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Joint ACCESS: high-speed assault connector (HSAC) for joint expeditionary logistics

Anil, Kivanc

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

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TECHNICAL REPORT

Joint ACCESS:
High-Speed Assault Connector (HSAC) for Amphibious Seabasing Operations and Joint Expeditionary Logistics

by

Student Members

LTjg Kivanc Anil, Turkish Navy
LTjg Mehmet Avcu, Turkish Navy
LT Jon Brisar, USNR
LTjg Adnen Chaabane, Tunisian Navy
LTjg Sotirios Dimas, Hellenic Navy
LT Matt Harding, USN
LT Timothy King, USNR
LT Steven Peace, USN
LCDR Francisco Perez-Villalonga, Spanish Navy
LT Derek Peterson, USNR
LT Rolando Reuse, Chilean Navy
LT Scott Roberts, USN

Faculty Members

Fotis Papoulias
Robert Harney

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ABSTRACT

The current notion of seabasing requires that three Battalion Landing Teams (BLT) of a 2025 Joint Expeditionary Brigade (JEB) need to be able to transit from the Sea Base to the objective within a 10 hour period. Of the three BLTs, two of them must be transported by surface craft a distance of no more than 200nm in sea state 4 or less. The two surface bound BLTs need to be loaded onto the transporting craft and delivered to shore, whether it is a port facility or austere beachhead. There is no current or future system of connectors to meet all the time-distance, sea state, and interface flexibility requirements for this aspect of seabasing. To meet these requirements a High Speed Assault Connector (HSAC) is needed which either augments current or replaces existing connector platforms to deliver and support the required forces ashore. The Joint ACCESS is a HSAC that brings the necessary speed, payload capacity, interface capability, and mission flexibility needed to fill the Sea Base to shore transportation gap. With a maximum speed of 43kts and payload capacity of 800LT, 12 Joint ACCESS trimaran can transit 200nm and fully offload in 7 hours. Its beachable design uses a floating bow ramp to reach out to austere beaches, while its combat system suite provides self defense in addition to robust offensive capabilities.

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I. INTRODUCTION

This report is prepared in order to fulfill the requirements of the Total Ship Systems Engineering program at the Naval Postgraduate Scholl and in partial support to the Wayne Meyer Institute of Systems Engineering. The goal was to develop a High Speed Assault Connector (HSAC) that will support the transport, logistics, and operations of a 2025 Joint Expeditionary Brigade (JEB). The seaborne components of the 2025 JEB comprised of 2 Battalion Landing Teams (BLT) must be transported from the Sea Base to the point of entry up to 200nm away within a 10 hour period. After the deployment of forces ashore, there must be a continuous and efficient flow of materials and supplies to maintain the logistics train between the Sea Base and those forces until it is decided that they need to be withdrawn. Throughout the force deployment process, there must be adequate support for the landing forces as they make their way onto and through the beach as well as their withdrawal from it.

The need for the design and development for a HSAC is rooted in the Chief of Naval Operations' (CNO) assessment in Sea Power 21 where seabasing is stated to be a future naval forces capability. In 2002, the Total Ship System Engineering (TSSE) team focused on the development of a system of ships that would facilitate the notion of deploying a Marine Expeditionary Brigade (MEB) from a Sea Base indefinitely. This work was later followed up by the 2003 TSSE design team which developed the Littoral Combatant Ship (LCS) to provide the "Sea Shield" defense layer for the Sea Base. Now it is the 2004 TSSE design team’s task to develop a system of ships that will transport the seaborne components of a 2025 JEB from the Sea Base to the shore, provide a reliable logistics train for the deployed forces, and provide beach operation support.

The amphibious craft and doctrine in place today can provide for an amphibious assault on almost any beach in the world. The issue is that this process is extremely slow, highly specialized to the United States Marine Corps and relies heavily on port access close to the area of assault for continual logistics support. Seabasing removes the reliance on suitable ports for offloading material and has evolved to include forces beyond the United States Navy and Marine Corps. In addition, it is now desired that the components of a 2025 JEB be deployed from the Sea Base to the beach within a 10 hour period. No ship or combination of ships in the U.S. Naval Fleet can meet these requirements. The HSAC is the vital link that will ultimately make the Sea Base to shore connection a reality.

The objective of this project is to develop and design a vessel that will work in conjunction with today’s current and future vessels to meet the requirements of force deployment, logistics sustainment, and operational amphibious support of Sea Base to beachhead operations. A secondary objective is to design this vessel so that it can serve a dutiful purpose in the fleet when not conducting its primary mission, especially during non-wartime periods. The end product should be a ship that not only brings seabasing to becoming more a reality, but also brings greater overall flexibility and capability to the U.S. Navy.

II. JOINT EXPEDITIONARY LOGISTICS OVERVIEW

A. OPERATIONAL CONCEPT

1. Objective

This Operating Concept describes the postulated view of Joint Expeditionary Operations (JEO) and the associated Joint Expeditionary Logistics (JELo) in the 2025 time frame as developed by the Systems Engineering and Analysis cohort Six (SEA-6). Emphasis is on full integration, where all aspects of United States-led military power are fused and synchronized. JEO can be considered in phases: Pre-Crisis, Closure, and Sustainment. The section is intended to describe the entire operation from 1) Pre-Crisis to a need for military power, 2) the application of military power until objectives are reached, and 3) the withdrawal and redeployment of that military power. Figure 1 pictures these three areas of operations that scope the project.

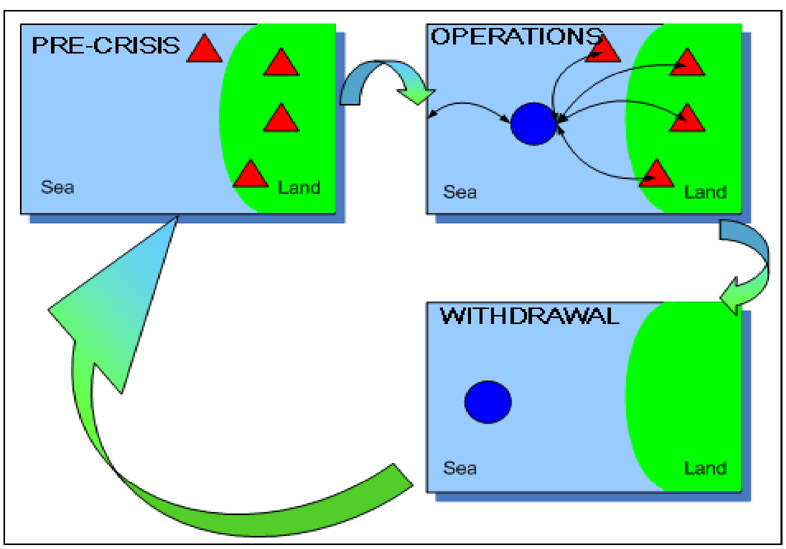

Figure 1. Joint Expeditionary Operations.

2. Overview

The Expeditionary Forces must be capable of seizing the initiative within 10 days, achieve the expeditionary objectives within 30 days, then reconstitute and redeploy within the next 30 days (10-30-30). The Expeditionary Logistics systems must meet the demand of the Combined Task Force Commander (CTF CDR) without slowing the desired operations tempo.

These operations may occur in any of the littoral regions of the world, day or night, all weather,[1] up to sea state 5 (6-8 ft. waves)[2] and sustained winds up to 20 knots.[3]

The Area of Operations (AO) and objectives are in a geographic location where conventional access (road/rail, neighbor over flight, and/or permissive port/airfield facilities) is not available. The objectives may be at sea, on land, in the air, in space, or in cyberspace. Power is projected and sustained from a Sea Base in crises or conflicts where a Sea Base adds combat capability.[4]

The Area of Operations (AO) may include limited[5] land-based Forward Logistics Sites (FLSs)[6] which support the Expeditionary Forces. These FLSs are as far as 2,000[7] straight-line miles from the AO (actual transit distances

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[1] All weather implies rain, snow, ice, reduced visibility, high and low temperatures.

[2] Sea Basing CONOPS, p. 14.

[3] Defense Mapping Agency Hydrographic/Topographic Center, *The American Practical Navigator,* 1995 ed., Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, 1995, p. 535.

[4] Sea Basing CONOPS, pp. 1-3.

[5] The requirement for expeditionary forces is driven in part by an antiaccess environment. As such, it is reasonable to assume that the number available will not be in the ideal location nor have every desired capability.

[6] As described in Professor David Schrady's Expeditionary Logistics Framework.

[7] N42 Draft Sea Base Logistical CONOPS, 04 June 2004.

may be longer due to geography).[8] Critical straight-line air routes are not available and plans are based on flight through international airspace.[9] The littoral region of the AO may include regions that are both favorable and unfavorable[10] to amphibious landings.

The assumed threat includes any adversary ranging from non-state actors (terrorists, insurgents, etc.) with low technology to a near-peer competitor with one or more comparable or superior defense technologies.[11] In both cases, the potential for highly asymmetric threats is assumed.

3. Expeditionary Forces

Expeditionary Forces are those that…

> "…are rapidly deployable, employable and sustainable throughout the global battlespace regardless of antiaccess, or area-denial environments and independent of existing infrastructure. Designated elements based in the United States, abroad or forward deployed [are] configured for immediate employment and sustained operations in austere environments. These forces [are] capable of seamlessly transitioning to sustained operations as a crisis or conflict develops."[12]

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[8] May be the case when a strategic strait is between the FLS and the AO.

[9] The whole Sea Base concept assumes an antiaccess environment. This would be worst case. Additionally, many U.S. strategic lift aircraft do not have Global Airspace Management Technology (United States Air Force Vision 2020).

[10] Examples: mangrove swamps, high-rugged cliffs, barrier reefs/islands, etc.

[11] National Military Strategy, 2004, p. 2.

[12] Quote by the Secretary of Defense in the Joint Operations Concepts, November 2003.

The Combined[13] Expeditionary Force is a United States-dominated, Joint Force augmented by one or more allied partners. This Force uses the Component Commander construct as used in the Joint Component Commander organization. These joint forces are fully integrated.[14] Specifically, they share common equipment, training, doctrine and terminology. These forces range in size from a two-man Special Operations Forces (SOF) unit to an Expeditionary Brigade-sized force (~5,000 ground combat troops). Some elements of Expeditionary Forces are forward deployed. Expeditionary Forces and their materiel will be moved, assembled and sustained using multimode vehicles called Connectors.

B. JOINT EXPEDITIONARY OPERATION PHASES

1. Pre-crisis

Pre-Crisis describes the configuration and disposition of the Expeditionary Forces (EXFORCES), shown abstractly in Figure 2 with no preexisting connections.

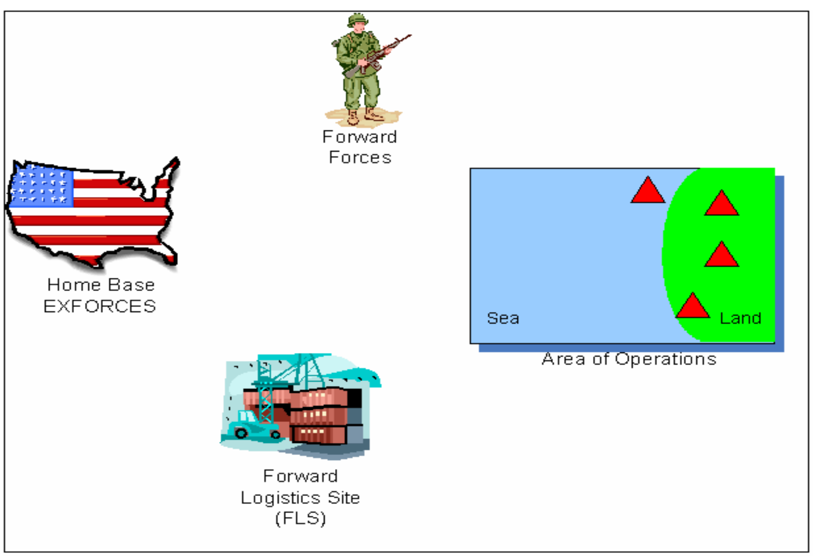

Figure 2. Pre-Crisis

[13] U.S. Joint Force and another state entity.

[14] Modeled after the SOF and Special Operations Command, Commander forces.

2. Closure

Once the nation decides to employ military power, the Expeditionary Forces (EXFORCES) begin closing on the Area of Operations (AO), with associations as labeled in Figure 3. A portion of Forces come direct from forward locations, some Forces direct from home base and some Forces through a Forward Logistics Site (FLS) on their way. Because of their location and equipment, key elements of these forces arrive ahead of the others.

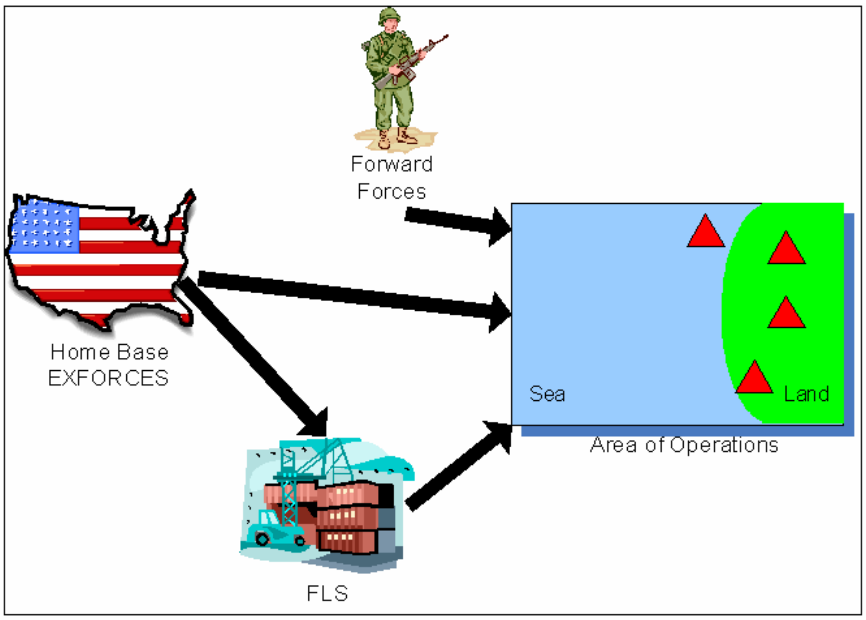

Figure 3. Closure

Within 10 days of the Deploy Order,[15] the CTF CDR will put the Preliminary Elements[16] of the ground forces at the initial objectives. These objective(s) may be within 240 miles[17] of the Sea Base. The Sea Base may be within 25-100 miles of the coastline[18]. The Preliminary Elements shall

[15] Quote by Vice Admiral Nathman in the Navy League of the United States, June 2004.

[16] Preliminary Elements will vary by situation and objectives within that situation.

[17] Sea Basing CONOPS, p. 14.

[18] Ibid, p. 15.

deploy to the initial objective(s) within one period of darkness (10 hours).[19] These elements are able to either complete the operation or prepare the battlefield for Follow-on Forces.

Expeditionary Force Protection projects layered organic and external defensive power to protect Joint and Combined assets and to dissuade and deter possible adversaries during Expeditionary Operations. Expeditionary Force Protection defends against the threats described in Section II. The Joint Expeditionary Logistics (JELo) system and Sea Base supports the requirements of Expeditionary Force Protection.

Forcible Entry Operations are used in a nonpermissive environment to locate, counter, or penetrate vulnerable seams in an adversary's access denial system to enable the flow of Follow-on Forces. The essence of Forcible Entry Operations is Ship to Objective Maneuver (STOM) in order to expedite the speed of action relative to the enemy over time. This superior tempo uses the rapid buildup of focused combat power ashore via vertical and surface lift capabilities, tactical/operational flexibility and maneuver at and from the sea.[20]

3. Sustainment

At some point, a majority of the Force has converged on the Area of Operations (AO) and operation has reached a steady level of effort. Figure 4 shows the level of complexity of the logistics lines needed to support this phase.

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[19] Expeditionary Maneuver Warfare List, 16 June 2003, p. 21.

[20] Ship to Objective Maneuver (STOM), Commandant of the Marine Corp, LtGen Paul K. Van Riper, 25 July 1997.

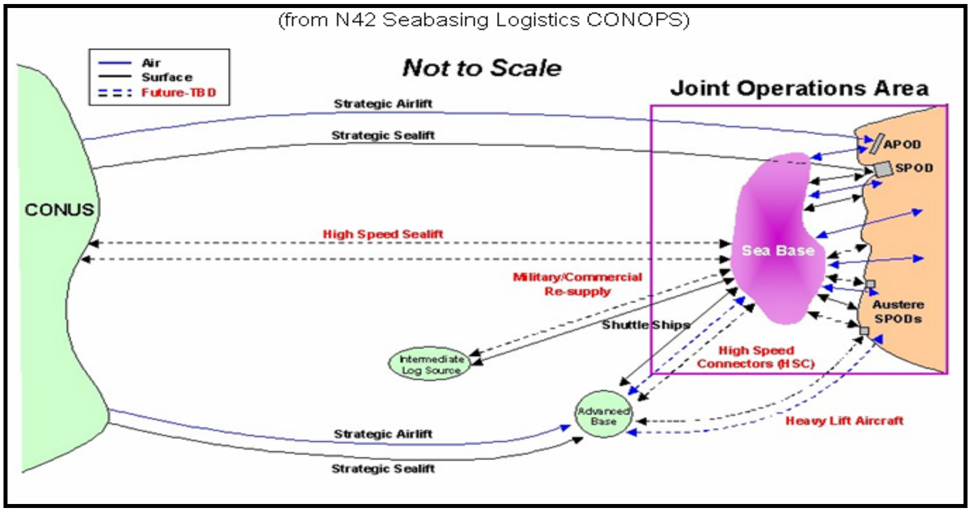

Figure 4. Sustained Operations

Sustained Expeditionary Operations (Figure 4) are those expeditionary operations that last for a period of 30 days or longer. Forces that have closed within the AO are able to plan and execute movement and maneuver from the Sea Base with the following capabilities:[21]

1. Maneuver and support a battalion from sea, 110 NM, within 10 hours.
2. Maneuver and support a battalion from the sea, 200 NM, within 24 hours.
3. Maneuver and support smaller forces (e.g. recon, radio relay teams) from the sea, 240 NM, as required to support operations.

4. Phased Based Logistics

Table 1 below lists the critical logistics concepts needed to enable the each phase of JEO.

[21] Ibid.

Table 1. Phase Associated Logistics Concepts

JEO Phase	Associated Logistics Concepts
Pre-Crisis	• reach around the globe • scale to conflict level • berth and sustain crew and troops • interface with the Forward Logistics Site(s) • transfer material and personnel (onload/offload) while underway • survive expected threats • integrate with the Expeditionary Force Protection • defend themselves commensurate with their role (transport/Sea Base) • support Unmanned Vehicle (UV) operations • interface among each other and the Sea Base • carry, deploy, and support Preliminary Elements • maintain mobility against expected combat damage • enable assembly of personnel and materiel • reconfigure to meet mission requirements • scale in capacity, speed, range, and interoperability • balance between onload/offload speed and platform stability/maneuvering • maintain capacity, speed, range, and interoperability so that weather effects don't adversely impact operational tempo • maintains sufficient availability to complete mission
Closure	• have space and modular facilities to support en route and on-station planning • support SOF equipment and operations • secure SOF equipment and information • maintain forward progress sufficient to preserve operational tempo • resupply in transit up to sea state 5 • interface among each other and the Sea Base • operate with transfer mechanisms to move personnel and materiel within the Sea Base and to/from the Sea Base
Sustainment	• change configuration to support given mission • decontaminate themselves

C. JOINT EXPEDITIONARY LOGISTICS EMPLOYMENT

To facilitate the JELo closure phase, the U.S. Navy is currently relying on FLSs like Diego Garcia and the current inventory of Maritime Pre-positioning Force (MPF) ships to be able to bring the appropriate gear and supplies to the objective. Ships under development like the Maritime Pre-positioning Force (Future) (MPF(F)) and the Rapid Strategic Lift Ship (RSLS) are the vessels that the Navy is looking toward to reduce the closure time of massing the required equipment and supplies for a brigade size force at the Sea Base. Though these new designs try to address the issue of transporting large amounts of material rapidly over long distances to the Sea Base, they fail to address how that material is going to make its way from the sea base to the shore.

As stated in the previous JELo description, the requisite troops, vehicles, and supplies need to be transported from the Sea Base and taken to shore. Current connector technologies such as Landing Craft Air Cushion (LCAC) and Landing Craft Utility (LCU) have an effective range of 25nm or less and their speed is heavily dependent on the sea state. To deliver and continually support forces ashore with these technologies requires bringing a large number of support ships, such as the MPF(F), to within 25nm of the coastline, greatly increasing their susceptibility to hostile fire.

There is a significant gap in the U.S. Navy's ability to transport the requisite forces and material from the Sea Base to the shore over the proposed 200nm distance and maximum sea state 5. To close or remove this gap, a new capable high speed connector needs to be developed to provide the transportation of the initial forces to the shore within a 10 hour period and then be able to provide continuous logistic support until the force needs to be removed. Until this HSAC is developed, maneuvering forces from the Sea Base to the shore in excess of 25nm will remain a difficult, if not an impossible challenge.

II. DEFINING THE REQUIREMENTS

A. INITIAL REQUIREMENTS

SEA-6 requested that the TSSE program develop a conceptual design for a logistics transport to act as a connector between the Sea Base and shore to augment or replace existing connector platforms. This logistics transport was to be a HSAC to close the gap SEA-6 had identified in their JElo study of being able to transport and support a 2025 JEB from the Sea Base to the shore. From the SEA-6 employment perspective this meant:

- The HSAC system or system of systems must be capable of delivering two BLTs (~8000LT consisting of troops, cargo, and gear) from the Sea Base to the shore.
- The HSAC system or system of systems must deliver the requisite payload a distance of 200nm in sea state 5 or less within a 10 hour period
- The HSAC system or system of systems must interface with the Sea Base, developed ports, and austere beaches in order to transfer cargo to and from the ship.

The TSSE faculty members then augmented these requirements with the following three additional requirements that they deemed were necessary for the HSAC design:

- The HSAC must support amphibious operations ashore in addition to its delivering payload.
- The HSAC must be capable of performing secondary missions.
- The HSAC must be capable of independent operations.

From these initial requirements, the design team then formulated the functional and operational requirements that would shape the HSAC design.

B. REQUIREMENT DEVELOPMENT

The TSSE design team reviewed the initial requirements provided by SEA-6 and the TSSE faculty and examined the guidance set forth in the 2004 TSSE project document (Appendix I). Three weeks were then spent reviewing numerous documents related to the Seabasing Concept, Joint Logistics Over the Shore (JLOTS), transport factor, and high speed transport in order to fully understand the design problem. After reviewing this material, the team was ready to proceed with detailed functional and operational requirement development.

1. Defining the Operating Environment

Prior to generating any detailed requirements, the TSSE team defined the operational environment in which the HSAC would operate. The transit area between the sea base and the shore received the most attention. This area was subdivided into a loading zone at the sea base, a transit zone from the sea base towards the beach, and an unloading zone at the beach. The threat the ship would expect to encounter was then defined for each zone based on input from SEA-6 documentation and the broad operational experience within the TSSE team. Figure 5 illustrates the breakdown of the zones and the corresponding threats the HSAC may encounter.

The Loading Zone was defined as the immediate area surrounding the sea base. The team assumed that the HSAC would be protected by the defense systems associated with the protection of the sea base while the HSAC is loading and unloading at the seabase.

The Transit Zone spans the distance from the sea base to within about one mile of the beach. Based on SEA-6 documentation, the distance from the sea base to the shore can be as much as 200 nautical miles. Within this zone, the HSAC is expected to encounter enemy ships, small boats, aircraft, and missiles. It was assumed that other assets assigned to the littoral will provide protection from any undersea threat.

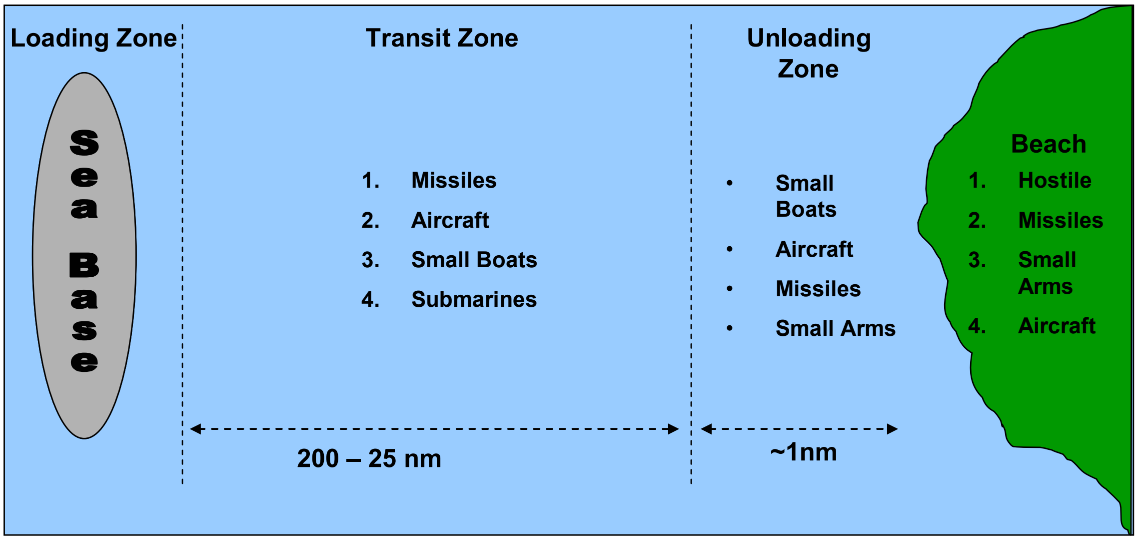

Figure 5. HSAC Operating Environment

Approximately one mile out from the beach to the beach is the area categorized as the Unloading Zone. At this point in the design process, it was unclear how the HSAC would deliver its cargo to the shore, so the Unloading Zone was pushed offshore one mile to cover the possibility of offloading the HSAC to another waterborne craft for delivery to the beach. In this zone, the HSAC is expected to encounter small boats, aircraft, missiles, and small arms fire. The team made the assumption that the boat lanes leading to the beach would be mine free prior to the HSAC entering the Unloading Zone.

The beach was defined as the fourth zone in the operating environment. Here the HSAC is expected to encounter hostile ground forces, missiles, small arms fire, and aircraft. Although enemy forces may possibly present on the beach during landing operations, it was assumed that any potential beach landing would be conducted in a reduced threat environment.

2. Detailed Requirement Development

Having established the operating environment and having a clear set of initial requirements, the team developed the mission needs statement listed in Appendix II. From this mission needs statement, the team developed the needed operational and functional requirements for the HSAC. To begin this requirement development process, the 12 person design team was divided into three sub-teams; ship capabilities and characteristics, combat system capabilities, and payload interfacing. Each sub-team then generated a list of specific requirements that the HSAC must satisfy to effectively meet the initial requirements set forth by SEA-6 and the TSSE faculty. These requirements would then be reviewed and combined to form the HSAC Operational Requirement Document (ORD).

a. Ship Capabilities and Characteristics.

This team was charged with developing notional requirements that defined the HSAC's performance, ability to execute its mission, and maneuver throughout the oceans of the world, ranging from blue water to the littoral. The requirements developed under this category are listed in Appendix III.

It was decided that while the primary mission of the HSAC is to deliver cargo from the sea base to the shore, it is necessary for the ship to be capable of trans-oceanic voyages in order to be a self-sustaining, deployable ship. The possibility of having another ship transport the HSAC from a CONUS base to an advanced land base and/or to the sea base was eliminated early in the process because of the considerable restrictions it placed the design alternatives of the HSAC.

b. Combat System Capabilities.

This group developed notional requirements to accomplish the primary mission within the defined threat environment and to satisfy the Threat Mitigation Requirements in the Mission Needs Statement. These requirements are listed in Appendix III.

The key concept produced by the development of these requirements was that the HSAC would carry a combat systems suite in order to provide self defense and to project power ashore at short range, protecting the landing force both during transit and offload. The self defense capabilities of the HSAC would be short range systems, relying heavily on other assets within umbrella of the "Sea Shield" to protect the HSAC from more formidable blue water threats.

c. Payload Interfacing.

This team was tasked with developing notional requirements that define the amount and type of cargo that the HSAC will be required to carry throughout the amphibious operation (tons and volume at a minimum). The requirements for this category were driven by the initial two BLT composition shown in Appendix V.

While the requirements were being generated, it was decided that the HSAC will transport the Expeditionary Fighting Vehicles (EFVs) from the sea base to the shore. Initially it was discussed that the EFVs may make the transit from the sea base to the beach on their own power, but the limited range of the EFV would only allow for this if the sea base was less than 60 nautical miles from the beach. Since our initial requirements called for the sea base to be as far as 200 nautical miles from the beach, it was decided that the design would best be accomplished if the EFVs are assumed to always be included in the HSAC load-out. This decision was made early in the design process because the 98 EFVs that are in two BLTs have a significant impact on the necessary payload capacity of the ship due to their large weight and footprint area.

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 HSAC 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. One week of class time was spent by the TSSE team reviewing and analyzing each requirement in order to develop the final list.

To generate a final prioritized list of requirements each team first weighted their requirements on a scale of 1 to 10 as shown in Appendix III. Then the Analytic Hierarchy Process (AHP) was used to generate an overall weight value for each of the sub-teams' design requirements. As depicted in Appendix III, the payload requirements were most influential with an overall weight of 53.90%. The ship characteristic requirements were next with a weight of 29.73% followed by combat systems with a weight of 16.38%. The individual team weighting was normalized using the AHP derived weights to allowing the team to rank the derived requirements relative to each other. Finally, all the requirements were prioritized using their normalized weight, resulting in the final operational and functional requirement list seen in Appendix III. With this detailed set of requirements, the team was prepared to move forward with the design process.

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III. ANALYSIS OF ALTERNATIVES

A. GENERATION OF MEASURES OF PERFORMANCE

Starting from the payload, speed, and cargo requirements for the design, the design team developed three Measures of Performance (MOP) for the HSAC: flexibility, survivability, and transport factor.

1. Flexibility

This MOP depended on four factors: payload, draft, number of ships, and speed. The objective preferences for this MOP were as follows:

Objective Preferences (Flexibility)

	# of Ships	Speed	Payload	Draft
# of Ships	1	1	2	2
Speed	1	1	2	2
Payload	0.5	0.5	1	1
Draft	0.5	0.5	1	1

The above objective preferences led to the following weightings:

- Number of ships : 14.21%
- Speed : 14.21%
- Draft : 35.79%
- Payload : 35.79 %

After a careful examination of the above weighting factors, and to make the flexibility MOP more balanced, the team decided to give more weight to the speed and number of ships. The final weighting that was used for the rest of the AOA procedure is as follows:

- Number of ships : 20%
- Speed : 20%
- Draft : 30%

- Payload : 30%

The MOP score for flexibility is then scaled between 0 and 20 (with 20 being the best a ship can achieve).

2. Survivability

This MOP depended on three factors: number of ships, speed, and the ship's length. The objective preferences for this MOP were as follows:

Objective Preferences (Survivability)

	Speed	# of Ships	Length
# of Ships	1	2	2
Length	0.5	1	2
Speed	0.5	0.5	1

The above objective preferences led to the following weighting factors:

- # of ships : 49.34%
- Length : 31.08%
- Speed : 19.58%

The actual values used during the AOA phase were a round up of the above values as follows:

- # of ships : 50%
- Length : 30%
- Speed : 20%

The survivability MOP is then scaled between 0 and 20 (0 being the worst case scenario and 20 reflecting a ship with a perfect survivability).

3. Transport Factor

The last MOP selected for this design project was the transport factor (TF). The TF is a non dimensional relationship between the weight, design speed, and installed power of a ship given by:

$$TF = \frac{K_2 \cdot W}{SHP / K_1 \cdot V} = \frac{(1.678/550) \cdot W}{SHP / 2240 \cdot V}$$

where, W : Full Load Weight of Ship ($W_{SHIP} + W_{CARGO} + W_{FUEL}$)

W_{CARGO} : Weight of Cargo
W_{FUEL} : Weight of Fuel
W_{SHIP} : $W - W_{CARGO} - W_{FUEL}$
V_K : Design Speed
K_1 and K_2 : Conversion Constants for hp,lb and LT
SHP : Total Installed Power
More on TF can be found in [1].

By examining the TF for existing ships, the team concluded that the higher the TF, the better the design is. The team also learned that the highest possible TF with current technology for the speed range is around 48.

Figure 6 shows the operating envelop for the proposed designs. From this plot of transport factor vs speed, it is evident that the operating envelope is below the Carderock theoretical maximum which is the red line. On the graph are many other points which correspond to other ships, and the results are well above most of those. This is expected due to the fact that the ship’s main objective is to carry a large quantity of cargo at high speeds, and technological advances should allow the design to approach closer to the theoretical maximum. Therefore, the teams used a scale between zero and 50 for the TF values (none of the designs exceeded a TF value of 35, though).

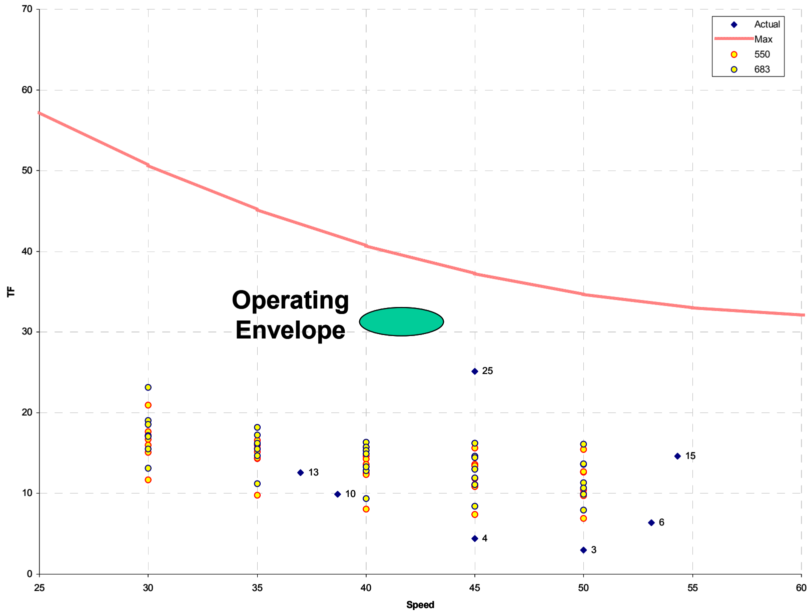

Figure 6. TF Operating Envelop

4. Overall measure of performance

All of the above measures of performance were then used to derive an overall MOP that will ultimately drive the design choice.

The weighting of each of the above MOPs in the overall MOP is as follows:

- Survivability : 42%
- Flexibility : 16%
- TF : 42%

Therefore, the

$$Normalized\ \text{MOP} = \left(.42\frac{\text{Survivability}}{20}\right)+\left(.16\frac{\text{Flexibility}}{20}\right)+\left(.42\frac{\text{TF}}{50}\right)$$

B. ANALYSIS OF ALTERNATIVES TOOL

As can be seen from the above discussion, the individual MOPs (and therefore the overall MOP) depended on parameters like speed, payload, number of ships, length of each variant, installed power, displacement, and draft. At this point of the design, a "tool" was needed that provided a good estimate of each of those factors as the design parameters were varied.

Because the team was familiar with the Massachusetts Institute of Technology (MIT) spreadsheets tool, the team decided to use this software as a "first cut" tool for the evaluation of different hull forms.

1. Overview of the MIT Spreadsheets Tool

This spreadsheet tool, commonly known as MAPC, uses parametric models and scaling to create high level designs of various hull types. The inputs are the desired speed, range, payload, sea state and maximum displacement. Some of the software's outputs include the fuel requirements, draft, displacement, length, beam and installed power. A sample interface is presented in Figure 7.

Modified at NPS for the TSSE "SEA ARCHER" Project
by LT. A. DALAKOS HN

Initial Input

Ranking		Value	Units
1	Desired Speed in Waves	30	knots
2	Desired Payload	2,000	long tons
3	Desired Range	500	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	12,000	long tons

Results		Hydrofoil	HYSWAS	SES	Semi-Planing Monohull	Catamaran	Trimaran	SWATH
Calm Water Speed [3,12]	knots	30.0	30.0	30.0	30.1	30.0	30.1	30.0
Speed in Waves [1,3,4,9,10,11]	knots	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Payload Weight [2,3,4,9]	long tons	2,000	2,000	2,000	1,000	2,000	2,000	2,000
Range at Speed in Waves [4,7,9]	nautical miles	500	500	500	100	500	500	500
Displacement [3,7]	ylong tons	5,391	4,682	5,437	2,115	5,631	5,334	5,824
Installed Power [3,6,7]	ylong tons	87,560	49,696	77,450	36,117	68,783	33,885	58,471
Engines [5]	ylong tons	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600	6 LM 1600
Fuel Carried On Board [3,7,8]	ylong tons	246	144	218	21	196	98	169
Length	feet	421	313	479	282	419	634	291
Beam	feet	107	90	90	56	134	153	129
Hullborne Draft	feet	57.9	43.7	19.8	20.9	19.1	15.9	26.7
Foilborne / Cushionborne Draft	feet	23.5	23.2	5.5	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 150,000,000	$ 133,000,000	$ 149,300,000	$ 114,900,000	$ 148,500,000	$ 141,200,000	$ 152,600,000
Lift to Drag Ratio		19.5	25.9	22.3	16.5	23.5	47.1	24.2

Figure 7. Sample Interface of the MIT Spreadsheets

2. Modification of the MIT Tool

In its original format, this tool used geometric and dynamic similarities along with regression analysis to generate its outputs. Also, it intended only for relatively small vessels with speeds up to 40 knots. The TSSE 2003 team modified this tool to account for larger and faster hull forms, though. In this design, these modified MIT spreadsheets were used to allow the comparison of the seven proposed hull types (Hydrofoils, HYSWASs, SWATHs, SESs, Planing monohulls, Catamarans, and Trimarans) for speeds up to 60 knots. Although the team did not conduct any analysis to validate the use of this tool for the purpose of the design, the latest generation of high speed Wave Piercing Catamarans (WPC) built by the Hobart Company INCAT have validated the use of this tool for large vessels at higher speeds.

Although the tool has provided only a first estimation of the key hull form parameters, it was deemed an adequate evaluation tool for the purpose of this stage of the AOA.

C. ANALYSIS OF ALTERNATIVES PHILOSOPHY

Starting from the required payload to carry (8000LT) and an approximate combat system payload of 150LT (derived from a preliminary study conducted on the combat system requirement for the ship), the team calculated the payload for the possible designs as follows: Each ship in a specific design will carry ([8000LT/(number of ships in the design)]+150LT). At this point, it was decided that all ships will have the same combat system payload but will be designed in a modular way as to allow for flexibility in the selection of the different combat system elements. As an example, for a design with 5 ships, each will have to carry a payload equal to: (8000/5)+150=1750LT.

1. Possible Designs

Because there were many possible designs that fulfill the requirements of the HSAC, it was necessary to divide the team into three groups where each group selected a payload range and conducted the needed analyses. The results of the analyses allowed the team to determine the characteristics (advantages and drawbacks) of the different designs.

Ships with payloads less than 2000LT were considered big ships, ships with a payload between 1000 and 2000LT were deemed medium size ships, and finally ships with a payload less than 1000LT were considered small ships.

Group I analyzed the data for the cases of two, three, and four ships variants (big ships), group II analyzed the data for five, seven and 10 ships variants (medium ships), and group III analyzed the data for 15 and 20 ships variants (small ships).

Each group was tasked to calculate the overall MOP for each possible payload (varying from 550LT in the case of 20 ships to 4150LT in the case of two big ships) and each possible hull type (the seven hull types in the MIT spreadsheets) for speeds varying from 30 knots to 50 knots (with a 5 knot increment).

The total number of possible runs was equal to 280(7 hull forms * 5possible speeds * 8 possible ship groupings =280)

All runs were then grouped to show the MOP for each possible hull type, speed, and payload.

Appendix IV shows the overall results collected from all three groups.

Appendix IV shows a sample of the MOP calculation results of the medium size ships.

2. Design Selection Tests

Due to time constraints, it was not possible to analyze all of the possible 280 designs and a method was neded down that number to a more reasonable figure. Based on a statistical analysis of the results from all runs, the following was noted:

1- MOP values varied between 0.2 and 0.5 (most ships exceeded 0.3, though).

2- For some ship designs MOP values varied dramatically as speed is changed.

Based on those observations the team decided to run all deigns through a series of three tests. In case they pass the last test, they are kept for further processing. If not, they are dropped out of the AOA process. The three tests were as follows:

Test1: If the average MOP is less than 0.4, then that is considered a bad design *(spreadsheet reads: Return ZERO if average< 0.4, otherwise, return the average MOP over all speeds).*

Test2: If the max (MOP)-min (MOP) exceeds 0.05, then the design is not robust enough and is considered as a bad design *(spreadsheet reads: Return ZERO if max (MOP)-min (MOP)>0.5, otherwise return the average MOP over all speeds)*.

Test3: Any design that has an average>0.45 **or** passes the two tests (regardless of the design's average MOP) is considered a good design and will be kept *(spreadsheet reads: Return the average MOP if a design passes test 3 and Zero if it does not pass it)*.

At this point, it is important to note that the reason it was decided to keep deigns with an average MOP>0.45 although they might not have passed test two (max (MOP)-min (MOP) exceeds 0.05) is that 0.45 figure was deemed a high enough MOP (compared to the average over all deigns) that cutting those deigns would not be fair.

Figure 8 shows a snapshot of the required excel work to run the three tests for the 15 ships variant. It can be seen clearly how only two out of the seven possible deigns made it through the three tests. For the particular case shown on the figure, only 15 Hydrofoils or 15 Catamarans would be considered adequate to meet the design requirements.

	15		15 ships				
	Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
	1	2	3	4	5	6	7
30	0.4032911	0.4196021	0.437716	0.3810574	0.4266967	0.4918212	0.419973
35	0.407435	0.4054498	0.417811	0.3651894	0.4198396	0.455274	0.396339
40	0.409043	0.3938541	0.402963	0.3511751	0.4129364	0.4310445	0.379645
45	0.408529	0.3859061	0.391949	0.3478963	0.4058566	0.4203088	0.37051
50	0.4073266	0.3781461	0.383412	0.3442935	0.400095	0.409754	0.361815
test1	0.4071249	0	0.40677	0	0.4130849	0.4416405	0
test2	0.4071249	0.3965916	0	0.3579223	0.4130849	0	0
test3	0.4071249	0	0	0	0.4130849	0	0

Figure 8. Excel work to establish the design selection tests

3. Design Selection Results

At the conclusion of the three tests, only 23 possible deigns passed the required tests and were kept for further processing.

a. *Modified cost model*

The next step in the AOA was to analyze each of the 23 designs with respect to cost. Again, the MIT spreadsheets were used to obtain a rough estimate of the cost of each of the possible ships. After an initial run, the team noticed that the MIT spreadsheets assigned almost the same cost to all possible designs no matter how much the speed and payload requirements were varied.

After a thorough examination of how the MIT spreadsheets calculated cost, the team realized that the model used a miscellaneous cost of $300M that is the same for all ships and is always added to the overall cost of any particular ship type. Also, the combat systems cost was not accurate enough and does not reflect what is needed for the design. At this point, the team deemed necessary to modify the cost model in order to have a more accurate idea on how much each of the variants will cost.

In building a modified cost model for the purpose of the HSAC design, the miscellaneous cost was disregarded; the combat system cost calculations were tailored to reflect the ship’s requirements, and only the cost of the machinery ($225/HP for installed HP) and structural weight ($10/lb) were accounted for. The team believed that the sum of the machinery cost, the structural weight cost, and the combat system cost is a more reasonable cost calculation model to sort the different designs.

Based on the TSSE 2003 design, and because the Sea Swat had a similar combat system suite to the one designed for this project, the team estimated the combat system cost for one ship to be equal to $50M. Starting from the realization that the cost of the combat system suite for a specific design should not increase linearly with the number of ships, the team developed a combat system cost model to account for designs that have a large number of ships as is illustrated in Appendix IV. The new combat system cost model results show that starting from a cost of $50M when one ship is built, the cost decreases to only $27M/ship when 20 ships were built; something that was deemed very reasonable.

Also, because building more ships of the same type involves a learning curve that can minimize the overall cost of the total number of ships (as compared to multiplying the cost of the lead ship by the number of ships), a "0.9" learning factor was used in the cost calculation to give credit to designs where only few ships were to be built.

The cost of the n^{th} ships was calculated according to the following formula: $Z_u = Ku^{\left(\frac{\log(s)}{\log(2)}\right)}$

where u = unit of interest; Z_U= resources for unit u

K = resources for 1st unit; s = learning curve slope.

Appendix IV illustrates the excel work involved in calculating the modified (new in the spreadsheet) cost for six of the possible 23 designs.

b. Final selection

The final step in the AOA is to analyze the 23 possible deigns with respect to cost. For each design, the overall MOP was plotted against cost. The resultant plot that reflects the final results is shown in Figure 9.

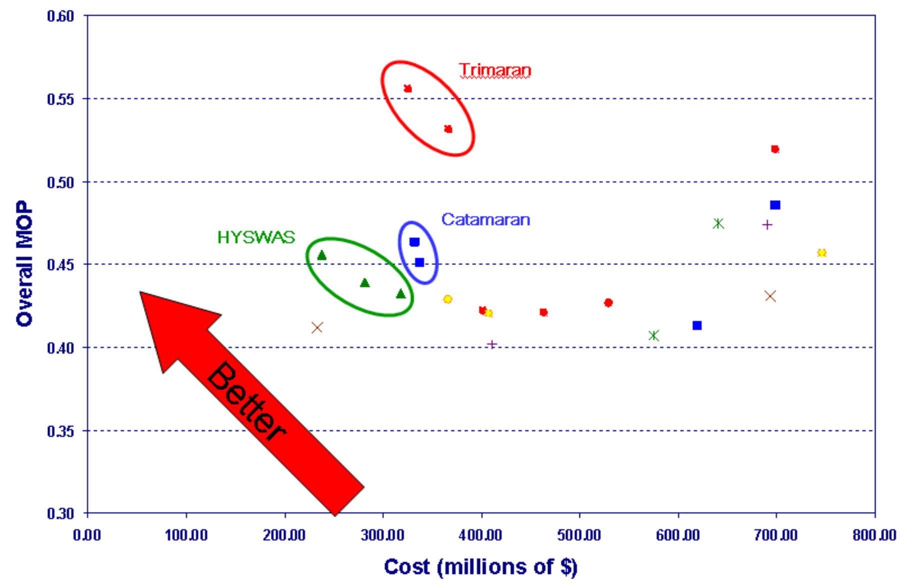

Figure 9. Cost vs. MOP for all possible designs

Because the team was looking for a grouping of ships with the highest MOP possible and the lowest cost, it was evident that the trimaran design led to the best design of all possible ones.

Because the ship's draft is a big design driver for the project, and taking into account the fact that the more ships a design includes, the lower the draft is, the team decided to select a number of medium size trimarans as the design of choice rather than to pick an exact number. The final number would depend on other constraints (cargo, ramp feasibility study, hull design study, machinery requirements, beach slope study and draft requirements, etc.) that will come up during further design analysis.

Figures 10 and 11 show that the three ship and four ship variants versus MOP broken out by speed. Again, it can be seen clearly how the trimaran hull form distinguished itself among all possible hull forms.

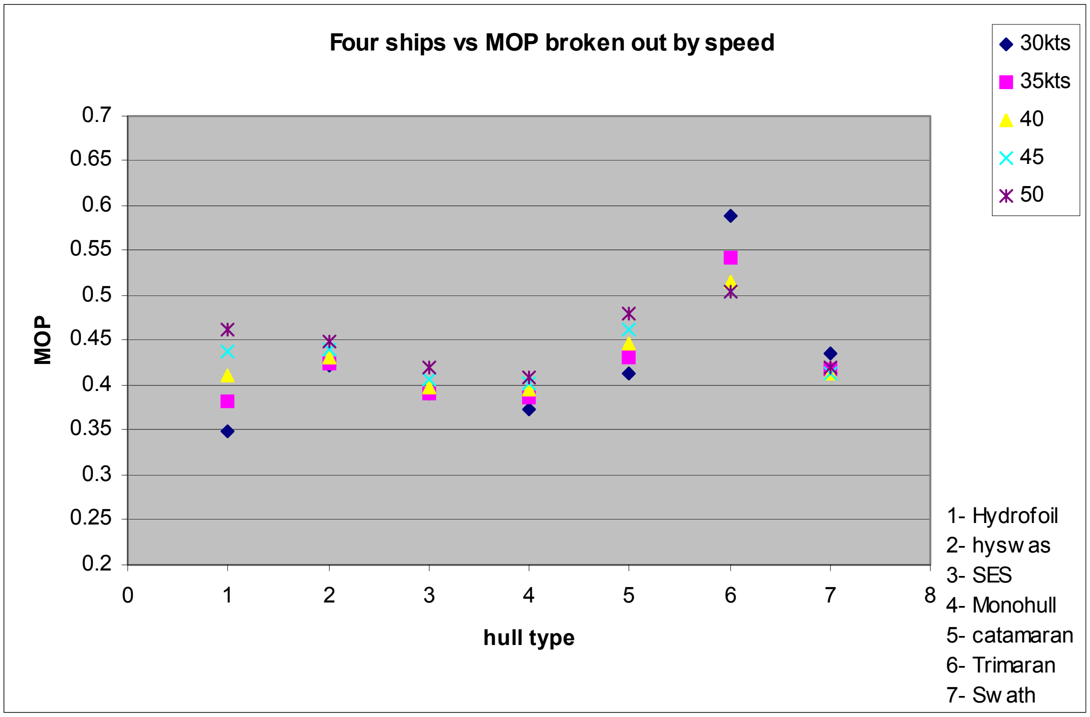

Figure 10. Four ship vs. MOP broken out by speed

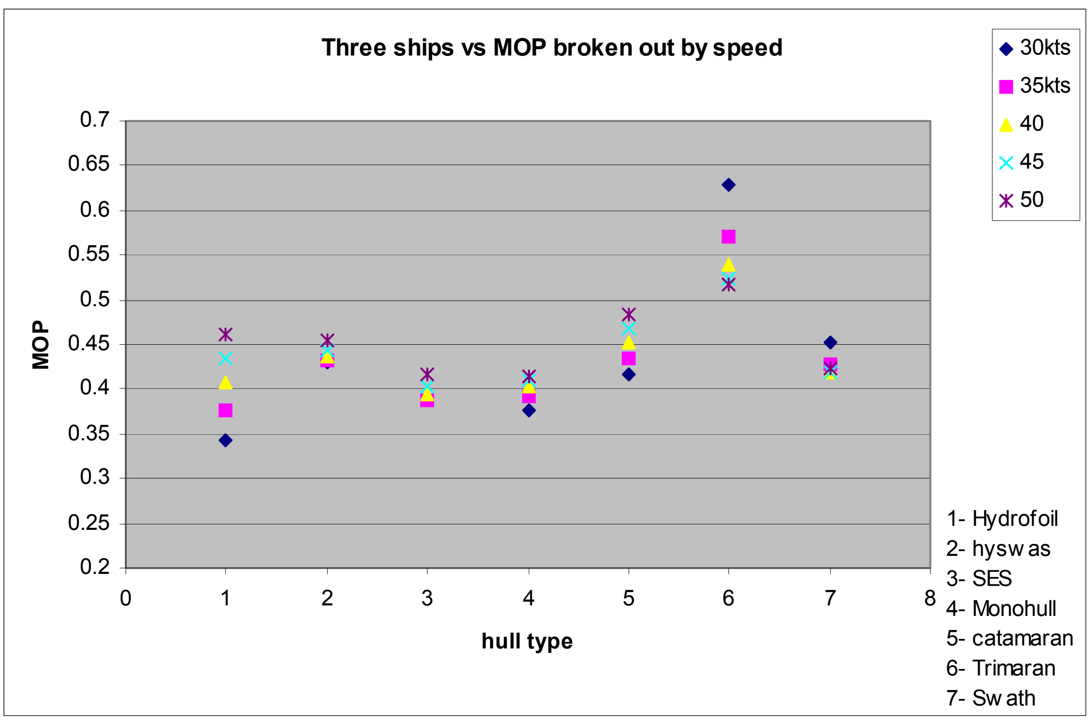

Figure 11. Three ships vs. MOP broken out by speed

D. SUMMARY

Analyzing the outcome of all possible hull designs, the trimaran displayed the best results to fulfill the requirements of the project. In addition, the trimaran had the best draft and the largest deck area which are both big design drivers for the project.

Based on these results, the team decided that the High Speed Assault Connect (HSAC) will be a design that involves a number of medium size trimaran.

E. BEACHABLE VS. NON-BEACHABLE FEASIBILITY STUDY

Current amphibious operation’s use two different methods to transfer troops and equipment to the beach: First, a beachable craft with a relatively low draft that is able to reach the beach and use a ramp to off-load troops and equipment. Second, a non-beachable ship that anchors or loiters 5-25nm off the beach and uses LCAC´s or AAV’s to transport troops and equipment to the each. Though both of these delivery methods are proven technologies, neither can meet the distance, speed, and sea state requirements that the current seabasing requirements stipulate. Thus the HSAC design must replace or augment these amphibious landing craft technologies.

The design team decided that the HSAC would either be a beachable ship or a non-beachable ship. The beachable variant would take the requisite cargo from the Sea Base directly to shore. The non-beachable variant would “ferry” loaded landing craft from the Sea Base to a short distance from the beach and then allow the landing craft take the cargo ashore. A feasibility study was conducted on each to determine which alternative to pursue.

After reviewing the Naval Research Advisory Committee’s (NRAC) concept for a LCAC “ferry,” the team initially believed that a non-beachable design that would “ferry” LCACs to and from the Sea Base would be the easiest and more direct design to implement[3]. Since LCACs are already actively employed, this design would require few tactical changes. It would extend the effective range of the LCAC from the Sea Base and would help minimize the effect the sea state has on LCAC performance by transporting the LCAC through the worst seas. The design automatically addressed the beaching issue by using the LCAC which is a proven high speed connector. Since the HSAC does not have to beach itself, the draft of the connector "ferry" would not be as big an issue and it is kept at a safer distance from the potentially hostile beach.

However, a LCAC can carry a maximum payload of 60LT and weighs 200LT when fully loaded. To move the approximate 8000LT of vehicles, troops, and gear that comprises two BLTs, at least 114 LCACs would be required, well above the current U.S Navy inventory. Thus a LCAC "ferry" design would require a significant payload capacity and significant number of ships to transport enough loaded LCACs to make the design worthwhile. Though the HSAC could be designed to facilitate multiple LCACs trips in an effort to reduce the number of LCACs required, the LCAC's 30 minute load and unload time combined with the HSAC transit time could exceed the 10 hour period allowed. Finally the mean time between failures of the LCAC and its approaching end of service life was of concern, greatly affecting the reliability of the overall system.

To start the beachable design analysis, the team examined the characteristics and capabilities of the *Newport* class LST. Of note from this examination was that the LST could carry 3000LT of cargo, had a 16ft average draft, had a stern gate for amphibious vehicle deployment and recovery, and had a deployable bow ramp. The *Newport* class LST performed a mission similar to the HSAC and proved that a large vessel could be made beachable. From here the team determined that newer technologies in the area of hull forms, structure, and propulsion could greatly enhance the design concepts implemented in the LST. The beachable variant would also provide a single connector solution that would maximize the 10 hour employment time. As a single connector solution, the design keeps the loading and unloading interfaces to a minimum, greatly increasing the overall reliability.

Making a craft beachable, however, creates structural issues for bow ramp design and requires additional structural reinforcement to facilitate beaching. The additional structure required along with the draft constraint could limit hull form options when trying to achieve high speeds with larger payloads. Beachable craft are more susceptible to shallow water mines than LCACs, requiring a low mine threat or mine clearance prior to beaching. Also, the beach characteristics (obstructions, slope, etc.) affect beachable vessels ability to land more than air cushion craft.

The technical risks posed by the beachable design seemed more surmountable than those posed by the LCAC "ferry," especially when a similar design had been implemented in the past. The beachable design provided a single connector solution that could carry a significantly larger payload. The payload capacity would be used for the required cargo and not have to account for the extra weight imposed by LCACs, reducing the number of ships required to complete the mission. After examining the pros and cons for each design variant it was determined that a beachable HSAC would be the most feasible alternative and the team proceeded to conduct its detailed design of the HSAC.

F. REFERENCES

1. Design Trends in High-Speed Transport Colen Kennell (Marine Techonology, Vol 35, No.3, July 1998, pp 127-134)MIT spreadsheets

2. TSSE 2003 Final Report.

3. Mendlow, Larry. *Seabasing.* Presentation given to TSSE students at the Naval Postgraduate School regarding NRAC's studies and ideas regarding seabasing. Monterey, CA. 5 August 2004.

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IV DESIGN PROCESS

A. CARGO DESIGN

1. Establishing the Cargo Parameters

As stated in the initial requirements, the system or systems of HSACs needed to be capable of transporting two Battalion Landing Teams (BLT) of a 2025 JEB from the Sea Base to shore within ten hours. The joint nature of the force and future time frame made it difficult to define exactly what vehicles, troops, and equipment would comprise a 2025 JEB. SEA-6 used the United States Marine Corps vision of a 2015 MPF(F) MEB as a surrogate [1] to develop the notional 2025 JEB listed in Appendix V. The 2025 JEB listed in Appendix V listed the weight, area, and volume for all the vehicles in the BLT. This provided an accurate picture of what needed to be transported, how much it weighed, and how much area it occupied. With this data in hand, a thorough analysis could begin on interface design and cargo placement.

2. Cargo Load Plan Development

The analysis of alternatives conducted earlier determined that a system of 10 medium size trimarans, each with a payload capacity of 800LT would be capable of transporting the two BLTs. However, the analysis of alternatives primarily examined the weight that needed to be moved and not the footprint area of the vehicles. The initial hull form design provided for a large cargo deck, 24.4m wide and 76.2m long, that spanned the side hulls of the trimaran, providing 1859m^2 of cargo area. The first step then was to ensure that the two BLTs would fit across 10 HSACs.

Table 2. Vehicle Data

Vehicle	2 BLTs	Length	Width	Area	Height
Humvee	204	16.84	7.1	119.564	8.5
EFV	98	29.85	12	358.2	10.46
M1A2	28	32.25	12	387	9.47
LAV	50	27.09	8.73	236.4957	8.825
ABV	4	32.25	12	387	9.47
AVLB	2	31	12	372	10.46
M9ACE	8	22	12	264	10.46
M88A2	2	29.38	11.25	330.525	10.25
ITV	16	16.67	5.67	94.5189	5.5
AVENGER	10	16.25	7.17	116.5125	8.67
MTVR	38	22.75	8	182	9.34
LW155	12	30.43	9.09	276.6087	7.42
M105	16	13.78	6.93	95.4954	8.17
MK155	6	15.03	7.98	119.9394	6.17
M101	34	12.24	6.14	75.1536	6.93
M149	2	13.42	6.86	92.0612	6.37
M116	2	12.34	6.25	77.125	2
AN/TPQ	2				
FORKLIFT	8	23.63	8.53	201.5639	10.14
CONTACT TRUCK	4	22.75	8	182	9.34
Vehicle Total:	546				

First, data was compiled and tabulated in Table 2 on all of the vehicles to include length, width, height, and weight. In some cases there were multiple variants of the same vehicle or piece of equipment. When faced with this situation, the heaviest weight and largest dimensions of the multiple variants were used. This allowed the design to be geared towards the worst case scenario and ensured that all vehicle variants would fit in the design. Also, several items in the BLT are vehicles still under development for which exact data was not readily available. The design team was forced to use conservative estimates for these items based on available data or existing vehicles of similar size. All of the weights used to describe the vehicles in the BLT include fuel, personnel, and the gear which the vehicle would carry.

Next, the footprint for each vehicle within one BLT was constructed and then placed across 10 of the initial cargo decks. To ensure loadout flexibility and feasibility, a 0.9m buffer separated each vehicle from a neighboring vehicle or ship structure. Though only one BLT was being placed on the ships, doubling the resulting placement would yield the overall weight and area requirements for two BLTs. After placing one BLTs worth of vehicles across the 10 cargo decks, 960m^2 of cargo area was occupied leaving only 899m^2 for the second BLT. In addition, this notional cargo deck did not include any interfaces to provide access to the cargo deck, which would further reduce the amount of area available cargo area. Thus, it was determined that initial cargo deck did not provide enough usable cargo area for two BLTs. It was also noted that the average loadout for one BLT over 10 HSACs was 420LT, making the average payload for two BLTs 840LT. This average payload exceeded the design payload by 40LT.

Due to the average payload weight and area requirement issues discussed above, it was decided to distribute the two BLTs across a system of 12 ships. Two BLTs occupied 19,200m^2 based on the initial 10 ship analysis. Using 12 HSACs would provide 22,311m^2 of cargo area, comfortably holding the two BLTs, while allowing for cargo deck interface placement. It would also allow one BLT to be embarked across six ships, providing mission commanders the ability to add or remove BLTs easily as the mission needs dictate.

Table 3. 1 Battalion Landing Team distribution

Vehicle	SHIP	1	SHIP	2	SHIP	3	SHIP	4	SHIP	5	SHIP	6
	qty		qty		qty		qty		qty		qty	
Humvee	17	137700	17	137700	17	137700	17	137700	17	137700	17	137700
EFV	9	655911	8	583032	8	583032	8	583032	8	583032	8	583032
M1A2	2	278160	3	417240	3	417240	2	278160	2	278160	2	278160
LAV	5	145000	4	116000	4	116000	4	116000	4	116000	4	116000
ABV		0		0		0		0	1	139080	1	139080
AVLB		0		0		0	1	93194		0		0
M9ACE		0		0	1	37799	1	37799	1	37799	1	37799
M88A2		0	1	140000		0		0		0		0
ITV	1	7900	1	7900	1	7900	2	15800	1	7900	2	15800
AVENGER	1	8300		0	1	8300	1	8300	1	8300	1	8300
MTVR	4	164000	3	123000	3	123000	3	123000	3	123000	3	123000
LW155	1	9200	1	9200	1	9200	1	9200	1	9200	1	9200
M105	2	10720	2	10720	1	5360	1	5360	1	5360	1	5360
MK155		0		0	1	6405	1	6405	1	6405		0
M101	2	5678	2	5678	4	11356	2	5678	4	11356	3	8517
M149		0		0		0		0		0	1	2600
M116		0		0		0		0	1	2360		0
AN/TPQ	1	43756		0		0		0		0		0
FORKLIFT	1	10000		0	1	10000	1	10000		0	1	10000
CONTACT TRUCK		0		0		0	2	40000		0		0
TOTAL PAYLOAD (LB)		1476325		1550470		1473292		1469628		1465652		1474548
TOTAL PAYLOAD (LT)		659		692		658		656		654		658

Using a 12 ship system also reduced the average loadout weight to 663LT with a worst case loadout of 693LT, both well below the design payload amount of 800LT. With the worst case payload over 100LT less than the ship's maximum payload, the HSAC will be able to grow and adapt to new equipment and loadout requirements in the future. Table 3 illustrates how one BLT was distributed across six HSACs.

3. Cargo Deck Design

The initial cargo deck layout was established to carry one sixth of a BLT, approximately 46 vehicles. Also determined in this initial work was the need for a stern gate for cargo on load at the Sea Base or Forward Logistics

Station (FLS). A bow ramp was also determined to be necessary for the offload of cargo at the beach. To continue with the detailed design work for the cargo spaces, it was necessary to establish the dimensions of the cargo spaces and to examine specific vehicle storage locations. The design team determined that it was prudent to allow for extra room within the cargo spaces to account for structural members and sufficient space for personnel to access any of the vehicles. Also of importance to the design team was to establish a cargo floor plan which would allow for rapid loading and unloading of vehicles.

The analysis of the cargo spaces to determine how many ships were necessary to transport both BLTs determined that two levels of cargo decks would be necessary to accommodate all of the vehicles. The largest area available within the hull was located on the first deck spanning the beam of the ship to include the side hulls, approximately nine meters above the baseline of the ship. Given a beam of 30 meters, the main cargo deck was limited to 21.4 meters in order to allow for structure and additional spaces or passageways that may be determined to be necessary on the same deck. In order to retain the main cargo deck within the area of the ship that extends from the main hull to the side hulls, the length was determined to be 76 meters, with the space beginning at the stern of the ship. A minimum of four meters of deck height was determined in order to allow for sufficient overhead clearance for any vehicle or container which the ship would carry.

The additional cargo deck was placed one deck below the main cargo deck and is restricted by the beam of the main hull, approximately 5 meters above the baseline. This was determined to be the best location because it would allow for storage of the heaviest vehicles lower in the ship, keeping the KG of the cargo as low as possible. In order to fit the largest vehicles single file, it was necessary for the compartment to be five meters wide. This cargo deck was to span the entire length of the ship in order to permit vehicles to drive in from the stern of the ship and drive out through the bow. Again, a minimum deck height of four meters was deemed necessary.

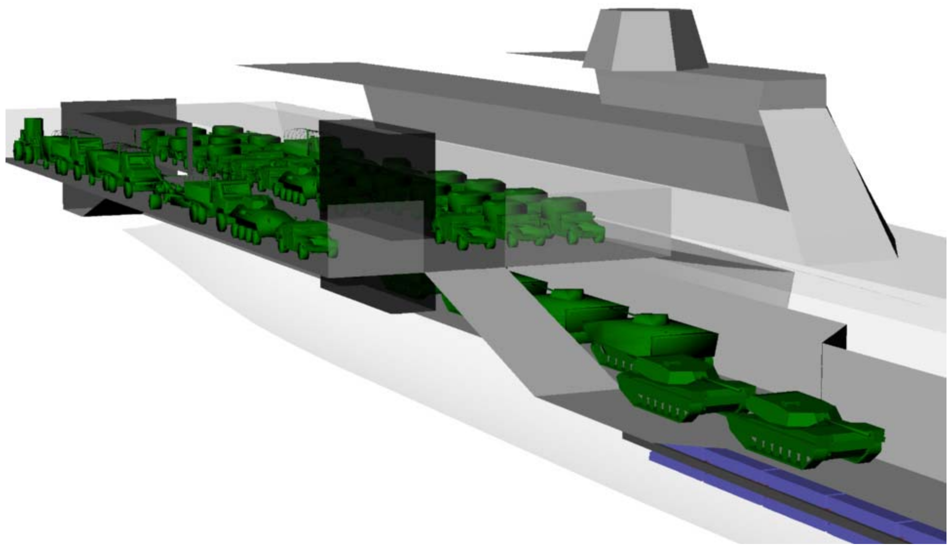


Figure 12. Main and Lower Cargo Decks Fully Loaded

Vehicle flow through the cargo spaces was of great importance to the design team because this would be a critical factor in allowing for rapid on and offload of the vehicles when conducting the primary mission. Several design features were developed in order to enhance the flow of cargo through the ship.

With the vehicles loading from the stern of the ship at the Sea Base or FLS, they would be able to roll on through the stern gate and would be easily stowed for transport facing the bow of the ship. When the ship is at the beach, the vehicles are facing forward and just simply will need to drive forward off the ship. Figure 12 provides a cut-away view of the cargo decks inside the ship.

A problem the design team faced was how to effectively move cargo from the lower cargo deck to the main cargo deck. Both the stern gate and bow ramp were determined to be located on the lower cargo deck level since that deck would pass through the entire length of the ship. A system was necessary to allow the loading vehicles at the stern to gain access to the main cargo deck, and also for those vehicles to easily move back down to the lower cargo deck during offload.

Fixed ramps were determined to be the best design to address this problem. As the vehicles roll on through the stern gate, they will need adequate space to either access the fixed ramp to drive up to the main deck, or pass to the side of the ramp and travel through the lower cargo deck. At the forward end of the main cargo deck, a second fixed ramp would allow the vehicles on that deck to drive down to the lower cargo deck and then out through the bow. Again, adequate space would be necessary for the vehicles on the lower deck to pass by the fixed ramp and continue forward to the bow. Both ramps have an 18 degree slope.

Limited by the main hull beam of xx meters, the design team desired to keep the lower cargo deck footprint within a 10 meter boundary. This permitted the lower cargo deck to have a width of five meters and for the forward and aft ramps to also have a width of five meters. In order to make it all fit within the confines of the main hull, it was decided to place the lower cargo deck to the left of centerline. The starboard bulkhead of the lower cargo deck would be on the ship's centerline with the port edge of the forward and aft ramps also located on centerline.

Through the ongoing collaboration with the hull and propulsion designers, space for the intake and exhaust ducts used by the gas turbine engines was to be allocated within the cargo area. The necessary space was three meters wide and twelve meters long. The engines were placed one deck below the lower cargo deck, and the intake and exhaust plenums would need to pass through both cargo decks along the ship's centerline.

There was adequate space in the main cargo deck, but the space intruded too much into the lower cargo deck, leaving only three and one half meters of width along the twelve meters of the intake and exhaust space. By extending the lower cargo deck from centerline all the way to the structure of the port side of the main hull, the minimum width of five meters was still achievable.

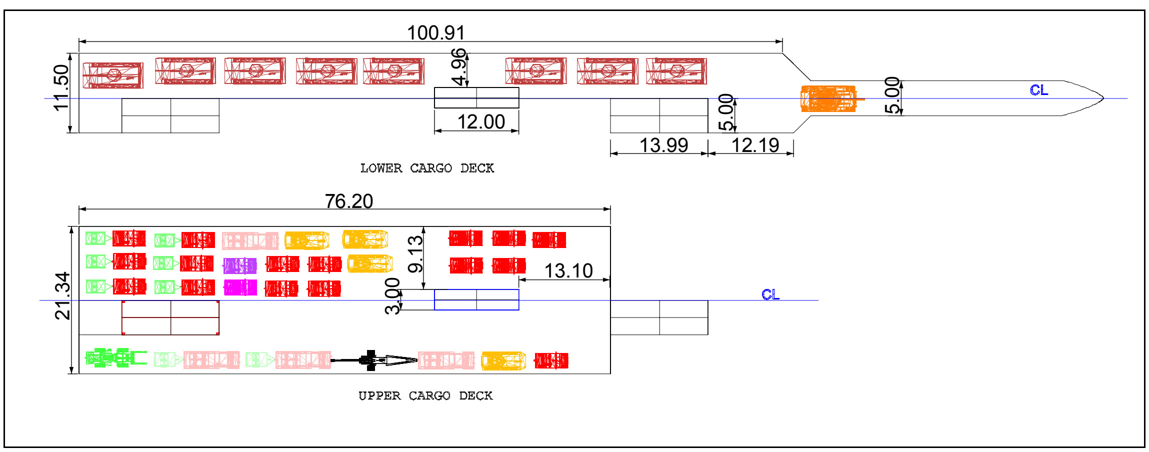


Figure 13. Main and Lower Cargo Deck Dimensions (meters)

Approximately 12 meters ahead of the forward ramp, the lower cargo deck narrows to a width of five meters for the remainder of the distance to the bow ramp. Figure 13 provides dimensions for each cargo deck and the forward and aft ramps.

Although the heating and ventilation system has not been engineered in this iteration of the ship design process, the design team identified the need for sufficient ventilation to be installed on both cargo decks. This is necessary to remove exhaust gasses while the vehicles are being on and offloaded, or whenever the vehicle engines may be started while inside the ship.

4. Vehicle Models

Three dimensional AUTOCAD models were obtained from Northrop Grumman Ship Systems of the vehicles which were to be carried by the ship. In several instances, the design team was forced to use similar type vehicles to simulate a vehicle for which a model was not available. For instance, a model of the M1A1 tank was used to simulate the M1A2. Figure 14 shows the three dimensional model of an MTVR which was used for the design.

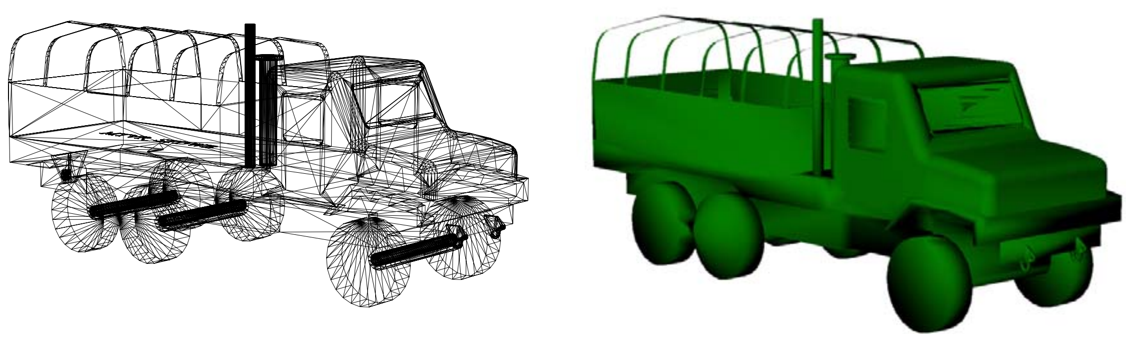


Figure 14. Three Dimensional Model of an MTVR

Three dimensional blocks were satisfactory for modeling the space which each vehicle would occupy, but the value of the actual vehicle model was excellent as a means to provide an accurate visual demonstration of how the vehicles will occupy space inside the cargo decks.

To ensure that the vehicles would fit within the cargo deck spaces, a one ship load-out was developed using the vehicle models. The design team found that the cargo decks provided adequate space for all of the required vehicles, with room for additional vehicles or for the vehicles to be moved while fully loaded.

The design vehicle load-out places the heaviest vehicles on the lower cargo deck. This includes the M1A2 tank and the Expeditionary Fighting Vehicle (EFV), which will be stowed single file along the length of the deck. This assists with keeping the KG of the cargo as low as possible. The average cargo weight per ship is 663 LT with a vertical center of gravity (KG) of 8.6 meters.

Also, since these vehicles are more difficult to maneuver, they will simply drive straight in and out of the ship with little or no need to maneuver. Only the vehicles stored aft of the forward ramp will need to negotiate a slight turn to centerline. With twelve meters of distance to move approximately three meters laterally, all of the vehicles will be able to negotiate this turn. The EFVs can be loaded in reverse so that they may easily drive back out through the stern gate while the ship is underway or beached.

While the main cargo deck is capable of holding any of the vehicles to be carried by the ship, it is designed to carry the lighter and more numerous vehicles. The lightest vehicles will be stored on the extreme port and starboard sides of the deck to minimize stress on the structure supporting the side hulls. There is also enough room on the main cargo deck to maintain a clear path from the aft ramp to the forward ramp with all of the vehicles onboard.

The obstacle caused by the gas turbine intake and exhaust is approximately 13 meters aft of the forward ramp, allowing room for all of the vehicles to maneuver around the obstruction and access the ramp.

5. Stern Gate Design

The key to achieving a rapid cargo on and offload rate was to design a simple and effective way for the cargo to be brought onboard and to then be removed at the beach. Since the ship will need to be able to load cargo at the Sea Base in addition to at a port, a roll on system was determined to be the quickest method.

Interfacing with the Sea Base proves to be the most difficult aspect for cargo on-load because the ship must be able to move cargo onboard in conditions up through sea state four. At such a sea state, craning operations can be slow and dangerous for both personnel and equipment. The roll-on method allows for a safer operation at the higher sea state without suffering a large degradation in the on-load rate.

Another road block in the Sea Base interface is that the composition of the Sea Base is not yet fully understood. Referring to existing documentation and exercises that have been used as test beds for the Sea Basing concept (REF [2]), the design team decided to interface the stern gate with a floating platform comparable to the floating causeway system used in the Navy Lighterage system. This platform would be provided by the Sea Base and will not be an organic component of the ship. The vehicles would be moved from an asset within the Sea Base on to the floating platform. The method in which the vehicles are moved at the Sea Base to the floating platform was not considered in this design.

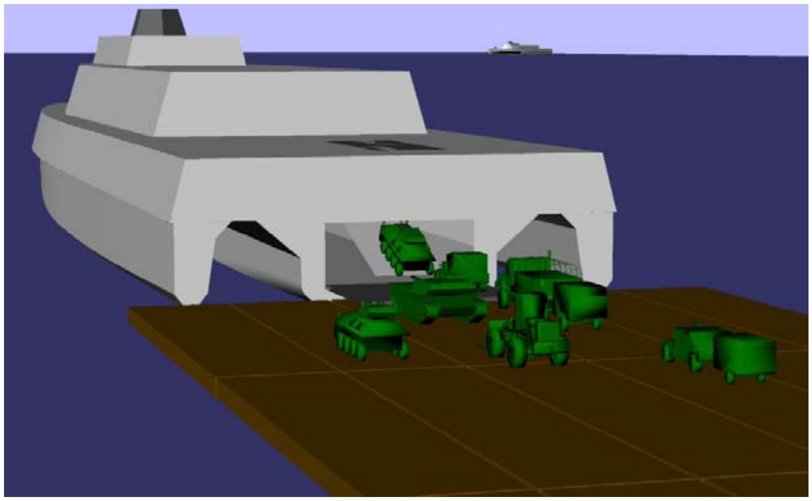


Figure 15. Stern Gate Operations at the Sea Base

A stern gate was chosen as the best method to allow direct access to the cargo decks for the vehicle on-load. The gate is 10 meters wide and nine meters high to allow up to two vehicles to load simultaneously, with one vehicle entering the lower cargo deck and the other driving up the aft ramp to the main cargo deck. Since the stern gate extends 4.5 meters above the lower cargo deck when in the vertical position, there will be a recession in the stern of the ship to allow for the gate to close completely and create a watertight seal around the opening into the lower cargo deck. The gate will be able to open from the vertical closed position down through a 120 degree range of motion. It will be raised and lowered using a hydraulic piston system capable of holding the gate in the down position while one vehicle drives on or off the ramp into the water.

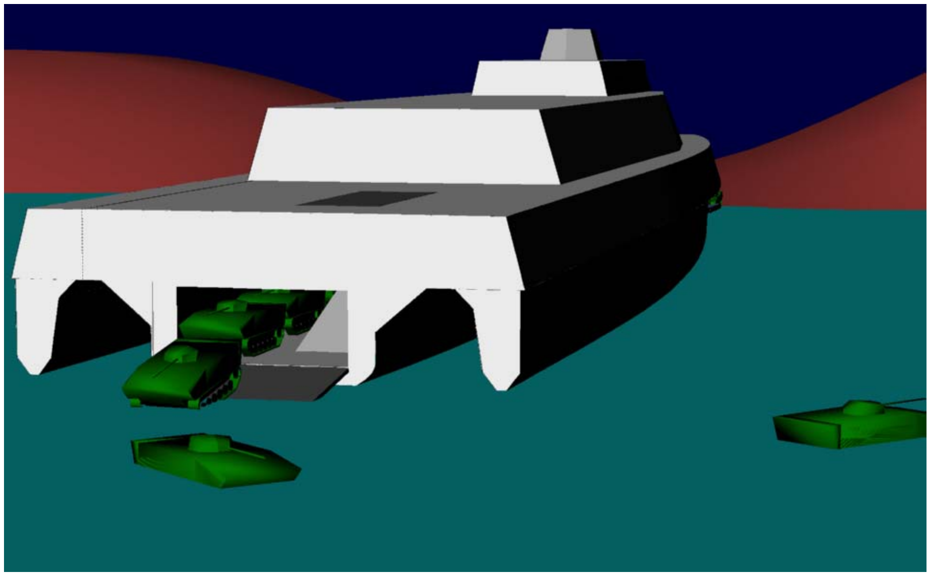


Figure 16. Stern Gate Operations at the Beach

Similar stern gates have been used onboard other U.S. amphibious naval vessels, including the LPD-17 and LSD-36 class ships. Since this is a proven technology that is currently in use, no further design work was done in this iteration of the design process to allow the design team to focus more on other areas of the ship design.

6. Bow Ramp

Keeping with the mindset that a roll-off design would provide the most rapid means of off-loading the ship, the design team developed a bow ramp that would allow all of the vehicles to drive under their own power off the ship and onto the beach. It was necessary to design a ramp which would be an organic component of the ship, provide adequate reach from the grounded ship to the beach, and be able to deploy and retrieve in a timely manner.

Several options were considered for the bow ramp design, to include a fixed ramp from the weather deck and an inflatable ramp. The design that was ultimately chosen is a floating ramp, comprised of eight five meters long sections, providing an effective ramp length of 35 meters.

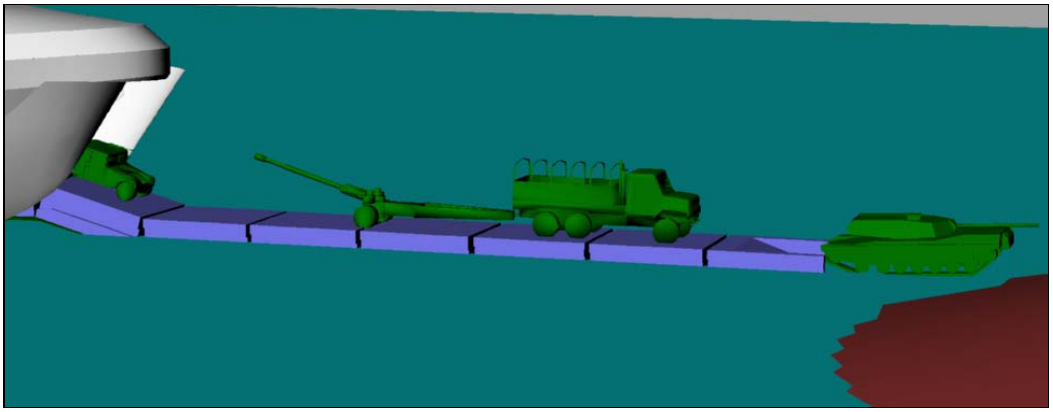


Figure 17. Bow Ramp Operation at the Beach

The fixed ramp design would have required the ramp to be stored high on the ship so that it could be deployed from the weather deck over the bow. This concept is similar to that of the ramp design on the LST-1179 Newport class ship. Since the vehicles were to be stored lower inside the ship, the problem of getting the vehicles from the cargo decks to the weather decks was an issue. In order to deploy and recover the ramp over the bow, an additional structure would be required on the bow. This would result in more weight both forward and high on the ship, and detract from the ship's optical and radar cross section.

An inflatable ramp appeared to be an attractive option and received more analysis. This concept would use high pressure air from the gas turbine engines to unroll and deploy the ramp. The deck structure would be slatted to allow the ramp to be rolled when deflated and stored inside the ship. The high pressure air would both inflate and unroll the ramp to the deployed position. This design had the potential to be much lighter in weight compared to the fixed ramp and would allow for the vehicles to offload from the lower cargo deck.

The inflatable ramp concept was rejected because of the many technical issues that were inherent to the design. A means to rapidly retrieve the ramp was difficult to develop, and the survivability of the ramp was questionable. Assuming the ramp would be constructed of a rubberized material capable of collapsing and rolling, it would be susceptible to puncture from underwater objects or hostile fire from the beach. A complicated bladder system internal to the ramp would be necessary to ensure adequate pressure throughout the ramp in the event of a puncture.

A floating ramp similar to the existing floating causeway used in the Naval Lighterage System was chosen to be the best alternative for the ship's bow ramp design. This design allows the ramp to be stored inside the hull of the ship, can be rapidly deployed and retrieved, and allows the vehicles to offload from the lower cargo deck. Table 4 compares the specifications of the NL floating causeway to the bow ramp designed for the ship.

Table 4. Bow Ramp Specifications

	NL Floating Causeway	HSAC Bow Ramp
Structure	Steel	Steel and Aluminum
Length	27.4 m	35.0 m (effective)
Beam	6.1 m	5.0 m
Depth	1.7 m	1.7 m
Displacement	62.5 LT	41.9 LT
Capacity	80.4 LT	124.2 LT

A capacity of 124.2 LT permits the bow ramp to hold up to two M1A2 tanks at one time. Since a typical ship load-out will typically consist of two or less M1A2 tanks, this constraint will not have a negative impact on the cargo off-load rate. At full load, the bow ramp will have a draft of 0.94 meters, leaving 0.76 meters of freeboard.

Bow ramp stability calculations were not conducted for this iteration of the ship design process. When deployed, the ramp will be connected to the ship and will also make contact with the bottom near the beach. Since these two supporting forces will be acting on the ramp in addition to the buoyancy force acting over the length of the ramp, stability in a variety of loading conditions should be acceptable. As such, the design team left these calculations to be completed in a later iteration of the design.

The ideal storage location for the ramp was found to be just below the lower cargo deck. Since the ship will likely add ballast astern when beaching, the ramp will need to drop a short distance from its storage level to the waterline once deployed. This presents a problem for recovering the ramp if it needs to be lifted out of the water while being retrieved.

In order to allow the ramp to move in and out of the ship and negotiate the change in height, the ramp is split up into eight five meters long sections. A flexible coupling system, similar to that found in the NL floating causeway, permits the ramp sections to bend as necessary to move in and out of the ship. Future developments with the Improved Naval Lighterage System (INLS) will further enhance the coupling system, allowing sections to be remotely detached by a pneumatic actuating system. (REF[4]).

