the enemy submarine access to the open ocean through continuous surveillance and communications to ensure friendly forces have detailed, real-time localization and track information on any submarine target of interest. This denies the enemy submarine the element of surprise and allows friendly forces to operate with confidence.
b. Conduct coordinated ASW, contribute to the Common Undersea Picture, maintain and share situational awareness and tactical control in a coordinated ASW environment.
c. Maintain the surface picture while conducting ASW in a high-density shipping environment.
d. Perform acoustic range prediction and ASW search planning.
e. Achieve a mission kill of ASW threats through engagement with hard kill weapons from on-board and off-board systems.
f. Employ signature management and soft kill systems to counter and disrupt the threat's detect-to-engage sequence in the littoral environment.
g. Deploy, control, recover, and conduct day and night operations with towed and off-board systems, and process data from off-board systems
h. Employ, reconfigure, and support SH-60R in ASW operations
i. Conduct ASW Battle Damage Assessment after engagements against undersea threats.

3.2.1.2. Mine Warfare (MIW)

The SEA TENTACLE, via the UUV systems delivered, shall provide the capability to conduct precise navigation to avoid previously identified minefields, and enable the employment of off-board or onboard sensors to perform mine avoidance along the SEA TENTACLE' intended track. The SEA TENTACLE will conduct mine warfare missions along its intended track and in operational areas as assigned with the on-board and off-board systems from deep water through the beach. The SEA TENTACLE will also make use of MIW environmental models and databases. The SEA TENTACLE will:

a. Coordinate/support mission planning and execution with Joint and Combined assets. MIW mission planning will include the use of organic and remotely operated sensors. The SEA TENTACLE will exchange MIW tactical information including Mine Danger Areas (MDA), mine locations, mine types, environmental data, bottom maps, off-board system locations, planned search areas and confidence factors

b. Deploy, control, and recover off-board systems, and process data from off-board systems.
c. Detect, classify, and identify surface, moored and bottom mines to permit maneuver or use of selected sea areas.
d. Conduct mine reconnaissance.
e. Perform bottom mapping.
f. Perform minefield break through/punch through operations using off-board systems.
g. Perform minesweeping using integrated mission systems.
h. Conduct precise location and reporting of a full range of MCM contact data. For example: identified mines and non-mine bottom objects.
i. Perform mine neutralization.
j. Employ, reconfigure, and support SH-60R for MIW operations.
k. Embark an EOD detachment.

3.2.1.3 Maritime surveillance (MARSURV)

In all mission configurations the SEA TENTACLE shall have core systems that provide the capability to conduct multi-sensor search, detection, classification, localization and tracking of surface contacts in its assigned area of responsibility. The SEA TENTACLE will also have the core capability to protect itself against small boat attacks, including the use of speed and maneuverability, and have the core capability to conduct warning and disabling fire. The SEA TENTACLE will have the capability to engage surface threats, particularly small fast boats, to minimize threats to friendly units. The SEA TENTACLE will:

a. Conduct integrated surface surveillance using onboard sensors.
b. Discriminate and identify friendly and neutral surface vessels from surface threats in high-density shipping environments.
c. Conduct coordinated SUW mission planning, contribute to and receive the Common Tactical Picture, and initiate engagement of surface threats. Maintain and share situational awareness and tactical control

in a coordinated SUW environment. When operating in company with other SUW assets, such as fixed-wing/rotary-wing attack aircraft and maritime patrol aircraft, the SEA TENTACLE must be capable of planning and coordinating the SUW mission.

d. Engage surface threats independently, or in coordination with other friendly forces. This includes threats in the line-of-sight and over-the-horizon. In addition to hard kill capabilities, the SEA TENTACLE will use agility and speed, signature management and soft kill measures to disrupt the threat’s detect-to-engage sequence and conduct offensive operations against surface threats.
e. Deploy, control, and recover off-board systems, and process data from off-board systems.
f. Employ, reconfigure, and support SH-60R series helicopters and smaller rotary wing aircraft for SUW operations.
g. Conduct SUW Battle Damage Assessment after engagements against surface threats.

3.2.2 Inherent Capabilities

The following sections provide specific performance requirements for the SEA TENTACLE, when outfitted with core systems and the appropriate mission package.

a. Maintenance and Support of Autonomous Deployed System (ADS)
b. Intelligence, Surveillance and Reconnaissance (ISR)
c. Special Operations Forces (SOF) Support
d. Ship Self Defense (SUW/AAW)
e. Home Land Defense (HLD)
f. Anti-Terrorism/Force Protection
g. Joint Littoral Mobility

3.2.2.1 Maintenance and Support of Autonomous Deployed System (ADS)

The SEA TENTACLE will provide capability for maintenance and support of sensors, supplies and equipment within the littoral operation environment. The SEA TENTACLE will:

a. Delivery and Retrieval of unmanned vehicles (UUV, UAV, and USV)
b. Provide facilities for secure stowage of replacement sensors, maintenance materials and test equipment.
c. Provide habitability support for embarked personnel.

d. Replenishment and refueling at sea of SH-60R and unmanned vehicles.

3.2.2.2 Intelligence, Surveillance and Reconnaissance (ISR)
In all mission configurations the SEA TENTACLE shall provide functionality that provides persistent ISR capability consistent information operations (IO) within a net-centric environment. Distributed ISR coverage shall include the capability to conduct Information Operations (IO), Electronic Warfare (EW), Military Deception (MILDEC), Operational Security (OPSEC), Computer Network Defense/Attack (CND/CNA), and Psychological Operations (PSYOP) in surface, overland and electronic domains. SEA TENTACLE shall function as an afloat network operations center (NOC) facilitating data through-put. SEA TENTACLE will utilize C2 open architecture that provides automated data collection, storage, and processing capabilities to conduct ISR planning and coordination, to make near-real-time input to enhance decision making, and facilitate order generation, weapons direction and ship system monitoring and control. The Mission Package will enable SEA TENTACLE to:

a. Use organic and non-organic resources to conduct surveillance and reconnaissance operations with onboard and off board equipment.
b. Use organic, non-organic, and national resources to collect, process and disseminate strategic, operational and tactical information.
c. Use ISR planning, coordination and execution tools.

3.2.2.3 Special Operations Forces (SOF) Support
The speed, agility, and shallow draft of SEA TENTACLE will give it the inherent capability to provide rapid movement of SOF personnel and material. SEA TENTACLE will provide capability for transport of personnel, supplies and equipment within the littoral operational area. SEA TENTACLE will:

a. Provide facilities for secure stowage of SOF equipment.
b. Provide habitability support for SOF personnel.
c. Replenishment and refueling of SOF vehicles.
d. Employ, reconfigure, and support SH-60R and smaller rotary wing aircraft for special operations.

3.2.2.4 Ship’s Self Defense (SUW/AAW)

The SEA TENTACLE shall have the capability to conduct defensive SUW and AAW. SEA TENTACLE shall employ systems that provide point detection against air and surface threats to include air-surface missiles (ASM) and surface-surface missiles (SSM). The SEA TENTACLE will have the capability to:

a. Perform a detect-to-engage sequence for incoming air and surface threats.
b. Provide point defense against SSM, ASM and threat aircraft through the use of hard-kill and soft-kill systems, RF signature management, counter-targeting, speed, and maneuverability in the littoral environment. SEA TENTACLE will be Link 16 and CEC (receive only) capable. The capabilities provided by CIWS Mk 15 1B, RAM, and NULKA should be considered.
c. Have the capability to operate in clear and severe natural and electronic countermeasures environments inherent in littoral operating areas.
d. Have the capability to evaluate engagements against air targets.
e. Employ, reconfigure, and support SH-60R and unmanned assets for SUW and AAW missions.
f. Provide facilities for secure stowage of ordnance and handling equipment.
g. Provide habitability and staging areas for stinger detachments.

3.2.2.5 Home Land Defense (HLD)
The SEA TENTACLE will have the inherent core capability to support HLD by providing rapid movement of small groups of personnel and material due to the SEA TENTACLE's speed, agility, and shallow draft. In support of national security and HLD objectives, the ship will be capable of assisting and conducting missions in coordination with the U.S. Coast Guard (USCG). SEA TENTACLE will:

a. Perform maritime interception, interdiction and law enforcement operations.
b. Provide staging areas for boarding teams.
c. Conduct maritime Law Enforcement Operations (LEO) including counter-narcotic operations with embarked law enforcement detachment.
d. Provide emergency, humanitarian, and disaster assistance.

e. Support Joint Special Operations Force (JSOF) hostage rescue operations.
f. Conduct marine environmental protection.
g. Perform naval diplomatic presence operations.
h. Employ, reconfigure, and support SH-60R and smaller rotary wing aircraft for HLD, and AT/FP operations.

3.2.2.6 Anti-Terrorism/Force Protection

The SEA TENTACLE will have the inherent core capability to conduct AT/FP through its speed, agility, and shallow draft. The SEA TENTACLE will:

a. Perform maritime interception, interdiction and law enforcement operations.
b. Provide staging areas for boarding teams.
c. Conduct maritime Law Enforcement Operations (LEO) including counter-narcotic operations with embarked law enforcement detachment.
d. Provide AT/FP to U.S. and friendly forces against attack in port, at anchorage, and during period of restricted maneuvering. Defensive capability will incorporate both passive design and active weapon measures, including non-lethal mechanisms, that can deter, delay, and defend against attack by terrorist and unconventional threats.
e. Employ, reconfigure, and support SH-60R and smaller rotary wing aircraft HLD, and AT/FP operations.

3.2.2.7 Joint Littoral Mobility

The SEA TENTACLE's speed, agility and shallow draft will give it the inherent capability to provide rapid movement of small groups of personnel and material. The SEA TENTACLE will provide transport and limited lift capability to move personnel, supplies and equipment within the littoral operation environment. The SEA TENTACLE will:

a. Provide facilities for secure stowage of transported materials and equipment.
b. Provide habitability support for transported personnel.
c. Replenishment and refueling at sea of SH-60R sized and smaller non-organic helicopters and SOF craft/boats.

3.3 Ship Performance Requirements

The SEA TENTACLE will provide core capabilities in the following areas in support of its focused and inherent mission areas.

3.3.1 Hull Performance

The SEA TENTACLE will have hull structural strength and provisions for growth allowances and fatigue life in accordance with its expect service life. The ship will withstand extreme environmental conditions such as high sea state, wind and air/sea temperature. The ship will withstand impacts from tugs, piers, and other hazards typical to routine ship operations in navigable waters. Tankage volume shall reflect environmental as well as fluid management requirements. It will provide adequate static and dynamic stability to ensure safe and efficient ship operation and not degrade personnel performance.

3.3.2 Survivability

The SEA TENTACLE will incorporate a total ship approach to survivability that addresses susceptibility, vulnerability, and recoverability, with crew survival as the primary objective. The principal means to be employed will be to minimize susceptibility through speed, agility, signature management and the core-defense weapon suite. The SEA TENTACLE' capability to reduce vulnerability by absorbing a weapon impact and retain seaworthiness and weapons system capability will be commensurate with ship's size and hull displacement and will emphasize crew survival and automated damage control and firefighting applications. The SEA TENTACLE will meet the requirements for Level I in accordance with OPNAVINST 9070.1. In addition to Level I requirements, the SEA TENTACLE will have the capability to:

a. Automate damage control actions to the most practical extent to support optimum manning level requirements to include automatic detection, location, classification and management of fire, heat, toxic gases and flooding, structural damage and hull breaching throughout the ship using a ship's damage control management system.
b. Economically maximize personnel protection, prevention of ship loss, and retention of self-defense capability through the use of fragmentation protection.

c. Employ an appropriate level of collective protection against chemical, biological, and radiological threats.
d. Deploy life rafts and other survival equipment in both intact and damaged conditions. Equipment must support 120% of the ship's maximum manning capacity.
e. Incorporate signature management to deny and disrupt the enemy's detect-to-engage sequence to reduce the probability that the ship will be hit by a threat.
f. Monitor and control own ship's emissions (EMCON) and apply tactical signature control through rapid control of electronic, infrared, optical and acoustic signatures in anti-surveillance, anti-targeting, and self defense roles.
g. Monitor own ship magnetic and acoustic signature to maximize ship survivability when operating in the vicinity of a minefield.

3.3.3 Ship Mobility

The SEA TENTACLE will maneuver and maintain itself in all expected operational environments and situations with emphasis on the worldwide littoral operation environment. It will be self-deployable and operate with naval strike and expeditionary forces. The ship's draft will permit it to operate in the littoral. The SEA TENTACLE will:

a. Provide the speed and endurance to deploy and operate with other friendly forces.
b. Perform seamanship and navigation evolutions such as: formation steaming, precision navigation, precision anchoring, recover man overboard, handle small boats and off-board mission systems, launching and recovering small boats, maneuvering for torpedo evasion and for ASCM countermeasures employment.
c. Perform deck evolutions such as: underway vertical and connected replenishment, recover man overboard, launch/recover off-board sensors and vehicles, handle small boats, tow or be towed, and when necessary, abandon ship.
d. Provide a redundant and responsive ship control system that enable effective evasive maneuvering against torpedoes, ASCMs, mines and small boat attack.
e. Support and conduct Search and Rescue (SAR) operations.

3.3.4 Aviation Support

The SEA TENTACLE will conduct aviation operations with the following capabilities:

a. Handling of organic, day/night, all weather manned rotary-wing and unmanned aviation assets to support the principal mission areas of ASW, MIW and Maritime Surveillance and operations such as, but not limited to SOF, Search and Rescue (SAR), Combat Search and Rescue (CSAR), MIO, MEDEVAC, EW and logistics. Aviation operations will support the SH-60R family of aircraft to include flight deck certification.
b. Class II facilities of NAEC-ENG-7576 to include electricity (400Hz), fresh water and fuel (landing, fueling, hangar, reconfigure, and rearm) for the SH-60R family of aircraft, and to conduct joint and interagency rotary wing capability (such as USCG helicopters, AH-58D AHIP or similar type helicopters), and employ and embark VTUAVs. The material for repairs and organic maintenance to support these aircraft should come onboard in a modular fashion and be tailored in size, and the air detachment should be optimally manned. Material support for SH-60R limited embarks shall not include Phased Maintenance.
c. Control manned and unmanned aircraft, including the capability to provide safety-of-flight for the controlled aircraft.
d. Aviation fire fighting capability should be automated to the maximum extent practicable.

3.3.5 Off board Vehicle and Systems Support

The SEA TENTACLE will:

a. Have the capability to support day and night operations with available air, surface and subsurface unmanned vehicle operations. These capabilities will include control, data-link, day/night launch and recover, refuel, hangar, maintain, and rearm. The SEA TENTACLE operations will support mission packages containing VTUAVs, USVs and UUVs.
b. Be capable of rapidly reconfiguring Unmanned Vehicles and their mission payloads, while the ship is underway. The ship must be capable of launch, recovery and control of multiple unmanned vehicles,

and should use common launch/recovery and control systems to the maximum extent practicable.

c. The SEA TENTACLE must be capable of employing manned and unmanned systems such a as RMS, LMRS, 11m RHIB, SPARTAN, AH-58D, SH-60RR/S and Fire Scout VTUAV, in support of meeting the focused mission requirements.

3.3.6 Command, Control, Computing and Communications (C4) Systems

SEA TENTACLE shall employ a distributed C4 open architecture that will support mission and ship tactical and non-tactical operations, including the capability to fully integrate into the Global Information Grid (GIG) under the FORCEnet concept. The C4 system shall conform to level three IAW the Navy's Open Architecture Computing Environment (OACE) guidelines and standards, will be interoperable with embarked Mission Packages and joint forces, and integrate all sensors, communications systems, and weapons systems in a single netted system. The SEA TENTACLE will:

a. Provide a total ship command control capability that provides automation of command and control functions, ship situational awareness, and decision-making.

b. Provide for the capability to simultaneously coordinate and control multiple manned and unmanned systems in support of SEA TENTACLE missions.

c. Fuse organic data and non-organic data to maintain integrated tactical picture.

d. Provide for onboard processing and data storage capabilities to accommodate handling and use of data generated by off board sensors.

e. Implement a Total Ship Computing Environment (TSCE), which includes processor, networks, storage devices and human system interfaces in support of core and modular mission capabilities that conforms to the Navy's Open Architecture (OA) Program guidelines and standards.

f. Provide multiple levels of security as required by mission systems.

g. Provide external communications capability to control and operate with embarked and off-board systems, communicate with theater sensor assets, operate with joint, allied, coalition and interagency forces, and use reach-back assets. The ship will have secure, reliable, automated, wide bandwidth, high date rate communications with ship based and shore based warfare component commanders.

h. Be interoperable with standard Navy and Joint data networks including CEC, Joint Planning Network, Joint Data Network, Global Command and Control System – Maritime (GCCS-M), SIPRNET, NIPRNET and Global Information Grid.

3.3.7 Manning/Habitability, Human Systems Integration (HSI), Safety and Training

The SEA TENTACLE will:

a. Provide sufficient berthing for ships company and any deploying forces.
b. Use a human centered design approach to automate decision processes and optimize manning. Exploit Smartship technologies wherever possible.
c. Maintain the health and welfare of the crew and deploying forces.
d. Provide ship upkeep and maintenance.
e. Provide physical security.
f. Ensure safety of equipment, personnel and ordnance.
g. Provide on demand training both in port and underway.

3.3.8 Readiness

The SEA TENTACLE will:

a. Meet the established Navy readiness criteria for shipboard system performance, unit level training, and equipment reliability that support the principle mission areas for every class.
b. Provide operational availability in accordance with the critical design parameters in section 3.1.

3.3.9 Logistics

The SEA TENTACLE program will:

a. Include shore based training, maintenance, supply and administrative functions.
b. Include life cycle support and modernization plan for the ship systems and functions minimizing the impact of technological obsolescence over the life of the ship.
c. Provide the capability to rearm, refuel, and replenish at sea.

d. Provide the capability to conduct vertical replenishment and personnel transfer operations at sea.
e. Provide a logistics support structure to support all ship missions and support the efficient management of life cycle costs.
f. Accommodate reach-back facilities and distant support to maximum extent possible.

3.3.10 Pollution Control and Environmental Constraints
The SEA TENTACLE will operate throughout its life cycle within established guidelines for pollution control including the minimization of discharges and emissions.

3.4 Operational Conditions of Readiness Requirements
The operational environment for the vessel is:

a. Capable of performing all defensive and assigned offensive combat functions
while in Readiness Condition I.
b. Capable of performing all defensive functions while in Readiness Condition II.
c. Continuous Readiness Condition III at sea.

3.4.1 Weather Environment

a. Limiting environmental conditions requirements applicable to the range of wind, temperature, and sea conditions in which the ship is to operate are as follows:

Condition	Requirements
Sea State 5	Full capability for all systems
Sea State 6	Continuous efficient operation (Note 1)
Topside ice loading of 0.4 kN/m^2	Full capability for all ship systems
Sea State 8 and above	Best heading survival without serious damage to mission essential subsystems
Air temperature -29° C to 50° C with a sustained wind velocity of 40 knots and wind loads of 1.5 kN/m^2	Full system capability for all equipment and machinery installed in exposed locations
Sea water temperature -2° C to 38° C	Full capability for all ship systems
Air temperature -40° C to 52° C at prime mover intake inlet	Full capability for power plant
Sand and dust concentrations up to 0.177 g/m^3, particles up to 150 µm	Full capability for all systems and manned spaces for temps above between 21° C and 52° C and relative humidity below 30%
Relative humidity 0 to 100%	Full capability for all systems

Note 1: Assumes selection of the most benign course and speed under the conditions stated. The SEA TENTACLE should be capable of withstanding intermittent wind velocities up to 100 knots without sustaining serious damage to mission essential equipment.

b. The SEA TENTACLE's system functional performance, by warfare area and combinations of warfare areas, shall be categorized under combinations of four separate reference environments. Conditions for these four environments are summarized as follows:

Good Environment	Typical Environment	Poor Environment	Arctic Environment
Clear Sea State 0-4 No ECM	Light Rain Sea State 3-5 Light to Moderate ECM	Moderate Rain Sea State 6 Heavy ECM	Light Snow Sea State 3-5 MIZ (50%), Light Topside Icing, Moderate ECM
Wind Light (Friendly EM Light)	Wind 20 knots (Friendly EM Moderate)	Wind 30 knots (Friendly EM Heavy)	Wind 50 knots (Friendly EM Moderate)

3.5 Regulatory and Statutory Requirements

The SEA TENTACLE will comply with applicable laws of the United States and other applicable requirements and standards of the following Regulatory Bodies and Agencies:

a. International Regulations for Preventing Collision at Sea, 1972 (72 COLREGS) and subsequent instructions and modifications.
b. Suez Canal Regulations.
c. Panama Canal Regulations, 35 CFR.
d. International Convention for Safety of Life at Sea (SOLAS).
e. Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat; OPNAVINST 5100.19D
f. U.S. Department of Health, Education, and Welfare, Public Health Service (USPHS) Publication No. 393; Handbook on Sanitation of Vessel Construction.
g. Postal Regulations.
h. Privacy Act.
i. Navy Regulations.
j. Classification by National or International regulatory body for Naval use.

k. International Convention for the Prevention of Pollution from Ships (MARPOL).

4.0 AFFORDABILITY

Affordability is a critical concern for any ship. The SEA TENTACLE is perceived to be relatively small, inexpensive to build, and have capacity to carry out the focused missions while also having the flexibility to support other missions through the modularity inherent in its cargo-carrying capacity. This will allow the SEA TENTACLE to be procured in numbers required in the Global CONOPS. A variety of deployment concepts and optimal mission manning requirements should be considered during the design and development phase to reduce life cycle costs. Life cycle cost must be addressed and considered in particular ship lifetimes.

APPENDIX V: SLED DESIGN

A. INTRODUCTION

Resources required for the 10nm x 10nm Harbor Gate Scenario represent the structural building blocks for the TSSE architecture. In compliance with SEA-8 requirements and its references including the updated UUV Master Plan, the TSSE alternative includes a functional hierarchy of three UUV types and a specially designed connector sled that is carried by the large UUV. This Appendix will give the important details of the sled design.

1. Sled Functions and Description

The primary purposes of the connector sled are to serve as a centralized hub for sensor communication within a 10x10 nm grid and to carry the sensors that ultimately make up the grid. The sled, seen in Figure V-1, has two cylindrical arms that house eight UUVs and the required cables. On top of one arm lies an acoustic modem that is capable of short range communication with the Sea Predator or other large UUV. A detachable radio frequency (RF) sensor bouy is mated to the top of the other arm. The RF bouy can be released and sent to the surface to transmit contact information back to the Sea TENTACLE or other communication node in the event that no assets are within acoustic modem range. Finally, the two arms are connected via a rectangular body that has six connector ports for 12.75” diameter UUVs. The 12.75” UUVs provide battery and sensor processing power to the sled.

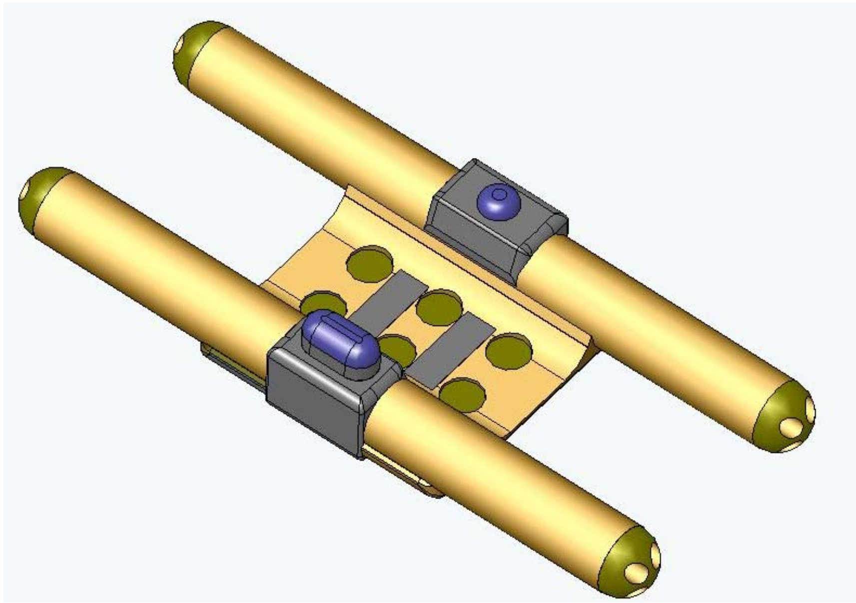


Figure V-1: Connector Sled

2. Sled Dimensions

The sled body is roughly 4.5′ wide, and is flared at the ends to match the contour of the Sea Predator body, as seen in Figure V-2. The body is 7′ long, which provides ample maneuvering room for the 12.75″ UUVs while docking. Docked 12.75″ diameter UUVs are shown in Figure V-3. The arms measure 21″ in diameter and are 20′ in length. The eight 6″ diameter UUVs are configured in a ring of four at each end of the arm, with their cables carried inside the arm body center. The 6″ UUVs are 42″ in length, and carry a spherical acoustic listening element that is 4″ in diameter (the size of a standard softball). The UUVs deploy from both ends of the arm as depicted in Figure V-4. The sled has a maximum loaded weight of 4,000 lbs, which represents the external payload capacity of the Sea Predator. The sled retains negative buoyancy with all sensors deployed, and remains in one location on the sea bottom.

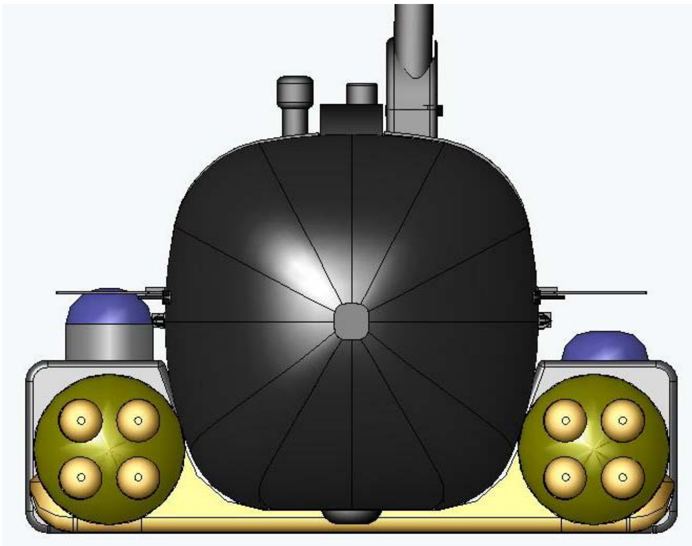


Figure V-2: Mounted Connector Sled

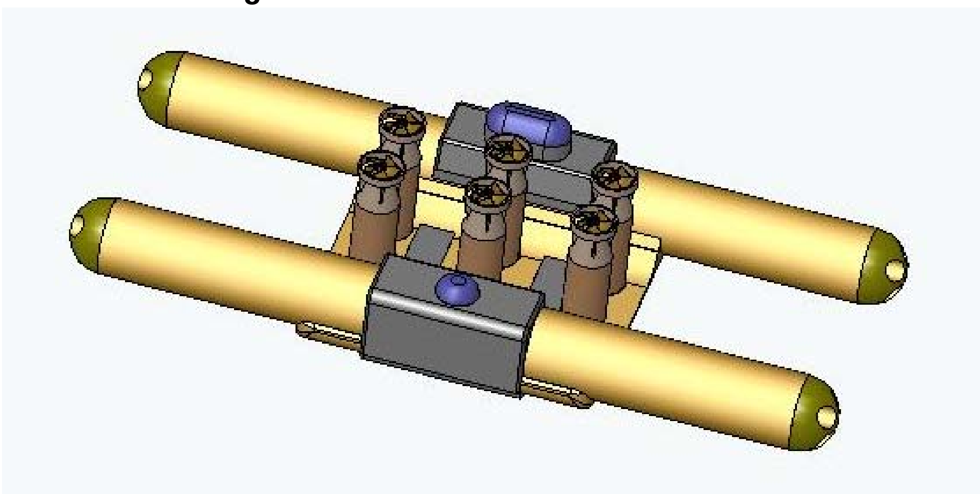


Figure V-3: 12.75″ UUVs Docked with Sled

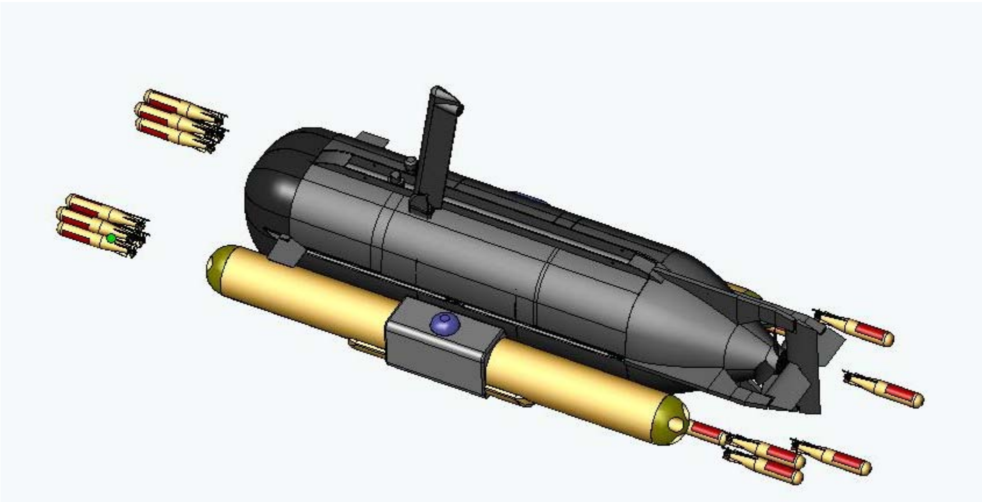


Figure V-4: 6″ UUV Deployment

3. Sled Payload Volume Calculations

The volume of the arms, 6″ UUVs, and cables were calculated using the standard formula for volume of a cylinder: $V_{cyl} = \pi r2h$, where r is the radius and h is the height. Each arm has an internal volume of 48.11 ft^3. Each 6″ diameter x 42″ long UUVs have an external volume of 0.687 ft^3. Per Figure V-5, sixty miles of cable are required to achieve adequate sensor spacing. The selected cable is 1/8″ in diameter which requires 27 ft^3 of space. Table V-1 lists the results of the sled payload volume.

Volume 21" diameter by 20' shell (ft^3):	Total Volume of Sled (ft^3)
48.11	96.21

"Ranger" UUV Volume Calculations			
Radius (in)	Length (in)	Volume (in^3)	Volume (ft^3)
3	42	1187.522	0.687

Spherical Array Element Volume Calculations		
Radius (in)	Volume (in^3)	Volume (ft^3)
1.91	21.89	0.013

Cable Volume Calculations				
Miles Required	Cable Diameter (in)	Cable Radius (in)	Volume (in^3)	Volume (ft^3)
60	0.125	0.063	46652.651	27.00
60	0.15625	0.078	72894.767	42.18
60	0.1875	0.094	104968.465	60.75
60	0.25	0.125	186610.604	107.99

Loaded Volume of One 21" Diameter Shell				
Available Interior Volume (ft^3)	Volume of 8 Ranger UUVs (ft^3)	1/8 " diam. Cable Volume (ft^3)	Spare Interior Volume (ft^3)	Unused Volume (%)
48.11	5.50	26.998	15.61	32.45

Table V-1: Internal Volume Calculations

As can be seen in Table V-1, the sled can carry eight 6″ diameter UUVs and sixty nautical miles of 1/8″ diameter cable, with over 32% reserve capacity. This allows room for less than 100% perfectly wound cable, or for additional motors and spools to help the 6″ UUVs pay out the cable. If additional room is required, or if a larger cable size is desired, the arms can be extended in height or length.

The sled overall width is fixed due to handling and storage limitations of the Sea TENTACLE.

An alternate approach to cable deployment, while not investigated in this study, would be to extend the length of the 6” UUVs to have the wires contained inside. Then, as the UUVs swim out, their payload decreases as they deploy the cable.

APPENDIX VI: SEA PREDATOR DATA

The data presented in this appendix were provided to the design team by NAVSEA/NSWC/PC and were utilized in the payload and ship design calculations.

Sea Predator Performance **Given**

Calculated

Clean Hull

speed (kt)	current (A)
1.15	1
1.85	3.28
3.11	7.6
4.21	12.75
5.72	24.41
6.86	39.37
7.98	61.94
9.93	122.75

Propulsion Battery

Voltage (V)	150
Capacity (Ahr)	360
Energy (Whr)	54000

Electronics Battery

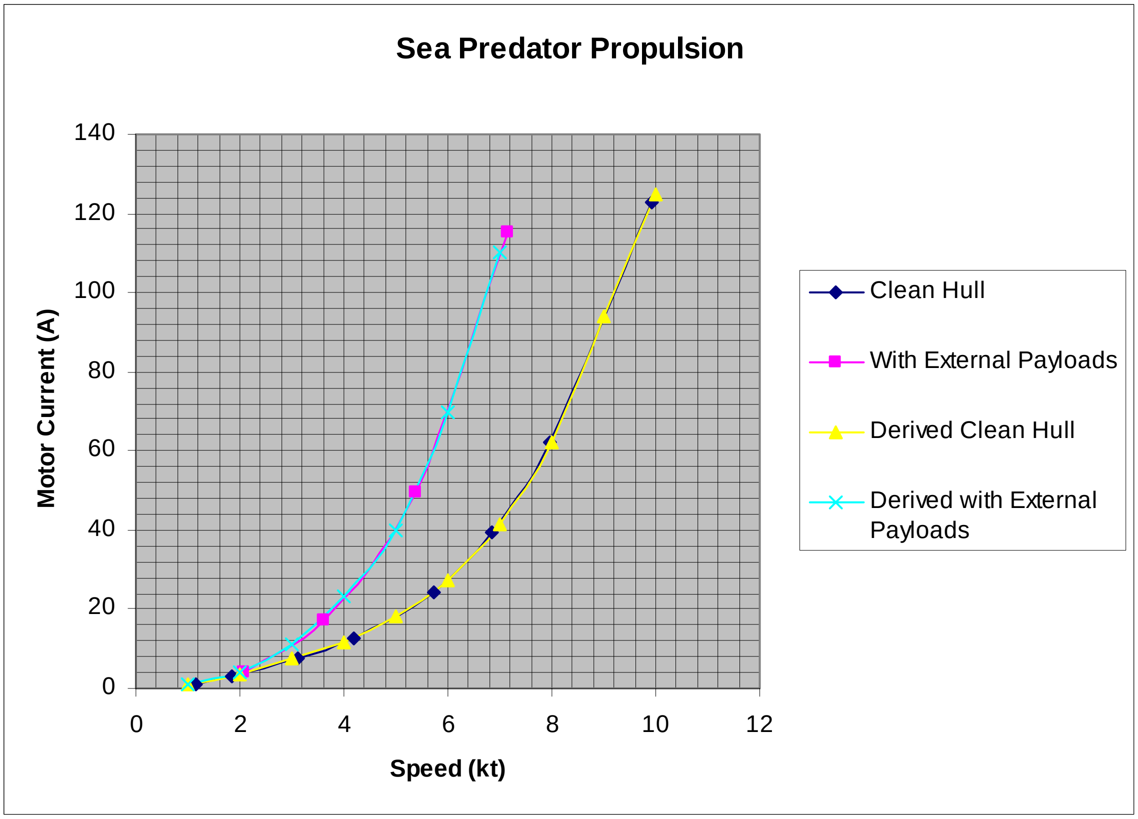
Voltage (V)	30
Capacity (Ahr)	360
Energy (Whr)	10800

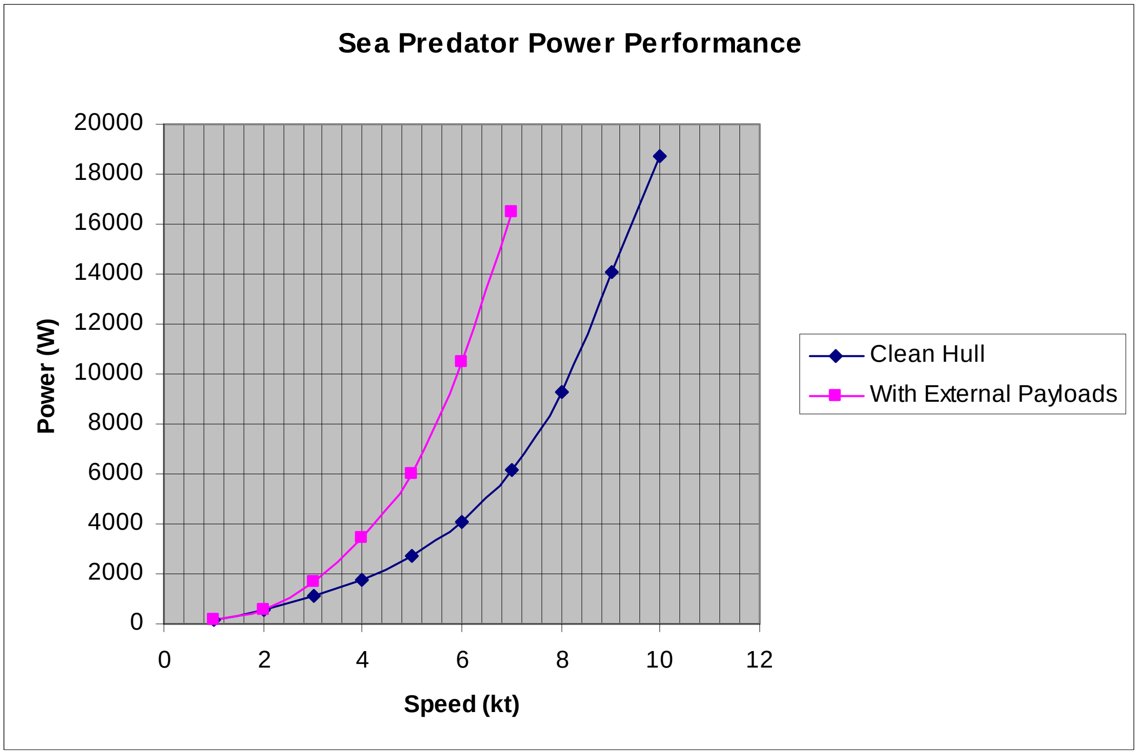
With External Payload

speed (kt)	current (A)
2.06	3.9
3.6	17.29
5.39	49.43
7.14	115.16

Derived from above data:

Speed (kt)	Clean current (A)	Externals current (A)	Clean Power (W)	Externals Power (W)
1	0.9	1	135	150
2	3.6	4	540	600
3	7.4	11	1110	1650
4	11.5	23	1725	3450
5	18.3	40	2745	6000
6	27.2	70	4080	10500
7	41.3	110	6195	16500
8	62		9300	
9	94		14100	
10	125		18750	

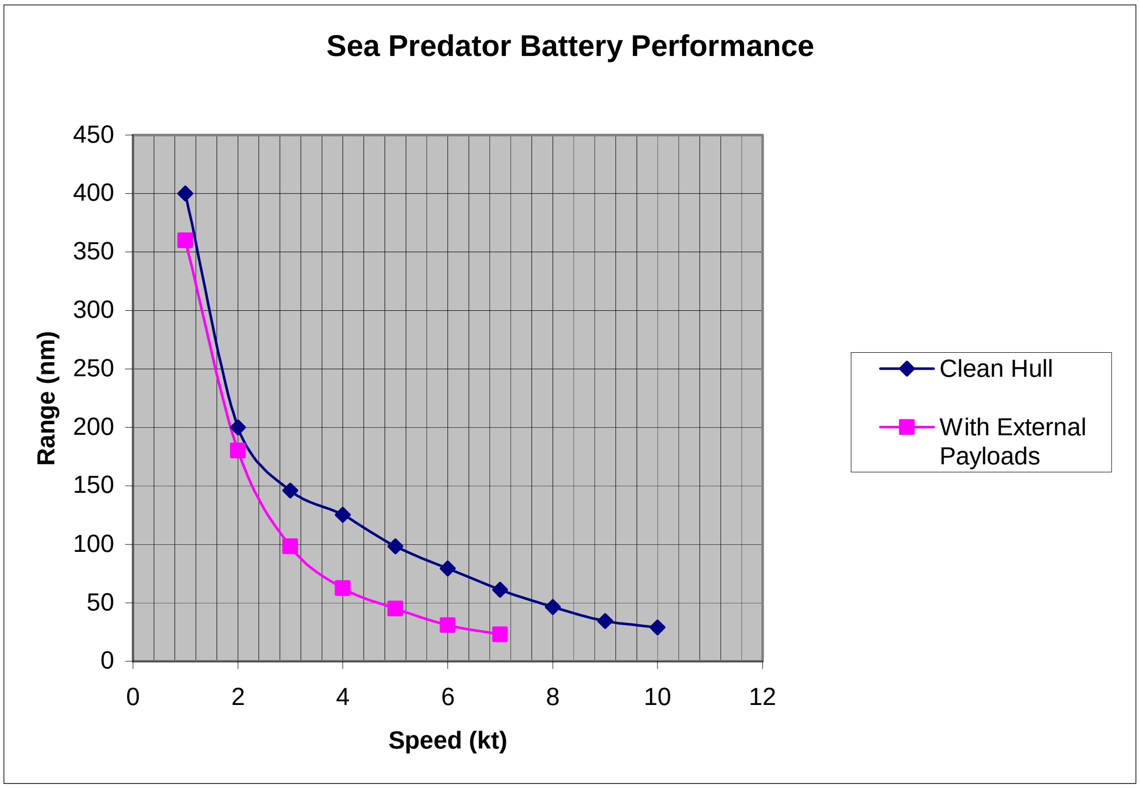




COURTESY NAVSEA PANAMA CITY

Propulsion Battery Performance

	Clean Hull		With External Payloads	
Speed (kt)	Time at Speed (hr)	Distance (nm)	Time at Speed (hr)	Distance (nm)
1	400	400	360	360
2	100	200	90	180
3	48.64864865	145.9459459	32.72727273	98.18181818
4	31.30434783	125.2173913	15.65217391	62.60869565
5	19.67213115	98.36065574	9	45
6	13.23529412	79.41176471	5.142857143	30.85714286
7	8.716707022	61.01694915	3.272727273	22.90909091
8	5.806451613	46.4516129		
9	3.829787234	34.46808511		
10	2.88	28.8		



COURTESY NAVSEA PANAMA CITY

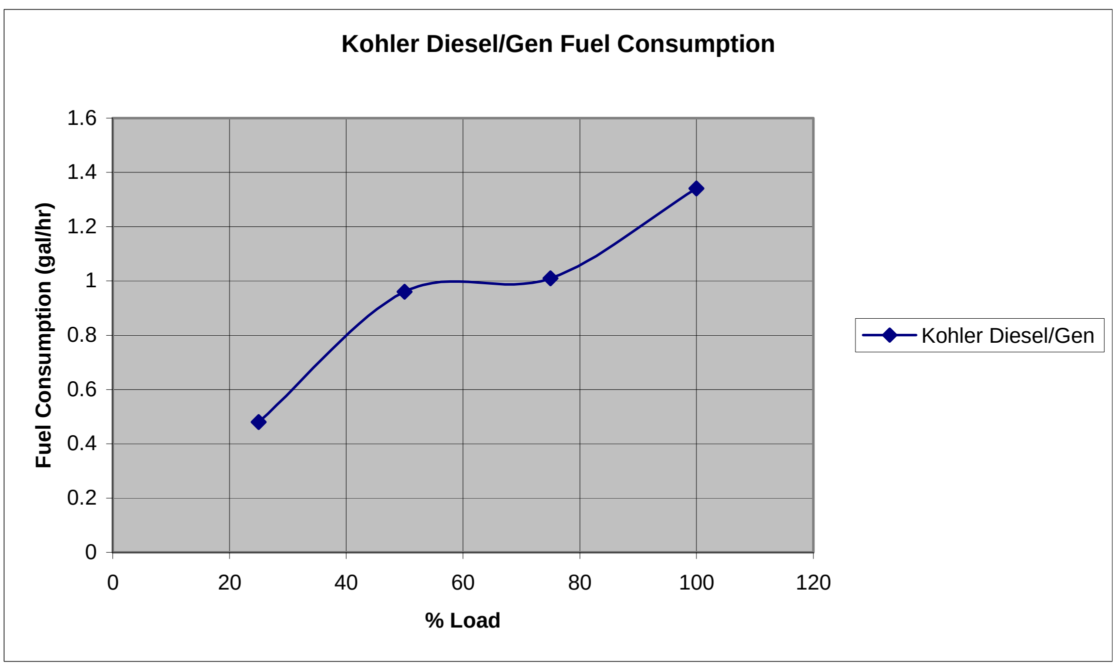
Diesel/Generator Performance			**Power Supply**	Available Energy
%load	**gal/hr**	**Power Output (W)**	**Output (W)**	from 60 gal. (Whr)
25	0.48	3500	2800	350000
50	0.96	7000	5600	350000
75	1.01	10500	8400	499009.901
100	1.34	14000	11200	501492.5373

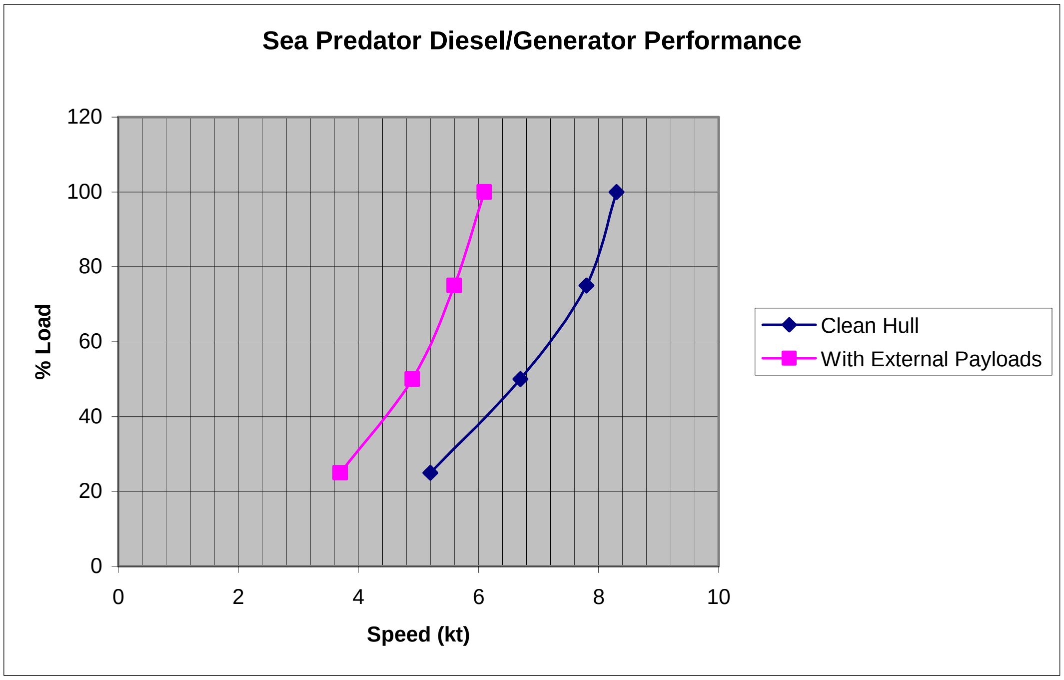
Power Supply Efficiency 0.8

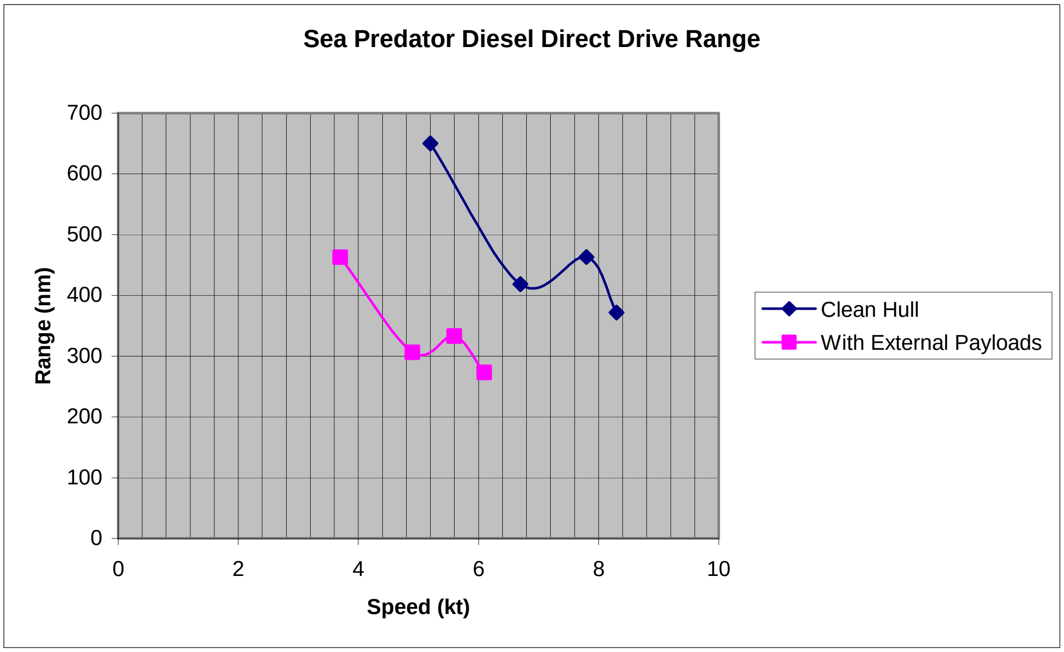
Diesel/Generator run time (hr)

20.83333	41.66667	62.5	83.33333333	104.1667	125
10.41667	20.83333	31.25	41.66666667	52.08333	62.5
9.90099	19.80198	29.7029703	39.6039604	49.50495	59.40594059
7.462687	14.92537	22.3880597	29.85074627	37.31343	44.7761194
10	20	30	40	50	60
gal.	gal.	gal.	gal.	gal.	gal.

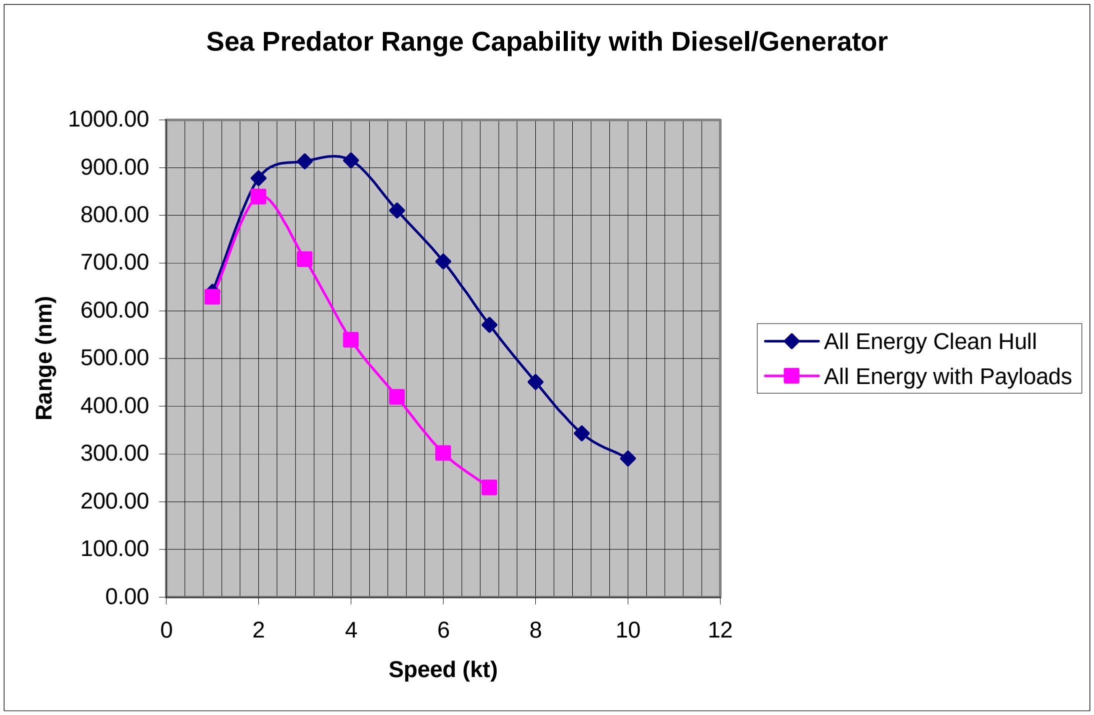
Output at Electronics Bat. Voltage (A)	Output at Propulsion Bat. Voltage (A)	SP Clean Hull Speed (kt)	SP With Ext Speed (kt)	SP Clean Hull Range (nm)	SP With Ext Range (nm)
93.333333	18.66667	5.2	3.7	650	462.5
186.66667	37.33333	6.7	4.9	418.75	306.25
280	56	7.8	5.6	463.36634	332.67327
373.33333	74.66667	8.3	6.1	371.64179	273.13433
(Power supply 75A max.)		Derived from speed/current curve		For 60 gal. of fuel	







COURTESY NAVSEA PANAMA CITY



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current (A)	Electronics Power Requirement (W)	
5	150	
10	300	
15	450	
20	600	
25	750	Nominal Hotel
30	900	
35	1050	
40	1200	
45	1350	
50	1500	

Total Battery Capacity (Electronics and Propulsion)
64800 Whr

Number of recharges available from Diesel at 100% load
7.739082366

Total Energy Available
566292.5373 Whr

All cases for 25A Electronics load, continuous

Ingr/Egr Time (hrs) at	for	Clean Hull Energy Required (Whr)	Externals Energy Required (Whr)	Available Energy Clean (Whr)	Available Energy Externals (Whr)	Clean hull Stationary Available time (hr)	Externals Stationary Available time (hr)	Search at (kts)	Clean hull Range (nm)	Externals Range (nm)
3 kts										
	1	1860	2400	564432.54	563893	752.5767164	751.8567164	2	875.0892051	835.3963516
								3	910.3750602	704.8656716
								4	912.2142017	537.0405117
								5	807.4857472	417.6981758
	2	3720	4800	562572.54	561493	750.0967164	748.6567164	2		
								3		
								4		
								5		
	5	9300	12000	556992.54	554293	742.6567164	739.0567164	2		
								3		
								4		
								5		
	10	18600	24000	547692.54	542293	730.2567164	723.0567164	2		
								3		
								4		
								5		
	15	27900	36000	538392.54	530293	717.8567164	707.0567164	2		
								3		
								4		
								5		
4 kts										
	1	2475	4200	563817.54	562093	751.7567164	749.4567164	2	874.1357168	832.7296849
								3	909.3831247	702.6156716
								4	911.2202623	535.326226
								5	806.6059189	416.3648425
	2	4950	8400	561342.54	557893	748.4567164	743.8567164	2		
								3		
								4		
								5		
	5	12375	21000	553917.54	545293	738.5567164	727.0567164	2		
								3		
								4		
								5		
	10	24750	42000	541542.54	524293	722.0567164	699.0567164	2		
								3		
								4		
								5		
	15	37125	63000	529167.54	503293	705.5567164	671.0567164	2		
								3		
								4		
								5		
5 kts										
	1	3495	6750	562797.54	559543	750.3967164	746.0567164	2		

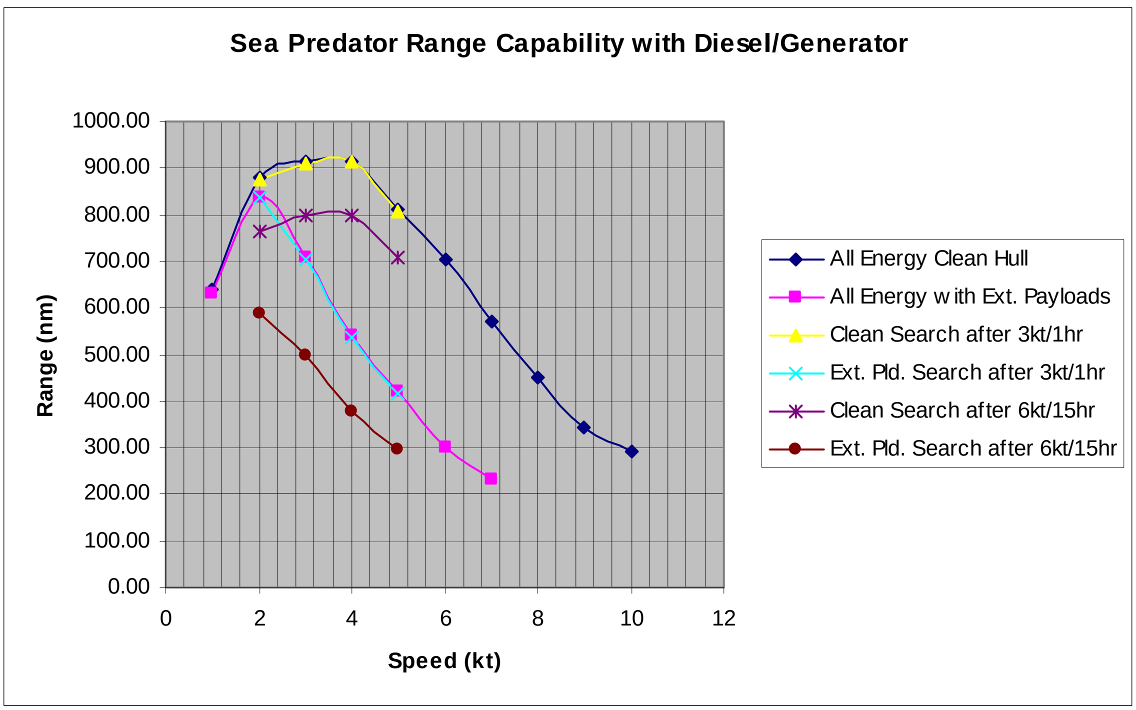
COURTESY NAVSEA PANAMA CITY

								3		
								4		
								5		
4 kts	15	37125	63000	529168	503292.5	705.556716	671.056716	2		
								3		
								4		
								5		
5 kts										
	1	3495	6750	562797.54	559542.537	750.3967164	746.0567164	2		
								3		
								4		
								5		
	2	6990	13500	559302.54	552792.537	745.7367164	737.0567164	2		
								3		
								4		
								5		
	5	17475	33750	548817.54	532542.537	731.7567164	710.0567164	2	850.8799	788.9519071
								3		
								4		
								5		
	10	34950	67500	531342.54	498792.537	708.4567164	665.0567164	2		
								3		
								4		
								5		
	15	52425	101250	513867.54	465042.537	685.1567164	620.0567164	2	796.69386	688.9519071
								3		
								4		
								5		
6 kts										
	1	4830	11250	561462.54	555042.537	748.6167164	740.0567164	2		
								3		
								4		
								5		
	2	9660	22500	556632.54	543792.537	742.1767164	725.0567164	2		
								3		
								4		
								5		
	5	24150	56250	542142.54	510042.537	722.8567164	680.0567164	2		
								3		
								4		
								5		
	10	48300	112500	517992.54	453792.537	690.6567164	605.0567164	2		
								3		
								4		
								5		
	15	72450	168750	493842.54	397542.537	658.4567164	530.0567164	2	765.64734	588.9519071
								3	796.52022	496.9281716
								4	798.12935	378.6119403
								5	706.49862	294.4759536
	30	144900	337500	421392.54	228792.537	561.8567164	305.0567164	2	653.32176	338.9519071
								3	679.66538	285.9906716
								4	681.03844	217.8976546

Energy Performance for Diesel/Generator at 100% load
Full Propulsion and Electronics Batteries at start
750W Hotel load
All Available Energy 566292.54 Whr

Power Requirement for Payload
0 Watts

Speed (kt)	Clean Time (hr)	Externals Time (hr)	Clean Time (day)	Externals Time (day)	Clean Range (nm	Externals Range (nm)
0	3775.283582		157.3035			
1	639.88	629.21	26.66161	26.21725	639.88	629.21
2	438.99	419.48	18.2911	17.47816	877.97	838.95
3	304.46	235.96	12.68576	9.831468	913.38	707.87
4	228.81	134.83	9.533544	5.617982	915.22	539.33
5	162.03	83.90	6.751222	3.495633	810.15	419.48
6	117.24	50.34	4.885201	2.09738	703.47	302.02
7	81.54	32.83	3.397483	1.367856	570.78	229.80
8	56.35		2.347813		450.78	
9	38.13		1.588924		343.21	
10	29.04		1.210027		290.41	



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APPENDIX VII: SEA TENTACLE THREAT SUMMARY

(U) The Sea TENTACLE System Threat Assessment Report (STAR) has not been prepared. If the ship becomes an official program of record, then a STAR will be produced that will serve as the threat reference for studies to determine future modifications and upgrades to the Sea TENTACLE and for use in program documentation. It will also provide basic threat documentation for Commander, Operational Test and Evaluation Force, to test and evaluate the overall Sea TENTACLE program. The Defense Intelligence Agency will validate this STAR for use in analyses supporting Defense Acquisition Board milestone decisions for Sea TENTACLE and program activities. While no specific Sea TENTACLE STAR exists, it is safe to assume that the threats encountered by this ship class will be similar to those of other surface ship programs of record. Specifically:

A. (U) The primary threats to Sea TENTACLE 0 will come from aircraft, surface ships, submarines and coastal defense units. The primary weapon threats will be anti-ship cruise missiles and naval mines. Secondary but significant threats will also come from submarine-launched torpedoes, tactical air-to-surface missiles, other air delivered conventional ordnance, chemical, biological and nuclear ordnance and, potentially, directed-energy weapons.

