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MONTEREY, CALIFORNIA

TECHNICAL REPORT

“TSUNAMI”:
MARITIME THREAT RESPONSE SHIP

December 2006

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2006	**3. REPORT TYPE AND DATES COVERED** Technical Report

4. TITLE AND SUBTITLE: "Tsunami:" Maritime Threat Response Ship **6. AUTHOR(S) TSSE 2006 MTR Group**	**5. FUNDING NUMBERS**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

14. SUBJECT TERMS SolidWorks, NASTRAN, TSUNAMI, Interceptor, Maritime Force	**15. NUMBER OF PAGES** 425
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

TOTAL SHIP SYSTEM ENGINEEERING

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Currently, no specifically designed system exists that provides a forward deployed option to board and search commercial traffic bound for the United States. With the increase in terrorist activity, the need for the United States to protect herself is evident and even paramount. One area of concern is the commercial traffic coming into various seaports of the United States. The desire to meet the potential adversary at the furthest point of attack and not impede the timeline of commercial traffic was the overarching objective for this project.

This report describes the designed system of systems that meets the preferred requirements of self-protection for the United States by inbound commercial shipping traffic. The intent of not impeding commercial traffic is also met. Through the Total Ship Systems Engineering (TSSE) process, a system that is forward deployed, addresses multiple ports and combines the presence of smaller interceptors on board a mothership was designed. This report presents the overall architecture of the above system while it concentrates in more detail on the conceptual design aspects of the mothership. The report is produced in order to satisfy the capstone project requirements of the TSSE program at the Naval Postgraduate School.

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I. INTRODUCTION

Currently, no specifically designed system exists that provides a forward deployed option to board and search commercial traffic bound for the United States. With the increase in terrorist activity, the need for the United States to protect herself is evident and even paramount. One area of address is the commercial traffic coming into various seaports of the United States. The desire to meet the enemy at the furthest point of attack and not impede the timeline of commercial traffic was the goal for this project. The resolution to this problem had to be potential accessible with in the next five years.

This report describes the designed system that meets the preferred requirements of self-protection for the United States by inbound commercial shipping traffic. The intent of not impeding commercial traffic is also met. Through the TSSE process a system, forward deployed, multiple ports and smaller interceptors on board a mothership was constructed. The project focuses on one city, San Francisco, but was designed for use via any city on either coast.

II. REQUIREMENTS

A. MISSION NEEDS STATEMENT

The mission statement was derived from Sea9's requirements, "Develop a conceptual, near-term, joint and inter-agency system of systems (SoS) in the 5-year timeframe to respond to terrorist threats to the United States that emanate from the Maritime Domain by (1) generating SoS architecture alternatives using existing systems, programs of record, and commercial off the shelf (COTS) technologies and developing concepts of operations and (2) recommending a cost-effective SoS that must minimize impact on commerce. The SoS would be deployed in three missions: prevention of a nuclear WMD attack, prevention or defeat of an attack using a merchant ship (SAW), and defeat of a suicide small boat attack (SBA) on a high value target (such as an oil tanker or passenger ferry).

B. OPERATIONAL REQUIREMENTS

Armed with the SEA-9 Mission Needs Statement (MNS) and assumptions listed in the previous section, the TSSE Team needed to develop potential Concept of Operations (CONOPS) before proceeding with system identification. Although the MNS stated what the system was required to do, there was no supporting documentation as to how it could be accomplished. In fact, no known CONOPS existed to address this specific need. To develop such a CONOPS, the team reviewed existing procedures in Maritime Interdiction Operations in the Arabian Gulf as well as Counter Drug Operations in the Gulf of Mexico and then expanded these concepts to the immense Pacific Ocean Theater.

Initial investigation focused on where the VOI's may originate. Because of the many potential stops a ship may make prior to exiting the South China Sea (Figure 1), it was determined that intercepts should not occur prior to VOI's entering the Philippine Sea. Considering that the entire voyage could range up to 9,000 nautical miles, there would also be ample time to conduct the intercept without having to navigate through constrained areas. Assuming that the orders to execute would be one day time late in addition to one extra day of preparation, there was little chance that an intercept in this area could be accomplished in the minimum time. Thus, the CONOPS was limited to open ocean intercepts. An advantage to moving the starting point into the open ocean was that the CONOPS would now become applicable to any port of departure, not just Singapore and Hong Kong. An open-ocean CONOPS would also allow an even greater spread of departure times.

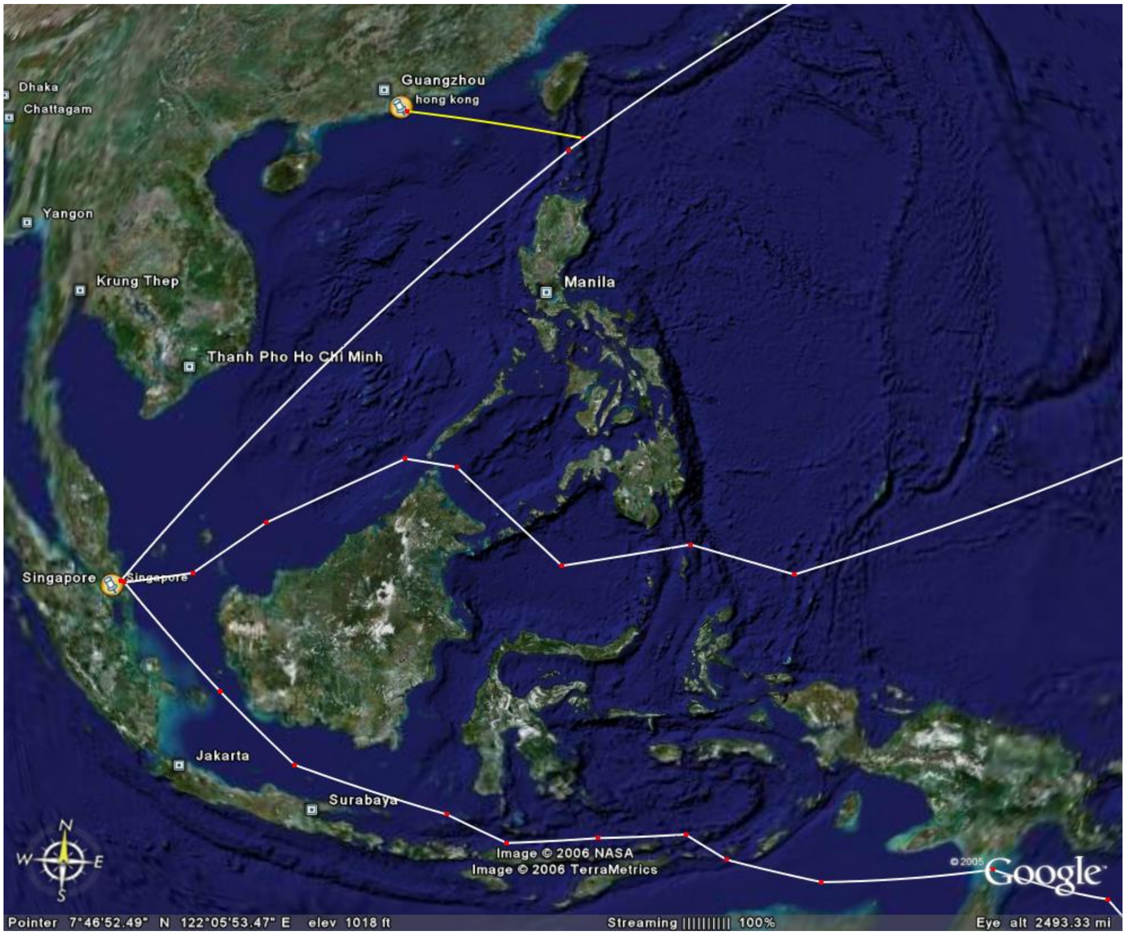


Figure 1. Southwest Asian Routes

With the ocean area constrained in the west, the TSSE Team looked at constraining the area in the eastern Pacific. Since the system needed to be robust enough to avoid any delay to commerce, a natural limit to where an intercept could begin developed. Considering a maximum search time of seven days and a speed of advance of 20 knots, a VOI must be intercepted prior to closing within 3,600 nm of San Francisco.

An intercept occurring inside this line may not be completed prior to arrival and would thus delay commerce (Figure 2).

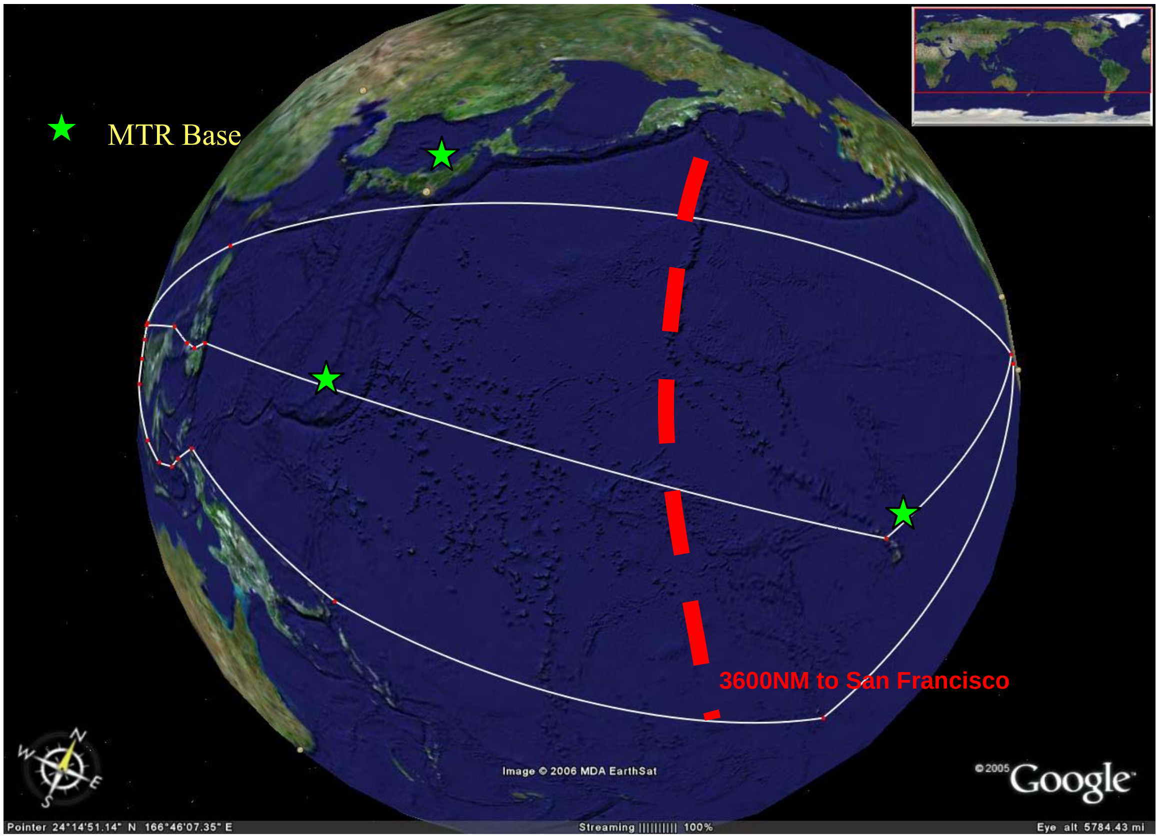


Figure 2. Great Circle Routes and Eastern Constraint

This intercept line not only further constrained the intercept area, but also made the CONOPS applicable to any Western US seaport. Figure 2 also depicts three potential MTR bases in Hawaii, Japan, and Guam. The key aspect of this forward deployment would be to get *in front* of the lead VOI as soon as possible to avoid any tail chases. The normal use of the northern route means that the majority of the systems should be based in Japan with Hawaii acting as a back-catch for any VOI's traveling along the rarely used central and southern routes.

The overall operations area thus defined, the TTSE Team recognized that this area was still too large to develop a specific CONOPS. As a result, a smaller traveling frame of reference linked to the VOI's was developed (Figure 3).

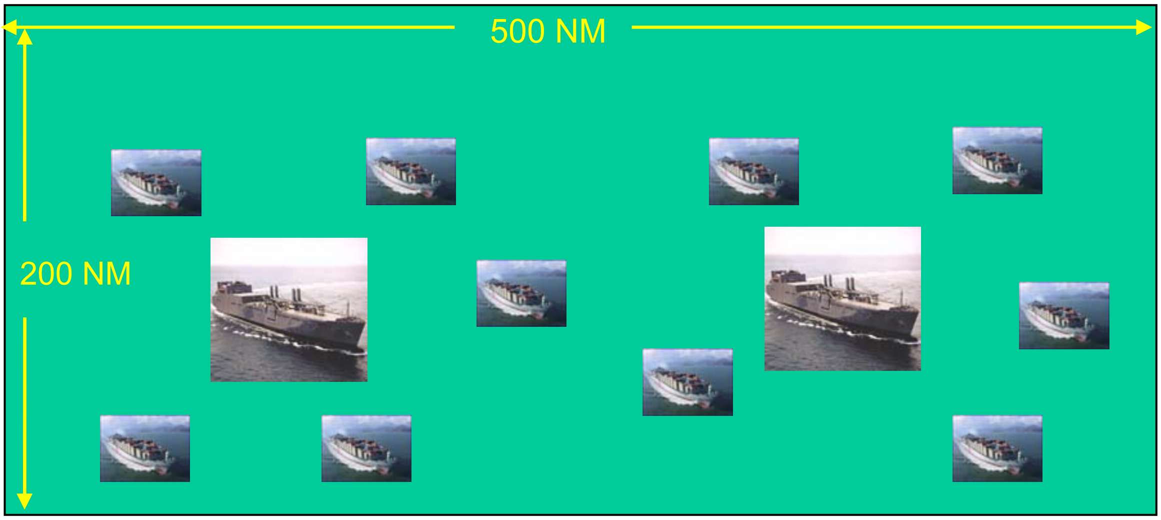


Figure 3. Traveling Operational Area

Considering the nominal 20 knot speed of advance, it could be expected that 10 VOI's would have a separation of approximately 500 nautical miles along the great circle route. Variation between ports of departure, navigational choices, enroute stops and other potential differences between VOI routes could result in widening this box around the great circle route up to 200 nautical miles. Thus, a box traveling at 20 knots was constructed for each major port of departure for a total of two boxes for 20 ships. Based on the experience from current Maritime Interdiction Operations, the assignment of two systems per box was made with the understanding that this setup would vary depending on the system selection. Consideration was made to keep the operational areas as general as possible to ensure that all potential systems could be equally considered.

III. CONCEPT DESIGN

A. HULL

1. Introduction

The Tsunami Hull is a combination of the Trimaran high speed type hull and the Small Water plane Area Twin Hull (SWATH) design. In order to create an open docking area with a fixed arch covering the aft section of the ship, the SWATH stern is employed. This enclosed area makes up the entire interceptor loading and unloading area of the ship. By combining the two different and very unique hull forms, the TSSE mothership concept can load and unload a 95 ton interceptor vessel into a mission bay safely and expeditiously using a robust fixed hoist mechanism without the use of other complicated, labor-intensive, and expensive systems. A full discussion of all parts of this section is provided in Appendix B.

2. Geometry

General Characteristics and Full Load Hydrostatics for Ship Overall

Characteristic	
Class	Trimaran-Swath Hybrid
Stern Type	Small Waterplane Twin Hull
No. Screws	2
SVC SPD, kts	32
LBP, ft	800
LOA, ft	812.1
LWL, ft	812.1
B, ft	132.0
BWL, ft	116.6

Freeboard,ft	46.0
T_m,ft	34.0
Volume, ft^3	720455.4
Δ_{FL},Lton	20598.9
Trim, ft	0
C_{WP}	0.43
C_M	0.37
C_P	0.73
C_B	0.27
LCB/LWL	0.62
LCB, ft	417.4
LCG, ft	417.4
LCF, ft	373.9
LCF/LWL	0.56
MT1, lton/in	2455.9
TPI, lton	80.7
KG, ft	30.6
KB, ft	20.1
KM, ft	49.8
GM_T, ft	19.17
GM_L, ft	962.0
BM_T, ft	29.7

BM_L, ft	972.5
Area WP, ft^2	33859.6

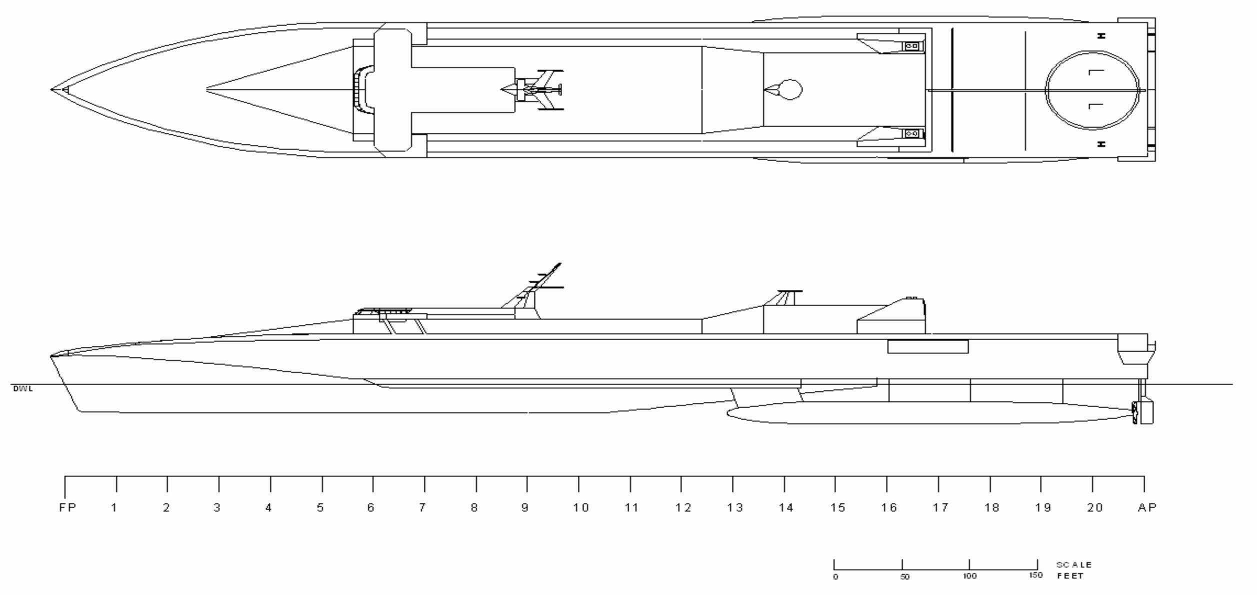


Figure 4. Plan View and Profile Vie

3. Stability

The stability of the Tsunami ship is a key factor in the mission success. To provide an adequate amount of stability to the interceptors during loading and unloading operations, the ship was design with a target Metacentric height 1.5 times greater than the typical Naval Auxiliary vessel. Data showed a typical AO or T-AO with a Metacentric height of 12 feet. The Tsunami side hulls and outriggers are positioned to provide a 19.17 feet Metacentric height at its design waterline.

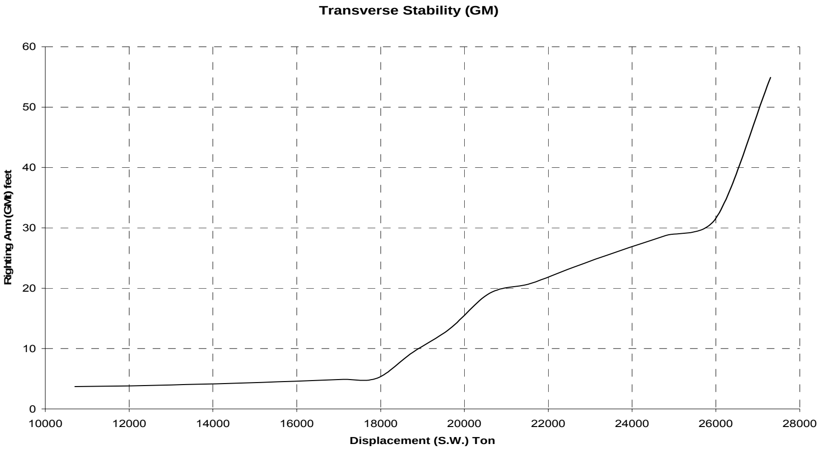


Figure 5. Transverse Stability (GM_T) in Fully Loaded Condition

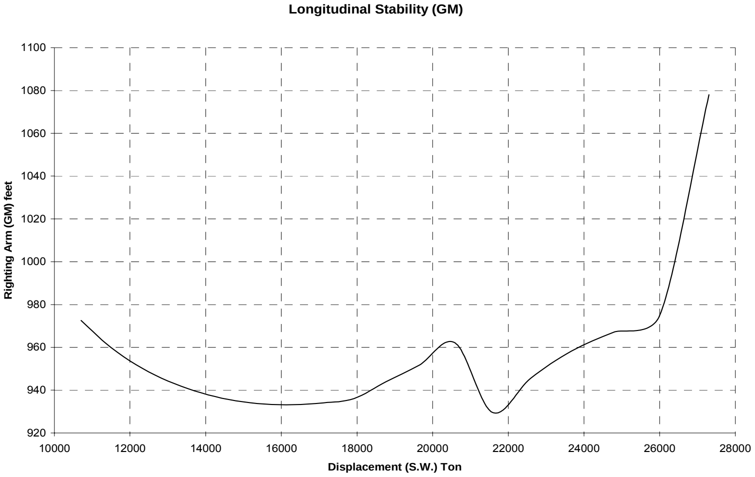


Figure 6. Longitudinal Stability (GM_L) in Fully Loaded Condition

4. Resistance

The unique design of the Tsunami required a systematic way of analyzing the resistance. The overall ship calculation was broken up into separate center hull and side hull calculations. The center hull analysis of the Tsunami ship used the standard mono hull based design analysis and calculated for viscous as well as wave resistance. Center hull offsets were input into the AUTOSHIP computer system interface; there values for resistance and horsepower were generated using the Holtrop method. Viscous resistance for the side hulls was calculated using a less sophisticated MATLAB program.

The overall resistance of the ship at a 20 knot design cruise speed is 183,630.12 lbf, which equates to approximately 14,893.8 EHP. A comparison of the SHP vs. Froude Number trends of other naval combatants and auxiliary vessel show the Tsunami resides in the fast aircraft carrier heavy cruiser realm.

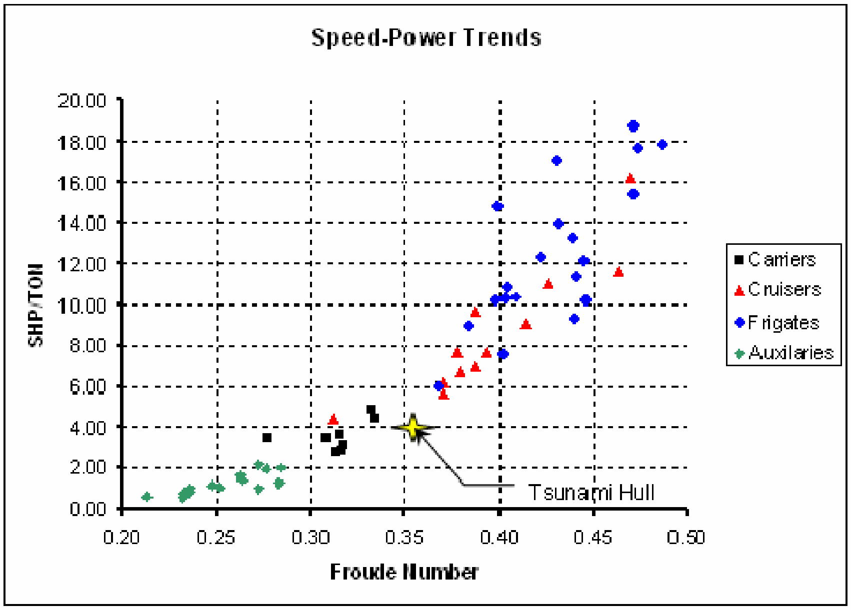


Figure 7. Comparison of Speed and Power Trends for Various Ship Class

5. Seakeeping

The sea keeping analysis of the Tsunami shows the ability of the ship to continue its mission in 12 feet seas. Analysis shows design selection for mission bay door height, slamming, pitch, and roll during interceptor hoisting operations at various sea states. The final analysis results show an overall operational envelope in sea state 5 and an operational index of over 70 percent.

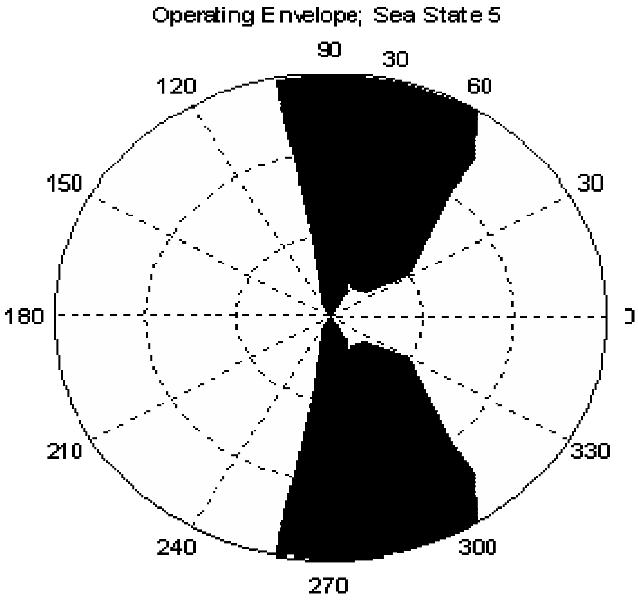


Figure 8. Operational Envelope in Sea State 5.

The limiting factors that affect the operational index were typically limitations in the roll of the ship. In conditions where the interceptor must be hoisted in sea state 5, and waves are hitting the ship on the beam, the ship's captain must consider changing course to a new heading in order to reduce roll of the ship. The mission bay door is set at 10 feet, which is the optimal height considering all sea states. Results showed there is not necessarily a need for stability control surfaces in sea state 5 nor does the slamming of the ship require a higher arching of the outriggers.

6. Wave Motion Analysis

It was necessary for the design of the center hull to minimize wake waves at 20 knots. In order to mitigate wake wave height and position the maximum wave height approximately 120 feet astern of the ship, a long sloping flat hull aft of the center hull midships was designed. Using SWAN2 wave motion analysis, the maximum wave height of the wake of the center hull is approximately 147 feet astern of the center hull transom. The maximum wake height at 20 knots is only 3.5 feet, compared to a Series 60 hull value of 4.5 feet. This shows that the design of the ship was effective at creating a lee suitable for conducting interceptor launch and recovery operations at 20 knots.

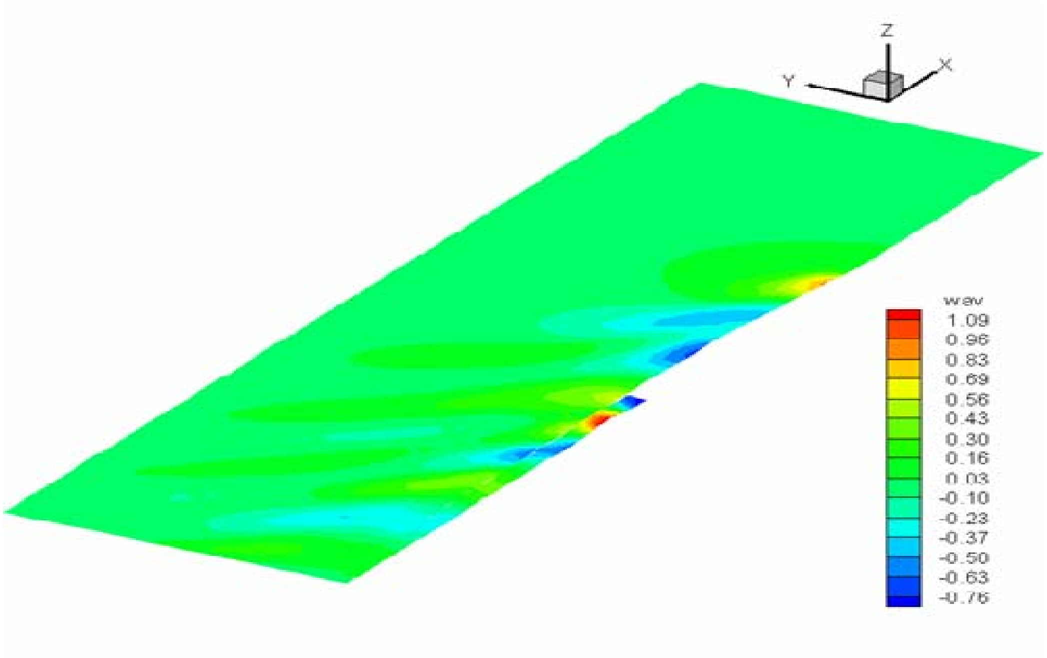


Figure 9. Wave Motion Analysis at 20knots.

B. PROPULSION

1. Propulsion Type

The main propulsion type selected for TSUNAMI is electric drive. The normal advantages associated with electric drive, such as matching power required to power generated and flexible arrangements, are accentuated by the unique requirements of the hull form. The power required to achieve TSUNAMI's objective maximum speed of 30 knots placed the ship within the realm of diesels and gas turbines, however, neither of these prime movers are easily adapted to direct drive propulsion with the screws isolated as they are in TSUNAMI's side-hulls.

2. Prime Movers

TSUNAMI requires 68.7 megawatts (MW) of power to achieve 30 knots and 17.4 MW for 20 knots. We expect to require an ordered speed of 24 knots utilizing 31.1 MW in sea state five to maintain a 20 knot speed of advance. Two Rolls Royce MT30 marine gas turbines were selected to meet this need as they provide 36 MW each allowing maximum speeds of 25.1 and 30.2 knots with one and both engines engaged respectively. MT30 marine gas turbines also have excellent weight to power ratios (172.2 kg/MW versus 173.4 and 191.1 kg/MW for the LM2500+ and LM6000 respectively) and better fuel consumption rates over its entire power band than the LM series. Gas turbines were selected over similarly powered diesel engines due to the engine rooms being located so high above the waterline that the greater weight of the diesel engines would have been detrimental to ship stability.

3. Auxiliary Power

Diesel engines were selected over gas turbines for the auxiliary power role because their much lower fuel consumption rates allowed for better low speed loitering endurance. Also, the placement of the auxiliary engineering spaces below the forward end of the mission bay allowed the weight of the diesels to improve ship stability, and would have made routing the uptakes of gas turbines prohibitively complex. Two Rolls Royce Bergen model B32:40L8A diesels providing 3.84 MW of power each were selected.

4. Propeller Selection

The Propeller Optimization Program version 1.5 created by the University of Michigan was utilized to aid in the design of propellers for TSUNAMI. Wageningen B-Screw series propellers of four, five and six blades were optimized for a speed of 20 knots in sea state five (24 knots ordered) and compared. Fixed pitch propellers were used instead of controllable pitch due to the two percent efficiency loss associated with controllable pitch and the ability of the electric drive motors ability to quickly reverse rotational direction. The chosen propeller was a five bladed screw 6.09 meters in diameter with a 6.5 meter pitch and an operating speed of 108 revolutions per minute at 24 knots ordered speed.

5. Power vs. Speed

The following graph shows the prime movers required to be engaged at varying speeds. The data includes expected losses and efficiencies in calm seas. The maximum calm water speed of TSUNAMI with all engines engaged is expected to be 30.75 knots.

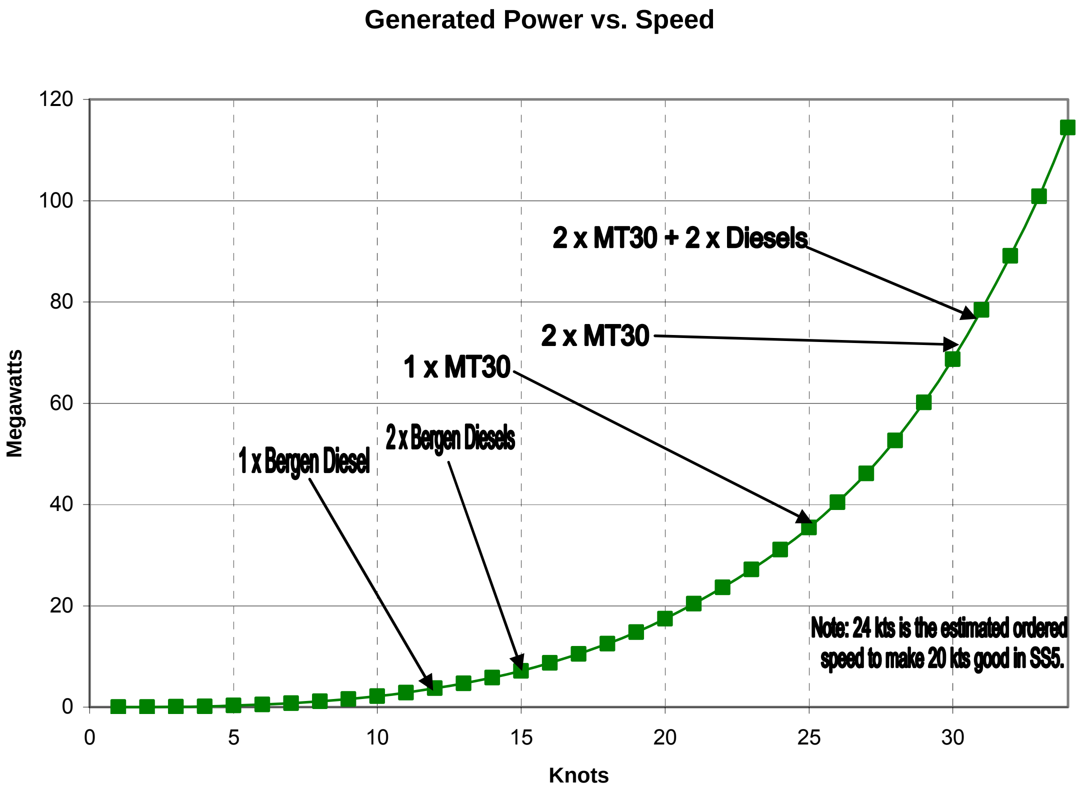


Figure 10. Generated Power vs Speed

6. Maneuvering Thruster

Given the large sail area of TSUNAMI, a bow thruster was added to enhance the low speed maneuverability performance of the ship. Additionally, our concept of operations includes being able to get underway on very short notice so we did not want to be dependant upon tugboat availability. The Wärtsilä LIPS model 250 thruster rated at 2 MW was selected as it provides 360° vectoring and is retractable to minimize drag at high speeds. This can also serve as an emergency propulsion unit capable of driving the ship at 9 knots.

C. ELECTRICAL

1. Integrated Power System

In keeping with the Navy's goal of building all electric ships, we have chosen the Integrated Power System (IPS) to be the power system for the MTR mother ship. There are many advantages to the IPS. Chief among these advantages is efficiency. All of the electrical generators for the IPS feed one distribution system. In addition, all of the prime movers onboard the ship (i.e. gas turbines and diesel generators) are coupled to these electrical generators. Therefore, the energy produced by the ship can be distributed and scaled. Any prime mover can produce electrical power for use by any of the ship's loads, to include the ship's largest load- propulsion. Additionally, only the amount of power needed for current operations is produced. By adjusting how many prime movers are running at any one time, you can make sure that they are running close to their maximum capacity, where they are the most efficient.

2. Electrical Generators

For the main power generation for our electrical distribution system, we chose American Super Conductor 40 MW High Temperature Superconductor (HTS) Generator. The primary reasons for choosing this generator is the high energy producing capacity and high energy density of the generator. Conventional generators were not a viable option due to their relatively low capacity. It would be prohibitive to use conventional generation due to the multiple generators that would be required to produce the equivalent of one HTS generator. Additionally, we decided to use HTS motors for propulsion. Thus, it makes sense to match the generating technology. This will ultimately lead to reduced manning and more uniform maintenance.

In order to supplement the large generators, we selected smaller diesel-powered generators. The diesel generators serve two purposes. The main purpose is to provide a source of power during low electrical load operations, where the larger HTS prime movers would be inefficient. Additionally, the diesel generators will provide emergency power in the event of a loss of one or both of the HTS Generators.

The prime mover chosen for the HTS 40 MW Superconducting generator is the Rolls Royce MT-30. This decision was primarily based upon the recommendation from American Superconductor representatives who happen to be using this turbine for current testing of the 40 MW HTS generator.

3. Electrical Motors

After a thorough review of existing technology and promising, relatively-mature new technology, we decided to use the American Superconductor HTS AC Synchronous Motors for propulsion. Two of these 36.5 MW motors will provide the necessary shaft horsepower (SHP) to support the MTR mission. The benefits of the HTS AC motor are many. These motors will have one-third the weight, one-half the size, higher fuel-efficiency and lower maintenance than a conventional copper-based motor. The added requirement of cryogenics to keep the motor cool is negligible. These motors are actively being pursued by ONR and have achieved several of the key production and testing milestones. The expected delivery date of an operational HTS AC motor to the Navy meets our timeline.

4. Electrical Distribution

The electrical distribution system chosen for the MTR mothership is the AC Zonal distribution system. The major advantages of the AC zonal distribution system are increased reliability and cost savings. A diagram of our electrical distribution system is shown in electrical appendix (D).

Since the power is distributed along redundant busses running down the port and starboard sides of the ship, a loss of either bus will not result in a complete loss of power to vital equipment. The loads in each zone can draw power from either side for redundancy. Since the Zumwalt-class (DDG1000) is currently scheduled to use the AC zonal distribution system, we were able to use their estimated data as a baseline to estimate weight and cost data for our ship.

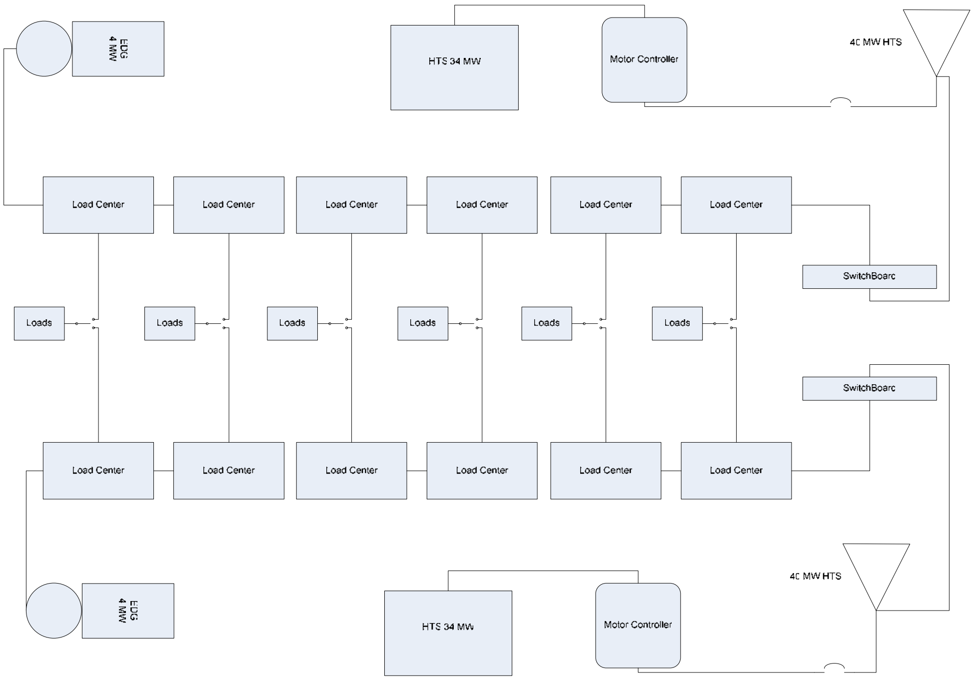


Figure 11. Overview of the ship's AC Zonal distribution system.

5. Conclusion

As shown from the discussion above, our goal was to use advanced technology in the electrical system of the MTR mothership. However, due to the relatively short time horizon provided, we needed to make sure we weren't betting on technologies which have yet to be developed. The DDG1000 program also provides a good benchmark on what technologies the Navy has already deemed to be ready for production. By combining DDG1000 design decisions along with some new, but relatively mature new technologies, we get the best mix of advanced technology with minimal risk.

D. COMBAT SYSTEMS

1. Overview

The design and selection for the MARITIME THREAT RESPONSE ship combat suite was based off the SAN ANTONIO class amphibious warship. The primary mission for this ship is to traverse the ocean on a great circle keeping station amongst merchant shipping. The following are the assumptions required to justify the LPD-17 combat suite.

2. Threats

With a ship of this size and the capacity to carry smaller ships it must be noted that the shear presence of the ship can be overwhelming to any adversary of the United States. The following is a list of threats that this ship is capable of handling:

a. Asymmetric Attack

The brute size of this ship inherently makes it vulnerable to asymmetric attack while in port or in a state of restricted maneuvering. Although the best approach to counter act this type of warfare is strong intelligence of the operating area, the MTR is outfitted with a series of dual .50 cal mounts on both the port and starboard sides of the ship. Furthermore, if the situation warrants an interceptor, RHIB, and air assets can be utilized for safe passage through restricted waters.

b. Merchant Vessel Attack

The purpose of this ship class is to pursue terrorists using merchant vessels are there method of movement. The MTR ship is not expected to be within close quarters to any merchant vessel, however, if the renegade vessels have a STYX weapon system the MTR does have a CIWS mounted system along with NULCA and SRBOC countermeasures.

3. Weapon Systems and Countermeasures

The following weapon systems are used onboard the MTR ship:

- Six dual .50 cal gun mounts providing 360 degree coverage from smaller air and sea threats.
- Two CIWS mounts to provide air defense in conjunction with RAM.
- Two RAM launchers
- SLQ-32 to add electronic warfare capabilities for surveillance and to queue for self defense.
- SRBOC and Nulka for air defense.
- Two MH-60 helicopters, not only to assist in completion of the primary mission, but as offensive weapon systems to provide increased project from the mothership. Weapons onboard include:
- M-60 machine guns
- Hellfire missiles

4. Communications and Data Links

The following is a list of communications equipment expected for the MTR ship. Since interceptors will likely be operating over the horizon satellite communications with HF back-up are emphasized.

- WSC-3
- AS-3226
- WSC-6 – high speed data transmission
- HF whip
- Bridge to Bridge
- LINK 16
- LINK 11
- Hawklink

5. Radars and Tactical Electronics

The following is a list of radars to be used on the MTR ship

- Furuno navigational radars
- SPS-48 3D air search radar
- TACAN

E. ARRANGEMENTS

The MTR ship has nine decks. The Main Deck, following convention, is the lower-most continuous deck of the ship which is exposed to the weather. This deck is 36 feet above the design waterline (DWL). There is one deck above the Main Deck, with the other seven below. The Outer hulls have two decks each, while the center hull has eight. The First and Second Decks are not continuous, as the Mission Bay cuts through three decks of the ship. The Third Deck stretches the entire length of the ship, but the center hull stops at frame 600, so the after portions of this deck are mounted above the outer hulls and do not cover the entire beam. The Fourth Deck is located two feet below the DWL, while the Fifth and Sixth Decks are fully submerged. The Seventh Deck is below the baseline of the center hull, and is the only deck aside from the two within the superstructure that is not 12 feet tall. These three (Main, 01, and Seventh) are all 10 feet.

A useful way to describe the arrangement scheme is to break down each deck in sequence. The 01-Level sits atop the Main Deck at a height of 46 feet and is broken into a forward and aft section. The forward section contains the ship control spaces (bridge and combat information center, as well as the commanding officer's cabin), while the after section houses only aviation staterooms and the helicopter control room. The bridge space spans the entire beam of the superstructure, with protruding bridge wings to facilitate maneuvering along a pier or in tight quarters. A person standing on the bridge has a phenomenal view forward and to the sides, and can see the Flight Deck from the bridge wings. The CIWS and other combat systems gear are all located as far out of view as possible for safety of navigation.

The Main Deck superstructure runs from frame 100 aft to frame 614, sloping downward at the forward end to accommodate the view from the pilothouse. Within the superstructure are the two helicopter hangars, aviation equipment storerooms, aviation weapons magazine, the Central Control Station (CCS), a crew training and fitness room, the Officer's Mess, and a series of staterooms and other living quarters. Outside, the Main Deck hosts the Flight Deck, which is an impressive 185 feet long by 110 feet wide. The Flight Deck size makes the ship extremely capable for a variety of aviation missions and airframes, though the hangars are specifically designed to fit SH-60 and MV-22 airframes. Two external passageways connect the Flight Deck to the Forecastle, passing the gas turbine intake/exhaust plenums and the ladder wells to the Main Spaces one deck below. After passing beneath the bridge wing, the top of the superstructure slopes downward from the 01-Level to the Main Deck, eventually reaching the deck level near where the forward CIWS mount rests slightly offset from the starboard bow. This leaves a wide-open expanse of deck space for line handling, underway replenishment, and anchoring evolutions. The Forecastle slopes downward from the superstructure as well, so that the forward end of the Main Deck actually rests on top of the First Deck.

The forward portions of the First, Second, and Third Decks contain mostly living spaces, giving individual crewmembers about 80 square feet of living space apiece. This is a lot of comfort room for the individual sailor, and could easily accommodate a surge crew size for other missions well in excess of the 335-man crew envisioned for the ship.

The after portions of the First, Second, and Third Decks are reserved for main spaces. The ship's gas turbine engines and generators are mounted to the Engine Room Middle Levels (Second Deck), while the static frequency converters for the electric drives and distribution systems are on the Second and Third Decks astern of the gas turbines. The Lower Levels of the Engine Rooms are reserved for fuel and lube oil processing. At the stern on the Third Deck are the Steering Gear rooms.

The Fourth Deck is the damage control deck for the center hull. Containing the two auxiliary diesel generators just forward and below the Mission Bay, the space also contains the top level of the auxiliary propulsion unit (APU), which is mounted near the bow and takes up space in three decks of the ship. This deck contains berthing forward, engineering and Mission Bay support spaces amidships, and a variety of damage control equipment, as well as the majority of the fuel oil transfer system. Aft, the only spaces conforming to the Fourth Deck are ladder wells port and starboard leading to the side hulls.

Decks Five and Six of the center hull are reserved mostly for fuel, water, and ballast tanks. The APU also passes through these decks forward, and there are some auxiliary engineering spaces here as well. Deck Five aft consists only of ladder wells in the struts. Deck Six aft contains fuel tanks at the forward end of the side hulls, but begins the port and starboard Main Propulsion spaces starting at the center strut. The Main Propulsion spaces span both decks of the outer hulls from the center strut aft to the screws. The spaces each contain high-temperature superconducting (HTS) motors, a short shaft, and cryogenics, cabling, and support equipment for main propulsion.

The Mission Bay, taking up the majority of Decks One, Two and Three, spans the beam of the ship (120 feet) and is 390 feet long. This vast expanse of space is designed to store up to six 120-foot-long Interceptor vessels (three on each side), with a center lane for transiting the vessels within the Mission Bay. This space is kept as open as possible in the design to maximize the flexibility of the ship's unique hull form. Assuming an even distribution of weight, the Mission Bay could be re-configured to accommodate more than 600 tons of additional equipment or cargo, giving the MTR ship a robust multi-mission capability.

F. INTERCEPTOR

The Wallypower 118 was first considered as a possible interceptor in the very first analysis of alternatives when the initial mothership/interceptor combinations were being considered. At that point, it was originally paired with the modified containership. As the team worked towards a design concept, the 118 became a proxy representing the "high speed displacement" class. It filled this role capably as the team's research was unable to find a more suitable example. Once the high speed displacement type of interceptor was chosen for the final design concept, the team decided to upgrade the 118 from proxy to full fledged selection due to the time constraints preventing designing a more optimal high speed displacement interceptor and because the 118 was relatively close to optimal already.

The high speed displacement hull was chosen because of its endurance, ability to sprint, berthing capacity and relatively small overall size. The 118's attributes are shown below.

Length	118 ft
Beam	26 ft 3 in
Draft	4 ft 1 in
Displacement (Diesel Configuration)	75 tons
Sprint Speed (Diesel Configuration)	45 kts, Sea State V
Berthing (modified)	27
Cruise (20kts) Endurance (Diesel Config.)	3900 nm
Propulsion (Diesel Configuration)	2 3,650-hp MTU 16V 4000s w/KaMeWa waterjets

Figure 12. Wallypower Attributes

APPENDIX A (CONCEPT DESIGN)

TABLE OF CONTENTS

I. INTRODUCTION

The 2006 Total Ships Systems Engineering (TSSE) Team operated as part of an integrated project with the Systems Engineering Analysis (SEA) Cohort Number 9 (SEA-9). Initial overall tasking was generated by faculty members of the Meyers Institute of Systems Engineering at the Naval Postgraduate School in Monterey, CA and concerned maritime threat response (MTR) in the 5-year timeframe. As part of the initial problem statement, SEA-9 was tasked to define and select a cost-effective System-of-Systems (SoS) architecture and a Concept of Operations (CONOPS) that would enable timely and effective responses to national security threats emanating from the maritime domain. At a minimum, a weapon of mass destruction (WMD) device smuggled onboard the vessel and then that vessel employed as a weapon itself would be considered. Intelligence regarding a threat to the United States would be assumed available for use by the System of Systems. The SoS would consist of systems currently in service, in development, or could be developed within the next five years. The TSSE Team would be tasked to perform an investigation of concepts of ship employment while conducting maritime threat response (MTR) and to use its newly-acquired knowledge to design either a single ship or a family of ships that could be incorporated into SEA-9's overall SoS architecture.

A. MARITIME THREAT RESPONSE OVERVIEW

Once the initial problem statement was defined, SEA-9 began a comprehensive research effort involving conversations and meetings with the stakeholders and subject-matter experts in order to shape and refine the problem and focus team efforts. Appropriate design reference missions that the System of Systems (SoS) must accomplish were defined. Understanding the scope of the problem with the limited time available for the project, it was decided to focus on a set of *representative* missions instead of attempting to find a solution for all possible threat scenarios. Although interests among the stakeholders were varied, there were some commonalities which allowed SEA-9 to analyze the most likely representative scenarios. These items are detailed in the following paragraphs.

1. Threat Ship Armed with Explosives

The greatest concern among the stakeholders remained the weapon of mass destruction (WMD) scenario. The potential widespread damage that could be inflicted from a nuclear device smuggled within a domestic port onboard a cargo ship carrying thousands of containers leaves no wonder as to why this was of principle concern for analysis. Furthermore, some stakeholders had addressed the concern of a WMD device being smuggled into the country via one of the thousands of smaller, ocean-going pleasure craft that enter domestic ports every day. Although this specific type of attack had been noted as a possibility, it was decided that this type of threat presented more of an issue in traffic awareness and the ability of obtaining the necessary intelligence to counter the threat instead of attempting to neutralize it once actionable intelligence was obtained. A cargo ship with the ability to carry thousands of containers at one time presented the greater challenge, resulting in SEA-9's decision to focus on that particular scenario for solution.

2. Threat Ship Utilized as Weapon

Another principle concern among stakeholders was that of utilizing a ship as a weapon (SAW). Several stakeholders expressed concern over the "trial run" hijacking of a merchant ship off of Sumatra in March 2003. In that particular case, pirates or hijackers took control of the ship, practiced driving it around for a period of time, then abandoned the ship without seizing any cargo. The parallels between this incident and the student pilots involved in the 9/11 attacks are obvious and a cause for concern. The SAW scenario would most likely be played out in one of two primary methods. In the first case, the ship would maintain course and speed until the last possible moment to carry out its attack. In the second case, the ship could be hijacked at sea, where subsequently the hijackers would alter the ship's course and speed to pursue a different destination for attack (Rogue Ship). Determining that the first case was more difficult to detect and counter, SEA-9 decided that the first scenario would be analyzed for solution.

3. Small Boat Attack

The last major concern for stakeholders was that of a small boat attack (SBA). Due to the amount of small boat traffic in and around domestic major ports intermixed with large commercial traffic, SEA-9 decided that this would also be a threat scenario to plan for as well.

B. PROBLEM STATEMENT

Stakeholder interviews and feedback resulted in a more specified problem statement that included the three most likely attack scenarios:

> Develop a conceptual, near-term, joint and inter-agency system of systems (SoS) in the 5-year timeframe to respond to terrorist threats to the United States that emanate from the Maritime Domain by (1) generating SoS architecture alternatives using existing systems, programs of record, and commercial off the shelf (COTS) technologies and developing concepts of operations and (2) recommending a cost-effective SoS that must minimize impact on commerce. The SoS would be deployed in three missions: prevention of a nuclear WMD attack, prevention or defeat of an attack using a merchant ship (SAW), and defeat of a suicide small boat attack (SBA) on a high value target (such as an oil tanker or passenger ferry).[2]

SEA-9's investigation of legacy systems and existing programs of record were utilized as means of determining the future capabilities of United States forces. Based on their analysis, SEA-9 generated a set of top-level requirements which would become the basis for the 2006 TSSE design project. SEA-9 requirements documents are included in their entirety as Appendix I.

C. TSSE TASKING

Although SEA-9 would focus its efforts on the 3 major scenarios (WMD, SAW, SBA), the 2006 TSSE Team would be tasked to design a ship based on the WMD and SAW scenarios only. Via the top-level requirements promulgated by SEA-9, the TSSE Team would investigate several architectures for appropriate response to an MTR scenario. Eventually, the TSSE would design a ship (or system of ships) which would possess the ability to deploy on short notice (within 24 hours) once intelligence was received that a vessel was inbound to the United States which fit an MTR threat profile. Once deployed, this system would intercept up to 20 inbound vessels of interest (VOI), where each vessel would be boarded and inspected prior to arrival at a point no closer than 100 nautical miles from the United States coastline. A representative scenario for analysis would include the recent departure of 20 vessels within a 24-hour period from two ports, Hong Kong and Singapore, and inbound to San Francisco via one of the three major shipping lanes from the Far East.

San Francisco was chosen due to numerous features that make it an attractive target for attack. The city has a population of 3.2 million people with an average of 11 million tourists and visitors each year. It is the fourth-largest port in the nation, where it receives an average of 10 overseas merchant vessels daily, primarily oil tanker and container ships. The Golden Gate Bridge, also located in San Francisco, is one of the nation's premiere landmarks and one of the most famous bridges in the world. The dramatic economic impact of a Golden Gate Bridge attack would be felt far beyond the immediate reaches of the San Francisco Bay area.

Analysis for 20 inbound vessels headed for San Francisco combines the worst-case inbound scenario with a dynamic metropolitan area containing national landmarks. Designing a system to counter the worst-case threat scenario would enable that same system to be utilized in less dynamic ones with a high confidence of success.[2]

Some assumptions would be made for analysis by the TSSE Team:

- 100% accurate intelligence on suspected VOI's
- Intelligence is no more than one day time-late
- Department of Energy (DOE) boarding teams require 24 hours or less surge notice prior to deployment
- DOE boarding teams inspection teams consist of 24 members and are highly-trained, but not special warfare capable
- Boarding teams require 2000lb of man-portable equipment
- Teams are self-sufficient to maintain continuous communications with continental US team base.
- No administrative and logistic time lost due to last-minute notice to move
- Zero resistance by crews or insurgents onboard suspected VOI's
- Minimal impact on commerce traffic - No more than 20 ships depart Hong Kong/Singapore bound for San Francisco
- Most VOI's will travel the north route
- Global Maritime Intelligence system provides near-real-time locations for VOI

- Maximum 7 day Search per VOI

Details of the MTR scenarios are covered in Chapter II.

II. CONCEPT OF OPERATIONS

Armed with the SEA-9 Mission Needs Statement (MNS) and assumptions listed in the previous section, the TSSE Team needed to develop potential Concept of Operations (CONOPS) before proceeding with system identification. Although the MNS stated what the system was required to do, there was no supporting documentation as to how it could be accomplished. In fact, no known CONOPS existed to address this specific need. To develop such a CONOPS, the team reviewed existing procedures in Maritime Interdiction Operations in the Arabian Gulf as well as Counter Drug Operations in the Gulf of Mexico and then expanded these concepts to the immense Pacific Ocean Theater.

Initial investigation focused on where the VOI's may originate. Because of the many potential stops a ship may make prior to exiting the South China Sea (Figure 1), it was determined that intercepts should not occur prior to VOI's entering the Philippine Sea. Considering that the entire voyage could range up to 9,000 nautical miles, there would also be ample time to conduct the intercept without having to navigate through constrained areas. Assuming that the orders to execute would be one day time late in addition to one extra day of preparation, there was little chance that an intercept in this area could be accomplished in the minimum time. Thus, the CONOPS was limited to open ocean intercepts. An advantage to moving the starting point into the open ocean was that the CONOPS would now become applicable to any port of departure, not just Singapore and Hong Kong. An open-ocean CONOPS would also allow an even greater spread of departure times.

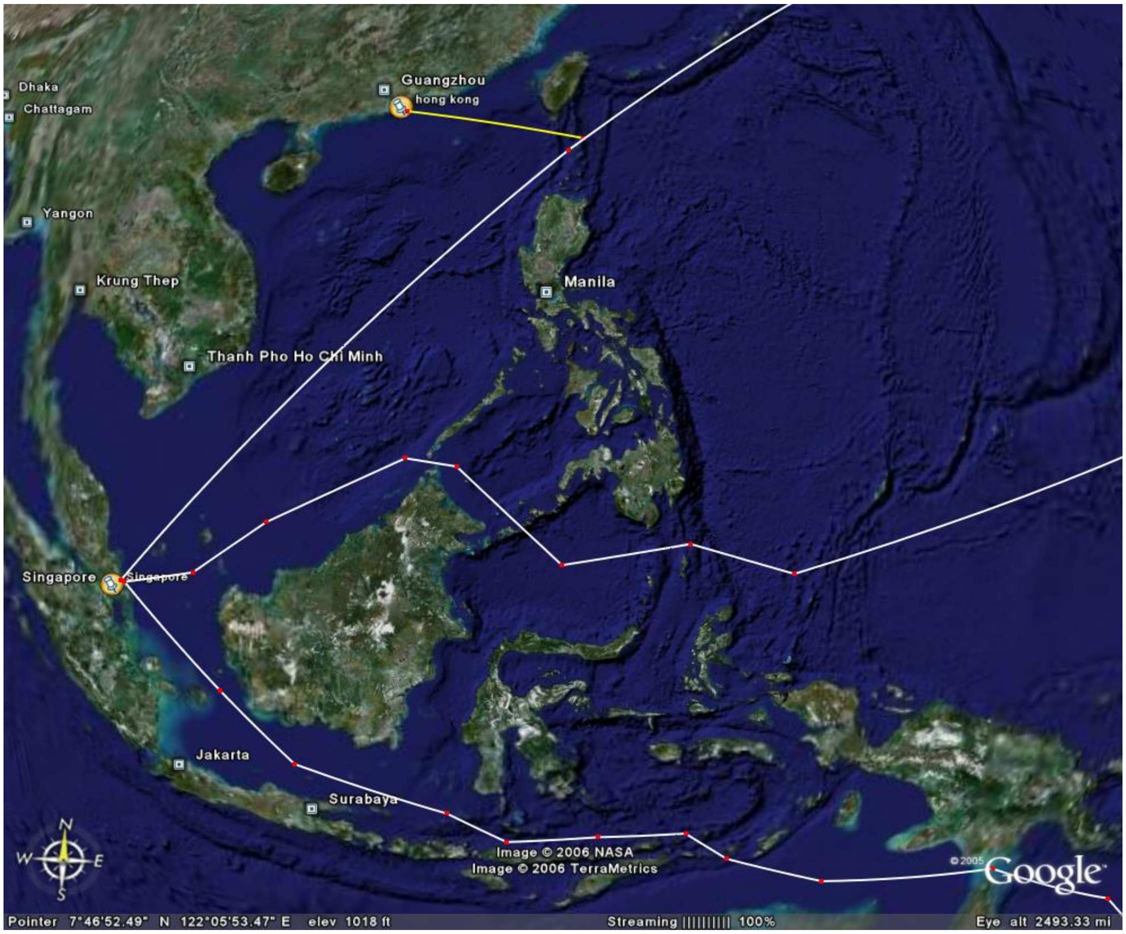


Figure 13. Southwest Asian Routes

With the ocean area constrained in the west, the TSSE Team looked at constraining the area in the eastern Pacific. Since the system needed to be robust enough to avoid any delay to commerce, a natural limit to where an intercept could begin developed. Considering a maximum search time of seven days and a speed of advance of 20 knots, a VOI must be intercepted prior to closing within 3,600 nm of San Francisco. An intercept occurring inside this line may not be completed prior to arrival and would thus delay commerce (Figure 2).

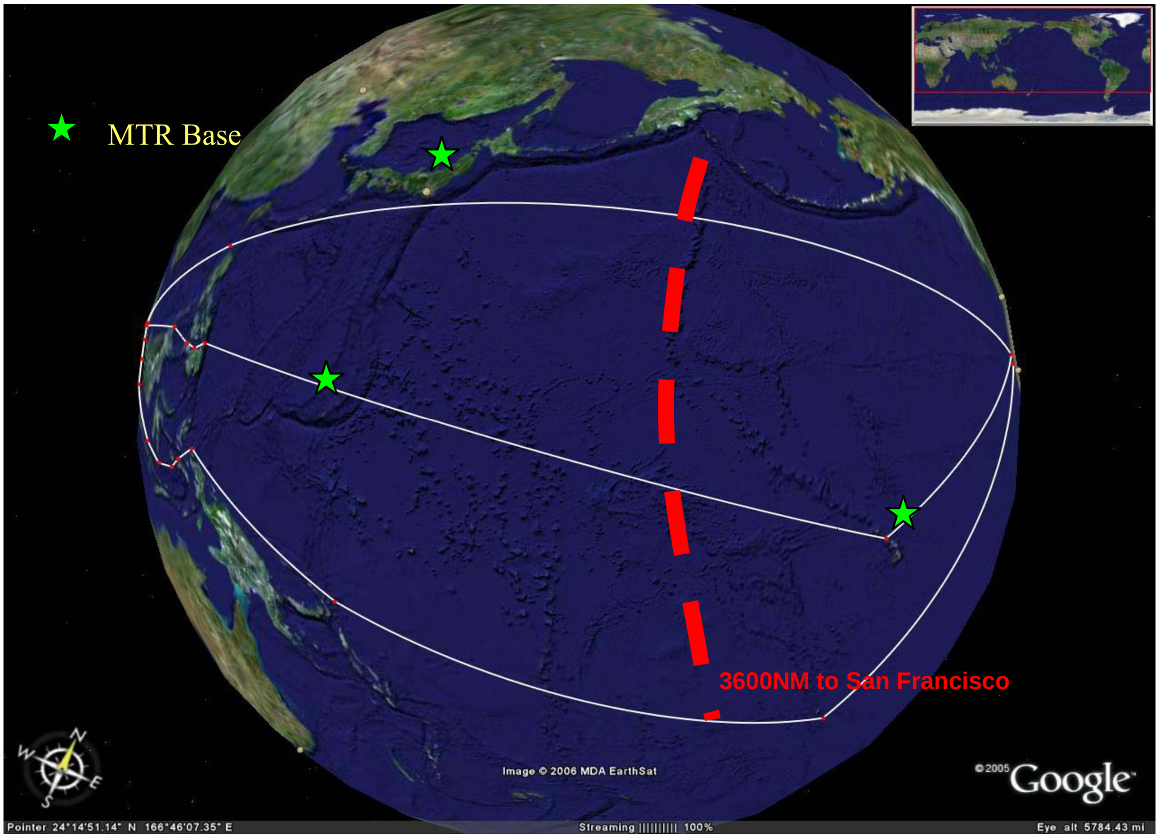


Figure 14. Great Circle Routes and Eastern Constraint

This intercept line not only further constrained the intercept area, but also made the CONOPS applicable to any Western US seaport. Figure 2 also depicts three potential MTR bases in Hawaii, Japan, and Guam. The key aspect of this forward deployment would be to get *in front* of the lead VOI as soon as possible to avoid any tail chases. The normal use of the northern route means that the majority of the systems should be based in Japan with Hawaii acting as a back-catch for any VOI's traveling along the rarely used central and southern routes.

The overall operations area thus defined, the TTSE Team recognized that this area was still too large to develop a specific CONOPS. As a result, a smaller traveling frame of reference linked to the VOI's was developed (Figure 3).

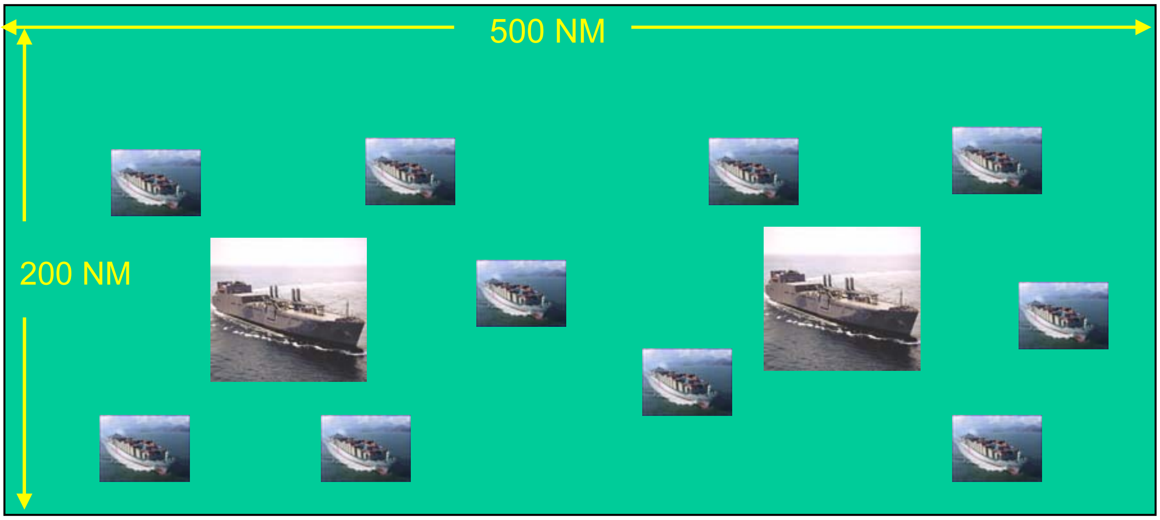


Figure 15. Traveling Operational Area

Considering the nominal 20 knot speed of advance, it could be expected that 10 VOI's would have a separation of approximately 500 nautical miles along the great circle route. Variation between ports of departure, navigational choices, en-route stops and other potential differences between VOI routes could result in widening this box around the great circle route up to 200 nautical miles. Thus, a box traveling at 20 knots was constructed for each major port of departure for a total of two boxes for 20 ships. Based on the experience from current Maritime Interdiction Operations, the assignment of two systems per box was made with the understanding that this setup would vary depending on the system selection. Consideration was made to keep the operational areas as general as possible to ensure that all potential systems could be equally considered. One possible sequence of events utilizing four systems is described below:

- Day 1: Twenty merchant vessels sail out of Singapore and Hong Kong bound for San Francisco.
- Day 2: US Intel assets learn that a WMD or other terrorist smuggling operation has commenced on a merchant vessel inbound to San Francisco. The ships departing Hong Kong have reached the great circle route at Luzon. The ships leaving Singapore are two days behind.
    - Joint Task Force MTR is activated and placed under TACON or USCG District Eleven (OPCON to USNORTHCOM).
    - MTR 1 & MTR 2 given 24 hour surge notice.
    - MTR 3 & MTR 4 given 48 hour surge notice.