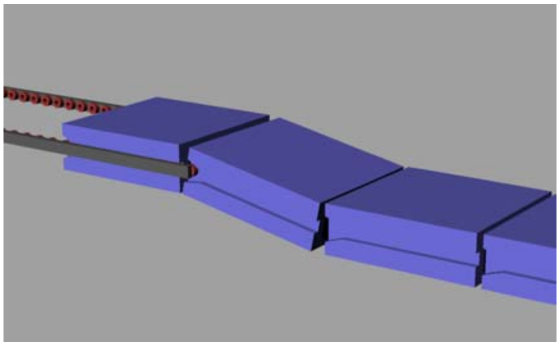
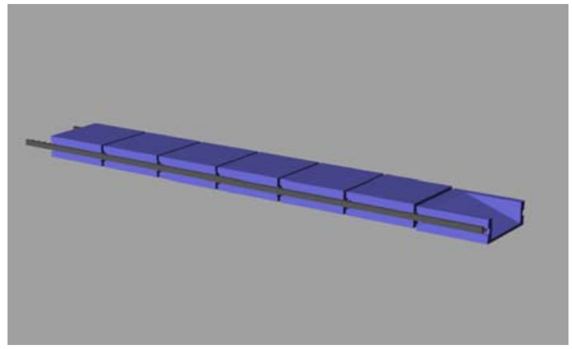



Figure 18. Bow Ramp Track with Rollers (seven of eight sections shown)

The ramp will be stored on a track just under the lower cargo deck. The track will have a series of rollers and each section of the ramp will have a grooved track embedded within the structure. One end of the ramp section groove flares open to a wider opening, allowing that section to make the height transition while being retrieved and deployed. Figure 18 illustrates how the roller track inside the ship interfaces with the grooved track on each ramp section.

The first ramp section, the end which will touch the beach, is sloped so that the vehicles can negotiate the transition from the ramp to the beach. More importantly, it allows easier access for the vehicles to drive from the beach back on to the ramp when conducting loading operations at the beach.

An electric motor will be dedicated to the task of deploying and retrieving the bow ramp. It will drive the ramp out by pushing on a rigid connection with the last section of the ramp. The last section, or section number eight, will not leave the ship when the ramp is fully deployed. This section will have a mechanical stop to prevent it from leaving the ramp track, and will provide the rigid connection for the ramp to the ship and act as part of the transition from the lower cargo deck to the floating ramp. For retrieval, the rigid connection to the eighth section will pull the ramp back into the track. The motor and connection system is estimated to deploy and retrieve the ramp at a rate of 0.22 meters per second, resulting in a deployment and retrieval time under three minutes.

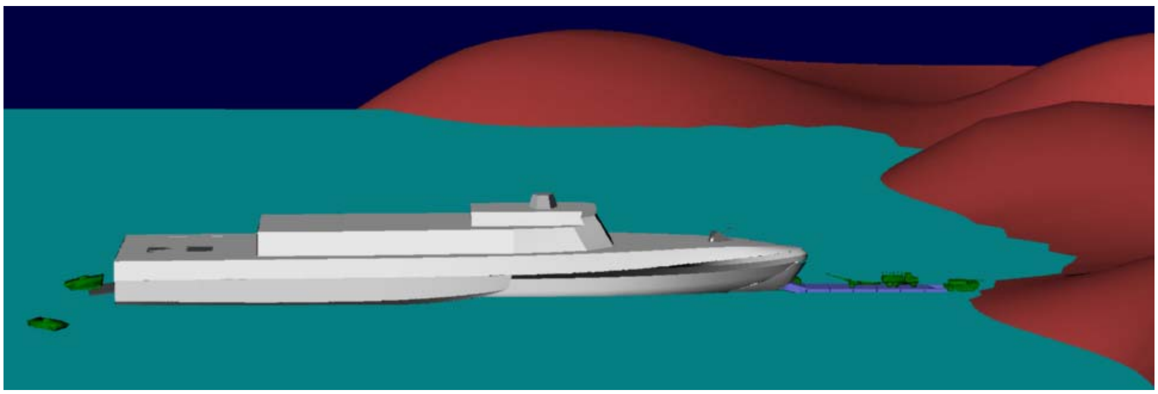


Figure 19. Operations at the Beach

7. Bow Doors

The floating bow ramp design required a method to allow quick, reliable, and efficient ramp deployment and recovery, while at the same time providing a clear vehicle path from the lower cargo deck to the ramp. Deployment and recovery rates of the vehicles and ramp would be maximized if both could utilize the same path. This would reduce the total number of interfaces involved, reduce the number of points of failure, and provide a straight path from the ship to the beach. Therefore, it was determined that bow doors needed to be designed.

Though no current displacement craft in the U.S. Navy inventory has bow doors, pre-Newport class LSTs and current operational commercial ferries have implemented bow doors, proving their feasibility and functionality. The Newport class LST moved away from bow doors to allow for a fine bow, in order to achieve its design requirement of 20+ knots. The trimaran hull form also has a fine bow, making the design of bow doors a challenge. However, today's structural and material technology makes large bow door development possible.

Placing doors in the bow, where the ship experiences extreme forces due to ship speed and the overall sea state, causes concern for water intrusion into the ship. Current commercial ferries have addressed this problem in their design by developing watertight doors that are located directly aft of the bow doors. This technology will maintain the watertight integrity of the HSAC while transiting at high speeds and in high sea states.

Having decided that bow doors were feasible, the next step was to determine what type of bow opening to implement. Regardless of the implementation chosen, the bow opening would need to be large enough for both the vehicles and ramp to pass through. The first approach considered was a single piece door that was hinged on one side of the hull and latched on the other side. The concept was that the door would swing open to one side as one unit. However, even if the door itself was manufactured from composites, it would place an extreme load on the door hinge. Handling this intense load would require a massive amount of structure, adding weight to the bow and reducing the available space for the door opening. In addition, the single door must travel through a large range of motion before the ramp and vehicles can exit the ship. This large range of motion increases the amount of time between the ship beaching and the first vehicle hitting the beach, which is undesirable in a hostile environment. These three issues were unacceptable to the design and therefore the single swing out door was rejected.

The design team then considered the possibility of having two bow doors that would swing outward from the ship. This solution greatly reduced the amount of stress and weight the hinges would have to encounter. It also reduced the range of motion required for the doors since they would open outward from the centerline. However, the bow of the trimaran hull had extreme curves making hinge design extremely difficult. Though an elaborate hinge could be developed to facilitate dual bow doors, its complexity could make it prone to failure. Due to the technical risk of hinge development, the dual outward swinging bow doors were eliminated as a design alternative.

Next the design team looked at developing a bow that would flip open similar to how the nose of a C-5 Galaxy transport aircraft opens, as Figure 20 illustrates. This design was attractive in that the only hinge required would be along the flat weather deck. The portion of the bow that would open could be made of composites or aluminum reducing the amount of weight that needed to be lifted. Hydraulic rams would then be used to lift the bow up, allowing the ramp and vehicles to exit the ship. Since the hinge would be a simple design and hydraulic rams are a proven technology, this solution would be highly reliable. In addition, this solution reduced the number of door seals required. With the bow swinging up there would be only one seal required horizontally along the lower edge of the door and two (one on each side) seals going vertically up the hull where the bow section met the hull. This design was deemed more feasible and more functional than the previous two design alternatives and therefore considered a possible alternative.

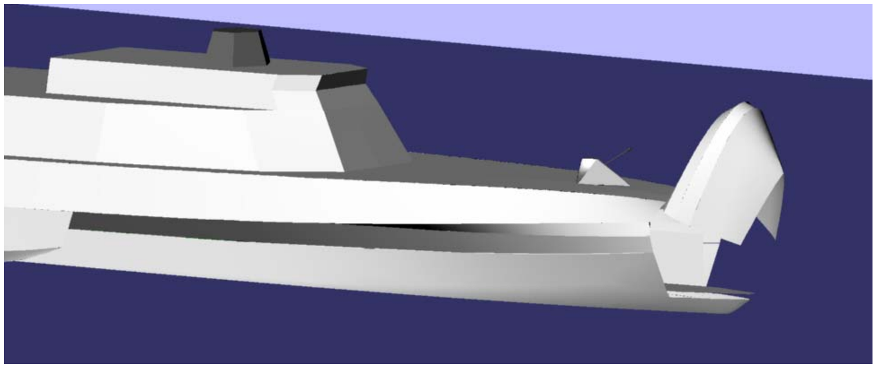


Figure 20. C-5 Style Bow Door

Though extremely functional from a cargo access and ramp deployment perspective, the C-5 style bow door option did not work well with the amphibious support requirements. With a desire to have main gun mounted on the bow, having the bow door flip up severely limited the firing arcs of the main gun when the door was open. The purpose of the main gun was to provide suppressive and cover fire for the troops and vehicles as they left the ship and hit the beach. Since this style door opening prevents the main gun from performing as required, another bow door alternative needed to be developed.

The design team then reexamined the dual outward swinging bow door design. Instead of having the doors hinged and swinging outward, the doors were mounted on hydraulic actuators and pushed directly outward. The hydraulic actuators solved the hinge problem by eliminating the hinges completely. Thus, the doors could be sized just large enough to facilitate a 5m wide and 6.2m high opening for vehicle passage and ramp deployment. By using hydraulic actuators, the range of motion for the doors was reduced as the rear part of the door had to move outward less than the forward portion of the door. The doors would be constructed of composite materials for reduced weight and higher strength. Figure 21 depicts how the hydraulically actuated bow doors would function.

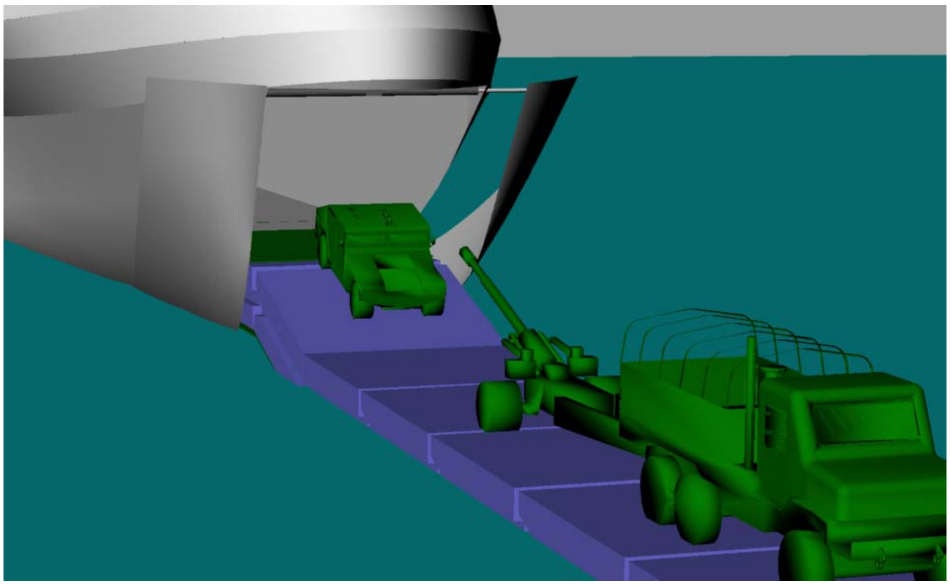


Figure 21. Hydraulically Actuated Bow Doors

The hydraulically actuated bow doors proved the most functional and feasible design solution for the HSAC design. In addition to implementing this bow door setup, the design team placed an armored watertight door aft of the bow doors. The addition of the watertight door not only added watertight integrity to the ship, but the armor plating provided crew and cargo protection during bow door opening and ramp deployment.

8. Flight Deck and Flight Elevator Design

The HSAC needed to be able to facilitate the launch and recovery of the various rotary winged aircraft of the 2025 JEB. Of particular interest were the CH-53X, MV-22, and SH-60R due to their logistics role with the Sea Base. Having an overall length of 30.3m and a maximum width of

25m (with rotors spinning), the CH-53X presents the largest deck area requirement. The flight deck was then designed to be 30.2m long and 27.89m wide, allowing the CH-53X to land with minimal amount of fuselage overhanging the hull. Forward of the flight deck a single hangar was installed, capable of storing one SH-60R. The hangar was deemed necessary to increase mission flexibility and provide for secondary mission support. Since embarking one SH-60R met the primary mission requirements and due to limited available space, one hangar bay was sufficient.

To allow for vertical delivery and transfer of cargo and vehicles, a flight deck elevator was designed to facilitate cargo movement between the flight deck and main cargo deck. The elevator is 5m wide, 14m long, and placed directly above the aft cargo ramp as Figure 22 illustrates.

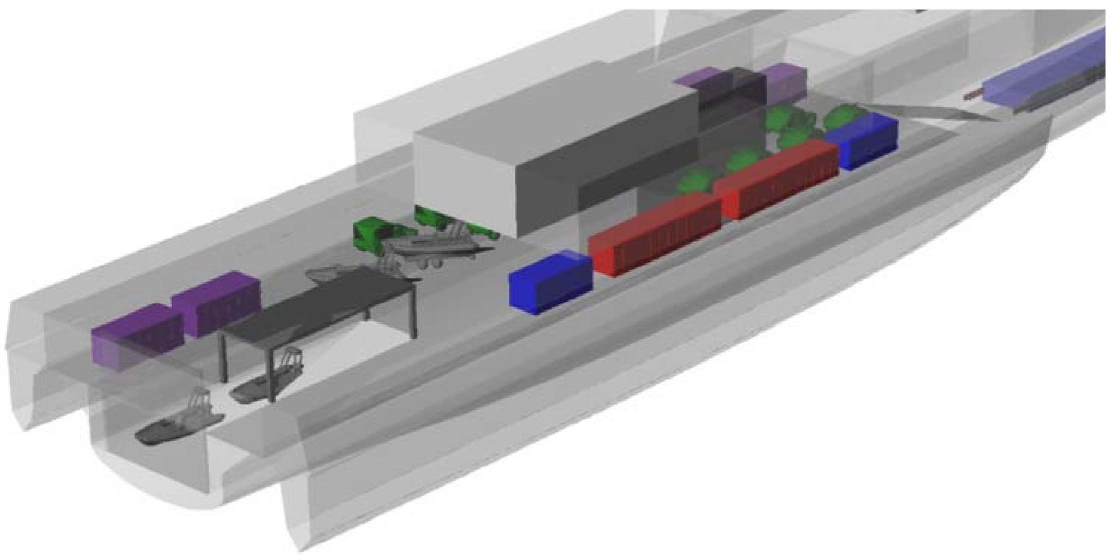


Figure 22. Flight Deck Elevator and Helicopter Hangar

This location was chosen to facilitate the implementation of the elevator without occupying any additional cargo area. The elevator is large enough to handle any vehicle from a BLT. It can also raise and lower a folded SH-60R allowing the main cargo deck to be used as a large hangar for additional SH-60R helicopters when the BLT is not embarked.

9. References

1. Naval Postgraduate School Technical Report, "Seabasing and Joint Expeditionary Logistics", By Systems Engineering and Analysis Cohort 6 (SEA-6). Montery, CA. December 2004

2. PDF file saved in the following TSSE shared drive location \\Kiska\TSSE\2004\Background\Reading\HSC-JLOTS titled LIMITED OBJECTIVE EXPERIMENT 2-04: JOINT LOGISTICS OVER THE SHORE

3. Phone call with Jeff Green, Mechanical Engineer, Naval Surface Warfare Center, Carderock Division

4. Phone call with Lawrence Mendlow, Technical Director, Sealift Support Program Office, Naval Facilities Engineering Command

B. HULL DESIGN

1. Design Process

In order to design the best ship, from a system of systems perspective, requires the right balance among a large number of different systems. Each system is able to perform efficiently in accordance with a given set of requirements in the systems.

A major problem during the ship's design process was the multiple conflicting interests that changed the ship's design in numerous ways. When each sub-team, would change a specific part of the ship's system of systems, those changes would influence the entire ship's system. This made a dramatic change in the performance of that system as a whole. When designing a conventional ship, such as monohull merchant ship intended for container transportation, there is a lot of available information and theoretical studies. But by changing one aspect of the ships system the entire ship responds differently.

When designing a ship, intended for new concepts of system, without previous experience or background, it opens an environment with plenty of uncertainty in the ship as a system. This increases the difficulty in starting the proper design during the early stages of the process causing new problems, new conflicts and new constraints will emerge causing delays in the design process which needs to be reviewed and analyzed for further changes. Many studies where performed in this design in order to narrow the number of alternatives and focus the final product for a well balanced system of systems.

After the Analysis of Alternatives a trimaran hull was selected as the best platform. There is a growing interest in trimaran hulls for multiple purposes, a great number of preliminary designs and studies can be found in the literature, but very few of them are already in operation. Because of this, any preliminary calculations, such as hull and structure weight can’t be done based on previous designs and the risk of resulting in an unfeasible ship is higher than normal.

Realizing that refinements would be necessary should towing tank data be made available and the weight and position of all equipment is known precisely, a preliminary hull design was done in order to produce working estimates and show possible conflicting areas.

The goals of this preliminary design were:

- Produce a feasible design that can be reasonably built with short or mid term technology.
- Analyze the space available for cargo.
- Analyze the different ways that cargo can be transferred to shore.
- Conduct a preliminary structure analysis to determine the expected hull weight and possible interferences with cargo movement on board.
- Determine if enough space is available for engines and other machinery.
- Study different types of propulsors.

The ship also must be able to operate in shallow waters, getting as close as possible to the beach in order to unload the cargo and at the same time possess enough speed, range, seakeeping and maneuverability qualities to operate in open waters.

A recently trimaran built by Austal Shipyards, the "Benchijigua Express" owned by Fred Olsen Lines and intended for cargo and passenger traffic, represents one of the most advanced trimaran already built. Based on her main particulars a trimaran hull was drawn. This served as the "parent" hull for our dsign.

2. Type

During the past several years the subject of high speed sea transportation, for both civil and military purposes, has experienced important developments. Aviation based gas turbines, fast diesel engines, water jets and other emerging technologies applied to ship design can lead to speeds at sea without precedents.

In order to take advantage of these power plants, naval architects are exploring new hull configurations other than traditional monohulls. Although a great variety of hull configurations can be used for fast speed transportation, some of them are still conceptual designs and others have been successfully used.

In order to determine the optimal hull configuration, several hull types were evaluated:

- Hydrofoil
- HYSWAS
- SES
- Semi-Planning
- Monohull
- Catamaran
- Trimaran
- SWATH

The analysis was done using the Maritime Applied Physics Corporation's spreadsheet collection (MPAC). This tool uses primary basis vessels for each type of hull to provide the block coefficients and ratios L/B and B/T.

The inputs were desired speed, range, payload, sea state, and maximum displacement. Speed loss due to sea state was considered for the alternatives. A detailed study of the different alternatives and MPAC's result can be find in Chapter III.

The goal of this Analysis of Alternatives was to identify the optimal hull configuration and narrow the number of hull alternatives to a manageable level for the available time to conduct the present study.

Hull types such as SWATH and Hydrofoils were initially rejected because of excessive draft for a ship that is intended for shallow waters. Planning hulls were also rejected due to excessive vertical accelerations when planning, which were considered too high for heavy weight transportation and also due to highly demanding structural reinforcements.

Candidate hull types, which can be built using short and mid term technology and with a relatively low technological risk, were monohulls, catamarans, trimarans and Surface Effect Ships (SES). Each one of them presents clear advantages and disadvantages. The following sections present some of the advantages and disadvantages of these candidate hull types:

a. Monohull

A monohull is the traditional type of hull and there is large experience designing, building and operating them. This type of vessel, due to the amount of available information and experience, is the less risky option. It requires less development effort and, therefore, is one of the cheapest alternatives. Research and development expenses, that will increase the overall cost of the project, are estimated as low for this kind of hulls.

Having large hull volume, monohulls offer great flexibility when designing cargo spaces, engine rooms and accommodation. Due to their large water plane area, and consequently their relative tolerance to loading changes, they can be operated with a variable deadweight. Therefore, they provide the biggest growth margin for future requirements. Monohulls also provide satisfactory seakeeping, when sailing in open waters, and adequate maneuverability when getting close to shore. Most amphibious ships are monohulls and their operation is satisfactory for most of the world navies.

Figure 23. Newport Class LST (www.fas.org)

At ordinary cruise speeds a monohull becomes a very attractive option and is worldwide accepted as an excellent cargo platform. However, when the speed increases, the power plant becomes excessively large and so does fuel consumption.

Another important handicap arises when placing heavy load in upper decks, namely the lack of adequate stability. The HSSC is intended for different scenarios and will have a large number of different cargo configurations. Flexibility is a very important goal to achieve in this application. Stability is also a major concern when considering helicopter operations. Several of these aspects can be improved using a multihull platform.

b. Trimaran

Although few trimarans have been built recently, there are enough conceptual studies that have been centered on a trimaran hull configuration.

Figure 24. Triton Research Vessel (www.globalsecurity.org)

Some of the relevant characteristics can be summarized as follows:

- **Hull Resistance:** A slender center hull with large L/B ratio offers reduced hull resistance compared to an equivalent monohull, especially at high speeds. Although the outrigger hulls increase the overall ship resistance, this is compensated by the savings in center hull resistance. Therefore, a smaller power plant is required and the resulting fuel savings can be important. Less fuel means that more cargo can be transported at faster speeds than a similar and comparable monohull.
- **Seakeeping and Stability:** A trimaran's outrigger hulls provide improved transverse stability which means that heavy weights can be transported in the upper decks with minimal stability degradation. Trimarans are able to operate in higher sea states compared to other hulls configurations, especially when compared to catamarans, which can exhibit a "corkscrew" motion. The HSSC is intended to transport troop ready-to-fight and their comfort is an important concern. Secondary missions for HSSC such as medical and humanitarian evacuation also require superior seakeeping.
- **Deck Area:** Trimarans have about 40% more deck area for a given tonnage than monohulls and this fraction can be increased with increasing side hull separation, although the latter may result in resistance and seakeeping compromise. This extra deck area offers great flexibility for accommodation purposes. Furthermore, it offers more space for helicopter operations and cargo arrangement. Side hulls separation is not a free variable and has some negative effects, requiring more structural weight and may result in increased resistance due to wave interference. The 2003 TSSE project offers a very detailed study of both resistance and seakeeping characteristics of trimaran hulls similar in size to the one considered in this work. Most of the results obtained from the 2003 study have been incorporated in this study as well.

c. Catamaran

Catamarans are a popular option for passenger transportation and many of them have been built and are in operation during the past several years. Since a catamaran is a multihull, it exhibits many of the same advantages as trimarans, namely large deck area and improved stability. On the other hand, they have reduced waterline area, limiting the range of cargo conditions that can be used, and a "corkscrew" motion in certain sea states and sea directions that can cause seasickness for unaccustomed crew and passengers.

Figure 25. Buque Bus (www.shiptechnolgy.com)

Crew comfort and embarked personnel combat readiness is an important issue for the Sea Connector, and the associated inability of catamarans to operate at high sea states significantly handicaps this hull type's applicability in this problem. Finally, when we conducted a preliminary study of existing catamarans, we saw that their cargo capacity is far away of what HSSC is expected to transport. Although cargo capacity will increase in the future, there is an associated technical risk that should be taken into consideration.

d. SES

Surface Effect Ships were initially conceived for naval ship applications early in the 70's. A SES greatly minimizes the wetted surface by forcing air down between the two hulls and resulting in a low resistance. A SES also offers very low draft, which is an important advantage when trying to reach degraded beaches. In this aspect such ships would exhibit the largest usability.

Power requirements in order to move the lifting fans reduce dramatically their endurance and there are also limited operational capabilities up to sea state 3. These two issues became very negative aspects when the ship is intended to be operated form a distant base (sea base) located in open waters.

3. Selection

After the Analysis of Alternatives and the application of the MOP criteria, the trimaran hull configuration emerged as the preferred one. This result is in agreement with the preliminary analysis of the different types of hull discussed previously.

Trimarans are traditionally classified as multi-hulls in clear opposition to monohulls. However, in many aspects, their performance is closer to monohulls rather than catamarans and, some authors prefer the term Stabilized Slender Monohull.

As discussed above, their advantages and disadvantages can be summarized as follows:

Advantages:

- Reduced hull resistance at high speed.
- Improved stability.

- Large cargo spaces in upper decks.

Disadvantages:

- Reduced space in lower decks, especially for tanks and engines.
- Structural risk when grounding.
- Rapid stability degradation when a side hull is damaged.
- Reduced forward ramp width.

4. Dimensions

In order to get a feasible hull form with a relatively low risk, we based the parent ship on the recently launched "Benchijigua Express" as mentioned earlier. She is the largest trimaran currently in existence and represents the current state-of-the-art for such ships. Built by Austal Yards, it is intended for car and passenger transportation in the Canary Islands (Spain) and represents an excellent starting point to estimate near or mid term technology.

The 126.7 meter cargo-vehicle-passenger ferry "Benchijigua Express" is larger than any existing diesel-powered fast ferry – catamaran or monohull – and is the world's largest aluminum ship. Ordered in June 2003, the ferry will sail at loaded speeds in excess of 40 knots, providing capacity for 1350 passengers, over 350 cars or 450 trucks. The following figure presents a picture of the "Benchijigua Express".

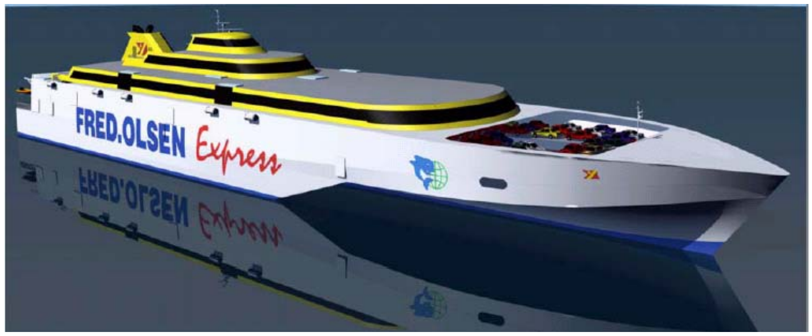


Figure 26. Benchijigua Express

In order to determine the main dimensions and ratios of our ship, other existing or conceptual trimarans, in addition to the one mentioned above, were studied. Our conclusions are summarized below:

5. Length/Beam Ratio (L/B)

Length/Beam ratios range between 8 and 18. Large L/B ratios have the clear advantage of reducing the wave component of the resistance requiring a smaller power plant to be moved, especially at high speed. But these ships require a careful study of the structural strength, and this concern becames more important when the ship is intended for heavy weights transportation and off-loading onto a beach.

In order to minimize such risk we selected the following range:

$$L/B \approx 11-14$$

6. Froude Number (Fn)

The terms high and low speed must be used in conjunction with the length of the ship. A 35kts carrier can be a slow ship and a 15kts boat a fast ship depending on the length. The non-dimensional Froude Number is defined as:

$$Fn = \frac{V}{\sqrt{gL}}$$

This is the relation between speed and length used to link both dimensions. When Fn<0.4 the ship is said to be in a displacement mode. Once Fn increases above 0.4 the ship reaches a semi-displacement mode and, for higher values, is said to be a planning hull. Although planning hulls require less power when the sail above Fn=0.4, extra power is necessary to initiate this regime.

We concluded that a planning hull was not desired for the purposes of this design because of the increase of vertical accelerations that will lead to higher structural requirements and rugged slashes. This will present difficulties during loading and off-loading and will increase the risk for cargo integrity. Therefore, speed and length were selected in order to keep the ship in a displacement regime.

$$Fn \approx 0.4 - 0.5$$

7. Cargo Ratio

As previously mentioned, the relative lack of adequate information for existing trimaran ships was a major concern. This resulted in some difficulty to estimate the weights and the amount of cargo that the ship would be able to transport.

From an analysis of existing ships, we concluded that about 35% of the total displacement could be used for cargo and consumables transport. In this way a 4900Ton vessel can carry 1700Ton of cargo and fuel, fresh water and other consumables.

Naturally these numbers would need to be verified and will depend on other factors such as double bottom height, placement of tanks under the deck, and cargo dimensions. Some light items will require more room than others.

8. Center Hull Form

Having determined a feasible range of main dimensions, ratios and proportion we analyzed different options to generate a hull form that matched the requirements for the ship.

The first step was to determine the midship section coefficient. Three alternatives were considered as discussed below:

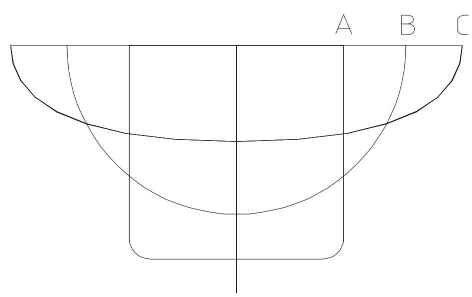


Figure 27. Center Hull Form Alternatives

a. Alternative A

This results in a deep hull with very low beam and squared bilges. This alternative provides the largest L/B ratio but also the largest draft (T). This configuration offers a very low wave-making resistance, due to large L/B ratio, but it is highly penalized because of the large draft. This was considered a negative aspect that would limit the ability of the ship to reach the beach.

A short beam reduces the available space under the deck to mount engines and will also present difficulties with regards to proper arrangement of ramps that allow cargo movement to upper decks and to shore.

b. Alternative C

This results in large values of beam and a minimum draft. It has a clear advantage when trying to reach the beach but by reducing the L/B ratio we lose the advantage of low resistance at high speeds. It is a more flexible option due to the large beam, which facilitates engine room arrangement and cargo movement, but it is highly penalized due to the increase in hull resistance.

C. Alternative B

This alternative is the one with intermediate values of beam and draft and it also offers the least wetted surface from all three. Although by increasing the L/B ratio there will be an important reduction of wave-making resistance, the reduced wetted surface will result in less viscous resistance.

For the above reasons, alternative B was preferred and was the selected one. It is also the candidate midship section for the car ferry developed by Nigel Gee and Associates for Norasia. A typical midship section is shown in the following figure.

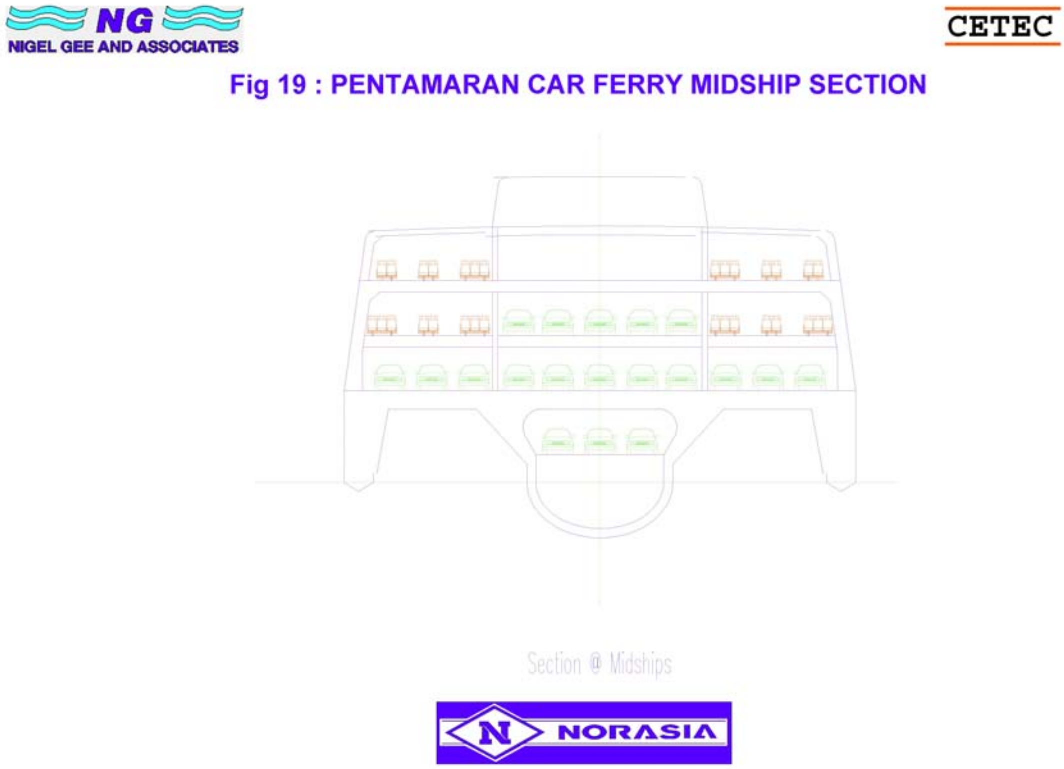


Figure 28. Typical Midship Section of Alternative B

9. Draft

Low draft is required to be able to reach the beach easily. By selecting a medium draft hull form we are penalizing the ability to carry out the ship's mission.

In order to reduce this problem we used a parabolic keel profile, reducing the draft forward. In addition, water ballast tanks are located forward, under the double bottom deck and, when empty, the ship will trim aft.

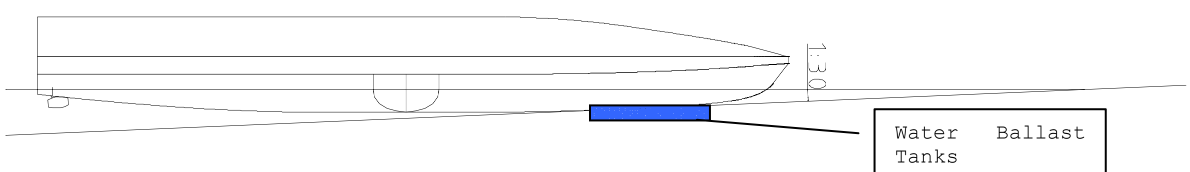


Figure 29. Parabolic Keel Profile

10. Side Hull Form

Side hull separation was selected in order to minimize the overall hull resistance, looking for positive interference between waves generated by center and side hulls. The TSSE 2003 Sea Swath project deeply analyzed this configuration and their results were used in this study. Based on their conclusions, the following length and dimensions were selected:

- Length Side Hull = 40% Length Center Hull
- Volume Side Hull = 5% Volume Center Hull

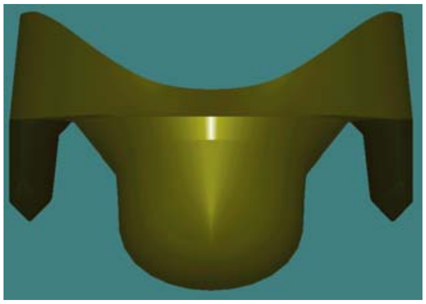
When the center hull is sailing at a Froude Number less than 0.4, in a displacement regime, the side hulls, due to its shortest length, are operating closer to a planning regime. Because of this peculiarity, the side hull form corresponds to a typical planning hull with a deep V shape.

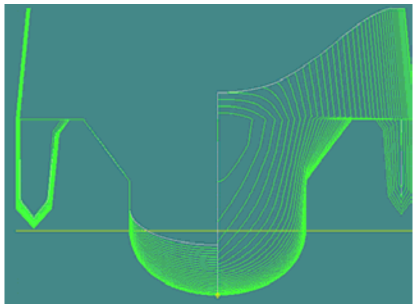
The hull was modeled as NURBS surface using the Autoship software. The following table and figure show the ship's main particulars and rendered shape.

Table 5. Ship Main Particulars

Main Particulars			
Displacement	Δ	4923	Ton
Volume	∇	4803	m^3
Draft to Baseline	T	4.500	m
Overall Length	LOA	149.000	m
Waterline Length	LWL	145.761	m
Molded Beam	B	30.000	m
Waterline Beam	BWL	13.158	m
Wetted Surface	WSA	2194.761	m^2
Max cross sect area		47.45	m^2

Waterplane area	WPA	1711.236	m^2
	Cp	0.731	
	Cb	0.586	
	Cm	0.801	
	Cwp	0.892	
	LCB from zero pt	70.225	m
	LCF from zero pt	66.905	m
	KB	2.763	m
	BMt	4.383	m
	BMl	503.215	m
	GMt	7.146	m
	GMl	505.978	m
	KMt	7.146	m
	KMl	505.978	m
	Immersion (TPc)	17.54	tonne/cm
	RM at 1deg = GMt.Disp.sin(1)	646.228	tonne.m





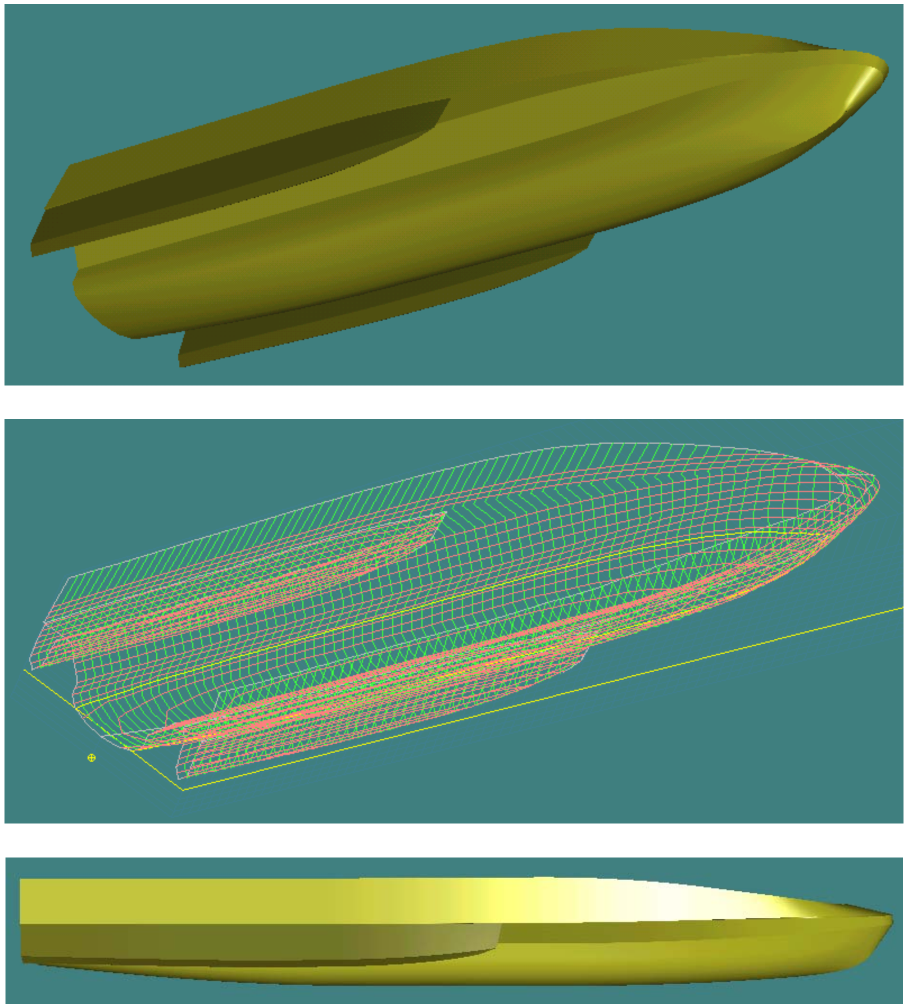


Figure 30. Rendered Hull Form

11. Resistance

Hull resistance was estimated extrapolating the information available from the 2003 TSSE Capstone Project “Sea Swath”, a ship with similar dimensions and ratios, following standard procedures.

	Sea Swath		HSSC	
Loa	124.30	1.200	149.16	m.
Lwl	121.80	1.200	146.16	m.
Lpp	121.80	1.200	146.16	m.
B	15.270	1.200	18.32	m.
Bwl	9.620	1.200	11.54	m.
T	0.145	1.200	0.17	m.
Tfp	0.135	1.200	0.16	m.
Tap	0.154	1.200	0.18	m.
D	4.382	1.200	5.26	m.
∇	2780	1.728	4803.8	m^3.
Δ	2850	1.728	4923.9	Ton.
Cp	0.671	1	0.671	
Cb	0.542	1	0.542	
Cm	0.807	1	0.807	
Lcb	3.456	1.200	4.147	m.
Lcb	2.837	1	2.837	%
S	1457	1.440	2098.1	m^2.
Lwl	48.72	1.200	58.46	m.
S	182.125	1.440	150.0	m^2.

	ν	1E-06
	ρ_{ad}	1.000
	ρ_{as}	1.025
	λ	1.200
Form Factor	k	0.1
Additive Correction	ΔCf	
	C_{AA}	0.000
	C_A	0.000

Towing Tank Test

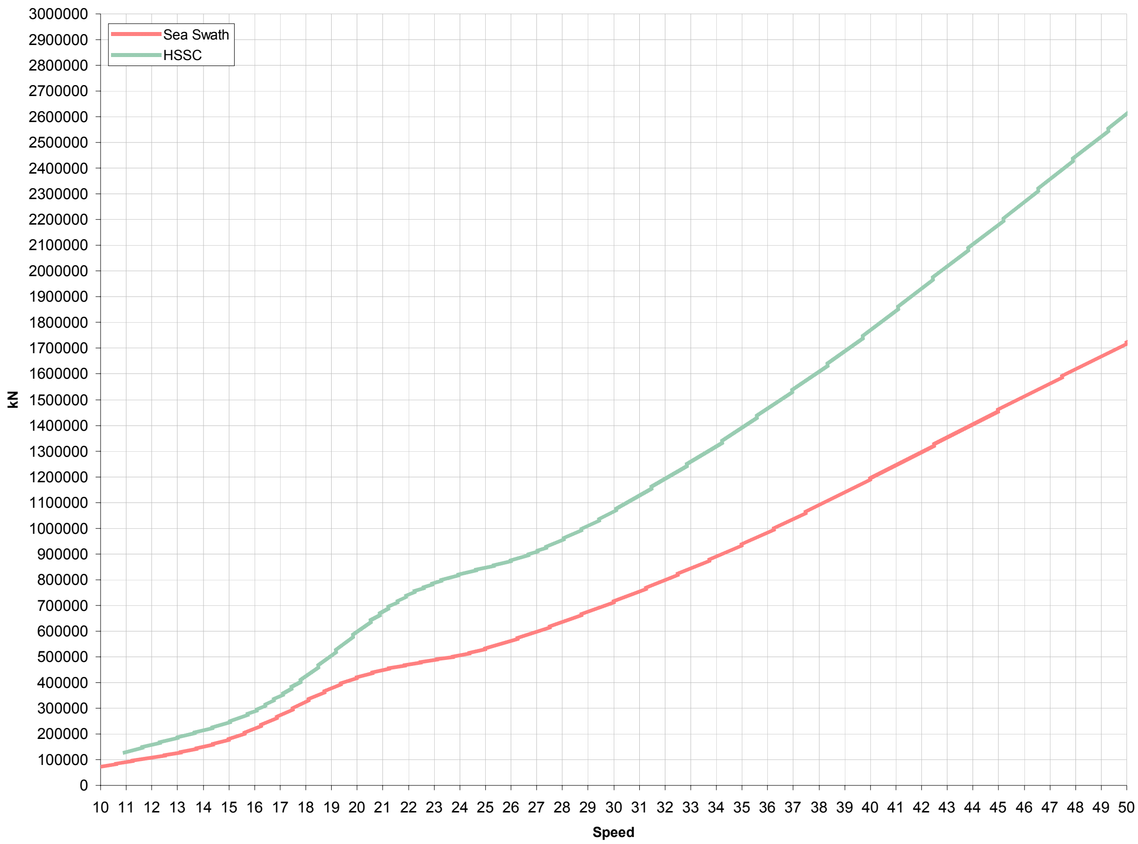
Vs		Vm	Fn	RNcm	RNsm	Rtm	Ctm	CFcm	CFsm	CVcm	CVsm	Caa	Crm
Kt		m/s		x10^-6	x10^-6	N	x10^3	x10^3	x10^3	x10^3	x10^4	x10^3	x10^3
10		5.144	0.149	545.8	218.3	71961	3.732	1.652		1.818	0.000	0.000	1.915
15		7.717	0.223	818.7	327.5	178400	4.112	1.569		1.726	0.000	0.000	2.386
20		10.289	0.298	1091.6	436.6	419625	5.441	1.514		1.666	0.000	0.000	3.776
25		12.861	0.372	1364.5	545.8	529373	4.393	1.473		1.621	0.000	0.000	2.773
30		15.433	0.446	1637.4	654.9	712729	4.107	1.441		1.585	0.000	0.000	2.522
35		18.006	0.521	1910.2	764.1	935636	3.962	1.415		1.556	0.000	0.000	2.405
40		20.578	0.595	2183.1	873.3	1192624	3.866	1.392		1.532	0.000	0.000	2.334
45		23.150	0.670	2456.0	982.4	1458076	3.735	1.373		1.511	0.000	0.000	2.224
50		25.722	0.744	2728.9	1091.6	1719120	3.567	1.356		1.492	0.000	0.000	2.075
55		28.294	0.819	3001.8	1200.7	1975317	3.387	1.341		1.476	0.000	0.000	1.911

Vs	Vs		Fn	RNcs	RNcs	Ctm	CFcs	CFss	CVcs	CVss	ΔCf	Ca	Caa	Crm	Rtcb	Rtsb	RT
Kt	m/s			x10^-9	x10^-9	x10^3	x10^3	x10^3	x10^3	x10^3	x10^3	x10^3	x10^3	x10^3	kN	kN	kN
11.0	5.635		0.149	0.717	0.287	3.670	1.596		1.755	0.000	0.000	0.000	0.000	1.915	125.3	0.0	125.3
16.4	8.453		0.223	1.076	0.430	4.055	1.517		1.668	0.000	0.000	0.000	0.000	2.386	311.5	0.0	311.5
21.9	11.271		0.298	1.435	0.574	5.386	1.464		1.611	0.000	0.000	0.000	0.000	3.776	735.8	0.0	735.8
27.4	14.089		0.372	1.794	0.717	4.341	1.425		1.568	0.000	0.000	0.000	0.000	2.773	926.4	0.0	926.4
32.9	16.906		0.446	2.152	0.861	4.057	1.395		1.534	0.000	0.000	0.000	0.000	2.522	1246.7	0.0	1246.7
38.3	19.724		0.521	2.511	1.004	3.912	1.370		1.507	0.000	0.000	0.000	0.000	2.405	1636.5	0.0	1636.5
43.8	22.542		0.595	2.870	1.148	3.818	1.348		1.483	0.000	0.000	0.000	0.000	2.334	2085.9	0.0	2085.9
49.3	25.360		0.670	3.229	1.291	3.687	1.330		1.463	0.000	0.000	0.000	0.000	2.224	2549.8	0.0	2549.8
54.8	28.177		0.744	3.587	1.435	3.520	1.314		1.445	0.000	0.000	0.000	0.000	2.075	3005.2	0.0	3005.2
60.2	30.995		0.819	3.946	1.578	3.341	1.300		1.430	0.000	0.000	0.000	0.000	1.911	3451.4	0.0	3451.4

Figure 31. Hull Resistance Calculations

The computed resistance curve for the ship shows a hump, at higher speed than the base ship. Because of this hump, the HSSC will avoid speeds between 22 and 24kts during transit.

Figure 32. Resistance Curve



12. Deck Layout

The depth of the ship is 14.000m. Three decks were installed with the following criteria:

Double Bottom is with a depth of 2.000m. Volume under this deck was calculated in order to estimate the tanks capacity and to ensure that this capacity is enough to provide the required endurance.

Lower Cargo Deck with a depth of 5.000m. In order to accommodate the gas turbine containers, double bottom at the engine rooms sections was lowered to 1.000m. Clearance between decks is enough to allow placement of the electric propulsion motors.

Upper Deck is with a depth of 9.500m. This is selected to give enough clearance to the highest vehicle intended to be transported.

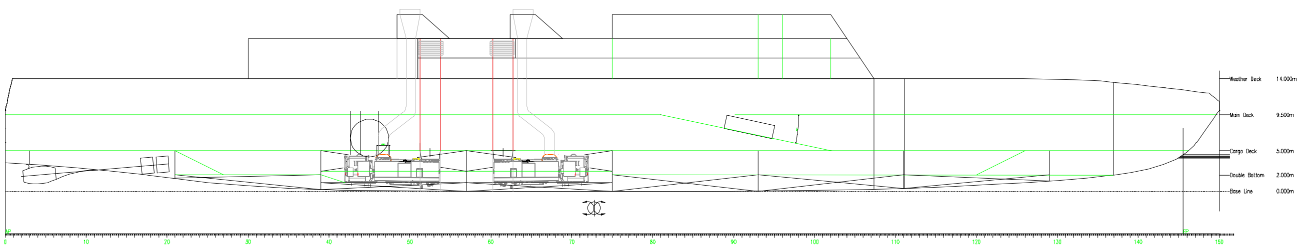


Figure 33. Deck Layout

13. Tankage

Most of the tanks were located below the double bottom decks, taking advantage of the rounded bottom selected to reduce resistance.

In addition, provisions were made to mount daily service tanks high in the engine rooms.

Forward double bottom tanks were dedicated for ballast in order to increase the aft trim when reaching the beach.

Fresh water tanks, with a full load capacity of 227tons were located between water ballast and fuel tanks, separated by a cofferdam to avoid contaminations.

Combustible tanks, with a total capacity of 820tons, located aft of the fresh water tanks provides enough endurance for 2000nm at 20kts. Aft tanks are dedicated to aircraft fuel in order to support the embarked helicopter.

14. Structure

a. First Estimate

A preliminary structural design was done to estimate the hull weight and to study the available space for cargo decks. Section Modulus and Moment of Inertia Calculations were performed based on the American Bureau of Shipping GUIDE FOR BUILDING AND CLASSING HIGH-SPEED NAVAL CRAFT.

The following items were included in the calculation of the section modulus and moment of inertia provided they are continuous or effectively developed within a span 0.4*L* from midships, have adequate buckling strength, and are gradually tapered beyond the midship 0.4*L.*

- Deck plating (strength deck and other effective decks)
- Shell and inner bottom plating
- Deck and bottom girders
- Plating and longitudinal stiffeners of longitudinal bulkheads
- All longitudinals of deck, sides, bottom, and inner bottom

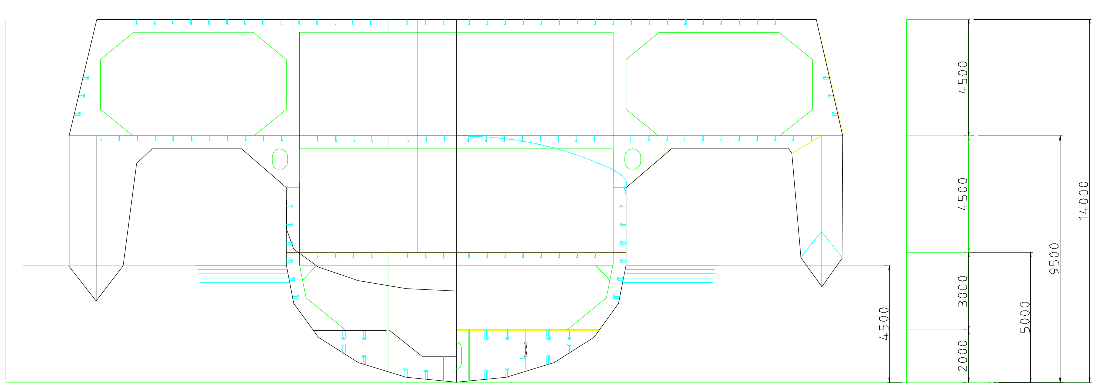


Figure 34. Depiction of First Estimation

ITEM	Element Type	Number n	Thickness t (cm)	Height h or r (cm)	Long. Area A (cm^2)	Area A (cm^2)	Total Area A_T (cm^2)	C.G. dn (m)	Moment A*dn (cm^2m)	2nd Moment A*dn2 (cm^2m^2)
Strength Deck Plating	Rectangular	1	1.40	545		763.00	763.00	9.00	6867.00	61803.00
Strength Deck Stringer Plate	Rectangular	1	1.60	130		208.00	208.00	9.00	1872.00	16848.00
Strength Deck Longitudinals	W 160x14; F40x14	10			0.00000084	0.00000084	0.0000084	8.90	0.000075	0.000665
Sheer Strake	Rectangular	1	1.60	80		128.00	128.00	10.50	1344.00	14112.00
Side Plating	Rectangular	1	1.40	630		882.00	882.00	6.95	6129.90	42602.81
2nd Deck Plating	Rectangular	1	1.40	675		945.00	945.00	5.00	4725.00	23625.00
Bilge (Curved Portion)	Circle	1	1.40	190		417.83	417.83	1.09	457.28	500.44
Inner Bottom Plating	Rectangular	1	1.40	545		763.00	763.00	2.00	1526.00	3052.00
Inner Bottom Margin Plate	Rectangular	1	1.60	130		208.00	208.00	2.00	416.00	832.00
Inner Bottom Longitudinals	W 200x10;F66x15	10			0.0000015	0.0000015	0.000015	1.72	0.000026	0.000044
Side Girders	Rectangular	2	1.20	200		240.00	480.00	1.00	480.00	480.00
Center Girder (1/2)	Rectangular	1	0.60	200		120.00	120.00	1.00	120.00	120.00
Bottom Plating	Rectangular	1	1.40	485		679.00	679.00	0.00	0.00	0.00
Bottom Longitudinals	W 200x10;F66x15	10			0.0000015	0.0000015	0.000015	0.28	0.000004	0.000001
Upper Hatch Side Girder		1								
Lower Hatch Side Girder		1								
							5593.83		23937.18	163975.25

Section Modulus Calculation

A=	11187.66
D_q =	4.28
I_n=	334199.20
I_o=	129334.86
c_{top}=	4.72
(Section Modulus) Z_{top}=	27396.86
c_{bottom}=	4.28
(Section Modulus) Z_{bottom}=	30224.01

Maximum Stress Calculation For Hogging Situation

(at 64.0 m forward) For hogging M_{max}=	10042
(Max) Tensile Stress in the deck=	35.95
(Max) Compressive Stress in the bottom plating=	32.58

Weight Estimations For Middle Section

FOR STEEL

Specific Weight =	77000
(Cross Section Area) A=	1.12
Approximate Weight of Hull Per Length =	8.7843
Length of Our Ship =	147.00
Approximate Weight =	1291.2989

FOR ALUMINUM ALLOY

Specific Weight =	27000
Approximate Weight of Hull Per Length =	3.0802
Approximate Weight =	452.7931

Figure 35. First Estimate Calculations

b. Detailed Calculations

After the preliminary estimates for structural design shown above, a more detail spreadsheet calculation was performed to determine the hull weight and to study the available space for cargo decks. In order to get such detailed structural design data, longitudinal stiffeners were detailed and selected with sufficient cross section areas and inertias. Dimensions were selected according to the distances between decks. Both steel and aluminum were evaluated for structural weight, and steel was selected for the design. The following figure presents a sample of the calculations:

SEA CONNECTOR
Midship Section and Longitudinal Structure Weight Calculation

ITEM	Element Type	Number n	Thickness t (cm)	Width h or r (cm)	Long. Area A (cm^2)	Area A (cm^2)	Total Area A_T (cm^2)	C.G. dn (m)	Moment A*dn (cm^2m)	2nd Moment A*dn2 (cm^2m^2)	Local 2nd Moment Io (cm^2m^2)
Main Deck Plating	Rectangular	1	1.00	1075		1075.00	1075.00	9.00	9675.00	87075.00	0.009
2nd Deck Plating	Rectangular	1	1.00	675		675.00	675.00	5.00	3375.00	16875.00	0.006
Inner Bottom Plating	Rectangular	1	1.20	675		810.00	810.00	2.00	1620.00	3240.00	0.010
Bottom Plating	Rectangular	1	1.70	475		807.50	807.50	0.00	0.00	0.00	0.019
Main Side Shell Plate	Rectangular	1	1.10	566		622.60	622.60	7.00	4358.20	30507.40	830.133
Lower Side Shell Plate	Rectangular	1	1.30	300		390.00	390.00	3.50	1365.00	4777.50	292.500
Bilge Shell Plate	Circle	1	1.40	190		417.83	417.83	1.09	457.28	500.44	105.284
Side Girders	Rectangular	2	1.20	200		240.00	480.00	1.00	480.00	480.00	160.000
Center Girder (1/2)	Rectangular	1	0.60	200		120.00	120.00	1.00	120.00	120.00	40.000
Main Deck Tripping Brackets	ST 8 WF (29 lb/ft)	3			54.97		164.90	8.84	1457.74	12886.44	0.166
2nd Tripping Brackets	ST 8 WF (29 lb/ft)	3			54.97		164.90	4.84	798.13	3862.95	0.166
Main Side Tripping Bracket	ST 8 WF (29 lb/ft)	1			54.97		54.97	7.40	406.76	3010.03	0.055
Main Side Tripping Bracket	ST 8 WF (29 lb/ft)	1			54.97		54.97	6.20	340.80	2112.96	0.055
Lower Side Tripping Bracket	ST 8 WF (29 lb/ft)	1			54.97		54.97	4.00	219.87	879.48	0.135
Lower Side Tripping Bracket	ST 8 WF (29 lb/ft)	1			54.97		54.97	3.00	164.90	494.71	0.135
Main Deck Longitudinals	L 5x3x(3/8) (in) (9.8 lb/ft)	10			18.45		184.52	8.91	1644.04	14648.36	0.128
2nd Deck Longitudinals	L 5x3x(3/8) (in) (9.8 lb/ft)	6			18.45		110.71	4.91	543.58	2668.99	0.077
Inner Bottom Longitudinals	L 5x3x(3/8) (in) (9.8 lb/ft)	8			18.45		147.61	1.91	281.94	538.51	0.103
Bottom Longitudinals	L 5x3x(3/8) (in) (9.8 lb/ft)	5			18.45		92.26	0.08	7.66	0.64	0.064
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	8.60	137.60	1183.36	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	8.20	131.20	1075.84	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	7.80	124.80	973.44	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	7.00	112.00	784.00	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	6.60	105.60	696.96	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	5.80	92.80	538.24	0.006
Main Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	5.40	86.40	466.56	0.006
Lower Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	4.52	72.32	326.89	0.004
Lower Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	3.52	56.32	198.25	0.004
Lower Side Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	2.52	40.32	101.61	0.004
Bilge Shell Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	1.67	26.72	44.62	0.004
Bilge Shell Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	1.34	21.44	28.73	0.004
Bilge Shell Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	1.01	16.16	16.32	0.004
Bilge Shell Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	0.68	10.88	7.40	0.004
Bilge Shell Longitudinals	L 4x3x(3/8) (in) (8.5 lb/ft)	1			16.00		16.00	0.35	5.60	1.96	0.004
							6722.70		28356.05	191122.55	1429.117

Section Modulus Calculation

A= 13445.41 cm^2
D_g = 4.22 m
I_n= 385103.34 cm^2m^2
I_o= 145894.27 cm^2m^2
c_{top}= 4.78 m
(Section Modulus) Z_{top}= 30508.75 cm^2m
c_{bottom}= 4.22 m
(Section Modulus) Z_{bottom}= 34588.87 cm^2m

Maximum Stress Calculation For Hogging Situation

(at 64.0 m forward) For hogging M_{max}= 10042.00 MT-m
(Max) Tensile Stress in the deck= 32.28 MPA
(Max) Compressive Stress in the bottom plating= 28.47 MPA

Weight Estimations For Longitudinal Structure

FOR STEEL

Specific Weight = 77000 N/m^3
(Cross Section Area) A= 1.34 m^2
Weight of Hull (Longitudinal) Per Length = 10.5571 MT/m
Length of Our Ship = 147.00 m
Approximate Weight = 1551.89 MT

FOR ALUMINUM ALLOY

Specific Weight = 27000 N/m^3
Weight of Hull (Longitudinal) Per Length = 3.7018 MT/m
Approximate Weight = 544.17 MT

Figure 36. Detailed Calculations

c. *Structural Weight*

Both steel and aluminum were compared to get the structural weight. Steel was finally selected for the final design. Total structural weight of the trimaran including longitudinal and transverse framing was calculated by using an Excel spreadsheet. The main results are shown below:

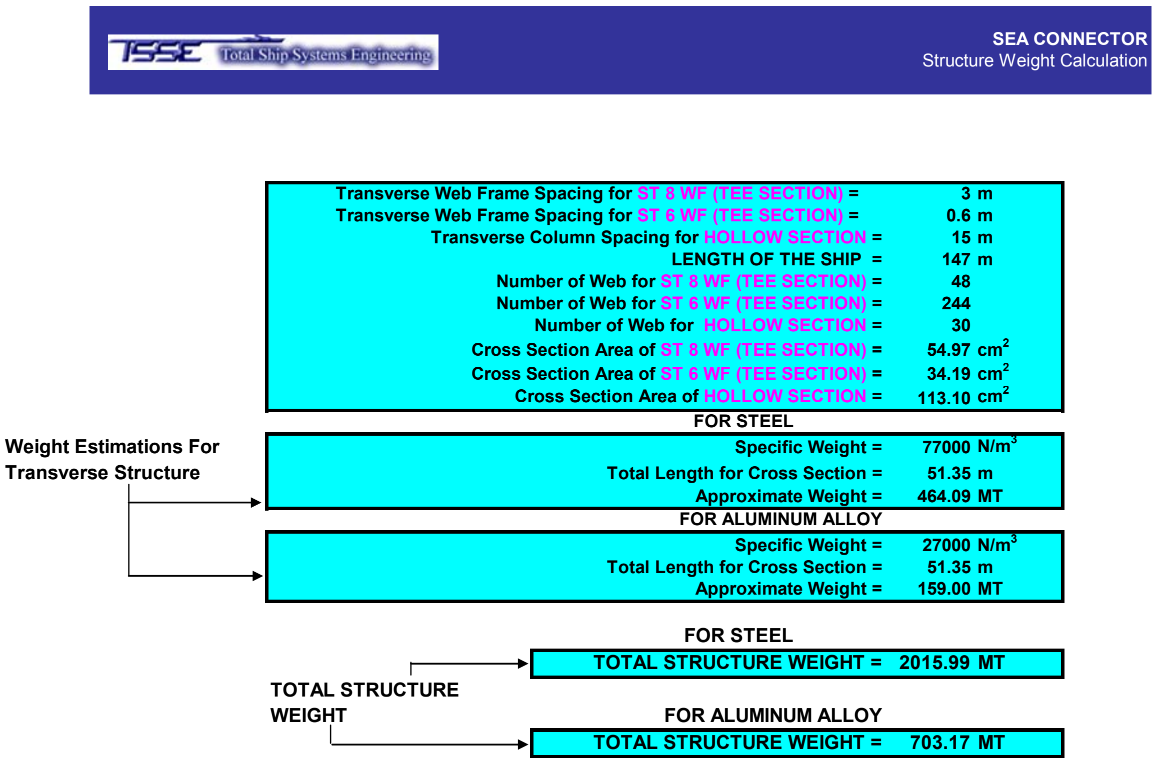


Figure 37. Structural Weight Calculations

d. *Longitudinal Strength*

The midship section modulus was used along with an estimate of the maximum bending moment in order to determine the strength of the main deck and keel.

In order to provide enough longitudinal resistance, steel was selected for the hull.

Table 6. Longitudinal Strength Data

Max. Shear	**263.12 MT**	**At**	**21.000f**		
Max. Bending Moment	**10042 MT-m**	**at**	**64.000f**	**(Hogging)**	

Longitudinal Strength

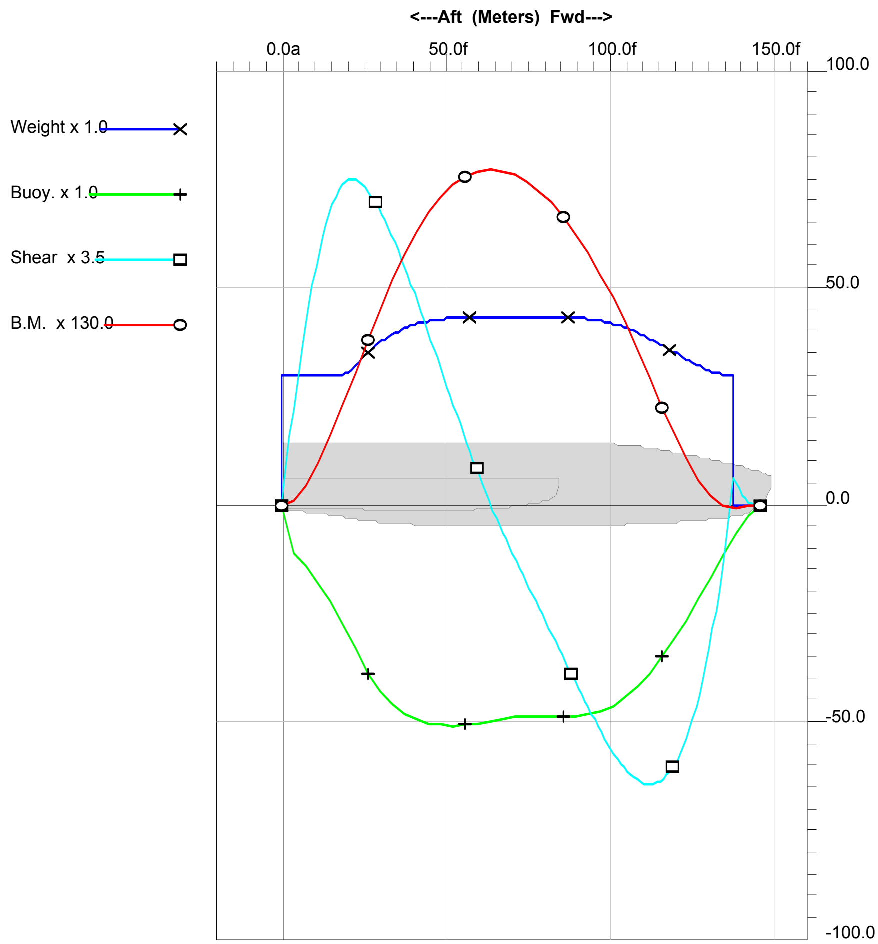


Figure 38. Longitudinal Strength Plot

15. Hull Calculations

The software package Autohydro was used for the Naval Architecture calculations. Sample calculations are shown in Appendix VI and they include the following:

- Hydrostatics.
- Cross Curves of Stability
- Tanks Calibration
- Floodable Length
- Longitudinal Strength
- Intact Stability
- Damaged Stability.

Intact stability calculations were based on the High Speed Craft 2000 Multihull criteria in order to determine the stability adequacy of the vessel. This set of rules is suggested by American Bureau of Shipping and is described in “Guide for Building and Classing High Speed Naval Craft”.

In addition, damaged stability was analyzed and several contingency cases were studied. Trimarans are highly dependant of side hull integrity to achieve adequate stability. Side hull damage was a major concern and several cases were evaluated. This ship is able to withstand the loss of half a side hull and the simultaneous damage of three forward watertight compartments. Under these extreme conditions, however, the main deck is immersed and flooded. Therefore, at this iteration of the design, main cargo deck will require watertight doors.

C. COMBAT SYSTEM DESIGN

1. Mission need statement

As the roles, missions, and capabilities of today’s Navy evolve into the 21st century, so does the role of the combat system on board naval vessels. Dominance of the battlefield and the electromagnetic spectrum based on the ability to use and deny its use by the enemy at will is dependent on robust weapons systems and electronic warfare suites that can sustain the unique threats of the 21st century.

As threats become more complex and asymmetric, the need to develop sensors, weapons systems and EW systems that can respond to changing environments is critical to superior battlefield surveillance, dominance and survivability.

The ability to detect, identify and take appropriate actions as necessary to counter a threat is central to the meaning of naval superiority and that is precisely what the proposed Ship Self Protection System (SSPS) is calling for.

a. Background

Weapons systems are the ensemble of elements that are used to destroy or perhaps simply disable a threat and as a result, also to threaten and defend.

Electronic warfare, on the other hand, can be defined as the control and manipulation of the electro-magnetic and electro-optical spectrum (i.e. radar, radio, and infrared) during military operations. Electronic warfare has always played a key role in deceiving the enemy and protecting the ship, its cargo, and its sailors.

b. Mission

Generally, Combat System suites protect the ship through a series of actions that vary from deception, jamming, and suppression, to attack and destruction. The HSAC SSPS is designed to be effective against a wide range of threats without affecting the ship's dynamics or maneuverability capabilities. The mission is accomplished when any threat can be encountered.

2. Operational Requirements

a. Description of Proposed System

The SSPS is envisioned as a self-protection suite, which includes all the necessary sensors, EW elements and the shipboard weapons systems elements that are necessary to mitigate all threats discussed in the threat analysis part of this chapter.

Dealing with a threat environment of continuously growing complexity requires a smart marriage of hardware and software. The SSPS should be designed to cope with extremely dense environments, long-range smart weapons and all kinds of radars. In addition to the ever-present need for short reaction times, this also requires a combination of high sensitivity, high selectivity, and high probability of intercept from the different SSPS subsystems.

b. Operational and Support Concept

The Ship Self Protection System (SSPS) will be distributed and installed on all units of the HSAC design. The ship's multiple roles require capability for the following missions:

Air Warfare Capabilities

- Detect, track, and destroy up to 8 simultaneous "leaker" missiles that escape defenses supplied by other fleet units
- Detect, track, and identify UAV, low slow flyers, attack aircraft
- Defend against and engage hostile UAVs and low slow flyers (less than 200kts)

Surface Warfare Capabilities

- Detect, track, and identify surface threats to the horizon
- Defend against and destroy small (less than 200ft long), high speed (in excess of 40kts) surface craft
- Deconflict potentially hostile craft from friendly and neutral shipping

Undersea Warfare Capabilities

- Avoid underwater mines
- Conduct evasive torpedo maneuvers

Amphibious Warfare Capabilities

- Sustain hostile small caliber fire

- Provide suppressive fire for amphibious forces
- Provide Naval Surface Fire Support (NSFS) for amphibious forces
- Fuel and support rotary wing aircraft supporting amphibious operations both day and night
- Provide for surface defense of Area of Assault

Command & Control Capabilities

- Conduct Electronic Protection Operations
- Communicate with U.S. and coalition forces via both secure and unsecured channels
- Maintain a CIC capable of collecting, processing, displaying, evaluating and disseminating tactical information
- Provide a data link capability
- The multi-role missions and the need to operate from the sea base (up to 200 nm from the target area) define the operational requirements and functionality of the SSPS.

The SSPS should be able to Detect and Counter typical threads of current and future aggressors (people, institutions and platforms). These include Air to Surface, Ground to Surface, Surface to Surface, Subsurface to Surface, Mines, and terrorist attacks.

c. Threat Environment

As said, mission and multiple roles of the HSAC define multiple threats to counter. The basic threats that need to be considered are:

- Radar guided weapons
- IR guided weapons
- Laser guided weapons
- Small boat attacks

- Mines
- Terrorist attacks
- Basic enemy fire from shore locations or localized direct threats

d. Expanded Sensor Operations/Ballistic Missile Defense

The vessel will be equipped with a Multi Functioning Radar (MFR) and Cooperative Engagement Capability (CEC). This will enable a battle group to use the HSAC as a picket ship to extend the sensor range of the surface combatants comprising the sea force. This ability will be especially important for two main reasons. First, it will have great impacts in littoral environments where shallow water will deter larger vessels from entering the area, and secondly, as a replacement for the decommissioning frigates which previously held this role.

The HSAC can also be used as a sensor platform for Ballistic missile defense. The SPY-3 radar on this vessel can be used as a mobile missile detection platform enabling other surface combatants to be freed up to engage the targets or for other operations. With more combatants in a position to engage ballistic missiles vice being paired up as the sensor and the shooter, more area can be covered and a greater probability of kill can be expected.

3. Statement of Work

a. Objective

This project involves the complete design and integration of a Ship Self Protection System for the HSAC. The result will be a modular system deign that has to be fully integrated into the ship’s architecture.

b. Tasks

(1) Develop Top Level Structure

A system level block diagram and overall layout is required. Basic information along with key design specifications relating to the systems requirements should be included. Power consumption, electromagnetic compatibility, and different sensors and systems placement on board the ship need to be considered from the beginning of development. Weight and volume limitations need to be incorporated at first hand.

(2) Choice of System Components

The functional components need to follow the threats as described in the Operational Concept. In summary, all of following available components should be analyzed as suitable options for the SSPS, and then a decision on the preeminent sub-systems to use should be made.

Sensor Suite:

- Multifunctional Radar
- Electro-Optical System
- IR search and track System
- Volume Search Radar
- Navigation Radar
- Basic Mine Detection System

EW suite:

- Radar warning Receiver
- Laser Warning receiver
- Missile Approach Warning System
- Directed Infrared Countermeasures
- Active/Passive Decoy System
- IFF System

Shipboard Weapons:

- High rate of fire medium range gun
- Medium range missile
- Free Electron Laser System

- High Power Microwave Systems
- Crew served weapons, small arms and non lethal weapons
- Other short range weapon systems

The components considered necessary for SSPS must be integrated following the top-level structure. An updateable threat library needs to be the base of the decision making process for most of the EW system components. The design must be modular in nature so that the HSAC can change missions and meet new threat requirements as deemed necessary.

4. Ship Self Protection System Overview

In this part, the Technical Specifications of the Ship Self Protection System for the HSAC are presented. In accordance with the Operational Requirements Document, the SSPS is designed to provide protection against a variety of threats.

Throughout the discussion below we assume that the ship has adequate weight, space, cooling and electrical power provisions to accommodate the SSPS system requirements.

a. System Overview

Figure 39 below depicts the proposed operational block diagram of the SSPS for the Joint ACCESS. It includes all the sensor elements that will feed a system controller with specific target information. The system controller will, then, assign appropriate countermeasures to mitigate each of the threats based on their type and priority.

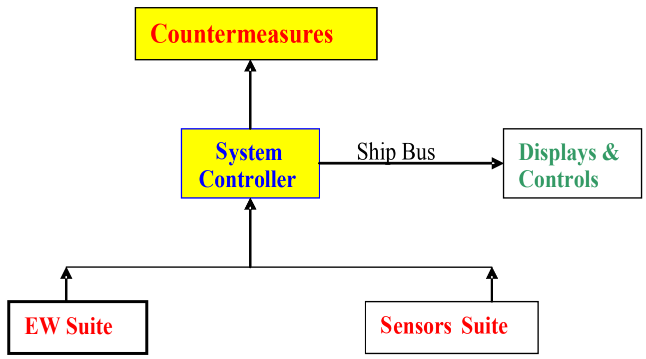


Figure 39. Block diagram of proposed SSPS

b. Design Philosophy:

The HSAC will utilize a layered defense concept for protecting the ship, its embarked troops and cargo, and the landing forces ashore. It will leverage on technology that is being currently developed for the U.S. Navy, while certain systems that will be specific to HSAC mission need statement and operational requirement document are also being proposed.

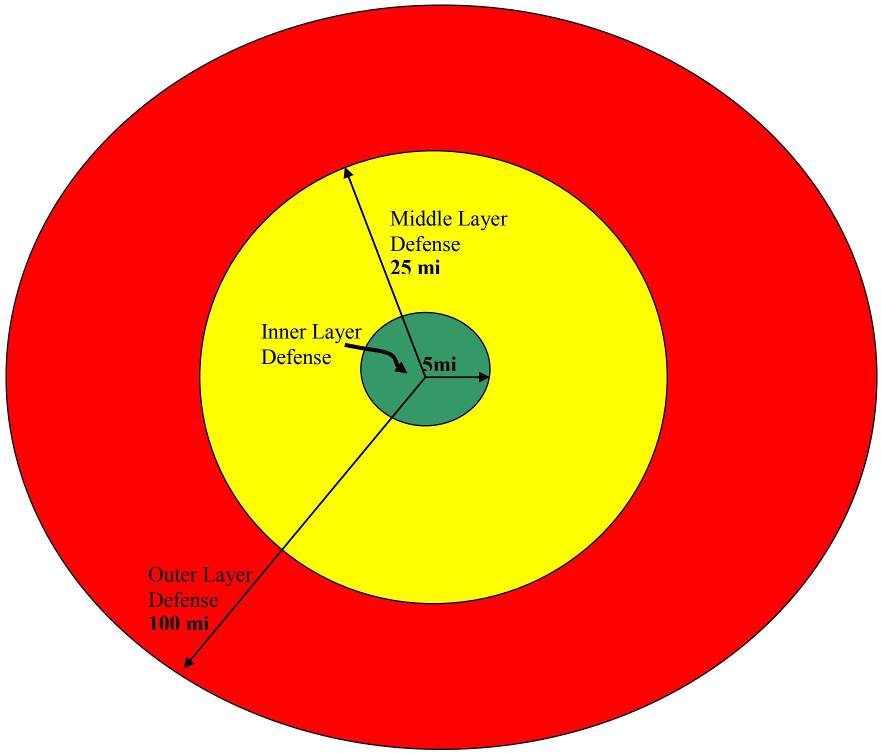


Figure 40. Design Philosophy

The HSAC will be heavily dependant on the long-range defenses of the Sea Shield and in particular the Littoral Combat Ship (LCS). This ship will be different from the LCS in that it will achieve higher speed and maneuverability, though. It will also have a larger complement of troops and cargo and will have a diminished capability in both self and landing force protection that is offered by the LCS. The HSAC will be outfitted with weapon and sensor suites to provide protection from known threats to primary mission within area of operation up to 25 miles.

It is planned that the combined number of HSAC vessels will utilize the advantage of distributed multiple platforms for a combined blanket of protection for increased survivability. The ability to use technology to share sensor and weapon data between fleet assets will raise the effectiveness of conducting the primary mission over a larger area of operations.

c. Threat Analysis

The threat anticipated to naval forces moving ashore from a sea base in 2025 will be the heavy protection of territorial waters / shoreline and the disruption of surface traffic to and from the sea base. These systems will be employed to interdict transport vessels in order to slow down high speed operations and to maximize damage while troops and cargo are still embarked. Threat objectives will be the coordinated effort of using all target acquisition and support agencies, of the littoral force and sea base that are available, for the purpose of denying enemy combat power over the landing force during the initial trough final stages of movement ashore. Central to the threat's defensive plan is the early identification and rapid denial and disruption in the littorals. Enemy systems are found to operate in multiple threat areas to include space, air, surface, undersea, electronic, and information warfare.

The High Speed Assault Connector (HSAC) war fighting capabilities will be designed with an Inner (0 to 5 miles), Middle (5 to 25 miles), and Outer (25 to 100 miles) defense layers. Although this will mitigate threats in combat systems terms, particular attention will need to be placed on the known threats to the primary mission. With the primary mission of the HSAC being the transit to the landing zone and the off load of cargo, the threat analysis will center on that transit and landing. To identify the major expected threats it is prudent to breakdown the mission into known areas of operation. These will be, in part, moving from sea base to 25 miles from landing zone, transit inside 25 mile boundary to 1 mile out, and the final move from 1 mile out to cargo off load on the beach. It is expected that threats to the HSAC will grow as it approaches the landing zone. In no way are these areas, as they are laid out, firm boundaries. They are only being used as a reference to classify major threats and crossover between two or more areas. The threats will next be analyzed and broken down by area.

From the sea base to the 25 mile range, the craft will be in the same threat status as open ocean combatants. These will be the threats from enemy fleet assets in the realm of surface warfare, undersea warfare, and air warfare. Enemy surface combatants will utilize ship to ship cruise missile technology with support by large scale deck mounted guns. Sub Surface assents will include both submarines that will be able to launch various torpedo variants and possible sensor networks to identify and aid in HSAC tracking. Air warfare will be of a hybrid nature or modified approach to current tactics. Standard air to surface anti ship missiles fired from combat aircraft will still remain the primary air threat, but with the enemies need to lessen the effect of the HSAC air defense, which may include friendly fighter aircraft, it can be expected that commercial aircraft of different sizes will be employed as deceptively hiding air attack platforms.

Within 25 miles of land the above threats will still be valid. The upgraded threat within the new zone will be primarily in the realm of surface warfare, but not limited to it. Small surface combatants ranging from small cutter vessels to patrol craft will be used to deter transit within close proximity to and in territorial waters. These vessels will be multiple in numbers and of increased speed compared to the major enemy fleet assets. All will be capable of ship to ship cruise missile attack with the added ability for close in attack with deck mounted guns and torpedo launchers. Because of decreased cost and availability of these ships compared to larger scale surface combatants, the most likely engagement of the HSAC by the enemy will be by this means. In addition to the realized surface threat within this area, the potential surprise attack form deceptively hidden surface platforms may either start the enemies small craft assault or wait to prey on damaged HSAC vessels after engagement. These vessels will range from pleasure craft to small commercial vessels (fishing) that have been outfitted with a hidden one launch missile or rocket. Another concern within this area is the possibility of engagement from land assets. Coastal defense may include cruise missile facilities with the ability to reach out into the area. Although this technology can have farther reaching capability, the enemy will not utilize these facilities until the HSAC is within 25 miles for 2 reasons. First will be to protect these facilities from our fleet and air assets which can target and destroy these sites, and secondly to increase their probability of kill by launching when the HSAC is within its most effective weapon range, which will lead to a decrease in the available reaction time for the HSAC.

The landing zone area ranges from 1 mile out from land and into the beach area. The HSAC may be susceptible to small boat attack, beach defenses, and from fire from troops that may occupy the landing area. The small boat attack will be varied from the paragraph above in that small RHIB type of craft or surf riders like jet skis may be employed for attack or for a possible boarding attempt due to the HSAC need to drastically cut speed prior to the beach. The offensive capability will range from machine gun fire and rocket propelled grenades from both the craft and from the beach, to potential mortar or artillery fire from troops or armor units. Mining of beach area to deter landing will also need to be considered. Theses threats have historically have had exceptional effectiveness due to unpredictability and to its simple low tech nature.

In the following pages, each of the major subsystems of the SSPS will be discussed in terms of their functionality and operational/technical specifications.

5. EW suite:

The EW suite of the HSAC will provide Electronic Support (ES), Electronic Attack (EA), and Electronic Protection (EP) capabilities in the radar and infrared parts of the electromagnetic spectrum. The primary functions of the EW suite are the detection and identification of threat emitters as well as automatic employment of coordinated on-board countermeasures. The best system that fits the above description is the Navy's next generation Advanced Integrated Electronic Warfare System (AIEWS).

This system is designed for layered and coordinated countermeasures in the littoral environment and provides final layer of self-protection against air threat leakers and ASCMs for individual ships. Because the subsystems of the AIEWS are still classified, we decided to conduct a thorough analysis of all possible subsystems and concluded that and the following EW elements are necessary to accomplish the EW suite mission.

a. Radar Warning Receiver

The purpose of the Radar Warning Receiver (RWR) is to provide information to the SSPS about Radio Frequency threats (radars and active RF-guided missiles) that are searching for, tracking or illuminating the ship. RWRs are generally the simplest form of ES receiver consisting of unsophisticated low-sensitivity (on the order of -40dBm) equipment that is present to cover the bands and characteristics of expected threats and exploits the range advantage to indicate a threat before it reaches its firing range [1].

Because we are considering the year 2015 technology and from RWR trade off analysis performed in Appendix VII, it was concluded that the HSAC RWR system should be based on Digital Receiver technology and should meet the requirements of a modern high-performance ES receiver as listed in Table 7.

Table 7. Modern High Performance ES Receivers

Frequency range	0.5-40GHz
Sensitivity	Less than –75dBm
Dynamic range	greater than 70dBm
Frequency resolution	better than 2MHz
Bearing accuracy	better than 1 degree rms
Pulse Rate	10^7 pulses/sec
Pulse width resolution	25ns
TOA resolution	50ns
Amplitude accuracy	1dB

The data collected by the RWR receiver are analyzed in terms of angle of arrival, time of arrival, pulse width, PRF, frequency, scan rate, amplitude in order to detect the type of threat (radar and platform), based on the information stored in the threat library. The RWR controller then sends the available data for each threat to the SSPS System controller for further correlation with the data coming from other SSPS sensors and/or the ship’s other sensors and data links.

b. Radio Frequency Jammer

The purpose of the Radio Frequency (RF) Jammer is to emit RF jamming signals in order to protect the ship from being detected, tracked or intercepted by enemy radars and RF guided missiles.

Usually, naval vessels have Radar Cross Sections (RCS) that are very large (as contrasted with the airborne situation) which requires very large Jammer ERP to cover the target. Also, ships are relatively immobile and it is difficult to avoid an accurately targeted missile once launched.

For the HSAC, it was decided to use the basic SLQ-32V for self-protection jamming using transponder and repeater jamming techniques with high ERP. The HSAC will rely on other fleet assets (E-A6B prowler) to provide stand off and escort jamming when necessary. The calculation in Appendix VII shows that the use of the SLQ-32 to cover the HSAC up to 2km from shore illuminating radars is feasible.

c. Missile Approach Warning System

The purpose of the Missile Approaching Warning System (MAWS) is to provide information to the SSPS about missiles that are approaching the ship. Its role is especially important in the case of IR guided missiles, since these cannot be detected by the RWR.

MAWSs may be either active or passive. The former uses a pulse Doppler radar to detect and track missiles by means of their skin return, while the latter responds to either the IR or UV signature of the exhaust plume from the missile's rocket engine [2].

The radar provides the advantage of providing all-weather range and range-rate data that enables calculation of time-to-impact data. Disadvantages involve the difficulty of extracting the small missile RCS target from competing clutter. An additional criticism of active radar is the possibility of it being used to as a beacon for an anti-radiation type missile.

Passive MAWSs employ IR sensors to detect a missile's plume out to the physical horizon. This is very crucial to the success of the mission especially those ASCMs become stealthier and are able to skim even closer to the ocean surface. Even with a low RCS, the heat signature of the plume is still detectable by the MAWS IR sensors. These sensors generally provide relatively accurate angular data, but range must be estimated on the basis of signal strength.

By the year 2015, we speculate that this technology will be mature enough so that the two types of sensors may be combined in a hybrid system, offering the best combined benefits of each [3].

The data from the IR sensors are fed to the MAWS receiver for processing. The resulting threat information (angle of arrival, velocity, signature and/or type, if the missile’s signature is already stored in the threat library) is then sent to the SSPS System for correlation with other sensor data and the employment of the appropriate countermeasures.

After a threat is detected the sensor will be able to continuously track the target to provide the necessary information to the DIRCM, if the SSPS System decides to employ it to counter the threat.