B. (U) While operating in littoral regions, additional threats from coastal artillery, multiple rocket launchers, small boats and torpedoes from coastal defense sites may be encountered. Tertiary threats include preemptive attacks or covert action from special operations forces, combat divers and terrorists. Potential foreign weapons threats may be supported by command, control and communications, surveillance / reconnaissance and countermeasures systems. As with weapons systems, the capabilities of these systems will be country specific and widely disparate.

C. (U) The STAR will examine at the SECRET / NOFORN level, specifically for Sea TENTALCE, the Operational Threat Environment, Threats To Be Countered, System Specific Threat, the Reactive Threat, the Technologically Feasible Threat and Critical Intelligence Categories.

APPENDIX VIII: SEAKEEPING STUDIES

Introduction

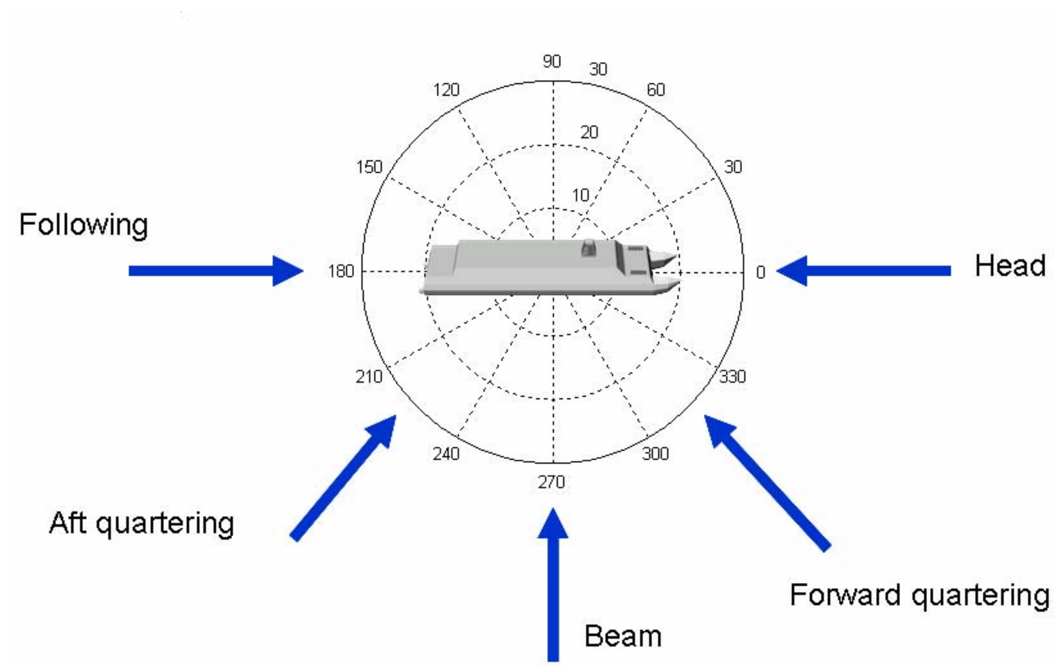
The purpose of the seakeeping studies performed for the SEA TENTACLE and presented in this appendix was to provide direct input to design decisions especially with regards to side and stern door placement for vehicle operations (launch and recovery) and handling. The general procedure that was followed and is outlined in this section is as follows:

1. Calculate the ship added-mass, damping coefficients, as well as the hydrodynamic exciting forces using two dimensional strip theory calculations.
2. Evaluate the ship response in regular seas for a variety of ship speeds and headings.
3. Within linear theory, evaluate ship response in random seas using regular wave results.
4. Set limiting values of the response and calculate the operating envelope.
5. Adjust design parameters in order to achieve an acceptable operating envelope.

This process is explained in the following subsections.

Formulation

The first step was to generate the two dimensional (sectional) added-mass, damping, and exciting force coefficients for the ship to use. This was accomplished with a standard ship motions prediction code. Two-dimensional calculations in regular waves were done for ship headings from zero to 180 degrees in increments of 15 degrees, as shown in the attached figure. Ship speeds were varied from zero to 6 knots in increments of 1 knot, and from zero to 30 knots in increments of 5 knots. This generated a set of regular wave results for both low and all speed operations and round the clock ship headings.



Regular wave results generated a set of transfer functions (response amplitude operators) for the ship's responses. Using standard convolution integrals and assuming long-crested fully developed seas of the Pierson-Moscowitz formulation, we calculated the spectrum of various responses for the ship. Integrating of the response spectra over the entire frequency range gave us values for several statistical response events. The following events were chosen for the analysis, along with their assumed limiting values:

1. Ship roll – limiting value of 5 degrees of significant single amplitude.
2. Ship pitch – limiting value of 3 degrees of significant single amplitude.
3. Absolute vertical velocity at the ramp – limiting value of 2 m/sec of significant single amplitude. This depends on the (x,y) location of the ramp.
4. Expected number of wetness events at the ramp – limiting value of 30 events per hour.

The significant single amplitude is defined as the average of the one-third of the highest number of events in the random process. A wetness event is defined when the relative vertical position between a point on the ship and the wave hits zero. This depends not only on the (x,y) location of the point, but it also very heavily dependent on the z-location of the point above the water. All of the above limiting values were based on standard design limits placed on helicopter operations. The team felt that this is the closest analogy to vehicle launch and recovery operations. Also we recognize that additional seakeeping events, such as bow slamming could limit the operating envelope of the ship, but these events were not considered here due to time limits.

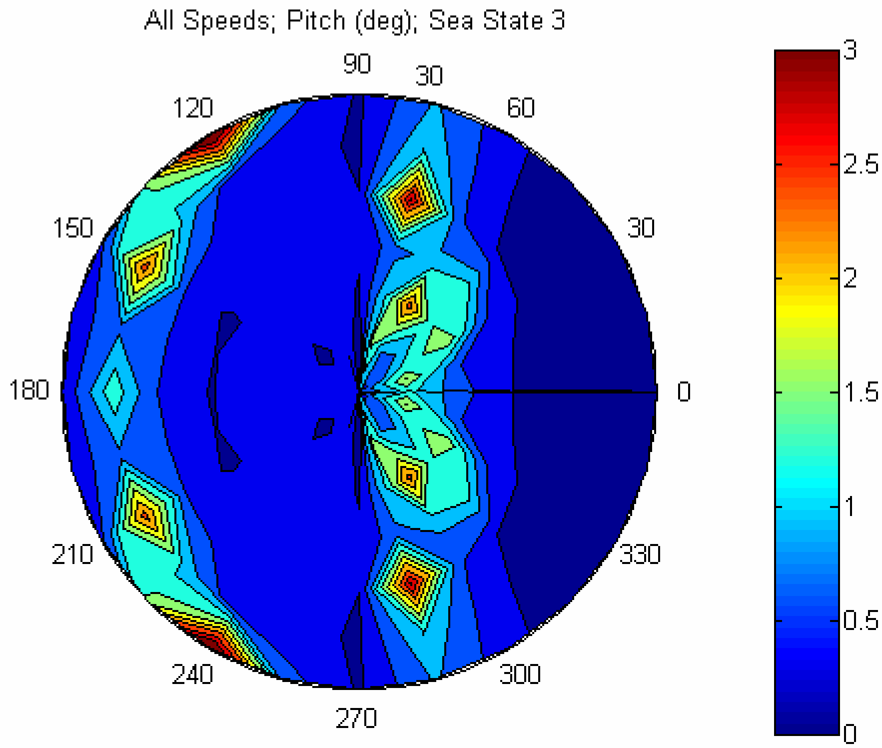
Results

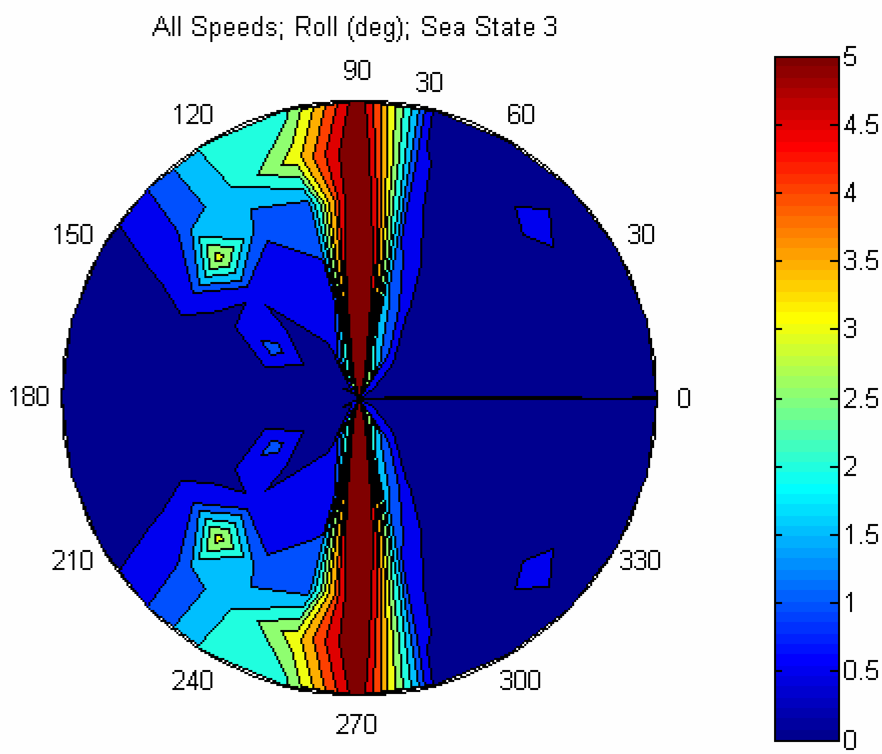
Our results are shown in groups as follows:

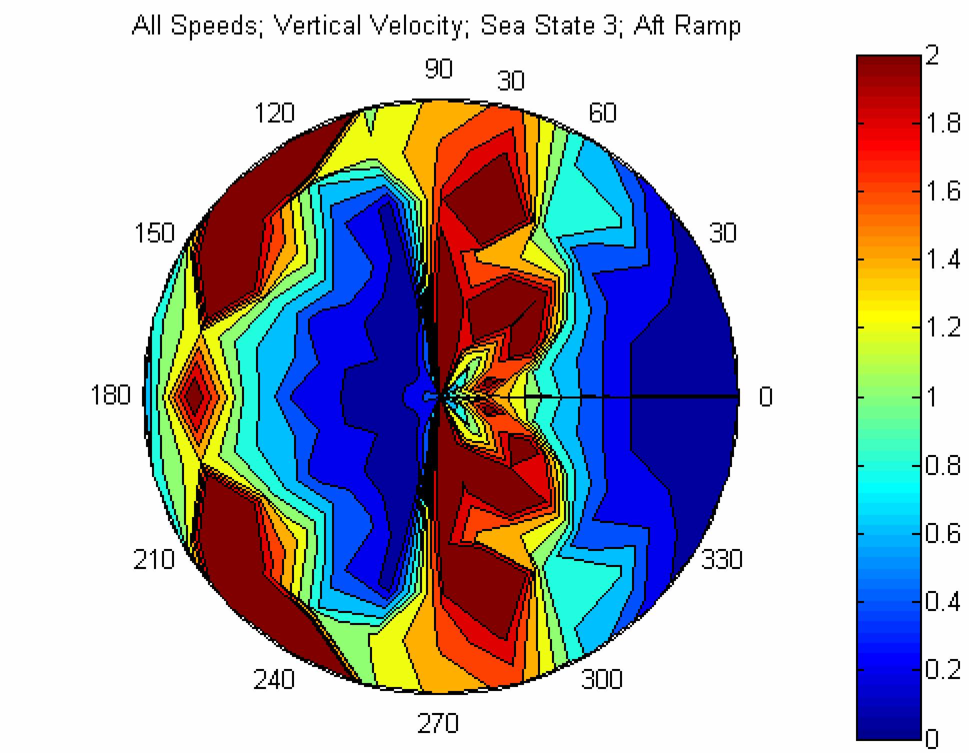
1. First, we present a sample of random wave results for a few typical ship responses.
2. A more complete set of graphs is then shown for the operability envelope of the ship in various conditions. This set is a combination of the previous results.
3. Finally, the operability index is calculated based on the operability envelope results and we use it to justify our design decisions.

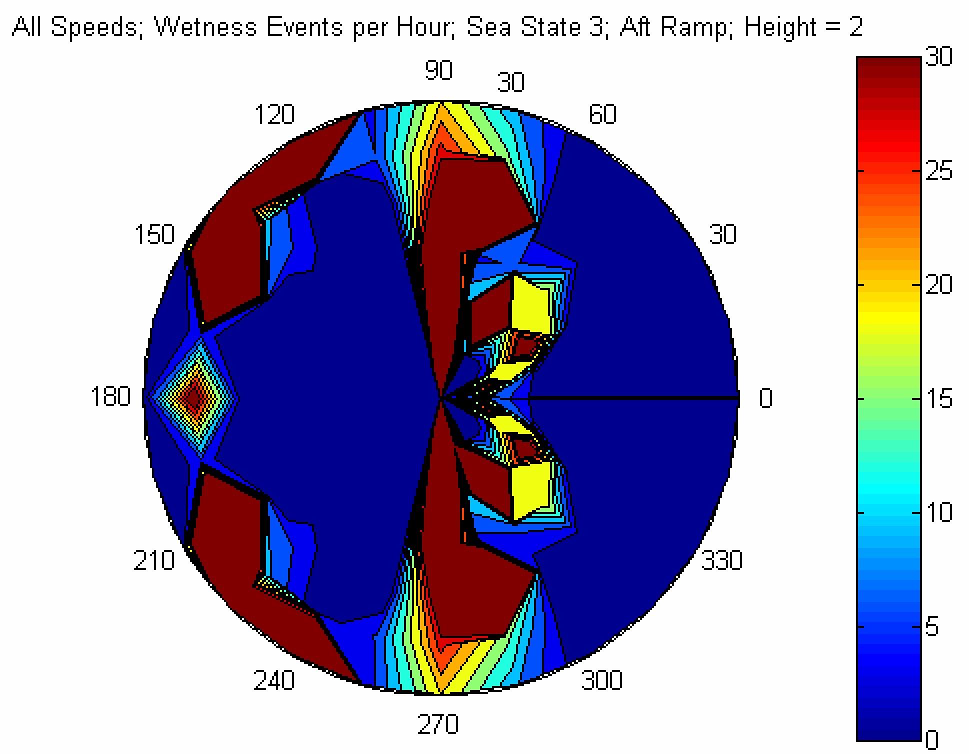
Random Wave Results

Typical results in random waves are presented in the following figures. For brevity we only show results for sea state 3 and for the significant values for pitch, roll, absolute vertical velocity at the aft ramp, and wetness events per hour also at the aft ramp. As can be seen, pitch is highest for aft quartering seas, while roll, as expected, achieves its highest values for beam seas. The absolute vertical velocity at the aft ramp is a combination of the various response characteristics of the ship and it appears that beam and aft quartering seas have the greatest effect. Also, beam and aft quartering seas produce the highest numbers of the expected wetness events per hour. These results are for an assumed aft ramp height at 2 meters from the calm waterline. As expected, the results are very sensitive to this height, and this is shown in the operating envelope graphs that follow next.


All Speeds; Pitch (deg); Sea State 3
90
30
60
120
150
30
180
0
210
330
240
300
270
3
2.5
2
1.5
1
0.5
0


All Speeds; Roll (deg); Sea State 3
90
30
60
120
150
30
180
0
210
330
240
300
270
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0


All Speeds; Vertical Velocity; Sea State 3; Aft Ramp
90
30
120
60
150
30
180
0
210
330
240
300
270
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

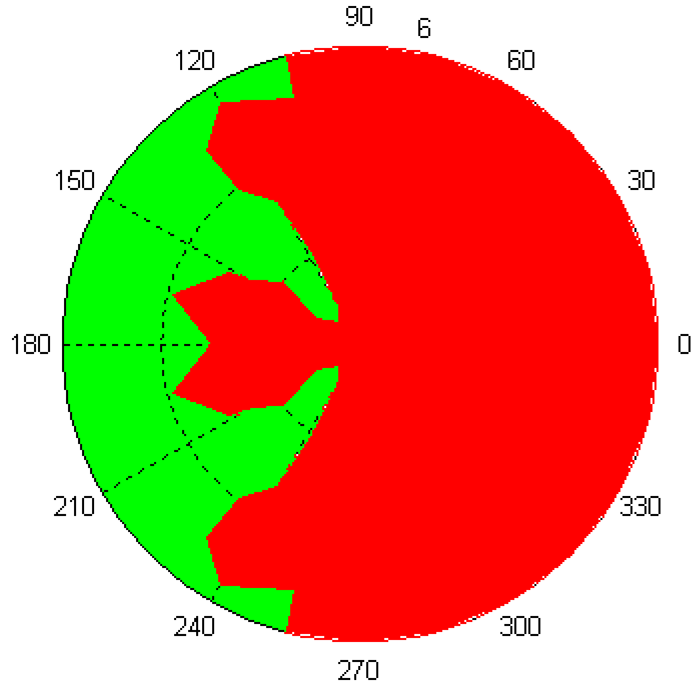

All Speeds; Wetness Events per Hour; Sea State 3; Aft Ramp; Height = 2
90
30
120
60
150
30
180
0
210
330
240
300
270
30
25
20
15
10
5
0

Operating Envelopes

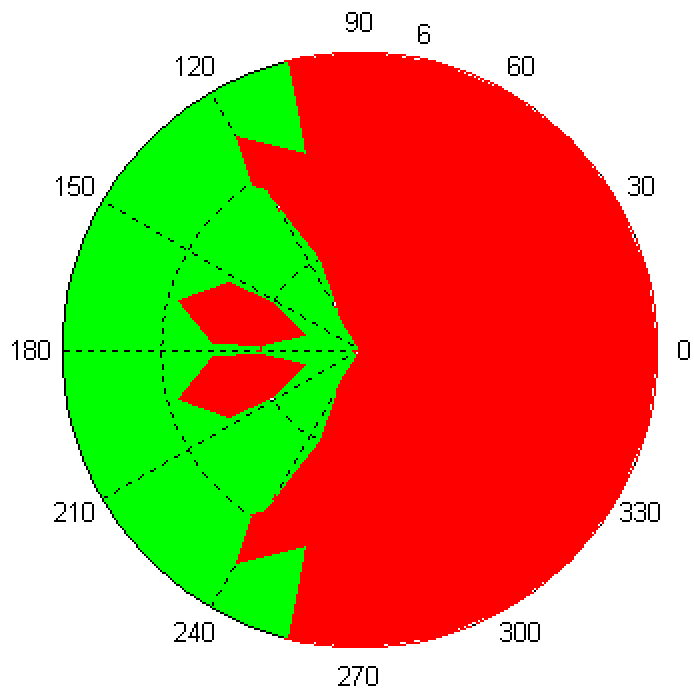
The following set of figures show the operating envelope progression for the side door in sea state three as the door height is varied from 1 to 2 meters above the calm waterline. These results were obtained for the low speed operations of the ship, zero to six knots. Red areas represent regions where at least one of the previous limiting criteria is violated while green areas represent safe operating regions according to the stated criteria. It can be seen that the operating area seems to level off for a side door height of approximately 2 meters. This seems to be acceptable even for higher sea states, as the results indicate, although as expected the operability area is smaller.

The results for the aft ramp and side door in sea states 3 and 4 are also shown in the attached figures. These results cover the entire speed range from zero to 30 knots. It can be seen that in all cases the seakeeping response of the ship allows for an acceptable operability region for ramp/door placement about 2 meters above the calm waterline.

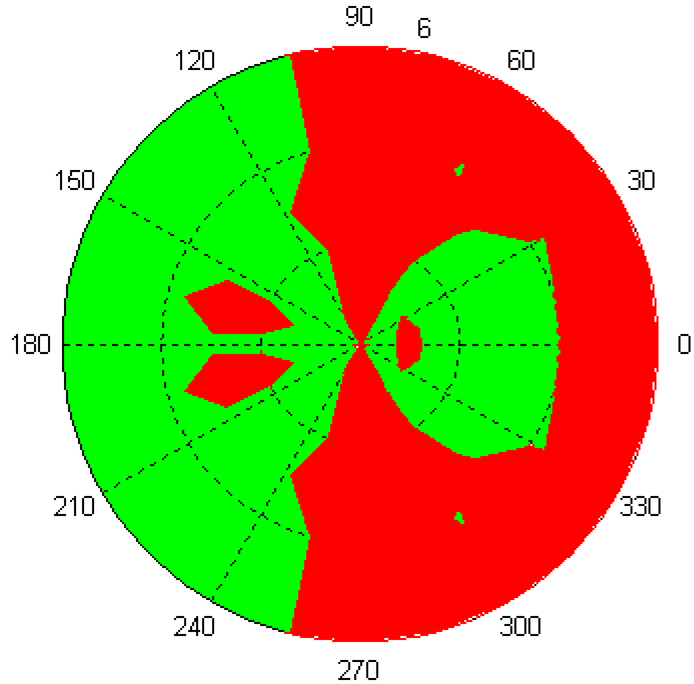
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1



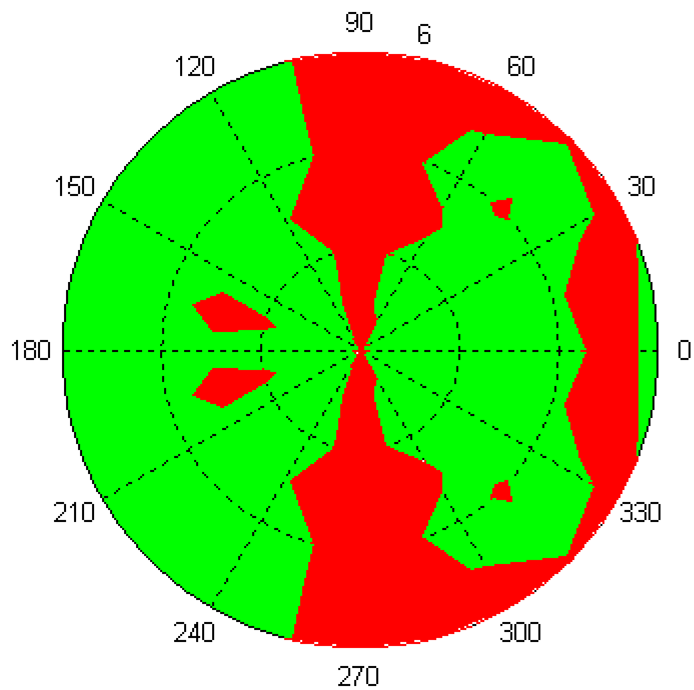
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.1



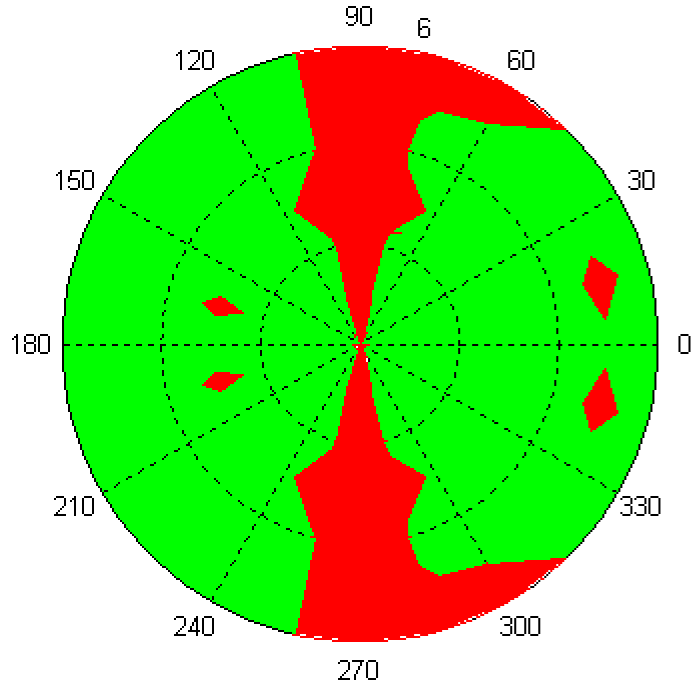
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.2



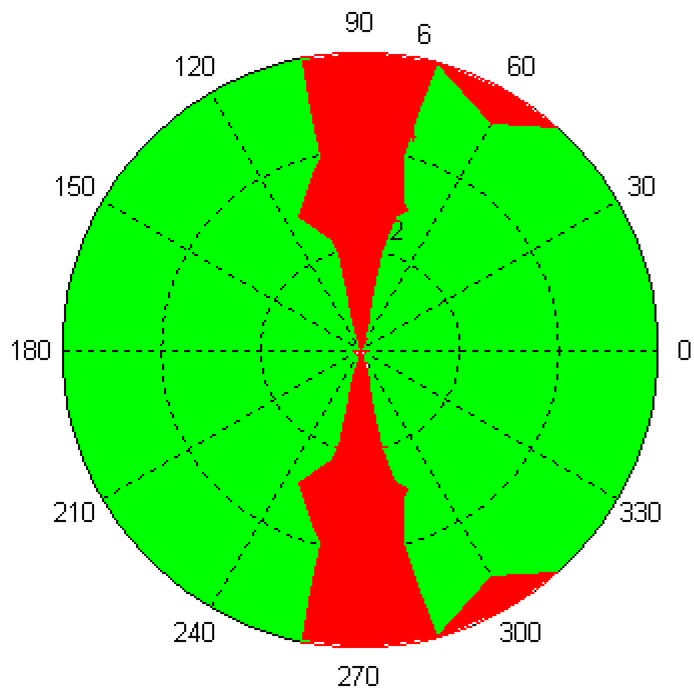
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.3

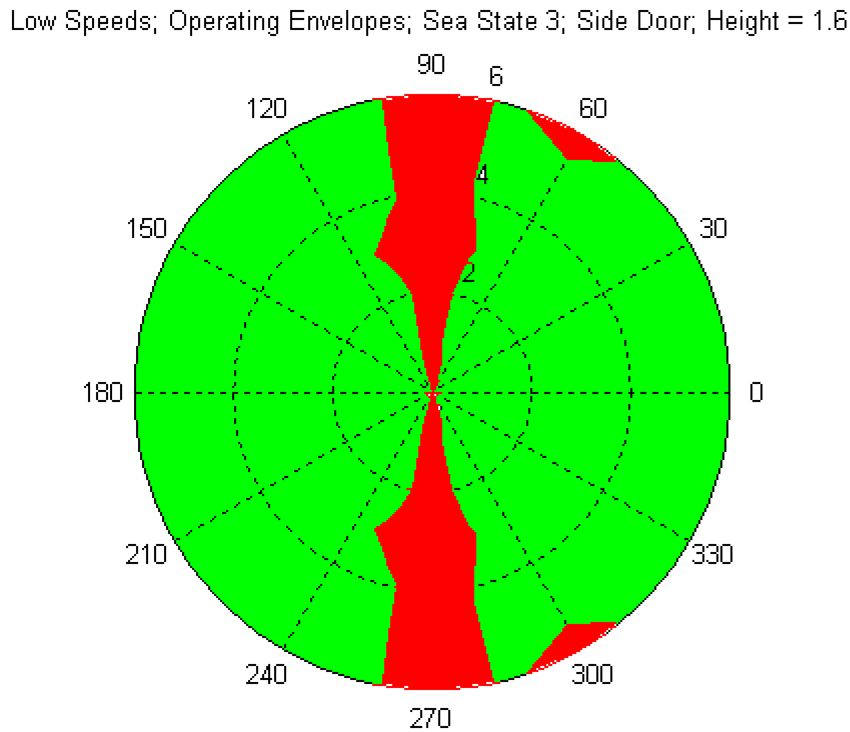


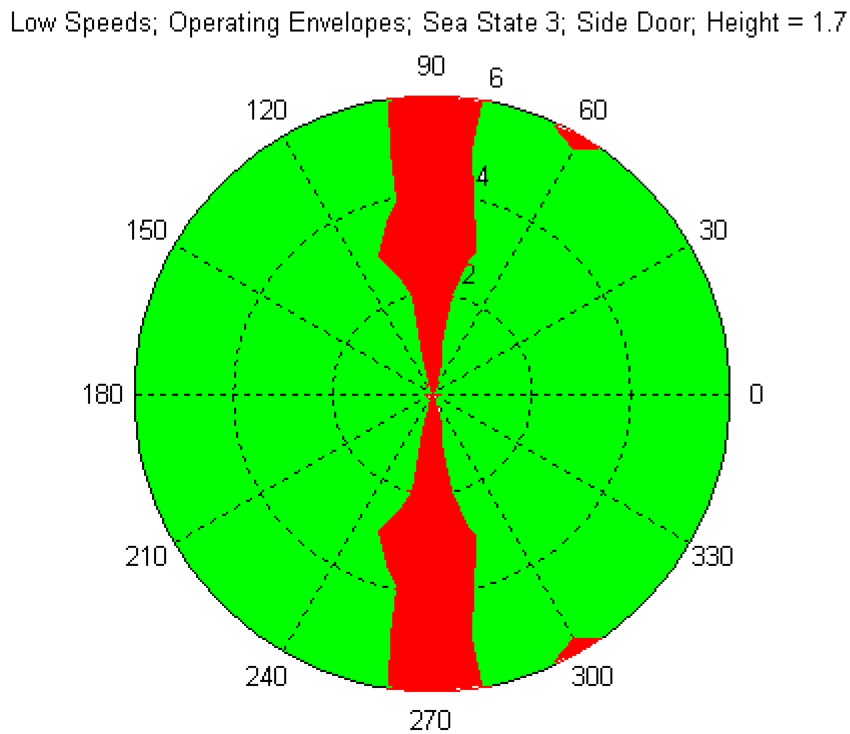
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.4



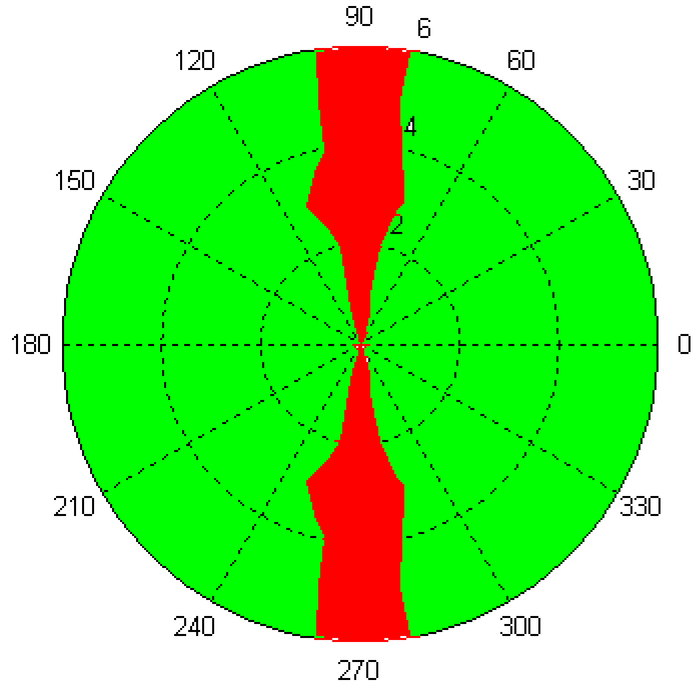
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.5



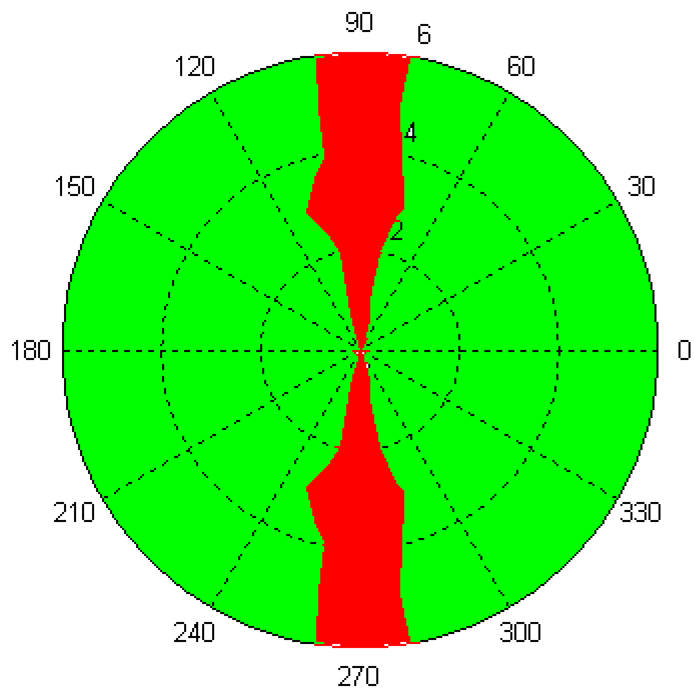

Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.6
90
6
60
120
4
150
30
2
180
0
210
330
240
300
270


Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.7
90
6
60
120
4
150
30
2
180
0
210
330
240
300
270

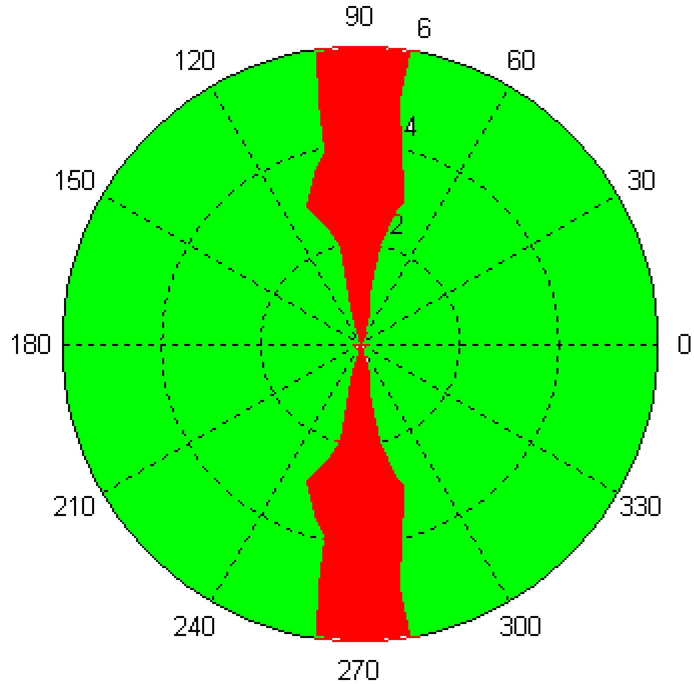
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.8



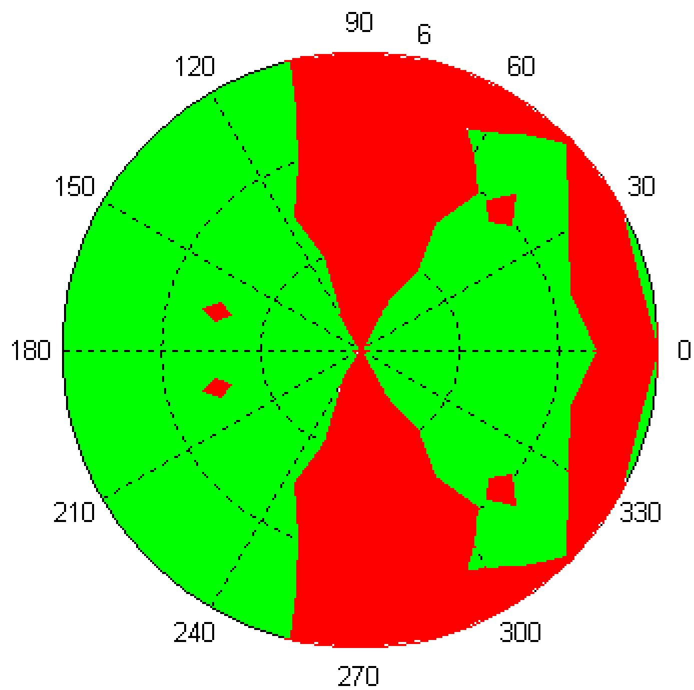
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.9



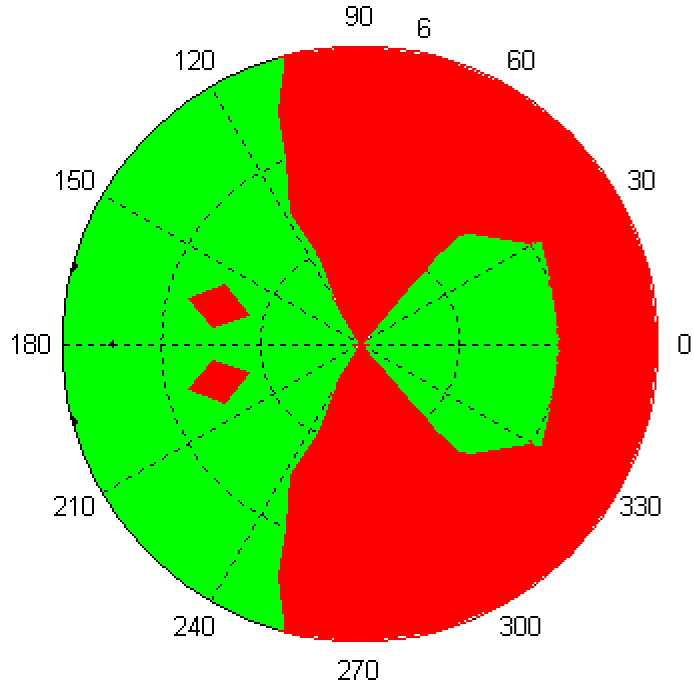
Low Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 2



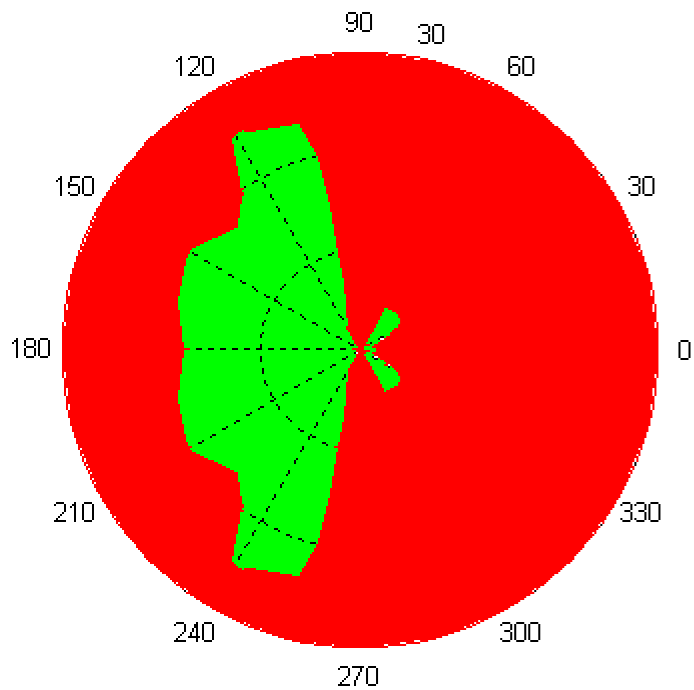
Low Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 2



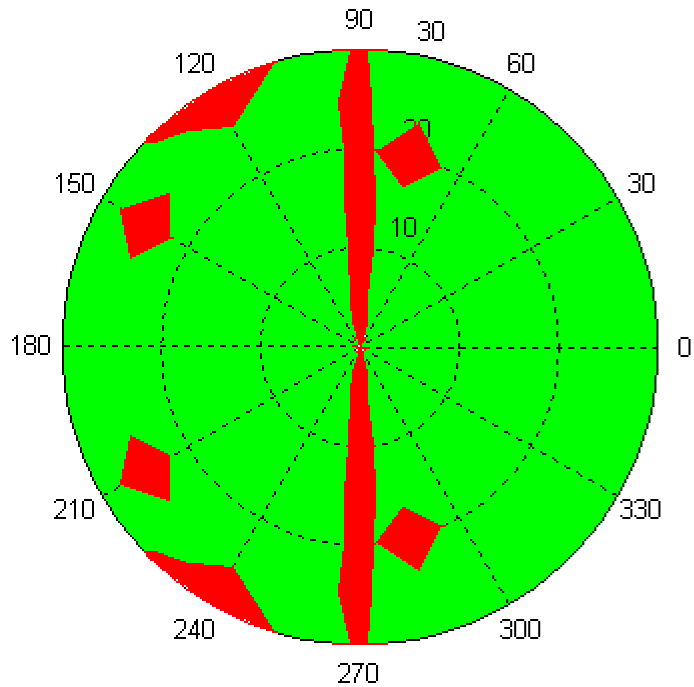
Low Speeds; Operating Envelopes; Sea State 5; Side Door; Height = 2



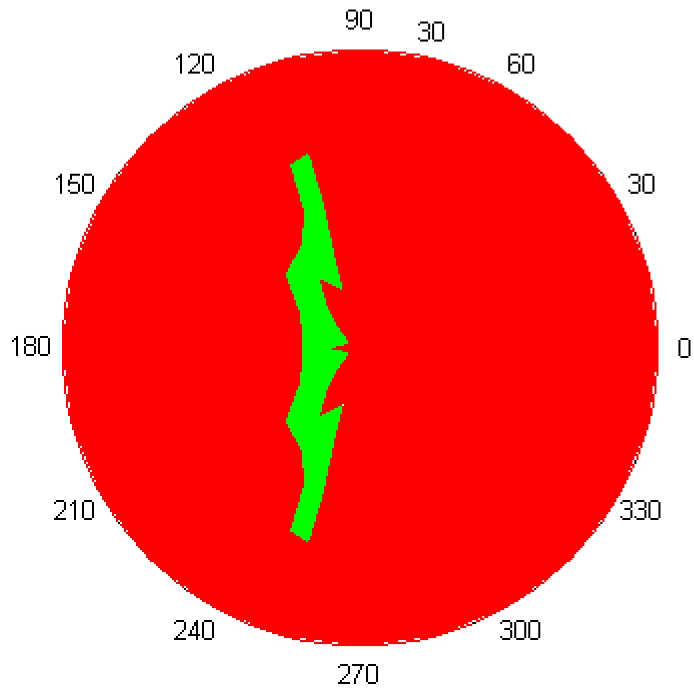
All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.9



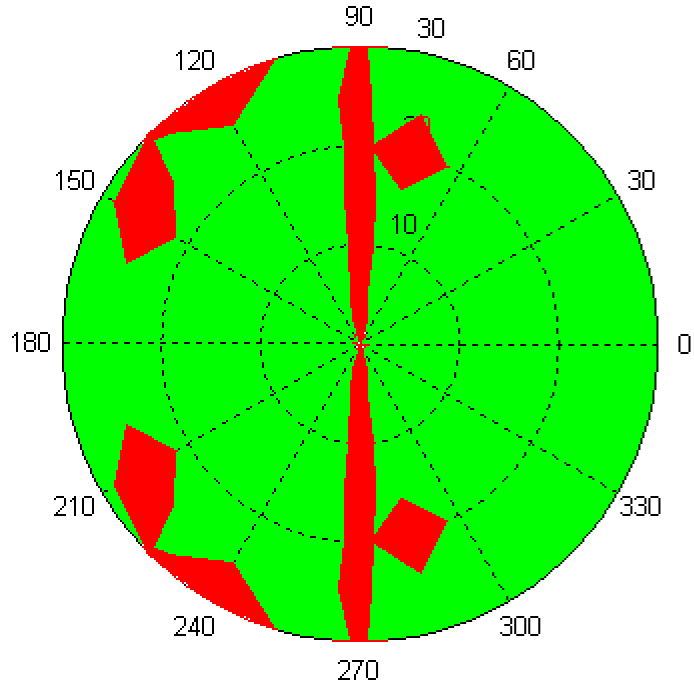
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 2



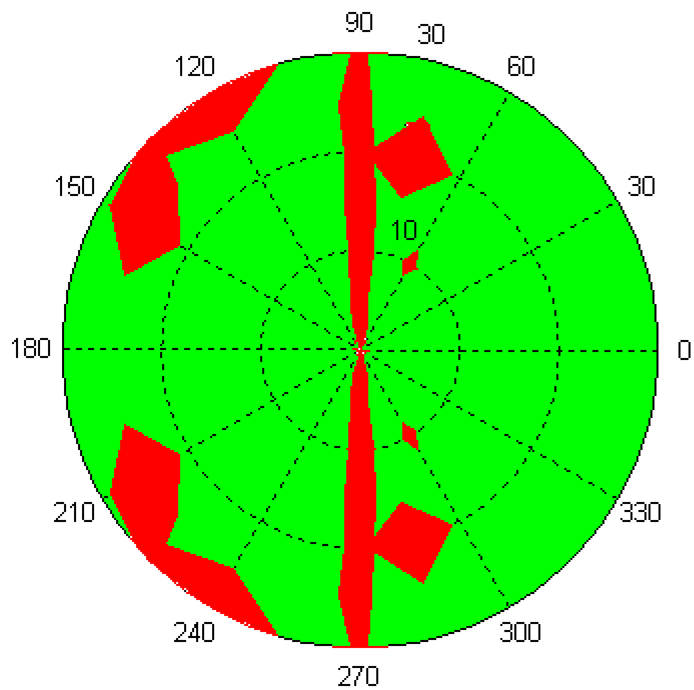
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1



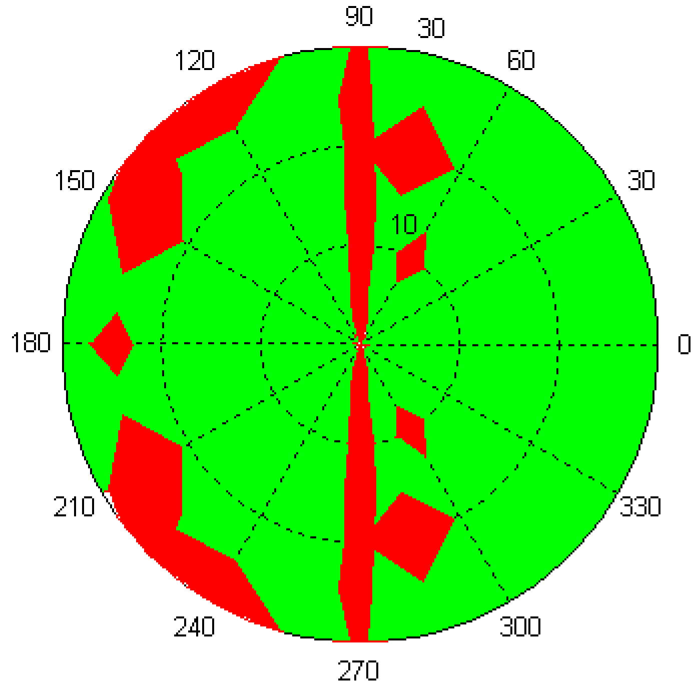
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.9



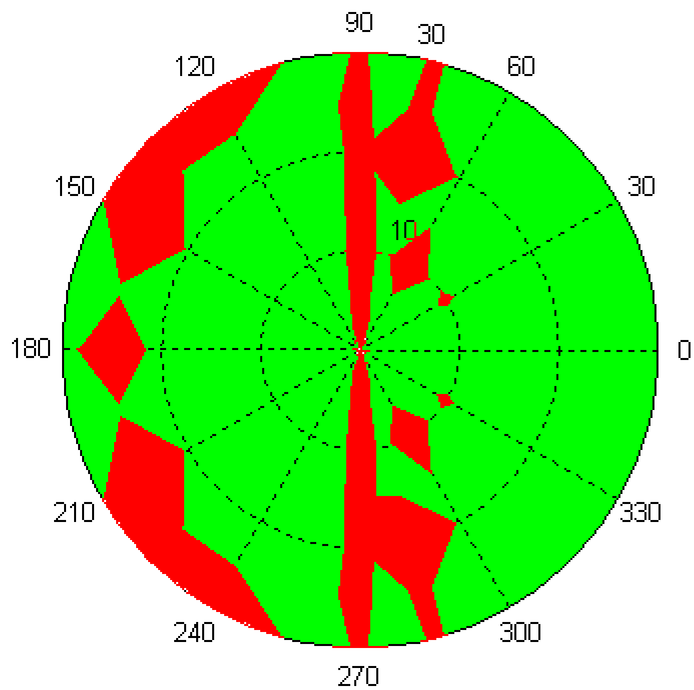
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.8



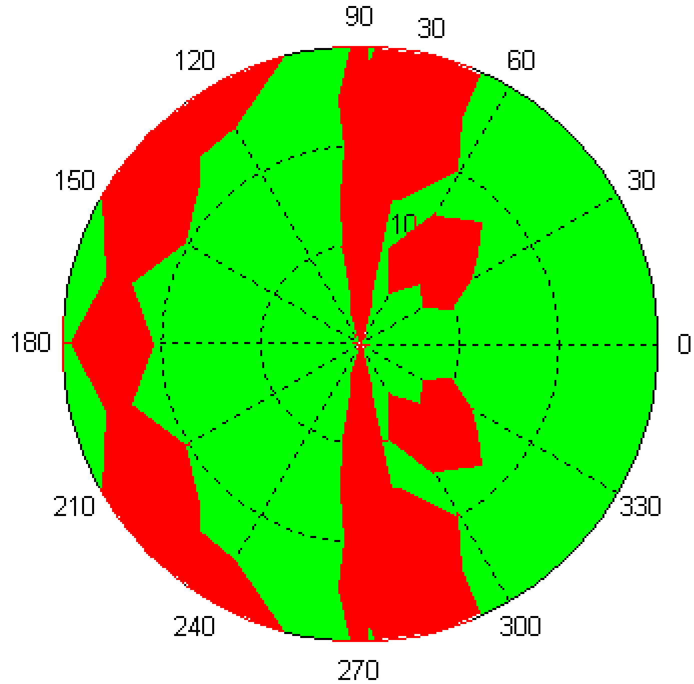
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.7



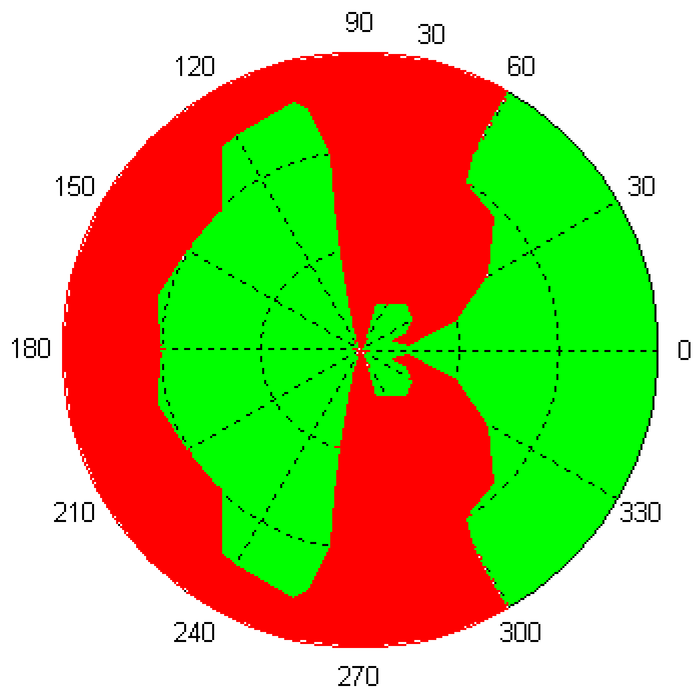
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.6



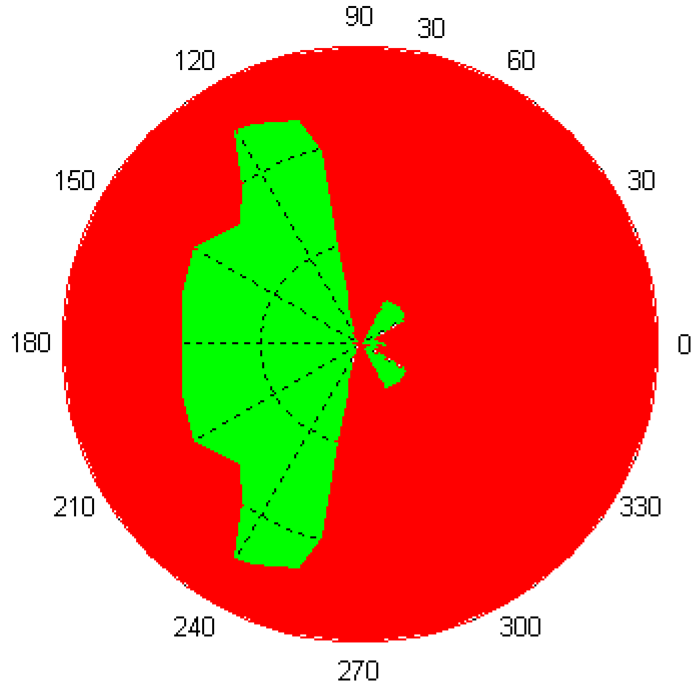
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.5



All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.4



All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.3



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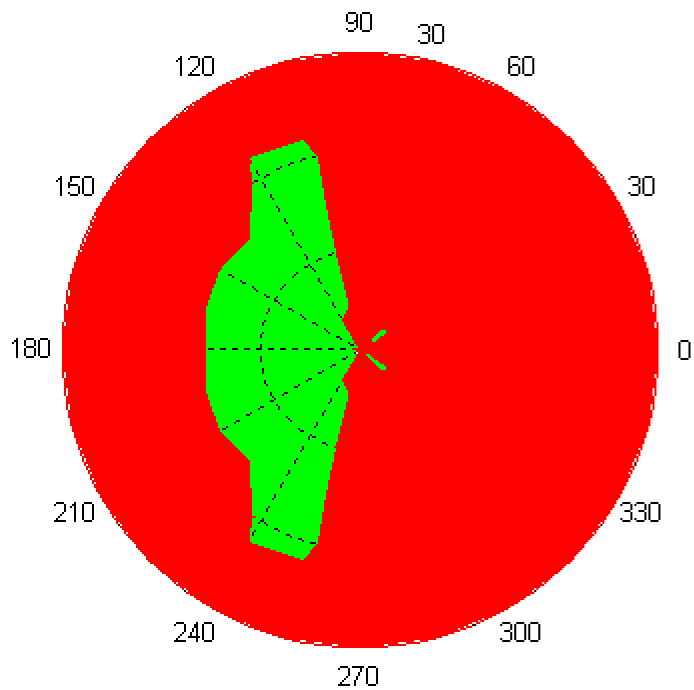
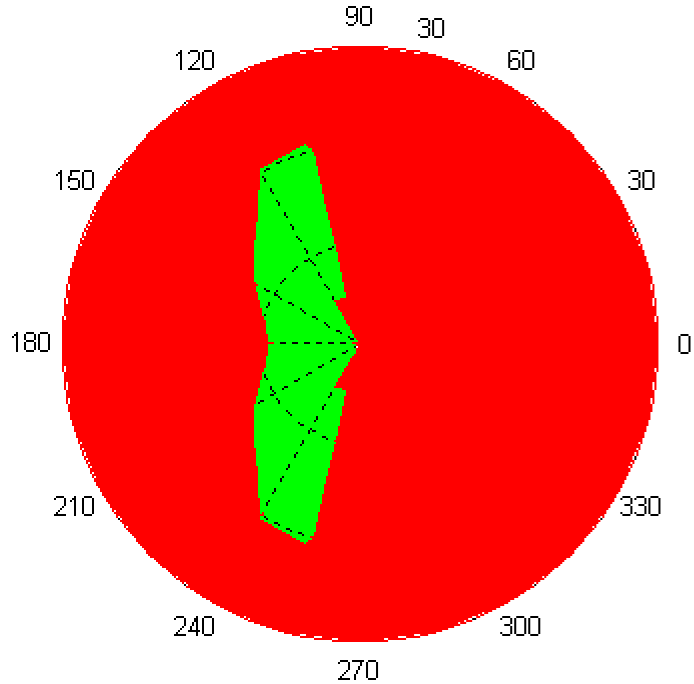
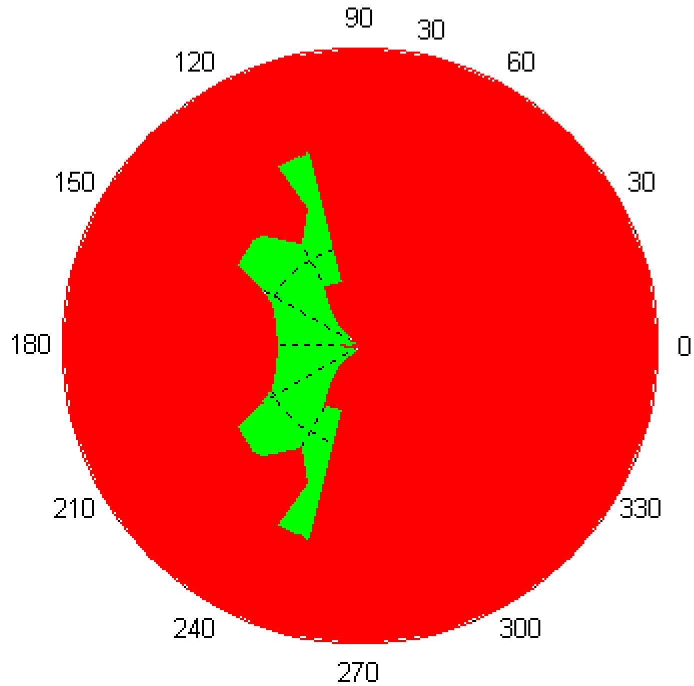
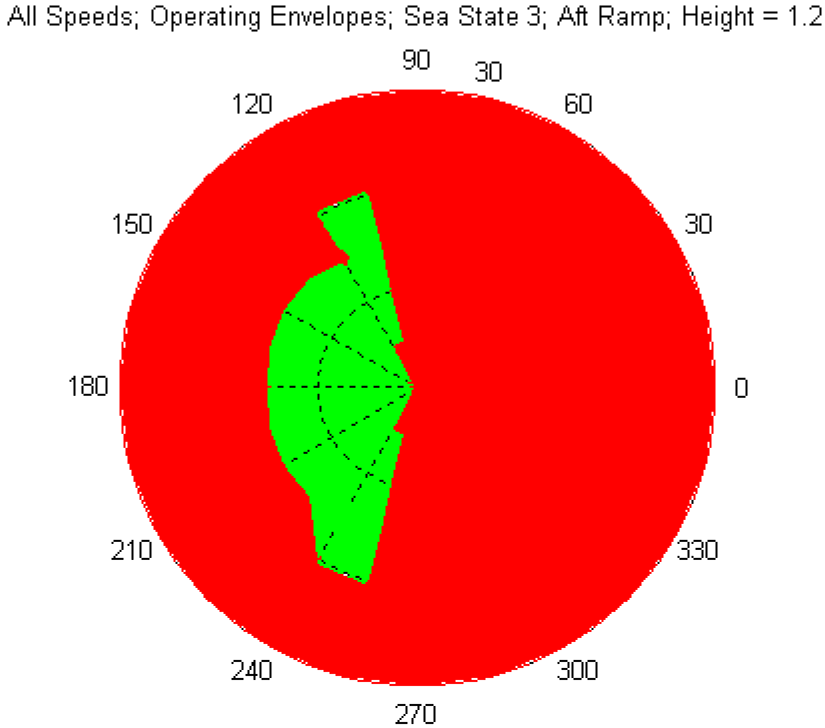