  - 10 MTR teams (INCONUS) are given 24-hour surge notice & 10 MTR teams (INCONUS) are given 48-hour surge notice for deployment to Yokosuka, Japan.

- Day 3: The ships from Hong Kong are now 1,000 nautical miles from Yokosuka. If allowed, a Broadcast Notice to Mariners has been issued requiring all ships inbound to San Francisco to pass within 5 nautical miles of a designated rendezvous point along the great circle route near the closest point of approach to Japan to minimize size of traveling operational area. If not allowed, this operational area may expand to the nominal 200 nautical miles. MTR teams 1-10 begin to arrive in Japan and are berthed aboard MTR 1 and MTR 2.
- Day 4: MTR 1 and MTR 2 depart Yokosuka, Japan. Each MTR system consists of the following:
  - 1) One MTR mother-ship or tanker
  - 2) Organic MH-60 helicopters
  - 3) Shore based MV-22 support for ferrying boarding teams from shore to MTR system
  - 4) 6 MTR Interceptor vessels or Destroyers/Frigates/LCS's
  - 5) 5 MTR boarding teams
  - 6) 1 SEAL Platoon or equivalent SOF unit
  - 7) 6 Complete boarding kits
  - MTR teams 11-20 arrive in Japan and are berthed aboard MTR 3 and MTR 4.
- Day 5: MTR 1 arrives at the rendezvous point and begins deploying interceptors. As the first five ships are sighted on radar, they are contacted via bridge-to-bridge radio and informed that they will be boarded by US law enforcement and customs personnel. Interceptors or Destroyers/Frigates/LCS's are dispatched to conduct boarding's on the first 5 ships with an MH-60 airborne to cover the initial safety inspections. Once the initial safety inspection is complete, then the Interceptor or aircraft will deliver boarding kits for inspection. The first two or three merchants are allowed to pass the mothership/tanker, which will then follow roughly in the middle of the first 5 merchants along the course to San Francisco. MTR 2 repeats the process with merchants 6-10.MTR 3 and MTR 4 depart Japan for the rendezvous point.
- Day 6: MTR 3 and MTR 4 arrive at the rendezvous point one day ahead of the Singapore merchant ships.
- Day 7: MTR 3 and MTR 4 repeat the same process as MTR 1 and MTR 2 for conducting initial boarding and equipment transfer.

Note that this scenario addresses the worst case situation in which the ships are spread as far as possible and the inspections would require the full seven days. It is expected that in almost all cases, two MTR systems could handle the entire load by falling back through the line of VOI's as inspections are completed.

Further development of the CONOPS was frozen at this point, as there was enough guidance to begin investigating which systems would best meet the scenarios described above. An even more detailed CONOPS regarding how the teams would be supported would be developed in parallel with the investigation of different types of systems and units within those systems. The discussion of this portion of the analysis is detailed in Chapter V.

III. SYSTEMS ENGINEERING DESIGN PROCESS

A. TECHNICAL MANAGEMENT

1. Planning

Before any work could be accomplished, it was necessary for the TSSE Team to generate a process implementation strategy that would maximize productivity for the next 12 months that lied ahead. With stakeholders already identified and top-level requirements to meet, the TSSE Team needed to come up with an overall plan to accomplish SEA-9 tasking. Once the TSSE Team organizational structure was established, a work breakdown structure was created to assign specific tasks to personnel.

A calendar-based schedule identifying critical-path milestones was created, which would become the primary tool for monitoring overall progress of the TSSE project. This timeline is included as an appendix _. All source documents, including applicable software, would be identified throughout the entire process at appropriate stages during execution of the project. Personnel were made aware of and gained access to the information databases in order to conduct independent research. Reporting requirements and progress assessment metrics were established for different phases of the project to ensure timely completion and compliance with top-level requirements. Risk management would be assessed where the TSSE Team deemed necessary throughout the project. As part of the overall technical effort, measures of effectiveness (MOE), and more specifically, key performance parameters (KPP), would be utilized in order to obtain break-out systems. Decision and risk matrices would be also be necessary in the comparison of competing systems and in making critical analysis and design decisions during the project. Re-emphasis was placed on preserving requirements traceability.

Immediately recognizing the iterative process of analysis and design, the TSSE Team adopted the Spiral Systems Engineering Process. This model was then tailored to fit the TSSE MTR project.

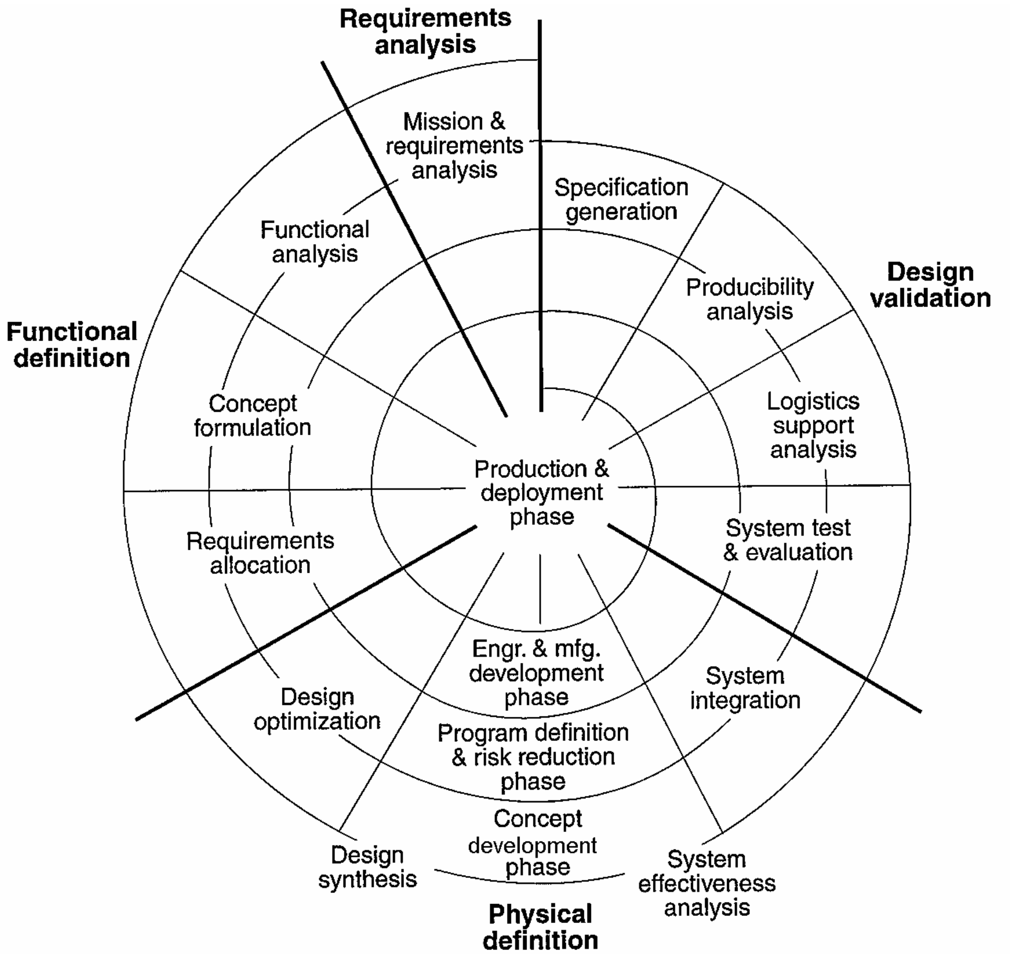


Figure 16. Spiral Model of the Defense System Life Cycle

One source document, in particular, the TSSE Team utilized as a guide was Naval Systems Engineering Guide, Naval Sea Systems Command, October 2004. Key concepts from this source document were used extensively throughout execution of this project. An outline of these concepts for MTR analysis and design are included as an appendix.

2. Needs Analysis

The TSSE Team generated a mission needs statement to provide guidance towards a common goal:

> Develop a Maritime Threat Response system capable of providing long-range detection, classification, and neutralization of asymmetrical threats to the United States which may be contained aboard merchant vessels bound for the United States (San Francisco, CA) via the three main shipping lanes out of the Far East.[2]

A needs hierarchy was promulgated, which prioritized the different subcategories (detection, classification, neutralization) necessary to meet the primary need of preventing the threat.

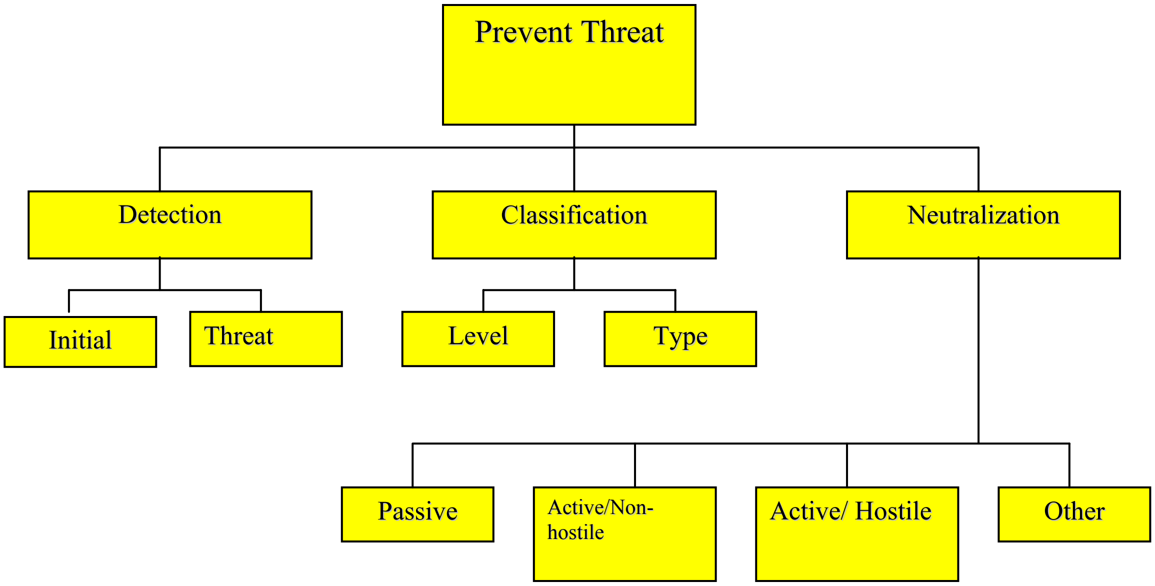


Figure 17. MTR Needs Hierarchy

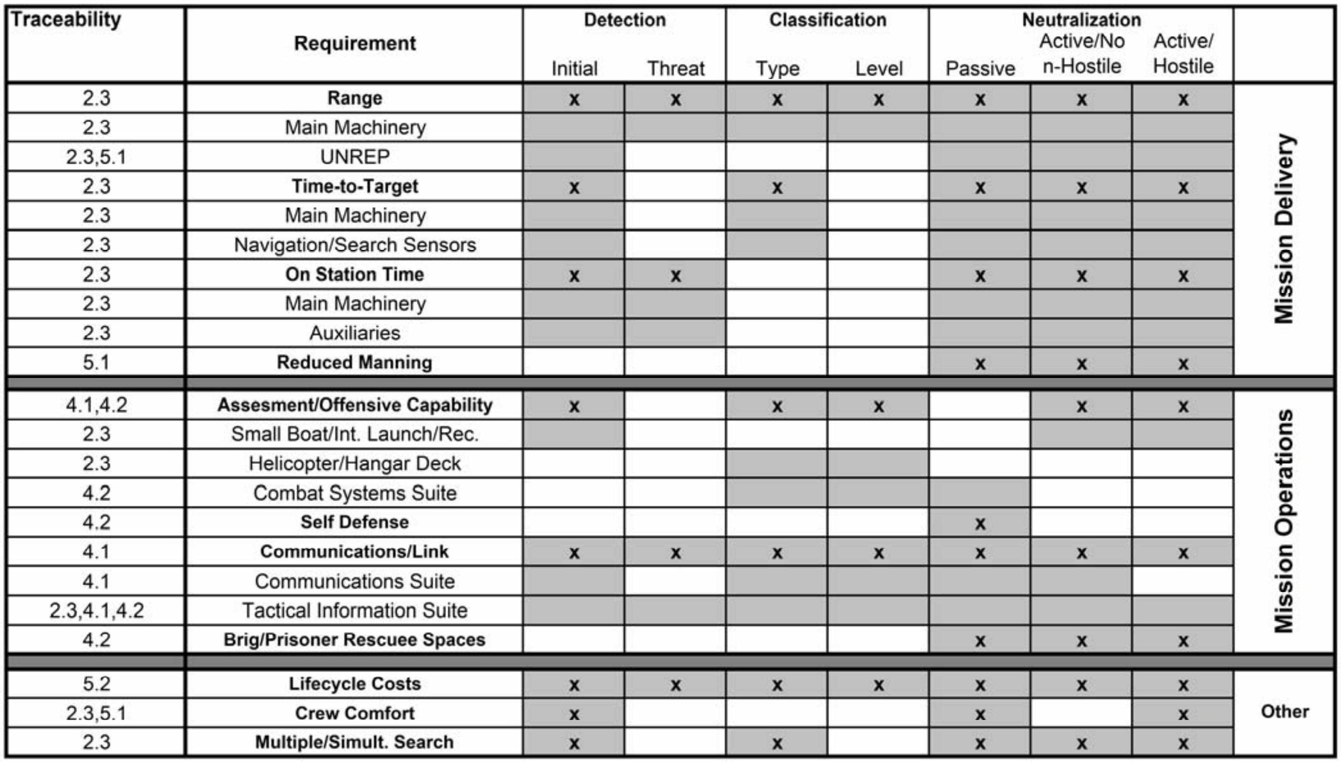
3. Requirements Analysis

Once primary needs were established for the project, it was possible for the TSSE Team to generate a set of requirements based upon the primary needs that would become the basis for an eventual ship design. Driven by the CONOPS, the requirements would fall under one of the following categories:

- Functional (System/Mission Level)

- Operational (Subsystem/Functional Level)
- Support

The TSSE Team studied MTR techniques and shared past Visit, Boarding, Search, and Seizure (VBSS) experiences. The TSSE Team, consisting of OOD-qualified Surface Warfare Officers, found it necessary and worthwhile by obtaining input from NPS faculty, aviation and civilian law-enforcement personnel who were specifically identified as having boarding experience as well. Based on these inputs, the TSSE Team generated an initial requirements matrix that would become the basis for measures of effectiveness/performance comparisons of competing systems and architectures. The goal would be to appropriately weight each attribute and objectively compare the total scores to obtain a break-out system that would result in the final solution for future design. Traceability codes tied each attribute within this requirements matrix to a particular need that originated from SEA-9. This traceability tied each attribute to some higher-level need in order to achieve the common goals of the MTR mission. See Figure 9 for description of traceability codes.



Traceability	Requirement	Detection		Classification		Neutralization			
		Initial	Threat	Type	Level	Passive	Active/Non-Hostile	Active/Hostile	
2.3	**Range**	x	x	x	x	x	x	x	**Mission Delivery**
2.3	Main Machinery	▨	▨	▨	▨	▨	▨	▨	
2.3,5.1	UNREP	▨				▨	▨	▨	
2.3	**Time-to-Target**	x		x		x	x	x	
2.3	Main Machinery	▨		▨		▨	▨	▨	
2.3	Navigation/Search Sensors	▨		▨		▨	▨	▨	
2.3	**On Station Time**	x	x			x	x	x	
2.3	Main Machinery	▨	▨			▨	▨	▨	
2.3	Auxiliaries	▨	▨			▨	▨	▨	
5.1	**Reduced Manning**					x	x	x	
4.1,4.2	**Assesment/Offensive Capability**	x		x	x		x	x	**Mission Operations**
2.3	Small Boat/Int. Launch/Rec.	▨					▨	▨	
2.3	Helicopter/Hangar Deck			▨	▨				
4.2	Combat Systems Suite			▨	▨	▨			
4.2	**Self Defense**					x			
4.1	**Communications/Link**	x	x	x	x	x	x	x	
4.1	Communications Suite	▨		▨	▨	▨	▨		
2.3,4.1,4.2	Tactical Information Suite	▨	▨	▨	▨	▨	▨	▨	
4.2	**Brig/Prisoner Rescuee Spaces**					x	x	x	
5.2	**Lifecycle Costs**	x	x	x	x	x	x	x	**Other**
2.3,5.1	**Crew Comfort**	x				x		x	
2.3	**Multiple/Simult. Search**	x		x		x	x	x	

Figure 18. Initial MTR Requirements/Needs Correlation Matrix

4. Analysis of Alternatives (Single-Ship, Multi-Ship/Multi-Port, Mothership/Interceptor)

Once the initial requirements analysis was completed, the TSSE Team broke up into three separate groups for consideration of the 3 alternative architectures. The first consideration was a single-ship option, where a single ship from a single port would deploy and intercept a vessel of interest (VOI) for boarding and inspection. The second consideration was a multi-ship/multi-port concept, where more than one ship from more than one port would deploy and intercept VOI's for boarding and inspection. The third consideration was a Mothership/Interceptor concept, where a mother ship would deploy, transit at best speed and deploy multiple interceptors at appropriate locations to intercept VOI's for boarding and inspection. Three subcategories were analyzed within each concept: today, near-term (conversion), and long-term (future build).

As a result of the initial analysis, the multi-ship, multi-port system architecture consisting of motherships carrying a multiple of interceptors broke out as the best solution; however, it was recognized that this particular architecture would best work if deployed from multiple ports instead of just one. This change was incorporated into the initial CONOPS. With a new SEA-9 approved CONOPS in hand, it was then necessary to review and modify the requirements that would support the new, revised CONOPS. Findings of the preliminary decisions were presented to SEA-9 and NPS faculty for review in March 2006. Details of this analysis are included in Chapter V.

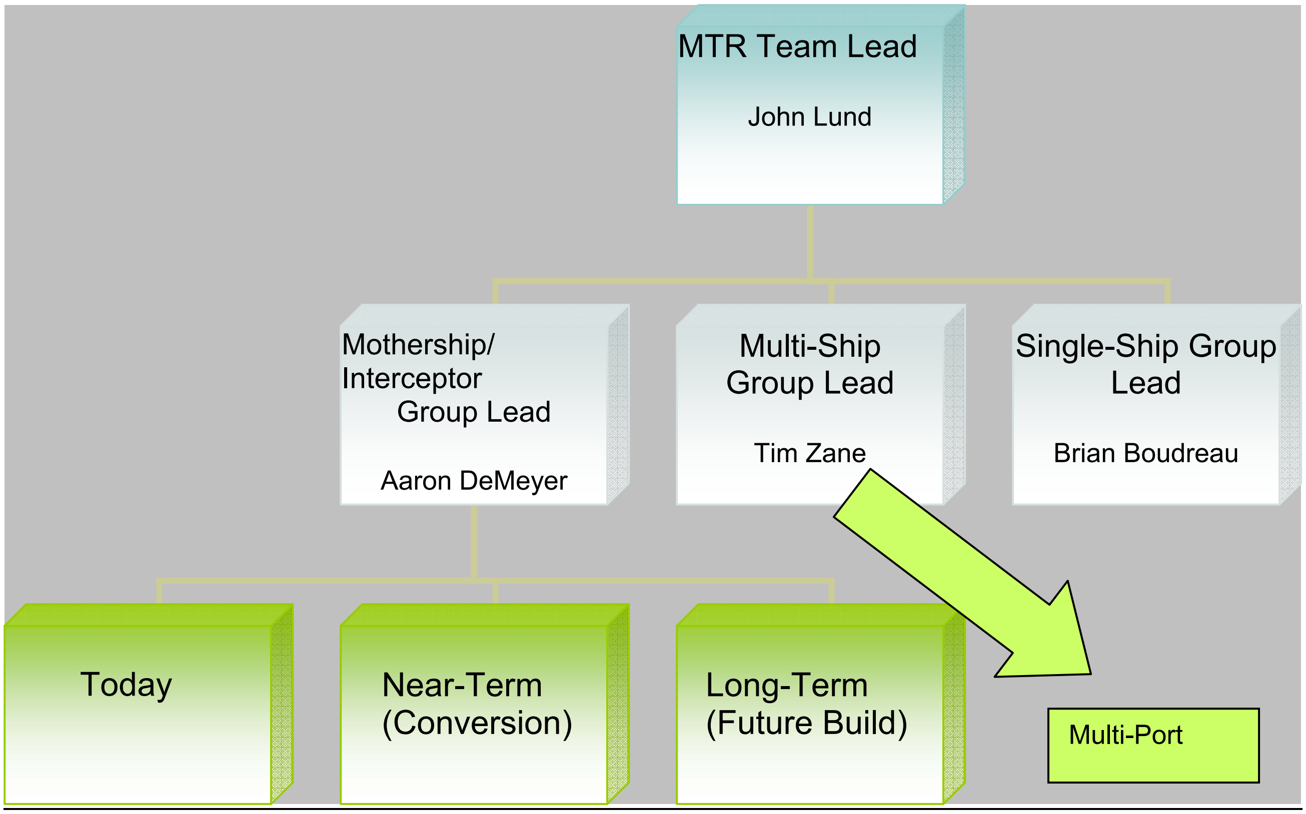


Figure 19. Analysis of Alternatives Work Breakdown Structure

5. Analysis of Alternatives (Mothership/Interceptor)

Once a concept model was established, the TSSE Team broke up into individual groups to investigate the front-running categories of motherships and interceptors. Although the motherships and interceptors possessed mostly all of the same attributes, they had different levels of significance based on the *type* of platform analyzed in order to effectively support the mission CONOPS. Through the use of questionnaires disseminated among NPS faculty and students, the stakeholders, the TSSE Team was able to *further* refine the requirements to identify the most significant attributes (key performance parameters). Utilizing an Analytic Hierarchy Process (AHP) method of weighting these specific attributes, the TSSE Team was able to identify a break-out system consisting of one type of mothership and one type of interceptor. This combination, or a derivative thereof, would emerge as the system solution within the multi-ship/multi-port architecture. It would be this solution that the TSSE Team would take to the next phase for design. Findings of the preliminary decisions were presented to

SEA-9 and NPS faculty for review in June 2006. Details of this analysis are included in Chapter VI.

B. SYSTEM DESIGN

1. Requirements Definition

Requirements from the analysis phase became the critical design parameters for the ship. Specifically, the *key performance parameters* (KPP) from the final mothership measure of performance (MOP) matrix would be utilized as the overall primary indicators of end product performance.

2. Solution Definition

The TSSE Team now reorganized its structure to meet the challenge of ship design. Specific tasking was broken down as shown in Figure 7. An integration team, consisting of three major sub-groups (Hull/Mechanical, Electrical, and Combat Systems), was created to generate the overall ship design.

a. Hull/Mechanical

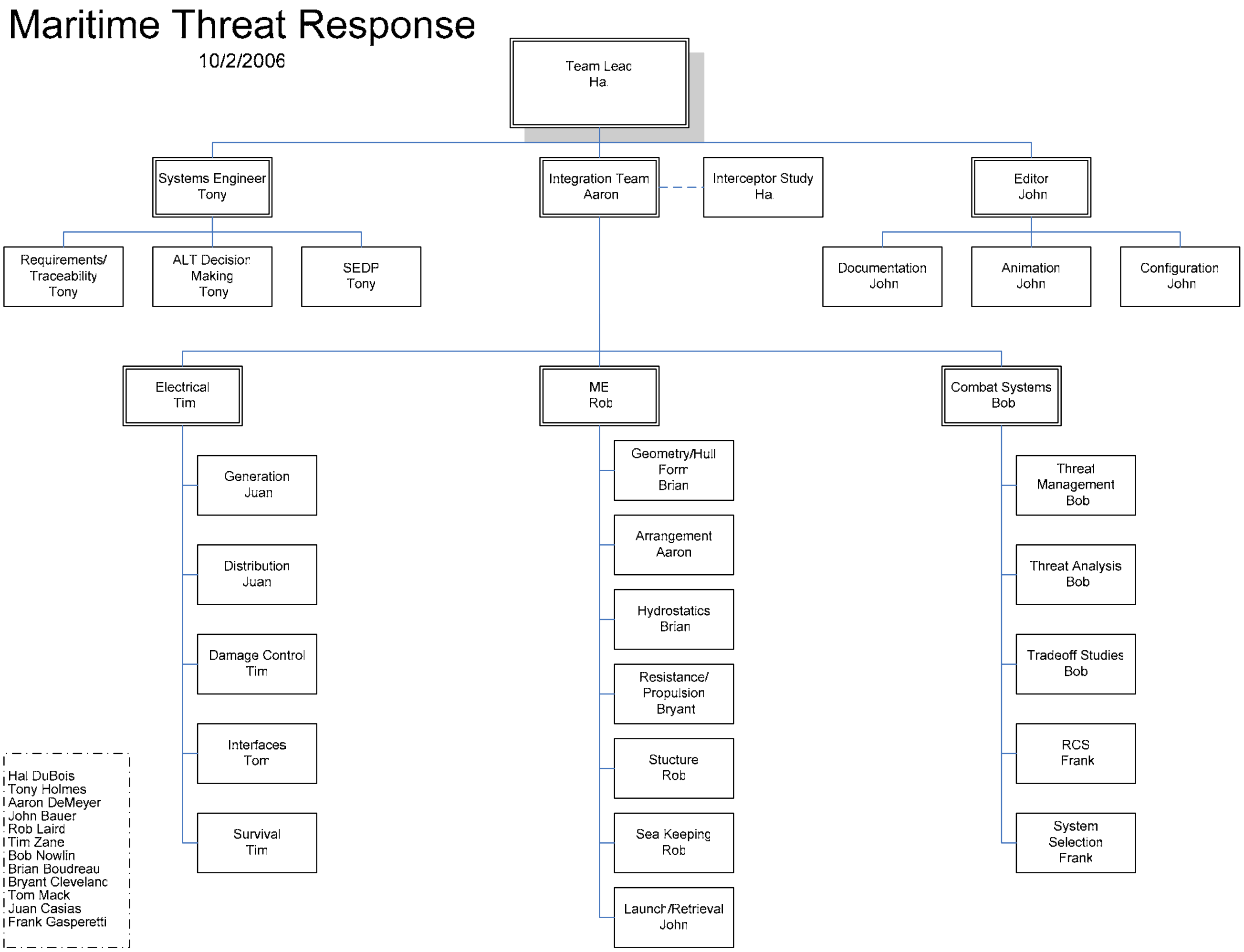
This sub-group was responsible for all calculations which would provide the final structure and hull form/geometry, including individual component arrangement for seakeeping and stability considerations. Resistance and propulsion calculations were necessary to determine engine, shafting, and propeller selections. Designing a system capable of launching/retrieving a 100-ton vessel in potentially high sea states presented itself as a major engineering challenge. Resources from other groups were pulled to solve this problem as required.

b. Electrical

This sub-group was responsible for providing electrical generation and distribution, including the types of generators used. In addition, damage control and survival considerations were included in design calculations.

c. Combat Systems

This sub-group was responsible for threat analysis and management. Trade-off studies were conducted to provide optimal radar cross-section reduction, combat system(s) selection, and weapons placement.



2006 TSSE Team Organization

C. ASSESSMENT AND CONTROL

Overall project progress was monitored via weekly meetings by comparing current progress against the calendar-based schedule, which included critical-path milestones. These weekly meetings provided a forum for the group to give progress reports, discuss rationale for certain assumptions and decisions made, gain new perspectives from others, and most importantly, a chance for every member to provide direct input into the overall project. Major decisions where a solution wasn't easily apparent were made by consensus. Issues affecting the critical path were discussed, and the schedule was modified as necessary. Minutes were recorded after each session and catalogued for future reference.

Recognizing that small changes can cause significant effects in other areas during the design process, a version control document was generated to keep other groups informed when changes were made by a single design sub-group. Documenting changes and allowing other design sub-groups to observe the effects within their own design area allowed for a controlled, iterative process that minimized lost time.

Manpower was shifted to maximize resources where needed. Examples of this were movement of personnel from the electrical sub-group to the mechanical sub-group, and creation of a new sub-group specifically for design of the launch and retrieval system.

IV. REQUIREMENTS

A. INITIAL REQUIREMENTS

SEA-9 mandated that the TSSE Team design a ship (or system of ships) that would have the ability to detect, track, and if necessary, neutralize a potential MTR threat inbound from the Far East. This ship would possess the capability to deploy within 24 hours within receipt of actionable intelligence and after necessary boarding teams had arrived at ports of departure. Once deployed, this ship would be able to intercept, board, and search up to 20 VOI's on one of 3 major shipping lanes inbound from two ports (Hong Kong, Singapore). In addition to minimizing disruptions to merchant traffic, a boarding must be completed prior to arrival at a point no closer than 100 nautical miles from the coast of San Francisco.

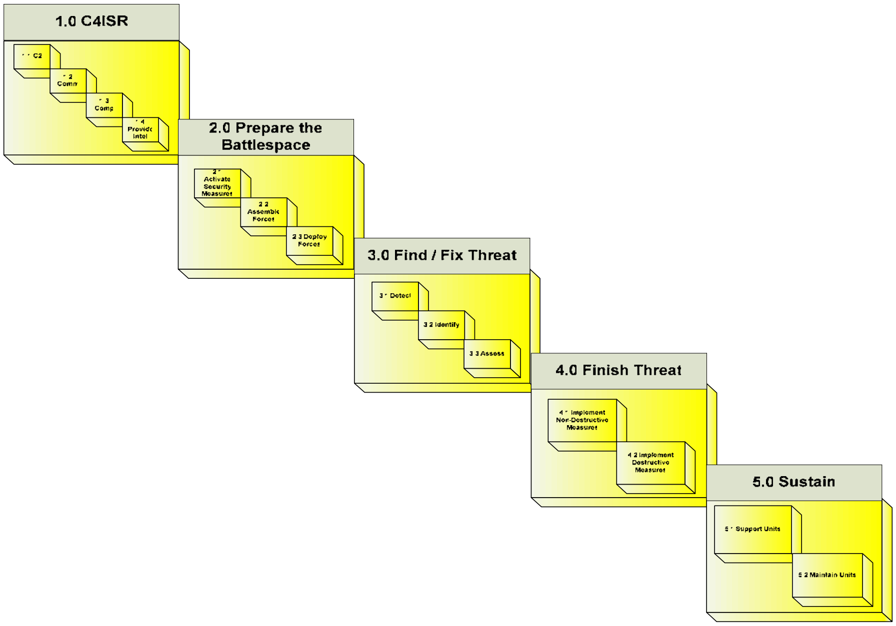


Figure 20. SEA-9 MTR Top-Level Functional Requirements

The TSSE Team's tasking was derived from sub-functions embedded within SEA-9's functional requirements and became TSSE's guidelines for analysis and contribution to the overall MTR project.

2.3 DEPLOY FORCES

- 2.3.1 Embark
- 2.3.2 Move into positions
- 2.3.3 Move teams
- 2.3.4 Recover teams

4.1 NONDESTRUCTIVE MEASURES

- 4.1.1 Tell COI to maneuver
- 4.1.2 Force COI to maneuver
- 4.1.3 Onboard measures
- 4.1.4 Off-board measures

4.2 DESTRUCTIVE MEASURES

- 4.2.1 Disable
- 4.2.2 Sink
- 4.2.3 Recapture

5.1 SUPPORT UNITS

- 5.1.1 Deliver Consumables to Units
- 5.1.2 Refuel Platforms
- 5.1.3 Provide Manning for Sustained Operations
- 5.1.4 Provide Barracks

5.2 MAINTAIN UNITS

- 5.2.1 Identify Maintenance Deficiencies
- 5.2.2 Provide Non-Depot Level Maintenance
- 5.2.3 Time to Provide Deport-Level Maintenance

1. TSSE MTR Top-Level Functional Requirements

The TSSE Team started out by deriving more specific functional and operational requirements based on the top-level requirements listed above. These initial requirements became the basis for analysis and would be refined throughout the iterative process of analysis and design.

B. REQUIREMENTS DEVELOPMENT

1. Detailed Requirement Development

a. Ship Capabilities and Characteristics

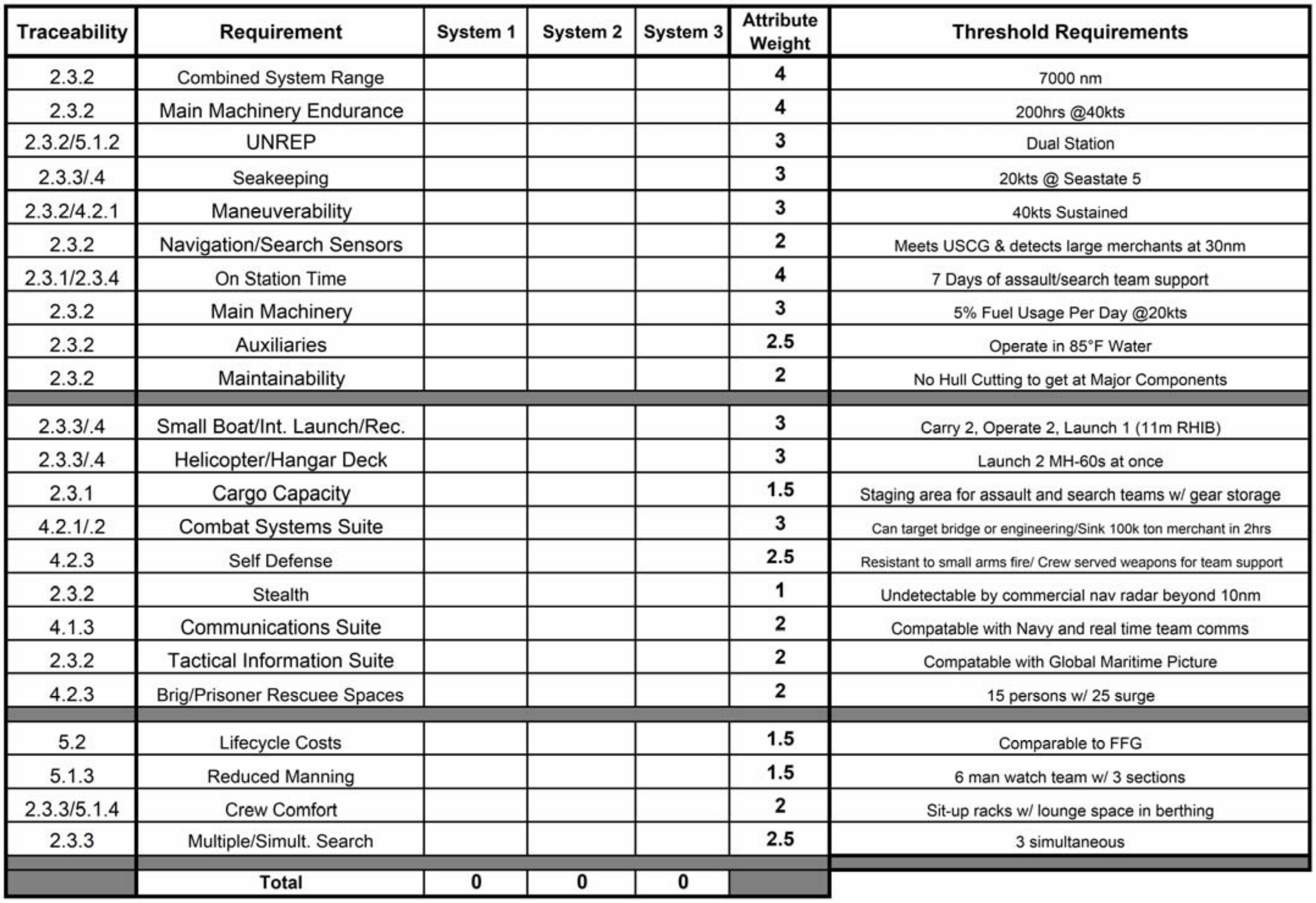
The TSSE Team established an initial set of requirements based on the projected operating environment of an MTR scenario. The ship would require machinery and auxiliary systems to support extended high-speed ocean transits to intercept and board VOI’s at sustained speeds of at least 20 knots with minimal impact on commerce traffic. Furthermore, the ship would be required to safely deploy and recover a multiple of smaller vessels and aircraft, possibly at severe sea states and in inclement weather. Also, the ship would need to be capable of underway replenishment (UNREP) for sustained operations as necessary.

b. Combat System Capabilities

A key concept was that the ship must be a warship capable of participating in offensive combat operations, such as disabling or sinking a large container ship, by weapons from own ship or embarked asset. Combat system capabilities would be somewhat limited, however, and the ship would most likely depend on other friendly forces for protection from long-range threats.

2. Measures of Effectiveness/Measures of Performance

An initial matrix was generated with SEA-9 providing attribute weight factors. Three competing system architectures (Single-Ship, Multi-Ship/Multi-Port, Mothership/Interceptor) were compared to obtain the best overall system architecture.



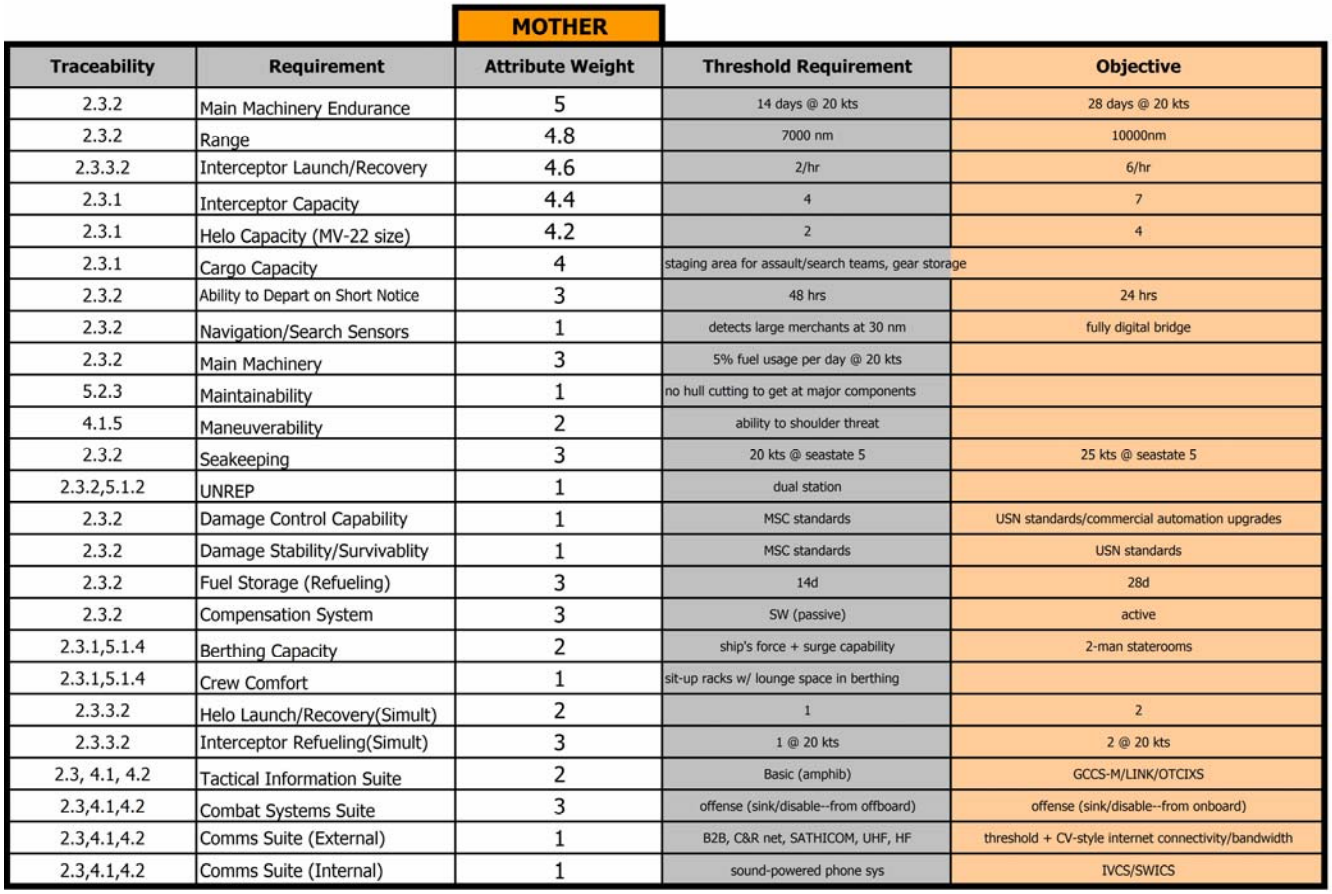
Traceability	Requirement	System 1	System 2	System 3	Attribute Weight	Threshold Requirements
2.3.2	Combined System Range				**4**	7000 nm
2.3.2	Main Machinery Endurance				**4**	200hrs @40kts
2.3.2/5.1.2	UNREP				**3**	Dual Station
2.3.3/.4	Seakeeping				**3**	20kts @ Seastate 5
2.3.2/4.2.1	Maneuverability				**3**	40kts Sustained
2.3.2	Navigation/Search Sensors				**2**	Meets USCG & detects large merchants at 30nm
2.3.1/2.3.4	On Station Time				**4**	7 Days of assault/search team support
2.3.2	Main Machinery				**3**	5% Fuel Usage Per Day @20kts
2.3.2	Auxiliaries				**2.5**	Operate in 85°F Water
2.3.2	Maintainability				**2**	No Hull Cutting to get at Major Components
2.3.3/.4	Small Boat/Int. Launch/Rec.				**3**	Carry 2, Operate 2, Launch 1 (11m RHIB)
2.3.3/.4	Helicopter/Hangar Deck				**3**	Launch 2 MH-60s at once
2.3.1	Cargo Capacity				**1.5**	Staging area for assault and search teams w/ gear storage
4.2.1/.2	Combat Systems Suite				**3**	Can target bridge or engineering/Sink 100k ton merchant in 2hrs
4.2.3	Self Defense				**2.5**	Resistant to small arms fire/ Crew served weapons for team support
2.3.2	Stealth				**1**	Undetectable by commercial nav radar beyond 10nm
4.1.3	Communications Suite				**2**	Compatable with Navy and real time team comms
2.3.2	Tactical Information Suite				**2**	Compatable with Global Maritime Picture
4.2.3	Brig/Prisoner Rescuee Spaces				**2**	15 persons w/ 25 surge
5.2	Lifecycle Costs				**1.5**	Comparable to FFG
5.1.3	Reduced Manning				**1.5**	6 man watch team w/ 3 sections
2.3.3/5.1.4	Crew Comfort				**2**	Sit-up racks w/ lounge space in berthing
2.3.3	Multiple/Simult. Search				**2.5**	3 simultaneous
	Total	**0**	**0**	**0**		

Figure 21. Initial Measures of Effectiveness/Measure of Performance

The multi-ship, multi-port system architecture consisting of motherships carrying a multiple of interceptors deploying from several ports emerged as the best solution.

3. Final Requirements Development

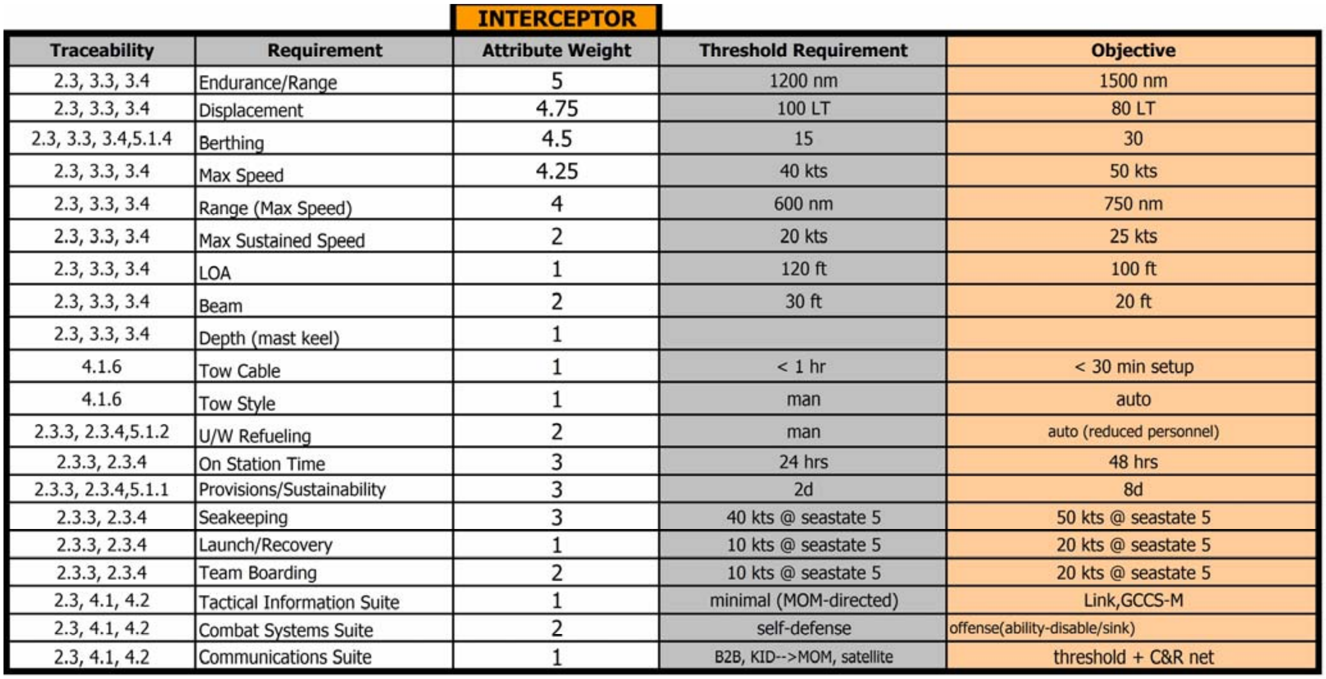
A more refined matrix was then generated, where potential mothership candidates were compared to obtain the best overall hull form for transporting, deploying, and retrieving a multiple of interceptors and air assets.



		MOTHER		
Traceability	Requirement	Attribute Weight	Threshold Requirement	Objective
2.3.2	Main Machinery Endurance	5	14 days @ 20 kts	28 days @ 20 kts
2.3.2	Range	4.8	7000 nm	10000nm
2.3.3.2	Interceptor Launch/Recovery	4.6	2/hr	6/hr
2.3.1	Interceptor Capacity	4.4	4	7
2.3.1	Helo Capacity (MV-22 size)	4.2	2	4
2.3.1	Cargo Capacity	4	staging area for assault/search teams, gear storage	
2.3.2	Ability to Depart on Short Notice	3	48 hrs	24 hrs
2.3.2	Navigation/Search Sensors	1	detects large merchants at 30 nm	fully digital bridge
2.3.2	Main Machinery	3	5% fuel usage per day @ 20 kts	
5.2.3	Maintainability	1	no hull cutting to get at major components	
4.1.5	Maneuverability	2	ability to shoulder threat	
2.3.2	Seakeeping	3	20 kts @ seastate 5	25 kts @ seastate 5
2.3.2,5.1.2	UNREP	1	dual station	
2.3.2	Damage Control Capability	1	MSC standards	USN standards/commercial automation upgrades
2.3.2	Damage Stability/Survivablity	1	MSC standards	USN standards
2.3.2	Fuel Storage (Refueling)	3	14d	28d
2.3.2	Compensation System	3	SW (passive)	active
2.3.1,5.1.4	Berthing Capacity	2	ship's force + surge capability	2-man staterooms
2.3.1,5.1.4	Crew Comfort	1	sit-up racks w/ lounge space in berthing	
2.3.3.2	Helo Launch/Recovery(Simult)	2	1	2
2.3.3.2	Interceptor Refueling(Simult)	3	1 @ 20 kts	2 @ 20 kts
2.3, 4.1, 4.2	Tactical Information Suite	2	Basic (amphib)	GCCS-M/LINK/OTCIXS
2.3,4.1,4.2	Combat Systems Suite	3	offense (sink/disable--from offboard)	offense (sink/disable--from onboard)
2.3,4.1,4.2	Comms Suite (External)	1	B2B, C&R net, SATHICOM, UHF, HF	threshold + CV-style internet connectivity/bandwidth
2.3,4.1,4.2	Comms Suite (Internal)	1	sound-powered phone sys	IVCS/SWICS

Figure 22. Mothership Requirements with AHP Weight Factors

In addition, a more refined matrix was generated to obtain the best overall interceptor hull form that would be compatible with the mothership.

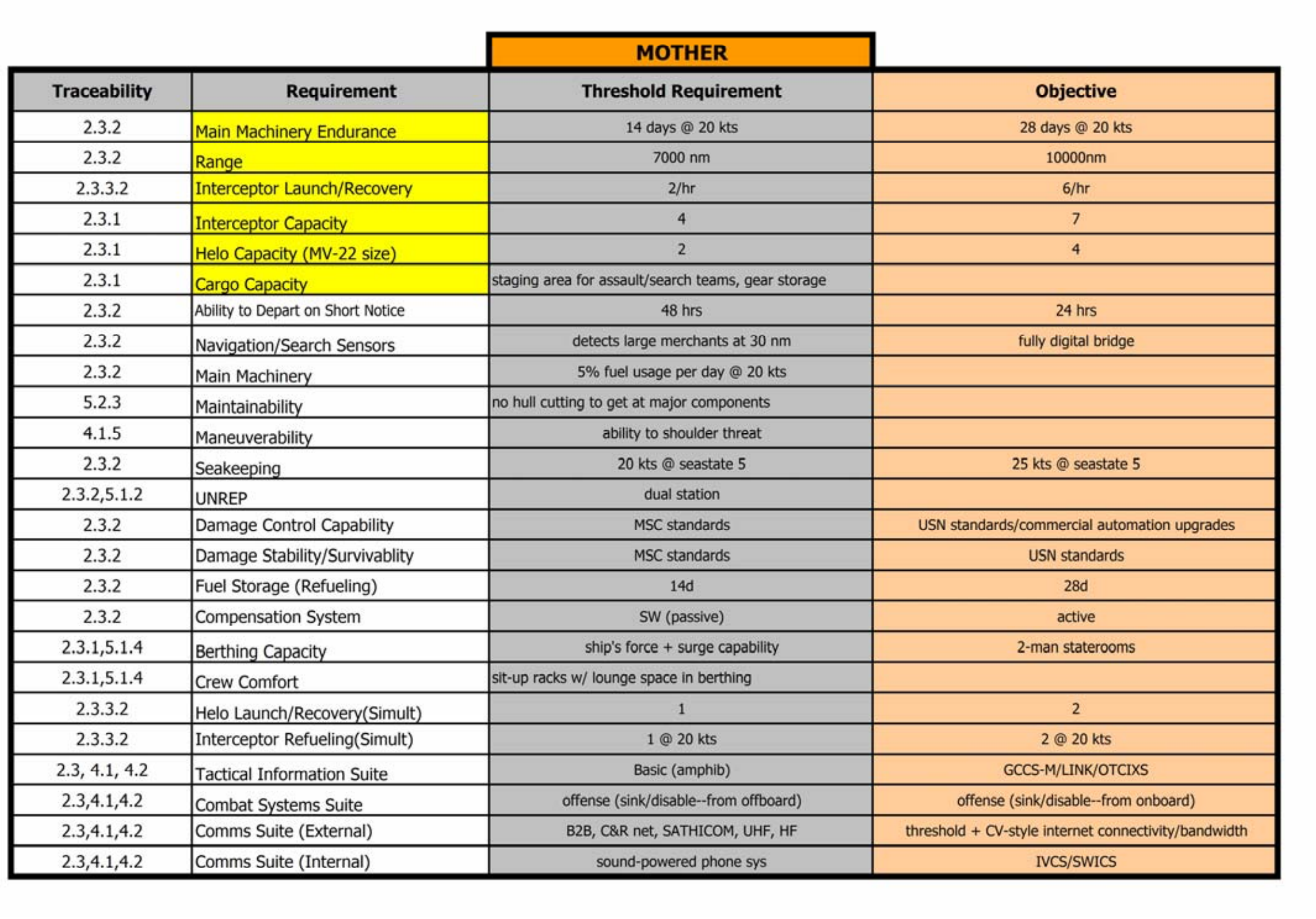


INTERCEPTOR

Traceability	Requirement	Attribute Weight	Threshold Requirement	Objective
2.3, 3.3, 3.4	Endurance/Range	5	1200 nm	1500 nm
2.3, 3.3, 3.4	Displacement	4.75	100 LT	80 LT
2.3, 3.3, 3.4,5.1.4	Berthing	4.5	15	30
2.3, 3.3, 3.4	Max Speed	4.25	40 kts	50 kts
2.3, 3.3, 3.4	Range (Max Speed)	4	600 nm	750 nm
2.3, 3.3, 3.4	Max Sustained Speed	2	20 kts	25 kts
2.3, 3.3, 3.4	LOA	1	120 ft	100 ft
2.3, 3.3, 3.4	Beam	2	30 ft	20 ft
2.3, 3.3, 3.4	Depth (mast keel)	1		
4.1.6	Tow Cable	1	< 1 hr	< 30 min setup
4.1.6	Tow Style	1	man	auto
2.3.3, 2.3.4,5.1.2	U/W Refueling	2	man	auto (reduced personnel)
2.3.3, 2.3.4	On Station Time	3	24 hrs	48 hrs
2.3.3, 2.3.4,5.1.1	Provisions/Sustainability	3	2d	8d
2.3.3, 2.3.4	Seakeeping	3	40 kts @ seastate 5	50 kts @ seastate 5
2.3.3, 2.3.4	Launch/Recovery	1	10 kts @ seastate 5	20 kts @ seastate 5
2.3.3, 2.3.4	Team Boarding	2	10 kts @ seastate 5	20 kts @ seastate 5
2.3, 4.1, 4.2	Tactical Information Suite	1	minimal (MOM-directed)	Link,GCCS-M
2.3, 4.1, 4.2	Combat Systems Suite	2	self-defense	offense(ability-disable/sink)
2.3, 4.1, 4.2	Communications Suite	1	B2B, KID-->MOM, satellite	threshold + C&R net

Figure 23. Interceptor Requirements with AHP Weight Factors

Critical design parameters for the mothership are summarized in the following figure. The first 6 attributes are designated key performance parameters (KPP), and are listed in order of significance.



		MOTHER	
Traceability	**Requirement**	**Threshold Requirement**	**Objective**
2.3.2	Main Machinery Endurance	14 days @ 20 kts	28 days @ 20 kts
2.3.2	Range	7000 nm	10000nm
2.3.3.2	Interceptor Launch/Recovery	2/hr	6/hr
2.3.1	Interceptor Capacity	4	7
2.3.1	Helo Capacity (MV-22 size)	2	4
2.3.1	Cargo Capacity	staging area for assault/search teams, gear storage	
2.3.2	Ability to Depart on Short Notice	48 hrs	24 hrs
2.3.2	Navigation/Search Sensors	detects large merchants at 30 nm	fully digital bridge
2.3.2	Main Machinery	5% fuel usage per day @ 20 kts	
5.2.3	Maintainability	no hull cutting to get at major components	
4.1.5	Maneuverability	ability to shoulder threat	
2.3.2	Seakeeping	20 kts @ seastate 5	25 kts @ seastate 5
2.3.2,5.1.2	UNREP	dual station	
2.3.2	Damage Control Capability	MSC standards	USN standards/commercial automation upgrades
2.3.2	Damage Stability/Survivablity	MSC standards	USN standards
2.3.2	Fuel Storage (Refueling)	14d	28d
2.3.2	Compensation System	SW (passive)	active
2.3.1,5.1.4	Berthing Capacity	ship's force + surge capability	2-man staterooms
2.3.1,5.1.4	Crew Comfort	sit-up racks w/ lounge space in berthing	
2.3.3.2	Helo Launch/Recovery(Simult)	1	2
2.3.3.2	Interceptor Refueling(Simult)	1 @ 20 kts	2 @ 20 kts
2.3, 4.1, 4.2	Tactical Information Suite	Basic (amphib)	GCCS-M/LINK/OTCIXS
2.3,4.1,4.2	Combat Systems Suite	offense (sink/disable--from offboard)	offense (sink/disable--from onboard)
2.3,4.1,4.2	Comms Suite (External)	B2B, C&R net, SATHICOM, UHF, HF	threshold + CV-style internet connectivity/bandwidth
2.3,4.1,4.2	Comms Suite (Internal)	sound-powered phone sys	IVCS/SWICS

Figure 24. Mothership Critical Design Factors

These critical design parameters emerged as the blueprint for TSSE ship design. The goal would be to design a ship to *at least* the minimum threshold requirements. By coupling this design with the optimal design interceptor, the result would be a system architecture that would support the dynamic mission requirements and give the best chances of success in an MTR mission.

V. ANALYSIS OF ALTERNATIVES (SINGLE-SHIP, MULTI-SHIP/MULTI-PORT, MOTHERSHIP/INTERCEPTOR)

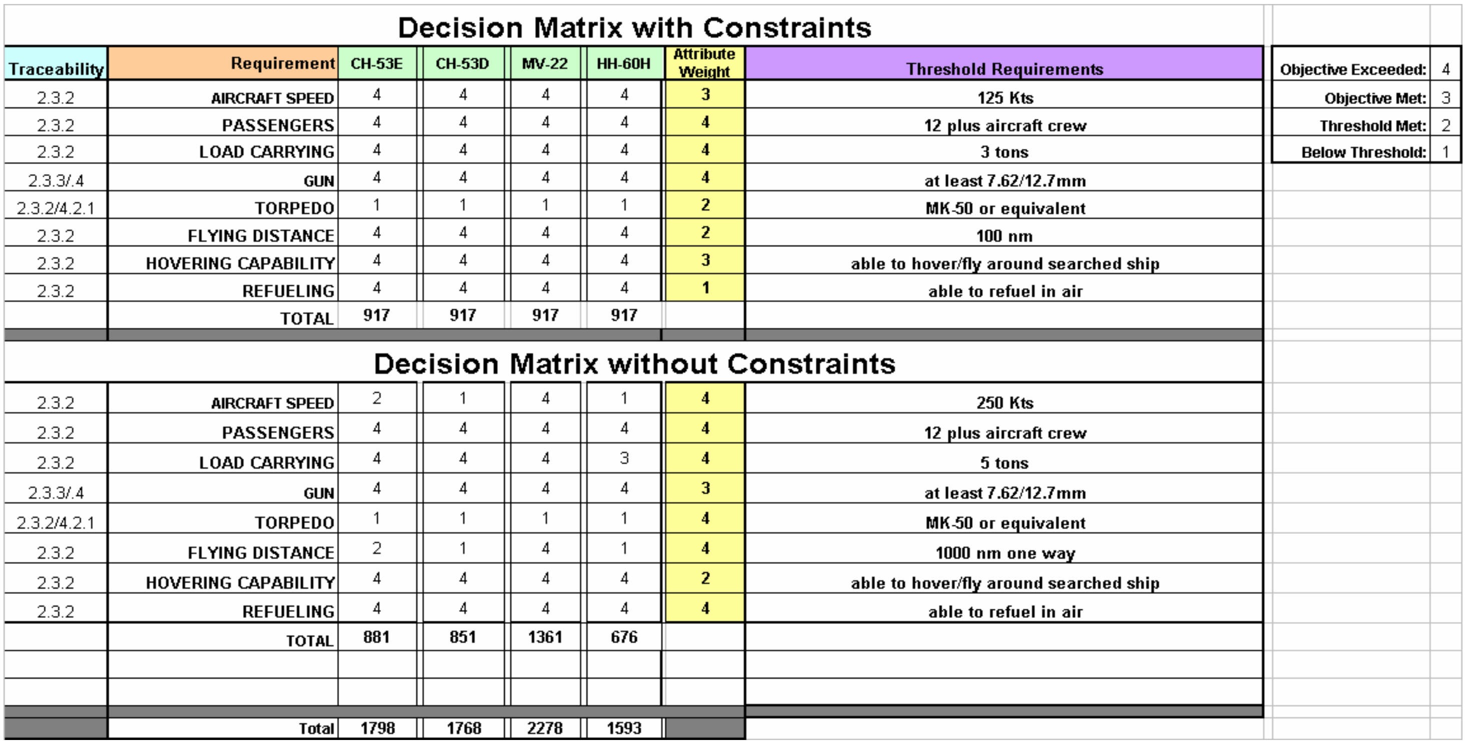
Initial steps to round down solutions required that the TSSE Team break up into three separate groups to consider different system architectures that would satisfy the MTR CONOPS. Three subcategories were then analyzed within each system's architecture: today, conversion (near-term), and future-build (long-term).

A. SINGLE-SHIP CONCEPT

The first consideration was the single-ship option, where a single ship from a single port would deploy and intercept a vessel of interest (VOI) for boarding and inspection.

1. Aircraft Analysis

In support of single-ship boarding operations, it was necessary that embarked aircraft have adequate range and load-carrying capabilities, specifically up to 24 troops and 2,000 pounds of support gear. Aircraft under consideration for the single-ship concept were the CH-53D, CH-53E, HH-60H, and MV-22. Decision matrices, with varying constraints of speed, loading, and range, were generated to identify the best type of aircraft for this mission.



Decision Matrix with Constraints

Traceability	Requirement	CH-53E	CH-53D	MV-22	HH-60H	Attribute Weight	Threshold Requirements
2.3.2	AIRCRAFT SPEED	4	4	4	4	3	125 Kts
2.3.2	PASSENGERS	4	4	4	4	4	12 plus aircraft crew
2.3.2	LOAD CARRYING	4	4	4	4	4	3 tons
2.3.3/.4	GUN	4	4	4	4	4	at least 7.62/12.7mm
2.3.2/4.2.1	TORPEDO	1	1	1	1	2	MK-50 or equivalent
2.3.2	FLYING DISTANCE	4	4	4	4	2	100 nm
2.3.2	HOVERING CAPABILITY	4	4	4	4	3	able to hover/fly around searched ship
2.3.2	REFUELING	4	4	4	4	1	able to refuel in air
	TOTAL	917	917	917	917		

Objective Exceeded:	4
Objective Met:	3
Threshold Met:	2
Below Threshold:	1

Decision Matrix without Constraints

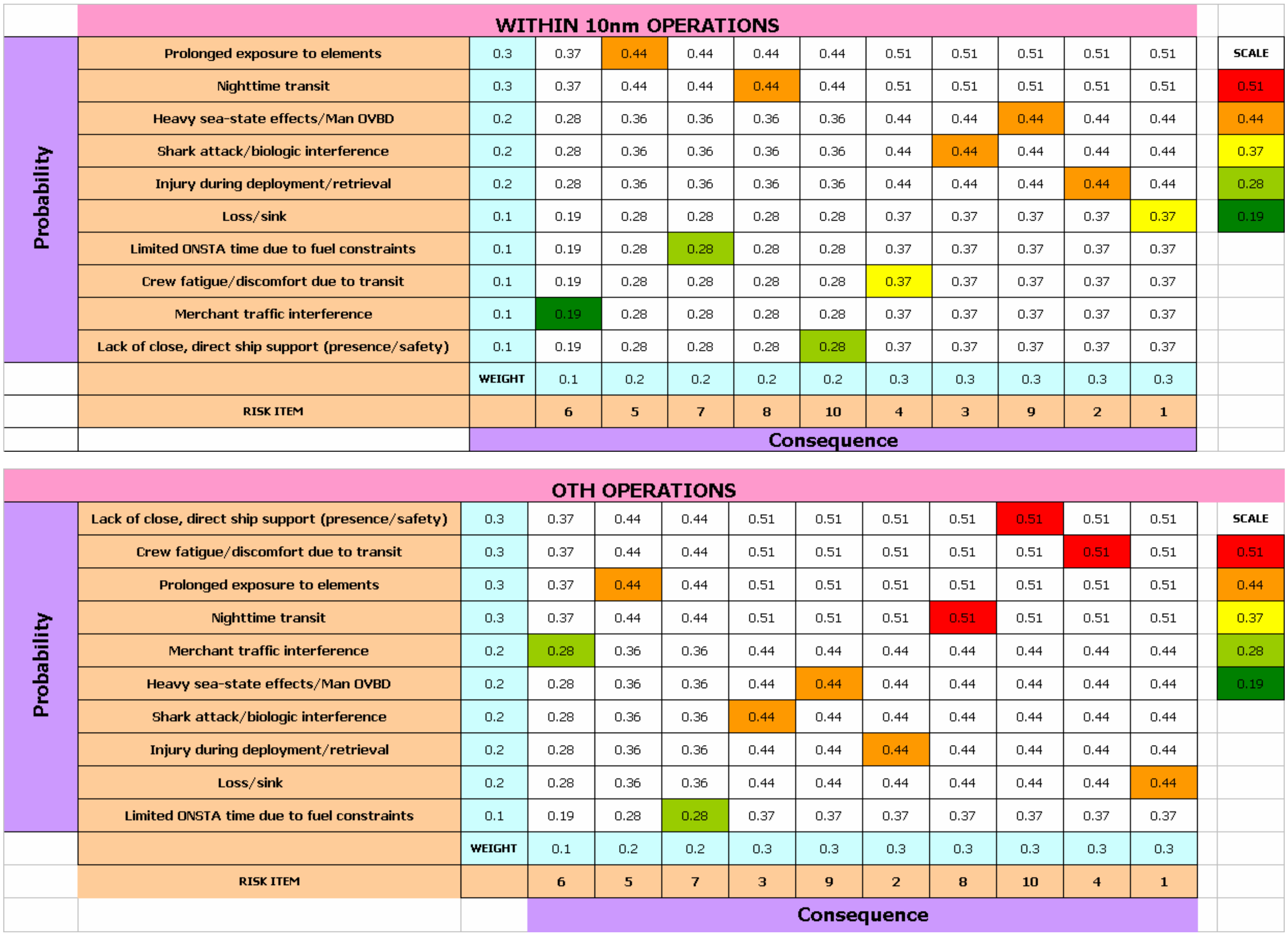
Traceability	Requirement	CH-53E	CH-53D	MV-22	HH-60H	Attribute Weight	Threshold Requirements
2.3.2	AIRCRAFT SPEED	2	1	4	1	4	250 Kts
2.3.2	PASSENGERS	4	4	4	4	4	12 plus aircraft crew
2.3.2	LOAD CARRYING	4	4	4	3	4	5 tons
2.3.3/.4	GUN	4	4	4	4	3	at least 7.62/12.7mm
2.3.2/4.2.1	TORPEDO	1	1	1	1	4	MK-50 or equivalent
2.3.2	FLYING DISTANCE	2	1	4	1	4	1000 nm one way
2.3.2	HOVERING CAPABILITY	4	4	4	4	2	able to hover/fly around searched ship
2.3.2	REFUELING	4	4	4	4	4	able to refuel in air
	TOTAL	881	851	1361	676		
	Total	1798	1768	2278	1593		

Figure 25. Aircraft Alternatives Decision Matrix

No particular aircraft broke out as being the best with imposed constraints. With constraints removed, however, the MV-22 broke out as the best potential aircraft for consideration due to its superiority in overall speed and range.