Because we are considering threats of the year 2015, the use of a hybrid MAWS on board the HSAC was deemed necessary to alert the crew of the presence of hostile fire control radar and missile carrying IR/EO passive sensors.

d. Directed Infrared Countermeasures (DIRCM)

The purpose of the DIRCM system is to employ countermeasures against IR guided and Laser guided missiles, based on the information and cueing provided by the SSPS System. This system will be capable of transmitting laser energy against both IR missiles in the

3-5μm region and laser-guided missiles operating in the 1.06μm frequency. Earlier versions of this type of system use the laser in a deceptive jamming mode to cause the missile seeker to break lock. The reflected laser energy coming from the threat missile's seeker is demodulated to provide information about the tracking technique the missile IR sensor is utilizing. This, in turn, allows for the proper modulation to be applied to the jamming waveform to achieve deception.

The newer versions use the laser beam to damage the seeker optics and IR detector, which in effect blinds the missile. This is the only technique that can be used against 3rd generation IR seekers, which employ Staring Array type detectors. Indeed, deception countermeasures against these types of sensors are largely inefficient [4].

The analysis done in Appendix VII shows that the laser system is the best available option and that power requirements of such system are easily achievable with today's technology and certainly achievable in the year 2015 time frame.

e. Chaff/Flare/Decoy Dispenser

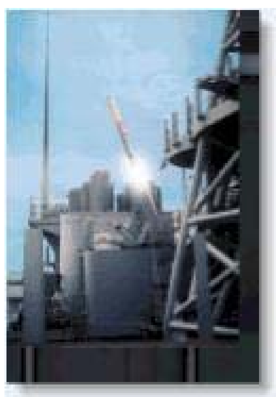
Chaff is the oldest, and still the most widely used radar countermeasure. It is generally used to protect tactical aircraft, strategic aircraft and ships in either a corridor-laying or self-protection mode. Shipboard Chaff can be used in one of three modes: deception, saturation and seduction.

Based on current technology, it was decided that the most appropriate Decoy Launching System (DLS) to use onboard the HSAC is the Mk 53 (NULKA). The NULKA is a rapid response Active Expendable Decoy (AED) System capable of providing highly effective defense for ships of cruiser size and below against modern radar homing anti-ship missiles. It is being developed in cooperation with Australia ("Nulka" means "be quick!" in Aborigine language). It is intended to counter a wide spectrum of present and future radar-guided anti-ship missiles (ASMs) assessed to have passive decoy rejection and active angular deflection electronic countermeasures rejection capabilities. It is designed to over-come the inherent shortfalls of chaff, which are wind dependence, lack of placement flexibility, relatively slow reaction time, and susceptibility to Doppler discrimination. Combination of thrust and flight control enables successful launches to be made in severe sea state and high wind conditions [5].

The system that weighs approximately 3000 Lbs when fully loaded allows for automatic or operator designation of missile threat and, upon designation of a particular threat, will respond rapidly by launching an autonomous airborne decoy. Prior to launch, the system calculates optimum decoy flight trajectory for mission and programs that trajectory into the decoy’s flight control unit (FCU). With programmable and controllable flight path, the rocket hovers and positions itself to provide more attractive target for the threat missile. The decoy payload is provided with design that is optimized to provide effective protection to both large and small surface ships. An up close view of the decoy is provided in Figure 41.

The system can either be integrated with the Combat System or used with the stand-alone AED Fire Control System. The DLS MK 53 Mod 4 is a modified DLS MK 36 Mod 12 by the addition of two NULKA launching tubes to each of the four MK 137 Mod 2 launchers and a Decoy Launch Processor.

The Nulka decoy employs a broad-band radio frequency repeater mounted atop a hovering rocket platform. After launch, the Nulka decoy radiates a large, ship-like radar cross section while flying a trajectory that seduces and decoys incoming ASMs away from their intended targets. The decoy is designed to counter a wide variety of present and future radar Anti-Ship Missile (ASM) guided threats by radiating a large radar cross section signal while flying a ship-like trajectory thus enabling one decoy to counter multiple threats.



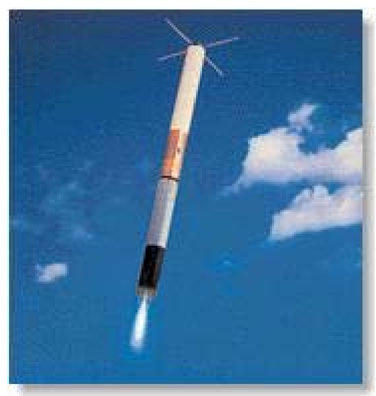


Figure 41. Nulka System

6. Sensors Suite:

a. Multi-Function Radar

The Multi-Function radar (MFR) was selected as the radar of choice for the HSAC. This 3 dimensional system combines the functions provided by more than five separate radars currently aboard Navy combatant ships.

It is essentially the SPY-3 radar currently undergoing development. The size and weight estimation of the SPY-3 radar are shown in Figure X.

This system is an active phased array X-band radar designed to meet all horizon search and fire control requirements and provide missile control 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.

According to the analysis done in [6], the system will have a 76Km detection range against ASCM threats. Because most ship radars are horizon limited rather than electronics detection range limited, a careful examination of the placement of this system onboard the HSAC should be conducted. As a matter of fact, in a stand alone situation, the HSAC will only be able to detect ASCMs threat up to the physical horizon of the MFR.

The horizon detection range of the MFR should exceed the missile range of the Evolved Sea Sparrow missile (30km) to allow for ample time for missile tracking. In addition, this system will be optimized for the littoral environment and provide superior clutter rejection.

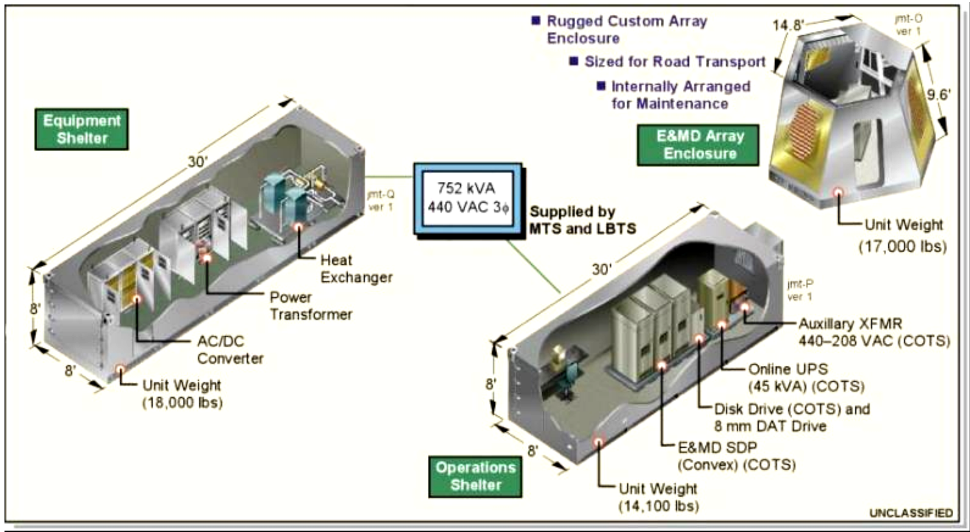


Figure 42. SPY-3 weight and size estimation

This solid-state, active array radar system will not only scan the horizon for high-speed, low-level cruise missile threats, but also provide fire-control illumination for HSAC air defense weapons. MFR is designed to detect the most advanced low-observable anti-ship cruise missile (ASCM) threats and support fire-control illumination requirements for the Evolved Sea Sparrow Missile to support engagement of the most stressing ASCMs. The MFR mast design supports new ship-design requirements for reduced radar cross-section, significantly reduced manning requirements and total ownership cost reduction.

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.

c. Navigation radar

The navigation radar will allow the HSAC to switch off the high power (and distinctive) radar suites and utilize a simple system for navigation. Because the HSAC has to transit more than 100 miles before it reached the area of its primary mission (within 25 miles from the coast), the navigation radar will enhance the deception capability of the ship by giving signature comparable to commercial vessels. This is especially important during the early stages of transit (from sea base to about 25 miles from shore) during the first hours of the eight hours period of darkness.

Figure 43. Navigation Radar

The navigation radar that will be installed on board the Joint ACCESS will be an S-band radar that assures target detection in adverse weather conditions where X-band radars are heavily affected by sea or rain clutter.

Such equipment is readily available in a variety of configurations: 30 or 60 kW output, short or long antenna radiator, with standard electronic plotting facility and optional Automatic Radar Plotting Aid (ARPA). These plotting aids are essential in ship borne radars to reduce the workload of ship personnel, and improve the standard of collision avoidance.

The display unit shown in Figure 43 will employ a 21" high-resolution multi-color monitor that provides an effective diameter of 275 mm. Radar echoes will be presented in a selected color with a day or night background color for easy observation in all lighting. Different colors are assigned to marks, symbols and text for user-friendly operation. The control head has logically arranged controls in a combination of push keys, rotary controls and a well-organized menu structure, and can be separated from the display unit via a flexible cable. The display pedestal contains all major modules and may be separated from the monitor part.

The operational features of the navigation radar will also include all functions required by the IMO and IEC, such as, Head-up/ Course-up/ North-up orientation, parallel index lines, True Motion, sensor status message for compass, SDME, GPS and other electronic position-fixing systems, wind parameters, depth sounder data, etc.

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 HSAC.

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 HSAC operating in the littorals can be faced with threats such as floating mines and fast small craft, which are difficult to detect due to low radar reflectivity and small cross-sectional areas. 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. With its suite of EO sensors, auto-tracking capability, and accurate stabilization, the TISS II has demonstrated the ability to support other roles such as navigation, suspect ship boarding, and air defense [5].

A thorough analysis of this system and its components can be found in Appendix VII.

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 HSAC 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 future 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 HSAC 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 (used in the Canadian "City"-class frigates) 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 by Figure 44, eight Mod 0 modules can be installed on each of the ship's side hulls.

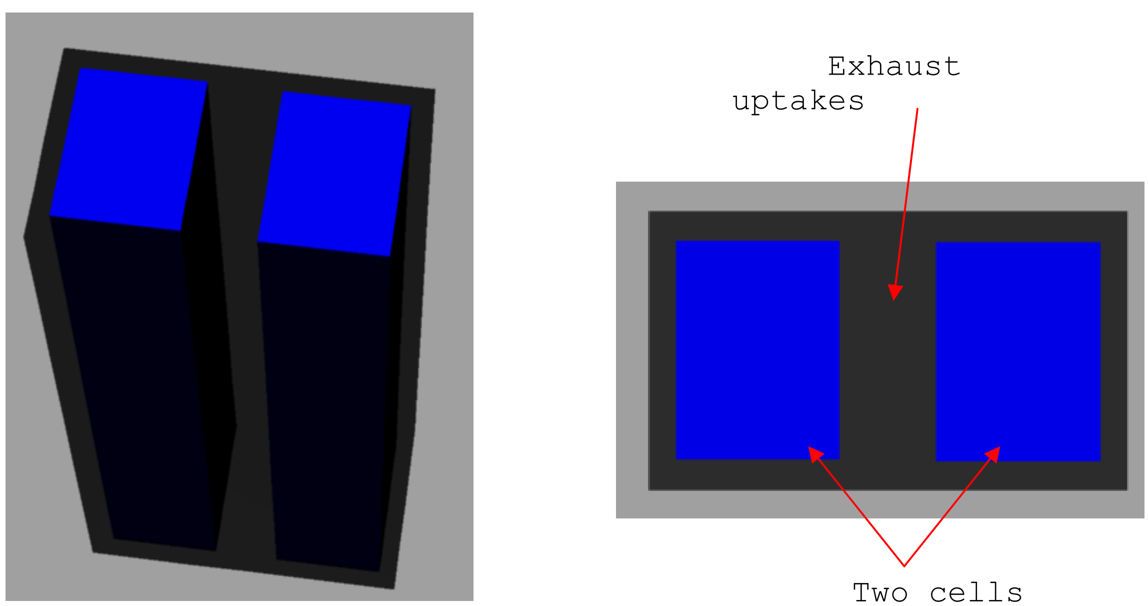


Figure 44. MK 48 Mod-0 Launcher System

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.

b. Small caliber Gun System

According to the conclusions of the Trade-Off-Analysis conducted in Appendix VII, the high rate of fire gun that will be installed onboard the HSAC is the Mk3 BOFORS 57mm gun. This gun has been selected because of its small weight and volume, high firing rate, and excellent maximum and minimum range values that fall in accordance with the HSAC inner layer defense range requirements.

Figure 45. 57mm Gun System

The 57 mm naval gun as shown in Figure 45 can fill both anti-air and anti-surface capabilities for the

HSAC. With a rate of fire of 220 rounds per minute, a short firing sequence, a stealth-designed cupola, an effective maximum range of just over ten miles, and air burst ammunition, this gun is highly effective against fast moving surface vessels and small boats.

c. High Power Microwave Active Denial System

(1) Introduction

The high power microwave system that will be installed onboard the ship is a non-lethal, counter-personnel directed energy weapon. It uses breakthrough technologies to provide unprecedented, standoff, non-lethal capabilities.

This active denial system (ADS) projects a focused, speed-of-light millimeter-wave energy beam to induce an intolerable heating sensation on an adversary's skin and cause that individual to be repelled without injury. This non-lethal technology was developed in response to Department of Defense needs for field commanders to have options short of the use of deadly force. This capability is expected to save countless lives by providing a means to stop individuals without causing injury, before a deadly confrontation develops.

Non-lethal technologies can be used for protection of the Joint Access and in other situations in which the use of lethal force is undesirable. ADS will provide these capabilities in close in, as well as, at longer standoff ranges.

Currently, the Air Force has taken the lead on this technology and has produced prototypes operating from a Hummvee mount and has personnel portable systems in the works. Mounting of a ship system should not be of great difficulty due to increased power available on a ship and less space restrictions compared to a vehicle mount.

(2) HSAC Mission Application

The ADS system will enable the HSAC to engage threats inside its inner defense layer without expending ordinance. During the approach to the landing zone a major threat to the vessel will be from small boats. As we have learned from the USS Cole incident, these boats can be modified into mobile bombs. Because the crew of these vessels is typically exposed in pilot houses or open decks, they are susceptible to engagement by ADS. Although countering the system by getting under cover will occur in some instances, the time expended by the enemy to do so will aid in time needed to engage the threat by ship weapons. In addition, the ADS will allow the HSAC to sweep the beach prior to landing and continue to protect areas to the outside of the landing zone from an assault by ground forces on foot. The system is intended to protect military personnel against small-arms fire, which is generally taken to mean a range of 1,000 meters. This range suits ship needs to confront these threats.

More on how HPMADS work and its operating statements can be found in Appendix VII.

d. Twin M240C Mounted Machine Gun

In addition to the weapon systems described above, the team decided that the ship needs a very high rate of fire machine gun to deter hostile fire from the shore once the ship reaches the landing area. After a careful examination of the available weapons that can accomplish this mission, it was decided to use the twin mount M240C machine gun as shown in Figure 46 (Two M240C connected side by side).

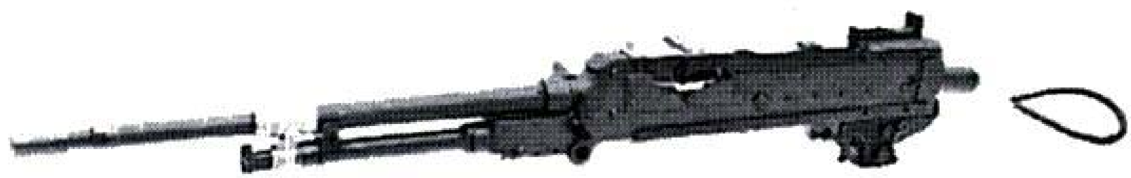


Figure 46. Single M240C Machine Gun (Twin mount not shown)

This weapon is currently being used on the Bradley Fighting vehicle and by Seal team operators; therefore familiarity of this weapon with embarked troops will be high and that will enable the Joint ACCESS to use some of its troops aboard to defend itself, its cargo and its troops when a high rate of fire is desired to cover a short distance.

Two mounts for the weapon will be positioned on both the port and starboard side, fore and aft (for a total of four mounts). Since the weapon is light and moveable, the vessel will be outfitted with eight guns that can be used at the discretion of the ship in one or multiple mounts. In addition to a very high adjustable cyclic rate between 750 and 950 rpm (2800ft/sec muzzle velocity), this system offers an excellent maximum range of 3725 meters which is well outside expected useful need. Guns can be connected to either a standard 200 round ammunition box or heavier 600 or 1200 variations.

8. Final System Overview

Figure 47 shows the final system overview after all the subsystem elements are selected.

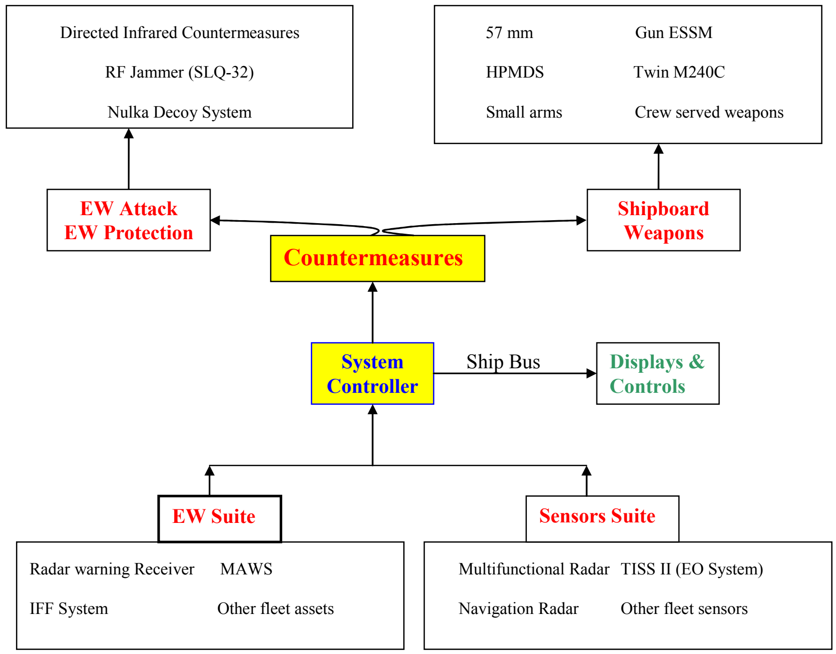


Figure 47. Final System Overview

All of the system sensors, including the EW elements, will fuse their target information to the system control, which based on an updated threat library and other sensor fusion algorithms, will assign the appropriate countermeasure that meets the threat's type and priority. This procedure can be done either automatically or manually based on the judgment of the ship's command.

9. Combat Engagement Flow

In the following section, we will proposed a concept for employing the sensor suites and combat systems elements onboard the HSAC 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 Littoral Combat Ship and other 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 HSAC 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 SSPS 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 and divert it from a collision course with the HSAC. If the target escapes all defenses, the twin M240C machine gun will then engage it.

This entire sequence can be either automatic or commanded by the Tactical Officer in charge. During the entire sequence, the SSPS will provide bearing and speed directions to optimize the RCS of the ship.

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 SSPS will allocate the most appropriate weapon system to engage the threat. Long range detection (beyond the radar horizon of the MFR) and engagement (>25 miles) may be possible if the LCS or other fleet assets are in the vicinity.

If the target enters the lethal range of the ESSMs, the SSPS 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 57mm gun will be employed to engage it. The Nulka system will also be used to deceive the target and redirect it from its collision course with the HSAC. The SSPS will also employ the HPMADS system and the M240C machine guns to deter or repel the personnel of any "unknown" vessel that closes to less than 3km range from the Joint ACCESS. If a target escapes all defenses, or that it is not a high enough priority to be engaged with the ESSM or the 57mm gun, the twin 40mm machine gun will engage it.

Depending on the target type and the type of threat it poses, the SSPS will decide on the best course of action and the weapon system that can best engage the target.

c. Subsurface warfare

Submarine warfare will be designated to either the LCS or other fleet assets. The TVs of the TISS II electro-optical system is capable of imaging floating mines, and submarine periscopes under clear visibility conditions but no mine destruction capabilities are envisioned for the HSAC, though.

10. Reliability

The evaluation of the SSPS in terms of reliability is based on the concept of the reliability / survival function. The reliability is expressed and provided in terms of Mean Time Between Failure (MTBF) and the instantaneous failure rate λ.

a. Definition

Reliability is the probability that a system will perform in a satisfactory manner for a given period when used under specified conditions. A system's overall reliability can be determined by the development of reliability models. The complexity of these reliability models is dependent upon various factors such as mission profiles, function criticality, and redundancy characteristics. The general approach is to capture the modeling effort with the use of Reliability Block Diagrams.

b. Reliability Prediction Analysis

The reliability analysis can be used to define the quantitative parameters for each sub-system or the complete system, and may be expressed in number of failures in a given set period of time, set number of cycles or set number of operations, such as rounds fired from a small caliber gun, etc.

A common expression used to define an item's reliability is its Mean-Time-Between-Failure, commonly known as its MTBF. Once this figure is known it can be used to determine the reliability of an item in terms of a probability of success or failure, over a given operating period.

c. Reliability Analysis (Methods)

There are two methods available for determining the reliability of an item (this could be a piece part to a complete system) and are:

(1) Reliability Prediction

This is the process used to determine the MTBF of an item. This is achieved by performing a prediction analysis.

(2) Similarity

This method is used to determine what the reliability of a new product will be based upon the "known" reliability of an existing product with similar attributes. These attributes can be the type of technology used, digital circuitry, complexity of components and also comparable operating environments and scenarios [9].

The reliability of the SSPS is the product of the individual reliabilities of its different subsystems such that for a given MTBF, we define $\lambda = 1/MTBF$ and the overall reliability of the system using the exponential distribution is then calculates by

$$R = \prod_i e^{-\lambda_i t} = e^{-\left(\sum \lambda_i\right)t}$$

where λ= failure rate per hour*10^{-3}, and t is the number of hours

The reliability calculation of the ship self protection system is not detailed in this project. The failure rates provided in Table 8 do not reflect accurate data but are provided for illustrative purposes only. A Reliability prediction data summary spreadsheet table below was provided for use with the most important subsystems, once MTBF data is acquired.

Table 8. Reliability Calculation

Component Part	λ/ Part (%/1000 Hours)	Quantity of parts	(λ/Part) (Qunatity)
RWR	0.2	1	0.2
RFJ	0.3	1	0.3
MAWS	0.2	1	0.2
DICM	0.3	1	0.3
MFR	0.2	1	0.2
Nav. Radar	0.3	1	0.3
EO System	0.2	1	0.2
ESSM	0.3	32	9.6
57mm Gun	0.5	1	0.5
HPM System	0.5	2	1
Twin M240C	0.5	4	2
		Σ=	14.80%

Failure rate (λ)= 14.80% /1000 hours

MTBF= 1000/ 0.148 **6757 hours**

11. Availability and Cost Effectiveness

The metrics of Availability is derived from the following common definitions:

a. *Operational Availability*

The probability that a system when used under stated conditions in an actual operational environment will operate satisfactorily when call upon.

b. *Achieved Availability*

Similar definition as Operational Availability, but includes preventive and scheduled maintenance.

c. *Inherent Availability*

The probability that a system or equipment, when used under stated conditions in an ideal support environment, will operate satisfactorily at any point in time as required but it excludes preventive or scheduled maintenance actions, logistics delay time and admin delay time.

d. System Effectiveness

This is defined as the probability that a system can successfully meet an overall operational demand within a given time when operated under specific conditions.

e. Cost Effectiveness

Relates to the measure of a system in terms of mission fulfillment and total life cycle cost, and needs to be expressed in a suitable way, referencing to the specific mission of the HSAC. [10]

12. Maintainability

The SSPS Maintenance will be organized in a way that will facilitate system operation and maintenance from forward sea bases. All subsystems will incorporate Built-In-Test capabilities with Automated Fault Detection. Maintenance will be implemented in the commonly known three levels which are as described in following paragraphs.

a. Organizational Maintenance

Organizational maintenance is the responsibility of and performed by the equipment operator; scheduled preventive maintenance services are performed by trained personnel. Operational maintenance consists of proper equipment operation, safety and serviceability inspections, lubrication, and minor adjustments and services.

b. Intermediate Maintenance

Intermediate maintenance is the responsibility of and performed by a designated maintenance shop. The extent of intermediate maintenance encompasses the removal, replacement, repair, alteration, calibration, modification, and the rebuilding and overhauling of individual components, assemblies, and subassemblies.

c. Depot Maintenance

Depot maintenance is performed on equipment requiring major overhaul or comprehensive restoration to return an item of equipment to a "like-new" condition. Depot level maintenance uses production line and assembly line methods whenever practical.

d. Modular Design

Modular design should be incorporated in order to allow facilitated access and replacement of components. Functional subsystems will comprise Line Replaceable Units (LRUs). The SPS-level Built-In-Tests will troubleshoot malfunctions to the LRU level, allowing remove and replace maintenance functions to be executed at the O maintenance level (i.e. flight line), facilitating operations from forward deployment bases.

13. Risk Management:

a. Purpose

The purpose of the risk management plan is to:

- Provide a disciplined and documented approach to risk management throughout the SSPS life cycle and its upgrades.
- Support management decision making by providing integrated risk assessments (taking into account cost, schedule, performance and safety concerns).
- Communicate to management the significance of assessed risk levels and the decisions made with respect to them.

b. Definition

- RISK: An undesirable situation or circumstance that has a realistic probability of occurring and an unfavorable consequence on the overall mission success.
- Risk Levels

- High – Likely to cause significant degradation of the performance, even with special project emphasis
- Medium – Can potentially cause disruption of schedule, increase in cost, and/or degradation of performance. Normal project emphasis will probably be sufficient to overcome issues
- Low – Has little or no potential for disruption of schedule, increase in cost, and/or degradation of performance. Normal project activities will probably be sufficient to overcome issues.

c. Components of risk

Risk is the product of the probability of the unwanted outcome x loss experienced if the outcome occurs [8]. Figure 48 clearly outlines this principle.

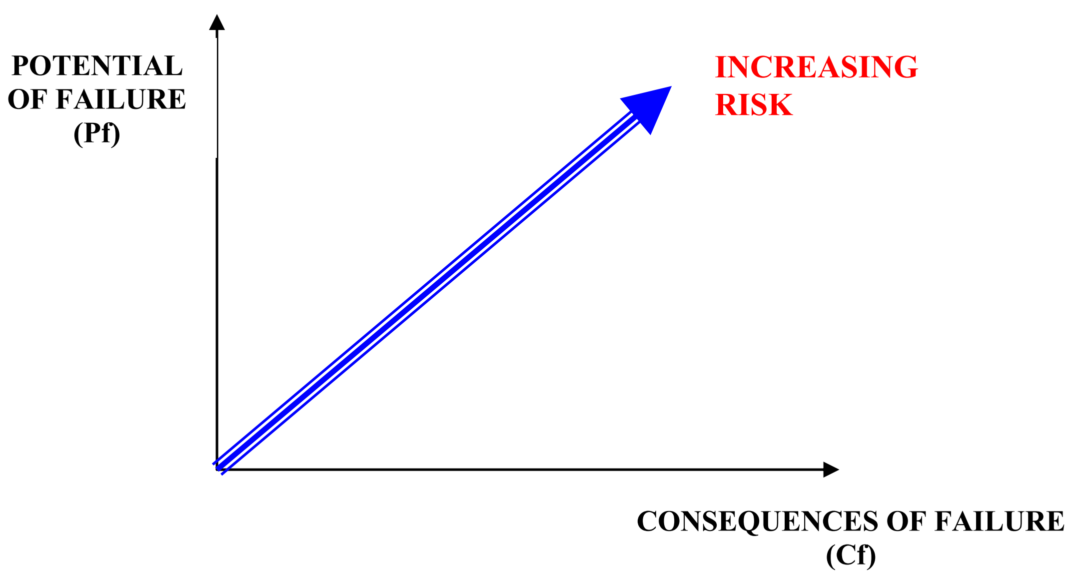


Figure 48. Risk Analysis

d. Phases

- Risk Assessment – Identify possible risks, and determine root causes

- Risk Analysis – Determine probability of occurrence, and determine most likely consequence of identified risk
- Risk Abatement –Identify potential risk reduction actions, and analyze and prioritize changes to existing plans

e. Risk Management Plan for the HSAC

Figure 49 shows the proposed Risk management Plan for the SSPS onboard the Joint Access.

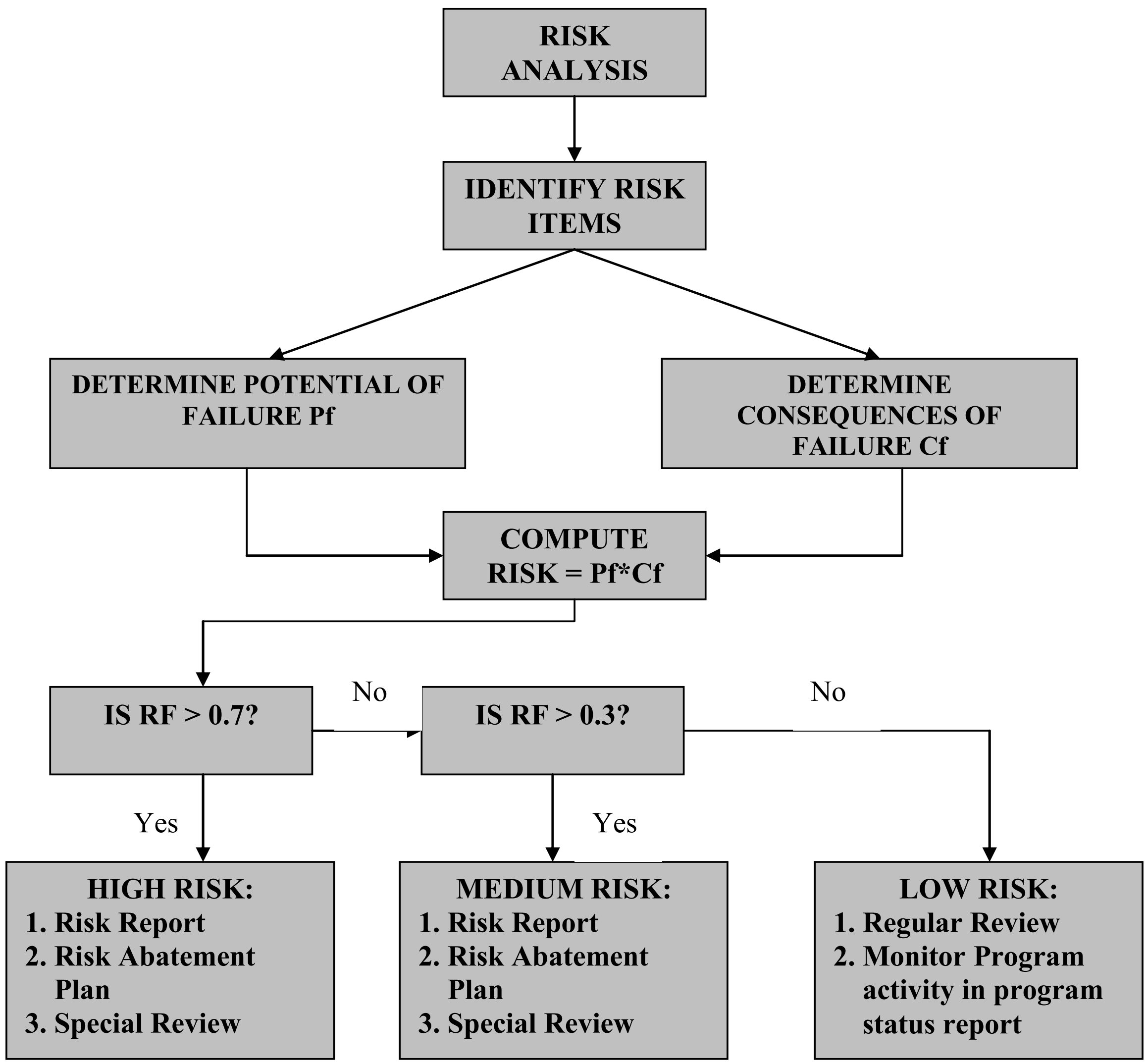


Figure 49. Risk Management Plan for the HSAC

14. Survivability Analysis

In this survivability analysis, it was decided to start from the outer layer and analyze the probability of kill down to the inner layer of the self defense zones.

Most of the threat in the outer layer will be taken care of by the LCS and other fleet assets. It was assumed that half of these threats (aircraft, missile, etc.) will be destroyed by non HSAC weapons. Therefore, the P_{kill} of the HSAC in the outer layer is:

P_{kouter}=1-0.5*0.5= 0.75

Inside the middle layer, the ESSM is the main countermeasure to put down any threat. It was assumed that the missile reliability includes 3 components: the capability to track the target, the capability to guide the seeker to the target, and the capability of properly detonating the fuse at the target.

Data collected from previous reports that assessed the performance of the RIM-7 missile will be used for the rest of this analysis. It has been assumed that there will be sufficient number of missiles to engage each ASCM.

The ESSM missile is assumed to have a reliability of 90% and a warhead lethality (given a hit) of 75%. Therefore a Single Shot Kill Probability against any ASCM is

P_{SSK} = 0.90 × 0.85= 0.765

Because the probability of a single shot kill is relatively low, it is probably more practical and safer to deploy two missiles to ensure a higher probability of kill against any ASCM threat. Therefore, the P_{K-ESSM}= 1-(1- 0.765)^2 =94.5%

A figure of 60% has been assigned to the HPMADS ability to soft-kill (repel) an enemy once it engages it. This is the probability that the denial system will render an enemy unable to fight once it is subject to the HPM projected high energy beam.

$P_{k\text{-}HPM}$ = 60%

The Twin M240C mounted machine gun system has been assigned a $P_{k\text{-}twin}$ = 20%, once they engage the threat.

The electronic warfare systems have been given a $P_{k\text{-}EW}$ = 60% effectiveness against ASCMs.

Therefore the total effectiveness of the layered defense (going from the outer to the inner layer) is defined as:

$$P_{KTOTAL} = 1-(1-P_{Kouter})(1-P_{K-ESSM})(1-P_{KHPM})(1-P_{twinM\,240C})(1-P_{K-EW})$$

P_{Ktotal}=1-(1-0.750)(1-0.945)(1-0.600)(1-0.200)(1-0.600)=0.998

According to the ORD of the HSAC, each of the HSAC variants should be able to counter a maximum threat involving 8 simultaneous ASCMs. Therefore, assuming 96 incoming ASCMs (8 missiles for each of the 12 HSACs conducting one single mission), the possibility of 1 or more missiles leaking through all the defenses of the HSAC is:

$P_{Leakage}$ = $1-0.998^{8}$ = 0.175

Given this value, .175*12= 2 of the total number of 12 HSAC could be hit in this worst case scenario attack.

The remaining squadron of ten ships would remain a viable fighting force.

15. RCS Calculations

The ship’s RCS was calculates using three methods. The first is an empirical method, the second is by using the

POFACETS software developed at the Naval Post Graduate School, and the last method is the XPATCH software.

All calculations were conducted in the 300MHz frequency band.

a. ***Empirical Method:***

By now, there have been sufficient measurements and trials to allow ranking and scaling of RCS calculations to take place for naval vessels. There are a lot of empirical formulas out in the literature but the most suggested one for low grazing angles is developed by Skolnik. It calculates the RCS of a ship based on its displacement (or length if displacement is not known) and the frequency used.

$$\sigma = 1644 F^{0.5} D^{1.5}$$

where D is the ship's displacement in kilotons and F is the frequency is GHz.

According to this formula, the mean RCS of the ship based on its displacement is

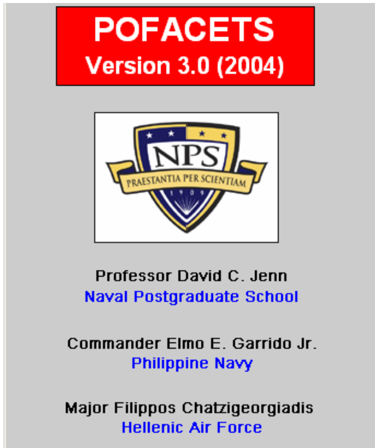
$$RCS_{SHIP} = 1644 \times 0.3_{GHz}^{0.5} \times 5_{Ktons}^{1.5} = 10067 = 40dBsm$$

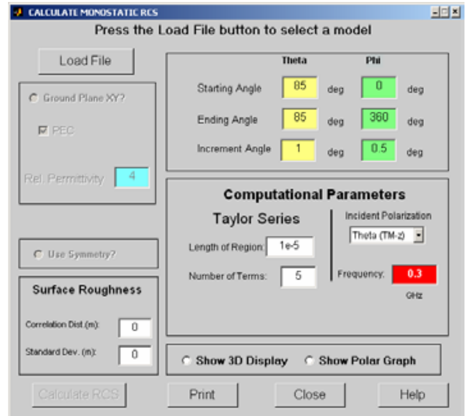
This approximation varies with aspect angle and it is suggested that 13dB is added to provide the broadside "flash" while 8dB must be subtracted to reach the minima. Therefore, we estimate the ship's RCS to vary between 32dBsm (for minima) and 53dBsm for broadside angle.

b. ***POFACETS Method:***

(1) Inputs

POFACETS version 3.0 is RCS calculation software developed by Professor David C. Jenn (NPS), Commander Elmo E. Garrido Jr. (Phillipine Navy) and Major Filippos Chatzigeorgiadis (Hellenic Air Force).





(2) Results

The POFACETS Method, led to the following results:

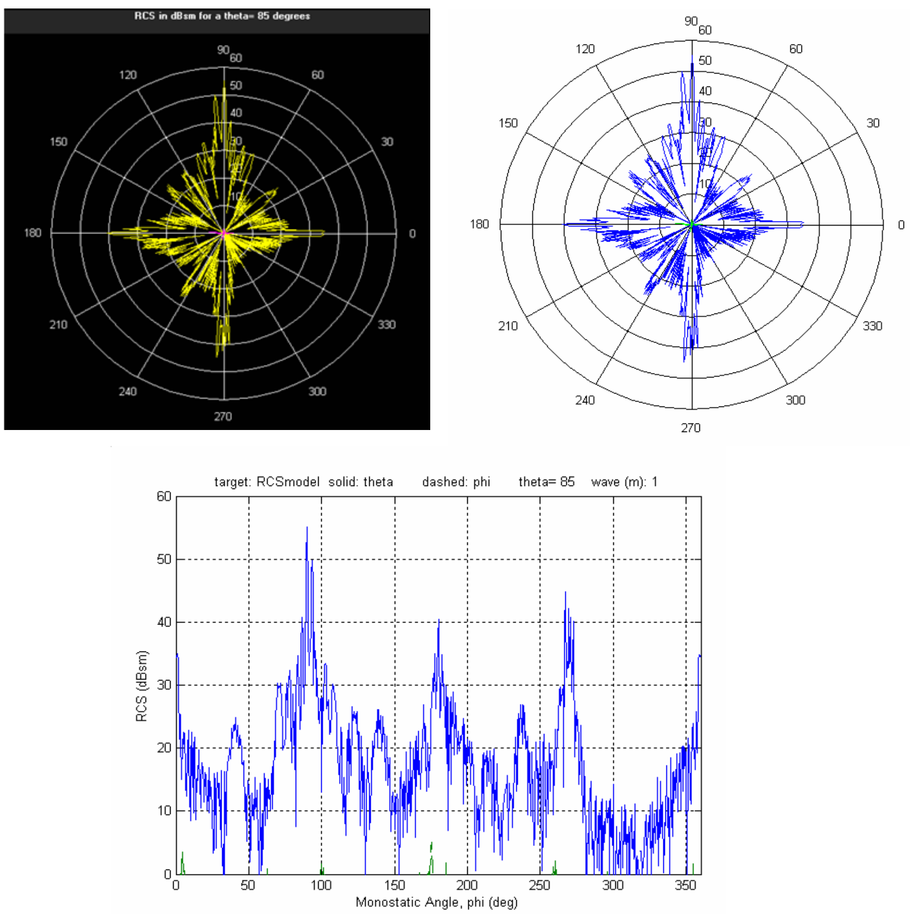


Figure 50. POFACETS Results

(2) Conclusion:

As shown in Figure 50, we can clearly see that the POFACETS results led to significantly lower numbers than the empirical formula results. The median RCS was about 20dBsm. The broadside RCS (90 and 270 degrees) was in the 45dBsm while the minimum was significantly lower than 32dBsm.

d. Xpatch results:

Because the XPATCH software provides DOD baseline measurements, it was necessary to run it against our model. Due to distribution limitations, the program is run by Dr. David Jenn (ECE Department).

In order to use Xpatch, we first converted our ship's rhino file into a ".facet" file. We did this using the Cifer conversion utility included in the Urbana software that is available in the ECE microwave lab. The most important target information after the conversion process and some of the Urbana options are outlined next:

```
Target is Perfect Electric Conductor (PEC)
Target name: rhino3.facet
Length unit is meter
Target total facet surface area =   15106.79
Facets:  good=  696       bad(thrown  out)=  178
  absorb=  0
Target geometry: facet
1st bounce: z-buffer(FD)   Higher bounce: SBR
Edge diffrac: none
Ray divergence factor is set to 1
All mono-static rcs are in dBsm & angles in deg
```

Then, we provided Dr. Jenn with the "rhino3.facet" file. He run the program and provided us with the results in an ASCII format.

After plotting the results in Matlab (as shown in Figure 51, we noticed that the XPATCH results were very comparable to the POFACETS results. The median RCS was about 20dBsm, while the broadside angles led to an RCS in the vicinity of the 45dBsm.

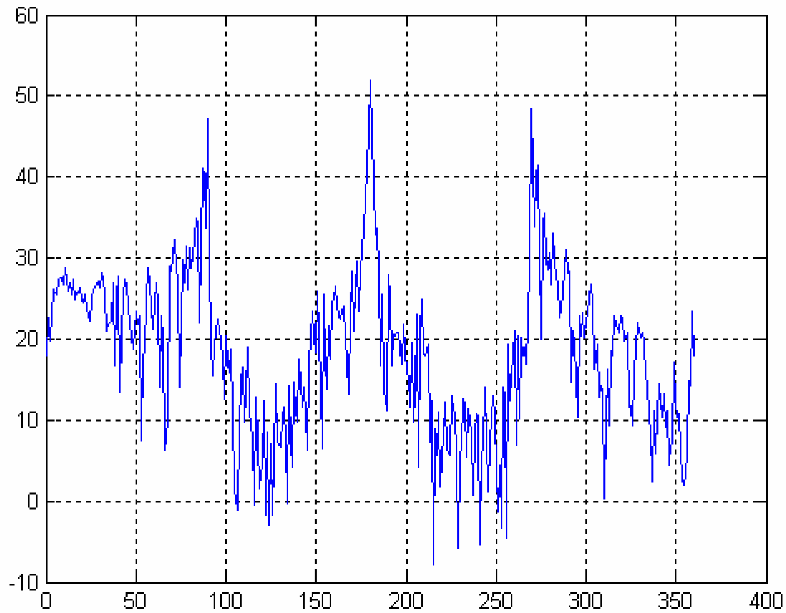


Figure 51. XPATCH RCS calculations results

16. References

[1] Schleher, C., "Electronic Warfare in The Information Age", *Electronic Warfare Support*, Norwood, MA: Artech House, 1999.

[2] Schleher, C., "Electronic Warfare in The Information Age", *Expandable and Decoy Systems*, Norwood, MA: Artech House, 1999.

[3] Herskovitz, D., "Killing Them Softly", *J. Electronic Defense*, Aug. 1993.

[4] Pollock, D., The Infrared & Electro-optical Systems Handbook, Vol. 7 Countermeausres Systems, Bellington, WA: SPIE Optical Engineering Press, 1993

[5] EC4690 Class notes

[6] TSSE 2003 final project

[7] www.drs.com

[8] TS3001 Class notes

[9] MIL-HDBK-217, Military handbook, *Reliability and Failure Rate Data for Electronic Equipment* (Washington, D.C.: Department of Defense)

[10] Blanchard, B.S., and W.J. Fabrycky, *Systems Engineering and Analysis*, 3rd ed., prentice hall, Inc. Upper Saddle River, N.J., 1998

[11] FN Manufacturing, Inc

D. PROPULSION

1. Propulsion Plant Analysis

An in-depth analysis of propulsion plant alternatives was conducted. The possibilities ranged from purely mechanical drive to purely electrical drive to a combination of the two. Ultimately, the benefits of electric drive far outweighed the other alternatives, and therefore an integrated propulsion system to the electrical distribution system was chosen for the HSAC.

a. Propulsion Plant Trade Off Analysis

There are many aspects to consider when selecting a propulsion plant type. Among those are: size and weight of the propulsion plant, efficiency, reliability, power, acceleration, and modularity. Most of the possible marine propulsion plant types were researched and considered in light of the Operational Requirements Document (ORD) and the Mission Needs Statement (MNS). The propulsion plants considered were: Conventional Steam Plants, Nuclear Steam Plants, Fuel Cells, Diesel Engines, and Gas Turbine Engines.

b. Conventional Steam Plant

Conventional steam plants are very efficient at low speeds. High power is also available for high speeds even though efficiency is low. Another advantage of steam plants is the ability to use steam for many auxiliary systems. In addition to these advantages, a steam plant is easy to start up, but start up time is long and requires a high volume and weight. Steam plant fuel efficiency is low, therefore requiring much more volume and weight for fuel storage. Manning for a conventional steam plant is high, and maintenance demands are extensive due to long overhaul periods. Based on design considerations such as needing a high speed vessel to carry large amounts of cargo, the conventional steam plant was removed from further consideration.

c. Nuclear Steam Plant

Nuclear power plants are highly efficient at all speeds and powers. Large storage volumes for fuel are not required due to the nuclear reactor having its own fuel. There are however, many disadvantages to a nuclear powered steam plant. Nuclear power plants are very heavy due to shielding and require extensive manning which is not necessary for other plant types. Radiation and political issues are also significant concerns. Nuclear power plants take an extremely long time to start up and require extensive maintenance practices. All information with regard to nuclear power is classified, therefore it would be difficult to obtain information and conduct the required analyses. Based on the above disadvantages and practical difficulties, a nuclear steam plant design was removed from further considerations.

d. Fuel Cells

Fuel cells are a clean, efficient source of power. However, even though there is promising technology in the field of fuel cells, current capabilities are well below that required by the Joint ACCESS. Current technology power levels are significantly below the required power level of approximately 60 MW at full speed and load. Based on this technology gap, fuel cells were removed from further consideration.

e. Diesels

Diesel engines are very cost efficient and have low specific fuel consumption. In contrast, however, diesel engines have low power to weight ratios and have intensive manpower requirements. Diesels also require large storage volumes for fuel oil. Another disadvantage of a diesel engine is that in order to meet the power requirements of the Joint ACCESS, multiple engines per shaft would be required which leads to space and arrangement problems. Based on these disadvantages, diesel engines were removed from further consideration.

f. Gas Turbines

Gas turbines have many features and characteristics that make it an attractive option for surface ships. Gas turbines are modular in design, one can be removed for maintenance and it can either be repaired or replaced with a new, identical gas turbine. Gas turbines have high power to weight ratios, and are very efficient at the high power requirements of the Joint ACCESS. Gas turbines have very fast startup times and require little maintenance and manning. Gas turbines have low noise signature compared to diesels and are a very reliable source for high power applications.

Gas turbines typically do have high infrared signatures, but this disadvantage pales in comparison to the advantages of gas turbines. Due to the fact that gas turbines are a reliable, efficient power source currently on many naval combatants, gas turbines were chosen as the power plant for the Joint ACCESS.

2. Gas Turbine Comparisons

a. ICR WR21

The ICR WR21 (Intercooler Recuperator) combines the most advanced technological advancements in gas turbine machinery. The Intercooler Recuperator can reduce specific fuel consumption by as much as 14% over single cycle gas turbines, as well as greatly reduce the infrared signature due to the intercooling stage. The main disadvantage of this gas turbine is the very high weight compared to other single cycle gas turbines. Other disadvantages are high volume, cost, and risk associated with the newer design.

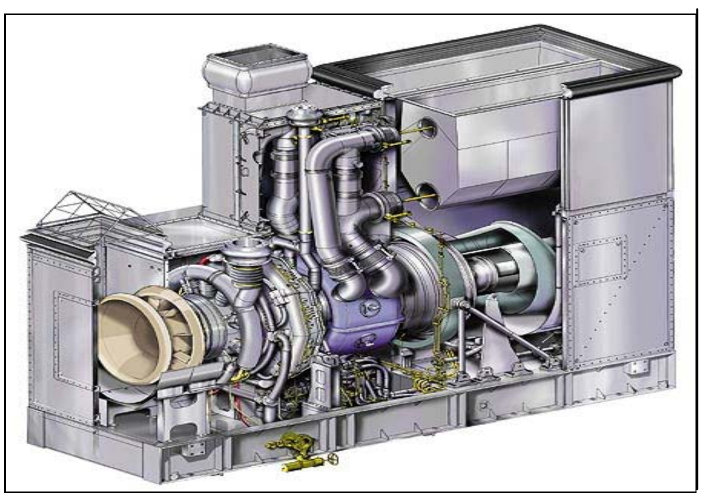


Figure 52. ICR WR21 Gas Turbine

b. MT30 TRENT

The MT30 Trent is a high efficiency, high power gas turbine. The power available from the MT30 is 36 MW, therefore, two of them would be sufficient to overcome the total power required at full speed and load of the Joint ACCESS. The MT30 is also efficient at lower power levels, which is uncommon for gas turbines. The major disadvantage of the MT30 is its excessive volume compared to other gas turbines.

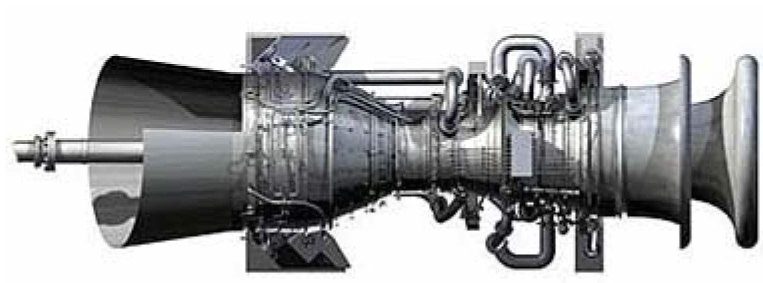


Figure 53. MT 30 Gas Turbine

c. LM 2500

The LM2500 is a proven reliable gas turbine and can be found in many naval applications. The LM2500 is fairly efficient and requires minimal maintenance (40 hours of maintenance out of every 10,000 hours of operation). The efficiency of this gas turbine can be greatly increased by using the exhaust for other applications such as boilers and other auxiliary systems. The LM2500 has a higher volume and lower power output than the improved version (the LM2500+); therefore, it was removed from further consideration.

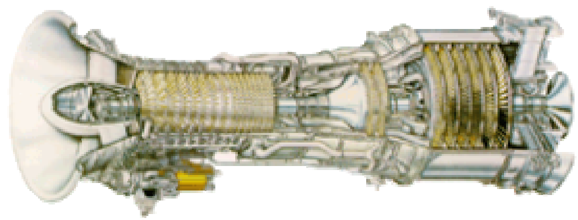


Figure 54. LM2500 Gas Turbine

d. LM 2500+

As previously stated, the LM2500+ is an upgraded version of the LM2500. This engine has lower installed cost per horsepower lower life-cycle cost than its predecessor. The LM2500+ operates at 3600 RPM to achieve 40,000 brake horsepower (BHP) with a single cycle efficiency of 39% operating at ISO conditions. The LM2500+ delivers 25% more power than the LM2500 primarily by adding another compressor stage on the front of the LM2500 compressor and increasing the airflow through the engine by as much as 23%. The LM2500+ is one of the most desirable on the market for high power applications primarily due to its high efficiency and reliability, low SFC, and modularity.

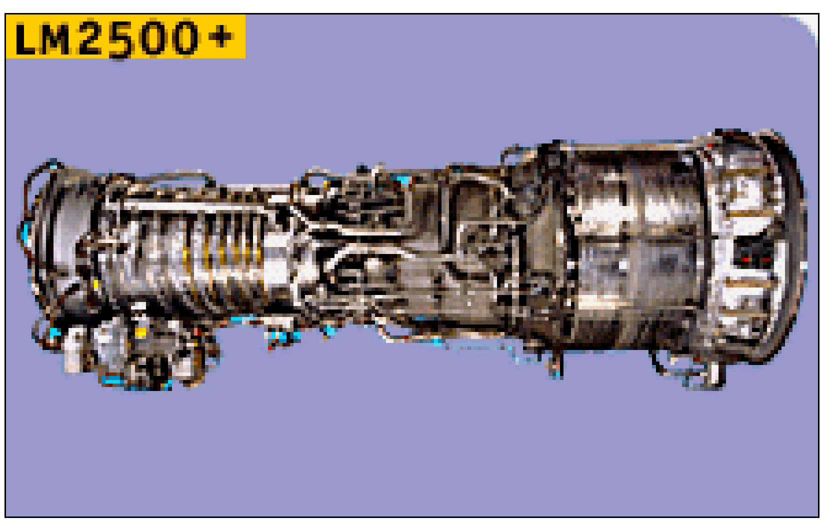


Figure 55. LM2500+ Gas Turbine

e. LM 1600

The LM1600 is another high-efficiency gas turbine primarily due to the high pressure ratios of the compressors, high turbine inlet temperatures, and conservation of cooling air. This gas turbine is fairly small, and power output is only around 13 MW. Even though this gas turbine has a high power to weight ratio, the Joint ACCESS would require at least 5 of them, so the LM1600 was removed from further consideration.

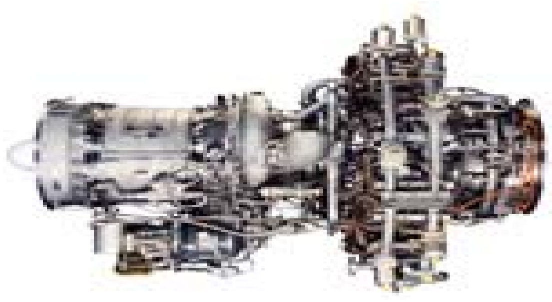


Figure 56. LM 1600 Gas Turbine

f. LM 6000

"The LM6000 is the most fuel-efficient simple-cycle gas turbine in its size class today, delivering more than 40 MW with a thermal efficiency over 40%." (Reference [internet www.geae.com/engines/marine/lm6000.html]) The LM6000 is the ultimate in single cycle engines with regard to efficiency and power to weight ratio. The main disadvantage of this engine is the requirement for a large, heavy water cooling system. Also, two LM6000 engines would be needed for a total of 80 MW which is significantly more than the required 60 MW of the Joint ACCESS. Due to the high volume and weight requirements for the cooling system, the LM6000 was removed from further consideration.

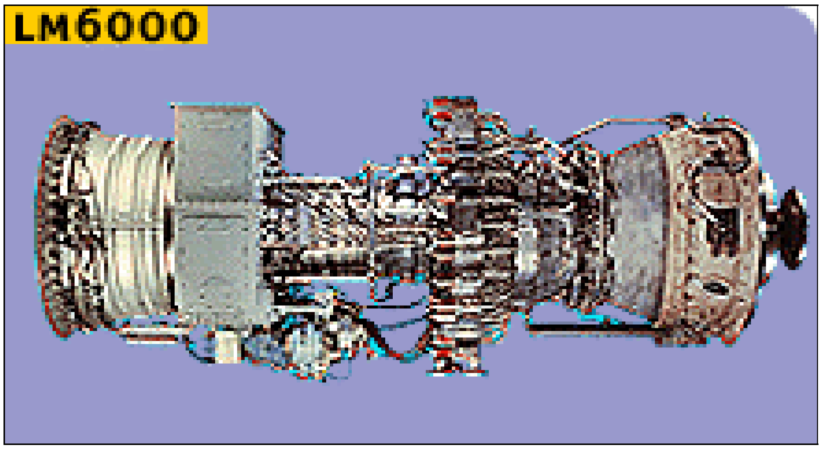


Figure 57. LM6000 Gas Turbine

As previously discussed, the LM1600 was removed from consideration due to the fact that it is too small for our application. The LM6000 was removed from further consideration due to the need for a high volume and weight water cooling system. The LM2500 was removed from further consideration since the LM2500+ can provide 25% more power at a significantly lower volume. Based on the following figure, the ICR WR21 was removed from further consideration due to its excessive weight over the other gas turbines.

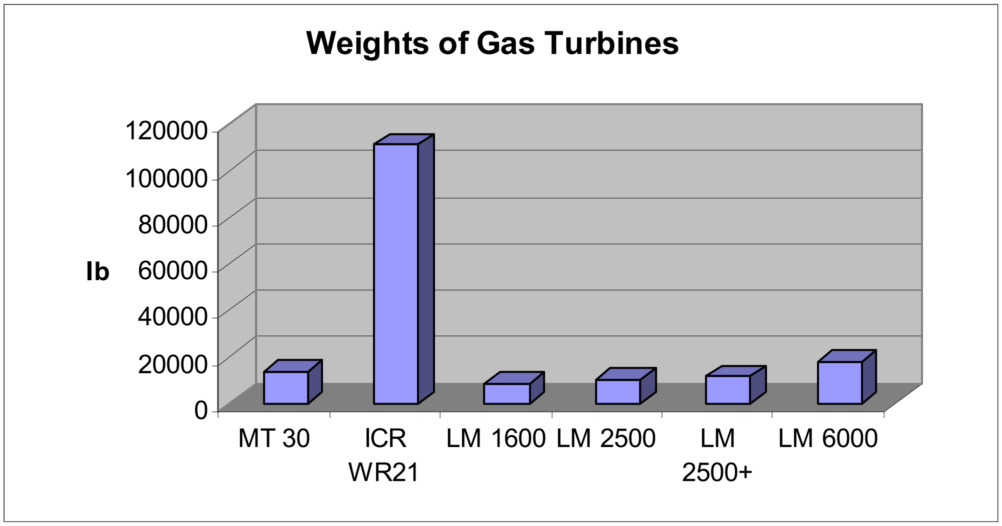


Figure 58. Weight Comparison for Gas Turbines

Only the LM2500+ and the MT30 Trent remained as feasible gas turbines for the Joint ACCESS, therefore, the LM2500+ and the MT30 were chosen for further comparison for the final selection.

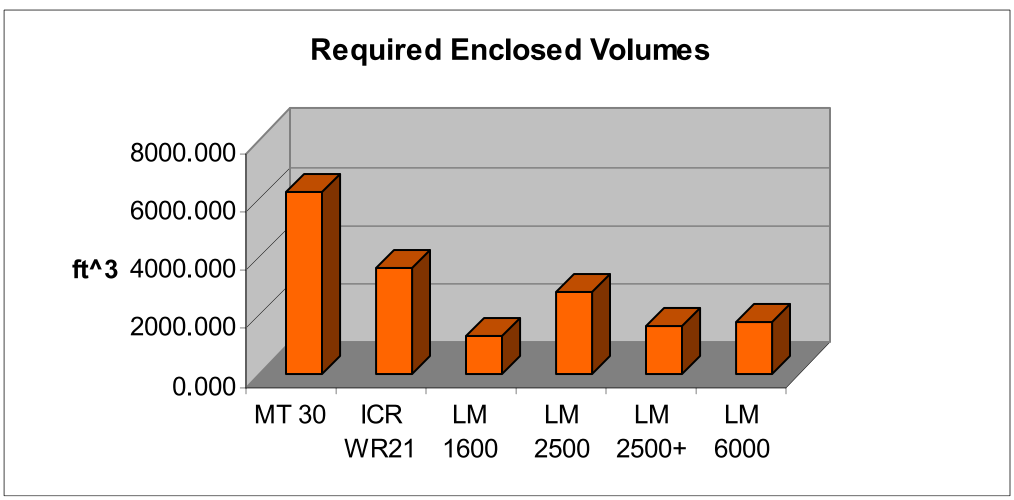


Figure 59. Volume Requirements for Gas Turbines

Resistance calculations of the hull form were used to generate the specific power requirements for propelling the Joint Access, as shown in the next figure power versus speed.

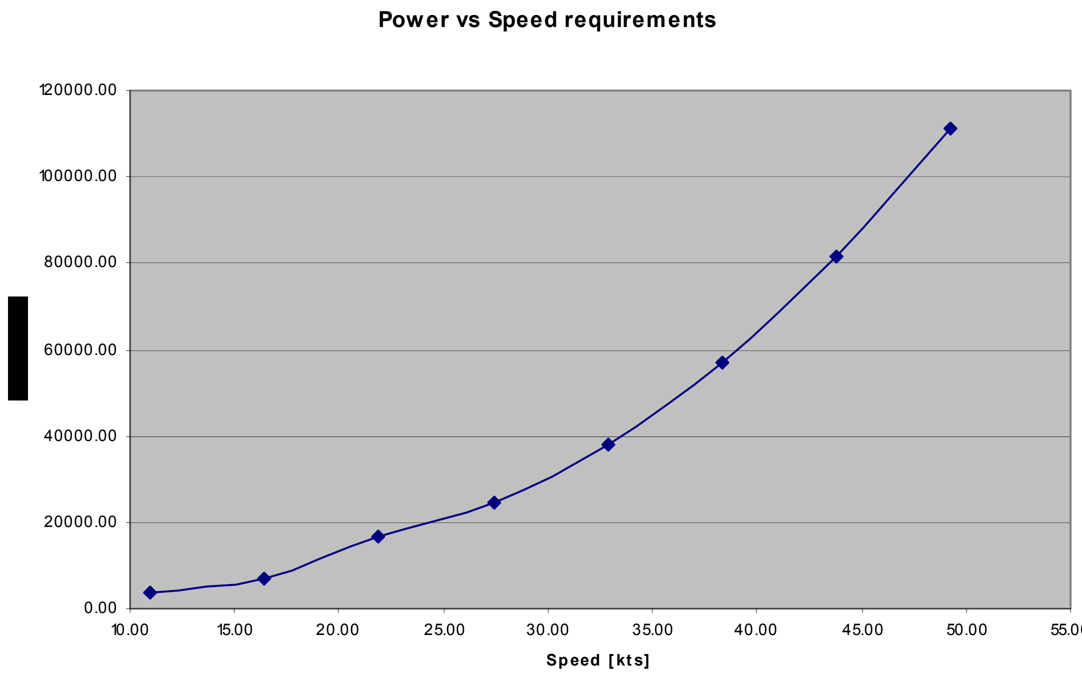


Figure 60. Joint ACCESS Power vs Speed

The ship required 38000 HP for achieving a speed of 33 knots, including the required electrical load of about 2 MW. As stated above the two engines that could fit better in the vessel were the LM2500+ and the MT30. These two engines were examined for their efficiency, performance and better utilization as far as vessel’s needs.

Both engines could power the ship up to 33 knots, but for a desired speed of 40 knots, a second engine must be installed. The MT30, even though it gives about 5.5MW more that the LM2500+, could not offer a speed more than 37 knots. Fuel efficiency and consumption charts are presented as the next figures for the two gas turbines.

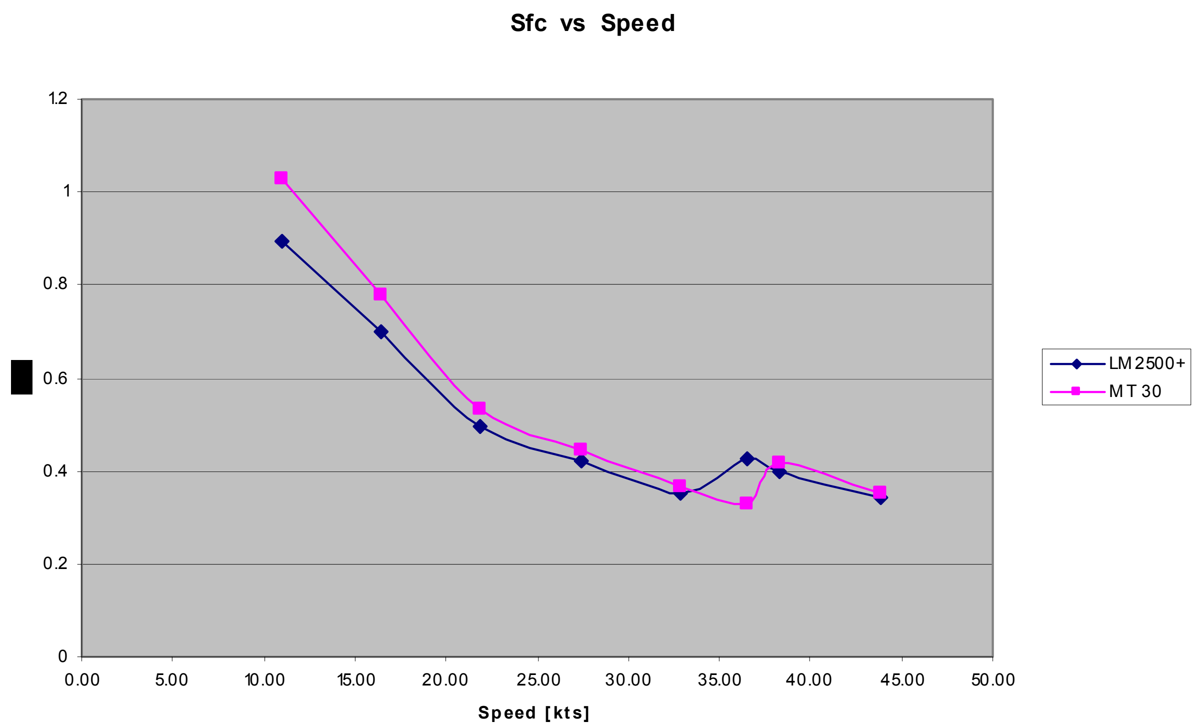


Figure 61. LM 2500+ and MT30 Fuel Efficiency Comparison

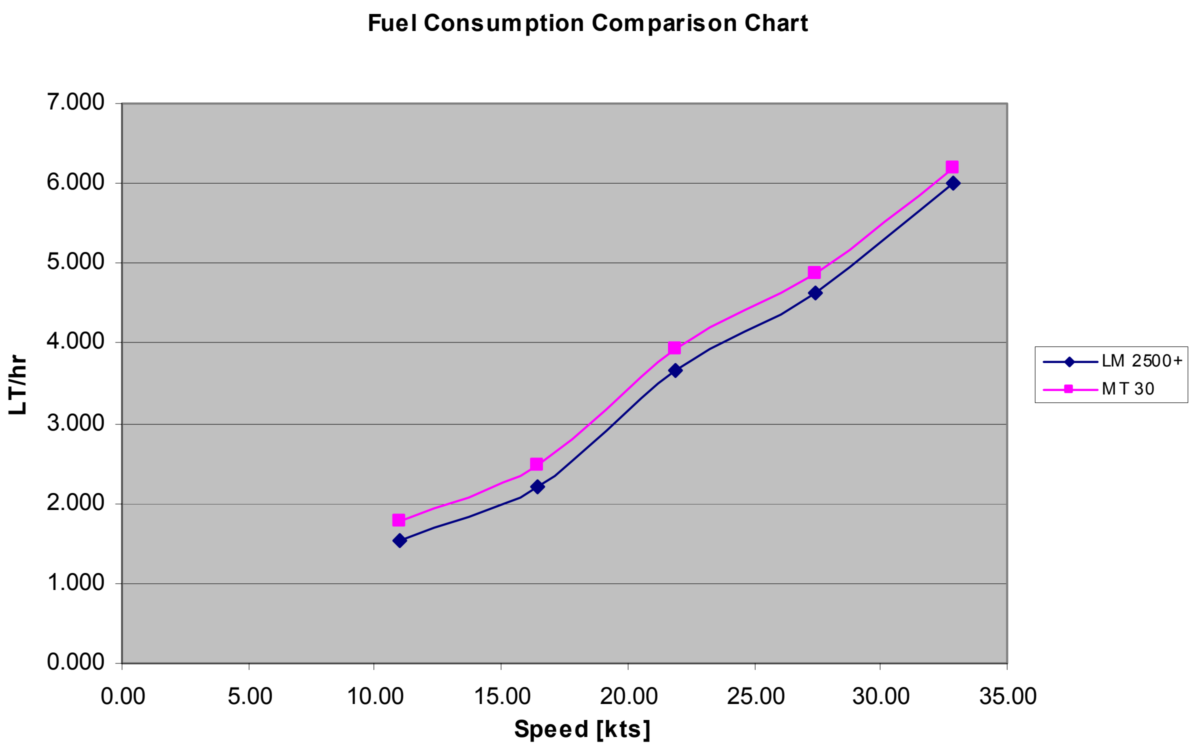


Figure 62. LM 2500+ and MT30 Fuel Consumption Comparison

An analysis of the fuel required for an endurance of 2600NM was conducted, assuming a cruising speed of 33 knots, which is achievable from both engines, and the LM2500+ required 3% less fuel.

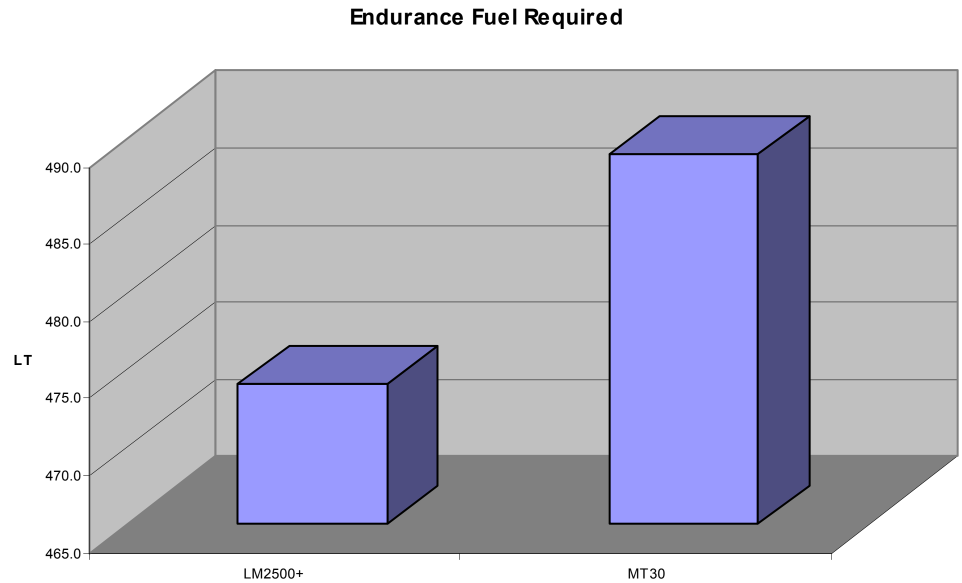


Figure 63. LM 2500+ and MT30 Endurance Fuel Comparison

The difference between the LM2500+ and MT30 Trent was not dramatic, therefore the LM2500+ had to be examined to determine how much fuel would be required to attain the desirable endurance. According to the next plot, the knee of the curve occurs at the desirable cruise speed of 33 knots for the Joint ACCESS.

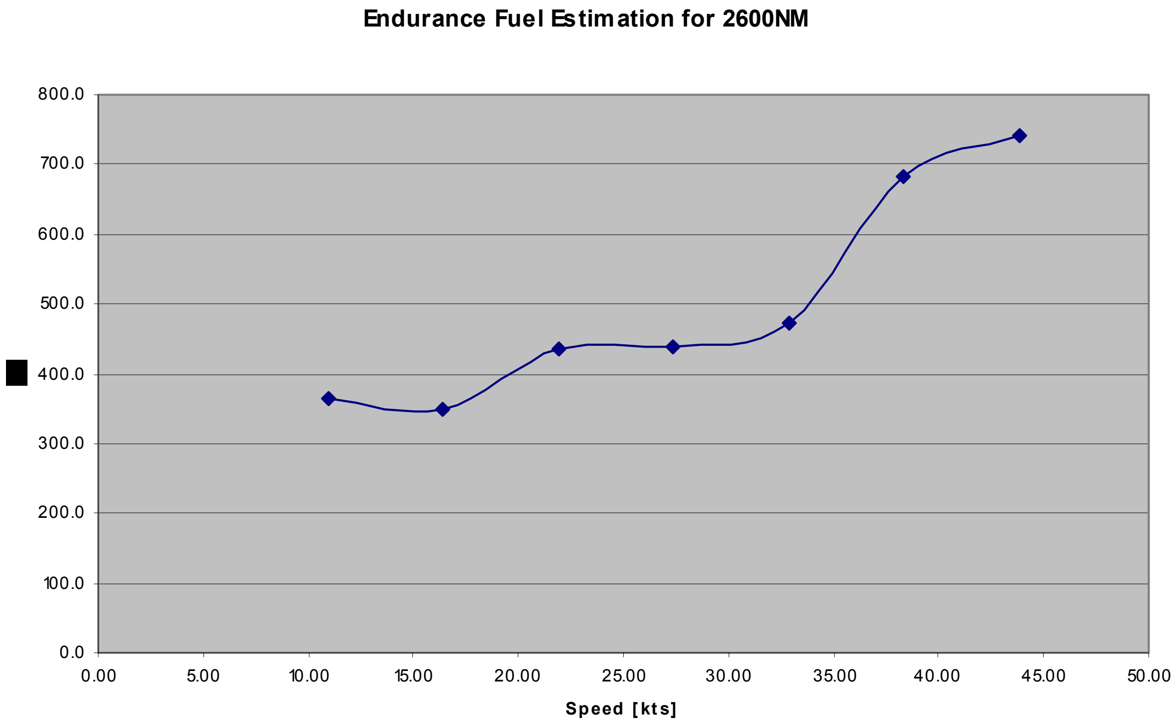


Figure 64. Joint ACCESS Fuel Estimation

The LM2500+ was chosen as the prime mover because it outperformed the other engines in volume, weight, and efficiency requirements and because of the power requirement of about 60 MW; it fits very well within the design of the Joint ACCESS. The vessel will use one Gas turbine for cruising up to a speed of 33 knots and a second one for achieving higher speeds up to a maximum of 43 knots during operational phases for deploying cargo. A third relatively small gas turbine will be used as an emergency power back up and for providing the required power during harboring. The Allison AG9140 was selected to serve as the back up generator

3. Electric Propulsion Motor Trade Off Analysis

A propulsion motor trade off analysis was conducted between conventional motors, DC Homo-polar motors and High Temperature Superconducting (HTS) AC Synchronous motors.

Both the DC Homo-polar and the HTS are superconducting motors, and a comparison was done between superconducting motors and conventional. The table below shows a comparison of superconducting applications to conventional.

Table 9. Comparison of Superconducting Electric Power Applications to Conventional Technologies

Superconducting Electric Power Applications	System Performance	Reliability & Maintenance	Efficiency	Operating Lifetime	Installed Cost [1]	Competing Technology
AC synchronous generators	Improved steady state and transient	Must be equivalent	Higher by 0.5-1.0%	Longer	Equal or higher	Gaseous and liquid-cooled
AC synchronous motors	No change	Must be equivalent	Higher by 1.0 to 2.0%	Longer	Higher	Induction and addition of VSD
AC underground transmission	Ability to double the rated capacity	Must be equivalent to conven. undrgd.	Slightly higher	Longer	Higher	▪ Cu/A1 ▪ "FACTS" ▪ extruded
Fault-Current Limiters for transmission & distribution	Reduces transient currents on system components	Comparable to circuit breakers	More efficient T & D system	Longer than circuit breakers	2 to 10x circuit breaker	▪ Solid State breakers ▪ Reactors ▪ "FACTS"
Transformers for transmission & distribution	No change [2]	Must be equivalent to conven. transf.	Slightly higher by 0.1-0.2% [3]	Longer	Higher	▪ Iron Core
Storage Superconducting Magnetic Energy Storage (SMES)	Improves power quality and conditioning, spinning reserve, VAR & AGC	Comparable to other T&D components	Most efficient storage technology	Longer	Higher	▪ Flywheels ▪ VAR Comp. ▪ Batteries ▪ STATCOM ▪ Capacitors

Superconducting technology greatly increases the overall efficiency of the system. Also, superconducting technologies have longer lifecycles than conventional. The only downside of superconducting motors is higher cost, but this is mitigated by having a longer lifecycle. Also, superconducting motors are much smaller than conventional, and space consideration is of extreme importance onboard the Joint ACCESS.

After comparing conventional motors with superconducting motors, conventional motors were removed from further consideration.

a. DC Superconducting Homo-Polar Motor

For propulsion R&D purposes, the Navy built a 25,000 HP induction motor that weighs 117 tons and has a volume of 2500 ft^3. A DC homo-polar motor that provides 60% more power weighs less than a third, and occupies a volume roughly half of the R&D induction motor. The DC homo-polar motor generates a very low noise signature, so it is quite stealthy. The downside of this motor is that it requires two cryo-coolers, each weighing aroung 200 lbs.

b. HTS AC Synchronous Motor

As shown in the figures below, the American Superconductors HTS AC Synchronous motor is approximately one fifth the size and one third the weight of a conventional motor of equivalent power.

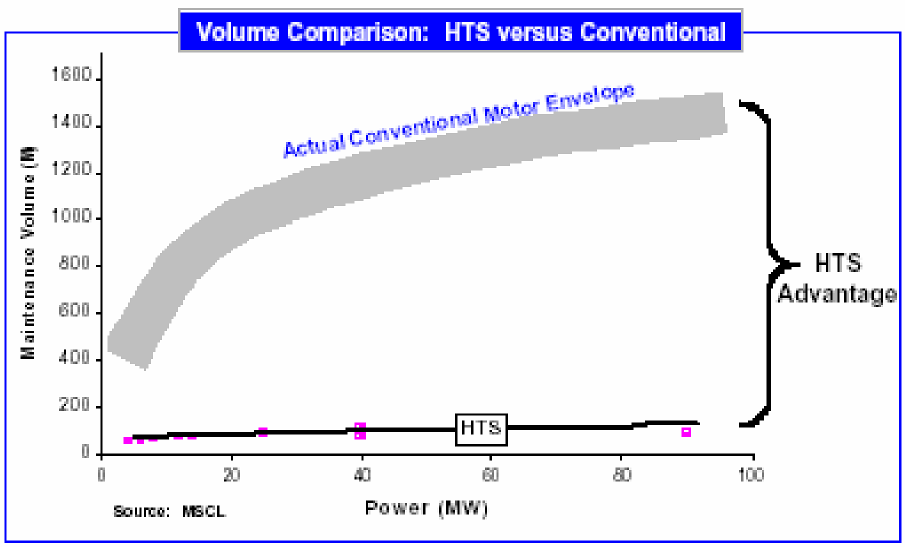


Figure 65. Volume Comparison of HTS vs. Conventional Motor

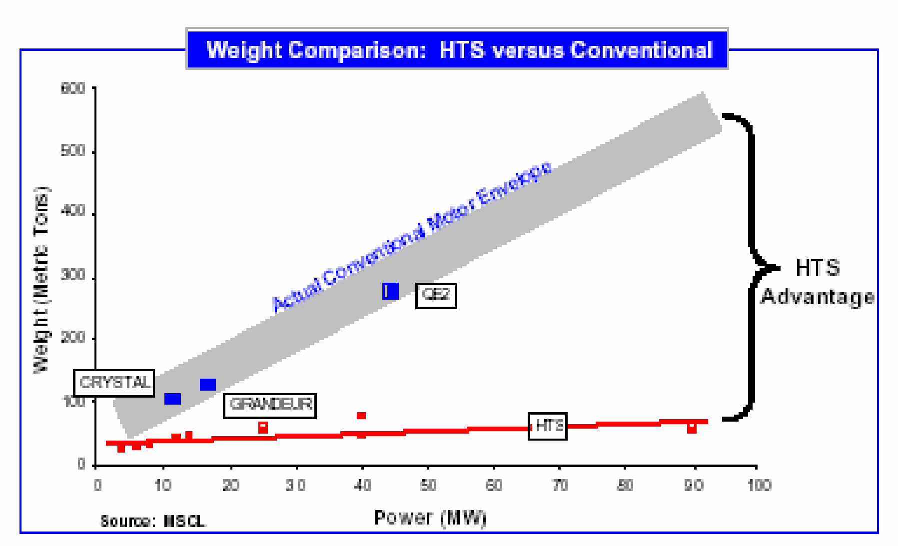


Figure 66. Weight Comparison of HTS vs. Conventional Motor

The HTS can be driven at several times the rated output for short periods of time, giving the ship added operational flexibility when emergency propulsion is required.

The HTS is also smaller than the DC homo-polar motor as shown in the figure below.

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

Figure 67. HTS AC Synchronous vs. DC Homopolar Motor Dimension Comparison

The design team was informed by a representative of the manufacturing company that the dimensions of the desired motor of 15 MW would not be much larger than their current 5MW motor due to the relative high RPMs that the propulsors will operate. Therefore, the HTS motor will fit very well inside the narrow main hull form.

Based primarily on the size and weight advantage of the HTS over the DC homo-polar motor, the HTS was chosen as the electric drive motor for the Joint ACCESS

4. Propulsor Trade Off Analysis

The most popular available technologies were taken into account for the trade off studies of the propulsor type. These are propellers, electrical pods and water jets. Since there was a high-speed requirement for the design, water jets have an overall advantage compared with the other technologies.

a. Propeller

The disadvantages of conventional propellers are: increased navigational draft, lower efficiency at higher speeds, and limitations that could be introduced because of the narrow beam and shallow draft that was desirable for the Joint ACCESS. Nevertheless, propellers are the most popular propulsor solution with the smallest risk.

b. Podded Propulsors

The disadvantages of podded propulsors are the additional amount of resistance, increased aft draft, additional drive trains, and the total complexity of the system. Considering our hull dimension limitations and the beachable operational concept of our craft, despite their significant maneuverability, podded propulsors are not a viable alternative for the JOINT ACCESS.

c. Conventional Water Jets

The biggest weakness of water jets is the added water weight problem. The water that fills the duct for the jet to operate, and the additional infrastructure required, greatly increase the ship's aft weight.

d. Bird-Johnson AWJ-21

This great weakness had been overcame with the selection of the Rolls Royce Advanced Water Jet propulsor application (AWJ-21™) by Bird – Johnson company. The AWJ-21™ is a podded water jet which is mounted at the aft part of the hull as shown in the figure below.

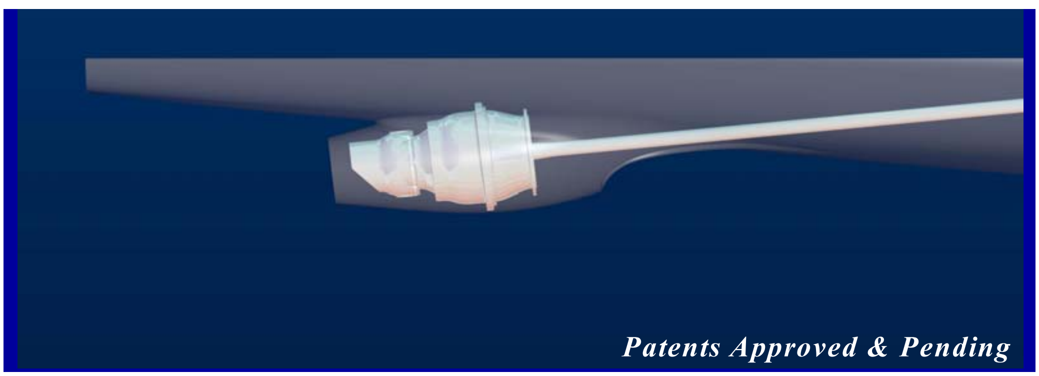


Figure 68. AWJ-21™ Integrated into Hull

The Joint ACCESS will be propelled by four AWJ-21™ s, each driven by an HTS motor as stated in the above section. The AWJ-21™ is based on an advanced mixed-flow pump design which is highly efficient even at low speeds in contrast to conventional water jets. Another basic attribute is the patented underwater discharge configuration which has been incorporated into its design. These two basic characteristics offer an improved cavitation performance, greater tolerance to poor inflow conditions, and reduce the jet-related wake disturbances and noise level, which gives this water jet a stealth character, as the manufacturing company asserts.

The AWJ-21™ features an integrated steering and reversing system with a single hull penetration which provides superior maneuverability even at low speeds. This will offer a great potential to the concept of deploying cargo by "touching" the beach with the bow and maintaining ship's position by self power to the jets, in contrast with old beachable vessels that had to go onto the beach. Furthermore, the need for reversing drive shaft direction is eliminated. The next figure presents a cut-away view of the water jet.

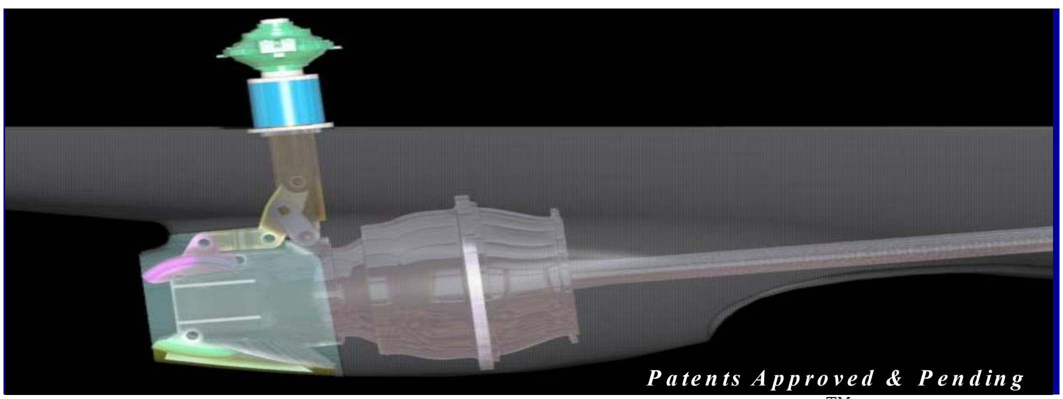


Figure 69. Cut-Away View of AWJ-21™

Another advantage is that they need not be considered during "Mediterranean" mooring maneuvers of the vessel, because they are not exposed since they are not placed at or near the transom. Another great benefit is that they typically will not have an impact on the navigational draft. Rolls Royce provided the team with data that they used for estimating the operational RPM and size. Despite the fact that the team did not have specific dimensions and characteristics for the 15 MW jets that were chosen for the design, size and RPM vs. power were plotted in order to make a rough estimation of the jet's features. From Figure 70 it can be seen that the AWJ-21™ of the JOINT ACCESS will operate at a maximum power around 450 rpm and from Figure 71 that the approximate diameter for the desirable jet of 15 MW will be around 1.70 m.