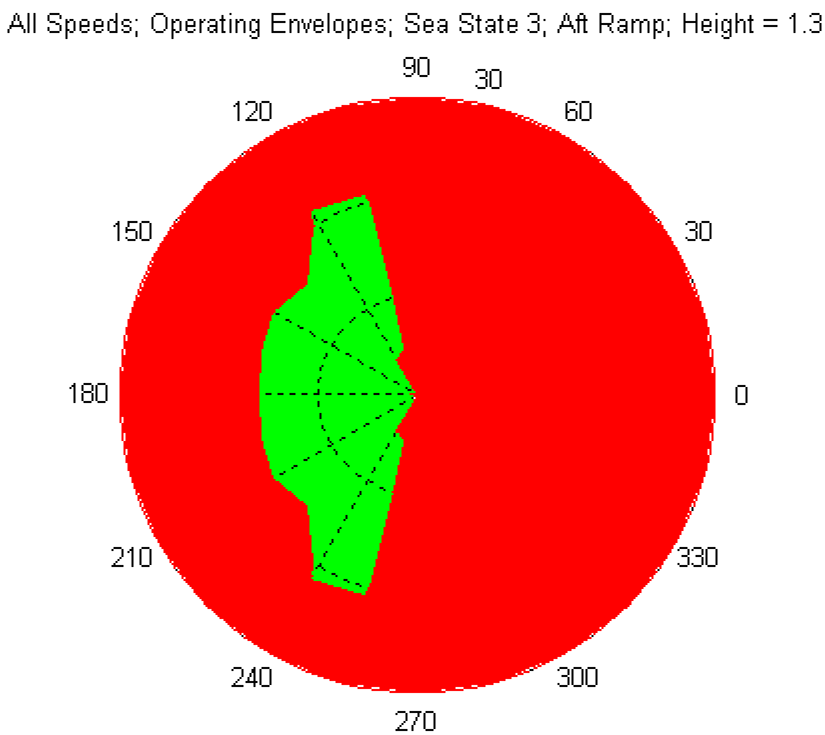
All Speeds; Operating Envelopes; Sea State 3; Side Door; Height = 1.1



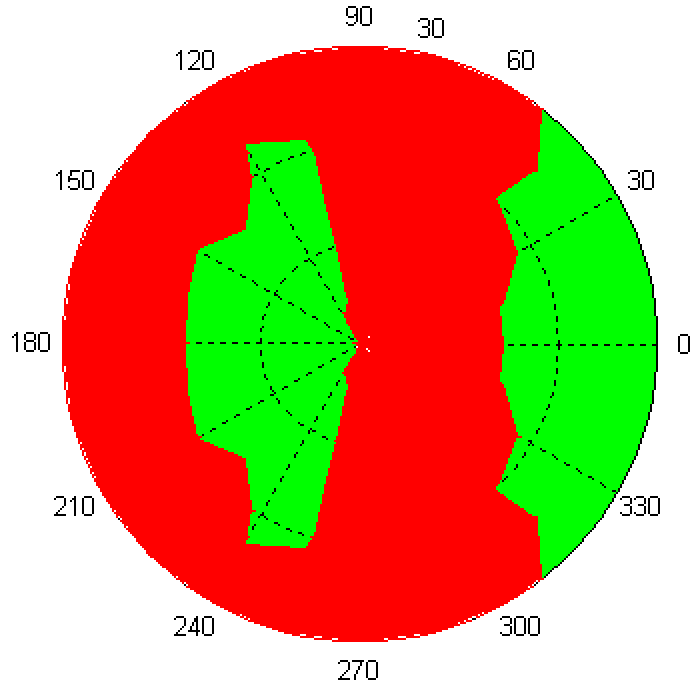
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.1



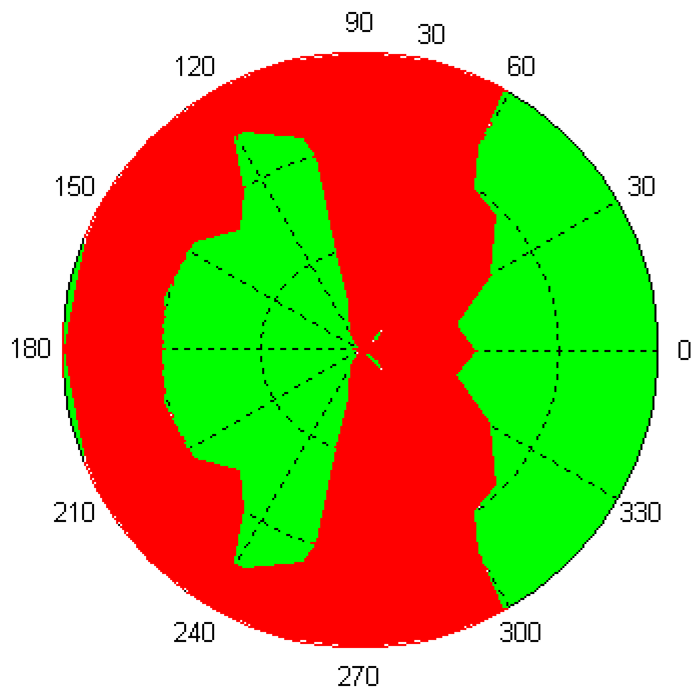

All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.2
90
30
120
60
150
30
180
0
210
330
240
300
270


All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.3
90
30
120
60
150
30
180
0
210
330
240
300
270

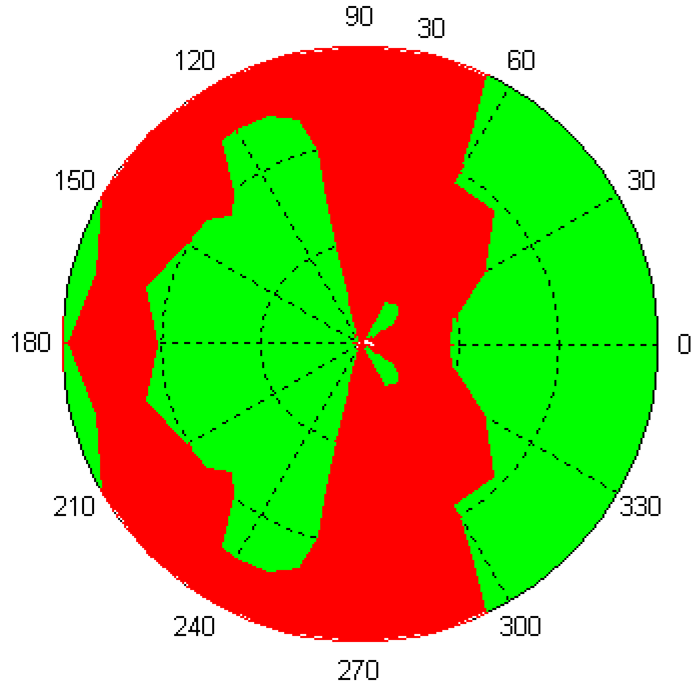
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.4



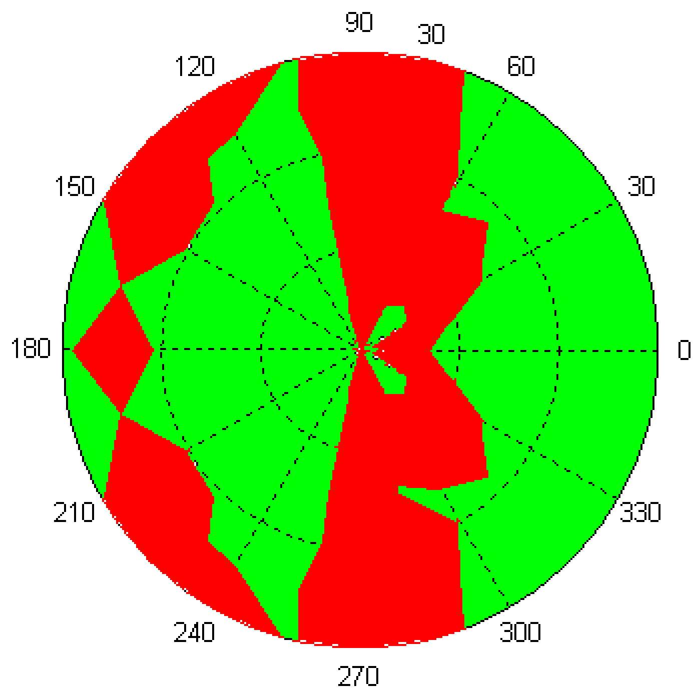
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.5



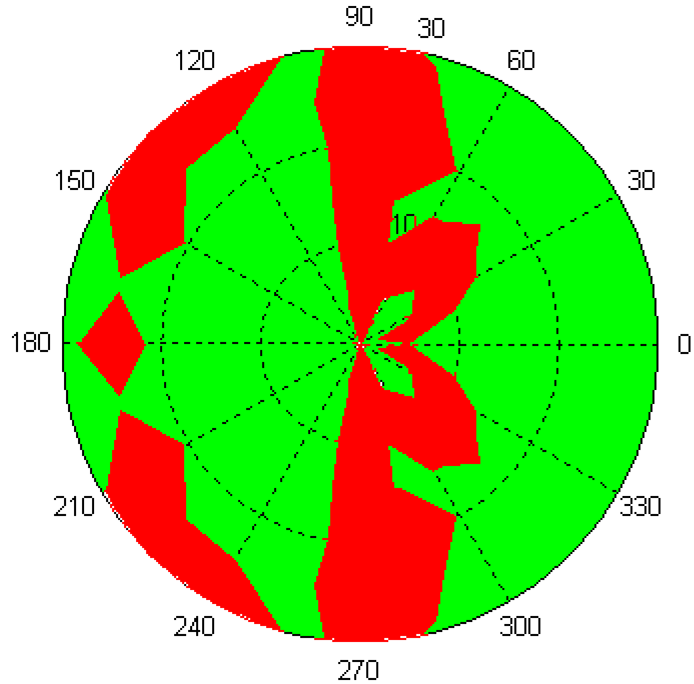
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.6



All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.7



All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1.8



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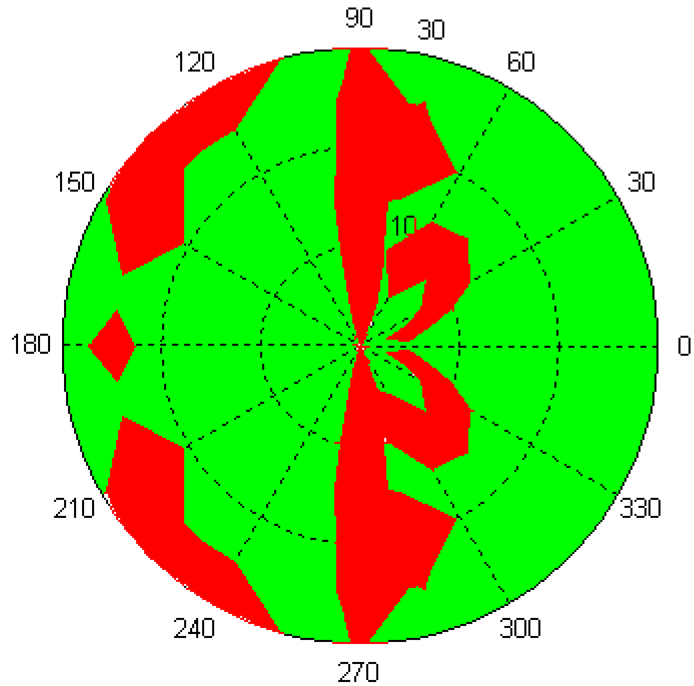
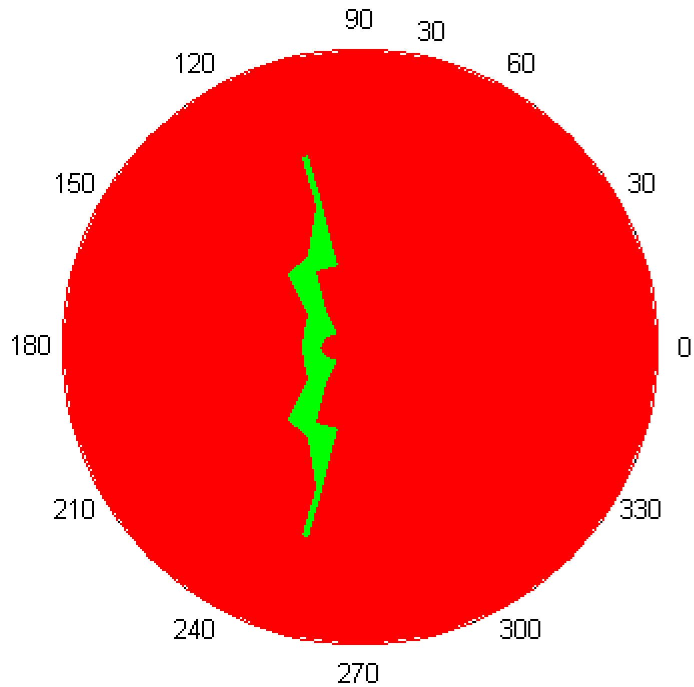
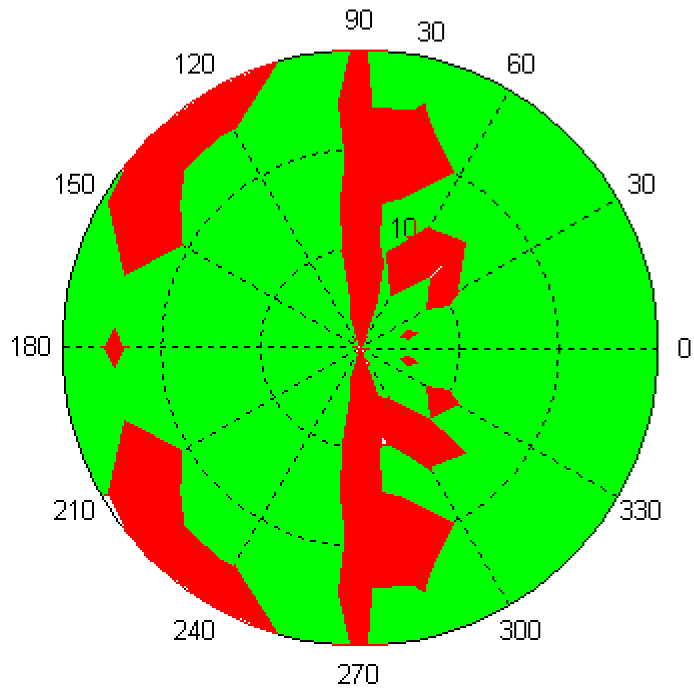
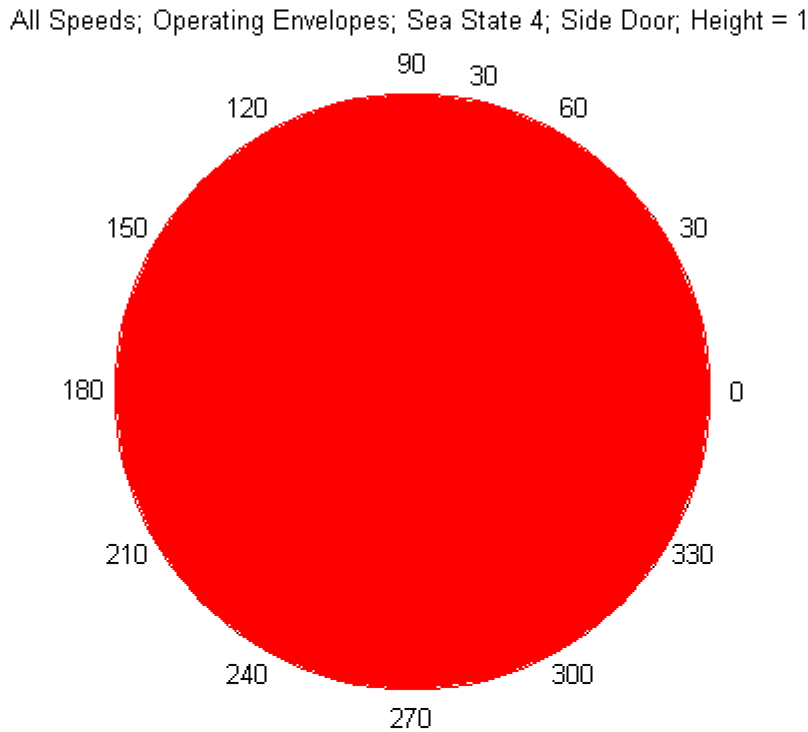


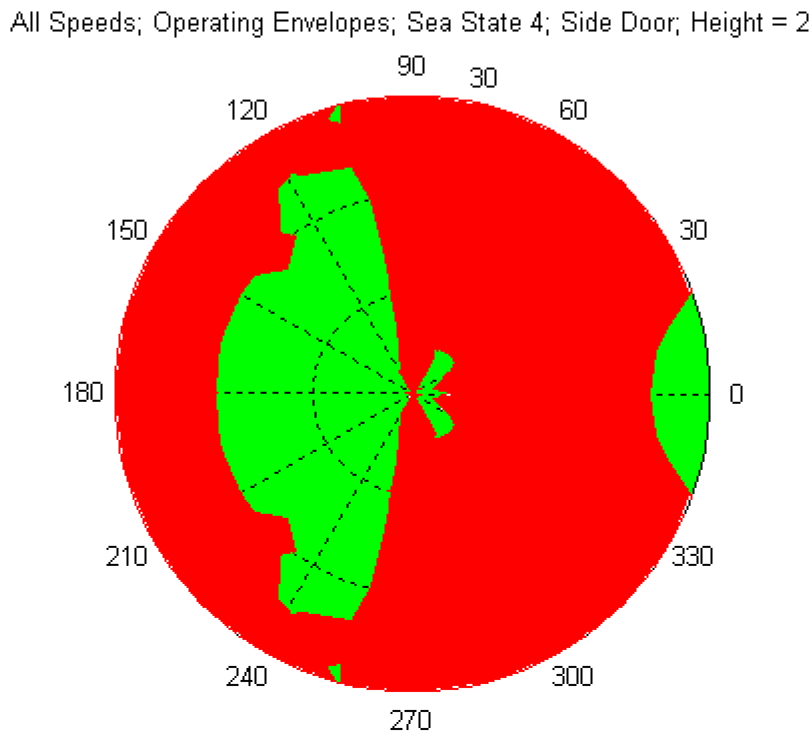
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 1

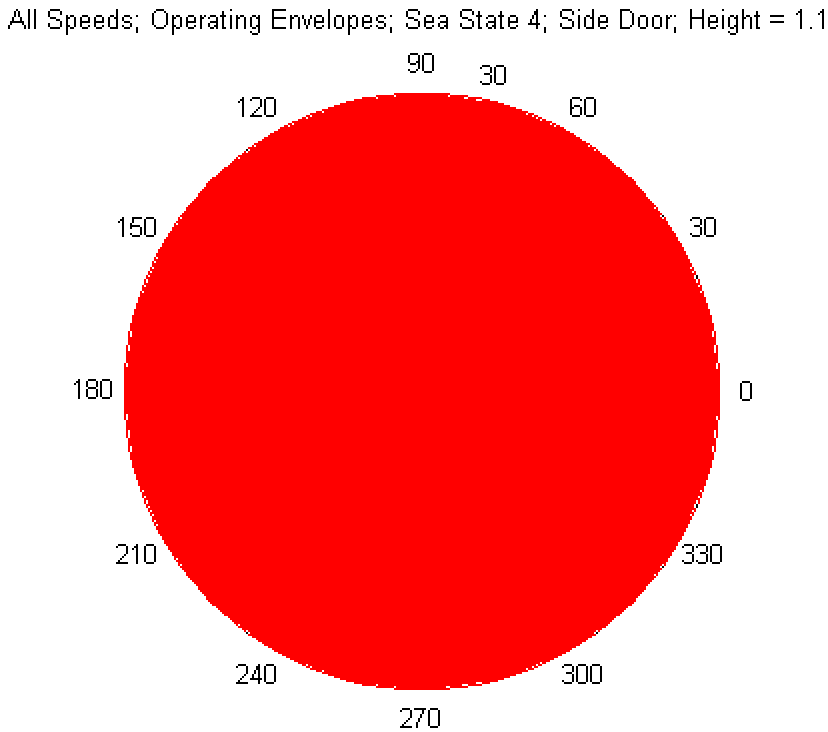


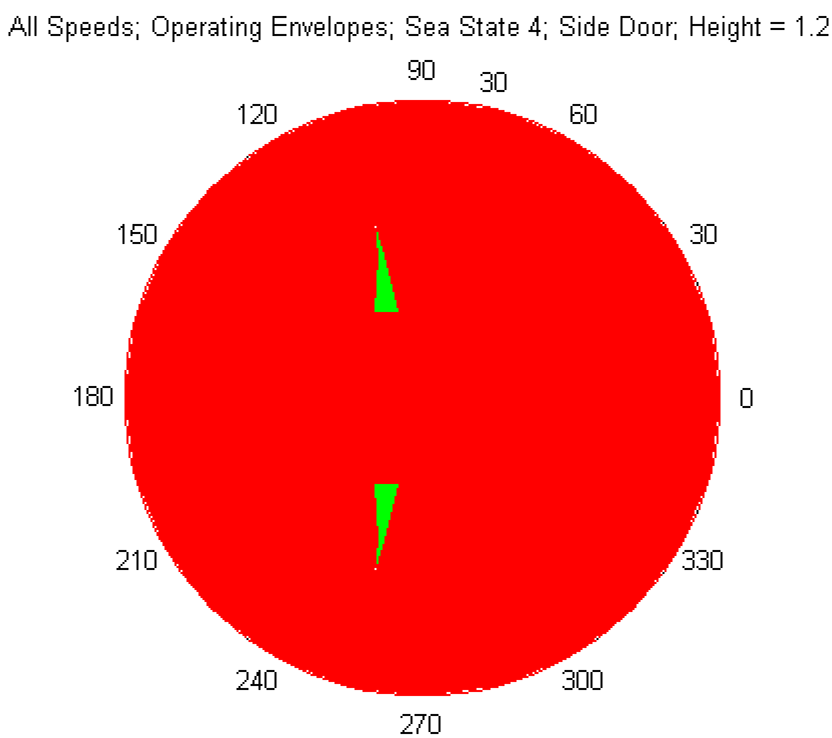
All Speeds; Operating Envelopes; Sea State 3; Aft Ramp; Height = 2



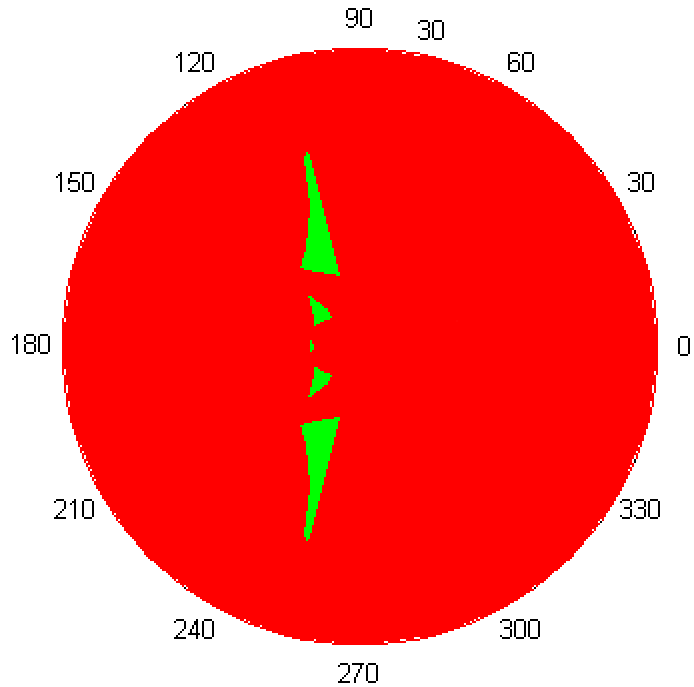

All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1
90
30
120
60
150
30
180
0
210
330
240
300
270


All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 2
90
30
120
60
150
30
180
0
210
330
240
300
270

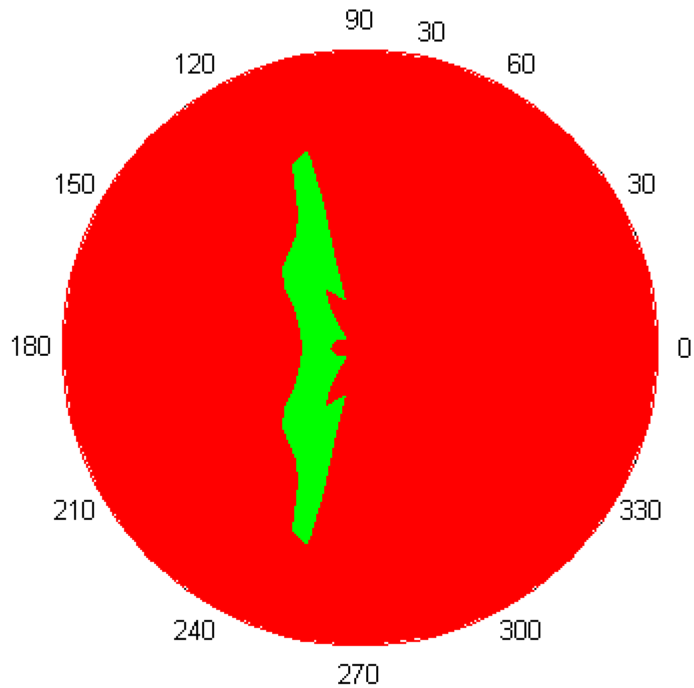

All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.1
90
30
120
60
150
30
180
0
210
330
240
300
270


All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.2
90
30
120
60
150
30
180
0
210
330
240
300
270

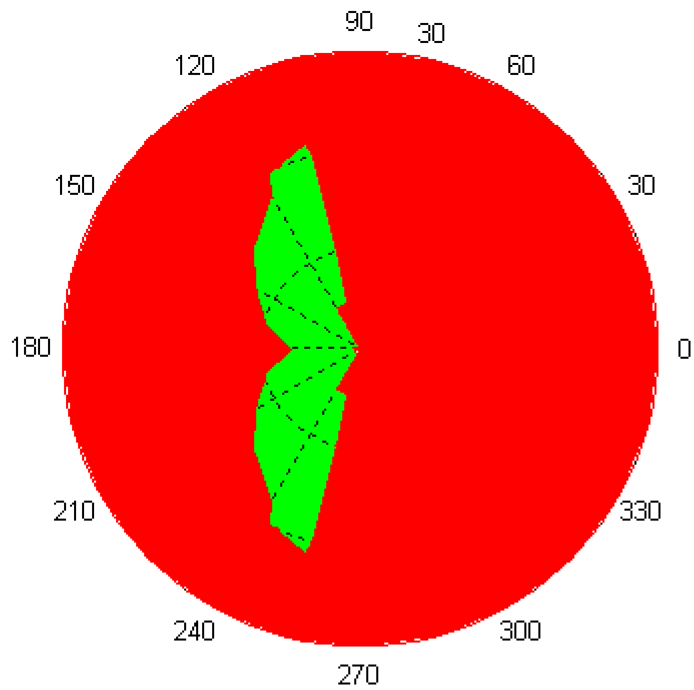
All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.3



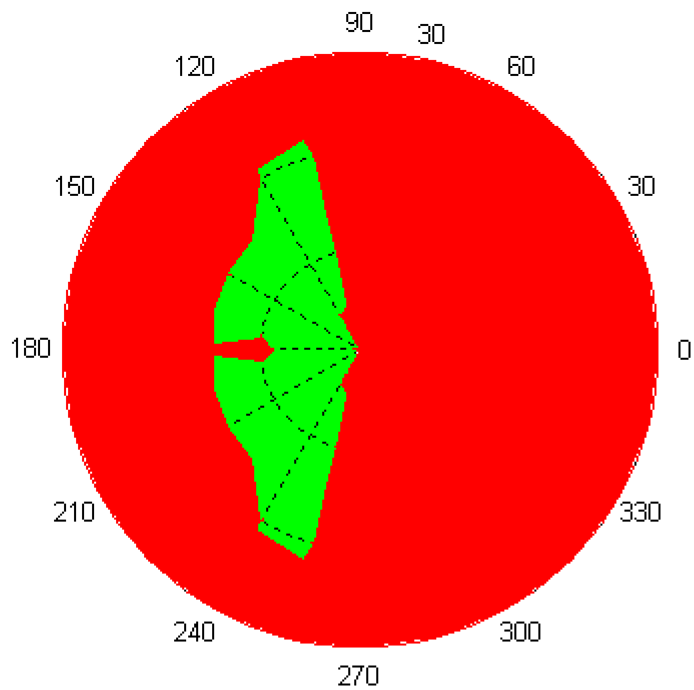
All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.4



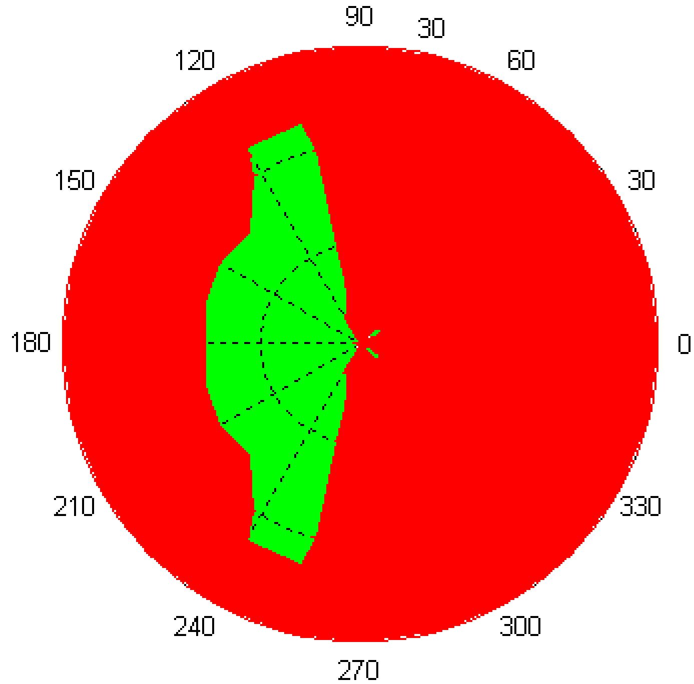
All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.5



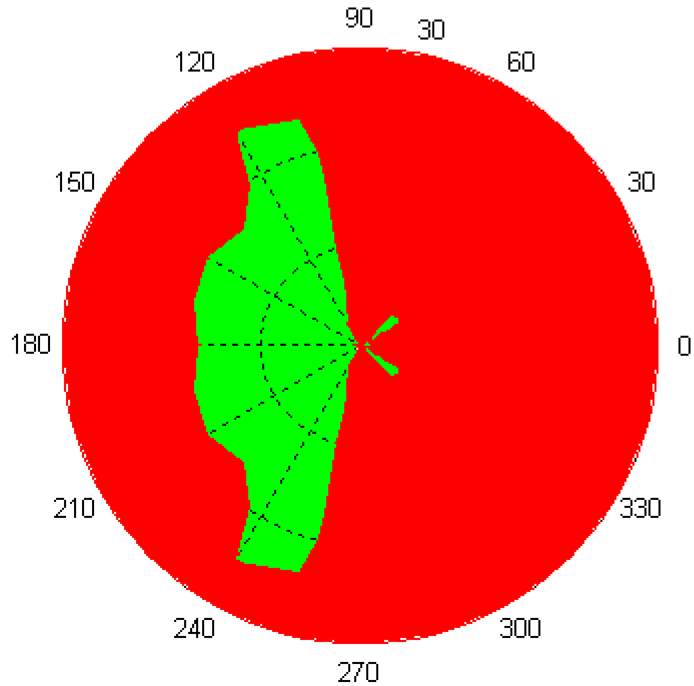
All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.6



All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.7



All Speeds; Operating Envelopes; Sea State 4; Side Door; Height = 1.8

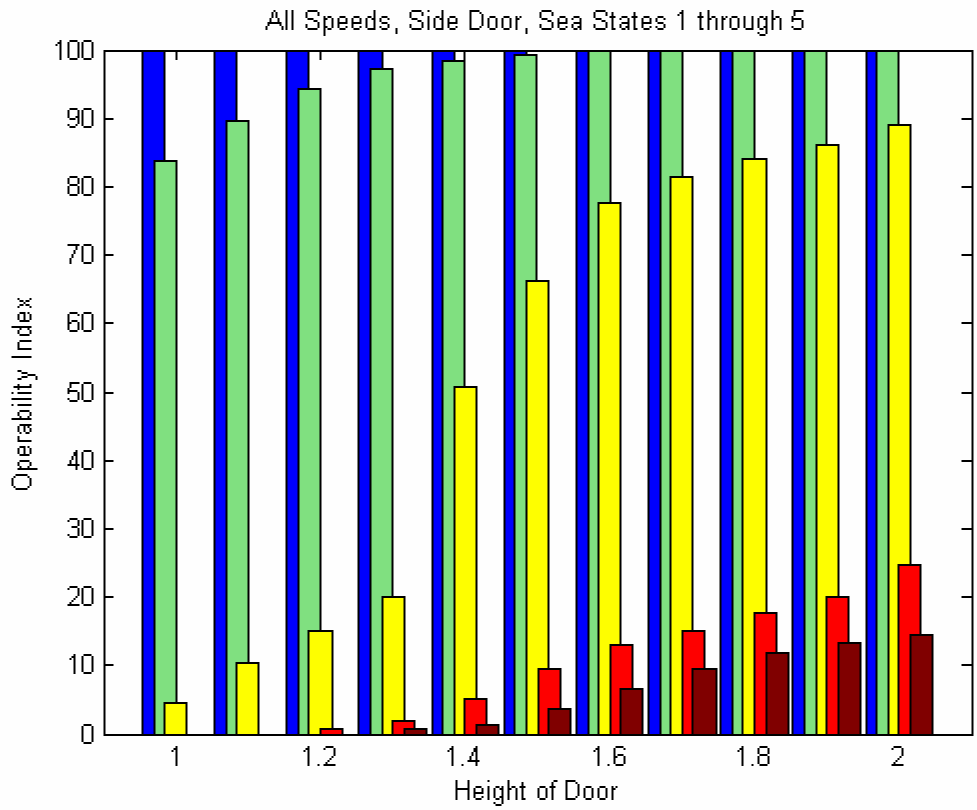


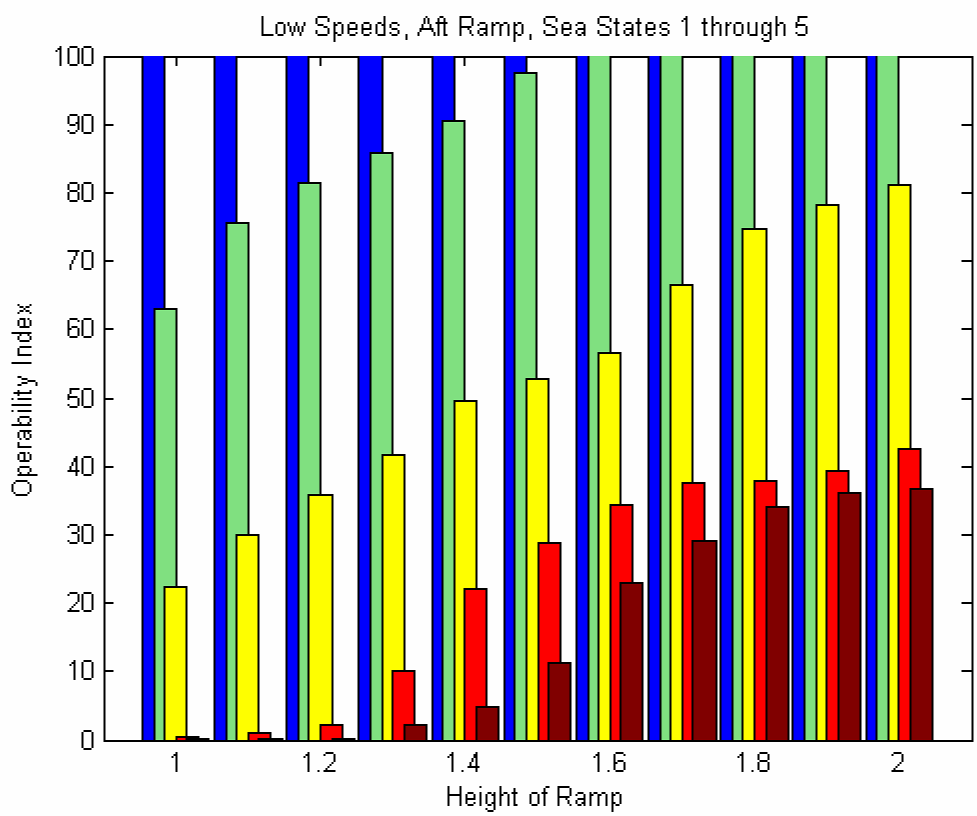
Operability Index

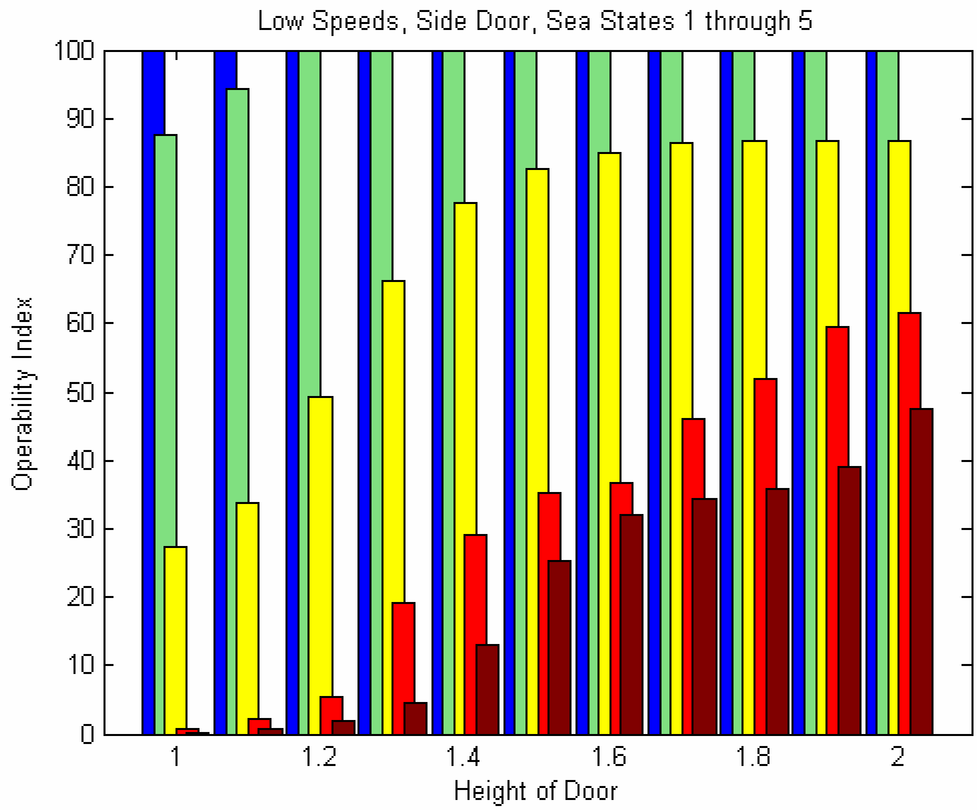
A numerical measure of the operability of the ship according to the assumed criteria can be evaluated by comparing the green (acceptable) to the total area in each polar plot. This ratio, expressed in a percentage format, is known as the operability index and is a function of sea state as well as design conditions such as ship speed and ramp/door placement.

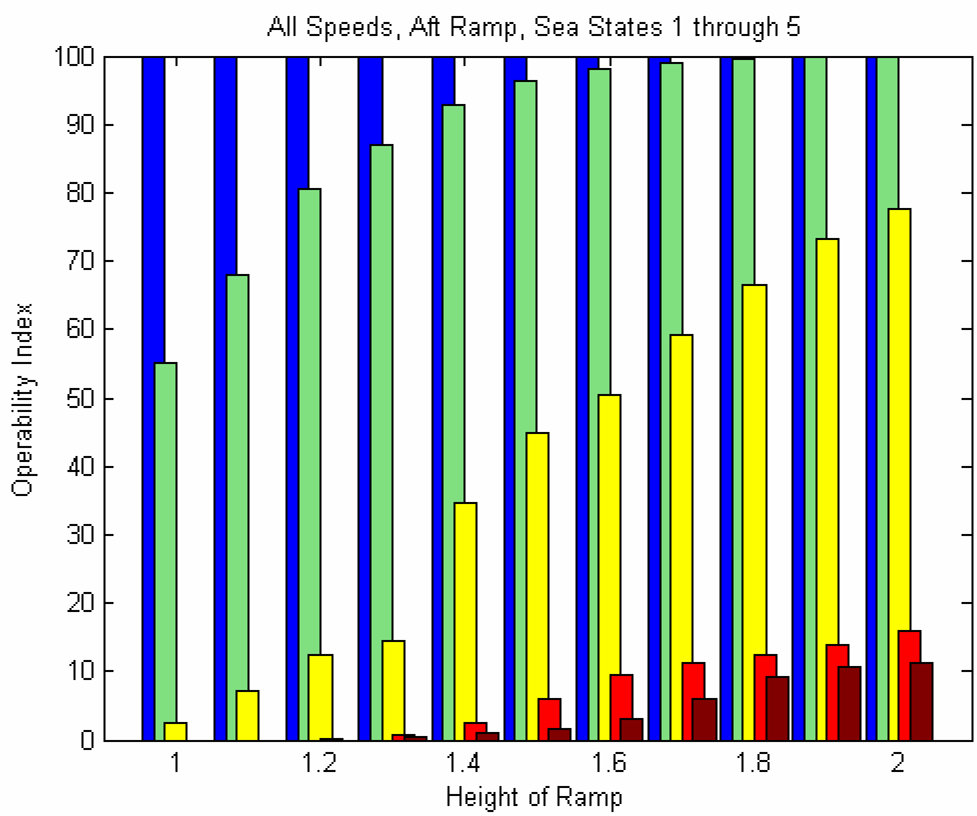
The operability index results are shown in the following figures for both the aft ramp and side door and for five sea states according to the following color chart. We can see that we arrive at an acceptable operability index even for high sea states and throughout the zero to thirty knots speed range.

Further calculations could be performed by considering the probability of occurrence for each sea state in the ship's expected area of operations. The weighted sum of each sea state and its corresponding operability index would produce a combined operability index for that particular geographical area. Such calculations were not performed, since it was felt that they would not alter significantly the design decisions, especially when one considers multiple operation areas of the ship.


All Speeds, Side Door, Sea States 1 through 5
Operability Index
Height of Door
0
10
20
30
40
50
60
70
80
90
100
1
1.2
1.4
1.6
1.8
2

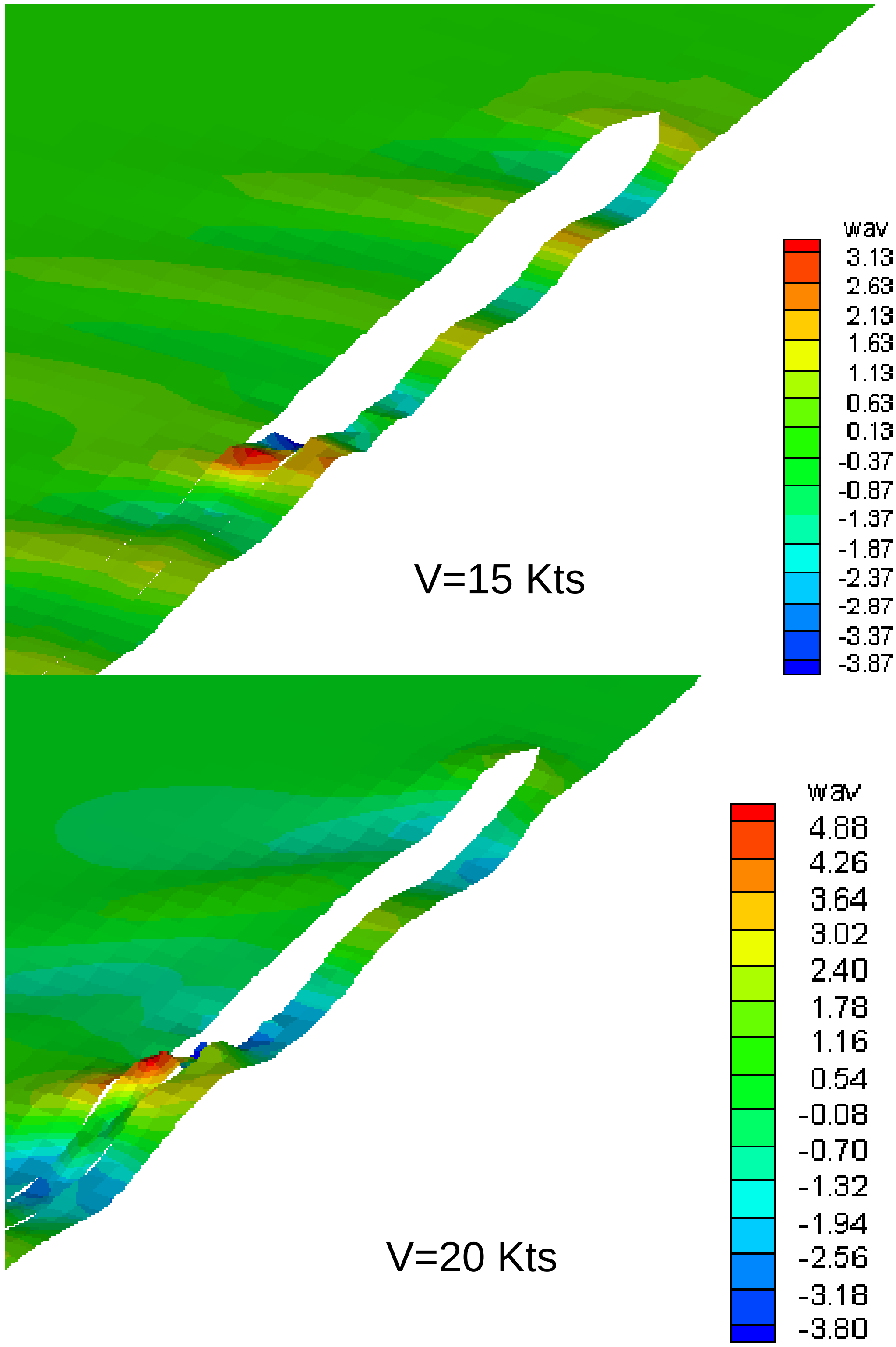

Low Speeds, Aft Ramp, Sea States 1 through 5
Operability Index
Height of Ramp
0
10
20
30
40
50
60
70
80
90
100
1
1.2
1.4
1.6
1.8
2


Low Speeds, Side Door, Sea States 1 through 5
Operability Index
100
90
80
70
60
50
40
30
20
10
0
1
1.2
1.4
1.6
1.8
2
Height of Door


All Speeds, Aft Ramp, Sea States 1 through 5
Operability Index
100
90
80
70
60
50
40
30
20
10
0
1
1.2
1.4
1.6
1.8
2
Height of Ramp

Design Implications

Based on the previous results, the team decided to fix the side door and aft ramps to approximately 2.2 meters above the calm waterline. Recognizing that ship's motions in waves is only part of the picture, we conducted also a study of the wave pattern of SEA TENTACLE and the expected wetness in calm seas by considering the ship's wake. These calculations were performed by utilizing SWAN, a 3-dimensional panel code provided by MIT. Sample calculations are shown below. Based on these results we expect the vehicle launch and recovery operability region of the ship to be limited to speeds not exceeding 15 knots.


wav
3.13
2.63
2.13
1.63
1.13
0.63
0.13
-0.37
-0.87
-1.37
-1.87
-2.37
-2.87
-3.37
-3.87
V=15 Kts
wav
4.88
4.26
3.64
3.02
2.40
1.78
1.16
0.54
-0.08
-0.70
-1.32
-1.94
-2.56
-3.18
-3.80
V=20 Kts

APPENDIX IX: TRANSVERSE STRESS ANALYSIS

1. The Geometry of the Model:

A 3-D Structural view of the model is in the Figure IX-1. Since the geometry of the midship section doesn't change along a considerable length of the ship, we decided to use a 2-D model instead of a 3-D model.

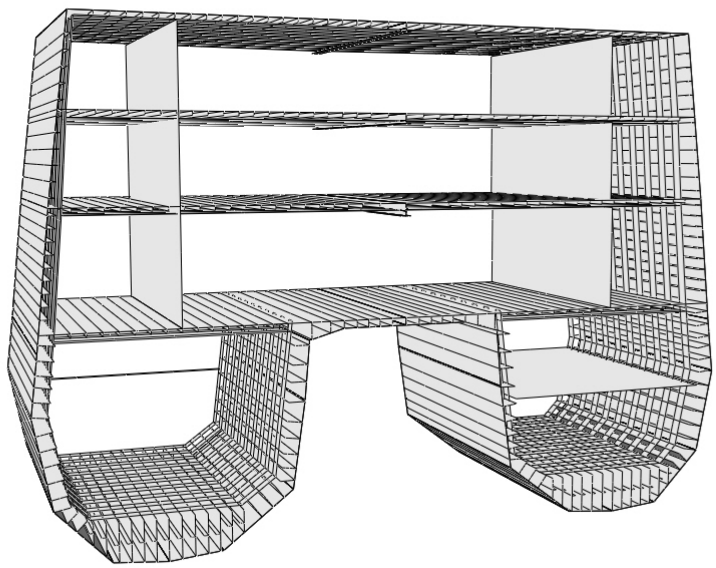


Figure IX-1. The 3-D structural view of Sea TENTACLE

2. Static Loads and Buoyancy:

There are two kinds of force in our calculations. One of them is the buoyancy which states that the weight of a statically floating body must equal the weight of the volume of water that it displaces, and the other is the payload weight such as engines, UUVs etc. During the design phase, these loads were defined, but we had to assemble these weights per element per length in order to use them in FEMLAB software. The weight and buoyancy distribution is shown in Figure IX-2.

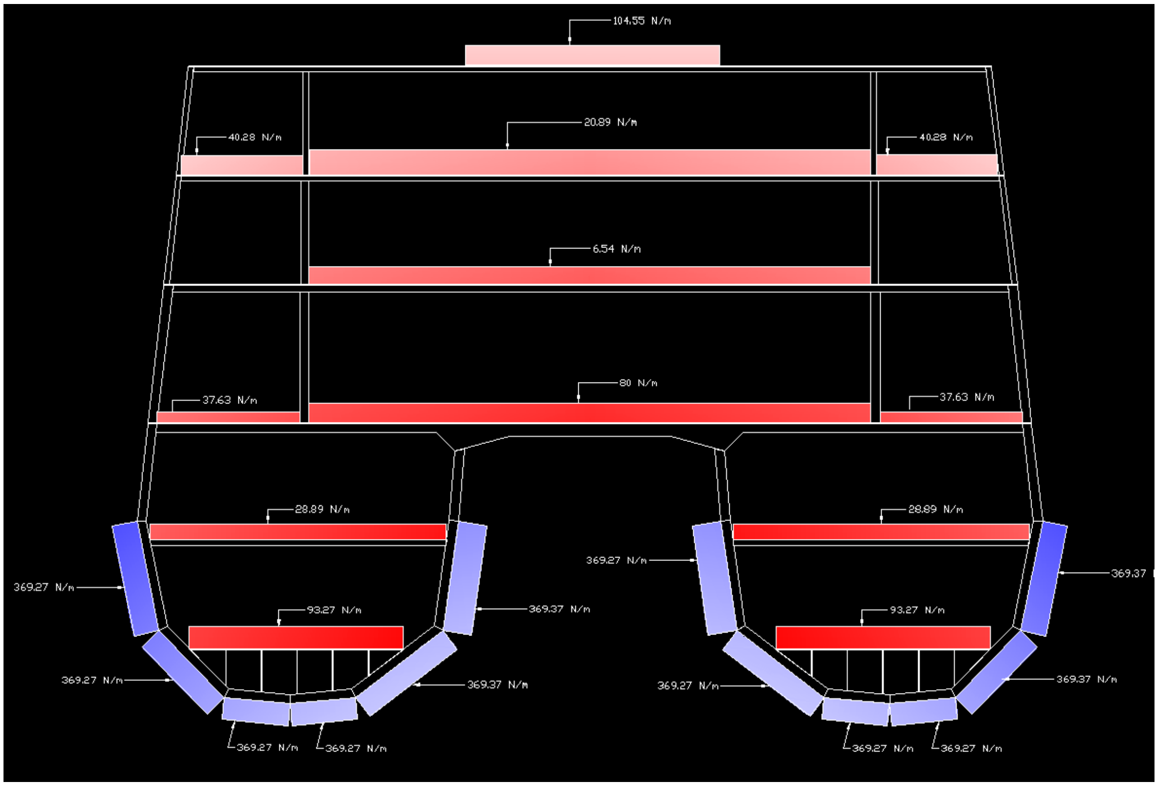


Figure IX-2. The static loads of Sea TENTACLE

In Figure IX-2, the forces which are shown in blue are buoyancy forces which are the positive y-direction. The forces which are shown in red are the loads of the ship with the negative direction. FEMLAB software allows the user to enter the loads in two ways, first as load per length and second as load per area by using element thicknesses. We decided to enter the loads as load per length. We need to calculate the force per element and per length. Since we know the total weight and length of the component, we calculated the weight per length. By multiplying this value with the deck thickness, we can obtain the force per element per length. Here are the amounts of buoyancy forces and the loads;

Buoyancy:

Total buoyancy force **:** 628340.31 N/m
Total buoyancy boundary length **:** 30.62 m
Buoyancy boundary thickness **:** 18 mm
Buoyancy force per element per length: 369.37 N/m

Loads:

- **2 x Engine Rooms**

Total weight	**:** 686700 N
Engine room length	**:** 15 m
Total weight per length	**:** 45780 N/m
Deck thickness	**:** 12 mm
Weight per element	**:** 549.36 N (45.78 X 12)
Deck element length	**:** 5.89 m
Weight per length	**:** 93.27 N/m

- **2 x Auxilaries Rooms**

Total Weight	**:** 294300 N
Engine room length	**:** 15 m
Total weight per length	**:** 19620 N/m
Deck thickness	**:** 12 mm
Weight per element	**:** 235.44 N (19.62 X 12)
Deck element length	**:** 8.15 m
Weight per length	**:** 28.889 N/m

- **2 x Spare UUVs**

Total Weight	**:** 98100 N
UUV length	**:** 8 m
Total weight per length	**:** 12262.5 N/m
Deck thickness	**:** 12 mm
Weight per transverse deck element	**:** 147.15 N (12.2625 X 12)
Deck element length	**:** 3.91 m
Weight per length	**:** 37.63 N/m

- **UUVs**

Total Weight	**:** 824040 N
UUV length	**:** 8 m
Total weight per length	**:** 103005 N/m
Deck thickness	**:** 12 mm
Weight per transverse deck element	**:** 1236.06 N (103.005 X 12)
Deck element length	**:** 15.44 m
Weight per length	**:** 80 N/m

- **<u>Mess Deck</u>**

Total Weight	**:** 98100 N
Mess deck length	**:** 12 m
Total weight per length	**:** 8175 N/m
Deck thickness	**:** 12 mm
Weight per transverse deck element	**:** 98.1 N (8.175 X 12)
Deck element length	**:** 15 m
Weight per length	**:** 6.54 N/m

- **<u>CIC</u>**

Total Weight	**:** 294300 N
CIC room length	**:** 13 m
Total weight per length	**:** 22638.46 N/m
Deck thickness	**:** 12 mm
Weight per transverse deck element	**:** 271.66 N (22.64 X 12)
Deck element length	**:** 13 m
Weight per length	**:** 20.89 N/m

- **<u>2 x State Rooms</u>**

Total Weight	**:** 39240 N
State room length	**:** 3.5 m
Total weight per length	**:** 11211.43 N/m
Deck thickness	**:** 12 mm
Weight per transverse deck element	**:** 134.54 N (11.211 X 12)
Deck element length	**:** 3.34 m
Weight per length	**:** 40.28 N/m

- **<u>Radar Mast</u>**

Total Weight	**:** 637650 N
Radar mast length	**:** 14 m
Total weight per length	**:** 45546.43 N/m
Deck thickness	**:** 16 mm
Weight per transverse deck element	**:** 728.743 N (45.546 X 16)
Deck element length	**:** 6.97 m
Weight per length	**:** 104.55 N/m

3. Transverse Stress Analysis:

In order to calculate the transverse stresses, we used FEMLAB software as a finite element solver.

a) Since we want to calculate the plane stresses, we selected plane stress static analysis model from the application modes as shown in Figure IX-3.

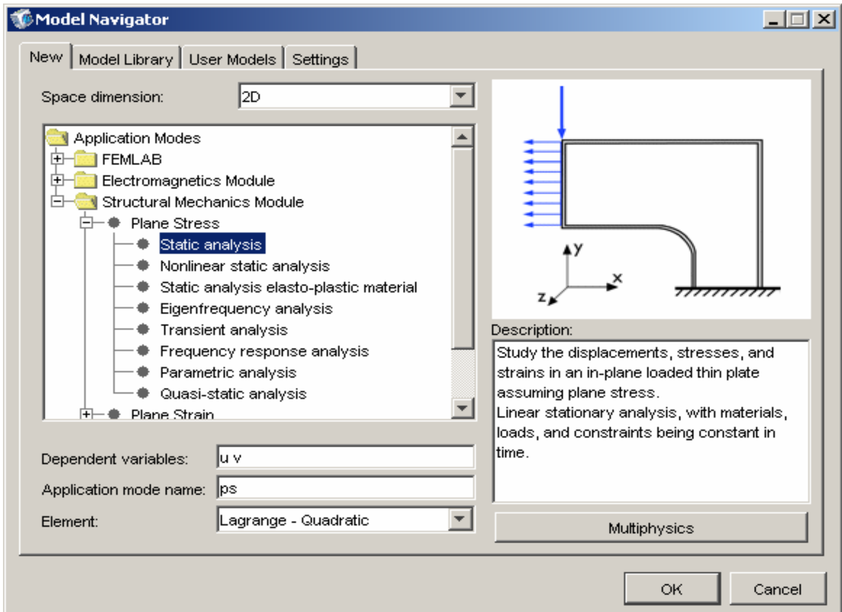


Figure IX-3. Selection of the model type

b) We did not draw the domain by using this software. We drew it by using Auto CAD and imported to FEMLAB as ahown in Figure IX-4.