2. Small Boat Analysis

Another consideration under the single-ship architecture was prolonged operation of small boats during boarding operations. An item of contention within the group was whether or not a deployed small boat (Rigid Hull Inflatable Hull, (RHIB)) should be within sight of own ship while conducting boarding operations. Due to differing opinions within the group, a risk matrix was generated to determine the viability of having a ship deploy its small boat and allow it to operate over the horizon (>10 nm) and out of sight while a boarding was conducted.



	WITHIN 10nm OPERATIONS												
Probability	Prolonged exposure to elements	0.3	0.37	0.44	0.44	0.44	0.44	0.51	0.51	0.51	0.51	0.51	SCALE
	Nighttime transit	0.3	0.37	0.44	0.44	0.44	0.44	0.51	0.51	0.51	0.51	0.51	0.51
	Heavy sea-state effects/Man OVBD	0.2	0.28	0.36	0.36	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44
	Shark attack/biologic interference	0.2	0.28	0.36	0.36	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.37
	Injury during deployment/retrieval	0.2	0.28	0.36	0.36	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.28
	Loss/sink	0.1	0.19	0.28	0.28	0.28	0.28	0.37	0.37	0.37	0.37	0.37	0.19
	Limited ONSTA time due to fuel constraints	0.1	0.19	0.28	0.28	0.28	0.28	0.37	0.37	0.37	0.37	0.37	
	Crew fatigue/discomfort due to transit	0.1	0.19	0.28	0.28	0.28	0.28	0.37	0.37	0.37	0.37	0.37	
	Merchant traffic interference	0.1	0.19	0.28	0.28	0.28	0.28	0.37	0.37	0.37	0.37	0.37	
	Lack of close, direct ship support (presence/safety)	0.1	0.19	0.28	0.28	0.28	0.28	0.37	0.37	0.37	0.37	0.37	
		WEIGHT	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	
	RISK ITEM		6	5	7	8	10	4	3	9	2	1	
		Consequence											

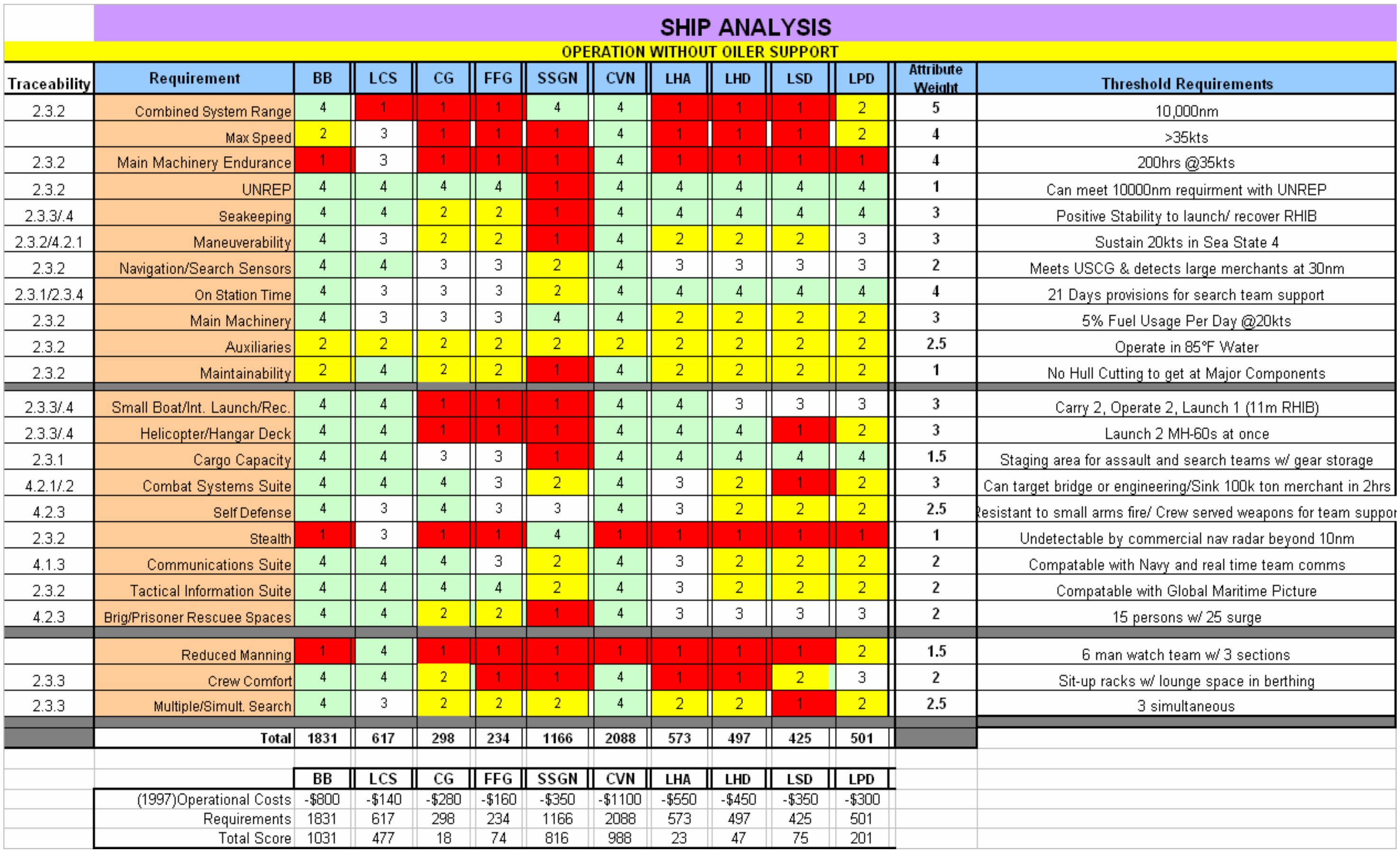
	OTH OPERATIONS												
Probability	Lack of close, direct ship support (presence/safety)	0.3	0.37	0.44	0.44	0.51	0.51	0.51	0.51	0.51	0.51	0.51	SCALE
	Crew fatigue/discomfort due to transit	0.3	0.37	0.44	0.44	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	Prolonged exposure to elements	0.3	0.37	0.44	0.44	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.44
	Nighttime transit	0.3	0.37	0.44	0.44	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.37
	Merchant traffic interference	0.2	0.28	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.28
	Heavy sea-state effects/Man OVBD	0.2	0.28	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.19
	Shark attack/biologic interference	0.2	0.28	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	
	Injury during deployment/retrieval	0.2	0.28	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	
	Loss/sink	0.2	0.28	0.36	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	
	Limited ONSTA time due to fuel constraints	0.1	0.19	0.28	0.28	0.37	0.37	0.37	0.37	0.37	0.37	0.37	
		WEIGHT	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
	RISK ITEM		6	5	7	3	9	2	8	10	4	1	
			Consequence										

Figure 26. Small Boat Risk Matrix

As expected, moderate increases in risk associated with an increased transit time of a small boat operating over the horizon and out of sight of own ship resulted, which might be acceptable given the mission considered. However, the *significant increase* in risk associated with the lack of close, direct ship support, crew fatigue/discomfort due to increased transit time, and unobserved nighttime transit to/from own ship enabled the Single-Ship Group to decide that that close boardings (within sight) would be the best option.

3. Ship Analysis

All major surface ship types were considered during analysis, such as Cruiser-Destroyer (CG, DDG, FFG), Amphibious (LHA, LHD, LSD, LPD), Littoral Combat Ship (LCS), nuclear-powered fast-attack submarine (SSN), and Battleship (BB).



SHIP ANALYSIS

OPERATION WITHOUT OILER SUPPORT

Traceability	Requirement	BB	LCS	CG	FFG	SSGN	CVN	LHA	LHD	LSD	LPD	Attribute Weight	Threshold Requirements
2.3.2	Combined System Range	4	1	1	1	4	4	1	1	1	2	5	10,000nm
	Max Speed	2	3	1	1	1	4	1	1	1	2	4	>35kts
2.3.2	Main Machinery Endurance	1	3	1	1	1	4	1	1	1	1	4	200hrs @35kts
2.3.2	UNREP	4	4	4	4	1	4	4	4	4	4	1	Can meet 10000nm requirment with UNREP
2.3.3/.4	Seakeeping	4	4	2	2	1	4	4	4	4	4	3	Positive Stability to launch/ recover RHIB
2.3.2/4.2.1	Maneuverability	4	3	2	2	1	4	2	2	2	3	3	Sustain 20kts in Sea State 4
2.3.2	Navigation/Search Sensors	4	4	3	3	2	4	3	3	3	3	2	Meets USCG & detects large merchants at 30nm
2.3.1/2.3.4	On Station Time	4	3	3	3	2	4	4	4	4	4	4	21 Days provisions for search team support
2.3.2	Main Machinery	4	3	3	3	4	4	2	2	2	2	3	5% Fuel Usage Per Day @20kts
2.3.2	Auxiliaries	2	2	2	2	2	2	2	2	2	2	2.5	Operate in 85°F Water
2.3.2	Maintainability	2	4	2	2	1	4	2	2	2	2	1	No Hull Cutting to get at Major Components
2.3.3/.4	Small Boat/Int. Launch/Rec.	4	4	1	1	1	4	4	3	3	3	3	Carry 2, Operate 2, Launch 1 (11m RHIB)
2.3.3/.4	Helicopter/Hangar Deck	4	4	1	1	1	4	4	4	1	2	3	Launch 2 MH-60s at once
2.3.1	Cargo Capacity	4	4	3	3	1	4	4	4	4	4	1.5	Staging area for assault and search teams w/ gear storage
4.2.1/.2	Combat Systems Suite	4	4	4	3	2	4	3	2	1	2	3	Can target bridge or engineering/Sink 100k ton merchant in 2hrs
4.2.3	Self Defense	4	3	4	3	3	4	3	2	2	2	2.5	Resistant to small arms fire/ Crew served weapons for team suppor
2.3.2	Stealth	1	3	1	1	4	1	1	1	1	1	1	Undetectable by commercial nav radar beyond 10nm
4.1.3	Communications Suite	4	4	4	3	2	4	3	2	2	2	2	Compatable with Navy and real time team comms
2.3.2	Tactical Information Suite	4	4	4	4	2	4	3	2	2	2	2	Compatable with Global Maritime Picture
4.2.3	Brig/Prisoner Rescuee Spaces	4	4	2	2	1	4	3	3	3	3	2	15 persons w/ 25 surge
	Reduced Manning	1	4	1	1	1	1	1	1	1	2	1.5	6 man watch team w/ 3 sections
2.3.3	Crew Comfort	4	4	2	1	1	4	1	1	2	3	2	Sit-up racks w/ lounge space in berthing
2.3.3	Multiple/Simult. Search	4	3	2	2	2	4	2	2	1	2	2.5	3 simultaneous
	Total	1831	617	298	234	1166	2088	573	497	425	501		

	BB	LCS	CG	FFG	SSGN	CVN	LHA	LHD	LSD	LPD
(1997)Operational Costs	-$800	-$140	-$280	-$160	-$350	-$1100	-$550	-$450	-$350	-$300
Requirements	1831	617	298	234	1166	2088	573	497	425	501
Total Score	1031	477	18	74	816	988	23	47	75	201

Figure 27. Ship Analysis Decision Matrix

Key attributes in comparing different ship types are listed in figure 29. Utilizing the above threshold requirements as a guide, different classes of ship seemed to possess some general commonalties where meeting a specific threshold requirement was not feasible. With only a few exceptions, virtually all categories of ships did not meet minimum threshold requirements for stealth and/or reduced manning.

Cruiser-Destroyer (CRUDES): Could not meet minimum threshold requirements for range, speed, and main machinery endurance. In addition, minimum threshold requirements for the operating number of RHIB's and air assets could not be met.

Amphibious: Could not meet minimum threshold requirements for range, speed, and endurance. LSD's, in particular, did not meet minimum threshold requirements for operation of air assets and necessary combat suite for targeting and sinking a VOI.

Nuclear-Powered Fast-Attack Submarine (SSN): Could not meet minimum threshold requirements for underway replenishment, seakeeping/maneuverability on the surface in sea state 4, multiple RHIB/air operations, or crew comfort.

In addition to comparing different ship types, it was necessary to compare these potential systems in an operating environment where small boats would conduct boardings in close proximity to own ship (within sight) and at a distance of greater than 10 nautical miles from own ship (over the horizon, (OTH)). Two main categories were considered:

Sequential Boardings: A single ship deploys one small boat to conduct one boarding at a time.

Simultaneous Boardings: A single ship deploys multiple small boats so that multiple boardings can occur at the same time.

Decision matrices for these categories are illustrated in the following tables respectively.

OTH SEQUENCIAL BOARDING

	Weight	LCS	CG	FFG	SSN	BB	CVN	LHA	LHD	LSD	LPD
SITUATION REQUIREMENTS											
MANEUVERING & STATION KEEPING	**12**	1	0	0	0	1	1	0	0	0	0
ENDURANCE	**12**	0.5	0	0	1	1	1	0	0	0	0.25
AIR DROP OPERATIONS	**3**	1	0.5	0.5	0	0.5	1	1	1	0.5	1
RHIB OPERATIONS	**1**	0.75	0.75	0.5	0.25	0.75	1	1	1	1	1
VISIBLE NAVAL PRESENCE	**1**	1	1	1	0	1	1	1	1	1	1
WEAPONS COVERAGE	**1**	1	1	1	0.75	1	1	1	1	1	1
IMMEDIATE EMERGENCY EGRESS	**2**	1	1	1	0.75	1	1	1	1	1	1
IMMEDIATE SHIP ATTACK	**0.5**	1	1	1	0.5	1	1	0.75	0.75	0.75	0.75
	Total	**20.25**	**6.75**	**6.5**	**2.75**	**18.75**	**20.5**	**8.375**	**8.375**	**6.875**	**8.375**

CLOSE SEQUENCIAL BOARDING

	Weight	LCS	CG	FFG	SSN	BB	CVN	LHA	LHD	LSD	LPD
SITUATION REQUIREMENTS											
MANEUVERING & STATION KEEPING	**12**	1	0	0	0	1	1	0	0	0	0
ENDURANCE	**12**	0.5	0	0	1	1	1	0	0	0	0.25
AIR DROP OPERATIONS	**3**	1	0.5	0.5	0	0.5	1	1	1	0.5	1
RHIB OPERATIONS	**1**	0.75	0.75	0.5	0.25	0.75	1	1	1	1	1
VISIBLE NAVAL PRESENCE	**2**	1	1	1	0	1	1	1	1	1	1
WEAPONS COVERAGE	**1**	1	1	1	0.75	1	1	0.5	0.5	0.5	0.5
IMMEDIATE EMERGENCY EGRESS	**2**	1	1	1	0.75	1	1	1	1	1	1
IMMEDIATE SHIP ATTACK	**0.5**	1	1	1	0.5	1	1	0.75	0.75	0.75	0.75
	Total	**21.25**	**7.75**	**7.5**	**2.75**	**19.75**	**21.5**	**8.875**	**8.875**	**7.375**	**8.875**

Figure 28. Sequential Boarding Decision Matrix

OTH SIMULTANEOUS BOARDING

	Weight	LCS	CG	FFG	SSN	BB	CVN	LHA	LHD	LSD	LPD
SITUATION REQUIREMENTS											
MANEUVERING & STATION KEEPING	**12**	1	0	0	0	1	1	0	0	0	0
ENDURANCE	**12**	0.5	0	0	1	1	1	0	0	0	0.25
AIR DROP OPERATIONS	**3**	1	0.5	0.5	0	0.5	1	1	1	0.5	1
RHIB OPERATIONS	**1**	0	0	0	0	0	0	0	0	0	0
VISIBLE NAVAL PRESENCE	**1**	0	0	0	0	0	0	0	0	0	0
WEAPONS COVERAGE	**1**	1	1	1	1	0.5	0.5	1	1	1	1
IMMEDIATE EMERGENCY EGRESS	**2**	0	0	0	0	0	0	0	0	0	0
IMMEDIATE SHIP ATTACK	**0.5**	0.5	0.5	0.5	0.5	0.5	0.75	0.75	0.75	0.75	0.75
	Total	**16.25**	**2.75**	**2.75**	**1.25**	**14.25**	**15.88**	**4.375**	**4.375**	**2.875**	**4.375**

CLOSE SIMULTANEOUS BOARDING

	Weight	LCS	CG	FFG	SSN	BB	CVN	LHA	LHD	LSD	LPD
SITUATION REQUIREMENTS											
MANEUVERING & STATION KEEPING	**12**	1	0	0	0	1	1	0	0	0	0
ENDURANCE	**12**	0.5	0	0	1	1	1	0	0	0	0.25
AIR DROP OPERATIONS	**3**	1	0.5	0.5	0	0.5	1	1	1	0.5	1
RHIB OPERATIONS	**1**	0.75	0.75	0.5	0.25	0.75	1	1	1	1	1
VISIBLE NAVAL PRESENCE	**2**	1	1	1	0	1	1	1	1	1	1
WEAPONS COVERAGE	**1**	1	1	1	1	1	1	1	1	1	1
IMMEDIATE EMERGENCY EGRESS	**2**	1	1	1	0.5	1	1	1	1	1	1
IMMEDIATE SHIP ATTACK	**0.5**	1	1	1	0.5	1	1	0.75	0.75	0.75	0.75
	Total	**21.25**	**7.75**	**7.5**	**2.5**	**19.75**	**21.5**	**9.375**	**9.375**	**7.875**	**9.375**

Figure 29. Simultaneous Boarding Decision Matrix

For close/sequential, over-the-horizon/sequential, and close/simultaneous boarding, CRUDES and amphibious ship classes did not meet minimum threshold requirements for maneuvering, station keeping, and endurance. The SSN did not meet minimum threshold requirements for air drop capability. A more demanding over-the-horizon/simultaneous boarding scenario provided further restrictions than the three above in that a visible Naval presence would most likely not be possible, eliminating the opportunity for close support in the event of boarding team emergency egress. To re-emphasize the point made in Chapter 5.A.2, this was the major deciding factor for a system that would enable close support by own ship while conducting boarding. Personnel safety was considered paramount, and a visible naval presence around a potentially hostile VOI would give the inspection teams the best chances of safety under all circumstances.

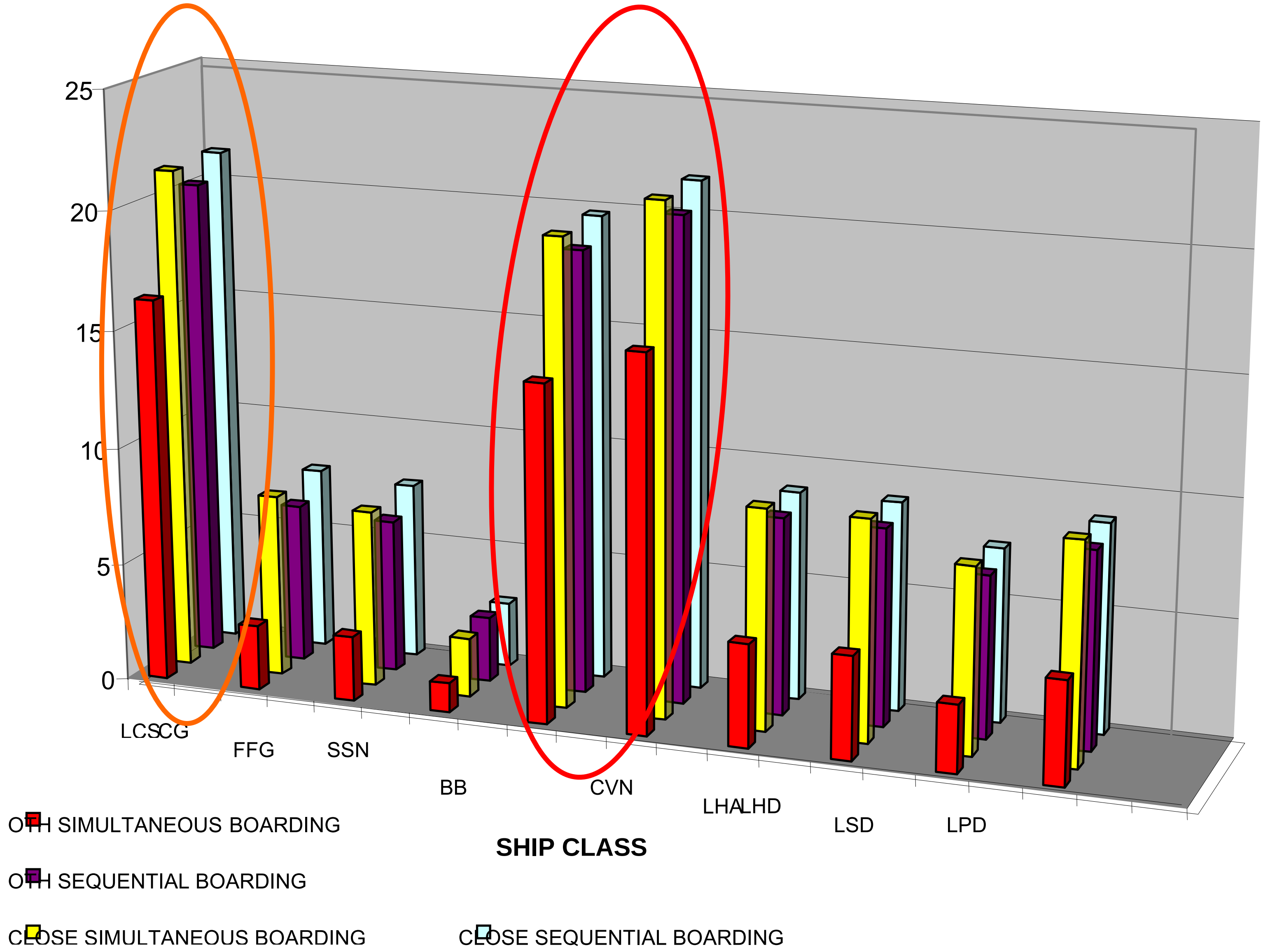


Figure 30. Ship Mission Measures of Performance

4. Conclusions

Through a measure of performance profile for all ship types as shown in Figure 31, the Single-Ship Group identified three break-out systems (ships) as their present-day, near-term, and long-term solutions for a single-ship MTR scenario:

a. Today: Nuclear-Powered Aircraft Carrier (CVN)

This option possesses nuclear propulsion which gives unlimited range at sustained high speeds with a large enough flight deck to sustain any mission. In addition, a CVN has enough storage capacity for numerous RHIB's or other intercept boats of choice with necessary command and control infrastructure to manage a major MTR operation.

b. Near-Term (Conversion): Battleship (BB) or Littoral Combat Ship (LCS)

1. A battleship possesses an endurance of 5,600 nautical miles at 35 knots, and range of 17,000 nautical miles at 20 knots. This option would require re-commissioning and necessary modifications for air support. Massive size of ship could easily accommodate larger boats for VOI boarding. 16-inch guns would give desired effect to any potentially hostile vessel. Best location for stationing would be Pearl Harbor.

2. LCS, if available, could be fitted with MTR modules for sustained operations located at numerous bases throughout the Pacific Ocean or any area of interest.

c. Long-Term (Future-Build): New Class

A new class of warship would have the capability of ranges in excess of 20,000 nautical miles without refueling at 45 to 50 knots and deliver two or more high speed boats with well-equipped passengers to multiple targets safely and effectively.

B. MULTI-SHIP, MULTI-PORT CONCEPT

1. Multi-Port Analysis

This concept would utilize the ability to intercept three or more inbound VOI's from various ports located in the Pacific Ocean, otherwise known as a "zone defense" method. A multi-port solution would reduce individual ship requirements in various ways. First, the ability to deploy from multiple ports in vicinity of the major shipping lanes would result in shorter *per ship* routes, minimizing time on full-power transits for intercept. Instead of relying on a single intercept ship for total system range, a multi-port concept would allow a much greater system range through the *combined* ranges of all ships by enabling hand-off capability of the VOI from one intercept ship to the next. Handing off of one intercept ship to another would reduce the required on-station time for an intercept ship, freeing it up for other potential boardings within its particular zone. Finally, a pre-positioned multi-port force would offer maximum maneuverability and visible Naval presence for any maritime scenario.

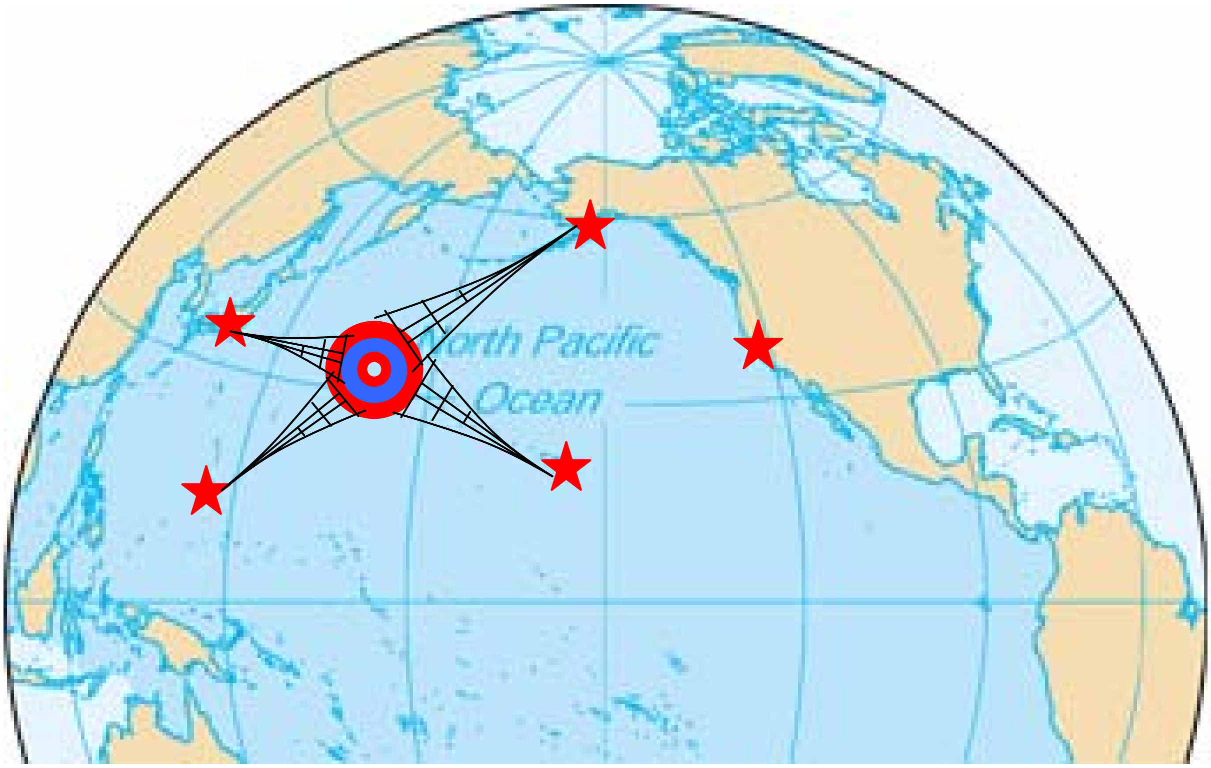
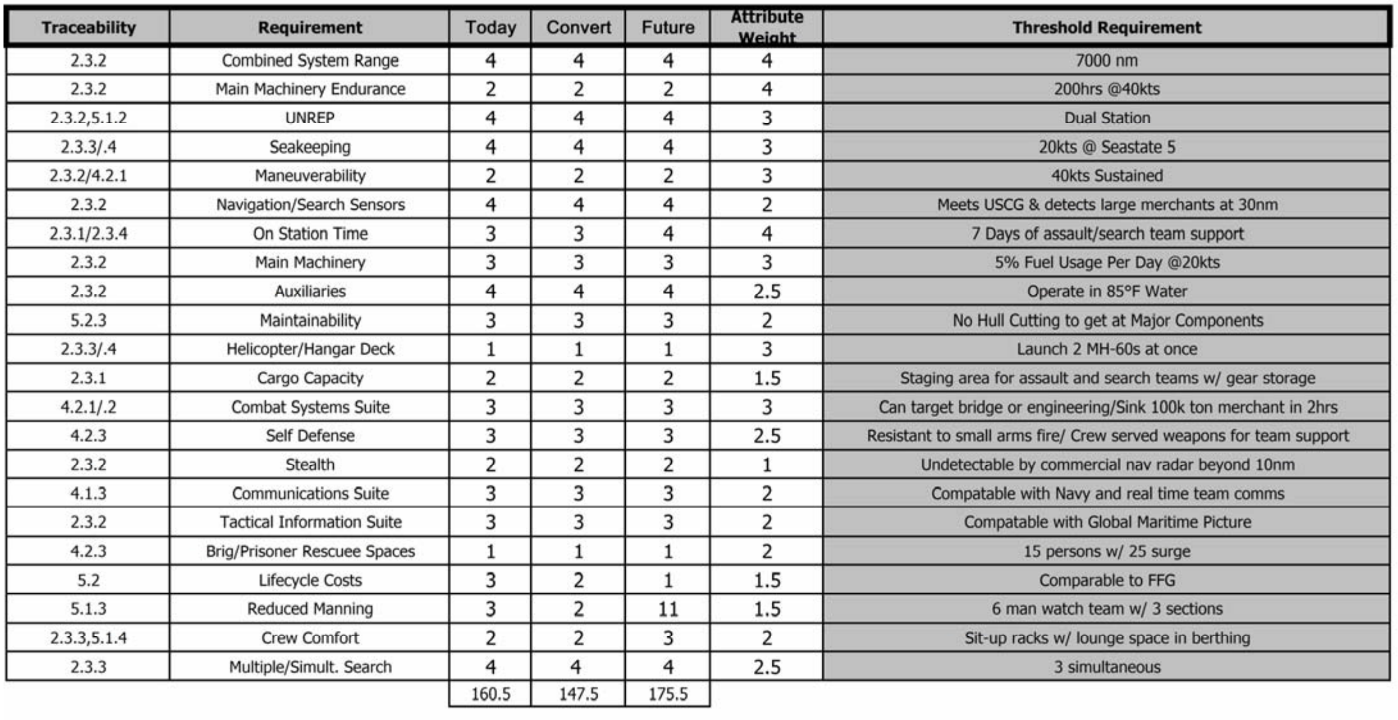


Figure 31. Multi-Port Pre-Positioned Force



Traceability	Requirement	Today	Convert	Future	Attribute Weight	Threshold Requirement
2.3.2	Combined System Range	4	4	4	4	7000 nm
2.3.2	Main Machinery Endurance	2	2	2	4	200hrs @40kts
2.3.2,5.1.2	UNREP	4	4	4	3	Dual Station
2.3.3/.4	Seakeeping	4	4	4	3	20kts @ Seastate 5
2.3.2/4.2.1	Maneuverability	2	2	2	3	40kts Sustained
2.3.2	Navigation/Search Sensors	4	4	4	2	Meets USCG & detects large merchants at 30nm
2.3.1/2.3.4	On Station Time	3	3	4	4	7 Days of assault/search team support
2.3.2	Main Machinery	3	3	3	3	5% Fuel Usage Per Day @20kts
2.3.2	Auxiliaries	4	4	4	2.5	Operate in 85°F Water
5.2.3	Maintainability	3	3	3	2	No Hull Cutting to get at Major Components
2.3.3/.4	Helicopter/Hangar Deck	1	1	1	3	Launch 2 MH-60s at once
2.3.1	Cargo Capacity	2	2	2	1.5	Staging area for assault and search teams w/ gear storage
4.2.1/.2	Combat Systems Suite	3	3	3	3	Can target bridge or engineering/Sink 100k ton merchant in 2hrs
4.2.3	Self Defense	3	3	3	2.5	Resistant to small arms fire/ Crew served weapons for team support
2.3.2	Stealth	2	2	2	1	Undetectable by commercial nav radar beyond 10nm
4.1.3	Communications Suite	3	3	3	2	Compatable with Navy and real time team comms
2.3.2	Tactical Information Suite	3	3	3	2	Compatable with Global Maritime Picture
4.2.3	Brig/Prisoner Rescuee Spaces	1	1	1	2	15 persons w/ 25 surge
5.2	Lifecycle Costs	3	2	1	1.5	Comparable to FFG
5.1.3	Reduced Manning	3	2	11	1.5	6 man watch team w/ 3 sections
2.3.3,5.1.4	Crew Comfort	2	2	3	2	Sit-up racks w/ lounge space in berthing
2.3.3	Multiple/Simult. Search	4	4	4	2.5	3 simultaneous
		160.5	147.5	175.5		

Figure 32. Multi-Ship/Multi-Port Decision Matrix

2. Conclusions

a. Today: Bases Currently Utilized

A current-day solution is to utilize Pacific bases currently in use by U.S. Armed Forces (USN/USCG):

- Yokosuka, Japan
- Pearl Harbor, Hawaii
- San Diego, California
- Everett, Washington
- Juneau, Alaska
- Alameda, California

b. Near-Term (Conversion): Bases That Could Be Utilized

A near-term solution would utilize other bases to provide more complete area coverage:

- Sasebo, Japan
- Guam
- Singapore

c. Long-Term (Future-Build)

The following are considered long-term future options that could be constructed or renovated to accommodate U.S. Armed Forces assets:

- Bases:
- Philippines
- Australia

1. Sea bases, constructed and maintained 2,000 nautical miles from San Francisco along major shipping lanes

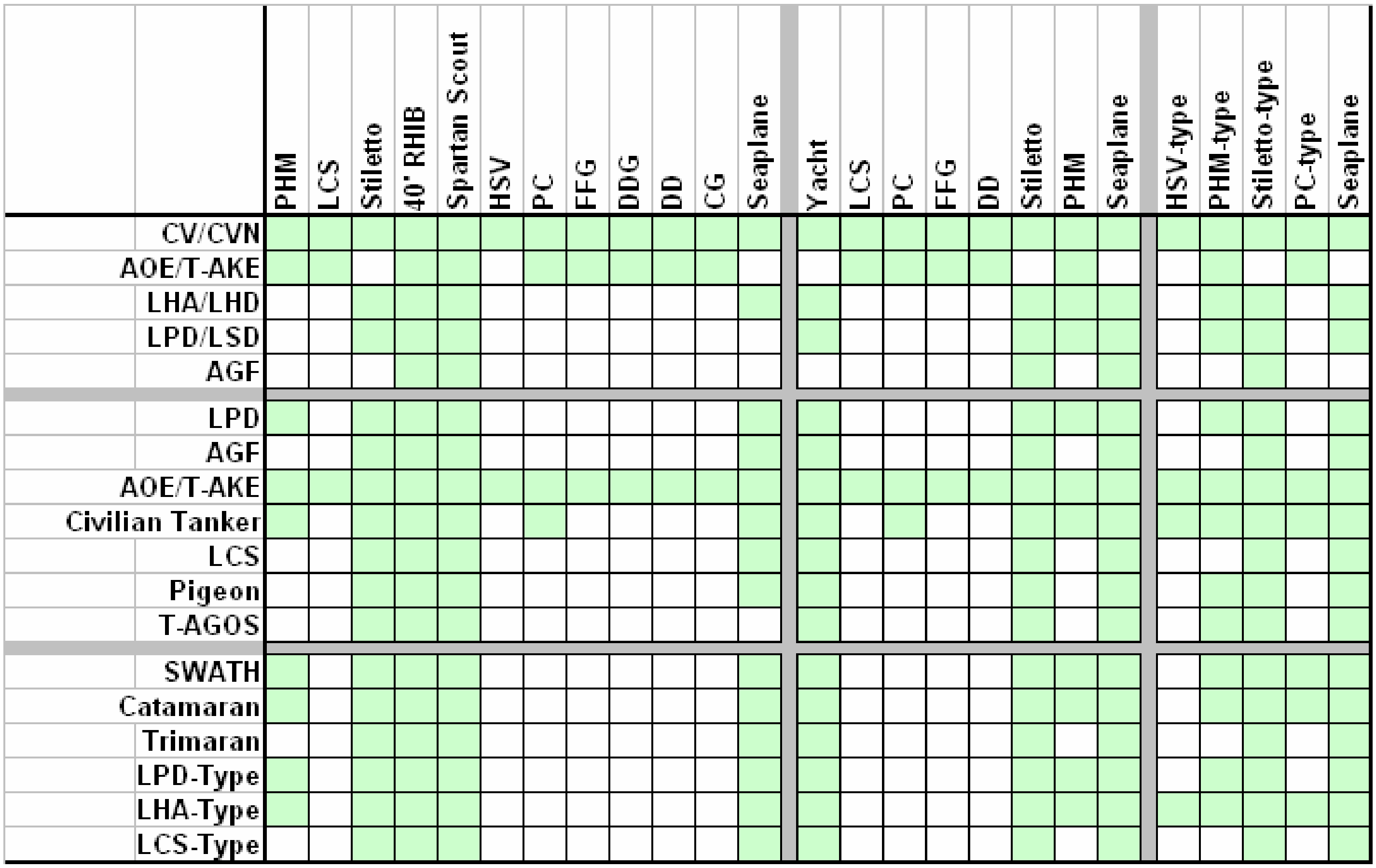
C. MOTHERSHIP/INTERCEPTOR CONCEPT

1. Analysis

The basic configuration of this concept would consist of a mothership carrying a multiple of interceptors and air assets for deployment and retrieval. To initially narrow the problem, the first step was to establish some basic attributes for each type of vessel. The mothership had to be a large, stable platform that would be able to carry at least 4 interceptors. In addition, the mothership would require aviation capabilities for at least two helicopters or two MV-22's. The engineering plant would have to sustain a speed of at least 20 knots for a range equivalent of a trans-Pacific route (approximately 9,000 nautical miles).

The interceptor had to be a small, stable platform that would be able to carry at least 30 personnel (24 passengers + 6 crew). The engineering plant would have to sustain a speed of at least 30 knots for a range equivalent of 1,500 nautical miles (500 nautical mile sprint). In addition, the interceptor would have to be self-sustaining and operate autonomously for at least 3 days.

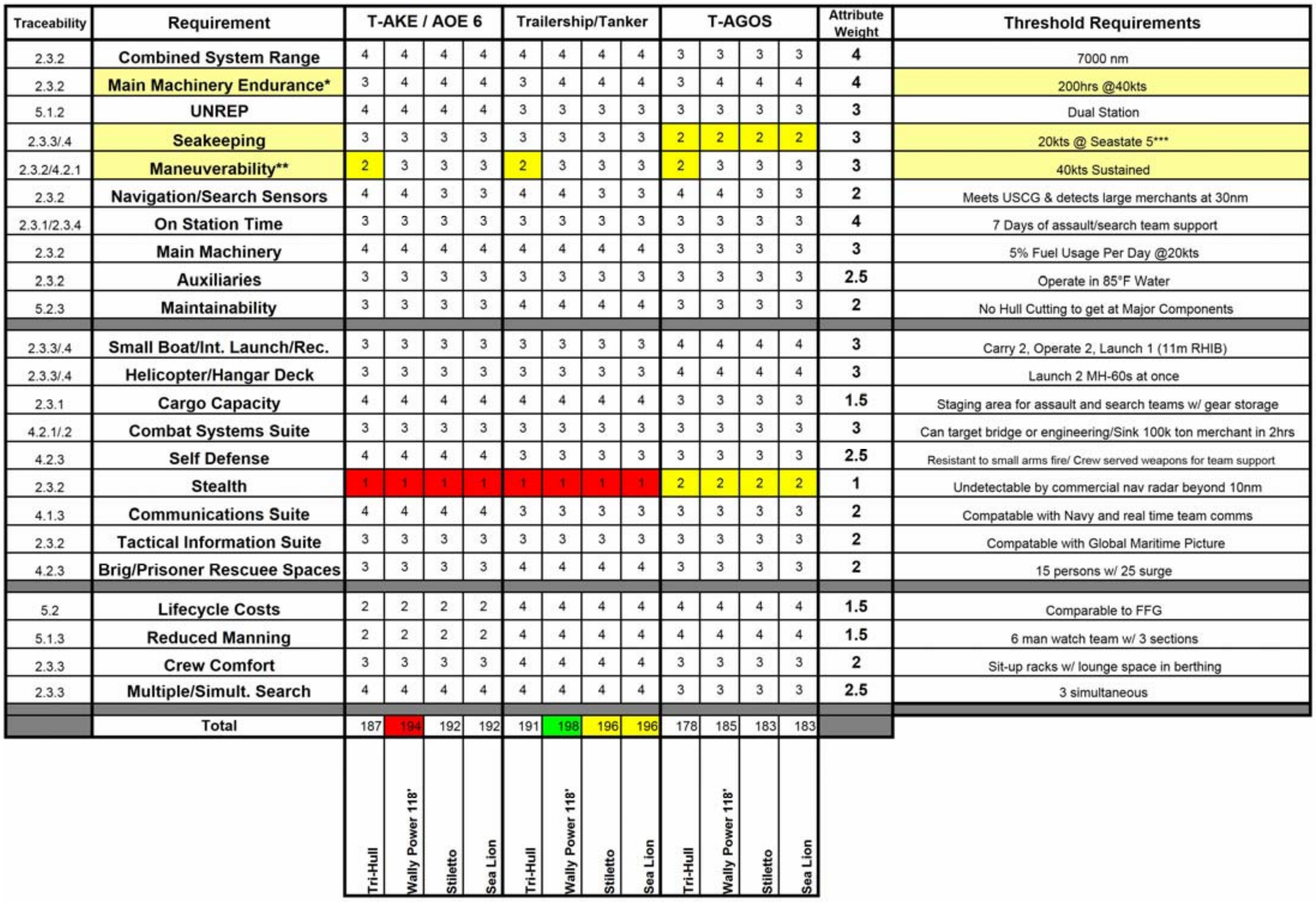
This concept provided countless possibilities. A correlation matrix, as follows, was generated based on possible choices to identify potential systems for further consideration. Shaded areas denote those combinations that were deemed feasible for further consideration, either in as-is configurations or with modifications to meet MTR requirements.



	PHM	LCS	Stiletto	40' RHIB	Spartan Scout	HSV	PC	FFG	DDG	DD	CG	Seaplane	Yacht	LCS	PC	FFG	DD	Stiletto	PHM	Seaplane	HSV-type	PHM-type	Stiletto-type	PC-type	Seaplane
CV/CVN	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
AOE/T-AKE	🟩	🟩		🟩	🟩		🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩		🟩			🟩		🟩	
LHA/LHD			🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩		🟩	🟩		🟩
LPD/LSD			🟩	🟩	🟩								🟩					🟩	🟩	🟩		🟩	🟩		🟩
AGF				🟩	🟩													🟩		🟩			🟩		
LPD	🟩		🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩		🟩	🟩		🟩
AGF			🟩	🟩	🟩							🟩	🟩					🟩		🟩			🟩		🟩
AOE/T-AKE	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Civilian Tanker	🟩		🟩	🟩	🟩		🟩					🟩	🟩		🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
LCS			🟩	🟩	🟩							🟩	🟩					🟩		🟩			🟩		🟩
Pigeon			🟩	🟩	🟩							🟩	🟩					🟩		🟩		🟩	🟩		🟩
T-AGOS			🟩	🟩	🟩								🟩					🟩		🟩		🟩	🟩		🟩
SWATH	🟩		🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩		🟩	🟩	🟩	🟩
Catamaran	🟩		🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩		🟩	🟩	🟩	🟩
Trimaran			🟩	🟩	🟩							🟩	🟩					🟩		🟩			🟩		🟩
LPD-Type	🟩		🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩		🟩	🟩		🟩
LHA-Type	🟩		🟩	🟩	🟩							🟩	🟩					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
LCS-Type			🟩	🟩	🟩							🟩	🟩					🟩		🟩			🟩		🟩

Figure 33. Mothership/Interceptor Correlation Matrix

A decision matrix, Figure 35 was then generated based on possible choices to identify potential break-out systems as a possible final solution. Although many combinations seemed feasible, two interceptors (Littoral Combat Ship (LCS), Wallypower 118’ motor yacht) emerged as best-suited for compatibility with potential motherships and in meeting the goals of the MTR mission.



Traceability	Requirement	T-AKE / AOE 6				Trailership/Tanker				T-AGOS				Attribute Weight	Threshold Requirements
		Tri-Hull	Wally Power 118'	Stiletto	Sea Lion	Tri-Hull	Wally Power 118'	Stiletto	Sea Lion	Tri-Hull	Wally Power 118'	Stiletto	Sea Lion		
2.3.2	Combined System Range	4	4	4	4	4	4	4	4	3	3	3	3	4	7000 nm
2.3.2	Main Machinery Endurance*	3	4	4	4	3	4	4	4	3	4	4	4	4	200hrs @40kts
5.1.2	UNREP	4	4	4	4	3	3	3	3	3	3	3	3	3	Dual Station
2.3.3/.4	Seakeeping	3	3	3	3	3	3	3	3	2	2	2	2	3	20kts @ Seastate 5***
2.3.2/4.2.1	Maneuverability**	2	3	3	3	2	3	3	3	2	3	3	3	3	40kts Sustained
2.3.2	Navigation/Search Sensors	4	4	3	3	4	4	3	3	4	4	3	3	2	Meets USCG & detects large merchants at 30nm
2.3.1/2.3.4	On Station Time	3	3	3	3	3	3	3	3	3	3	3	3	4	7 Days of assault/search team support
2.3.2	Main Machinery	4	4	4	4	4	4	4	4	3	3	3	3	3	5% Fuel Usage Per Day @20kts
2.3.2	Auxiliaries	3	3	3	3	3	3	3	3	3	3	3	3	2.5	Operate in 85°F Water
5.2.3	Maintainability	3	3	3	3	4	4	4	4	3	3	3	3	2	No Hull Cutting to get at Major Components
2.3.3/.4	Small Boat/Int. Launch/Rec.	3	3	3	3	3	3	3	3	4	4	4	4	3	Carry 2, Operate 2, Launch 1 (11m RHIB)
2.3.3/.4	Helicopter/Hangar Deck	3	3	3	3	3	3	3	3	4	4	4	4	3	Launch 2 MH-60s at once
2.3.1	Cargo Capacity	4	4	4	4	4	4	4	4	3	3	3	3	1.5	Staging area for assault and search teams w/ gear storage
4.2.1/.2	Combat Systems Suite	3	3	3	3	3	3	3	3	3	3	3	3	3	Can target bridge or engineering/Sink 100k ton merchant in 2hrs
4.2.3	Self Defense	4	4	4	4	3	3	3	3	3	3	3	3	2.5	Resistant to small arms fire/ Crew served weapons for team support
2.3.2	Stealth	1	1	1	1	1	1	1	1	2	2	2	2	1	Undetectable by commercial nav radar beyond 10nm
4.1.3	Communications Suite	4	4	4	4	3	3	3	3	3	3	3	3	2	Compatable with Navy and real time team comms
2.3.2	Tactical Information Suite	3	3	3	3	3	3	3	3	3	3	3	3	2	Compatable with Global Maritime Picture
4.2.3	Brig/Prisoner Rescuee Spaces	3	3	3	3	4	4	4	4	3	3	3	3	2	15 persons w/ 25 surge
5.2	Lifecycle Costs	2	2	2	2	4	4	4	4	4	4	4	4	1.5	Comparable to FFG
5.1.3	Reduced Manning	2	2	2	2	4	4	4	4	4	4	4	4	1.5	6 man watch team w/ 3 sections
2.3.3	Crew Comfort	3	3	3	3	4	4	4	4	3	3	3	3	2	Sit-up racks w/ lounge space in berthing
2.3.3	Multiple/Simult. Search	4	4	4	4	4	4	4	4	3	3	3	3	2.5	3 simultaneous
	Total	187	194	192	192	191	198	196	196	178	185	183	183		

Figure 34. Mothership/Interceptor Decision Matrix

2. Conclusions

a. Today: Amphibious Ship/MK-5 or Oiler/PC, LCS, or FFG

Two options were identified:

- An amphibious ship (or some variant) possesses the capacity to carry several MK-5 interceptors. Potentially long intercept routes for a MK-5 in high sea states would, however, result in poor crew conditions. The MK-5 interceptor would be limited in its ability for extended duration, independent operations.

Figure 35. Amphibious Ship with MK-5 Interceptor

- A small group of ships resembling a Search Action Group (SAG), consisting of an oiler-type platform (mothership) and other surface ships (interceptors), gives extended system ranges due to the mothership having the capability to refuel its own interceptors. In addition, each interceptor is a surface combatant itself, capable of extended duration, independent operations.

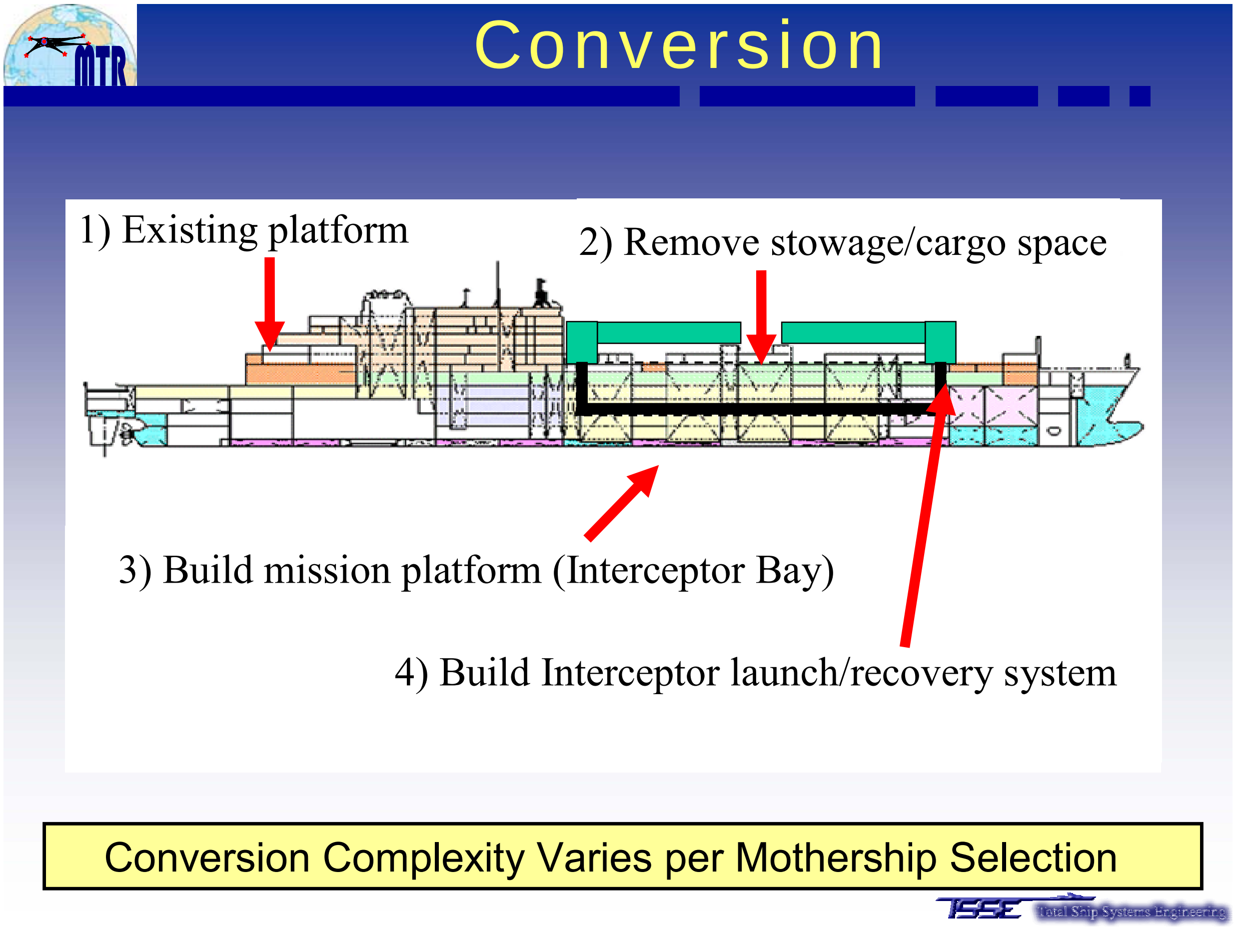
Figure 36. Oiler Ship with Coastal Patrol Ship (PC), Littoral Combat Ship (LCS), Guided-Missile Fast Frigate (FFG)

b. Near-Term (Conversion): Mothership

Due to the vast number of interceptors to choose from with countless capabilities and dimensions, a near-term solution would consist of a large ship conversion to build what would be considered the ideal mothership. With the interceptors requiring no outer hull configurations or dimensional changes, the new mothership would contain conversion specifications to accommodate the interceptors. The WallyPower motor yacht would become the primary interceptor of choice.

Figure 37. Container/Trailer Ship with WallyPower Motor Yacht

The larger ships selected for further consideration for mothership conversion were the container/trailer and military/merchant oiler ships (AOE/T-AKE). Figure 39 shows how a basic conversion to a container/trailer ship might look.



Conversion

1) Existing platform

2) Remove stowage/cargo space

3) Build mission platform (Interceptor Bay)

4) Build Interceptor launch/recovery system

Conversion Complexity Varies per Mothership Selection

Figure 38. Container/Trailer Ship Conversion

c. Long-Term (Future-Build): New Class

A new class of mothership would have the capability of ranges in excess of 20,000 nautical miles without refueling at sustained speeds at over 20 knots. In addition, this mothership would possess the capability to carry, deploy, and retrieve at least 5 WallyPower-size Interceptors.

D. FINAL CONCLUSIONS

1. Summary of Analysis of Alternatives (A0A)

a. Single-Ship

The nuclear-powered aircraft carrier scored the highest numerically of but policy issues may not consider its use in an MTR scenario. In addition, it is unlikely that a CVN would enter into this type of scenario unaccompanied, so it is assumed that an entire Battle Group would be utilized for this type of mission.

b. Multi-Ship/Multi-Port

A multi-port option allows a significant reduction in time-to-station and endurance parameters, and thus the required number of interceptors to be reduced. This removal of constraints allows for reasonable parameters of a future design.

The Littoral Combat Ship (LCS) and guided-missile frigate (FFG) scored numerically similar to the interceptors; however, lifecycle costs would dramatically increase as interceptor size increases (ex. DDG, CG) without added MOE benefits.

c. Mothership/Interceptor

The ship conversion system (Trailership/WallyPower) scored the highest numerically. It was considered that additional investigation may lower conversion costs and increase survivability.

2. Final Recommendations

As a function of urgency and cost, it was necessary to consider what was available in present day and what could be converted in the short-term (5 years) to provide an adequate solution to the MTR mission.

a. Today's Solution

Deploy a CVN Battle Group or an Oiler accompanied by either one or more fast frigates or Littoral Combat Ship (if available).

b. Near-Term Solution

Convert a container/trailer ship to carry multiple interceptors (WallyPower).

c. Long-Term Solution

Design from the keel up a new mothership that, as production numbers increase, could be less expensive than future conversions of existing hull forms.

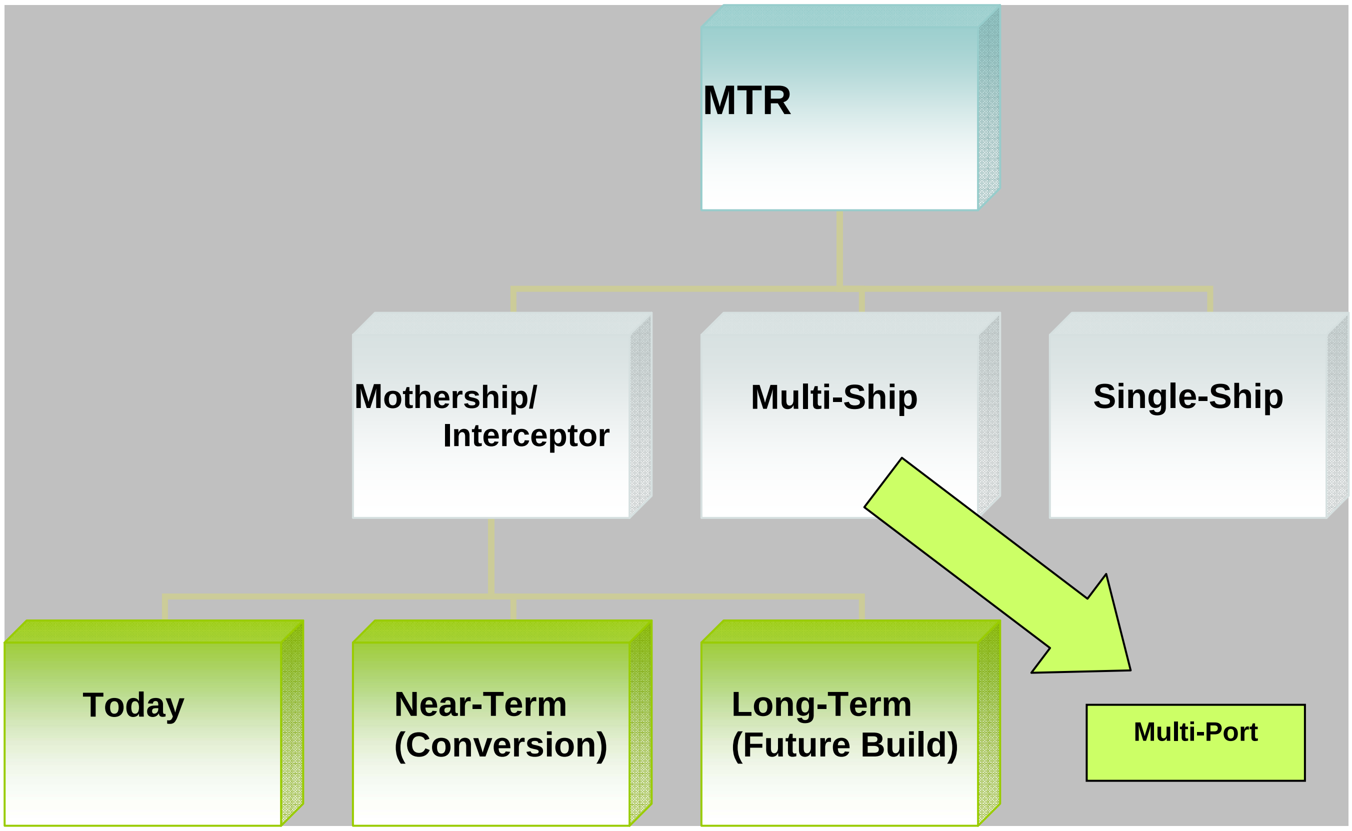


Figure 39. Analysis of Alternatives Results

At the conclusion of this analysis, it was realized that a multi-ship, multi-port system architecture consisting of motherships carrying a multiple of interceptors strategically placed at different ports would provide the best chances of combating any potential MTR threat. The next phase of analysis would become more specific by analyzing potential mothership/interceptor solutions.

E. SEA-9 INTERFACE

During TSSE's presentation of findings in March 2006, SEA-9 decided to pursue a *today* solution, consisting of an oiler-type platform combined with a fast-frigate (FFG) or Littoral Combat Ship (LCS), for future investigation. The TSSE Team, recognizing the need to pursue a project that would end up with an eventual ship design, decided to pursue a mothership/interceptor concept that would include either a near-term conversion or future-build option of a large ship.

VI. ANALYSIS OF ALTERNATIVES (MOTHERSHIP/INTERCEPTOR)

A. NARROWING THE PROBLEM

Now that the TSSE Team had a mothership/interceptor model to work with, it was time to consider the many possible combinations and eliminate all but the best one for further investigation and eventual design. Re-emphasizing the near-term concept for analysis, it must be relevant and within the 5-year horizon for building, and most importantly, satisfy the CONOPS.

1. CONOPS Revisited

With details of how the CONOPS still undecided, it was necessary for the TSSE Team to go back and review the available options. Previous assumptions cited in Chapter 1 still assumed valid, a typical sequence of events was reviewed:

<u>Day 1</u>

- Ships sail out of Hong Kong/Singapore

<u>Day 2</u>

- Joint Task Force (JTF) MTR activated
- 24-hour sail order issued
- By day 4, MTR system is on trade route ahead of all inbound merchants

<u>Day 4</u>

- Boardings commence on inbounds from Hong Kong
- Second MTR system sails to intercept vessels out of Singapore

<u>Initial Boarding Sequence</u>

- Interceptor brings boarding team for ISI
- MTR boarding kit airlifted from Mothership after ISI complete
- Merchant and interceptor travel together without impeding speed of commerce throughout inspection

Boarding Operations

The sequence of events was constant up through the initial boarding sequence; however, it was beyond this point unclear as to how the sequence should progress. The options are listed below:

Option 1

Interceptors remain alongside merchants throughout operation (Either long-range or towed by merchant)

Option 2

Interceptors provide limited logistics and crew swap support on approximately 12-hour intervals.

Option 3

Single interceptor provides “shuttle” support for multiple boarding teams/multiple merchants.

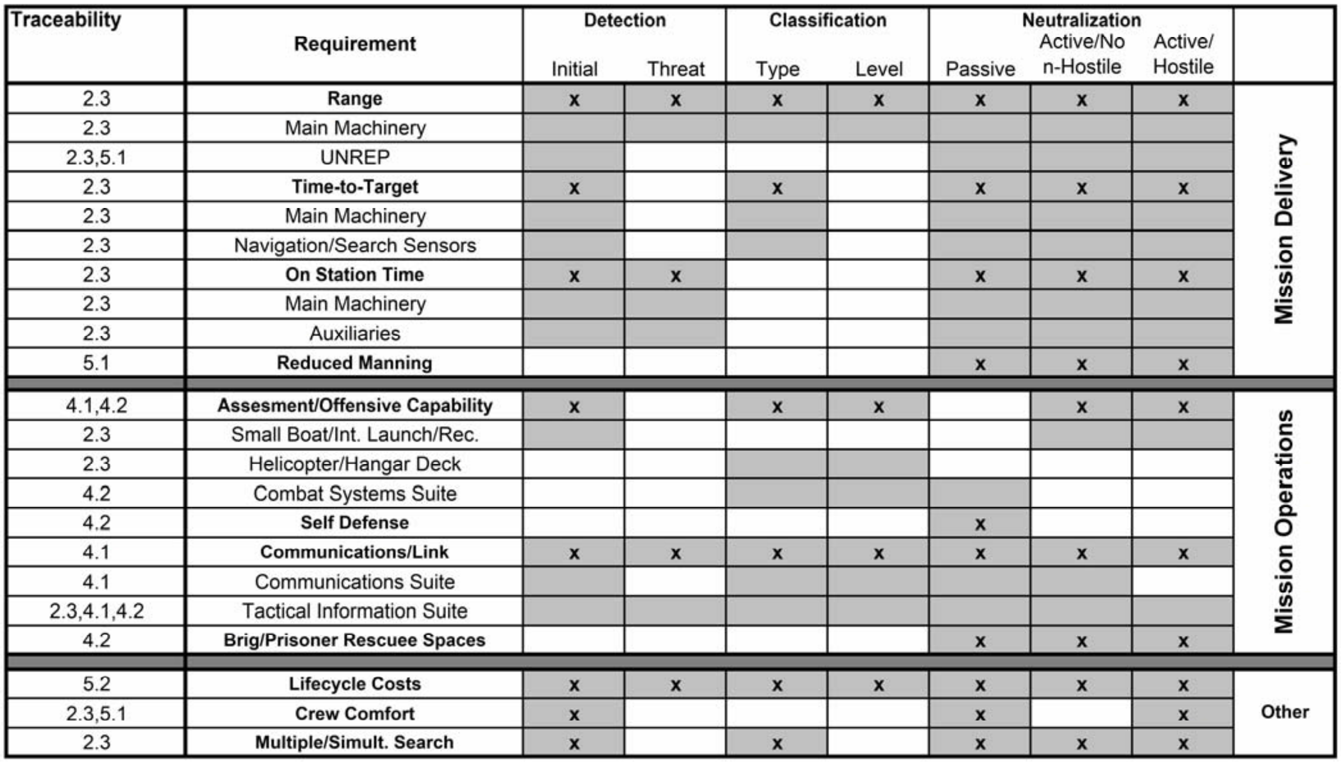
Option 4

Interceptors remain alongside merchants until relieved on station by other interceptors.

Before selecting the best option, it was realized that more stakeholder input would be required. This is revisited again in part B of this chapter.

2. Requirements Revisited

The next step of development was to review the initial requirements and see where changes needed to occur. Through this *refinement* of requirements, a single mothership/interceptor combination would emerge as the final solution for TSSE Team design. Although the mission would be accomplished through a coordinated effort of both the mothership and the interceptor, it was necessary to determine which platform would carry the predominant role of specific requirements for the entire system. For example, endurance/range would primarily reside with one platform while speed/sprint capability would primarily reside with the other one. While both platforms would possess self-defense capability, one would be predominantly chosen for offensive capability for disabling or sinking a hostile VOI.