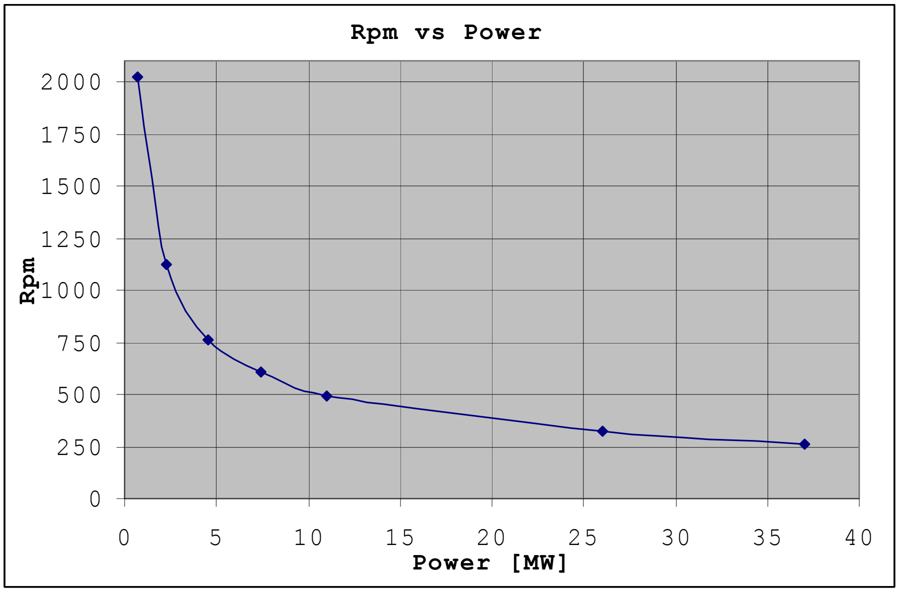


Figure 70. AWJ-21™ Speed vs. Power

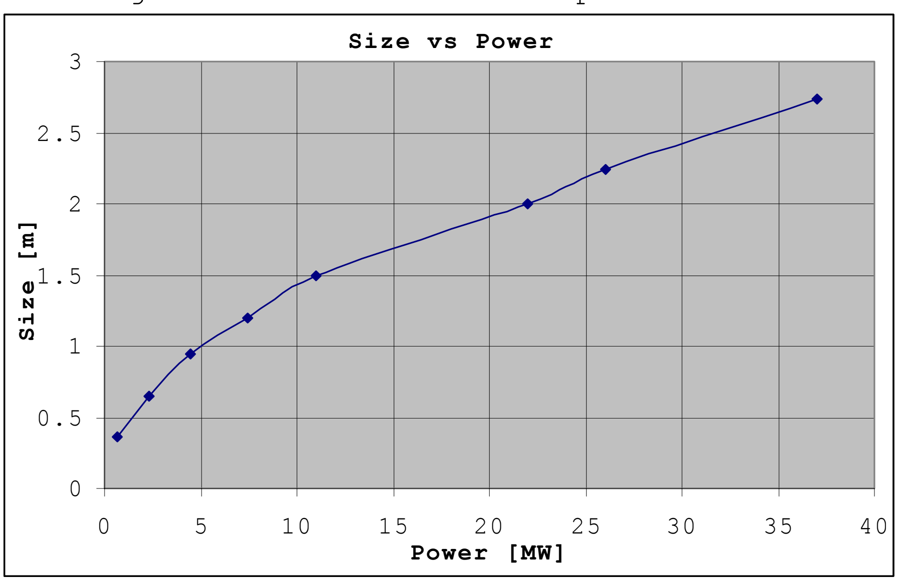


Figure 71. AWJ-21™ Size vs. Power

Due to the fact that the aft hull of the vessel sweeps up 3 m from the mid section until the transom, it leaves plenty of clearance for placing the water jet with no impact on the ship's draft. A comparison was conducted with a conventional propeller, using a propeller optimization program, resulting in a propeller diameter of 4.5 m which would result in a 2 m or more increase of the aft draft.

The technology this water jet employs allows it to operate at 2 – 3 times the rpm of a conventional propeller and requires less torque for driving it, therefore results in electric drive motors with a smaller size and weight. This improvement makes the AWJ-21™ ideal for electric driven systems.

Also, by examining the data of the Kamewa water jet SII series that is presented in Appendix VIII, the team concluded that the water that is inside the system weighs approximately 60-65% of the total corresponding structural weight. Eliminating this water column is extremely beneficial to reducing the total weight of the propulsion system.

For all the reasons above the AWJ-21™ is more than adequate to fulfill the operational concept of the Joint ACCESS and is selected as the ship's propulsor.

E. ELECTRICAL DISTRIBUTION

1. Distribution Design Analysis

To provide a robust, flexible, and reliable electrical distribution system for the Joint ACCESS, we decide to pursue a DC zonal distribution system. The DC Zonal distribution allows for simpler and faster fault detection by isolating faults to their corresponding zones. Since the generator frequency is decoupled from the actual distribution equipment, the prime movers can be run at their optimum speed. Finally, the zonal distribution itself allows for greater survivability in the event of battle damage.

The DC zonal distribution works well in the Joint ACCESS design for several reasons. First with a significantly reduced crew size, the DC zonal distribution system allows control systems to isolate the general and possibly the exact location of the fault. This greatly reduces the number of men and man hours required to isolate and repair the problem. Secondly, the Joint ACCESS' offensive and defensive capabilities are limited due to its primary mission, relying on the protection of "Sea Shield" for overall defense from enemy attacks. The DC zonal distribution helps increase the survivability of the Joint ACCESS in the event of a casualty and helps ensure that it can continue on and complete its mission. Finally from the propulsion analysis, it was determined that an electric drive would propel the ship. The DC zonal distribution will tap directly off the propulsion bus without causing any other design changes.

2. Actual Distribution

The distribution system that was implemented was derived from the Office of Naval Research (ONR) Challenge Problem. This reference system was chosen due to its emphasis on creating a reliable, dependable, and survivable system that not only met the current needs of the ship but also allowed for the expansion of future high power weapons. Figure 72 depicts overall electrical distribution with an example of one DC zone.

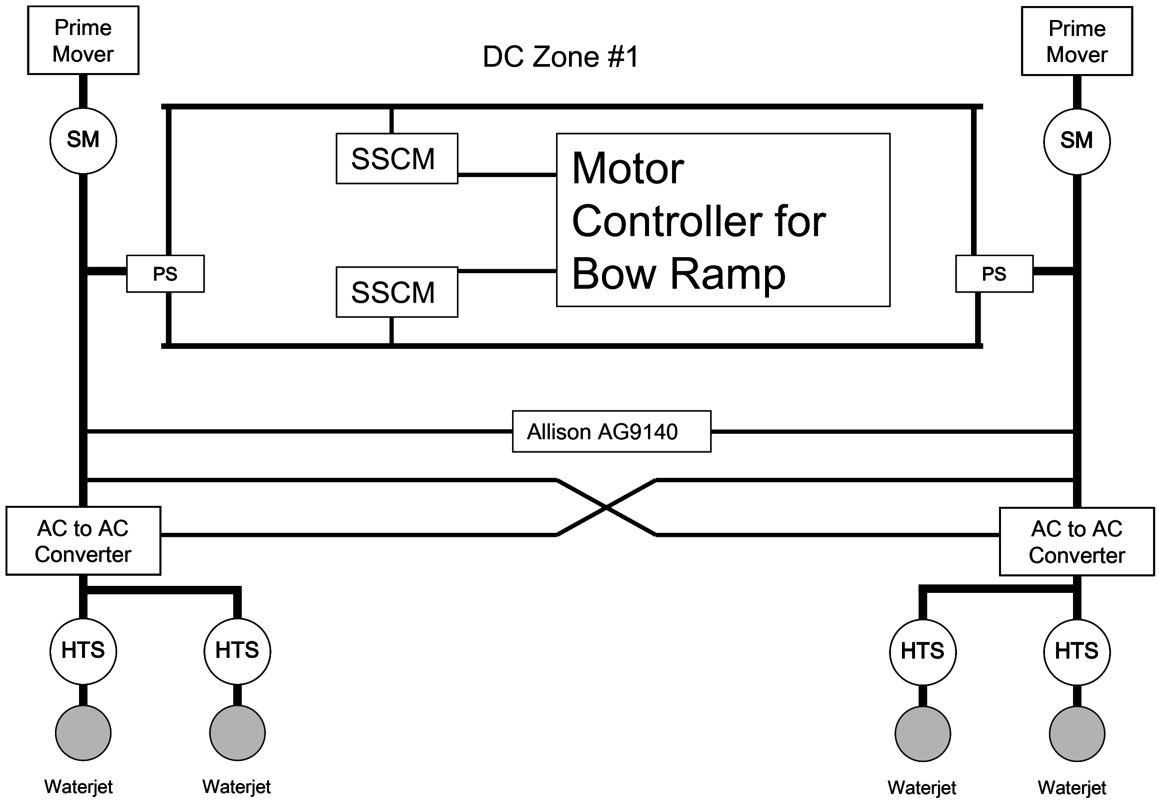


Figure 72. Joint ACCESS Example Electrical Distribution

To provide the total 58MW required for propulsion and the 2MW for combat systems and hotel loads while underway, two LM2500+ gas turbines producing 30.5MW each (61MW total) were used as the prime movers. The LM2500+ gas turbines each power a 13.8kV AC bus, one on the port side and the other on the starboard side. Each AC bus goes through an AC to AC converter and powers two HTS AC synchronous motors which drive two waterjets. The AC busses are cross connected so that either LM2500+ can provide power to all four HTS AC synchronous motors in the event of a LM2500+ casualty.

For powering the ship in port, an Allison AG9140 producing 3.2MW is connected to both port and starboard AC busses. In the event of one or two LM2500+ casualties, the

AG9140 can supply combat system and hotel load power, along with limited propulsion power.

The combat systems equipment and hotel loads all draw their power off of port and starboard 1100V DC busses. Each buss is connected to the port and starboard AC busses via a power supply. The ship is then divided up into six zones as Figure 73 illustrates. Each of the six zones then pulls its power off of both the port and starboard DC busses.

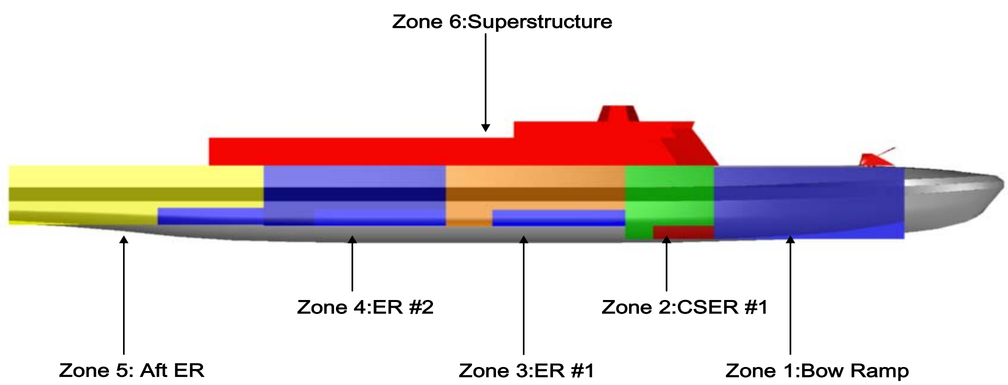


Figure 73. Joint ACCESS DC Zonal Zones

3. References

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http://www.usna.edu/EPNES/ONR_Control_Challenge.pdf

F. DAMAGE CONTROL

Use of an Automated Damage Control System (ADCS) will assist in the HSAC achieving the requirement for reduced manning. Use of this system in conjunction with concepts like DC Flex will enable a significant reduction in personnel needed to combat a casualty compared to the large number of personnel are assigned to damage control organizations onboard ships currently. The damage control system, including the chemical, biological and radiation warfare system is described below.

1. Detectors

The following proposed fire detection systems, smoke detectors, carbon monoxide detectors, fire and flame detectors, CCTV system, heat detectors, smart micro sensors, humidity detectors, and liquid level detectors will be utilized onboard the for HSAC.

A ship-wide array of sensors will allow continuous monitoring compartment by compartment. The system will indicate the exact location of the damage. Progressive damage or changes in damage will be updated or reported in real time. Controlling actions can then be directed to the exact area where required. The speed of the response will be increased by eliminating the need for investigators to search for the damage within zones able to bet detected. Multi-sensor fire detectors will monitor each compartment. Fiber optical or electrostatic smoke detectors, triple wavelength infrared flame, carbon monoxide, closed circuit television, and high performance optical, or fiber optical heat sensors will detect smoke and fires. Monitoring of a fire's progression from the first sign of smoke through the initiation of a fire will occur until the physical limits of the detectors are reached. Various alarm thresholds can depict different conditions from the same sensor. Safety of Life at Sea (SOLAS) guidelines were used in determining the type of fire and smoke detectors required in each space.

Compartments located below the damage control deck will also be monitored for flooding by liquid level detectors. Flooding detectors will consist of multiple sensors located from the bilge level to the overhead which will aid in the calculation of stability information. The detectors will be located to indicate the presence of liquid at 2 and 6 inches, and at heights to monitor flooding at 10%, 25%, 50%, 75%, and 100% of the Compartment.

All the remote operated valves and compartment accesses will also be monitored for their exact material condition. Paint lockers and pump rooms will be monitored for atmospheric content. Sewage spaces will be monitored for hydrogen sulfide gas. Air conditioning and refrigeration rooms will be monitored for refrigerants and low oxygen levels. Other appropriate monitoring will be conducted in spaces subjected to hazards that are present. Immediate notification to control stations will prevent unaware watch standers from entering the compartments. The type of detectors installed in each type of compartment is shown below in Table 10.

Table 10. Installation of Detectors Onboard

Compartment	3I	CCTV	HPO	FO	Smart	Humidit	Liquid
Machinery	X	X	X		X		X
Engine	X		X		X		
Magazine				X	X	X	X
Elect Equip	X			X	X	X	
Hanger	X	X		X			
Flight Deck		X					
CIC	X			X	X		
Bridge			X		X		
Cargo Deck	X	X		X			
Berthing			X		X		
Galley			X		X		
Passageways					X		
Paint					X		
Pump rooms					X	X	X
AC /					X	X	X

All sensors will be connected to a data network allowing the various processing centers to access the information. The processing centers in turn pass the information to the control centers for display and decision-making. Multiple interconnected data networks will be strategically routed throughout the ship with redundant networks in place to increase survivability of the system. Processing centers will send information to the control centers which will be able to evaluate the information or be set up to initiate automatic response to an alarm. Control stations will be located in main watch stations to including the Bridge, CIC, Damage Control Lockers, and Engineering Control Center. All control stations will have full control and display capabilities but not the ability to process the data. Therefore loss of a single control station will not adversely affect the system. Watch standers will be able to monitor the alarms and visually watch actions of the damage control organizations as they occur. Actions performed by damage control personnel will be added manually to the display by a control station operator.

On scene personnel would have wireless hand held input/output into the ADCS for direction and information update as needed.

2. Installed Detector Descriptions.

The following is the description of the installed Damage Control detectors installed on the HSAC.

a. Smoke Detectors

Photoelectric smoke sensors operate by projecting a beam of light across a sensing chamber. A photosensitive receiver detects changes in the projected light pattern caused by smoke particles within the chamber. These detectors provide good response to smoke with larger particles. However, they are subject to false alarms from other airborne particulates.[1] Optical detectors (including fiber optics) are based upon the photoelectric principle, except the beam is not confined to a sensing chamber and may be projected across open areas. These detectors can monitor areas up to 25 meters across, and areas subjected to high airflow rates. An ionization detector uses an extremely small quantity of radioactive material to make the air in the detector chamber conduct electricity. Smoke from a fire interferes with the electrical current and triggers the alarm. Smaller particles are detectable, as compared to the photoelectric sensor, providing higher sensitivity in critical compartments. These detectors can also be prone to false alarms from airborne particulate matter. Electrostatic detectors operate by detecting naturally charged particles across a set of electrodes. The principle of operation is the same as the ionization detectors without the need for a radiation source, as with an ionization detector. These detectors are not as sensitive as ionization detectors and do not alarms with "nuisance" smoke, such as burnt toast. These detectors generally require smoke from a developed fire to trigger an alarm.

b. Carbon Monoxide Detectors

Irrespective of how intelligent a smoke detector is it still needs the smoke to be introduced to the detector before it can be sensed and an alarm decision made. It is difficult if the protected area is large and open or the seat of the fire is in a hidden area such as a linen locker or adjacent unprotected room. [1] In a slow smoldering fire situation, typical of those started by discarded cigarette ends in soft furnishings or smoldering sawdust and other organic materials, smoke may not be given off for many minutes, even several hours in certain situations, after ignition. During this time the insidious carbon monoxide gas can build up to a level sufficiently high so that, on awakening, sleeping persons are too disoriented to evacuate the area. When smoke is given off and has reached the detector it can frequently be too late to stop the rapid spread of the fire. It is also well known that smoke escaping into corridors can cool and fall to the floor thus making them impassable by the time the smoke reaches the detectors at the ceiling and generates an alarm condition. Smoke can also be prevented from reaching the detectors by barriers of hot air building towards the ceiling. CO fire detectors react well to smoldering pyrolysis fire (wood), and glowing smoldering fire (cotton), but open plastic fires (polyurethane), and liquid fires (n-heptane) do not produce sufficient CO gas to trigger an alarm. CO fire detectors are particularly well suited to accommodation areas where there is a risk of slow smoldering fires causing death through the build up of CO, limiting occupants' ability to evacuate.

c. Fire/Flame Detectors

Infrared and ultraviolet detectors operate on the ability to distinguish respective radiation wavelengths that are only given off during a fire. These optical sensors are capable of monitoring large open areas by a single sensor. Infrared sensors can be subject to false alarms by such things as electrical arcs, whereas ultraviolet sensors are subject to false alarms by such things as arc-welding, electrical arcs, x-rays and lighting. Certain infrared sensors can also be used to monitor temperatures by annualizing the returned radiation spectrum. UV flame detectors are very sensitive to arc-welding, electrical arcs, x-rays and lighting. Although it is possible to eliminate false alarms from lighting and electrical arcs by the inclusion of time delay processing the elimination of false alarms from arc welding and x-rays is much more difficult to achieve. The detectors' sensitivity to these false alarm sources can be a significant problem. There are external influences, whose presence can have a detrimental effect on the ability of the detector to see flame radiation. The main inhibitors of UV propagation are oil mists or films, heavy smoke or hydrocarbon vapor and water films. These phenomenon are present in machinery spaces and on offshore platforms and can significantly reduce the intensity of the UV signal if present in the flame detection path. The shortcoming of UV detectors for offshore and machinery space applications has resulted in operators preferring the Triple Wavelength Infra Red Flame Detectors.

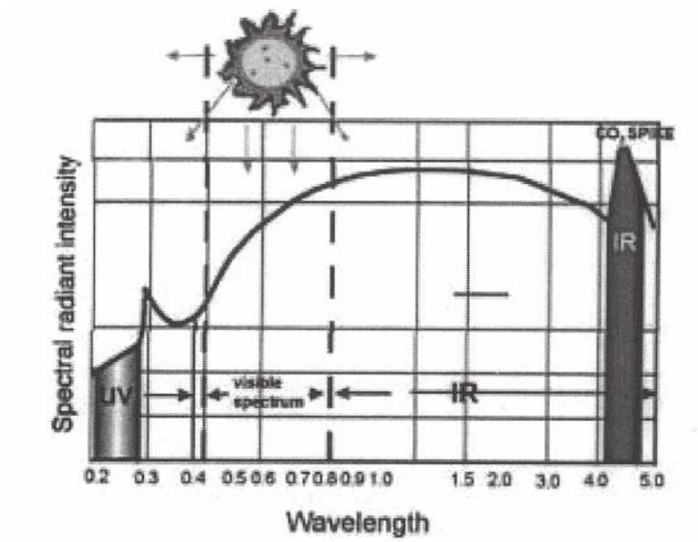

Figure 74. Typical Hydrocarbon Fire Spectrum[1]

The use of Triple Wavelength Infra-Red Detection principles has overcome the main shortcoming of Infra Red Flame Detectors, namely response to solar radiation and black body radiation.

d. Closed Circuit Smoke and Flame Detection System

The system uses standard CCTV Cameras. The system functions by comparing one frame with the next, so that any change can be evaluated. Compound Obscuration evaluates the total attenuation of light from the camera to the furthest point in the field of view. The algorithm is able to de-couple smoke quantity from smoke density i.e. large clouds of thin smoke can be identified as well as small areas of dense smoke.

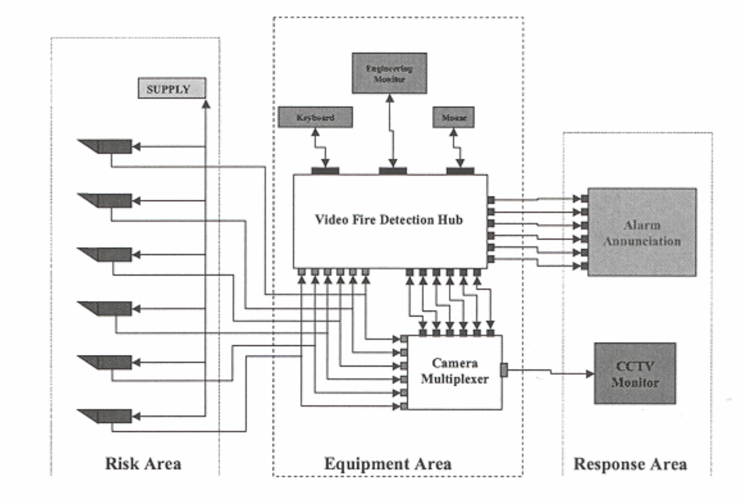

Figure 75. Schematic Video Smoke and Flame[1]

The system can also be used to detect visible oil mist, high-pressure oil leakage from pipes, and steam leaks the moment they occur.

e. Heat Detectors

Heat detectors come in different types including spot detectors and line detectors. Spot detectors sense temperature at a specific location. Line detectors consist of a cable run where temperatures can be detected at a point along the cable, within a certain distance, typically 1.5 meters. Heat detectors work on five basic principles as follows in the paragraphs below. Fixed temperature sensors alarm when temperature reaches a fixed point. Fixed temperature heat detectors are suited to alarm in the presence of slowly rising temperatures. Fixed temperature heat detectors are suited for installation where high heat output fires are expected or in areas where ambient conditions will not allow use of other detection methods, Rate-of-rise sensors alarm when rate of temperature increase exceeds a predetermined value. It is common practice to have fixed rate sensors in combination with rate-of-rise sensors, providing good all round heat protection. Thermoelectric effect sensors detect a change in electric resistance in response to an increase in temperature. These sensors are typically "hot wire" anemometers used for sensing temperature changes in fluid flows, including ventilation ducts.

Fiber optical heat detection is possible by use of monitoring the scattering of light down the fiber optic, which is proportional to the temperature sensed along the cable. The signals are immune to electromagnetic interference thereby ensuring integrity of readings from electrically noisy areas, for example around power cables and transformers. The system can continue to operate in the event of a fiber break by exploiting the signal processing techniques. The system can reconstitute the temperature profile of the entire fiber length regardless of the position of the break. Depending on the nature of the break a few measurement points in the immediate vicinity of the break may be lost. In the case of multiple breaks, the length accessible to the system will continue to be measured. The optical fiber temperature sensing system has wide ranging applications especially where small changes in temperature need to be detected, like pipe leakages, overheating of sensitive equipment, and magazine areas.

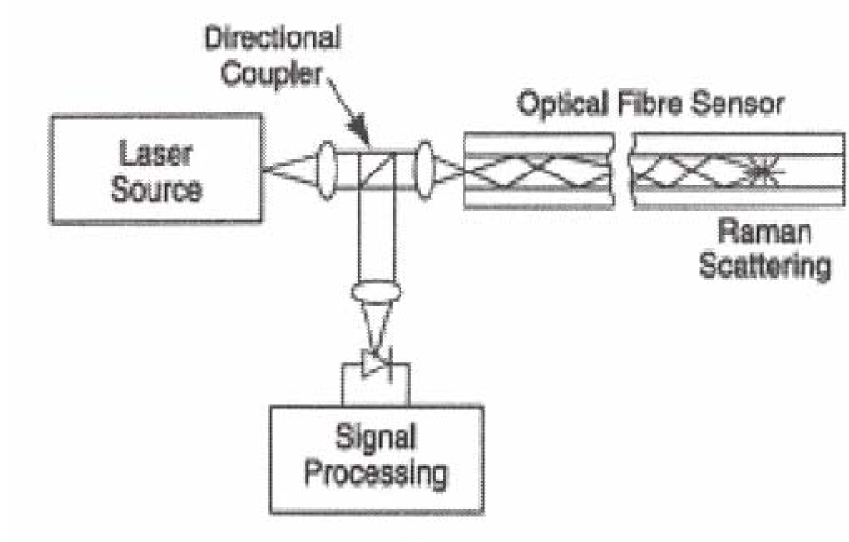

Figure 76. Principle of Fiber Optical Detector[1]

The High Performance Optical Detector has sensitivity to both hot, fast, "Clean" burning fires (domain of the ion-chamber detector) and cold, slow smoldering fires (domain of the optical detector). [1] The High Performance Optical Detector senses the flaming fires that generate a significant rise in air temperature together with a small increase in visible smoke. To sense this temperature rise, two thermistors are arranged in a similar fashion to that found in a standard rate-of-rise heat detector. One thermistor is mounted so as to be exposed to the air while the second is shielded inside the detector's body. If the temperature rises slowly then the thermistor temperature will be approximately equal and no adjustment to optical sensitivity occurs. If however the air temperature changes very rapidly, the exposed thermistor will heat more quickly than the reference thermistor (heat shielded by the detector body) and a temperature difference will be established. The electrical circuit senses that the exposed thermistor is hotter than the reference thermistor and reduces the alarm threshold of the optical sensor accordingly. If there is smoke present at a level above the reduced threshold then an alarm will be raised. Otherwise the detector will remain in its enhanced sensitivity state, without giving an alarm until the temperature stabilizes. The High Performance Optical offers a significant performance improvement over standard optical detectors, with a much more uniform performance, across open cellulose fires (wood), and liquid fires (heptanes).

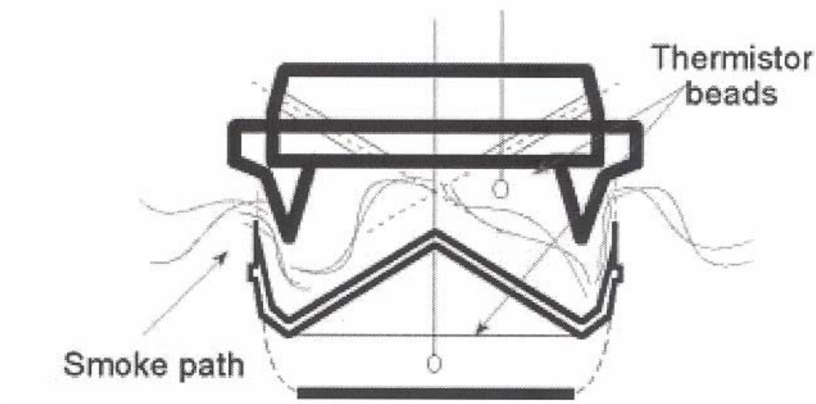

Figure 77. High Performance Optical Detector[1]

The use of this detector that contains no radio-active material, together with its systems design flexibility, now offers the ship operator a cost effective, stable, false-alarm-free alternative to the ion- chamber detector.

f. Smart Microsensors

A smart microsensor is a miniature voltammetric / electro catalytic (V/EC) microsensor made of ceramic-metallic (cermet) materials that identify many different gases by their electrical signatures. [2]

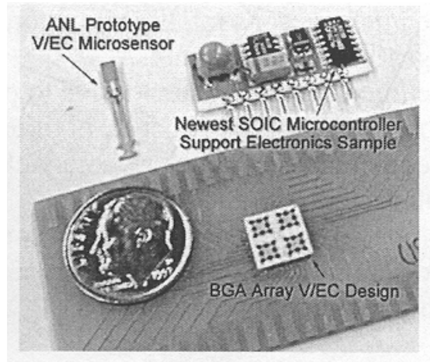

Figure 78. Smart Microsensor[2]

The micro sensor's intelligent pattern recognition system can be trained to recognize a wide variety of gases and gas mixtures. The microsensor is inexpensive to produce (< 25 cents per microsensor), and is proving rugged enough to survive in hostile, high-temperature environments. The microsensor can be remotely cleaned and does not require electrolyte replenishment or replacement. Compared with conventional sensors, power requirements are low (milliwatts). The neural network signature processing is scalable and can be implemented on equipment from a microcontroller up to a larger PC.

g. Humidity Detectors

Humidity sensor contains a capacitive element that changes value in response to the relative humidity in the air. An integrated circuit timer translates this capacitance into a digital frequency.

h. Liquid Level Detectors

Typical flooding detectors are open/closed 'dry' contact type switches operating by a float mechanism. A number of these sensors can be mounted at various heights within a tank or compartment to determine the liquid level. These switches are either on or off, and the level of desired accuracy dictates the number of sensors. "Wet" type contact switches use the fluid level to complete an electrical circuit and provide the alarm. These sensors are not as desirable as the dry contact switches. Continuous reading tank level sensors are available and operate by a detecting a resistance float sensor along a shaft, providing readings accurate to within one-half inch. These sensors typically monitor normal tank levels. These continuous level sensors can also monitor for excessive liquid loss indicating a damage situation, or provide unmanned filling operations. The open/closed contact switches can also be utilized for detecting actuator and access status. Fiber optical sensors have also been developed to provide this detection.

i. Conclusions

Other than fire detection, compartments will also be monitored for humidity and temperature, to calculate heat stress. Paint lockers and pump rooms will be monitored for explosive gases and lack of oxygen. Sewage spaces will be monitored for hydrogen sulfide gas. Air conditioning and refrigeration rooms will be monitored for refrigerants and low oxygen levels. Other appropriate monitoring will be conducted in spaces subjected to localized hazards. 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 unaware watch standers from entering the compartments

3. Installed Firefighting Systems

The proposed fire suppression systems, FM-200, carbon dioxide, AFFF, and water mist will be implemented on the HSAC. Active damage control measures will be required to keep the damage contained and from progressing through out the ship. Fire extinguishing methods include the use of a ship-wide water mist sprinkler system, AFFF flooding, FM 200 system and carbon dioxide flooding. Independent extinguishing agents, such as carbon dioxide flooding for the paint locker and FM 200 for the electronics equipment compartments will protect specialized spaces. Water mist sprinklers will protect machinery spaces. Combinations of the water mist sprinklers and AFFF sprinklers will be used to combat fuel fires in the machinery spaces, hangar bay, and cargo deck. The type of fire suppression systems installed in each type of compartment is shown below in Table 11.

Table 11. Installed DC Systems

Compartment	FM200	CO2	Water	AFFF
Machinery Spaces			X	X
Engine enclosures		X		
Magazine Areas				
Elect Equip Rooms	X			
Hanger			X	X
Flight Deck				X
CIC	X			
Bridge	X			
Cargo Deck			X	X
Berthing	X			
Galley	X			X
Passageways	X			
Paint Lockers		X		
Pump rooms		X		
AC / Refrigeration		X		

a. Installed Firefighting System Descriptions

The following is a description of the systems that will be installed in the spaces referenced in the previous section.

(1) FM-200 Fire Suppression Systems

FM-200, heptafluoropropane, is one of the new Halon alternative agents now in use to protect essential applications traditionally protected by Halon 1301. This agent has many similar characteristics to Halon 1301 and is safe in normally occupied areas. FM-200 systems are available in spheres or cylinders. [3]

(2) Carbon Dioxide Fire Suppression Systems

Clean agent carbon dioxide systems, have been an industry standard for many decades and are still the preferred agent in many applications. There are several common local application systems, which are utilized to extinguish fires in dip tanks, quench tanks and industrial operations where spilled fuel is a possibility. Local application systems are also popular in the marine market, especially in engine compartments.

(3) Water Mist System

Water mist systems extinguish fires primarily by removing heat from the materials involved in the combustion process. Water is applied to the fire in very fine droplets, which appear to the observer as a dense fog. The ratio of droplet surface area to water volume is large and conversion to steam occurs very efficiently. The latent heat of vaporization, which is a physical phenomenon associated with the change of state of water to a gas (steam), removes heat from the fire and the steam produced also helps to smother the fire by displacing oxygen in the vicinity of the fire. [5]

Water mist systems are also safer for people and the environment. These systems only use potable or natural seawater, with no adverse side effects. Lower flow rates equate to less cleanup than traditional water sprinkler systems. Tests have 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. A general reluctance to provide water extinguishing for class "C" fires exists because of fears of conductivity.

The Navy sponsored a program at the Applied Physics Laboratory/Johns Hopkins University (APL/JHU) to evaluate the effects of water mist on energized electrical equipment. Equipment selected for testing consisted of 3 phase-450 VAC motors, motor controllers and switchboards that were representative of equipment to be installed in the machinery spaces of LPD-17. The objective was to determine potential for equipment damage and to identify personnel electric shock hazards resulting from the discharge of mist onto energized equipment. Results showed that the conductivity of salt free potable water is very low. Shock hazards could only exist after a sustained mist flow of sufficient duration to cause plating out or pooling of water on equipment surfaces. There was essentially no current leakage for motors or motor controllers. Shock hazard with switchboards is negligible within the first 15 minutes if the boards are clean and properly grounded. The summary conclusion relative to LPD-17 is the probability of creating a shock hazard is low and that watch standers in the space would not have to evacuate prior to mist activation even if all equipment is energized. Water mist systems have been successfully tested on telecommunications switchgear equipment, consisting primarily of vertically mounted circuit boards. The results of a multi-year water mist research and development program by the Naval Research Laboratory, Chesapeake Beach Detachment says that large fires are easier to extinguish than small fires, due mainly to the displacement of oxygen by the expansion of the water mist to steam, obstructed fires become more difficult to extinguish with increased water droplet horizontal travel distance, well-ventilated fires are difficult, but not impossible, for water mist and water mist performs superior to gases in well ventilated scenarios. Deep-seated Class A fires are difficult to totally extinguish, though surface flaming is suppressed, and mist enhances room tenability by cooling and smoke scrubbing. The system effectively extinguishes flammable liquid pool fires as well as spray fires, which could ignite from a ruptured hose or pipe in a process using flammable liquids. Water mist applications include, but are not limited to, engine and generator set enclosures, machinery spaces with incidental storage of flammable liquids, oil pumps, gear boxes, and drive shafts.

(4) 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 require a very low energy input to produce high quality foam. AFFF agents suppress fire by separating the fuel from the air (oxygen). Depending on the type of foam system, this is done in several ways: Foam blankets the fuel surface smothering the fire, the fuel is cooled by the water content of the foam, or the foam blanket suppresses the release of flammable vapors that can mix with the air. They can be applied through a wide variety of foam delivery systems. This versatility makes AFFF an obvious choice for handling of flammable liquids.

b. Other Considerations

Although not implemented on the HSAC, other installed equipment may be substituted depending on vendor climate and cost considerations. Therefore descriptions of gear that could be substituted are described below.

(1) NAFS-III

NAFS-III consists of HCFC mixed by 82 % HCF22, 9.5% HCFC124, 4.75% HCFC123. It is able to extinguish fires in the B and C rating classes and electrical goods. HCFC exists in gas form after spraying and extinguishing. There is no liquid or solid residue, no remaining trace, and therefore no stain results. This type of fire suppression is good for oil stores, paint lockers, flammable chemical stores and electronics equipment compartments.

(2) Inergen Fire Suppression Systems

Inergen is another new alternative agent replacing traditional Halon 1301. Inergen is a high-pressure agent and is stored in cylinders similar to Carbon Dioxide. This agent is comprised of three naturally occurring gases nitrogen, argon and carbon dioxide. The system is laid out with a central bank of cylinders manifolded together and the agent is dispersed through a pressure reducer and a piping system. Critical areas that require non-water based extinguishing agent that is electrically nonconductive, safe for use in human occupied facilities, and not damage sensitive electronic equipment. The strategy of fire extinguishment employed by an Inergen system is like no other modern suppression system in use today. An Inergen system lowers the oxygen content of the protected area to a point sufficient to sustain human life, but insufficient to support combustion.

(3) FE-13 Fire Suppression Systems

FE-13, trifluromethane, is the safest of the three most commonly used clean agents (FE-13, FM-200 and Inergen). Systems are typically designed at 16-21% concentrations but FE-13 has no exposure restrictions until concentrations reach 30% or higher. The ability to design at higher than required concentrations, makes FE-13 an ideal agent for occupied areas, where very rapid extinguishments is desired. [4] Two other characteristics make this a unique agent that should be seriously considered for our clean agent requirements. First, nozzles can be located at heights of up to 25 feet as compared to only 12 feet for FM-200 systems. Second, due to its low boiling point, FE-13 can be used in temperatures as low as 40° F. As with other clean agents, FE-13 can be used in any area with high valued electronics such as computer facilities, battery rooms and telecommunications facilities. It also has many industrial applications including unheated storage areas.

4. Chemical, Biological and Radiation (CBR) System

HSAC will be capable of performing launching and recovering of the aircraft for all types of CBR contaminated environments. Long-range detection systems for chemical, biological and radioactive agents will be installed on HSAC. Also, portable chemical and biological mass spectrometers, joint chemical agent detectors, radiac equipment, and CBR protective clothes will be available at each damage control locker, and hangar bay. A collective protection system will protect the manned areas against CBR warfare in HSAC. All aircraft will be decontaminated in the elevators, which are a part of the collective protection system, after recovery. In case of emergency, one elevator will be adequate to operate and decontaminate the contaminated aircraft, although for redundancy purposes two of the elevators will have the capability.

5. Personal Locator Device (PLD)

The ship's crew will be issued a PLD. The PLD is a kind of electronic bracelet, transmitting the identity of the crew. Receivers around the ship will detect the signals from the PLDs, and a data network will be connected to the damage control data network. There will be three modes of operation of PLD: (1) personal location, (2) personal paging, and (3) emergency notification. From the damage control displays, the location of each person will be monitored. Emergency notification mode will be used by the crewmember him/herself, if he/she is in an emergency situation, to notify the watch stander.[8]

6. Crew Egression

Five on each side of the ship, a total of ten, throw over board life rafts with twenty-five personnel capacity, will be installed. The total capacity of the life rafts is 250, being ten percent more than the crew size. They will be evenly distributed and will be inside a shield to reduce their contribution to radar cross section.

Figure 79. A Typical Life Raft for HSAC[9]

7. Ship Numbering System

All crew members must be able to operate key Damage Control (DC) equipment and fittings in order to effectively control/stop damage. Therefore, it is essential that drills incorporating the use of all fittings be conducted to train and keep personnel proficient in their operation. In order to locate and operate DC fittings, everyone must have a clear understanding of shipboard compartmental and DC fitting numbering.

All compartments and fittings on the HSAC will be numbered according to appropriate Navy standards. A full description of the numbering to be used can be found in Appendix IX.

8. Battle Stations

For a ship to survive under battle conditions, it must be able to rapidly man battle stations and set material condition zebra and also to be able to operate under these conditions for an extended period. Also, there are evolutions that assume that the ship is at General Quarters before it can be accomplished. The HSAC must train personnel in manning battle stations and making initial preparations for action. Use the appropriate damage control exercise, "Manning Battle Stations", to evaluate personnel performance. In depth view of battle stations, Salvage ship, and Abandon ship information can be found in Appendix IX.

9. Conditions of Readiness

The setting of material condition is the process of securing the appropriate damage control fittings at designated times. After damage, there exists a strong possibility of the spreading of fire, smoke, and flooding. The proper setting of material condition will enhance the Damage Control organization's ability to contain and control damage. Material Conditions of readiness descriptions can be found in Appendix IX.

10. Damage Control Total Ship Survivability

The concept of Total Ship Survivability has been formalized from recent events and conclusions drawn from the Falkland Islands and Desert Storm Conflicts. The HSAC as a whole must be able to combat casualties either inflicted by weapon payloads or by internal forces and maintain mission integrity.

The casualty response will be prioritized to restore vital systems and\or combat fires and flooding. Vital systems include electrical power (60 Hz and 400 Hz), firemain, chilled water, dry air (and others).

a. Ship's Priorities

(1) Peacetime

i.. Return to port
ii. Safety of the crew

(2) Wartime (Battle conditions) - in descending order

i. Fight: Maintain/Restore Combat Systems to prevent further damage by being able to detect the next threat and being able to neutralize that threat. If the ship loses its ability to detect and engage, then it becomes a useless floating target.

ii. Move: If the ship does lose its detect and engage ability, then it must make all efforts to regain 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 warship in order to land and off load cargo.

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.

Considerations for Damage Control Ship Survivability can be found in Appendix IX.

11. Introduction to Firefighting

The HSAC design has to embrace a wide range of sometimes conflicting requirements. Were it possible to design a fire proof ship, it would be prohibitively expensive. A major requirement is to contain systems and equipment in the minimum of space. This in itself can create problems in the event of a fire. Cost and weight restraints also play a part in reaching a compromise. As a result, warships contain a number of high risk compartments such as magazines, machinery spaces, fuel tanks, control and operations spaces, where a hit could seriously affect the ship's capability to move or fight. In the event of a fire on board ship there is no where to go and no fire department to handle the situation. The fire must be controlled and extinguished. Shipboard personnel must be trained to do this. As the saying goes "YOU CAN RUN, BUT

YOU CAN'T HIDE". In the event of a shipboard fire there isn't even anywhere to run. The objectives of a Damage Control Organization will be to: Take preliminary actions taken to prevent damage, minimize and localize damage, and Restore space or equipment to use.

Firefighting perspective that needs to be understood is that preliminary actions are most important. The best situation is not to have a fire, and prevention. Prevention for eliminating the risk of a fire would be but not limited to:

- Good Housekeeping
- Proper stowage of flammables/explosives
- Fire Marshall program
- General maintenance
- Watchststander training
- DC Organization training
- All hands training
- Embarked troop training

Terms and organization for Shipboard Firefighting can be found in Appendix IX.

12. References

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[6] http://www.juruconsultant.com/workstation/articles/firesuppression

[7] An Investigation into Impacts of Adding an Automated Damage Control System to a Coast Guard 270' WMEC Cutter, Jon G. Gage, Thesis, Naval Postgraduate School, Monterey, California

[8] Automating Damage Control to reduce Manning for Future Ship Designs, Lance Lantier, Individual Project, Naval Postgraduate School, Monterey, California

[9] TSSE Project Report 2001

G. HABITABILITY

The habitability analysis was conducted based on the definitions and instructions given in the Shipboard Habitability Design Criteria Manual **[1&2]**. The HSAC has at least one berth per permanently assigned crewmember and surge troops. Berths are permanently installed. Officers, CPOs and crew are accommodated in separate berthing compartments. Embarked Marine Officers, SNCOs/Troop are accommodated in separate berthing compartments as well. The berthing space configuration of the HSAC allows female crewmember berthing accommodations to be separate. Individual staterooms with private heads are provided for the Commanding Officer and Executive Officer. Officers and CPO are accommodated in double tier bunks. Crew/Troop/SNCOs are accommodated in three tier bunks. The number of berths per tier does not exceed three. The berthing space allocation for officers includes additional space for unobstructed walking and working areas. The initial estimate of berthing space allocation and habitability weights are tabulated in Table 12 and Table 13.

Table 12. Accommodation Arrangement

	Number	Area/Person (ft^2)	Area (ft^2)
Commanding Officer	1	180	180
Executive Officer	1	100	100
Officers (Ship's company)	5	88	440
Officers (Surge)	26	33	858
CPO (Ship's company)	10	33	330
Crew (Ship's company)	49	24	1176
SNCO/Troop (Surge)	234	24	5616
Officer Wardroom	N/A	N/A	215
CPO/Enlisted Mess	N/A	N/A	500
Galley	N/A	N/A	370
Stores, Offices, Workshops	N/A	N/A	600
Medical Facility	N/A	N/A	600
		Total Area Required	**10985**

Table 13. Habitability Weight Estimation

	Approximate Quantitiy	Approximate Weight (lbs)	Total (lbs)
People	66	180	11,880
Berth (CO/XO)	2	200	400
Two-tier Berth (Officer / CPO)	50	300	15,000
Sit-up Berth (Crew / Troop / SNCO)	279	450	125,550
Stowage	100	180	18,000
Table	35	80	2,800
Chair	140	30	4,200
Dishwasher	10	150	1,500
Washing Machine	10	150	1,500
Dryer	10	150	1,500
Refregirator/Freezer	10	360	3,600
Television, big screen	2	210	420
Television, table model	2	60	120
Toilet	40	35	1,400
Washbasin	40	35	1,400
Stores			32,200
Water			920,920
Galley Equipment			15,000
Miscellaneous			10,000
		TOTAL :	**1,167,390**

The officer berthing arrangement is as follows.

USN Berthing:

- (1) CO cabin
- (1) XO stateroom
- (4) 2 person staterooms

- Private and shared heads

USMC Berthing:

- (5) 6 person bunkrooms
- Shared heads

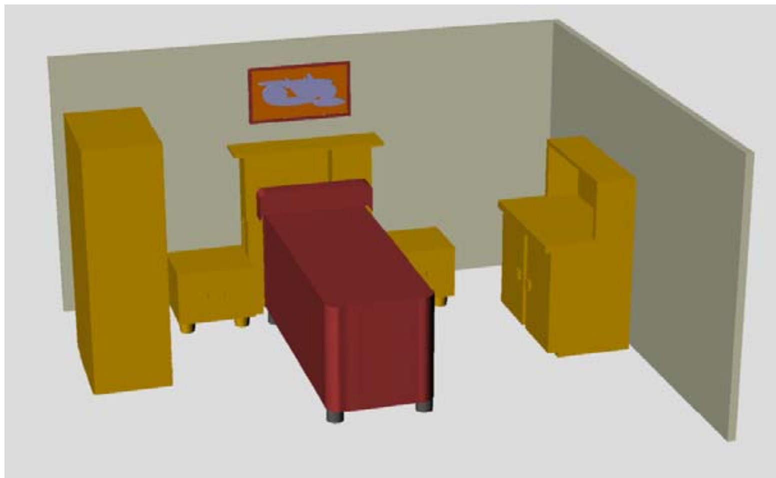

Figure 80. Typical CO Stateroom Arrangement

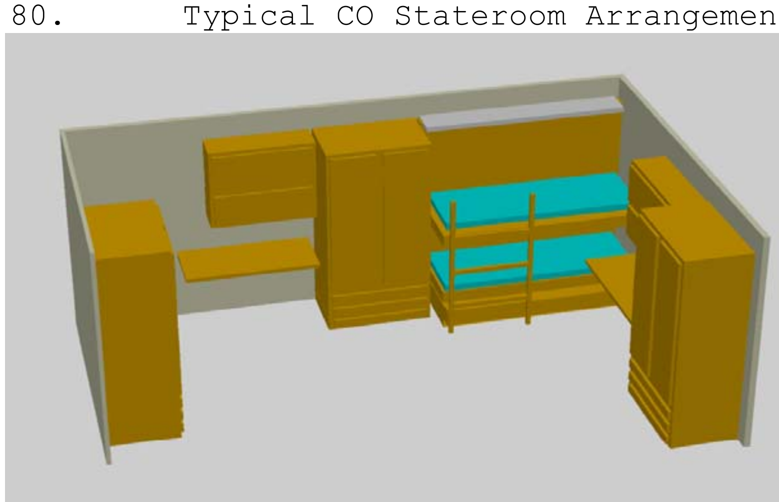

Figure 81. Typical Officer (USN) Stateroom Arrangement

The CPO/SNCO berthing arrangement is as follows.

CPO Berthing

- (2) 6 person bunkrooms
- Semi-private heads
-
- USMC SNCO Berthing

- Assigned one of four USMC berthing compartments

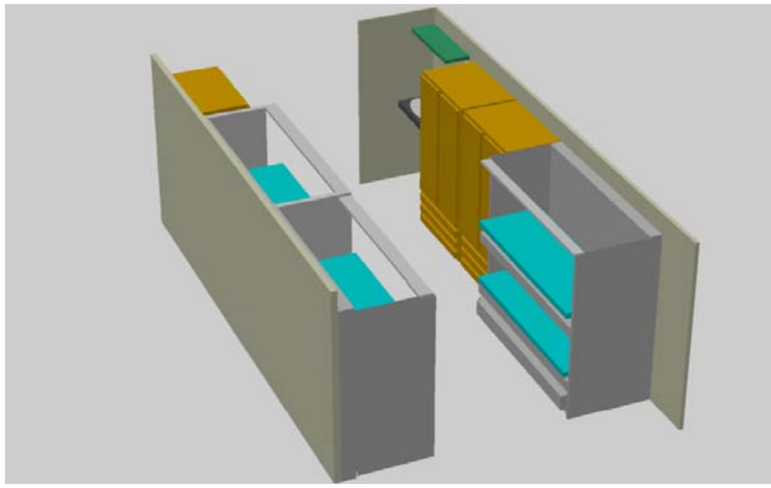

Figure 82. Typical CPO Stateroom Arrangement

The U.S. Navy’s Sit-Up berth has been selected for installation aboard the HSAC for Crew/Troop/SNCO berthing. The sit-up berth improves quality of life at sea by allowing the occupant to sit upright in the bank when not sleeping, with ample space to read, write or relax, as shown in Figure 83. Features include forty percent more stowage space than a classical berth, a pneumatic lift assist for opening and closing the rack, a stowage area for boots and Marine battle helmets, towel bars, and stirrup steps to aid ingress and egress. Each occupant also enjoys the benefit of a writing/reading surface, electrical outlet, mirror, individual fan unit, and a small shelf for personal items. The height and width dimensions are the same as for the traditional module, however the sit-up berth is about two feet longer.

Figure 83. Sit-up Berth (Ref [3])

Ship’s Crew Berthing:

- (1) 36 person compartment
- (1) 24 person compartment
- (1) 12 person compartment (Women-at-Sea determined compartment size)
- Three tiers per berth (Sit-up Berth)
- (4) Shared heads (one assigned to females)
- Embarked Marine (Troop/SNCO) Berthing:
- (3) 69 person compartments
- Three tiers per berth (Sit-up Berth)
- (3) Shared heads

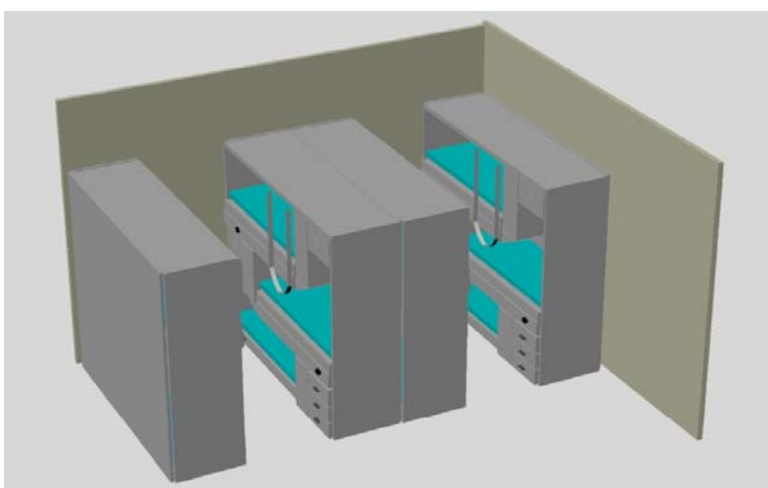

Figure 84. Typical Crew Berthing Arrangement

The HSAC has stowage available per person in accordance with NAVSEA requirements. For troop hand-carried weapons, helmets and field packs, secure stowage is available on HSAC. There are separate sanitary facilities for males and females associated with berthing spaces. The sanitary spaces are placed on the same level as the berthing space they support. All water closets are enclosed completely and have a privacy door and the showers are of the individual stall type. All berthing, messing, medical, electronics and necessary control spaces are air conditioned. Fluorescent lighting is the main source of general illumination in living and work spaces.

The values listed in Table 14 are recommended quantities of potable water required aboard ship. Depending on the ship type, and the operating area, these values may change.

Table 14. Recommended Amounts of Potable Water Aboard Ship (Ref [5])

Type of use	Gallons per man per day
Drinking Water	0.5 – 1.0
Galley and Scullery	1.5 – 4.0
Personal and Hygiene	5.0 – 20.0
Laundry	5.0 – 10.0
TOTAL	**12.0 – 35.0**

The HSAC is capable of providing thirty gallons per day per ship's company of satisfactory quality distilled habitability water. It is also capable of providing twenty one gallons per day per embarked troop of satisfactory quality distilled habitability water. For habitability purposes, the HSAC has stowage for an additional 40 gallons per accommodation. There are water coolers provided for both living and work spaces. Sufficient number of water heaters is provided to make certain an adequate supply of hot water to all showers and washbasins. Separate water heaters that run at a higher temperature are provided for workspaces (galley, laundry, etc). There is also automatic potable water disinfection equipment installed on the HSAC.

1. References

[1] OPNAVINST 9640.1A: *Shipboard Habitability Program*, 3 September 1996

[2] *Shipboard Habitability Design Criteria Manual* (T9640-AB-DDT-010/HAB), 1 December 1995.

[3] *LPD 17 San Antonio Class, Quality of Life on the LPD 17 Class,* NAVSEA (PMS 317) DET NEW ORLEANS, OFFICIAL U.S. NAVY WEB SITE; 12 November 2003, URL: http://www.pms317.navy.mil/tech/qol.asp. Accessed Oct 28, 2004.

[4] *Sit-Up Berth*, MARINETALK; URL: http://www.marinetalk.com/articles_HTML /xxx00030222TU.html. Accessed Oct 31, 2004

[5] *Water Supply Afloat, Manual of Naval Preventive Medicine, Chapter 6*, Bureau of Medicine and Surgery NAVMED P-5010-6 (Rev 1990) Washington, D.C.

[6] TSSE Project Report 2001

[7] TSSE Project Report 2002

H. REDUCED MANNING ANALYSIS

Whenever new ships are designed, analysis of reduced manning becomes more important than ever in the design of the ship. It is important because it provides potential benefits in operating cost reduction and increasing quality of crew’s ship life. Besides that, automation technology starts to be more dependable and stable than ever also. In manning determination every person is justified by the work they are required to perform. The work is established by the system/equipment/function on board which is the product of a design. As the automation increase, fewer personnel are required to operate and maintain the ship and its systems. The crew size required for given ship design is the sum of all personnel needed to function simultaneously to meet the most demanding ship's condition of readiness over a sustained period of time. This figure shows the general procedure for reduced manning analysis in the Navy.

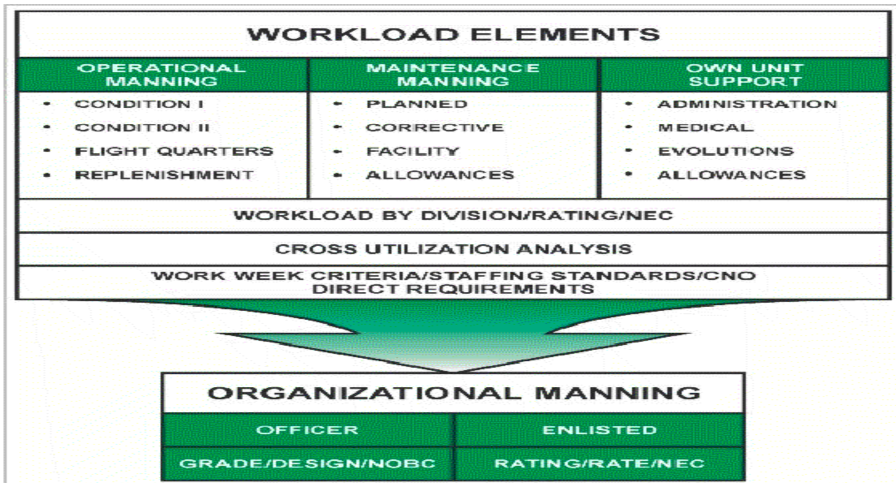

Figure 85. Reduced Manning Procedure

The TSSE team followed almost the same procedure to get actual numbers for ship company in general aspect. First, required watch stations were determined to begin the analysis. To determine what the required watch stations are, the watch station bills were used. They were found by applying not only the concept of low maintenance design of equipment, but also the progressed automation of our design. The number for all required repair personnel were determined as 11. The determination of this number was based on the above criterias and that operators could work as a maintenance personnel also. To provide enough information and support reducing manning, the following approaches were used. Self-diagnostic software, automation (computerized) of combat systems, condition based maintenance and development of the training which increase the quality level of the crews.

In the self-diagnostic software, the problems in the computers can be solved by running a diagnostic and refining them. This software reduces the time required for repairment and the number of personnel who will maintain the system. The idea of automation leads to increasing level of use of the computers and softwares. This idea is also valid in the automation of combat systems and engineering. Condition based maintenance is an idea that decreases the redundant maintenance requred for the system. This type of maintenance accomplishes this duty by controlling the systems and measuring the values extracted from them. If a measurement of the system comes to the limit, maintenance will be performed at the first step. This will prevent the time consumption which is required to wait for the regular maintenance time. Finally, the last maintenance will be done by ship maintenance. However, less people will be required because the maintenace is conditional.

Furthertmore, wide area network system will be used to reduce the manning. This system provides enough information to other system computers and determines where the problem is. Therefore the network will reduce the reaction time for the problem and also repair work. It is very convinient for our analysis of reduced manning. Finally, the subject of the training of the crews will be performed for them to increase the ability of skills and reaction times when they run into more important problems (damages, maintenance problems etc.). The training program will make the crew be ready in every bad situation of the ship and so will help reduce manning. Engineering training team will be not necessary to give this program and will be eliminated.

After the above aspects are applied, the TSSE team reached the final numbers for ship company. The following shows the tabulation of the rank, section watch, GQ and the personnel numbers in detailed and total numbers.

Table 15. Manning Breakdown

STATION DESCRIPTION	Rank	3 Section Watch	GQ Only	Other	Position Total	Ship Total	Notes
COMMAND							
CO	O			1	1	1	
XO/OPS	O			1	1	1	
SHIP CONTROL							
PILOT HOUSE							
OFFICER OF THE DECK (OOD)	O/CPO	3			3	3	AOPS/OSC/AUXO
PETTY OFFICER OF THE DECK (POOD)	E	3			3	3	QM
COMMAND AND CONTROL							
TACTICAL ACTION OFFICER	O	3			3	3	CHENG/CSO/OPS
CIC WATCH OFFICER	CPO/E	3			3	3	EWC/OSC/OS1
TACTICAL INFORMATION COORDINATOR	E	3			3	3	Maint during non-GQ
SURFACE WARFARE COORDINATOR	O		1		1	0	Non GQ OOD
AIR DEFENSE COORDINATOR	O		1		1	0	Non GQ OOD
RADIO CENTRAL							
COMMS WATCH	CPO/E	3			3	3	Off w atch conduct maint / 1 ITC
COMBAT SYSTEMS EQUIPMENT ROOM							
COMBAT SYS MAINTENANCE CENTRAL							
CSOOW	CPO/E	3			3	3	GMC/ETC/FC1
ELECTRONIC REPAIRMAN	E	3			3	3	Off w atch conduct maint

STATION DESCRIPTION	Rank	3 Section Watch	GQ Only	Other	Position Total	Ship Total	Notes
WEAPONS CONTROL							
BOFORS LOADER DRUM ROOM							
MOUNT CAPTAIN/LOCAL OPERATOR	E		1		1	1	Act as maint tech non-Cond I
VERTICAL LAUNCHING SYS							
VLS MONITOR/TECH	E		1		1	1	Act as maint tech non-Cond I
ENGINEERING CONTROL							
CENTRAL CONTROL STATION							
EOOW	CPO/E	3			3	3	EMC/GSMC/GSM1
PROP PLANT CTL CONSOLE OPER	E	3			3	3	MM Off w atch conduct maint
ELEC PLANT CTL CONSOLE OPER	E	3			3	3	EM Off w atch conduct maint
ROVING WATCH/TECHNICIAN	E	3			3	3	Off w atch conduct maint
DAMAGE CONTROL							
DAMAGE CONTROL CENTRAL							
DAMAGE CONTROL ASSISTANT (DCA	O		1		1	0	CHENG
REPAIR 2							
REPAIR LOCKER OFFICER	CPO		1		1	0	Non-GQ EOOW
ON-SCENE LEADER	E		1		1	1	DC
#1 NOZZLEMAN	E		1		1	0	Non-GQ CCS Tech
#1 HOSEMAN	E		1		1	0	Non-GQ Comms
#1 HOSEMAN	E		1		1	1	BM
#1 PLUGMAN	E		1		1	1	BM
ELECTRICIAN	E		1		1	0	Non-GQ EPCC
#1 UTILITY MAN	E		1		1	0	MS
#2 UTILITY MAN	E		1		1	0	MS
#3 UTILITY MAN	E		1		1	1	GM/FC
#4 UTILITY MAN	E		1		1	0	SK
REPAIR 5							
REPAIR LOCKER OFFICER	CPO		1		1	0	Non-GQ EOOW
ON-SCENE LEADER	E		1		1	1	DC
#1 NOZZLEMAN	E		1		1	0	Non-GQ CCS Tech
#1 HOSEMAN	E		1		1	0	Non-GQ Comms
#1 HOSEMAN	E		1		1	0	MM
#1 PLUGMAN	E		1		1	0	MM
ELECTRICIAN	E		1		1	0	Non-GQ EPCC
#1 UTILITY MAN	E		1		1	0	MS
#2 UTILITY MAN	E		1		1	0	MS
#3 UTILITY MAN	E		1		1	1	GM/FC
#4 UTILITY MAN	E		1		1	0	SK

STATION DESCRIPTION	Rank	3 Section Watch	GQ Only	Other	Position Total	Ship Total	Notes
HELO CONTROL							
FLIGHT CONTROL							
HCO	O			1	1	0	Off Watch OOD
LSE	O			1	1	0	Air Det
CHOCK AND CHAIN #1	E			1	1	0	PN
CHOCK AND CHAIN #2	E			1	1	0	YN
HELO FIRE FIGHTING TEAM							
ON SCENE LEADER (OSL)	CPO			1	1	1	DCC
HOT SUITMAN #1	E			1	1	0	REP 2/5
HOT SUITMAN #2	E			1	1	0	REP 2/5
NOZZLE	E			1	1	0	REP 2/5
HOSE	E			1	1	1	BM
HOSE	E			1	1	1	BM
PLUGMAN	E			1	1	0	REP 2/5
NOZZLE	E			1	1	0	REP 2/5
HOSE	E			1	1	1	BM
HOSE	E			1	1	1	BM
PLUGMAN	E			1	1	0	REP 2/5
MEDICAL							
CORPSMAN [IDC]	CPO			1	1	1	HMC
CORPSMAN	E			1	1	1	HM
MESSING							
SENIOR MESS SPECIALIST	E			1	1	1	MS1
MESS SPECIALIST	E	6			6	6	MS
SUPPLY SUPPORT							
STOCK CONTROL SUPERVISOR	E			1	1	1	SK1
LOCATE/ISSUE CLERK	E	3			3	3	SK
ADMIN							
SHIPS OFFICE	E			2	2	2	PN/YN
Total					95	49	

DEPARTMENTS	O	CPO	E	TOTAL
COMMAND	2	0	0	2
COMBAT SYSTEMS	1	2	9	12
ENGINEERING	2	3	12	17
OPERATIONS	2	4	16	22
MEDICAL	0	1	1	2
SUPPLY/ADMIN	0	0	11	11
	7	10	49	66

OFFICER BILLETS		
CO	1	CDR
XO/OPS	1	LCDR
LANDING (Marine Officer/Embarks with Marines)		MAJ
OPS	1	LCDR
CSO/WEPS	1	LT(DH)
CHENG/DCA	1	LT(DH)
AUX/ELEC	1	LT(DIVO)
NAV/AOPS	1	LT(DIVO)
	7	
CPO BILLETS		
GMC	1	
DCC	1	
EWC	1	
GSMC	1	
OSC	2	
EMC	1	
ITC	1	
HMC	1	
BMC	1	
	10	
ENLISTED BILLETS		
PN	1	AD
YN	1	AD
SK	3	AD
MS	6	AD
GM	2	CS
FC	2	CS
BM	6	OP
DC	2	EN
EM	3	EN
GSM	3	EN
OS	4	OP
ET	3	CS
IT	3	OP
EW	2	CS
QM	3	OP
MM	3	EN
HM	1	MD
HT	1	EN
	49	

1. References

[1] *Is The Navy Serious About Reduced Manning on Its Ships, J. Robert Bost, James G. Mellis, Philip A. Dent*; URL: http://www.manningaffordability.com/ s&tweb/ PUBS/ Bost _Mellis_Dent/Bost _Mellis_ Dent.htm. Accessed December 6, 2004

[2] TSSE Project Report 2001

[3] TSSE Project Report 2003

I. ENVIRONMENTAL CONCERNS

Our ship design can be operated with no disturbing the ambiance. For this purpose, following two systems will be used.

1. Oil-Water Separators

There will always exist water of bilge in the ships. There are several reasons for bilge water. Main and auxiliary engines of the ship will cause this situation. Furthermore the air condition systems will drain water to the bilge. Therefore the ships need oil water separators to minimize this discharge. NAVSEA identified a membrane ultra-filtration as the most progressing technology for shipboard applications. This system has following capabilities.

A. It is compatible with the Navy's existing Oil-Water Separator system.

B. It is adaptable to space and ship integration constraints.

C. It can make the existing discharge requirement of fifteen-ppm oil meet consistently.

D. It has capability to meet the future discharge constraints.

Bilge water flows to the waste holding tank (oily). Then it flows to the Oil-Water Separator. The separator creates two discharges which will flow to the membrane and will be held in the waste oil tank. One of them is effluent which flows to the membrane. The other is concentrated waste oil which is held in the waste oil tank. The ultra-filtration process allows water and dissolved particles from the Oil-Water Separator effluent to pass through a semi-permeable ceramic membrane. The filtration membrane system (ultra-filtration) makes the influent concentrate from the Oil-Water Separator. This membrane system is very affordable for the maintenance purposes, and because it is an automated system, it requires low manning.

2. CHT System

Urinals, waste drains from showers, laundries and soil drains from water will be accepted by this system. This system consists of different functional elements. The followings are these functional elements which will be used in this system.

a. Transfer element

There are two marine sewage pumps connected in parallel for each tank. The discharges of these pumps depend on the position of the discharge valve. The discharge locations are tender, barge or shore facility. The direct discharge location is the overboard.

b. Holding Element

Tanks must be durable for the time period 12 hours. This depends on the ship design process. Each CHT tank will have inside surfaces without stiffeners. According to the Naval Ship's Technical Manual chapter, each surface of CHT tank must be covered or coated. Each tank will have ventilation to the air and an orifice for overflow to the sea. Besides that, tanks have manholes for maintenance and control in any situation. The ventilation system will not allow the gases which are coming from CHT tanks to the other machine parts like compressors.

c. Collecting Element

This element has diverter valves. The way of the soil and waste depends on the position of these valves. Overboard and CHT tank will be these ways for discharge. Wastes will be separate from soil drains until they reach their overboard diverter valves. Then they will be combined. The gravity is the forcing factor for the drains above the waterline. The drains below the waterline will be ejected by CHT system. There must exist also garbage drains which are connected to the waste drains. They have the slope 3 in/ft. While the garbage grinder performs the seawater for flushing, the waste downstream of this will be of copper-nickel alloy.

Smaller CHT system will be used for our ship design which will have relatively small tank capacity. CHT system can be used in any of the three different operation modes. These modes will be determined according to the following situations.

A. While the ship is at port, CHT system will collect, hold and transfer all discharge which will be consisting of soil and waste drains to the shore facility.
B. While the ship is at the sea, if the areas are free from the restricted ones, CHT system will divert discharges from soil and waste drains overboard.
C. There are restricted zones for transiting. For this situation, CHT system will just collect and hold the discharges from soil drains.

1. References

[1] TSSE Project Report 2001

[2] TSSE Project Report 2003

J. COST AND WEIGHT ESTIMATION

Using parametric weight design estimation equations, a first order light ship weight, total deadweight, and total ship weight was calculated and shown in the summary Table 16 below. The light ship weight calculations estimate the weight of the ship's structural components, machinery, outfit and hull engineering weight, and a weight margin. The total deadweight of the ship estimates the ship's cargo weight, fuel oil weight, lube oil weight, freshwater weight, the weight of the crew and their effects, and the weight of the provisions. The detail of the calculations is in Appendix X.

Table 16. Ship Weight Summary

Group	Name	Weight
100	Hull Structure	1943
200	Propulsion Plant	91
300	Electric Plant	118
400	Command and	112
500	Auxiliary Systems	302
600	Outfit and	159
700	Armament	164
Liquids &		1022
6% Margin		235
Payload		820
Total		4966

Based on the ship's first order weight estimation, the acquisition cost of the Joint ACCESS could be determined using a weight scaled model similar to that employed in the 2003 SEA SWATH, 2002 TSSE SEA FORCE and 2001 TSSE SEA

ARCHER studies. This model used CER's from the S-CVX study conducted in 1998.

The Joint ACCESS model incorporates non-traditional weight fractions, high cost for specialized equipment required to meet the ship's missions, and one time costs for Government Furnished Equipment (GFE) that is presently under development. Cost estimates for Joint ACCESS are summarized in the table below. Appendix X shows the total cost of the twelfth ship of production assuming a learning curve exponent of 0.95.

Table 17. Cost Estimate

Concept	Cost (Mill $)
Ship Construction	156
Propulsion and Electric Distribution	230
Cargo Interfaces	10
Combat System	80
Total (For 1 Ship)	476

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V. DESIGN EVALUATION

The design met the requirements set by SEA-6 and the TSSE Faculty. In addition, it produced a robust multi-mission capable self-sustaining vessel that:

- Can augment the MPF(F) by accommodating the embarked troops and cargo from the FLS and/or CONUS to the Sea Base.
- Transit 2640nm @34kts fully loaded with 15% fuel remaining.
- Furthermore, it has defensive and offensive combat capabilities.

The extensive capabilities of this HSAC lead the team to name it the "Joint ACCESS" for it allows joint forces to quickly and forcefully access areas of the world from a distant Sea Base, which no current vessel can do. Specifically, the Joint ACCESS delivers a joint force's amphibious combat cargo while providing expeditionary support. These capabilities are built into the ship's name as Figure 86 demonstrates.

Figure 86. Joint ACCESS Name and Ship Seal

A. PRIMARY MISSION EVALUATION

The Joint ACCESS satisfies the high speed assault connector requirements as shown in Table 18.

Table 18. Design Requirement Satisfaction

Top Level Requirements	**Joint ACCESS Capability**
Carry two BLTs (~8000LT of Cargo).	A system of twelve ships can transport 9600LT of cargo.
Transport the two BLTs 200nm in one 10 hour period	Each ship can make the 200nm trip at 43kts fully loaded in less than 8 hours and can offload in 2 hours.
Interface with the Sea Base and the beach.	RO-RO capable stern gate and a flight deck with elevator allow for cargo exchange at the Sea Base. 35m floating bow ramp allows for cargo loading/unloading at the beach.
Support amphibious operations ashore in addition to payload delivery.	Flexible combat systems suite provides defensive and offensive capabilities.
Conduct independent operations.	Self-sustaining for up to 10 days and can transit 3380nm @20kts
Conduct secondary missions.	Flight deck, flight deck elevator, helicopter hangar and large flexible cargo areas allow multi-mission capabilities.

In addition to satisfying the above requirements, the Jint ACCESS can effectively augment the MPF(F) ships during seabasing operations. The Joint ACCESS has the facilities to embark 260 troops and their gear and transport them from the forward logistics site or CONUS to the Sea Base. Thus the system of 12 Joint ACCESS vessels can arrive at the Sea Base ready to deploy the two BLTs ashore. This ability not only reduces the number of cargo transfers required at the Sea Base, but also greatly decreases the time needed for employment.

B. SECONDARY MISSIONS

In addition to the capabilities inherent in the Joint ACCESS, the ship integrates well with supporting forces. Multiple support missions can be conducted. These include but are not limited to:

1. Special Operations Support

The Joint ACCESS will provide mobility for the support and sustainment of SOF in support of the Global War on Terrorism and other traditional SOF missions. While operating in low-threat environments, the Joint ACCESS will embark SOF elements, along with mobility assets and unmanned vehicles to interdict terrorists, weapons of mass destruction, and other high-value targets.

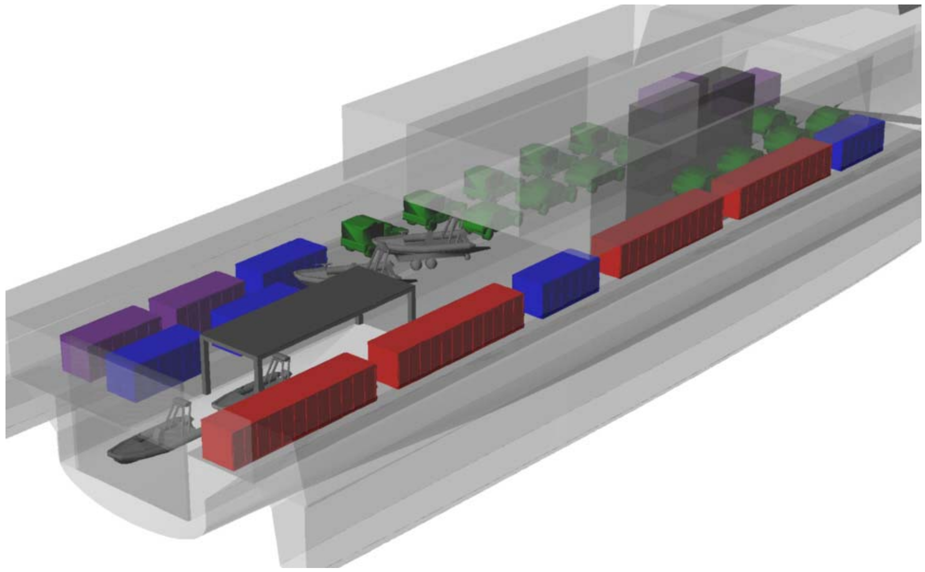


Figure 87. Example Special Operations Support Loadout

2. Embassy and High Asset Reinforcement

As a potential crisis develops, the Joint ACCESS will rapidly deploy a security force, with embarked rotary-wing assets, to reinforce a threatened embassy or high asset without reliance on host nation basing or over flight rights.

3. Humanitarian Assistance/Disaster Relief

The Joint ACCESS' high-speed, its capability to operate in austere, degraded and minor port environments, its interface with the beach, as well as its ability to carry multi-mission Conex boxes, make it ideally suited for supporting HA/DR missions. Because infrastructure at the crisis site is often destroyed or severely degraded, the capability of the Joint ACCESS to deliver supplies to the shore absent port services, tugs, or other infrastructure, allows the JFC to deliver initial forces and relief supplies.

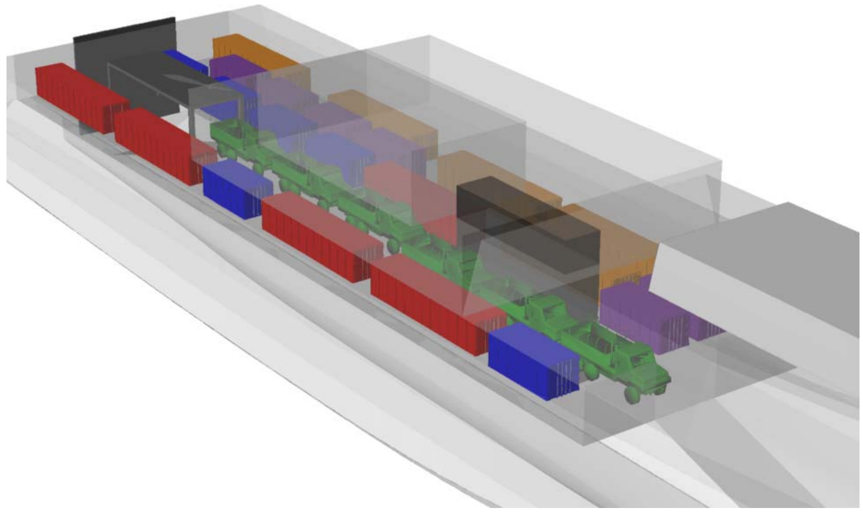


Figure 88. Example Humanitarian and Evacuation Operations Loadout

4. Theater Security Cooperation

With the growing importance of theater engagement activities as a critical element of the Global War on Terrorism, the Joint ACCESS will provide a platform well suited for executing these engagement missions. As naval forces shift to a surge response posture, forward based Joint ACCESS' will fill the void left by the decrease in the availability of other platforms to conduct engagement activities throughout the world. The access provided by the Joint ACCESS is especially important in the conduct of port visits and combined training in less developed countries that lack developed infrastructure.

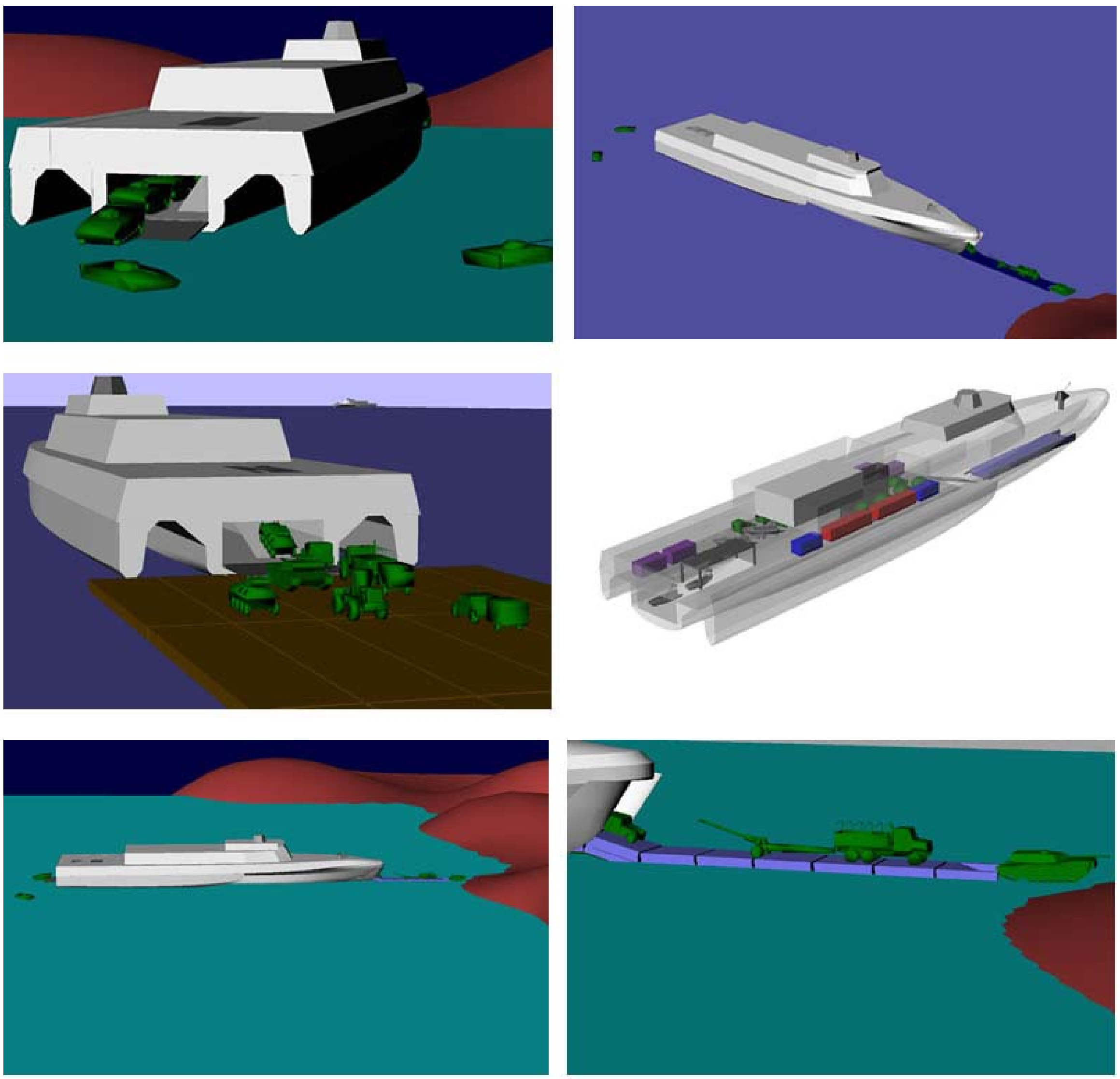
5. Maritime Interdiction

The modularity of the Joint ACCESS' and their ability to operate independently in the littoral environment will enable them to be rapidly configured to conduct these supporting operations.

C. CONCLUSION

The 2004 TSSE design team acknowledges that it was unable to perform a thorough analysis on all the technical issues that exist with every ship design. However, the team believes that to achieve the HSAC mission, displacement craft such as the Joint ACCESS need to be researched and implemented.

The following renderings depict the ship and its conceptual employment.



APPENDIX I 2004 TSSE PROJECT GUIDANCE

TSSE Total Ship Systems Engineering

June, 2004

TS4002
2004 Capstone Design Project

Sea Connector in Support of Joint Expeditionary Warfare

1. **TASK.** Your TSSE capstone design project is to examine the concepts associated with the use of "sea connectors" in support of expeditionary warfare. From this examination you will produce a design for a ship to enable effective deployment of forces from the sea base to the theater of operations. The purpose of your design is to produce a Sea Connector that is able to fight in a littoral environment.

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. **TEAM.** After an initial kickoff period in which the faculty will exert some leadership, 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 coordinate your efforts closely. The faculty will expect all 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. *You may expect to be quizzed on such matters.*

4. **BACKGROUND.** All background information and documents are located in the \\kiska\tsse\2004\Background\Reading folder. Your first task is to familiarize yourselves with those documents.

5. **APPROACH.**

A. Phase I-a (July). You are the "analysis team". Your first task is to understand the concepts associated with seabasing and expeditionary warfare. Review and understand the logistics requirements from the SEA team. The goal is to determine a set of requirements for the Sea Connector ship. This will require you to consider such things as: threat analysis; existing combat systems capabilities of the Sea Base; and required combat systems capabilities. Furthermore, your ship must be flexible so that it can assist in all aspects of expeditionary warfare including littoral combat and logistic support. Pay particular emphasis on the use of unmanned systems. As you develop your concept of operations, consider the role of the ship in non-expeditionary warfare scenarios. You must also establish desired interfaces with transfer assets (e.g. helos, boats, LCACs, etc.); survivability levels needed; etc.

B. Phase I-b (August). By the end of July you should have developed an initial concept of operations and have acquired desired payload 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 ship and for its possible variants. Ensure that your overall measure of effectiveness is computable and the SEA team agrees with 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. If we deem your report to be of sufficient quality, we will publish it as an NPS technical report, showing all of us as the authors.

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.

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 who 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.

HSAC Mission Needs Statement

Primary Operational/Threat Environment

1. Sea Base
    a. Loading/Unloading point for troops, cargo, etc.
    b. Defenses handled by Sea Base support ships
2. Transit Zone
    a. Area of water possibly outside Sea Base's defensive umbrella
    b. 100-200nm in distance
    c. Threats:
        i. Missiles
        ii. Aircraft
            1. Low slow flyers
            2. Fighter aircraft
        iii. Small Boats
        iv. Submarines
3. Unloading Zone
    a. Area of water between Transit Zone and Beach
    b. Approximately 1nm in distance
    c. Boat lane cleared prior to landing
    d. Threats:
        i. Small Boats
        ii. Mines
        iii. Aircraft
        iv. Missiles
        v. Small Arms Fire
4. Beach
    a. Area to place troops, cargo, etc. ashore
    b. Prepped for assault prior to landing
    c. Threats:
        i. Hostile Beach
        ii. Missiles
        iii. Small Arms Fire
        iv. Aircraft

Requirements

1. Mission
    a. Primary Mission
        i. Deliver required cargo from the sea base to shore within a specified period of time (8-10 hours)
        ii. Support operations on/to the beach
    b. Secondary Mission(s)

        i. Intel gathering
        ii. Humanitarian/NCO
        iii. Unmanned vehicle 'command ship'
        iv. Limited MIW
        v. MIO
2. Threat Mitigation
    a. Missiles
        i. Detection
        ii. Self defense
    b. Aircraft
        i. Detection
        ii. Self defense
        iii. Both airframe and ordinance
    c. Small Boats
        i. Self defense
        ii. Attack
    d. Small Arms Fire
        i. Self defense
        ii. Project firepower ashore at short range
    e. Hostile Beach
        i. Project firepower ashore at short range
    f. Mines
        i. Detection
        ii. Clearing?
        iii. Hardening against
    g. Submarines
        i. Evasion
        ii. Countermeasures

3. Interface with Sea Base
    a. Sea Base is located up to 200nm from shore.
4. Able to facilitate loading and unloading of cargo with facilities ranging from a developed port to an undeveloped beach.
5. Implement technologies that facilitate reduced manning.
6. Meet U.S. Navy Combatant Ship Standards.
7. Able to deliver the primary elements of a Joint MEB sized force.
8. Able to operate with existing and future military forces.
9. Meet mission requirements in up to sea state 5.