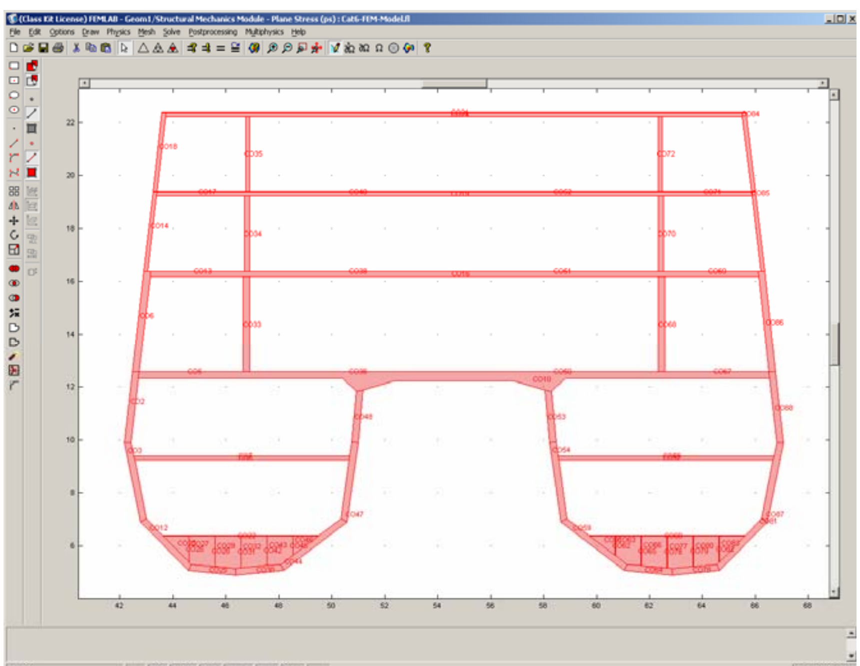


Figure IX-4. The drawing of the domain

c) We defined the boundary conditions. At this step, we assumed the centerline of the ship as fixed such as cantilever beam in order to observe the deformations and the deformed body. Figure IX-5 shows the uniform weight distribution and its location as blue lines. As seen from the figure, the centerline which is fixed is showed as a red line.

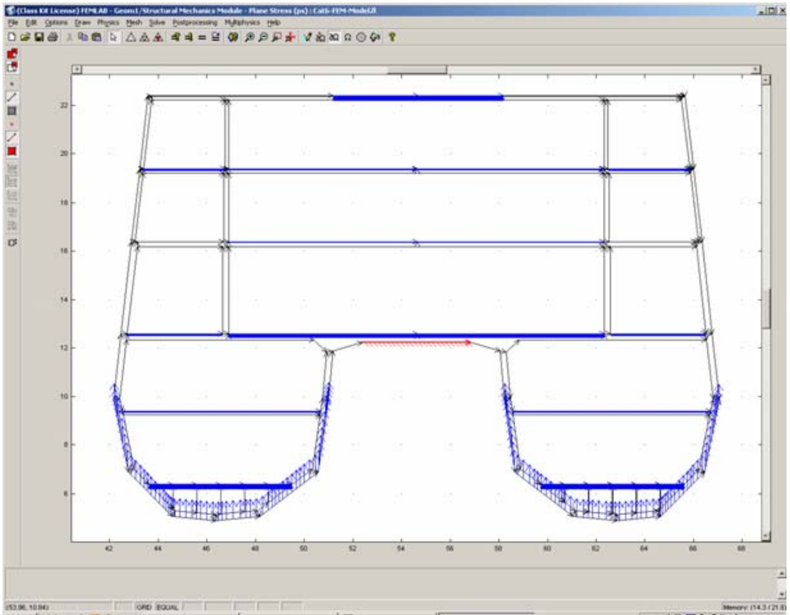


Figure IX-5. After defining the boundary conditions and forces

d) We selected the material type as shown in Figure IX-6 and the thicknesses for each element by using the data shown in Figure IX-7.

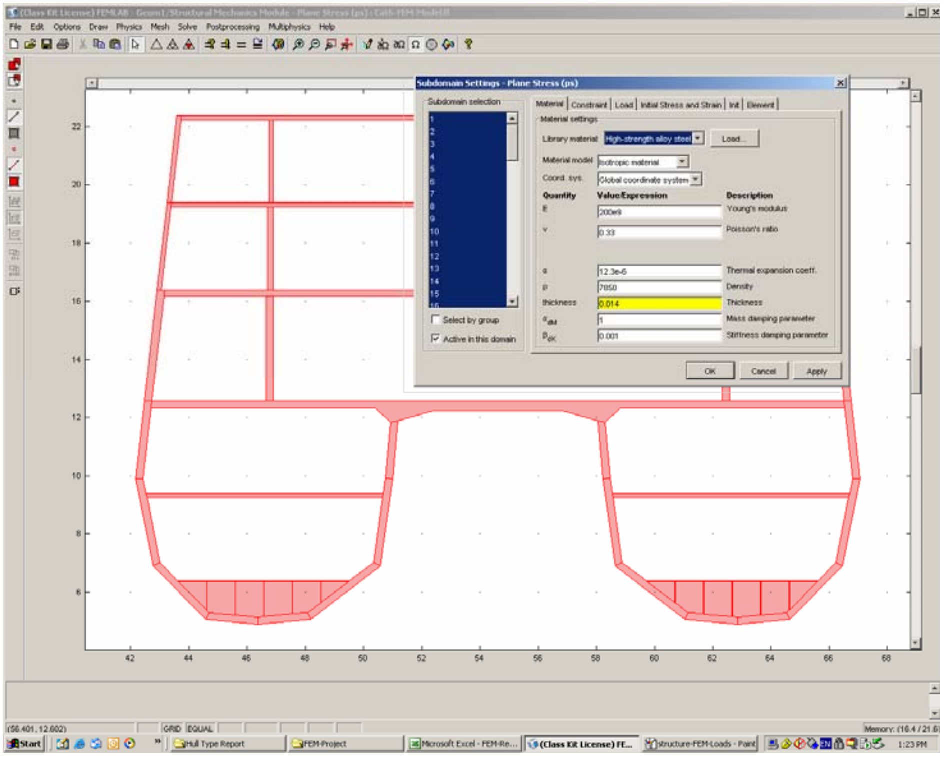


Figure IX-6. Selection of the material type

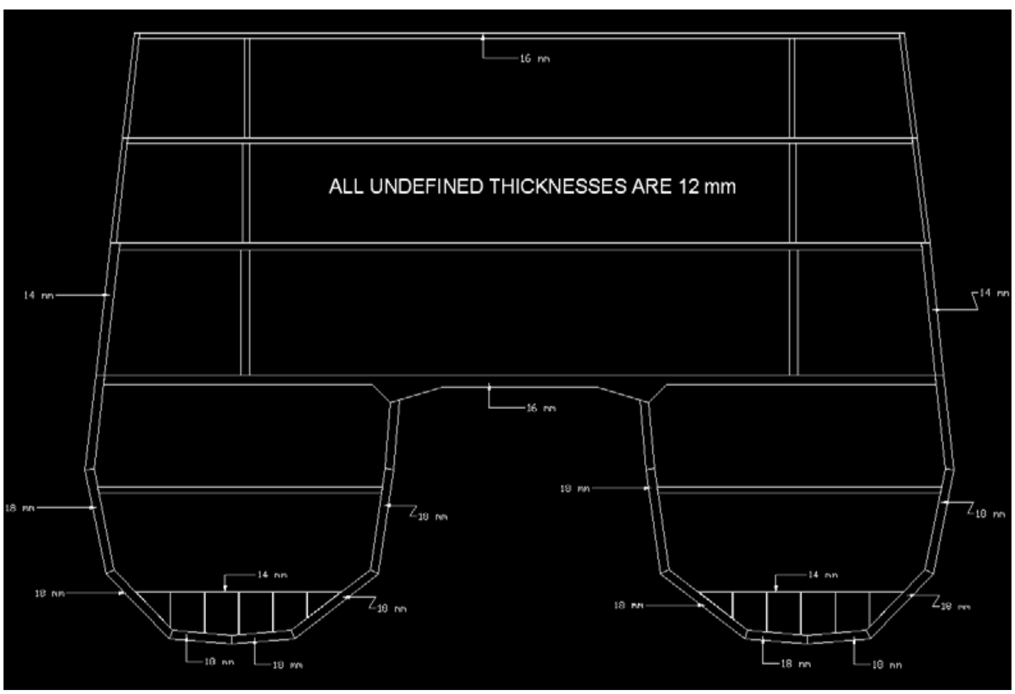


Figure IX-7. The element thicknesses

e) After defining the boundary conditions and selecting the material type, the next step was meshing the domain. We used linear, quadratic and triangular mesh patterns in this project. At this step, we defined the mesh parameters such as the number of elements as shown in Figure IX-8.

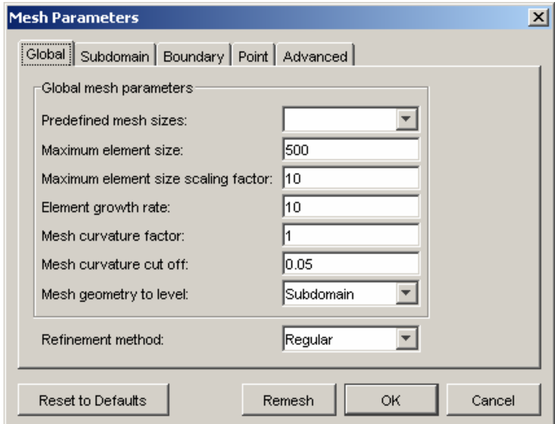


Figure IX-8. Entering the mesh parameters

Initially, we selected a fine mesh which has 170000 elements in the domain. But the program failed due to "out of memory" error. So we decided to increase the element size. Finally, we came up with a coarse mesh which has a total number of 40000 elements in the domain, but still a fine mesh around the intersections of the sub domains, because from our engineering intuition we were expecting the max stresses to occur at these points. Figure IX-9 shows the final mesh.

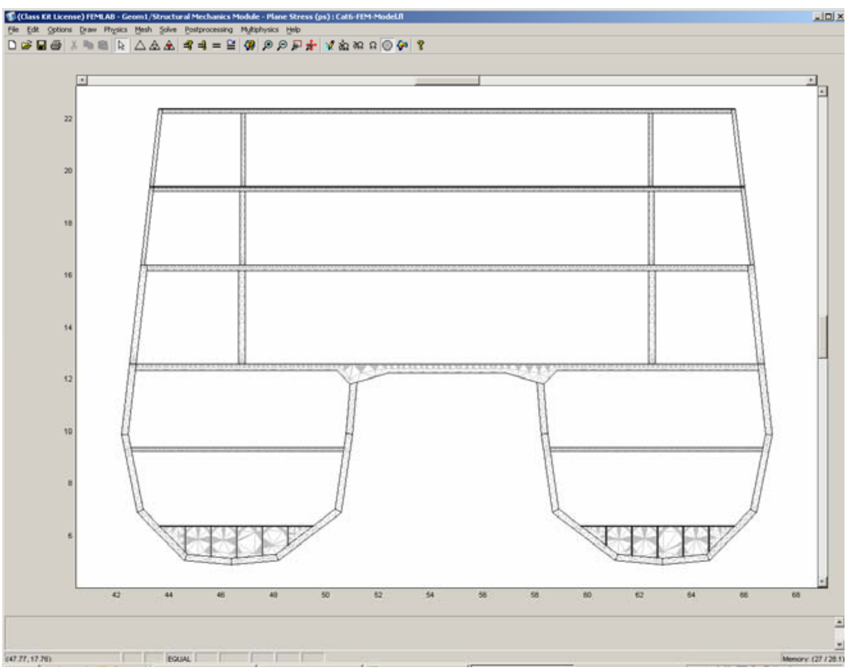


Figure IX-9. The mesh of the domain

f) We issued the final command of the program and solved the problem. As a result, the program gives us several kinds of plots. Figure IX-10 shows us the deformed body with the stress distribution for steel hull. Maximum and minimum values and locations of stress and deformation are also shown in the figure. But we exaggerated the deformation plot by 50 times in order to observe the deformed body shape. Figure IX-11 shows the stress distribution along the deck for steel hull.

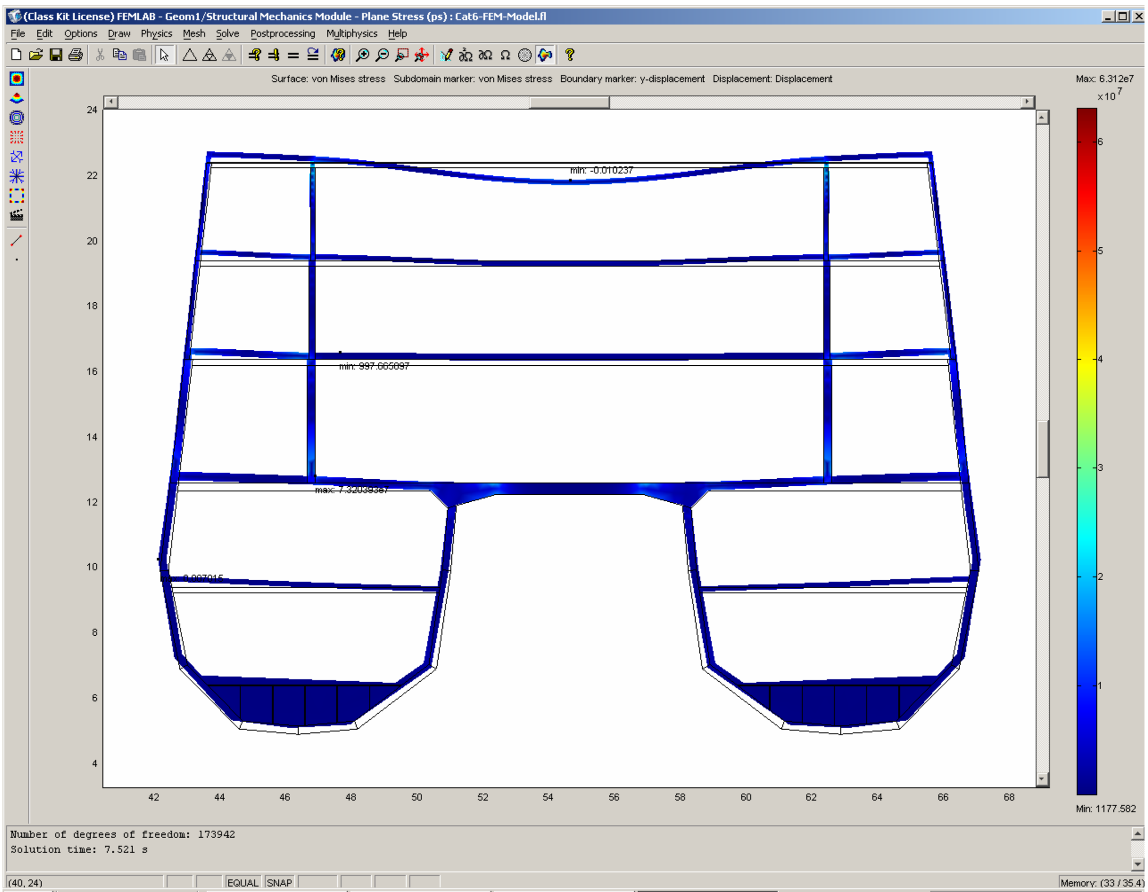


Figure IX-10. The plot of the deformed body with stress distribution

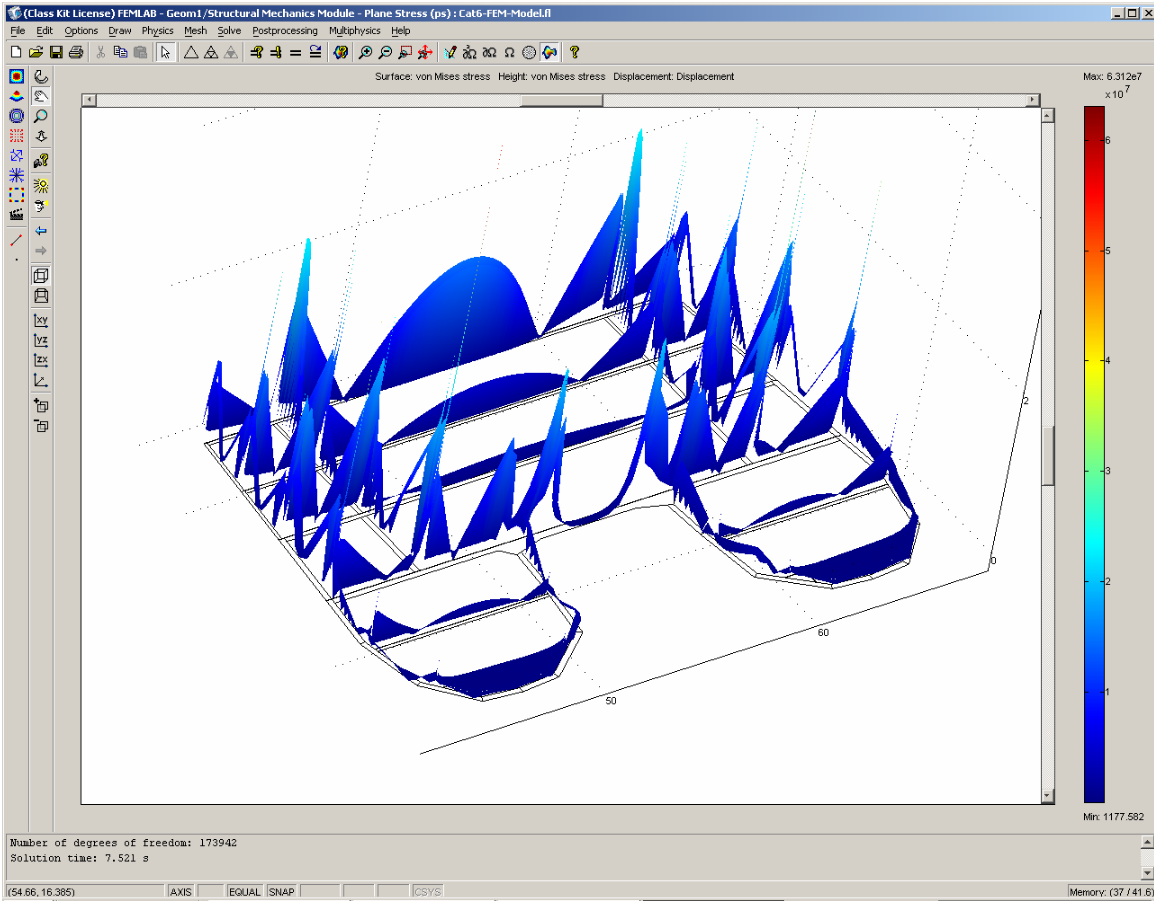


Figure IX-11. Stress distribution

4. RESULTS

Analysis Type	Max. Stress (MPa) X S.F.	Max. Deformation (mm)
Transverse Stress	146.4	7.015 (in +y direction) 10.24 (in –y direction)

Table IX-1. Final Results

APPENDIX X: STABILITY BOOKLET

1. HULL DATA

a. Fully Loaded

TANK CONFIGURATION

FUEL TANKS

TANK	LOAD %	WEIGHT (MT)
FT1 (4-38-1-F)	98.50%	12.06
FT2 (4-38-2-F)	98.50%	12.06
FT3 (4-38-3-F)	98.50%	34.29
FT4 (4-38-4-F)	98.50%	34.29
FT5 (3-80-1-F)	98.50%	196.1
FT6 (3-80-2-F)	98.50%	196.1
FT7 (3-80-3-F)	98.50%	90.9
FT8 (3-80-4-F)	98.50%	90.9
FT9 (2-165-1-F)	98.50%	350.3
FT10 (2-165-2-F)	98.50%	350.3
FT11 (2-165-3-F)	98.50%	179.8
FT12 (2-165-4-F)	98.50%	179.8
FT13 (3-200-1)	98.50%	71.8
FT14 (3-200-2)	98.50%	71.8
	TOTAL =	1870.5

BALLAST TANKS

TANK	LOAD %	WEIGHT (MT)
CB1 (4-26-1)	0%	0
CB2 (4-26-2)	0%	0
CB3 (3-67-1)	0%	0
CB4 (3-67-2)	0%	0
CB5 (4-264-1)	0%	0
CB6 (4-264-2)	0%	0
	TOTAL =	0

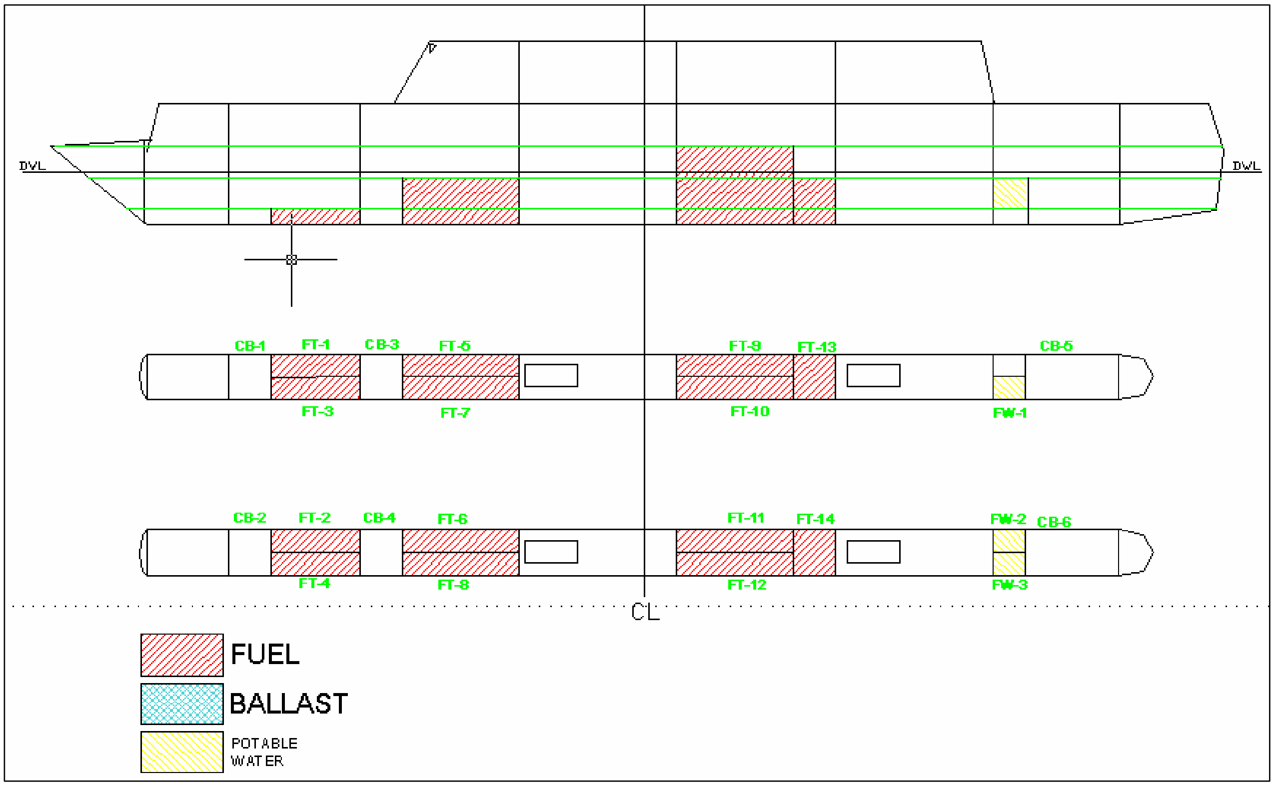
LUBE OIL TANKS

TANK	LOAD %	WEIGHT (MT)
LO STORG (3-116-1-F)	100%	11.5
LO STORG (3-116-2-F)	100%	11.5
LO SETTLE (3-130-1-F)	100%	11.5
LO SETTLE (3-130-2-F)	100%	11.5
LO STORG (3-214-1-F)	100%	11.5
LO STORG (3-214-2-F)	100%	11.5
LO SETTLE (3-227-1-F)	100%	11.5
LO SETTLE (3-227-2-F)	100%	11.5
	TOTAL =	92

FRESH WATER TANKS

TANK	LOAD %	WEIGHT (MT)
FW1	99%	19.75
FW2	99%	19.75
FW3	99%	39.51
	TOTAL =	79.01

LOAD	WEIGHT (MT)	LCG (M)	VCG (M)	TCG (M)
LIGHTSHIP	3034			
FLUIDS	2041.51			
PAYLOAD + FIXED WEIGHTS	1947.49			
TOTAL =	7023	-0.89	5.923	-0.144



HYDROSTATIC PROPERTIES			
Draft Amidships (m)	5.198	LCB from Amidships (+ve fwd) (m)	-0.888
Displacement (tonne)	7023	LCF from Amidsh. (+ve fwd) (m)	-0.816
Heel to Starboard (degrees)	-0.51	KB (m)	2.965
Draft at FP (m)	5.251	KG fluid (m)	5.925
Draft at AP (m)	5.144	BM_t (m)	19.005
Draft at LCF (m)	5.197	BM_L (m)	260.973
Trim (+ve by stern) (m)	-0.107	GM_t (m)	16.046
WL Length (m)	117.442	GM_L (m)	258.014
WL Beam (m)	24.553	KM_t (m)	21.969
Wetted Area (m^2)	3268.975	KM_L (m)	263.937
Waterplane Area (m^2)	1664.682	Immersion (TPc) (tonne/cm)	17.066
Prismatic Coefficient	0.925	MT_c (tonne•m)	154.523
Block Coefficient	0.746	RM at 1deg = GM_t•Disp•sin(1) (tonne•m)	1966.81
Midship Area Coefficient	0.806	Max deck inclination (degrees)	0.5
Waterplane Area Coefficient	0.964	Trim angle (+ve by stern) (degrees)	-0.1

b. Half Loaded

TANK CONFIGURATION

FUEL TANKS

TANK	LOAD %	WEIGHT (MT)
FT1 (4-38-1-F)	98.50%	12.06
FT2 (4-38-2-F)	98.50%	12.06
FT3 (4-38-3-F)	98.50%	34.29
FT4 (4-38-4-F)	98.50%	34.29
FT5 (3-80-1-F)	30.00%	59.7
FT6 (3-80-2-F)	30.00%	59.7
FT7 (3-80-3-F)	98.50%	90.9
FT8 (3-80-4-F)	98.50%	90.9
FT9 (2-165-1-F)	5.00%	17.77
FT10 (2-165-2-F)	5.00%	17.77
FT11 (2-165-3-F)	98.50%	179.8
FT12 (2-165-4-F)	98.50%	179.8
FT13 (3-200-1)	98.50%	71.8
FT14 (3-200-2)	98.50%	71.8
	TOTAL =	932.64

BALLAST TANKS

TANK	LOAD %	WEIGHT (MT)
CB1 (4-26-1)	0%	0
CB2 (4-26-2)	0%	0
CB3 (3-67-1)	0%	0
CB4 (3-67-2)	0%	0
CB5 (4-264-1)	0%	0
CB6 (4-264-2)	0%	0
	TOTAL =	0

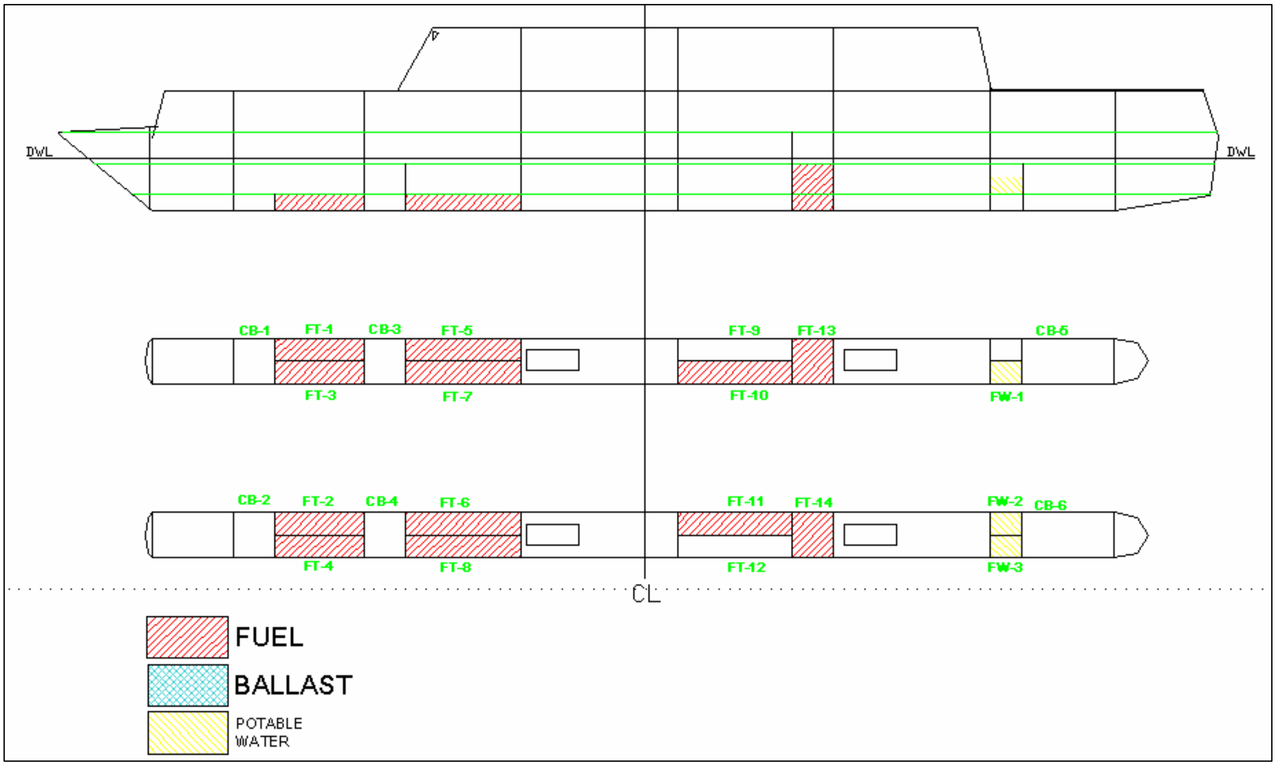
LUBE OIL TANKS

TANK	LOAD %	WEIGHT (MT)
LO STORG (3-116-1-F)	50%	6
LO STORG (3-116-2-F)	50%	6
LO SETTLE (3-130-1-F)	50%	6
LO SETTLE (3-130-2-F)	50%	6
LO STORG (3-214-1-F)	50%	6
LO STORG (3-214-2-F)	50%	6
LO SETTLE (3-227-1-F)	50%	6
LO SETTLE (3-227-2-F)	50%	6
	TOTAL =	48

FRESH WATER TANKS

TANK	LOAD %	WEIGHT (MT)
FW1	50%	9.98
FW2	50%	9.98
FW3	50%	19.95
	TOTAL =	39.91

LOAD		WEIGHT (MT)			
LIGHTSHIP		3034			
FLUIDS		1020.55			
PAYLOAD + FIXED WEIGHTS		1741.45			
			LCG (M)	**VCG (M)**	**TCG (M)**
	TOTAL =	**5796**	**-0.55**	**6.167**	**-0.142**



HYDROSTATIC PROPERTIES			
Draft Amidships (m)	4.473	**LCB from Amidships (+ve fwd) (m)**	-0.549
Displacement (tonne)	5796	**LCF from Amidships (+ve fwd) (m)**	-0.893
Heel to Starboard (degrees)	-0.43	**KB (m)**	2.569
Draft at FP (m)	4.592	**KG fluid (m)**	6.249
Draft at AP (m)	4.353	**BM_t (m)**	22.404
Draft at LCF (m)	4.471	**BM_L (m)**	305.352
Trim (+ve by stern) (m)	-0.239	**GM_t (m)**	18.725
WL Length (m)	116.474	**GM_L (m)**	301.673
WL Beam (m)	24.416	**KM_t (m)**	24.973
Wetted Area (m^2)	2923.9	**KM_L (m)**	307.921
Waterpl.ane Area (m^2)	1623.589	**Immersion (TP_c) (tonne/cm)**	16.645
Prismatic Coefficient	0.912	**MT_c (tonne•m)**	149.094
Block Coefficient	0.724	**RM at 1deg = GM_t•Disp•sin(1) (tonne•m)**	1894.008
Midship Area Coefficient	0.794	**Max deck inclination (degrees)**	0.4
Waterplane Area Coefficient	0.963	**Trim angle (+ve by stern) (degrees)**	-0.1

c. Empty

TANK CONFIGURATION

FUEL TANKS

TANK	LOAD %	WEIGHT (MT)
FT1 (4-38-1-F)	5.00%	0.612
FT2 (4-38-2-F)	5.00%	0.612
FT3 (4-38-3-F)	5.00%	1.74
FT4 (4-38-4-F)	5.00%	1.74
FT5 (3-80-1-F)	5.00%	9.95
FT6 (3-80-2-F)	5.00%	9.95
FT7 (3-80-3-F)	5.00%	4.606
FT8 (3-80-4-F)	5.00%	4.606
FT9 (2-165-1-F)	5.00%	17.77
FT10 (2-165-2-F)	5.00%	17.77
FT11 (2-165-3-F)	5.00%	9.13
FT12 (2-165-4-F)	5.00%	9.13
FT13 (3-200-1)	5.00%	3.638
FT14 (3-200-2)	5.00%	3.638
	TOTAL =	94.892

BALLAST TANKS

TANK	LOAD %	WEIGHT (MT)
CB1 (4-26-1)	0%	0
CB2 (4-26-2)	0%	0
CB3 (3-67-1)	0%	0
CB4 (3-67-2)	0%	0
CB5 (4-264-1)	0%	0
CB6 (4-264-2)	0%	0
	TOTAL =	0

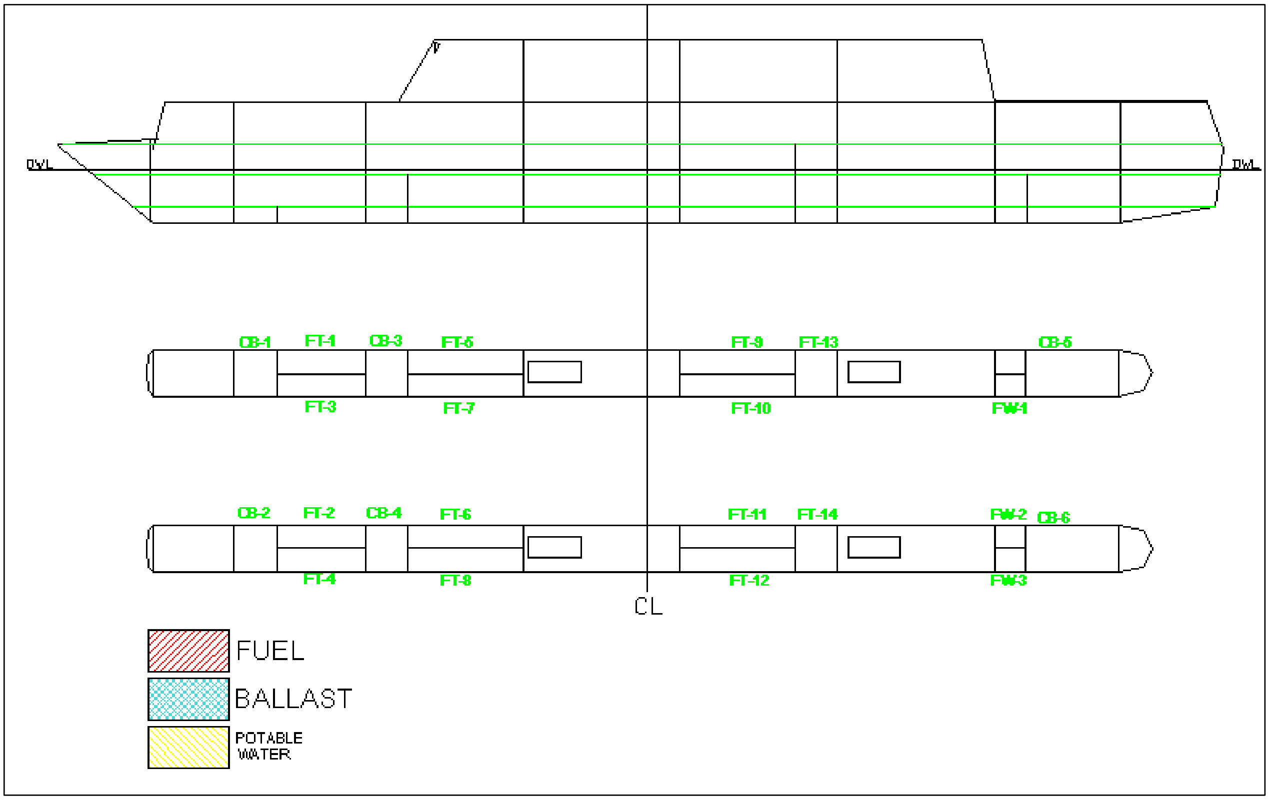
LUBE OIL TANKS

TANK	LOAD %	WEIGHT (MT)
LO STORG (3-116-1-F)	0%	0
LO STORG (3-116-2-F)	0%	0
LO SETTLE (3-130-1-F)	0%	0
LO SETTLE (3-130-2-F)	0%	0
LO STORG (3-214-1-F)	0%	0
LO STORG (3-214-2-F)	0%	0
LO SETTLE (3-227-1-F)	0%	0
LO SETTLE (3-227-2-F)	0%	0
	TOTAL =	0

FRESH WATER TANKS

TANK	LOAD %	WEIGHT (MT)
FW1	0%	0
FW2	0%	0
FW3	0%	0
	TOTAL =	0

LOAD		WEIGHT (MT)			
LIGHTSHIP		3034			
FLUIDS		94.892			
PAYLOAD + FIXED WEIGHTS		1556.108			
			LCG (M)	**VCG (M)**	**TCG (M)**
	TOTAL =	**4685**	**-0.64**	**6.698**	**-0.134**



HYDROSTATIC PROPERTIES			
Draft Amidships (m)	3.794	**LCB from Amidships (+ve fwd) (m)**	-0.639
Displacement (tonne)	4685	**LCF from Amidships (+ve fwd) (m)**	-1.116
Heel to Starboard (degrees)	-0.37	**KB (m)**	2.198
Draft at FP (m)	3.884	**KG fluid (m)**	6.888
Draft at AP (m)	3.705	**BM_t (m)**	26.85
Draft at LCF (m)	3.792	**BM_L (m)**	361.771
Trim (+ve by stern) (m)	-0.179	**GM_t (m)**	22.161
WL Length (m)	115.457	**GM_L (m)**	357.082
WL Beam (m)	24.248	**KM_t (m)**	29.048
Wetted Area (m^2)	2602.673	**KM_L (m)**	363.969
Waterplane Area (m^2)	1571.721	**Immersion (TP_c) (tonne/cm)**	16.113
Prismatic Coefficient	0.916	**MT_c (tonne•m)**	142.65
Block Coefficient	0.717	**RM at 1deg = GMt•Disp•sin(1) (tonne•m)**	1811.897
Midship Area Coefficient	0.783	**Max deck inclination (degrees)**	0.4
Waterplane Area Coefficient	0.968	**Trim angle (+ve by stern) (degrees)**	-0.1

2. HYDROSTATICS

Draft Amidships (m)	0	1	2	3	4	5	6
Displacement (tonne)	0	711	1932	3433	5021	6687	8395
Heel to Starboard (degrees)	0	0	0	0	0	0	0
Draft at FP (m)	0	1	2	3	4	5	6
Draft at AP (m)	0	1	2	3	4	5	6
Draft at LCF (m)	0	1	2	3	4	5	6
Trim (+ve by stern) (m)	0	0	0	0	0	0	0
WL Length (m)	93.75	108.476	112.72	114.142	115.564	116.986	118.408
WL Beam (m)	0	21.62	23.8	24.039	24.279	24.518	24.659
Wetted Area (m^2)	0	1116.502	1751.806	2226.172	2699.209	3174.943	3651.182
Waterplane Area (m^2)	0	965.769	1409.245	1508.304	1586.941	1662.516	1666.886
Prismatic Coefficient	0	0.935	0.932	0.94	0.94	0.937	0.932
Block Coefficient	0	0.696	0.643	0.72	0.749	0.758	0.786
Midship Area Coefficient	0	0.744	0.69	0.767	0.797	0.809	0.843
Waterpl.ane Area Coefficient	0	0.969	0.962	0.974	0.971	0.966	0.96
LCB from Amidships (+ve fwd) (m)	1.702	-0.209	-0.875	-1.147	-1.19	-1.14	-1.061
LCF from Amidships (+ve fwd) (m)	1.702	-0.756	-1.459	-1.449	-1.149	-0.867	-0.607
KB (m)	0	0.582	1.181	1.76	2.312	2.858	3.395
KG (m)	5.923	5.923	5.923	5.923	5.923	5.923	5.923
BMt (m)	0	103.277	58.417	35.192	25.29	19.872	16.139
BM_L (m)	0	1289.219	737.556	465.726	341.695	272.684	220.686
GMt (m)	-5.923	97.937	53.676	31.029	21.679	16.807	13.611
GM_L (m)	-5.923	1283.879	732.815	461.563	338.083	269.618	218.158
KMt (m)	0	103.86	59.599	36.952	27.602	22.73	19.534
KM_L (m)	0	1289.802	738.738	467.486	344.006	275.541	224.081
Immersion (TPc) (tonne/cm)	0	9.901	14.448	15.463	16.269	17.044	17.089
MTc (tonne•m)	0	77.802	120.699	135.115	144.743	153.741	156.165
RM at 1deg = GMt.Disp.sin(1) (tonne•m)	0	1214.663	1809.383	1859.015	1899.558	1961.396	1994.164
Max deck inclination (degrees)	0	0	0	0	0	0	0
Trim angle (+ve by stern) (degrees)	0	0	0	0	0	0	0

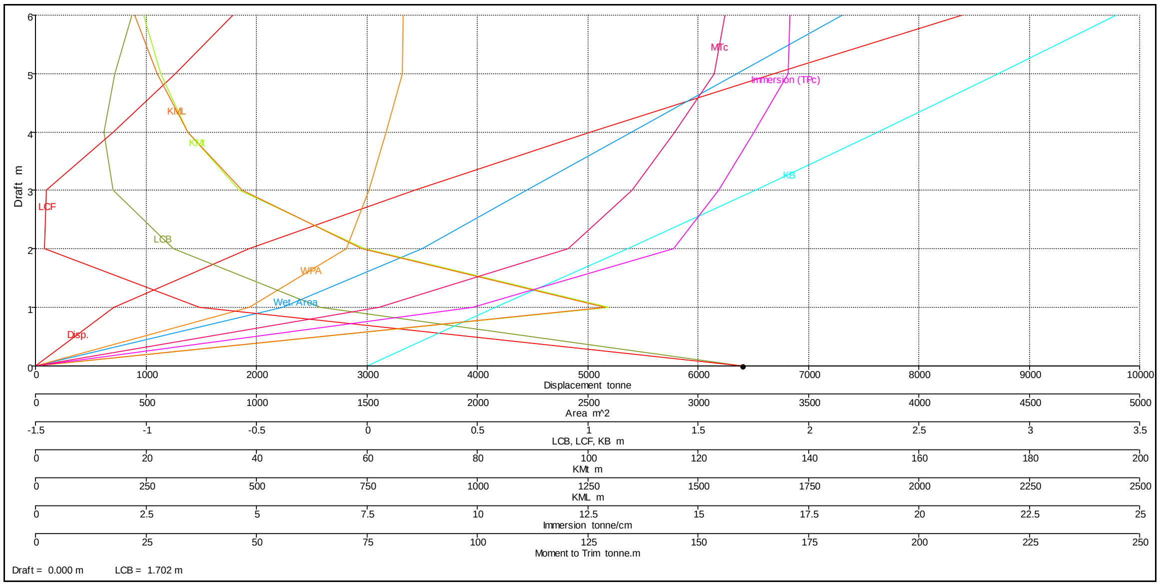


Figure XX – Hydrostatics Curves

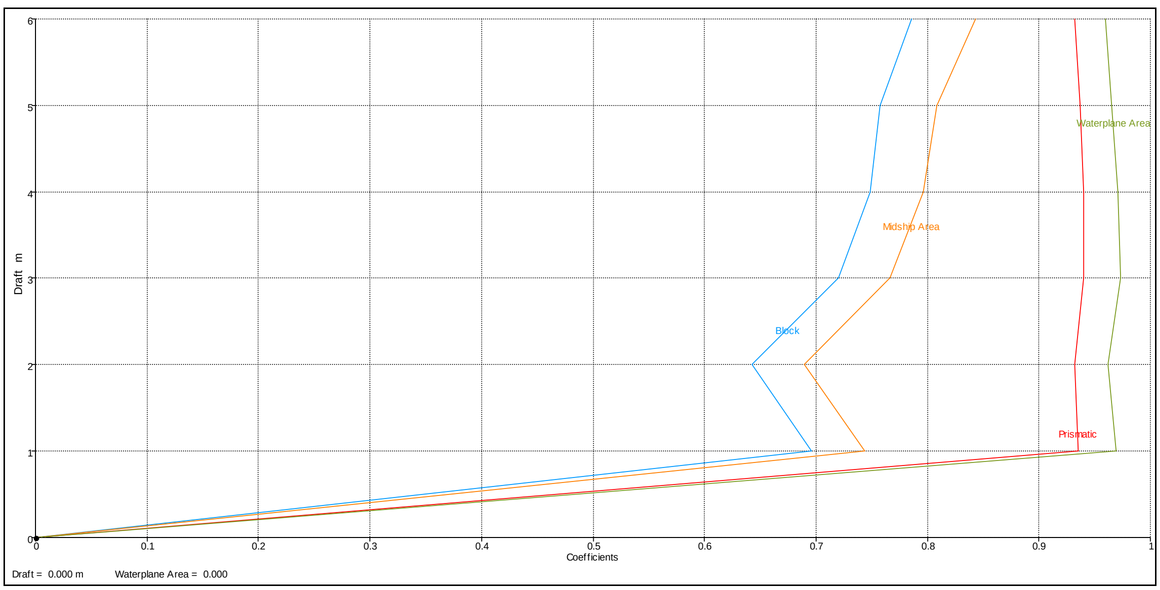


Figure XX – Curves of Form

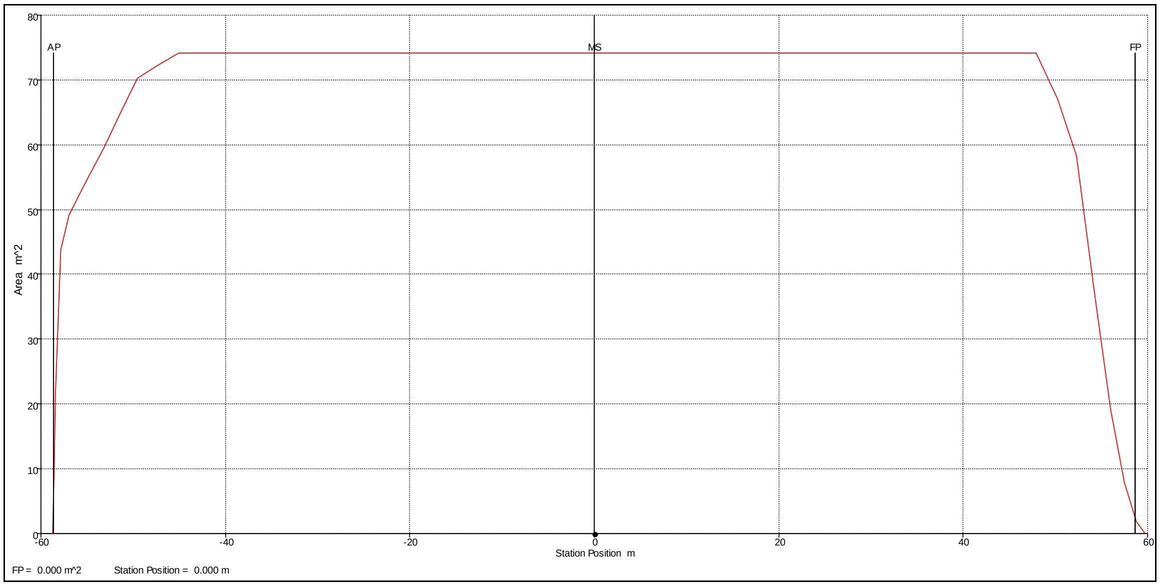


Figure XX – Curve of Areas

3. TANK CALIBRATION

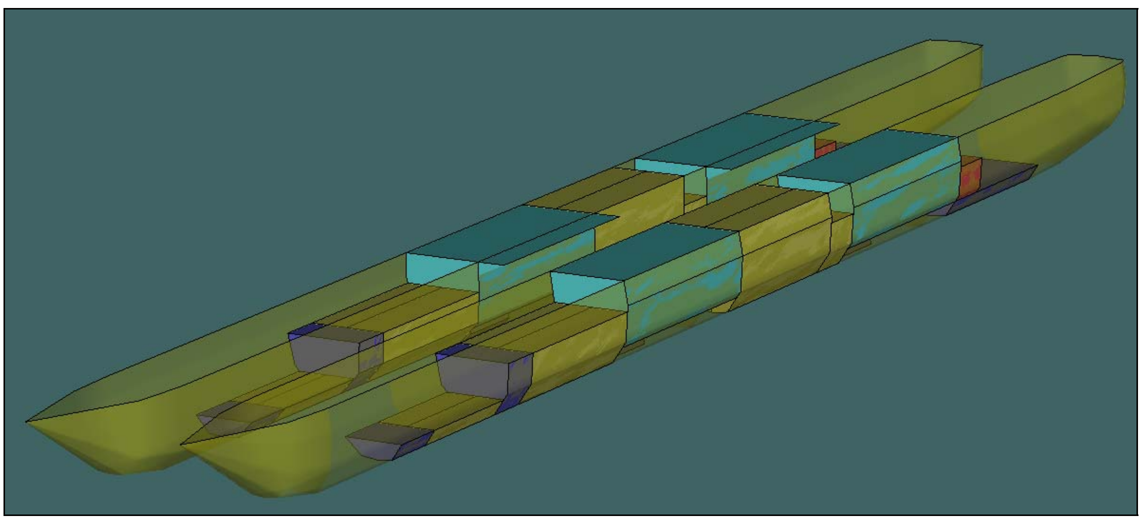


Figure XX – Tank Arrangement

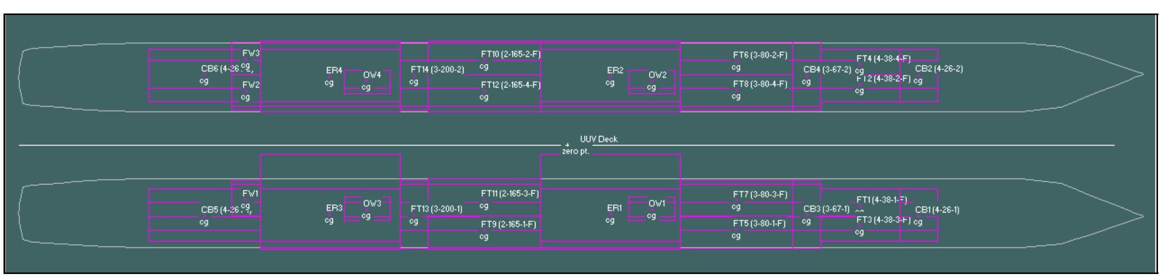
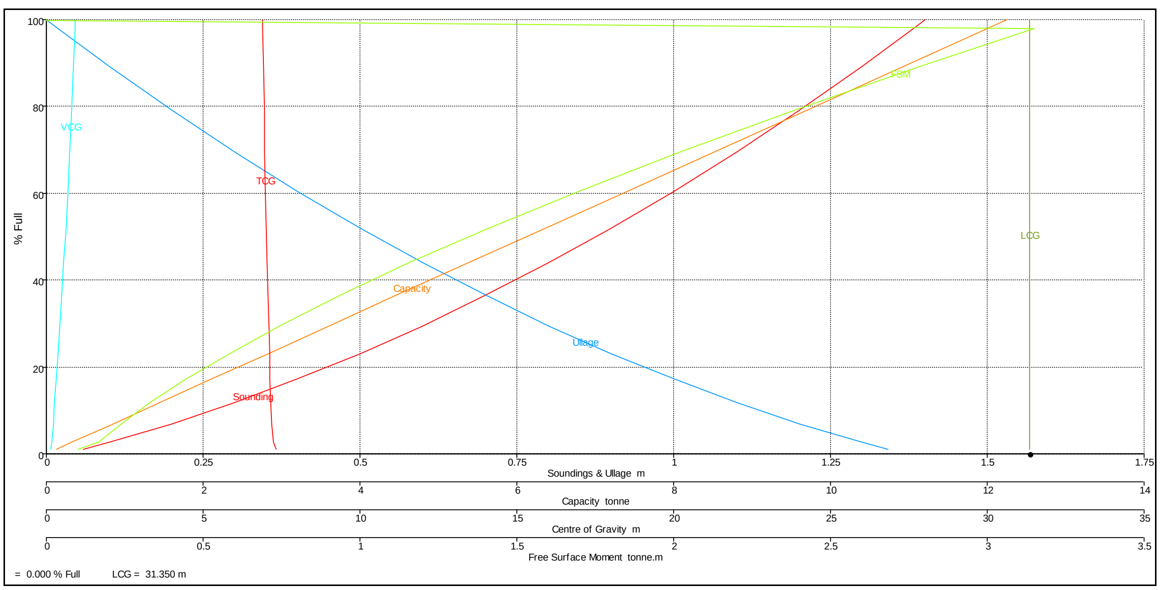
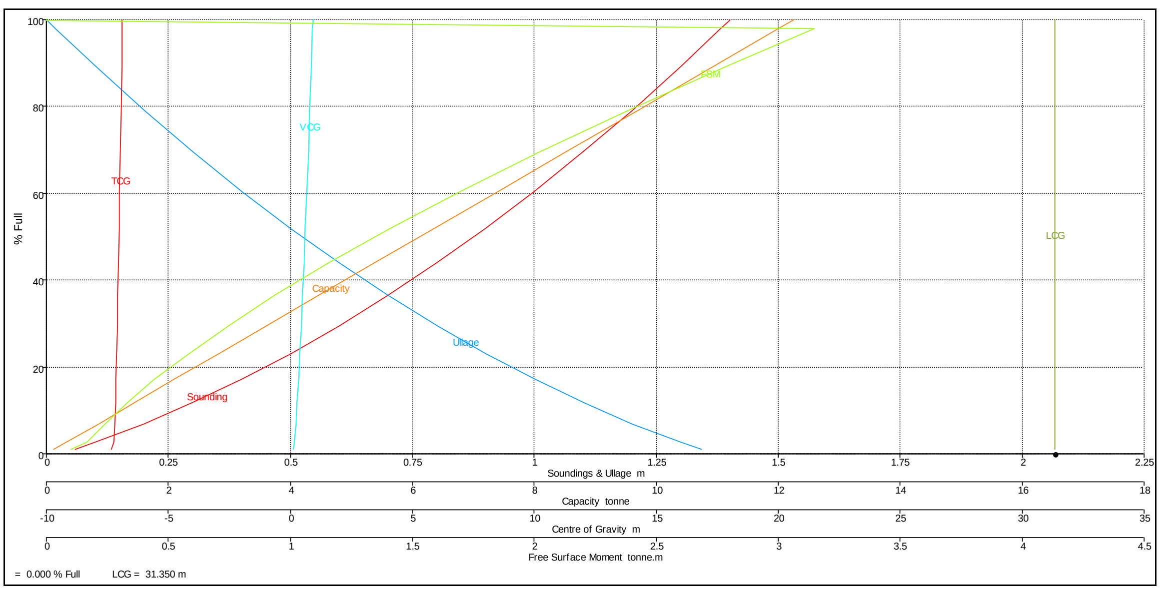


Figure XX – Tank Arrangement

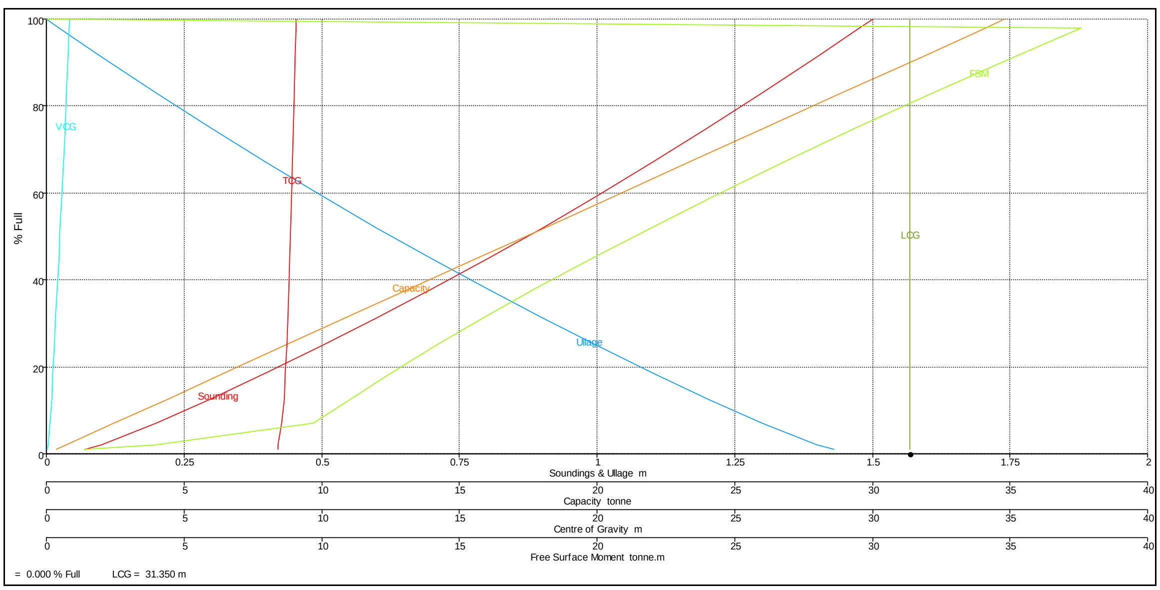
FT1 (4-38-1-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
1.401	0	100	12.97	12.248	31.35	6.889	0.928	0
1.4	0.001	99.9	12.957	12.235	31.35	6.889	0.928	0
1.382	0.019	98	12.709	12.001	31.35	6.894	0.917	3.15
1.3	0.101	89.2	11.576	10.931	31.35	6.915	0.865	2.785
1.2	0.201	79.1	10.263	9.691	31.35	6.94	0.804	2.381
1.1	0.301	69.5	9.019	8.516	31.35	6.966	0.742	2.019
1	0.401	60.5	7.843	7.406	31.35	6.991	0.681	1.696
0.9	0.501	51.9	6.736	6.36	31.35	7.016	0.62	1.408
0.8	0.601	43.9	5.697	5.379	31.35	7.041	0.56	1.156
0.7	0.701	36.4	4.726	4.463	31.35	7.066	0.501	0.935
0.6	0.801	29.5	3.824	3.611	31.35	7.091	0.442	0.745
0.5	0.901	23.1	2.99	2.824	31.35	7.115	0.384	0.582
0.4	1.001	17.2	2.225	2.101	31.35	7.14	0.328	0.445
0.3	1.101	11.8	1.529	1.443	31.35	7.166	0.272	0.331
0.2	1.201	6.9	0.9	0.85	31.35	7.195	0.217	0.239
0.1	1.301	2.6	0.34	0.322	31.35	7.245	0.163	0.165
0.058	1.343	1	0.13	0.122	31.35	7.323	0.138	0.1