Traceability	**Requirement**	**Detection**		**Classification**		**Neutralization**			
		Initial	Threat	Type	Level	Passive	Active/Non-Hostile	Active/Hostile	
2.3	**Range**	x	x	x	x	x	x	x	**Mission Delivery**
2.3	Main Machinery	▨	▨	▨	▨	▨	▨	▨	
2.3,5.1	UNREP	▨				▨	▨	▨	
2.3	**Time-to-Target**	x		x		x	x	x	
2.3	Main Machinery	▨		▨		▨	▨	▨	
2.3	Navigation/Search Sensors	▨		▨		▨	▨	▨	
2.3	**On Station Time**	x	x			x	x	x	
2.3	Main Machinery	▨	▨			▨	▨	▨	
2.3	Auxiliaries	▨	▨			▨	▨	▨	
5.1	**Reduced Manning**					x	x	x	
4.1,4.2	**Assesment/Offensive Capability**	x		x	x		x	x	**Mission Operations**
2.3	Small Boat/Int. Launch/Rec.	▨					▨	▨	
2.3	Helicopter/Hangar Deck			▨	▨				
4.2	Combat Systems Suite			▨	▨	▨			
4.2	**Self Defense**					x			
4.1	**Communications/Link**	x	x	x	x	x	x	x	
4.1	Communications Suite	▨		▨	▨	▨	▨		
2.3,4.1,4.2	Tactical Information Suite	▨	▨	▨	▨	▨	▨	▨	
4.2	**Brig/Prisoner Rescuee Spaces**					x	x	x	
5.2	**Lifecycle Costs**	x	x	x	x	x	x	x	**Other**
2.3,5.1	**Crew Comfort**	x				x		x	
2.3	**Multiple/Simult. Search**	x		x		x	x	x	

Figure 40. Initial MTR Requirements/Needs Correlation Matrix

a. Mothership Attributes

The TSSE Team decided that the mothership must be able to sustain a 10,000 nautical-mile endurance range at a cruising speed of at least 20 knots. In addition, it must have enough cargo space to embark all air, interceptor, and DOE inspection teams and necessary support gear for sustained independent operations. The mothership must have enough stability to safely deploy/retrieve interceptors and air assets, up to sea state 5, if necessary. Since offensive capability (disable/sink) would reside primarily with the mothership, it would require robust tactical and combat suites in addition to command-and-control to fully carry out the requirements of such a mission. Mothership refined requirements are shown as follows.

The following motherships were considered:

- Roll-On, Roll-Off (RO-RO)
  - Container/Trailership
- Multi-hulled vessel (ex. Trimaran)
  - High-speed ferry
- Heavy-lift ship
  - Amphibious (LPD/LSD)

b. Interceptor Attributes

The interceptor, on the other hand, would be required to sustain a significant endurance range at a cruising speed of at least 20 knots. Aiding in achieving that task would be a much smaller hull form with minimal provisions and capability in order to maximize speed. The interceptor would be fitted with weapons for self-defense capability. Since overall operations would be directed by the mothership, minimal provisions for tactical and combat suites would be necessary. The goal for the interceptor would be to have a design to carry out the mission with as minimal manning as possible, but at least have enough capacity for boarding team transport. Interceptor refined requirements are shown in Figure 42.

The following interceptors were considered:

- High-speed displacement mono-hull
- Advanced hull lightweight craft
- Planing mono-hull
- Patrol craft variant
- Seaplane
- Hovercraft
- Hydrofoil

The TSSE Team took the refined requirements and broke up into several groups which would investigate all categories of motherships and interceptors. Once the investigation was completed, the refined requirements matrices were filled in with representative data from research. This allowed immediate elimination of vessel types considered too far outside the bounds of requirements. The question still remained, however, as to which CONOPS was best, and which combination of vessels would meet that particular CONOPS.

3. Stakeholders Revisited

It was now necessary to obtain feedback from the stakeholders for final CONOPS resolution. A questionnaire was disseminated among NPS faculty, SEA-9 and TSSE students to compare different CONOPS and mothership/interceptor possibilities. The responses from the questionnaires enabled the TSSE Team to derive a final CONOPS solution and guidance as how to weight specific attributes of the MOE matrices. A sample questionnaire is included as an appendix. Some key points were derived from the questionnaire and are summarized below:

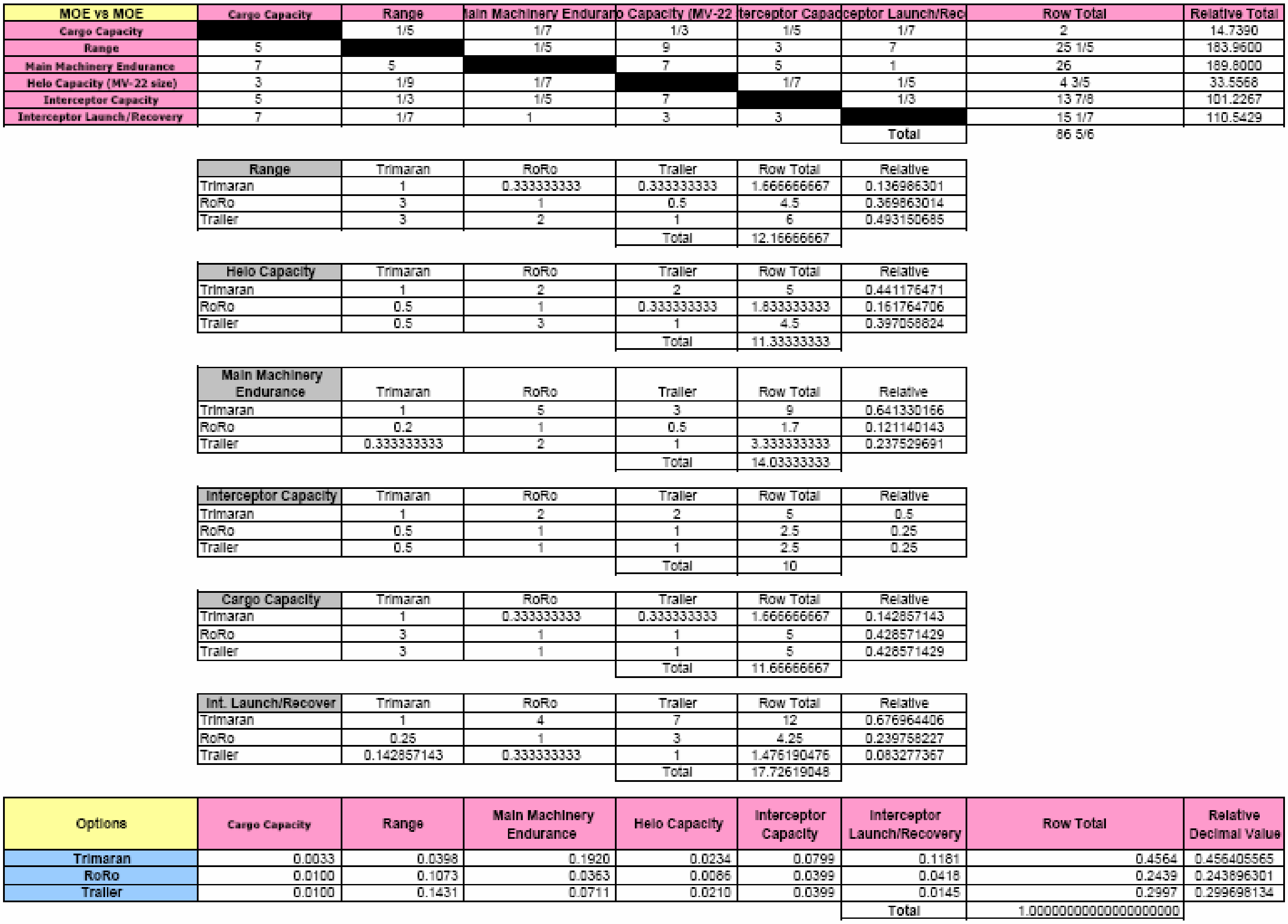
- General comments
    - Interceptors should not be towed, but should maintain continuous or nearly continuous coverage.
    - One mothership should be able to search up to 5
    - VOI's at a time.
    - Aviation and medical support are desirable, but not mission-critical.
    - A 12-hour maximum delay in commerce is acceptable.
- Mothership
    - Stern launch/recovery is much preferred to side launch/recovery.
    - Mission accomplishment (station keeping) is vital to the mission.
- Interceptor
    - High cruising range at 20 knots is vital.
    - Berthing must be able to accommodate 12-man berthing plus necessary crew.
    - Limited provisions (MRE/pre-packaged foods) are acceptable for duration of mission.

B. FINAL CONOPS SELECTION

The key points of the questionnaire provided the needed direction to finalize CONOPS boarding operations. Boarding Option 4 (interceptors remain alongside merchants until relieved on station by other interceptors) was chosen overall. A typical boarding sequence would require the mothership to strategically drop off an interceptor, with attached boarding team, for pursuit to a specific VOI. An optimal placement of the interceptor would allow it to *cruise* to the intended target; a non-optimal placement would require an interceptor to *sprint* to its intended target. Upon arrival, the inspection team would board the VOI. Weather, sea state conditions permitting and with VOI approval, inspection equipment transfer would occur at that time. For inclement conditions where personnel and/or equipment personnel are/is not feasible, transfer could occur via air drop from an organic air asset. The interceptor would remain in vicinity of the VOI for duration of the search. Due to an expected VOI search lasting less than 7 days, the interceptor would be expected to carry out assigned duties without relief. For a mission extending to 7 days, the interceptor would require temporary relief for refueling. This could be accomplished by another interceptor (optimal) or by organic air asset. Either method would ensure adequate VOI surveillance is maintained at all times. The interceptor would not require mothership recovery for refueling.

C. FINAL MOTHERSHIP/INTERCEPTOR SELECTION

Now in possession of a final CONOPS, it was possible to derive a final solution consisting of one mothership and one interceptor that could support that CONOPS. The remaining choices were narrowed down to three mothership and four interceptor candidates. To transform the refined requirements matrix into a *decision* matrix, specific weighting factors had to be added based on stakeholder input. Utilizing the Analytic Hierarchy Process (AHP) method of weight factoring, the key performance parameters (KPP) for each platform were predominantly compared against each other by possessing the highest weight factors. These concepts are illustrated in the following figures.



MOE vs MOE	Cargo Capacity	Range	lain Machinery Endurar	o Capacity (MV-22	terceptor Capac	ceptor Launch/Rec	Row Total	Relative Total
Cargo Capacity		1/5	1/7	1/3	1/5	1/7	2	14.7390
Range	5		1/5	9	3	7	25 1/5	183.9600
Main Machinery Endurance	7	5		7	5	1	26	189.8000
Helo Capacity (MV-22 size)	3	1/9	1/7		1/7	1/5	4 3/5	33.5568
Interceptor Capacity	5	1/3	1/5	7		1/3	13 7/8	101.2267
Interceptor Launch/Recovery	7	1/7	1	3	3		15 1/7	110.5429
						Total	86 5/6	

Range	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	0.333333333	0.333333333	1.666666667	0.136986301
RoRo	3	1	0.5	4.5	0.369863014
Trailer	3	2	1	6	0.493150685
			Total	12.16666667	

Helo Capacity	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	2	2	5	0.441176471
RoRo	0.5	1	0.333333333	1.833333333	0.161764706
Trailer	0.5	3	1	4.5	0.397058824
			Total	11.33333333	

Main Machinery Endurance	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	5	3	9	0.641330166
RoRo	0.2	1	0.5	1.7	0.121140143
Trailer	0.333333333	2	1	3.333333333	0.237529691
			Total	14.03333333	

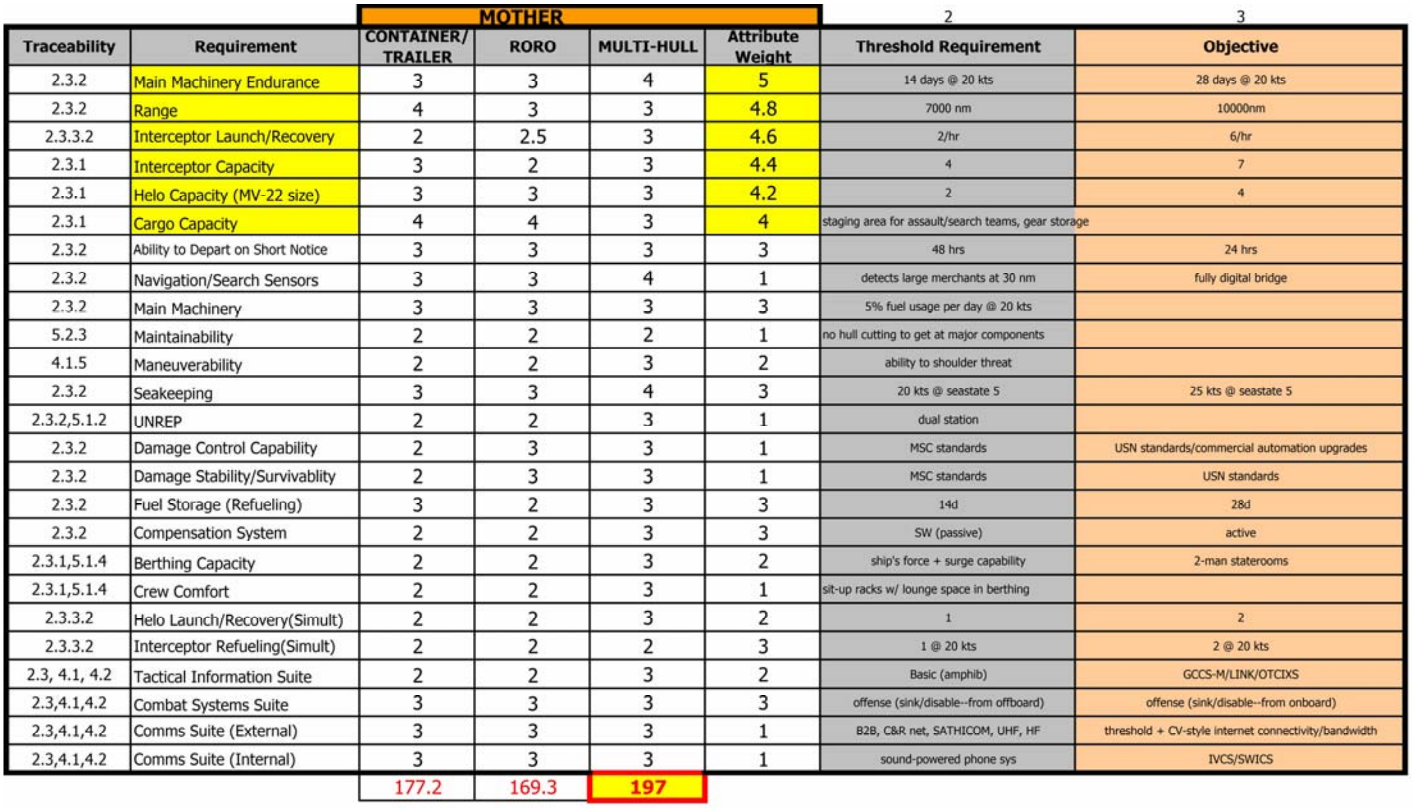
Interceptor Capacity	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	2	2	5	0.5
RoRo	0.5	1	1	2.5	0.25
Trailer	0.5	1	1	2.5	0.25
			Total	10	

Cargo Capacity	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	0.333333333	0.333333333	1.666666667	0.142857143
RoRo	3	1	1	5	0.428571429
Trailer	3	1	1	5	0.428571429
			Total	11.66666667	

Int. Launch/Recover	Trimaran	RoRo	Trailer	Row Total	Relative
Trimaran	1	4	7	12	0.676964406
RoRo	0.25	1	3	4.25	0.239758227
Trailer	0.142857143	0.333333333	1	1.476190476	0.083277367
			Total	17.72619048	

Options	Cargo Capacity	Range	Main Machinery Endurance	Helo Capacity	Interceptor Capacity	Interceptor Launch/Recovery	Row Total	Relative Decimal Value
Trimaran	0.0033	0.0398	0.1920	0.0234	0.0799	0.1181	0.4564	0.456405565
RoRo	0.0100	0.1073	0.0363	0.0086	0.0399	0.0418	0.2439	0.243896301
Trailer	0.0100	0.1431	0.0711	0.0210	0.0399	0.0145	0.2997	0.299698134
						Total	1.0000000000000000000	

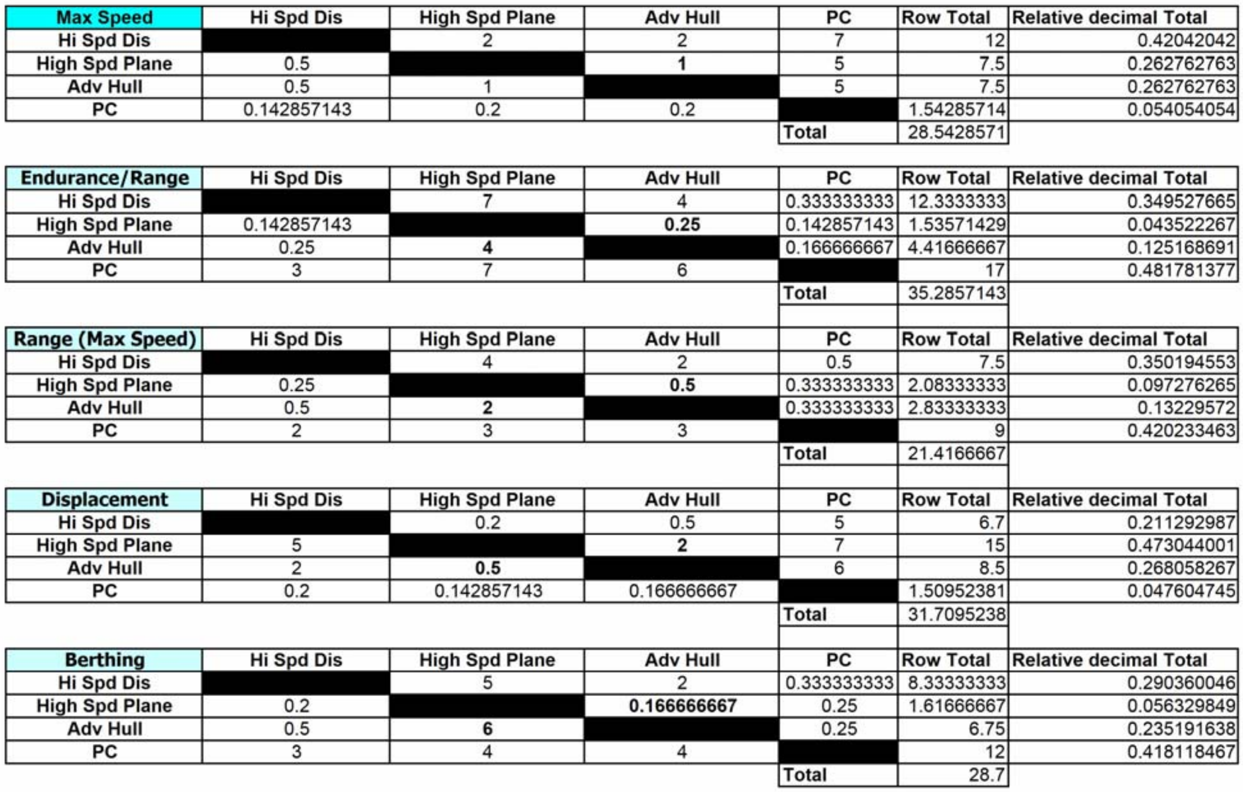
Figure 41. Mothership AHP Weight Factors



		MOTHER				2	3
Traceability	**Requirement**	**CONTAINER/ TRAILER**	**RORO**	**MULTI-HULL**	**Attribute Weight**	**Threshold Requirement**	**Objective**
2.3.2	Main Machinery Endurance	3	3	4	5	14 days @ 20 kts	28 days @ 20 kts
2.3.2	Range	4	3	3	4.8	7000 nm	10000nm
2.3.3.2	Interceptor Launch/Recovery	2	2.5	3	4.6	2/hr	6/hr
2.3.1	Interceptor Capacity	3	2	3	4.4	4	7
2.3.1	Helo Capacity (MV-22 size)	3	3	3	4.2	2	4
2.3.1	Cargo Capacity	4	4	3	4	staging area for assault/search teams, gear storage	
2.3.2	Ability to Depart on Short Notice	3	3	3	3	48 hrs	24 hrs
2.3.2	Navigation/Search Sensors	3	3	4	1	detects large merchants at 30 nm	fully digital bridge
2.3.2	Main Machinery	3	3	3	3	5% fuel usage per day @ 20 kts	
5.2.3	Maintainability	2	2	2	1	no hull cutting to get at major components	
4.1.5	Maneuverability	2	2	3	2	ability to shoulder threat	
2.3.2	Seakeeping	3	3	4	3	20 kts @ seastate 5	25 kts @ seastate 5
2.3.2,5.1.2	UNREP	2	2	3	1	dual station	
2.3.2	Damage Control Capability	2	3	3	1	MSC standards	USN standards/commercial automation upgrades
2.3.2	Damage Stability/Survivablity	2	3	3	1	MSC standards	USN standards
2.3.2	Fuel Storage (Refueling)	3	2	3	3	14d	28d
2.3.2	Compensation System	2	2	3	3	SW (passive)	active
2.3.1,5.1.4	Berthing Capacity	2	2	3	2	ship's force + surge capability	2-man staterooms
2.3.1,5.1.4	Crew Comfort	2	2	3	1	sit-up racks w/ lounge space in berthing	
2.3.3.2	Helo Launch/Recovery(Simult)	2	2	3	2	1	2
2.3.3.2	Interceptor Refueling(Simult)	2	2	2	3	1 @ 20 kts	2 @ 20 kts
2.3, 4.1, 4.2	Tactical Information Suite	2	2	3	2	Basic (amphib)	GCCS-M/LINK/OTCIXS
2.3,4.1,4.2	Combat Systems Suite	3	3	3	3	offense (sink/disable--from offboard)	offense (sink/disable--from onboard)
2.3,4.1,4.2	Comms Suite (External)	3	3	3	1	B2B, C&R net, SATHICOM, UHF, HF	threshold + CV-style internet connectivity/bandwidth
2.3,4.1,4.2	Comms Suite (Internal)	3	3	3	1	sound-powered phone sys	IVCS/SWICS
		177.2	169.3	**197**			

Figure 42. Mothership AOA with AHP Weight Factors

The multi-hull ship (trimaran) emerged as the best solution due its superior main machinery endurance, maneuverability, sea keeping, and potential interceptor launch/recovery rate.



Max Speed	Hi Spd Dis	High Spd Plane	Adv Hull	PC	Row Total	Relative decimal Total
Hi Spd Dis		2	2	7	12	0.42042042
High Spd Plane	0.5		**1**	5	7.5	0.262762763
Adv Hull	0.5	1		5	7.5	0.262762763
PC	0.142857143	0.2	0.2		1.54285714	0.054054054
				Total	28.5428571	

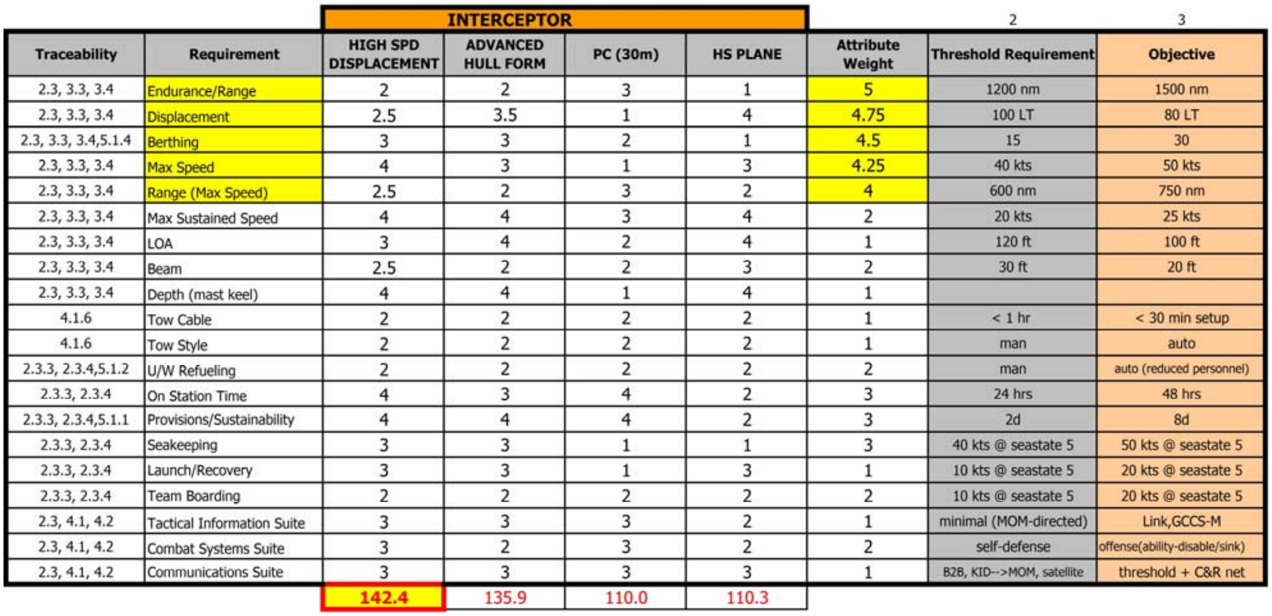
Endurance/Range	Hi Spd Dis	High Spd Plane	Adv Hull	PC	Row Total	Relative decimal Total
Hi Spd Dis		7	4	0.333333333	12.3333333	0.349527665
High Spd Plane	0.142857143		**0.25**	0.142857143	1.53571429	0.043522267
Adv Hull	0.25	**4**		0.166666667	4.41666667	0.125168691
PC	3	7	6		17	0.481781377
				Total	35.2857143	

Range (Max Speed)	Hi Spd Dis	High Spd Plane	Adv Hull	PC	Row Total	Relative decimal Total
Hi Spd Dis		4	2	0.5	7.5	0.350194553
High Spd Plane	0.25		**0.5**	0.333333333	2.08333333	0.097276265
Adv Hull	0.5	**2**		0.333333333	2.83333333	0.13229572
PC	2	3	3		9	0.420233463
				Total	21.4166667	

Displacement	Hi Spd Dis	High Spd Plane	Adv Hull	PC	Row Total	Relative decimal Total
Hi Spd Dis		0.2	0.5	5	6.7	0.211292987
High Spd Plane	5		**2**	7	15	0.473044001
Adv Hull	2	**0.5**		6	8.5	0.268058267
PC	0.2	0.142857143	0.166666667		1.50952381	0.047604745
				Total	31.7095238	

Berthing	Hi Spd Dis	High Spd Plane	Adv Hull	PC	Row Total	Relative decimal Total
Hi Spd Dis		5	2	0.333333333	8.33333333	0.290360046
High Spd Plane	0.2		**0.166666667**	0.25	1.61666667	0.056329849
Adv Hull	0.5	**6**		0.25	6.75	0.235191638
PC	3	4	4		12	0.418118467
				Total	28.7	

Figure 43. Interceptor AHP Weight Factors



		INTERCEPTOR					2	3
Traceability	**Requirement**	**HIGH SPD DISPLACEMENT**	**ADVANCED HULL FORM**	**PC (30m)**	**HS PLANE**	**Attribute Weight**	**Threshold Requirement**	**Objective**
2.3, 3.3, 3.4	Endurance/Range	2	2	3	1	5	1200 nm	1500 nm
2.3, 3.3, 3.4	Displacement	2.5	3.5	1	4	4.75	100 LT	80 LT
2.3, 3.3, 3.4,5.1.4	Berthing	3	3	2	1	4.5	15	30
2.3, 3.3, 3.4	Max Speed	4	3	1	3	4.25	40 kts	50 kts
2.3, 3.3, 3.4	Range (Max Speed)	2.5	2	3	2	4	600 nm	750 nm
2.3, 3.3, 3.4	Max Sustained Speed	4	4	3	4	2	20 kts	25 kts
2.3, 3.3, 3.4	LOA	3	4	2	4	1	120 ft	100 ft
2.3, 3.3, 3.4	Beam	2.5	2	2	3	2	30 ft	20 ft
2.3, 3.3, 3.4	Depth (mast keel)	4	4	1	4	1		
4.1.6	Tow Cable	2	2	2	2	1	< 1 hr	< 30 min setup
4.1.6	Tow Style	2	2	2	2	1	man	auto
2.3.3, 2.3.4,5.1.2	U/W Refueling	2	2	2	2	2	man	auto (reduced personnel)
2.3.3, 2.3.4	On Station Time	4	3	4	2	3	24 hrs	48 hrs
2.3.3, 2.3.4,5.1.1	Provisions/Sustainability	4	4	4	2	3	2d	8d
2.3.3, 2.3.4	Seakeeping	3	3	1	1	3	40 kts @ seastate 5	50 kts @ seastate 5
2.3.3, 2.3.4	Launch/Recovery	3	3	1	3	1	10 kts @ seastate 5	20 kts @ seastate 5
2.3.3, 2.3.4	Team Boarding	2	2	2	2	2	10 kts @ seastate 5	20 kts @ seastate 5
2.3, 4.1, 4.2	Tactical Information Suite	3	3	3	2	1	minimal (MOM-directed)	Link,GCCS-M
2.3, 4.1, 4.2	Combat Systems Suite	3	2	3	2	2	self-defense	offense(ability-disable/sink)
2.3, 4.1, 4.2	Communications Suite	3	3	3	3	1	B2B, KID-->MOM, satellite	threshold + C&R net
		142.4	135.9	110.0	110.3			

Figure 44. Interceptor AOA with AHP Weight Factors

The high-speed displacement ship (WallyPower) emerged as the best solution due its superior speed, cargo/berthing capacity, on-station time, seakeeping, and sustainability. In addition, this platform possessed desirable volume and weight dimensions for transport within a mothership and subsequent launch and retrieval.

Highest weighting of those attributes deemed most important by the stakeholders ensured that the final selection of the two platforms would be the best solution. This method enabled alternative architecture comparison with a final break-out system consisting of a trimaran mothership and a high-speed displacement interceptor, which became the TSSE Team's solution to the MTR mission CONOPS. A typical representation is shown in Figure 46.

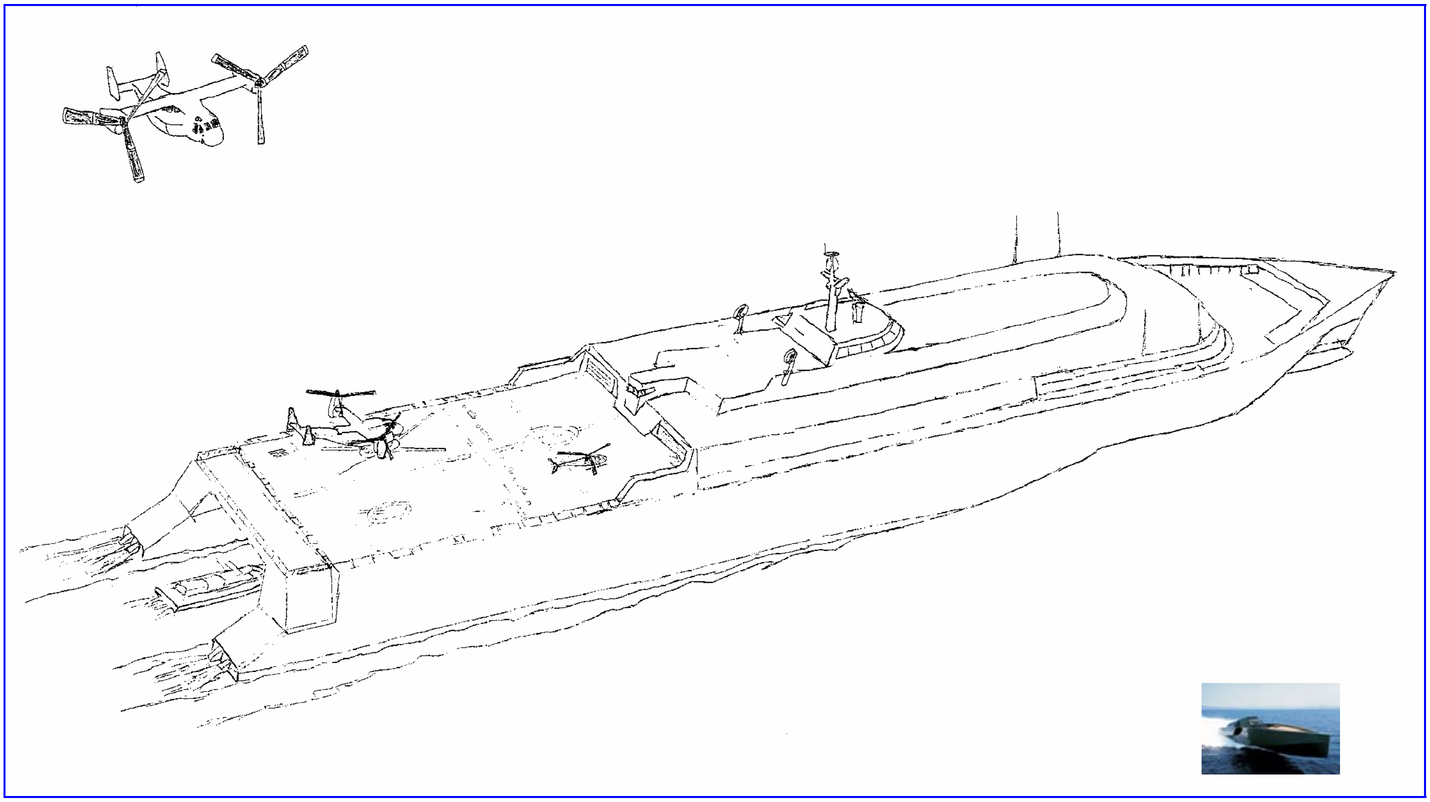


Figure 45. Trimaran Mothership with WallyPower 118 Interceptor

With the technical management and analysis portion of the project now complete, the TSSE Team was now ready to move on to the DESIGN phase of the project. This phase would involve a keel-up design of a trimaran mothership that would have the capability of transporting, launching, and retrieving at least 5 WallyPower interceptors.

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APPENDIX B (HULL)

TABLE OF CONTENTS

I. INTRODUCTION

The design of the Tsunami Interceptor Carrier was conceived under the idea to create a mothership that not only supports and commands operations of a fleet of smaller vessels, but to also have the ability to launch and recover those vessels in a relatively short period of time in the most common sea conditions of the Northern Pacific. Additional considerations based on the concept of operations included the need to carry the full compliment of interceptors 7,000 nautical miles through the duration of the mission with no replenishment assets available. Based on these needs, a new and innovative ship design was developed.

The Total Ship Systems Engineering Maritime Threat Response Tri-hybrid Hull, referred to as the Tsunami ship is a unique design concept that comprises of the Trimaran and SWATH hull forms for ships. This report will discuss the preliminary development of mission sub-systems, initial architectures, as well as the final iterate design of the Tsunami ship. This section of the report will review the mission requirements that drive geometric design and address the historical perspective of the components that make up the design. Additionally, this section will briefly address the modern advances in ship design, analysis, construction techniques, and propulsions that allow for a revolutionary design such as the Tsunami ship to be viable within 5 years.

The Tsunami Hull is a combination of the Trimaran high speed type hull and the Small Water plane Area Twin Hull (SWATH) design. In order to create an open docking area with a fixed arch covering the aft section of the ship, the SWATH hull is employed. As discussed in later sections, approximately 120ft in length is required to be enclosed by the aft arch of the ship. This enclosed area makes up the entire loading and unloading area of the ship. By combining the two different and very unique hull forms, the TSSE mothership concept can load and unload a 95 ton interceptor vessel into a mission bay safely and expeditiously using a robust fixed hoist mechanism without the use of complicated, labor-intensive, and expensive systems.

II. CONCEPT DEVELOPMENT

A. REQUIREMENTS FOR HOIST SYSTEM

Traceability Code (2.3.3 / 2.3.4)

Critical to the success of the Maritime Threat Response System's mission, the ship required to perform the mothership mission must be able to load and unload multiple boats equipped with personnel and detection devices used to search merchant shipping while underway. In order to accomplish this task without interfering with shipping transit times, the MTR Concept of operations limits to no more than a 12 hour delay of the merchant ships of interest. This time restriction significantly reduces the ability of a ship's crew to launch and recover intercept vessels at regular prolonged intervals. This also restricted the actual type of interceptor used for MTR. Additionally, the requirements impose operation of both vessels in sea state five. Based on the TSSE Concept of Operation analysis, the most viable loading point is at the stern of the ship on the centerline with sufficient headway to reduce wave effects on both the mothership and interceptor vessels. Further detail of the interceptor hoist selection process is covered in the Mission Bay Appendix of this report.

The operational analysis of alternative in the preliminary stages of the systems engineering project showed the need for a 95 ton, 28ft beam, and 120 foot long interceptor. Based on this result, conventional launching and recovery systems were ruled out. Such designs as a sling arm davit or ramp were deemed too hazardous by initial surveys conducted by the TSSE group. Additionally, based on recent analysis of movable overhead hoist systems, the hoist designers believed a vertical stationary hoisting system with movable pallets over a moon pool would be the simplest and most effective means of launch and recovery.

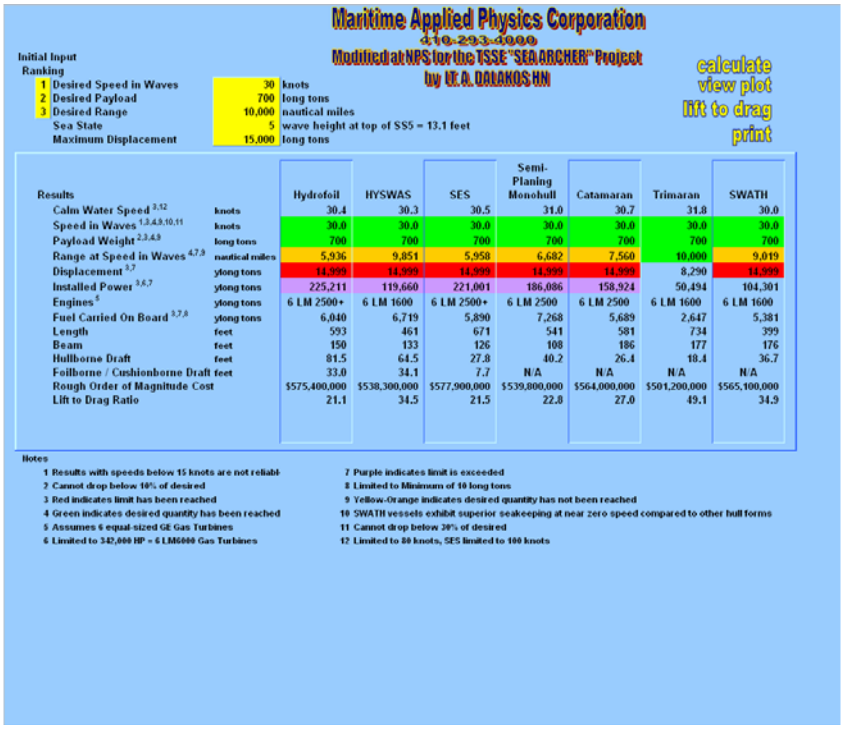
In addition to the location, the device to which the interceptor is recovered is critical to the hull integrated design. The weight of the interceptor and complexity of the launch/recovery problem required the hoisting equipment to be integrated into the design of the ship and not merely an added on sub-system of the ship. It had been determined by the TSSE hoist design team that a FIXED overhead hoist would be used to lower and raise the interceptor out of the sea, and a pallet with rollers on the deck would be used translate the ship into a securing area located within the hull of the ship.

The required location of the launch and recovery of the interceptor and the decision for a fixed overhead hoisting harness in an arch type of arrangement drove the minimum dimensions that would be required for the TSSE mothership. Additionally, it was recognized that it would be prudent not to suspend the interceptor for any lengthy amount of time. Thus, it was necessary to design the stern of the ship in such a way that would allow for the interceptor to be towed in the water, pulled into positioned under the hoist harness where it can be attached to the lifting system. Then it would pulled vertically out of the water and lifted to a specified height in which the pallet may roll out of the mission bay and under the interceptor, thusly bridging the loading bay allowing the interceptor to be lowered onto the pallet and released from the harness.

B. HULL DESIGN GENERAL CHARACTERISTICS

The hull of the Tsunami is a hybrid merging of the large Trimaran hull and the small water plane twin hull or SWATH type of ships. Preliminary analysis using the MIT MAPC Excel based software for ship type comparison showed for the range, speed, sea state, and payload the Trimaran and SWATH designs were the most feasible. However, the program showed that the SWATH alone did not have the range and payload capability required by the concept of operations.

To make the initial sizing predictions for the MTR ship, a preliminary design assumption had to be made based on payload weights provided by the concept of operations. A combined payload weight of 750 tons was used for initial predictions.



Maritime Applied Physics Corporation
410-293-4000
Modified at NPS for the TSSE "SEA ARCHER" Project
by LT. A. DALAKOS HN

Initial Input

Ranking			
1	Desired Speed in Waves	30	knots
2	Desired Payload	700	long tons
3	Desired Range	10,000	nautical miles
	Sea State	5	wave height at top of SS5 = 13.1 feet
	Maximum Displacement	15,000	long tons

Results		Hydrofoil	HYSWAS	SES	Semi-Planing Monohull	Catamaran	Trimaran	SWATH
Calm Water Speed [3,12]	knots	30.4	30.3	30.5	31.0	30.7	31.8	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	700	700	700	700	700	700	700
Range at Speed in Waves [4,7,9]	nautical miles	5,936	9,851	5,958	6,682	7,560	10,000	9,019
Displacement [3,7]	ylong tons	14,999	14,999	14,999	14,999	14,999	8,290	14,999
Installed Power [3,6,7]	ylong tons	225,211	119,660	221,001	186,086	158,924	50,494	104,301
Engines [5]	ylong tons	6 LM 2500+	6 LM 1600	6 LM 2500+	6 LM 2500	6 LM 2500	6 LM 1600	6 LM 1600
Fuel Carried On Board [3,7,8]	ylong tons	6,040	6,719	5,890	7,268	5,689	2,647	5,381
Length	feet	593	461	671	541	581	734	399
Beam	feet	150	133	126	108	186	177	176
Hullborne Draft	feet	81.5	64.5	27.8	40.2	26.4	18.4	36.7
Foilborne / Cushionborne Draft	feet	33.0	34.1	7.7	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$575,400,000	$538,300,000	$577,900,000	$539,800,000	$564,000,000	$501,200,000	$565,100,000
Lift to Drag Ratio		21.1	34.5	21.5	22.8	27.0	49.1	34.9

Notes
1 Results with speeds below 15 knots are not reliabl
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 6 equal-sized GE Gas Turbines
6 Limited to 342,000 HP = 6 LM6000 Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

Figure 46. MIT Maritime Applied Physics Corporation Comparison Program

Further research showed that the stability of the SWATH ship, like those for oceanic research and off shore oil recovery, is very desirable for maintaining a stable platform in heavy seas. An attribute very favorable while conducting interceptor launch and recover aboard ships at sea. The submerged hulls of the SWATH are predicted to act as a damping source to slow the heave and roll of the ship. The displacement and range characteristics of the Trimaran would provide the necessary payload capacity without adding significant hydrodynamic resistance.

The Trimaran section of the ship was chosen due to the need to carry a large range of payload, i.e. from zero up to six 100 ton interceptors through the entire mission duration to meet the range and speed requirements. The center hull of the ship will form a large water plane area and therefore provide higher tons per inch (TPI) that would otherwise not be provided by the SWATH design alone. The Trimaran was chosen over a monohull design due to its expected improved roll stability characteristics and lower hydrodynamic resistance for an equivalent monohull ship of the same dimensions.

C. INITIAL STAGES OF DESIGN

In the early stages of the design process, a number of sketches of possible ship designs were presented. The major attributes of the design contained a fully enclosed mission bay and a covered loading bay. Initial sketches of the TSSE hull form were of a pure Trimaran design with three standard hulls. The stager location of the outriggers were at an unconventional -26% (percent aft perpendicular of outrigger reference to the aft perpendicular of the center hull). This proved insufficient to meet the desired platform stability and maintain the ship within acceptable dimensions. However, research has shown that in order to maintain the Trimaran's superior stability, the demi-hulls of the Trimaran should be positioned at approximately a 50% stagger. This design alone would be inadequate for the mission of the mothership. This lead into two other options: either a Pentamaran design or the use of the SWATH underwater hulls as the side hulls of the ship

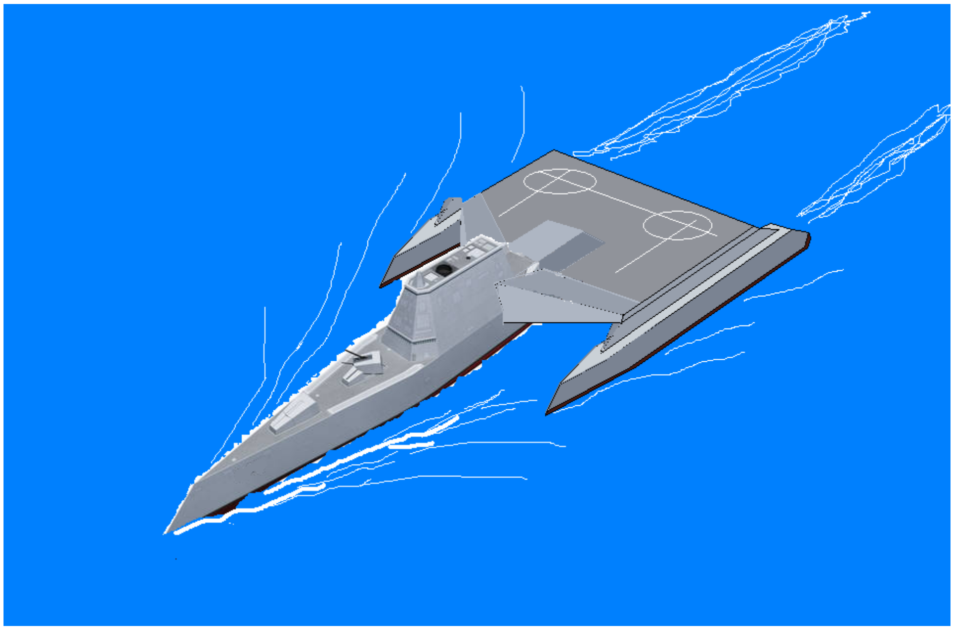


Figure 47. First Conceptual Drawing of MTR Mothership

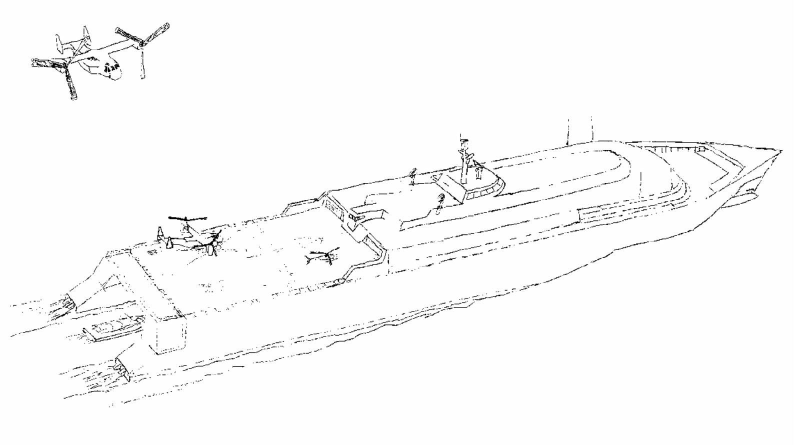


Figure 48. First Accepted Sketch of MTR Trimaran

The assumed initial dimension of the ship was set to approximately 900 feet long and 130ft beam. No analysis was performed on the earliest TSSE Trimaran designs due to the consensus that a pure Trimaran with a beam within the set limits would not provide sufficient stability for launching and recovery of interceptors. The pure Trimaran design was scrapped due to lack of group support and immediate desire of the design group to proceed with a submerged hull concept. The standard pontoon type side hull typically seen on a Trimaran hull were immediately replaced with the fully submerged side hulls of a SWATH type of ship when rendering began.

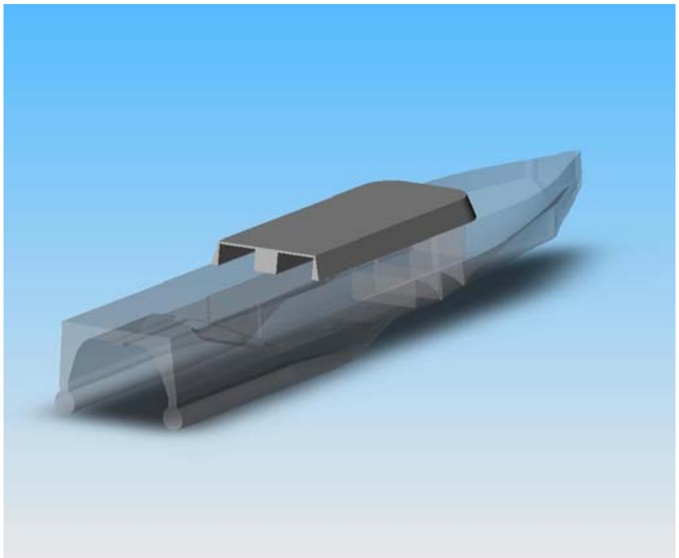


Figure 49. Initial Ship Rendering in Solid Works

D. HISTORICAL COMPARISON

1. Trimaran

To fulfill the need to create a ship that can not only have the carrying capacity to accommodate six 100 ton vessels and other payloads typical of a navy support ship, but also have the maneuvering and speed of the modern combatant, the TSSE team looked toward the Trimaran concept. Although there are very few examples of large trimarans, numerous smaller ones exist. With the design of the Littoral Combat Ship and the recent delivery of the AUSTAL Hull-260 Benchijigua Express for FRED OLSEN Transportation International, larger trimarans have become the forefront of modern maritime research. The AUSTAL Hull-260 was completed in August of 2005 and delivered to a Spanish RO-PAX ferry company for routine high speed transport out of Portugal.

The overall conceptual design of the center hull for the Tsunami ship was based off the AUSTAL Hull-260 and the analysis performed by Naval Surface Warfare Center Caderock on the AUSTAL Hull-260. However, specific wetted area of the hull form, size, and shape was based on resistance calculation iterations. The analysis conducted by the NSWCC, in collaboration with the AUSTAL Corporation, showed to be very promising for the development of large high speed military transports. However, this is not to say that there had not been any points of concern.

Figure 50. Benchijigua Express, AUSTAL Hull-260 Design.

The NSWCC research findings showed the tendency for Finite Element analysis calculation to over estimate stress “hot spots” in the hull that where not measured on test runs of the actual ship[3]. Test run results also showed localized areas at the transom of the hull were experiencing equal loading in lateral as well as longitudinal directions[3]. This result will directly correlate to the transom of the Tsunami ship, since the archway of the transom is wide to accommodate interceptors. A more detailed discussion of the ship structure is left to the Loading and Structural section of this report.

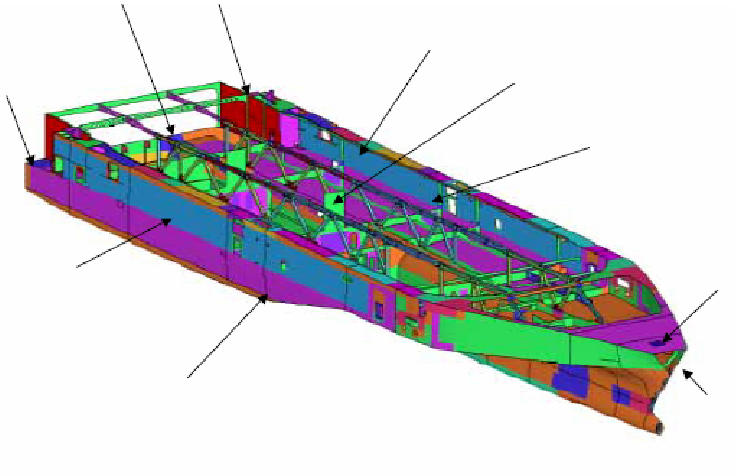


Figure 51. Structural Analysis Model of the AUSTAL Hull-260

Additional reports of the initial sea trials also showed better than computed values for resistance, maneuverability, and propulsion efficiency. The Hull-260 design has proven the Trimaran design reduces resistance to comparable capacity ships by 20%[6]. For the purpose of the Maritime Threat Response mission, the efficient hull form allows for either greater endurance at a lower cruising speed, or greater speed with lower propulsion requirements. Additionally, since the requirements call out for operations in sea state 5, a Trimaran design, as it has been found is the most effective choice, over gigantic mono-hulls, for prolonged operations in less than desirable seas.

2. Pentamaran

There are very few examples of actual Pentamaran arrangements. Only the few recent developments in Trimaran design have activated corporate interest in the Pentamaran concept. One such concept being developed by a British designer, Nigel

Gee, and a consortium, is the ADX Express, which is backed by numerous companies including Rolls-Royce. So although the shipping industry believes it is a viable option, there have been no known deliveries to date of the large Pentamaran design and thus no available design parameters.

Figure 52. Pentamaran Concept design by British designers Nigel Gee

In addition to the lack of design data, two attributes were the key factors that led the TSSE team away from Pentamaran designs. First, the arch of the aft section will support a significant amount of the load when lifting an interceptor out of the water. This will require an estimated 33% of the total displacement of the ship to prevent a significant aft trim during lifting operations. The aft side hulls of the Pentamaran will have to be large enough to accommodate this requirement and as a result have a large water plane area at the waterline. This design showed a large amount of wetted surface area that would be susceptible to wave resistance. Secondly, the large pontoons of the after section of the Pentamaran would not provide the damping resistance desired for continuous operation in sea state 5. Although, the forward outriggers would provide additional stability, the amount of wetted surface needed to provide substantial counter moments would also have associated with it additional wave and viscous drag.

3. Small Water plane Area Twin Hull (SWATH)

The SWATH hull is a proven design that shows significant stability with minimal water plane area. Additionally, the SWATH design has shown outstanding sea keeping while maintaining speed in high sea states. The large underwater hulls are not susceptible to surface wave resistance and provide significant damping force on the ship for reduced heave and roll period which allows for smooth operations in rough seas. The SWATH hull was not considered as the primary singular design due to the limitations of storage space for fuel and payload. The concept of lifting is however, proven in the operations of various research SWATH vessels around the world. Due to the dimensional limitations, a SWATH would not be able to accommodate six interceptors however, a SWATH mated up with a more conventional vessel would.

Figure 53. US Navy SWATH Research Vessel

III. GEOMETRIC PROPERTIES

A. DIMENSIONAL REQUIREMENTS

1. Mission Bay

Traceability Code (TC 2.3.3 / 2.3.4)

In order to accommodate the six prescribed interceptors, the Mission Bay must be designed to the minimum dimensions 390ft x 120ft x 35ft. The shape and minimum dimensions of the ship is restricted to ensure the Mission Bay is enclosed and dry. Sea keeping analysis also required that the mission bay deck height be set 10 feet above the waterline. The hoist is to be located centerline with interceptor access at the stern of the ship.

2. Berthing and Docking Restrictions

Traceability Code (TC 2.3.2 / 4.2.1)

It was deemed necessary by the design team to limit the beam of the ship to 134 feet, and limit the draft to 35 feet. The implementation of these limitations would allow the Tsunami ship to fit within the berthing locations currently in place for aircraft carriers and large merchant ships. Additionally, the design included these requirements due to the limited locations within the United States with facilities to physically dry-dock a ship with a beam over 134ft. The assumption was made that facilities available to aircraft carriers would also be available to the Tsunami ship if other non-aircraft carrier facilities are not available.

3. Panama Canal and Coronado Bridge

Traceability Code (TC 2.3.2)

Although the limitation for the Panama Canal is 109 feet beam, it was determined by the design team that the required range of the Tsunami ship of 7,000 to 10,000 nautical miles and the improved stability from the wider beam is a significantly greater benefit to the alternative of transiting through the Panama Canal. Since the Tsunami ship is not a first strike platform, rapid transit from one ocean to another is irrelevant to concept of operations.

The maximum mast height to pass under the Coronado Bridge in San Diego, California, one of the possible staging areas for the Maritime Threat Response ships, is 200 feet. The maximum height of the Golden Gate Bridge, in San Francisco is 746 feet. The final designed height of the Tsunami ship is 120 feet.

4. Sea keeping and Endurance

Traceability Code (TC 2.3.3 / 2.3.4)

The minimum threshold range required to accomplish the mission is determined to be 7000 nautical miles. To ensure continuous uninterrupted merchant progression over the great circle shipping route, the mothership and interceptors must also be able to sustain mission operations through Sea State 5. Additionally, the mothership must be able to recover the interceptors in Sea State 5 and continue with merchant traffic.

B. CENTER HULL

The geometric properties of the Center hull were based on the concept of designing a hull that was wave piercing at the bow and very low displacement at the stern. A bow piecing hull would reduce resistance through the water and increase the fuel efficiency of the ship. Although, it is understood the piercing design would not add a great deal of reserve buoyancy in rough seas, it is expected the side hulls of the trimaran would compensate. Additionally, it would be expected that no personnel would be on the forecastle is severe weather conditions.

The shallow hull at the stern of the center hull was used to reduce the wake effects at the immediate stern of the center hull. This reduction in turbulence would accommodate the interceptors that are in tow in the hoist bay of the ship. The shallow design should reduce the rate of energy transfer into the displaced water from the stern of the ship, which is what creates the large wakes seen by other vessels such as cruisers. The reduced buoyancy lost by the stern of the center hull will be carried by the two side hulls that are positioned 200 feet aft of the stern of the center hull. The concept is to reduce the wake experienced directly behind the center hull to accommodate interceptor operations. Additionally, all ship's propulsion will be placed in the side hulls in order to mitigate turbulent flow from the centerline in the hoist bay area from any propulsion wash. Further detail on wake analysis is in the Wave Motion section of this appendix.

Center Hull Coefficients

C_b	*0.521*
C_p	0.567
C_{wp}	0.750
C_m	0.92

Figure 54. Center Hull Offsets for Calculations

	15	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600
24	1.72	3.40	6.65	9.90	13.20	16.50	19.80	23.10	26.40	29.53	31.84	32.96	33.00	33.00	33.00	33.00	32.99	32.98	32.96	32.87	23.98
22	1.50	3.17	6.47	9.77	13.08	16.40	19.72	23.03	26.34	29.48	31.80	32.92	32.95	32.95	32.94	32.92	32.89	32.81	32.58	31.20	
20	1.32	2.98	6.29	9.60	12.92	16.25	19.58	22.91	26.23	29.38	31.70	32.83	32.86	32.85	32.82	32.77	32.66	32.40	31.52		
18	1.22	2.82	6.08	9.40	12.73	16.06	19.40	22.73	26.06	29.22	31.56	32.68	32.72	32.69	32.64	32.51	32.26	31.61	28.00		
16	1.20	2.70	5.86	9.15	12.47	15.80	19.14	22.49	25.83	29.01	31.35	32.48	32.51	32.47	32.36	32.13	31.62	29.98			
14	1.19	2.61	5.63	8.84	12.14	15.46	18.80	22.16	25.52	28.71	31.07	32.20	32.23	32.16	31.99	31.59	30.59	24.38			
12	1.18	2.53	5.40	8.51	11.73	15.02	18.35	21.72	25.11	28.33	30.70	31.84	31.87	31.76	31.49	30.81	28.30				
10	1.17	2.46	5.19	8.18	11.33	14.55	17.82	21.16	24.57	27.83	30.23	31.38	31.40	31.24	30.82	29.41	17.41				
8	1.16	2.40	4.99	7.87	10.93	14.08	17.24	20.48	23.85	27.16	29.61	30.80	30.81	30.54	29.72	26.36					
6	1.14	2.32	4.81	7.57	10.53	13.61	16.62	19.66	22.87	26.15	28.66	29.89	29.88	29.37	27.67						
4	1.04	2.12	4.48	7.20	10.13	13.13	15.94	21.44	24.55	27.10	28.37	28.32	27.25	21.01	18.61						
2	0.74	1.57	3.58	6.03	8.76	11.65	14.34	16.73	18.97	21.51	24.07	25.41	25.17	20.02							
0	0.09	0.20	0.45	0.75	1.10	1.46	1.79	2.09	2.37	2.69	3.01	3.18	3.15	2.50							

i) Note 1: All values are in feet

ii) Note 2: Molded Base Line of the Center hull is set equivalent to the 10 ft waterline of side halls

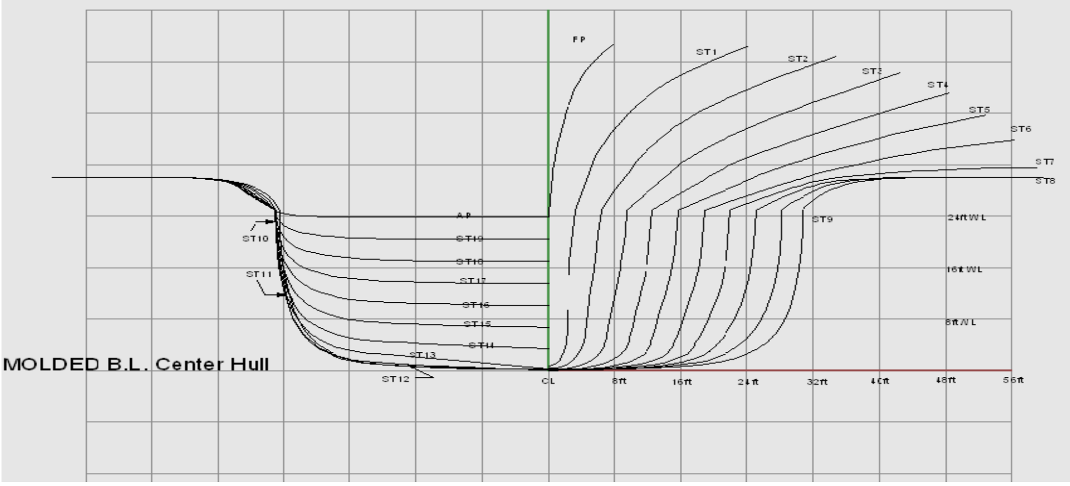


Figure 55. Body Plan: Center Hull

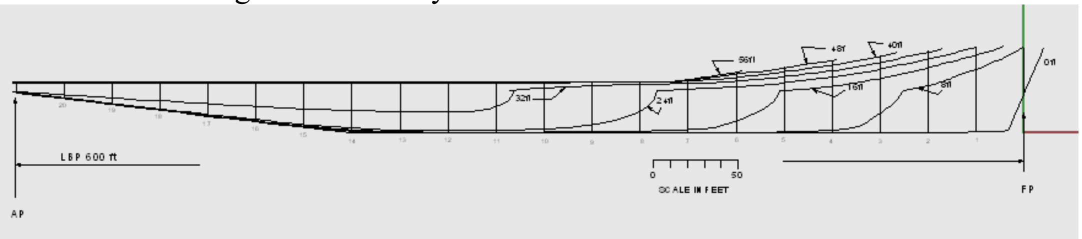


Figure 56. Sheer Plan: Center Hull

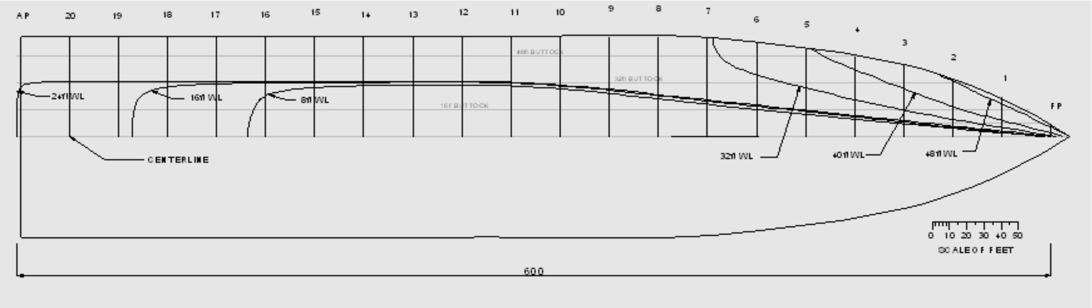


Figure 57. Half-Breadth Plan: Center Hull: .Side Hull

The submerged hulls of the SWATH type stern section will carry one-third of the buoyancy force 15 feet below the waterline and thus reducing the generation of surface waves and directing wake flow through a smooth transition from behind the center hull to well behind the ship. To augment the flow direction attributes of the side hulls, the geometry properties of the Side hulls are based on the profile of the typical modern fast attack submarine. Each designed with an elliptical bow and a hyperbolic stern. The following variables define the hydrodynamic shape of the hull for static stability and resistance calculation modeling.

D	= 23.3 ft	Side hull Equivalent Diameter
l	= 157.5 ft	Side hull length not parallel to the long axis
L	= 300 ft	Side hull overall length
L_f	= 68 ft	forward length
L_a	= 90 ft	aft length
n_f	= 2.0	forward shape factor
n_a	= 2.0	aft shape factor
PMB	= 142.5 ft	parallel to mid body

From SLICE and SWATH resistance, the entrance is defined as a parabolic body of length L_f, approximately equal to 2.5 times the diameter[1]. The run is defined as the ellipsoid body having a length L_a, approximately equal to 3.6 times the diameter. For the Tsunami side hulls, the diameter was taken as the equivalent diameter of the elliptical cross section.

The parallel middle body is the straight section of the hull where the sum of the forward length, aft length, and PMB is equal to the overall length of the side hull. The shape factor coefficients n_f and n_a define the shape of the fore and aft bodies. Coefficients of the form are defined as (Al-jowder 1995);

- C_{wsf} = forward wetted surface coefficient
- C_{wsa} = aft wetted surface coefficient

The coefficients were calculated using built in Gamma functions of MATLAB. The following is the list of geometry coefficients used in resistance calculations for the Tsunami side hulls.

- C_{wsf} = 0.7852
- C_{wsa} = 0.6667

1. Submerged Hulls

For simple SWATH ships with lower hulls having a circular cross-section, the hydrodynamic heave added mass divided by the ship mass is about 0.70 (Lamb 1988). For a monohull, the heave added mass is equal to the mass of the ship. Research has shown that an elliptical cross-section of the lower hull with the horizontal axis 1.8 times the vertical axis amounts 120 percent of the ship's mass. This results in a heave period that is 14 percent longer than the configuration with circular hulls. It has been determined by the Navy that a 1.8 percent design is impractical and has determined a 1.4 percent design is the most practical. The cross sections of the side hulls of the Tsunami ship have a 28 foot horizontal axis and a 20 foot vertical axis which follows the 1.4 percent elliptical design.