APPENDIX III REQUIREMENT GENERATION

A. SHIP CHARACTERISTIC REQUIREMENTS

			Ship Characteristics weight:		29.73%	Rank
	Ship Characteristics Prioritized Requirements	Weighting				
1	Endurance for minimum one round trip from sea base to beach at full load and full speed	10			2.972583	1
2	Able to interface with developed and undeveloped ports, harbors and beaches to transfer cargo	9			2.675325	2
3	Able to interface with sea base and current Naval assets to transfer cargo	9			2.675325	2
4	Must meet mission requirements at Sea State 5	9			2.675325	2
5	Able to transit 2000nm in less than 8 days in sea state 5 (wave height 8-12 ft) without replenishment	7			2.080808	5
6	Able to operate in shallow water without degradation in performance	7			2.080808	5
7	Able to Replenish-at-Sea (RAS)	6			1.78355	7
8	Full accommodations required for embarked crew	6			1.78355	7
9	Fuel and support rotary wing aircraft supporting amphibious operations both day and night	6			1.78355	7

B. COMBAT SYSTEM REQUIREMENTS

			Combat Systems weight:	16.38%	Rank
	Combat Systems Prioritized Requirements	Weighting			
1	Defend against and destroy small (less than 200ft long), high speed (in excess of 40kts) surface craft	10		1.637807	1
2	Detect, track, and destroy up to 8 simultaneous "leaker" missiles that escape defenses supplied by other fleet units	10		1.637807	1
3	Sustain hostile small caliber fire	9		1.474026	3
4	Provide suppressive fire for amphibious forces	9		1.474026	3
5	Communicate with U.S. and coalition forces via both secure and unsecure	8		1.310245	5
6	Provide a data link capability	8		1.310245	5
7	Maintain a CIC capable of collecting, processing, displaying, evaluating and disseminating tactical information	8		1.310245	5
8	Conduct evasive torpedo maneuvers	7		1.146465	8
9	Employ ASW countermeasures	7		1.146465	8
10	Detect, track, and identify UAV, low slow flyers, attack aircraft	7		1.146465	8
11	Provide Naval Surface Fire Support (NSFS) for amphibious forces	7		1.146465	8
12	Detect, track, and identify surface threats to the horizon	6		0.982684	12
13	Provide for surface defense of Area of Assault (AOA)	6		0.982684	12
14	Defend against and engage hostile UAVs and low slow flyers (less than 200kts)	5		0.818903	14
15	Conduct Electronic Protection Operations	4		0.655123	15
16	Deconflict potentially hostile craft from friendly and neutral shipping	3		0.491342	16
17	Detect underwater mines	3		0.491342	16
18	Avoid underwater mines	2		0.327561	18
19	Fuel and support rotary wing aircraft supporting amphibious operations both day and night	1		0.163781	19

C. PAYLOAD INTERFACING REQUIREMENTS

	Pay Load Prioritized Requirements		Pay Load Weight	53.90%	
		Weighting			Rank
1	The HSAC System of Systems must provide minimum lift capacity of 7,963 tons (including EFV transport).	10		5.38961	1
2	The HSAC System of Systems must provide minimum deck area of 98,163 square feet (including EFV transport).	10		5.38961	1
3	The HSAC must be capable of offloading cargo to beach and/or unimproved pier.	10		5.38961	1
4	The HSAC must be capable of interfacing with LPD, LHA, LHD, LSD, and MPF(F) class ships.	9		4.850649	4
5	The HSAC cargo area must be dimensioned to a minimum height requirement to handle and store a standard 20ton TEU (8'6")	8		4.311688	5
6	THE HSAC must be capable of providing interfaces and services to payload (i.e. electrical power, data-link, fueling)	1		0.538961	6

D. ANALYTIC HIERARCHY PROCESS (AHP) REQUIREMENT GENERATION

Objective Preferences					
	CS	Payload	Ship		
CS	1	0.333333	0.5		
Payload	3	1	2		
Ship	2	0.5	1		
Sum	6	1.833333	3.5		
Weights on Objectives					
	CS	Payload	Ship	Avg	Percent
CS	0.166667	0.181818	0.142857	0.163781	16.38%
Payload	0.5	0.545455	0.571429	0.538961	53.90%
Ship	0.333333	0.272727	0.285714	0.297258	29.73%

E. FINAL OPERATIONAL AND FUNCTIONAL REQUIREMENTS

	Requirement	Tean	Value	Ran	Team
1	The HSAC System of Systems must provide minimum lift capacity of 7,963 tons (including EFV transport).	10	5.39	1	Payload
2	The HSAC System of Systems must provide minimum deck area of 98,163 square feet (including EFV transport).	10	5.39	1	Payload
4	The HSAC must be capable of offloading cargo to beach and/or unimproved pier.	10	5.39	1	Payload
3	The HSAC must be capable of interfacing with LPD, LHA, LHD, LSD, and MPF(F) class ships.	9	4.85	4	Payload
6	height requirement to handle and store a standard 20ton TEU (8'6")	8	4.31	5	Payload
1	Endurance for minimum one round trip from sea base to beach at full load and full speed	10	2.97	1	Ship
2	Able to interface with developed and undeveloped ports, harbors and beaches to transfer cargo	9	2.68	2	Ship
3	Able to interface with sea base and current Naval assets to transfer cargo	9	2.68	2	Ship
4	Must meet mission requirements at Sea State 5	9	2.68	2	Ship
5	Able to transit 2000nm in less than 8 days in sea state 5 (wave height 8-12 ft) without replenishment	7	2.08	5	Ship
6	Able to operate in shallow water without degradation in performance	7	2.08	5	Ship
7	Able to Replenish-at-Sea (RAS)	6	1.78	7	Ship
8	Full accommodations required for embarked crew	6	1.78	7	Ship
9	Fuel and support rotary wing aircraft supporting amphibious operations both day and night	6	1.78	7	Ship
1	Defend against and destroy small (less than 200ft long), high speed (in excess of 40kts) surface craft	10	1.64	1	CS
2	Detect, track, and destroy up to 8 simultaneous "leaker" missiles that escape defenses supplied by other fleet units	10	1.64	1	CS
5	Sustain hostile small caliber fire	9	1.47	3	CS
6	Provide suppressive fire for amphibious forces	9	1.47	3	CS
7	Communicate with U.S. and coalition forces via both secure and unsecure channels	8	1.31	5	CS
8	Provide a data link capability	8	1.31	5	CS
9	Maintain a CIC capable of collecting, processing, displaying, evaluating and disseminating tactical information	8	1.31	5	CS

10	Minimal manning	4	1.19	10	Ship
3	Conduct evasive torpedo maneuvers	7	1.15	8	CS
4	Employ ASW countermeasures	7	1.15	8	CS
10	Detect, track, and identify UAV, low slow flyers, attack aircraft	7	1.15	8	CS
11	Provide Naval Surface Fire Support (NSFS) for amphibious forces	7	1.15	8	CS
12	Detect, track, and identify surface threats to the horizon	6	0.98	12	CS
13	Provide for surface defense of Area of Assault (AOA)	6	0.98	12	CS
14	Defend against and engage hostile UAVs and low slow flyers (less than 200kts)	5	0.82	14	CS
15	Conduct Electronic Protection Operations	4	0.66	15	CS
11	Able to transit 2000nm in less than 10 days in up to sea state 8 (wave height 25-40ft) without replenishment	2	0.59	11	Ship
5	THE HSAC must be capable of providing interfaces and services to payload (i.e. electrical power, data-link, fueling)	1	0.54	6	Payload
16	Deconflict potentially hostile craft from friendly and neutral shipping	3	0.49	16	CS
17	Detect underwater mines	3	0.49	16	CS
18	Avoid underwater mines	2	0.33	18	CS
19	Fuel and support rotary wing aircraft supporting amphibious operations both day and night	1	0.16	19	CS

APPENDIX IV ANALYSIS OF ALTERNATIVE DATA

A. OVERALL MOP RESULTS FOR ALL COMBINATIONS

2 ships

	Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
30	0.342191	0.449848	0.387279	0.38479	0.426827	0.442271	0.485414
35	0.377021	0.449548	0.386855	0.404311	0.447522	0.347952	0.453666
40	0.408567	0.452919	0.392445	0.416887	0.465315	0.281379	0.438972
45	0.437378	0.459179	0.112771	0.424876	0.481608	0.233838	0.434471
50	0.463961	0.467752	0.125301	0.430924	0.497275	0.198932	0.436559

3 ships

Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
0.343801	0.42984	0.387121	0.376368	0.415776	0.627776	0.452178
0.377128	0.431442	0.387181	0.392421	0.435057	0.57083	0.428763
0.407249	0.436518	0.393129	0.402279	0.452047	0.53883	0.419628
0.434763	0.444303	0.403015	0.408956	0.468001	0.523089	0.419104
0.460205	0.454243	0.415671	0.415135	0.483659	0.517947	0.424179

4 ships

Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
0.348871	0.421113	0.391037	0.373974	0.412369	0.589141	0.436414
0.381164	0.424002	0.391462	0.387636	0.430813	0.541209	0.418008
0.41032	0.430218	0.397681	0.395964	0.447377	0.515975	0.412241
0.436972	0.439018	0.407772	0.402265	0.463206	0.505157	0.414136
0.461672	0.449867	0.420588	0.409044	0.478948	0.503643	0.421036

5 ships

	Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
	1	2	3	4	5	6	7
30	0.275451	0.312919	0.314196	0.28576	0.317034	0.436347	0.324023
35	0.304634	0.323033	0.321749	0.30163	0.344973	0.421384	0.327652
40	0.331662	0.335356	0.333362	0.314533	0.363817	0.413479	0.331671
45	0.356997	0.349386	0.347695	0.326737	0.382313	0.414992	0.340801
50	0.381033	0.364765	0.363947	0.339745	0.400873	0.422562	0.353284

7 ships

Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
0.291113	0.319738	0.328084	0.294926	0.322713	0.419594	0.323275
0.319518	0.342495	0.33768	0.319592	0.361843	0.435067	0.346576
0.345838	0.343886	0.347766	0.321663	0.372004	0.410319	0.339481
0.370559	0.358624	0.362261	0.334267	0.390515	0.414914	0.350181
0.394081	0.374634	0.378638	0.348239	0.409226	0.424739	0.363854

10 ships

Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
0.319575	0.339899	0.354667	0.316175	0.339637	0.417491	0.335356
0.347201	0.351833	0.362894	0.329356	0.374694	0.422133	0.353037
0.37283	0.365758	0.374999	0.34176	0.393257	0.422391	0.361177
0.396964	0.381201	0.389703	0.35523	0.411875	0.429703	0.373297
0.420007	0.397835	0.406238	0.370463	0.430812	0.441516	0.388051

15 ships

	Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
	1	2	3	4	5	6	7
30	0.403291	0.419602	0.437716	0.381057	0.426697	0.491821	0.419973
35	0.407435	0.40545	0.417811	0.365189	0.41984	0.455274	0.396339
40	0.409043	0.393854	0.402963	0.351175	0.412936	0.431045	0.379645
45	0.408529	0.385906	0.391949	0.347896	0.405857	0.420309	0.37051
50	0.407327	0.378146	0.383412	0.344294	0.400095	0.409754	0.361815

20 ships

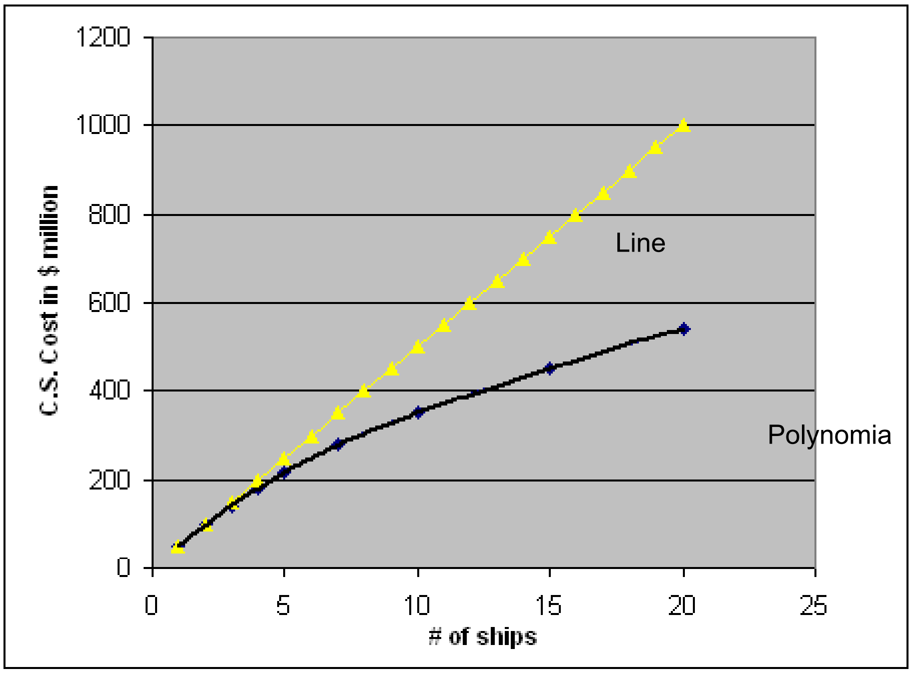
Hydrofoil	HYSWAS	SES	Monohull	Catamaran	Trimaran	SWATH
0.469671	0.493421	0.505792	0.45618	0.499312	0.57552	0.494325
0.474546	0.478343	0.4853	0.44015	0.492529	0.534782	0.468535
0.476765	0.465946	0.47002	0.424849	0.485446	0.507713	0.450348
0.476631	0.457087	0.458488	0.419003	0.47821	0.494835	0.440026
0.475784	0.448682	0.449683	0.415616	0.472034	0.482762	0.430454

B. MOP RESULTS OF THE MEDIUM SIZE SHIPS

	5	7	10	5	7	10	5	7	10	5	7	10	5	7	10
Payload Weight 2,3long tons	1750	1293	950	1750	1293	950	1750	1293	950	1750	1293	950	1750	1293	950
30 KNOTS	Hydrofoil	Hydrofoil	Hydrofoil	HYSWAS	HYSWAS	HYSWAS	SES	SES	SES	Monohull	Monohull	Monohull	Catamaran	Catamaran	Catamaran
Survivability	6.26275	6.990406	8.237655	5.518328	6.314631	7.626102	6.678555	7.367351	8.578601	5.849811	6.616026	7.90071231	6.271048	7.006234	8.261482
Felexibility	5.038719	5.470441	6.160724	6.008667	6.350925	6.95746	7.715597	7.901518	8.363655	7.218355	7.449274	7.95197086	6.761027	6.538736	6.392819
TF	12.33618	11.97033	11.58314	17.73388	16.22895	14.77279	13.3597	13.11404	12.81033	12.51988	11.47568	10.3148463	15.62549	14.67526	13.69084
MOP	0.275451	0.291113	0.319575	0.312919	0.319738	0.339899	0.314196	0.328084	0.354667	0.28576	0.294926	0.31617543	0.317034	0.322713	0.339637
35 KNOTS															
Survivability	7.063234	7.791234	9.038817	6.324161	7.120577	8.432166	7.497973	8.185565	9.395649	6.657655	7.425483	8.71225123	7.08671	7.822445	9.078281
Felexibility	5.838053	6.269304	6.959127	6.800505	7.142606	7.748976	8.507569	8.693988	9.156607	8.012527	8.242249	8.74339909	8.553903	8.731362	9.185178
TF	13.04779	12.58896	12.10865	16.16928	16.16928	13.42454	11.45606	11.45606	10.99197	11.6332	11.6332	9.10134847	15.20482	15.20482	13.16297
MOP	0.304634	0.319518	0.347201	0.323033	0.342495	0.351833	0.321749	0.33768	0.362894	0.30163	0.319592	0.3293558	0.344973	0.361843	0.374694
40 KNOTS															
Survivability	7.865135	8.593408	9.841255	7.130514	7.927053	9.238776	8.31975	9.005974	10.21475	7.469541	8.239523	9.52900853	7.905224	8.641542	9.898008
Felexibility	6.63544	7.066314	7.755775	7.591617	7.933544	8.539727	9.298565	9.485549	9.948709	8.803698	9.031819	9.53095081	9.345482	9.522675	9.976204
TF	13.50132	12.95789	12.39497	14.8669	13.56537	12.31265	10.03078	9.851912	9.630955	10.38611	9.092667	7.78605887	14.64803	13.6131	12.57013
MOP	0.331662	0.345838	0.37283	0.335356	0.343886	0.365758	0.333362	0.347766	0.374999	0.314533	0.321663	0.34175968	0.363817	0.372004	0.393257
45 KNOTS															
Survivability	8.668116	9.396618	10.64468	7.9374	8.734078	10.04594	9.144074	9.828784	11.03608	8.28607	9.058785	10.3516414	8.726562	9.463519	10.72067
Felexibility	7.43134	7.8619	8.551069	8.381982	8.723715	9.329697	10.08851	10.27612	10.73989	9.591419	9.81751	10.3141378	10.13578	10.31268	10.7659
TF	13.75192	13.13516	12.50202	13.76728	12.54987	11.3808	8.923929	8.767607	8.574524	9.04743	7.796755	6.58719462	14.04395	13.00954	11.97777
MOP	0.356997	0.370559	0.396964	0.349386	0.358624	0.381201	0.347695	0.362261	0.389703	0.326737	0.334267	0.35523001	0.382313	0.390515	0.411875
50 KNOTS															
Survivability	9.471978	10.20068	11.44892	8.744838	9.541666	10.8537	9.971165	10.65421	11.85984	9.107862	9.883913	11.1807928	9.550769	10.28845	11.54636
Felexibility	8.226031	8.656316	9.345231	9.171575	9.513098	10.11885	10.87731	11.06561	11.53007	10.37523	10.59884	11.0924825	10.92476	11.10134	11.55421
TF	13.84684	13.16859	12.47834	12.82753	11.685	10.59007	8.039773	7.901715	7.731111	7.795064	6.653131	5.58654092	13.44146	12.42356	11.41724
MOP	0.381033	0.394081	0.420007	0.364765	0.374634	0.397835	0.363947	0.378638	0.406238	0.339745	0.348239	0.37046345	0.400873	0.409226	0.430812

C. COST MODEL

# ships	Combat System Cost	Cost/ship
1	50	50
2	98	49
3	141	47
4	180	45
5	215	43
7	280	40
10	350	35
15	450	30
20	540	27



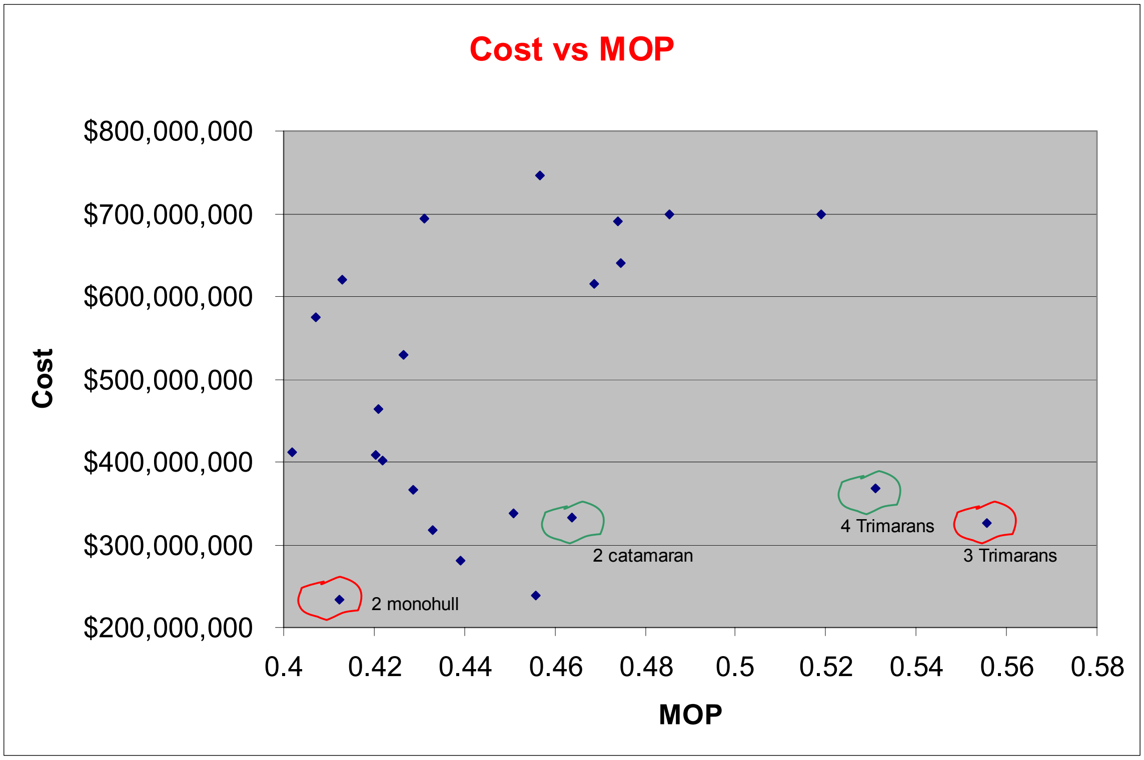
D. COST CALCULATION

Figure 89.

Excel work to calculate the cost according to the new cost

Learning curve=0.9

		HYSWAS-2	Monohull-2	Catamaran-2	HYSWAS-3	Catamaran-3	Trimaran-3
		1	2	3	4	5	6
30		0.44984773	0.38478972	**0.426826788**	0.429840363	0.415775549	**0.62777641**
35		0.44954772	0.40431136	**0.447521768**	0.431442471	0.435056994	**0.5708295**
40		0.45291902	0.41688715	**0.465314781**	0.436517769	0.452046917	**0.53882951**
45		0.45917945	0.42487634	**0.481607985**	0.444303049	0.468000619	**0.5230886**
50		0.46775168	0.43092426	**0.497275097**	0.454242516	0.483658605	**0.51794713**
test1		0.45584912	0.41235777	**0.463709284**	0.439269234	0.450907737	**0.55569423**
test2		0.45584912	0.41235777	**0**	0.439269234	0	**0**
test3= Average MOP		0.45584912	**0.41235777**	**0.463709284**	**0.439269234**	**0.450907737**	**0.55569423**
Old MIT Cost		510400000	508100000	**538900000**	489600000	510300000	**506000000**
Machinery and Structural Weight cost		152533994	147933994	**209533994.1**	166400991.2	228500991.2	**215600991**
Combat System adjusted cost		250533994	245933994	**350533994.1**	307400991.2	369500991.2	356600991
Learning curve Adjusted Cost		238007294	**233637294**	**333007294.4**	**281395480.7**	**338241944.6**	**326433259**
Cost of nth ship		125266997	122966997	175266997.1	102466997.1	123166997.1	118866997
	2	112740297	110670297	157740297.3	92220297.35	110850297.3	106980297
	3	106001683	104055409	148311982.1	86708186.3	104224650.2	100585964
	4	101466268	99603267.6	141966267.6	82998267.61	99765267.61	96282267.6
	5	98082395.4	96281525.9	137231731.4	80230298.1	96438123.24	93071280.3
	6	95401514.5	93649868.1	133480783.9	78037367.67	93802185.2	90527368
	7	93192111.1	91481031.1	130389502.8	76230100.51	91629820.67	88430845
	8	91319640.8	89642940.8	127769640.8	74698440.85	89788740.85	86654040.8
	9	89699258.5	88052310	125502487.1	73372986.31	88195522.94	85116445.3
	10	88274155.8	86653373.3	123508558.3	72207268.29	86794310.92	83764152.3
	11	87004508.3	85407037.5	121732134.2	71168710.85	85545947.98	82559372.2
	12	85861363.1	84284881.3	120132705.5	70233630.91	84421966.68	81474631.2
	13	84823039.6	83265622.2	118679937.9	69384293.95	83401049.84	80489356.6
	14	83872900	82332928	117350552.5	68607090.46	82466838.61	79587760.5
	15	82997910.1	81474003.6	116126312.7	67891358.54	81606517.19	78757474.6
	16	82187676.8	80678646.8	114992676.8	67228596.76	80809866.76	77988636.8
	17	81433785.6	79938597.6	113937871.8	66611922.23	80068613.95	77273262.5
	18	80729332.7	79247079	112952238.4	66035687.68	79375970.64	76604800.8
	19	80068586.8	78598465	112027757.5	65495204.97	78726301.64	75977813
	20	79446740.2	77988036	111157702.5	64986541.46	78114879.82	75387737.1


Cost vs MOP
$800,000,000
$700,000,000
$600,000,000
$500,000,000
$400,000,000
$300,000,000
$200,000,000
Cost
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
0.56
0.58
MOP
2 monohull
2 catamaran
4 Trimarans
3 Trimarans

APPENDIX V CARGO DESIGN DATA

A. TWO BATTALION LANDING TEAM COMPOSITION

SUMMARY OF PERSONNEL AND EQUIPMENT BY LANDING SEQUENCE PRIORITY

MPF(F) MEB SEA BASED MANEUVER ELEMENT (SURFACE)

NOTE: UNITS LISTED ARE PER BATTALION TASK FORCE. FOR SURFACE, WEIGHTS AND AREAS ARE DOUBLED (IN RED TEXT/HIGHLIGHT)

Landing Priority	Unit	# Pax	Equipment Type	Equipment Quantity	Indiv Weight (lbs)	Total Weight (lbs)	Indiv Area (ft^2)	Total Area (ft^2)
1	Rifle Co 1 (Rein)	233	EFV-P	12	72,879	874,548	360.0	4320.0
	AA Plt							
2	Tank Plt 1	8	M1A1	2	133,815	267,630	387.0	774.0
		8	M1A1 w/TWMP	2	141,075	282,150	506.8	1013.6
3	Rifle Co 2 (Rein)	233	EFV-P	12	72,879	874,548	360.0	4320.0
	AA Plt							
4	Tank Plt 2	8	M1A1	2	133,815	267,630	387.0	774.0
		8	M1A1 w/TWMP	2	141,075	282,150	506.8	1013.6
5	A Command	143	EFV-P	10	71,344	713,440	360.0	3600.0
	AA Plt	8	EFV-C	1	66,351	66,351	360.0	360.0
	CEB Plt							
	81mm Mortars							
6	Rifle Co 3 (Rein)	233	EFV-P	12	72,879	874,548	360.0	4320.0
	AA Plt							
7	Tank Plt 3	16	M1A1	4	133,815	535,260	387.0	1548.0
8	Tank Co Hq	8	ABV	2	1,350	2,700	468.0	936.0
	Det, CEB Co	4	AVLB	1	93,194	93,194	468.0	468.0
	Det, Engr Spt Plt	8	M1A1	2	133,815	267,630	387.0	774.0
	(ABV&ACE)	5	M88A2	1	141,173	141,173	340.5	340.5
	Det, AT Plt, Tank Bn	4	M9 ACE	4	37,799	151,197	215.3	861.0
		8	M998 HMMWV w/M101Trlr	2	12,118	24,236	185.3	370.7
		3	M998 HMMWV w/M116 Trlr	1	12,778	12,778	196.1	196.1
		3	MRC JTRS HMMWV	2	8,720	17,440	64.8	129.7
		4	M1043 HMMWV	1	10,158	10,158	109.8	109.8
		18	M1045 HMMWV	6	9,918	59,508	109.2	655.2
		9	M998 HMMWV	3	8,918	26,754	109.3	327.9
9	CAAT Plt	24	ITV	8				
	Scout Snipers	40	M1043 HMMWV	10	10,158	101,580	109.8	1097.9
	TACP	32	M1045 HMMWV	8	10,218	81,744	109.2	873.6
		9	M998 HMMWV	3	8,918	26,754	109.3	327.9

		2	MRC JTRS HMMWV w/M101 Trlr	1	11,770	11,770	140.9	140.9
10	B Command	18	EFV-P	1	72,454	72,454	360.0	360.0
	Det, AA Plt	12	EFV-C	1	67,551	67,551	360.0	360.0
	Arty Bn LNO Tm	4	M998 HMMWV w/M101 Trlr	1	12,118	12,118	185.3	185.3
	NGLO Team	9	MRC JTRS HMMWV	3	9,170	27,510	64.8	194.5
11	LAR Co B	84	LAV 25	14	28,685	401,590	173.3	2425.5
		4	LAV AT	4	30,624	122,496	171.5	686.0
		6	LAV C2	1	29,121	29,121	174.6	174.6
		2	LAV L	3	29,429	88,287	173.5	520.6
		3	LAV M	2	30,047	60,094	172.2	344.4
		6	LAV R	1	31,103	31,103	200.0	200.0
12	A Command Veh/Pers	8	M1043 HMMWV	2	10,158	20,316	109.8	219.6
		12	M998 HMMWV	3	9,218	27,654	109.3	327.9
		12	MRC JTRS HMMWV	4	10,670	42,680	64.8	259.4
		4	MRC JTRS HMMWVw/M101 Trlr	1	10,870	10,870	140.9	140.9
13	Det, Arty Btry C (3 Guns)	3	M1043 HMMWV	1	9,858	9,858	109.8	109.8
		12	M998 HMMWV w/M101 Trlr	3	12,118	36,354	185.3	556.0
		24	MTVR w/LW155	3	46,208	138,624	214.4	643.1
		9	MTVR w/M105 Trlr	3	53,068	159,204	310.6	931.9
		6	MRC JTRS HMMWV	2	9,170	18,340	64.8	129.7
14	Avenger Section	10	Avenger	5	13,613	68,065	116.5	582.3
		3	MRC JTRS HMMWV	1	9,170	9,170	64.8	64.8
15	Arty Btry C (-) (3 Guns)	4	M1043 HMMWV	1	10,158	10,158	109.8	109.8
	Det, CBR Plt, HQ Btry	4	M998 HMMWV w/M101 Trlr	1	12,118	12,118	185.3	185.3
		3	MRC JTRS HMMWV	1	9,170	9,170	64.8	64.8
		4	MTVR	1	45,008	45,008	214.4	214.4
		24	MTVR w/LW155	3	46,208	138,624	214.4	643.1
		15	MTVR w/M105 Trlr	5	53,068	265,340	310.6	1553.1
		3	MTVR w/M149 WB	1	50,308	50,308	307.8	307.8
		2	4K Forklift	2	12,004	24,008	106.2	212.3
		4	M1035 HMMWV	1	8,890	8,890	106.3	106.3
		12	AN/TPQ (4 HMMWV& 4 Trlr)	1	53,476	53,476	108.5	108.5
16	Det, CEB Co B (Veh/Pers)	6	MTVR Dumptruck w/MK155	3	52,541	157,623	339.0	1017.1
		3	M998 HMMWV	1	8,918	8,918	109.3	109.3

17	B Command (Veh/Pers)	18	M998 HMMWV	6	8,918	53,508	109.3	655.7
		9	M998 HMMWV w/M101 Trlr	3	11,818	35,454	185.3	556.0
		6	MRC JTRS HMMWV	2	9,170	18,340	64.8	129.7
18	Inf Bn Combat Trains	6	M1035 HMMWV	2	8,590	17,181	106.3	212.5
		8	M997 HMMWV	2	11,550	23,101	122.4	244.9
		21	M998 HMMWV	7	8,918	62,426	109.3	765.0
		3	M998 HMMWV w/M101 Trlr	1	11,818	11,818	185.3	185.3
19	Inf Bn DS CSS Co B	2	4K Forklift	2	12,004	24,008	106.2	212.3
		10	M1043	2	10,458	20,916	109.8	219.6
		10	M997 HMMWV	2	11,850	23,701	122.4	244.9
		24	M998 HMMWV	6	9,218	55,308	109.3	655.7
		8	Contact Truck	2	22,200	44,400	214.4	428.8
		16	M998 HMMWV w/M101 Trlr	4	12,118	48,472	185.3	741.4
		3	MRC JTRS HMMWV	2	8,720	17,440	64.8	129.7
Totals per Bn Task Force	**Unit**	**# Pax**	**Equipment Type**	**Equipment Quantity**	**Indiv Weight (lbs)**	**Total Weight (lbs)**	**Indiv Area (ft2)**	**Total Area (ft2)**
		1558		**237**	**2,604,574.4**	**8,760,044.2**	**14,594.7**	**49,081.7**
Sub-Totals for Surface A42SBME	**Unit**	**# Pax**	**Equipment Type**	**Equipment Quantity**	**Indiv Weight (lbs)**	**Total Weight (lbs)**	**Indiv Area (ft2)**	**Total Area (ft2)**
		3116		**474**	**5,209,148.8**	**17,520,088.4**	**29,189.3**	**98,163.3**
PRIORITIES ABOVE FOR INITIAL STOM. PRIORITIES								

B. SIX SHIP CARGO DISTRIBUTION

Distribution of one battalion landing team on six HSAC ships:

Vehicle	SHIP	1	SHIP	2	SHIP	3	SHIP	4	SHIP	5	SHIP	6
	qty		qty		qty		qty		qty		qty	
Humvee	17	137700	17	137700	17	137700	17	137700	17	137700	17	137700
EFV	9	655911	8	583032	8	583032	8	583032	8	583032	8	583032
M1A2	2	278160	3	417240	3	417240	2	278160	2	278160	2	278160
LAV	5	145000	4	116000	4	116000	4	116000	4	116000	4	116000
ABV		0		0		0		0	1	139080	1	139080
AVLB		0		0		0	1	93194		0		0
M9ACE		0		0	1	37799	1	37799	1	37799	1	37799
M88A2		0	1	140000		0		0		0		0
ITV	1	7900	1	7900	1	7900	2	15800	1	7900	2	15800
AVENGER	1	8300		0	1	8300	1	8300	1	8300	1	8300
MTVR	4	164000	3	123000	3	123000	3	123000	3	123000	3	123000
LW155	1	9200	1	9200	1	9200	1	9200	1	9200	1	9200
M105	2	10720	2	10720	1	5360	1	5360	1	5360	1	5360
MK155		0		0	1	6405	1	6405	1	6405		0
M101	2	5678	2	5678	4	11356	2	5678	4	11356	3	8517
M149		0		0		0		0		0	1	2600
M116		0		0		0		0	1	2360		0
AN/TPQ	1	43756		0		0		0		0		0
FORKLIFT	1	10000		0	1	10000	1	10000		0	1	10000
CONTACT TRUCK		0		0		0	2	40000		0		0
TOTAL PAYLOAD (LB)		1476325		1550470		1473292		1469628		1465652		1474548
TOTAL PAYLOAD (LT)		659		692		658		656		654		658

C. CARGO VERTICAL CENTER OF GRAVITY CALCULATIONS

VERTICAL CENTER OF GRAVITY CALCULATIONS FOR ONE BATTALION LANDING TEAM OF CARGO DISTRIBUTED OVER SIX HSAC SHIPS

			SHIP 1			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	9	655911	3.188208	7.094104	4653101
M1A2	139080	2	278160	2.886456	6.943228	1931328
LAV	29000	5	145000	2.68986	10.84493	1572515
ABV	139080		0	2.886456	10.94323	0
AVLB	93194		0	2.886456	10.94323	0
M9ACE	37799		0	2.886456	10.94323	0
M88A2	140000		0	3.1242	11.0621	0
ITV	7900	1	7900	1.6764	10.3382	81671.78
AVENGER	8300	1	8300	2.642616	10.82131	89816.86
MTVR	41000	4	164000	2.846832	10.92342	1791440
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	2	10720	2.490216	10.74511	115187.6
MK155	6405		0	1.880616	10.44031	0
M101	2839	2	5678	2.112264	10.55613	59937.72
M149	2600		0	1.941576	10.47079	0
M116	2360		0	0.6096	9.8048	0
AN/TPQ	43756	1	43756	2.5908	10.7954	472363.5
FORKLIFT	10000	1	10000	3.090672	11.04534	110453.4
CONTACT TRUCK	20000		0	2.846832	10.92342	0
TOTAL PAYLOAD WEIGHT(LB)			1476325			**12462145**
TOTAL PAYLOAD WEIGHT(LT)			659.0737			
				VCG of CARGO=		**8.441329**

			SHIP 2			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	8	583032	3.188208	7.094104	4136090
M1A2	139080	3	417240	2.886456	6.943228	2896992
LAV	29000	4	116000	2.68986	10.84493	1258012
ABV	139080	0	0	2.886456	10.94323	0
AVLB	93194	0	0	2.886456	10.94323	0
M9ACE	37799	0	0	2.886456	10.94323	0
M88A2	140000	1	140000	3.1242	11.0621	1548694
ITV	7900	1	7900	1.6764	10.3382	81671.78
AVENGER	8300	0	0	2.642616	10.82131	0
MTVR	41000	3	123000	2.846832	10.92342	1343580
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	2	10720	2.490216	10.74511	115187.6
MK155	6405	0	0	1.880616	10.44031	0
M101	2839	2	5678	2.112264	10.55613	59937.72
M149	2600	0	0	1.941576	10.47079	0
M116	2360	0	0	0.6096	9.8048	0
AN/TPQ	43756	0	0	2.5908	10.7954	0
FORKLIFT	10000	0	0	3.090672	11.04534	0
CONTACT TRUCK	20000	0	0	2.846832	10.92342	0
TOTAL PAYLOAD WEIGHT(LB)			1550470			**13024495**
TOTAL PAYLOAD WEIGHT(LT)			692.1741			
				VCG of CARGO=		**8.400353**

			SHIP 3			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	8	583032	3.188208	7.094104	4136090
M1A2	139080	3	417240	2.886456	6.943228	2896992
LAV	29000	4	116000	2.68986	10.84493	1258012
ABV	139080		0	2.886456	10.94323	0
AVLB	93194		0	2.886456	10.94323	0
M9ACE	37799	1	37799	2.886456	10.94323	413643.1
M88A2	140000		0	3.1242	11.0621	0
ITV	7900	1	7900	1.6764	10.3382	81671.78
AVENGER	8300	1	8300	2.642616	10.82131	89816.86
MTVR	41000	3	123000	2.846832	10.92342	1343580
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	1	5360	2.490216	10.74511	57593.78
MK155	6405	1	6405	1.880616	10.44031	66870.17
M101	2839	4	11356	2.112264	10.55613	119875.4
M149	2600		0	1.941576	10.47079	0
M116	2360		0	0.6096	9.8048	0
AN/TPQ	43756		0	2.5908	10.7954	0
FORKLIFT	10000	1	10000	3.090672	11.04534	110453.4
CONTACT TRUCK	20000		0	2.846832	10.92342	0
TOTAL PAYLOAD WEIGHT(LB)			1473292			**12158929**
TOTAL PAYLOAD WEIGHT(LT)			657.7196			
				VCG of CARGO=		**8.252898**

			SHIP 4			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	8	583032	3.188208	7.094104	4136090
M1A2	139080	2	278160	2.886456	6.943228	1931328
LAV	29000	4	116000	2.68986	10.84493	1258012
ABV	139080		0	2.886456	10.94323	0
AVLB	93194	1	93194	2.886456	10.94323	1019843
M9ACE	37799	1	37799	2.886456	10.94323	413643.1
M88A2	140000		0	3.1242	11.0621	0
ITV	7900	2	15800	1.6764	10.3382	163343.6
AVENGER	8300	1	8300	2.642616	10.82131	89816.86
MTVR	41000	3	123000	2.846832	10.92342	1343580
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	1	5360	2.490216	10.74511	57593.78
MK155	6405	1	6405	1.880616	10.44031	66870.17
M101	2839	2	5678	2.112264	10.55613	59937.72
M149	2600		0	1.941576	10.47079	0
M116	2360		0	0.6096	9.8048	0
AN/TPQ	43756		0	2.5908	10.7954	0
FORKLIFT	10000	1	10000	3.090672	11.04534	110453.4
CONTACT TRUCK	20000	2	40000	2.846832	10.92342	436936.6
TOTAL PAYLOAD WEIGHT(LB)			1469628			**12671778**
TOTAL PAYLOAD WEIGHT(LT)			656.0839			
				VCG of CARGO=		**8.622439**

			SHIP 5			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	8	583032	3.188208	7.094104	4136090
M1A2	139080	2	278160	2.886456	6.943228	1931328
LAV	29000	4	116000	2.68986	10.84493	1258012
ABV	139080	1	139080	2.886456	10.94323	1521984
AVLB	93194		0	2.886456	10.94323	0
M9ACE	37799	1	37799	2.886456	10.94323	413643.1
M88A2	140000		0	3.1242	11.0621	0
ITV	7900	1	7900	1.6764	10.3382	81671.78
AVENGER	8300	1	8300	2.642616	10.82131	89816.86
MTVR	41000	3	123000	2.846832	10.92342	1343580
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	1	5360	2.490216	10.74511	57593.78
MK155	6405	1	6405	1.880616	10.44031	66870.17
M101	2839	4	11356	2.112264	10.55613	119875.4
M149	2600		0	1.941576	10.47079	0
M116	2360	1	2360	0.6096	9.8048	23139.33
AN/TPQ	43756		0	2.5908	10.7954	0
FORKLIFT	10000		0	3.090672	11.04534	0
CONTACT TRUCK	20000		0	2.846832	10.92342	0
TOTAL PAYLOAD WEIGHT(LB)			1465652			**12627935**
TOTAL PAYLOAD WEIGHT(LT)			654.3089			
				VCG of CARGO=		**8.615916**

			SHIP 6			
Vehicle	weight (lbs)	# of vehicles	Total weight (lb)	Height (m)	Vehicle VCG (m)	weight*vcg (lb*m)
Humvee	8100	17	137700	2.5908	10.7954	1486527
EFV	72879	8	583032	3.188208	7.094104	4136090
M1A2	139080	2	278160	2.886456	6.943228	1931328
LAV	29000	4	116000	2.68986	10.84493	1258012
ABV	139080	1	139080	2.886456	10.94323	1521984
AVLB	93194		0	2.886456	10.94323	0
M9ACE	37799	1	37799	2.886456	10.94323	413643.1
M88A2	140000		0	3.1242	11.0621	0
ITV	7900	2	15800	1.6764	10.3382	163343.6
AVENGER	8300	1	8300	2.642616	10.82131	89816.86
MTVR	41000	3	123000	2.846832	10.92342	1343580
LW155	9200	1	9200	2.261616	10.63081	97803.43
M105	5360	1	5360	2.490216	10.74511	57593.78
MK155	6405		0	1.880616	10.44031	0
M101	2839	3	8517	2.112264	10.55613	89906.58
M149	2600	1	2600	1.941576	10.47079	27224.05
M116	2360		0	0.6096	9.8048	0
AN/TPQ	43756		0	2.5908	10.7954	0
FORKLIFT	10000	1	10000	3.090672	11.04534	110453.4
CONTACT TRUCK	20000		0	2.846832	10.92342	0
TOTAL PAYLOAD WEIGHT(LB)			1474548			**12727305**
TOTAL PAYLOAD WEIGHT(LT)			658.2804			
				VCG of CARGO=		**8.631327**

D. WEIGHT AND BUOYANCY CALCULATIONS

BOW RAMP WEIGHT AND BOUYANCY CALCULATIONS

Bow Ramp Section Specifications:

L = 5 meters
W = 5 meters
D = 1.7 meters

Ramp is comprised of eight sections as described above, seven of which will experience buoyancy forces when the ramp is fully deployed.

Density of Aluminum: $\rho_{al} = 2700\, kg/m^3$

Density of Steel: $\rho_{steel} = 7850\, kg/m^3$

Aluminum to Steel Density Ratio: $\dfrac{\rho_{al}}{\rho_{steel}} = 0.34$

Existing NL causeway Structure Density (steel):

$$\rho = \frac{140000 lb}{9900 ft^3} = 14.14\, lb/ft^3$$

HSAC Bow Ramp Structure Density (estimate half steel/half aluminum construction):

$$\rho_{estimated} = 0.34\left(14.14\, lb/ft^3\right) = 9.5\, lb/ft^3$$

Bow Ramp Weight:

Total Volume (8 sections)= $(40)(5)(1.6) = 320 m^3 = 11300.7 ft^3$

Total Volume (7 floating sections)= $(35)(5)(1.6) = 280 m^3 = 9888.1 ft^3$

Weight of 40 meter ramp (8 sections) = $\left(11300.7 ft^3\right)\left(9.5\, lb/ft^3\right) = 107357 lb = 47.93 LT$

Weight of 35 meter ramp (7 floating sections) = $\left(9888.1 ft^3\right)\left(9.5\, lb/ft^3\right) = 93937 lb = 41.94 LT$

Bow Ramp Draft Unloaded:

$$\Delta = \left(9888.1 ft\right)\left(9.5\, lb/ft^3\right) = 93937 lb = 41.94 LT$$

$$\nabla = (41.94LT)\left(35\, {ft^3}/{LT}\right) = 1467.8\,ft^3 = 41.56m^3$$

$$T = {(41.56m^3)}/{(5m)(35m)} = 0.23m$$

Maximum desired draft = *1.0m*

Desired cargo capacity = two M1A2 tanks, at 62.1LT each

Bow Ramp Calculated Draft with 124.2LT load:

$$\Delta_{load+structure} = 124.2LT + 41.94LT = 166.1LT$$

$$\nabla = (166.1LT)\left(35\, {ft^3}/{LT}\right) = 5813.5\,ft^3 = 164.6m^3$$

$$\boxed{T_{\max load} = {164.6m^3}/{(5m)(35m)} = 0.94m}$$

E. OFFLOAD RATE CALCULATIONS

It was assumed that a vehicle starting all the way at the stern of the HSAC could traverse the full length of the ship and fully deployed bow ramp at 5mph or 2.24m/s.

Length of ship = 149m

Length of deployed ramp = 35m

Total travel distance = 184m

Time to traverse total distance = $\frac{184m}{2.24\,{}^{m}\!/\!{}_{s}} = 82.14s$

The above calculated offload time is the absolute worst case time for a vehicle leaving the ship. Vehicles closer to the bow have to travel a shorter distance than those closer to the stern. In addition, the EFVs and LAVs can exit out the stern instead of using the bow ramp. Thus using this worst case time for all the loaded vehicles should produce a reasonable estimate for the offload time. It is also important to note that the initial vehicles to disembark will be unsecured from sea while the ramp is being deployed. Then as the initial vehicles leave the remaining vehicles are unsecured in preparation for their departure.

Vehicles loaded = 47

Worst-case offload time = $47 * 82.14s = 3860.50s = 1.072 hours$

Buffer added for extenuating events = 1 hour

Total Estimated Offload Time = ~2 hours

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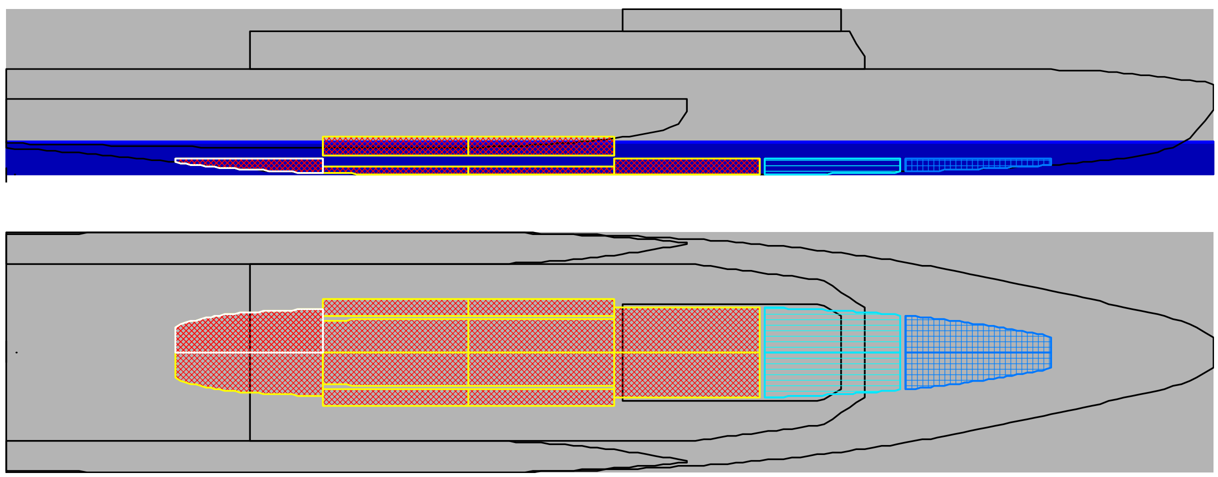
APPENDIX VI HULL CALCULATIONS

A.   HULL DATA

Floating Status

Draft FP	4.500 m	Heel	zero	GM(Solid)	9.823 m
Draft MS	4.500 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	4.500 m	Wind	0.0 kn	GM(Fluid)	9.823 m
Trim	0.00 deg.	Wave	No	KMT	14.843 m
LCG	69.697f m	VCG	5.020 m	TPcm	18.65



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		819.94	100.00%
FRESH WATER		227.10	100.00%
WATER BALLAST		110.43	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	3,810.00	68.300f	0.000	6.000u
Total Fixed:	**3,810.00**	**68.300f**	**0.000**	**6.000u**

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985
Subtotals:	**100.00%**	**819.94**	**60.901f**	**0.000**	**1.994**	

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
FW1.P	100.00%	113.55	101.504f	2.046p	1.235	0.985
FW1.S	100.00%	113.55	101.504f	2.046s	1.235	0.985
Subtotals:	**100.00%**	**227.10**	**101.504f**	**0.000**	**1.235**	

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
WB1.P	100.00%	55.21	117.785f	1.438p	1.455	0.985
WB1.S	100.00%	55.21	117.785f	1.438s	1.455	0.985
Subtotals:	**100.00%**	**110.43**	**117.785f**	**0.000**	**1.455**	

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
Totals:		**1,157.46**	**74.294f**	**0.000**	**1.794**	

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	**Intact**	**1.025**	**4,967.53**	**69.697f**	**0.000**	**2.791**	**0.950**
SubTotals:			**4,967.53**	**69.697f**	**0.000**	**2.791**	

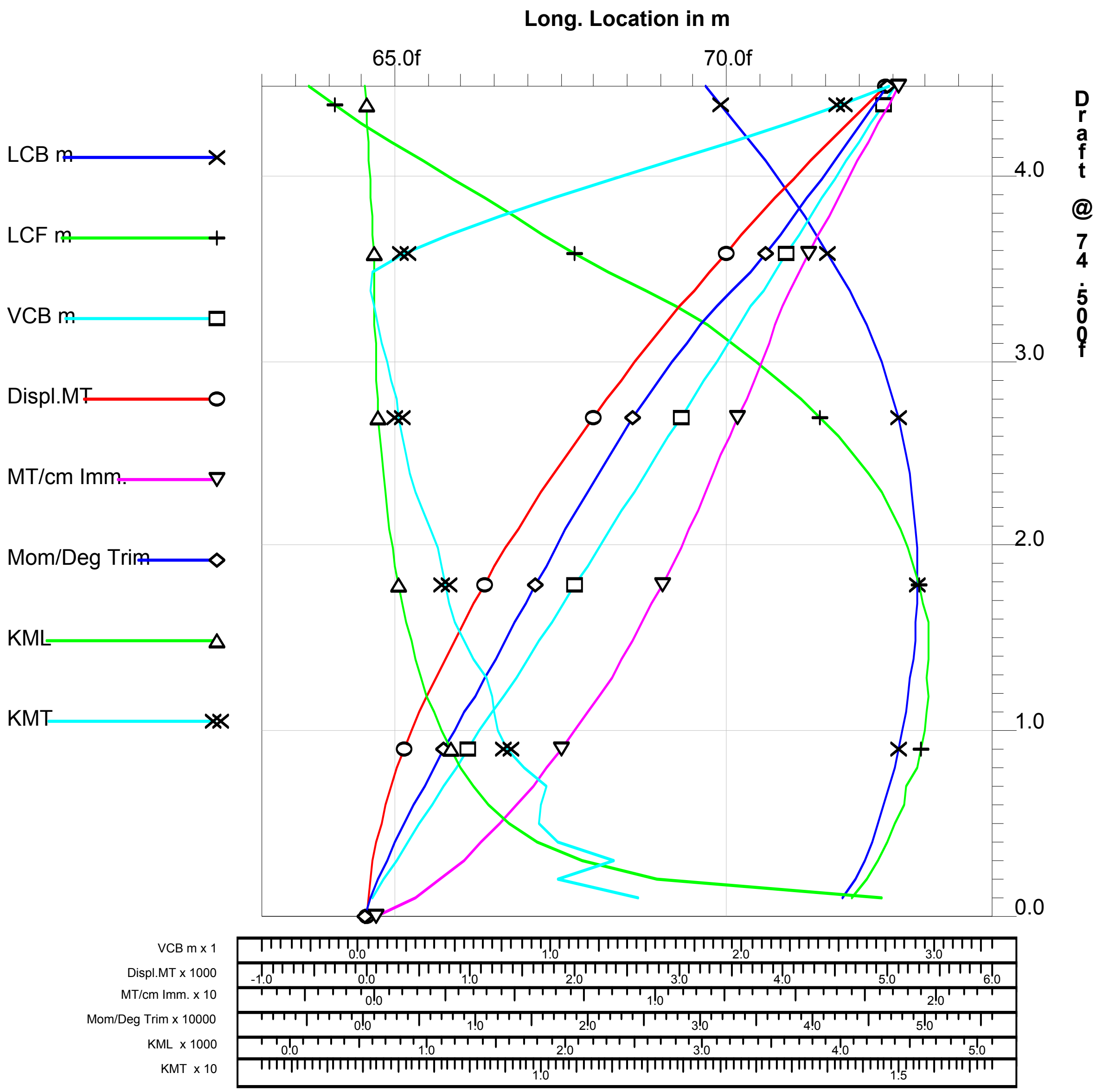
B. HYDROSTATICS

Draft is from Baseline.
Trim: 0.00 deg., No heel, VCG = 6.000

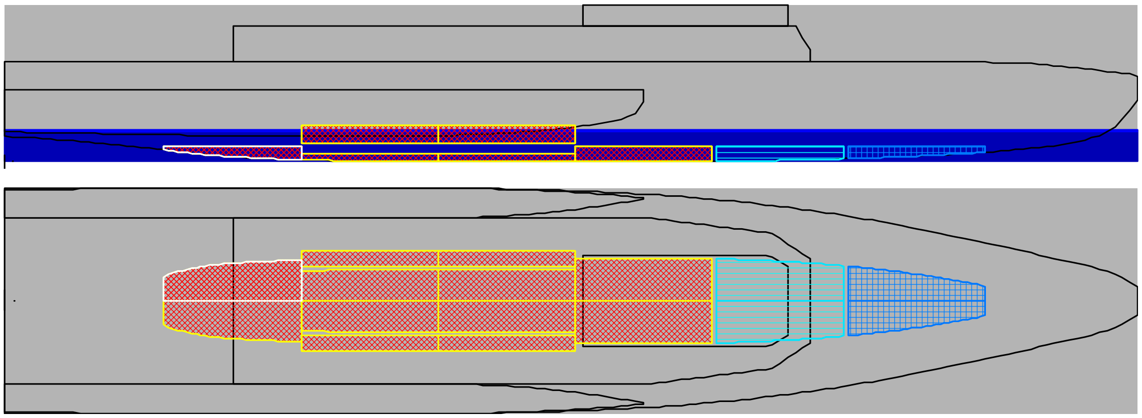
Draft at 74.500f (m)	Displ (MT)	LCB (m)	VCB (m)	LCF (m)	TPcm (MT/cm)	MTcm (MT-m /deg)	KML (m)	KMT (m)
0.000	0.000							
0.100	7.931	71.742f	0.066	71.879f	1.448	594.657	4,301.723	11.345
0.200	26.676	71.930f	0.128	72.115f	2.298	1236.824	2,662.185	10.214
0.300	53.994	72.064f	0.191	72.266f	3.148	1991.351	2,118.908	11.013
0.400	88.723	72.179f	0.254	72.407f	3.790	2764.115	1,790.833	10.221
0.500	129.726	72.282f	0.316	72.541f	4.410	3571.172	1,583.115	9.960
0.600	176.907	72.370f	0.379	72.675f	5.024	4418.229	1,436.810	9.990
0.700	230.252	72.448f	0.442	72.697f	5.632	5340.515	1,334.797	10.075
0.800	289.045	72.518f	0.505	72.853f	6.122	6198.808	1,234.630	9.749
0.900	352.723	72.583f	0.567	72.922f	6.604	7099.704	1,159.147	9.524
1.000	421.163	72.640f	0.630	72.971f	7.074	8001.117	1,094.377	9.388
1.100	494.273	72.689f	0.692	73.012f	7.538	8913.863	1,039.184	9.323
1.200	572.004	72.732f	0.754	73.039f	7.996	9832.132	990.753	9.314
1.300	654.215	72.768f	0.817	73.009f	8.426	10787.380	950.656	9.228
1.400	740.324	72.800f	0.879	73.023f	8.799	11680.080	909.863	9.053
1.500	830.113	72.826f	0.941	73.033f	9.160	12561.960	872.959	8.905
1.600	923.496	72.846f	1.002	73.046f	9.508	13418.780	838.447	8.788
1.700	1020.400	72.861f	1.064	72.961f	9.867	14350.160	811.684	8.702
1.800	1120.783	72.869f	1.125	72.900f	10.215	15251.660	785.604	8.641
1.900	1224.653	72.870f	1.187	72.818f	10.563	16167.050	762.304	8.603
2.000	1331.987	72.862f	1.248	72.725f	10.896	17087.560	740.952	8.553
2.100	1442.453	72.847f	1.310	72.621f	11.190	18001.750	720.976	8.436
2.200	1555.860	72.824f	1.371	72.483f	11.480	18934.830	703.219	8.328
2.300	1672.158	72.793f	1.432	72.318f	11.767	19890.510	687.471	8.233
2.400	1791.323	72.753f	1.493	72.129f	12.054	20868.730	673.422	8.153
2.500	1913.357	72.705f	1.554	71.913f	12.341	21874.400	660.966	8.088
2.600	2038.269	72.648f	1.615	71.674f	12.631	22912.690	650.011	8.035
2.700	2166.087	72.582f	1.676	71.409f	12.923	23987.520	640.436	7.995
2.800	2296.835	72.506f	1.738	71.117f	13.220	25109.100	632.296	7.966
2.900	2430.443	72.421f	1.799	70.786f	13.494	26287.780	625.651	7.899
3.000	2566.675	72.325f	1.860	70.438f	13.755	27486.140	619.510	7.824
3.100	2705.507	72.219f	1.921	70.068f	14.016	28726.340	614.289	7.755
3.200	2846.944	72.104f	1.982	69.689f	14.274	29991.040	609.519	7.694
3.300	2991.049	71.977f	2.043	69.228f	14.547	31391.950	607.275	7.642
3.400	3137.848	71.838f	2.104	68.784f	14.815	32789.630	604.664	7.598
3.500	3287.456	71.686f	2.166	68.214f	15.116	34404.420	605.560	7.634
3.600	3440.279	71.521f	2.227	67.695f	15.453	35827.530	602.625	8.075
3.700	3596.557	71.344f	2.289	67.229f	15.803	37098.040	596.939	8.703
3.800	3756.353	71.160f	2.351	66.782f	16.151	38316.600	590.385	9.414
3.900	3919.581	70.968f	2.414	66.334f	16.494	39505.680	583.429	10.178
4.000	4086.282	70.770f	2.476	65.874f	16.847	40708.030	576.729	10.987
4.100	4256.575	70.565f	2.539	65.399f	17.211	41945.430	570.551	11.823
4.200	4430.531	70.352f	2.602	64.921f	17.578	43179.730	564.345	12.661
4.300	4608.139	70.134f	2.666	64.482f	17.943	44373.480	557.666	13.446
4.400	4789.379	69.913f	2.730	64.074f	18.304	45520.370	550.509	14.180
4.500	4974.211	69.689f	2.794	63.697f	18.661	46620.790	542.950	14.867

Water Specific Gravity = 1.025.

Hydrostatic Properties at Trim = 0.00, Heel = 0.00



C. TANK CALIBRATION



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
COMBUSTIBLE		819.94	100.00%
FRESH WATER		227.10	100.00%
WATER BALLAST		110.43	100.00%

Tank Status

COMBUSTIBLE (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985
Subtotals:	**100.00%**	**819.94**	**60.901f**	**0.000**	**1.994**	

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
FW1.P	100.00%	113.55	101.504f	2.046p	1.235	0.985
FW1.S	100.00%	113.55	101.504f	2.046s	1.235	0.985
Subtotals:	**100.00%**	**227.10**	**101.504f**	**0.000**	**1.235**	

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
WB1.P	100.00%	55.21	117.785f	1.438p	1.455	0.985
WB1.S	100.00%	55.21	117.785f	1.438s	1.455	0.985
Subtotals:	**100.00%**	**110.43**	**117.785f**	**0.000**	**1.455**	

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
Totals:		**1,157.46**	**74.294f**	**0.000**	**1.794**	

Tank Capacities for JP1.P containing DIESEL OIL (0.850)

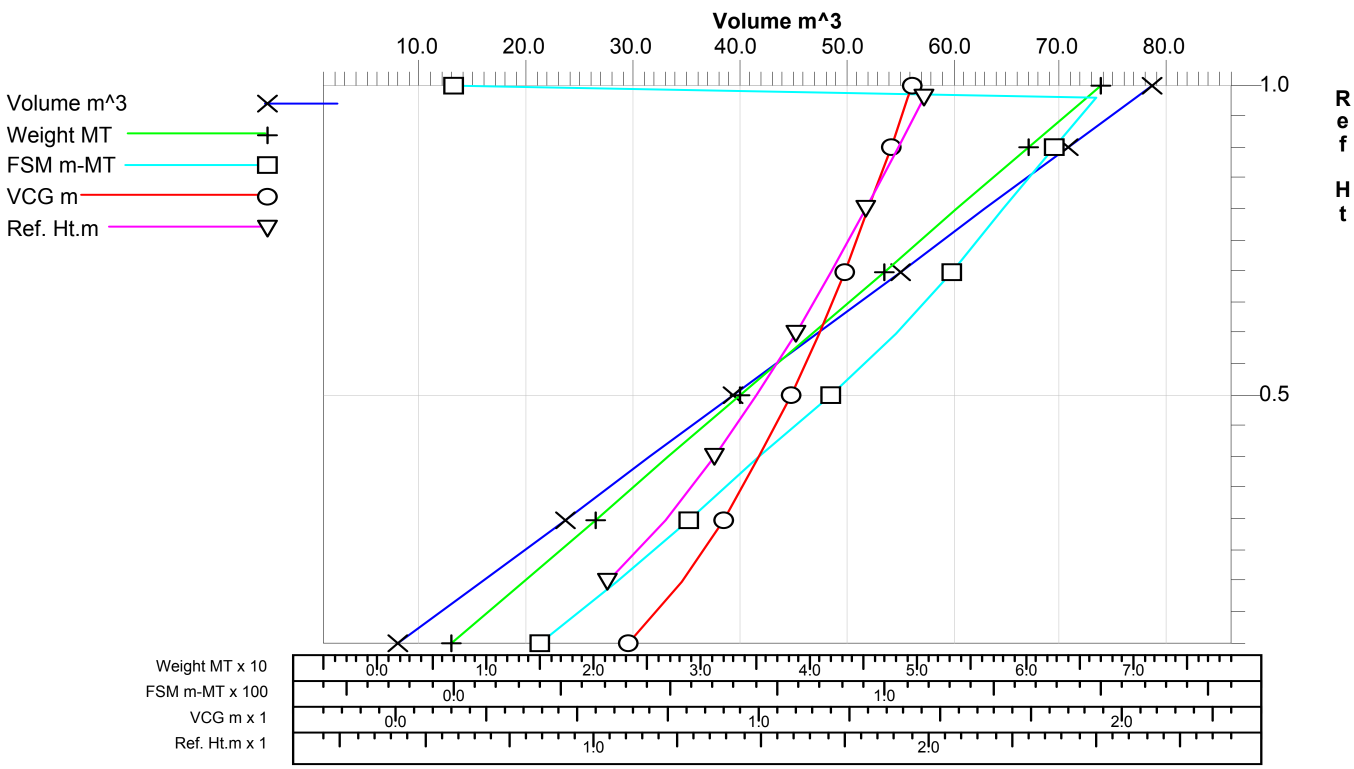
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.82	10.00%	7.86	6.68	35.409f	1.163p	0.635	19.52
1.04	20.00%	15.73	13.37	34.551f	1.359p	0.787	37.77
1.21	30.00%	23.59	20.05	33.975f	1.488p	0.902	54.28
1.36	40.00%	31.45	26.74	33.533f	1.586p	0.998	70.72
1.49	50.00%	39.32	33.42	33.173f	1.667p	1.083	87.31
1.60	60.00%	47.18	40.10	32.864f	1.736p	1.160	102.38
1.71	70.00%	55.04	46.79	32.599f	1.798p	1.231	115.07
1.81	80.00%	62.91	53.47	32.377f	1.855p	1.297	127.09
1.91	90.00%	70.77	60.15	32.191f	1.908p	1.359	138.97
1.98	98.00%	77.06	65.50	32.063f	1.948p	1.407	148.43
	100.00%	78.63	66.84	32.033f	1.958p	1.419	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
JP1.P	0.000	0.000	0.000

Tank Characteristics



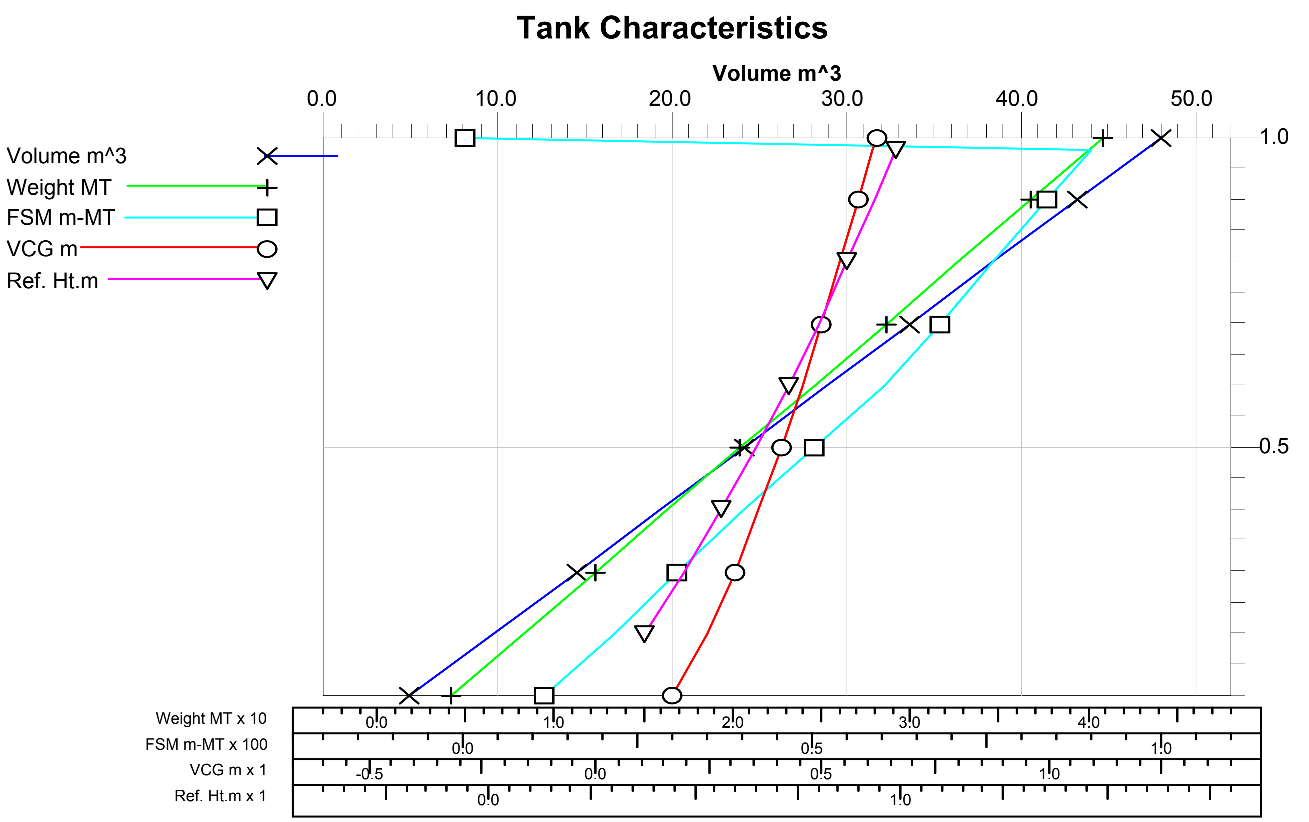
Tank Capacities for JP2.P containing DIESEL OIL (0.850)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.26	10.00%	4.80	4.08	49.951f	0.797p	0.169	11.44
0.37	20.00%	9.60	8.16	49.279f	0.984p	0.243	21.65
0.47	30.00%	14.40	12.24	48.966f	1.112p	0.303	30.65
0.56	40.00%	19.21	16.33	48.792f	1.213p	0.357	40.11
0.65	50.00%	24.01	20.41	48.683f	1.299p	0.407	50.36
0.72	60.00%	28.81	24.49	48.606f	1.377p	0.453	60.12
0.80	70.00%	33.61	28.57	48.542f	1.445p	0.497	68.21
0.87	80.00%	38.41	32.65	48.491f	1.505p	0.539	75.88
0.93	90.00%	43.21	36.73	48.450f	1.559p	0.579	83.55
0.99	98.00%	47.05	40.00	48.422f	1.599p	0.610	89.86
	100.00%	48.01	40.81	48.417f	1.609p	0.618	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
JP2.P	0.000	0.000	0.000



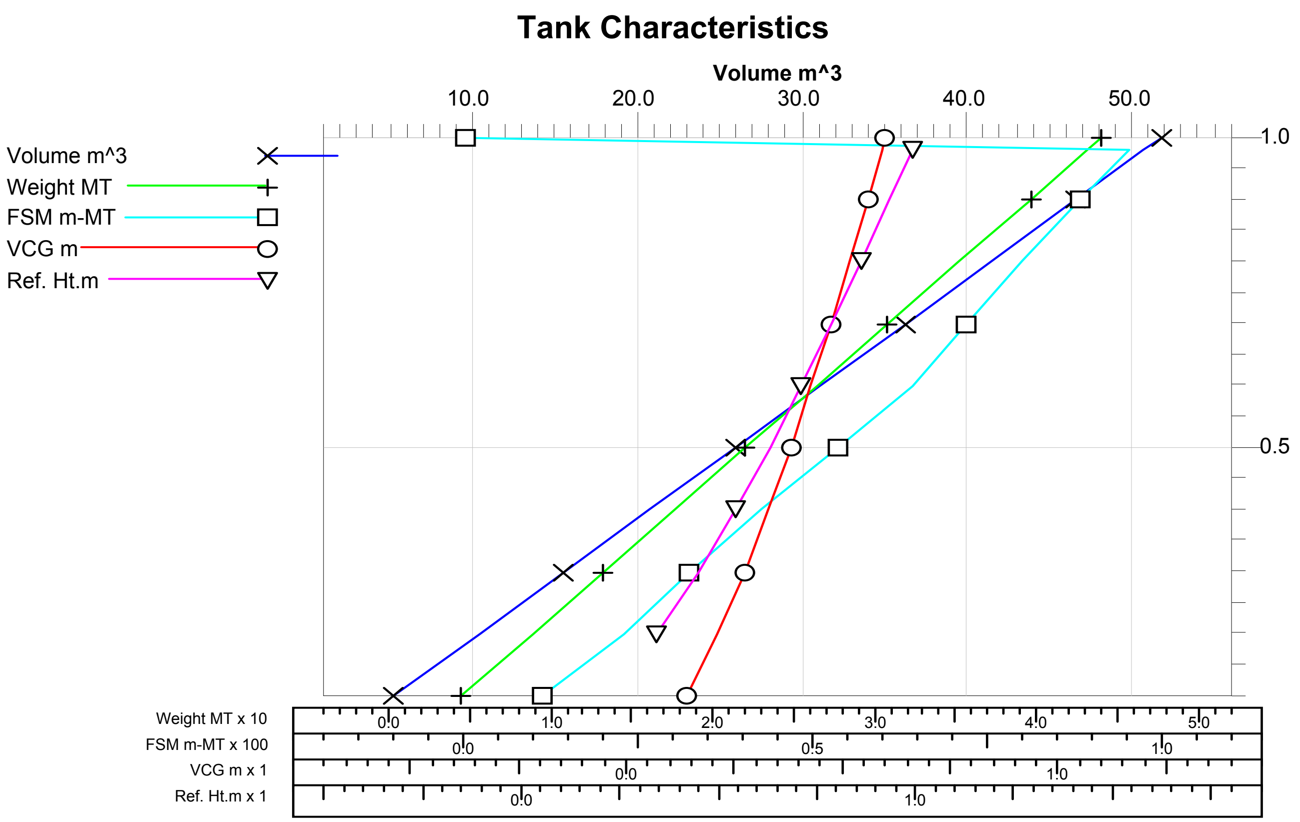
Tank Capacities for JP3.P containing DIESEL OIL (0.850)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.22	10.00%	5.17	4.40	65.997f	0.783p	0.135	11.29
0.34	20.00%	10.34	8.79	65.998f	0.993p	0.209	22.84
0.45	30.00%	15.51	13.19	65.999f	1.127p	0.270	32.14
0.54	40.00%	20.68	17.58	65.999f	1.232p	0.326	42.43
0.63	50.00%	25.86	21.98	65.999f	1.322p	0.378	53.64
0.71	60.00%	31.03	26.37	65.999f	1.403p	0.426	64.09
0.79	70.00%	36.20	30.77	65.999f	1.473p	0.472	71.87
0.86	80.00%	41.37	35.16	65.999f	1.534p	0.515	79.95
0.93	90.00%	46.54	39.56	65.999f	1.589p	0.558	88.31
0.99	98.00%	50.68	43.08	65.999f	1.630p	0.590	95.19
	100.00%	51.71	43.96	66.000f	1.640p	0.598	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
JP3.P	0.000	0.000	0.000



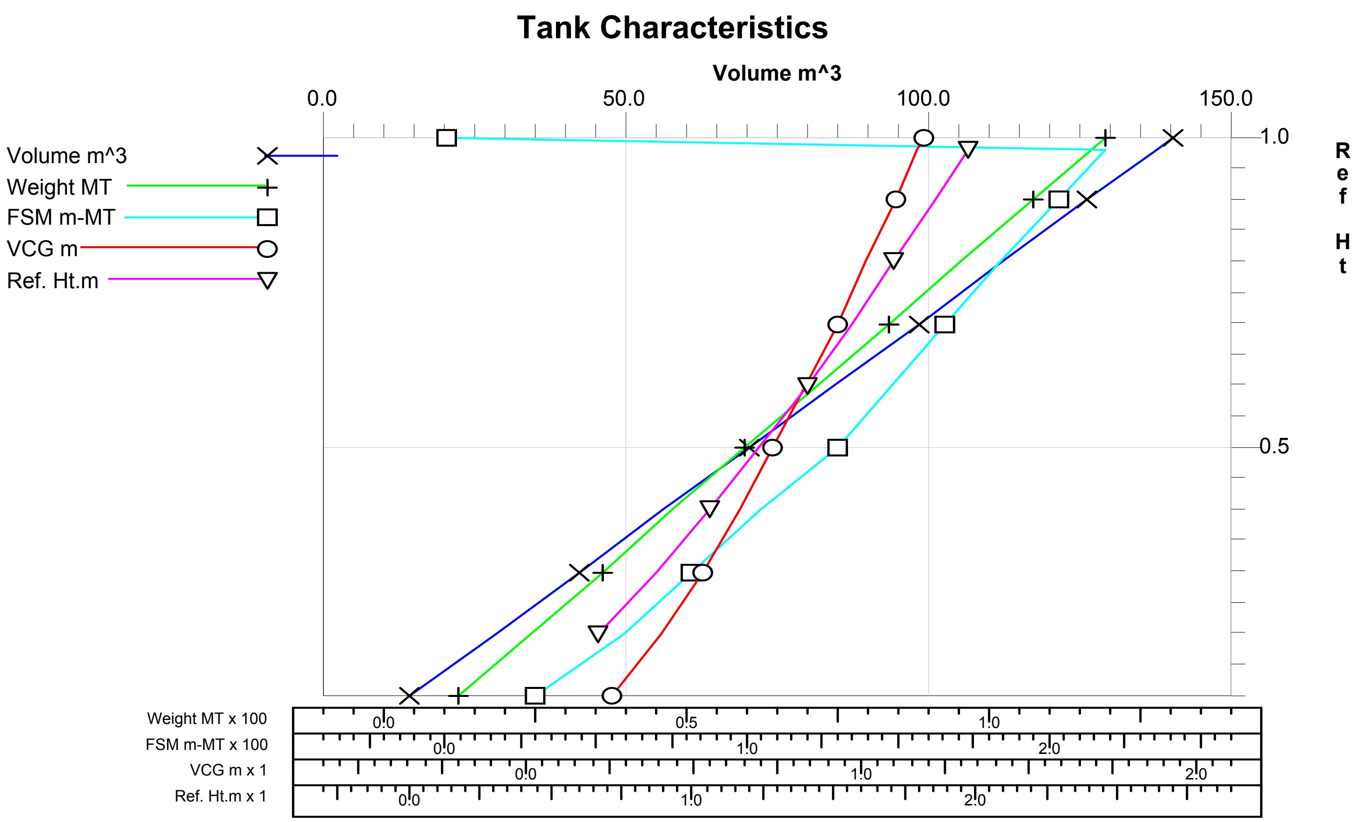
Tank Capacities for JP4.P containing DIESEL OIL (0.850)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.42	10.00%	14.03	11.92	83.978f	1.092p	0.254	29.34
0.66	20.00%	28.05	23.84	83.985f	1.357p	0.399	58.64
0.87	30.00%	42.08	35.77	83.989f	1.541p	0.522	81.03
1.06	40.00%	56.10	47.69	83.990f	1.680p	0.633	104.42
1.23	50.00%	70.13	59.61	83.992f	1.797p	0.736	129.70
1.40	60.00%	84.16	71.53	83.992f	1.897p	0.832	147.46
1.56	70.00%	98.18	83.46	83.993f	1.983p	0.924	165.16
1.71	80.00%	112.21	95.38	83.994f	2.058p	1.013	183.53
1.86	90.00%	126.23	107.30	83.994f	2.127p	1.099	202.52
1.97	98.00%	137.45	116.84	83.994f	2.179p	1.165	217.99
	100.00%	140.26	119.22	83.995f	2.191p	1.182	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
JP4.P	0.000	0.000	0.000



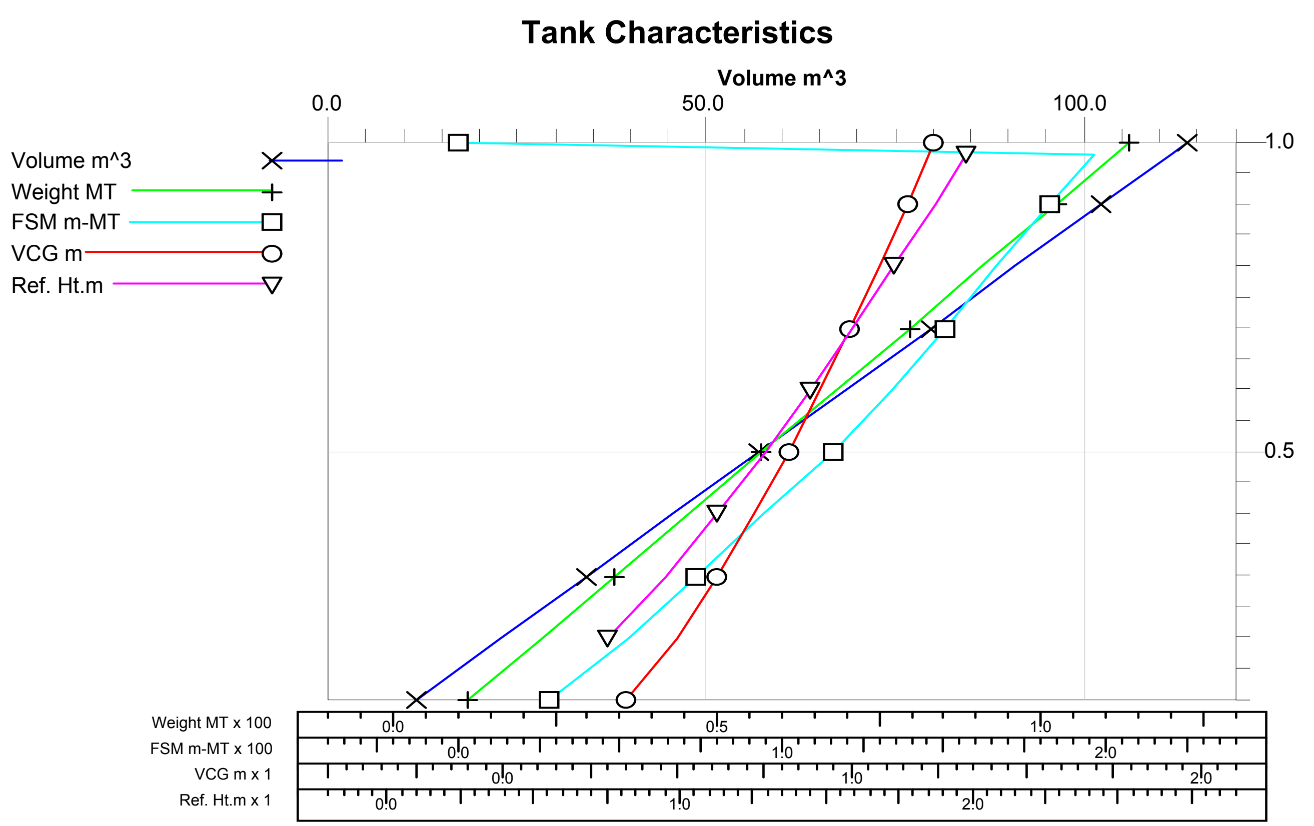
Tank Capacities for FW1.P containing FRESH WATER (1.000)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.52	10.00%	11.35	11.35	100.189f	1.048p	0.353	27.59
0.75	20.00%	22.71	22.71	100.788f	1.279p	0.495	52.54
0.95	30.00%	34.06	34.06	101.041f	1.444p	0.613	73.38
1.12	40.00%	45.42	45.42	101.187f	1.571p	0.718	93.83
1.29	50.00%	56.77	56.77	101.278f	1.678p	0.815	115.56
1.44	60.00%	68.13	68.13	101.346f	1.771p	0.907	133.58
1.59	70.00%	79.48	79.48	101.400f	1.851p	0.993	149.68
1.73	80.00%	90.84	90.84	101.442f	1.922p	1.077	165.87
1.87	90.00%	102.19	102.19	101.476f	1.987p	1.157	182.61
1.98	98.00%	111.28	111.28	101.498f	2.035p	1.219	196.38
	100.00%	113.55	113.55	101.504f	2.046p	1.235	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
FW1.P	0.000	0.000	0.000



Tank Capacities for WB1.P containing WATER BALLAST (1.025)

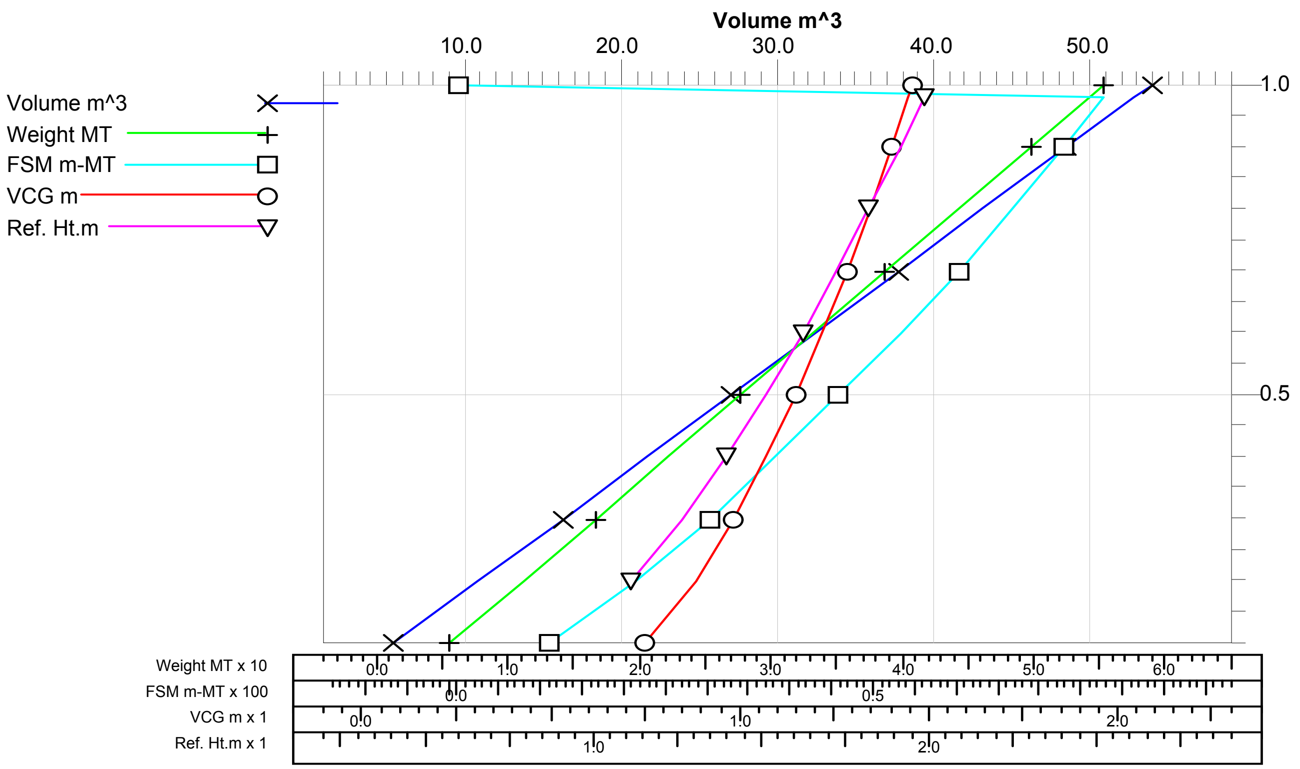
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.91	10.00%	5.39	5.52	114.566f	0.879p	0.744	10.89
1.11	20.00%	10.77	11.04	115.493f	1.009p	0.880	21.20
1.26	30.00%	16.16	16.56	116.113f	1.094p	0.983	30.28
1.39	40.00%	21.55	22.09	116.576f	1.159p	1.069	38.22
1.51	50.00%	26.93	27.61	116.914f	1.215p	1.146	45.75
1.62	60.00%	32.32	33.13	117.170f	1.267p	1.216	53.28
1.72	70.00%	37.71	38.65	117.370f	1.315p	1.280	60.14
1.82	80.00%	43.09	44.17	117.533f	1.359p	1.342	66.53
1.91	90.00%	48.48	49.69	117.669f	1.400p	1.400	72.70
1.98	98.00%	52.79	54.11	117.762f	1.431p	1.444	77.58
	100.00%	53.87	55.21	117.785f	1.438p	1.455	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WB1.P	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for DS1.P containing DIESEL OIL (0.850)