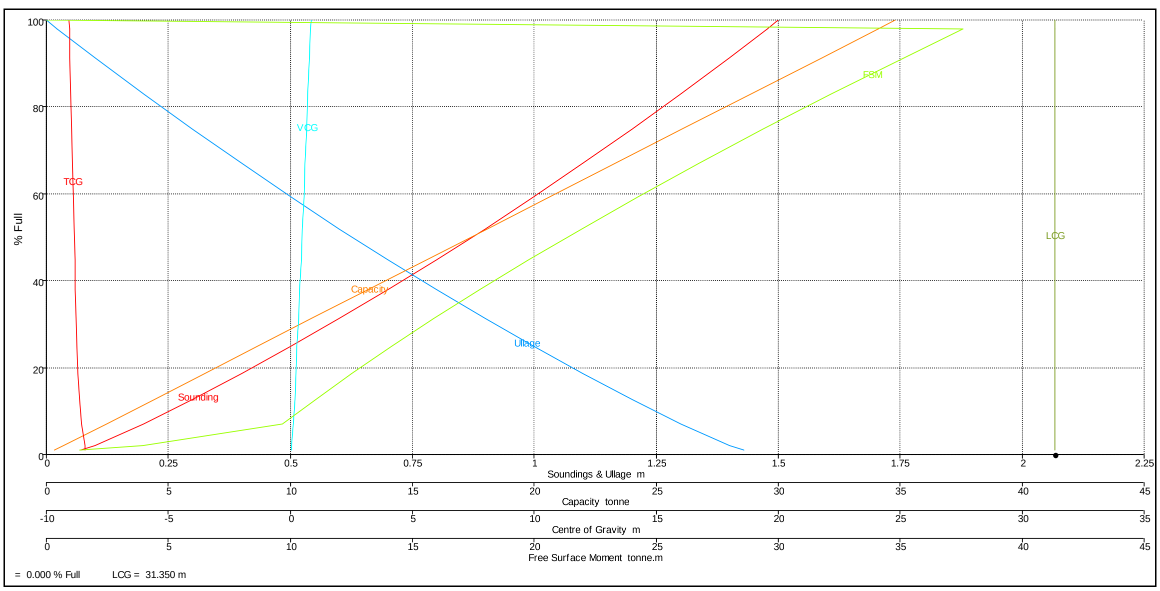
FT2 (4-38-2-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
1.401	0	100	12.97	12.248	31.35	-6.889	0.928	0
1.4	0.001	99.9	12.957	12.235	31.35	-6.889	0.928	0
1.382	0.019	98	12.709	12.001	31.35	-6.894	0.917	3.15
1.3	0.101	89.2	11.576	10.931	31.35	-6.915	0.865	2.785
1.2	0.201	79.1	10.263	9.691	31.35	-6.94	0.804	2.381
1.1	0.301	69.5	9.019	8.516	31.35	-6.966	0.742	2.019
1	0.401	60.5	7.843	7.406	31.35	-6.991	0.681	1.696
0.9	0.501	51.9	6.736	6.36	31.35	-7.016	0.62	1.408
0.8	0.601	43.9	5.697	5.379	31.35	-7.041	0.56	1.156
0.7	0.701	36.4	4.726	4.463	31.35	-7.066	0.501	0.935
0.6	0.801	29.5	3.824	3.611	31.35	-7.091	0.442	0.745
0.5	0.901	23.1	2.99	2.824	31.35	-7.115	0.384	0.582
0.4	1.001	17.2	2.225	2.101	31.35	-7.14	0.328	0.445
0.3	1.101	11.8	1.529	1.443	31.35	-7.166	0.272	0.331
0.2	1.201	6.9	0.9	0.85	31.35	-7.195	0.217	0.239
0.1	1.301	2.6	0.34	0.322	31.35	-7.245	0.163	0.165
0.058	1.343	1	0.13	0.122	31.35	-7.323	0.138	0.1



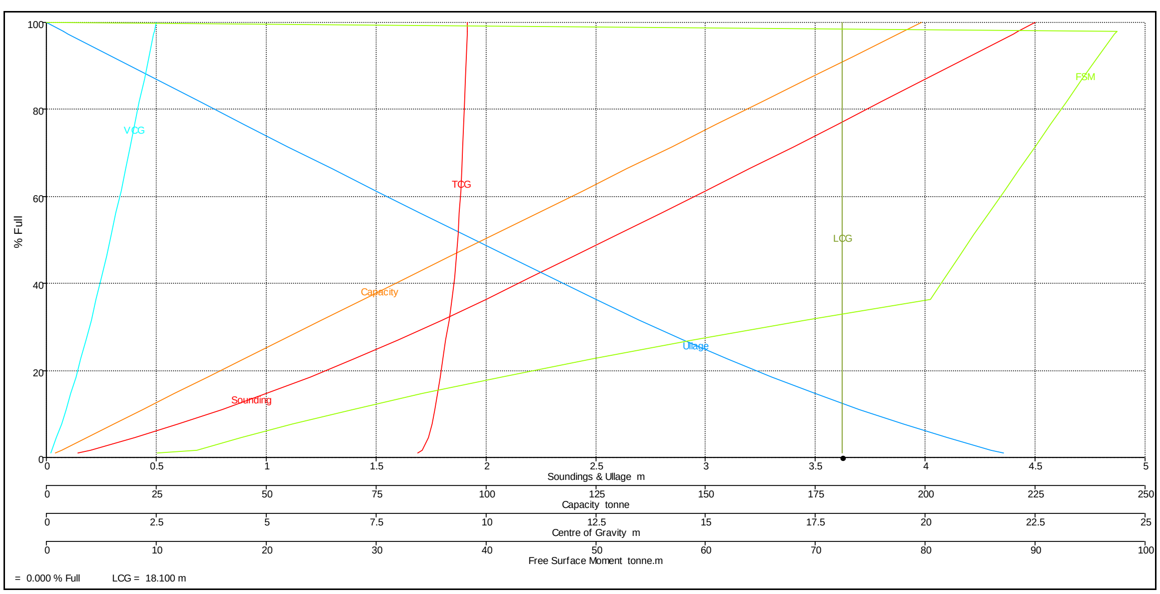
FT3 (4-38-3-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
1.5	0	100	36.863	34.81	31.35	9.061	0.844	0
1.477	0.023	98	36.121	34.109	31.35	9.054	0.831	37.576
1.4	0.1	91.4	33.681	31.805	31.35	9.029	0.787	35.161
1.3	0.2	83	30.59	28.886	31.35	8.997	0.73	32.18
1.2	0.3	74.8	27.591	26.054	31.35	8.965	0.673	29.373
1.1	0.4	67	24.682	23.308	31.35	8.933	0.617	26.734
1	0.5	59.3	21.865	20.648	31.35	8.901	0.561	24.258
0.9	0.6	51.9	19.14	18.074	31.35	8.869	0.506	21.94
0.8	0.7	44.8	16.505	15.586	31.35	8.836	0.451	19.774
0.7	0.8	37.9	13.962	13.184	31.35	8.802	0.396	17.756
0.6	0.9	31.2	11.51	10.869	31.35	8.768	0.342	15.88
0.5	1	24.8	9.149	8.64	31.35	8.731	0.289	14.141
0.4	1.1	18.7	6.88	6.497	31.35	8.69	0.235	12.534
0.3	1.2	12.8	4.702	4.44	31.35	8.639	0.182	11.053
0.2	1.3	7.1	2.615	2.469	31.35	8.554	0.128	9.694
0.1	1.4	2.1	0.761	0.718	31.35	8.4	0.067	3.959
0.07	1.43	1	0.371	0.351	31.35	8.4	0.047	1.369



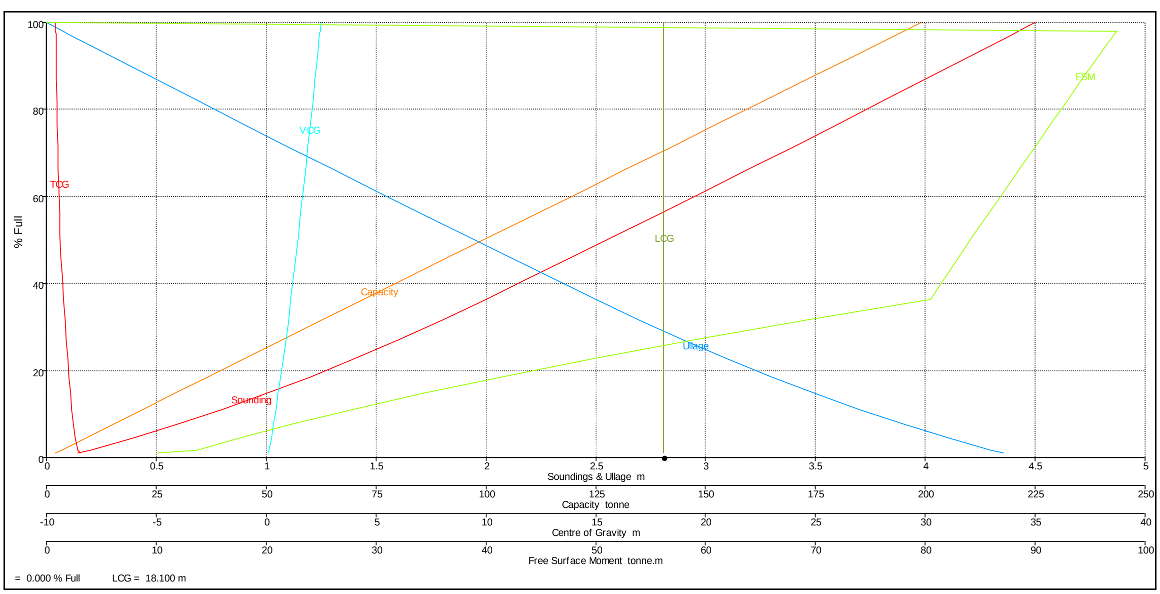
FT4 (4-38-4-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
1.5	0	100	36.863	34.81	31.35	-9.061	0.844	0
1.477	0.023	98	36.121	34.109	31.35	-9.054	0.831	37.576
1.4	0.1	91.4	33.681	31.805	31.35	-9.029	0.787	35.161
1.3	0.2	83	30.59	28.886	31.35	-8.997	0.73	32.18
1.2	0.3	74.8	27.591	26.054	31.35	-8.965	0.673	29.373
1.1	0.4	67	24.682	23.308	31.35	-8.933	0.617	26.734
1	0.5	59.3	21.865	20.648	31.35	-8.901	0.561	24.258
0.9	0.6	51.9	19.14	18.074	31.35	-8.869	0.506	21.94
0.8	0.7	44.8	16.505	15.586	31.35	-8.836	0.451	19.774
0.7	0.8	37.9	13.962	13.184	31.35	-8.802	0.396	17.756
0.6	0.9	31.2	11.51	10.869	31.35	-8.768	0.342	15.88
0.5	1	24.8	9.149	8.64	31.35	-8.731	0.289	14.141
0.4	1.1	18.7	6.88	6.497	31.35	-8.69	0.235	12.534
0.3	1.2	12.8	4.702	4.44	31.35	-8.639	0.182	11.053
0.2	1.3	7.1	2.615	2.469	31.35	-8.554	0.128	9.694
0.1	1.4	2.1	0.761	0.718	31.35	-8.4	0.067	3.959
0.07	1.43	1	0.371	0.351	31.35	-8.4	0.047	1.369



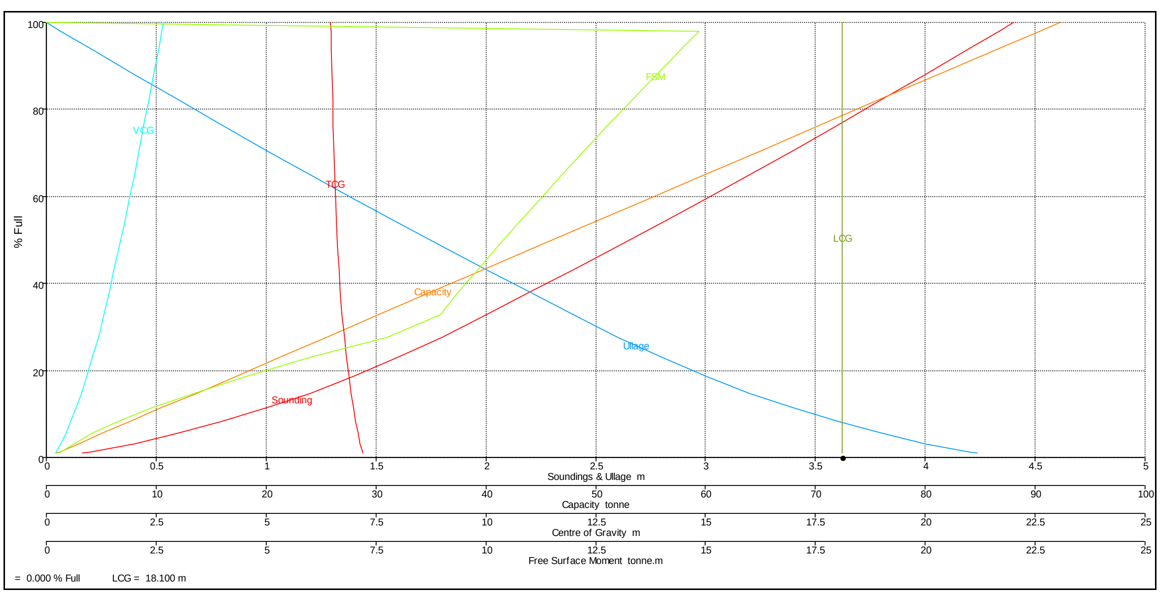
FT5 (3-80-1-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
4.5	0	100	210.877	199.131	18.1	9.575	2.492	0
4.424	0.076	98	206.637	195.128	18.1	9.57	2.452	97.424
4.4	0.1	97.4	205.329	193.892	18.1	9.568	2.439	97.248
4.2	0.3	92.1	194.277	183.456	18.1	9.552	2.333	95.765
4	0.5	86.9	183.281	173.072	18.1	9.536	2.227	94.298
3.8	0.7	81.7	172.342	162.742	18.1	9.518	2.121	92.845
3.6	0.9	76.6	161.459	152.466	18.1	9.499	2.015	91.408
3.4	1.1	71.4	150.633	142.243	18.1	9.478	1.908	89.985
3.2	1.3	66.3	139.863	132.073	18.1	9.455	1.801	88.577
3	1.5	61.2	129.151	121.957	18.1	9.43	1.693	87.185
2.8	1.7	56.2	118.494	111.894	18.1	9.401	1.584	85.806
2.6	1.9	51.2	107.895	101.885	18.1	9.367	1.475	84.443
2.4	2.1	46.2	97.352	91.929	18.1	9.328	1.364	83.094
2.2	2.3	41.2	86.865	82.027	18.1	9.281	1.251	81.759
2	2.5	36.2	76.435	72.178	18.1	9.222	1.135	80.438
1.8	2.7	31.4	66.291	62.599	18.1	9.158	1.018	69.065
1.6	2.9	26.9	56.663	53.507	18.1	9.093	0.902	58.818
1.4	3.1	22.5	47.549	44.901	18.1	9.029	0.787	49.639
1.2	3.3	18.5	38.951	36.782	18.1	8.965	0.673	41.468
1	3.5	14.6	30.869	29.149	18.1	8.901	0.561	34.246
0.8	3.7	11	23.302	22.004	18.1	8.836	0.451	27.916
0.6	3.9	7.7	16.25	15.344	18.1	8.768	0.342	22.418
0.4	4.1	4.6	9.713	9.172	18.1	8.69	0.235	17.695
0.2	4.3	1.8	3.692	3.486	18.1	8.554	0.128	13.686
0.144	4.356	1	2.109	1.991	18.1	8.452	0.094	10.126



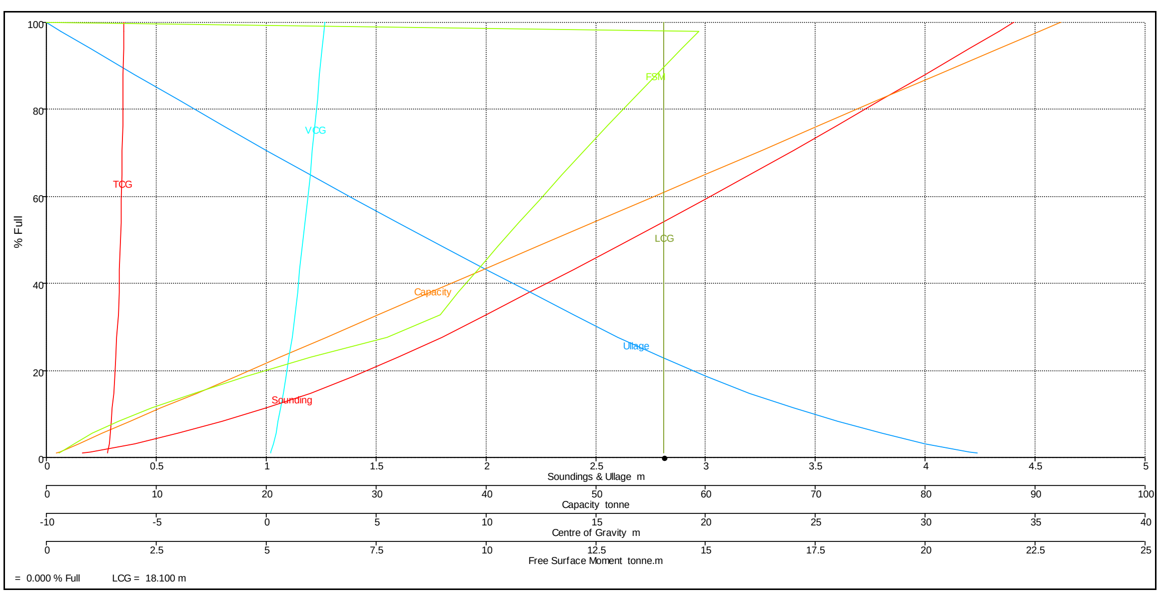
FT6 (3-80-2-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
4.5	0	100	210.877	199.131	18.1	-9.575	2.492	0
4.424	0.076	98	206.637	195.128	18.1	-9.57	2.452	97.424
4.4	0.1	97.4	205.329	193.892	18.1	-9.568	2.439	97.248
4.2	0.3	92.1	194.277	183.456	18.1	-9.552	2.333	95.765
4	0.5	86.9	183.281	173.072	18.1	-9.536	2.227	94.298
3.8	0.7	81.7	172.342	162.742	18.1	-9.518	2.121	92.845
3.6	0.9	76.6	161.459	152.466	18.1	-9.499	2.015	91.408
3.4	1.1	71.4	150.633	142.243	18.1	-9.478	1.908	89.985
3.2	1.3	66.3	139.863	132.073	18.1	-9.455	1.801	88.577
3	1.5	61.2	129.151	121.957	18.1	-9.43	1.693	87.185
2.8	1.7	56.2	118.494	111.894	18.1	-9.401	1.584	85.806
2.6	1.9	51.2	107.895	101.885	18.1	-9.367	1.475	84.443
2.4	2.1	46.2	97.351	91.929	18.1	-9.328	1.364	83.093
2.2	2.3	41.2	86.865	82.027	18.1	-9.281	1.251	81.759
2	2.5	36.2	76.435	72.178	18.1	-9.222	1.135	80.438
1.8	2.7	31.4	66.291	62.599	18.1	-9.158	1.018	69.065
1.6	2.9	26.9	56.663	53.507	18.1	-9.093	0.902	58.818
1.4	3.1	22.5	47.549	44.901	18.1	-9.029	0.787	49.639
1.2	3.3	18.5	38.951	36.782	18.1	-8.965	0.673	41.468
1	3.5	14.6	30.869	29.149	18.1	-8.901	0.561	34.246
0.8	3.7	11	23.302	22.004	18.1	-8.836	0.451	27.916
0.6	3.9	7.7	16.25	15.344	18.1	-8.768	0.342	22.418
0.4	4.1	4.6	9.713	9.172	18.1	-8.69	0.235	17.695
0.2	4.3	1.8	3.692	3.486	18.1	-8.554	0.128	13.686
0.144	4.356	1	2.109	1.991	18.1	-8.452	0.094	10.126



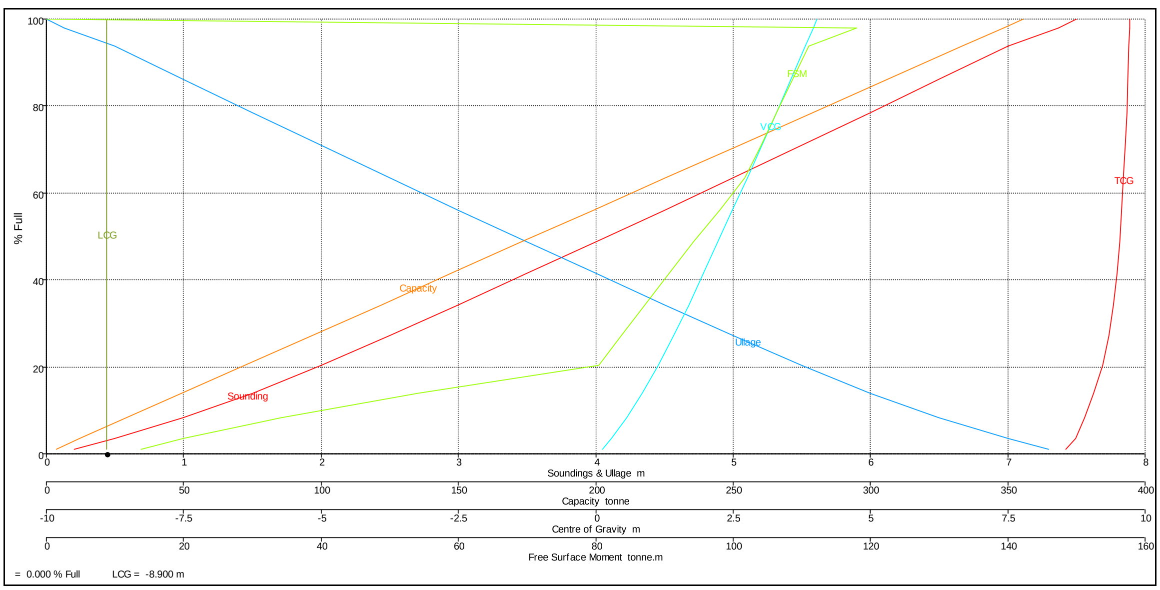
FT7 (3-80-3-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
4.401	0	100	97.725	92.282	18.1	6.469	2.67	0
4.4	0.001	100	97.697	92.255	18.1	6.469	2.67	0
4.335	0.066	98	95.76	90.426	18.1	6.473	2.633	14.854
4.2	0.201	93.9	91.787	86.674	18.1	6.483	2.558	14.459
4	0.401	88	85.956	81.168	18.1	6.498	2.447	13.884
3.8	0.601	82.1	80.204	75.737	18.1	6.513	2.336	13.325
3.6	0.801	76.3	74.531	70.38	18.1	6.529	2.224	12.781
3.4	1.001	70.5	68.937	65.097	18.1	6.546	2.113	12.252
3.2	1.201	64.9	63.421	59.888	18.1	6.565	2.001	11.738
3	1.401	59.3	57.984	54.754	18.1	6.585	1.889	11.239
2.8	1.601	53.9	52.626	49.695	18.1	6.607	1.775	10.754
2.6	1.801	48.4	47.347	44.71	18.1	6.632	1.661	10.283
2.4	2.001	43.1	42.147	39.799	18.1	6.661	1.546	9.826
2.2	2.201	37.9	37.025	34.963	18.1	6.694	1.428	9.383
2	2.401	32.7	31.982	30.201	18.1	6.736	1.306	8.953
1.8	2.601	27.7	27.057	25.55	18.1	6.786	1.179	7.754
1.6	2.801	23	22.481	21.229	18.1	6.838	1.053	6.017
1.4	3.001	18.7	18.292	17.273	18.1	6.889	0.928	4.562
1.2	3.201	14.8	14.489	13.682	18.1	6.94	0.804	3.362
1	3.401	11.3	11.072	10.456	18.1	6.991	0.681	2.394
0.8	3.601	8.2	8.042	7.594	18.1	7.041	0.56	1.632
0.6	3.801	5.5	5.399	5.098	18.1	7.091	0.442	1.052
0.4	4.001	3.2	3.142	2.967	18.1	7.14	0.328	0.628
0.2	4.201	1.3	1.271	1.2	18.1	7.195	0.217	0.337
0.164	4.237	1	0.974	0.92	18.1	7.209	0.198	0.297



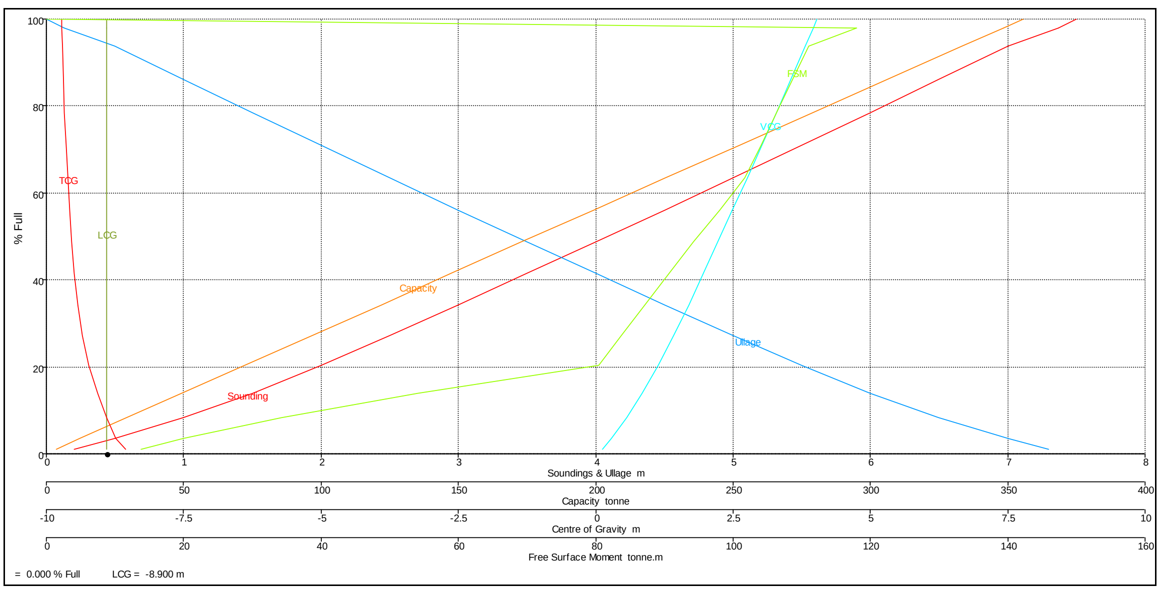
FT8 (3-80-4-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
4.401	0	100	97.725	92.282	18.1	-6.469	2.67	0
4.4	0.001	100	97.697	92.255	18.1	-6.469	2.67	0
4.335	0.066	98	95.76	90.426	18.1	-6.473	2.633	14.854
4.2	0.201	93.9	91.787	86.674	18.1	-6.483	2.558	14.459
4	0.401	88	85.956	81.168	18.1	-6.498	2.447	13.884
3.8	0.601	82.1	80.204	75.737	18.1	-6.513	2.336	13.325
3.6	0.801	76.3	74.531	70.38	18.1	-6.529	2.224	12.781
3.4	1.001	70.5	68.937	65.097	18.1	-6.546	2.113	12.252
3.2	1.201	64.9	63.421	59.888	18.1	-6.565	2.001	11.738
3	1.401	59.3	57.984	54.754	18.1	-6.585	1.889	11.239
2.8	1.601	53.9	52.626	49.695	18.1	-6.607	1.775	10.754
2.6	1.801	48.4	47.347	44.71	18.1	-6.632	1.661	10.283
2.4	2.001	43.1	42.147	39.799	18.1	-6.661	1.546	9.826
2.2	2.201	37.9	37.025	34.963	18.1	-6.694	1.428	9.383
2	2.401	32.7	31.982	30.201	18.1	-6.736	1.306	8.953
1.8	2.601	27.7	27.057	25.55	18.1	-6.786	1.179	7.754
1.6	2.801	23	22.481	21.229	18.1	-6.838	1.053	6.017
1.4	3.001	18.7	18.292	17.273	18.1	-6.889	0.928	4.562
1.2	3.201	14.8	14.489	13.682	18.1	-6.94	0.804	3.362
1	3.401	11.3	11.072	10.456	18.1	-6.991	0.681	2.394
0.8	3.601	8.2	8.042	7.594	18.1	-7.041	0.56	1.632
0.6	3.801	5.5	5.399	5.098	18.1	-7.091	0.442	1.052
0.4	4.001	3.2	3.142	2.967	18.1	-7.14	0.328	0.628
0.2	4.201	1.3	1.271	1.2	18.1	-7.195	0.217	0.337
0.164	4.237	1	0.974	0.92	18.1	-7.209	0.198	0.297



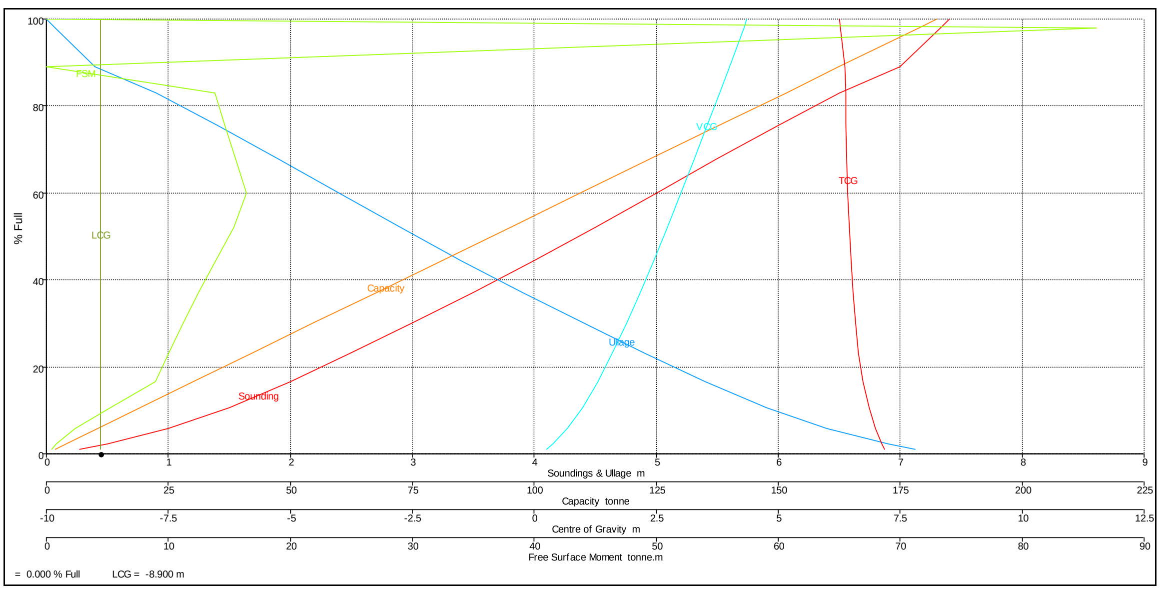
FT9 (2-165-1-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
7.5	0	100	376.637	355.659	-8.9	9.726	4.026	0
7.372	0.128	98	369.067	348.51	-8.9	9.721	3.956	118.037
7	0.5	93.7	352.997	333.335	-8.9	9.708	3.807	111.097
6.5	1	86.1	324.142	306.088	-8.9	9.687	3.545	108.718
6	1.5	78.5	295.496	279.036	-8.9	9.664	3.283	106.374
5.5	2	70.9	267.057	252.182	-8.9	9.639	3.02	104.064
5	2.5	63.4	238.826	225.524	-8.9	9.609	2.756	101.787
4.5	3	56	210.877	199.131	-8.9	9.575	2.492	97.995
4	3.5	48.7	183.281	173.072	-8.9	9.536	2.227	94.298
3.5	4	41.4	156.039	147.347	-8.9	9.489	1.961	90.695
3	4.5	34.3	129.151	121.957	-8.9	9.43	1.693	87.185
2.5	5	27.2	102.616	96.9	-8.9	9.348	1.42	83.766
2	5.5	20.3	76.435	72.178	-8.9	9.222	1.135	80.438
1.5	6	13.8	52.042	49.143	-8.9	9.061	0.844	54.099
1	6.5	8.2	30.869	29.149	-8.9	8.901	0.561	34.246
0.5	7	3.4	12.917	12.197	-8.9	8.731	0.289	19.963
0.203	7.297	1	3.766	3.556	-8.9	8.557	0.129	13.733



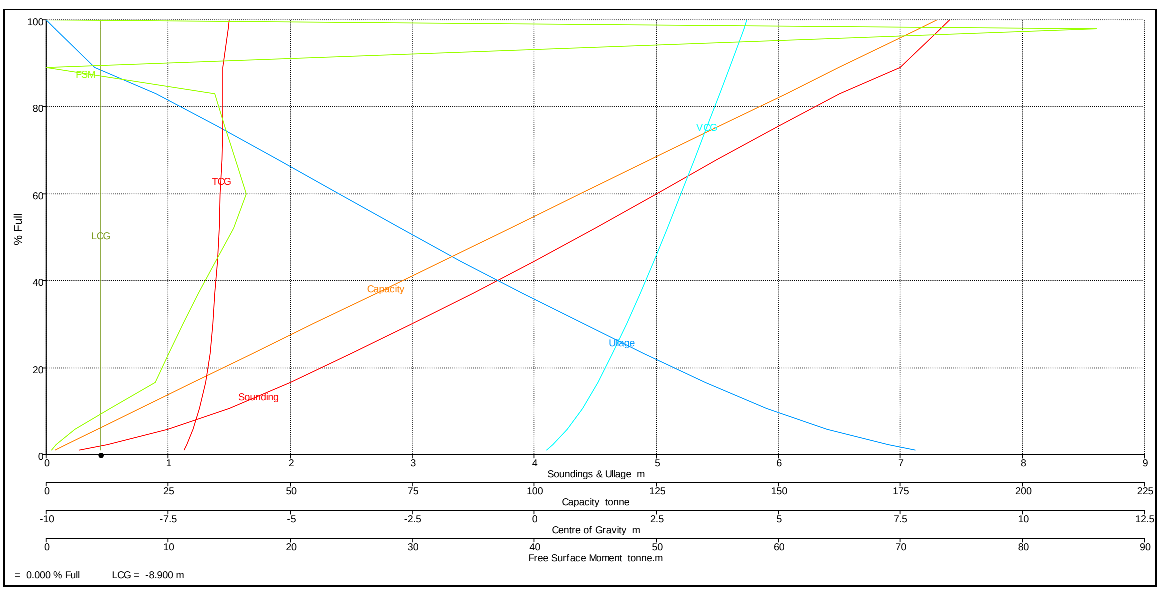
FT10 (2-165-2-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
7.5	0	100	376.637	355.659	-8.9	-9.726	4.026	0
7.372	0.128	98	369.067	348.51	-8.9	-9.721	3.956	118.037
7	0.5	93.7	352.997	333.335	-8.9	-9.708	3.807	111.097
6.5	1	86.1	324.142	306.088	-8.9	-9.687	3.545	108.718
6	1.5	78.5	295.496	279.036	-8.9	-9.664	3.283	106.374
5.5	2	70.9	267.057	252.182	-8.9	-9.639	3.02	104.064
5	2.5	63.4	238.826	225.524	-8.9	-9.609	2.756	101.787
4.5	3	56	210.877	199.131	-8.9	-9.575	2.492	97.995
4	3.5	48.7	183.281	173.072	-8.9	-9.536	2.227	94.298
3.5	4	41.4	156.039	147.347	-8.9	-9.489	1.961	90.695
3	4.5	34.3	129.151	121.957	-8.9	-9.43	1.693	87.185
2.5	5	27.2	102.616	96.9	-8.9	-9.348	1.42	83.766
2	5.5	20.3	76.435	72.178	-8.9	-9.222	1.135	80.438
1.5	6	13.8	52.042	49.143	-8.9	-9.061	0.844	54.099
1	6.5	8.2	30.869	29.149	-8.9	-8.901	0.561	34.246
0.5	7	3.4	12.917	12.197	-8.9	-8.731	0.289	19.963
0.203	7.297	1	3.766	3.556	-8.9	-8.557	0.129	13.733



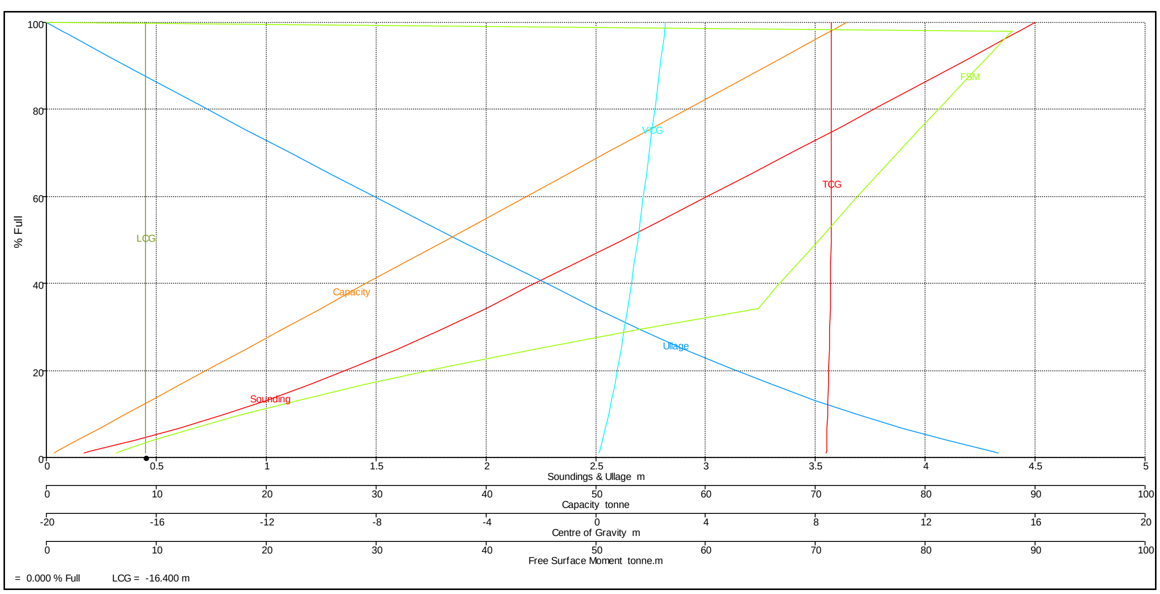
FT11 (2-165-3-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
7.401	0	100	193.284	182.519	-8.9	6.248	4.358	0
7.328	0.073	98	189.399	178.85	-8.9	6.268	4.294	86.049
7	0.401	89	172.008	162.428	-8.9	6.371	3.994	0
6.5	0.901	83	160.516	151.575	-8.9	6.377	3.793	13.792
6	1.401	75.5	145.926	137.798	-8.9	6.388	3.538	14.632
5.5	1.901	67.8	131.048	123.749	-8.9	6.405	3.275	15.505
5	2.401	60	115.883	109.428	-8.9	6.429	3.004	16.413
4.5	2.901	52.1	100.681	95.073	-8.9	6.462	2.725	15.35
4	3.401	44.5	85.956	81.168	-8.9	6.498	2.447	13.884
3.5	3.901	37.1	71.724	67.729	-8.9	6.538	2.169	12.515
3	4.401	30	57.984	54.754	-8.9	6.585	1.889	11.239
2.5	4.901	23.1	44.737	42.245	-8.9	6.646	1.604	10.053
2	5.401	16.5	31.982	30.201	-8.9	6.736	1.306	8.953
1.5	5.901	10.5	20.338	19.205	-8.9	6.864	0.99	5.256
1	6.401	5.7	11.072	10.456	-8.9	6.991	0.681	2.394
0.5	6.901	2.2	4.222	3.987	-8.9	7.115	0.384	0.822
0.276	7.125	1	1.932	1.825	-8.9	7.173	0.258	0.433



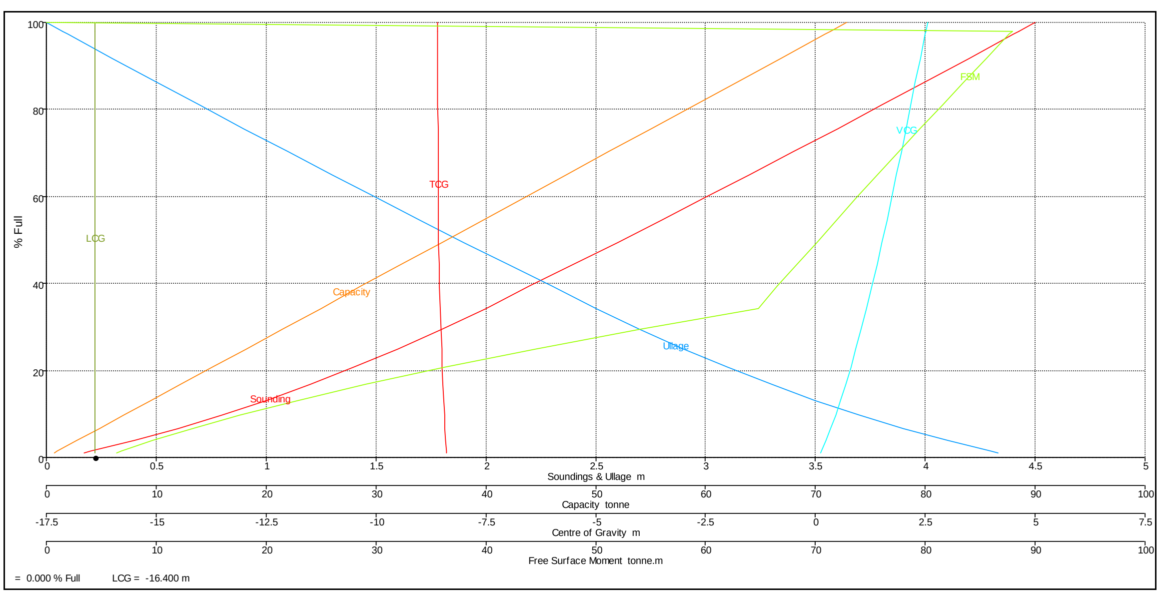
FT12 (2-165-4-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
7.401	0	100	193.284	182.519	-8.9	-6.248	4.358	0
7.328	0.073	98	189.399	178.85	-8.9	-6.268	4.294	86.049
7	0.401	89	172.008	162.428	-8.9	-6.371	3.994	0
6.5	0.901	83	160.516	151.575	-8.9	-6.377	3.793	13.792
6	1.401	75.5	145.926	137.798	-8.9	-6.388	3.538	14.632
5.5	1.901	67.8	131.048	123.749	-8.9	-6.405	3.275	15.505
5	2.401	60	115.883	109.428	-8.9	-6.429	3.004	16.413
4.5	2.901	52.1	100.681	95.073	-8.9	-6.462	2.725	15.35
4	3.401	44.5	85.956	81.168	-8.9	-6.498	2.447	13.884
3.5	3.901	37.1	71.724	67.729	-8.9	-6.538	2.169	12.515
3	4.401	30	57.984	54.754	-8.9	-6.585	1.889	11.239
2.5	4.901	23.1	44.737	42.245	-8.9	-6.646	1.604	10.053
2	5.401	16.5	31.982	30.201	-8.9	-6.736	1.306	8.953
1.5	5.901	10.5	20.338	19.205	-8.9	-6.864	0.99	5.256
1	6.401	5.7	11.072	10.456	-8.9	-6.991	0.681	2.394
0.5	6.901	2.2	4.222	3.987	-8.9	-7.115	0.384	0.822
0.276	7.125	1	1.932	1.825	-8.9	-7.173	0.258	0.433



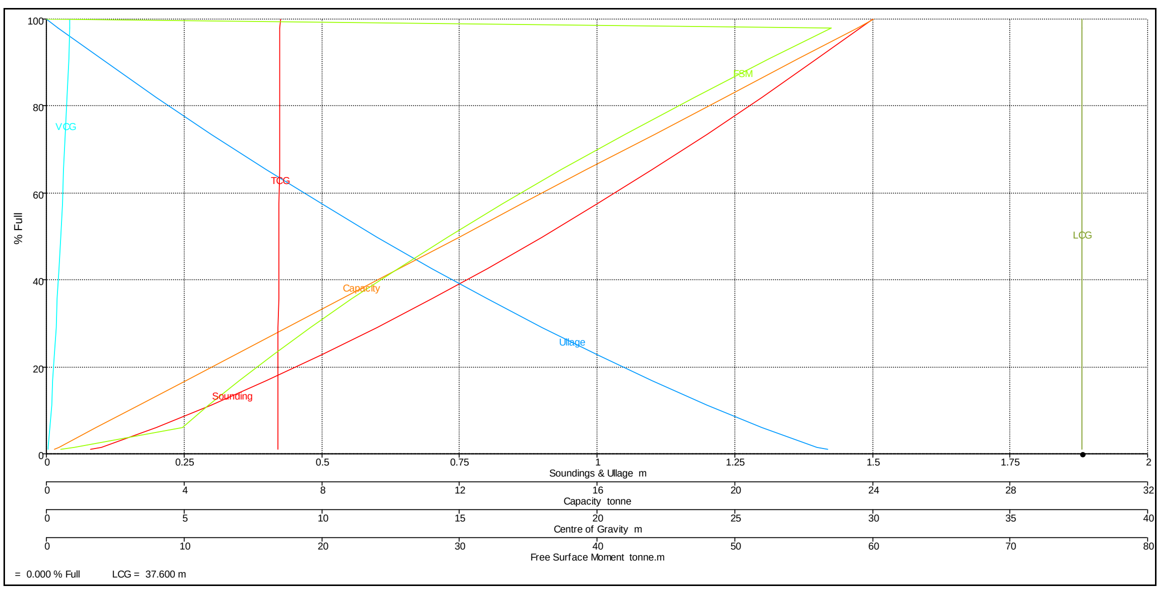
FT13 (3-200-1-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
4.5	0	100	77.151	72.853	-16.4	8.591	2.549	0
4.427	0.073	98	75.599	71.388	-16.4	8.591	2.509	87.934
4.4	0.1	97.2	75.022	70.844	-16.4	8.591	2.495	87.649
4.2	0.3	91.8	70.792	66.849	-16.4	8.591	2.387	85.57
4	0.5	86.3	66.595	62.885	-16.4	8.591	2.279	83.524
3.8	0.7	80.9	62.432	58.954	-16.4	8.59	2.171	81.512
3.6	0.9	75.6	58.303	55.055	-16.4	8.588	2.062	79.531
3.4	1.1	70.3	54.207	51.188	-16.4	8.586	1.954	77.584
3.2	1.3	65	50.146	47.353	-16.4	8.583	1.845	75.668
3	1.5	59.8	46.118	43.549	-16.4	8.58	1.735	73.784
2.8	1.7	54.6	42.124	39.778	-16.4	8.575	1.624	71.931
2.6	1.9	49.5	38.164	36.038	-16.4	8.569	1.513	70.11
2.4	2.1	44.4	34.238	32.331	-16.4	8.561	1.4	68.32
2.2	2.3	39.3	30.346	28.656	-16.4	8.551	1.284	66.56
2	2.5	34.3	26.487	25.012	-16.4	8.536	1.165	64.831
1.8	2.7	29.5	22.759	21.491	-16.4	8.52	1.045	54.073
1.6	2.9	25	19.255	18.183	-16.4	8.504	0.925	44.577
1.4	3.1	20.7	15.977	15.088	-16.4	8.488	0.807	36.263
1.2	3.3	16.8	12.925	12.205	-16.4	8.472	0.69	29.053
1	3.5	13.1	10.098	9.536	-16.4	8.456	0.575	22.868
0.8	3.7	9.7	7.497	7.079	-16.4	8.441	0.462	17.63
0.6	3.9	6.6	5.121	4.835	-16.4	8.426	0.351	13.259
0.4	4.1	3.8	2.97	2.805	-16.4	8.412	0.242	9.679
0.2	4.3	1.4	1.045	0.987	-16.4	8.401	0.132	6.809
0.17	4.33	1	0.778	0.735	-16.4	8.4	0.113	6.438



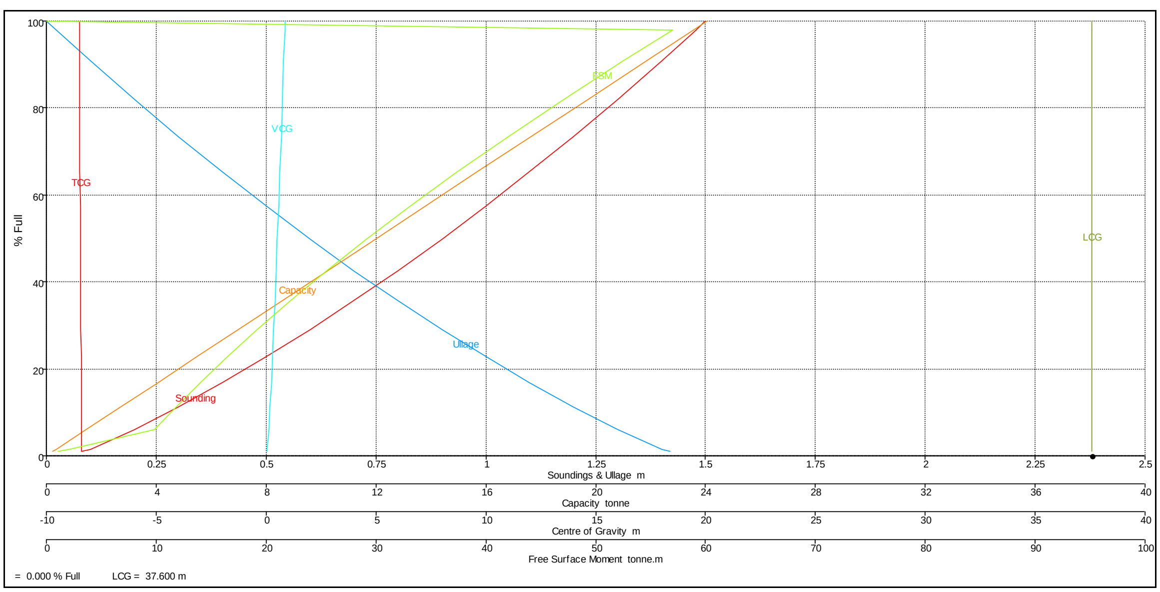
FT14 (3-200-2-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
4.5	0	100	77.151	72.853	-16.4	-8.591	2.549	0
4.427	0.073	98	75.599	71.388	-16.4	-8.591	2.509	87.934
4.4	0.1	97.2	75.022	70.844	-16.4	-8.591	2.495	87.649
4.2	0.3	91.8	70.792	66.849	-16.4	-8.591	2.387	85.57
4	0.5	86.3	66.595	62.885	-16.4	-8.591	2.279	83.524
3.8	0.7	80.9	62.432	58.954	-16.4	-8.59	2.171	81.512
3.6	0.9	75.6	58.303	55.055	-16.4	-8.588	2.062	79.531
3.4	1.1	70.3	54.207	51.188	-16.4	-8.586	1.954	77.584
3.2	1.3	65	50.146	47.353	-16.4	-8.583	1.845	75.668
3	1.5	59.8	46.118	43.549	-16.4	-8.58	1.735	73.784
2.8	1.7	54.6	42.124	39.778	-16.4	-8.575	1.624	71.931
2.6	1.9	49.5	38.164	36.038	-16.4	-8.569	1.513	70.11
2.4	2.1	44.4	34.238	32.331	-16.4	-8.561	1.4	68.32
2.2	2.3	39.3	30.346	28.656	-16.4	-8.551	1.284	66.56
2	2.5	34.3	26.487	25.012	-16.4	-8.536	1.165	64.831
1.8	2.7	29.5	22.759	21.491	-16.4	-8.52	1.045	54.073
1.6	2.9	25	19.255	18.183	-16.4	-8.504	0.925	44.577
1.4	3.1	20.7	15.977	15.088	-16.4	-8.488	0.807	36.263
1.2	3.3	16.8	12.925	12.205	-16.4	-8.472	0.69	29.053
1	3.5	13.1	10.098	9.536	-16.4	-8.456	0.575	22.868
0.8	3.7	9.7	7.497	7.079	-16.4	-8.441	0.462	17.63
0.6	3.9	6.6	5.121	4.835	-16.4	-8.426	0.351	13.259
0.4	4.1	3.8	2.97	2.805	-16.4	-8.412	0.242	9.679
0.2	4.3	1.4	1.045	0.987	-16.4	-8.401	0.132	6.809
0.17	4.33	1	0.778	0.735	-16.4	-8.4	0.113	6.438



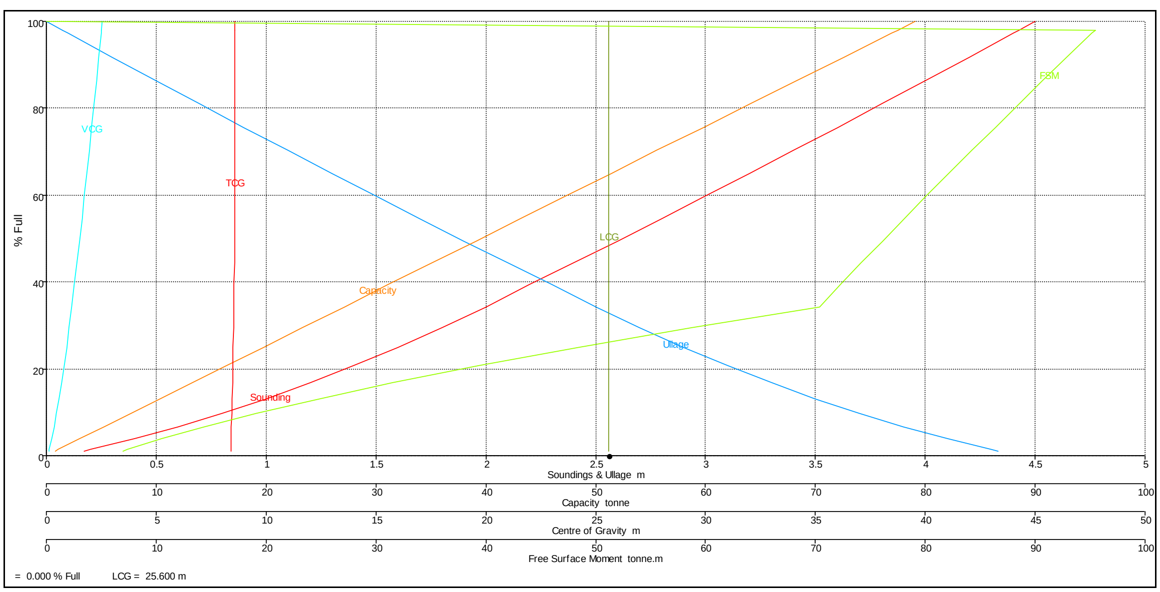
CB1 (4-26-1-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
1.5	0	100	23.451	24.042	37.6	8.496	0.866	0
1.478	0.022	98	22.979	23.558	37.6	8.494	0.853	57.009
1.4	0.1	90.8	21.303	21.84	37.6	8.488	0.807	52.493
1.3	0.2	82	19.231	19.715	37.6	8.48	0.749	47.081
1.2	0.3	73.5	17.233	17.668	37.6	8.472	0.69	42.055
1.1	0.4	65.3	15.311	15.697	37.6	8.464	0.633	37.401
1	0.5	57.4	13.464	13.803	37.6	8.456	0.575	33.102
0.9	0.6	49.9	11.692	11.987	37.6	8.449	0.519	29.147
0.8	0.7	42.6	9.996	10.247	37.6	8.441	0.462	25.52
0.7	0.8	35.7	8.374	8.585	37.6	8.434	0.406	22.207
0.6	0.9	29.1	6.827	7	37.6	8.426	0.351	19.194
0.5	1	22.8	5.356	5.491	37.6	8.419	0.296	16.466
0.4	1.1	16.9	3.96	4.06	37.6	8.412	0.242	14.01
0.3	1.2	11.3	2.639	2.706	37.6	8.406	0.188	11.812
0.2	1.3	5.9	1.393	1.428	37.6	8.401	0.132	9.856
0.1	1.4	1.5	0.358	0.367	37.6	8.4	0.067	2.052
0.081	1.419	1	0.233	0.239	37.6	8.4	0.054	1.078



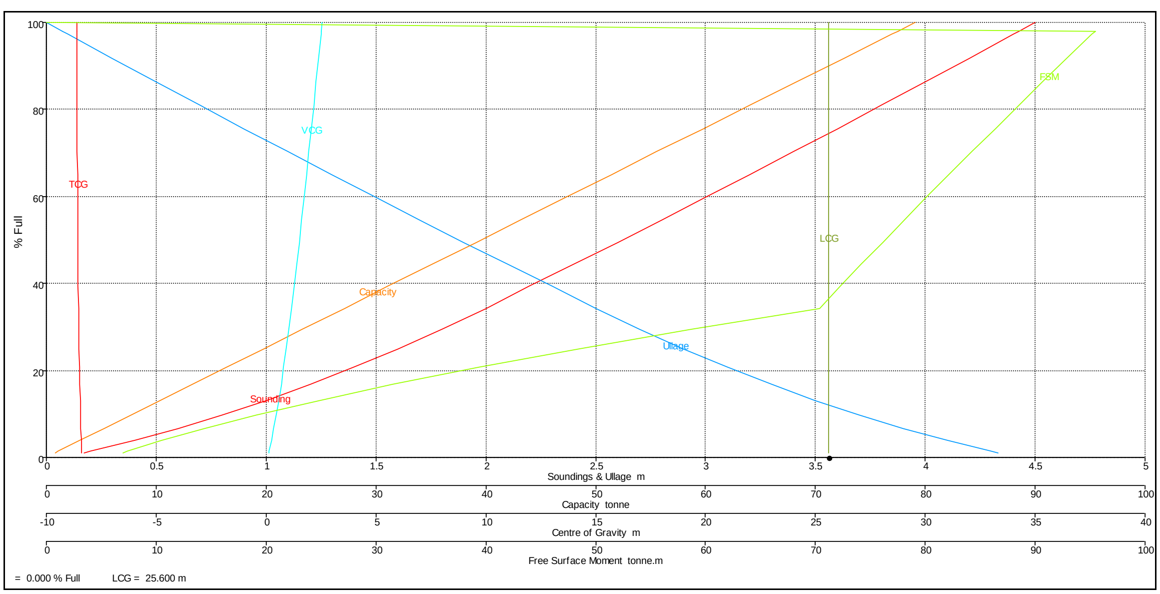
CB2 (4-26-2-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
1.5	0	100	23.451	24.042	37.6	-8.496	0.866	0
1.478	0.022	98	22.979	23.558	37.6	-8.494	0.853	57.009
1.4	0.1	90.8	21.303	21.84	37.6	-8.488	0.807	52.493
1.3	0.2	82	19.231	19.715	37.6	-8.48	0.749	47.081
1.2	0.3	73.5	17.233	17.668	37.6	-8.472	0.69	42.055
1.1	0.4	65.3	15.311	15.697	37.6	-8.464	0.633	37.401
1	0.5	57.4	13.464	13.803	37.6	-8.456	0.575	33.102
0.9	0.6	49.9	11.692	11.987	37.6	-8.449	0.519	29.147
0.8	0.7	42.6	9.996	10.247	37.6	-8.441	0.462	25.52
0.7	0.8	35.7	8.374	8.585	37.6	-8.434	0.406	22.207
0.6	0.9	29.1	6.827	7	37.6	-8.426	0.351	19.194
0.5	1	22.8	5.356	5.491	37.6	-8.419	0.296	16.466
0.4	1.1	16.9	3.96	4.06	37.6	-8.412	0.242	14.01
0.3	1.2	11.3	2.639	2.706	37.6	-8.406	0.188	11.812
0.2	1.3	5.9	1.393	1.428	37.6	-8.401	0.132	9.856
0.1	1.4	1.5	0.358	0.367	37.6	-8.4	0.067	2.052
0.081	1.419	1	0.233	0.239	37.6	-8.4	0.054	1.078