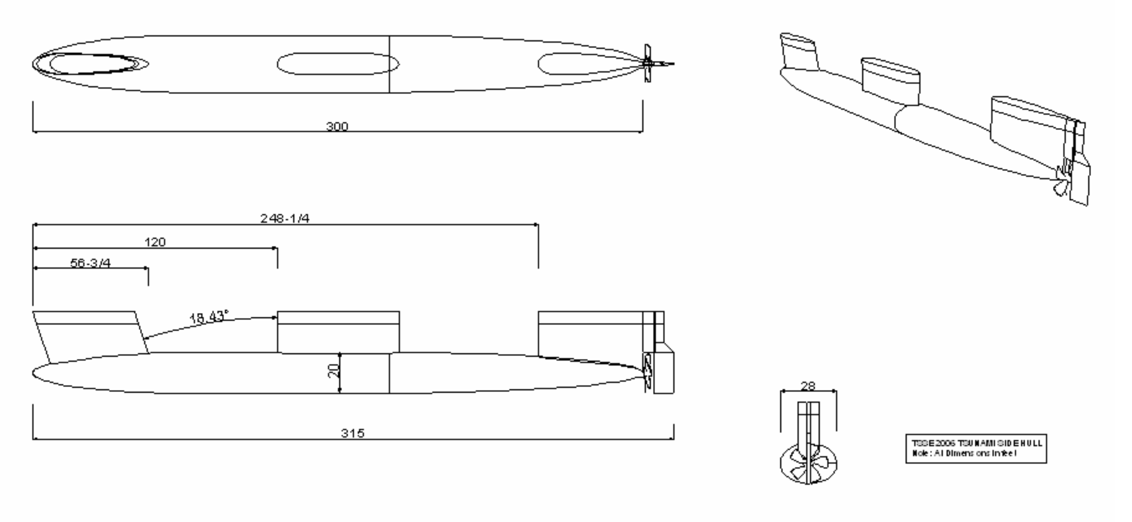


Figure 58. TSUNAMI Side Hull 3-View Drawings

2. Struts

The cross section of the forward and aft strut are approximately based on a NACA 0020 airfoil; A camber of 0% and a maximum thickness of 20% of the chord length. The forward and aft struts are 50 feet long with 10 feet at the widest section.

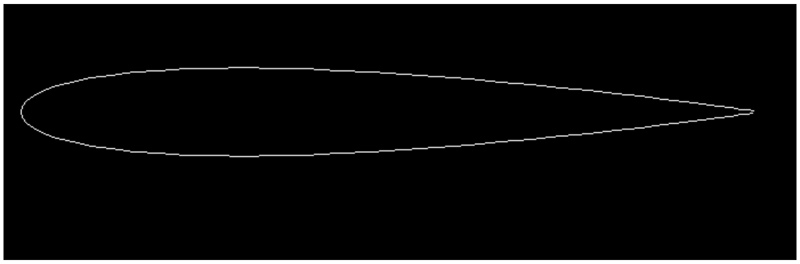


Figure 59. Standard NACA 0020 Airfoil

The forward strut has a 10 degree sweep from the point it attaches to the transom section to the point it connects to the submerged side hull.

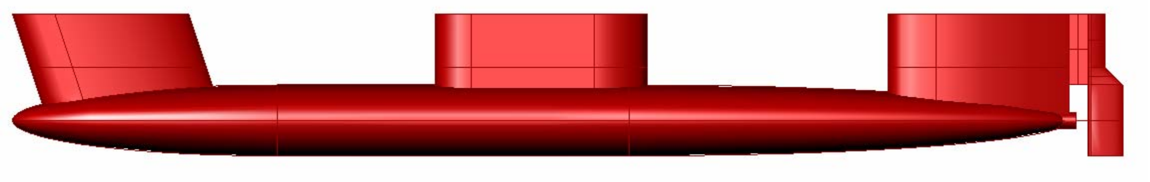


Figure 60. Profile View of Strut Arrangement

Figure 61.

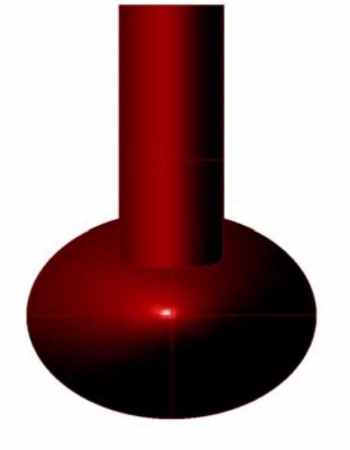


Figure 62. Front View Struts and Submerged Hull.

3. Transom Section

The Hoist section of the Tsunami hull is the center of the design. The uniqueness of the design is built upon the concept of a centerline loading area in which the interceptors can be drawn into the ship. The split stern section allows the interceptor to be hoisted as close to the center of buoyancy of the mothership as possible, thereby theoretically reducing the vertical acceleration the hoist cables would have to endure.

The hoist section of the ship is 200 feet long and 120 feet wide. The Hoist Bay of the stern section is 120 ft long and 40ft wide. This design provides sufficient clearance for the interceptor in the water, and limits the span of the pallet required to carry the interceptor into the mission bay. The additional 80 ft at the aft section of the hoist bay provides the interceptor pilot maneuvering space to allow for safe hook up of the tow line.

The overhead section of the hoist bay consists of the hoist and the track rolling payout dolly. The rolling payout dolly provides vertical and lateral support of the tow line while the interceptor crew connects up the towline to the ground tackle of the interceptor. The hoist mechanisms are located in the overhead of the hoist section of the ship. The main deck area of the hoist section consists of the flight deck. Additional strengthening for the arch of the hoist section has been considered for the hoisting operations, MV-22 certifications, and vibrations from main propulsion screws. Based on the results of the AUSTAL T126 Meter stress analysis conducted by Naval Surface Warfare Center Caderock, the transom of this type of hull may experience high levels of localized stress.

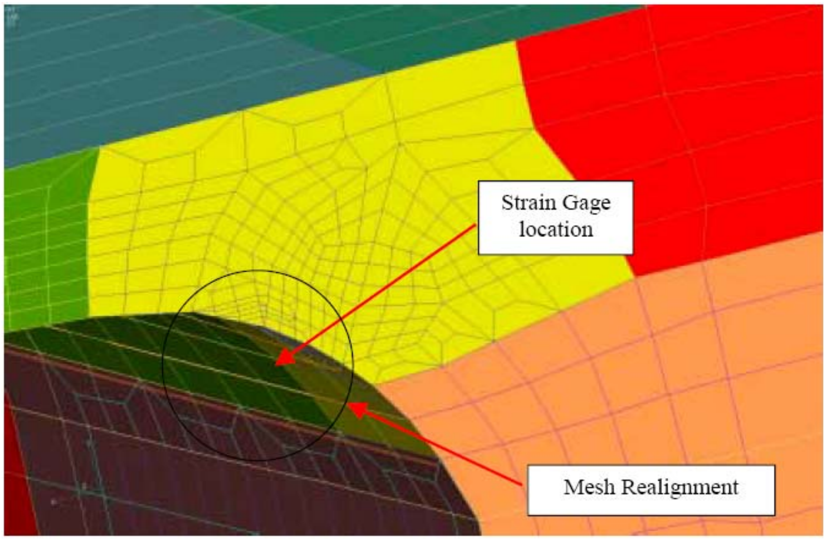


Figure 63. Finite Element Model of AUSTAL Hull 260 Trimaran Transom

The results show the knee bend at the transom experiences large longitudinal and lateral loading. As a result of this analysis, the design of the structure which makes up the transom of the Tsunami hull needs be strengthened to take up these loads or designed to prevent localizing the loads. A more detailed discussion of the hoist systems of the mission bay are covered in the Mission Bay section.

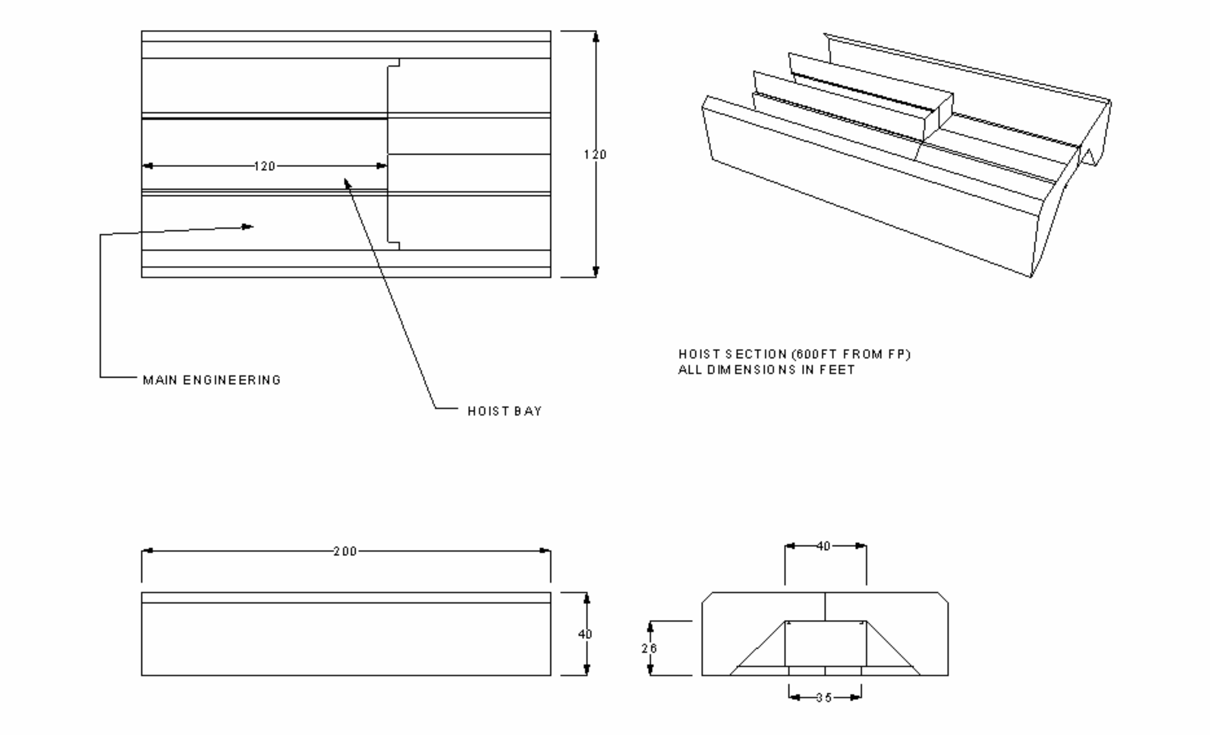


Figure 64. Stern Section: Hoist Bay Three View Drawings.

Tsunami Overall

The overall calculations were made using a simplified model with all sections attached in the Rhino Marine Software. It was determined through a series of comparison with manual calculation of the center hull geometry that the Rhino Marine software was a reliable source of geometric calculations for the overall ship.

Characteristic	
Class	Trimaran-Swath Hybrid
Stern Type	Small Waterplane Twin Hull
No. Screws	2
SVC SPD, kts	32
LBP, ft	800
LOA, ft	812.1
LWL, ft	812.1
B, ft	132.0
BWL, ft	116.61
Freeboard,ft	46.0
T_m,ft	34.0
Volume, ft^3	720455.39
Δ_{FL},Lton	20598.86
Trim, ft	0
C_{WP}	0.43
C_M	0.37
C_P	0.73
C_B	0.27
LCB/LWL	0.62
LCB, ft	417.43
LCG, ft	417.43
LCF, ft	373.86
LCF/LWL	0.56
MT1, lton/in	2455.88
TPI, lton	80.67
KG, ft	30.6
KB, ft	20.11
KM, ft	49.77
GM_T, ft	19.17
GM_L, ft	962.01
BM_T, ft	29.66
BM_L, ft	972.51
Area WP, ft^2	33859.56

Figure 65. General Characteristics and Full Load Hydrostatics for Ship Overall

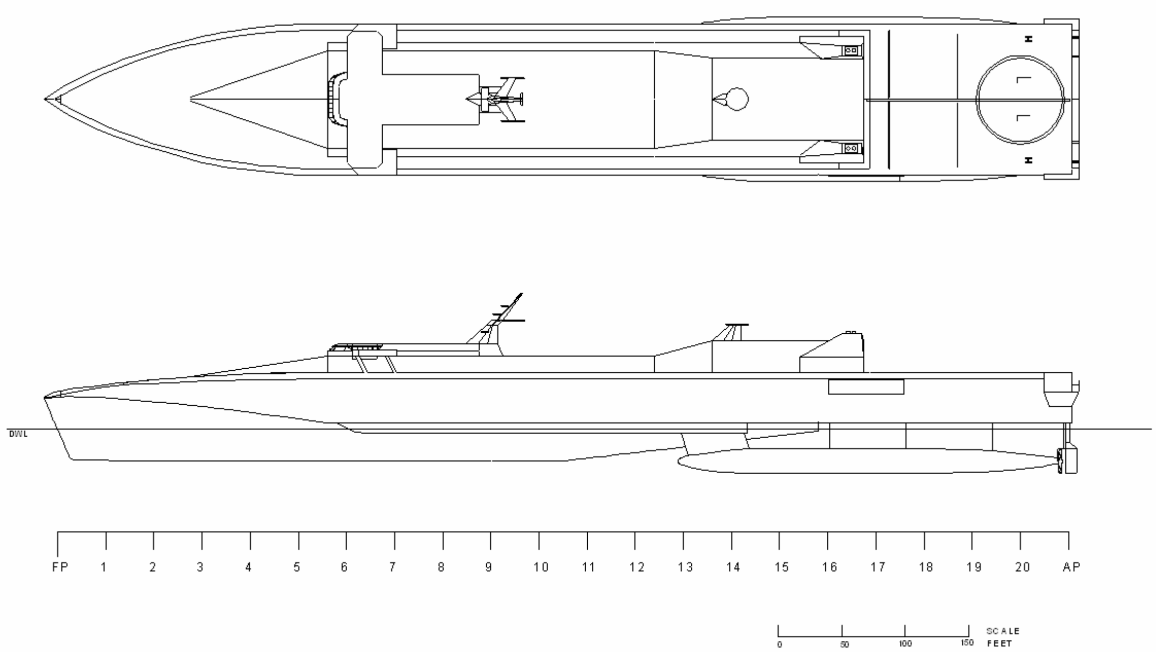


Figure 66. Plan View and Profile

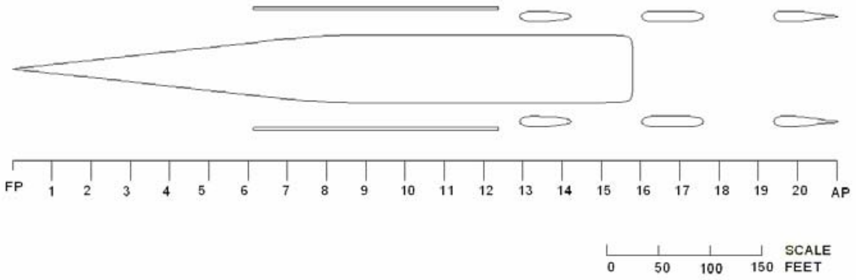


Figure 67. Design Waterline Plan View

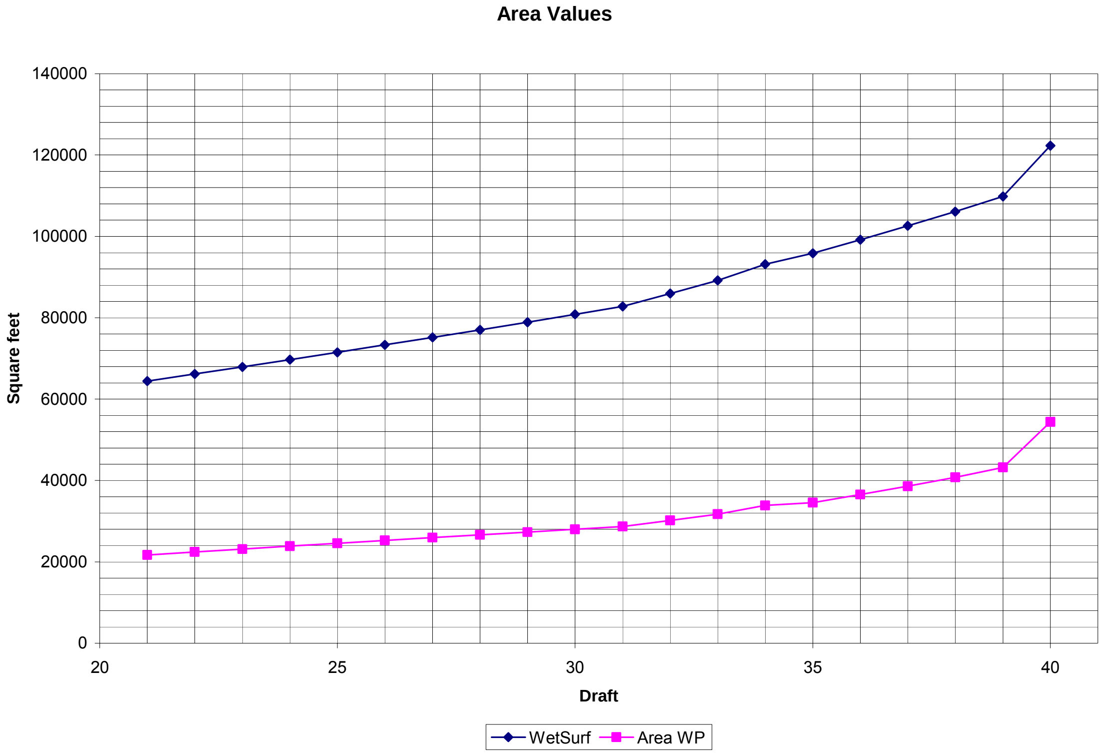


Figure 68. Wetted Surface Area and Area of the Waterplane for various

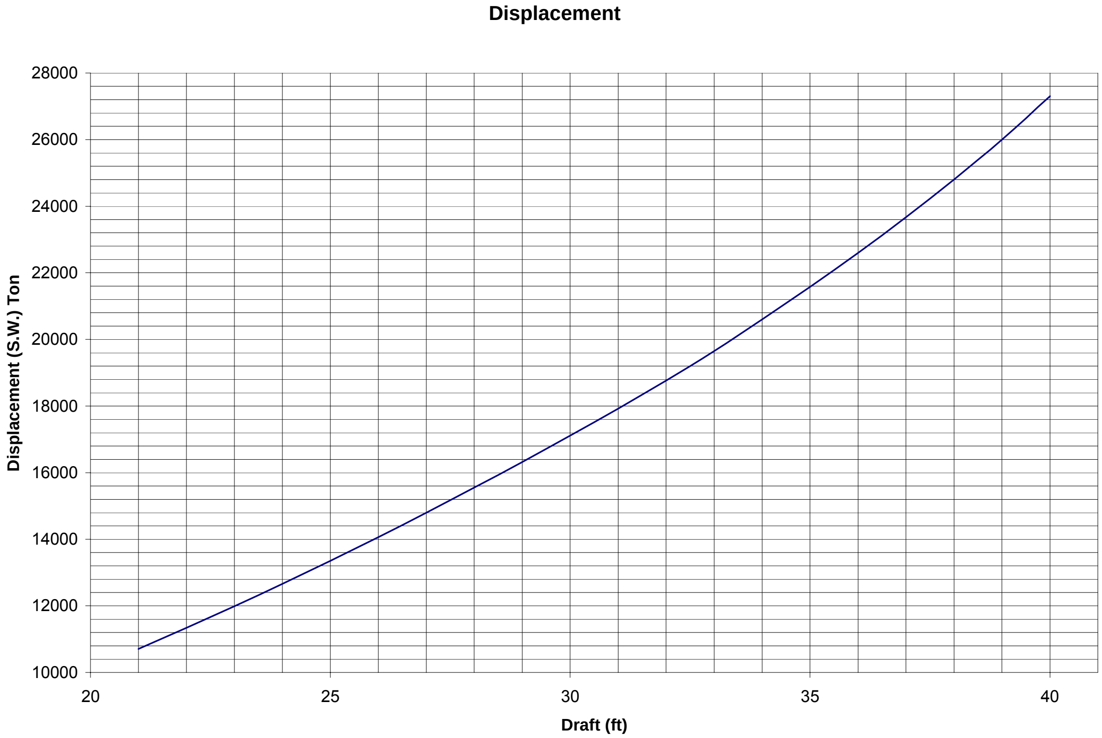


Figure 69. Displacement of the Tsunami Hull

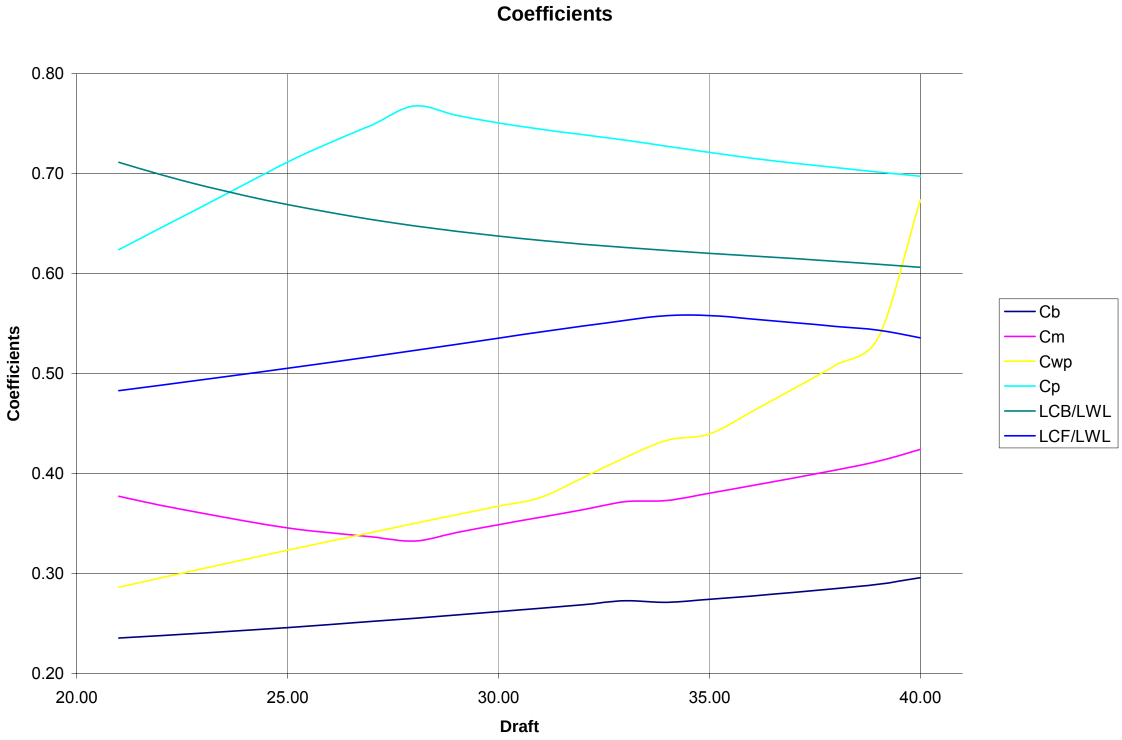


Figure 70. Coefficients of the Tsunami Hull

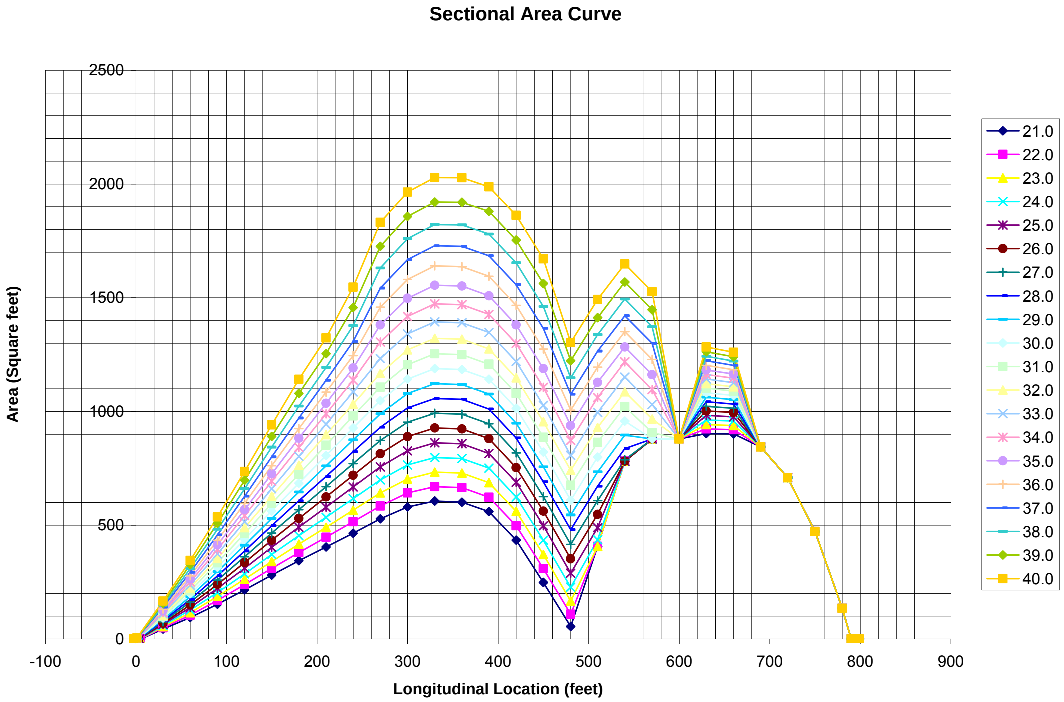


Figure 71. Section Area for the Tsunami Hull

Draft	*Weight*	*LCG*	*TCG*	*VCG*
21.00	10708.91	478.15	0.00	30.60
22.00	11339.07	469.81	0.00	30.60
23.00	11990.13	462.30	0.00	30.60
24.00	12661.74	455.55	0.00	30.60
25.00	13353.76	449.49	0.00	30.60
26.00	14065.91	444.06	0.00	30.60
27.00	14797.92	439.20	0.00	30.60
28.00	15549.67	434.88	0.00	30.60
29.00	16320.96	431.04	0.00	30.60
30.00	17111.66	427.64	0.00	30.60
31.00	17921.68	424.65	0.00	30.60
32.00	18763.20	422.00	0.00	30.60
33.00	19648.71	419.62	0.00	30.60
34.00	20598.86	417.43	0.00	30.60
35.00	21577.38	415.45	0.00	30.60
36.00	22593.64	413.52	0.00	30.60
37.00	23667.74	411.53	0.00	30.60
38.00	24801.98	409.50	0.00	30.60
39.00	26000.60	407.44	0.00	30.60
40.00	27302.05	405.24	0.00	30.60

Figure 72. Hydrostatic Analysis

Draft	*Volume*	*Displ*	*LCB/LWL*	*LCB*	*TCB*	*VCB*	*A0*	*XA0*
21.00	374549.46	10708.91	0.71	478.15	0.00	12.87	903.17	638.90
22.00	396589.69	11339.07	0.70	469.81	0.00	13.35	923.61	639.58
23.00	419360.64	11990.13	0.69	462.30	0.00	13.85	944.05	639.83
24.00	442850.79	12661.74	0.68	455.55	0.00	14.36	964.50	639.96
25.00	467054.50	13353.76	0.67	449.49	0.00	14.89	984.94	640.04
26.00	491962.14	14065.91	0.66	444.06	0.00	15.42	1009.69	562.68
27.00	517564.44	14797.92	0.65	439.20	0.00	15.97	1036.34	523.03
28.00	543857.57	15549.67	0.65	434.88	0.00	16.53	1061.31	342.33
29.00	570833.53	16320.96	0.64	431.04	0.00	17.09	1127.05	342.49
30.00	598488.90	17111.66	0.64	427.64	0.00	17.67	1192.93	342.64
31.00	626819.58	17921.68	0.63	424.65	0.00	18.25	1258.94	342.78
32.00	656252.17	18763.20	0.63	422.00	0.00	18.84	1327.03	342.90
33.00	687223.42	19648.71	0.63	419.62	0.00	19.46	1399.20	343.02
34.00	720455.39	20598.86	0.62	417.43	0.00	20.11	1478.73	343.12
35.00	754679.48	21577.38	0.62	415.45	0.00	20.76	1560.97	343.22
36.00	790223.77	22593.64	0.62	413.52	0.00	21.42	1646.32	343.43
37.00	827791.05	23667.74	0.61	411.53	0.00	22.11	1735.45	343.80
38.00	867461.51	24801.98	0.61	409.50	0.00	22.81	1829.04	344.25
39.00	909383.86	26000.60	0.61	407.44	0.00	23.53	1928.08	344.66
40.00	954902.83	27302.05	0.61	405.24	0.00	24.30	2036.10	344.78

Figure 73. Hydrostatic Analysis

Draft	*Area WP*	*LCF*	*LCF/LWL*	*VCF*	*Mtrans*	*Mlong*	*BMtrans*	*BMlong*
21.00	21672.60	326.34	0.48	21.00	13.31	982.20	21.44	990.33
22.00	22406.39	329.77	0.49	22.00	12.36	970.78	21.01	979.43
23.00	23131.46	333.23	0.49	23.00	11.43	961.33	20.58	970.48
24.00	23847.25	336.76	0.50	24.00	10.52	953.65	20.16	963.29
25.00	24557.65	340.36	0.51	25.00	9.63	947.40	19.75	957.52
26.00	25255.35	344.05	0.51	26.00	8.76	942.43	19.34	953.01
27.00	25947.67	347.81	0.52	27.00	7.92	938.64	18.94	949.67
28.00	26635.48	351.65	0.52	28.00	7.09	936.11	18.56	947.58
29.00	27315.41	355.55	0.53	29.00	6.28	934.81	18.19	946.71
30.00	27994.34	359.50	0.54	30.00	5.50	934.68	17.83	947.01
31.00	28665.01	363.51	0.54	31.00	4.72	935.66	17.47	948.41
32.00	30200.71	367.22	0.55	32.00	7.96	942.50	21.12	955.66
33.00	31740.47	370.77	0.55	33.00	10.88	949.31	24.42	962.86
34.00	33859.56	373.86	0.56	34.00	15.77	958.61	29.66	972.51
35.00	34563.16	373.61	0.56	35.00	16.39	925.25	30.63	939.49
36.00	36540.95	371.11	0.55	36.00	18.08	940.21	32.66	954.79
37.00	38603.75	368.51	0.55	37.00	19.72	951.86	34.61	966.75
38.00	40760.88	365.82	0.55	38.00	21.33	959.81	36.52	975.00
39.00	43212.41	363.11	0.54	39.00	23.24	966.58	38.70	982.04
40.00	54375.29	357.80	0.54	40.00	45.52	1068.60	61.22	1084.30

Figure 74. Hydrostatic Analysis

Draft	*GMt*	*GMl*	*RM@1Deg*
21.00	3.71	972.60	692.88
22.00	3.76	962.18	744.14
23.00	3.83	953.73	801.55
24.00	3.92	947.05	865.93
25.00	4.03	941.80	940.23
26.00	4.16	937.83	1021.55
27.00	4.32	935.04	1114.45
28.00	4.49	933.51	1219.02
29.00	4.68	933.21	1333.72
30.00	4.90	934.08	1462.69
31.00	5.12	936.06	1602.40
32.00	9.36	943.90	3065.07
33.00	13.28	951.71	4553.65
34.00	19.17	962.01	6890.58
35.00	20.79	929.65	7827.63
36.00	23.48	945.61	9257.75
37.00	26.12	958.26	10787.45
38.00	28.73	967.21	12435.67
39.00	31.64	974.98	14356.41
40.00	54.92	1078.00	26167.99

Figure 75. Hydrostatic Analysis

Long. Loc.	*Area*	*Girth*
FP	0	0
1	0.267	4.873
30	117.422	48.585
60	250.211	52.874
90	393.350	58.033
120	542.169	63.712
150	693.420	69.674
180	842.711	75.394
210	990.115	80.912
240	1138.310	86.683
270	1305.177	112.918
300	1417.835	117.882
330	1473.088	120.297
360	1469.399	120.167
390	1426.810	118.582
420	1298.901	115.132
450	1106.165	109.952
480	872.623	84.119
510	1061.428	181.664
540	1217.605	216.168
570	1095.736	219.920
600	879.500	227.266
630	1162.773	189.516
660	1146.090	190.344
690	844.320	148.771
720	709.229	136.351
750	472.819	111.330
780	135.091	59.508
790	0	0
799	0	0

Figure 76. Hydrostatic Analysis

Draft	*TPI*	*MT1*
21.00	51.64	1318.90
22.00	53.39	1379.42
23.00	55.11	1443.51
24.00	56.82	1511.24
25.00	58.51	1582.41
26.00	60.17	1657.02
27.00	61.82	1735.15
28.00	63.46	1817.26
29.00	65.08	1903.54
30.00	66.70	1994.23

Draft	*TPI*	*MT1*
31.00	68.30	2089.51
32.00	71.96	2202.23
33.00	75.63	2321.36
34.00	80.67	2455.88
35.00	82.35	2481.43
36.00	87.06	2638.61
37.00	91.98	2796.46
38.00	97.12	2953.03
39.00	102.96	3115.54
40.00	129.56	3614.44

Figure 77. Hydrostatic Analysis

raft	*Cb*	*Cm*	*Cwp*	*Cp*	*Cpaft*	*Cpfwd*
21.00	0.24	0.38	0.29	0.62	3.42	0.49
22.00	0.24	0.37	0.30	0.65	3.42	0.51
23.00	0.24	0.36	0.30	0.67	3.39	0.54
24.00	0.24	0.35	0.31	0.69	3.35	0.56
25.00	0.25	0.35	0.32	0.71	3.31	0.59
26.00	0.25	0.34	0.33	0.73	1.57	0.57
27.00	0.25	0.34	0.34	0.75	1.34	0.59
28.00	0.26	0.33	0.35	0.77	1.01	0.54
29.00	0.26	0.34	0.36	0.76	0.99	0.54
30.00	0.26	0.35	0.37	0.75	0.97	0.54
31.00	0.27	0.36	0.38	0.74	0.96	0.54
32.00	0.27	0.36	0.40	0.74	0.95	0.54
33.00	0.27	0.37	0.42	0.73	0.94	0.54
34.00	0.27	0.37	0.43	0.73	0.93	0.54
35.00	0.27	0.38	0.44	0.72	0.92	0.53
36.00	0.28	0.39	0.46	0.72	0.91	0.53
37.00	0.28	0.40	0.48	0.71	0.89	0.53
38.00	0.28	0.40	0.51	0.71	0.88	0.53
39.00	0.29	0.41	0.54	0.70	0.87	0.53
40.00	0.30	0.42	0.67	0.70	0.87	0.53

Figure 78. Hydrostatic Analysis

B. MAIN DECK AND SUPERSTRUCTURE

1. Pilot House and Forecastle

The -5.6 degree sloping downward forecastle design is expected to reduce the shadow zone area directly in front of the bow thereby increasing the view from the pilot house and enhancing safe maneuvering without having to increase the elevation of the pilot house in excess of the height of the helicopter hangars. The distance in front of the bow that cannot be seen from the pilot house is measured to be 230 feet. The contoured design of the bow and superstructure are also expected to reduce aerodynamic drag to enhance fuel efficiency. Additionally the pilot house spans the entire beam of the ship to ensure visibility fore to aft of the entire ship to ensure safe maneuvering and control during import operations and ensure proper visibility while closely operating with interceptors.

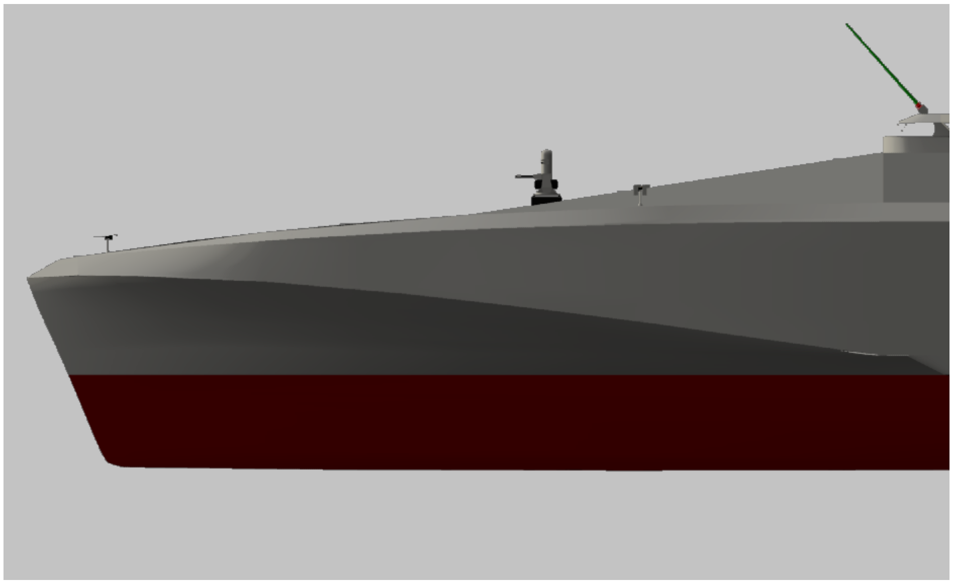


Figure 79. Close Profile View of Bow

2. Superstructure

The superstructure of the Tsunami runs 434 ft from the forward perpendicular to the flight deck. The superstructure consists of 2 levels forward and aft between the aircraft hangars with a single level in the mid section. The sides of the superstructure are angled 23.66 degrees from the main deck to provide some reduction of the radar cross section of the clean ship.

Figure 80. Bow View of Superstructure

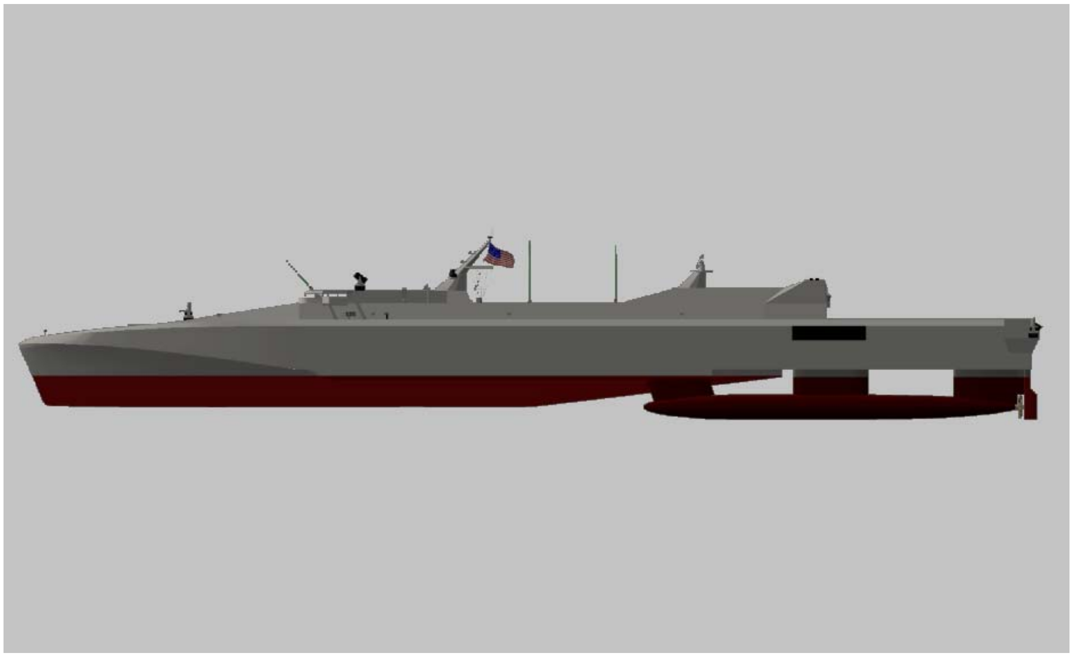


Figure 81. Superstructure Profile View

3. Flight Deck

The flight deck of the Tsunami ship is 156 feet long 110 feet wide and 46ft above the waterline. The flight deck is designed to accommodate two simultaneous launchings of SH-60 type helicopters or one launching of a V-22 Osprey VTOL aircraft. The height above the waterline and wide beam of the ship significantly improves operational conditions and reduces wetting events in heavy seas. Hangar facilities are immediately forward of the flight deck and provide embarkation for 2 aircraft.

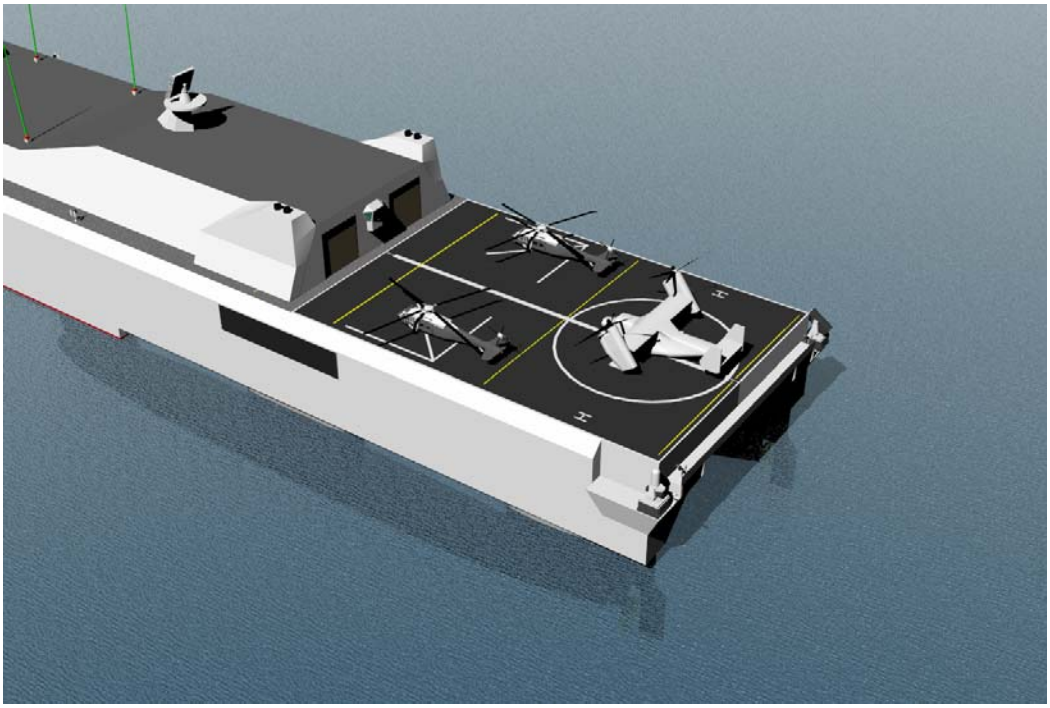


Figure 82. Flight Deck with Aircraft Profile

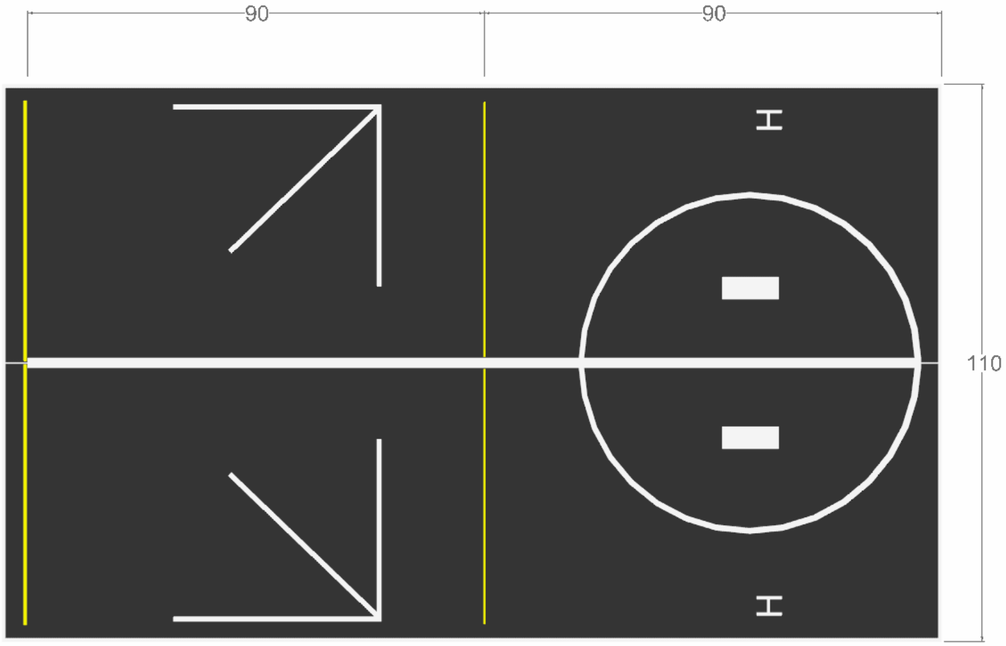


Figure 83. Flight Deck Layout

IV. STATIC STABILITY

A. FULLY LOADED CONDITION

The static upright stability calculations were made using the Rhino Marine hydrodynamic analysis tools. Due to the complex design of the Tsunami ship, the stability calculations were based on a simplified model which excluded any buoyancy attributed by the side struts (more specifically, the forward and aft strut) due to their relative small size compared to the center and submerged side hulls. Variations in calculations of the coefficients develop when the calculations include the struts. Based on previous research by the Center for Transportation Development, the center hull coefficients alone may be considered the characteristic coefficients for a trimaran analysis.

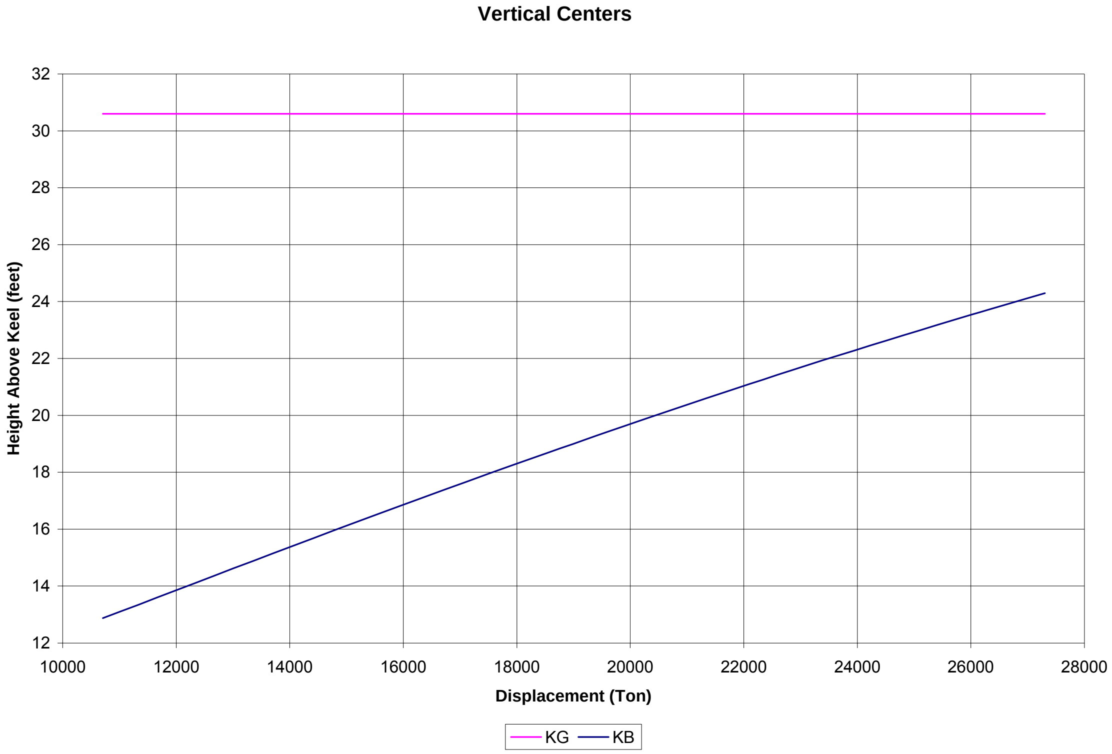


Figure 84. Vertical Center of Gravity (KG) and Vertical Center of Buoyancy (KB)

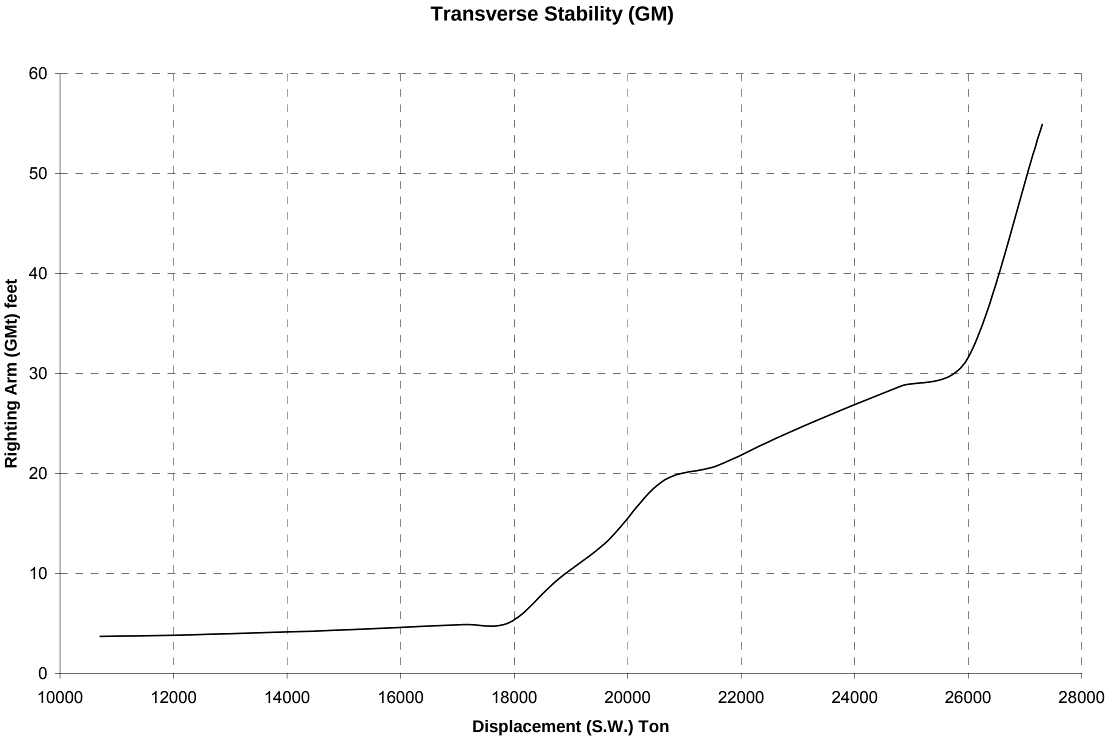


Figure 85. Transverse Stability (GM_T) in Fully Loaded Condition

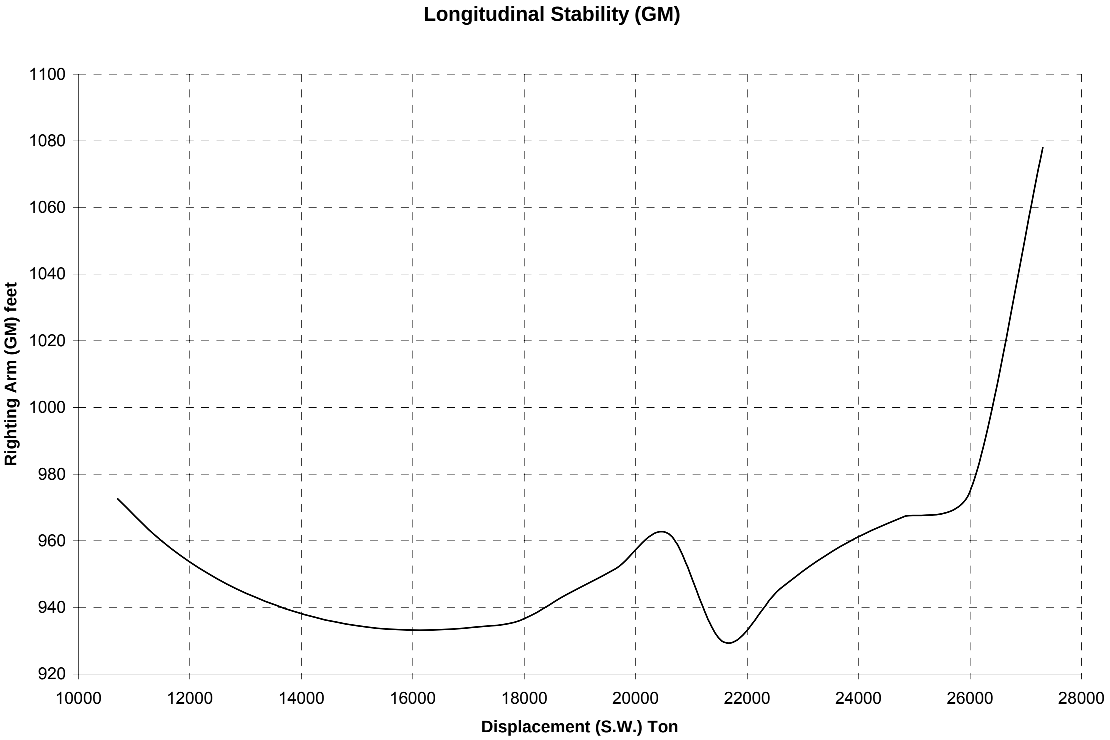


Figure 86. Longitudinal Stability (GM_L) in Fully Loaded Condition

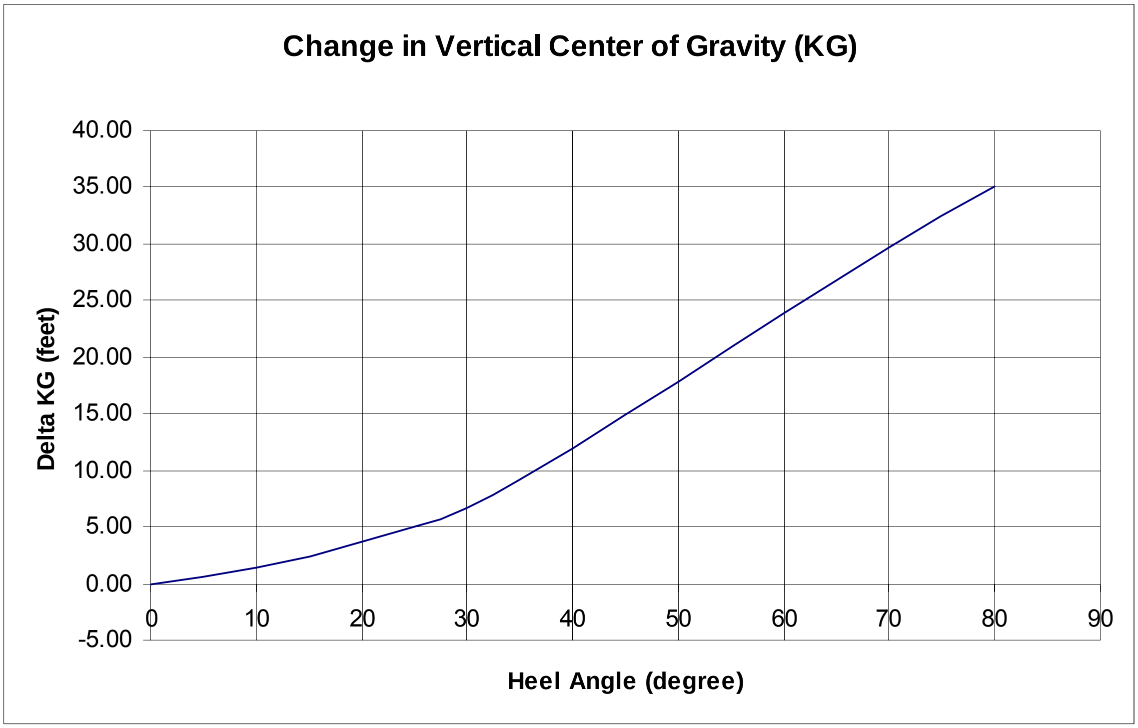


Figure 87. Change in KG for various Heeling Angles

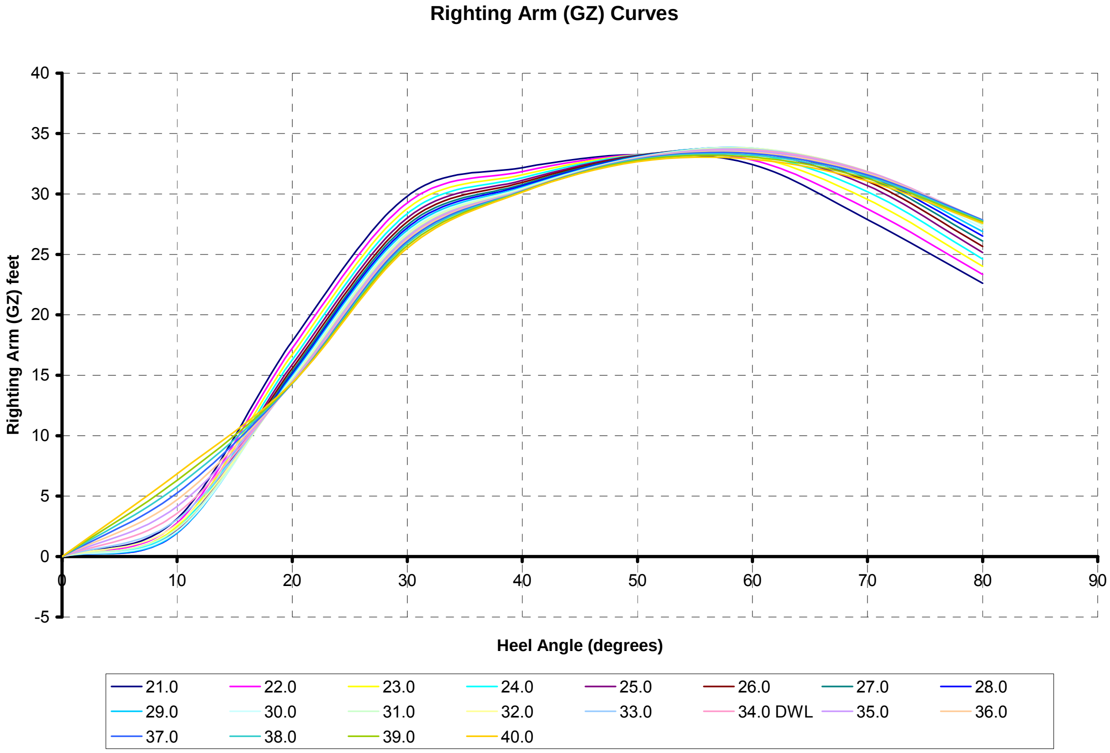


Figure 88. Righting Arm (GZ) in Fully Loaded Condition for Various Drafts

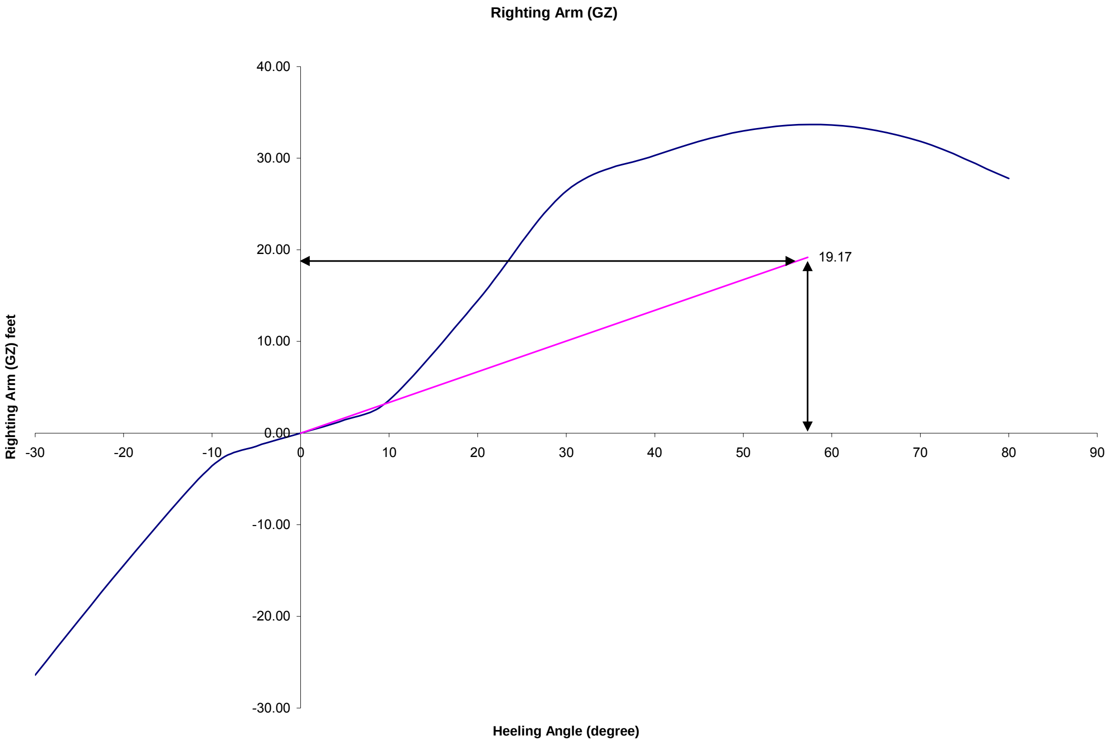


Figure 89. Righting Arm (GZ) and Metacentric Height at Design Waterline

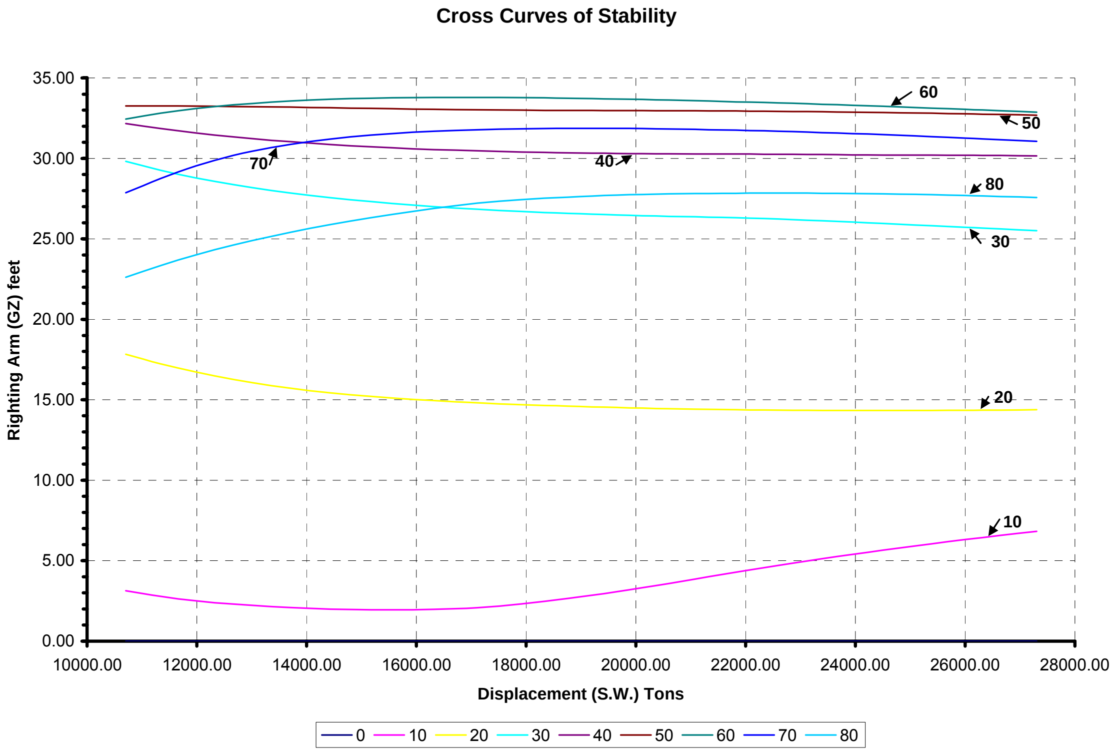


Figure 90. Cross Curves of Stability

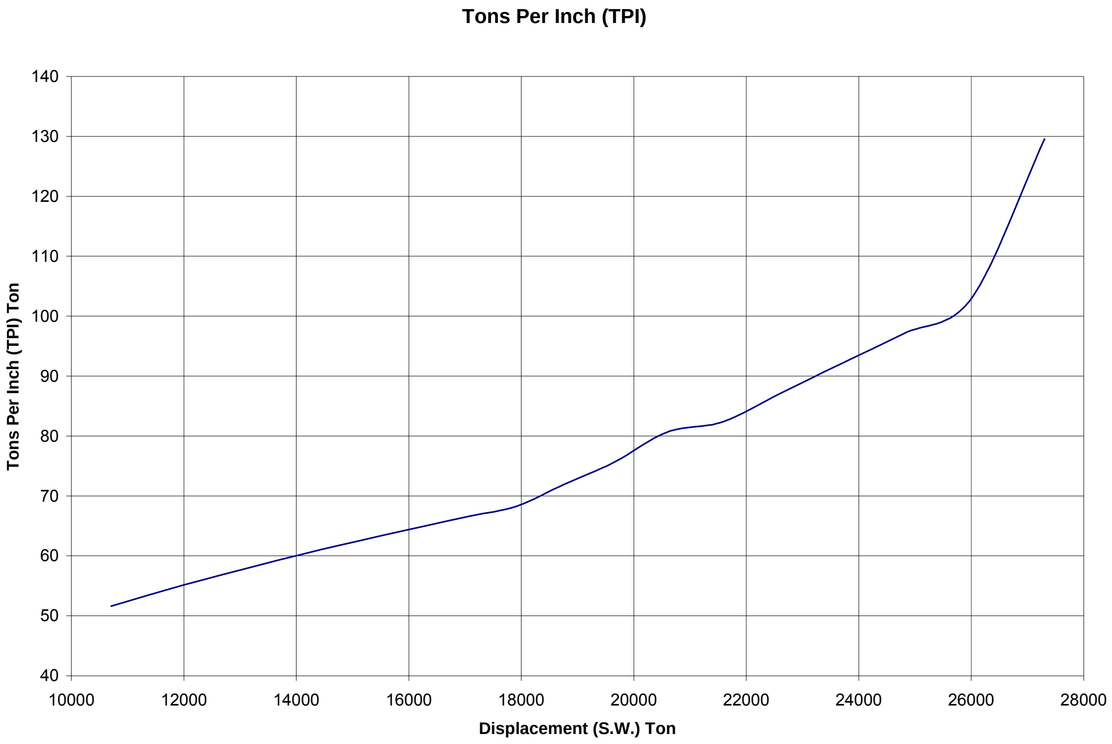


Figure 91. Tons Per Inch for Various Displacements

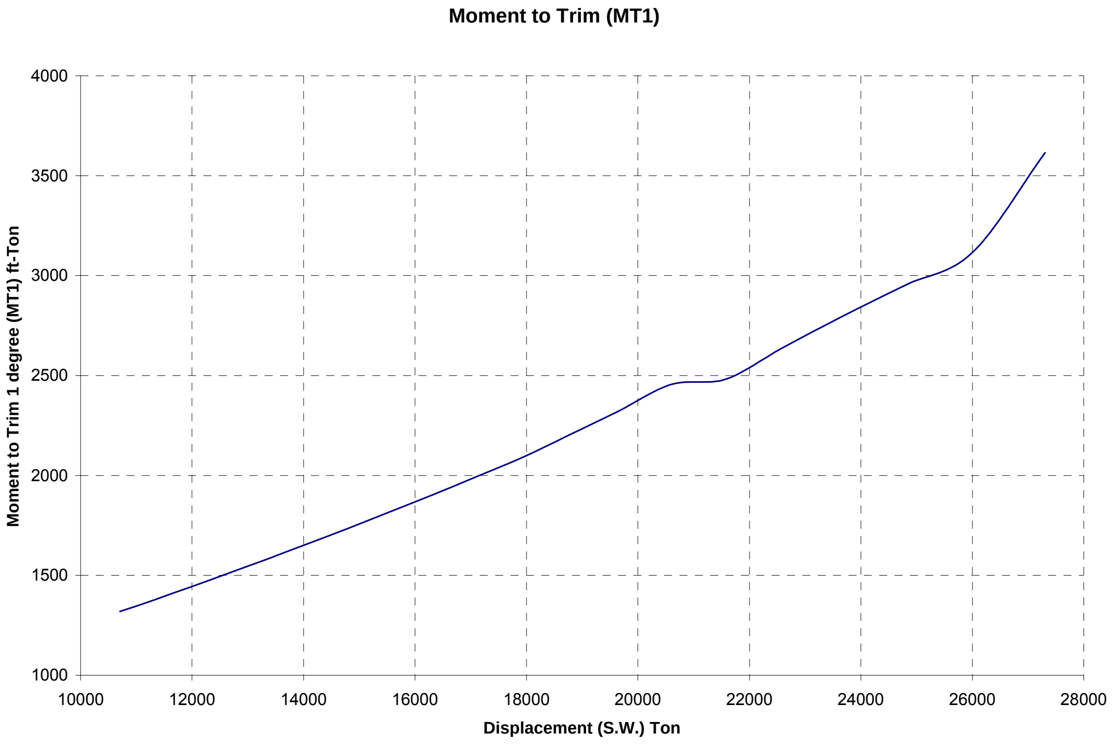


Figure 92. Required Moment to Trim the Ship 1 degree

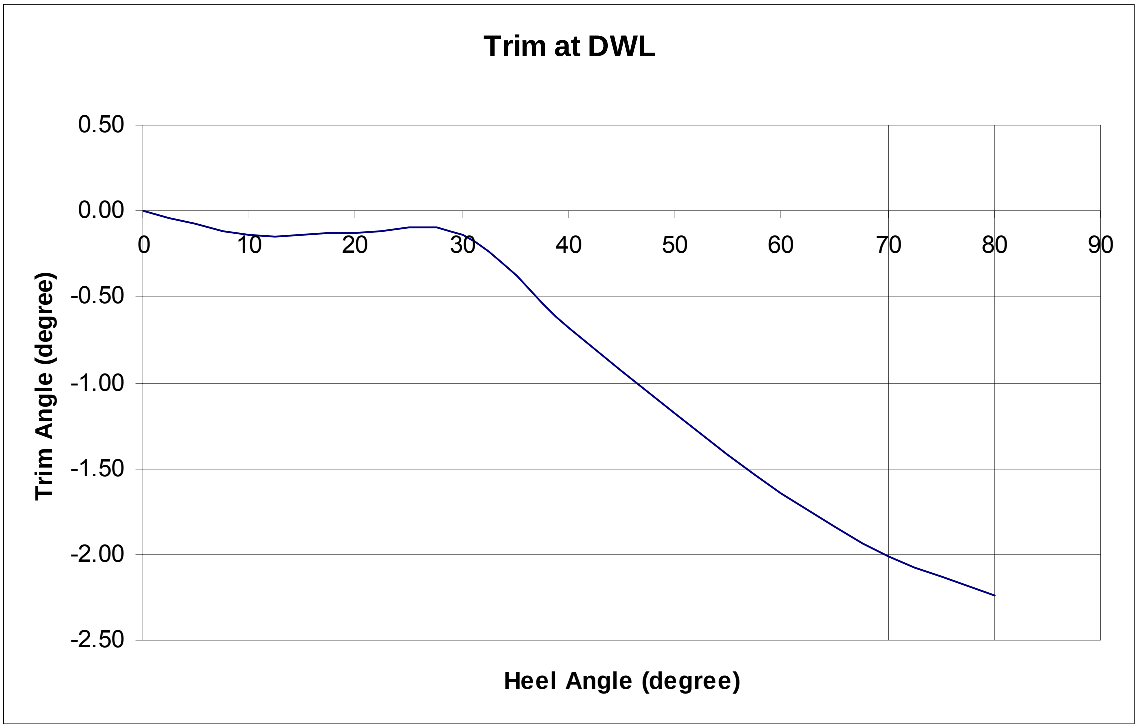


Figure 93. Resultant Trim at Various Heeling Angles applied to the Design Waterline

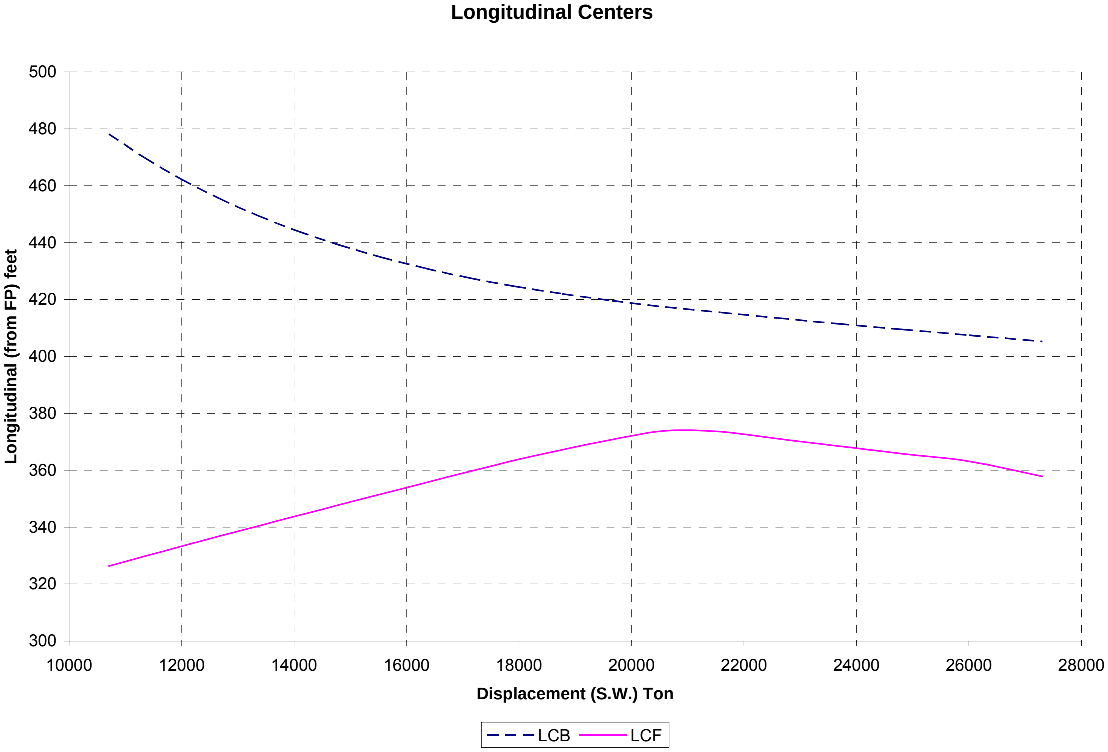


Figure 94. Longitudinal Center of Buoyancy and Longitudinal Center of Floatation

Rollover Data								
Heel @ T = 34.0	Trim	DeltaVCG	Origin Depth	Right. Mom.	Right. Arm.	Neutral Axis	MetShelf Slope	MetShelf Intercept
-30	-0.14	6.71	24.21	-543933.80	-26.41	3.17	-0.08	102.23
-20	-0.13	3.74	29.35	-297614.45	-14.45	-1.35	0.28	-5.87
-10	-0.14	1.33	33.19	-73724.53	-3.58	2.47	0.01	61.04
-5	0.00	0.30	33.58	-29739.07	-1.44	0.10	-0.02	56.33
0	0.00	0.00	34.00	0.42	0.00	0.00	-0.02	57.66
5	0.00	0.30	33.58	29740.52	1.44	-0.10	-0.02	56.33
10	-0.14	1.33	33.19	73725.59	3.58	-2.47	0.01	61.04
20	-0.13	3.74	29.35	297615.40	14.45	1.35	0.28	-5.87
30	-0.14	6.71	24.21	543934.69	26.41	-3.17	-0.08	102.23
40	-0.68	11.89	19.87	623889.65	30.29	-2.98	-0.10	108.37
50	-1.18	17.79	13.83	678955.31	32.96	-2.78	-0.09	100.24
60	-1.65	23.84	6.85	692639.35	33.63	-2.52	-0.06	77.69
70	-2.02	29.62	-1.07	655709.72	31.83	-1.68	-0.02	59.50
80	-2.24	35.06	-10.00	572495.92	27.79	-0.57	-0.01	54.20

Figure 95. Stability Analysis at Design Waterline

B. Select Interceptor Loading Conditions

The following section addresses the static stability conditions when the mothership has less than full capacity of interceptor boats in the Mission Bay.