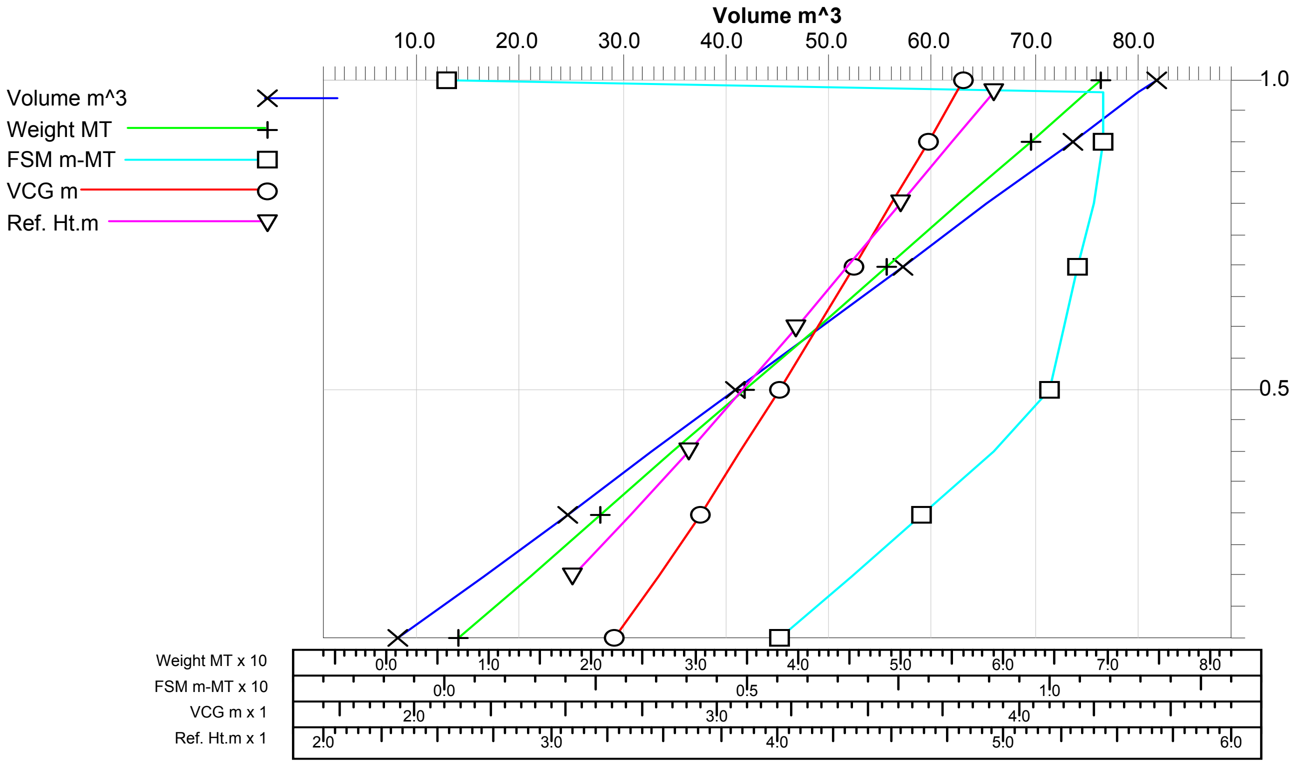
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.81	10.00%	8.17	6.94	48.086f	5.275p	2.658	5.52
3.09	20.00%	16.34	13.89	48.065f	5.317p	2.804	6.74
3.35	30.00%	24.50	20.83	48.054f	5.348p	2.942	7.87
3.60	40.00%	32.67	27.77	48.048f	5.375p	3.076	9.06
3.84	50.00%	40.84	34.71	48.042f	5.399p	3.204	9.98
4.08	60.00%	49.01	41.66	48.036f	5.419p	3.330	10.22
4.31	70.00%	57.18	48.60	48.031f	5.433p	3.453	10.47
4.54	80.00%	65.34	55.54	48.028f	5.445p	3.574	10.71
4.77	90.00%	73.51	62.49	48.025f	5.456p	3.694	10.88
4.95	98.00%	80.05	68.04	48.023f	5.463p	3.790	10.88
	100.00%	81.68	69.43	48.023f	5.464p	3.813	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
DS1.P	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for DS2.P containing DIESEL OIL (0.850)

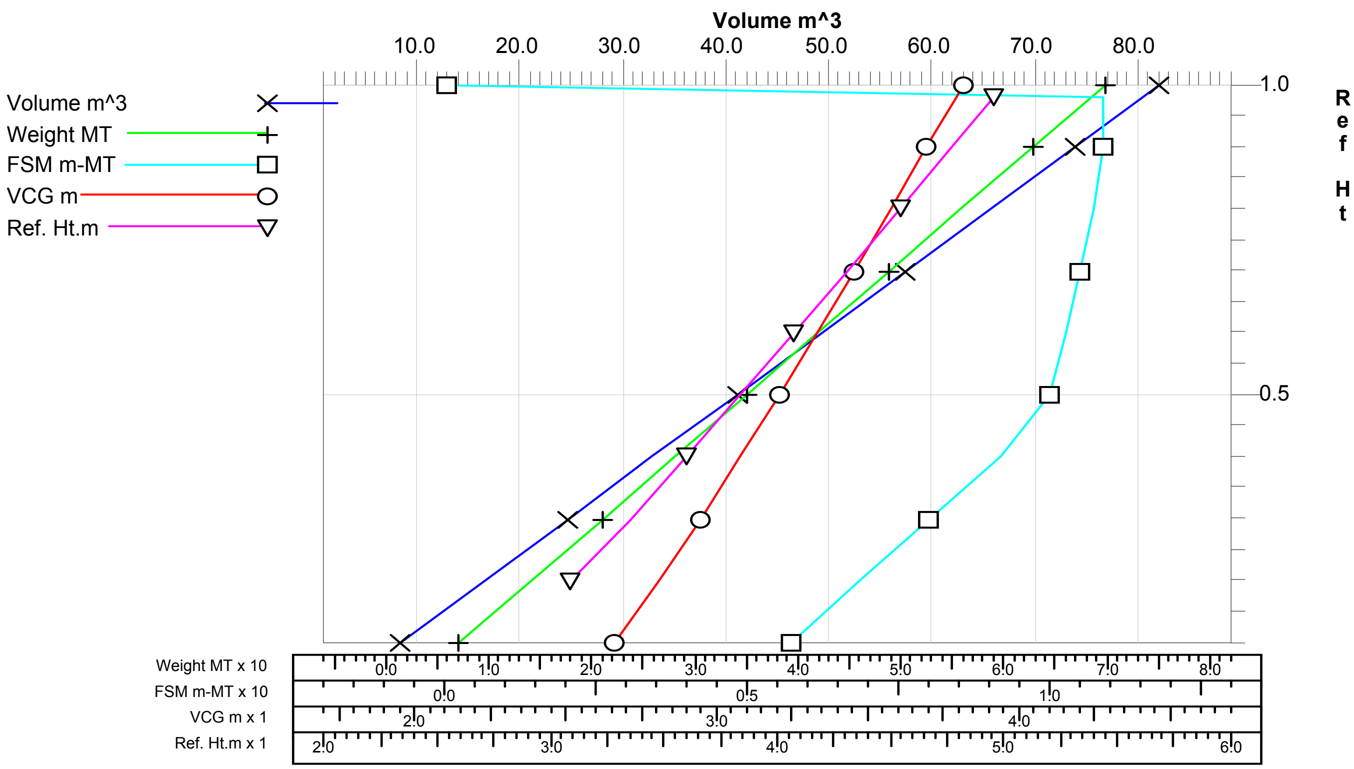
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.81	10.00%	8.20	6.97	65.999f	5.286p	2.656	5.73
3.08	20.00%	16.40	13.94	65.999f	5.326p	2.801	6.84
3.35	30.00%	24.61	20.91	65.999f	5.355p	2.939	7.98
3.60	40.00%	32.81	27.89	66.000f	5.382p	3.072	9.17
3.84	50.00%	41.01	34.86	66.000f	5.405p	3.201	10.00
4.07	60.00%	49.21	41.83	66.000f	5.424p	3.326	10.25
4.31	70.00%	57.41	48.80	66.000f	5.438p	3.449	10.49
4.54	80.00%	65.61	55.77	66.000f	5.449p	3.571	10.73
4.77	90.00%	73.82	62.74	66.000f	5.459p	3.691	10.88
4.95	98.00%	80.38	68.32	66.000f	5.466p	3.787	10.88
	100.00%	82.02	69.72	66.000f	5.467p	3.810	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
DS2.P	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for JP1.S containing DIESEL OIL (0.850)

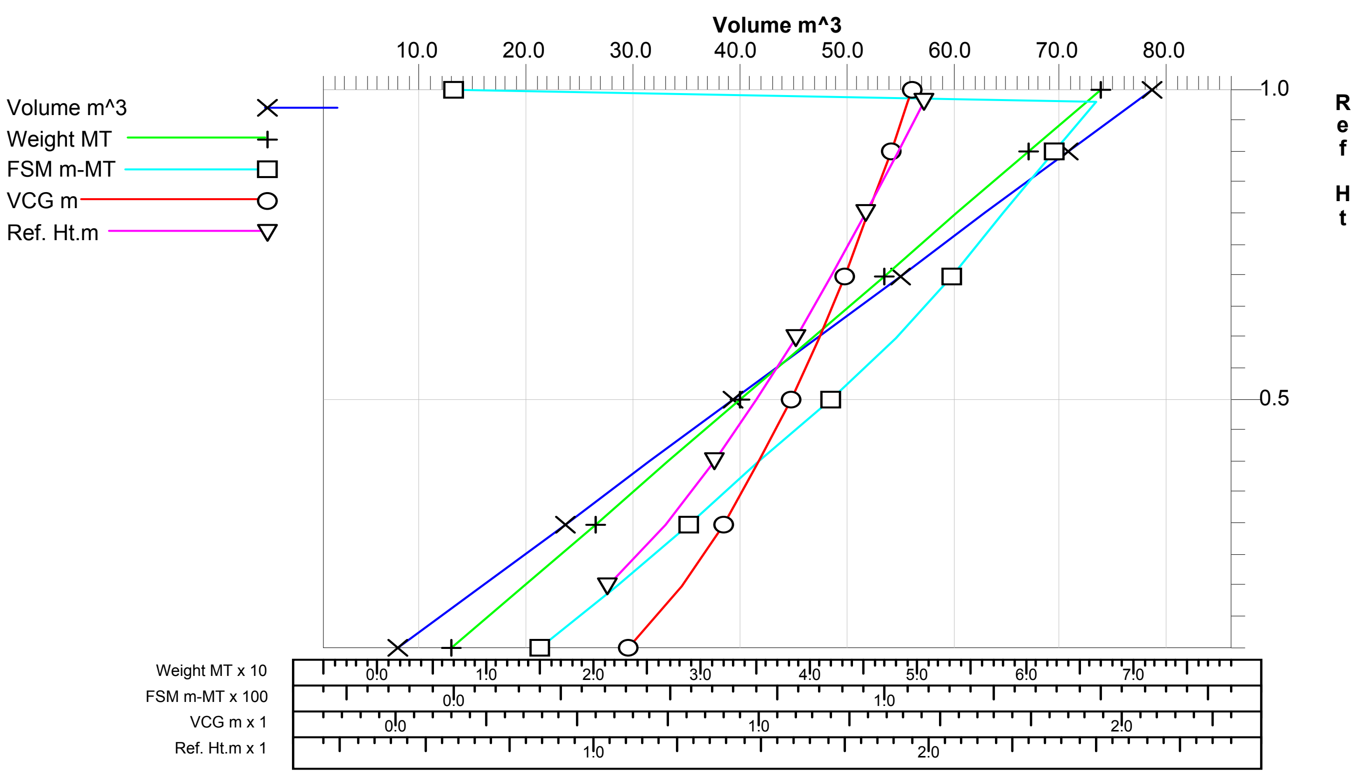
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.82	10.00%	7.86	6.68	35.409f	1.163s	0.635	19.52
1.04	20.00%	15.73	13.37	34.551f	1.359s	0.787	37.77
1.21	30.00%	23.59	20.05	33.975f	1.488s	0.902	54.28
1.36	40.00%	31.45	26.74	33.533f	1.586s	0.998	70.72
1.49	50.00%	39.32	33.42	33.173f	1.667s	1.083	87.31
1.60	60.00%	47.18	40.10	32.864f	1.736s	1.160	102.38
1.71	70.00%	55.04	46.79	32.599f	1.798s	1.231	115.07
1.81	80.00%	62.91	53.47	32.377f	1.855s	1.297	127.09
1.91	90.00%	70.77	60.15	32.191f	1.908s	1.359	138.97
1.98	98.00%	77.06	65.50	32.063f	1.948s	1.407	148.43
	100.00%	78.63	66.84	32.033f	1.958s	1.419	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
JP1.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for JP2.S containing DIESEL OIL (0.850)

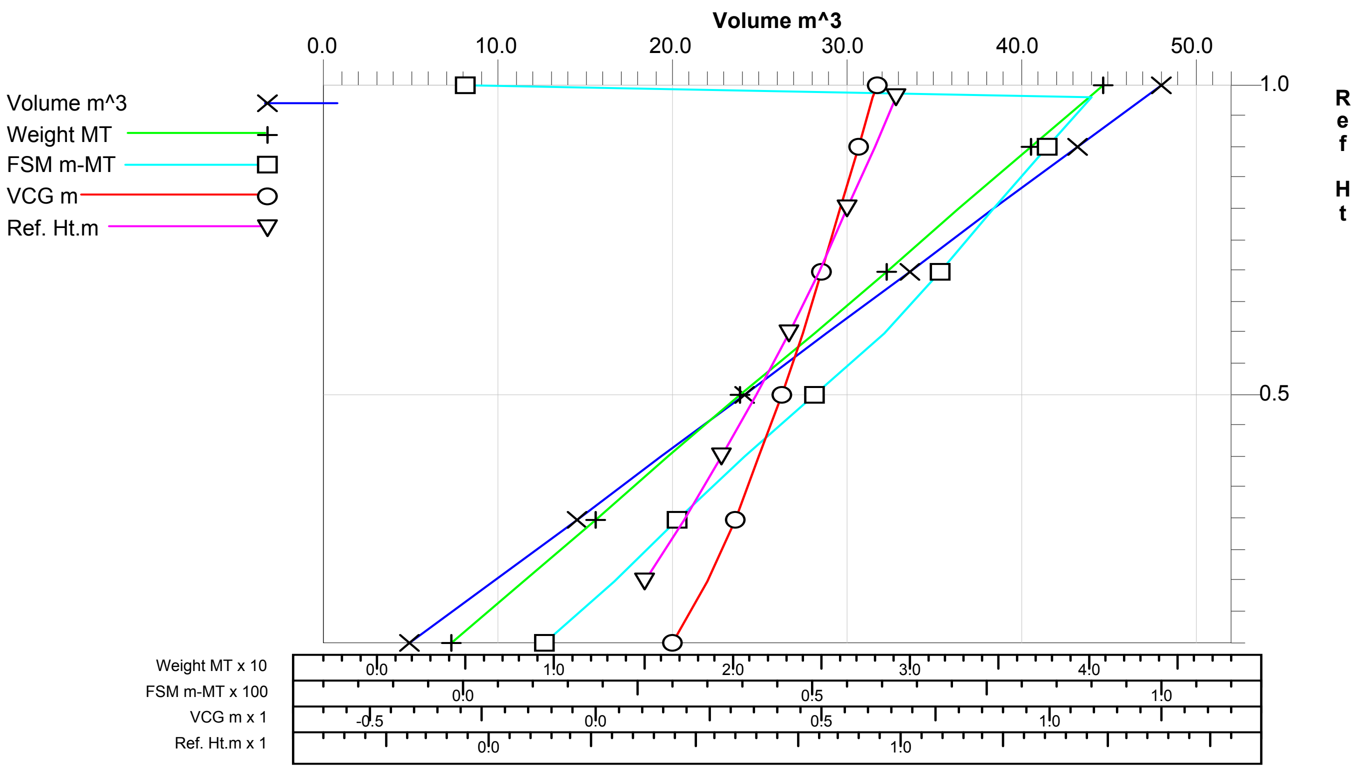
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.26	10.00%	4.80	4.08	49.951f	0.797s	0.169	11.44
0.37	20.00%	9.60	8.16	49.279f	0.984s	0.243	21.65
0.47	30.00%	14.40	12.24	48.966f	1.112s	0.303	30.65
0.56	40.00%	19.21	16.33	48.792f	1.213s	0.357	40.11
0.65	50.00%	24.01	20.41	48.683f	1.299s	0.407	50.36
0.72	60.00%	28.81	24.49	48.606f	1.377s	0.453	60.12
0.80	70.00%	33.61	28.57	48.542f	1.445s	0.497	68.21
0.87	80.00%	38.41	32.65	48.491f	1.505s	0.539	75.88
0.93	90.00%	43.21	36.73	48.450f	1.559s	0.579	83.55
0.99	98.00%	47.05	40.00	48.422f	1.599s	0.610	89.86
	100.00%	48.01	40.81	48.417f	1.609s	0.618	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
JP2.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for JP3.S containing DIESEL OIL (0.850)

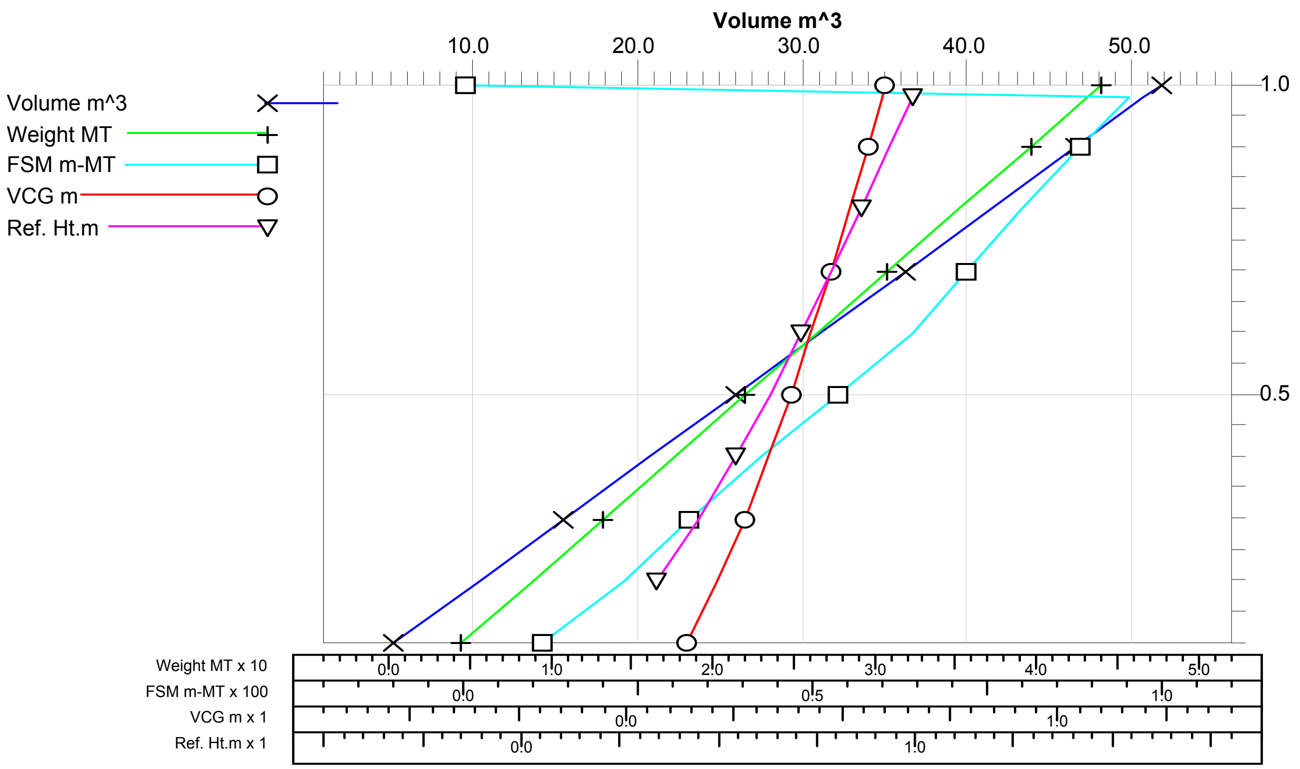
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.22	10.00%	5.17	4.40	65.997f	0.783s	0.135	11.29
0.34	20.00%	10.34	8.79	65.998f	0.993s	0.209	22.84
0.45	30.00%	15.51	13.19	65.999f	1.127s	0.270	32.14
0.54	40.00%	20.68	17.58	65.999f	1.232s	0.326	42.43
0.63	50.00%	25.86	21.98	65.999f	1.322s	0.378	53.64
0.71	60.00%	31.03	26.37	65.999f	1.403s	0.426	64.09
0.79	70.00%	36.20	30.77	65.999f	1.473s	0.472	71.87
0.86	80.00%	41.37	35.16	65.999f	1.534s	0.515	79.95
0.93	90.00%	46.54	39.56	65.999f	1.589s	0.558	88.31
0.99	98.00%	50.68	43.08	65.999f	1.630s	0.590	95.19
	100.00%	51.71	43.96	66.000f	1.640s	0.598	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
JP3.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for JP4.S containing DIESEL OIL (0.850)

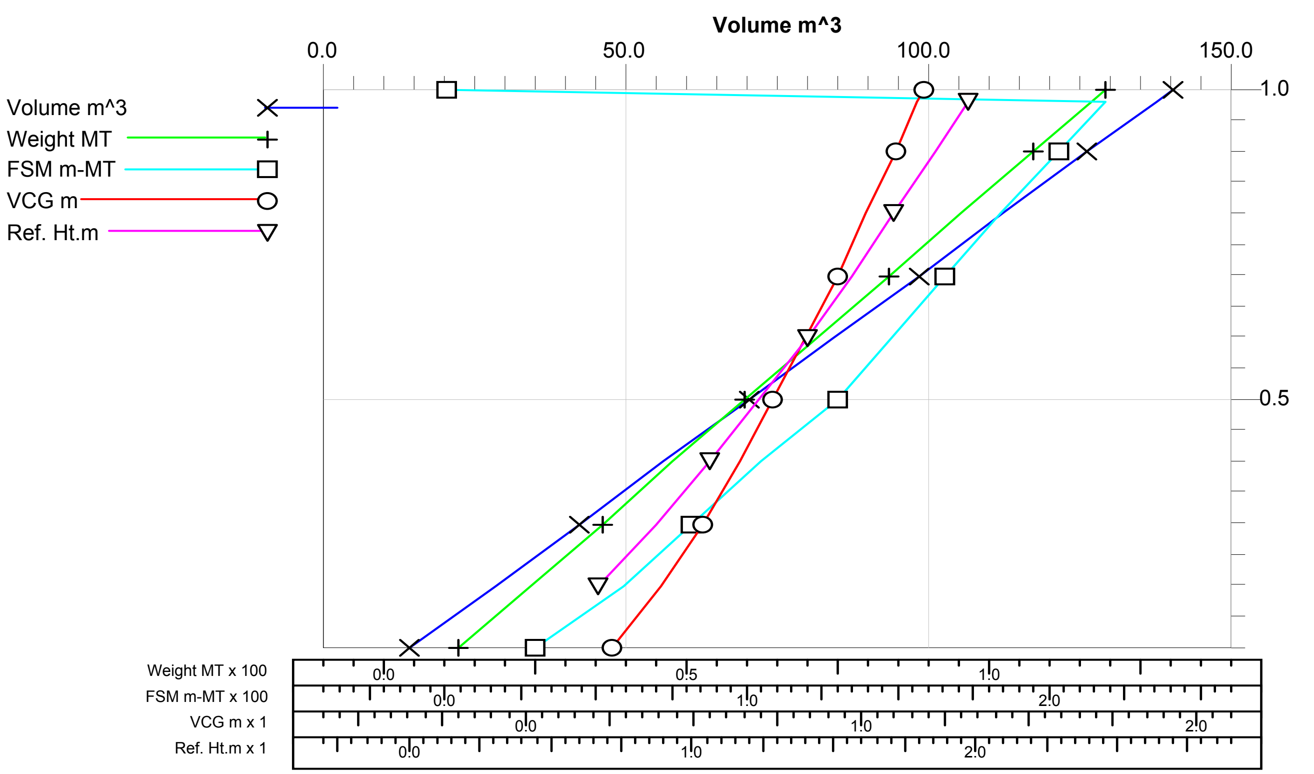
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.42	10.00%	14.03	11.92	83.978f	1.092s	0.254	29.34
0.66	20.00%	28.05	23.84	83.985f	1.357s	0.399	58.64
0.87	30.00%	42.08	35.77	83.989f	1.541s	0.522	81.03
1.06	40.00%	56.10	47.69	83.990f	1.680s	0.633	104.42
1.23	50.00%	70.13	59.61	83.992f	1.797s	0.736	129.70
1.40	60.00%	84.16	71.53	83.992f	1.897s	0.832	147.46
1.56	70.00%	98.18	83.46	83.993f	1.983s	0.924	165.16
1.71	80.00%	112.21	95.38	83.994f	2.058s	1.013	183.53
1.86	90.00%	126.23	107.30	83.994f	2.127s	1.099	202.52
1.97	98.00%	137.45	116.84	83.994f	2.179s	1.165	217.99
	100.00%	140.26	119.22	83.995f	2.191s	1.182	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
JP4.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for FW1.S containing FRESH WATER (1.000)

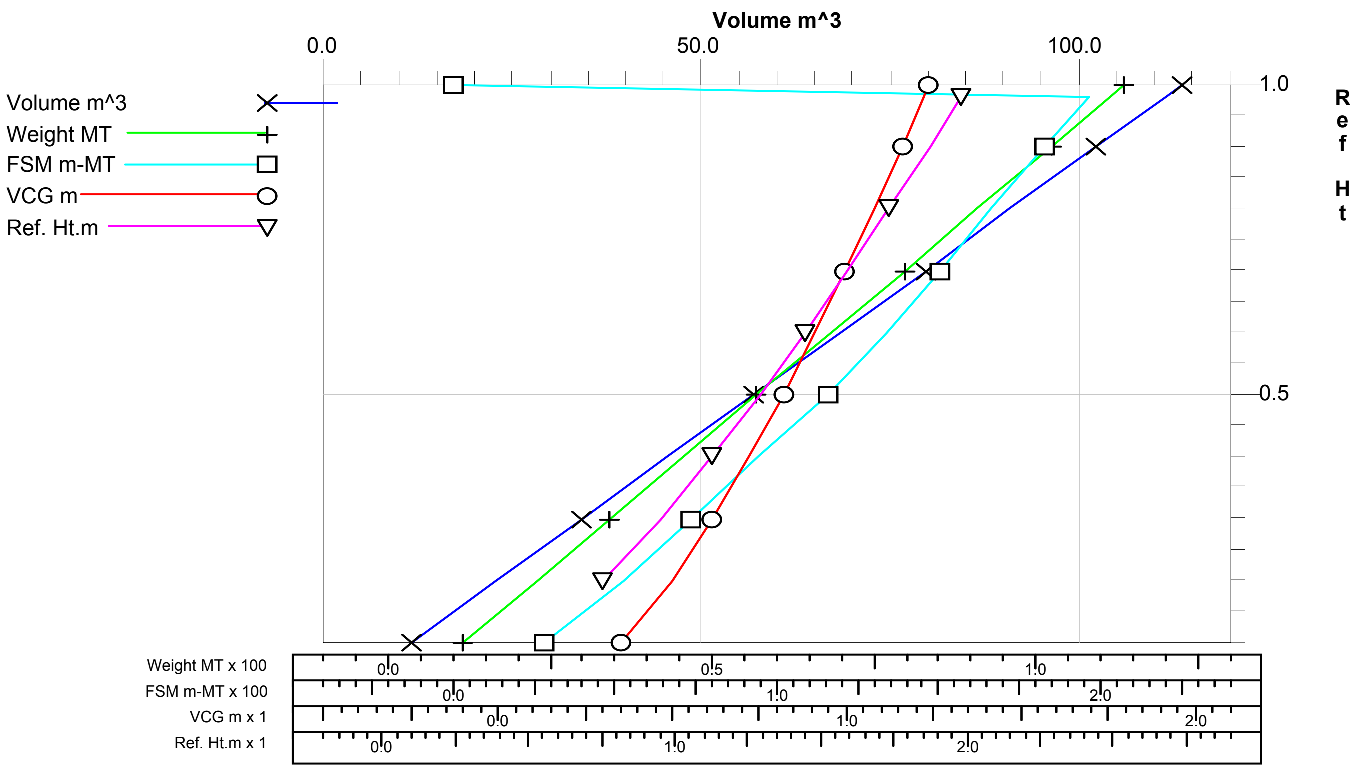
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.52	10.00%	11.35	11.35	100.189f	1.048s	0.353	27.59
0.75	20.00%	22.71	22.71	100.788f	1.279s	0.495	52.54
0.95	30.00%	34.06	34.06	101.041f	1.444s	0.613	73.38
1.12	40.00%	45.42	45.42	101.187f	1.571s	0.718	93.83
1.29	50.00%	56.77	56.77	101.278f	1.678s	0.815	115.56
1.44	60.00%	68.13	68.13	101.346f	1.771s	0.907	133.58
1.59	70.00%	79.48	79.48	101.400f	1.851s	0.993	149.68
1.73	80.00%	90.84	90.84	101.442f	1.922s	1.077	165.87
1.87	90.00%	102.19	102.19	101.476f	1.987s	1.157	182.61
1.98	98.00%	111.28	111.28	101.498f	2.035s	1.219	196.38
	100.00%	113.55	113.55	101.504f	2.046s	1.235	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
FW1.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for DS1.S containing DIESEL OIL (0.850)

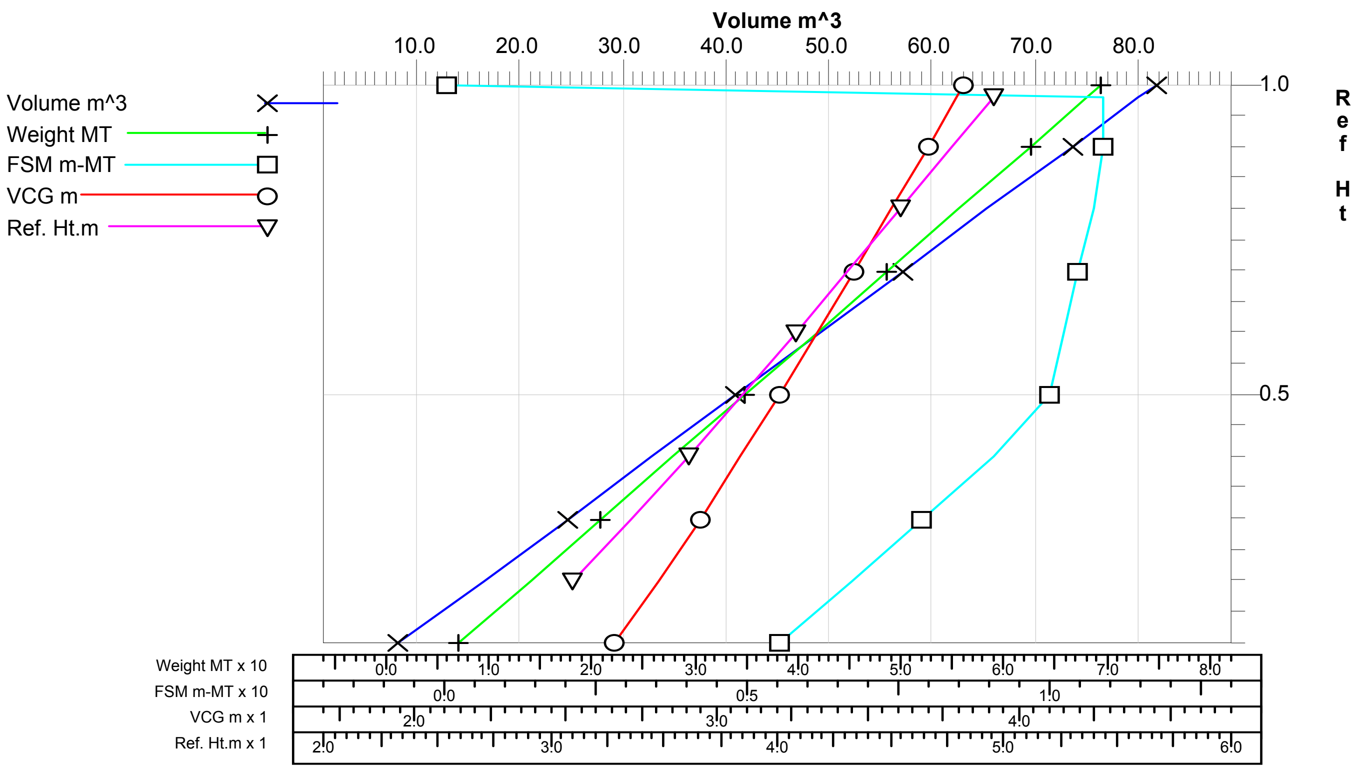
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.81	10.00%	8.17	6.94	48.086f	5.275s	2.658	5.52
3.09	20.00%	16.34	13.89	48.065f	5.317s	2.804	6.74
3.35	30.00%	24.50	20.83	48.054f	5.348s	2.942	7.87
3.60	40.00%	32.67	27.77	48.048f	5.375s	3.076	9.06
3.84	50.00%	40.84	34.71	48.042f	5.399s	3.204	9.98
4.08	60.00%	49.01	41.66	48.036f	5.419s	3.330	10.22
4.31	70.00%	57.18	48.60	48.031f	5.433s	3.453	10.47
4.54	80.00%	65.34	55.54	48.028f	5.445s	3.574	10.71
4.77	90.00%	73.51	62.49	48.025f	5.456s	3.694	10.88
4.95	98.00%	80.05	68.04	48.023f	5.463s	3.790	10.88
	100.00%	81.68	69.43	48.023f	5.464s	3.813	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
DS1.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for DS2.S containing DIESEL OIL (0.850)

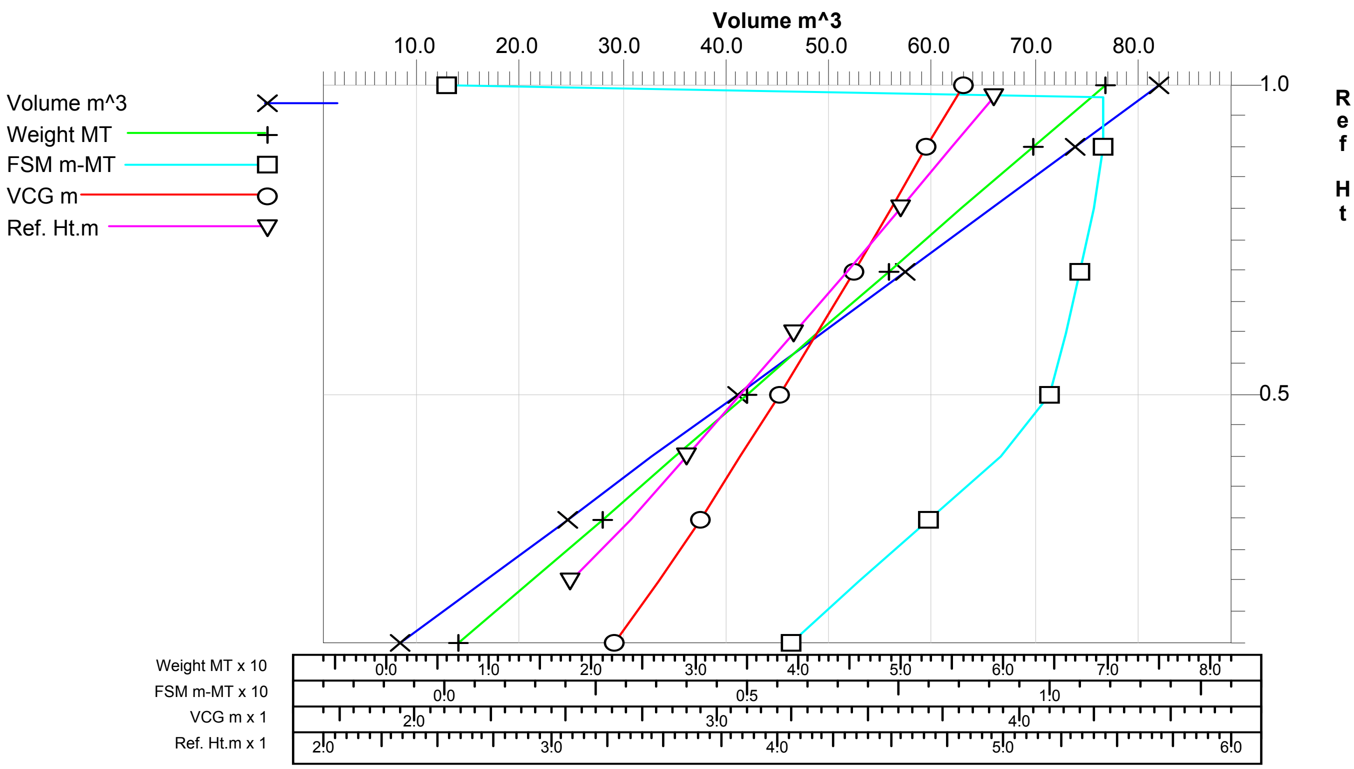
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.81	10.00%	8.20	6.97	65.998f	5.286s	2.656	5.73
3.08	20.00%	16.40	13.94	65.999f	5.326s	2.801	6.84
3.35	30.00%	24.61	20.91	65.999f	5.355s	2.939	7.98
3.60	40.00%	32.81	27.89	66.000f	5.382s	3.072	9.17
3.84	50.00%	41.01	34.86	66.000f	5.405s	3.201	10.00
4.07	60.00%	49.21	41.83	66.000f	5.424s	3.326	10.24
4.31	70.00%	57.41	48.80	66.000f	5.438s	3.449	10.49
4.54	80.00%	65.61	55.77	66.000f	5.449s	3.571	10.73
4.77	90.00%	73.82	62.74	66.000f	5.459s	3.691	10.88
4.95	98.00%	80.38	68.32	66.000f	5.466s	3.787	10.88
	100.00%	82.02	69.72	66.000f	5.467s	3.810	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
DS2.S	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for WB1.S containing WATER BALLAST (1.025)

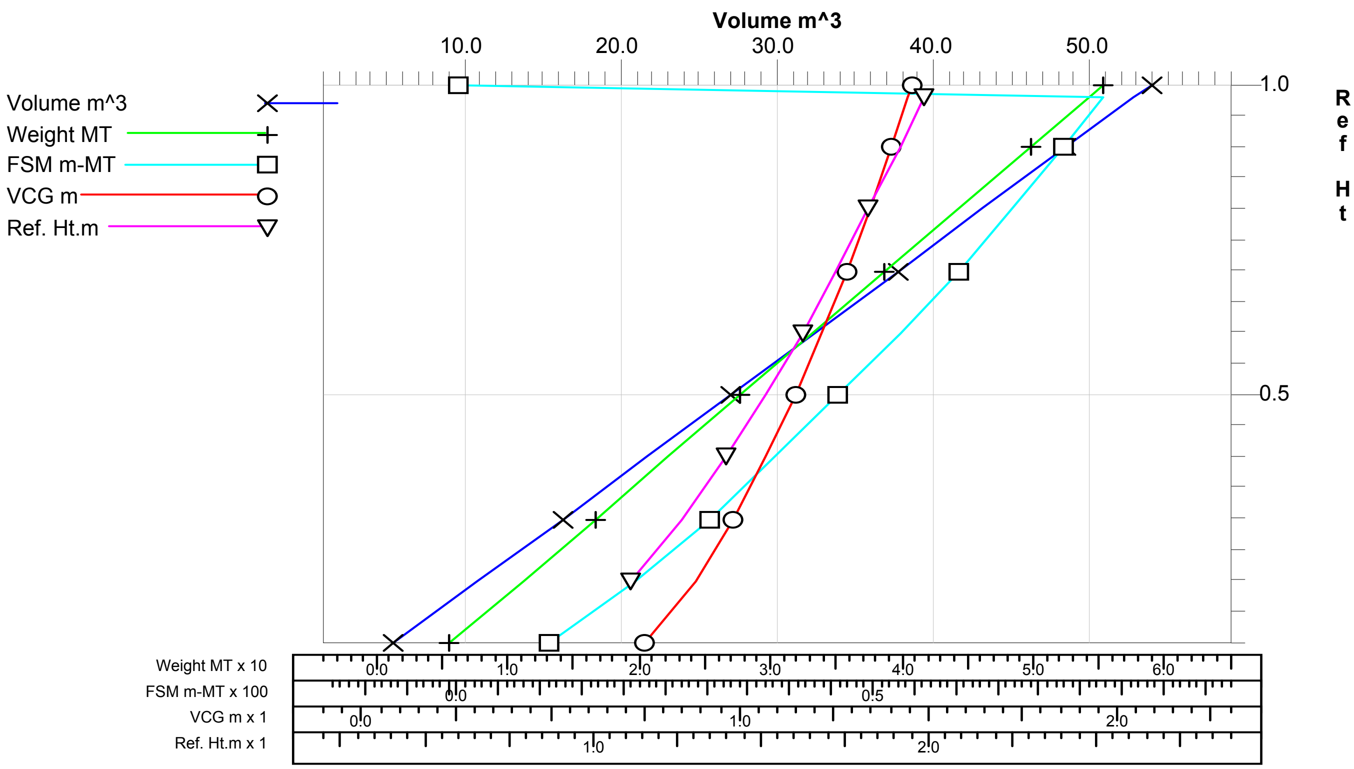
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.91	10.00%	5.39	5.52	114.566f	0.879s	0.744	10.89
1.11	20.00%	10.77	11.04	115.493f	1.009s	0.880	21.20
1.26	30.00%	16.16	16.56	116.113f	1.094s	0.983	30.28
1.39	40.00%	21.55	22.09	116.576f	1.159s	1.069	38.22
1.51	50.00%	26.93	27.61	116.914f	1.215s	1.146	45.75
1.62	60.00%	32.32	33.13	117.170f	1.267s	1.216	53.28
1.72	70.00%	37.71	38.65	117.370f	1.315s	1.280	60.14
1.82	80.00%	43.09	44.17	117.533f	1.359s	1.342	66.53
1.91	90.00%	48.48	49.69	117.669f	1.400s	1.400	72.70
1.98	98.00%	52.79	54.11	117.762f	1.431s	1.444	77.58
	100.00%	53.87	55.21	117.785f	1.438s	1.455	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WB1.S	0.000	0.000	0.000

Tank Characteristics



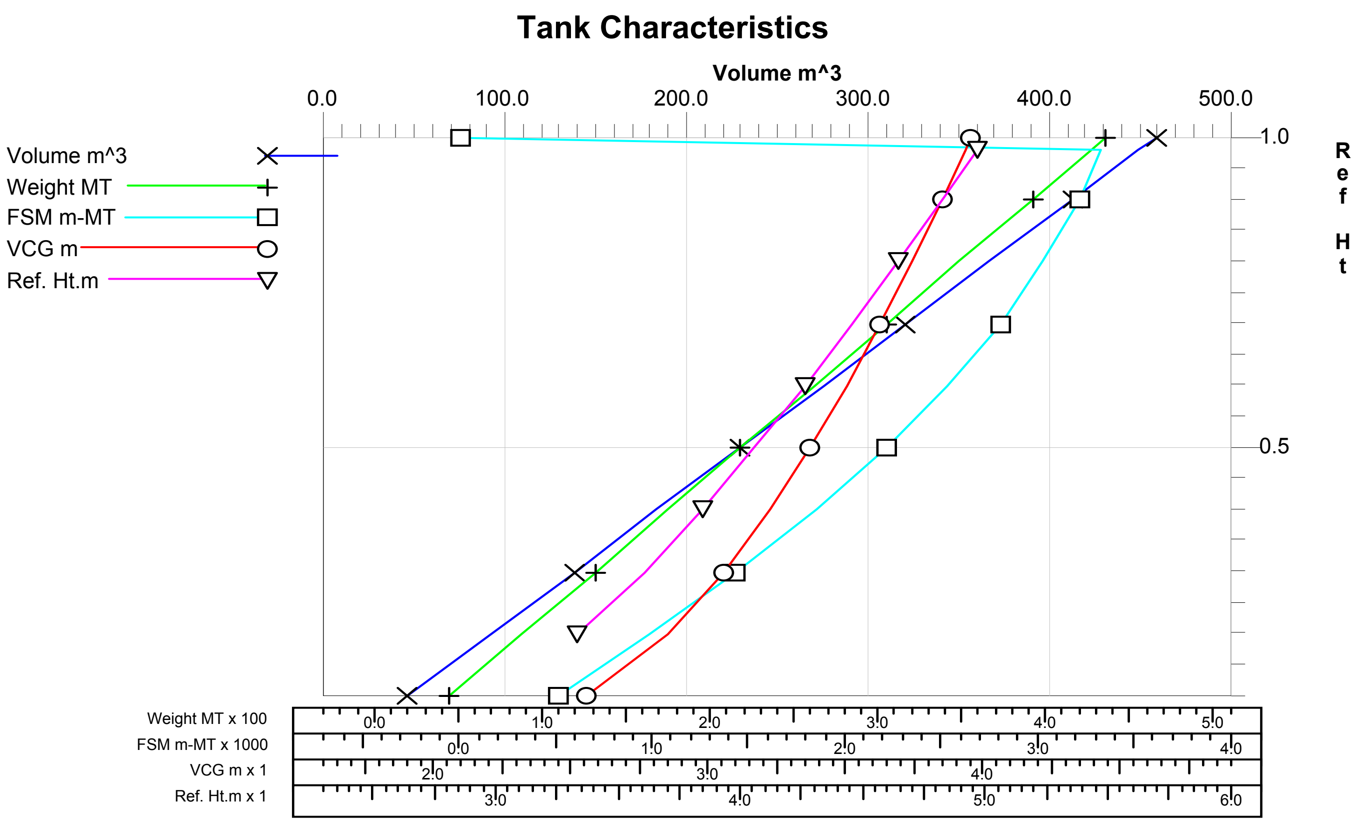
Tank Capacities for WT1.C containing CE (0.950)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.92	10.00%	45.81	43.52	17.464f	0.000	2.553	510.07
3.32	20.00%	91.63	87.05	16.051f	0.000	2.846	982.15
3.60	30.00%	137.44	130.57	14.913f	0.000	3.054	1,431.73
3.84	40.00%	183.26	174.10	14.088f	0.000	3.222	1,848.83
4.05	50.00%	229.07	217.62	13.518f	0.000	3.367	2,214.23
4.26	60.00%	274.89	261.15	13.102f	0.000	3.498	2,526.59
4.45	70.00%	320.70	304.67	12.784f	0.000	3.620	2,797.96
4.64	80.00%	366.52	348.19	12.533f	0.000	3.736	3,023.28
4.82	90.00%	412.33	391.72	12.330f	0.000	3.846	3,208.13
4.96	98.00%	448.98	426.54	12.192f	0.000	3.931	3,323.89
	100.00%	458.15	435.24	12.161f	0.000	3.952	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
WT1.C	0.000	0.000	0.000



Tank Capacities for WT2.C containing CE (0.950)

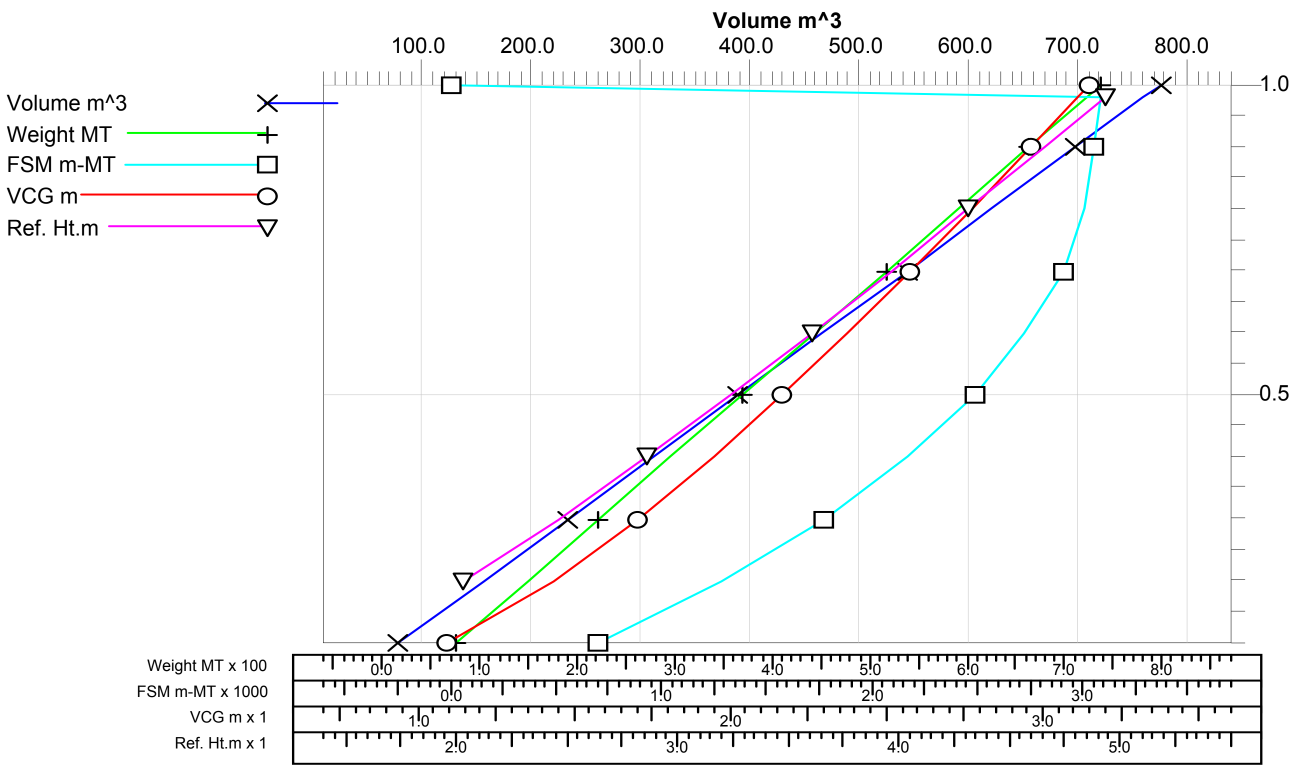
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
1.50	10.00%	77.52	73.64	33.136f	0.000	1.092	699.78
2.02	20.00%	155.04	147.29	32.001f	0.000	1.431	1,280.86
2.46	30.00%	232.55	220.93	31.478f	0.000	1.702	1,770.35
2.86	40.00%	310.07	294.57	31.173f	0.000	1.942	2,164.57
3.24	50.00%	387.59	368.21	30.973f	0.000	2.164	2,485.08
3.60	60.00%	465.11	441.86	30.829f	0.000	2.374	2,719.30
3.96	70.00%	542.63	515.50	30.721f	0.000	2.575	2,904.02
4.31	80.00%	620.14	589.14	30.635f	0.000	2.770	3,004.84
4.66	90.00%	697.66	662.78	30.566f	0.000	2.960	3,051.63
4.93	98.00%	759.68	721.70	30.521f	0.000	3.110	3,075.58
	100.00%	775.18	736.43	30.510f	0.000	3.147	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT2.C	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for WT3.C containing CE (0.950)

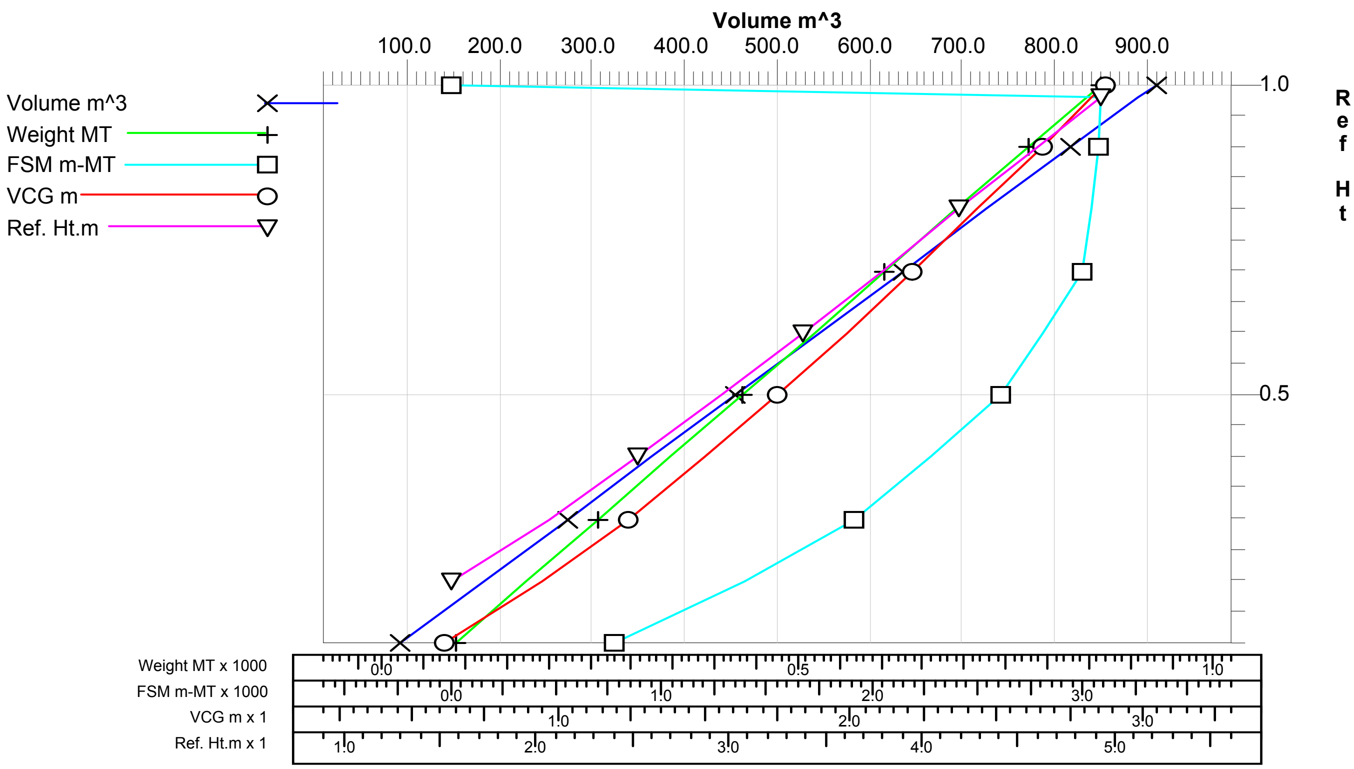
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.99	10.00%	90.80	86.26	48.422f	0.000	0.610	773.94
1.56	20.00%	181.60	172.52	48.252f	0.000	0.946	1,387.53
2.06	30.00%	272.40	258.79	48.184f	0.000	1.235	1,913.28
2.52	40.00%	363.21	345.05	48.144f	0.000	1.499	2,276.50
2.95	50.00%	454.01	431.31	48.119f	0.000	1.746	2,609.98
3.37	60.00%	544.81	517.57	48.101f	0.000	1.982	2,805.03
3.79	70.00%	635.61	603.83	48.088f	0.000	2.210	2,994.00
4.19	80.00%	726.41	690.10	48.077f	0.000	2.433	3,035.25
4.60	90.00%	817.21	776.36	48.069f	0.000	2.651	3,074.17
4.92	98.00%	889.86	845.37	48.063f	0.000	2.823	3,083.69
	100.00%	908.02	862.62	48.062f	0.000	2.865	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT3.C	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for WT4.C containing CE (0.950)

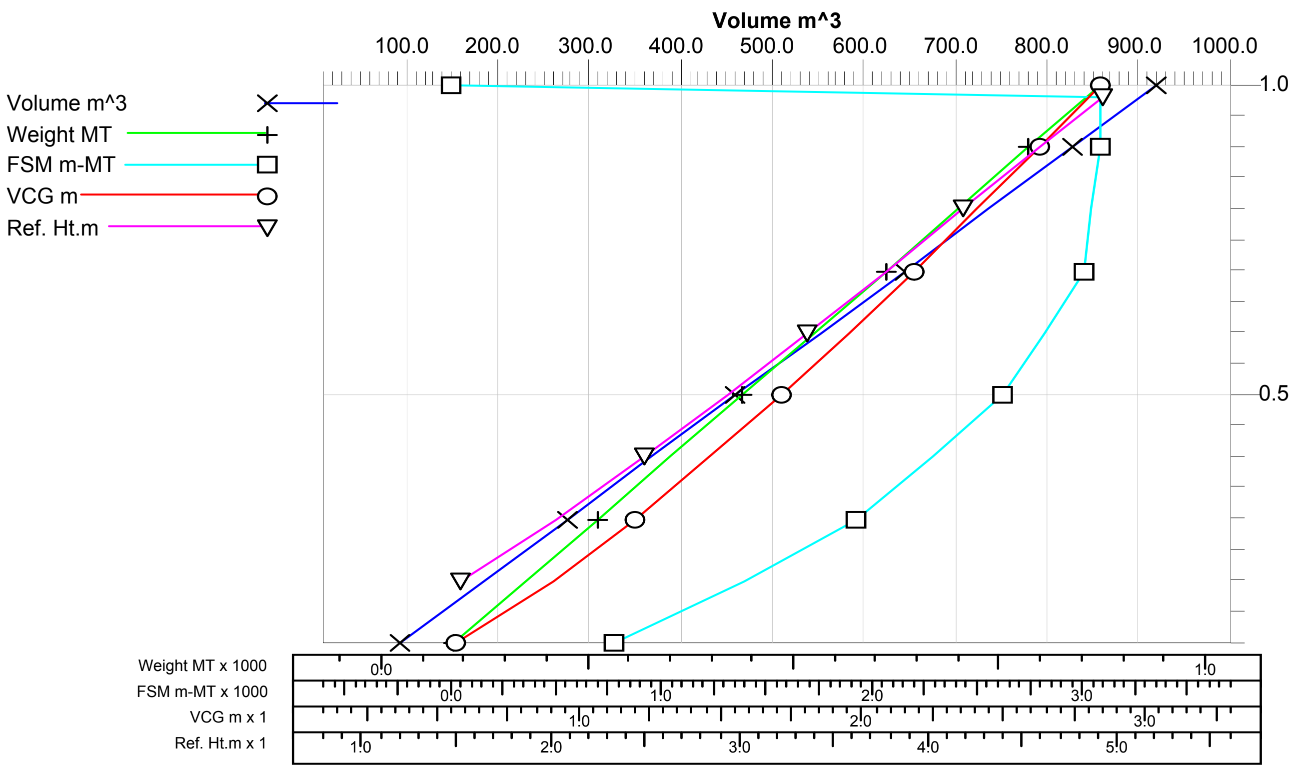
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.95	10.00%	91.83	87.24	65.999f	0.000	0.566	776.61
1.52	20.00%	183.66	174.48	66.000f	0.000	0.905	1,392.13
2.03	30.00%	275.50	261.72	66.000f	0.000	1.196	1,920.47
2.49	40.00%	367.33	348.97	66.000f	0.000	1.462	2,283.05
2.93	50.00%	459.16	436.21	66.000f	0.000	1.711	2,614.21
3.36	60.00%	551.00	523.45	66.000f	0.000	1.950	2,810.21
3.77	70.00%	642.83	610.69	66.000f	0.000	2.181	2,997.68
4.18	80.00%	734.66	697.93	66.000f	0.000	2.405	3,036.60
4.59	90.00%	826.49	785.17	66.000f	0.000	2.625	3,075.70
4.92	98.00%	899.96	854.97	66.000f	0.000	2.799	3,083.69
	100.00%	918.33	872.42	66.000f	0.000	2.842	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT4.C	0.000	0.000	0.000

Tank Characteristics



Tank Capacities for WT5.C containing CE (0.950)

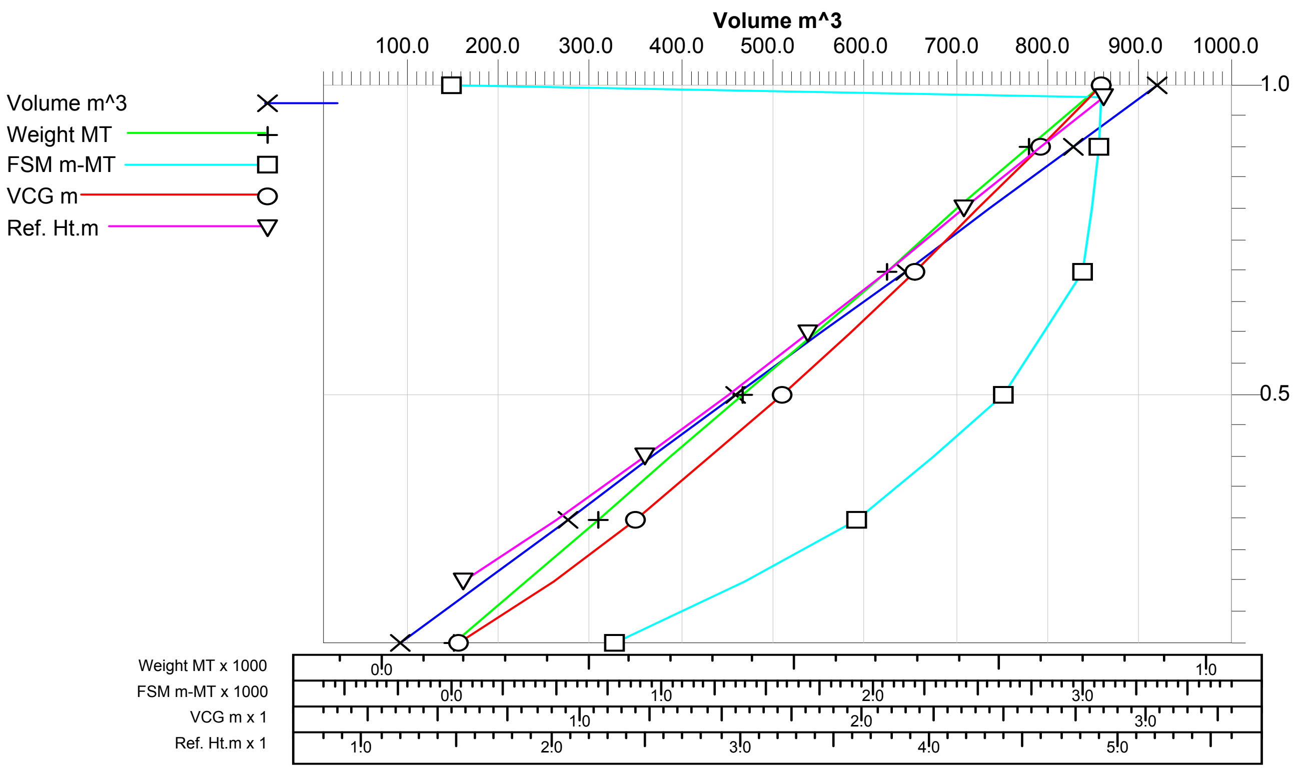
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
0.95	10.00%	91.80	87.21	83.990f	0.000	0.567	776.03
1.52	20.00%	183.60	174.42	83.993f	0.000	0.905	1,391.14
2.03	30.00%	275.41	261.64	83.994f	0.000	1.196	1,919.18
2.49	40.00%	367.21	348.85	83.995f	0.000	1.462	2,281.62
2.93	50.00%	459.01	436.06	83.996f	0.000	1.712	2,612.71
3.36	60.00%	550.81	523.28	83.996f	0.000	1.951	2,808.67
3.77	70.00%	642.62	610.49	83.996f	0.000	2.181	2,996.22
4.18	80.00%	734.42	697.70	83.997f	0.000	2.406	3,035.28
4.59	90.00%	826.22	784.91	83.997f	0.000	2.626	3,074.51
4.92	98.00%	899.66	854.68	83.997f	0.000	2.800	3,082.63
	100.00%	918.02	872.13	83.997f	0.000	2.843	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT5.C	0.000	0.000	0.000

Tank Characteristics



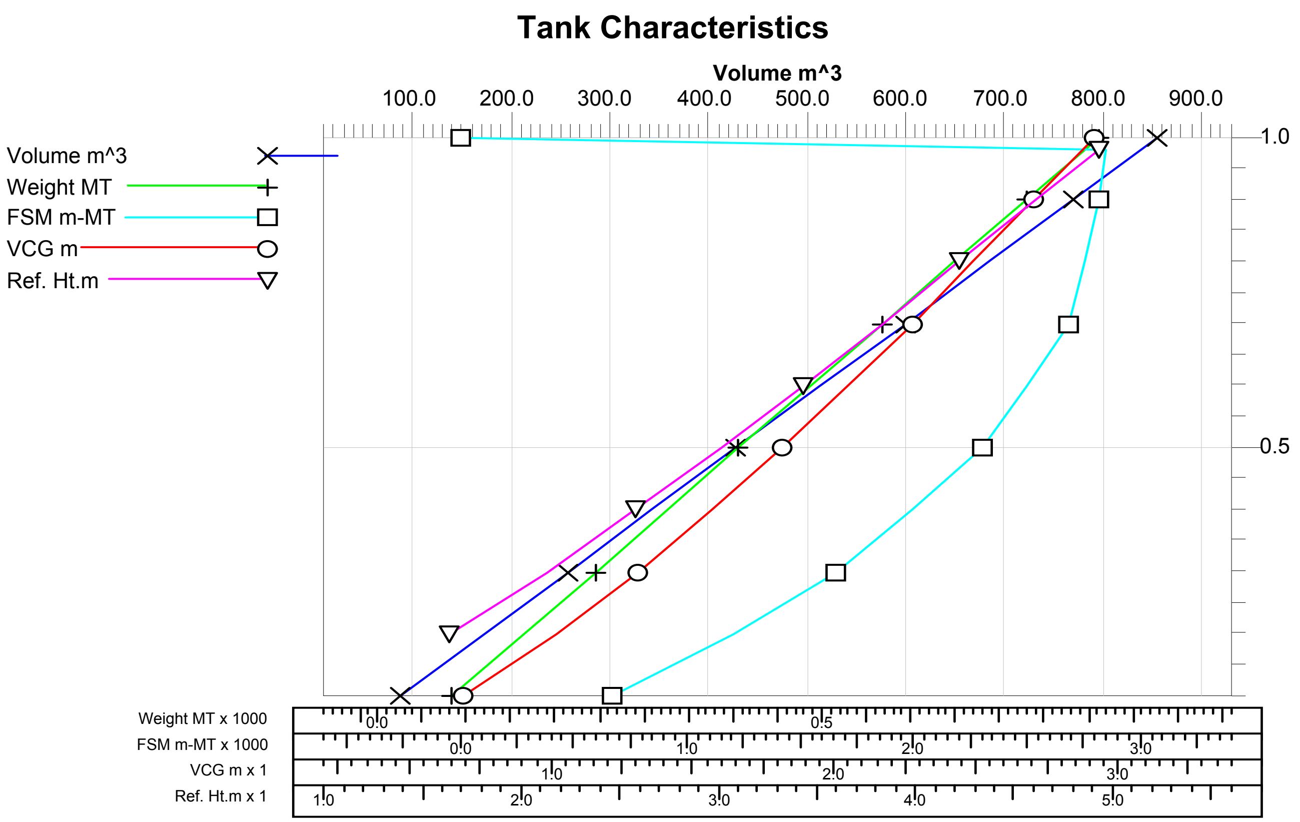
Tank Capacities for WT6.C containing CE (0.950)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
1.06	10.00%	85.40	81.13	101.018f	0.000	0.683	666.12
1.63	20.00%	170.79	162.25	101.327f	0.000	1.019	1,198.45
2.12	30.00%	256.20	243.39	101.455f	0.000	1.307	1,656.80
2.58	40.00%	341.60	324.52	101.533f	0.000	1.568	1,991.83
3.01	50.00%	427.00	405.65	101.584f	0.000	1.813	2,300.42
3.42	60.00%	512.40	486.78	101.624f	0.000	2.046	2,494.05
3.82	70.00%	597.80	567.91	101.654f	0.000	2.271	2,680.45
4.22	80.00%	683.20	649.04	101.680f	0.000	2.489	2,754.38
4.61	90.00%	768.60	730.17	101.702f	0.000	2.703	2,813.38
4.92	98.00%	836.92	795.08	101.717f	0.000	2.871	2,848.23
	100.00%	854.00	811.31	101.721f	0.000	2.913	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT6.C	0.000	0.000	0.000



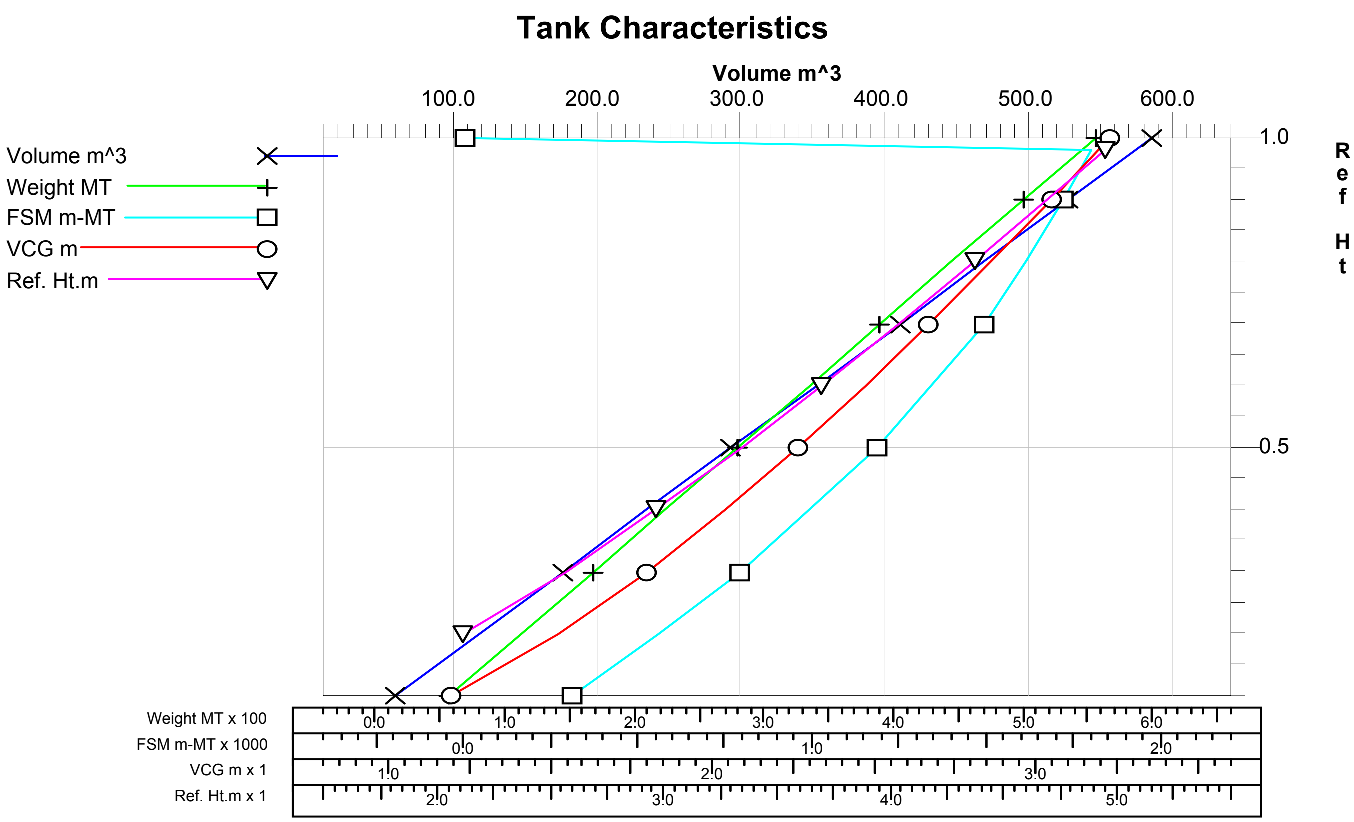
Tank Capacities for WT7.C containing CE (0.950)

Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m^3)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
1.58	10.00%	58.52	55.59	117.084f	0.000	1.191	307.58
2.11	20.00%	117.03	111.18	117.907f	0.000	1.523	559.60
2.56	30.00%	175.55	166.77	118.275f	0.000	1.794	791.56
2.96	40.00%	234.06	222.36	118.497f	0.000	2.036	993.02
3.34	50.00%	292.58	277.95	118.650f	0.000	2.258	1,182.10
3.69	60.00%	351.09	333.54	118.765f	0.000	2.468	1,339.93
4.03	70.00%	409.61	389.13	118.857f	0.000	2.667	1,488.46
4.36	80.00%	468.12	444.72	118.932f	0.000	2.858	1,613.89
4.69	90.00%	526.64	500.31	118.997f	0.000	3.044	1,718.14
4.94	98.00%	573.45	544.78	119.043f	0.000	3.188	1,795.57
	100.00%	585.15	555.90	119.054f	0.000	3.223	

Reference Point

Part	Long.(m)	Trans.(m)	Vert.(m)
WT7.C	0.000	0.000	0.000



Tank Capacities for WT8.C containing CE (0.950)

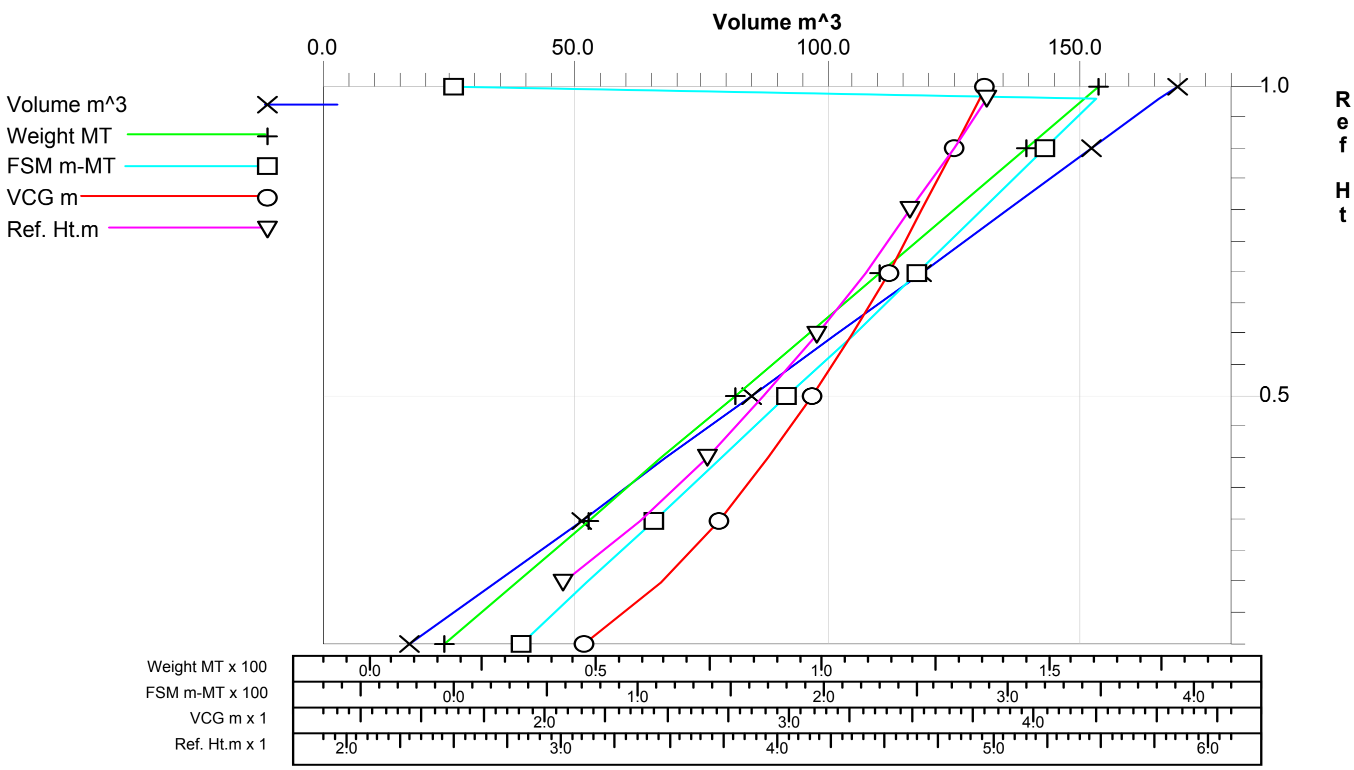
Trim: 0.00 deg., No Heel

Ref Ht (m)	Load (%)	Volume (m³)	Weight (MT)	Lcg (m)	Tcg (m)	Vcg (m)	Fsm (m-MT)
2.54	10.00%	16.92	16.07	132.002f	0.000	2.158	35.48
3.01	20.00%	33.84	32.15	132.622f	0.000	2.472	71.58
3.36	30.00%	50.76	48.22	133.012f	0.000	2.711	108.16
3.67	40.00%	67.68	64.29	133.300f	0.000	2.913	143.95
3.93	50.00%	84.60	80.37	133.532f	0.000	3.090	179.65
4.18	60.00%	101.52	96.44	133.725f	0.000	3.251	215.69
4.40	70.00%	118.44	112.52	133.893f	0.000	3.400	250.57
4.61	80.00%	135.36	128.59	134.040f	0.000	3.539	284.91
4.81	90.00%	152.27	144.66	134.172f	0.000	3.669	319.27
4.97	98.00%	165.81	157.52	134.268f	0.000	3.769	346.85
	100.00%	169.19	160.74	134.291f	0.000	3.793	

Reference Point

Part	Long. (m)	Trans. (m)	Vert. (m)
WT8.C	0.000	0.000	0.000

Tank Characteristics



D. CROSS CURVES OF STABILITY

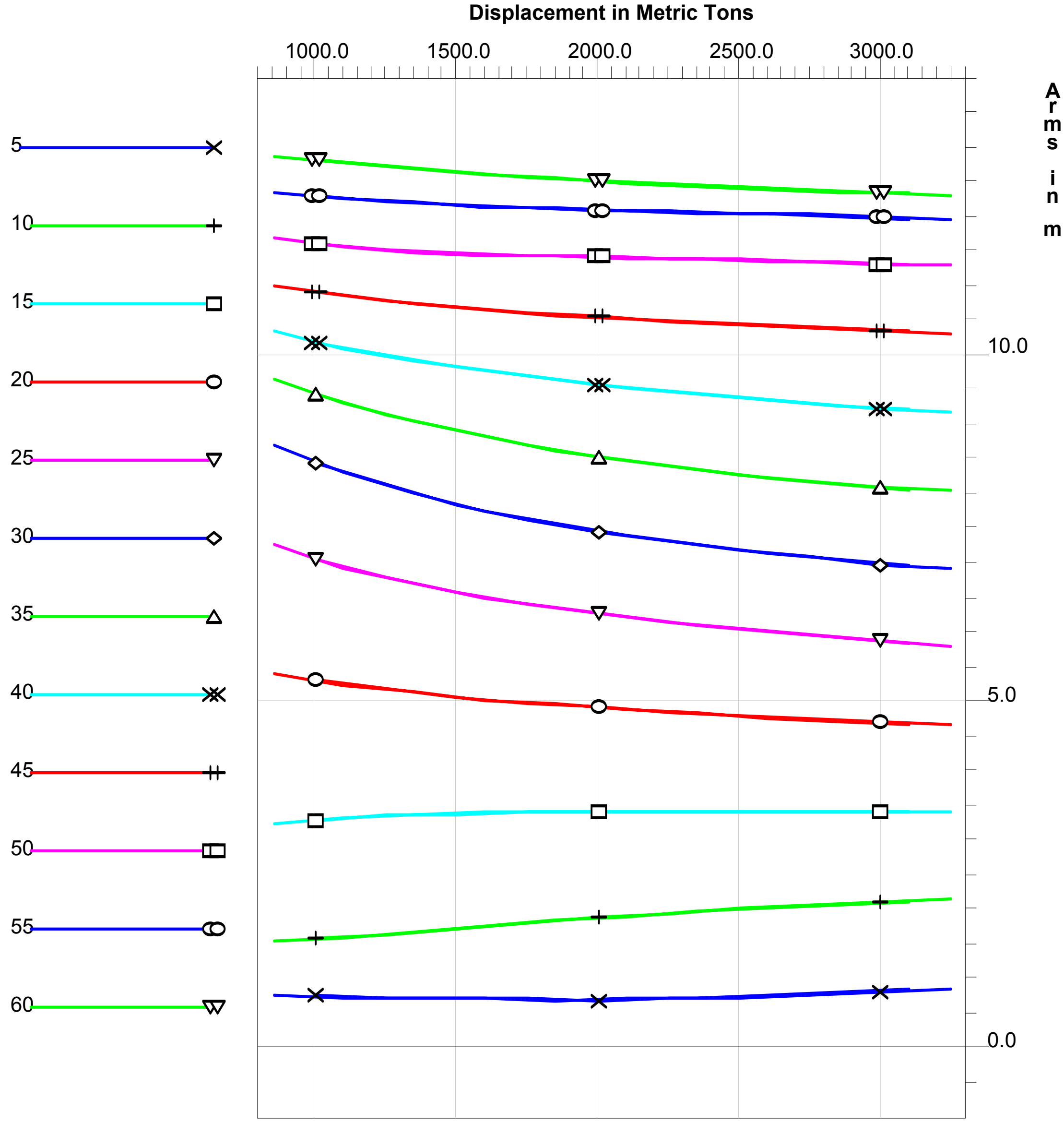
Righting Arms(heel) for VCG = 0.00
Trim zero at heel = 0 (RA Trim = 0)

Displ (MT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s	35.000s
1000.000	0.761s	1.588s	3.309s	5.309s	7.068s	8.459s	9.466s
1250.000	0.742s	1.654s	3.360s	5.181s	6.793s	8.128s	9.164s
1500.000	0.726s	1.731s	3.394s	5.078s	6.580s	7.864s	8.916s
1750.000	0.714s	1.810s	3.417s	4.992s	6.409s	7.648s	8.714s
2000.000	0.712s	1.885s	3.432s	4.919s	6.268s	7.469s	8.546s
2250.000	0.726s	1.954s	3.439s	4.855s	6.150s	7.320s	8.406s
2500.000	0.754s	2.015s	3.443s	4.799s	6.050s	7.193s	8.290s
2750.000	0.792s	2.067s	3.444s	4.750s	5.964s	7.087s	8.192s
3000.000	0.836s	2.112s	3.443s	4.706s	5.890s	6.997s	8.110s
3250.000	0.883s	2.152s	3.441s	4.668s	5.825s	6.922s	8.041s
3500.000	0.933s	2.186s	3.438s	4.634s	5.768s	6.858s	7.983s
3750.000	0.984s	2.216s	3.435s	4.604s	5.718s	6.803s	7.933s
4000.000	1.033s	2.242s	3.431s	4.576s	5.672s	6.757s	7.891s
4250.000	1.080s	2.265s	3.427s	4.551s	5.631s	6.716s	7.856s
4500.000	1.124s	2.284s	3.424s	4.528s	5.596s	6.682s	7.828s
4750.000	1.164s	2.302s	3.420s	4.507s	5.564s	6.652s	7.807s
5000.000	1.202s	2.318s	3.417s	4.488s	5.536s	6.627s	7.793s

Displ (MT)	40.000s	45.000s	50.000s	55.000s	60.000s	Arm	Angle
1000.000	10.197s	10.915s	11.635s	12.299s	12.830s		
1250.000	10.001s	10.790s	11.536s	12.227s	12.742s		
1500.000	9.843s	10.697s	11.475s	12.170s	12.660s		
1750.000	9.707s	10.622s	11.444s	12.133s	12.583s		
2000.000	9.588s	10.555s	11.422s	12.104s	12.519s		
2250.000	9.485s	10.496s	11.404s	12.079s	12.466s		
2500.000	9.392s	10.448s	11.385s	12.055s	12.420s		
2750.000	9.311s	10.403s	11.361s	12.029s	12.382s		
3000.000	9.239s	10.360s	11.330s	11.998s	12.346s		
3250.000	9.181s	10.317s	11.292s	11.961s	12.311s		
3500.000	9.137s	10.277s	11.248s	11.917s	12.274s		
3750.000	9.101s	10.239s	11.199s	11.867s	12.232s		
4000.000	9.070s	10.203s	11.148s	11.809s	12.181s		
4250.000	9.043s	10.169s	11.094s	11.746s	12.122s		
4500.000	9.018s	10.135s	11.040s	11.678s	12.055s		
4750.000	8.997s	10.102s	10.985s	11.608s	11.981s		
5000.000	8.979s	10.068s	10.930s	11.535s	11.901s		

Water Specific Gravity = 1.025.