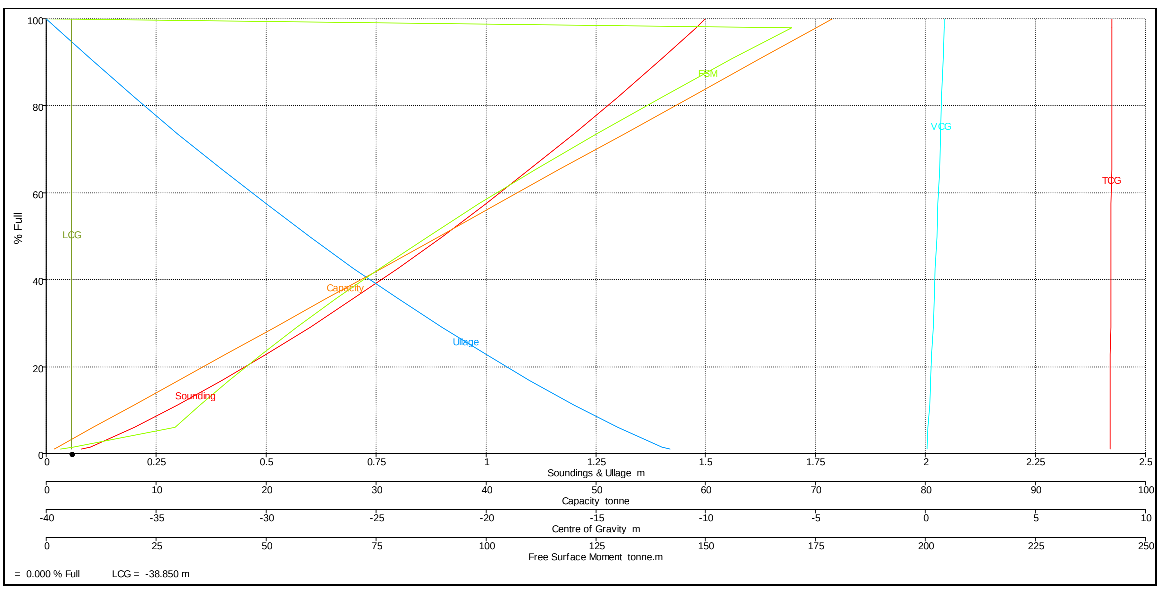
CB3 (3-67-1-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
4.5	0	100	77.151	79.095	25.6	8.591	2.549	0
4.427	0.073	98	75.599	77.504	25.6	8.591	2.509	95.467
4.4	0.1	97.2	75.022	76.913	25.6	8.591	2.495	95.158
4.2	0.3	91.8	70.792	72.576	25.6	8.591	2.387	92.901
4	0.5	86.3	66.595	68.273	25.6	8.591	2.279	90.68
3.8	0.7	80.9	62.432	64.005	25.6	8.59	2.171	88.495
3.6	0.9	75.6	58.303	59.772	25.6	8.588	2.062	86.345
3.4	1.1	70.3	54.207	55.573	25.6	8.586	1.954	84.23
3.2	1.3	65	50.146	51.409	25.6	8.583	1.845	82.15
3	1.5	59.8	46.118	47.28	25.6	8.58	1.735	80.105
2.8	1.7	54.6	42.124	43.186	25.6	8.575	1.624	78.094
2.6	1.9	49.5	38.164	39.126	25.6	8.569	1.513	76.117
2.4	2.1	44.4	34.238	35.101	25.6	8.561	1.4	74.173
2.2	2.3	39.3	30.346	31.111	25.6	8.551	1.284	72.263
2	2.5	34.3	26.487	27.155	25.6	8.536	1.165	70.385
1.8	2.7	29.5	22.759	23.332	25.6	8.52	1.045	58.706
1.6	2.9	25	19.255	19.741	25.6	8.504	0.925	48.396
1.4	3.1	20.7	15.977	16.38	25.6	8.488	0.807	39.369
1.2	3.3	16.8	12.925	13.251	25.6	8.472	0.69	31.542
1	3.5	13.1	10.098	10.353	25.6	8.456	0.575	24.827
0.8	3.7	9.7	7.497	7.686	25.6	8.441	0.462	19.14
0.6	3.9	6.6	5.121	5.25	25.6	8.426	0.351	14.395
0.4	4.1	3.8	2.97	3.045	25.6	8.412	0.242	10.508
0.2	4.3	1.4	1.045	1.071	25.6	8.401	0.132	7.392
0.17	4.33	1	0.778	0.797	25.6	8.4	0.113	6.989



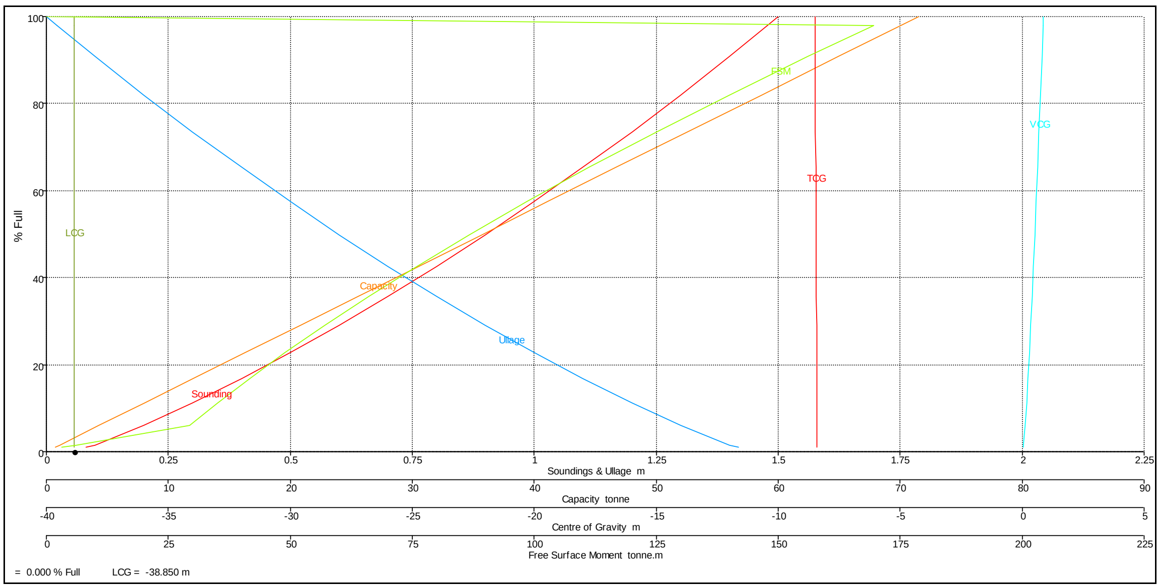
CB4 (3-67-2-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
4.5	0	100	77.151	79.095	25.6	-8.591	2.549	0
4.427	0.073	98	75.599	77.504	25.6	-8.591	2.509	95.467
4.4	0.1	97.2	75.022	76.913	25.6	-8.591	2.495	95.158
4.2	0.3	91.8	70.792	72.576	25.6	-8.591	2.387	92.901
4	0.5	86.3	66.595	68.273	25.6	-8.591	2.279	90.68
3.8	0.7	80.9	62.432	64.005	25.6	-8.59	2.171	88.495
3.6	0.9	75.6	58.303	59.772	25.6	-8.588	2.062	86.345
3.4	1.1	70.3	54.207	55.573	25.6	-8.586	1.954	84.23
3.2	1.3	65	50.146	51.409	25.6	-8.583	1.845	82.15
3	1.5	59.8	46.118	47.28	25.6	-8.58	1.735	80.105
2.8	1.7	54.6	42.124	43.186	25.6	-8.575	1.624	78.094
2.6	1.9	49.5	38.164	39.126	25.6	-8.569	1.513	76.117
2.4	2.1	44.4	34.238	35.101	25.6	-8.561	1.4	74.173
2.2	2.3	39.3	30.346	31.111	25.6	-8.551	1.284	72.263
2	2.5	34.3	26.487	27.155	25.6	-8.536	1.165	70.385
1.8	2.7	29.5	22.759	23.332	25.6	-8.52	1.045	58.706
1.6	2.9	25	19.255	19.741	25.6	-8.504	0.925	48.396
1.4	3.1	20.7	15.977	16.38	25.6	-8.488	0.807	39.369
1.2	3.3	16.8	12.925	13.251	25.6	-8.472	0.69	31.542
1	3.5	13.1	10.098	10.353	25.6	-8.456	0.575	24.827
0.8	3.7	9.7	7.497	7.686	25.6	-8.441	0.462	19.14
0.6	3.9	6.6	5.121	5.25	25.6	-8.426	0.351	14.395
0.4	4.1	3.8	2.97	3.045	25.6	-8.412	0.242	10.508
0.2	4.3	1.4	1.045	1.071	25.6	-8.401	0.132	7.392
0.17	4.33	1	0.778	0.797	25.6	-8.4	0.113	6.989



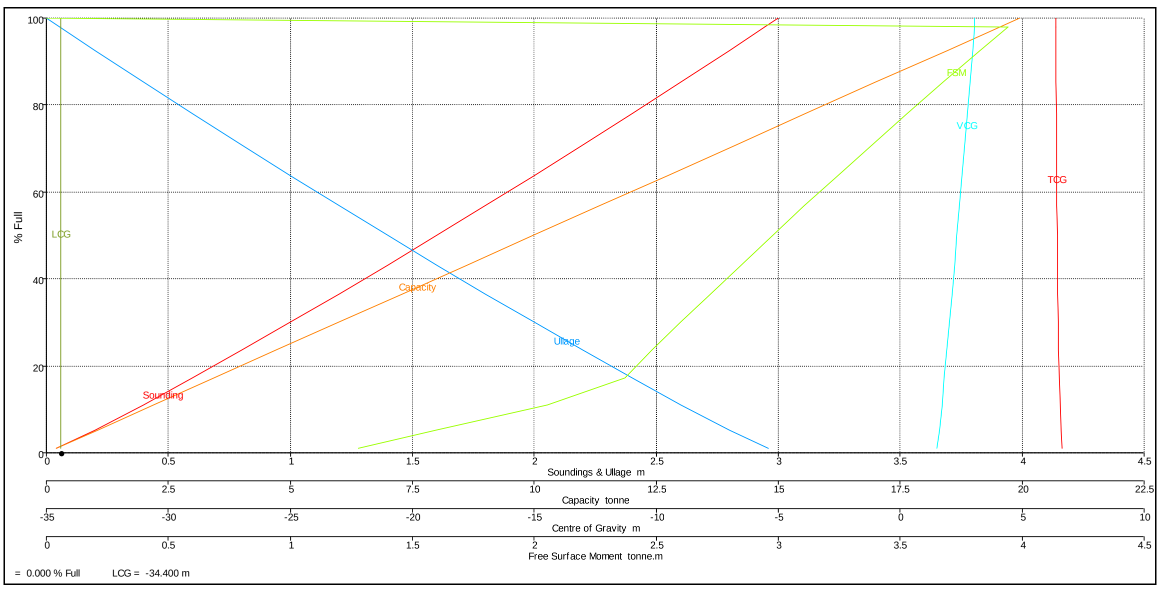
CB5 (4-264-1-F)								
Sounding (m)	Ullage (m)	% Full	Capacity (m^3)	Capacity (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t•m)
1.5	0	100	69.767	71.525	-38.85	8.496	0.866	0
1.478	0.022	98	68.362	70.085	-38.85	8.494	0.853	169.601
1.4	0.1	90.8	63.377	64.974	-38.85	8.488	0.807	156.165
1.3	0.2	82	57.212	58.653	-38.85	8.48	0.749	140.067
1.2	0.3	73.5	51.27	52.561	-38.85	8.472	0.69	125.115
1.1	0.4	65.3	45.551	46.699	-38.85	8.464	0.633	111.267
1	0.5	57.4	40.056	41.065	-38.85	8.456	0.575	98.48
0.9	0.6	49.9	34.785	35.661	-38.85	8.449	0.519	86.712
0.8	0.7	42.6	29.737	30.486	-38.85	8.441	0.462	75.922
0.7	0.8	35.7	24.912	25.54	-38.85	8.434	0.406	66.066
0.6	0.9	29.1	20.312	20.824	-38.85	8.426	0.351	57.102
0.5	1	22.8	15.935	16.336	-38.85	8.419	0.296	48.988
0.4	1.1	16.9	11.781	12.078	-38.85	8.412	0.242	41.681
0.3	1.2	11.3	7.851	8.049	-38.85	8.406	0.188	35.14
0.2	1.3	5.9	4.145	4.249	-38.85	8.401	0.132	29.321
0.1	1.4	1.5	1.065	1.092	-38.85	8.4	0.067	6.105
0.081	1.419	1	0.693	0.711	-38.85	8.4	0.054	3.206



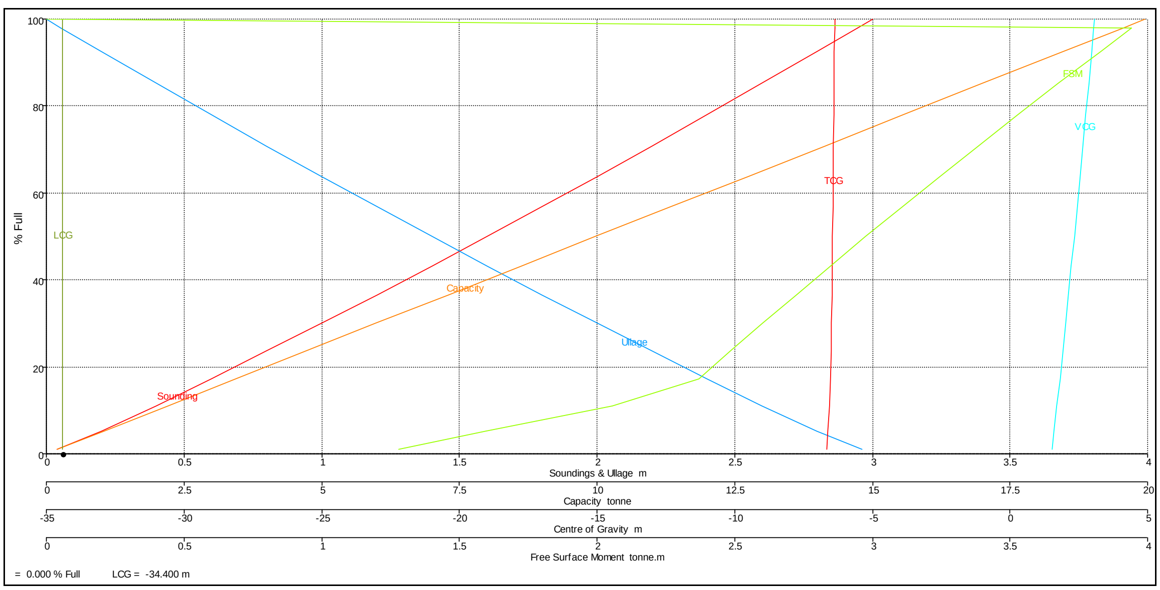
CB6 (4-264-2-F)								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
1.5	0	100	69.767	71.525	-38.85	-8.496	0.866	0
1.478	0.022	98	68.362	70.085	-38.85	-8.494	0.853	169.601
1.4	0.1	90.8	63.377	64.974	-38.85	-8.488	0.807	156.165
1.3	0.2	82	57.212	58.653	-38.85	-8.48	0.749	140.067
1.2	0.3	73.5	51.27	52.561	-38.85	-8.472	0.69	125.115
1.1	0.4	65.3	45.551	46.699	-38.85	-8.464	0.633	111.267
1	0.5	57.4	40.056	41.065	-38.85	-8.456	0.575	98.48
0.9	0.6	49.9	34.785	35.661	-38.85	-8.449	0.519	86.712
0.8	0.7	42.6	29.737	30.486	-38.85	-8.441	0.462	75.922
0.7	0.8	35.7	24.912	25.54	-38.85	-8.434	0.406	66.066
0.6	0.9	29.1	20.312	20.824	-38.85	-8.426	0.351	57.102
0.5	1	22.8	15.935	16.336	-38.85	-8.419	0.296	48.988
0.4	1.1	16.9	11.781	12.078	-38.85	-8.412	0.242	41.681
0.3	1.2	11.3	7.851	8.049	-38.85	-8.406	0.188	35.14
0.2	1.3	5.9	4.145	4.249	-38.85	-8.401	0.132	29.321
0.1	1.4	1.5	1.065	1.092	-38.85	-8.4	0.067	6.105
0.081	1.419	1	0.693	0.711	-38.85	-8.4	0.054	3.206



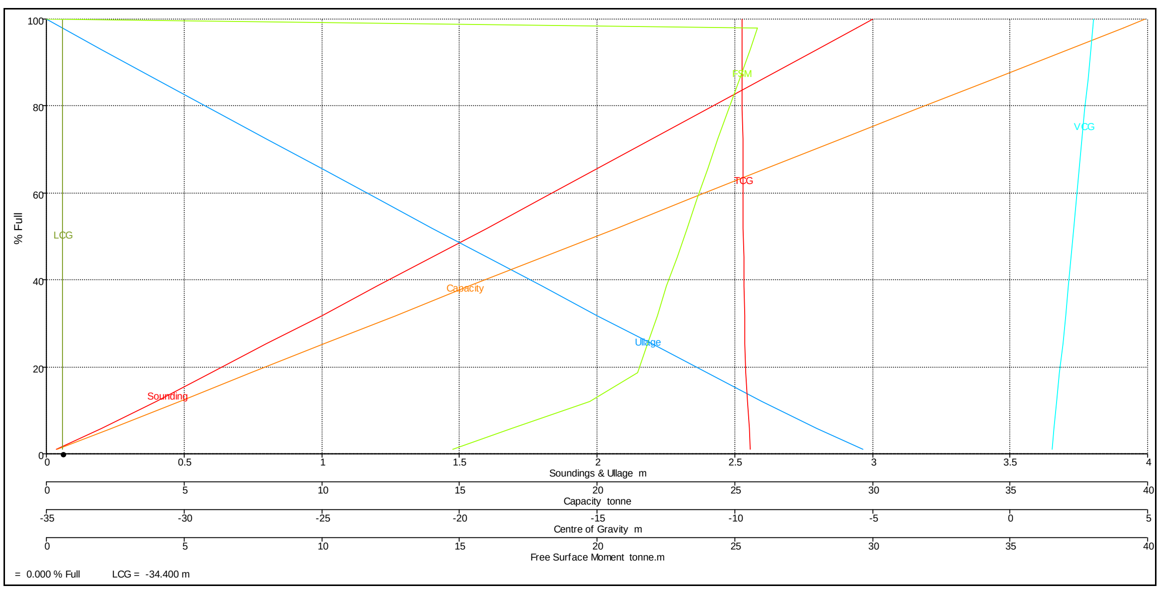
FRESH WATER 1								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
3	0	100	19.954	19.954	-34.4	6.372	3.072	0
2.946	0.054	98	19.553	19.553	-34.4	6.374	3.043	3.942
2.8	0.2	92.6	18.469	18.469	-34.4	6.382	2.965	3.829
2.6	0.4	85.2	17.004	17.004	-34.4	6.391	2.859	3.676
2.4	0.6	78	15.559	15.559	-34.4	6.401	2.753	3.528
2.2	0.8	70.8	14.133	14.133	-34.4	6.412	2.647	3.384
2	1	63.8	12.727	12.727	-34.4	6.422	2.542	3.244
1.8	1.2	56.8	11.341	11.341	-34.4	6.433	2.437	3.108
1.6	1.4	50	9.975	9.975	-34.4	6.444	2.332	2.976
1.4	1.6	43.2	8.629	8.629	-34.4	6.457	2.228	2.848
1.2	1.8	36.6	7.302	7.302	-34.4	6.47	2.124	2.723
1	2	30	5.995	5.995	-34.4	6.485	2.02	2.602
0.8	2.2	23.6	4.708	4.708	-34.4	6.504	1.916	2.485
0.6	2.4	17.2	3.441	3.441	-34.4	6.53	1.812	2.371
0.4	2.6	11	2.203	2.203	-34.4	6.57	1.706	2.055
0.2	2.8	5.3	1.053	1.053	-34.4	6.613	1.602	1.595
0.039	2.961	1	0.199	0.199	-34.4	6.646	1.52	1.28



FRESH WATER 2								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
3	0	100	19.954	19.954	-34.4	-6.372	3.072	0
2.946	0.054	98	19.553	19.553	-34.4	-6.374	3.043	3.942
2.8	0.2	92.6	18.469	18.469	-34.4	-6.382	2.965	3.829
2.6	0.4	85.2	17.004	17.004	-34.4	-6.391	2.859	3.676
2.4	0.6	78	15.559	15.559	-34.4	-6.401	2.753	3.528
2.2	0.8	70.8	14.133	14.133	-34.4	-6.412	2.647	3.384
2	1	63.8	12.727	12.727	-34.4	-6.422	2.542	3.244
1.8	1.2	56.8	11.341	11.341	-34.4	-6.433	2.437	3.108
1.6	1.4	50	9.975	9.975	-34.4	-6.444	2.332	2.976
1.4	1.6	43.2	8.629	8.629	-34.4	-6.457	2.228	2.848
1.2	1.8	36.6	7.302	7.302	-34.4	-6.47	2.124	2.723
1	2	30	5.995	5.995	-34.4	-6.485	2.02	2.602
0.8	2.2	23.6	4.708	4.708	-34.4	-6.504	1.916	2.485
0.6	2.4	17.2	3.441	3.441	-34.4	-6.53	1.812	2.371
0.4	2.6	11	2.203	2.203	-34.4	-6.57	1.706	2.055
0.2	2.8	5.3	1.053	1.053	-34.4	-6.613	1.602	1.595
0.039	2.961	1	0.199	0.199	-34.4	-6.646	1.52	1.28



FRESH WATER 3								
Sounding (m)	**Ullage (m)**	**% Full**	**Capacity (m^3)**	**Capacity (t)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**FSM (t•m)**
3	0	100	39.91	39.91	-34.4	-9.744	3.032	0
2.942	0.058	98	39.108	39.108	-34.4	-9.741	3.003	25.83
2.8	0.2	93	37.126	37.126	-34.4	-9.736	2.929	25.549
2.6	0.4	86.1	34.356	34.356	-34.4	-9.728	2.827	25.159
2.4	0.6	79.2	31.6	31.6	-34.4	-9.72	2.725	24.772
2.2	0.8	72.3	28.859	28.859	-34.4	-9.712	2.623	24.39
2	1	65.5	26.131	26.131	-34.4	-9.703	2.521	24.011
1.8	1.2	58.7	23.418	23.418	-34.4	-9.694	2.419	23.636
1.6	1.4	51.9	20.719	20.719	-34.4	-9.684	2.317	23.266
1.4	1.6	45.2	18.034	18.034	-34.4	-9.673	2.215	22.899
1.2	1.8	38.5	15.364	15.364	-34.4	-9.659	2.113	22.536
1	2	31.8	12.708	12.708	-34.4	-9.643	2.012	22.177
0.8	2.2	25.2	10.066	10.066	-34.4	-9.622	1.91	21.822
0.6	2.4	18.6	7.438	7.438	-34.4	-9.591	1.807	21.47
0.4	2.6	12.1	4.839	4.839	-34.4	-9.538	1.704	19.752
0.2	2.8	5.9	2.355	2.355	-34.4	-9.483	1.601	16.892
0.035	2.965	1	0.398	0.398	-34.4	-9.437	1.517	14.747

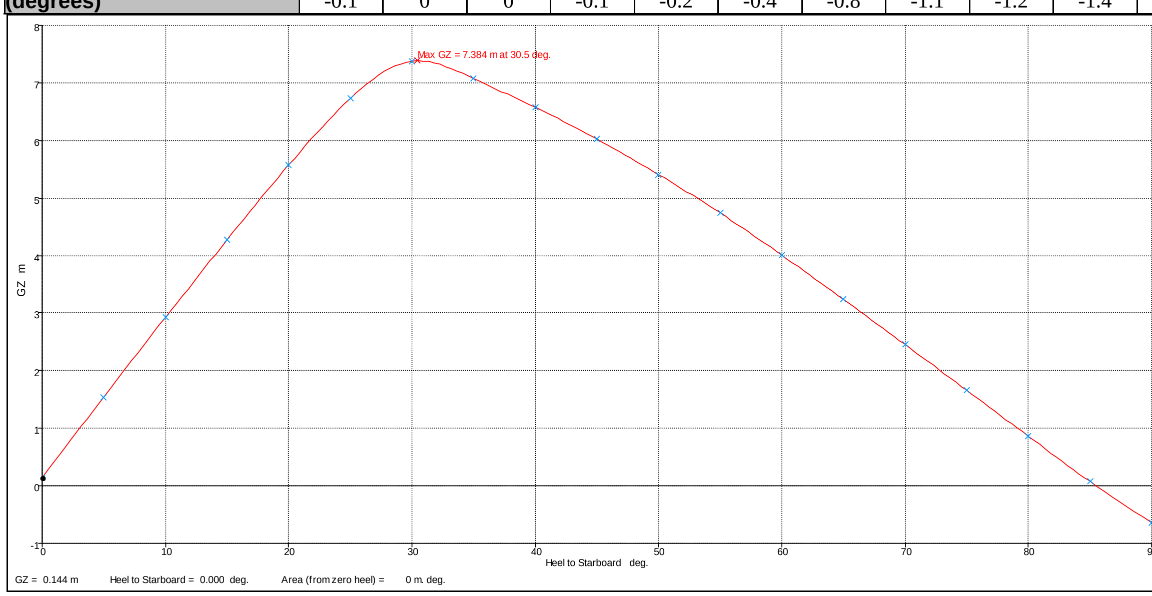


4. INTACT STABILITY

A. FULLY LOADED

LOAD		WEIGHT (MT)
LIGHTSHIP		3034
FLUIDS		2041.51
PAYLOAD + FIXED WEIGHTS		1947.49
	TOTAL =	**7023**

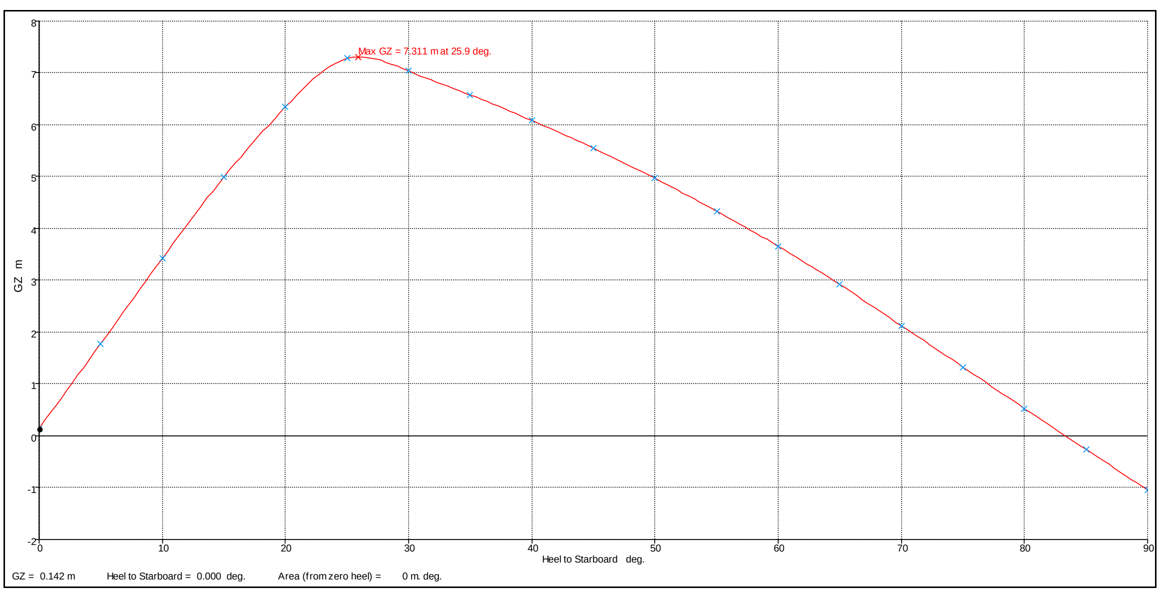
Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	7023	7023	7024	7023	7024	7023	7023	7024	7024	7024	7024
Draft at FP (m)	5.252	5.24	5.219	5.28	5.35	5.317	5.299	4.803	3.922	2.886	1.639
Draft at AP (m)	5.144	5.14	5.128	5.057	4.872	4.54	3.753	2.556	1.369	0.083	-1.342
WL Length (m)	117.334	118.368	119.565	119.743	113.874	112.871	111.819	106.629	106.631	106.631	106.63
Immersed Depth (m)	5.242	5.943	6.688	7.483	8.217	8.788	9.273	9.309	9.062	8.859	8.708
WL Beam (m)	24.552	24.605	24.909	25.269	25.106	25.072	22.656	14.159	14.384	14.699	15.172
Wetted Area (m^2)	3268.986	3268.426	3654.861	4457.843	4764.69	4741.557	4472.333	4292.269	4274.768	4261.843	4255.66
Waterplane Area (m^2)	1664.675	1658.461	1589.179	1551.859	1475.837	1441.009	1028.639	787.351	752.752	741.941	749.852
Prismatic Coefficient	0.926	0.919	0.912	0.898	0.922	0.907	0.893	0.939	0.94	0.941	0.942
Block Coefficient	0.757	0.664	0.605	0.532	0.511	0.466	0.554	0.775	0.737	0.69	0.633
LCB from Amidships (+ve fwd) (m)	-0.888	-0.888	-0.888	-0.884	-0.874	-0.865	-0.831	-0.799	-0.784	-0.772	-0.765
VCB from DWL (m)	2.232	2.288	2.463	2.773	3.155	3.542	3.841	3.833	3.745	3.658	3.575
GZ (m)	0.144	1.543	2.922	4.273	5.572	6.732	7.378	7.073	6.577	6.02	5.408
LCF from Amidship (+ve fwd) (m)	-0.816	-0.781	-1.402	-3.104	-3.275	-2.213	-1.254	-8.114	-9.615	-10.857	-11.695
TCF to zero point (m)	0	0.644	0.898	1.558	3.016	4.872	8.617	11.678	11.762	11.732	11.615
Max deck inclination (degrees)	0.1	5	10	15	20	25	30	35	40	45	50
Trim angle (+ve by stern) (degrees)	-0.1	0	0	-0.1	-0.2	-0.4	-0.8	-1.1	-1.2	-1.4	-1.5



B. HALF LOADED

LOAD	WEIGHT (MT)
LIGHTSHIP	3034
FLUIDS	1020.55
PAYLOAD + FIXED WEIGHTS	1741.45
TOTAL =	5796

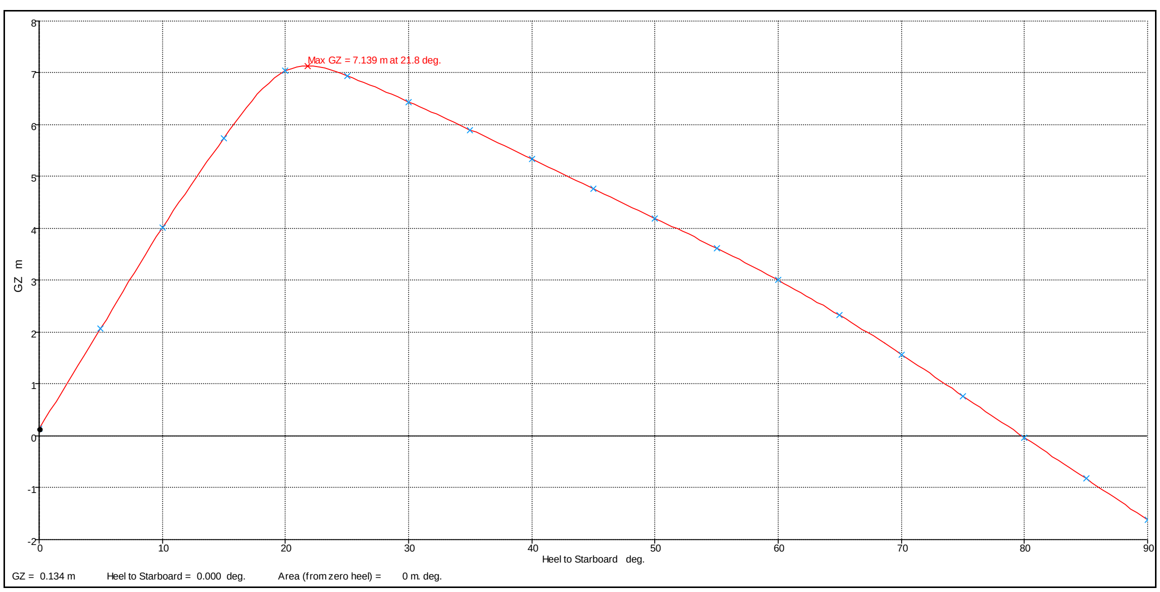
Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	5797	5796	5796	5797	5797	5796	5797	5796	5796	5796	5796
Draft at FP (m)	4.593	4.575	4.527	4.47	4.406	4.289	3.539	2.482	1.323	0.053	-1.402
Draft at AP (m)	4.354	4.345	4.318	4.245	4.016	3.457	2.43	1.339	0.094	-1.357	-3.034
WL Length (m)	116.384	117.409	118.436	119.614	120.581	114.074	114.515	115.945	116.822	117.235	117.402
Immersed Depth (m)	4.571	5.269	5.996	6.701	7.337	7.852	7.784	7.49	7.164	6.947	6.833
WL Beam (m)	24.416	24.476	24.701	24.611	24.33	23.593	13.54	13.617	13.364	13.363	13.542
Wetted Area (m^2)	2924.097	2919.716	2905.776	3386.367	3810.321	3730.73	3457.23	3386.262	3339.679	3326.6	3331.64
Waterplane Area (m^2)	1623.431	1625.303	1621.609	1501.605	1375.587	1061.843	896.604	962.508	1010.074	1024.938	1034.502
Prismatic Coefficient	0.912	0.906	0.902	0.897	0.878	0.906	0.901	0.887	0.878	0.871	0.866
Block Coefficient	0.734	0.631	0.55	0.516	0.491	0.556	0.744	0.715	0.696	0.667	0.622
LCB from Amidships (+ve fwd) (m)	-0.549	-0.55	-0.551	-0.549	-0.543	-0.521	-0.509	-0.508	-0.501	-0.493	-0.478
VCB from DWL (m)	1.902	1.967	2.165	2.494	2.89	3.239	3.183	3.04	2.893	2.756	2.644
GZ (m)	0.142	1.777	3.425	4.992	6.341	7.279	7.035	6.574	6.082	5.55	4.967
LCF from Amidship (+ve fwd) (m)	-0.898	-0.905	-0.968	-1.732	-2.677	-1.945	-5.457	-5.136	-5.512	-6.071	-6.165
TCF to zero point (m)	0	0.676	1.335	2.209	3.691	7.75	11.596	11.718	11.675	11.423	11.049
Max deck inclination (degrees)	0.1	5	10	15	20	25	30	35	40	45	50
Trim angle (+ve by stern) (degrees)	-0.1	-0.1	-0.1	-0.1	-0.2	-0.4	-0.5	-0.6	-0.6	-0.7	-0.8



C. EMPTY SHIP

LOAD	WEIGHT (MT)
LIGHTSHIP	3034
FLUIDS	94.892
PAYLOAD + FIXED WEIGHTS	1556.108
TOTAL =	4685

Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	4685	4685	4684	4684	4685	4685	4684	4684	4684	4684	4684
Draft at FP (m)	3.884	3.864	3.807	3.662	3.431	2.747	1.82	0.791	-0.377	-1.741	-3.365
Draft at AP (m)	3.705	3.695	3.655	3.526	3.205	2.37	1.377	0.272	-0.982	-2.439	-4.191
WL Length (m)	115.38	116.401	117.428	118.349	119.337	119.584	119.613	119.642	119.671	119.804	119.917
Immersed Depth (m)	3.868	4.566	5.292	5.928	6.436	6.492	6.348	6.152	5.906	5.724	5.618
WL Beam (m)	24.247	24.338	24.317	23.811	23.023	12.737	12.719	12.697	12.689	12.714	12.554
Wetted Area (m^2)	2602.774	2595.604	2568.811	2489.093	2732.632	2572.185	2616.409	2648.896	2674.295	2695.633	2714.33
Waterplane Area (m^2)	1571.509	1573.955	1546.57	1452.488	1169.4	898.605	934.871	981.151	1040.03	1114.962	1199.834
Prismatic Coefficient	0.917	0.911	0.908	0.909	0.904	0.9	0.894	0.889	0.882	0.875	0.866
Block Coefficient	0.728	0.609	0.527	0.494	0.538	0.722	0.708	0.693	0.68	0.652	0.614
LCB from Amidships (+ve fwd) (m)	-0.639	-0.639	-0.64	-0.64	-0.635	-0.63	-0.624	-0.617	-0.612	-0.615	-0.605
VCB from DWL (m)	1.595	1.677	1.919	2.262	2.64	2.681	2.597	2.5	2.391	2.272	2.148
GZ (m)	0.134	2.072	4.01	5.742	7.039	6.945	6.442	5.904	5.342	4.767	4.198
LCF from Amidship (+ve fwd) (m)	-1.122	-1.147	-0.94	-0.719	-0.991	-2.566	-2.731	-2.852	-2.943	-3.022	-3.404
TCF to zero point (m)	0	0.668	1.575	3.092	5.898	10.607	10.813	10.939	10.986	10.958	10.808
Max deck inclination (degrees)	0.1	5	10	15	20	25	30	35	40	45	50
Trim angle (+ve by stern) (degrees)	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4



5. DAMAGED STABILITY

An analysis of the stability of the ship was conducted for some worst case scenarios. The most critical compartment of the ship is the UUV hangar on the first platform. There are no watertight doors or divisions along the hangar to provide compartmentalization, due to the rail and hoisting systems. If the water level reaches the hangar area and this compartment gets flooded that would be the worst-case flooding for the ship. In all damaged stability calculations it is assumed that all watertight doors and hatches in the superstructure are closed.

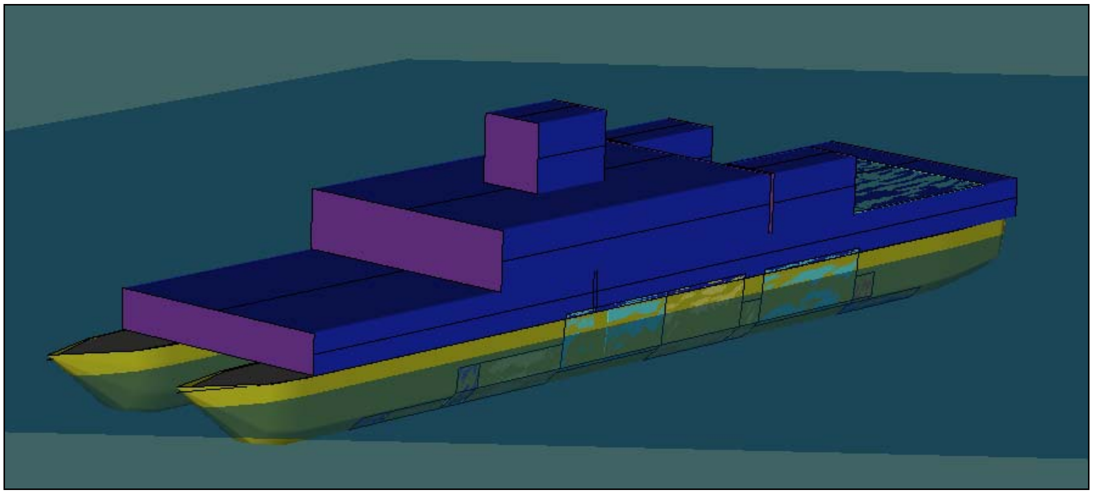


Figure – The Model Used in Stability Calculations

a. Case 1

Flooded Compartments: Engine Room 1 (Starboard side)
Engine Room 3 (Starboard side)
All Fuel Tanks at Port side at 5% level
All Fuel Tanks at Starboard side at 98.5% level

Draft Amidships (m)	5.275
Displacement (tonne)	7195
Heel to Starboard (degrees)	7.94
Draft at FP (m)	4.933
Draft at AP (m)	5.617
Draft at LCF (m)	5.278
Trim (+ve by stern) (m)	0.684
WL Length (m)	118.758
WL Beam (m)	24.859

Wetted Area (m^2)	3427.932
Waterplane Area (m^2)	1627.936
Prismatic Coefficient	0.876
Block Coefficient	0.603
Midship Area Coefficient	0.716
Waterplane Area Coefficient	0.935
LCB from Amidship (+ve fwd) (m)	-2.521
LCF from Amidship (+ve fwd) (m)	-0.533
KB (m)	2.866
KG fluid (m)	6.1
BM_t (m)	18.363
BM_L (m)	248.469
GM_t (m)	15.436
GM_L (m)	245.541
KM_t (m)	21.23
KM_L (m)	251.335
Immersion (TP_c) (tonne/cm)	16.69
MTc (tonne•m)	150.657
RM at 1deg = GM_t•Disp•sin(1) (tonne•m)	1938.418
Max deck inclination (degrees)	7.9
Trim angle (+ve by stern) (degrees)	0.3

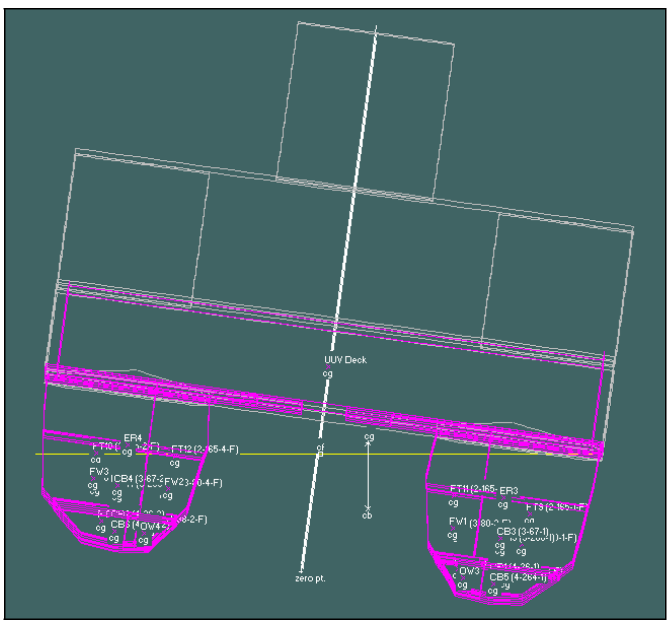
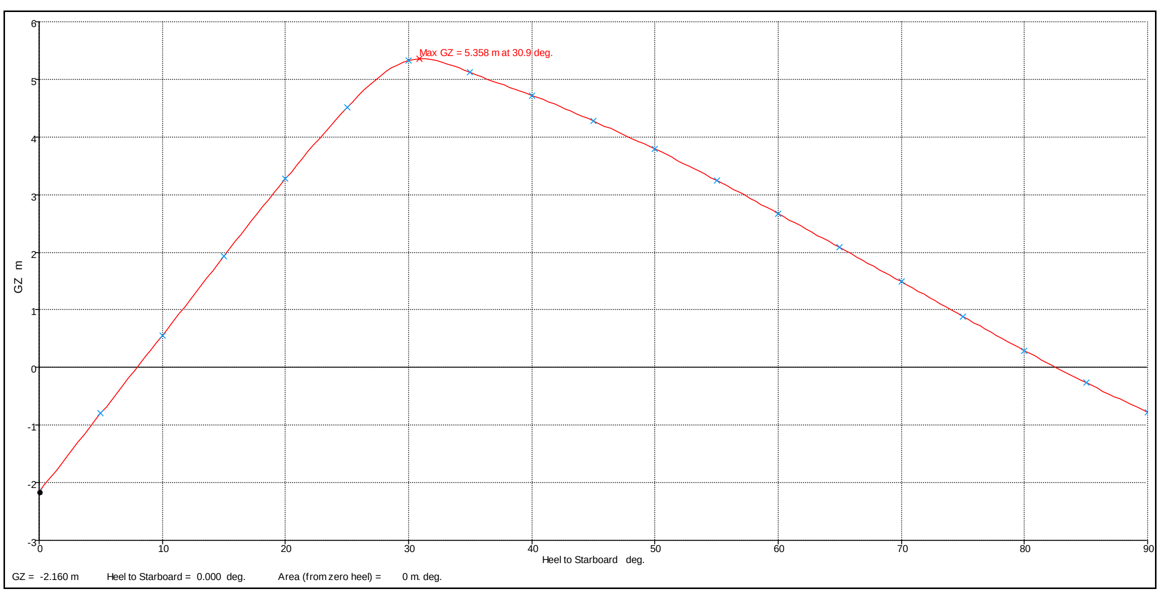


Figure – Heel after damage Case 1

Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	7195	7195	7195	7195	7195	7196	7196	7196	7195	7196	7196
Draft at FP (m)	4.972	4.958	4.92	4.935	4.96	4.893	4.651	3.806	2.739	1.505	0.074

Draft at AP (m)	5.615	5.613	5.623	5.578	5.435	5.153	4.714	3.896	2.947	1.907	0.766
WL Length (m)	117.006	118.028	119.159	120.074	113.418	112.394	109.707	106.5	106.5	111.86	112.908
Immersed Depth (m)	5.54	6.248	7.014	7.719	8.286	8.677	8.883	8.726	8.476	8.316	8.271
WL Beam (m)	24.594	24.663	24.948	25.299	25.176	24.988	23.76	14.5	14.838	15.282	15.925
Wetted Area (m^2)	3312.956	3311.708	3857.421	4594.537	4860.3	4826.028	4637.591	4446.826	4473.756	4464.933	4451.861
Waterplane Area (m^2)	1661.874	1657.844	1603.394	1571.464	1513.8	1502.866	1091.133	771.147	703.901	688.902	704.432
Prismatic Coefficient	0.889	0.881	0.873	0.87	0.932	0.953	0.991	1.02	1.014	0.959	0.94
Block Coefficient	0.736	0.646	0.59	0.525	0.509	0.497	0.601	0.784	0.795	0.729	0.656
LCB from Amidships (+ve fwd) (m)	-2.515	-2.517	-2.518	-2.518	-2.517	-2.507	-2.497	-2.5	-2.503	-2.512	-2.524
VCB from DWL (m)	2.283	2.338	2.511	2.803	3.173	3.555	3.902	3.907	3.836	3.758	3.697
GZ (m)	-2.16	-0.8	0.557	1.931	3.275	4.506	5.331	5.117	4.722	4.277	3.788
LCF from Amidship (+ve fwd) (m)	-0.872	-1.005	-1.159	-3.107	-4.87	-4.825	-5.398	-7.015	-7.432	-6.847	-6.345
TCF to zero point (m)	0	0.645	1.014	1.63	3.053	4.787	7.757	11.577	11.881	11.951	11.883
Max deck inclination (degrees)	0.3	5	10	15	20	25	30	35	40	45	50
Trim angle (+ve by stern) (degrees)	0.3	0.3	0.3	0.3	0.2	0.1	0	0	0.1	0.2	0.3



In this damaged case the water level is still under the UUV hangar, and the ship can float in equilibrium at a heeling angle of 7.94 degrees to starboard and at a 0.3 degree trim to stern. The ship can generate a positive righting arm with up to 82 degrees heel.

b. Case 2

Flooded Compartments: Engine Room 1 (Starboard side)
Engine Room 3 (Starboard side)
Engine Room 2 (Port side)
Engine Room 4 (Port side)
All Fuel Tanks at Port side at 98.5% level
All Fuel Tanks at Starboard side at 98.5% level
All Ballast Tanks at 99% level

Draft Amidships (m)	6.652
Displacement (tonne)	9508
Heel to Starboard (degrees)	-0.52
Draft at FP (m)	6.044
Draft at AP (m)	7.261
Draft at LCF (m)	6.683
Trim (+ve by stern) (m)	1.217
WL Length (m)	118.651
WL Beam (m)	25.001
Wetted Area (m^2)	4708.926
Waterplane Area (m^2)	1707.3
Prismatic Coefficient	0.87
Block Coefficient	0.434
Midship Area Coefficient	0.849
Waterplane Area Coefficient	0.576
LCB from Amidship (+ve fwd) (m)	-2.984
LCF from Amidship (+ve fwd) (m)	-2.939
KB (m)	3.748
KG fluid (m)	5.472
BM_t (m)	13.544
BM_L (m)	222.515
GM_t (m)	11.82
GM_L (m)	220.791
KM_t (m)	17.292
KM_L (m)	226.263
Immersion (TP_c) (tonne/cm)	17.503
MTc (tonne•m)	179.005
RM at 1deg = GM_t•Disp•sin(1) (tonne•m)	1961.285
Max deck inclination (degrees)	0.8
Trim angle (+ve by stern) (degrees)	0.6

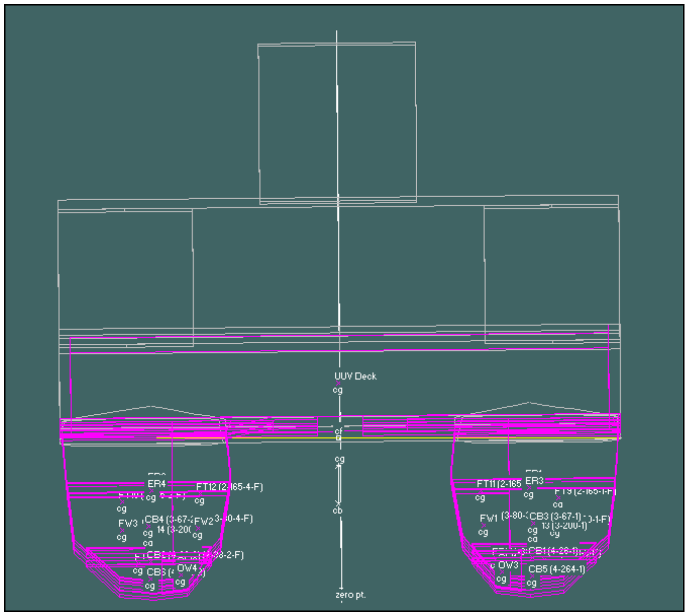
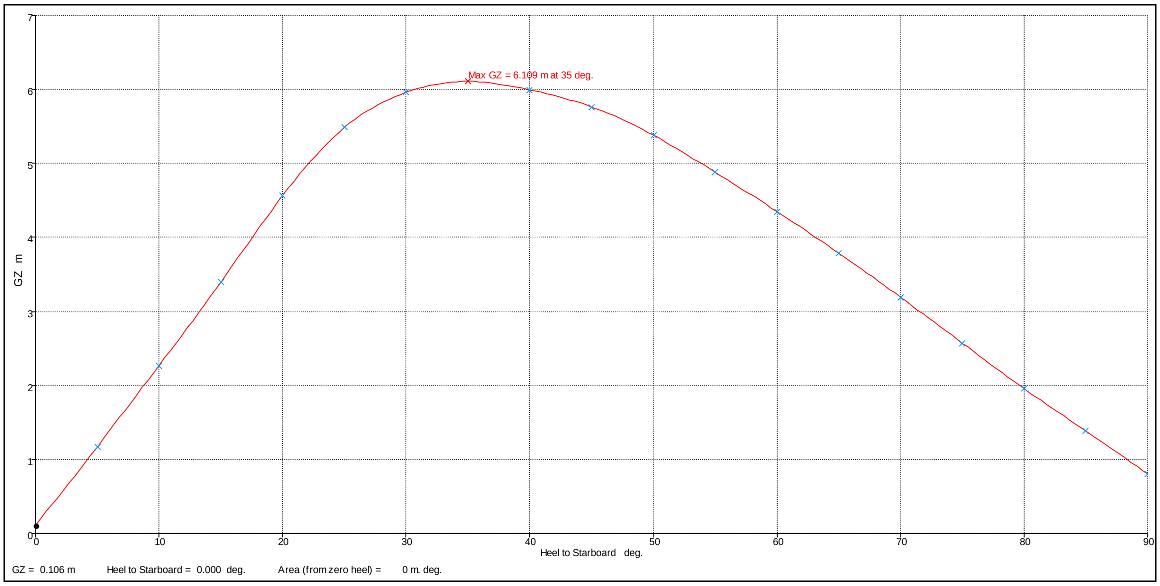


Figure – Heel after Damage Case 2

Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	9509	9508	9509	9509	9509	9508	9508	9508	9507	9507	9508
Draft at FP (m)	6.046	6.107	6.235	6.308	6.351	6.404	6.547	6.756	6.957	7.11	6.651
Draft at AP (m)	7.262	7.201	7.053	6.898	6.735	6.69	6.815	7.14	7.661	8.215	8.782
WL Length (m)	118.552	119.6	116.894	116.06	115.172	114.27	113.436	112.618	111.707	107.95	106.507
Immersed Depth (m)	7.121	7.78	8.41	9	9.518	10.068	10.682	11.356	12.044	12.719	13.317
WL Beam (m)	25	24.924	25.117	25.458	26.004	26.184	26.538	27.274	26.533	24.105	14.294
Wetted Area (m^2)	4706.915	5506.87	5796.676	5785.26	5744.518	5911.409	6058.937	6187.627	6271.687	6267.876	6071.409
Waterplane Area (m^2)	1675.682	1800.067	1916.242	2004.787	2052.354	1788.62	1593.284	1430.827	1217.892	956.842	596.726
Prismatic Coefficient	0.876	0.858	0.887	0.903	0.919	0.931	0.932	0.924	0.912	0.931	0.939
Block Coefficient	0.439	0.502	0.491	0.46	0.435	0.413	0.384	0.362	0.395	0.516	0.838
LCB from Amidships (+ve fwd) (m)	-2.976	-2.977	-2.972	-2.967	-2.964	-2.968	-2.967	-2.961	-2.978	-2.982	-3.016
VCB from DWL (m)	2.936	2.975	3.085	3.255	3.502	3.901	4.468	5.153	5.879	6.533	6.923
GZ (m)	0.106	1.174	2.269	3.397	4.567	5.485	5.96	6.109	5.994	5.764	5.381
LCF from Amidship (+ve fwd) (m)	-2.245	-6.232	-5.907	-5.021	-4.492	-4.753	-5.296	-5.941	-6.531	-7.884	-8.316
TCF to zero point (m)	0	0.757	1.627	2.384	3.029	2.679	2.665	2.92	3.5	4.307	7.522
Max deck inclination (degrees)	0.6	5	10	15	20	25	30	35	40	45	50
Trim angle (+ve by stern) (degrees)	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.5	1



In this damaged case the water level is still under the UUV hangar, and ship can float in equilibrium at a heeling angel of 0.52 degrees to port and at a 0.6 degrees trim to stern. But the water level is critically close to flooding the UUV hangar. The ship can generate positive a righting arm with up to 90 degrees of heel.

c. Case 3

Flooded Compartments: Engine Room 1 (Starboard side)
Engine Room 3 (Starboard side)
Engine Room 2 (Port side)
Engine Room 4 (Port side)
Cosal Storeroom
Waterjet Drive Motor Compartment
All Fuel Tanks at Port side at 98.5% level
All Fuel Tanks at Starboard side at 98.5% level
All Ballast Tanks at 99% level
UUV Hangar

Draft Amidships (m)	8.794
Displacement (tonne)	15291
Heel to Starboard (degrees)	-0.6
Draft at FP (m)	6.532
Draft at AP (m)	11.056
Draft at LCF (m)	8.943
Trim (+ve by stern) (m)	4.523
WL Length (m)	119.323
WL Beam (m)	25.001
Wetted Area (m^2)	8644.277
Waterplane Area (m^2)	2701.304
Prismatic Coefficient	0.715

Block Coefficient	0.471
Midship Area Coefficient	0.658
Waterplane Area Coefficient	0.905
LCB from Amidship (+ve fwd) (m)	-9.143
LCF from Amidship (+ve fwd) (m)	-3.862
KB (m)	5.45
KG fluid (m)	6.751
BM_t (m)	9.656
BM_L (m)	181.761
GM_t (m)	8.355
GM_L (m)	180.46
KM_t (m)	15.106
KM_L (m)	187.211
Immersion (TP_c) (tonne/cm)	27.694
MTc (tonne•m)	235.297
RM at 1deg = GM_t•Disp•sin(1) (tonne•m)	2229.617
Max deck inclination (degrees)	2.3
Trim angle (+ve by stern) (degrees)	2.2

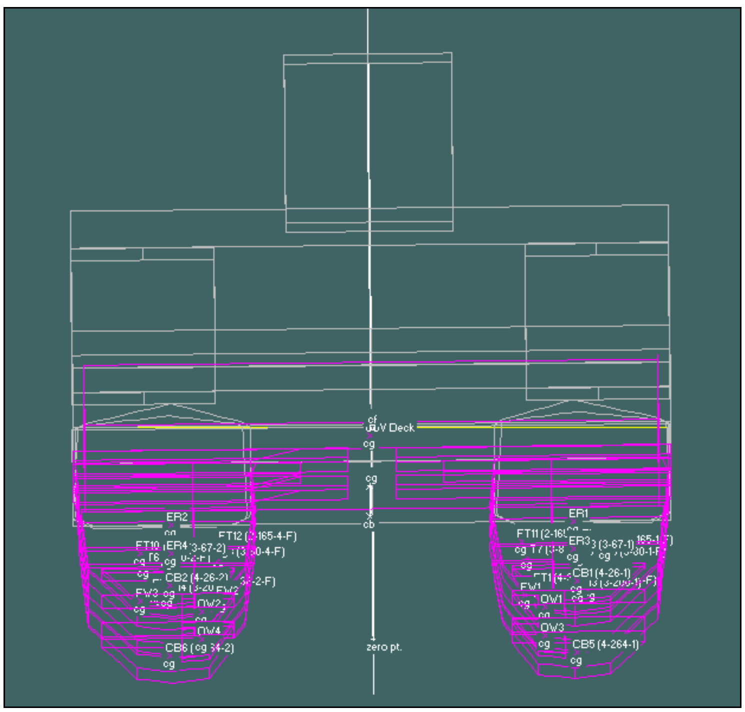


Figure – Heel after Damage Case 3

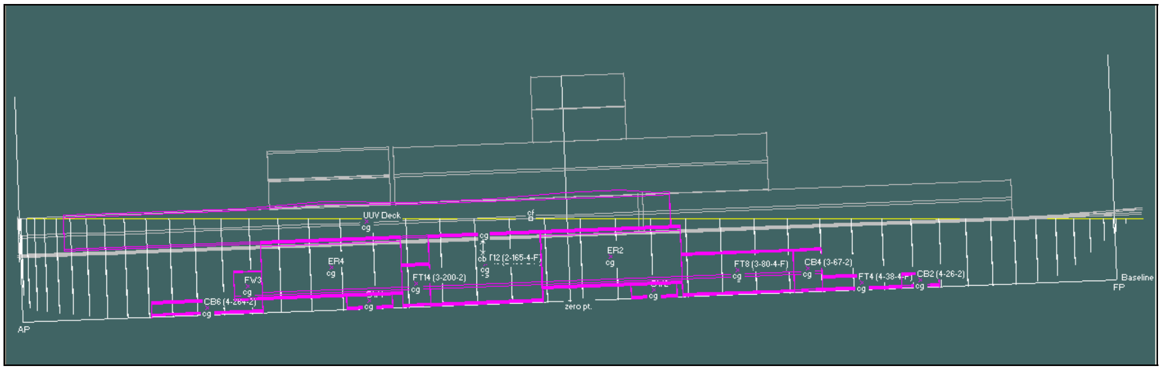
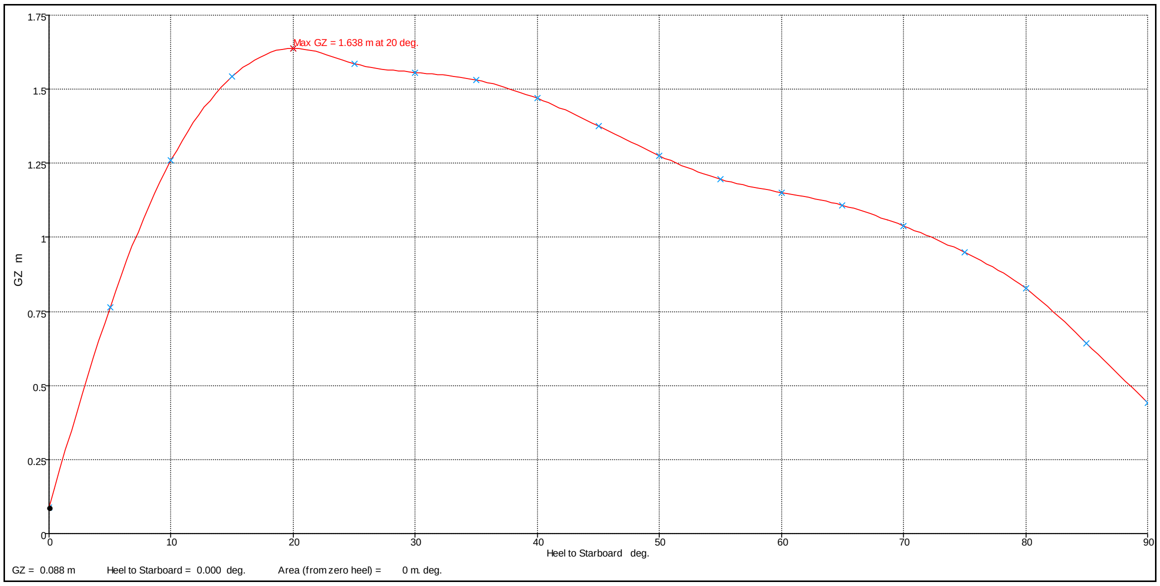