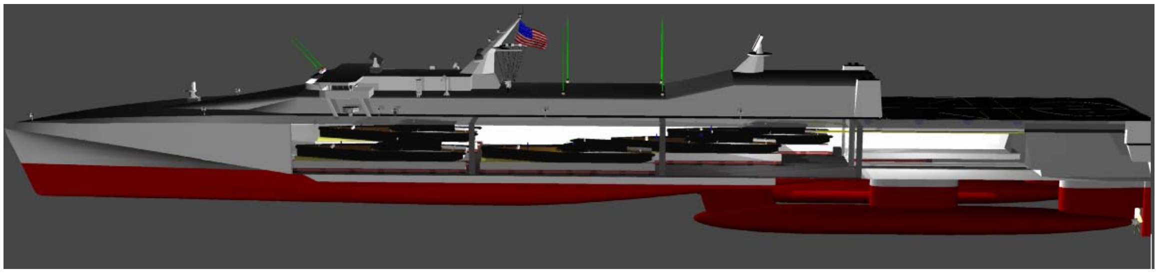


Figure 96. TSUNAMI side look

The following conditions are modeled with no compensating ballast:

- Five Interceptors secured in the Mission Bay
- Two Interceptors removed from the same side of the Mission Bay
- Two Interceptors Removed with one in Hoist Bay
- Three Interceptors removed from the same side of the Mission Bay
- Zero Interceptors in Mission Bay with one in Hoist
- Mission Bay and Hoist Bay empty

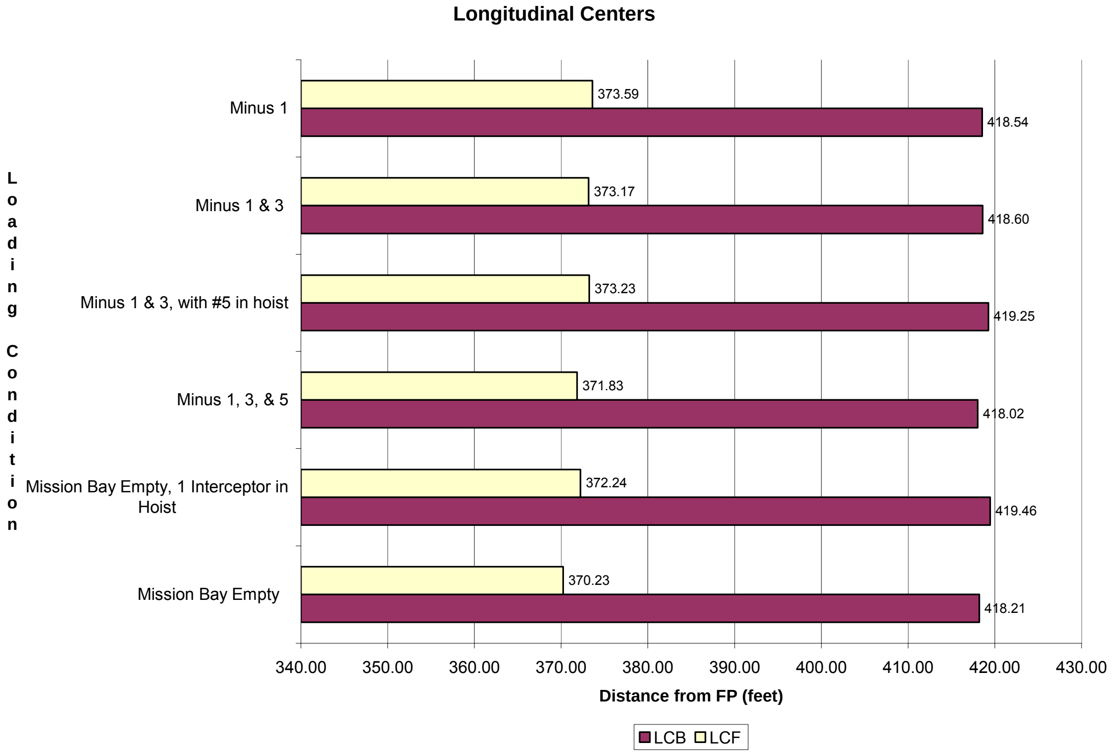


Figure 97. Longitudinal Center of Buoyancy and Floatation for various Loadings

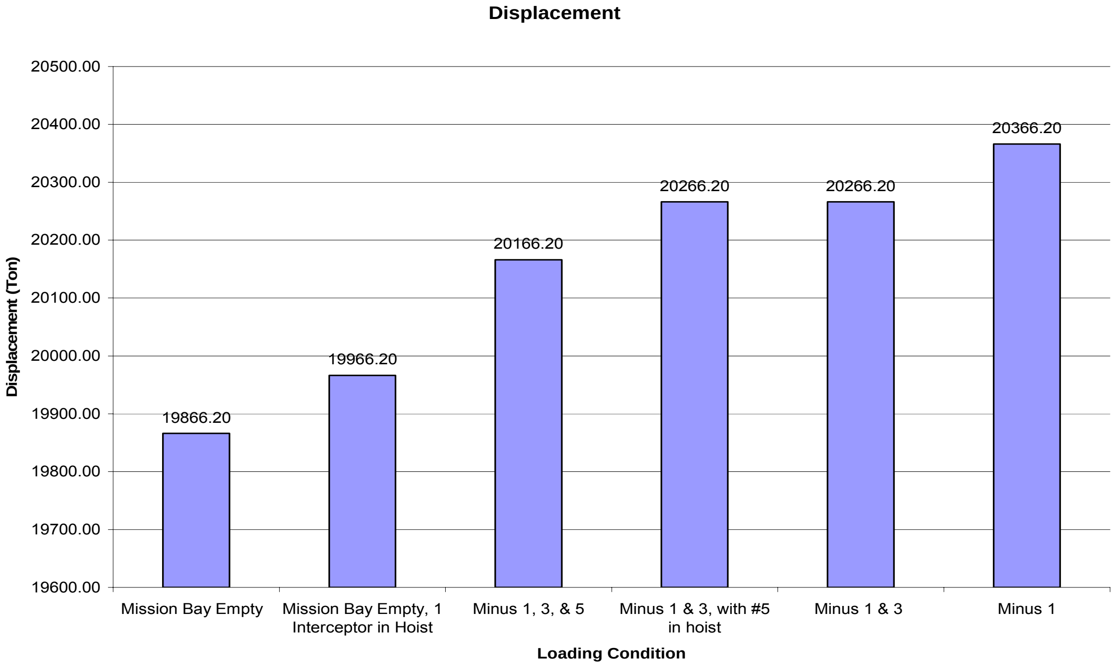


Figure 98. Effect of Various Loads on Ship Displacement

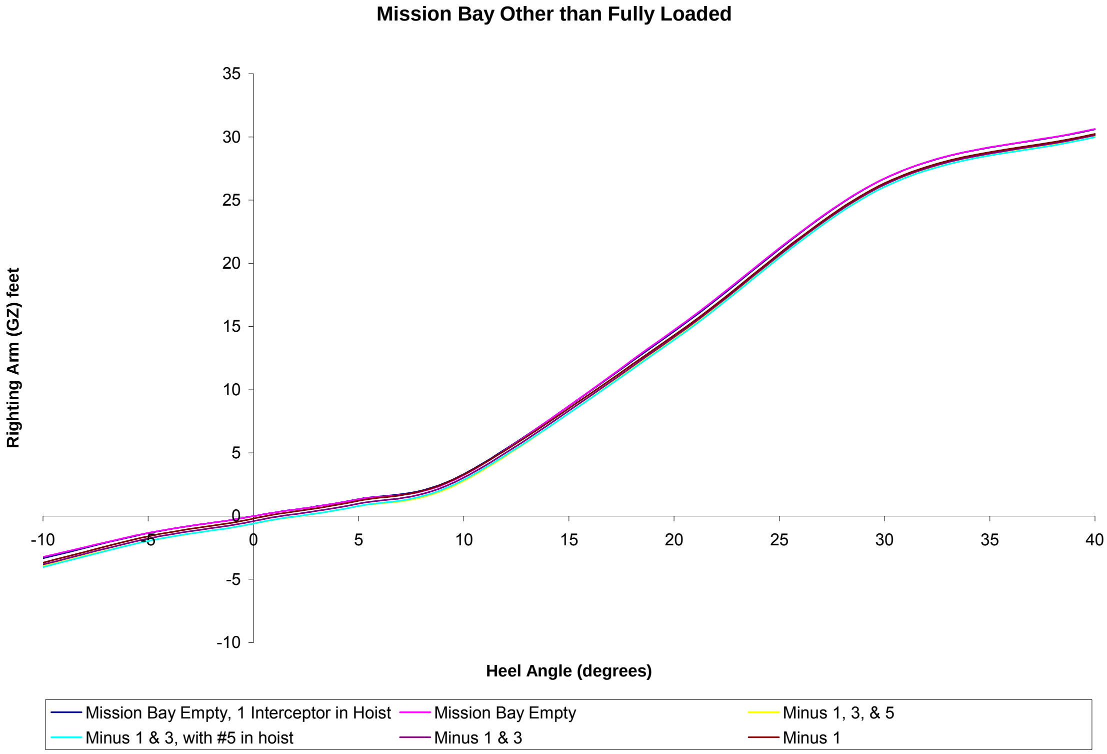


Figure 99. Righting Arm (GZ) for Partial Loading Conditions

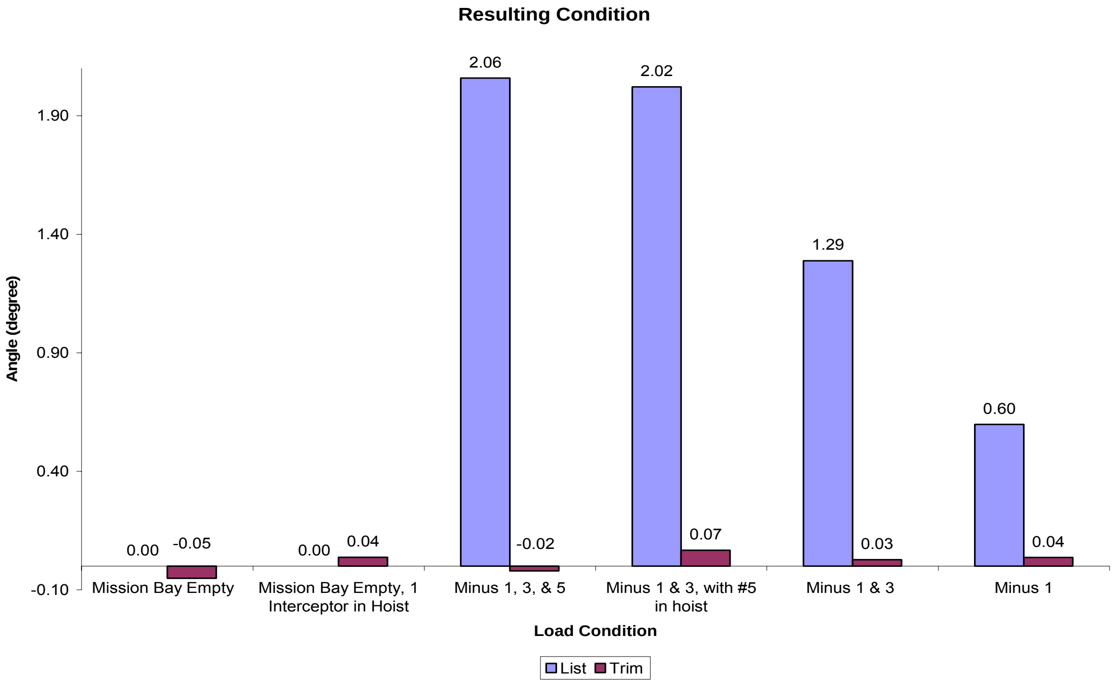


Figure 100. Resultant List and Trim from Partial Loading Conditions

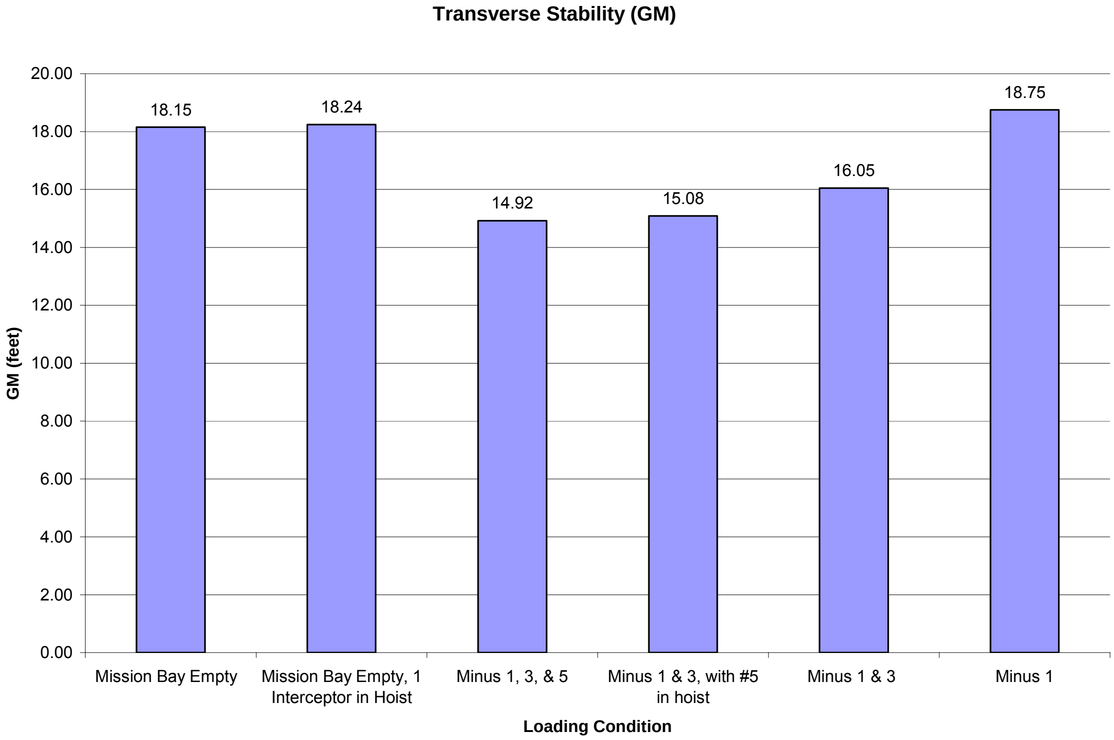


Figure 101. Transverse Stability for Partial Loading Conditions

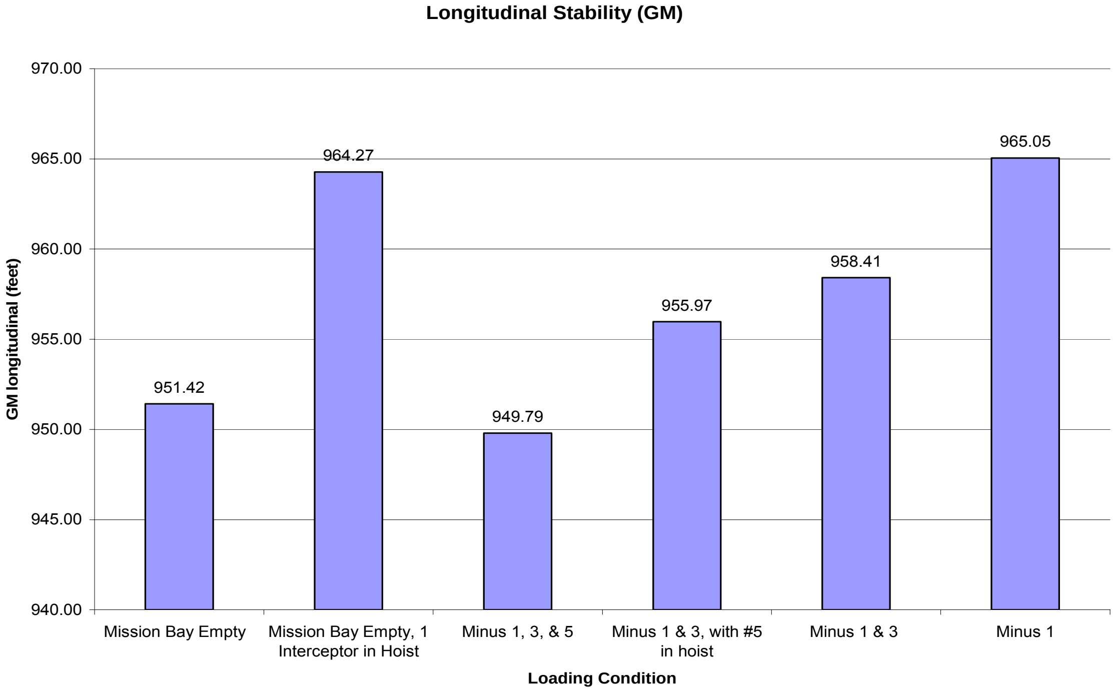


Figure 102. Longitudinal Stability for Various Loading Conditions

C. NAVY DESIGN DATA SHEET 079-1 REQUIREMENTS

The Department of the Navy DDS-079-1 outlines specific requirements for all new designs of Navy ships to specifically meet. This report address the requirements for high speed turn heeling, a 100 knot wind heeling, and heeling due to all personnel on board standing on one side.

1. High Speed Turn

The parameters for the high speed turning calculations are as follows:

- Lever Arm between the Vertical Center of Gravity and the Center of underwater volume (L) = 13.97 ft
- Tactical Radius of the Turn (Tr) = 1600 ft
- Gravity (g) = 32.2 ft/sec^2
- Speed in the Turn (V) = 30 knots
- Angle of Incline (θ) = radians
- Heeling Arm due to the Turn (HA_{TURN})

The following equation from the DDS-079 was applied:

$$HA_{TURN} = \frac{V^2 L \cos(\theta)}{gT_R}$$

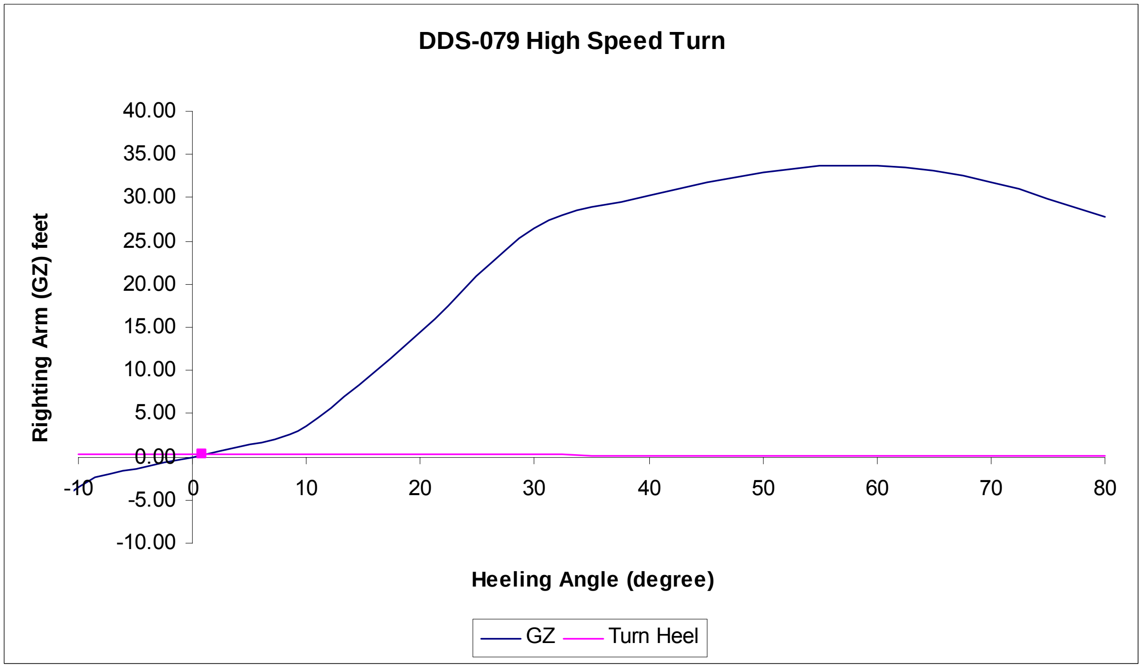


Figure 103. Tsunami Righting Arm and Heel Due to 30kt Turn

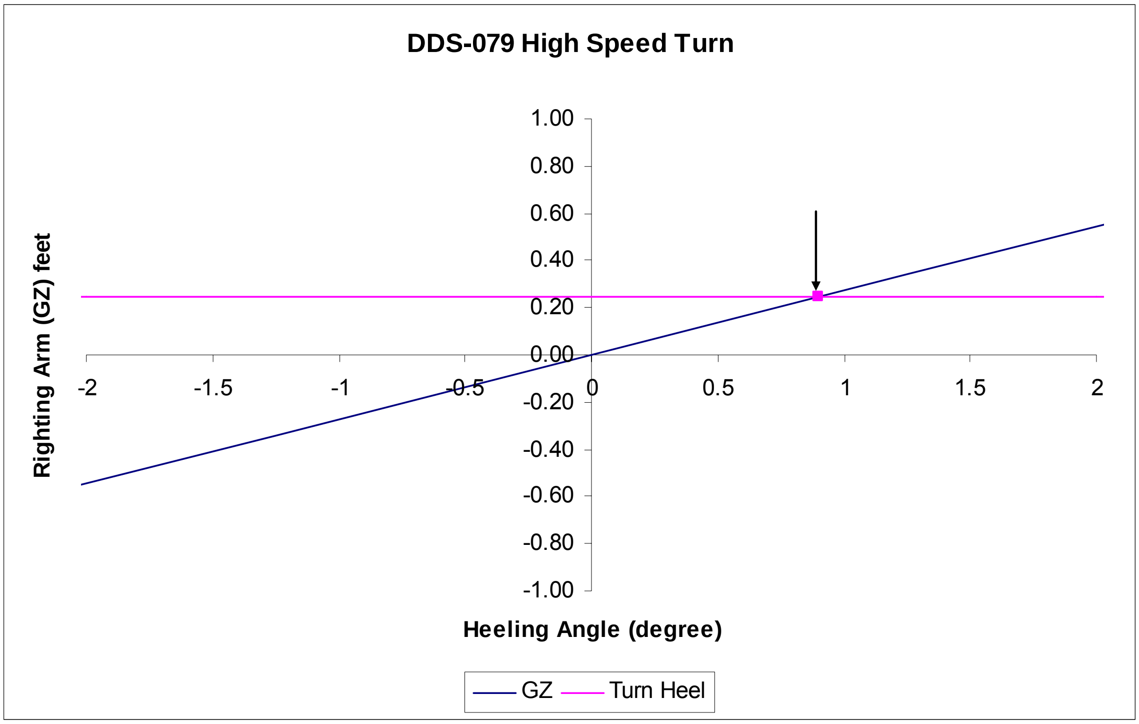


Figure 104. Heeling Angle for 30kt Turn

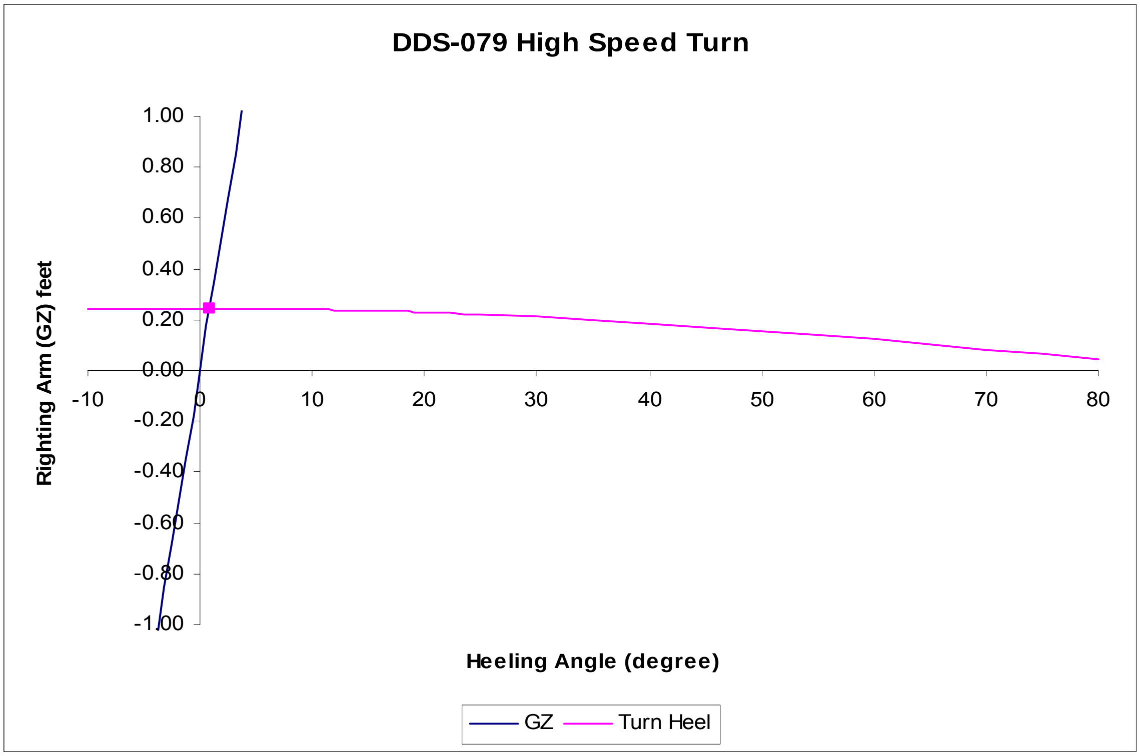


Figure 105. Heeling Curve for 30kt Turn

2. 100knot Winds

The design requirement, set by the Department of the Navy, expect that an intact ship must maintain adequate stability in 100 knot wind velocities. More specifically, ocean going ships must be expected to weather the full force of tropical cyclones. These ships include those which are expected to move with amphibious and striking forces. The DDS-079-1 requires that the intersection where the heeling curve resulting from a 100 knot wind crosses the righting arm curve of the ship is not greater that 0.6 of the maximum righting arm. In the case of the Tsunami hull, the equilibrium point is 0.035 of the maximum righting arm.

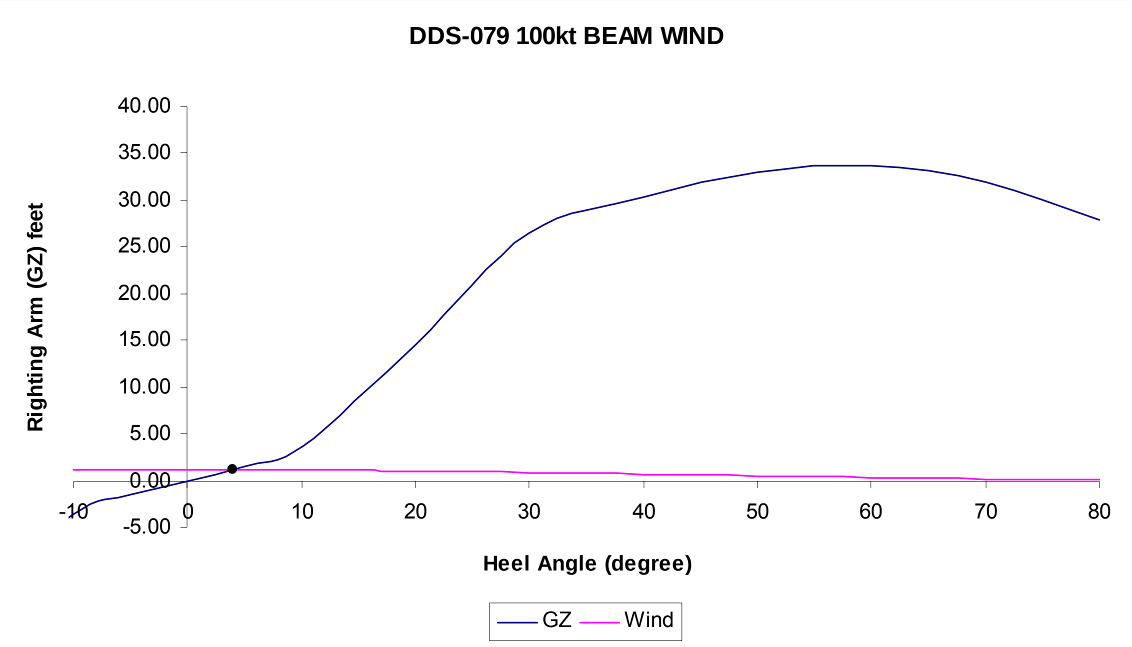


Figure 106. Tsunami Righting Arm with 100kt Beam Wind

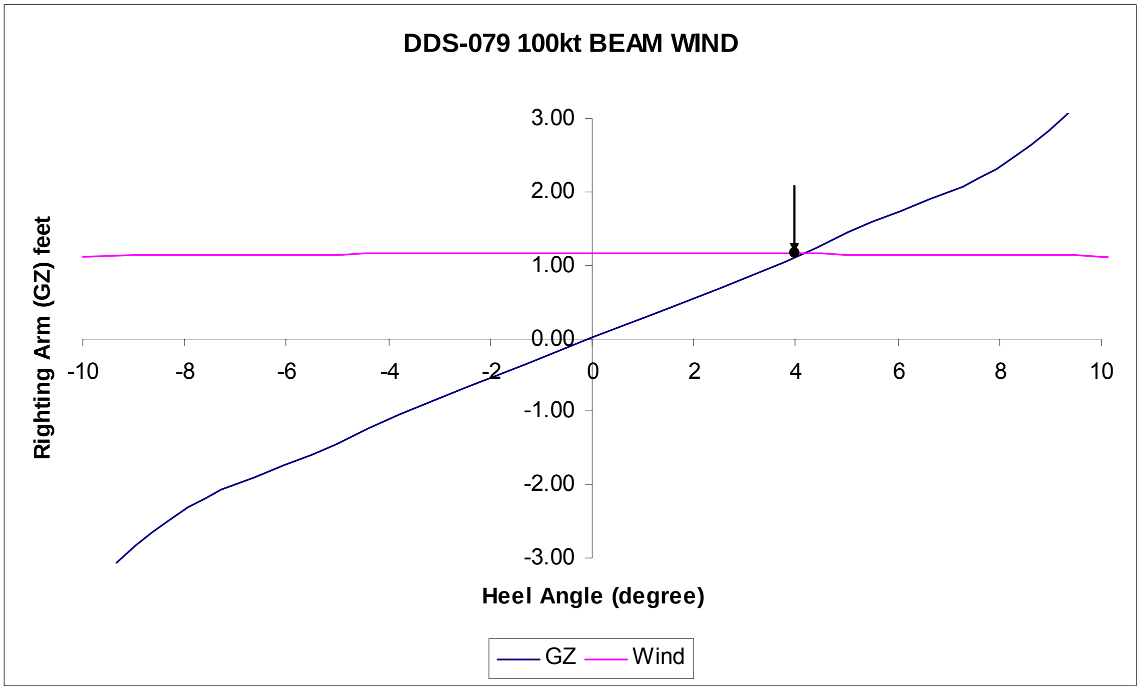


Figure 107. Heeling Angle for 100kt Beam Wind

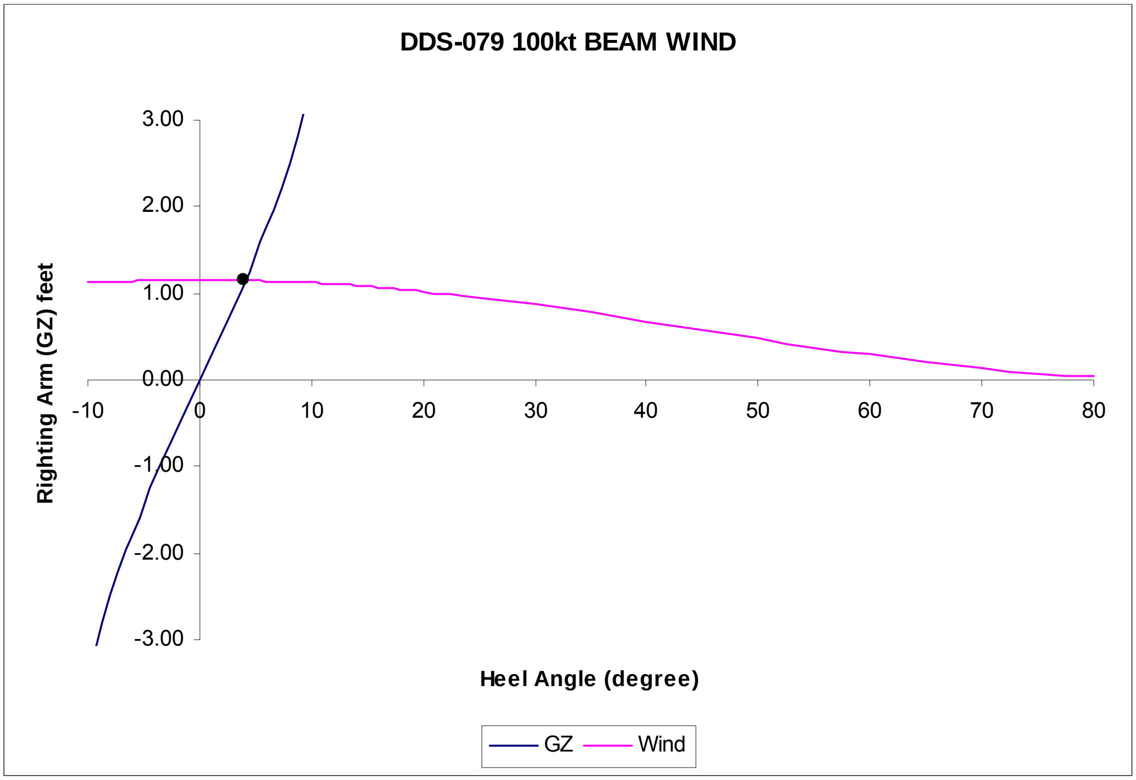


Figure 108. Heeling Curve for 100kt Beam Wind

3. 400 Personnel Crowding

Design Data Sheet 079-1 provides guidance for the crowding of a large number of personnel on one side of the ship which results in producing a heeling moment. The heeling arm curve intersection with the righting arm curve cannot exceed 0.6 the maximum righting arm for the ship. In the case for the Tsunami hull, the heeling arm at equilibrium is 0.005 the maximum righting arm.

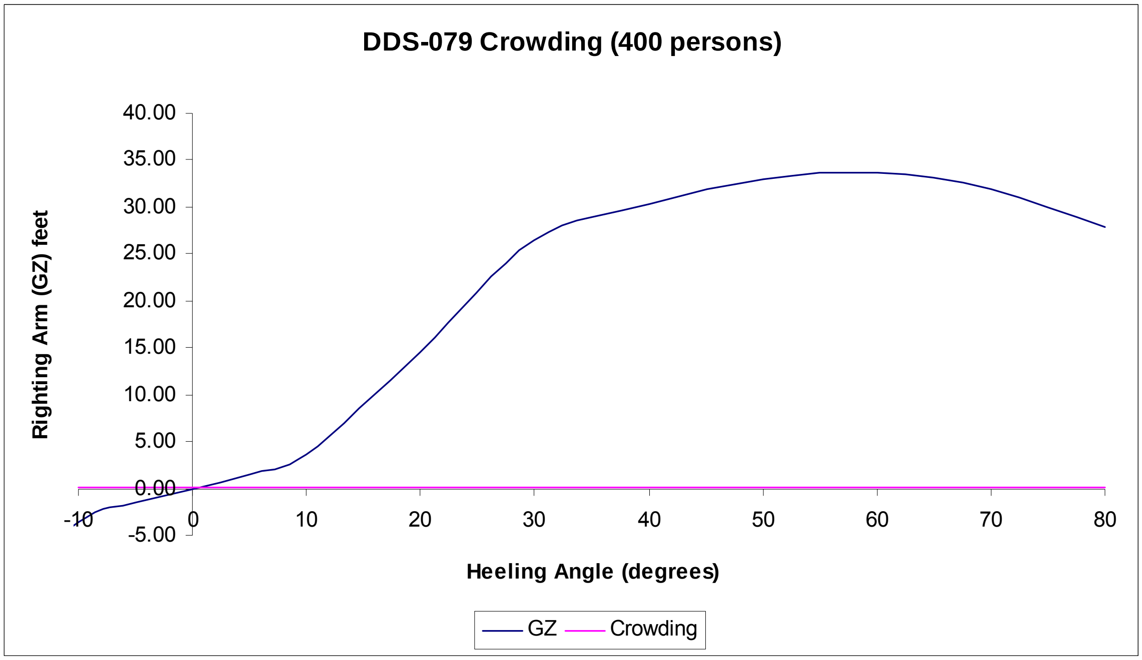


Figure 109. Tsunami Righting Arm with 400 Persons Crowding One Side

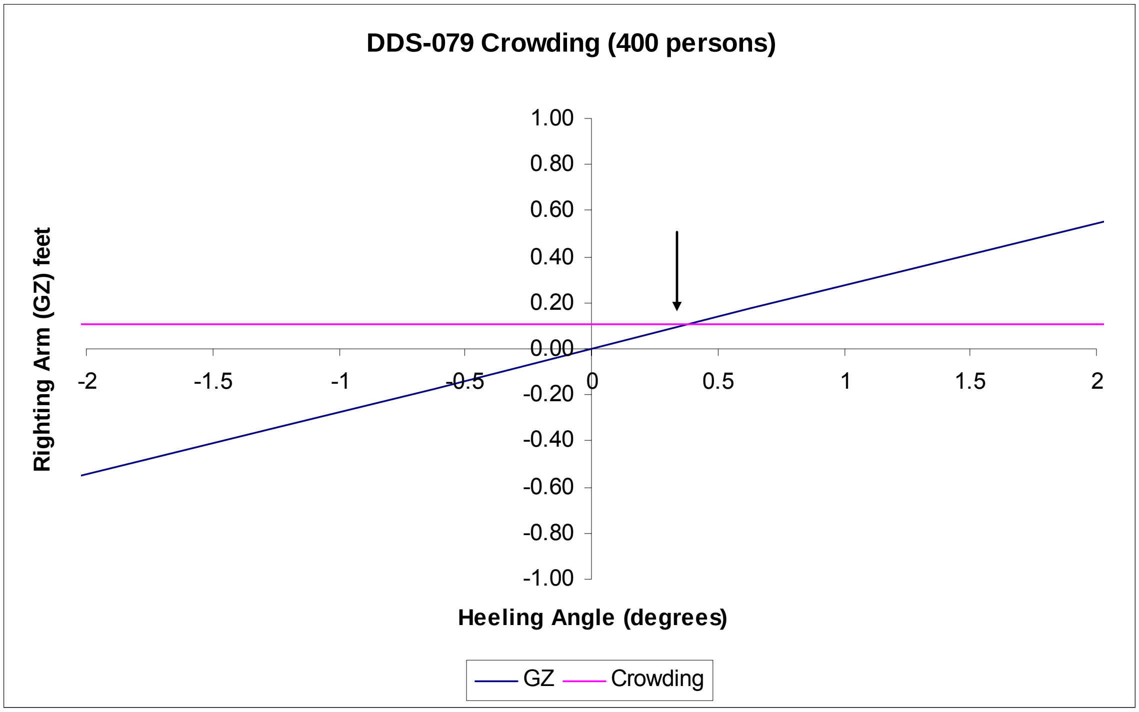


Figure 110. Heeling Angle for 400 Persons Crowding One Side

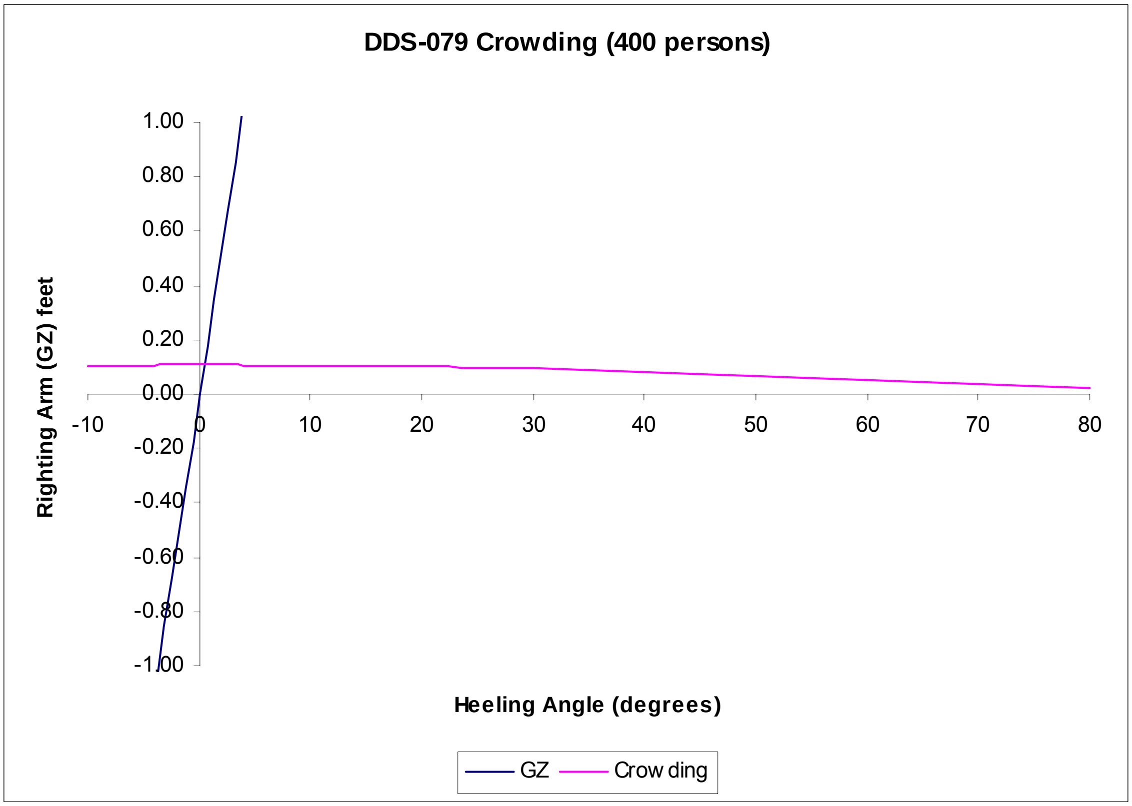


Figure 111. Heeling Curve for 400 Persons Crowding One Side

V. RESISTANCE

A. REQUIREMENTS

Traceability Code (TC 2.3.2)

The mothership must be able to carry the full payload of interceptors 7000 nautical miles relatively fuel efficiently to the rendezvous location to deploy the fleet of interceptors.

Traceability Code (TC 2.3.3 / 2.3.4)

The mothership must be able to maintain 20 knots cruising speed and 30 knots sprint speed in sea state 5.

B. CENTER HULL

The center hull analysis of the Tsunami ship used the standard mono hull based design analysis. Center hull offsets were input into the computer systems; there values for resistance were generated. Viscous and wave making resistance calculations were performed using the Holtrop method in the AUTOPWR/AUTOSHIP software package.

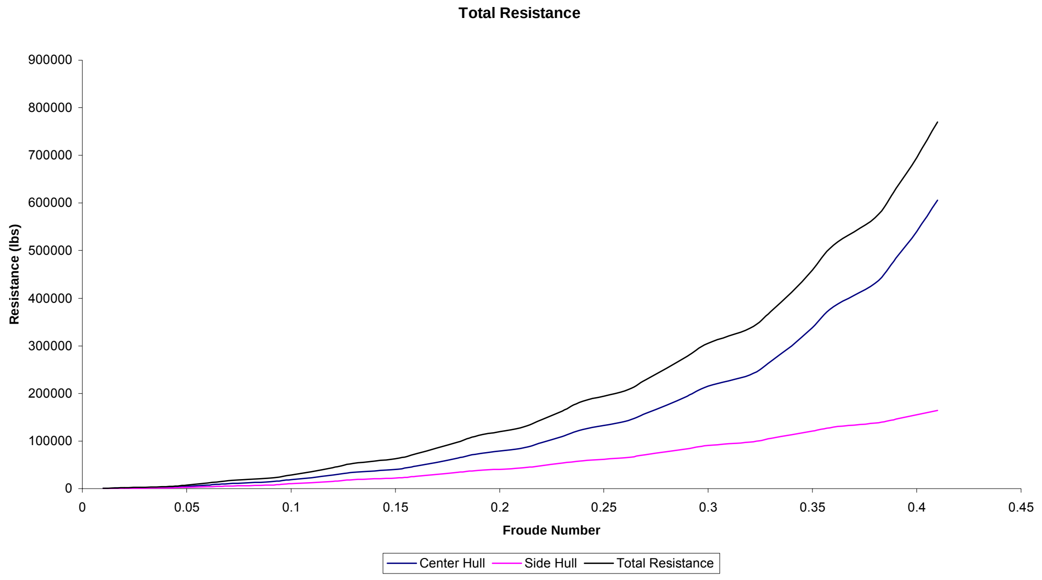


Figure 112. Overall Resistance Curves for Tsunami Hull

C. SIDE HULL AND STRUTS

1. Viscous Resistance

For the fully submerged body, more specifically the side hulls of the Tsunami Ship, the viscous frictional resistance are the driving component of total resistance. The viscous resistance for the side hulls is calculated as;

$$R_V = \frac{1}{2}\rho U^2 S C_V \tag{0.1}$$

Viscous resistance coefficient is,

$$C_V = C_F + C_A + C_r \tag{0.2}$$

The viscous resistance coefficient for the side hulls consists of; the frictional resistance coefficient C_F, the correlation allowance C_A (which is assumed constant), and the coefficient due to parasitic form drag C_r. See table for viscous resistance results.

2. Frictional Resistance Coefficient C_F

Calculations of the frictional resistance coefficient are based of the International Towing Tank Conference (ITTC 1957) Curve,

$$C_F = \frac{0.075}{\left(\log_{10}\mathrm{Re} - 2\right)^2} \tag{0.3}$$

See table for frictional resistance coefficient values.

3. Correlation Allowance Coefficient C_A

The correlation allowance is assumed to be constant CA = 0.0004

4. Form Drag Coefficient C_r

Due to the complexity of the form drag relation to boundary layers and flow separation, an empirical calculation based on curve fitting of experimental data for the form drag coefficient was applied (Al-jowder 1995). The following equation for the form drag coefficient uses the coefficients from side hull geometry;

$$C_r = \frac{0.00789D}{L - l - L_f C_{wsf} + L_a C_{wsa}}. \qquad (0.4)$$

Form Drag, $C_r = 0.000719$

5. Wave Resistance

Wave making resistance is the component of resistance associated with the energy dissipated to the environment through; surface wave pattern resistance and wave breaking resistance. Wave breaking resistance is assumed to be insignificant to overall resistance for the side hulls since they are positioned 15ft below the surface. Wave making resistance of the side hulls is considered to be significantly lower than the viscous resistance. Additionally, based on the weight of the complexity of calculation versus the impact on overall resistance, wave resistance of the side hulls is left to future research.

Based on the fact that the wetted surface of the struts on Tsunami is less than 10 percent of the wetted surface of the center hull, the significant coefficient of resistance encountered with struts in tandem is deemed to be inconsequential to overall resistance.

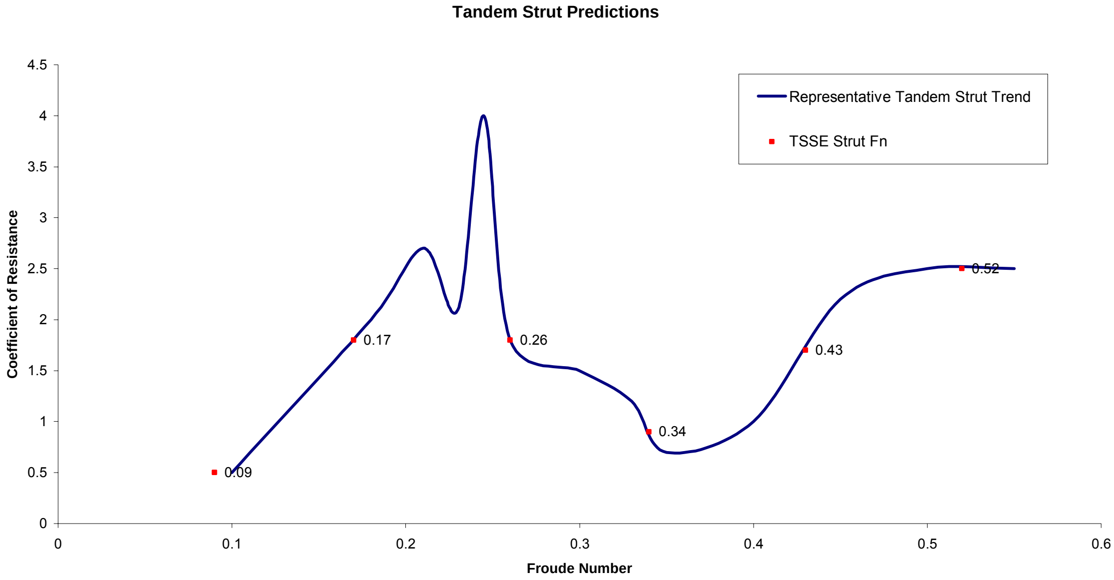


Figure 113. Coefficient of Resistance for Tandem Side Hull Struts

Considering only Froude's Friction formula (Zubaly 2004), the resistance results for a hypothetical combined strut on a single side is;

S_{STRUT} = 3600 sqft

L_{STRUT} = 300 feet

V = 30 knots

$$f = 0.00871 + \frac{0.0530}{(L+8.8)} \tag{0.5}$$

$$R_F = fSV^{1.825} \tag{0.6}$$

$$R_F = 15868.7 lbs \tag{0.7}$$

These results equate to roughly 2 percent of the resistance generated by the side hull and center hull at maximum design speed. It can therefore be assumed for the purpose of this report that the wave resistance of the struts will not affect horsepower calculations and thus can be left for future research endeavor when finer calculations are required.

D. EFFECTIVE HORSEPOWER

The bulk of shaft horsepower (SHP) calculations, iterations, and detailed discussion are left to the Propulsion section of this report. For the purpose of first run calculations an assumed value for propulsion efficiency was 0.65. The calculation of effective horsepower resulting overall hull resistance is carried out through the following;

$$EHP = \frac{\left(2R_{SIDE} + R_{CENTER}\right)V}{550} \tag{0.8}$$

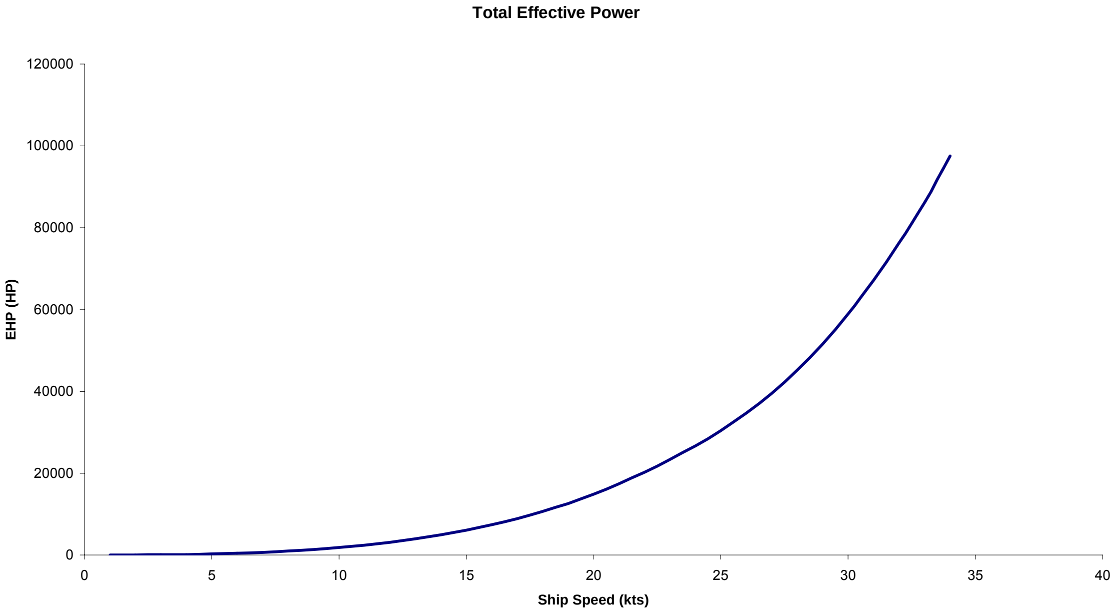


Figure 114. Total Effective Horse Power

The figure below shows where the Tsunami hull characteristics fall within the spectrum of modern warships. Based on the comparison of the Froude number and shaft horsepower per tonnage, the Tsunami hull can be characterized as a fast aircraft carrier or a heavy cruiser. At lower speeds the Tsunami hull falls within the region of auxiliary vessels.