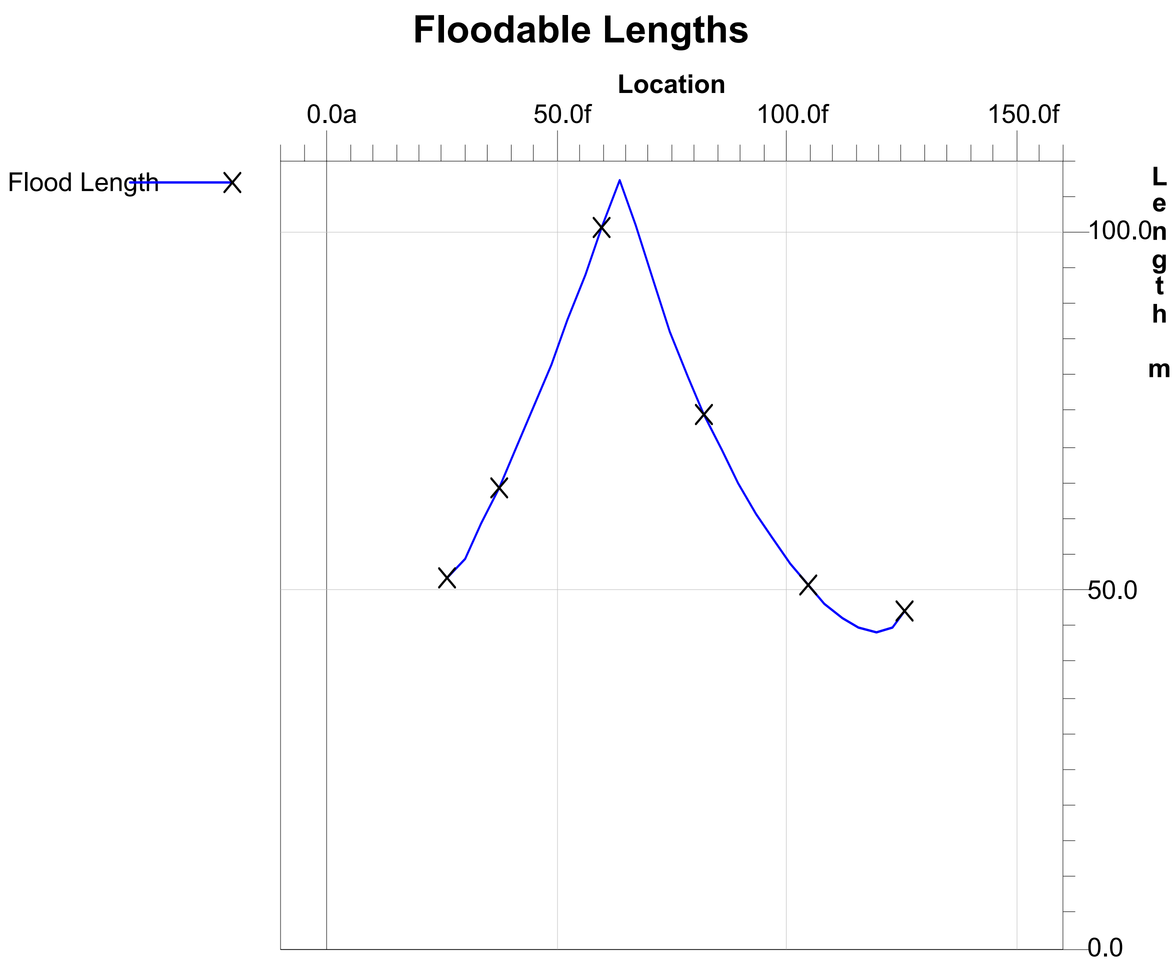
Cross Curves



E. FLOODABLE LENGTH

Displacement: 4973.88MT Water Specific Gravity: 1.025 Draft: 4.50 m
L: 69.698f T: 0.000 V: 7.000 m
Required GM: 0.50 m Uniform Permeability: 0.985

Center (m)	Length (m)	Trim (deg)	GM (m)
125.404f	47.19	3.654f	3.48
122.925f	44.96	3.600f	3.65
119.200f	44.28	3.565f	3.85
115.475f	44.90	3.464f	4.04
111.750f	46.29	3.367f	4.20
108.025f	48.38	3.261f	4.36
104.300f	50.94	3.151f	4.59
100.575f	53.99	3.031f	4.73
96.850f	57.33	2.894f	4.91
93.125f	60.94	2.739f	5.08
89.400f	65.04	2.574f	5.10
85.675f	69.61	2.381f	4.99
81.950f	74.52	2.144f	4.75
78.225f	80.02	1.849f	4.47
74.500f	86.22	1.448f	4.31
70.775f	93.14	0.918f	4.74
67.050f	100.98	0.203f	4.34
63.325f	107.29	1.215a	3.33
59.600f	100.62	1.913a	4.15
55.875f	94.13	2.484a	4.68
52.150f	87.79	2.979a	5.11
48.425f	81.64	3.431a	5.58
44.700f	75.62	3.811a	6.12
40.975f	69.86	4.168a	6.60
37.250f	64.43	4.514a	7.08
33.525f	59.37	4.843a	7.57
29.800f	54.53	5.171a	8.04
25.850f	51.70	5.381a	8.35


Floodable Lengths
Location
0.0a
50.0f
100.0f
150.0f
Flood Length
100.0
50.0
0.0
Length m

Longitudinal Strength

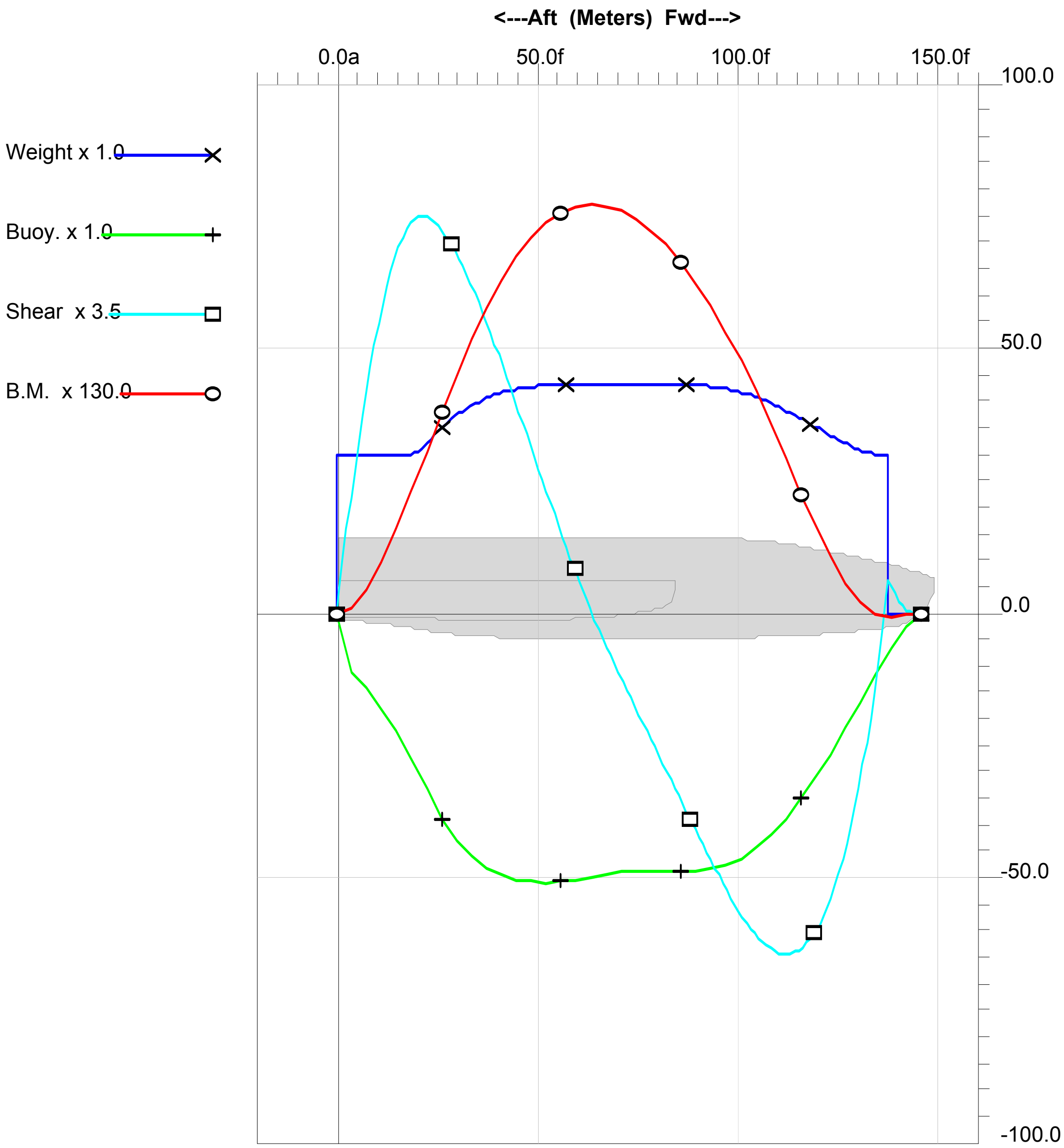
Location (m)	Weight (MT)	Buoyancy (MT/m)	Shear (MT)	Bending (MT-m)
145.491f	0.000	0.000	0.00	0
145.000f	0.000	0.084	0.02	0
144.000f	0.000	0.523	0.32	0
143.000f	0.000	1.187	1.18	-1
142.000f	0.000	2.009	2.78	-3
141.000f	0.000	2.959	5.26	-7
140.000f	0.000	4.019	8.75	-14
139.000f	0.000	5.178	13.35	-25
138.000f	0.000	6.408	19.14	-41
137.500f	0.000	7.050	22.51	-51
137.500f	30.000			
137.000f	30.000	7.691	11.20	-59
136.000f	30.000	9.015	-10.45	-60
136.000f	30.020			
135.000f	30.091	10.365	-30.82	-39
134.000f	30.212	11.736	-49.91	2
133.000f	30.381	13.116	-67.79	60
132.000f	30.592	14.499	-84.47	137
131.000f	30.843	15.880	-100.00	229
130.000f	31.128	17.259	-114.41	336
129.000f	31.442	18.630	-127.75	458
128.000f	31.780	19.978	-140.06	591
127.000f	32.138	21.307	-151.37	737
126.000f	32.516	22.626	-161.73	894
125.000f	32.910	23.930	-171.17	1061
124.000f	33.311	25.193	-179.72	1236
123.000f	33.725	26.442	-187.42	1420
122.000f	34.151	27.677	-194.30	1611
121.000f	34.572	28.861	-200.39	1808
120.000f	35.001	30.035	-205.73	2011
119.000f	35.433	31.185	-210.34	2219
118.000f	35.860	32.292	-214.24	2432
117.000f	36.292	33.388	-217.48	2648
116.000f	36.716	34.438	-220.07	2866
115.000f	37.137	35.458	-222.05	3087
114.000f	37.557	36.457	-223.44	3310
113.000f	37.959	37.396	-224.27	3534
112.000f	38.362	38.321	-224.57	3759
111.000f	38.750	39.196	-224.37	3983
110.000f	39.126	40.035	-223.69	4207
109.000f	39.495	40.848	-222.56	4430
108.000f	39.841	41.600	-221.01	4652
107.000f	40.182	42.336	-219.05	4872
106.000f	40.499	43.013	-216.72	5090
105.000f	40.805	43.660	-214.03	5306
104.000f	41.095	44.269	-211.02	5518
103.000f	41.363	44.828	-207.70	5728
102.000f	41.623	45.367	-204.09	5933
101.000f	41.850	45.835	-200.23	6136
100.000f	42.069	46.285	-196.13	6334
99.000f	42.263	46.682	-191.81	6528
98.000f	42.440	47.043	-187.30	6717
97.000f	42.601	47.369	-182.61	6902
96.000f	42.734	47.641	-177.78	7083
95.000f	42.860	47.895	-172.80	7258
94.000f	42.949	48.078	-167.72	7428
93.000f	43.033	48.249	-162.55	7593
92.000f	43.087	48.360	-157.30	7753
91.000f	43.126	48.443	-152.01	7908
90.000f	43.144	48.483	-146.68	8057
89.000f	43.151	48.502	-141.34	8201

88.000f	43.151	48.508	-135.98	8340
87.000f	43.151	48.513	-130.62	8473
86.000f	43.151	48.518	-125.26	8601
85.000f	43.151	48.523	-119.89	8724
84.000f	43.151	48.529	-114.51	8841
83.000f	43.151	48.534	-109.13	8953
82.000f	43.151	48.539	-103.74	9059
81.000f	43.151	48.545	-98.35	9160
80.000f	43.151	48.550	-92.96	9256
79.000f	43.151	48.555	-87.55	9346
78.000f	43.151	48.560	-82.15	9431
77.000f	43.151	48.566	-76.74	9511
76.000f	43.151	48.571	-71.32	9585
75.000f	43.151	48.576	-65.89	9653
74.000f	43.151	48.582	-60.46	9716
73.000f	43.151	48.587	-55.03	9774
72.520f	43.151	48.590	-52.42	9800
72.000f	43.151	48.597	-49.59	9827
71.000f	43.151	48.637	-44.13	9873
70.000f	43.151	48.707	-38.60	9915
69.000f	43.151	48.801	-33.00	9951
68.000f	43.151	48.914	-27.29	9981
67.000f	43.151	49.042	-21.46	10005
66.000f	43.151	49.181	-15.50	10024
65.000f	43.151	49.324	-9.40	10036
64.000f	43.151	49.470	-3.16	10042
63.000f	43.151	49.615	3.24	10042
62.000f	43.151	49.756	9.77	10036
61.000f	43.151	49.890	16.45	10023
60.000f	43.151	50.014	23.25	10003
59.000f	43.151	50.128	30.17	9976
58.000f	43.151	50.229	37.19	9943
57.000f	43.151	50.317	44.32	9902
56.000f	43.151	50.392	51.52	9854
55.000f	43.151	50.460	58.80	9799
54.000f	43.149	50.524	66.14	9736
53.000f	43.147	50.583	73.54	9667
52.000f	43.128	50.616	81.01	9589
51.000f	43.099	50.630	88.51	9505
50.000f	43.064	50.631	96.06	9412
49.000f	42.998	50.586	103.64	9312
48.000f	42.933	50.537	111.24	9205
47.000f	42.837	50.440	118.84	9090
46.000f	42.732	50.326	126.44	8967
45.000f	42.607	50.179	134.02	8837
44.000f	42.461	49.997	141.58	8699
43.000f	42.304	49.793	149.09	8554
42.000f	42.114	49.538	156.54	8401
41.000f	41.917	49.267	163.93	8241
40.000f	41.682	48.935	171.23	8073
39.000f	41.440	48.589	178.43	7899
38.000f	41.153	48.172	185.52	7717
37.000f	40.863	47.742	192.47	7528
36.000f	40.523	47.234	199.26	7332
35.000f	40.172	46.702	205.88	7129
34.000f	39.778	46.101	212.31	6920
33.000f	39.359	45.455	218.52	6705
32.000f	38.906	44.748	224.49	6483
31.000f	38.413	43.968	230.18	6256
30.000f	37.902	43.146	235.58	6023
29.000f	37.324	42.210	240.65	5785
28.000f	36.723	41.218	245.34	5542
27.000f	36.085	40.147	249.62	5294
26.000f	35.383	38.950	253.43	5043
25.000f	34.646	37.665	256.72	4787

24.000f	33.878	36.276	259.43	4529
23.000f	33.065	34.738	261.47	4269
22.000f	32.239	33.081	262.73	4007
21.000f	31.500	31.445	263.12	3744
20.000f	30.868	29.860	262.59	3481
19.000f	30.370	28.328	261.06	3219
18.000f	30.043	26.851	258.45	2959
18.000f	30.000			
17.000f	30.000	25.441	254.59	2702
16.000f	30.000	24.078	249.35	2450
15.000f	30.000	22.763	242.77	2204
14.000f	30.000	21.494	234.90	1965
13.000f	30.000	20.281	225.79	1735
12.000f	30.000	19.116	215.48	1514
11.000f	30.000	17.990	204.04	1304
10.000f	30.000	16.908	191.48	1106
9.000f	30.000	15.882	177.88	922
8.000f	30.000	14.897	163.27	751
7.000f	30.000	13.949	147.69	595
6.000f	30.000	13.044	131.19	456
5.000f	30.000	12.184	113.80	333
4.000f	30.000	11.359	95.57	229
3.000f	30.000	10.568	76.54	142
2.000f	30.000	9.828	56.74	76
1.000f	30.000	9.121	36.21	29
0.000	30.000	4.221	14.99	4
0.500a	30.000	0.000	0.00	0
0.500a	0.000			

Max. Shear	263.12 MT	At	21.000f		
Max. Bending Moment	10042 MT-m	at	64.000f	(Hogging)	

Longitudinal Strength



F. INTACT STABILITY

HSV - Multihull Stability Criteria

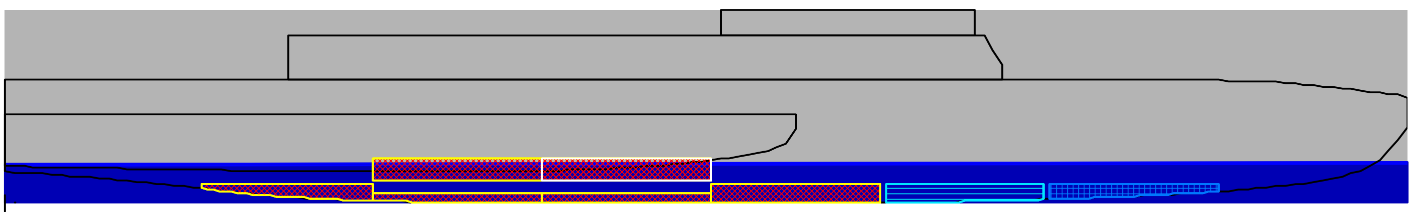
1. Full Load - Departure

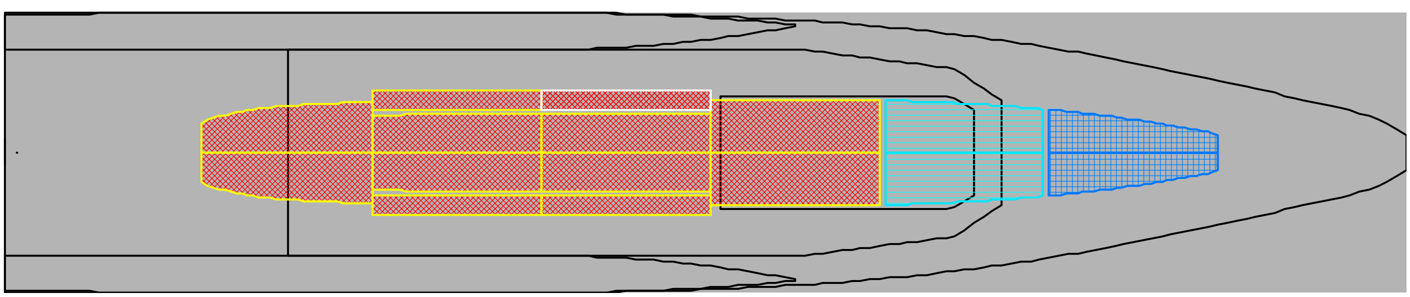
Floating Status

Draft FP	4.512 m	Heel	zero	GM(Solid)	7.213 m
Draft MS	4.503 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	4.494 m	Wind	0.0 kn	GM(Fluid)	7.213 m
Trim	0.02/145.00	Wave	No	KMT	14.841 m
LCG	69.758f m	VCG	7.628 m	TPcm	18.66

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	2,090.72	63.207f	0.000	4.229
Displacement	4,979.31	69.758f	0.000	7.628





Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		819.94	100.00%
FRESH WATER		227.10	100.00%
WATER BALLAST		110.43	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	600.00	45.000f	0.000	6.500u
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	39.21	50.000f	0.000	5.000u
UPPER DECK CARGO	200.00	45.000f	0.000	11.000u
Total Fixed:	**3,821.85**	**68.385f**	**0.000**	**9.395u**

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985	0.00
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985	0.00
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985	0.00
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985	0.00
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985	0.00
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985	0.00
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985	0.00
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985	0.00
Subtotals:	**100.00%**	**819.94**	**60.901f**	**0.000**	**1.994**		**0.00**

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	**100.00%**	**113.55**	**101.504f**	**2.046p**	**1.235**	**0.985**	**0.00**
FW1.S	**100.00%**	**113.55**	**101.504f**	**2.046s**	**1.235**	**0.985**	**0.00**
Subtotals:	**100.00%**	**227.10**	**101.504f**	**0.000**	**1.235**		**0.00**

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
WB1.P	**100.00%**	**55.21**	**117.785f**	**1.438p**	**1.455**	**0.985**	**0.00**
WB1.S	**100.00%**	**55.21**	**117.785f**	**1.438s**	**1.455**	**0.985**	**0.00**
Subtotals:	**100.00%**	**110.43**	**117.785f**	**0.000**	**1.455**		**0.00**

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		**1,157.46**	**74.294f**	**0.000**	**1.794**		**0.00**

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	**Intact**	**1.025**	**4,978.06**	**69.759f**	**0.000**	**2.795**	**0.950**
SubTotals:			**4,978.06**	**69.759f**	**0.000**	**2.795**	

Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.01f	4.495	0.000	0.000	9.997 (1)	Equil
5.00s	0.10f	4.289	0.532	0.023	7.872 (1)	
10.00s	0.25f	3.925	0.989	0.090	5.750 (1)	
15.00s	0.42f	3.476	1.439	0.196	3.615 (1)	
20.00s	0.61f	2.935	1.875	0.341	1.490 (1)	
23.56s	0.76f	2.493	2.180	0.467	-0.005 (1)	FldPt
25.00s	0.82f	2.301	2.307	0.523	-0.602 (1)	
30.00s	1.03f	1.578	2.808	0.746	-2.622 (1)	
35.00s	1.22f	0.778	3.413	1.017	-4.533 (1)	
40.00s	1.38f	-0.116	4.071	1.343	-6.316 (1)	
45.00s	1.58f	-1.126	4.670	1.725	-7.976 (1)	
50.00s	1.80f	-2.218	5.083	2.152	-9.528 (1)	
55.00s	2.04f	-3.355	5.286	2.606	-10.975 (1)	
57.77s	2.18f	-3.996	5.313	2.863	-11.731 (1)	MaxRa
60.00s	2.29f	-4.516	5.296	3.069	-12.309 (1)	
65.00s	2.54f	-5.700	5.135	3.525	-13.513 (1)	
70.00s	2.79f	-6.912	4.824	3.961	-14.571 (1)	
75.00s	3.05f	-8.139	4.384	4.363	-15.472 (1)	
80.00s	3.30f	-9.358	3.839	4.723	-16.216 (1)	
85.00s	3.52f	-10.546	3.212	5.031	-16.800 (1)	
90.00s	3.72f	-11.666	2.519	5.282	-17.235 (1)	

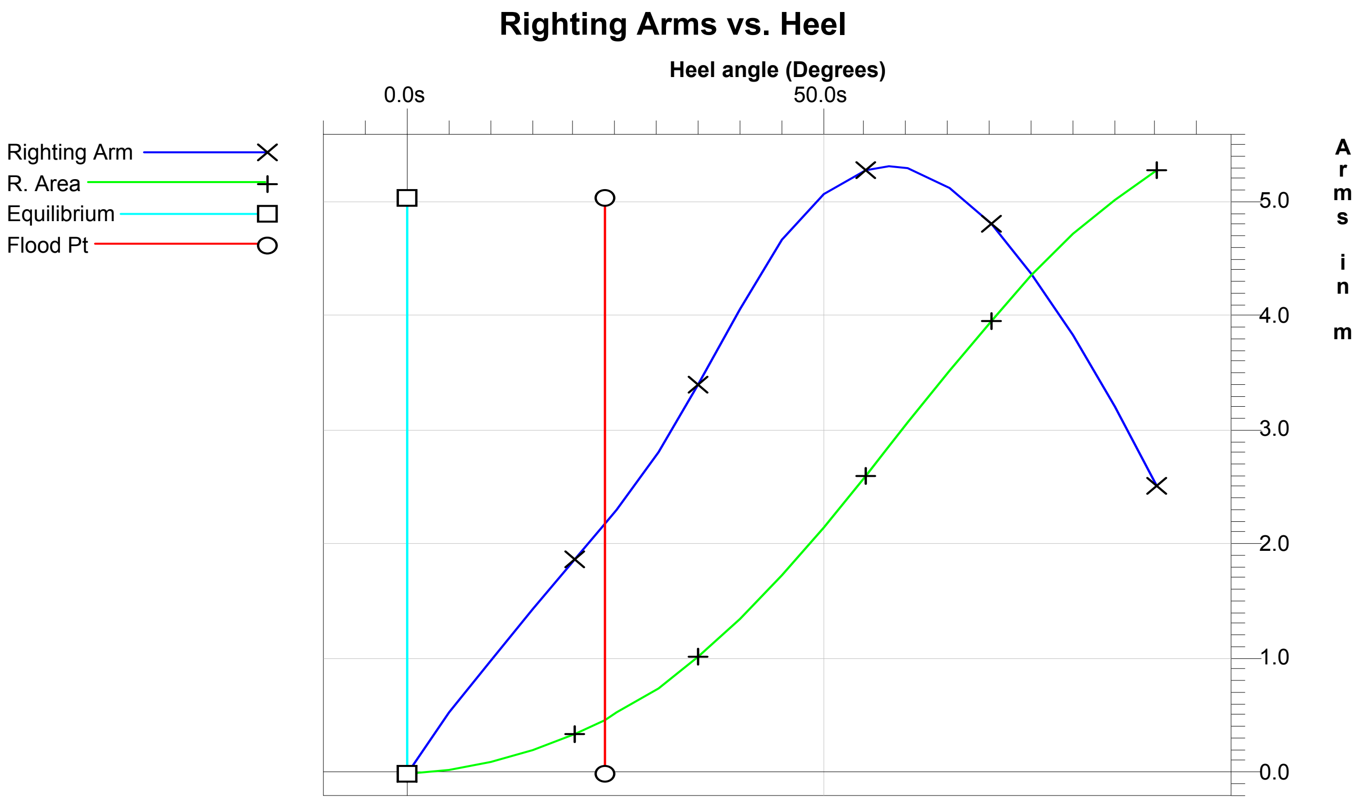
Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.

Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	9.997

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.467	0.438	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	57.77	47.77	Yes



Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
Flood Pt
5.0
4.0
3.0
2.0
1.0
0.0
Arms in m

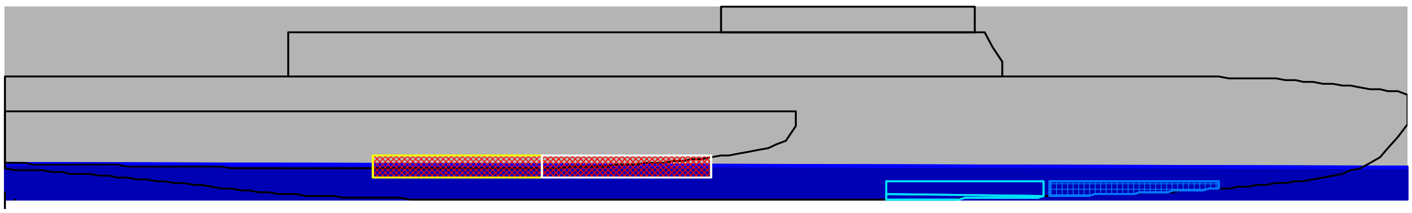
2. Full Load - Arrival

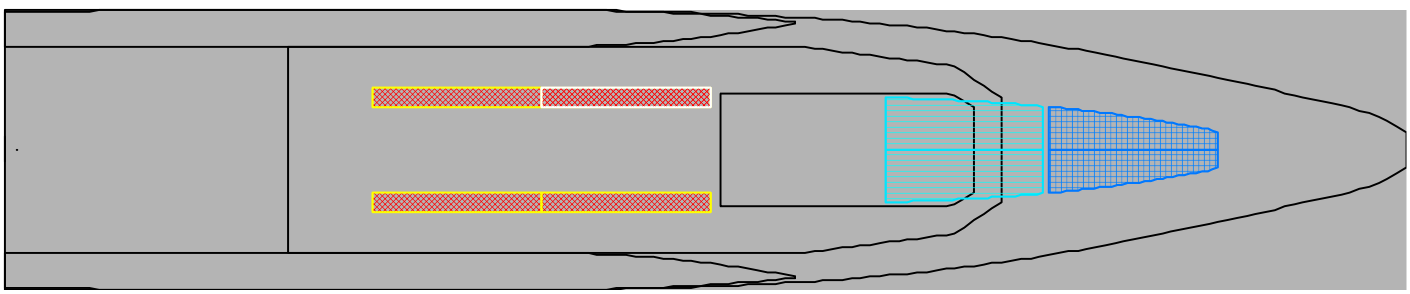
Floating Status

Draft FP	3.870 m	Heel	zero	GM(Solid)	3.584 m
Draft MS	4.047 m	Equil	Yes	F/S Corr.	0.013 m
Draft AP	4.224 m	Wind	0.0 kn	GM(Fluid)	3.570 m
Trim	aft 0.35/145.00	Wave	No	KMT	12.388 m
LCG	69.257f m	VCG	8.804 m	TPcm	17.28

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	1,309.39	57.690f	0.000	5.972
Displacement	4,197.99	69.257f	0.000	8.804





Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		278.29	33.94%
FRESH WATER		22.71	10.00%
WATER BALLAST		110.43	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	600.00	45.000f	0.000	6.500u
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	3.92	50.000f	0.000	5.000u
UPPER DECK CARGO	200.00	45.000f	0.000	11.000u
Total Fixed:	3,786.56	68.556f	0.000	9.436u

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
Subtotals:	33.94%	278.29	57.030f	0.000	3.812		0.00

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	10.00%	11.35	99.986f	1.056p	0.353	0.985	27.95
FW1.S	10.00%	11.35	99.986f	1.056s	0.353	0.985	27.95
Subtotals:	10.00%	22.71	99.986f	0.000	0.353		55.91

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
WB1.P	100.00%	55.21	117.785f	1.438p	1.455	0.985	0.00
WB1.S	100.00%	55.21	117.785f	1.438s	1.455	0.985	0.00
Subtotals:	100.00%	110.43	117.785f	0.000	1.455		0.00

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		411.42	75.708f	0.000	2.988		55.91

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	4,196.66	69.241f	0.000	2.519	0.950
SubTotals:			4,196.66	69.241f	0.000	2.519	

Righting Arms vs Heel Angle

Free Surface Adjustment	0.013
Adjusted VCG	8.817

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.14a	4.225	0.000	0.000	10.424 (1)	Equil
5.00s	0.04a	4.018	0.341	0.015	8.296 (1)	
10.00s	0.11f	3.640	0.776	0.063	6.176 (1)	
15.00s	0.30f	3.170	1.199	0.149	4.046 (1)	
20.00s	0.51f	2.604	1.599	0.271	1.926 (1)	
24.62s	0.73f	1.994	1.948	0.415	-0.002 (1)	FldPt
25.00s	0.75f	1.939	1.977	0.428	-0.160 (1)	
30.00s	1.00f	1.177	2.377	0.617	-2.183 (1)	
35.00s	1.24f	0.325	2.863	0.846	-4.106 (1)	
40.00s	1.45f	-0.611	3.432	1.120	-5.898 (1)	
45.00s	1.68f	-1.657	4.002	1.444	-7.548 (1)	
50.00s	1.93f	-2.812	4.420	1.812	-9.070 (1)	
55.00s	2.21f	-4.041	4.613	2.208	-10.470 (1)	
56.79s	2.32f	-4.497	4.627	2.353	-10.941 (1)	MaxRa
60.00s	2.52f	-5.331	4.583	2.611	-11.737 (1)	
65.00s	2.84f	-6.671	4.349	3.002	-12.859 (1)	
70.00s	3.16f	-8.029	3.949	3.366	-13.833 (1)	
75.00s	3.46f	-9.378	3.421	3.688	-14.658 (1)	
80.00s	3.72f	-10.676	2.796	3.960	-15.340 (1)	
85.00s	3.94f	-11.887	2.099	4.174	-15.889 (1)	
90.00s	4.09f	-12.970	1.353	4.325	-16.314 (1)	

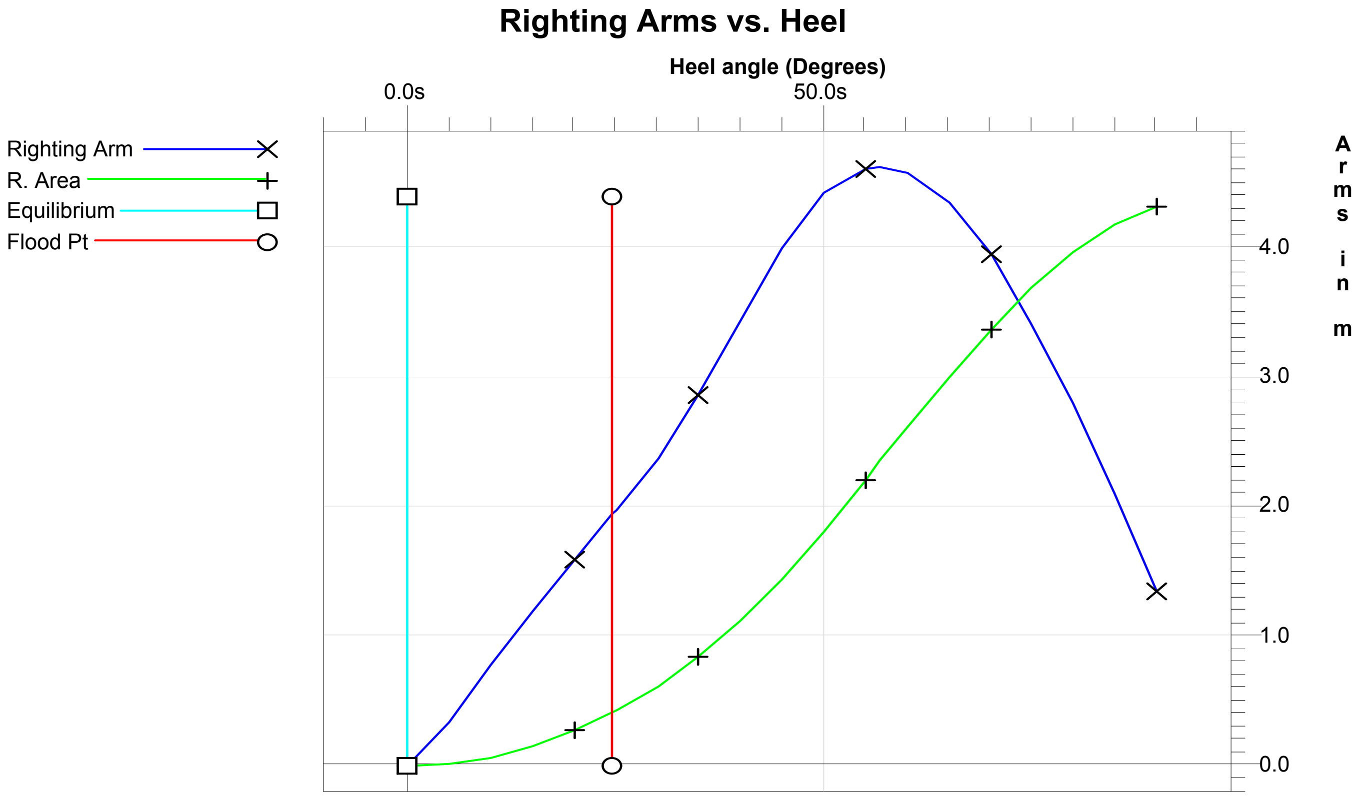
Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.
A Free Surface Moment of 55.9 MT-m was used to adjust the VCG.

Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	10.424

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.415	0.386	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	56.79	46.79	Yes


Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
Flood Pt
Arms in m
4.0
3.0
2.0
1.0
0.0

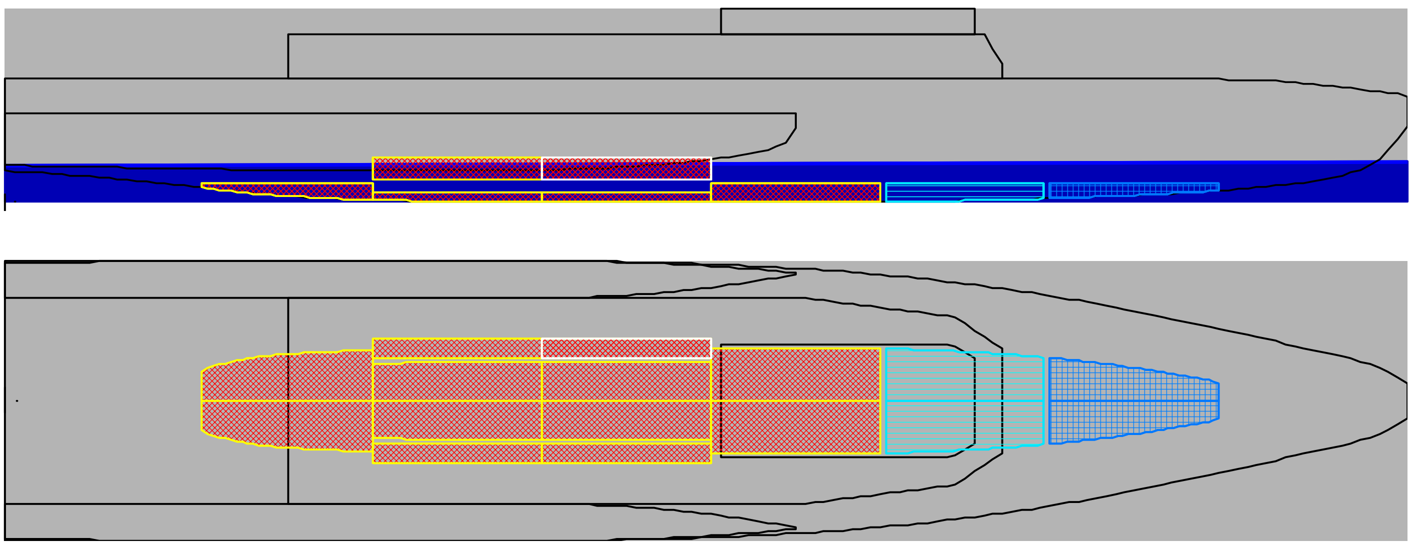
3. Half Load - Departure

Floating Status

Draft FP	4.522 m	Heel	zero	GM(Solid)	6.164 m
Draft MS	4.407 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	4.292 m	Wind	0.0 kn	GM(Fluid)	6.164 m
Trim	fwd 0.23/145.00	Wave	No	KMT	13.651 m
LCG	70.794f m	VCG	7.487 m	TPcm	18.16

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	1,890.71	65.133f	0.000	3.513
Displacement	4,779.31	70.794f	0.000	7.487



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		819.94	100.00%
FRESH WATER		227.10	100.00%
WATER BALLAST		110.43	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	600.00	45.000f	0.000	6.500u
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	39.21	50.000f	0.000	5.000u
UPPER DECK CARGO	0.00	0.000	0.000	0.000
Total Fixed:	3,621.85	69.676f	0.000	9.306u

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985	0.00
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985	0.00
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985	0.00
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985	0.00
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985	0.00
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985	0.00
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985	0.00
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985	0.00
Subtotals:	100.00%	819.94	60.901f	0.000	1.994		0.00

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	100.00%	113.55	101.504f	2.046p	1.235	0.985	0.00
FW1.S	100.00%	113.55	101.504f	2.046s	1.235	0.985	0.00
Subtotals:	100.00%	227.10	101.504f	0.000	1.235		0.00

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
WB1.P	100.00%	55.21	117.785f	1.438p	1.455	0.985	0.00
WB1.S	100.00%	55.21	117.785f	1.438s	1.455	0.985	0.00
Subtotals:	100.00%	110.43	117.785f	0.000	1.455		0.00

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		1,157.46	74.294f	0.000	1.794		0.00

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	4,778.19	70.803f	0.000	2.727	0.950
SubTotals:			4,778.19	70.803f	0.000	2.727	

Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.09f	4.293	0.000	0.000	10.110 (1)	Equil
5.00s	0.18f	4.083	0.492	0.021	7.986 (1)	
10.00s	0.34f	3.712	0.975	0.086	5.867 (1)	
15.00s	0.51f	3.253	1.448	0.191	3.735 (1)	
20.00s	0.71f	2.701	1.905	0.338	1.614 (1)	
23.87s	0.88f	2.210	2.249	0.478	-0.005 (1)	FldPt
25.00s	0.93f	2.054	2.353	0.524	-0.474 (1)	
30.00s	1.16f	1.318	2.864	0.751	-2.491 (1)	
35.00s	1.35f	0.504	3.478	1.027	-4.399 (1)	
40.00s	1.52f	-0.402	4.147	1.359	-6.180 (1)	
45.00s	1.73f	-1.427	4.761	1.748	-7.834 (1)	
50.00s	1.97f	-2.544	5.196	2.184	-9.373 (1)	
55.00s	2.22f	-3.718	5.418	2.649	-10.802 (1)	
58.05s	2.39f	-4.455	5.453	2.939	-11.617 (1)	MaxRa
60.00s	2.50f	-4.932	5.438	3.124	-12.111 (1)	
65.00s	2.78f	-6.180	5.278	3.593	-13.284 (1)	
70.00s	3.06f	-7.455	4.959	4.040	-14.309 (1)	
75.00s	3.34f	-8.732	4.510	4.455	-15.183 (1)	
80.00s	3.60f	-9.992	3.959	4.825	-15.901 (1)	
85.00s	3.84f	-11.197	3.325	5.143	-16.472 (1)	
90.00s	4.03f	-12.326	2.627	5.403	-16.896 (1)	

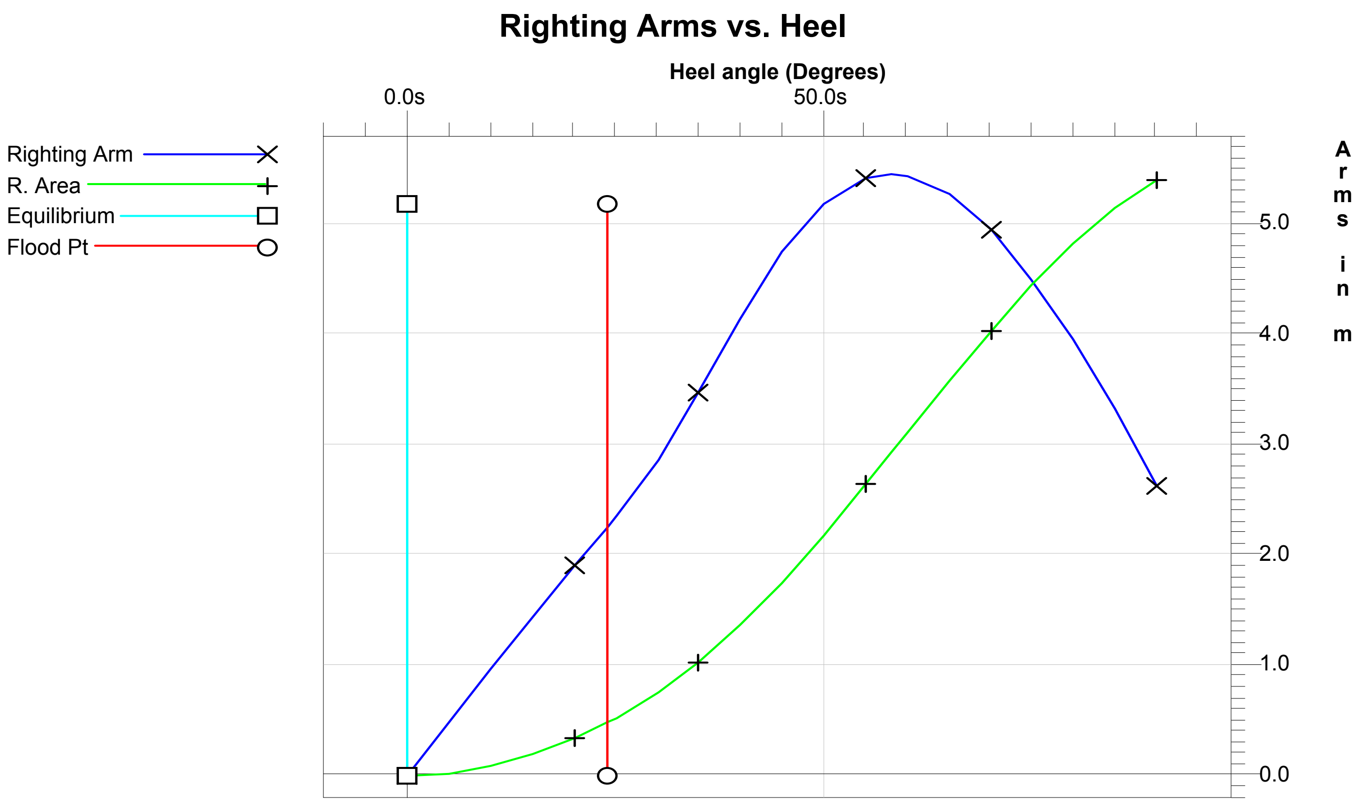
Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.

Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	10.110

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.478	0.449	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	58.05	48.05	Yes



Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
Flood Pt
5.0
4.0
3.0
2.0
1.0
0.0
Arms in m

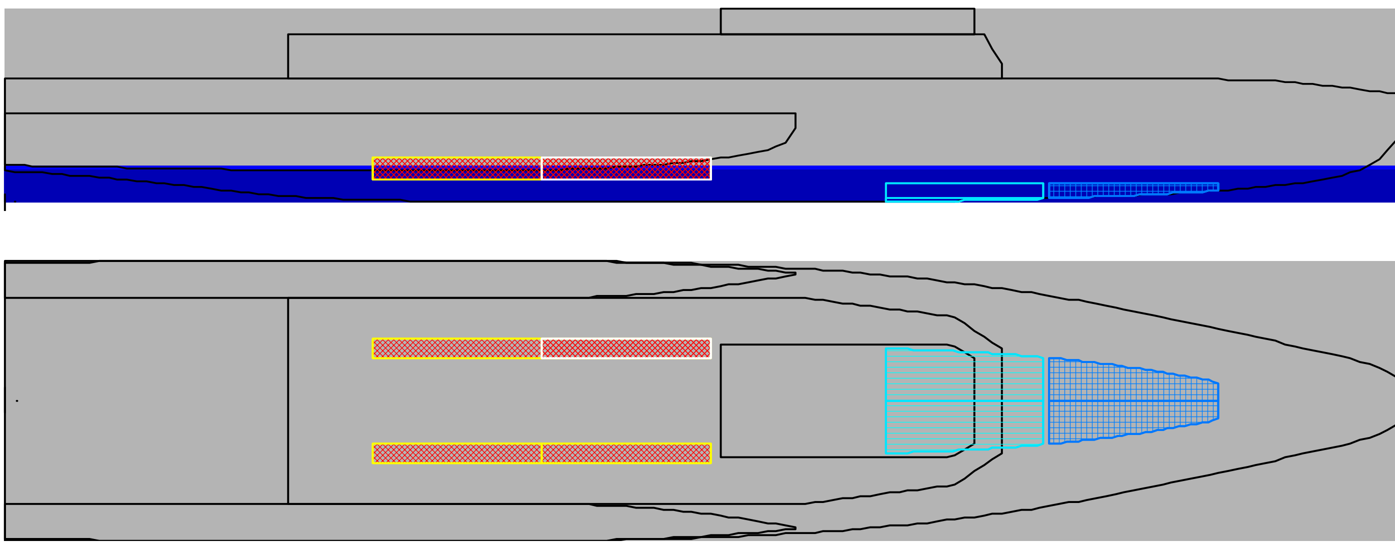
4. Half Load - Arrival

Floating Status

Draft FP	3.890 m	Heel	zero	GM(Solid)	2.080 m
Draft MS	3.942 m	Equil	Yes	F/S Corr.	0.014 m
Draft AP	3.995 m	Wind	0.0 kn	GM(Fluid)	2.066 m
Trim	0.11/145.00	Wave	No	KMT	10.775 m
LCG	70.471f m	VCG	8.694 m	TPcm	16.71

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	1,109.39	59.981f	0.000	5.065
Displacement	3,997.99	70.471f	0.000	8.694



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		278.29	33.94%
FRESH WATER		22.71	10.00%
WATER BALLAST		110.43	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	600.00	45.000f	0.000	6.500u
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	3.92	50.000f	0.000	5.000u
UPPER DECK CARGO	0.00	0.000	0.000	0.000
Total Fixed:	3,586.56	69.870f	0.000	9.349u

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
Subtotals:	33.94%	278.29	57.030f	0.000	3.812		0.00

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	10.00%	11.35	100.130f	1.050p	0.353	0.985	27.69
FW1.S	10.00%	11.35	100.130f	1.050s	0.353	0.985	27.69
Subtotals:	10.00%	22.71	100.130f	0.000	0.353		55.39

WATER BALLAST (SpGr 1.025)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
WB1.P	100.00%	55.21	117.785f	1.438p	1.455	0.985	0.00
WB1.S	100.00%	55.21	117.785f	1.438s	1.455	0.985	0.00
Subtotals:	100.00%	110.43	117.785f	0.000	1.455		0.00

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		411.42	75.716f	0.000	2.988		55.39

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	3,997.43	70.466f	0.000	2.443	0.950
SubTotals:			3,997.43	70.466f	0.000	2.443	

Righting Arms vs Heel Angle

Free Surface Adjustment	0.014
Adjusted VCG	8.708

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.04a	3.996	0.000	0.000	10.548 (1)	Equil
5.00s	0.05f	3.801	0.285	0.012	8.415 (1)	
10.00s	0.21f	3.416	0.743	0.056	6.297 (1)	
15.00s	0.41f	2.932	1.192	0.141	4.172 (1)	
20.00s	0.63f	2.351	1.613	0.263	2.058 (1)	
24.95s	0.87f	1.676	2.004	0.420	0.000 (1)	FldPt
25.00s	0.87f	1.669	2.008	0.421	-0.022 (1)	
30.00s	1.14f	0.884	2.417	0.614	-2.037 (1)	
35.00s	1.39f	0.007	2.910	0.846	-3.953 (1)	
40.00s	1.62f	-0.952	3.485	1.125	-5.738 (1)	
45.00s	1.86f	-2.019	4.060	1.454	-7.380 (1)	
50.00s	2.13f	-3.201	4.494	1.828	-8.888 (1)	
55.00s	2.43f	-4.473	4.695	2.231	-10.266 (1)	
56.77s	2.55f	-4.943	4.710	2.376	-10.722 (1)	MaxRa
60.00s	2.76f	-5.821	4.663	2.641	-11.504 (1)	
65.00s	3.11f	-7.217	4.422	3.039	-12.594 (1)	
70.00s	3.44f	-8.622	4.018	3.408	-13.539 (1)	
75.00s	3.74f	-9.985	3.489	3.737	-14.349 (1)	
80.00s	4.00f	-11.268	2.868	4.015	-15.033 (1)	
85.00s	4.19f	-12.441	2.181	4.235	-15.592 (1)	
90.00s	4.30f	-13.471	1.448	4.394	-16.037 (1)	

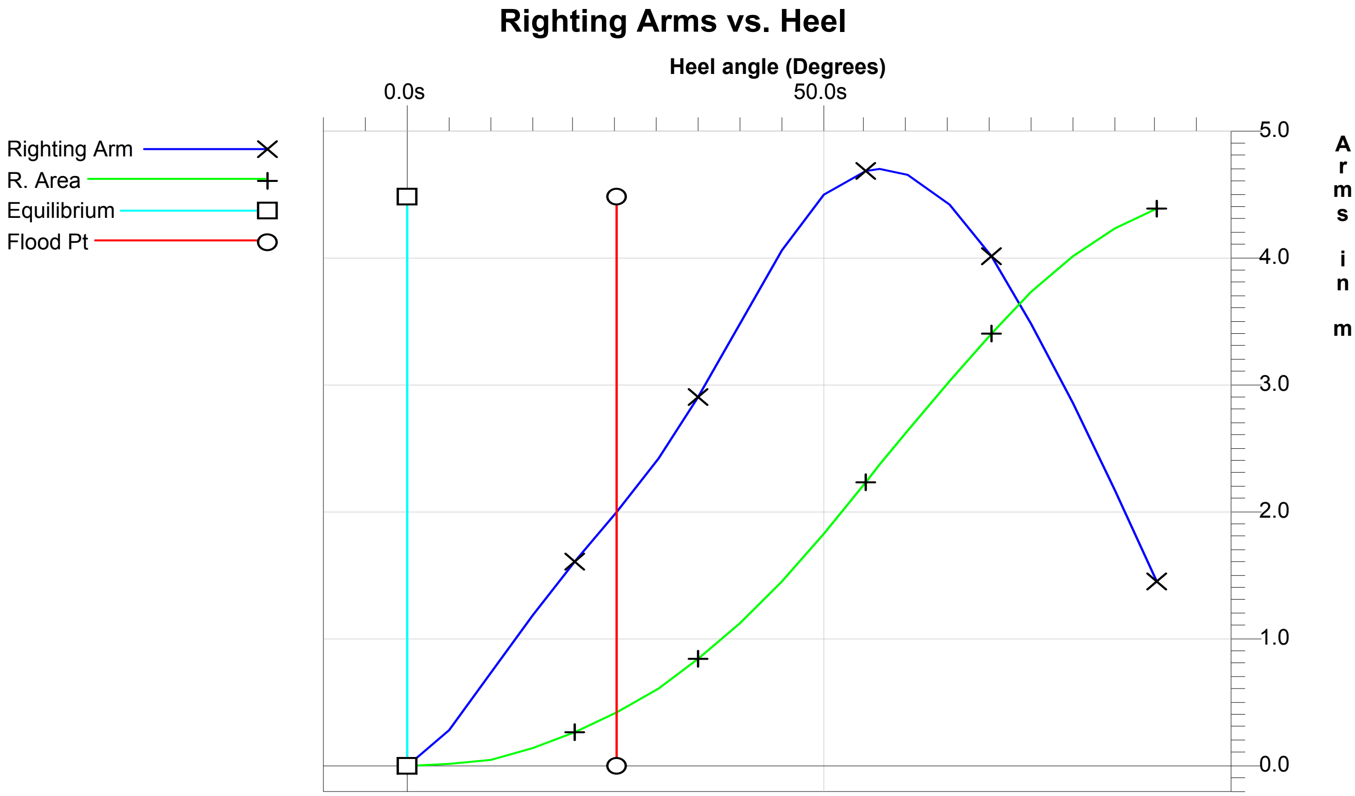
Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.
A Free Surface Moment of 55.4 MT-m was used to adjust the VCG.

Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	10.548

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.420	0.391	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	56.77	46.77	Yes



Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
Flood Pt
5.0
4.0
3.0
2.0
1.0
0.0
Arms in m

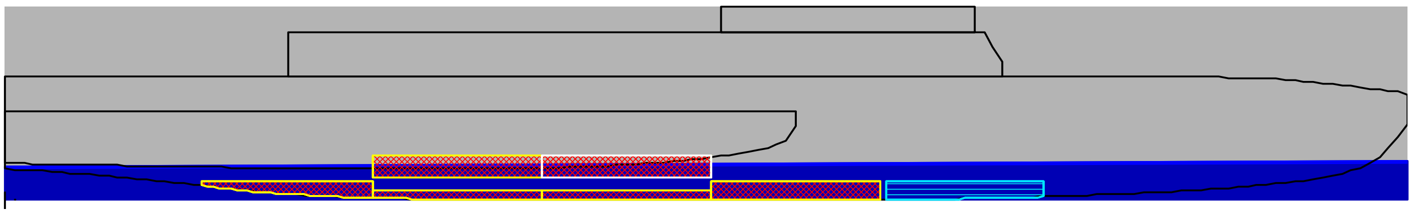
5. Empty - Departure

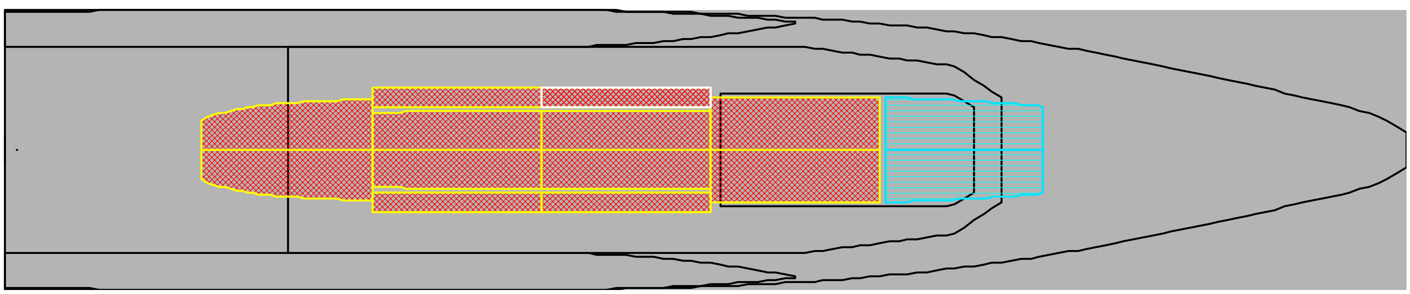
Floating Status

Draft FP	4.340 m	Heel	zero	GM(Solid)	1.873 m
Draft MS	4.015 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	3.689 m	Wind	0.0 kn	GM(Fluid)	1.873 m
Trim	fwd 0.65/145.00	Wave	No	KMT	9.669 m
LCG	73.323f m	VCG	7.796 m	TPcm	16.45

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	1,180.29	70.441f	0.000	2.187
Displacement	4,068.89	73.323f	0.000	7.796





Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		819.94	100.00%
FRESH WATER		227.10	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	0.00	0.000	0.000	0.000
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	39.21	50.000f	0.000	5.000u
UPPER DECK CARGO	0.00	0.000	0.000	0.000
Total Fixed:	3,021.85	74.575f	0.000	9.864u

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985	0.00
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985	0.00
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985	0.00
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985	0.00
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985	0.00
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985	0.00
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985	0.00
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985	0.00
Subtotals:	100.00%	819.94	60.901f	0.000	1.994		0.00

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	100.00%	113.55	101.504f	2.046p	1.235	0.985	0.00
FW1.S	100.00%	113.55	101.504f	2.046s	1.235	0.985	0.00
Subtotals:	100.00%	227.10	101.504f	0.000	1.235		0.00

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		1,047.04	69.707f	0.000	1.830		0.00

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	4,068.11	73.347f	0.000	2.475	0.950
SubTotals:			4,068.11	73.347f	0.000	2.475	

Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.26f	3.690	0.000	0.000	10.536 (1)	Equil
5.00s	0.34f	3.511	0.295	0.013	8.398 (1)	
10.00s	0.50f	3.119	0.801	0.059	6.283 (1)	
15.00s	0.70f	2.621	1.304	0.151	4.164 (1)	
20.00s	0.93f	2.024	1.780	0.286	2.058 (1)	
24.97s	1.18f	1.333	2.226	0.460	0.000 (1)	FldPt
25.00s	1.18f	1.328	2.229	0.461	-0.013 (1)	
30.00s	1.45f	0.531	2.710	0.676	-2.016 (1)	
35.00s	1.70f	-0.353	3.283	0.937	-3.916 (1)	
40.00s	1.92f	-1.318	3.934	1.251	-5.683 (1)	
45.00s	2.16f	-2.398	4.548	1.622	-7.316 (1)	
50.00s	2.43f	-3.596	5.008	2.040	-8.814 (1)	
55.00s	2.75f	-4.889	5.236	2.488	-10.181 (1)	
57.47s	2.91f	-5.558	5.263	2.715	-10.805 (1)	MaxRa
60.00s	3.09f	-6.259	5.235	2.947	-11.407 (1)	
65.00s	3.44f	-7.668	5.035	3.397	-12.491 (1)	
70.00s	3.77f	-9.071	4.677	3.821	-13.437 (1)	
75.00s	4.07f	-10.415	4.198	4.210	-14.259 (1)	
80.00s	4.32f	-11.678	3.630	4.552	-14.952 (1)	
85.00s	4.49f	-12.817	2.994	4.841	-15.532 (1)	
90.00s	4.61f	-13.821	2.307	5.073	-15.996 (1)	

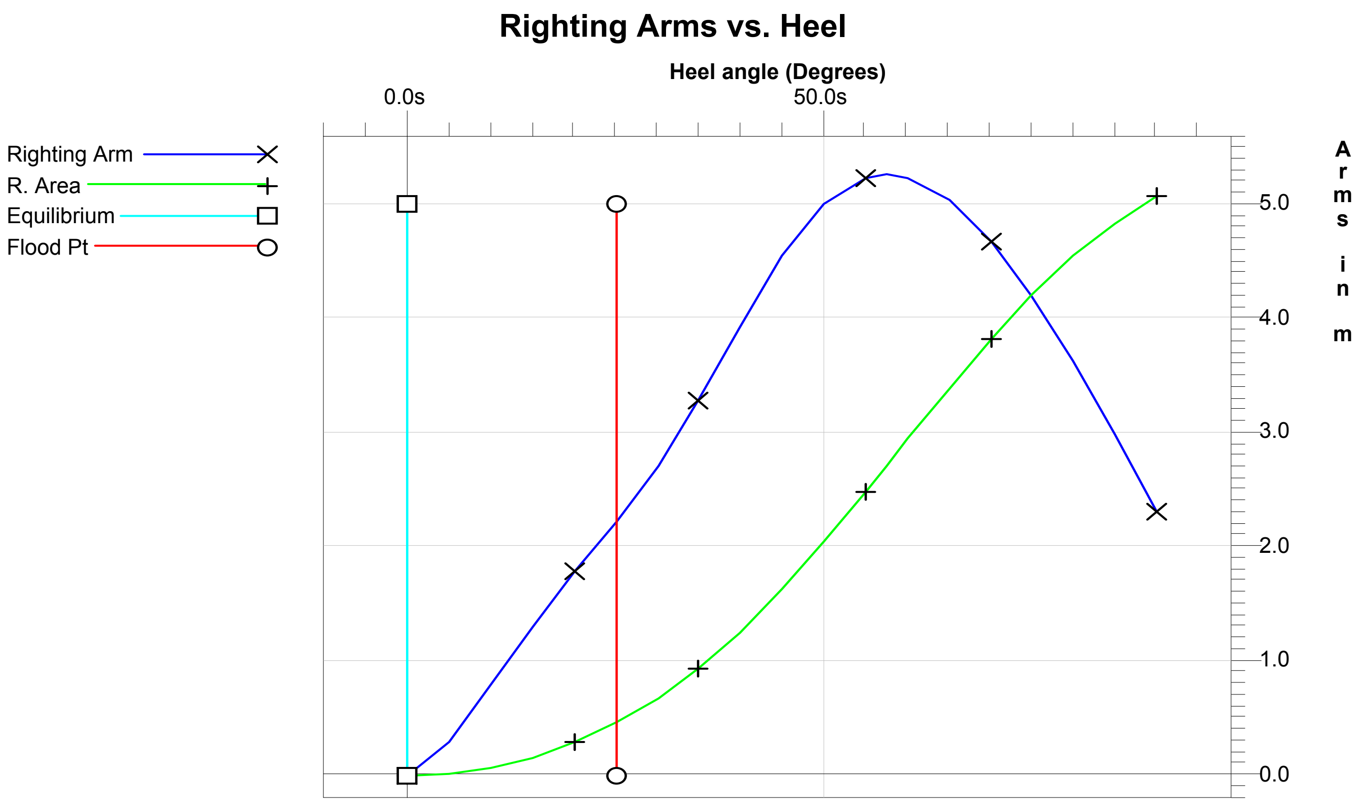
Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.

Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	10.536

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.460	0.431	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	57.47	47.47	Yes


Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
Flood Pt
5.0
4.0
3.0
2.0
1.0
0.0
Arms in m

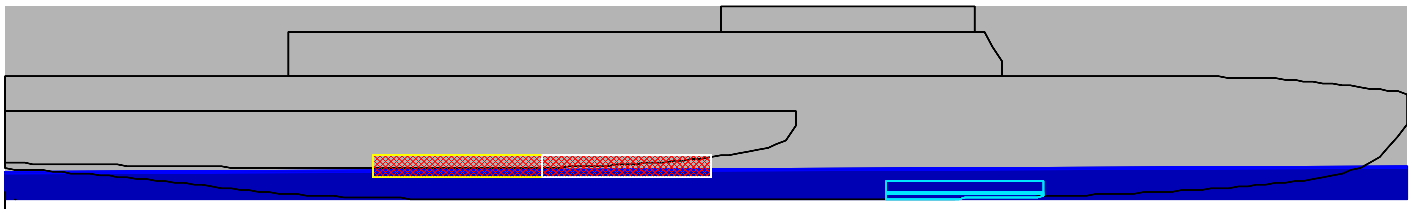
6. Empty - Arrival

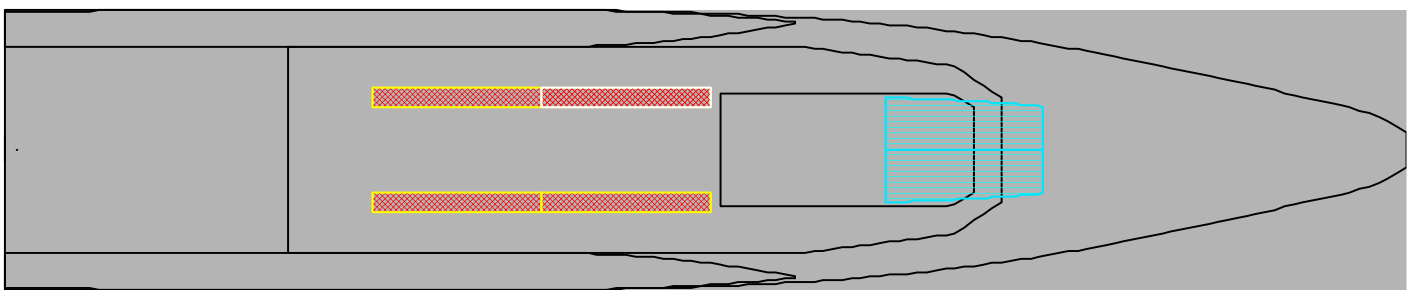
Floating Status

Draft FP	3.757 m	Heel	stbd 4.49 deg.	GM(Solid)	2.956 m
Draft MS	3.478 m	Equil	Yes	F/S Corr.	0.019 m
Draft AP	3.199 m	Wind	0.0 kn	GM(Fluid)	2.937 m
Trim	fwd 0.56/145.00	Wave	No	KMT	12.285 m
LCG	73.533f m	VCG	9.338 m	TPcm	15.69

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	398.96	66.532f	0.011s	3.907
Displacement	3,287.56	73.533f	0.001s	9.338





Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		278.29	33.94%
FRESH WATER		22.71	10.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	0.00	0.000	0.000	0.000
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	3.92	50.000f	0.000	5.000u
UPPER DECK CARGO	0.00	0.000	0.000	0.000
Total Fixed:	2,986.56	74.866f	0.000	9.921u

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
Subtotals:	33.94%	278.29	57.030f	0.000	3.812		0.00

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
FW1.P	10.00%	11.36	100.711f	0.878p	0.360	0.985	19.54
FW1.S	10.00%	11.35	100.258f	1.267s	0.362	0.985	41.39
Subtotals:	10.00%	22.71	100.484f	0.194s	0.361		60.93

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		301.00	60.309f	0.015s	3.552		60.93

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	3,287.67	73.561f	0.565s	2.193	0.950
SubTotals:			3,287.67	73.561f	0.565s	2.193	

Righting Arms vs Heel Angle

Free Surface Adjustment	0.019
Adjusted VCG	9.356

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.18f	3.282	-0.001	0.000	11.025 (1)	
5.00s	0.23f	3.162	0.027	0.001	8.858 (1)	
10.00s	0.41f	2.765	0.454	0.019	6.740 (1)	
15.00s	0.63f	2.228	0.927	0.079	4.633 (1)	
20.00s	0.89f	1.585	1.357	0.179	2.541 (1)	
25.00s	1.18f	0.837	1.743	0.315	0.487 (1)	
26.22s	1.25f	0.637	1.831	0.353	-0.007 (1)	FldPt
30.00s	1.49f	-0.022	2.105	0.483	-1.504 (1)	
35.00s	1.80f	-0.985	2.538	0.685	-3.395 (1)	
40.00s	2.10f	-2.040	3.045	0.928	-5.157 (1)	
45.00s	2.39f	-3.194	3.574	1.217	-6.767 (1)	
50.00s	2.71f	-4.487	3.980	1.547	-8.220 (1)	
55.00s	3.08f	-5.895	4.141	1.903	-9.523 (1)	
55.68s	3.13f	-6.092	4.144	1.952	-9.689 (1)	MaxRa
60.00s	3.45f	-7.362	4.059	2.263	-10.687 (1)	
65.00s	3.81f	-8.818	3.784	2.606	-11.725 (1)	
70.00s	4.11f	-10.211	3.366	2.919	-12.650 (1)	
75.00s	4.36f	-11.508	2.841	3.191	-13.466 (1)	
80.00s	4.54f	-12.694	2.234	3.413	-14.171 (1)	
85.00s	4.66f	-13.756	1.562	3.579	-14.761 (1)	
90.00s	4.71f	-14.696	0.838	3.684	-15.227 (1)	

Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.
A Free Surface Moment of 60.9 MT-m was used to adjust the VCG.

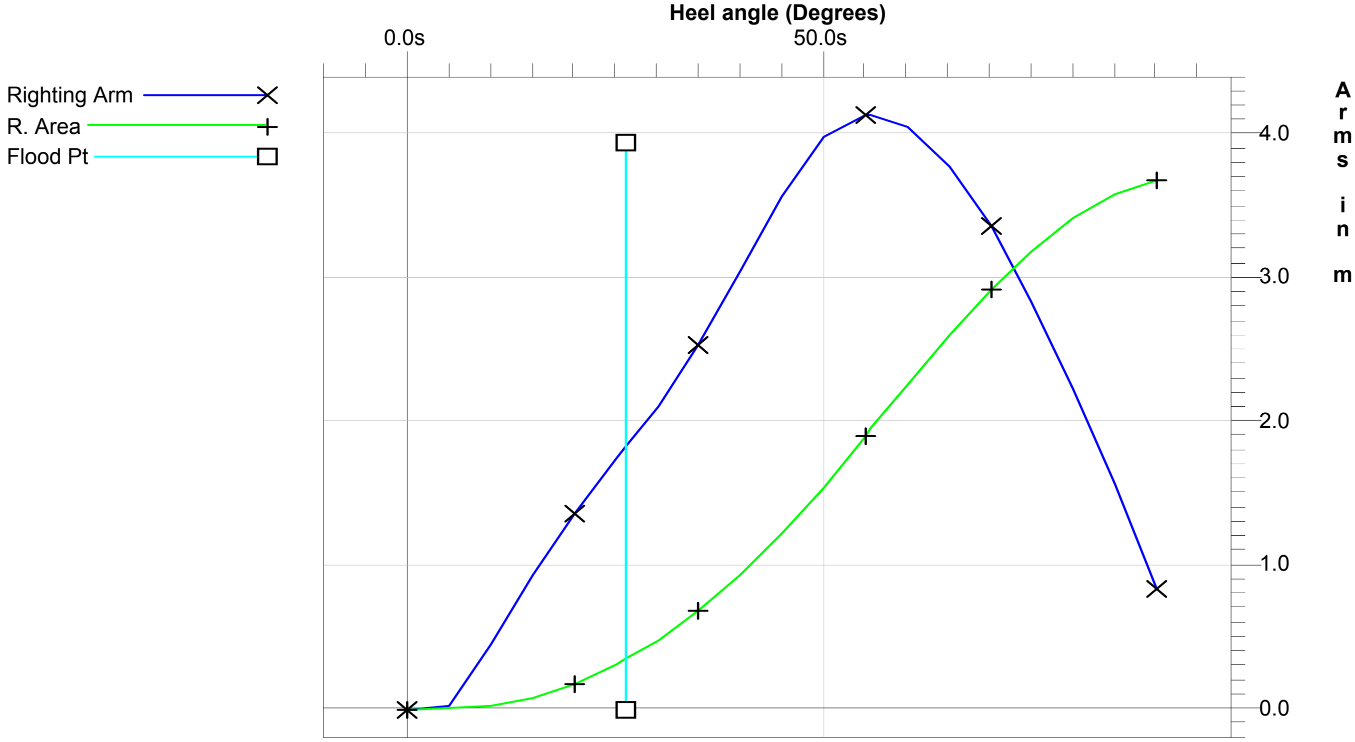
Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	11.025

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.353	0.324	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	55.68	45.68	Yes

Righting Arms vs. Heel



7. Condition Summary Report

Name	DISP (MT)	Tpr (m)	T (m)	Tpp (m)	FB (m)	KG (m)	XG (m)	KMT (m)
Full Load - Departure	4979	4.512	4.503	4.494	6.700	7.628	-69.758	14.841
Full Load - Arrival	4197	3.870	4.047	4.224	7.352	8.804	-69.257	12.388
Half Load - Departure	4779	4.522	4.407	4.292	6.684	7.487	-70.794	13.651
Half Load - Arrival	3997	3.890	3.942	3.995	7.325	8.694	-70.471	10.775
Empty - Departure	4068	4.340	4.015	3.689	6.854	7.796	-73.323	9.669
Empty - Arrival	3287	3.757	3.478	3.199	7.286	9.338	-73.533	12.285

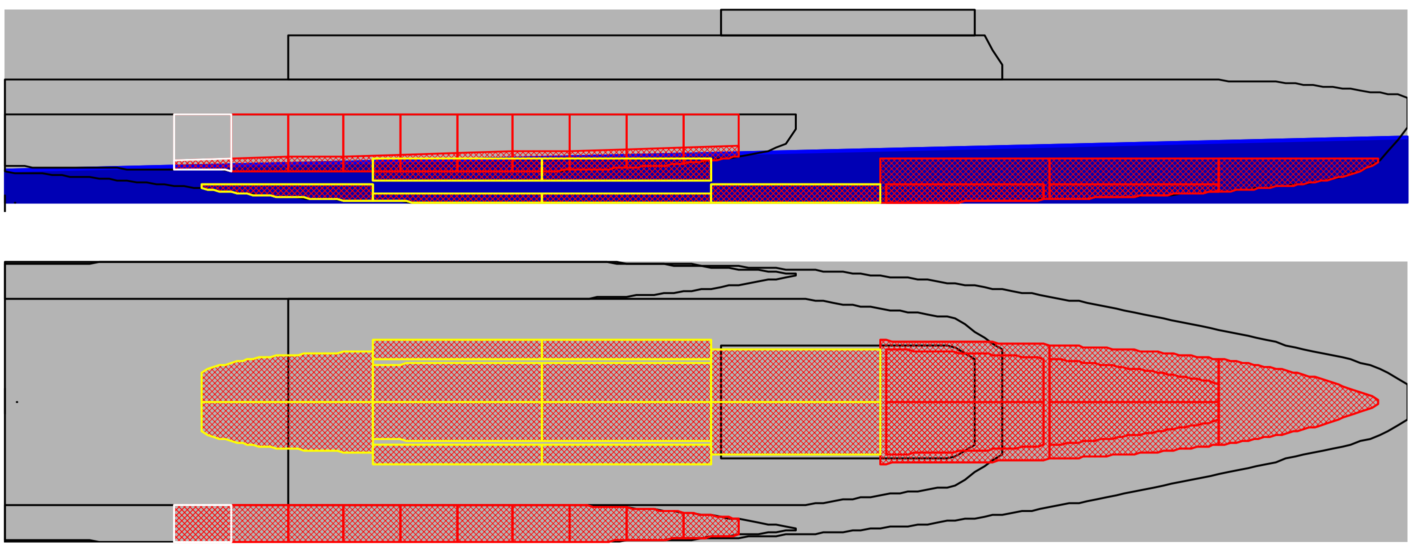
G. DAMAGED STABILITY

Floating Status

Draft FP	7.506 m	Heel	stbd 3.00 deg.	GM(Solid)	3.629 m
Draft MS	5.596 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	3.686 m	Wind	0.0 kn	GM(Fluid)	3.629 m
Trim	fwd 3.81/145.00	Wave	No	KMT	11.711 m
LCG	67.063f m	VCG	8.088 m	TPcm	17.96

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	2,888.60	74.500f	0.000	10.088
Deadweight	1,753.19	54.809f	0.000	4.792
Displacement	4,641.79	67.063f	0.000	8.088



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		819.94	100.00%

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	2,888.60	74.500f	0.000	10.088u
LOWER DECK CARGO	600.00	45.000f	0.000	6.500u
MISSION RELATED EXPANDABLES	76.68	90.000f	0.000	5.000u
SHIP FORCES	17.36	74.500f	0.000	5.000u
STORES	39.21	50.000f	0.000	5.000u
UPPER DECK CARGO	200.00	45.000f	0.000	11.000u
Total Fixed:	**3,821.85**	**68.385f**	**0.000**	**9.395u**

Tank Status

DIESEL OIL (SpGr 0.850)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
DS1.P	100.00%	69.43	48.023f	5.464p	3.813	0.950	0.00
DS1.S	100.00%	69.43	48.023f	5.464s	3.813	0.950	0.00
DS2.P	100.00%	69.72	66.000f	5.467p	3.810	0.950	0.00
DS2.S	100.00%	69.72	66.000f	5.467s	3.810	0.950	0.00
JP1.P	100.00%	66.84	32.033f	1.958p	1.419	0.985	0.00
JP1.S	100.00%	66.84	32.033f	1.958s	1.419	0.985	0.00
JP2.P	100.00%	40.81	48.417f	1.609p	0.618	0.985	0.00
JP2.S	100.00%	40.81	48.417f	1.609s	0.618	0.985	0.00
JP3.P	100.00%	43.96	66.000f	1.640p	0.598	0.985	0.00
JP3.S	100.00%	43.96	66.000f	1.640s	0.598	0.985	0.00
JP4.P	100.00%	119.22	83.995f	2.191p	1.182	0.985	0.00
JP4.S	100.00%	119.22	83.995f	2.191s	1.182	0.985	0.00
Subtotals:	**100.00%**	**819.94**	**60.901f**	**0.000**	**1.994**		**0.00**

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm	FSM (MT-m)
Totals:		**819.94**	**60.901f**	**0.000**	**1.994**		**0.00**

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	6,813.58	79.413f	0.514s	3.543	0.950
FW1.P	Flooded	1.025	-116.39	101.504f	2.046p	1.235	0.985
WB1.P	Flooded	1.025	-55.21	117.785f	1.438p	1.455	0.985
FW1.S	Flooded	1.025	-116.39	101.504f	2.046s	1.235	0.985
WB1.S	Flooded	1.025	-55.21	117.785f	1.438s	1.455	0.985
WT6.C	Flooded	1.025	-875.36	101.721f	0.000	2.913	0.950
WT7.C	Flooded	1.025	-599.79	119.054f	0.000	3.223	0.950
WT8.C	Flooded	1.025	-173.43	134.291f	0.000	3.793	0.950
SWT4.S	Flooded	1.025	-8.73	21.228f	13.731s	4.549	0.950
SWT5.S	Flooded	1.025	-12.87	27.161f	13.725s	4.608	0.950
SWT6.S	Flooded	1.025	-16.72	33.104f	13.712s	4.663	0.950
SWT7.S	Flooded	1.025	-19.87	39.070f	13.703s	4.733	0.950
SWT8.S	Flooded	1.025	-22.32	45.047f	13.698s	4.821	0.950
SWT9.S	Flooded	1.025	-24.09	51.030f	13.693s	4.928	0.950
SWT10.S	Flooded	1.025	-25.07	57.005f	13.690s	5.056	0.950
SWT11.S	Flooded	1.025	-23.40	62.920f	13.689s	5.226	0.950
SWT12.S	Flooded	1.025	-17.67	68.785f	13.689s	5.467	0.950
SWT13.S	Flooded	1.025	-8.99	74.485f	13.690s	5.794	0.950
SubTotals:			4,642.09	67.174f	0.225s	3.803	

Error: (H32722) Unable to evaluate (a)

Righting Arms vs Heel Angle with Damage

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	1.52f	3.639	-0.231	0.000	9.234 (1)	
5.00s	1.52f	3.648	0.108	-0.005	6.997 (1)	
10.00s	1.58f	3.465	0.301	0.014	4.790 (1)	
15.00s	1.63f	3.221	0.508	0.049	2.572 (1)	
20.00s	1.65f	2.922	0.837	0.107	0.389 (1)	
20.95s	1.65f	2.854	0.946	0.121	-0.011 (1)	FldPt
25.00s	1.64f	2.497	1.568	0.209	-1.668 (1)	
30.00s	1.65f	1.899	2.504	0.384	-3.603 (1)	
35.00s	1.69f	1.174	3.449	0.644	-5.437 (1)	
40.00s	1.74f	0.350	4.293	0.983	-7.166 (1)	
45.00s	1.81f	-0.537	4.912	1.386	-8.805 (1)	
50.00s	1.86f	-1.449	5.284	1.833	-10.358 (1)	
55.00s	1.90f	-2.354	5.430	2.302	-11.820 (1)	

56.45s	1.90f	-2.614	5.436	2.439	-12.226 (1)	MaxRa
60.00s	1.92f	-3.255	5.398	2.775	-13.180 (1)	
65.00s	1.93f	-4.153	5.224	3.240	-14.426 (1)	
70.00s	1.95f	-5.053	4.936	3.684	-15.545 (1)	
75.00s	1.98f	-5.961	4.550	4.099	-16.526 (1)	
80.00s	2.02f	-6.884	4.077	4.476	-17.355 (1)	
85.00s	2.08f	-7.827	3.523	4.808	-18.017 (1)	
90.00s	2.16f	-8.782	2.897	5.089	-18.505 (1)	

Weight and C.G. used above include tank loads.
The tank load centers were not allowed to shift with heel and trim changes.

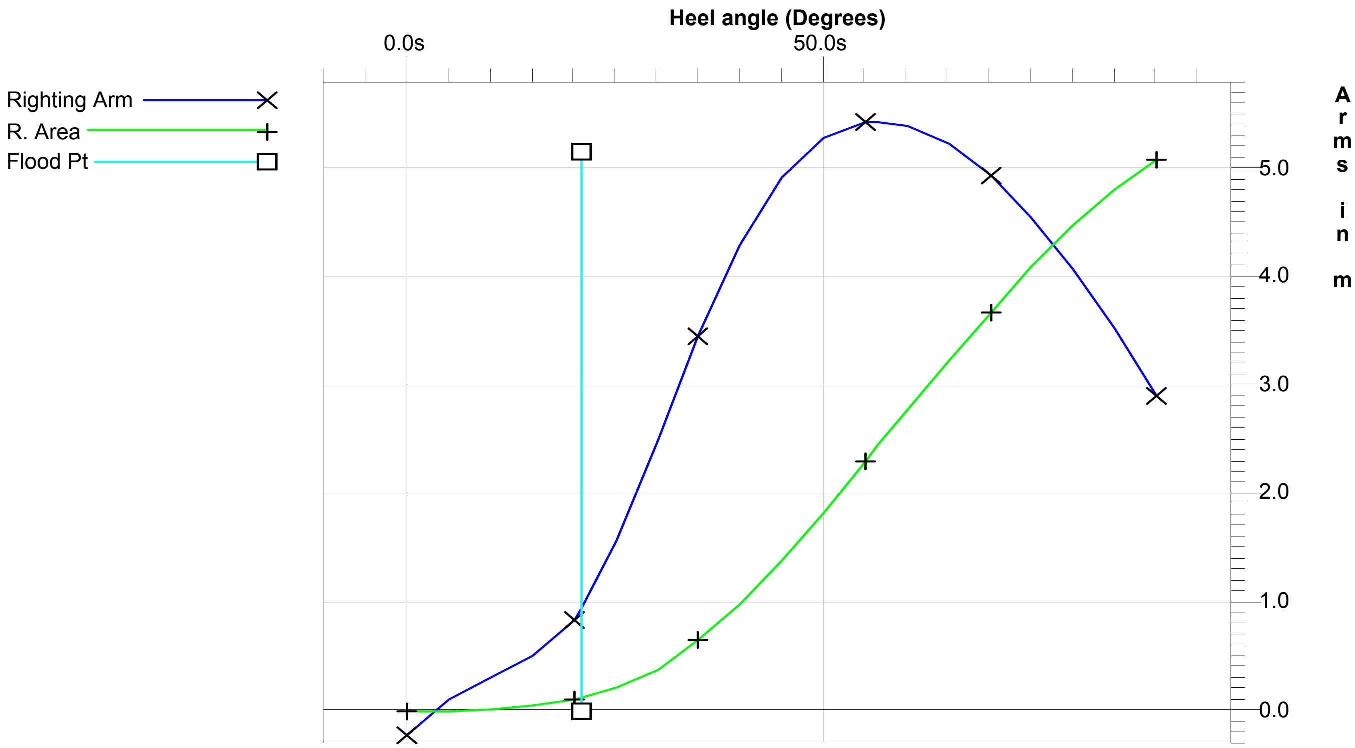
Unprotected Flood Points

Name	L,T,V (m)	Height (m)
(1) Floading Point (Er)	61.000f, 25.000s, 14.500	9.234

"HSV-MULTIHULL CRITERIA"

Limit	Min/Max	Actual	Margin	Pass
(18) Area from 0.00 deg to Flood or MaxRA	>0.0290 m-R	0.121	0.092	Yes
(19) Absolute Angle at MaxRA	>10.00 deg	56.45	46.45	Yes

Righting Arms vs. Heel



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APPENDIX VII COMBAT SYSTEM ANALYSIS

A. RWR TRADE OFF ANALYSIS

1. Sensitivity Calculations

The goal here is to determine the required RWR sensitivity, taking into consideration existing and potential future threats. The result of these calculations will be used to select the type of the RWR receiver.

a. Calculation Parameters

The RWR system must provide warning of threat radars both in search and track mode. For our purposes, the track mode will be examined, since it is the mode that poses the primary threat against the ship.