Figure – Trim After Damage Case 3

Heel to Starboard (degrees)	0	5	10	15	20	25	30	35	40	45	50
Displacement (tonne)	15290	15289	15290	15289	15290	15290	15290	15291	15290	15290	15291
Draft at FP (m)	6.536	6.511	6.37	6.149	5.974	5.908	6.015	6.259	6.598	6.998	7.486
Draft at AP (m)	11.051	11.131	11.515	12.265	13.298	14.561	15.799	17.081	18.566	20.377	22.543
WL Length (m)	119.216	120.112	117.193	116.092	115.084	114.217	113.501	112.865	112.246	110.84	108.796
Immersed Depth (m)	10.53	11.291	12.332	13.62	15.023	16.456	17.67	18.692	19.599	20.537	21.435
WL Beam (m)	25	25.095	25.386	25.882	26.487	26.219	23.114	18.682	17.105	21.788	23.323
Wetted Area (m^2)	8637.567	8588.551	8596.651	8643.324	8768.196	8934.874	9139.026	9079.987	9176.6	9098.046	9128.49
Waterplane Area (m^2)	2714.121	2463.776	2266.297	1983.665	1730.538	1512.956	1335.702	1246.215	1184.432	1130.791	1112.531
Prismatic Coefficient	0.716	0.713	0.737	0.742	0.741	0.739	0.741	0.745	0.749	0.758	0.771
Block Coefficient	0.475	0.438	0.407	0.412	0.437	0.461	0.465	0.462	0.465	0.473	0.416
LCB from Amidships (+ve fwd) (m)	-9.132	-9.146	-9.163	-9.18	-9.193	-9.222	-9.242	-9.253	-9.27	-9.292	-9.3
VCB from DWL (m)	3.693	3.749	3.963	4.358	4.902	5.554	6.172	6.758	7.342	7.918	8.449
GZ (m)	0.088	0.765	1.261	1.542	1.638	1.587	1.557	1.531	1.47	1.376	1.276
LCF from Amidship (+ve fwd) (m)	-4.045	-2.168	-0.109	1.793	2.376	3.005	3.73	3.342	2.645	1.714	0.551
TCF to zero point (m)	0	0.059	0.342	0.117	-0.218	-0.634	-1.152	-1.021	-0.641	-0.113	0.84
Max deck inclination (degrees)	2.2	5.5	10.3	15.3	20.3	25.3	30.3	35.2	40.2	45.2	50.2
Trim angle (+ve by stern) (degrees)	2.2	2.3	2.5	3	3.6	4.2	4.8	5.3	5.8	6.5	7.3



In this damaged case the ship can survive, but the water level reaches very close to the helicopter platform. The ship can float in equilibrium at a heeling angel of 0.6 degrees to port and at a 2.3 degrees trim to stern. The ship can generate a positive righting arm up to 90 degrees heel.

d. Case 4

Flooded Compartments: Engine Room 3 (Starboard side)
Engine Room 4 (Port side)
Waterjet Drive Motor Compartment
All Fuel Tanks in front of amidships at 5% level
All Ballast Tanks in front of amidships at 0% level
All Fuel Tanks in back of amidships at 98.5% level
All Ballast Tanks in back of amidships at 99% level
UUV Hangar

Draft Amidships (m)	7.842
Displacement (tonne)	13193
Heel to Starboard (degrees)	-0.7
Draft at FP (m)	4.307
Draft at AP (m)	11.377
Draft at LCF (m)	8.180
Trim (+ve by stern) (m)	7.070
WL Length (m)	114.445
WL Beam (m)	25.002
Wetted Area (m^2)	7131.768
Waterplane Area (m^2)	2281.596
Prismatic Coefficient	0.632
Block Coefficient	0.418
Midship Area Coefficient	0.661
Waterplane Area Coefficient	0.797
LCB from Amidship (+ve fwd) (m)	-13.637
LCF from Amidship (+ve fwd) (m)	-5.614
KB (m)	5.139
KG fluid (m)	7.189
BM_t (m)	10.575
BM_L (m)	161.494
GM_t (m)	8.523
GM_L (m)	159.442
KM_t (m)	15.714
KM_L (m)	166.633
Immersion (TP_c) (tonne/cm)	23.391
MT_c (tonne•m)	179.374
RM at 1deg = GM_t•Disp•sin(1) (tonne•m)	1962.434
Max deck inclination (degrees)	3.5
Trim angle (+ve by stern) (degrees)	3.5

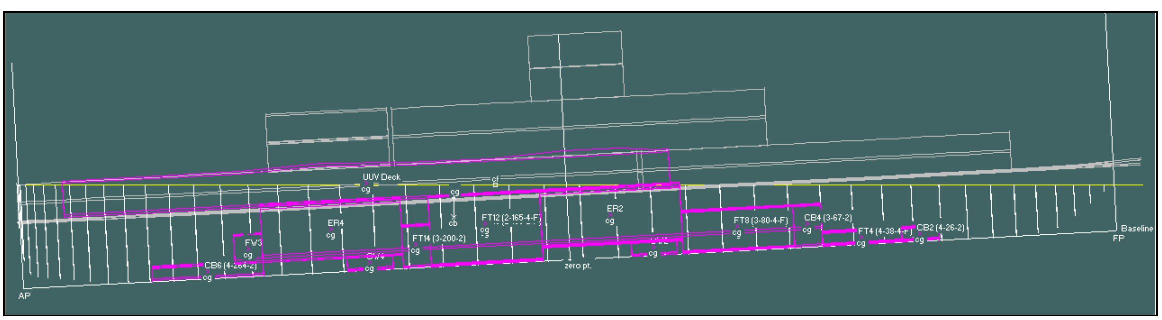
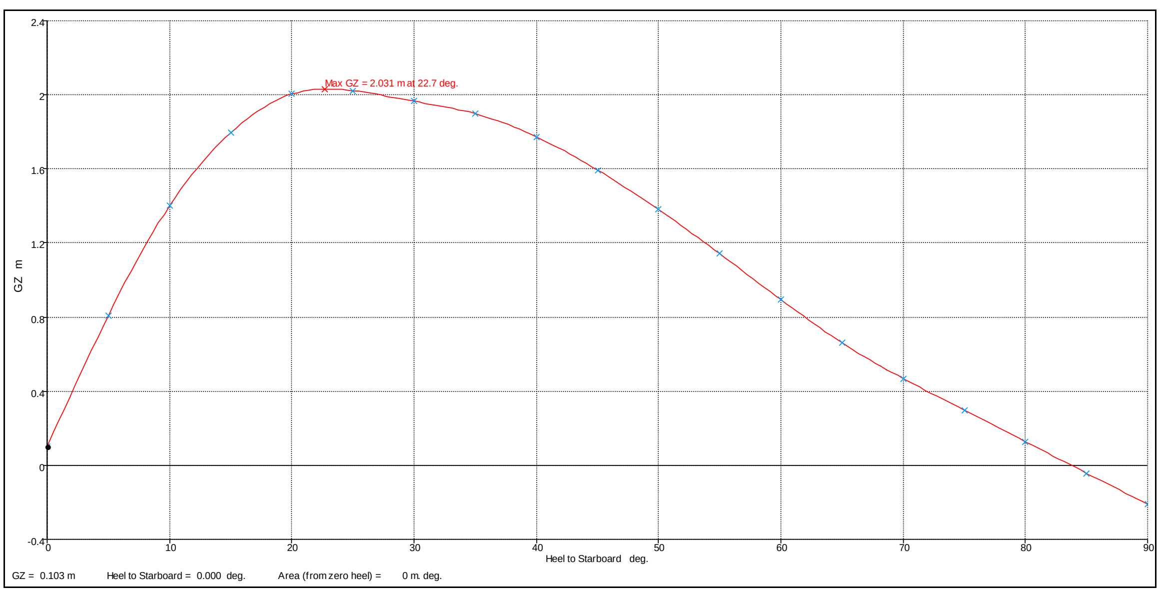


Figure – Trim after Damage Case 4

Heel to Starboard (degrees)	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
Displacement (tonne)	13193	13193	13193	13193	13193	13193	13194	13193	13193	13192	13194
Draft at FP (m)	4.308	4.216	3.986	3.616	3.131	2.496	1.679	0.679	-0.562	-2.116	-3.993

Draft at AP (m)	11.377	11.498	11.851	12.539	13.554	14.933	16.563	18.354	20.471	23.042	26.150
WL Length (m)	111.783	117.351	118.050	118.623	119.107	119.496	119.780	119.987	120.113	120.178	119.485
Immersed Depth (m)	10.653	11.450	12.454	13.675	15.037	16.527	17.988	19.298	20.658	22.085	23.430
WL Beam (m)	25.000	25.095	25.386	25.809	26.467	27.334	24.792	19.334	17.260	15.678	14.455
Wetted Area (m^2)	7117.386	7208.171	7390.603	7569.778	7719.546	7863.236	7976.701	8012.033	8007.261	8001.293	8004.159
Waterplane Area (m^2)	2221.321	2182.207	2088.932	1929.996	1734.025	1521.688	1274.807	1103.340	991.491	902.370	837.502
Prismatic Coefficient	0.647	0.625	0.630	0.628	0.621	0.611	0.602	0.596	0.591	0.586	0.585
Block Coefficient	0.432	0.382	0.345	0.328	0.329	0.320	0.373	0.363	0.359	0.352	0.346
LCB from Amidships (+ve fwd) (m)	-13.644	-13.652	-13.663	-13.691	-13.734	-13.776	-13.820	-13.876	-13.940	-14.019	-14.069
VCB from DWL (m)	3.518	3.582	3.780	4.151	4.667	5.300	5.935	6.504	7.047	7.564	8.039
GZ (m)	0.103	0.810	1.401	1.795	2.004	2.022	1.965	1.898	1.773	1.594	1.381
LCF from Amidship (+ve fwd) (m)	-6.110	-4.209	-2.421	-0.844	-0.010	-0.076	-0.127	-0.719	-1.353	-1.452	-1.118
TCF to zero point (m)	0.000	0.196	0.725	0.968	1.119	1.384	1.258	1.404	1.928	2.559	3.185
Max deck inclination (degrees)	3.4	6.1	10.7	15.6	20.5	25.6	30.6	35.6	40.6	45.6	50.6
Trim angle (+ve by stern) (degrees)	3.4	3.6	3.8	4.4	5.1	6.1	7.2	8.6	10.2	12.1	14.4

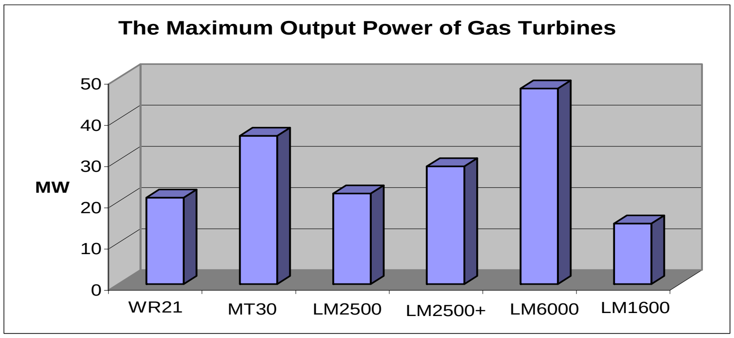


In this case the ship can survive, but the water level reaches very close to the helicopter platform. The ship can float in equilibrium at a heeling angel of 0.7 degree to port and at a 3.5 degree trim to stern. The ship can generate a positive righting arm up to 84 degrees of heel.

APPENDIX XI: FUEL REQUIREMENTS

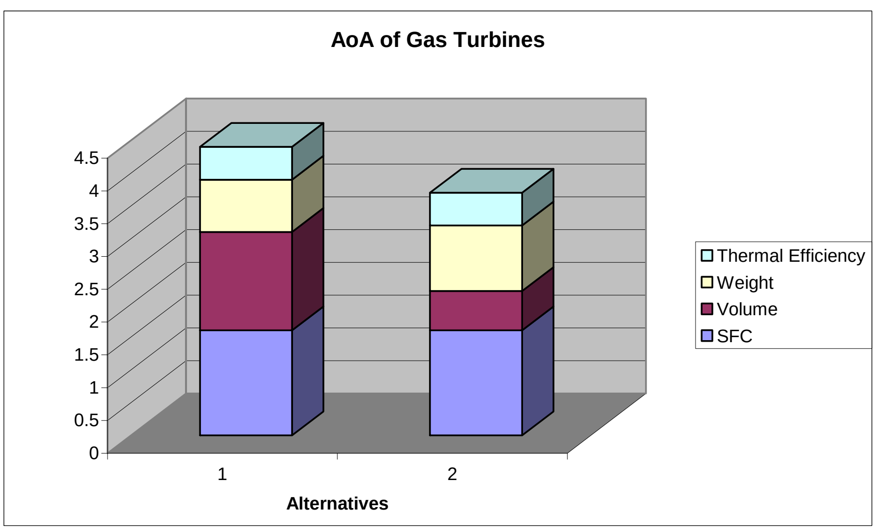
SEA TENTACLE fuel requirement was completed through an iterative process. Throughout the ship design process, various parameters such as hull size and resistance calculations contributed to increased or decreased fuel requirements.

	Output Power (MW)
WR21	21
MT30	36
LM2500	22
LM2500+	28.6
LM6000	47.5
LM1600	14.7

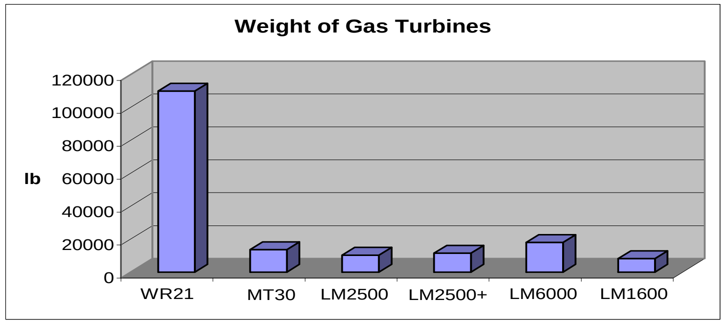


We chose one LM 6000 and two LM 2500+ gas turbine engines with an additional auxiliary/ emergency generator, Allison 501-K34. Based on various aspects of the engine configurations as shown here we assessed this to be our best alternative and started with it as a key constant to many of the design variables.

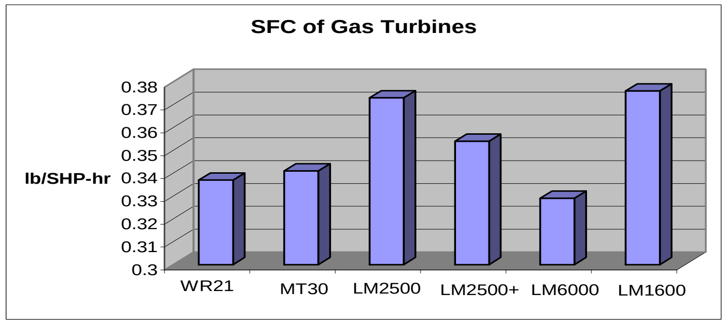
	Weighting Factor	Alternative - 1		Alternative - 2		
Specific Fuel Consumption	0.4	4	1.6	4	1.6	1
Volume	0.3	5	1.5	2	0.6	2
Weight	0.2	4	0.8	5	1	3
Thermal Efficiency	0.1	5	0.5	5	0.5	4
Total Score		4.4		3.7		5



	Weight (lb)	
WR21	110000	
MT30	13668.6	48501
LM2500	10300	
LM2500+	11545	
LM6000	18010	
LM1600	8200	



	SFC
WR21	0.337
MT30	0.341
LM2500	0.373
LM2500+	0.354
LM6000	0.329
LM1600	0.376



Based on this engine configuration the following fuel requirements were calculated. We chose to complete calculations in five knot increments from five to forty knots. The results are consolidated on the last spreadsheet pasted in this document. As can be seen in this spreadsheet, we chose a cruise speed of twenty knots and sprint speed of thirty-five knots.

Ships Fuel Requirements (5Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	5
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	686.3988
6	Average Endurance Power	HP	755.03868
	w/ship electric		4778.03868
7	Average Endurance Power/Rated Full Power		0.006144016
	w/ship electric		0.037648113
8	Average Endurance BHP	HP	786.498625
	w/ship electric		4977.123625
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	1.9
11	Propulsion Fuel Consumption	lb/hr	1494.347388
	w/ship electric		9456.534888
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	1494.347388
	w/ship electric		9456.534888
16	All-Purpose Fuel Rate	lb/SHP/hr	1.979166667
	w/ship electric		1.979166667
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	2.058333333
	w/ship electric		2.058333333
19	Average Endurance Fuel Rate	lb/SHP/hr	2.16125
	w/ship electric		2.16125
20	Endurance Fuel	LTONS	655.6449163
	w/ship electric		4149.054682
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**690.1525434**
	w/ship electric	**LTONS**	**4367.425981**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=		kW=	403.02
kW=HP*0.7457		HP=kW*1.341	
kW=	0	HP=	540.4498
	HP/.78737	686.3988	

Ships Fuel Requirements (10Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	10
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	4506.231
6	Average Endurance Power	HP	4956.8541
	w/ship electric		8979.8541
7	Average Endurance Power/Rated Full Power		0.040335667
	w/ship electric		0.070755927
8	Average Endurance BHP	HP	5163.389688
	w/ship electric		9354.014688
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	1.5
11	Propulsion Fuel Consumption	lb/hr	7745.084531
	w/ship electric		14031.02203
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	7745.084531
	w/ship electric		14031.02203
16	All-Purpose Fuel Rate	lb/SHP/hr	1.5625
	w/ship electric		1.5625
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	1.625
	w/ship electric		1.625
19	Average Endurance Fuel Rate	lb/SHP/hr	1.70625
	w/ship electric		1.70625
20	Endurance Fuel	LTONS	1699.077919
	w/ship electric		3078.055458
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**1788.503073**
	w/ship electric	**LTONS**	**3240.058377**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=		kW=	2645.84
kW=HP*0.7457		HP=kW*1.341	
kW=	0	HP=	3548.071
	HP/.78737	4506.231	

Ships Fuel Requirements (15Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	15
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	12822.33
6	Average Endurance Power	HP	14104.563
	w/ship electric		18127.563
7	Average Endurance Power/Rated Full Power		0.114773794
	w/ship electric		0.142834451
8	Average Endurance BHP	HP	14692.25313
	w/ship electric		18882.87813
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	0.506
11	Propulsion Fuel Consumption	lb/hr	7434.280081
	w/ship electric		9554.736331
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	7434.280081
	w/ship electric		9554.736331
16	All-Purpose Fuel Rate	lb/SHP/hr	0.527083333
	w/ship electric		0.527083333
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	0.548166667
	w/ship electric		0.548166667
19	Average Endurance Fuel Rate	lb/SHP/hr	0.575575
	w/ship electric		0.575575
20	Endurance Fuel	LTONS	1087.263462
	w/ship electric		1397.380188
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**1144.487855**
	w/ship electric	**LTONS**	**1470.926514**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=		kW=	7528.65
kW=HP*0.7457		HP=kW*1.341	
kW=	0	HP=	10095.92
	HP/.78737	12822.33	

Ships Fuel Requirements (20Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	20
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	26262.21
6	Average Endurance Power	HP	28888.431
	w/ship electric		32911.431
7	Average Endurance Power/Rated Full Power		0.235075332
	w/ship electric		0.259322568
8	Average Endurance BHP	HP	30092.11563
	w/ship electric		34282.74063
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	0.37
11	Propulsion Fuel Consumption	lb/hr	11134.08278
	w/ship electric		12684.61403
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	11134.08278
	w/ship electric		12684.61403
16	All-Purpose Fuel Rate	lb/SHP/hr	0.385416667
	w/ship electric		0.385416667
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	0.400833333
	w/ship electric		0.400833333
19	Average Endurance Fuel Rate	lb/SHP/hr	0.420875
	w/ship electric		0.420875
20	Endurance Fuel	LTONS	1221.269705
	w/ship electric		1391.343602
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**1285.547058**
	w/ship electric	**LTONS**	**1464.572212**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=	34282.74	kW=	15419.89
kW=HP*0.7457		HP=kW*1.341	
kW=	25564.64	HP=	20678.07
	HP/.78737	26262.21	

Ships Fuel Requirements (25Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	25
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	45150.93
6	Average Endurance Power	HP	49666.023
	w/ship electric		53689.023
7	Average Endurance Power/Rated Full Power		0.404149911
	w/ship electric		0.423037677
8	Average Endurance BHP	HP	51735.44063
	w/ship electric		55926.06563
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	0.7
11	Propulsion Fuel Consumption	lb/hr	36214.80844
	w/ship electric		39148.24594
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	36214.80844
	w/ship electric		39148.24594
16	All-Purpose Fuel Rate	lb/SHP/hr	0.729166667
	w/ship electric		0.729166667
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	0.758333333
	w/ship electric		0.758333333
19	Average Endurance Fuel Rate	lb/SHP/hr	0.79625
	w/ship electric		0.79625
20	Endurance Fuel	LTONS	3177.84944
	w/ship electric		3435.258581
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**3345.104674**
	w/ship electric	**LTONS**	**3616.061664**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=	55926.06	kW=	47500
kW=HP*0.7457		HP=kW*1.341	
kW=	41704.06	HP=	63697.5
	HP/.78737	80899.07	

Ships Fuel Requirements (30Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	30
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	69195
6	Average Endurance Power	HP	76114.5
	w/ship electric		80137.5
7	Average Endurance Power/Rated Full Power		0.619370478
	w/ship electric		0.631435998
8	Average Endurance BHP	HP	79285.9375
	w/ship electric		83476.5625
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	0.71
11	Propulsion Fuel Consumption	lb/hr	56293.01563
	w/ship electric		59268.35938
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	56293.01563
	w/ship electric		59268.35938
16	All-Purpose Fuel Rate	lb/SHP/hr	0.739583333
	w/ship electric		0.739583333
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	0.769166667
	w/ship electric		0.769166667
19	Average Endurance Fuel Rate	lb/SHP/hr	0.807625
	w/ship electric		0.807625
20	Endurance Fuel	LTONS	4116.426768
	w/ship electric		4333.998779
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**4333.080808**
	w/ship electric	**LTONS**	**4562.103978**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=	55926.06	kW=	40627.94
kW=HP*0.7457		HP=kW*1.341	
kW=	41704.06	HP=	54482.07
	HP/.78737	69195	

Ships Fuel Requirements (35Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	35
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	96588.62
6	Average Endurance Power	HP	106247.482
	w/ship electric		110270.482
7	Average Endurance Power/Rated Full Power		0.864573159
	w/ship electric		0.868866035
8	Average Endurance BHP	HP	110674.4604
	w/ship electric		114865.0854
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	0.96
11	Propulsion Fuel Consumption	lb/hr	106247.482
	w/ship electric		110270.482
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	106247.482
	w/ship electric		110270.482
16	All-Purpose Fuel Rate	lb/SHP/hr	1
	w/ship electric		1
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	1.04
	w/ship electric		1.04
19	Average Endurance Fuel Rate	lb/SHP/hr	1.092
	w/ship electric		1.092
20	Endurance Fuel	LTONS	6659.44039
	w/ship electric		6911.596283
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**7009.937252**
	w/ship electric	**LTONS**	**7275.364508**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation			
HP=	55926.06	kW=	56712.14
kW=HP*0.7457		HP=kW*1.341	
kW=	41704.06	HP=	76050.98
	HP/.78737	96588.62	

Ships Fuel Requirements (40Kts)

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	4500
2	Endurance Speed	KNOTS	40
3	Full Load Displacement	LTONS	8,000
4	Rated Full Power	HP	122890.1
	w/ship electric		126913.1
5	Design Endurance Power @ (2) & (3)	HP	122890.1
6	Average Endurance Power	HP	135179.11
	w/ship electric		139202.11
7	Average Endurance Power/Rated Full Power		1.1
	w/ship electric		1.096830114
8	Average Endurance BHP	HP	140811.5729
	w/ship electric		145002.1979
9	24-hour Average Electric Load	kW	3000
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	1.037
11	Propulsion Fuel Consumption	lb/hr	146021.6011
	w/ship electric		150367.2792
12	Generator Fuel Rate @ (9)	lb/kW/hr	0
13	Generator Fuel Consumption	lb/hr	0
14	Fuel Consumption for Other Services	lb/hr	0
15	Total All-Purpose Fuel Consumption	lb/hr	146021.6011
	w/ship electric		150367.2792
16	All-Purpose Fuel Rate	lb/SHP/hr	1.080208333
	w/ship electric		1.080208333
17	Fuel Rate Correction Factor Based on (7)		1.04
18	Specified Fuel Rate	lb/SHP/hr	1.123416667
	w/ship electric		1.123416667
19	Average Endurance Fuel Rate	lb/SHP/hr	1.1795875
	w/ship electric		1.1795875
20	Endurance Fuel	LTONS	8008.372186
	w/ship electric		8246.705471
21	Safety Factor		0.95
22	**Endurance Fuel Load**	**LTONS**	**8429.865459**
	w/ship electric	**LTONS**	**8680.742601**

Speed	EHP	SHP	kW
15	12346.07	15680.14	9206.615
35	95517.39	121312	71228.48

SFC @average power w/ ship's electric load

This takes into account that there will be no additional engines in operation, just the ship's electrical power is calculated in as required HP.

Conversion Calculation

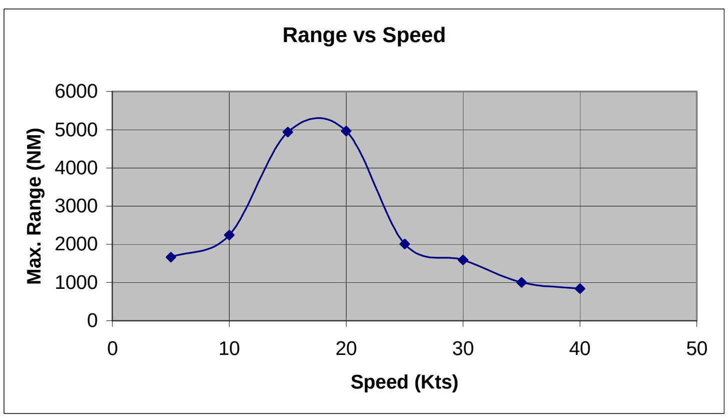
HP=	55926.06	kW=	72155.12
kW=HP*0.7457		HP=kW*1.341	
kW=	41704.06	HP=	96760.02
	HP/.78737	122890.1	

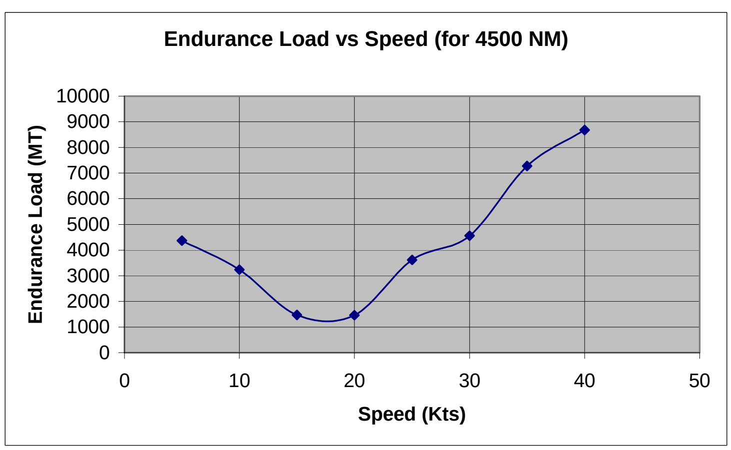
Ships Fuel Requirements Results

Speed (kts)	Max. Range (NM)	Speed (kts)	Endurance Load for 4500 NM (MT)
5	1664.18594	5	4367
10	2243.055556	10	3240
15	4940.516655	15	1471
20	4964.139344	20	1464
25	2009.817478	25	3616
30	1593.051293	30	4562
35	998.9690722	35	7275
40	837.2695853	40	8680

Total Fuel Capacity = 1710 MT
Fuel Stored = 5 %
Fuel Amount = 1615 MT

Cruise Speed = 20 kts
Sprint Speed = 35 kts





APPENDIX XII: COMBAT SYSTEM DESIGN

A. INTEGRATED COMBAT MANAGEMENT SYSTEM DESIGN

1. Mission need statement

"According to Navy guidance, the Navy is required to project power from the sea and maintain assured access in the littoral regions, which for naval vessels refers specifically to the transition between open ocean to more constrictive shallower waters close to shore—the littorals. "Anti-access" threats from mines, submarines, and surface forces threaten the Navy's ability to assure access to the littorals." – GAO, 2005

As the mission and threat environment for the Navy evolves particularly within the littoral regions, so does the role of the combat system on board naval vessels. Control of the waterspace within the littoral environment is heavily dependent upon employing net-centric system solutions within a highly challenging environment.

As emerging littoral threats become more mature, the need to implement integrated system of systems solutions fit for these dynamic rapidly changing environments is integral to effectively countering the littoral submarine threat.

The ability to facilitate prosecution of enemy submarines within the littoral environment is a priority for the navy of the 21st century. The integrated combat management system (ICMS) not only provides this capability but provides for distributed USW functionality between participating assets operating within a littoral environment.

a. Background

Seventy percent of the world's coasts are accessible to today's modern navy. More importantly, the surrounding littoral waters make the majority of the world’s sea lanes a littoral – brown water – environment. With shipping still serving as the arterial lifeline to global commerce, the importance of naval superiority within the littoral environment is just as important as ever. The proliferation of inexpensive low technology submarines provides a global threat to shipping commerce that must be deterred and countered. This emerging threats within the littorals are becoming more complex (i.e., air independent propulsion) and asymmetric (i.e., terrorist controlled), and thereby require innovative cutting-edge solutions to ensure naval superiority into the 21st century.

b. Mission

The IMCS for TENTACLE was designed to conduct missions in support of Sea Power 21 and Naval Power 21. The ICMS will enable focused mission capabilities that facilitate joint and friendly forces operations in the littoral. Littoral net-centric USW is the primary mission capability provided by ICMS. Secondary mission capabilities include SUW (maritime surveillance), AAW, and MIW as a subset of USW. ICMS is designed to be multi-mission capable and effective across the threat spectrum by embodying an integrated system of systems combat management architecture comprised of compatible onboard and interoperable distributed elements.

2. Operational Requirements

a. Description of Proposed System

The distributed functionality of ICMS is a central feature of the TENTACLE design and will provide the main war fighting capability for the various mission areas. Distributed functionality is characterized by the seamless integration of onboard system components, manned and unmanned off-board vehicles, the deployable sensor grid, and other participating assets.

The ICMS design must meet the top-level requirements specified by SEA-8. The ship's open system architecture will affordably maximize lifecycle flexibility for integration of emerging and legacy technologies. This will facilitate system of systems optimization and integration of distributed mission elements. The integrated elements of the open systems architecture will be designed to accommodate future mission areas, future ship flights, and technology refresh. System elements, to the greatest extent possible, should be designed with the intent of integrating into the ICMS core command and control architecture to minimize the use of unique equipment.

b. Operational and Support Concept

The ICMS will be distributed and installed on all units of the TENTACLE design. ICMS requires the capability for the following missions:

Littoral undersea warfare

- Detect all threat submarines in a given littoral area
- Establish antisubmarine barriers
- Detect, avoid, and/or neutralize mines
- Clear transit lanes
- Establish and maintain mine cleared areas

Littoral surface warfare

- Detect, track, and engage surface threats in a given littoral area

- Protect joint operating areas

Air Warfare Capabilities

- Provide point defense against threat anti-ship missiles and aircraft.
- Fuel and support rotary wing aircraft supporting TENTACLE operations both day and night.

Command & Control Capabilities

- Conduct Electronic Warfare operations
- Communicate with U.S. and coalition forces via both secure and unsecured channels
- Collect, process, display, evaluate and disseminate tactical information onboard, with the acoustic sensor grid and with participating assets.
- Provide a data link capability to include being interoperable with CEC platforms.

c. Threat Environment

A list of basic threats to be considered are:

- Anti-ship missiles (surface-surface, air-surface)
- Small boat attack
- Submarines and mines
- Enemy fire from shore locations

d. Expanded Sensor Operations

ICMS will be interoperable with the Distributed Autonomous Deployable Systems (DADS) which is a acoustical undersea wide area network (UWAN) comprised of a sensor grid of tethered and unmanned undersea vehicles (UUVs) capable of net-centric information operations with the TENTACLE platform. Further interoperability with Cooperative Engagement Capability (CEC) enables participating assets to use the TENTACLE as an afloat network operations center that extends the sensor range of the surface combatants comprising the sea force. The capability will have great impacts in littoral environments where shallow water and asymmetric threats deter larger vessels from operating effectively in the area.

3. Statement of Work

a. Objective

The ICMS design philosophy is based upon implementing an effective combat system that embodies sound open architecture system design principles. The optimal system will seek to seamlessly integrate the "best-fit" commercial/government off the shelf (COTS/GOTS) technology components into the TENTACLE seaframe.

b. Tasks

(1) Develop Systems of Systems Architecture

Iterative functional analysis shall be utilized to develop top level systems architecture. The resulting block implementation of the ICMS shall convey consideration of the four phases of the Boyd Cycle (i.e. observe, orient, decide, and act – OODA Loop). Basic information along with key design specifications relating to the systems requirements should be included. Conservation of parameters concerning power consumption, radio frequency spectrum management, and systems placement on board the ship shall be considered throughout development. Weight and volume parameters will act as primary constraints for the initial analysis of component alternatives.

(2) Choice of System Components

The development of systems architecture and subsequent component selection will be traceable to SEA top-level requirements. Components will be considered with suitability with the undersea warfare mission as the primary mission area. The following available components will be considered as options that satisfy the USW mission.

Sensor Suite:

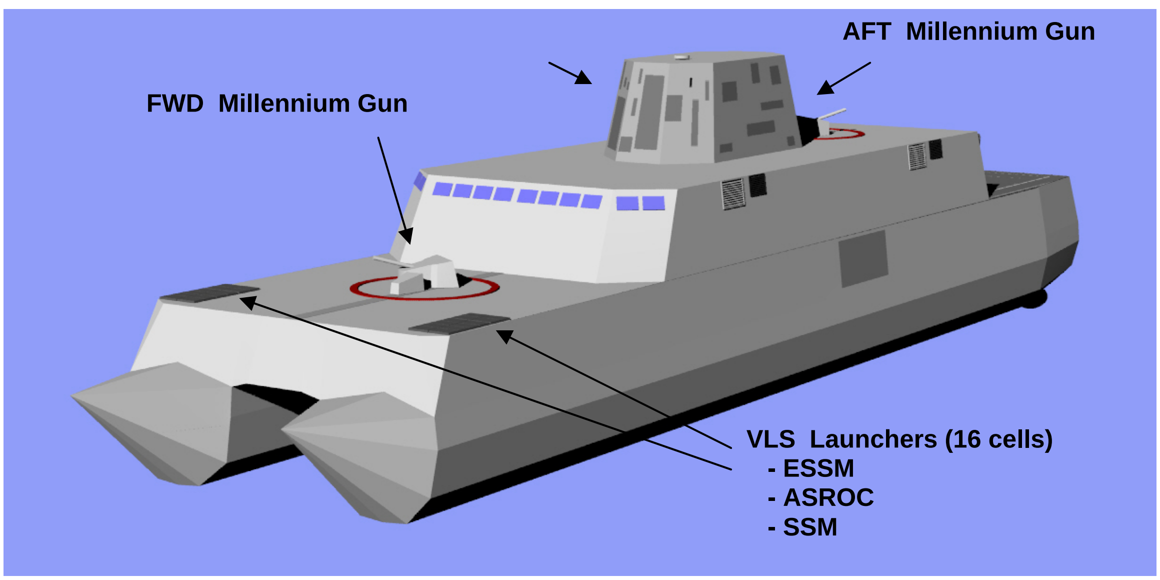
- Multifunctional Radar
- IR search and track System
- Volume Search Radar
- Navigation Radar
- Basic Mine Detection System

EW suite:

- Radar warning Receiver
- Missile Approach Warning System
- Active/Passive Decoy System
- IFF System

Shipboard Weapons:

- High rate of fire medium range gun
- Medium range missile
- Crew served weapons, small arms and non lethal weapons



Proposed technology solutions for ICMS will be compared according to how they would best satisfy top level requirements within the ICMS. Integrated technology solutions that embody multi-functionability and relatively small footprints shall take precedence over other component alternatives.

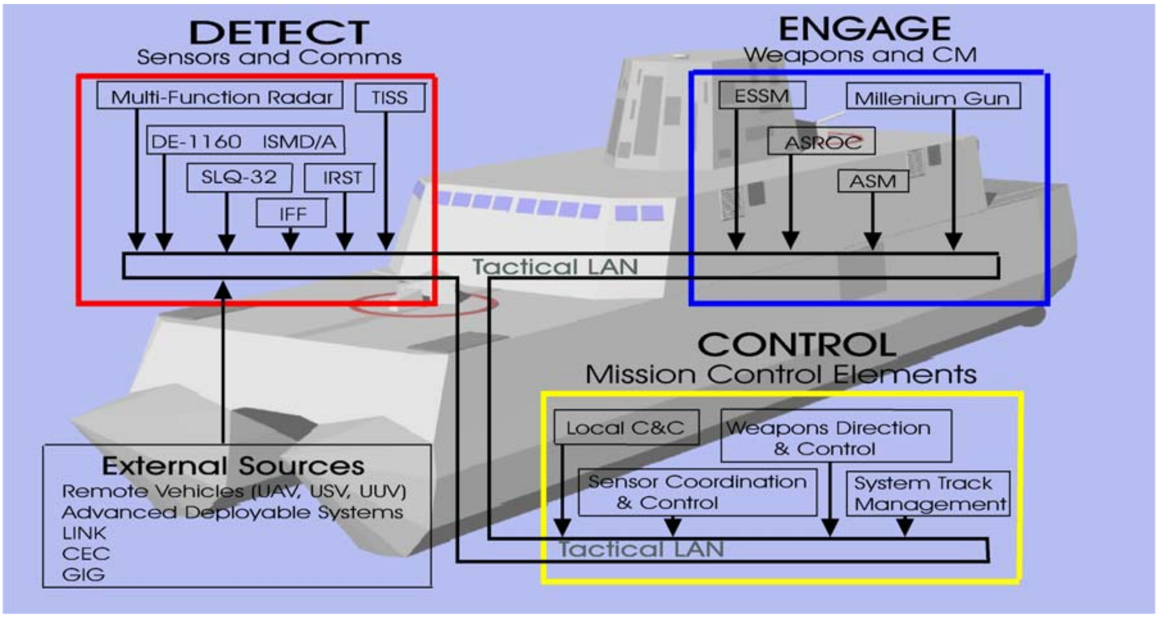
4. Integrated Combat Management System Overview

The purpose of this section is to present the technical specifications of the ICMS for the TENTACLE. In accordance with the top level requirements, the ICMS is designed to provide capability against a variety of threats.

Throughout the discussion below we assume that the TENTACLE seaframe has adequate weight, space, cooling and electrical power resources to facilitate ICMS operational support.

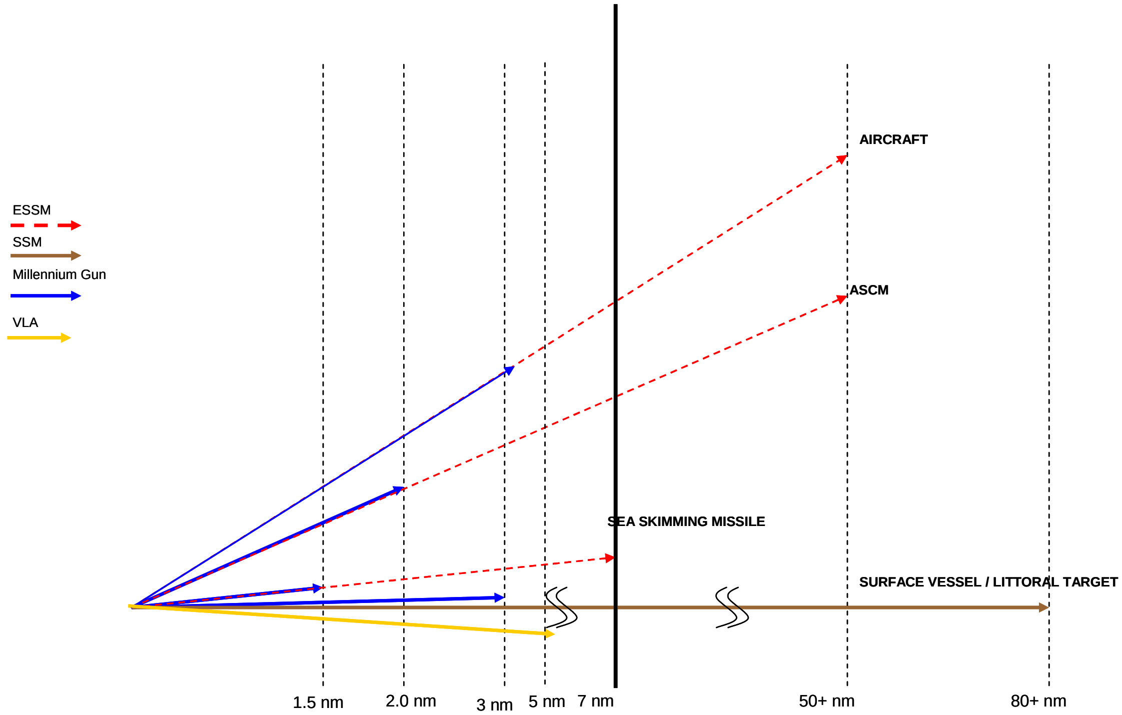
a. System Overview

The Figure below depicts the block implementation of the ICMS for Sea TENTACLE. It conveys in OODA like fashion all the system components necessary to complete the combat mission of the TENTACLE.



b. ICMS Design Philosophy:

Sea TENTACLE will utilize a layered defense concept for point defense of the seaframe shown below. It will leverage both existing and emerging technology.



The TENTACLE will utilize long-range defense provided by CEC participating assets. The ICMS will consist of weapon and sensor suites to provide capability against known littoral threats. Mid layer defense will be provided by onboard missiles, and inner layer defense will be provided by a combination of onboard missile and gun systems. Distributed functionality for ICMS and assets operating within a net-centric environment extend and enhance the performance of the ICMS.

The attached table shows a breakdown of different threats TENACLE can experience (vertical axis) and the organic system designed to mitigate the threat (horizontal axis). The method of mitigation is the value in the respective square, either through detection (D), soft kill (SK), and hard kill (HK). For the ship threat, the Evolved Sea Sparrow Missile can be used only after a future software modification (HK*).

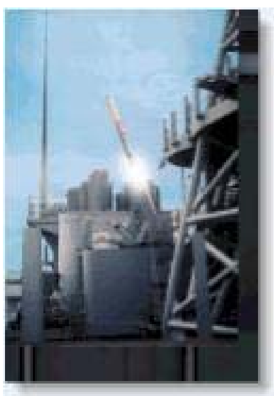
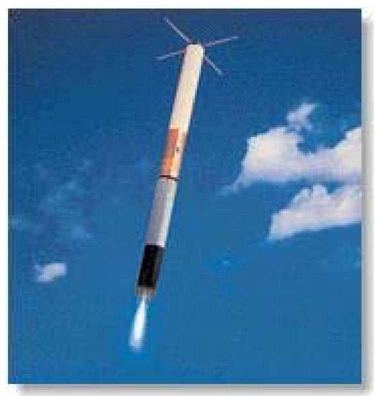
Threat	AMRFS	TISS	EW Suite	ISMD/A	ASROC	ESSM	SSM	Millenium Gun
ASCM	D	D	D - SK			HK		HK
Aircraft	D	D	D			HK		HK
Ship	D	D	D	D		HK *	HK	HK
Submarine				D	HK			
Small boats	D	D	D	D			HK	HK
Mines				D				HK
Shore Fire		D	D				HK	HK

In the following pages, each of the major subsystems of the ICMS will be discussed in terms of their functionality and operational/technical specifications.

5. Electronic Warfare (EW) suite:

The EW suite of the ICMS will provide Electronic Support (ES), Electronic Attack (EA), and Electronic Protection (EP) capabilities in the radar and infrared portions of the electromagnetic spectrum. The primary functions of the EW suite are the detection, localization and identification of threat emitters as well as automatic employment of shipboard countermeasures. A multi-function EW suite should be considered that best integrates into an Advanced Multi-function RF System (AMRFS) that minimizes both the RF signature and physical footprints within a highly integrated RF system.

The proposed EW suite is purposed for deployment of countermeasures and electronic warning against air threats for point defense. The multi-function EW suite shall include a radar warning receiver, RF jammer, missile approach warning system, directed infrared countermeasures, and a chaff/flare/decoy dispenser shown below.

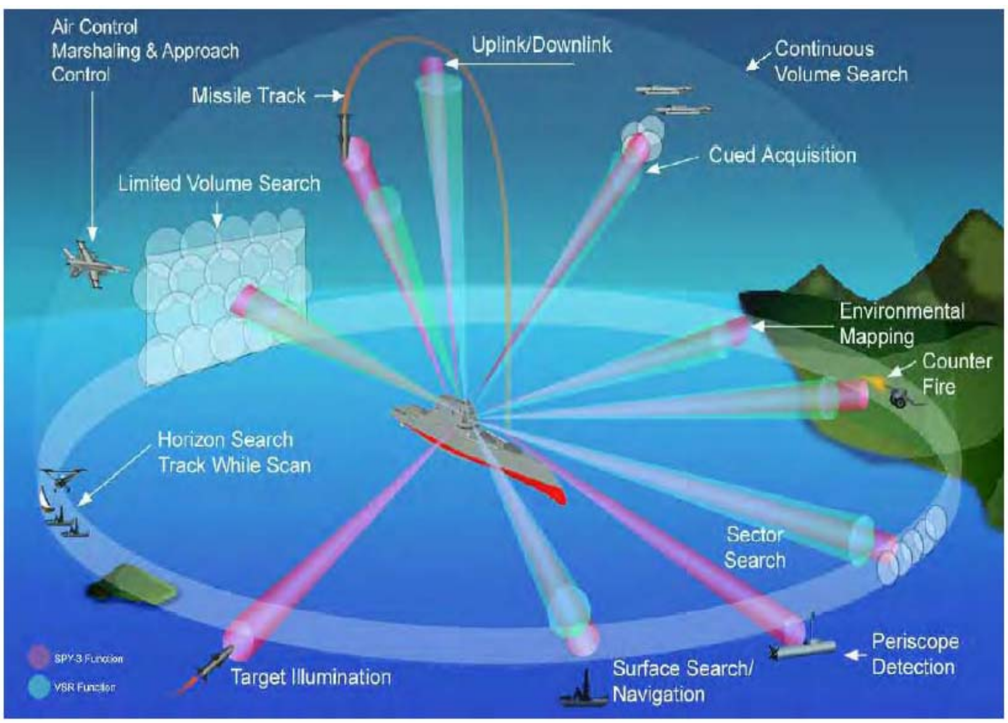
6. Sensors Suite:

a. Advanced Multi-Function RF System

The Advance Multi-Function RF System was selected on the basis of providing the capability to integrate radar, electronic warfare, and communication functions into a common set of RF apertures capable of supporting multiple simultaneous beams such that the functionality is defined by software rather than individualized hardware components. AMRFS is a system currently under development by the Office of Naval Research. The capabilities of AMRFS onboard TENTACLE were also derived from other more mature RF system solutions such as: Raytheon's Dual Band Radar, The Combined Antenna System, SPY-3 Radar, and ONR's Multifunction EW System.

The radar function of the AMRFS is defined by an active phased array X-band radar designed to meet all horizon and volume search and fire control requirements and provide missile guidance based on mid-course guidance and terminal homing. The most significant feature of the radar is to provide automatic detection, tracking, and illumination of low-altitude threat missiles in adverse environmental conditions routinely found in coastal waters.

AMRFS will have a 70+Km detection range against ASM threats. The horizon detection range of the AMFRS exceeds the missile range of the Evolved Sea Sparrow missile (30km) to allow for ample response.



Depiction of Capability of AMRFS

AMRFS communications functions provide for satellite communications (commercial Ku-Band & military DSCS (X-Band)) and Line-of-Sight Communications (Common Data Link (CDL, TCDL) (X-Band & Ku-Band)).

AMRFS EW functions include EA (noise jamming and deceptive jamming), ES (high probability of intercept – precision direction finding (HPOI-PDF), and high gain high sensitivity (HGHS)).

AMRFS self-maintenance functions include array & subsystem calibration, characterization, and diagnostics. The AMFRS single mast enclosure also supports design requirements for reduced radar cross-section, significantly reducing manning requirements and lifecycle costs.

The benefits of employing AMRFS are summed up as follows:

- Reduction in total number of required topside antenna arrays
- Increased potential for future growth without major ship alterations
- Tighter control over EMI/EMC issues
- Functionality is primarily defined by software
- potential for substantial reduction in life cycle costs
- Enables dynamic reallocation of RF Functions

Most importantly RF functions can be customized to tactical environment, enhancing war-fighting capabilities.

b. Cooperative Engagement Capability

Cooperative Engagement Capability (CEC) is a system of hardware and software that allows the sharing of radar data on air targets among ships. Radar data from individual ships of a Battle Group is transmitted to other ships in the group via a line-of-sight, data distribution system (DDS). Each ship uses identical data processing algorithms resident in its cooperative engagement processor (CEP), resulting in each ship having essentially the same display of track information on aircraft and missiles. An individual ship can launch an anti-air missile at a threat aircraft or anti-ship cruise missile within its engagement envelope, based on track data relayed to it by another ship. Program plans include the addition of E-2C aircraft equipped with CEP and DDS, to bring airborne radar coverage plus extended relay capability to CEC. CEP-equipped units, connected via the DDS network, are known as Cooperating Units (CUs).

As currently implemented, CEC is a major contributor to the Joint Vision 2010 concept of full-dimensional protection for the fleet from air threats. In concert with multi-Service sensor and engagement systems, it can contribute to a major expansion of the battle space. The Joint ACCESS will be able to engage threats within its engagement envelope based on data relayed to it by other fleet assets.

d. EO system:

After an extensive research on the available EO systems using current day technology, it was decided to use the Thermal Imaging Sensor System II (TISS II) as the EO system of choice for the TENTACLE.

The TISS II was developed from operational experience to effectively detect, and identify targets in a passive mode in the Persian Gulf and the Caribbean. The The challenges that TENTACLE will face will include ones which are difficult to detect due to low radar reflectivity and small cross-sectional areas such as small crafts. The problem of detecting potential threats becomes even more complex due to sea surface clutter, operating in small patrol areas, and the requirements to conduct operations at night and with poor visibility. Electro-optical (EO) sensors such as thermal imaging sensors, visible imaging sensors, and laser rangefinders provide additional situational awareness to complement current shipboard radars in a manner to overcome the issues of detection and identification of small surface targets.

The TISS II incorporates the above-mentioned EO sensors into a single stabilized platform with a suitable size and weight that allows mounting of the sensor onto the deck or mast of naval ships.

7. Shipboard Weapon Systems:

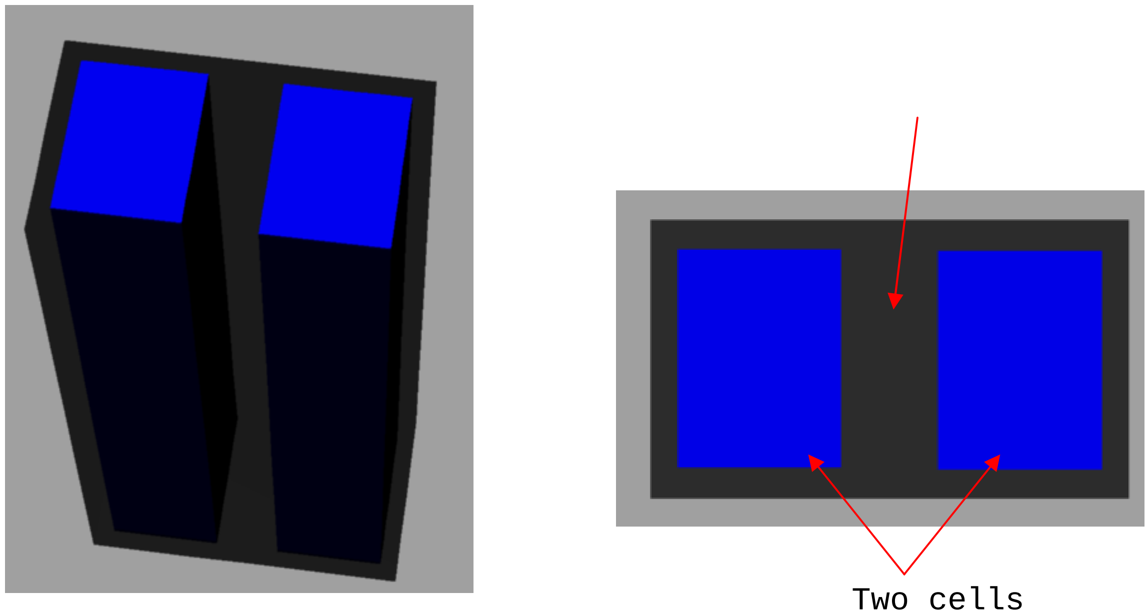
a. Evolved Sea Sparrow Missile (ESSM)

According to the Trade-Off Analysis conducted in Appendix VII , the Evolved Sea Sparrow Missile will be used as the medium range ship self-defense missile system for the Joint ACCESS. This missile will provide the TENTACLE with the capability to engage a variety of anti-ship cruise missiles (ASCMs) and aircrafts to support the medium and to a lower extend the inner self defense zones. This missile is very capable against low observable highly maneuverable missiles, and has a range that fits well the middle layer defense zone.

This missile, which is the successor to RIM-7M NATO Sea Sparrow is a tail-controlled missile for 50g maneuverability against anti-ship missiles maneuvering at up to 4g. The autopilot allows several ESSM to time-share a single illuminator in much the same way as the SM-2.

The ESSM uses an autopilot for mid-course guidance which is updateable via data link from the launching ship, switching to semi-active homing in the terminal phase of the engagement. It can also make flight corrections via radar and midcourse uplinks. A dual mode (semi-active and IR) homing head is a possible later growth option.

Because a Vertical Launching System (VLS) will not have directional issues when facing a saturation attack, has the advantage of providing a lower RCS, and does not have a reduced minimum firing range as compared to trainable launchers, it was decided that the ESSMs on board the TENTACLE will be fired from a vertical launching system. Loaded in a Mk 48 vertical launching system (using the Mk-164 launcher), 32 of these missiles, with a quick start guidance section, offer a significant increase in load-out, response time, and fire power for the naval combatants of the future. The Mod 0 version that will be used in this design project consists of two individual cells with exhaust uptakes between them and is designed to be installed on the ship’s side hulls. With dimensions of 190 inches high, 89 inches long and 52 inches deep, as illustrated below, eight Mod 0 modules can be installed on each of the ship’s side hulls.



MK 48 Mod-0 Launcher System

The total weight of the system is composed as follows:

- 02 Canisters: 1450 lbs
- 02 missiles: 1100 lbs
- Exhaust control: 725 lbs
- Shipboard mounting interface: 800 lbs

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.

Listed below are the features that make it ideal for the requirements of TENACLE’s middle layer defense.

- Weight: 620 lbs
- Warhead: 39 kg blast fragmentation
- Speed: Mach 4+
- Range: 50+ km

b. Small Caliber Gun

Comparisons were made between the Sea RAM, CIWS block 1B, Millennium Gun, and the Goal Keeper as alternatives for our inner defense layer. The 35-mm Millennium Gun, with a maximum range of 3.5 nm, best satisfies our design requirements. It is effective in the littoral environment against fast-attack surface craft and near-shore targets. Also it provides an inner-layer defense against sea-skimming, anti-ship, anti-radiation missiles as well as aircraft. Listed below are the features that make it a perfect fit for the requirements of the TENTACLE inner layer defense.

- Range (air): 3.5 nm
- Range (cruise missiles) : 1.08 nm
- Range (sea-skimming missiles): 0.8 nm
- Firing Rate: 1,000 rounds/min
- 152 sub-projectiles per round

The Millennium Gun essentially creates what Lockheed Martin (the gun’s manufacturer) calls a “wall of lead” by using an advanced round called, “Ahead”. This round disperses 152 metal sub projectiles that form a cone-shaped pattern aimed at the target. The cone shape is formed by a program that control’s the gun’s muzzle brake as each Ahead round leaves the barrel, setting the distance and dispersal pattern. The target’s control surfaces, seeker, and other vital components are completely destroyed. (Reference: http://www.lockheedmartin.com/)

Millennium Gun

8. Final System Overview

The following figures show the format of the TENTACLE ICMS. The complete Management System is divided into functional blocks. These consist of:

1.0 Search & Detect (SD)

2.0 Data/Information Services (DIS)

3.0 Planning, Assessment and Decision (PAS)

4.0 Weapon/Asset Services (WAS)

5.0 Mission Execution (ME)

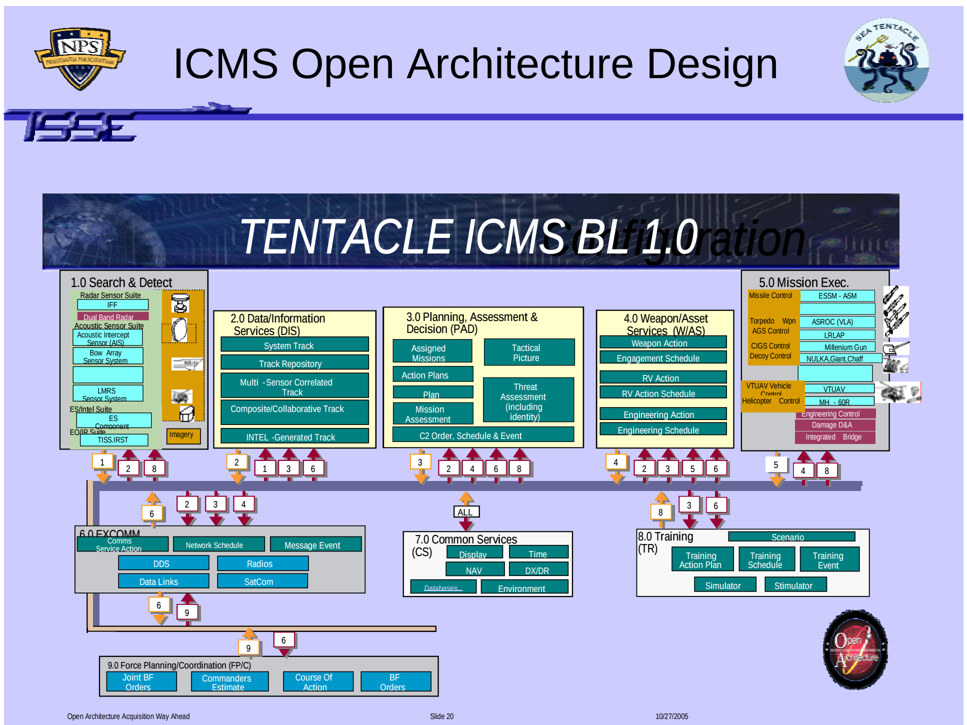
6.0 Exterior Communication (EC)

7.0 Common Services (CS)

8.0 Training (TR)

9.0 Force Planning Coordination (FPC)

The critical element of the architecture is the common network connecting each functional block. What facilitates this organization is the fact that all information leaving a block is digitized and “packetized”. This allows for the blocks to communicate using reliable TCP/IP connections. Additionally, this data can be transmitted off the ship to other units.