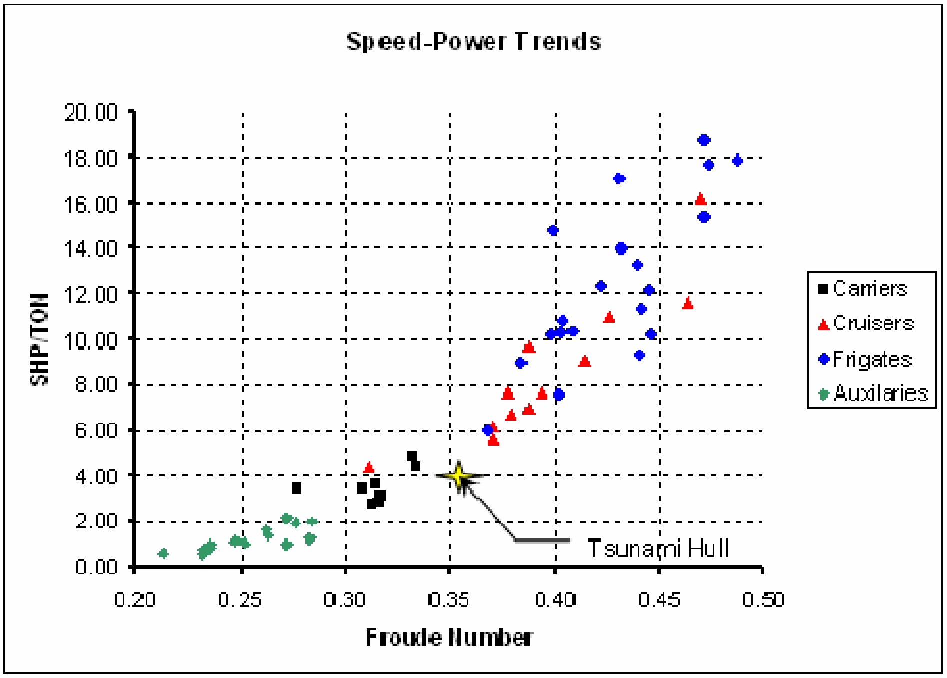


Figure 115. Comparison of Speed and Power Trends for Various Ship Class

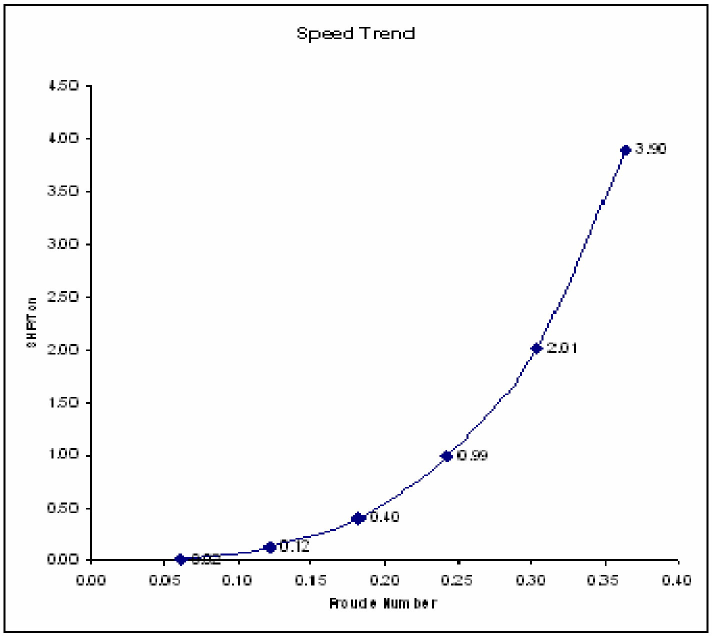


Figure 116. Speed and Power Trends for Tsunami Hull

Constants									Centerhull Coefficients	
ship L	600	ft			1kt	1.6878	ft/sec		Cwp	0.75
gravity	32.2	ft/sec^2			length	300	ft		Cm	0.92
	Center Hull	Side Hull	Total		density	1.9876	lb-sec^2/ft^4		Cb	0.521
Volume	495266.18	126902.087	749070.354	ft^3	Kin viscosity	0.000012615	ft^2/sec	at 60F	Cp	0.567
Displac	21417	LT			Wetted	19363.133	ft^2			
					Shaft Efficient	0.72			*Note coefficients tabulated from max displacement	

	Side Hull Resistance (EXCEL)						Center Hull (AUTOSHIP)		Combined	Horsepower		
knots	ft/sec	Re	Cf	Cr	Ca	Viscous Resist	Fn	Holtrop	resistance	EHP	SHP	SHP/TON
1	1.6878	40137931.03	0.002388548	0.00071944	0.0004	192.30	0.01	369.32	561.62	2.3	3.21	0.000150034
2	3.3756	80275862.07	0.002151209	0.00071944	0.0004	717.15	0.02	1356.53	2073.68	17.1	23.79	0.001110787
3	5.0634	120413793.1	0.002028418	0.00071944	0.0004	1553.01	0.04	2910.80	4463.81	55.4	76.93	0.003592158
4	6.7512	160551724.1	0.001947563	0.00071944	0.0004	2689.99	0.05	5008.68	7698.67	127.5	177.11	0.008269643
5	8.439	200689655.2	0.001888131	0.00071944	0.0004	4121.66	0.06	7634.85	11756.51	243.6	338.37	0.015799296
6	10.1268	240827586.2	0.001841568	0.00071944	0.0004	5843.30	0.07	10778.11	16621.41	413.6	574.48	0.026823745
7	11.8146	280965517.2	0.001803529	0.00071944	0.0004	7851.22	0.09	14430.17	22281.39	647.3	899.00	0.041976074
8	13.5024	321103448.3	0.001771524	0.00071944	0.0004	10142.36	0.10	18586.54	28728.90	954.3	1325.39	0.061885065
9	15.1902	361241379.3	0.001743995	0.00071944	0.0004	12714.20	0.11	23249.89	35964.09	1,344.4	1867.25	0.08718563
10	16.878	401379310.3	0.00171991	0.00071944	0.0004	15564.51	0.12	28434.97	43999.48	1,827.9	2538.69	0.118536181
11	18.5658	441517241.4	0.001698549	0.00071944	0.0004	18691.37	0.13	34173.59	52864.96	2,415.5	3354.80	0.156641903
12	20.2536	481655172.4	0.001679394	0.00071944	0.0004	22093.08	0.15	40517.59	62610.67	3,119.2	4332.21	0.202279094
13	21.9414	521793103.4	0.001662058	0.00071944	0.0004	25768.07	0.16	47539.02	73307.09	3,952.5	5489.51	0.256315771
14	23.6292	561931034.5	0.001646245	0.00071944	0.0004	29714.97	0.17	55327.70	85042.67	4,930.2	6847.55	0.319725169
15	25.317	602068965.5	0.001631726	0.00071944	0.0004	33932.50	0.18	63987.02	97919.52	6,069.3	8429.54	0.393591026
16	27.0048	642206896.6	0.001618317	0.00071944	0.0004	38419.47	0.19	73628.52	112047.99	7,387.9	10260.97	0.479103956
17	28.6926	682344827.6	0.001605872	0.00071944	0.0004	43174.82	0.21	84355.30	127530.12	8,905.4	12368.61	0.57751354
18	30.3804	722482758.6	0.001594269	0.00071944	0.0004	48197.53	0.22	96292.44	144489.97	10,643.5	14782.63	0.690228987
19	32.0682	762620689.7	0.001583409	0.00071944	0.0004	53486.66	0.23	109659.20	163145.86	12,630.9	17542.97	0.819114083
20	33.756	802758620.7	0.001573208	0.00071944	0.0004	59041.32	0.24	124588.80	183630.12	14,893.8	20685.90	0.965863675
21	35.4438	842896551.7	0.001563596	0.00071944	0.0004	64860.70	0.26	140819.90	205680.60	17,434.6	24214.68	1.130628773
22	37.1316	883034482.8	0.001554514	0.00071944	0.0004	70944.01	0.27	157840.00	228784.01	20,235.2	28104.50	1.312251837
23	38.8194	923172413.8	0.001545908	0.00071944	0.0004	77290.51	0.28	175463.70	252754.21	23,294.8	32353.88	1.510663688
24	40.5072	963310344.8	0.001537736	0.00071944	0.0004	83899.50	0.29	194158.80	278058.30	26,658.0	37024.99	1.72876654
25	42.195	1003448276	0.001529959	0.00071944	0.0004	90770.32	0.30	214869.40	305639.72	30,411.9	42238.69	1.972203887
26	43.8828	1043586207	0.001522542	0.00071944	0.0004	97902.32	0.32	238695.50	336597.82	34,667.4	48149.20	2.248176669
27	45.5706	1083724138	0.001515455	0.00071944	0.0004	105294.91	0.33	266678.30	371973.21	39,544.4	54922.71	2.564444816
28	47.2584	1123862069	0.001508673	0.00071944	0.0004	112947.51	0.34	299660.00	412607.51	45,158.0	62719.42	2.928487545
29	48.9462	1164000000	0.001502172	0.00071944	0.0004	120859.56	0.35	338142.50	459002.06	51,603.7	71671.77	3.346489915
30	50.634	1204137931	0.001495932	0.00071944	0.0004	129030.53	0.36	382151.60	511182.13	58,939.1	81859.92	3.822193487
31	52.3218	1244275862	0.001489933	0.00071944	0.0004	137459.90	0.38	431162.70	568622.60	67,170.0	93291.69	4.355964245
32	54.0096	1284413793	0.001484159	0.00071944	0.0004	146147.20	0.39	484141.40	630288.60	76,245.4	105896.43	4.9445035
33	55.6974	1324551724	0.001478594	0.00071944	0.0004	155091.94	0.40	540375.60	695467.54	86,134.5	119631.19	5.585805224
34	57.3852	1364689655	0.001473225	0.00071944	0.0004	164293.67	0.41	606022.70	770316.37	97,514.2	135436.32	6.323776556

Figure 117. Resistance and Horsepower Data

VI. SEAKEEPING

A. REQUIREMENTS

Traceability Code (TC 2.3.3 / 2.3.4)

The Maritime Threat Response ship Tsunami must sustain mission operations in Sea State 5 conditions. Mission operations include; recover interceptors, maintain 20 knots cruise speed, and launch aircraft.

Traceability Code (TC 2.3.1 / 2.3.4)

The Tsunami ship must sustain support operations for the inspection team through the duration of the mission. The mothership must not be hindered by external forces while transiting with merchant traffic.

B. UNIQUE SHIP DESIGN CONSIDERATIONS

To ensure the best possible ride for the Tsunami ship, to ensure mission success, the design team implemented the SWATH design for the side hulls of the ship. Research has shown that the SWATH design reduces the natural period of the heave of the ship by 14 percent. This reduction in the heave motion allows for a sizable damping force during hoist operations. The specific shape of the side hulls directly attribute to the heave damping. When the horizontal axis of the hull is 1.4 times that of the vertical axis, a 14 percent reduction in heave can be achieved. The side hulls of the Tsunami are 28 ft horizontal and 20 ft vertical elliptical hulls.

The heave natural period for the side hulls of Tsunami were determined using the following calculations:

$$T_{HEAVE} = 2\pi\sqrt{\frac{V\left(1+A_{hydro}\right)}{gA_{wp}}} \tag{0.9}$$

V = the displaced volume of the side hulls
A_{hydro} = the hydrodynamic heave added mass divided by the side hull mass
g = gravitational acceleration
A_{WP} = total waterplane area

C. SEAKEEPING ANALYSIS

The sea keeping analysis for the Tsunami hull was conducted using the MATLAB computer software generated for the Total Ship Systems Curriculum. The MATLAB code calculates the motion of the ship using motion simulations with excitations inserted.

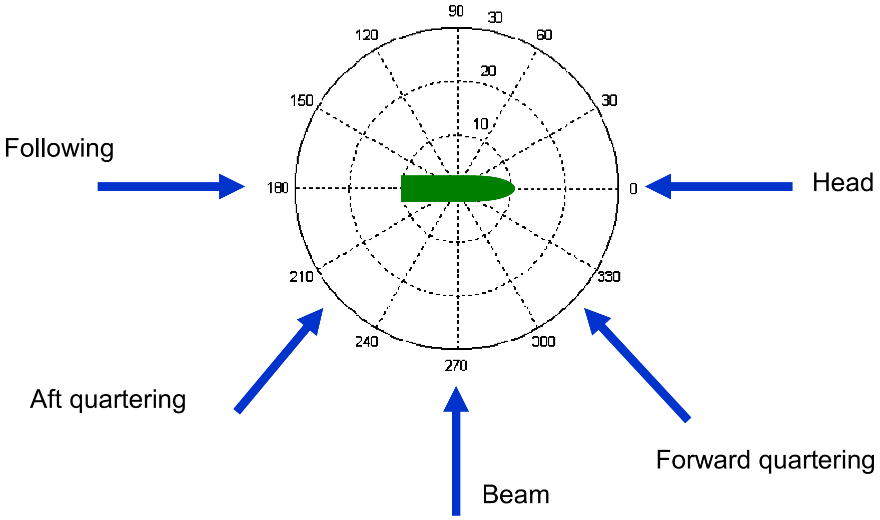
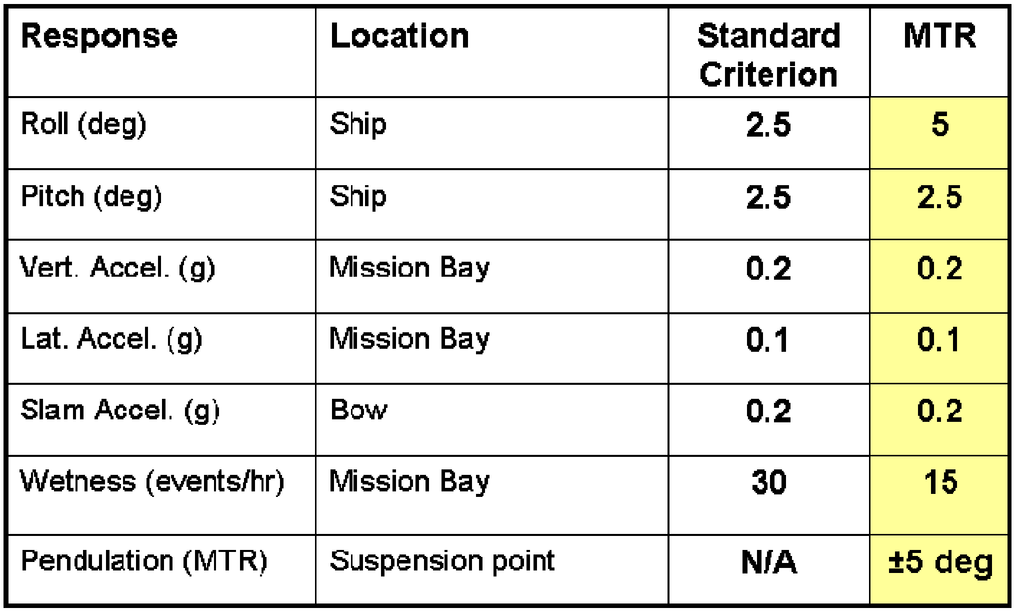


Figure 118. Ship Heading and Speed vs. Wave Heading Polar Plot

The figure above defines the polar plots of the MATLAB code. The table below shows the standard criterion used in sea keeping analysis. The roll criteria for the Tsunami doubled the standard criteria. By doubling the roll criteria values, the design team is able to model the reduced heave expected by using the SWATH hull designs on the side hulls.

The criteria for the wetness events experience at the mission door to emphasize the need for dry deck conditions. This allows for a more conservative estimate of the sea keeping of the Tsunami. Criterion for pitch, vertical acceleration, lateral acceleration, and slam acceleration were left as standard values.

An additional criteria implanted by the design team is a limit based on pendulation of the hoisted interceptor. This limit is imposed to mitigate the slamming of the hoisted interceptor into the sides of the hoisting section of the mothership. Although the hoist is designed to take advantage of the stability of a trapezoidal configuration, an additional level of safety will ensure any possible oversights would be compensated.



Response	Location	Standard Criterion	MTR
Roll (deg)	Ship	2.5	5
Pitch (deg)	Ship	2.5	2.5
Vert. Accel. (g)	Mission Bay	0.2	0.2
Lat. Accel. (g)	Mission Bay	0.1	0.1
Slam Accel. (g)	Bow	0.2	0.2
Wetness (events/hr)	Mission Bay	30	15
Pendulation (MTR)	Suspension point	N/A	±5 deg

Figure 119. Standard Criterion for Sea Keeping Analysis

The operational envelops show the maneuvering ranges in which the Tsunami ship can operate in varying sea states. As can be observed, operation only begins to be affected at sea state 3. At sea state 4 the ship is restricted from waves 080 thru 100 relative and 260 thru 280 relative. At sea state 5, these bands expand to 060 thru 100 relative and 260 thru 310 relative. It should be noted that these bands are not restrictive at all speeds.

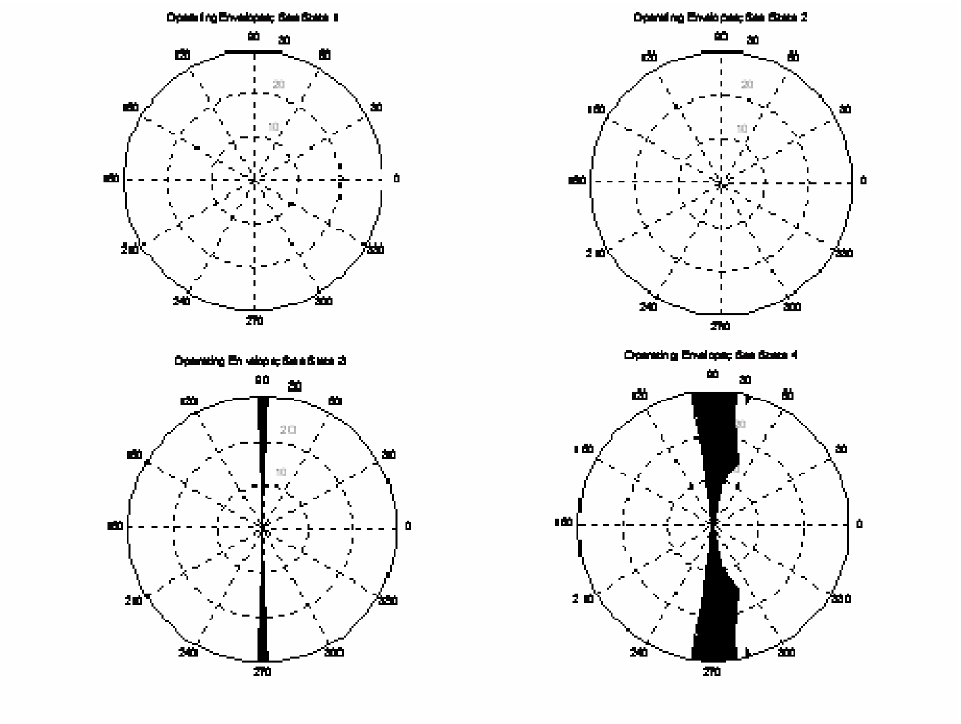


Figure 120. Operational Envelopes: Sea State 1 thru 4

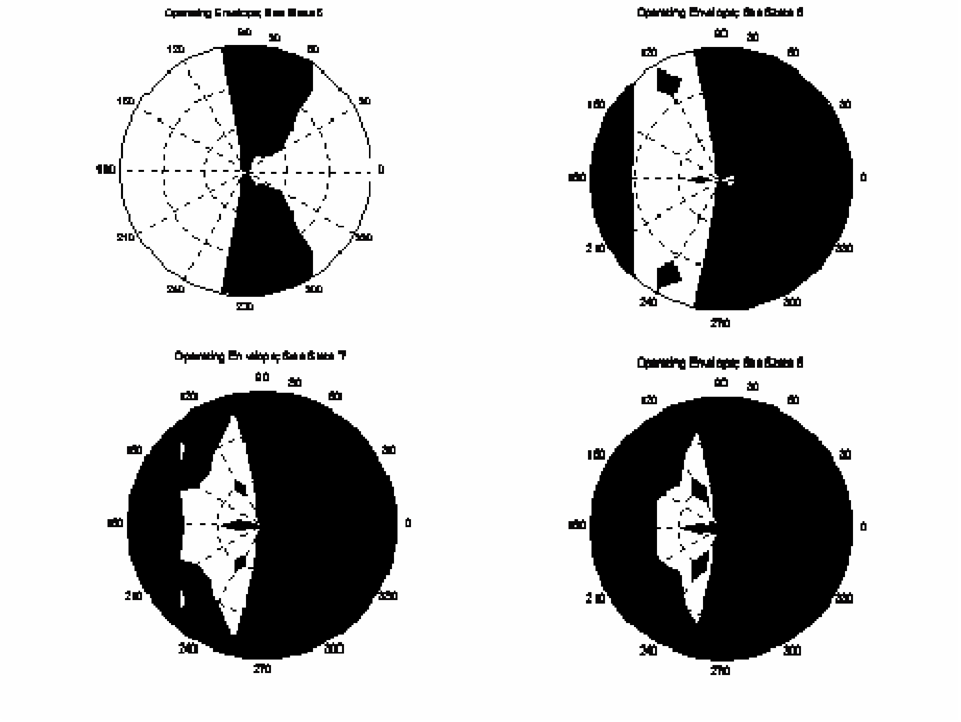


Figure 121. Operational Envelopes: Sea State 5 thru 8

The following series of figures show the results for the various specified criterion; roll, pitch, vertical acceleration, lateral acceleration, slamming acceleration, mission bay door wetness events per hour, and pendulation at sea state conditions ranging from 1 to 8.

1. Pendulation Motion

The seakeeping analysis results show only a minor degradation in operability between sea state 2 and sea state 4 due to pendulation motion. Pendulation motion refers to the motion the ship imparts on the hoist system while an interceptor is suspended over the moon pool. At sea state 5, the limit to pendulations is reached when waves are encountered through all speed ranges and between 060-100 and 260-300 relative to the bow. A significant reduction in operability occurs at and above sea state 6. In this case, in order to maintain operability, wave encounter must be kept close to or on the bow.

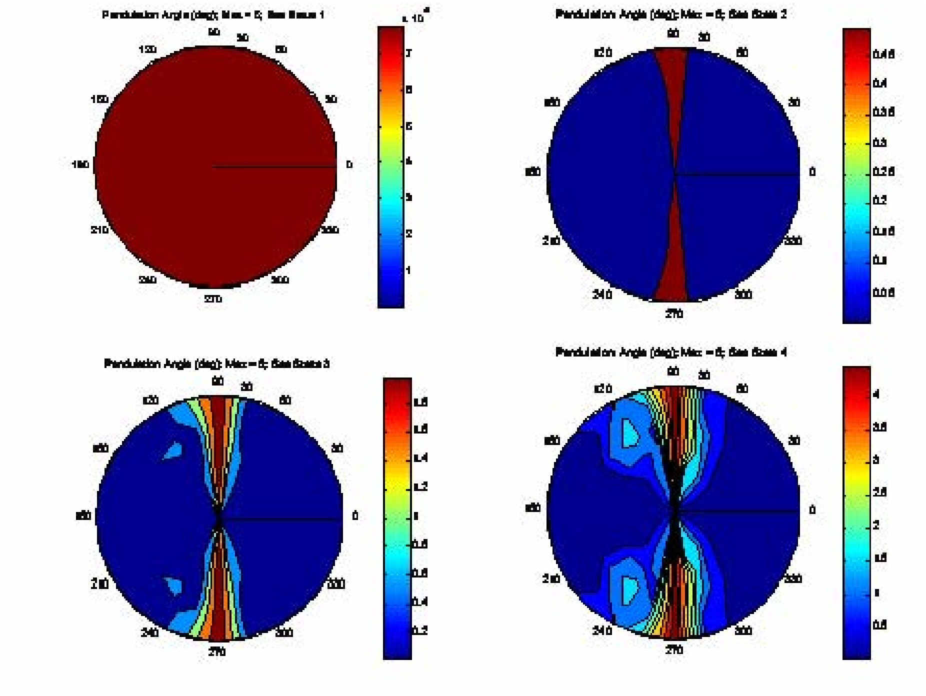


Figure 122. Pendulation Motion: Sea State 1 thru 4

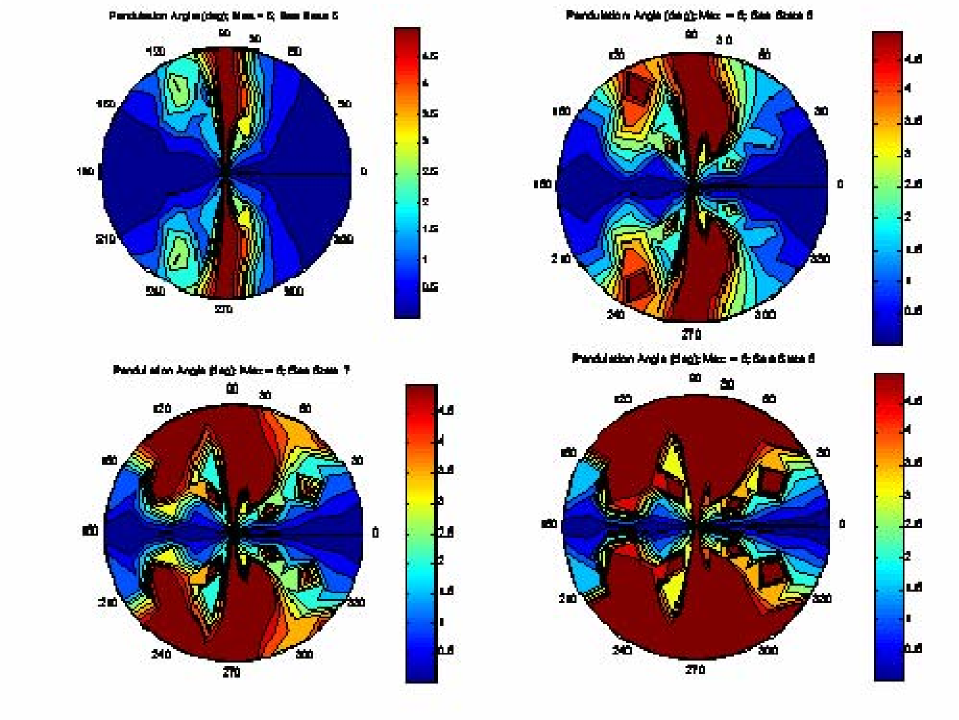


Figure 123. Pendulation Motion: Sea State 5 thru 8

2. Wetness Events

Wetness events refer to the elevation of the designated opening reaching the wave crest model. In other words, the number of times per hour a wave would be expected to enter the mission bay while the mission bay door is open. Since the mission bay is considered shelter for the interceptors, it is imperative that wetness events be minimized. In that respect, the criteria limitation imposed on the MATLAB analysis is reduced by half, thereby imposing a stricter limit to operational envelopes.

The results of the analysis show that only minor wetness events develop in sea state 4 when waves are encountered greater than 27 knots and 070 or 290 relative. Wetness events develop in sea state 5 when the ship is traveling in excess of 25 knots with waves encountered between 050 thru 090 or 310 thru 270 relative. In sea states 6 or greater, wetness events may be avoided only with waves abaft of the beam but not directly astern. These results only designate times where the mission bay door should be kept closed to avoid a wetness event in the mission bay.

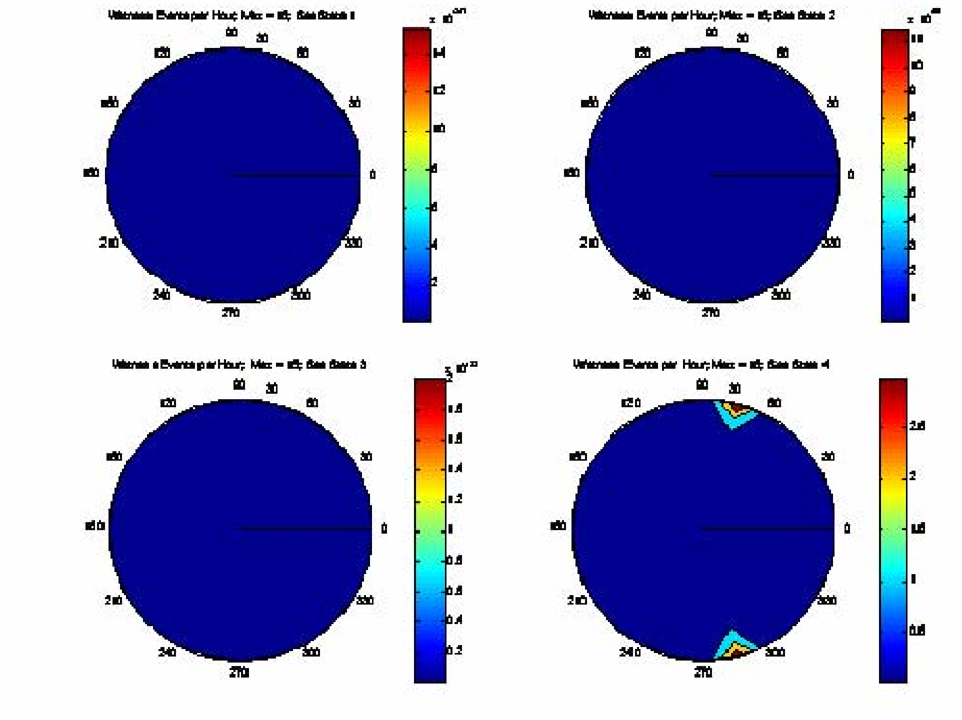


Figure 124. Wetness Events Per Hour: Sea State 1 thru 4

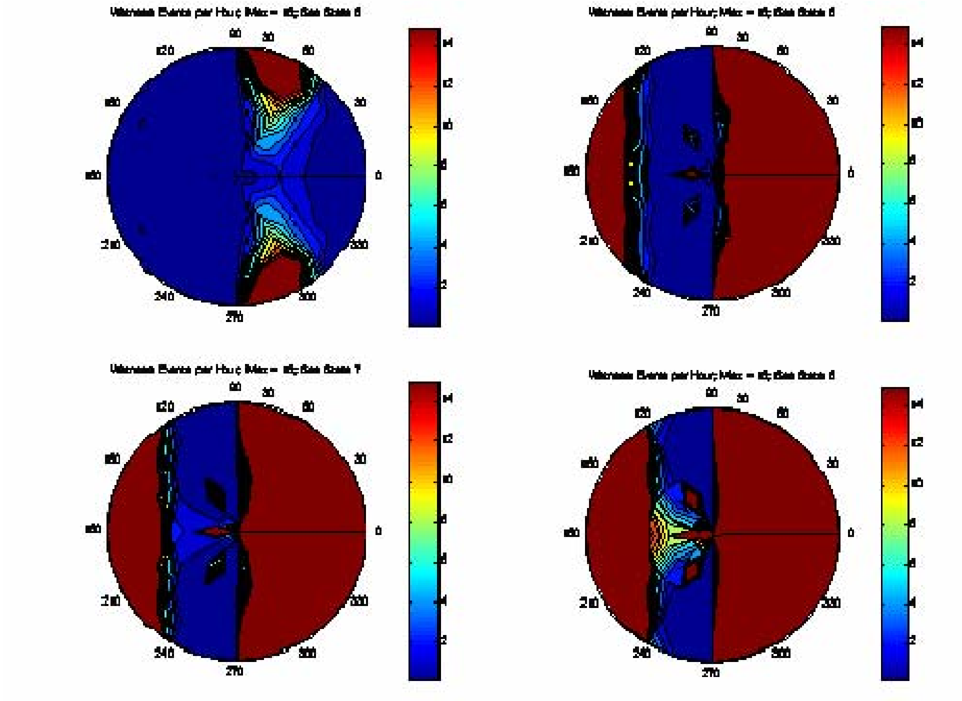


Figure 125. Wetness Events Per Hour: Sea State 5 thru 8

3. Accelerations

The restrictions imposed of the slam acceleration, vertical acceleration, and lateral acceleration is the same standard for all naval vessels. Due to the slenderness of the bow of the ship for wave cutting potential, the designers were expecting the sea keeping analysis shows significant values for slam acceleration at all sea states. There is significant slam acceleration for sea states at or above sea state 6 when waves are encountered forward of the beam. However, for typical seas expected on the mission, i.e. sea state 4 and sea state 5, the levels of slam acceleration, vertical acceleration, and lateral acceleration are well within the designated limits.

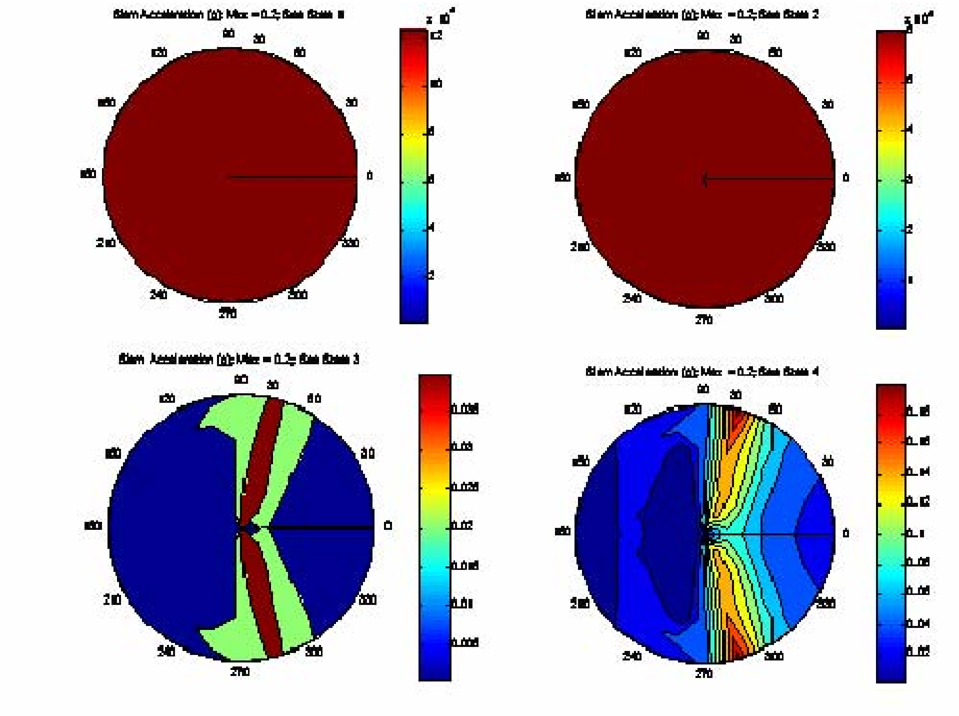


Figure 126. Slam Acceleration of the Bow: Sea State 1 thru 4

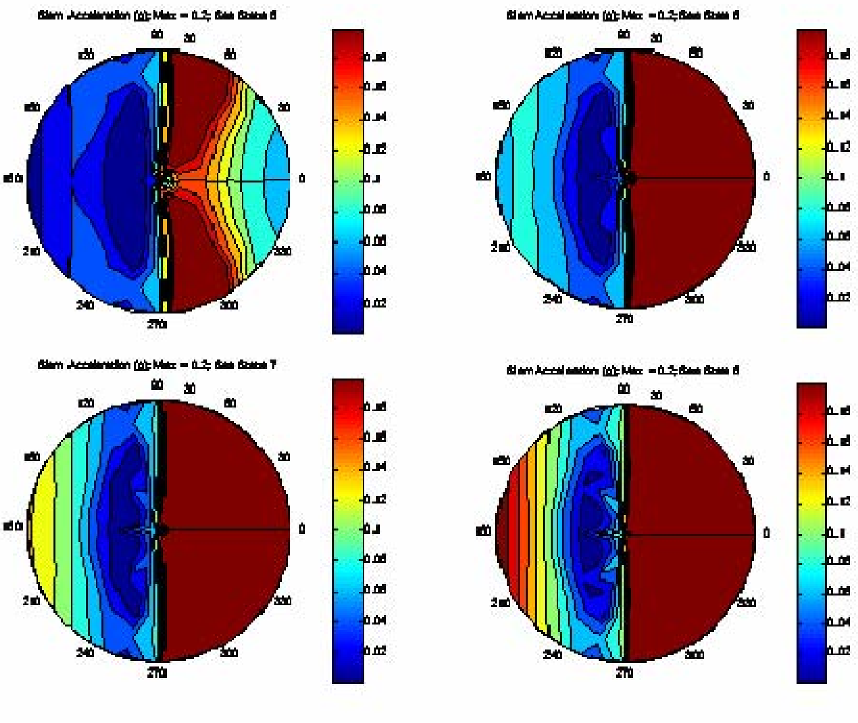


Figure 127. Slam Acceleration of the Bow: Sea State 5 thru 8

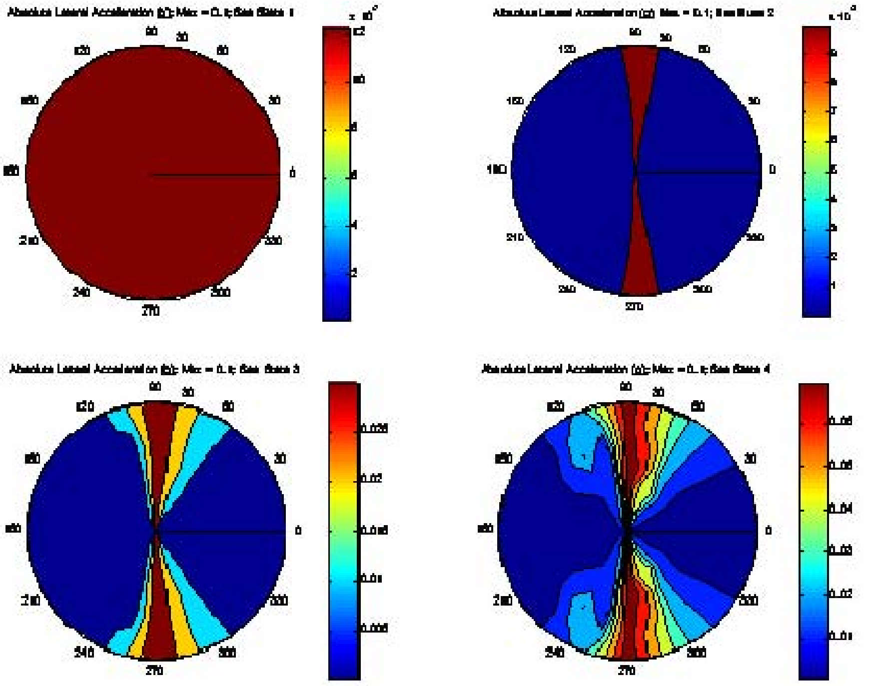


Figure 128. Lateral Acceleration: Sea State 1 thru 4

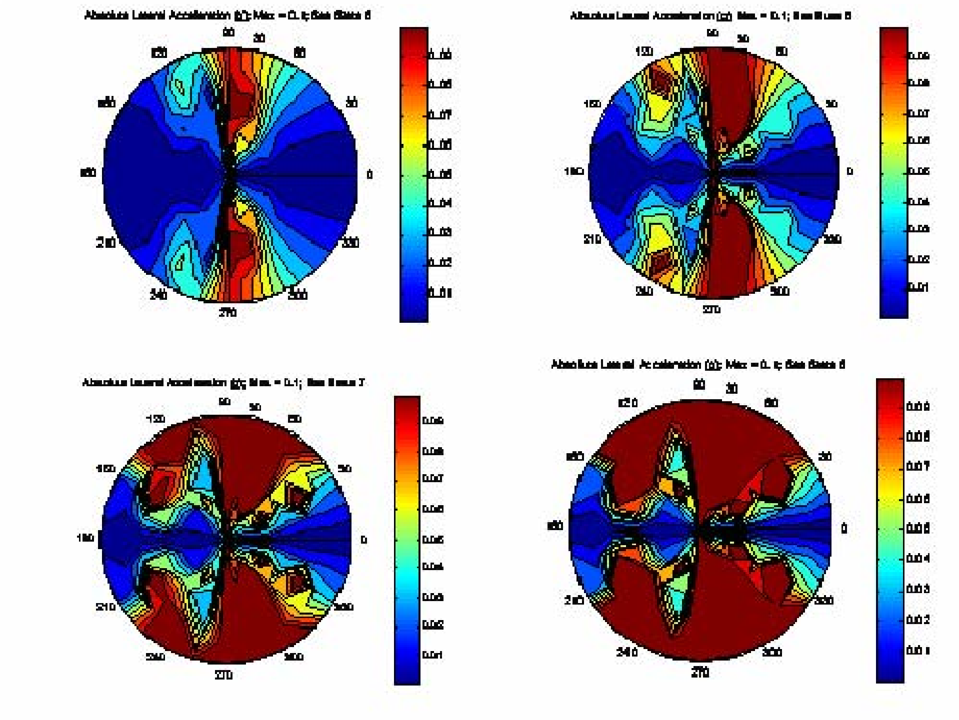


Figure 129. Lateral Acceleration: Sea State 5 thru 8

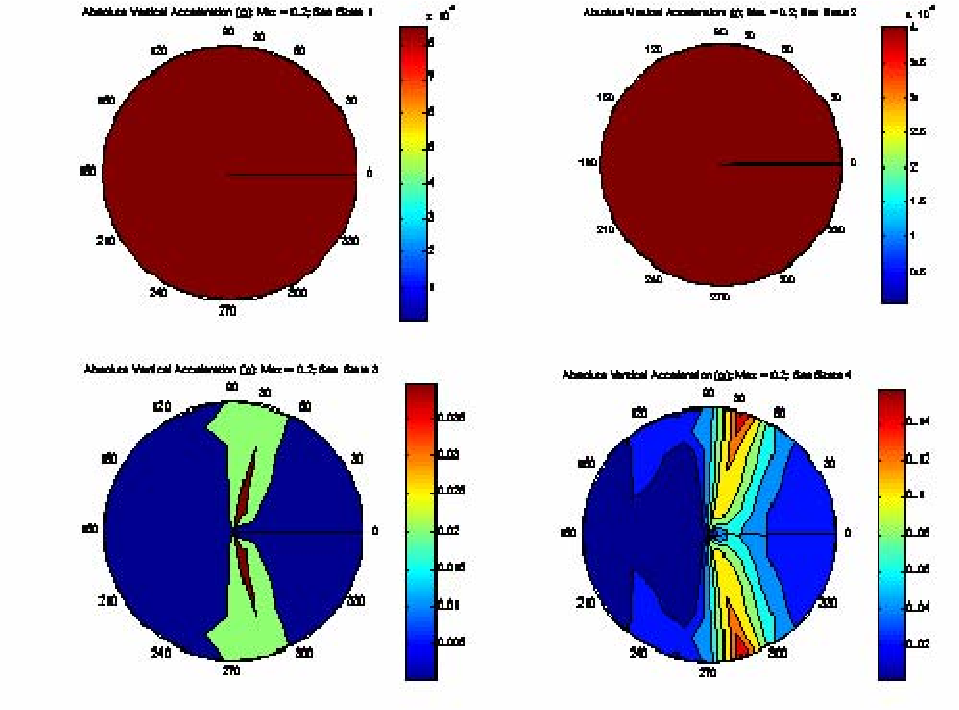


Figure 130. Vertical Acceleration: Sea State 1 thru 4

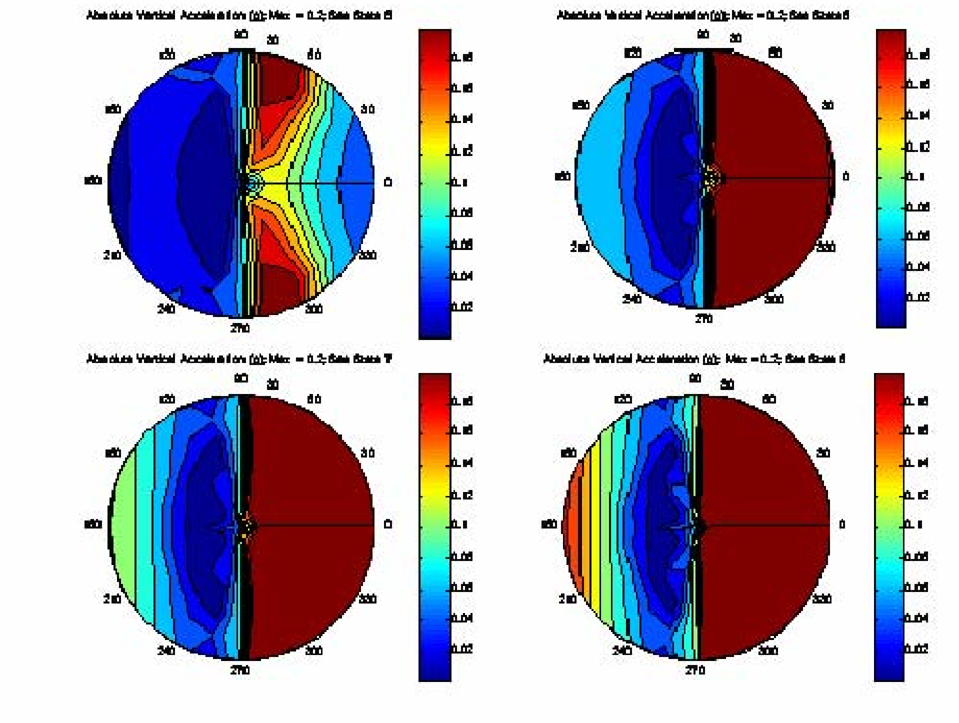


Figure 131. Vertical Acceleration: Sea State 5 thru 8

4. Pitch and Roll Angles

The pitching and roll analysis will show if there is a necessity for the addition of stability control surfaces. The criterion values for pitch and roll in the MATLAB analysis of the Tsunami ship are same as the standard for all naval vessels. The results for pitching show no significant limitations until sea state 6. The interpretation of the results show there is no need for a control surface to be located on the bow which would be used to mitigate excessive pitching.

The roll analysis shows limiting values for roll develop at sea state 2. This is however if waves are encountered directly on the beam. The trend shows that these limits stay relative restricted to the beam up to sea state 5. The limitation band begins to expand to all relative bearings forward of the beam. The limitation of roll imposed on the Tsunami ship is 5 degrees. This was determined to be the maximum desired angle while conducting mission bay operations. This in no way affects the operability of the ship itself, only the ability to load, launch, and traverse interceptors through the mission bay.

In this instance, it may be deemed necessary to had stability control surfaces to the ship to ensure level deck operations can be conducted at all times.

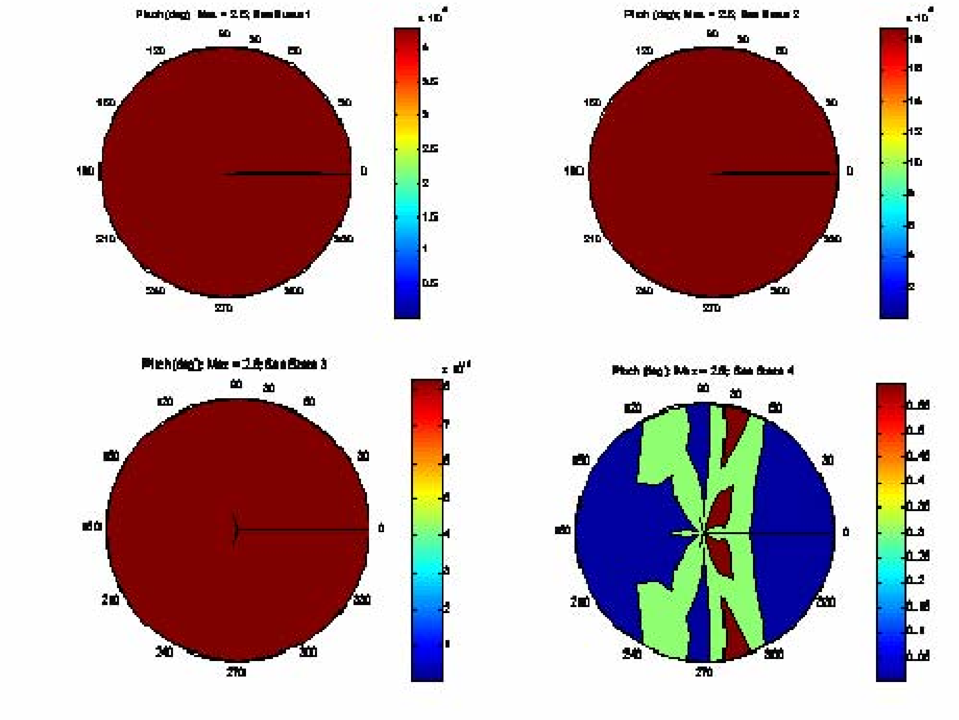


Figure 132. Pitch Angles: Sea State 1 thru 4

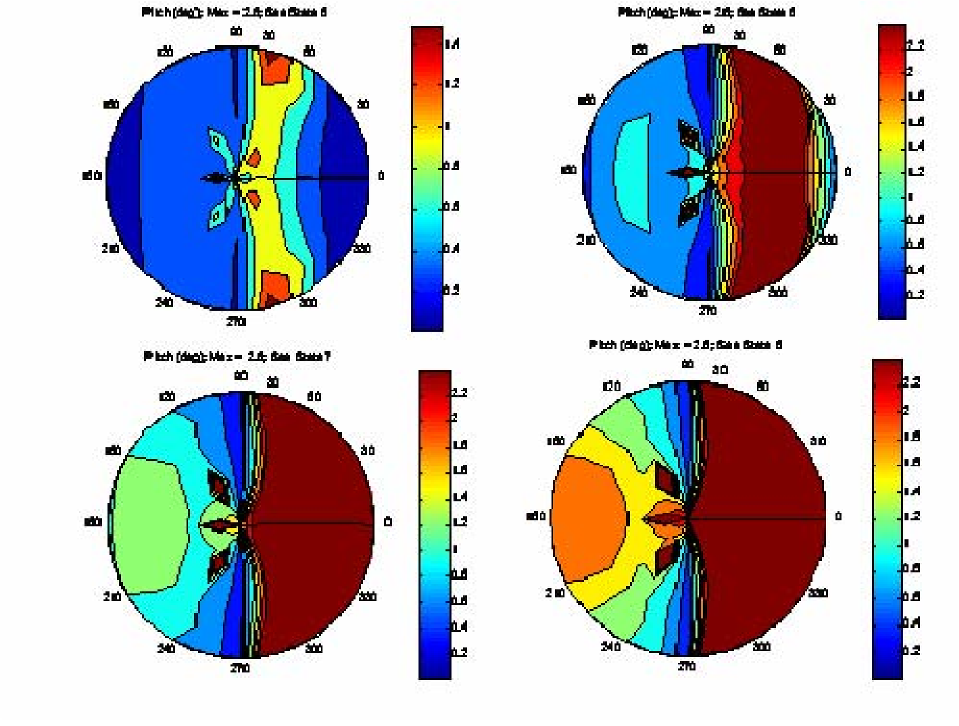


Figure 133. Pitch Angles: Sea State 5 thru 8

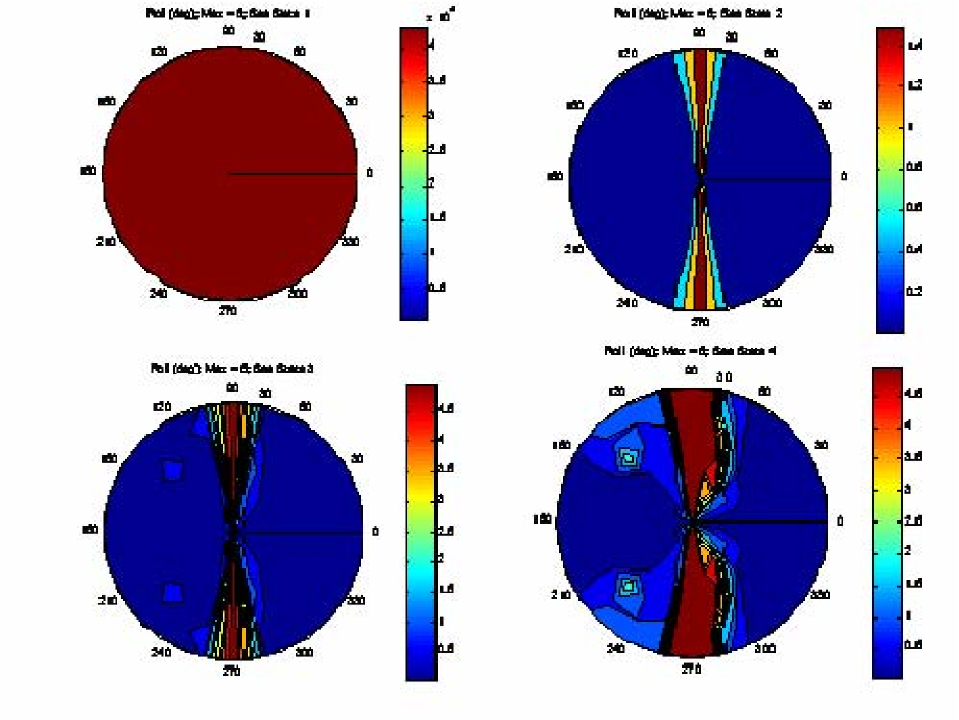


Figure 134. Roll Angles: Sea State 1 thru 4

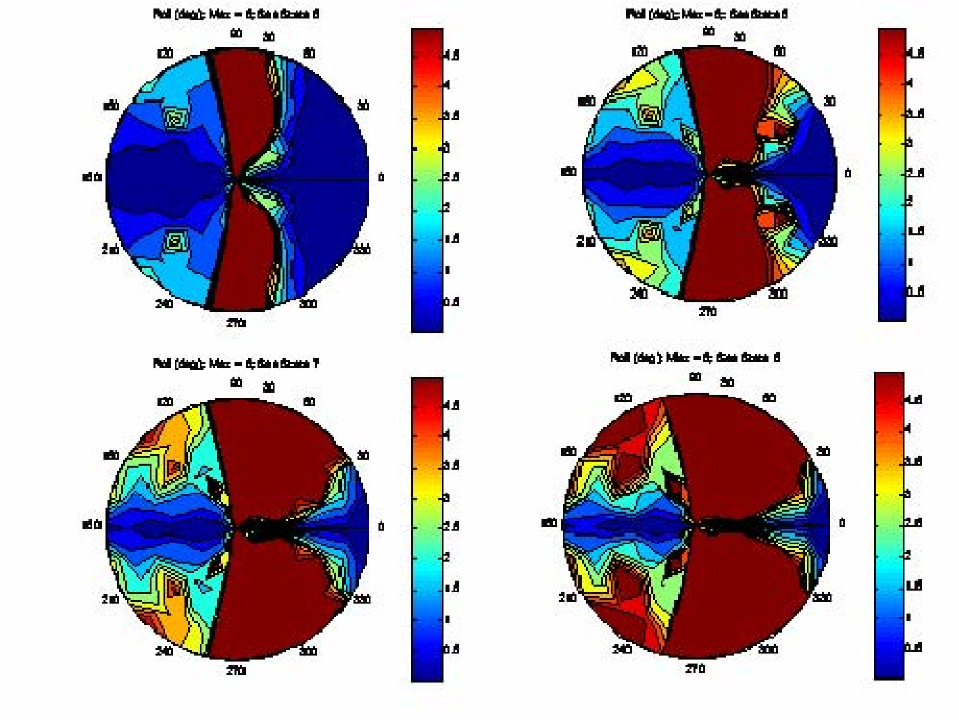


Figure 135. Roll Angles: Sea State 5 thru 8

5. Sea State 5 Summary

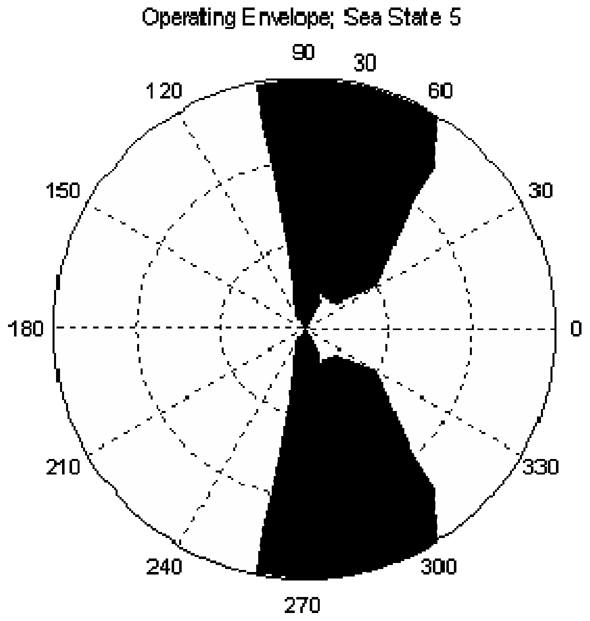


Figure 136. Sea Keeping Envelope for Mission Threshold Requirements

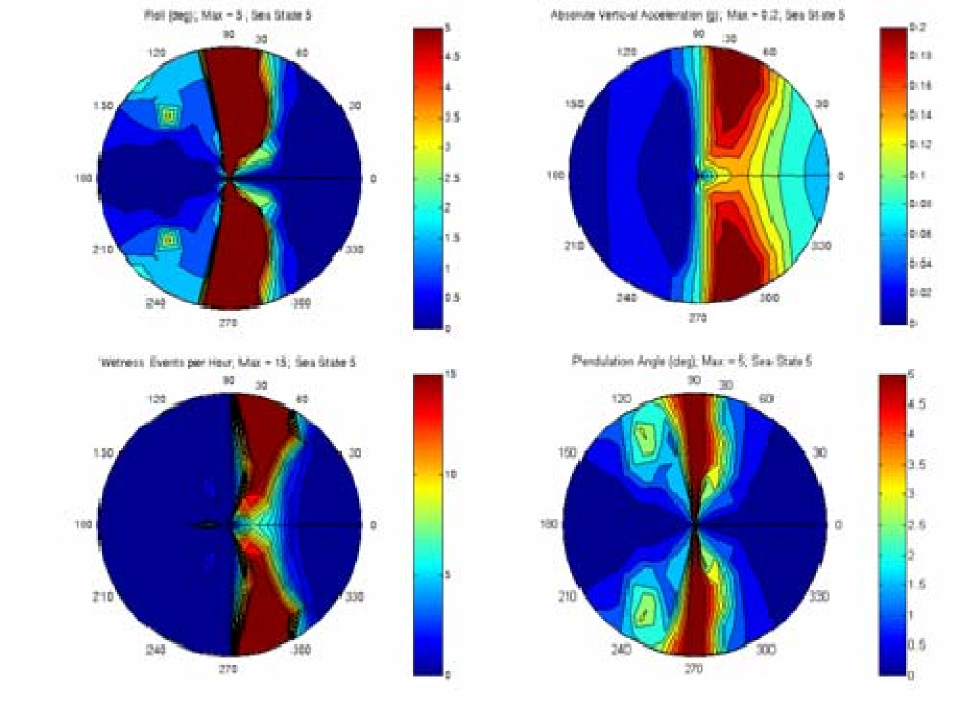


Figure 137. Sea Keeping Analysis for Sea State 5

The resulting operational envelopes imposed on the Tsunami mothership over the duration of the mission are based on the combined results of the seakeeping analysis for sea state 5. The operational envelop for a 20 knot ship speed is limited to waves impacting the hull outside 045 to 100 degrees relative to the bow of the ship and 315 to 260 degrees relative.

D. ENVIROMENTAL APPLICATION

Based on the designed concept of operations for the Maritime Threat Response mission, the Tsunami ship will generally be operating in the Northern Pacific ocean, making the great circle route from the Philippine Islands to San Francisco. Using data compiled by the United States Naval Oceanography Command, the design team created a model of expected wave and wind conditions for the operational area which have been applied to the sea keeping analysis results and resultant operational index.

The North Pacific Ocean wave model assembled by the Naval Oceanography Command was used to identify data points where the Tsunami ship will be in the vicinity of while conducting its mission transiting the great circle route with merchant traffic. The following data points of the March 1985 Northern Pacific atlas was used in this analysis; 41, 33, 34, 26, 23, 19, 22, 20, and 18. Although the bulk of loading and unloading should occur in the vicinity of markers 33 and 34, the necessity to load and unload interceptors through the duration of the mission is possible and expected. Based on the results of the sea keeping analysis, the most detrimental waves are approximately 045 to 100 and 260 to 315 relative to the bow of the ship. Since the ship is expected to travel the great circle route, a steady course of 043 True is assumed for eight day mission duration.

The data from the Oceanographic Atlas provides wave height and primary wave direction over annual periods for a 12 year span. The data was taken to calculate the probability of the mission encountering waves at a 12 foot height (i.e. Sea State 5) or greater, on the courses that would be detrimental to mission operations. The results show the probability of a DELAY in mission progression over the duration of an 8 day mission.

Marker	*SeaState5*	*>SS5*	*Port bow*	*Stbd bow*	*% Impact*
41	0.04	0.06	0.19	0.10	1.32%
33	0.06	0.07	0.10	0.04	1.30%
34	0.11	0.08	0.09	0.11	2.49%
26	0.12	0.15	0.08	0.12	3.97%
23	0.16	0.20	0.05	0.18	6.05%
19	0.17	0.26	0.06	0.14	6.74%
22	0.18	0.24	0.04	0.21	7.96%
20	0.17	0.24	0.02	0.19	6.60%

Figure 138. Limiting Sea State Event Probabilities and Impact on Mission Duration

The second and third columns of the table above shows the percentage of waves encountered that were Sea State 5 or greater. The fourth and fifth columns show the probability that those waves would impact the ship outside acceptable operational envelopes. The final column shows the calculated probability that the ship would have to change course to load and unload interceptors due to restrictions of the operational envelope. Taking the geometric mean of the percent impact on the mission at each marker results in an overall mission impact of 3.72%.

In other words, there is a 3.72 percent chance that the mothership will have to maneuver to a new course to launch or recover an interceptor. This may result in a zigzag route taken by the mothership to maintain progression over the great circle route with merchant traffic.