We will assume that the tracking radar is used to illuminate the ship, in order to guide an RF guided Air-to-Surface or a Surface-to-Surface missile. Because we are looking at both surface and air threats, we will consider the worst case scenario (the air threat) and use the AGM-84 Harpoon (that has a range of about 100km) as the anti-ship missile threat.

Hence, the range at which the desired RWR should detect the threat is 100km.

Two threat situations will be examined:

1. Conventional radar with peak power of 1KW and 30dB antenna gain, operating at 10GHz. According to the frequency selected, this is a fire control radar)
2. LPI radar with 0.1W of peak power and 30dB antenna gain, operating at 10GHz. (This is probably not the main fire control radar of the enemy aircraft, but rather a navigation LPI radar).

b. Formulation

A simplified formula for the received power at the RWR receiver is:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$, where

P_t is the radar's peak power
G_t is the radar's antenna gain
G_r is the RWR's antenna gain
λ the wavelength (3cm in our case)
R is the range of 100km between the tracking radar and the RWR

c. Results

For the conventional radar case:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} = \frac{(1000)(1000)(1000)(0.03)^2}{(4\pi)^2 (100000)^2} = 5.69E-7Watt = -62.4dBw = -32dBm$$

For the LPI radar case:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} = \frac{(0.1)(1000)(1000)(0.03)^2}{(4\pi)^2 (100000)^2} = 5.69E-11Watt = -102.4dBw = -72dBm$$

d. Conclusions

It is evident that conventional radars can be detected at the desirable distances (100km) by a RWR with very low sensitivity (-32dBm). However, this is not the case for the LPI radars, where the required sensitivity is much lower (-72dBm).

Because the use of LPI radar systems will become more widespread in the 2015 time frame, the RWR receiver that is selected for the HSAC will be capable of achieving a minimum sensitivity level of –72dBm.

2. Type Selection

The goal of this trade study is to determine which Radar Warning Receiver (RWR) type will be used.

a. Available Options

The following options were examined:

1. Crystal Video Receiver
2. Superheterodyne Receiver
3. Digital IFM (Instantaneous Frequency Measurement) Receiver
4. Channelized Receiver
5. Digital Receiver

Given the large number of available options, a different procedure will be followed in this trade study, aiming to eliminate those options that do not fulfill certain operational or technical requirements.

b. Sensitivity Requirements

As we have calculated in this part of this unit, the required sensitivity for our system must be at least –72dBm.

The table below lists the typical sensitivity of the available types of receivers. Those types of receivers with sensitivity less than –72dBm are written in bold.

Table 19. Typical sensitivities of the RWR options

Receiver type	**Sensitivity**
Crystal Video Receiver	**-40/-50dBm**
Superheterodyne Receiver	-70/-80dBm
Digital IFM Receiver	**-65dBm**
Channelized Receiver	-85dBm
Digital Receiver	Better than –75dBm

Hence, the Crystal Video, and the Digital IFM receiver types are rejected.

c. Probability of Intercept Requirements

We consider the Probability of Intercept (POI) as a very important requirement. A Probability of Intercept less than 100% would signify that threat emissions could potentially remain undetected. Hence the remaining options are assessed in regards with their POI.

The table in the next page lists the POI of the remaining types of receivers. Those types of receivers with POI < 100% are written in bold.

Table 20. POIs of the different RWR options

Receiver type	Sensitivity
Superheterodyne Receiver	**<100%**
Channelized Receiver	100%
Digital Receiver	~100%

Hence, the superheterodyne receiver types is rejected.

d. Evaluation Criteria

The following criteria were taken into consideration in the evaluation of the remaining options:

1. Dynamic Range
2. Frequency accuracy
3. Technological potential
4. Cost

e. Discussion

Next we examined the advantages and disadvantages of the two options.

Channelized receiver:

Advantages:

- 70dB dynamic range
- Frequency accuracy of 1MHz or less

Disadvantages:

- Based on Analog technology
- High cost

Digital receiver:

Advantages:

- More than 60dB dynamic range
- Frequency accuracy up to few Hertz in Pulse Doppler sequence of pulses
- Based on Digital technology
- Very high cost (expected to decrease over time)

f. Evaluation of Options

Given that both the Channelized and the Digital Receiver types have similar performance characteristics the driving factor for the selection of one and not the other was the technology upon which they are based.

The advantages that the digital technology offers (i.e. stability, reproducibility and programmability) are certainly very important factors. Of equal importance is the fact that one can safely predict significant advances in digital technology over the foreseeable future. In other words, it is expected that a digital system will be easier and cheaper to program, maintain and upgrade, while its cost is expected to be significantly reduced.

g. Decision

The Radar Warning Receiver of the SSPS will use a Digital Receiver type.

B. RF JAMMER TARDE OFF ANALYSIS

1. RF Jammer Calculations

The goal here is to determine the jammer peak power that is required in order to protect our fighter from a ground threat, consisting of a radar-guided Surface to Air Missile (SAM).

a. Calculation Parameters

We assume that the SAM threat has a minimum firing range of 2km from the shore (threat countered right before the HSAC hits the beach). If the HSAC remains undetected up to this range, it is considered safe.

The threat radar parameters are:

P_t=200KW (Peak Power)

G_t=37dB (Antenna Gain)

λ=0.1m (wavelength), i.e. Frequency 3GHz.

We will assume that the SLQ-32 is operating in repeater mode. This means that it aims to present to the threat radar an alternate (false) target, whose RCS is bigger than the ship's RCS.

The following parameters are assumed for the jammer:

Gj=10dB (antenna gain on transmit and receive)
Pj is what we want to calculate
G_e is the repeater electronic gain
Grep is the repeater overall gain (Gj*Ge*Gj:receive antenna, electronic gain, transmit antenna).

We also assume a polarization mismatch of 45 degrees between the radar and the jammer, which corresponds to a power loss factor L_p =2.

b. Formulation

If σ=10m^2 is the fighter's RCS, then the power received from the fighter at the radar receiver is:

$$S = \frac{P_t G_t^2 \sigma \lambda^2}{(4\pi)^3 R^4},$$

with R being the range between the radar and the fighter (i.e. R=1km).

The radar power at the receive side of the repeater jammer is:

$$P_R = \frac{P_t G_t \lambda^2 G_J}{(4\pi R)^2 L_p}$$

This is amplified by the electronic gain of the repeater, resulting in $P_J=P_R.G_e$ and is transmitted towards the radar.

The power received at the radar is:

$$J = P_R G_e \frac{G_J G_t \lambda^2}{(4\pi R)^2 L_p} = \frac{P_t G_t^{\,2} \lambda^4 G_J^{\,2} G_e}{(4\pi R)^4 L_p^{\,2}}$$

The Jam to Signal ratio at the radar is:

$$a = J/S = \frac{G_J^{\,2} \lambda^2 G_e}{(4\pi)\sigma L_p^{\,2}} \; .$$

We will assume that the radar is jammed when $\alpha=5$.

Solving for G_e yields:

$$G_e = \frac{a(4\pi)\sigma L_p^{\,2}}{G_J^{\,2} \lambda^2}$$

Now the Jammer Power can be computed as:

$$P_J = P_R G_e = \frac{P_t G_t \lambda^2 G_J G_e}{(4\pi R)^2 L_p \beta^2} = \frac{P_t G_t a \sigma L_p}{4\pi R^2 \beta^2 G_J}$$

where β is the repeater's chopping factor (typical value $\beta=0.5$).

<u>Results</u>

Now we have all the parameters needed to solve for P_J.

$$P_J = \frac{P_t G_t a \sigma L_p}{4\pi R^2 \beta^2 G_J} = \frac{(200E3)(10^{3.7})(5)(10)(2)}{4\pi (2000)^2 (0.5)^2 (10)} = 797 Watt$$

c. Conclusion

We can see that the repeater jammer will be able to jam the threat SAM radar, providing protection of the fighter up to the 2km range, if its peak power is 797Watt. This is certainly feasible by today's technology standards, since most repeaters can produce about 1KW pulses.

C. DIRCM TARDE OFF ANALYSIS

1. DIRCM Laser Power Calculation

In what follows, the required peak power from a laser transmitter in order to successfully jam the seeker of an Infra-Red guided missile is calculated.

a. Calculation Parameters

The goal of the laser jammer is not to confuse the missile's seeker by providing false target information (a task that would require less power and is not very efficient with year 2015 missile systems), but to inflict damage on the material itself of the detector. We will assume that the laser transmitter has a pulse width of 0.1μsec and that the laser frequency is within the band of the IR missile detector. The laser damage threshold for a pulse of this duration varies inversely with the pulse duration. Hence, the damage threshold is $E_o=10^{-7}W/cm^2$.

The IR seeker has a circular optical aperture of 10cm in diameter while the transmittance of the optics is assumed $\tau_o=0.7$. The IR detector area is assumed to be $A_d=10^{-4}cm^2$. The distance at which the damage is to be inflicted is R=1km (fair distance especially in the littoral), while the atmospheric transmittance is $\tau_a=0.9$.

The beamwidth of the laser beam is $5X10^{-4}$rad=0.5mrad which corresponds to an angular sub tense of the laser beam $\Omega_l=(5E-4)^2=2.5X10^{-7}$Sr.

b. Formulation

The power collected by the detector when the laser threshold is met is:

$$P_e = E_o A_d$$

This power must pass through the optics aperture. Hence:

$$P_e = \frac{P_l.\tau_\alpha.\tau_o.A_o}{\Omega_l.R^2}$$

where A_o is the area of the optical aperture and P_l the power of the laser jammer.

Equating these two formulas, we get:

$$E_o A_d = \frac{P_l.\tau_\alpha.\tau_o.A_o}{\Omega_l.R^2} \Rightarrow P_l = \frac{E_o A_d \Omega_l.R^2}{\tau_\alpha.\tau_o.A_o}$$

c. Results

In our case $A_o = \pi(\frac{10}{2}cm)^2 = 78.53cm^2$

Hence, converting everything to cm:

$$P_l = \frac{(10^7)(10^{-4})(2.5E-7)(100000)^2}{(0.9)(0.7)(78.53)} = 50.53KWatt$$

c. Conclusions

The peak power required can be considered moderate and certainly achievable by the existing technology. It certainly demands a significant amount of complexity and sophistication in the laser pointing mechanism, given the fact that it will be placed in the unsteady platform of the HSAC, though.

It must be kept in mind that in order for this level of power to be effective, the pulse width was set to 100nsec and the beamwidth to 0.5mrad.

2. DIRCM System selection

The goal of this trade study is to determine which type of Directed Infra-Red Counter Measures system will be used.

a. Available Options

The following options were examined:

1. "Hot Brick" IR Jammers (electrically heated rods)
2. Vapor Lamps
3. Laser systems

b. Evaluation Criteria

The following criteria were taken into consideration in the evaluation of the options:

1. Jamming techniques that can be implemented
2. Effectiveness against various IR seekers
3. Weight
4. Availability

c. Discussion

The following table contains the advantages and disadvantages of the three options.

Table 21. Advantages and Disadvantages of the Three MAWS Options

	Hot Brick Jammers	**Vapor Lamps**	**Laser**
Advantages	• No pointing mechanism needed • Available technology	• Modulation or barrage jamming • Good power efficiency • Available technology	• Modulation jamming. Physical destruction of the detector (in band) or the missile's optical aperture (out of band) • Effective against all types of IR missiles • Greater power efficiency (less weight) • Information can be obtained regarding the type of reticle and rotation freq. used • Laser technology available
Disadvantages	• Space modulation (pinwheel pattern with adjustable frequency and sweep rates) • Effective only against older generations of missile seekers without Counter-Counter Measures capabilities • Poor power efficiency • Has no way of obtaining information about the type of IR seeker	• Pointing mechanism is needed when narrow beam is used • Poor effectiveness against latest generation of IR missiles (staring arrays) • Has no way of obtaining information about the type of IR seeker	• Pointing accuracy represents a challenge • Very precise pointing mechanism is needed

d. Evaluation of Options

Because we are looking at the year 2015 threat environment, it is critical that th MWAS is able to detect ALL types of IR guided missiles, including the latest generation, which uses staring type sensors (Focal Plane Arrays). These missiles are basically immune to conventional countermeasures (i.e. flares and IR chaff).

As we can see from the table above, only the Laser systems can be considered as a serious counter measure against these missiles, while at the same time, the Laser systems perform equally well – if not better than the other two options- against older types of IR missiles.

e. Decision

The Laser countermeasures DIRCM system will be used for the DIRCM system of the SPS of our aircraft.

D. EO SYSTEM ANALYSIS

1. System Overview

The Thermal Imaging Sensor System (TISS) AN/SAY-1 is a stabilized imaging system that will provide surface ships with a day and night, high-resolution, infrared, visual imaging, and laser range-finder capability to augment existing optical, electronic, and radar sensors. This fully integrated multi-sensor system will support surveillance, detection, identification, and tracking of low-observable surface and air targets, including floating mines, periscopes, close-in surface boats, low-flying aircraft, and cruise missiles. TISS will also provide combat and operational support functions such as low-visibility navigation, night low-visibility ship-handling, search and rescue, and in-port security/sneak-swimmer defense.

2. System Description

The system that will be installed on the HSAC will be the Next Generation Thermal Imaging Sensor System, known as TISS II as it is the most advanced and up to date system in the U.S. Navy. It is a stabilized, multi-sensor Surveillance and Targeting System (S&TS). It features an advanced stabilization technology that results in exceptional stability, even when exposed to dynamic environments. This enables the use of high performance sensors with superior long-range capabilities onboard ships.

This system can be used in navigation and search-and-seizure operations, as well as in threat location and identification. It can provide high-quality video for surveillance and 3-D targeting data for use with existing weapon control systems.

In addition, it can use coordinates supplied by the Global Positioning System (GPS) satellites to pinpoint targets. Upon locating and identifying the target, TISS is able to hand off information to a variety of weapons systems, providing precise direction and control for guns or missiles. All of the system sensors are bore sighted with an internal tool that allows in-mission precision alignment. A high performance tracker rounds out the system. The result is a state of the art detection, identification, tracking and engagement in daylight, at night, and even in adverse weather conditions.

The system includes many automatic target tracking capabilities that can handle multiple targets. The tracker handles small targets, cluttered backgrounds, momentary obscurities (ship superstructure, clouds, etc.) and target crossings. Its high resolution infrared (IR) and television (TV) systems offer the ability to detect, identify, and track objects in all climates and areas. Together with shipboard radar and other sensors, TISS provides a robust situation awareness capability and provides three dimensional track capabilities that can be used to provide target pointing.

TISS II is envisioned to replace the Navy Mast-Mounted Sight (NMMS) as it is more advanced, smaller, and less expensive.

3. Sensor Overview:

For the purpose of this report, we will focus only on the optical sight that houses all the sensors.

The Optical Sight houses the TISS sensors, the Thermal Control Unit (TCU), and an the Optical Bore sight Tool (OBT). Sight coverage encompasses $\pm 270°$ in the azimuth and $-30°$ to $+85°$ elevation, with slew rates of $60°/s$ in azimuth and elevation. The slew acceleration in azimuth as well as in elevation is of $60/s^2$. The total weight of the turret is about 130Lbs with a diameter of 18 inches. The line of sight (LOS) stability is less than 15 microradians.

TISS is a lightweight, state-of-the- art sensor suite consisting of the following subsystems:

- a high-resolution Thermal Imaging Sensor (TIS),
- two Charged Coupled Devices (CCDs) daylight imaging Television Sensors (TVS),
- an Eye-Safe Laser Range Finder (ESLRF).
- it also incorporates an Automatic Video Tracker (AVT) that is capable of tracking up to two targets within the TISS field of view.

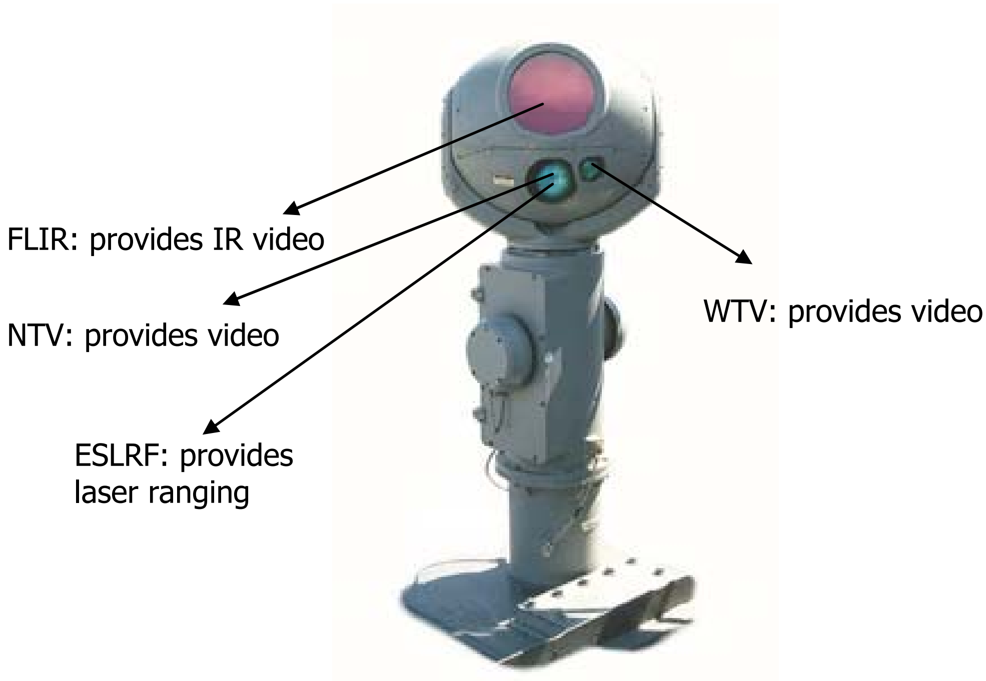

Figure 90. TISS II System

a. ***FLIR System Parameters:***

Table 21 illustrates the different FLIR system parameters.

Table 22. FLIR System Parameters

Parameter	Midwave option 1	Midwave option 2	Longwave option 3
Wavelength	3.8 – 4.8 micron	3.8 – 4.8 micron	65 – 10.25 micron
FPA Type	Staring	Staring	Scanning
FPA detector material	HgCdTe	HgCdTe	HgCdTe
FPA size	640 x 480	320 x 240	240 x 4
Detector pitch	27 micron	30 micron	25 x 28 micron
Focal Length	450mm/700mm/1.4m	450mm/700mm/1.4m	350mm
NETD	<0.025 Deg	<0.025 Deg	<0.1 Deg
FOV's (narrow, wide)	2.2 x 1.65/6.6 x 4.95	1.2 x 0.92/3.67 x 2.75	18 x 24/3.9 X4.2/1x1.5
Operating temp	95 ± 5 Deg K	95 ±5 DegK	95 ±5 Deg K
Cool down time	<7 minutes	<7 minutes	<10 minutes
Reliability	>4000 hr MTBF	>4000 hr MTBF	>2500 hr MTBF

In the Midwave option mode of operation1, the IR camera, also referred to as a thermal imager or Forward Looking Infrared (FLIR), weighs less than 30 lbs. and consists of a HgCdTe staring focal plane array (FPA), an integrated dewar and linear Sterling Cooler, and a dual field of view (FOV) optical train. The high resolution FPA operating in the 3-5μm of the electromagnetic spectrum consists of a total of 640 x 480 pixels. The cooler provides a cool down time of less than 7 minutes for the FPA at an operating temperature of about 95K. The optics provides a narrow FOV of 2.2° x1.65° and a wide FOV of 6.6°x4.95°. For the other modes of operation, the FLIR specifications are outlined in Table 21. The IR camera provides all weather and night time imaging capability.

The FLIR provides thermal imagery with either white-hot or black-hot polarity, selectable by the operator. The FLIR has an automatic gain and level control (AGLC) system which optimize the display of targets; manual override is provided. The FLIR also contains a closed cycle cryogenics system which cools and maintains the FLIR detectors at their operating temperature. The FLIR also sends video signals to the AVT for target track processing.

b. Laser System Parameters:

For determining range of targets, TISS uses an eye-safe laser rangefinder (ESLRF), which provides a $\pm 5m$ range accuracy to targets from 100m to 20,000m from the turret. The ESLRF provides high selectivity and prevents false returns from atmospheric aerosols, rain, and snow.

Table 23. Laser System Parameters

Parameter	ESLRF option 1	ESLRF option 2	LR/D option 3
Wavelength	1.54 micron	1.57 micron	1.064 micron
Pulse Rate	1 Hz	.>10 Hz	8 – 20 Hz
Power	7.8 mj/pulse	----------	----------
Beam Divergence	<800 microradian	----------	----------
Range Performance	20000 m	**FOUO**	**CLASSIFIED**
Range Accuracy	±5.0m	----------	----------
Range Resolution	±5.0m	----------	----------
Source	Nd:YAG Flashlamp	Nd:YAG diode pump	Nd:YAG Flashlamp
Detector	InGaAs	InGaAs	Si
Reliability	.>1 million shots	>100 million shots	>5 millions shots

c. TV Camera Parameters:

The different TV camera parameters are listed below:

Table 24.

Parameter	Narrow TV (NTV)	Wide TV (WTV)
Field of View (FOV) (diagonal)	2.2 degrees	8.0 degrees
Focal Length	317mm/650mm/1.4m	63mm
Aperture	77mm	21mm
F stop	3.0	3.0
Resolution	>800 TVL/PH	>800TVL/PH
CCD	1134 x 484 pixel	1134 x 484 pixel
Spectral Band	600 – 950 mm	600 – 950 mm
Low Light Level	0.5 lux	0.5 lux
Reliability	>7000 hrs MTBF	>7000 hrs MTBF

Table 25. TV Camera Parameters

Two fixed FOV Charge Coupled Device (CCD) cameras provide low light and daytime imaging capability with a spectral response of 600 to 950 mm for haze penetration and twilight or dawn operations. The operating sensitivity of the narrow diagonal FOV (2.2°) is from 0.5 lux to 100,000 lux to account for direct sunlight viewing. The operating sensitivity of the wide diagonal FOV (8°) is 0.5 lux for low light imaging. The low light capability is advantageous for viewing of shipboard running lights and lights along the shore during nighttime operations.

The TVS is capable of imaging floating mines, ships, boats, air targets, and submarine periscopes under clear visibility conditions (20 km). The TVS has an automatic gain and level control (AG/LC) which optimize the display of targets and minimize operator actions necessary to control the adjustments. Manual adjustments can also be made. The Automatic Video Tracker (AVT) processes the digital FLIR and/or TVS video data. The sensors with TISS provide a complete visible situational awareness to CIC in day, night, or harsh weather conditions.

4. Performance Evaluation:

For EO systems, the basic measure of determining if the system meets mission requirements is to determine the range performance of the target. Generally, this can be done in two ways.

The first method is based on theoretical calculations based on the specifications of the different sensors such as the FOV, effective focal length of the optics and the number of pixel dimensions in the FPA. Computer models such as the FLIR 92 and NAVTherm have been developed by the army to test the performance of IR systems. The final output in this case is the graph of the minimum resolvable temperature difference (MRTD) curve. A similar curve called the minimum resolvable contrast (MRC) is used to measure the performance of visible cameras where the contrast between the target and its background is plotted against the spatial frequency.

The other method of obtaining the MRTD and MRC curves is to perform laboratory testing of the EO sensors using a collimator that incorporates 4-bar charts, which can represent targets at various spatial frequencies.

The sensor performance of the TISS has been successfully evaluated to meet the operational requirements of the system using both methods of testing. Figure 91 shows an unclassified pictorial representation of the typical range performance of the TISS for various targets.

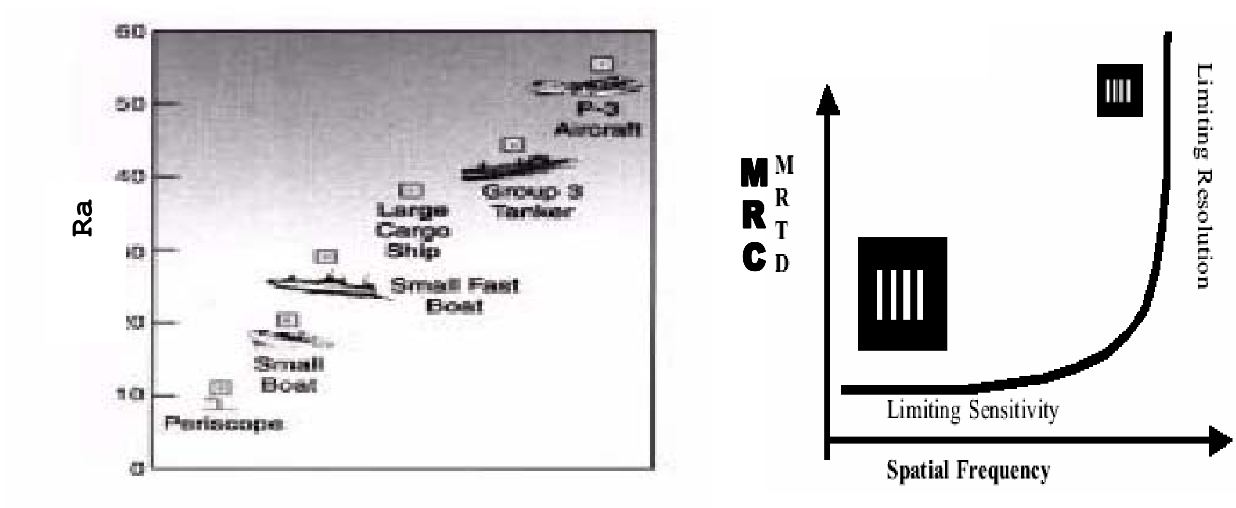

Figure 91. TISS Performance Evaluation

5. Conclusion:

TISS II is a very well tested, proven and now fielded EO sensor for the USN. It is functional and useful in various environments and conditions and provides early warning detection of threats that are essential to the success of the HSAC mission such as floating mines and small fast attack crafts. In addition, it can be used as a Navigation aid and a complimentary target identification system

E. MISSILE TRADE-OFF ANALYSIS:

Working in conjunction with future package designs and because we were looking for a missile that can handle both surface and air threats at ranges up to the middle defense layer, the following choices were analyzed for the choice of the medium range missile: Evolved Sea Sparrow Missile, Rolling Airframe Missile, and Standard Missile SM-2 Block III version for medium range.

		MISSILE TRADE OFF ANALYSIS					Joint Vision concept
Missile	Range Max	Range Min	Size	Quantity	Cost	maneuverability	
ESSM	8	8	8	8	8	8	10
RAM	8	8	8	8	5	6	6
SM-2	10	6	8	6	6	4	6
Weighting	*20%*	*20%*	*5%*	*20%*	*10%*	*15%*	*10%*
ESSM	1.6	1.6	0.4	1.6	0.8	1.2	1
RAM	1.6	1.6	0.4	1.6	0.5	0.9	0.6
SM-2	2	1.2	0.4	1.2	0.6	0.6	0.6

Table 26. Missile trade-off-analysis

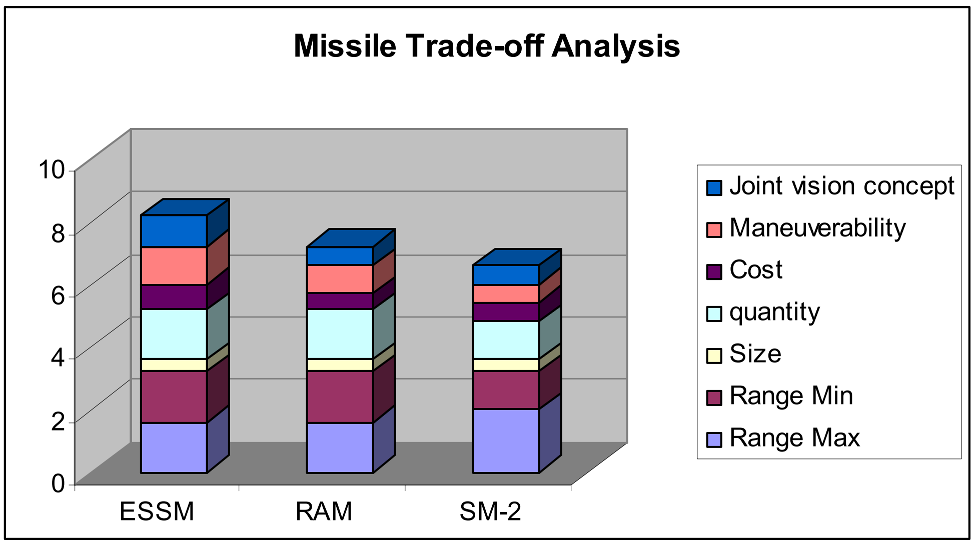

Figure 92. Missile trade-off-analysis results

ESSM contributes to the Joint Vision 2010 concept of full-dimensional protection by enhancing ship self-protection against air and surface threats that have "leaked" past outer air defenses. Given that some of the ships that will use ESSM are also platforms from which strike operations are executed, ESSM indirectly contributes to the concept of precision engagement. The ESSM will be the medium range of choice for the HSAC.

F. GUN TRADE-OFF ANALYSIS

The selection of the high rate of fire gun was based on the following criteria: firing rate, range and weight. The trade off analysis and the corresponding weightings of the different criteria are best described in Table 26 and Figure 93 below.

Table 27. Gun Trade-Off Analysis

	GUN TRADE OFF ANALYSIS		
Gun	Firing Rate	Weight	Range
5in	3	10	6
57mm	10	6	4
76mm	6	2	10
Weighting	**40%**	**30%**	**30%**
5in	1.2	3	1.8
57mm	4	1.8	1.2
76mm	2.4	0.6	3

The selection of the high rate of fire gun was based on the following criteria: firing rate, range and weight. The trade off analysis and the corresponding weightings of the different criteria are best described in Table 26 and Figure 93.

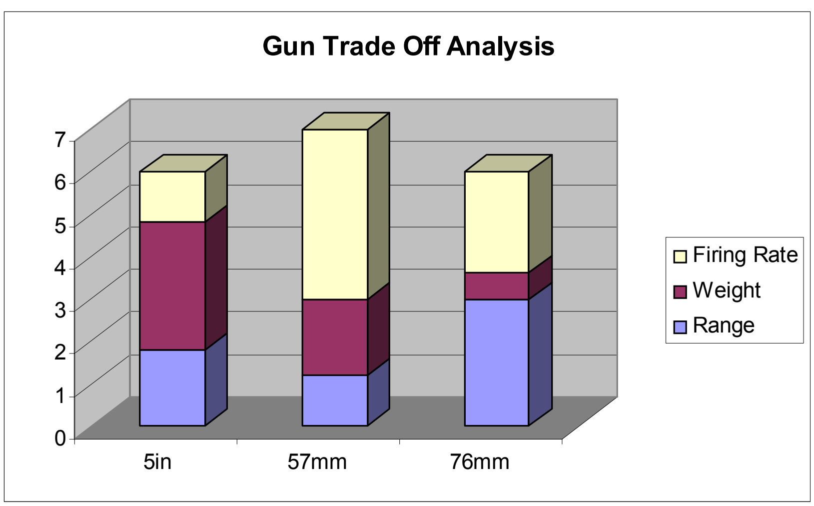

Figure 93. Gun trade-off-analysis results

From the trade-off analysis conducted above, the team decided to use the Mk 3 BOFORS 57 mm gun as the gun of choice for the HSAC. It was selected because of its high firing rate, small weight and volume, and good range for the purpose of defeating small boats and ASCMs.

G. OPERATING STATEMENTS OF THE HPMADS

The below operating statements are being used to give ball park figures on the ADS technology. Due to the nature and classification of the research, exact numbers and capabilities can not be given at this time. For more information on ADS, direct inquiries to the Air Force Research Laboratory, Kirtland AFB.

Active Denial Technology uses a transmitter producing energy at a frequency of 95Ghz and an antenna to direct a narrow focused beam of invisible beam towards a designated subject. Traveling at the speed of light, the energy reaches the subject and penetrates the skin to a depth of less than 1/64 of an inch. Almost instantaneously it produces a heating sensation that within seconds becomes intolerable and forces the subject to flee. The sensation immediately ceases when the individual moves out of the beam or when the system operator turns it off. Unofficial reports state that a 2-second burst from the system can heat the skin to a temperature of 130° F. At 50 °C, the pain reflex makes people pull away automatically in less than a second. Someone would have to stay in the beam for 250 seconds before it burnt the skin,

Despite this sensation, the beam does not cause injury because of the shallow penetration depth of energy at this wavelength and the low energy levels used. It exploits the body’s natural defense mechanism that induces pain as a warning to help protect it from injury. The heat-induced sensation caused by this technology, is nearly identical to the sensation experienced by briefly touching an ordinary light bulb that has been left on for a while. Unlike a light bulb, however, active denial technology will not cause rapid burning. The transmitter needs only to be on for a few seconds to cause the sensation.

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APPENDIX VIII PROPULSION DATA

A. TABLE FOR THE KAMEWA WATER JET S-SERIES

Main data

Water Jet	Power range	Measurements in mm															Weights in kg		
Size	kW	A	B	C ø	D ø	E	F	G	H	I	J	K	L	M	N	O	DW 1)	WW 2)	DW H 3)
63SII	1000-4000	688	831	1120	120	600	460	883	537	1881	1746	1011	630-915	2376	100	30°	1790	1020	111
71SII	2500-7000	743	885	1280	130	650	459	1000	595	2110	1973	1072	710-1000	2566	100	30	2420	1450	123
80SII	3000-8000	873	958	1450	150	750	514	1081	662	2313	2174	1184	800-1075	2897	100	30	3230	2080	123
90SII	4000-10000	999	1073	1660	170	850	557	1214	740	2590	2440	1329	900-1210	3139	100	30	4530	2940	336

1) Dry weight of unit incl. cylinders and shaft flange
2) Weight of water in pump and inlet. duct
3) Dry weight of Hydraulic unit with PTO Pump
Data prior to alteration without prior notice

Rolls-Royce

Rolls-Royce AB
P. O. Box 1010,
S-681 29 Kristinehamn, Sweden

Tel.: +46 550 840 00
Fax. +46 550 181 90
Homepage: www.rolls-royce.com

B. FACT SHEET FOR THE AWJ-21™ PROVIDED BY ROLLS-ROYCE

Fact sheet

Rolls-Royce

Bird-Johnson AWJ-21™

"A revolution in advanced waterjet technology for stealth, speed, and outstanding maneuverability"

Features

Greatly improved cavitation characteristics

High efficiency over broad operating range

Shock hardened component design

Single hull penetration for steering & reversing system

Drive-train flexibility

Description

AWJ-21™ is the adaptation of commercial waterjet technology to high performance ships, incorporating a patented underwater discharge configuration for improved cavitation performance.

Advanced pump design

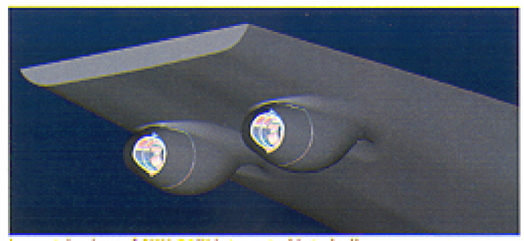
At the heart of AWJ-21™ is an advanced mixed-flow pump design - the most efficient available today. The mechanical design has been shock hardened for naval applications. Simple in construction, this pump provides superior cavitation performance, reduced vibration levels, greater tolerance to poor inflow conditions, and complete swirl-cancellation.

Stealth

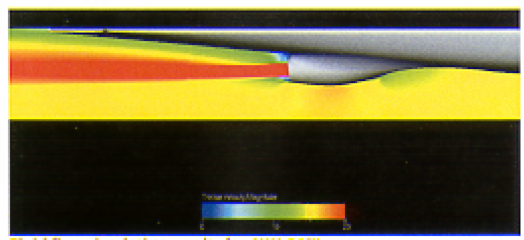
The combination of advanced pump design, and novel underwater configuration provide for very high "quiet" speeds, and greatly reduced cavitation and jet-related wake disturbances.

Littoral operations

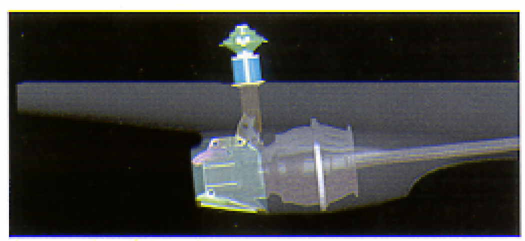
The relatively small size of AWJ-21™ in comparison to conventional fixed-pitch or controllable-pitch propellers results in very low draft of the vessel. In most applications, the propulsor is completely above baseline. The integrated steering and reversing system provides unsurpassed maneuverability at low speeds.



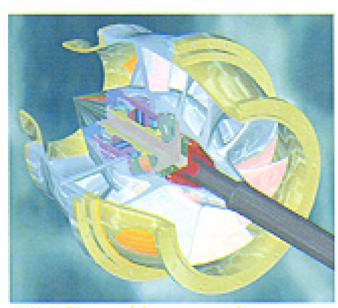
Isometric view of AWJ-21™ integrated into hull



Fluid flow simulation results for AWJ-21™



Cut-away view of AWJ-21™



AWJ-21™ propulsion pump unit

Fact sheet

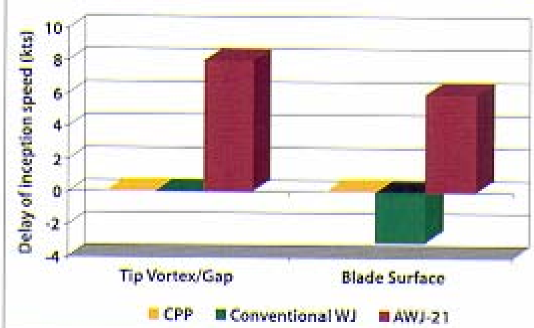
Electric or mechanical drive

When integrated into traditional mechanical drive trains, AWJ-21™ results in reduced ship weight/cost, and improved powering performance. AWJ-21™ is also ideal for integration with electric drive requiring only half the torque, and 2-3 times the rpm of a comparable conventional propulsor. Furthermore, the integrated jet reversing system eliminates any need to reverse drive shaft direction.

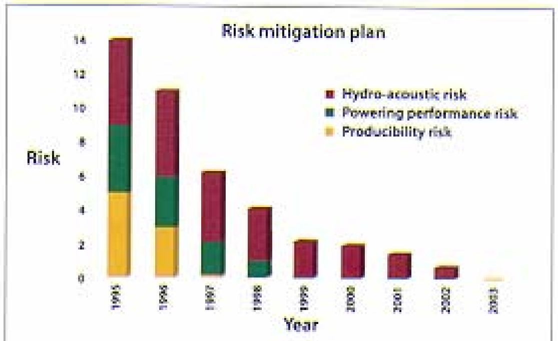
The new paradigm in propulsion

AWJ-21™ represents the most significant advancement in marine propulsion since the advent of the controllable pitch propeller – revolutionary technology for the future of super-quiet propulsion.

Frigate parametric study	C.P.P.	Conventional waterjet	AWJ-21™
#Unit/ship	2	2	2
Power/shaft (kw)	10890	10890	10890
Diameter prop/inlet (cm)	430	150	150
RPM @ full power	180	495	495
Shaft submergance (m)	3	0	3



Comparison of CPP, conventional waterjet, and AWJ-21™ for fast frigate application



Strategic risk-mitigation plan for AWJ-21™

Rolls-Royce®

Bird-Johnson Company
110 Norfolk Street
Walpole, MA 02081-1798 USA
Phone: (508)668-9610
Fax: (508) 668-5638
www.rolls-royce.com

Patents Awarded & Pending

C. ADVANCED WATERJET FOR THE 21ST CENTURY (AWJ-21)

Data that were utilized in the design were provided by Rolls-Royce. Please contact the TSSE faculty if you need access to the data.

D. GAS TURBINE TRADE OFF

Gas Turbines	Power (MW)	Power (HP)	SFC	l (ft)	w (ft)	h (ft)	vol (ft^3)	weight (lb)
MT 30	36	48276.792	0.34	30.09	12.59	16.5	6250.74615	13596.5
ICR WR21	25.2	33793.7544	0.337	26.25	8.67	15.83	3602.71013	111150
LM 1600	14.92	20008.04824	0.376	18.84	10	6.67	1256.628	8200
LM 2500	25.06	33606.01132	0.373	26.96	15.67	6.7	2830.50344	10300
LM 2500+	30.5	40901.1667	0.354	27.56	8.69	6.7	1604.62588	11545
LM 6000	42.75	57328.6905	0.329	30.5	7	8.3	1772.05	18010

Assume efficiency 0.80

V	V	Power	Power		Power	Power	Total Power	Total Power
Kt	m/s	KW	HP		KW	HP	KW	HP
10.95	5.64	706.27	947.12		882.83	1183.90	2882.83	3865.94
16.43	8.45	2633.50	3531.58		3291.87	4414.48	5291.87	7096.52
21.91	11.27	8292.58	11120.54		10365.73	13900.67	12365.73	16582.71
27.39	14.09	13051.60	17502.48		16314.50	21878.11	18314.50	24560.15
32.86	16.91	21077.68	28265.64		26347.10	35332.05	28347.10	38014.09
38.34	19.72	32277.89	43285.35		40347.36	54106.69	42347.36	56788.73
43.82	22.54	47020.71	63055.81		58775.89	78819.77	60775.89	81501.80
49.30	25.36	64660.81	86711.56		80826.01	108389.46	82826.01	111071.49
54.77	28.18	84677.50	113554.39		105846.88	141942.99	107846.88	144625.02
60.25	31.00	106975.83	143456.94		133719.79	179321.18	135719.79	182003.20

Option 1	Option 2		
LM2500+	MT 30	LT/hr	L
0.892	1.027	1.540	1.
0.697	0.780	2.210	2.
0.494	0.531	3.660	3.
0.422	0.444	4.622	4.
0.353	0.364	5.992	6.
0.397	0.416	10.076	10
0.343	0.353	12.490	12

	Up to 32.8 kts		Up to 43.8 kts		
V	Option 1	Option 2	Option 1	Option 2	Required fuel for the
Kt	1 LM2500+	1 MT30	2 LM2500+	2 MT30	endurance of 2600NM
10.95	1.540	1.772	1.540	1.772	365.5
16.43	2.210	2.470	2.210	2.470	349.6
21.91	3.660	3.927	3.660	3.927	434.3
27.39	4.622	4.868	4.622	4.868	438.8
32.86	5.992	6.180	5.992	6.180	474.1
38.34			10.076	10.538	683.3
43.82			12.490	12.838	741.1

Fuel at 33kts for the endurance

LM2500+	MT 30
474.1	488.9

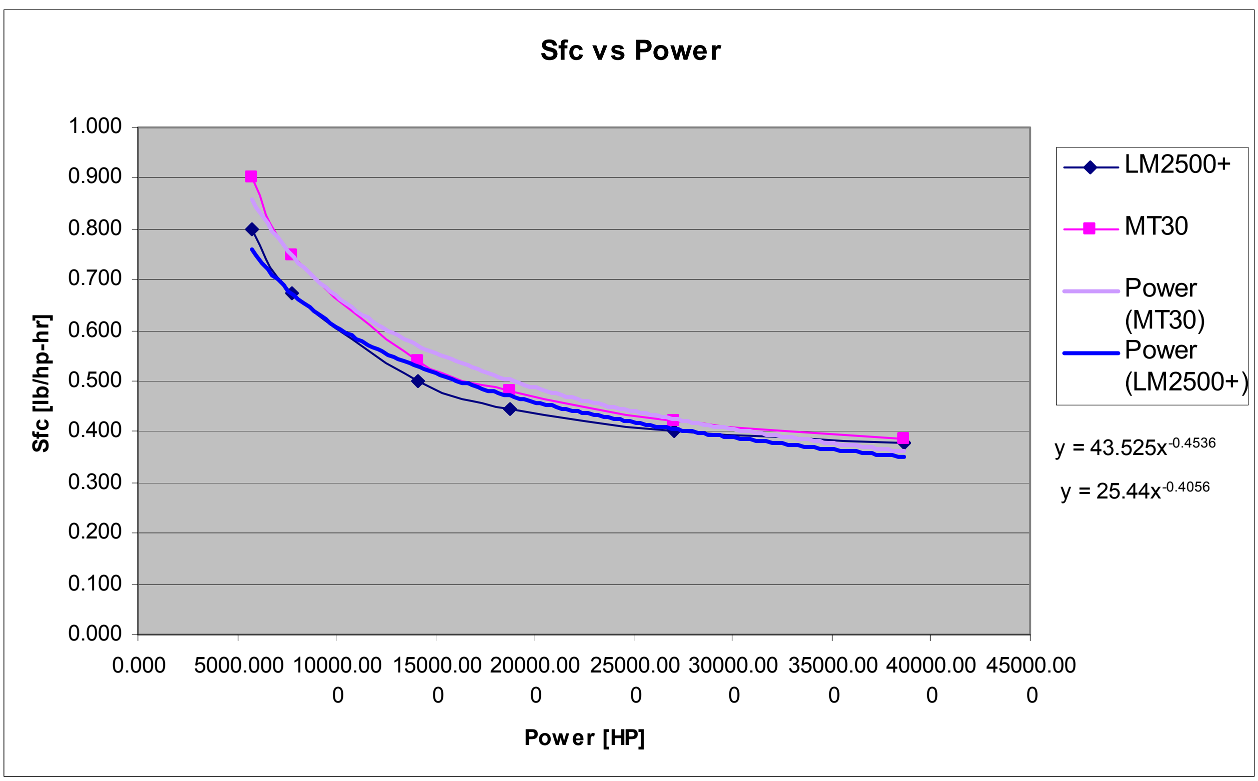
V (Kts)	LM2500+	MT 30	LM2500+	MT 30	Power
10	0.759	0.821	0.800	0.900	5731.791
15	0.641	0.684	0.675	0.750	7756.822
20	0.475	0.492	0.500	0.540	14092.649
25	0.422	0.438	0.445	0.480	18785.774
30	0.380	0.383	0.400	0.420	27037.672
35	0.358	0.351	0.377	0.385	38597.591

MT30 VS LM2500 +

	volume	weight	sfc	power/weight	total
weight factor	0.300	0.150	0.350	0.200	
MT30	0.500	0.700	0.600	0.700	
LM2500+	0.800	0.750	0.800	0.900	

weighted	volume	weight	sfc	power/weight	total
MT30	0.150	0.105	0.210	0.140	0.605
LM2500+	0.240	0.113	0.280	0.180	0.813

LM2500+		
sfc	0.215	kg/KW*hr
weight	20	tn
volume	67	m3
AWJ-21	4	tn
HSC motor	25	tn



APPENDIX IX DAMAGE CONTROL DATA

A. SHIP NUMBERING AND COMPARTMENT INDENTIFICATION

1. Ship Numbering System

a. Compartment Numbering

Compartments are numbered for identification to facilitate location. The identification number assigned locates each compartment specifically, and generally indicates the function and use of the compartment. Compartment numbers consist of four parts, separated by hyphens, in the following sequence: Deck Number, Frame Number, Position in relation to centerline of ship, and Compartment use.

b. Deck Number

The main deck is the basis for this numbering scheme and is numbered 1. The first deck below the main deck is numbered 2, and so on. The first horizontal division above the main deck is numbered 01, and the numbers continue consecutively for subsequent upper divisions boundaries. Compartments are numbered by the lowest deck within the space.

c. Frame number

The forward perpendicular is the basis for this numbering scheme and is numbered "0." "Frames" are consecutively numbered, based on frame spacing, until the aft perpendicular is reached. Forward of the forward perpendicular, frames are "lettered" starting from the perpendicular to the bullnose (A, B, C, etc.) while frames aft of the after perpendicular are "double lettered" to the transom (AA, BB, CC, etc.). Compartments are numbered by the frame number of the foremost bulkhead of the compartment. If this bulkhead is located between "frames," the number of the foremost "frame" within the compartment is used. Fractional numbers are not used except where frame spacing exceeds four feet.

d. Position in relation to centerline

The ship's centerline is the basis for this numbering scheme. Compartments located so that the centerline of the ship passes through them are assigned the number 0. Compartments located completely to starboard of the centerline are given odd numbers, and those to port of centerline are given even numbers. The first compartment outboard of the centerline to starboard is 1, the second is

3 and so forth. Similarly, the first compartment outboard the centerline to port is 2, the second is 4 and so forth. There may be cases in which the centerline of the ship would pass through more than one compartment, all of which may have the same forward bulkhead number. Whenever this occurs, that compartment having the portion of the forward bulkhead through which the centerline of the ship passes is assigned the number 0 and the other carry numbers 01, 02, 03 etc.

e. Compartment Use

A capital letter is used to identify the assigned primary use of the compartment. Only one capital letter is assigned, except that on dry and liquid cargo ships, a double letter identification is used to designate compartments assigned to carry cargo. Examples of compartment use are storage areas, various tanks, and living quarters.

2. Compartment / Fitting Identification

a. Bull's eyes

Bull's eyes shall be painted on a bulkhead of each compartment. Each bull's eye shall contain the compartment number, the foremost and aftermost frame of the compartment, and the division responsible for the compartment. They should be positioned so that they are readily visible upon entry into the compartment. Do not allow bull's eyes to be hidden behind file cabinets or doors. The letters shall be black, two inches in height, painted on a 12 inches high by 15 inches wide yellow or photo luminescent background. Remember, photo luminescent markings are prohibited where they may be visible from the weather.

b. Compartment designation plates

Compartment designation plates are located on the bulkhead above the access. Where space is insufficient, the label plates shall be located on the bulkhead adjacent to the access on the side away from the hinges. Compartment designation plates shall list the numbers of the access fitting, the compartments on both sides of the access as well as the name of the compartment accessed.

c. Frame and Bulkhead Label Plates

One frame label plate shall be installed in compartments over 24 feet in fore-and-aft length and every 24 feet of length of weather decks and hangar deck. A transverse bulkhead label plate shall be installed in compartments having a tightness requirement only if the bulkhead cannot be identified by other means, such as an access label plate.

d. Fitting Numbering

Fittings are numbered in a similar fashion as compartments with the omission of the fourth number (compartment use). More than one fitting may have the same three number designator (e.g. 3-150-0); so, to further identify each fitting, the type of fitting or the system the fitting belongs to must be included in the numbering.

For Example: A valve in the firemain system: FM COV 3-150-0

If a new fitting is installed in a system, it is issued a number using the above guidance. If a valve currently has that number it is renumbered accordingly.

B. BATTLE STATIONS

1. Traffic Flow

To rapidly man battle stations, all personnel must be able to transit the ship's passageways simultaneously without interference. To accomplish this, a generic traffic flow scheme has been defined which is:

UP AND FORWARD TO STARBOARD, DOWN AND AFT TO PORT

It is understood that this may not be feasible for all areas of the ship (i.e. narrow passageways or only one on the Damage Control Deck). In these conditions, the DCA will determine local traffic control schemes. Also, consideration may be made on setting material condition (i.e. not shutting watertight doors on the Damage Control Deck until a certain time after GQ is called).

2. Manned and Ready Report

The senior person in charge of the Damage Control Repair Station (DCRS) is responsible for giving the manned and ready report. A battle station may report manned and ready when the station has enough personnel to do the job. Although open to interpretation in some instances, this definition allows personnel to be more readily available in less time.

3. Battle Dress

Battle dress has been proven to minimize the personnel injuries from minor effects from weapon hits. It also serves as the basis for fire-fighting clothing. Battle dress is not the same for all battle watch stations, but basic battle dress includes:

- Long-sleeved shirt with sleeves rolled down and all buttons buttoned
- Trousers with pant legs tucked into socks
- Leather safety footwear
- Anti-flash Gear, gas mask, life vest

4. Distributed Stowage

To rapidly allow the damage control teams to prepare for action, their damage control equipment has been moved into the passageways under the scheme of Distributed Stowage. This scheme also divides these teams up so that not all of a given team and equipment are destroyed by a single weapon hit. During non-GQ incidents, distributed stowage will reduce the time for team response as well as reducing the confusion around the repair station itself. By disbursing equipment throughout a repair station's area of responsibility, you achieve redundancy, improved reaction time, and survivability. Elements of the new stowage philosophy are:

- Organize equipment by its function
- Relocate appropriate equipment to the passageways
- Relocate large equipment to the passageways and group, by function, near power and exhaust sources.

- Distribute teams and equipment by setting up port and starboard teams, fore and aft teams, and above and below deck teams.
- Provide adjusting shelves for repair stations.
- Utilize ship's shell by shelving and brackets.
- Plan for improvements to equipment.

C. SALVAGE SHIP OR SCUTTLE SHIP

If the ship has sustained damage so extensively that her survival is in question, the C.O. may decide either to continue efforts to save her or to scuttle the ship to prevent its use by hostile forces. Before the C.O. can make this decision, he needs as much information as possible from the Tactical Action Officer (TAO), Chief Engineer (CHENG), and DCA. If the decision is to save the ship, all efforts to control damage must be prioritized and attacked aggressively. If the decision is to scuttle the ship, several evolutions must occur simultaneously.

1. Abandon Ship and Emergency Destruction

All personnel not involved with the emergency destruction of equipment or classified information report to their abandon ship stations. Personnel involved with emergency destruction will carry out procedures outlined in the Emergency Destruction Bill. Scuttle ship procedures must be carried out only after emergency destruction has been completed. Personnel involved with emergency destruction will now report to their abandon ship station and abandon ship will commence. Once abandon ship has commenced, the C.O. will order the ship scuttled. As soon as this order is heard, it must be done quickly, safely, and completely as possible to prevent the ship from falling into enemy hands or to meet a tactical situation

The Engineer Officer, under the supervision of the Executive Officer, is responsible for maintaining the Scuttle Ship Bill. The Engineer Officer is responsible for the main engineering spaces during Salvage and Demolition. The DCA is responsible for all spaces outside of main engineering

a Scuttle Ship Bill (topics that will be addressed

- (1) Purpose
- (2) Responsibilities
  - i) Engineer Officer
  - ii) Damage Control Assistant
  - iii) Operations Officer
  - iv) Weapons Officer
  - v) First Lieutenant
- (3) Information
  - i) Equipment used
  - ii) Communications used
  - iii) Personnel involved
- (4) Procedures
  - i) Word passed
  - ii) Demolition of equipment
  - iii) Securing the detail
  - iv) Abandoning ship

Certain other pieces of equipment should also be completely destroyed to prevent salvage by enemy forces. Among the more important pieces are the following:

(1) All unclassified electronics equipment, weapons launchers and hoists.
(2) Generators, switchboards, and gyro compasses.
(3) Main engine bearings, reduction gears and turbine blades.

D. CONDITIONS OF READINESS AND OTHER CLASSIFICATIONS

1. Material Conditions of Readiness

X-RAY - Set when the ship is in almost no danger of attack or natural hazard, as when it is in a well protected harbor or secured at home base, in fair weather, during normal working hours. All closures and fittings classified X-RAY should be closed at all times. They are labeled with a black letter X.

YOKE - Set and maintained at sea, when entering or leaving port during peacetime, in port outside of normal working hours during peacetime, and in port during wartime. When material condition YOKE is set, both X-RAY and YOKE closures and fitting are secured. YOKE closures and fittings are labeled with a black Y.

ZEBRA - Set during General Quarters. It is also set when the ship is leaving or entering port during a time of war, or at any time the ship is in a damaging situation such as fire or flooding. When material condition ZEBRA is set all X-RAY, YOKE and ZEBRA closures and fittings are secured. ZEBRA closures and fittings are labeled with a red Z.

2. Other Damage Control Classifications

Circle X-Ray and Circle Yoke Assigned to fittings and closures that may be opened without special permission by personnel proceeding to or from battle stations, or as required for routine inspection, or access to vital spaces. They must be immediately closed and secured after passing through.

Circle Zebra In situations where the ship has material condition Zebra set for extended periods of time, the Commanding Officer can authorize the use of Circle Zebra closures and fittings to facilitate the feeding of the crew and to allow the use of selected sanitary spaces. They may be used in the same way as Circle X-Ray and Yoke fitting and closures.

Dog Zebra Closures and fittings that are required to be secured when condition Zebra is set or during periods of darken ship. These fittings and closures are located in decks and bulkheads exposed to the weather. Therefore, they must be closed during darken ship to prevent light from showing outside the ship.

William Closures and fittings that are open during all material conditions. William closures and fittings are only secured to control damage or casualties and to effect repairs.

Circle William Fittings that access ventilation that may be open and operating regardless of material condition of readiness. These fittings are required to be secured only to prevent the spread of the effects of damage or for CBR defense.

3. Modified Material Conditions of Readiness

Modified Yoke Same classification as condition Yoke except only X-Ray and Yoke fittings and closures below the waterline are closed. X-Ray and Yoke fittings and closures above the waterline may be open to improve accessibility and habitability. Commanding Officer's permission is required.

Modified Zebra Same classification as condition Zebra except only X-Ray, Yoke and Zebra fittings and closures below the waterline are closed. X-Ray, Yoke and Zebra fittings and closures above the waterline may be open to improve accessibility and habitability. Commanding Officer's permission is required.

E. SHIP SURVIVABLILITY

1. Damage Control Total Ship Survivability

When a total ship repsonse is needed, all personnel must understand what needs to be done. This will require prior training and coordination between command stations.

2. Considerations (Sources of Confusion)

a. C3 - Command, Control, and Communications

Command must make its priorities known to all and continuously update those priorities during action. A rigid chain of command must be maintained to ensure no duplication of effort while ensuring all action is taken. Controlling stations must be able to communicate and work together to ensure actions are coordinated. These stations include Combat Information Center (OIC: CICWO), Main Control (OIC: EOOW), and Damage Control Central (OIC: DCA). Also, to ensure that these stations easily work together, they must be looking at the same plan(s). Most ships have a Combat Systems Operational Sequencing System (CSOSS), Engineering Operational Sequencing System (EOSS), and Damage Control Book and Diagrams. A valve in a system (like Chilled Water) will have a Damage Control number and a CSOSS number and an EOSS number. Before a casualty can be effectively combated, these three numbers must be reduced to a single identifier. It is suggested that the DC number is used since it can be used to locate the valve. Communications must be clear at all times. This may require alternate means, especially if a controlling station must be evacuated due to damage or smoke.

b. Intense Heat and Heavy Smoke

The intense heat produced by burning fuel from a weapon will prevent fire fighting teams from approaching close enough for extinguishment. Also, damage inflicted by the weapon may render installed fire fighting systems inoperative. Until those teams are able to contain this fire; heat and smoke will continue to be produced and unless these products are controlled, the ship as a whole may become untenable. The proper use of containment strategies and smoke control will be the only way for the ship to continue in its operation. The above actions may require non-damage control personnel to take action (like OS's) thus they must also be trained in the how and why of smoke control and fire containment. The possibility of using installed ventilation systems to purge ship of smoke should be considered. Portable blowers found aboard ship do not have the capability to move vast quantities of smoke.

c. Personnel Casualties

The shock from weapon impact and detonation and then the fire ball that follows may injure a large number of personnel. The injuries will range from localized minor burns to an array of internal injuries. The number and extent of these casualties may quickly overcome the medical department. With a large number of minor personnel casualties, the damage control teams will be needed to assist the medical department. Their knowledge of basic first aid will be of great importance.

d. System(s) Restoration

Electrical power is probably the overall first priority since it supplies fire fighting water (electric driven fire pumps), lighting, basic communication systems, and electronic gear. Even though most power is 440 VAC, three phase, 60 Hz, 400 Hz power must NOT be forgotten. Even if electronics have supply (60 Hz) power, they will not work if they do not have gyro input (a 400 Hz load) or synchro power which is mainly 400 Hz. The best possible pre-damage electrical system line-up must be determined (split plant vs. parallel operation). Combat System support systems (chilled water, dry air, electronic cooling systems, and possibly firemain) must be restored rapidly and in a prioritized order. Controlling stations must know this order and act accordingly. Again, pre-damage system alignment should be determined.

e. Material Stowage

Prior to going into battle, it is advised that a ship performs Strip Ship. This evolution will remove materials unnecessary for combat. The removal of these materials will reduce the amount of secondary fires produced as well as the smoke. Other actions to ensure all stowed material is securely held in place shall also be taken. Special concern should be directed towards removal of hazardous materials (HAZMAT). Paint lockers and other flammable liquid storerooms should be emptied as much as possible. Engineering plant chemicals should be protected as much as possible. Damage control equipment must be distributed throughout the ship to reduce the loses from a single weapon hit. Thoughtful decisions on where this equipment should be placed will reduce the response time of damage control parties. Distributing of personnel should also be considered. Equipment should also be stowed topside to outfit personnel trying to regain access into the ship after being driven out by heat and smoke.

3. Pre-damage Actions

a. Knowledge

The crew's goal is to know as much as possible of your ship and its systems. Another goal should be to teach as many people as possible this knowledge (i.e. Embarked solders/marines). Ensure all hands have basic first aid training, also basic damage control training, more than the bare minimum qualification. Look at "superstructure" personnel as assets for damage control efforts. Vertical fire spread can be stopped by quick and proper action by these personnel.

b. Damage Containment Strategies

A preplan will be established to confine damage to a localized area. With this already thought out, it will be mentally easier to deal with the damage. The staging of DC equipment at strategic locations will allow these strategies to be rapidly put into place. The establishment of pre-damage system alignment will give personnel information needed to base casualty response to restore the systems to battle readiness.

4. General Emergencies

The ship may experience emergencies that are not best handled by the crew going to General Quarters. These situations may be best covered by a general set of guidelines in the form of a General Emergency Bill.

a. General Emergency Bill

The SORM will delineate the information and use of a General Emergency Bill. It is designed for major emergencies and is generic in response. The CHENG is responsible for ensuring the bill is current and ready for execution. The DCA should also ensure that it includes the latest of damage control directives, especially fire party organization and procedures. The bill cover actions taken by the entire crew when it is aboard as well as actions taken by a partial crew while in port. Everyone is required to know their actions during these situations. Also, if the person required to take action is not available or otherwise not able to take action, someone will have to take charge and ensure those actions are carried out. This bill is generic because not all possible situations can be planned out. It is up to the personnel in charge to determine which actions are required and ensure that they are carried out. This bill could also be made to cover casualties not requiring the attention and participation of the entire crew.

5. Mass Conflagration

A mass conflagration is damage of a magnitude that cannot be readily handled by the conventional damage control organization; therefore, all-hands participation is required to save the ship. It is not required to be fire, but also may be flooding, natural disaster, or mass casualties. The general emergency bill should be utilized to combat this casualty. Information to support the actions required to be taken may come from other bills (e.g. Main Space Fire Doctrine, Rescue of Survivors Bill, Civil Disaster Bill, Heavy Weather Bill, Toxic Gas Bill, etc.) All personnel must be trained to react instinctively to combat the possible disastrous effects of a major conflagration scenario. On scene leadership must quickly evaluate the situation, organize available personnel and damage control assets to contain and limit the casualties. The DCA must ensure to include the major conflagration exercise in training drills. This will help prepare a ship's total crew in their efforts to counter a mass conflagration situation. Consult FXP-4 for further information on the Major Conflagration Exercise.

6. Rescue and Assistance

Emergencies may arise on other ships or shore stations which require actions to be taken by personnel from your ship (i.e. the Rescue and Assistance Detail). It is not implied here that the HSAC will be required to supply assistance under all situations. Security of your own ship is paramount. The Rescue and Assistance detail is an organization of qualified personnel to render assistance to persons or activities outside the unit. The Rescue and Assistance Detail may be called away underway or inport. The following will apply to rescue and assistance:

a. Personnel assigned to the R&A detail will be known.
b. Equipment required by the R&A detail will be separate from ship Dc equipment needs:
c. In port, the R&A equipment chest be kept on the pier IAW local SOPA regulations.
d. During an actual casualty, only the needed equipment will be sent. Decision for equipment brought should be made by the Officer in Charge. Communications with the ship shall be maintained at all times.
e. The Rescue and Assistance Detail will be employed for the following situations (not all inclusive):
   - Plane crashes in the vicinity of the unit
   - Distress on another ship or ashore
   - Rescue of a large number of survivors
f. Because it is impossible to plan and drill for every possible R&A scenario, the personnel involved must be able to be flexible enough to respond and take the appropriate actions. Consult FXP-4 drill, Rescue and Assistance, for evaluating the R&A party in handling emergencies away from the ship.

F FIRE BASICS

1. The Fire

Terms associated with fires.

Flash Point: The lowest temperature at which a substance gives off sufficient vapor to form an ignitable mixture, usually not enough to sustain combustion. Storage requirements for flammable liquids aboard ship are based on the flash point.

Fire Point: A temperature slightly above flash point that allows for sustained combustion.

2. Fire Triangle components (SMOLDERING OR SURFACE GLOW)

- fuel
- oxygen
- heat

NOTE: These are the three requirements for a fire to start, removal of any one of these will prevent or extinguish most fires, however when open flame is present a fourth element comes into play.

Fire Tetrahedron components (OPEN FLAME)

- Fuel
- Oxygen
- Heat
- Uninhibited chain reaction of combustion, this accounts for the fire extinguishing properties of PKP and Halon.

Self Sustaining Reaction

- Burning vapor produces heat
- Heat releases and ignites more vapor
- Burning vapor produces more heat
- Heat control is as important as Flame control, particularly if the fire is getting out of hand.

3. Fire Dynamics

Growth Stage: Average space temperature is low and the fire is localized in the vicinity of its origin.

Flashover Stage: Normally occurs when the upper smoke layer temperature reaches approx. 1100 deg F. Characterized by the sudden propagation of flame through the unburnt gases and vapors in the hot upper layer.

Fully Developed Fire Stage: All combustibles in the space have reached their ignition temperature and are burning. Burning rate is limited by the amount of oxygen available. Unburnt fuel in the smoke may burn as it meets fresh air. A fully developed fire will normally be inaccessible by hose teams and require extinguishment by indirect attack. This stage can develop quickly in a main machinery space flammable liquid fire.

Decay Stage: Eventually, the fire consumes all available fuel and/or oxygen at which time combustion slows down and the fire goes out.

a. Types of Fires

•	Class "A" examples:	Paper, Mattresses, Rags, etc.
•	Class "B" examples:	Fuel Oil, Paint, Alcohol, etc.
•	Class "C" examples:	Controllers, Motors, etc.
•	Class "D" examples:	Special hazards, burning metals.

b. Extinguishing Methods

•	Cooling	Remove/Lower heat
•	Smothering	Remove/Displace oxygen
•	Interrupt Combustion	Break up Fire Tetrahedron
•	Starving	Remove fuel

G. DC ORGANIZATION FOR A FIRE

a. Different Types of Fire parties

(1) Repair Party (FIRE PARTY)

- Manned up during G.Q.
- Represents greatest level of readiness
- Rispatched from Locker to the scene of reported fires by RPL

(2) At-Sea (FIRE PARTY)

- Responds immediately to fire alarms when repair parties are not manned.
- Extinguish small fires without disrupting operations.
- Control fires until critical evolutions can be terminated and G.Q. can be set.

(3) In port Emergency Team

- Designed to handle any emergency in port during and after normal working hours.
- Required for each duty section

b. Functions That Make Up the Fire Party:

(1) Repair Party Leader

- normally only assigned during GQ
- responsible for organization and training of the personnel assigned to the DCRS must be PQS qualified

(2) Fire Marshal

- Required in port/at-sea during non-condition 1
- Proceeds directly to the scene of the fire to direct efforts of the RRT
- If fire is beyond "RRT" capabilities, F/M will turn over to On-Scene Leader, and assume other duties as directed. These duties may include:
  - Repair Party leader
  - Supervise communications
  - Post boundary men
  - Direct logistic support
- The F/M must assume a big-picture role and pay particular attention to potential for vertical fire spread.
- Recommend G.Q. if required

(3) On Scene Leader

- In charge at the scene
- Reports to scene of the fire equipped to assume control of the fire party
- Shall wear SCBA
- Directs all firefighting operations
- Establish comms with DCC or RPL with best means available
- designates equipment to be used

(4) Team Leader

- SCBA
- In charge of attack team
- Uses NFTI if required
- Directs firefighting effort
- Reports to the Scene Leader

(5) Nozzleman

- SCBA
- primary firefighter
- reports to / receives orders from Team Leader

- can function as Team Leader if NFTI is not required

(6) "Backup" Nozzleman

- SCBA
- Provides second hose (if required)
- utilized at Team Leader's /Scene Leader's discretion

(7) Hosemen

- SCBA
- tend hoses under direction of nozzle men
- relay orders and information between OSL and Team Leader

(8) Plug men

- one per hose
- should have SCBA available
- charges hoses when directed by OSL
- operates marine strainer
- rig and operate P-100
- rigs jumper hoses as required
- provides C02 / PKP as required
- rig and operate portable inline foam eductor

(9) Investigators

- investigates area to which assigned
- follows principles of investigation
    - rapid, but cautious
    - thorough
    - report findings
    - repeat investigation
- continuously reports to repair party leader/scene leader using best means available
- wears SCBA
- works in pairs
- patrols fire boundaries
- if fire/damage is found one investigator reports, other provides initial action.

(10) Boundarymen

- sets and maintains fire boundaries

- removes/relocates flammables from boundary
- cools bulkhead/overhead/deck as required
- SCBA recommended but not required unless within Smoke Boundary
- may be required to man installed Fire Fighting systems (i.e. AFFF, HALON, MAG SPRINKS)
- minimum of four assigned to fire party. More may be required
- depending on magnitude of fire.
- other resources for boundarymen

(11) Messenger

- relays orders and information
- familiar with standard damage control symbology
- thoroughly familiar with routes and accesses through the ship

(12) Phone Talker

- damage control central and each repair/unit locker
- operate the designated DC comms circuit
- rig emergency phone circuits when required
- use standard damage control symbology

(13) Electrician

- secures electrical power as directed.
- must be knowledgeable of vital circuitry
- overhauls class Charlie fires
- energizes electrical equipment
- assesses electrical damage and performs emergency repairs.

(14) Accessman

- SCBA required
- gains access to the fire affected space when directed by the scene leader.
- must be familiar with all forcible entry equipment
- does not have to be a "dedicated body".

(15) Reflash watch

- SCBA required

- is posted after fire is reported out
- have appropriate extinguishing agent(s)
- be positioned where best able to respond to reflash

(16) Overhaulman

- SCBA required
- work together with reflash watch to thoroughly extinguish fire
- secures potential reignition sources

(17) Smoke Controlman

- secure/manipulate ventilation systems
- install smoke curtains/blankets
- rig and employ desmoking equipment as directed by the scene leader.

(18) Dewaterman

- rig and employ appropriate dewatering equipment or systems
- when directed by the scene leader.

(19) First Aid

- all personnel shall be qualified to perform basic first aid

(20) Rapid Response Team

- proceeds directly to the scene
- no SCBA or protective clothing required
- attempts to extinguish/contain under direction of fire marshall
- (4) personnel to be assigned; may have other functions on fireparty; i.e. boundaryman, electrician
- reports to locker when relieved or carries out duties as directed
- not required for G.Q. repair party organization
- do not normally respond to emergencies in "steaming"
- engineering spaces

APPENDIX X COST AND WEIGHT ESTIMATION

A. WEIGHT ESTIMATION

SWBS	Description	Weight
110	SHELL + SUPPORTS	294.9
120	HULL STRUCTURAL BULKHEADS	390.5
130	HULL DECKS	402.9
140	HULL PLATFORMS	54.0
150	DECK HOUSE STRUCTURE	141.2
160	SPECIAL STRUCTURES	494.3
170	MAST + KINGPOST + SERV PLATFORM	19.9
180	FOUNDATIONS	70.6
190	SPECIAL PURPOSE SYSTEMS	74.8
	Group Total:	1943.2
230	PROPULSION UNITS	49.8
240	TRANSMISSION + PROPULSOR SYSTEMS	9.7
250	SUPPORT SYSTEMS	25.3
260	PROPULSION SUPPORT - FUEL, LUBE, OIL	3.7
290	SPECIAL PURPOSE SYSTEMS	2.7
	Group Total:	91.3
310	ELECTRICAL POWER GENERATION	20.8
320	POWER DISTRIBUTION	68.2
330	LIGHTING SYSTEMS	17.5
340	POWER GENERATION SUPPORT SYSTEMS	8.9
390	SPECIAL PURPOSE SYSTEMS	2.9
	Group Total:	118.3
410	COMMAND + CONTROL SYSTEMS	23.9
420	NAVIGATION SYSTEMS	2.5
430	INTERIOR COMMUNICATIONS	7.3
440	EXTERIOR COMMUNICATIONS	6.0
450	SURF SURV SYSTEMS (RADAR)	10.4
460	UNDERWATER SURV SYS	0.5
470	COUNTERMEASURES	3.3
480	FIRE CONTROL SYSTEMS	1.7
490	SPECIAL PURPOSE SYSTEMS	55.7
	Group Total:	111.3
510	CLIMATE CONTROL	45.8
520	SEA WATER SYSTEMS	27.0
530	FRESH WATER SYSTEMS	7.5
540	FUEL/LUBRICANTS, HANDELING+STORAGE	60.4
550	AIR, GAS + MISC FLUID SYSTEMS	9.3
560	SHIP CNTL SYSTEMS	0.0
570	UNDERWAY REPLENISHMENT SYSTEMS	45.9
580	MECHANICAL HANDELING SYSTEMS	84.1
590	SPECIAL PURPOSE SYSTEMS	21.9
	Group Total:	301.9
610	SHIP FITTINGS	0.4
620	HULL COMPARTMENTATION	24.9
630	PRESERVATIVES+COVERING	46.9
640	LIVING SPACES	20.8
650	SERVICE SPACES	8.3
660	WORKING SPACES	20.8
670	STOWAGE SPACES	35.3
680	SPECIAL PURPOSE SYSTEMS	1.1
	Group Total:	158.6

710	GUNS + AMMUNITION	36.2
720	MISSILES+ROCKETS	47.4
730	SMALL ARMS+PYROTECHNICS	4.3
740	MINES	0.0
750	DEPTH CHARGES	0.0
760	TORPEDOES	0.0
770	AIRCRAFT RELATED WEAPONS	0.8
780	SPECIAL PURPOSE SYSTEMS	7.8
790	SPECIAL PURPOSE SYSTEMS	67.7
	Group Total:	164.2
F10	SHIPS FORCE	17.3637
F20	MISSION RELATED EXPENDABLES	76.6828
F30	STORES	39.2138
F40	LIQUIDS, PETROLEUM BASED	851.5700
F50	LIQUIDS, NON-PETROLEUM BASED	37.8429
	Total Payload w eight:	1271.9133
	Group Total:	1022.7
	Full Load (LT):	3911.4
	Growth Margin:	6.0%
	Full Load Displacement (LT):	4146.1
	Light Ship (LT):	3123.5
	Dead Weight (LT):	
	Payload Fraction (with fuel):	
	Payload Fraction (without fuel):	

B. COST ESTIMATION

TSSE Joint ACCESS Cost Estimate										
		Lightship We	Total Dead Weigh	Total Shipw eight						
Ref Tot.		3127	1027	4154						
							ACCESS	ACCESS	ACCESS	ACCESS
				WT	Wt/Tot		MAT	MATERIAL	Labor	Labor
Description				(LT)		Other	CER	COSTS	CER	Hours
SHELL + SUPPORTS				294.934	0.09432		1181	$348,317	316	93199
HULL STRUCTURAL BULKHEADS				390.476	0.12487		1181	$461,152	316	123390
HULL DECKS				402.938	0.12886		1181	$475,870	316	127328
HULL PLATFORMS/FLATS				54.002	0.01727		1181	$63,776	316	17065
DECK HOUSE STRUCTURE				141.236	0.04517		1028	$145,191	692	97735
SPECIAL STRUCTURES				494.326	0.15808		1632	$806,740	251	124076
MASTS+KINGPOSTS+SERV PLATFORM				19.89766	0.00636		6183	$123,027	164	3263
FOUNDATIONS				70.618	0.02258		1028	$72,595	359	25352
SPECIAL PURPOSE SYSTEMS				74.772	0.02391	5000000	4758	$5,355,765	404	30208
	Structure Sum			1943.2	0.62143			$7,852,434		641617
PROPULSION UNITS				49.848	0.01594		144	$7,178	209	10418
TRANSMISSION+PROPULSIOR SYSTEMS				9.67882	0.00310		63	$610	162	1568
SUPPORT SYSTEMS				25.3394	0.00810		288	$7,298	412	10440
PROPUL SUP SYS -FUEL,LUBE OIL				3.7386	0.00120		36916	$138,014	1412	5279
SPECIAL PURPOSE SYSTEMS				2.65856	0.00085		288	$766	0	0
	Propulsion Sum			91.3	0.02919			$153,865		27705
ELECTRIC POWER GENERATION				20.77	0.00664		650	$13,501	4	83
POWER DIST. SYSTEM				68.16714	0.02180		98329	$6,702,807	1294	88208
LIGHTING SYSTEM				17.52988	0.00561		5450	$95,538	1329	23297
POWER GEN SUPPT. SYSTEM				8.9311	0.00286		14545	$129,903	1882	16808
SPECIAL PURPOSE SYSTEMS				2.94934	0.00094		788	$2,324	471	1389
	Electrical Sum			118.3	0.03785			$6,944,072		129786
COMMAND+CONTROL SYS				23.9463	0.00766		150000	$3,591,945	235	5627
NAVIGATION SYS				2.4924	0.00080		150000	$373,860	235	586
INTERIOR COMMS				7.2695	0.00232		150000	$1,090,425	235	1708
EXTERIOR COMMS				5.98176	0.00191		150000	$897,264	235	1406
SURF SURV SYS (RADAR)				10.385	0.00332		150000	$1,557,750	235	2440
COUNTERMEASURES				0.527558	0.00017		150000	$79,134	235	124
FIRE CONTROL SYS				3.3232	0.00106		150000	$498,480	235	781
SPECIAL PURPOSE SYS				1.74468	0.00056		150000	$261,702	235	410
	Command/Cont Sum			55.7	0.01780			$8,350,560		13083

	CLIMATE CONTROL				45.77708	0.01464		32868	$1,504,601	494	22614
	SEA WATER SYSTEMS				27.001	0.00863		50705	$1,369,086	679	18334
	FRESH WATER SYSTEMS				7.5	0.00240		34033	$255,248	529	3968
	FUELS/LUBRICANTS, HANDLING+STORAGE				60.4407	0.01933		42125	$2,546,064	271	16379
	AIR, GAS+MISC FLUID SYSTEM				9.26342	0.00296		70265	$650,894	647	5993
	SHIP CONTL SYS				0	0.00000		14025	$0	353	0
	UNDERWAY REPLENISHMENT SYSTMES				45.9017	0.01468		8035	$368,820	176	8079
	MECHANICAL HANDLING SYSTEMS				84.07696	0.02689		16853	$1,416,949	259	21776
	SPECIAL PURPOSE SYSTEMS				21.93312	0.00701		1888	$41,410	282	6185
		Auxiliary Sum			301.9	0.09654			$8,153,072		103328
	SHIP FITTINGS				0.4154	0.00013		55033	$22,861	882	366
	HULL COMPARTMENTATION				24.924	0.00797		11160	$278,152	741	18469
	PRESERVATIVES+COVERINGS				46.9402	0.01501		10789	$506,438	494	23188
	LIVING SPACES				20.77	0.00664		29677	$616,391	1235	25651
	SERVICE SPACES				8.308	0.00266		26174	$217,454	135	1122
	WORKING SPACES				20.77	0.00664		27376	$568,600	292	6065
	STOWAGE SPACES				35.309	0.01129		86901	$3,068,387	12	424
	SPECIAL PURPOSE SYSTEMS				1.12158	0.00036		35511	$39,828	694	778
		Hab Sum			158.6	0.05071			$5,318,111		76063
	GUNS + AMMUNITION				36.2	0.01158		100000	$3,620,000	235	8507
	MISSILES+ROCKETS				47.3556	0.01514		100000	$4,735,560	235	11129
	SMALL ARMS+PYROTECHNICS				4.3	0.00138		100000	$430,000	235	1011
	MINES				0	0.00000		100000	$0	235	0
	DEPTH CHARGES				0	0.00000		100000	$0	235	0
	TORPEDOES				0	0.00000		100000	$0	235	0
	AIRCRAFT RELATED WEAPONS				0.78926	0.00025		100000	$78,926	235	185
	SPECIAL PURPOSE SYSTEMS				7.80952	0.00250		100000	$780,952	235	1835
		Armament Sum			67.7	0.02165			$6,025,438		14160
	MATERIAL / LABOR SUMMATIONS				2736.6	0.87517		1991 Material Cost	$42,797,551		1005741
				(3% inflation rate)				Total 2004 Material Cost	$62,849,647		

				(3% inflation rate)				Total 2004 Material Cost	$62,849,647
	SHIPS FORCE				17.36372	0.00555			
	MISSION RELATED EXPENDABLES				76.68284	0.02452			
	STORES				39.21376	0.01254			
	LIQUIDS, PETROLEUM BASED				851.57	0.27233			
	LIQUIDS, NON-PETROLEUM BASED				37.84294	0.01210			
	FUTURE GROWTH MARGIN				249.24	0.07971		**Payload Cost**	
	Total Payload w eight:				1271.91326	0.40675		**$635,957**	
			Check Sums		4008.6	1.0			
	Ship assembly and support labor = .478*Labor				480744.042				
	Integration and Engineering Labor = .186*Labor				187067.7653				
	Program Management Labor = .194*Labor				195113.6907			**(12th ship) Labor cost**	
	Combined Labor Total Hours @ rate			30	1868666			**$56,059,985**	
			Hours					**Labor Cost**	
1	Total 1997 1st Ship Labor		2070544.23			1st Ship		$62,116,327	
2	Total 1997 2nd Ship Labor		1967017.02			2nd Ship		$59,010,511	
3	Total 1997 3rd Ship Labor		1908874			3rd Ship		$57,266,220	
4	Total 1997 4th Ship Labor		1868666.17			4th Ship		$56,059,985	
5	Total 1997 5th Ship Labor		1838062.72			5th Ship		$55,141,882	
6	Total 1997 6th Ship Labor		1813430.3			6th Ship		$54,402,909	
7	Total 1997 7th Ship Labor		1792861.61			7th Ship		$53,785,848	
8	Total 1997 8th Ship Labor		1775232.86			8th Ship		$53,256,986	
9	Total 1997 9th Ship Labor		1759827.15			9th Ship		$52,794,814	
10	Total 1997 10th Ship Labor		1746159.58			10th Ship		$52,384,787	
11	Total 1997 11th Ship Labor		1733887.23			11th Ship		$52,016,617	
12	Total 1997 12th Ship Labor		1722758.79			12th Ship		$51,682,764	
		Joint ACCESS Specialized Equipment used for ship cost estimate							
	osts are reflected back to 1991 at 3% inflation rate to align w ith CER's in given model.								
	Later, total is reflected to 2004 w ith same inflation rate.								
One Time Installs		Costs in 2004		Costs in 1991					
Engines/AWJ21		$120,000,000		$84,165,586					
Electric Plant		$70,000,000		$49,096,592		$230,000,000			
Composite Bow Door Sy		$10,000,000		$7,013,799		$80,000,000			
EW Suite		$10,000,000		$7,013,799					
Multi Function Radar		$25,000,000		$17,534,497					
Other Weps/Sensor Sys		$20,000,000		$14,027,598					
ESSM		$25,000,000		$17,534,497					
Automated DC systs.		$40,000,000		$28,055,195					
	SUMS	$320,000,000		$224,441,562					
							0.26	CS	
							0.03	hull	
							0.53	prop	

	Shipyard Overhead Tabulation					
	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	$65,000,000	
	Navy Program Cost Factor = 1%				$650,000	
	Total Non-recurring Eng. Cost				$65,650,000	
	Learning Curve Exponent			0.95		
Multi-Hull Adj		**unit cost with basic**	**With Multi-Hull**			
.30*Labor		**Shipyard Overhead**	**Labor Overhead**		**1st Ship with Eng Burden**	
$18,634,898		$151,833,658	$170,468,556		$236,118,556	
$17,703,153		$148,060,092	$165,763,245			
$17,179,866		$145,940,778	$163,120,644			
$16,817,996		$144,475,203	$161,293,199			
$16,542,564		$143,359,707	$159,902,272			
$16,320,873		$142,461,855	$158,782,728			
$16,135,754		$141,712,127	$157,847,881			
$15,977,096		$141,069,559	$157,046,655			
$15,838,444		$140,508,020	$156,346,465			
$15,715,436		$140,009,838	$155,725,274			
$15,604,985		$139,562,511	$155,167,496			
$15,504,829		$139,156,879	$154,661,708	**<------Acquisition Cost**		
					Twelveth Ship	
					Estimated System Cost (w/o Manning):	
					Ship	**$154,661,708**
					One Time Installs	$320,000,000
					Payload	$635,957
				Total System Cost		$475,297,664

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