ICMS Open Architecture Format

An example of its operation starts in the S&D block. Every sensor installed on the ship outputs its tracking information into the network. This data is the input into the DIS block which organizes the data into separate tracks. The key function is that data from all sensors (onboard and external) is linked to each target being tracked (Multi-Sensor Correlated Track and INTEL-generated Track). The track information is ported to the PAD, which maintains the Tactical Picture and uses it to make the

Threat Assessment. Once decisions are made regarding threat engagement, the weapon assignment from the PAD is communicated to the WAS whose key function is to maintain the weapon schedule. Finally, the weapon orders are sent to the Mission Execution which relays them to the actual weapon system.

A key aspect of the Open Architecture is that data leaving different functional blocks is in similar format so that information from all assets can be used by the decision making functions (blocks). The components of the Search & Detect block (i.e. IFF, AMRFS, EW suite) communicate their data to the Planning, Assessment and Decision block. The decision to classify a target as friendly or hostile, or the decision to fire a weapon is made using sensor data from all sensors tracking the target. This is in contrast to older systems such as SLQ-32 Electronic Sensor System, whose target data is rarely used as an input to automatic threat assessment systems.

Another benefit of the Open Architecture Design is that because the data is digitized in a standard format, receiving, tracking and utilizing the information is in the software domain. Any computer, loaded with the appropriate server software, can monitor and interact with all the operations on the network.

9. Combat Engagement Flow

In the following section, we will propose a concept for employing the sensor suites and combat systems elements onboard TENTACLE when a threat is detected.

a. Air Defense

The “contact” is first detected by the existing sensors onboard the ship and all available fleet assets in the area (these include radars, EO system as well as EW elements). The IFF system next classifies the “contact” as hostile, neutral or friendly. If it is identified by the IFF system as a threat, fire control information (Range, bearing and velocity) must then be obtained. If this data is unavailable, more sensors must then be allocated to track the target. Once the target information is obtained, the SSPS controller will propose the most appropriate weapon system to engage the target.

The outer layer defense consisting of the fleet assets will be notified of the threat and appropriate action must be taken by those assets to counter the thereat.

If the target escapes the outer layer defenses and enters the middle layer of the TENTACLE defense zone, an appropriate number of ESSMs will be fired once the threat is within their firing range. The number to fire depends on the number of threats and their characteristics.

If the target enters the inner layer defense zone (less than 5 miles from the ships), the Planning, Assessment and Decision (PAD) function of the ICMS will decide the optimum position and firing range to engage the 57mm gun to counter the threat. In addition, the Nulka system will be used to deceive the target (soft kill). Finally, if the target is still a threat, it will be engaged with automatic firing of the Millennium guns.

b. Surface Engagements

In a similar way to the air defense sequence, surface “contacts” are first detected by either the ship’s sensors or other fleet assets. If a “contact” is identified as a threat, fire control information must be obtained from the target. Once obtained, the ICMS will allocate the most appropriate weapon system to engage the threat. Long range detection (beyond the radar horizon of the AMRFS) and engagement (>25 miles) may be possible if fleet assets are in the vicinity.

If the target enters the lethal range of the ESSMs, the ICMS will decide if the target has high enough priority to utilize the ESSM to engage it.

If a target enters the inner defense zone, the Millennium gun will be employed to engage it. The Nulka system will also be used to deceive the target and redirect it TENTACLE.

Depending on the target type and the type of threat it poses, the ICMS will decide on the best course of action and the weapon system that can best engage the target.

c. Subsurface warfare

Submarine warfare consists of detecting and tracking of sub-surface contacts using data obtained from remote sensors and the organic SQS-89 and RMS system. Threat engagement is accomplished using the VLS launched Anti-Submarine Rocket (ASROC).

APPENDIX. THREAT ASSESSMENT

The threat used to create requirements for the TENTACLE Combat System was a fictitious country, whose naval force consisted of a large number of older, conventional vessels with a program for modernization. The table below lists all the different assets, proposed strength in future years and vessel specifications.

Although the primary mission of TANTACLE is to deploy and support unmanned subsurface vehicles in support of antisubmarine warfare in the littoral, the environment where TENTACLE would encounter an enemy is in the open ocean. This is because the goal of TENTACLE is to deploy the unmanned vehicles from a range of 200 nm and have the vehicles swim in to the littoral waters.

The following is a list of elaborations for the different vessel types used in the table.

Submarines

SSN Type 1

- Nuclear powered submarine constructed in mid 1970s
- 6 533mm torpedo tubes

SS Type 2

- Diesel-electric propulsion system
- Well suited for narrow water lanes and shallow sea areas
- Equipped with radars and sonar for target searching
- Dive depth of 300m
- 6 533mm torpedo tubes, 18 homing/wave guided torpedoes

- fitted to shoot anti-hip missiles with 300 km range

SS Type 3

- Current production
- ASCM launched while submerged
- Electric-diesel propulsion system possible future upgrade to Air Independent Propulsion System (AIPS)

SS Type 4

- Diesel submarine considered entirely obsolete by modern standards but useful for patrol and coastal defense duties

Destroyers

DDG Type 1

- Destroyer equipped with 8 supersonic 75 nm range se skimming missiles
- Ship to air missiles wit firing range of 25 km primarily for self defense
- Minimal anti-submarine capabilities
- Steam turbine propulsion system

DDG Type 2

- 16 ship-to-ship missile (2 8-cell launchers)
- Helicopter support (2)
- Short range anti-air missile
- Long range search radar for over-the-horizon targeting
- Primary mission is sector air defense

DDG Type 3

- Primary mission is anti-ship strikes
- Ship-to-ship missiles
- High speed/long range design
- Steam turbine propulsion system

- Helo support (1)

Frigates

- Primary mission is to escort other vessels
- Secondary mission is antisubmarine warfare
- Helicopter support (2)
- Antisubmarine missiles
- Surface-to-air missile (14 km range)

Patrol Craft

- Small, high speed, low cost, highly maneuverable against threat
- Primary mission is costal defense
- Several variants: anti ship missile, torpedo, anti-air gun

Mine Warfare

- Primary mission is coastal defense by utilizing a multi-directional mine-transport/laying system

NAVY

SYSTEM	Inventory									
Class	**2000**	**2005**	**2015**	**2025**	DISP (tons)	Length (ft)	Beam (ft)	Draft (ft)	Speed (kts)	Endurance
Submarines	**27**	**31**	**47**	**47**						
SSN type 1	5	5	5	5	5550	321.5	32.8	24.2	25	
SS Type 2	4	4	10	10	3,076	242.1	32.5	21.7	17	45 days
SS Type 3	1	5	15	15	2,250	246.0	27.6	17.5	22	
SS Type 4	17	17	17	17	2,100	249.0	25	16.7		8000 nm at 8 kts snorkling
Destroyers	**17**	**19**	**16**	**16**						
DDG Type 1	1	2	4	4	7,625	511.8	56.8	21.3	32	6,500 nm at 20 kts
DDG Type 2	-	1	1	1	6,600	490.0	49.5	18	31	14,000nm at 14 kts
DDG Type 3	16	16	11	11	3,730	433.1	42	15.3	32	2,970 nm at 18 kts
Frigates	**34**	**4**	**20**	**20**						
FFG Type 1	4	4	4	4	2,250	377.3	46	13	28	4,000 nm at 18 kts
FFG Type 2	30	30	16	16	1,925	338.5	33.4	10.2	28	3,500 nm at 18 kts
Guided Missile Boats	**86**	**77**	**60**	**60**						
PGG Type 1	14	22	30	30	478	203.0	24	7.3	32	
PGG Type 2	6	15	30	30	542	215.0	27.5	7.8	33.5	1,800 nm at 18 kts
PCFG Type 3	38	20	-	-	205	127.0	24.9	8.9	35	800 nm at 30 kts
PCFG Type 4	30	20	-	-	79.2	88.6	20.7	4.3	37.5	400 nm at 30 kts
Torpedo Boats	**16**	**9**	**-**	**-**						
PHT Type 1	16	9	-	-	45.8	71.5	20.7	11.8	50	500 nm at 30 kts
Patrol Boats	**195**	**188**	**178**	**178**						
PC Type 1	95	88	88	88	430	192.8	23.6	7.3	28	
PC Type 2	100	100	90	90	135	127.3	17.7	5.1	28.5	750 nm at 17 kts.
Mine Warfare	**64**	**79**	**79**	**79**						
MW Type 1	1	1	1	1	3,100	308.0	47.2	13.1	18	
MW Type 2	13	28	28	28	590	196.8	27.6	6.9	14	
MW Type 3	50	50	50	50	400	131.2	26.2	11.5	8	

Threat Matrix

APPENDIX XIII – RADAR CROSS SECTION (RCS) CALCULATIONS

A. INTRODUCTION

As stated in the EW handbook [1], “RCS is a characteristic of a given target that represents its size as seen by the radar…For a radar target; the power reflected in the radar’s direction is equivalent to the re-radiation of power captured by an antenna of area σ (RCS).” Consequently, there is a fundamental need in navy ship’s design to reduce the radar cross section to be able to achieve its mission.

Based on these concepts we applied an RCS study on our design, the Sea Tentacle, using two methods that are available and have been proven satisfactory. The first is an empirical method proposed by Skolnik and the second is a simulation based on the physical optics method for RCS estimation.

B. EMPIRICAL METHOD

Using ranking and scaling of several ships designs, Skolnik [2] suggested in 1980 a formula to estimate the median RCS of a ship based on its displacement and the frequency of operation of the seeker radar. This formula is given below

$$\boxed{\sigma_{\mathrm{m}^2} = 1644 \cdot \sqrt{D_{\mathrm{kT}}{}^3 \cdot f_{\mathrm{GHz}}}}$$

Where the RCS is in m^2, f_{GHz} is the radar frequency GHz and D is the ship displacement in kilotons.

For our design, with a displacement of around 7000 LT and a frequency of operation at 0.3 GHz, we obtained an RCS of

$$\sigma_{\text{Sea-Tentacle}} = 16677\ \mathrm{m}^2 = \boxed{42\ \mathrm{dBsm}}$$

The choice of the frequency of operation was random, but we started with 0.3 GHz because it represents typical anti-missile seeker characteristics. We used this value to calculate the RCS for both methods in order to compare results. However, we also plotted RCS vs frequency to demonstrate the relationship between these two parameters. The details can be found in Table XIII-1 and Figure XIII-1 below.

D (kT)	f (GHz)	RCS (sm)	RCS (dBsm)
7	0.3	16676.68	42.221095
7	0.5	21529.5	43.3303388
7	1	30447.31	44.8354887
7	1.5	37290.18	45.715945
7	2	43058.99	46.3406387
7	2.5	48141.42	46.8251888
7	3	52736.28	47.221095
7	3.5	56961.69	47.555829
7	4	60894.61	47.8457887
7	4.5	64588.49	48.1015513
7	5	68082.25	48.3303388
7	5.5	71405.26	48.5373022
7	6	74580.36	48.726245
7	6.5	77625.7	48.9000555
7	7	80556	49.0609789
7	7.5	83383.38	49.210795
7	8	86117.99	49.3509387
7	8.5	88768.39	49.4825834
7	9	91341.92	49.6067013
7	9.5	93844.9	49.7241068
7	10	96282.84	49.8354887

Table XIII-1 Frequency and RCS

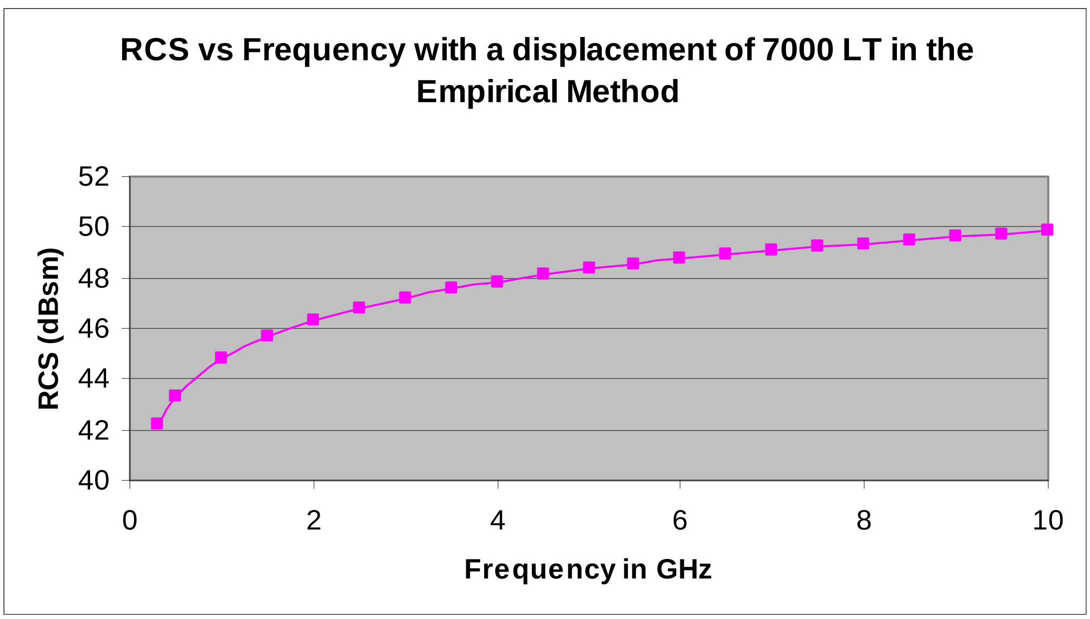


Figure XIII-1 RCS vs Frequency

It is important to note though, that the approximation for RCS varies with aspect angle. Anderson (1989) suggests that 13 dB should be added to the nominal RCS to provide a more accurate estimation of the broadside “flash.” Similarly, 8 dB should be subtracted from the nominal RCS to give the minimum value typically seen at the bow and stern aspect. This gives us an estimated RCS range for the Sea TENTACLE of(D=7000 LT and f=0.3 GHz)

$$34 \text{ dBsm} \le \sigma_{\text{Sea-Tentacle}} \le 55 \text{ dBsm}$$

C. POFACETS METHOD

Our second method of RCS estimation used POFACETS software to verify the empirical results and to determine the RCS as a function of:

- Ship Material
- Target angle
- Operating frequency of the enemy seeker

POFACETS is RCS estimation software based on the physical optics method and running on a Matlab © platform.

It was developed within the Naval Postgraduate School’s Electrical Engineering Department by Dr. David Jenn and thesis students.

The Combat Systems team used ship parameters from Hull Mechanical & Electrical design team generated with RHINO software.


sea-tentacle.3dm is the initial file generated by the HM&E team using RHINO. Figure XIII- 2 shows the initial design in the RHINO file.

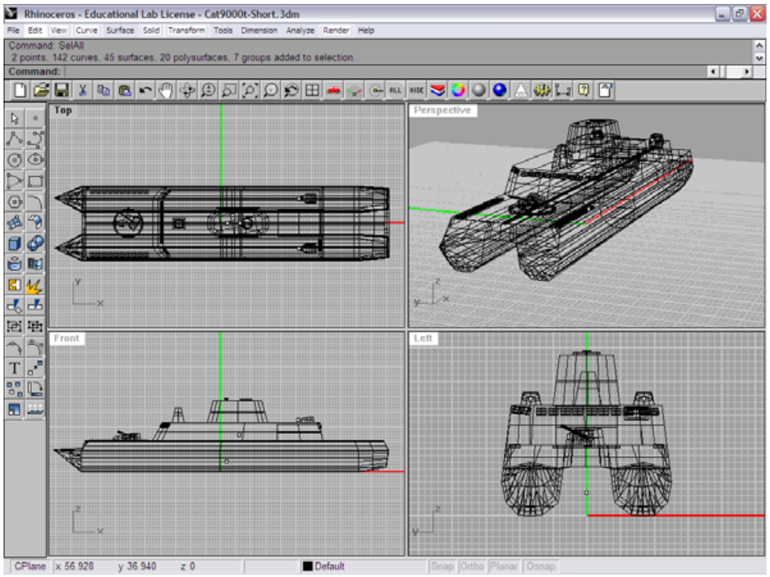


Figure XIII-2 Rhino Drawing of the Sea TENTACLE

We took this file and made some changes to reflect the RCS surfaces by deleting some of the subsurface structures. The RCS structures are shown in Figure XIII -3.

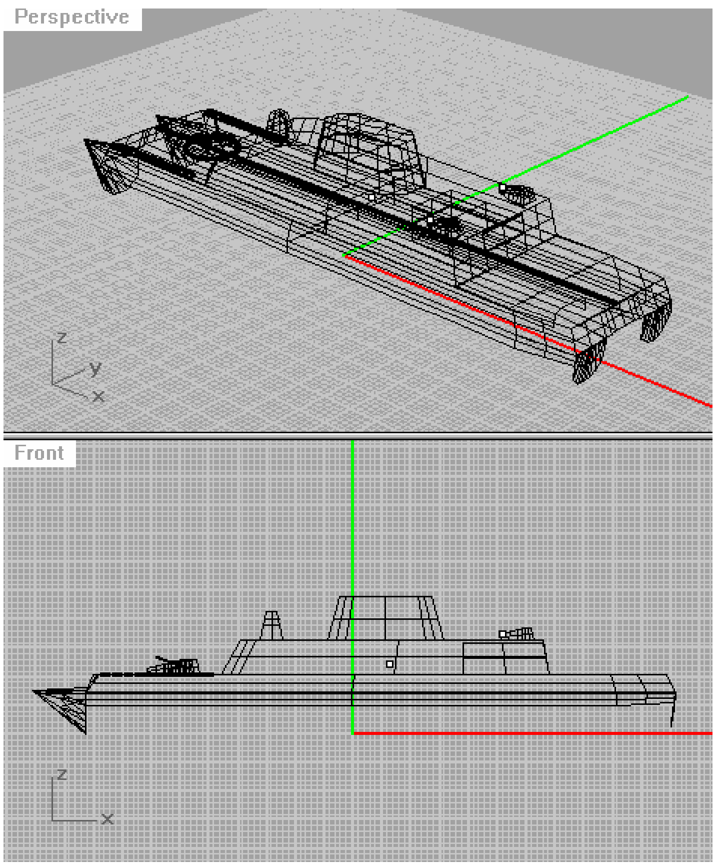
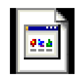


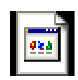
Figure XIII-3 Modified Rhino Drawing used for RCS Calculations

Then we converted the obtained RHINO file into a format that is suitable for use by other applications. This format is the IGES (*.igs and *.iges) which will be used to convert the RHINO file into facet file. To export the RHINO RCS structure we selected all objects (Ctrl+A or Edit, then Select then All Objects), then using the file menu “Export Selected” we saved the file “sea_tentacle.igs” by selecting “save as type” IGES (*.igs; *.iges). We obtained this file



sea_tentacle.igs

Then we converted the IGES file into facet file using the Cifer conversion utility included in the Urbana software that is available in the ECE microwave lab. We obtained this file



sea-tentacle.facet

which can be recognized by the POFACETS application that we will be running to estimate RCS.

After running Matlab and changing the current directory to “pofacets3.0”, we typed “pofacets” or clicked on

Pofacets.m .

This opened the window of POFACETS, shown as Figure XIII – 4.

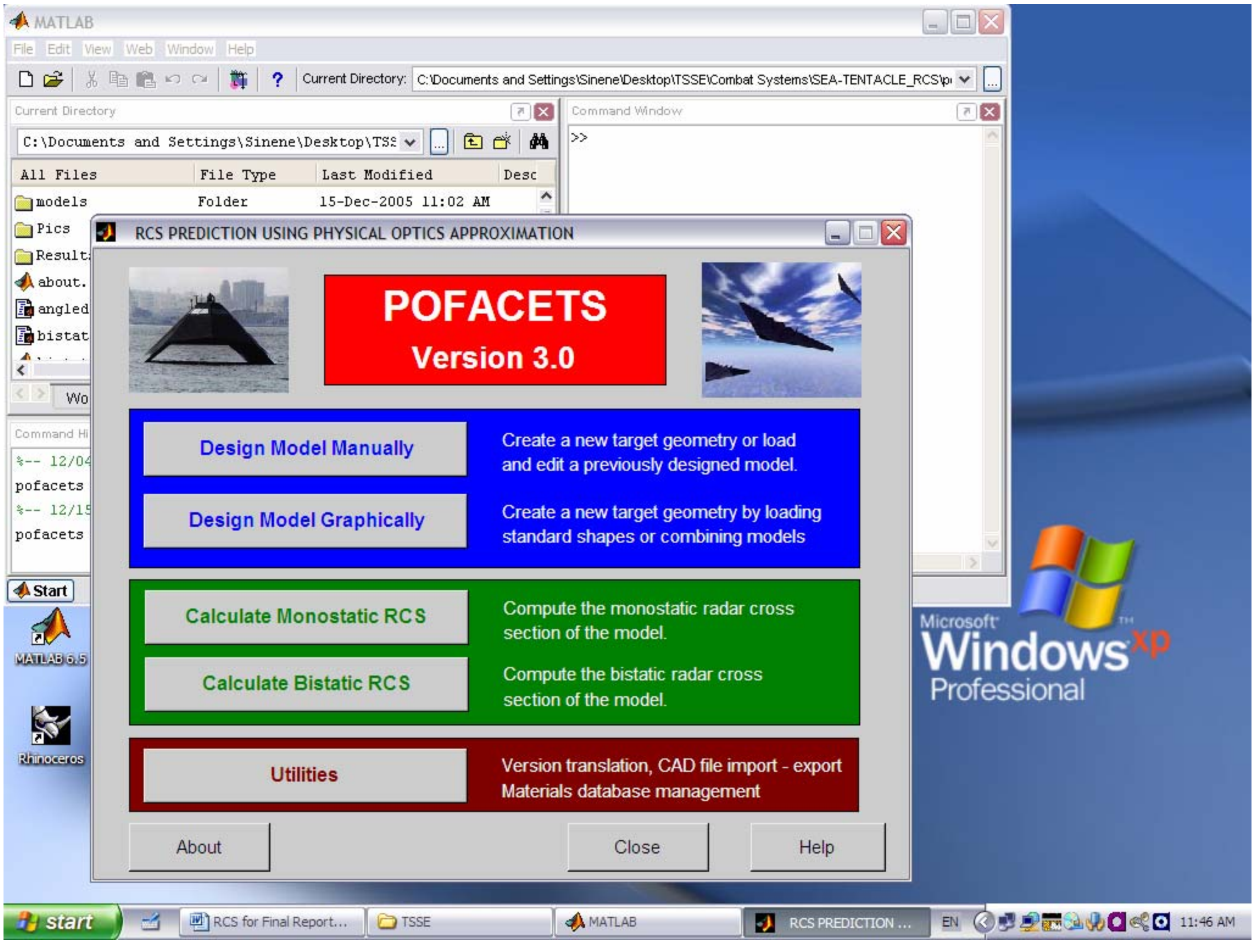


Figure XIII-4 POFACTES WINDOW

First, we clicked on the "utilities" button and chose import options "FACET & DEM" and saved the facet file as a Matlab © model. The Sea-TENTACLE Matlab © model that we generated was as follows:

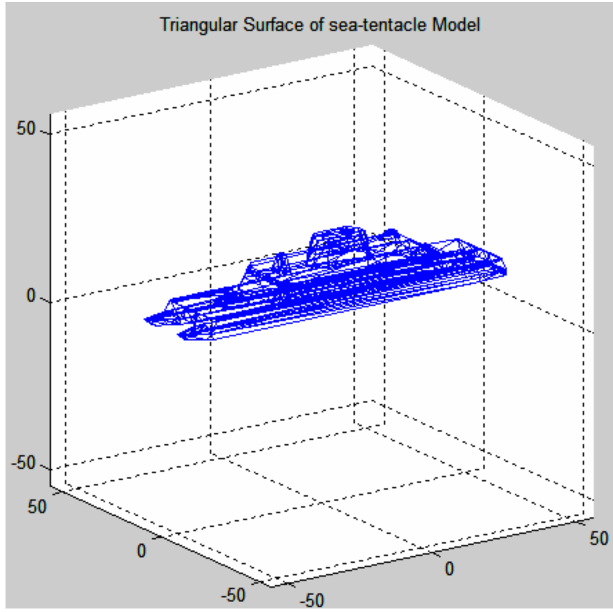


Figure XIII-5 Matlab © Model of the Sea TENTACLE

This first model allowed us to run the simulation by clicking on the "calculate monostatic RCS" in the pofacets main window. We selected the parameters as follows:

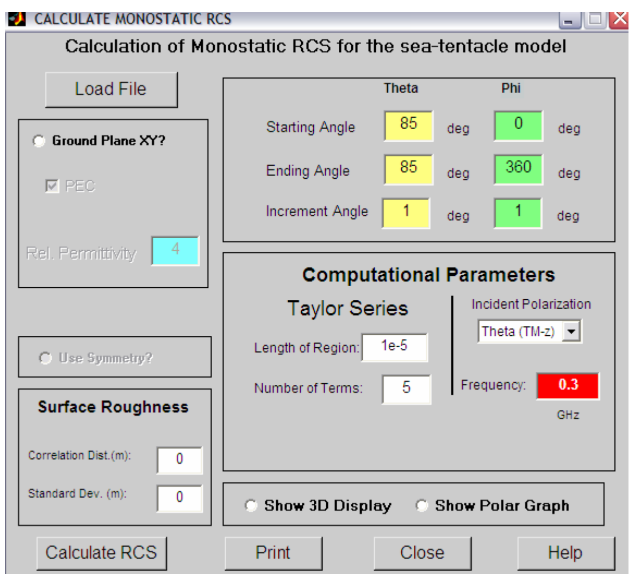


Figure XIII–6 Parameters for Monostatic RCS Calculations in POFACETS

After loading the model file the following window appeared:

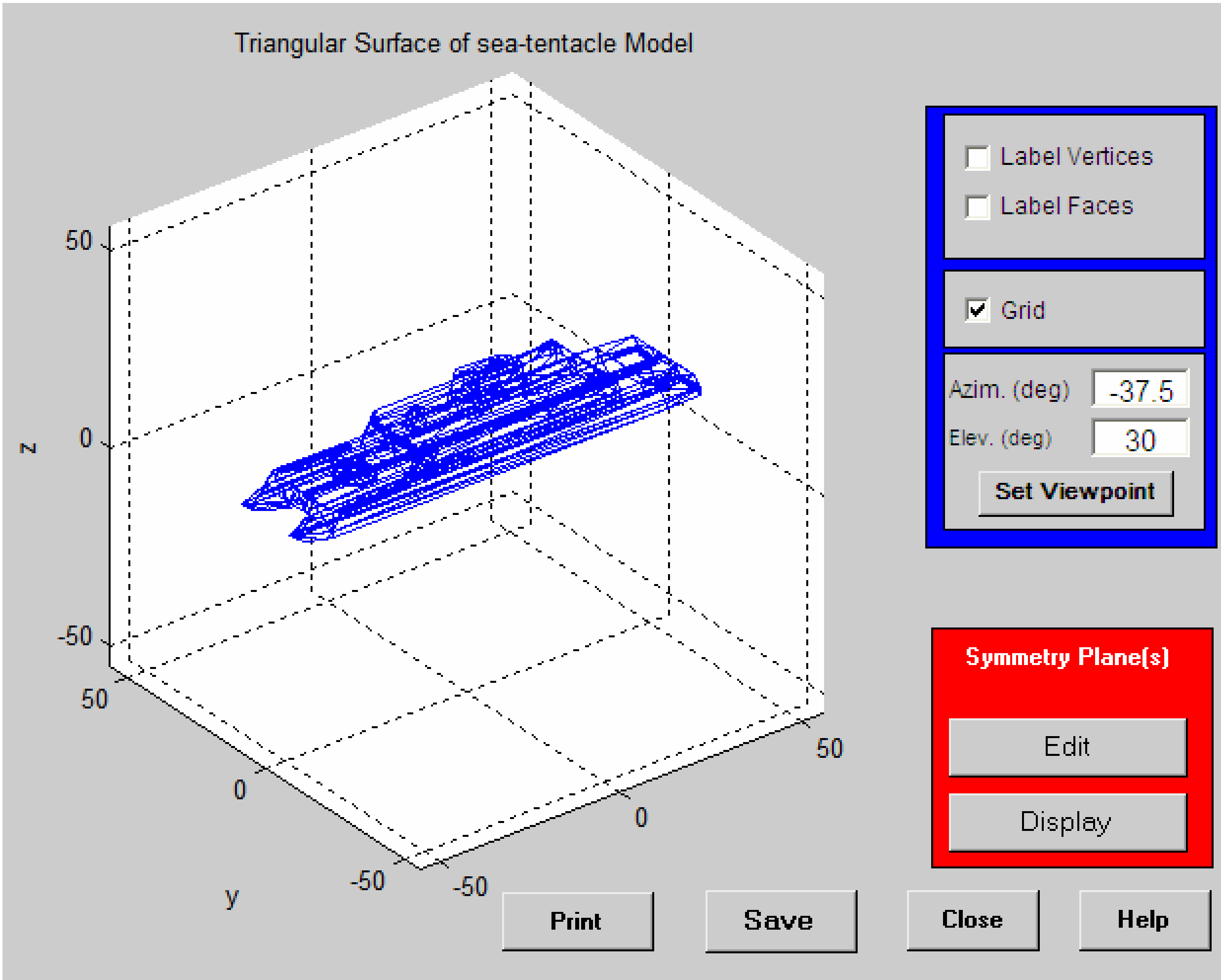


Figure XIII–7 Triangular Surface of the Sea TENTACLE

We verified the model and closed the window. Then we clicked on the “calculate RCS” button. POFACETS then generated the output in both linear and polar form, as seen in Figure XIII-8:

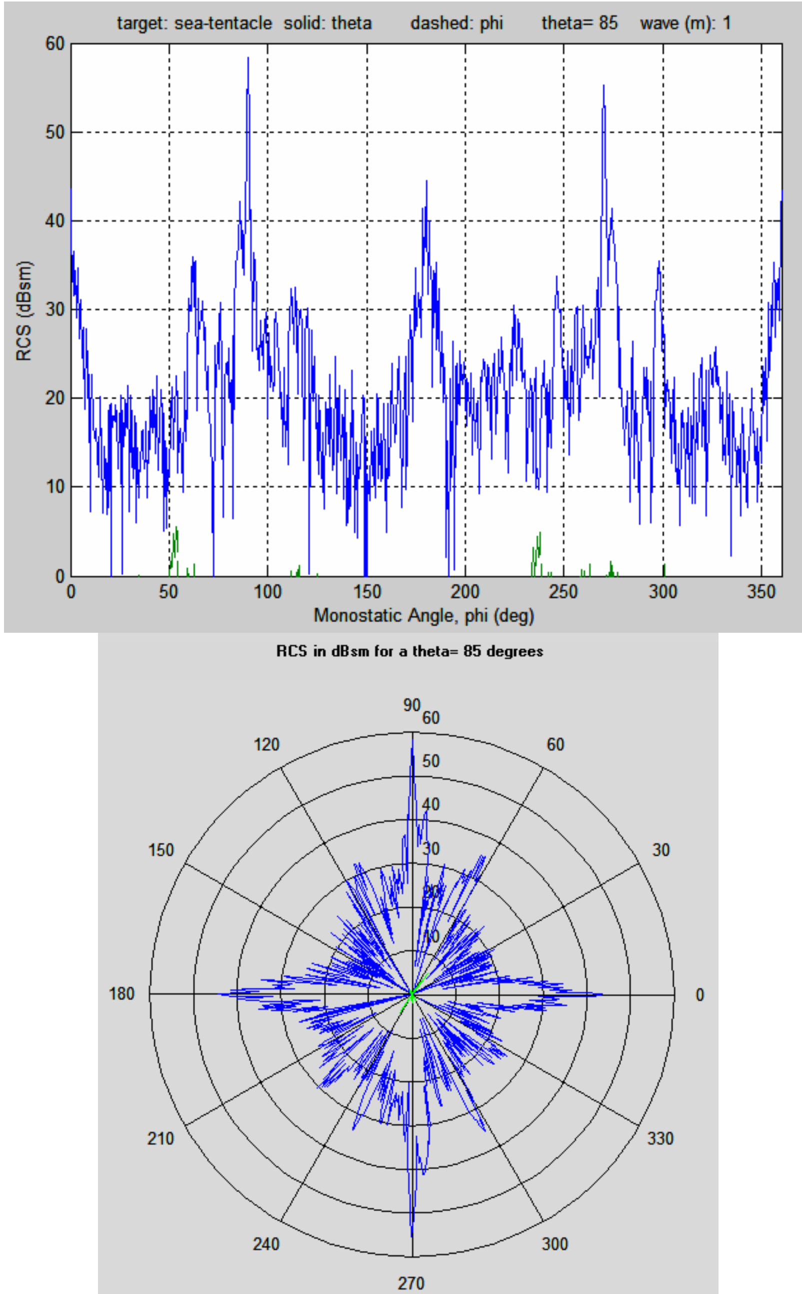


Figure XIII-8 Linear and Polar Plots of Sea TENTACLE RCS for 0.3GHz Seeker and all Steel Ship

The two plots show a median RCS for TENTACLE of around 25 dBsm, with peaks at more than 50 dBsm on the beams.

Then we proceeded by changing the material of the model from steel to composite to see the RCS results. We did that by going to “Design Model Graphically” in the main window of

POFACETS. We loaded the sea tentacle model, and then clicked on the “edit material” button

We selected composite and saved the model as “sea-tentacle-composite”. We run the simulation again as before and obtained the following results:

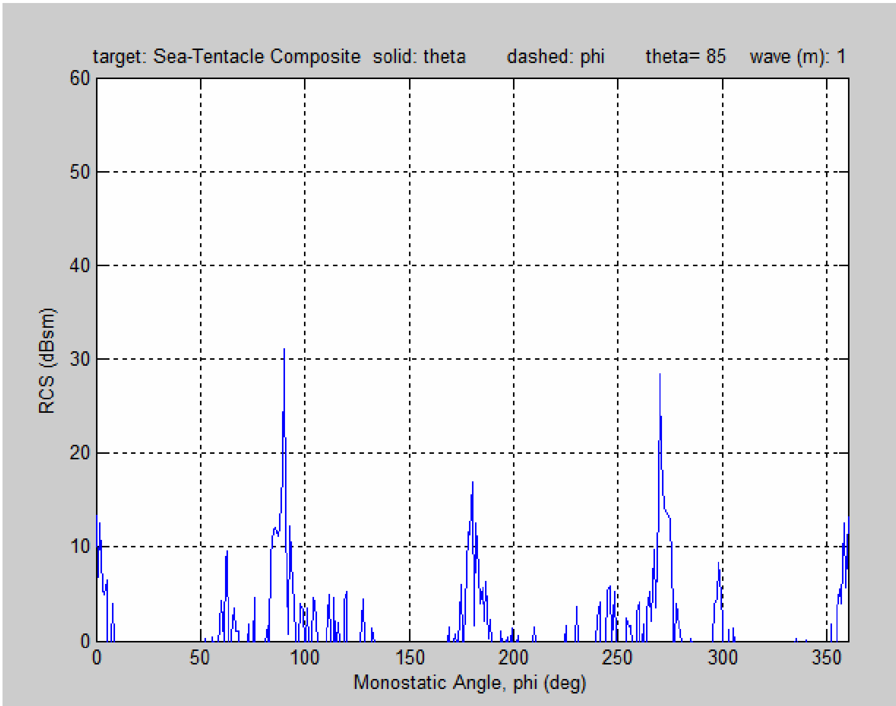
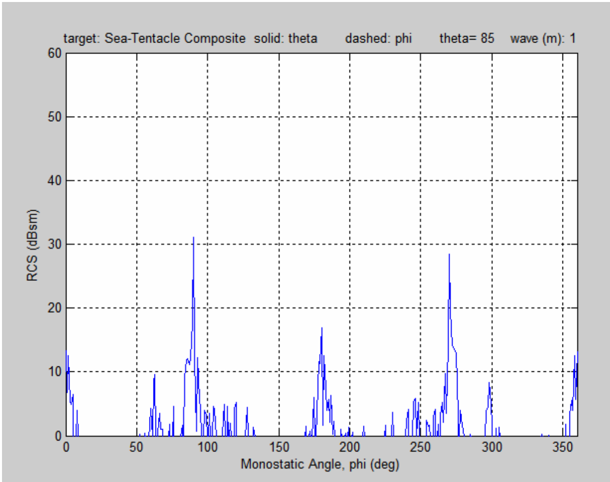
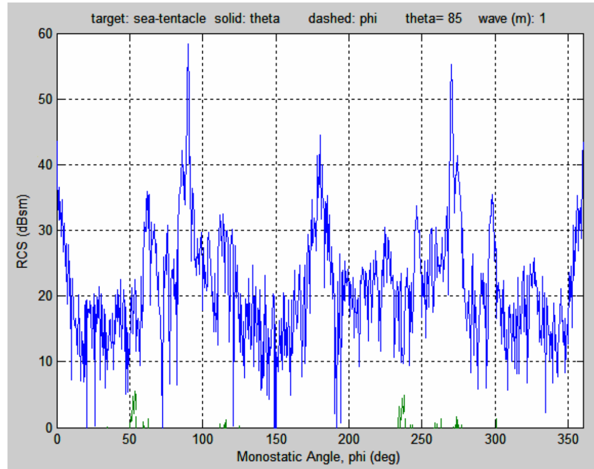


Figure XIII-9 Linear Plot of Sea TENTACLE RCS for 0.3GHz Seeker and all Composite Ship

As expected we obtained a better RCS with a composite model. A side by side comparison of steel and composite ships are given in Figure XIII-10:



Composite material ship yields a median RCS of approximately 5dBsm



Steel ship yields a median RCS of approximately 25dBsm

Figure XIII-10 Comparison of RCS for Composite vs Steel Construction

The side-by-side results show a 20dBsm reduction in the median RCS, if we chose to build a ship of composite material rather than a totally steel ship.

However, due to cost constraints, we decided to use a steel hull – composite superstructure design for the Sea TENTACLE platform.

Further RCS analysis would have proved beneficial in optimizing this design tradeoff.

Finally we performed RCS simulation vs. frequency of operation and obtained the following results:

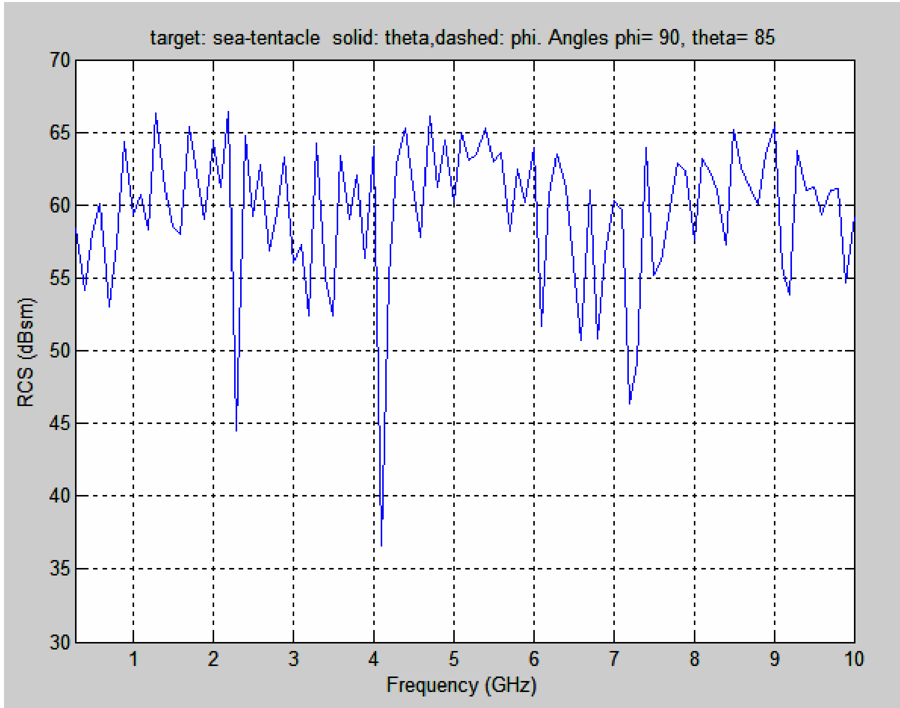


Figure XIII-11 RCS Results using a Steel Ship model vs. Seeker frequency at a 090/270 Target Angle

Steel material selection renders lowest RCS at frequencies:

- 2.3 GHz
- 4.1 GHz
- 7.2 GHz

D. CONCLUSIONS

We performed RCS estimation using two methods, empirical and simulation using POFACETS. Our two methods of choice agreed on the RCS results, and helped us be confident on certain design tradeoffs. POFACETS results facilitated material considerations. Composite material represented the best choice for building the Sea Tentacle since it gave the best RCS results. However, due to cost and structural constraints, the TSSE team decided to design a ship out of steel and composite material.

It is finally important to note that RCS analysis was done at the unclassified level and does not take into account the RF emissions.

APPENDIX XIV: MANNING CALCULATIONS

WATCH STATIONS

From 1988-2002, a series of twenty-three trade studies were conducted as a means of manning reduction for the DD(X) program by a combined team from Northrop Grumman Ingalls Shipyard and Raytheon. A summary of the twelve key trade study topics and scope of analyses is listed in Ref [1]. The main areas of focus were Human-Centered Design and Reasoning Systems, Cleaning and Preservation, Maintenance Strategy, Damage Control, Reach Back Technologies and Distance Support. The trade studies investigated innovative equipment, processes, and techniques used by commercial shipping, auto manufacturing, energy production, hotel, and airline industries.

As a result of the trade studies, it is estimated that the DD(X) program will see manned watch stations reduced by 2/3 versus the DDG-51 class of ship, and total watch standing personnel reduced by nearly 2/3 (some watch stations not permanently manned). The DD(X) will have twenty core watch stations manned. Using the same technology drivers as the DD(X) as outlined in Appendix V of Ref [1], it is estimated that the Sea TENTACLE will require only thirteen manned watch station. Table XIV-1 presents the core watch stations of the ship.

WATCH STATION LOCATION	WATCH STATION NAME	NUMBER OF PERSONNEL	SUB - TOTAL
Bridge	Officer of the Deck (OOD)	1	3
	Junior OOD	1	
	Quartermaster of the Watch	1	
Combat Information Center (CIC)	Tactical Action Officer	1	9
	CIC Supervisor	1	
	Air Search Radar Operator	1	
	Surface Radar Operator	1	
	Sonar Operator	1	
	Gun Operator	1	
	Missile Operator	1	
	Electronic Warfare Operator	1	
	Aircraft Controller	1	
Engineering	Engineering Officer of the Watch	1	1
		TOTAL	13

Table XIV-1 Sea TENTACLE Core Watch Stations

Using the recommendations in Ref [1], Sea TENTACLE took a human centered approach from the earliest phase of design, to ensure that all manning reductions possible could be taken. Also, the goal is to utilize the Reliability Based Maintenance (RBM) Strategy to reduce manning. RBM is a process that requires knowledge of the reliability of various systems and components. The RBM program has not been fully integrated into any existing programs, and thus the estimates for maintenance personnel will need to be reviewed at a later date.

OVERALL MANNING

The thirteen manned watch stations require a minimum of thirty-nine personnel for a three duty section rotation. The most notable watch reductions from current ship classes compared to the Sea TENTACLE are witnessed in Engineering. The DDG-51 requires nine personnel per duty section for Engineering watches, and DD(X) and Sea TENTACLE require only one person. Bridge watches also see a greater than 50% reduction from current fleet practice as the number changes from eight to three persons. Sea TENTACLE Combat Information Center (CIC) watches require only nine personnel, as compared to more than thirty on the DDG-51. Sea TENTACLE CIC manning is also much smaller than that of DD(X), as it has no land attack capabilities and a fewer shooting systems.

Although only thirty-nine personnel are required to stand watch, the overall crew size is estimated to be 107 personnel. Table XIV-2 lists the total manning breakdown.

Officers	Chief Petty Officers (CPO)	Enlisted	TOTAL
11	12	84	107

Departmental Breakdown	Officers	CPO	Enlisted
Engineering	3	4	21
Combat Systems	3	4	32
Operations	2	2	21
Supply	1	2	9

Rating Distribution							
Engineering		Combat Systems		Operations		Supply	
DCC	1	EW	3	BMC	1	SKC	1
DC	3	ETC	1	BM	9	SK	3
EMC	1	ET	9	ITC	1	MSC	1
EM	6	FCC/GMC	1	IT	3	MS	6
ENC	1	FC	3	OSC	1		
EN	3	GM	3	OS	9		
GSMC	1	STGC	1				
GSM	3	STG	6				
GSE	3						

Table XIV-2 Sea TENTACLE Manning Breakdown

ENGINEERING MANNING

As mentioned above, only three personnel are required for Engineering watch standing. However, a total of twenty-eight personnel will be required for the Department. The primary purpose for the disparity between the numbers of watch standers and total personnel is due to maintenance requirements and emergency responses. The gas turbines and advanced electronic system will plant require less routine maintenance when compared to legacy systems as the Navy shifts from the Preventative Maintenance System to the RBM System. However, when the ship is at General Quarters (GQ) condition, each engine room will require manned watch standers.

Damage Control personnel are minimally manned, and are primarily responsible for crew damage control training and initial emergency response to shipboard engineering casualties. Automated damage control systems, as discussed in Section V, account for the small number of damage control personnel.

COMBAT SYSTEMS MANNING

Combat Systems requires nine watch standers, namely the Sonar, Gun, and Missile console operators in CIC. As in Engineering Department manning, the bulk of Combat Systems Department manning is made up of maintenance and emergency response personnel. The advanced combat systems suite and its associated electronic equipment will still require several hundred hours of maintenance per week, even under the RBM strategy.

OPERATIONS MANNING

Operations Department requires a total of eighteen watch standers for six manned watch stations. The watches include Quartermaster of the Watch, CIC Supervisor, Air and Surface Radar Operators, Electronic Warfare Console Operator, and Aircraft Controller.

Four personnel will run and maintain the communications equipment, with maintenance support from the Combat Systems department personnel.

A total of nine junior enlisted Boatswain’s Mates led by a single CPO will perform the bulk of the ship’s exterior preservation and painting duties.

SUPPLY MANNING

It is estimated that the DD(X) will require 833 hours per week for supply, messing, and administration duties Ref [1]. It is assumed that Sea TENTACLE will require only 80%

of the time, or 672 hours, as it has fewer personnel, fewer systems, and reduced size compared to DD(X). Also, the Sea TENTACLE will have all personnel administration duties provided by a shore command. Thus, the 672 hours are only needed for supply and messing, with no administration.

Assuming a standard 8-hour work day per person, Supply Department requires a total of twelve personnel. The Supply Department will consist of a single Supply Officer, two Chief Petty Officers (CPO), and nine enlisted personnel. Stock control and parts distribution will be handled by one CPO and three enlisted. Messing will be handled by one CPO and six enlisted. Messing numbers are low due to innovative messing equipment as seen in many commercial shipping fleets.

Reference

1 GAO MILITARY PERSONNEL Report to Congressional Requesters: Navy Actions Needed to Optimize Ship Crew Size and Reduce Total Ownership Costs, June 2003.

APPENDIX XV: COST ESTIMATE

The following table presents the details of the SEA TENTACLE cost estimate using a bottom up approach. It should be mentioned that the accuracy of these calculations is dependent on the accuracy of the underlying cost estimating relationships.

TSSE Sea TENTACLE Cost Estimate (Bottom Up Approach)

Ship Weight Breakdown (LT)	
Lightship Weight	4504
Total Dead Weight	2323.61
Total Shipweight	6827.61

Cost Breakdown Summary	
1991 Material Cost	$109,073,762
2005 Material Cost @ 3% Inflation	$164,983,852
Payload Cost	$1,268,148
Specialized Equipment	$576,680,000
Total Non-recurring Eng. Cost	$515,650,000
Average Labor/Shipyard Costs	$374,115,763
Total System Cost for Lead Ship	**$1,487,414,044**
Total System Cost (tenth ship)	**$1,106,454,805**

Specialized Equipment (One Time Installs)	Costs in 1991	Costs in 2005
Engines/AWJ21	$79,334,137	$120,000,000
Electric Plant	$46,278,246	$70,000,000
EW Suite	$6,611,178	$10,000,000
Multi Function Radar (AMFRS)	$132,223,561	$200,000,000
ESSM	$449,560	$680,000
Automated DC systems	$26,444,712	$40,000,000
VLS	$10,577,885	$16,000,000
Other Weps/Sensor Systems	$13,222,356	$20,000,000
Catamaran Hull Costs	$66,111,781	$100,000,000

Payload Additions		
Ships Force	28.5394098	0.00634
Mission Related Expendables	126.0376806	0.02798
Stores	64.4526384	0.01431
Liquids, Non-Petroleum Based	1845.41	0.40973
Liquids, Petroleum Based	62.1995271	0.01381
Future Growth Margin	409.6566	0.09095
Total Payload weight:	2536.295856	0.56312

Shipyard Overhead Tabulation Data	
Shipyard Gen. & Admin O.H.	0.065
Shipyard Insurance	0.01
Shipyard Contingency	0.1
Shipyard Profit	0.04
Total Shipyard O.H. Rate	0.215
Engineering Burdened Rate	$50.00
Non-Recurring Engineering Hours	1300000
Learning Curve Exponent	0.9

Labor Breakdown	
Base Labor Hours	2066500
Ship assembly and support labor	987787
Integration and Engineering Labor	384369
Program Management Labor	400901
Combined Labor Total Hours @ rate	3839557
Labor Rate	30

Shipyard Specific Cost Breakdown	
Non-recurring Eng	$65,000,000
Design Costs	$200,000,000
Infrastructure Upgrades (catamaran)	$250,000,000
Navy Program Cost Factor = 1%	$650,000

Ship Iteration	Hours	Labor Cost (1991 Dollars)	Labor Cost (2005 Dollars)	Unit Cost with Shipyard O.H. Rate	With Multi-Hull Labor Overhead
1	4254356.787	$127,630,704	$38,289,211	$355,526,685	$393,815,896
2	4041638.947	$121,249,168	$36,374,751	$347,773,119	$384,147,870
3	3922172.212	$117,665,166	$35,299,550	$343,418,557	$378,718,107
4	3839557	$115,186,710	$34,556,013	$340,407,232	$374,963,245
5	3776675.944	$113,300,278	$33,990,083	$338,115,218	$372,105,301
6 (baseline for labor hours)	3839557	$115,186,710	$34,556,013	$340,407,232	$374,963,245
7	3683801.008	$110,514,030	$33,154,209	$334,729,926	$367,884,136

8	3647579.15	$109,427,375	$32,828,212	$333,409,640	$366,237,852	
9	3615924.952	$108,477,749	$32,543,325	$332,255,844	$364,799,169	
10	3587842.147	$107,635,264	$32,290,579	$331,232,226	$363,522,805	
				Average Acquisition Cost	$374,115,762.65	

Description	WT (LT)	Wt/Tot	MATERIAL CER	MATERIAL COSTS	LABOR CER	LABOR HOURS
HULL STRUCTURE	3034	0.67362	1181	$3,583,154	316	958744
MAST	15	0.00333	6183	$92,745	316	4740
SEA WATER PIPING	80	0.01776	4758	$380,640	164	13120
	3129.0	0.69472		$4,056,539		976604
COMB.AIR SYSTEM	50	0.01110	288	$14,400	412	20600
UPTAKES	40	0.00888	288	$11,520	412	16480
PROP.SEA WATER COOLING	40	0.00888	288	$11,520	412	16480
BOW THRUSTER 1	2	0.00044	144	$288	209	418
BOW THRUSTER 2	2	0.00044	144	$288	209	418
WATERJET 1	4	0.00089	144	$576	209	836
WATERJET 2	4	0.00089	144	$576	209	836
CCS	10	0.00222	288	$2,880	162	1620
ENG.ROOM 1	70	0.01554	36916	$2,584,120	1412	98840
ENG.ROOM 2	120	0.02664	36916	$4,429,920	1412	169440
ENG.ROOM 3	70	0.01554	36916	$2,584,120	1412	98840
ENG.ROOM 4	50	0.01110	36916	$1,845,800	1412	70600
	462.0	0.10258		$11,486,008		495408
POWER CONVERSION EQ 1	10	0.00222	98329	$983,290	1294	12940
POWER CONVERSION EQ 2	10	0.00222	98329	$983,290	1294	12940
SS POWER CABLE	100	0.02220	788	$78,800	471	47100
LIGHTING SYSTEMS	40	0.00888	5450	$218,000	1329	53160
AC MOTOR 1	30	0.00666	650	$19,500	4	120
AC MOTOR 2	30	0.00666	650	$19,500	4	120
SWBD 1	3	0.00067	98329	$294,987	1294	3882
SWBD 2	3	0.00067	98329	$294,987	1294	3882
SWBD 3	3	0.00067	98329	$294,987	1294	3882
FAN ROOM 1	1	0.00022	14545	$14,545	1882	1882
FAN ROOM 2	1	0.00022	14545	$14,545	1882	1882
FAN ROOM 3	1	0.00022	14545	$14,545	1882	1882
FAN ROOM 4	1	0.00022	14545	$14,545	1882	1882
FAN ROOM 5	1	0.00022	14545	$14,545	1882	1882
	234.0	0.05195		$3,260,066		147436
SONAR 1	10	0.00222	150000	$1,500,000	235	2350
SONAR 2	10	0.00222	150000	$1,500,000	235	2350
VLS 1	13	0.00289	150000	$1,950,000	235	3055
VLS 2	13	0.00289	150000	$1,950,000	235	3055
SRBOC 1	1	0.00022	150000	$150,000	235	235
SRBOC 2	1	0.00022	150000	$150,000	235	235
FWD MAGAZINE	1	0.00022	150000	$150,000	235	235
GUN 1	4	0.00089	150000	$600,000	235	940
BRIDGE	3	0.00067	150000	$450,000	235	705
CHARTROOM	1	0.00022	150000	$150,000	235	235
CIC	10	0.00222	150000	$1,500,000	235	2350
RADIO IT	5	0.00111	150000	$750,000	235	1175
AFT MAGAZINE	1	0.00022	150000	$150,000	235	235
C/S OFFICE	6	0.00133	150000	$900,000	235	1410
PRI FLY	6	0.00133	150000	$900,000	235	1410
RADAR/SENSOR	38	0.00844	150000	$5,700,000	235	8930
GUN 2	4	0.00089	150000	$600,000	235	940
	127.0	0.02820	150000	$19,050,000	235	29845
VENTILATION SYSTEMS	100	0.02220	32868	$3,286,800	494	49400
FIREMAIN AND FLUSHING	60	0.01332	50705	$3,042,300	679	40740

COMPRESSED AIR SYSTEMS	60	0.01332	70265	$4,215,900	647	38820
FIRE EXTINGUISHING SYS.	50	0.01110	50705	$2,535,250	679	33950
AUX.SYS.OP.FLUIDS	80	0.01776	42125	$3,370,000	271	21680
CHT CMPT	14	0.00311	70265	$983,710	647	9058
AFT CHT TANK	15	0.00333	70265	$1,053,975	647	9705
	379.0	0.08415		$18,487,935		203353
COSAL SR	25	0.00555	55033	$1,375,825	882	22050
LAUNDRY	10	0.00222	26174	$261,740	135	1350
SUPPLY OFFICE	4	0.00089	27376	$109,504	292	1168
Description	WT (LT)	Wt/Tot	MATERIAL CER	MATERIAL COSTS	LABOR CER	LABOR HOURS
DRY PROV	12	0.00266	86901	$1,042,812	12	144
REFRG.STR.	17	0.00377	86901	$1,477,317	12	204
CONVEYOR	4	0.00089	35511	$142,044	694	2776
REPAIR SHOP	8	0.00178	27376	$219,008	292	2336
ANCHOR	20	0.00444	55033	$1,100,660	882	17640
CHAIN LOCKER	10	0.00222	86901	$869,010	12	120
SMALL ARMS	1	0.00022	27376	$27,376	292	292
POST OFFICE	1	0.00022	27376	$27,376	292	292
SHIP OFFICE	2	0.00044	27376	$54,752	292	584
MED.ROOM	2	0.00044	27376	$54,752	292	584
O.F.BERTH.	5	0.00111	29677	$148,385	1235	6175
GYM	8	0.00178	29677	$237,416	1235	9880
REPAIR LOCKER 1	5	0.00111	27376	$136,880	292	1460
STORAGE	4	0.00089	86901	$347,604	12	48
REPAIR LOCKER 2	5	0.00111	27376	$136,880	292	1460
UUV WORKSHOP	3	0.00067	27376	$82,128	292	876
UUV HOISTS AND UTILS	5	0.00111	35511	$177,555	694	3470
RHIB 1	3	0.00067	35511	$106,533	694	2082
RHIB 2	3	0.00067	35511	$106,533	694	2082
SMALL RHIB 1	1.5	0.00033	35511	$53,267	694	1041
SMALL RHIB 2	1.5	0.00033	35511	$53,267	694	1041
GALLEY	5	0.00111	26174	$130,870	135	675
PAINT LOCKER	2	0.00044	27376	$54,752	292	584
MESS DECK	6	0.00133	26174	$157,044	135	810
ENLISTED BERTH.	10	0.00222	29677	$296,770	1235	12350
CPO BERTHING	5	0.00111	29677	$148,385	1235	6175
CO SR	2	0.00044	29677	$59,354	1235	2470
S/R GROUP	4	0.00089	29677	$118,708	1235	4940
W/R	2	0.00044	29677	$59,354	1235	2470
CARDIO	2	0.00044	29677	$59,354	1235	2470
	198.0	0.04396		$9,433,214		112099
UUV GROUP 1	84	0.01865	100000	$8,400,000	235	19740
UV SPARE GROUP 1	10	0.00222	100000	$1,000,000	235	2350
UV SPARE GROUP 2	10	0.00222	100000	$1,000,000	235	2350
UUV GROUP 2	84	0.01865	100000	$8,400,000	235	19740
UUV GROUP 3	84	0.01865	100000	$8,400,000	235	19740
UUV GROUP 4	84	0.01865	100000	$8,400,000	235	19740
WLD-1	5	0.00111	100000	$500,000	235	1175
WLD-1	5	0.00111	100000	$500,000	235	1175
HELO	20	0.00444	100000	$2,000,000	235	4700
UAV	3	0.00067	100000	$300,000	235	705
VLS 1	20	0.00444	100000	$2,000,000	235	4700
VLS 2	20	0.00444	100000	$2,000,000	235	4700
SRBOC 1	2	0.00044	100000	$200,000	235	470
SRBOC 2	2	0.00044	100000	$200,000	235	470
	433.0	0.09614		$43,300,000		101755