Fig. 1 GRID POINT-SUBPROJECTION AND SEQUENCE NUMBERS

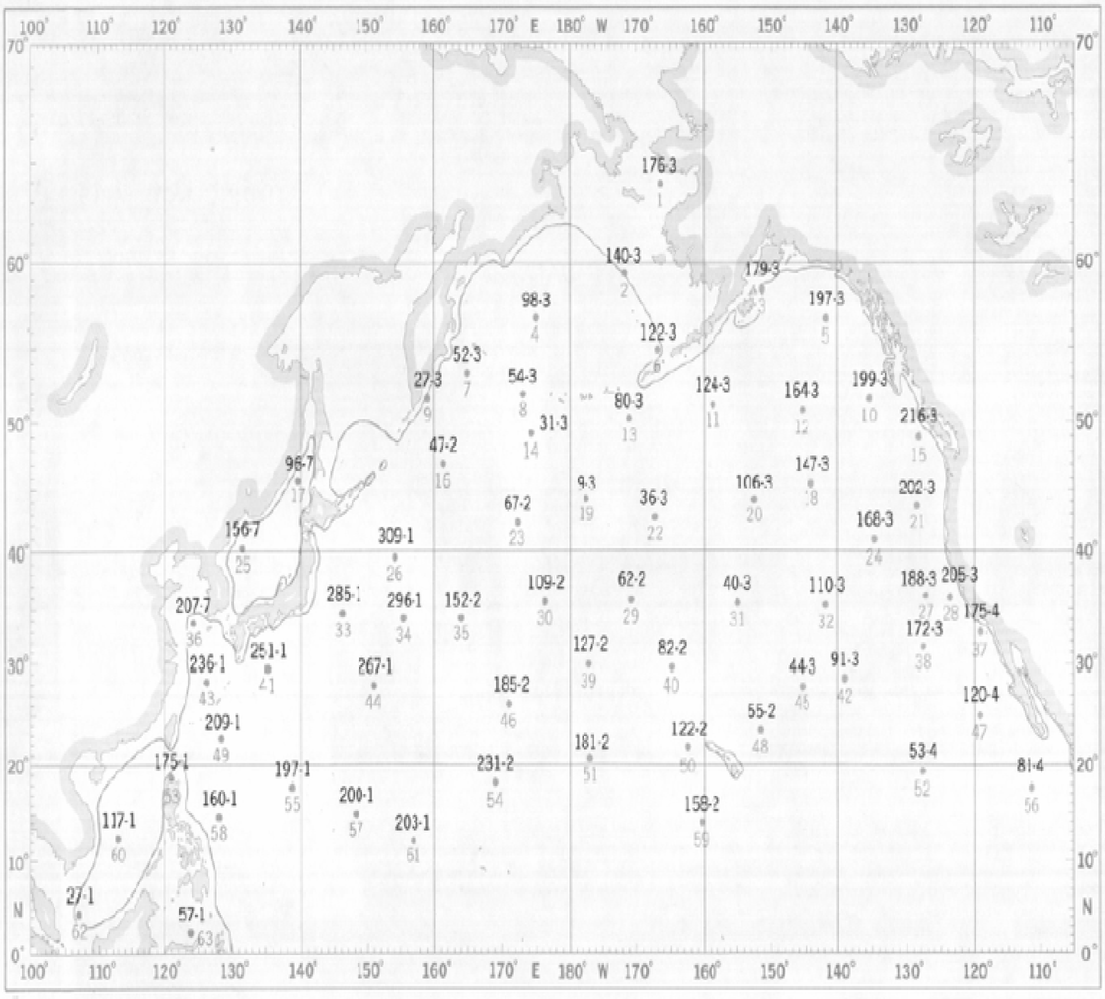
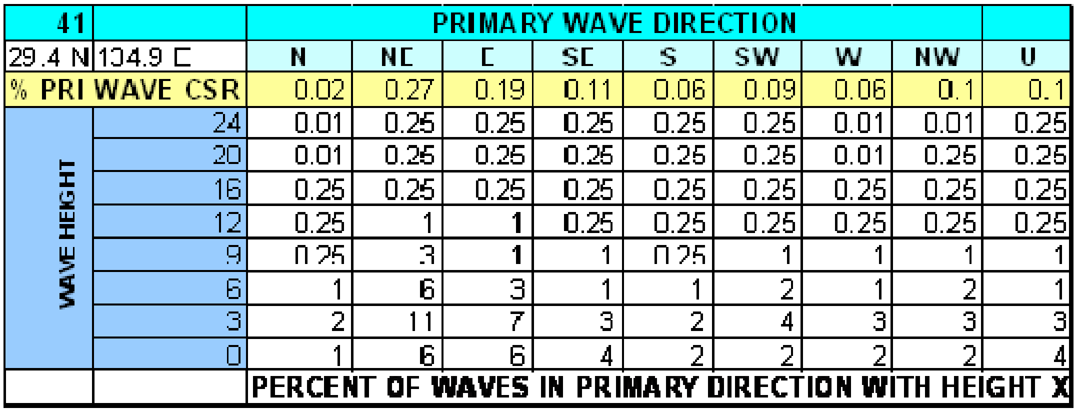
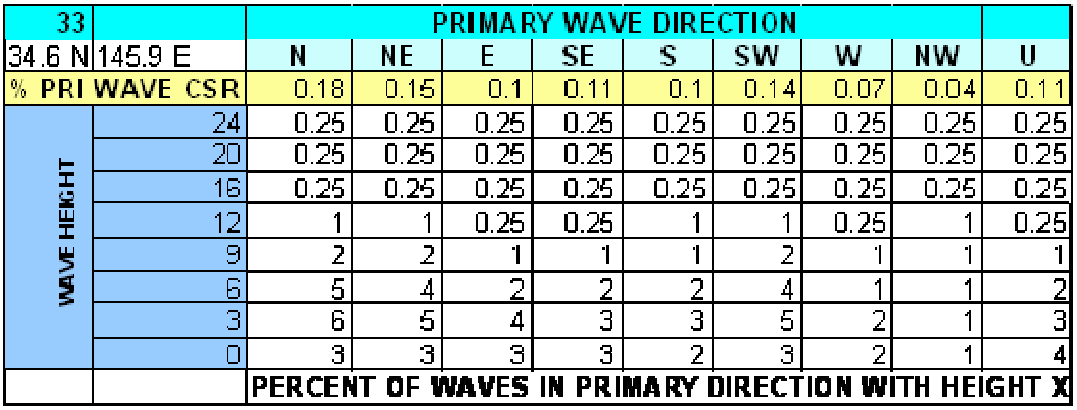


Figure 139. US NAVY Wave Model Climatic Atlas Data Markers, March 1985



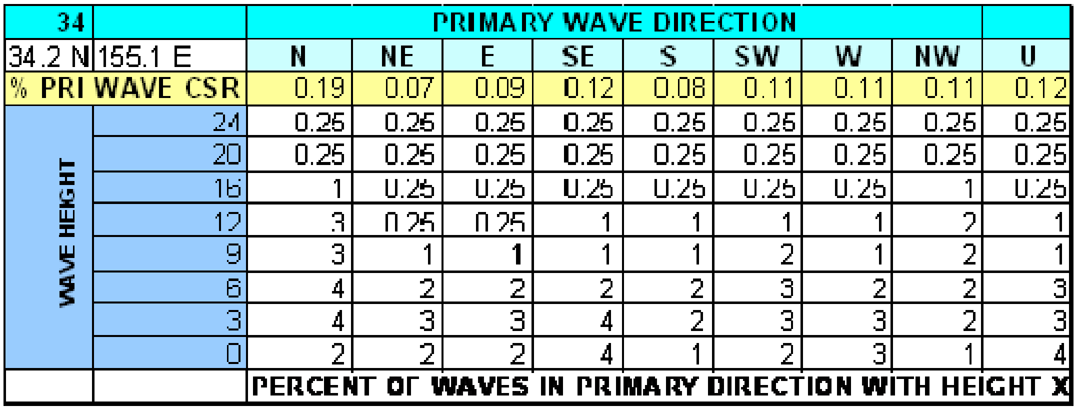
41		PRIMARY WAVE DIRECTION								
29.4 N	134.9 E	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.02	0.27	0.19	0.11	0.06	0.09	0.06	0.1	0.1
WAVE HEIGHT	24	0.01	0.25	0.25	0.25	0.25	0.25	0.01	0.01	0.25
	20	0.01	0.25	0.25	0.25	0.25	0.25	0.01	0.25	0.25
	16	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	12	0.25	1	1	0.25	0.25	0.25	0.25	0.25	0.25
	9	0.25	3	1	1	0.25	1	1	1	1
	6	1	6	3	1	1	2	1	2	1
	3	2	11	7	3	2	4	3	3	3
	0	1	6	6	4	2	2	2	2	4
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 140. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 41)



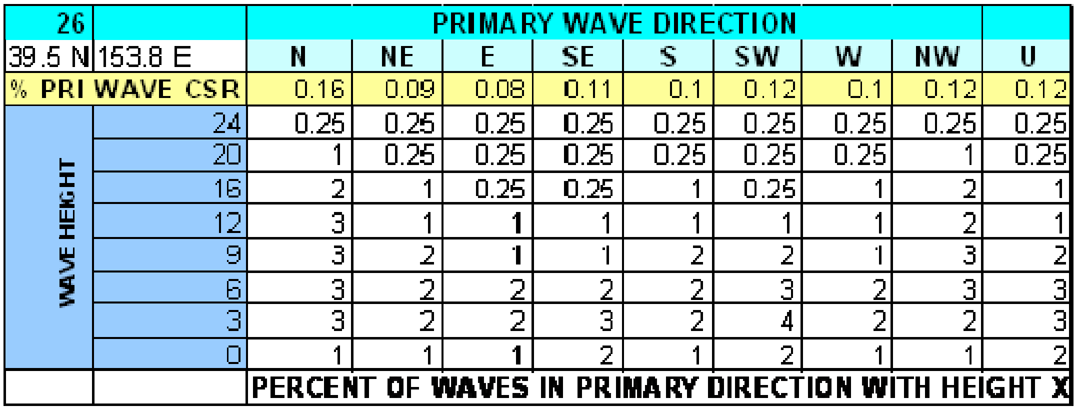
33		PRIMARY WAVE DIRECTION								
34.6 N	145.9 E	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.18	0.15	0.1	0.11	0.1	0.14	0.07	0.04	0.11
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	16	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	12	1	1	0.25	0.25	1	1	0.25	1	0.25
	9	2	2	1	1	1	2	1	1	1
	6	5	4	2	2	2	4	1	1	2
	3	6	5	4	3	3	5	2	1	3
	0	3	3	3	3	2	3	2	1	4
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 141. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 33)



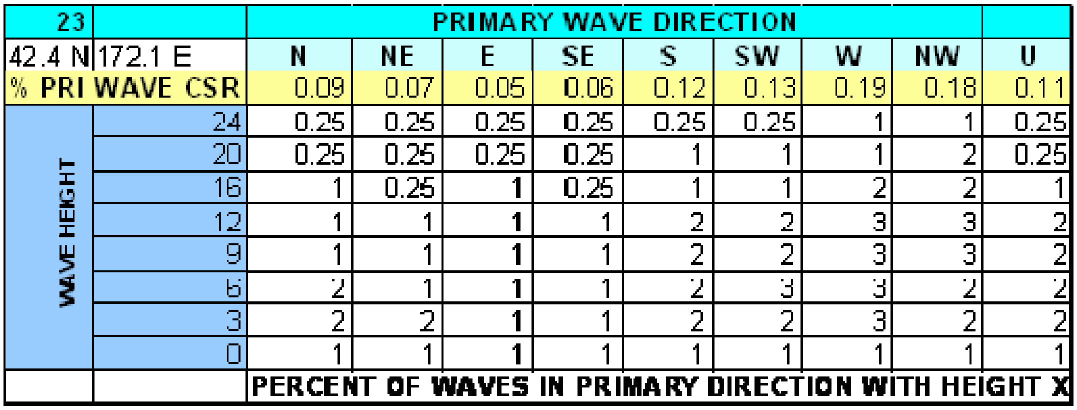
34		PRIMARY WAVE DIRECTION								
34.2 N	155.1 E	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.19	0.07	0.09	0.12	0.08	0.11	0.11	0.11	0.12
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	16	1	0.25	0.25	0.25	0.25	0.25	0.25	1	0.25
	12	3	0.25	0.25	1	1	1	1	2	1
	9	3	1	1	1	1	2	1	2	1
	6	4	2	2	2	2	3	2	2	3
	3	4	3	3	4	2	3	3	2	3
	0	2	2	2	4	1	2	3	1	4
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 142. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 34)



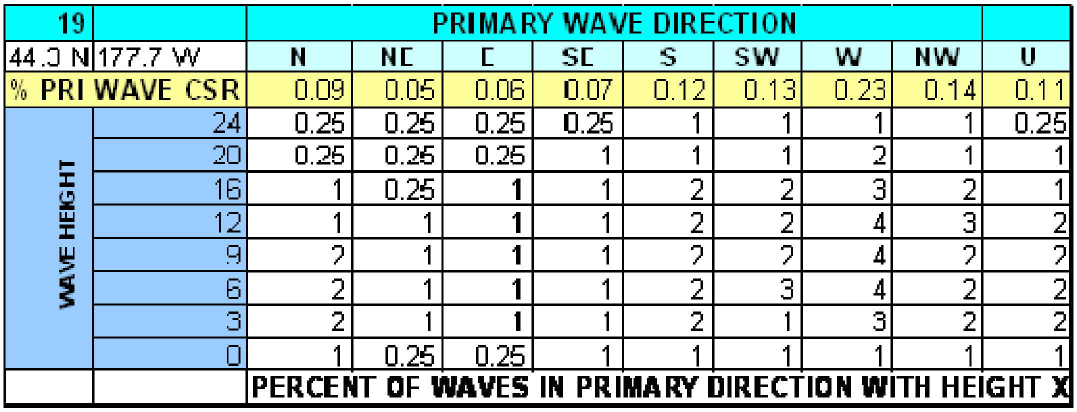
26		PRIMARY WAVE DIRECTION								
39.5 N	153.8 E	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.16	0.09	0.08	0.11	0.1	0.12	0.1	0.12	0.12
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	20	1	0.25	0.25	0.25	0.25	0.25	0.25	1	0.25
	16	2	1	0.25	0.25	1	0.25	1	2	1
	12	3	1	1	1	1	1	1	2	1
	9	3	2	1	1	2	2	1	3	2
	6	3	2	2	2	2	3	2	3	3
	3	3	2	2	3	2	4	2	2	3
	0	1	1	1	2	1	2	1	1	2
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 143. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 26)



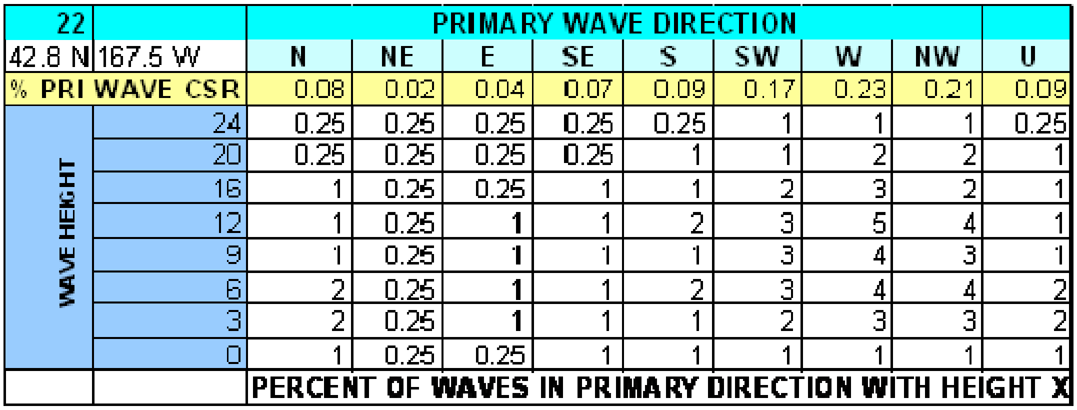
23		PRIMARY WAVE DIRECTION								
42.4 N	172.1 E	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.09	0.07	0.05	0.06	0.12	0.13	0.19	0.18	0.11
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	0.25	0.25	1	1	0.25
	20	0.25	0.25	0.25	0.25	1	1	1	2	0.25
	16	1	0.25	1	0.25	1	1	2	2	1
	12	1	1	1	1	2	2	3	3	2
	9	1	1	1	1	2	2	3	3	2
	6	2	1	1	1	2	3	3	2	2
	3	2	2	1	1	2	2	3	2	2
	0	1	1	1	1	1	1	1	1	1
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 144. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 23)



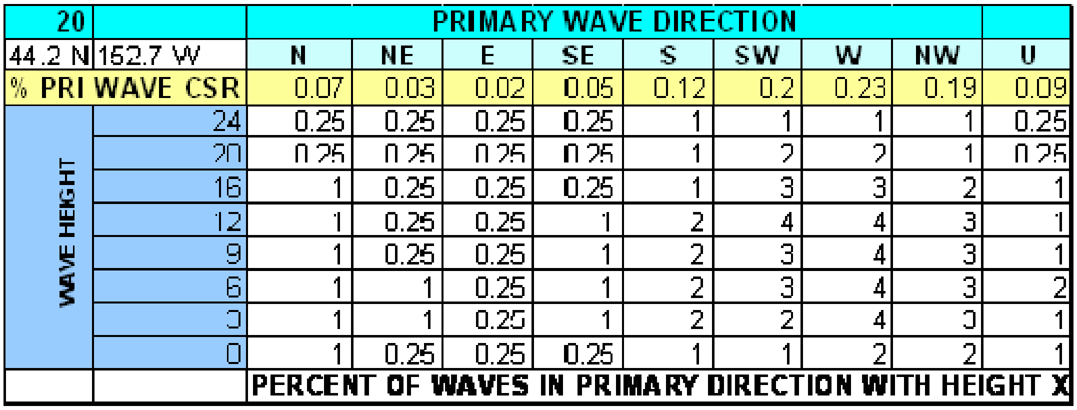
19		PRIMARY WAVE DIRECTION								
44.3 N	177.7 W	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.09	0.05	0.06	0.07	0.12	0.13	0.23	0.14	0.11
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	1	1	1	1	0.25
	20	0.25	0.25	0.25	1	1	1	2	1	1
	16	1	0.25	1	1	2	2	3	2	1
	12	1	1	1	1	2	2	4	3	2
	9	2	1	1	1	2	2	4	2	2
	6	2	1	1	1	2	3	4	2	2
	3	2	1	1	1	2	1	3	2	2
	0	1	0.25	0.25	1	1	1	1	1	1
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 145. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 19)



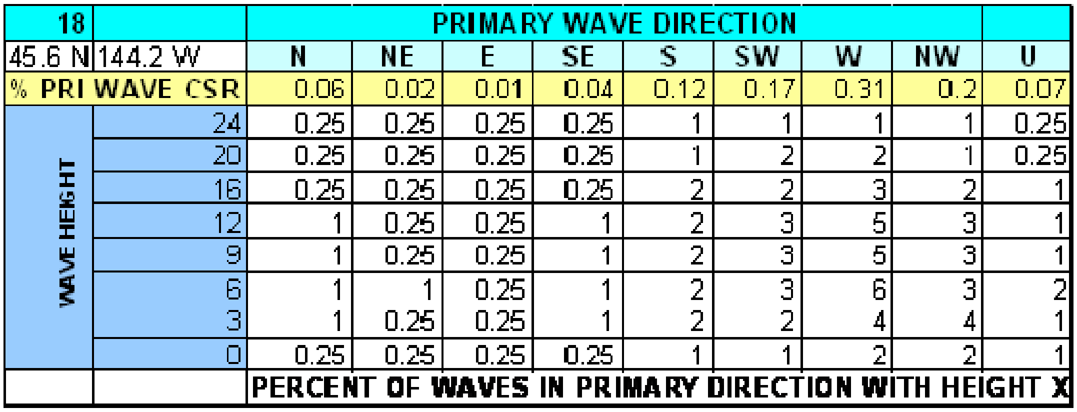
22		PRIMARY WAVE DIRECTION								
42.8 N	167.5 W	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.08	0.02	0.04	0.07	0.09	0.17	0.23	0.21	0.09
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	0.25	1	1	1	0.25
	20	0.25	0.25	0.25	0.25	1	1	2	2	1
	16	1	0.25	0.25	1	1	2	3	2	1
	12	1	0.25	1	1	2	3	5	4	1
	9	1	0.25	1	1	1	3	4	3	1
	6	2	0.25	1	1	2	3	4	4	2
	3	2	0.25	1	1	1	2	3	3	2
	0	1	0.25	0.25	1	1	1	1	1	1
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 146. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 22)



20		PRIMARY WAVE DIRECTION								
44.2 N	152.7 W	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.07	0.03	0.02	0.05	0.12	0.2	0.23	0.19	0.09
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	1	1	1	1	0.25
	20	0.25	0.25	0.25	0.25	1	2	2	1	0.25
	16	1	0.25	0.25	0.25	1	3	3	2	1
	12	1	0.25	0.25	1	2	4	4	3	1
	9	1	0.25	0.25	1	2	3	4	3	1
	6	1	1	0.25	1	2	3	4	3	2
	3	1	1	0.25	1	2	2	4	3	1
	0	1	0.25	0.25	0.25	1	1	2	2	1
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 147. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 20)



18		PRIMARY WAVE DIRECTION								
45.6 N	144.2 W	N	NE	E	SE	S	SW	W	NW	U
% PRI WAVE CSR		0.06	0.02	0.01	0.04	0.12	0.17	0.31	0.2	0.07
WAVE HEIGHT	24	0.25	0.25	0.25	0.25	1	1	1	1	0.25
	20	0.25	0.25	0.25	0.25	1	2	2	1	0.25
	16	0.25	0.25	0.25	0.25	2	2	3	2	1
	12	1	0.25	0.25	1	2	3	5	3	1
	9	1	0.25	0.25	1	2	3	5	3	1
	6	1	1	0.25	1	2	3	6	3	2
	3	1	0.25	0.25	1	2	2	4	4	1
	0	0.25	0.25	0.25	0.25	1	1	2	2	1
		PERCENT OF WAVES IN PRIMARY DIRECTION WITH HEIGHT X								

Figure 148. US NAVY Climatic Atlas Data: North Pacific Ocean (Marker 18)

E. OPERATIONAL INDEX

If the mission is to continue for eight consecutive days, and the recovery of interceptors consist of 0.3 total mission time, the 3.72% probability that the waves would not be in the operational envelope would cause a possible maximum 2.2 hour delay in mission ship progression. Based on the concept of operations, a 12 hour delay is the maximum limit not to interfere with shipping. Thusly it can be concluded, a maximum 2.2 hour delay is well within the threshold requirements of the concept of operations, a therefore, a zigzag maneuver will not be necessary. Due to the stable design of the Tsunami ship and vertical location of the mission deck, mission success is not affected by environmental variations. As a result of this analysis, all design requirements for sea keeping are met.

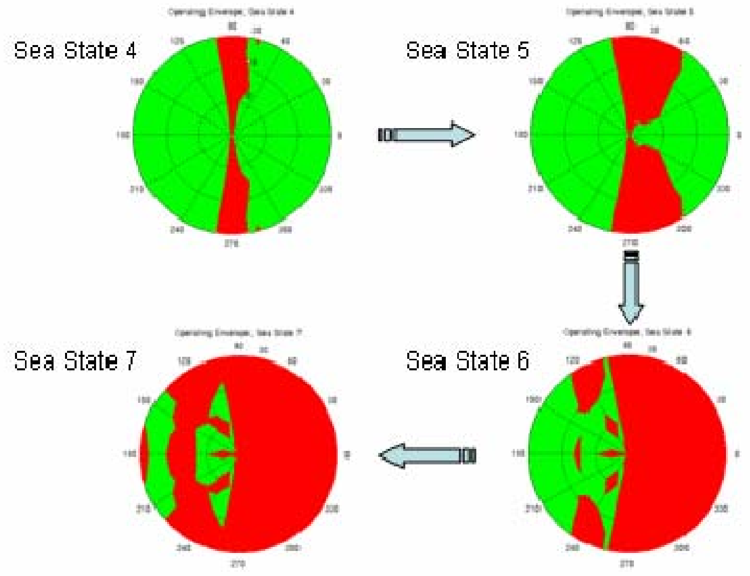


Figure 149. Overall Operational Envelopes for Sea State 4 through 7

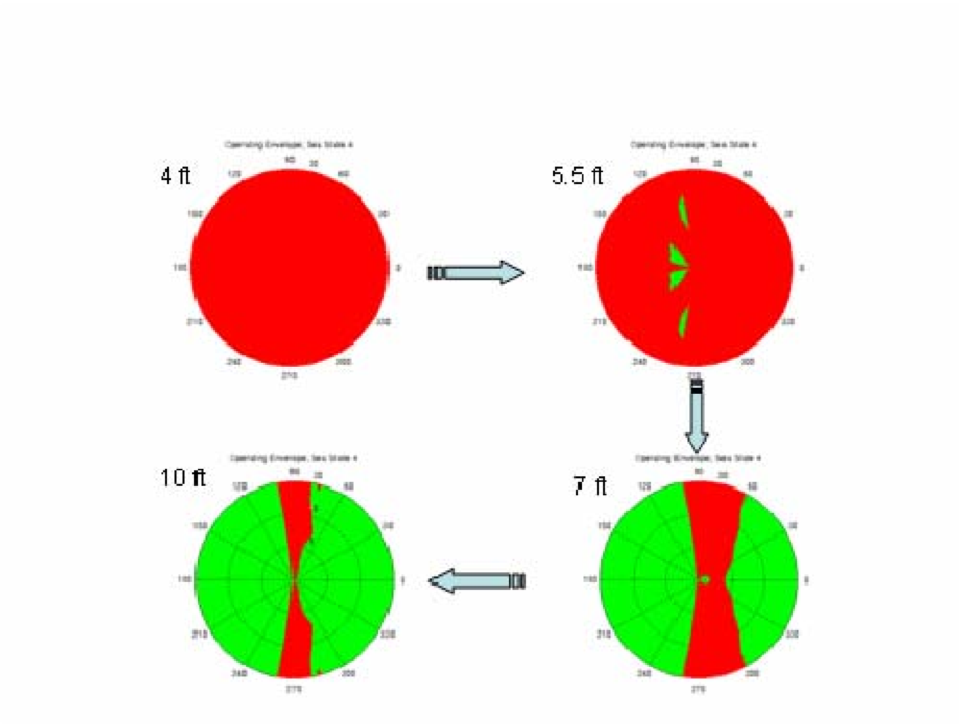


Figure 150. Operational Envelope Based on various Mission Bay Door Heights

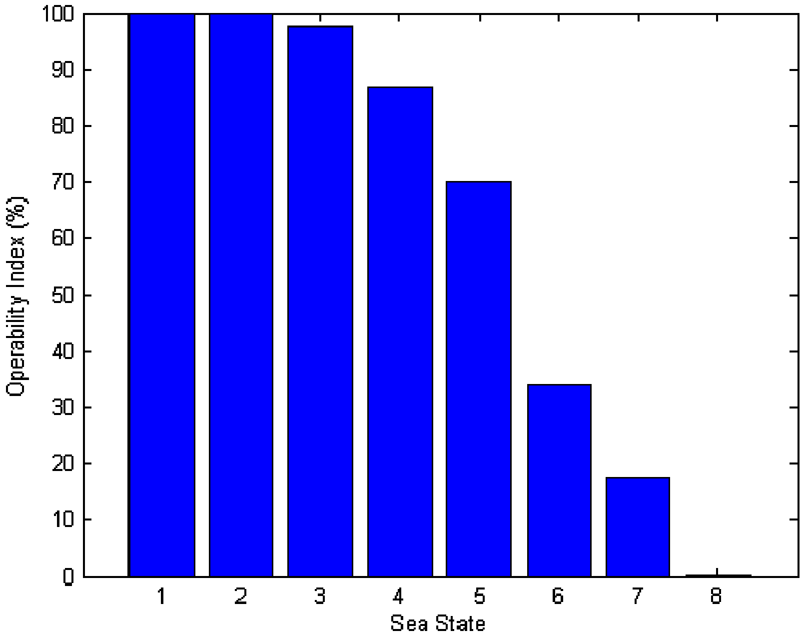


Figure 151. Overall Operability Index for Various Sea States

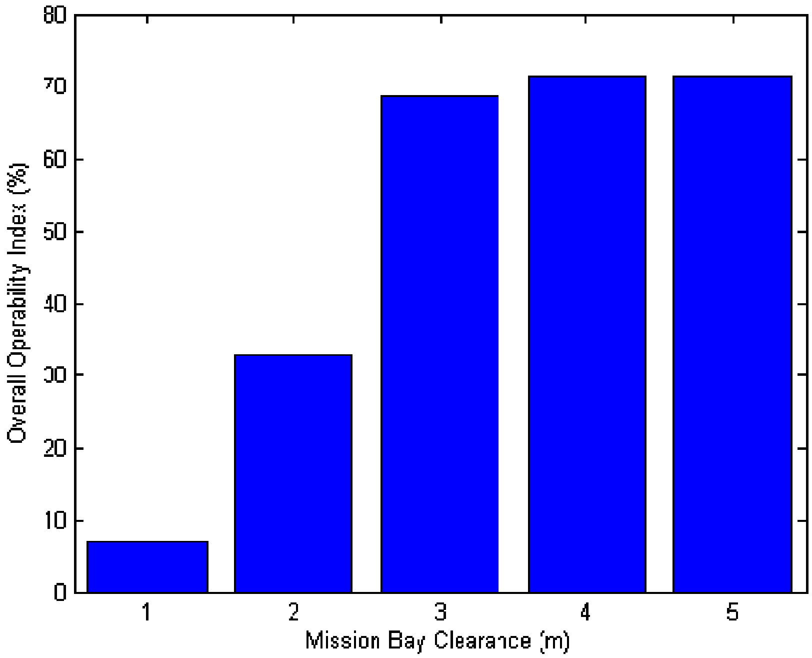


Figure 152. Operability Index as function of Mission Bay Door Height

VII. ANALYSIS OF WAVE MOTION

A. INTRODUCTION

This section analyzes the wave characteristics generated by the center hull at various speeds in calm waters. The unique design of the center hull was chosen to enhance high speed efficiency as well as reduce or reposition the wake generated by the center hull. Reducing the wake at the immediate stern of the center hull is important to the MTR mission due to the necessity to bring an interceptor in at close range to allow hook up to a hoisting mechanism. By reducing or repositioning the wake further down stream from the stern of the center hull, the interceptor (more specifically the crew) will have less instability while hooking the hoist cables to the interceptor.

All the analyses were performed using the SWAN2 wave motion simulator software. All the offsets for the center hull were converted to SI units and set with the origin at the mid-ship position. Only 15, 20, 25, and 30 knot speeds were simulated to provide data to verify position and magnitude of the wake. A series 60 cruiser hull was also simulated to provide comparison data.

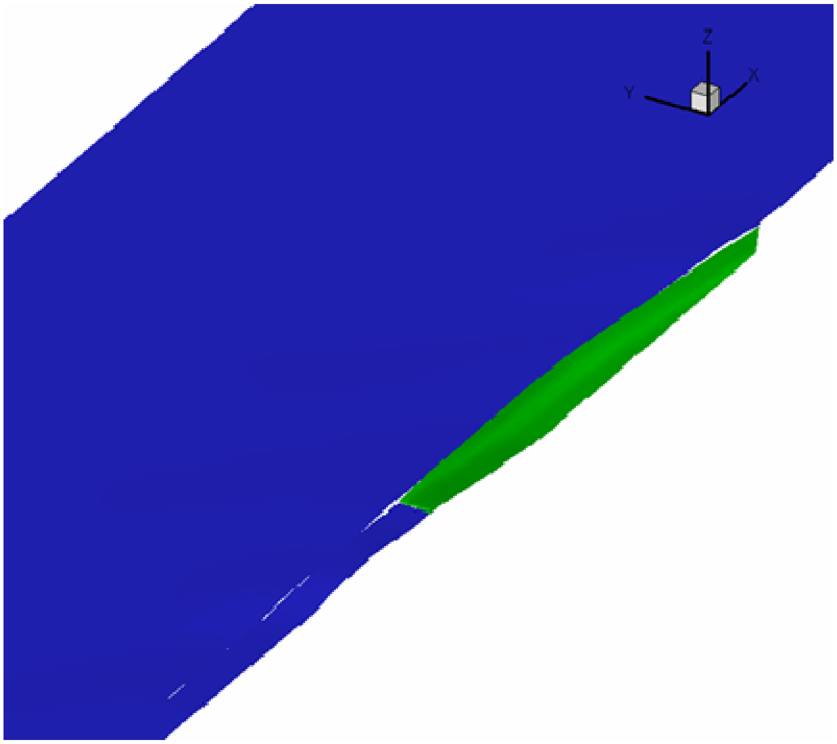


Figure 153. SWAN2 Wave Contour at Cruising Speed

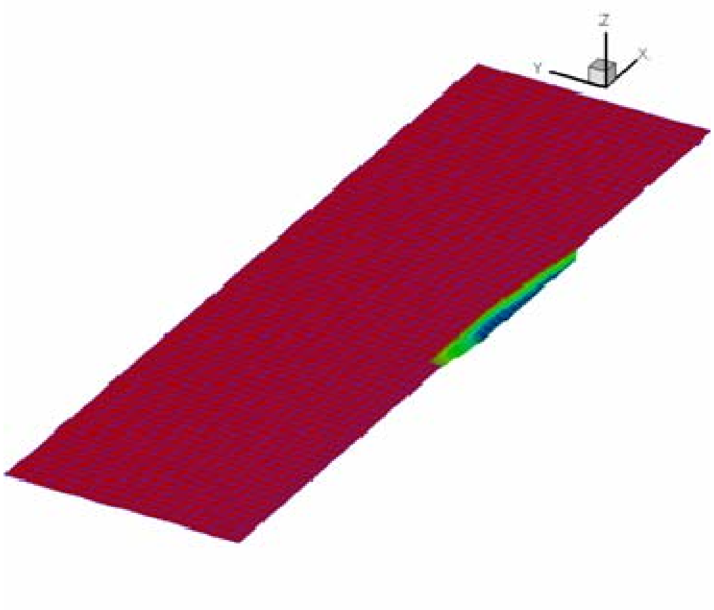


Figure 154. SWAN2 Mesh Data T-Center hull at cruising speed

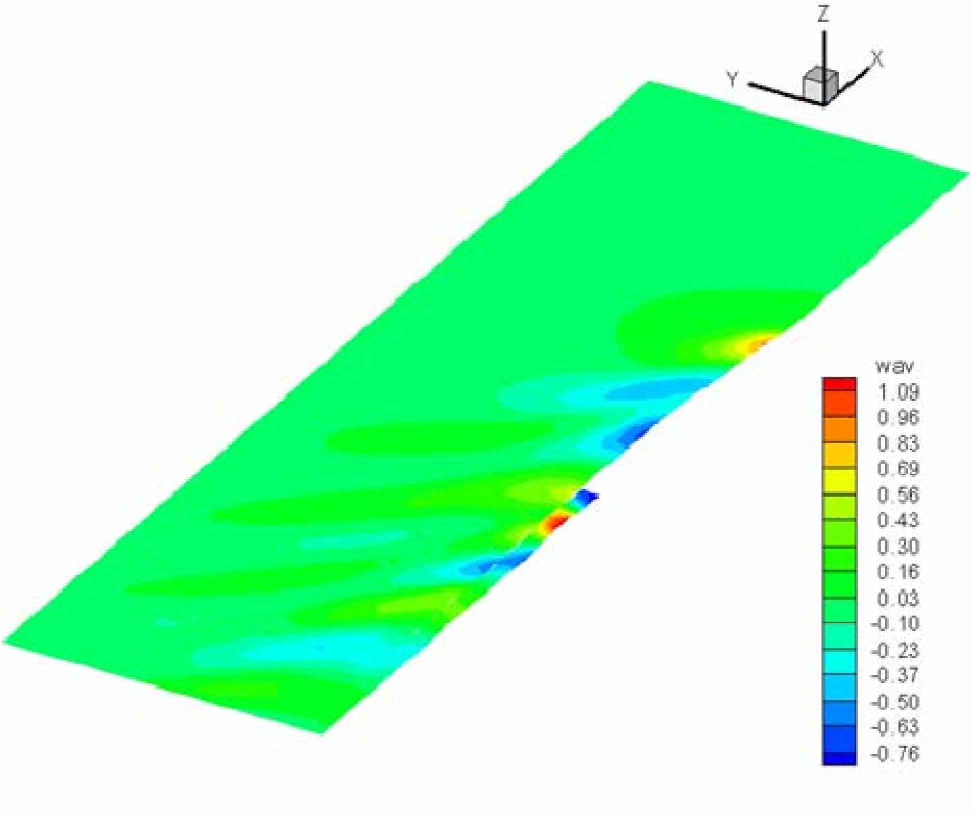


Figure 155. SWAN2 Wave Data Tsunami Center Hull at cruising speed

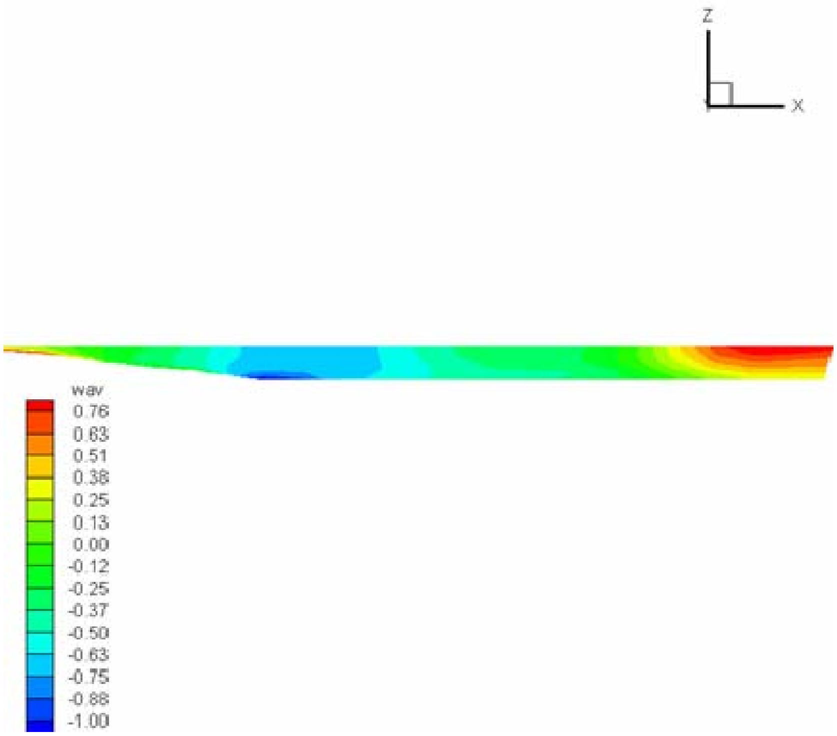


Figure 156. Tsunami Center Hull Pressure Distribution

B. SWAN2 ANALYSIS

The pressure distribution over the center hull of the mothership shows a well distributed high pressure area on the bow of the ship. At the area approximately 450 feet from the bow where the bottom of the hull begins to slope upward to the waterline shows a low pressure area. Since there is no propulsion at this position and added buoyancy from the side hulls will minimize squat, this region has little effect on the ship.

The following figures show the position of the wake wave and wave height relative to the stern of the center hull of the Tsunami mothership. For the analysis at 15kts, the wake position is approximately 98 feet aft of the transom of the center hull with a maximum wave height of less than one foot.

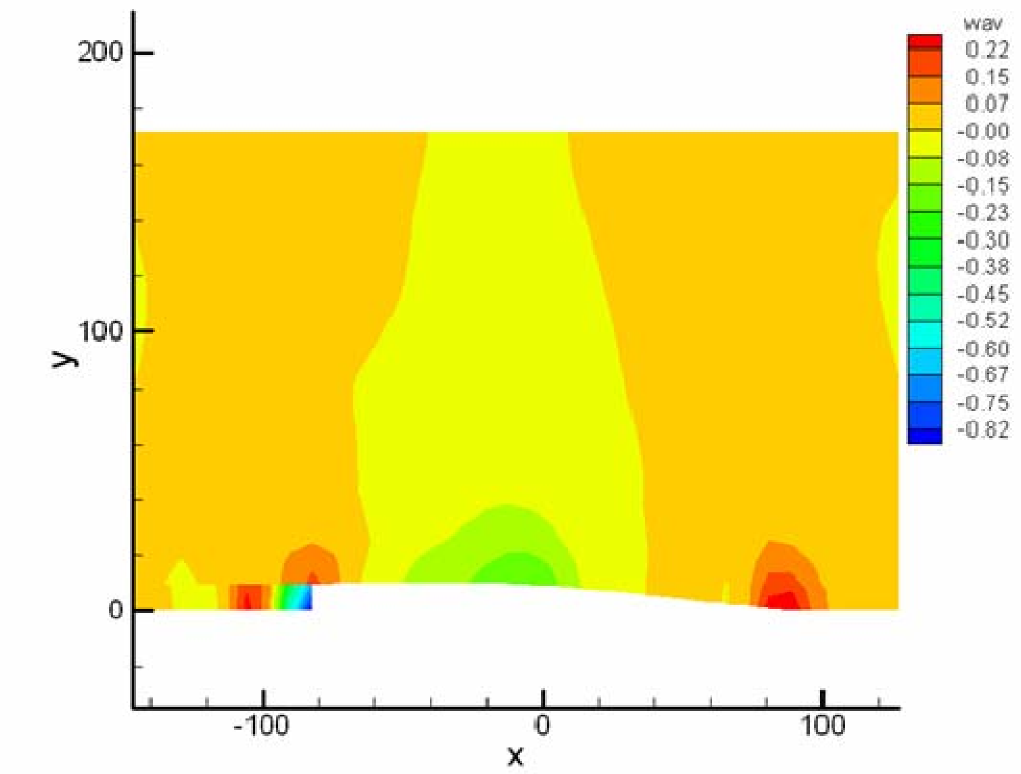


Figure 157. Wave Contours at 15kts

The SWAN2 analysis of the Center hull at 20 knots shows the position of the wake approximately 147 feet aft of the transom and a maximum wave height of 3.5 feet. The 147 feet places the wake wash between the area expected for towing operations hook up and the hoisting area. The interceptor would not be expected to transit through this wake zone under its own power, instead it would be towed through using the towing gear on the mothership. The towing operation would mitigate any instability that would be expected from attempting to control the interceptor with its own water jet engines.

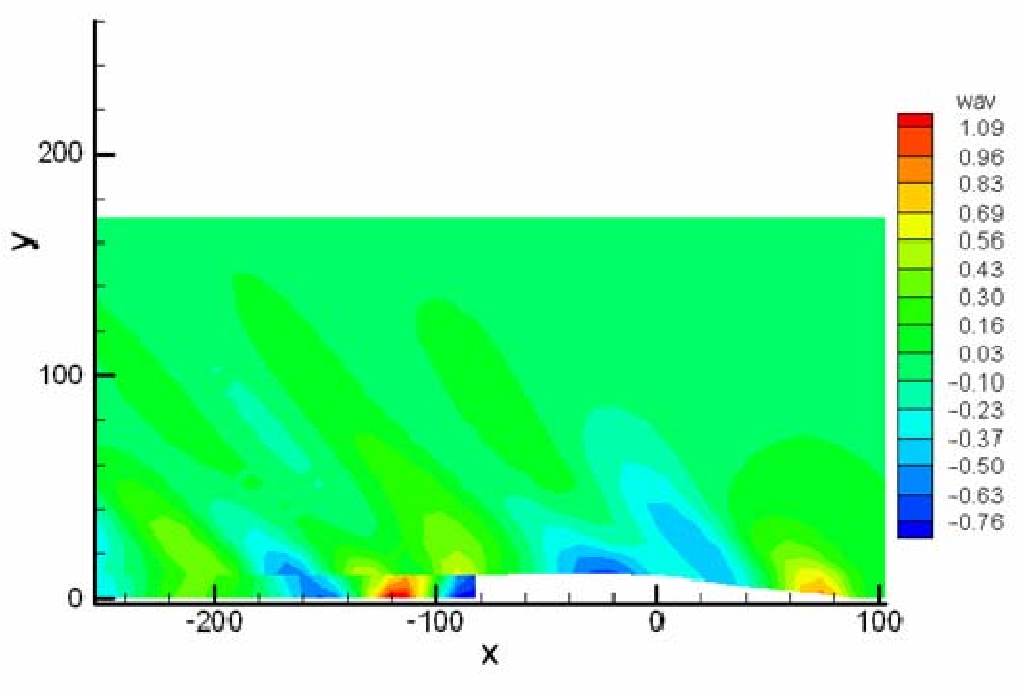


Figure 158. Wave Contours at 20kts

The SWAN2 analysis of 25 knots shows very little difference in wave position or wave height from 20 knot analysis. However, the wave position does move closer to the transom of the center hull to approximately 100 feet aft of the transom. This would probably be considered the limit to which the interceptor can remain stable during hoist hook up procedures.

Analysis of the center hull at 30 knots shows a reversing shift in the position of the wake and a larger wave height. Interceptor operations would not be expected when the Tsunami mothership is transiting at 30 knots. The wake position reverts back to the 147 feet behind the transom of the center hull. However, a 6 foot wake wave now develops. This is perfectly acceptable within the archway of the hoist bay since there are no weather decks in this area close to the waterline.

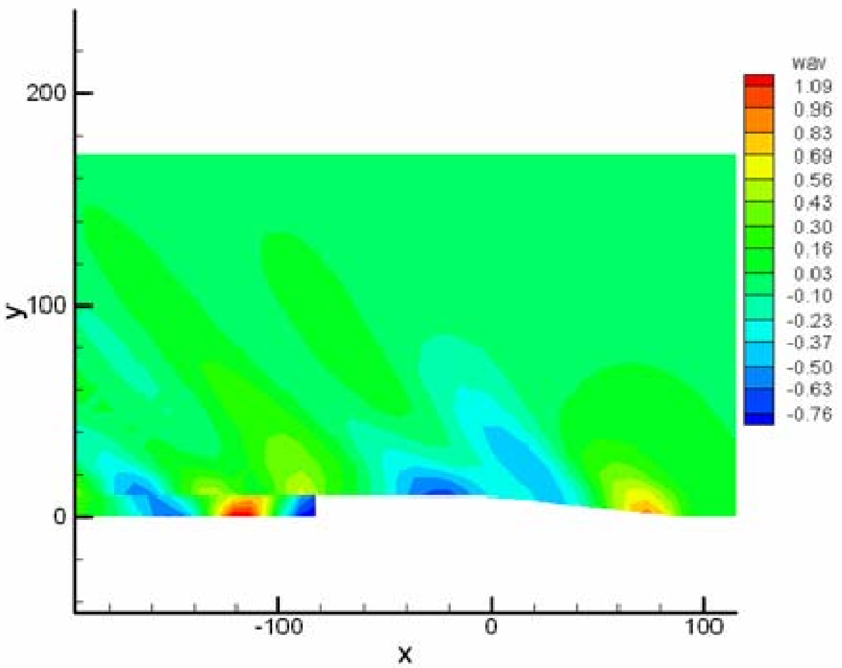


Figure 159. Wave Contours at 25kts

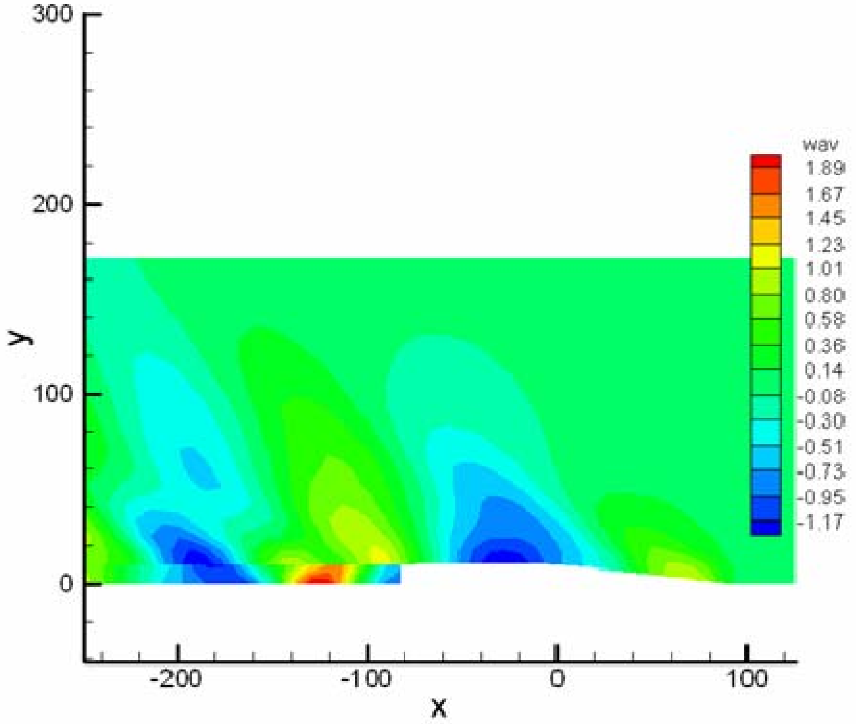


Figure 160. Wave Contours at 30kts

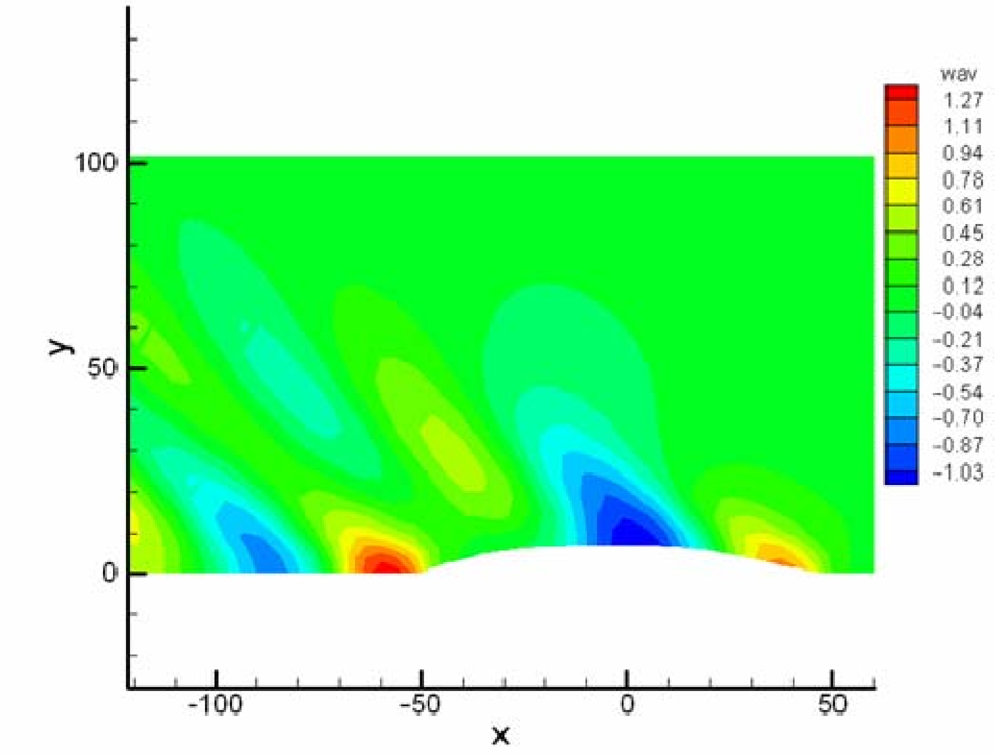


Figure 161. Series 60 Cruiser Analysis

The comparison of the Tsunami center hull to the series 60 cruiser test hull shows a significant difference in the position of the wake. On the Series 60 hull, the approximately 4.5 ft wake wave is directly behind the stern of the ship where on the Tsunami center hull the 3.5 ft wake wave is positioned approximately 147ft aft of the stern of the center hull. This analysis shows that the design of the center hull satisfies the requirement to position interceptors directly behind the center hull for loading and unloading into the mission bay.

Additionally, the maximum magnitude of the wake wave height is significantly less than that of a smaller cruiser. This reduces the amount of turbulence the pilot of the interceptor would expect when making his approach on the Tsunami mothership.

VIII. COMPUTER SOFTWARE SYSTEMS

The following computer programs were used in the development and analysis of the TSSE Maritime Threat Response Tsunami hull:

A. RENDERING SOFTWARE

SOLIDWORKS
RHINOCEROS 3.0 / FLAMINGO
AUTOSHIP 6.0.1

B. ANALYSIS SOFTWARE

- RHINOMARINE
  - Geometry Calculations
  - Stability Calculations
- AUTOSHIP / AUTOPWR 6.0.1
  - Resistance and Effective Horsepower Calculations
  - Geometry Verification
- EXCEL
  - Maritime Applied Physics Comparison Program
  - Resistance Calculation Verification
  - Center Hull Offsets and Geometry Verification
  - Risk Assessment
  - Wave Probability Predictions
- MATLAB 7.0
  - Side Hull Geometry Calculations
  - Sea keeping Calculations
- SWAN2
  - Wave Motion Analysis

IX. MATLAB CODES

A. SIDE HULL GEOMETRY CALCULATION CODE

```
function [f] = funcwsf(nf,x)
%
f = (1-x^nf)^(1/nf);
%


nf = 2;
F=@(x)(1-x.^nf).^(1/nf);
Cwsf = quad(F,0,1)
```

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APPENDIX C (ARRANGEMENTS)

TABLE OF CONTENTS

I. DESIGN PHILOSOPHY

The MTR hull is designed around two driving factors: the unique shape for seakeeping, and the Mission Bay. The arrangement of the ship's spaces, therefore, was also constrained by these factors. Whereas traditional ship design methods might start with the placement of main spaces, auxiliary spaces, and major combat systems, the placement of the Mission Bay took precedence in this case. The hull is designed to facilitate the hoisting and maneuvering of an Interceptor immediately astern of the center hull. Therefore, the Mission Bay begins at the extreme after end of the center hull to minimize the distance an Interceptor needs to travel to reach its storage location. Main spaces, tankage, and other vital spaces in the ship were then placed around the Mission Bay, taking into account weight, survivability, and ease of transit throughout the ship. The size of the Mission Bay drove the overall dimensions of the ship, making the amount of available internal volume much greater than that needed to man and run the ship. Care could be taken, therefore, to ensure crew comfort, increase the mission flexibility for secondary missions, and build redundancy and survivability into the ship wherever possible.

II. GENERAL ARRANGEMENTS

The goal of the design team was to separate the ship into several well-defined sections. Engineering spaces are separated from living spaces, which are generally separated from aviation spaces, and so forth. The Mission Bay serves as a divider between many sections, helping to describe the layout of spaces. A brief description of this system of sections is provided below.

A. LIVING QUARTERS

Forward of the Mission Bay, the First, Second, and Third Decks contain the majority of the living quarters. They are separated from the Main Engine Rooms and aviation spaces, which should maximize crew comfort with respect to noise. The Auxiliary Engine Room (on the Fourth Deck just below and astern of this section) containing the diesel generators should not provide a significant noise problem, as the generators will normally not be in use for the MTR mission. Living quarters for officers and senior DOE/riders are located on the Main Deck, directly above the Mission Bay. The Crew Training and Fitness Center (CTFC) are also located on this deck.

B. ENGINEERING SPACES

There are three general locations of engineering spaces on the ship. In the center hull, the engineering spaces are confined to the lower three decks (Four, Five and Six). This was done both to separate the spaces from the living quarters and to place heavy objects as low in the ship as possible for stability. The heavy diesel generators, APU, and much of the DC equipment onboard the ship are located here. Another benefit of placing the engineering spaces here is that Decks Four, Five, and Six span the length of the center hull without interruption. A fire in one of these spaces is accessible from forward or astern of the space, which is critical to the survivability of the ship. This location also aids in critical functions such as fuel transfer from the tanks in the center hull to the gas turbines aft.

The second general location for engineering spaces is above the side hulls astern of the Mission Bay. The Main Engine Rooms (MER) are located here, spanning Decks One, Two and Three immediately aft of the Mission Bay. The gas turbines are located on

Deck Two, in MER #1 and #2, Middle Level. Though well above the waterline (placing weight high), this choice was made to reduce the detrimental effect of the gas turbine intakes and exhaust plenums. In addition, this location is convenient for the crew, as access to the MERs can be found on the Main Deck via ladder well outboard of the hangars, or at the after outboard corners of the Mission Bay on the Third Deck.

The third general location for engineering spaces is within the side hulls. The side hulls are well below the waterline, most likely to suffer vibration and noise problems, and are presumably the least comfortable and least accessible location aboard the ship. For this reason, the HTS motors and necessary support equipment take up the majority of the manned spaces within the outer hulls. The motors should require relatively little maintenance, so accessibility is not an issue. In addition, placing the motors here allows the screws to be as deeply submerged as possible, increasing their effectiveness.

C. OPERATIONS SPACES

The MTR ship does not require a large amount of operations or combat systems space. However, care was taken to ensure that these spaces would be co-located as much as possible. The 01-Level (forward) contains the bridge, chart room, combat information center (CIC), and commanding officer's stateroom. The generous allotment for each of these spaces should easily accommodate the command and control, navigation, and mission planning needs of the ship. Immediately below on the Main Deck, the ship's wardroom is also large, built to accommodate mass briefings and meals for a large officer contingent. A well-appointed wardroom lounge just astern of the wardroom itself should make the wardroom easily available as additional workspace when not in use. Also on the Main Deck are equipment spaces for combat systems and a common office complex (COC) for ship's officers. Living quarters located nearby are for ship's officers, Interceptor officers, senior DOE/riders, and aviators. This allows the officers easy access to office space, but keeps them close to battle stations in case of emergency.

Though possibly better described as an engineering space, the Central Control Station (CCS) is also located on the Main Deck near the COC. This location is useful in that other ship control stations are nearby. Though the Fourth Deck would provide space for CCS, its location well below most of the other key watch stations and not more convenient to MER #1 or MER #2 than the Main Deck makes it less than ideal as a control station. CCS also serves as Damage Control Central, providing centralized support for topside, aviation, Mission Bay, living quarters, and engineering spaces.

D. AVIATION SPACES

The spaces designated for aviation are aft on the Main Deck and on the 01 Level at the after end of the hangar bays. The obvious reason for this is the location of the Flight Deck. The aviation spaces are large, able to easily accommodate two aircraft, and capable of surging to support many more. A twenty-foot-wide area between the hangars holds offices, storerooms, and a weapons magazine. The helicopter control tower is located between the hangars on the 01 Level, providing an excellent view of the Flight Deck. Weapons stations at the corners of the Flight Deck are recessed below the Main Deck so as to minimize any impact on flight operations.

E. MISSION BAY

This is the main purpose of the MTR ship. The Mission Bay contains the six interceptors, the transport dollies, and all necessary support equipment to facilitate the mission of the ship. The space is designed to be as wide open as possible, both to facilitate the movement of Interceptors within the bay, and also to ensure that the ship has flexibility for other missions. This cavernous space covers nearly half the ship’s length, and also nearly half of the height.

III. LOCATIONS OF HEAVY EQUIPMENT

One of the most important considerations to be made in the arrangements was the placement of heavy items aboard the ship. As described in the hydrostatics, the ship's longitudinal centers of buoyancy and gravity needed to align perfectly, and consideration was made to ensuring that the KG was also kept as low as possible to improve the ship's roll stability. To facilitate this process, a table of weights and centers was developed. A significant amount of integration went into this process. Propulsion, electrical, and operational decisions governed the locations, sizes, and weights of equipment and tankage as well. A few of these integration factors are outlined below.

A. POWER GENERATION SYSTEMS

Early in the design process, the decision was made to work with all-electric propulsion and power. This decision provided considerable flexibility for the placement of vital equipment, as the power generation machinery need not be co-located with the propulsion system. A redundant configuration of two gas turbine generators and two large diesel generators was chosen to meet the power loads required to operate the ship. To improve ship survivability, the design decision was to physically separate the diesel generators from the gas turbines. As a result, the gas turbine engines are located well above the waterline aft of the Mission Bay above the side hulls, while the heavy diesel generator sets are located forward of the Mission Bay below the waterline in the center hull. The configuration results in three engine spaces (the gas turbine generators each occupy separate spaces straddling the open area between the side hulls) widely separated, which is a great advantage in terms of casualty or damage control.

B. TANKAGE

With the power systems identified, a spreadsheet was developed to determine the amount of marine diesel fuel (DFM) required to meet the mission requirements. The spreadsheet accounts for the expected fuel consumption rate of the ship during a nominal mission, taking into account the types of engines in use, the specific fuel consumption, and the duration of the mission. The basic assumption was that the ship would generally operate at a 20-knot cruising speed in accordance with the concept of operations

(CONOPS), but would spend about 20% of the time at full power. In addition, a margin was added to account for uncertainties.

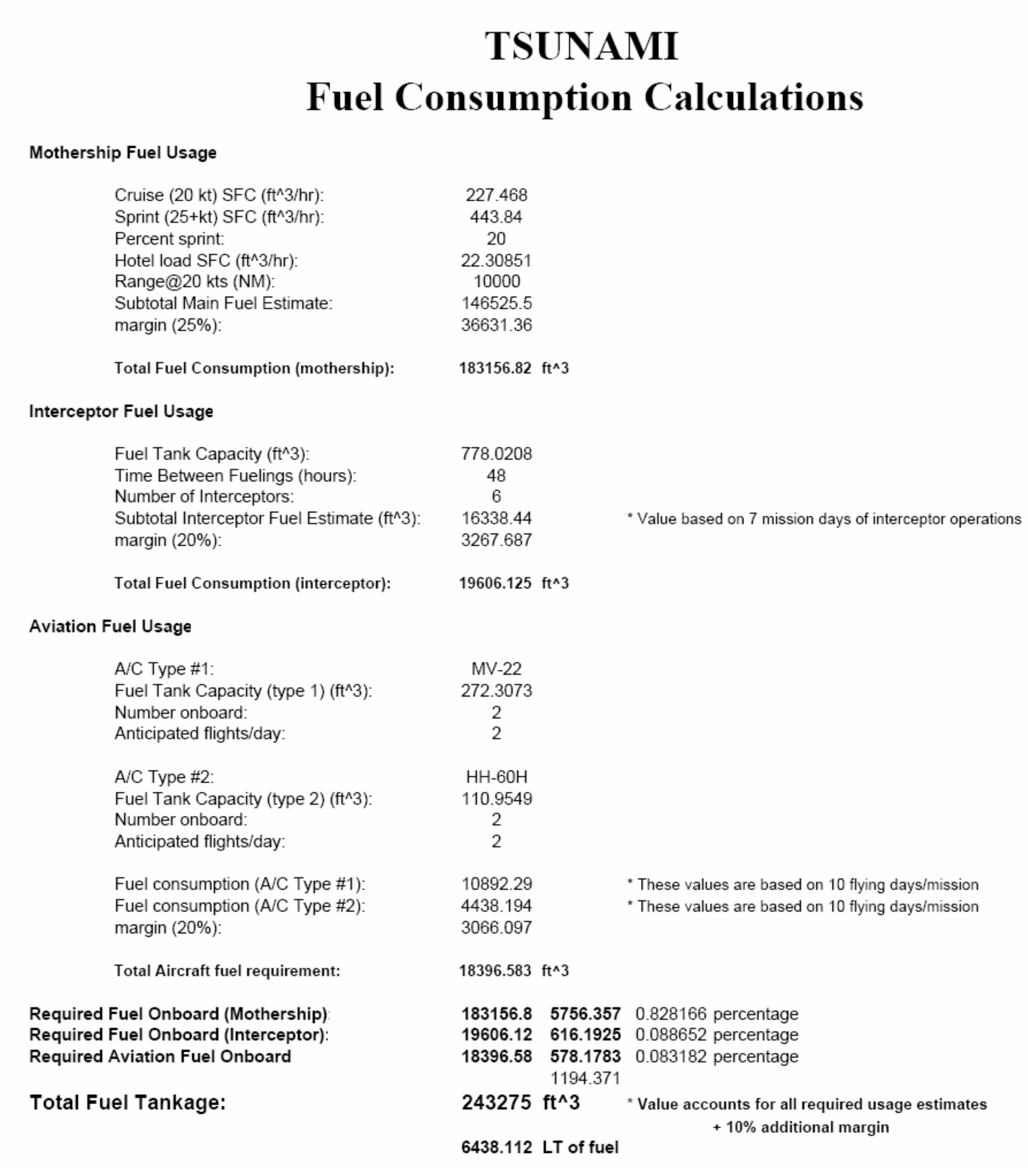
Another significant source of fuel requirements for this ship is the Interceptors. With expected full boarding mission duration of seven days, each Interceptor was expected to require fuel every 48 hours. Using the Wally Power 118' fuel tank size as a baseline, and accounting for six interceptors, the appropriate fuel requirement was derived, with another margin for uncertainties.

A third and final source of fuel requirements is for aviation. Here, an assumption was made that the ship may encounter a need to host significantly more capability than is expected for organic aviation support for the MTR mission. Expecting to operate two SH-60 airframes for 10 flying days and two full fuel loads per day each, a further requirement was added to support a similar amount of flight hours for two MV-22 aircraft. This more than doubles the aviation fuel requirements, but stretches the capability and timeliness of the MTR ship's deployment schedule by allowing the ship to leave port without some of the ship riders. A steady stream of cargo and personnel can flow from shore to the MTR system at sea until outside of MV-22 range without impacting the effectiveness of the MTR mission.

With the baseline fuel requirements determined, another margin was added to ensure that the ship would retain a significant quantity of fuel at the end of a nominal mission. Table 1 outlines the fuel consumption estimates used in this analysis.

C. PROPULSION SYSTEMS

With the design decision for all-electric propulsion, the next milestone was to determine the type of propulsion to utilize. The decision, discussed elsewhere, was to use conventional screws located at the stern of the outer hulls. The chosen prime movers, therefore, were located immediately forward of the screws to eliminate the need for heavy shafting and take advantage of the ability to place such heavy objects low in the ship. The frequency converters for the prime movers are located several decks above the motors, immediately astern of the gas turbine generators. This decision co-locates the frequency converters for propulsion with the ones required for power distribution, also minimizing the length of heavy cabling required between the motors, generators, and converters.



TSUNAMI
Fuel Consumption Calculations

Mothership Fuel Usage

Cruise (20 kt) SFC (ft^3/hr):	227.468	
Sprint (25+kt) SFC (ft^3/hr):	443.84	
Percent sprint:	20	
Hotel load SFC (ft^3/hr):	22.30851	
Range@20 kts (NM):	10000	
Subtotal Main Fuel Estimate:	146525.5	
margin (25%):	36631.36	
Total Fuel Consumption (mothership):	**183156.82**	**ft^3**

Interceptor Fuel Usage

Fuel Tank Capacity (ft^3):	778.0208		
Time Between Fuelings (hours):	48		
Number of Interceptors:	6		
Subtotal Interceptor Fuel Estimate (ft^3):	16338.44		* Value based on 7 mission days of interceptor operations
margin (20%):	3267.687		
Total Fuel Consumption (interceptor):	**19606.125**	**ft^3**	

Aviation Fuel Usage

A/C Type #1:	MV-22		
Fuel Tank Capacity (type 1) (ft^3):	272.3073		
Number onboard:	2		
Anticipated flights/day:	2		
A/C Type #2:	HH-60H		
Fuel Tank Capacity (type 2) (ft^3):	110.9549		
Number onboard:	2		
Anticipated flights/day:	2		
Fuel consumption (A/C Type #1):	10892.29		* These values are based on 10 flying days/mission
Fuel consumption (A/C Type #2):	4438.194		* These values are based on 10 flying days/mission
margin (20%):	3066.097		
Total Aircraft fuel requirement:	**18396.583**	**ft^3**	

Required Fuel Onboard (Mothership):	**183156.8**	**5756.357**	0.828166 percentage	
Required Fuel Onboard (Interceptor):	**19606.12**	**616.1925**	0.088652 percentage	
Required Aviation Fuel Onboard	**18396.58**	**578.1783**	0.083182 percentage	
		1194.371		
Total Fuel Tankage:	**243275**	**ft^3**		*** Value accounts for all required usage estimates + 10% additional margin**
	6438.112	**LT of fuel**		

Figure 162. TSUNAMI fuel consumption estimates for tankage arrangements

D. MISSION BAY SYSTEMS

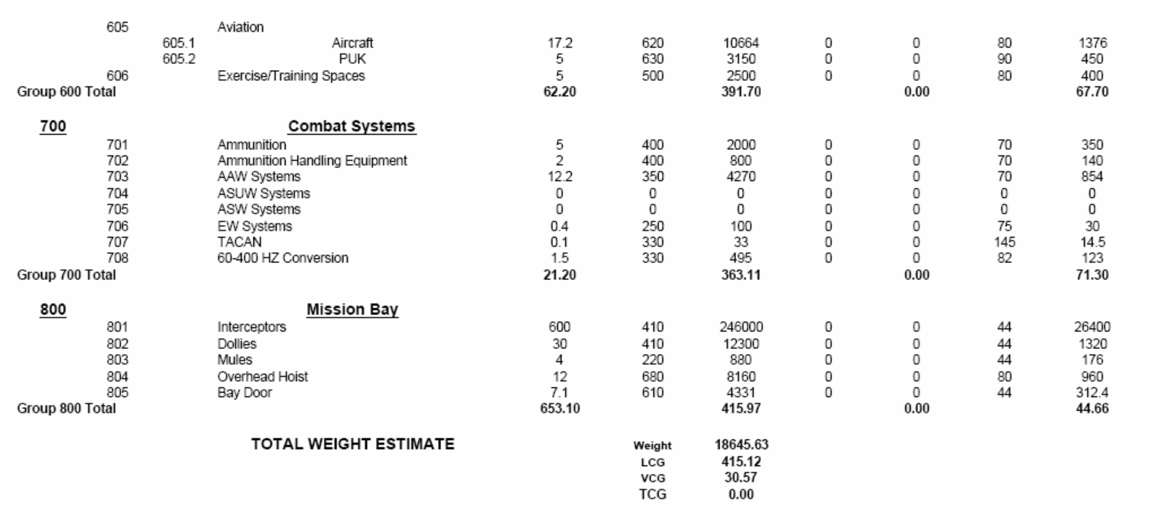
A critical component in terms of weight and stability is the Mission Bay itself. The ship is designed to hoist, traverse, and store up to six Interceptors, at an estimated weight of 100 LT each. This is a significant cargo, even for a ship displacing 20,000 tons. In addition, the pallets carrying the Interceptors are not light, and the Mission Bay is envisioned to have a large door at the stern to prevent swamping the Mission Bay while not in use launching or recovering Interceptors. These weights could not be moved significantly within the Mission Bay for equipment placement, but were certainly taken into account while placing other equipment in the ship.

D. GROUP WEIGHTS AND CENTERS

Armed with a general location of major equipment, tanks, and machinery, an effort was made to determine just how much of the ship's total displacement would consist of non-structural components. To aid in this effort, the MTR Team chose to utilize the Rammstein database available within the TSSE shared electronic library. Dividing the ship's components into major groups along conventional lines, the team either placed actual weights (where known from design decisions) or assumed weights (derived from Rammstein database information conforming to either *Arleigh Burke* DDGs or *San Antonio* LPDs depending upon the type of equipment) to fill in as complete a preliminary table as possible. Loads were then given locations conforming to spaces identified on the ship and moved until the estimated LCG aligned with the LCB from our hydrostatic data. Another assumption made was that the preliminary group weights and centers table is incomplete, so the total weight of non-structural loads was then computed by dividing the subtotal by 0.8 to arrive at an assumed non-structural load total. The margin weights were assumed to be evenly distributed throughout the ship for ease of computation. From the non-structural load computation, an estimate could be made for the "budget" of available structure weights by subtracting the value from the ship's design displacement. Table 2 below lists the partial group weights and centers as developed in the weight study described.

TSUNAMI Group Weights and Centers

							Location			
Group	Index	Sub-index	Description	Weight (LT)	Longitudinal	lcg	Transverse	tcg	Vertical	vcg
100			**Hull Structure**							
	101		Hull Plating	4500		?	0	0	35	157500
	102		Keel	500		?	0	0	6	3000
	103		Longitudinals	1200		?	0	0	35	42000
	104		Transverse Framing	1100		?	0	0	35	38500
	105		Deck Plating	1000		?	0	0	40	40000
	106		Mission Bay Transverse Framing	600		?	0	0	80	48000
	107		Strut Framing	1100		?	0	0	27	29700
	108		Rudders	19.8	810	16038	0	0	15	297
	109		Fuel Tankage					0		
		109.1	DFM	5407.550424	407.344	2202733.22	0	0	18.293	98920.31991
		109.2	JP5	1123.307576	407.344	457572.6012	0	0	18.293	20548.66549
	110		Potable Water Tankage	59.58	550	32769	0	0	25	1489.5
Group 100 Total				**16610.24**		**409.84**		**0.00**		**28.90**
200			**Propulsion**							
	201		HTS Motors	147.64	760	112206.4	0	0	3	442.92
	202		Propellers	30	810	24300	0	0	10	300
	203		Shafts	0		0	0	0	10	0
	204		Cabling	0		0	0	0	33	0
	205		Auxiliary Propulsion Systems	33.46	110	3680.6	0	0	25	836.5
Group 200 Total				**211.1**		**664.08**		**0.00**		**7.48**
300			**Electrical**							
	301		Gas Turbine Engines	43.3	645	27928.5	0	0	58	2511.4
	302		Gas Turbine Generators	66.92	670	44836.4	0	0	58	3881.36
	303		Diesel Engines	80	200	16000	0	0	22	1760
	304		Diesel Generators	43.42	220	9552.4	0	0	22	955.24
	305		Frequency Converters	97.84	720	70444.8	0	0	59	5772.56
	306		Fuel Oil Service Systems	11.53	620	7148.6	0	0	30	345.9
	307		Lube Oil Service Systems	8.67	650	5635.5	0	0	30	260.1
	308		ZEDS							
		308.1	Zone IPCs	24	410	9840	0	0	45	1080
		308.2	Power Bus Systems	43.5	410	17835	0	0	45	1957.5
		308.3	Shore Power Systems	3.57	650	2320.5	0	0	80	285.6
		308.4	Cabling	106.13	410	43513.3	0	0	45	4775.85
Group 300 Total				**528.88**		**482.25**		**0.00**		**44.60**
400			**Command and Surveillance**							
	401		Navigation Systems	6.07	250	1517.5	0	0	100	607
	402		Internal Communications Suite	82.61	410	33870.1	0	0	45	3717.45
	403		External Communications Suite	50.64	320	16204.8	0	0	90	4557.6
	404		Combat Information Center	51.06	320	16339.2	0	0	90	4595.4
Group 400 Total				**190.38**		**356.82**		**0.00**		**70.79**
500			**Auxiliary Systems**							
	501		Potable Water Systems	41.01	275	11277.75	0	0	40	1640.4
	502		Gray Water Systems				0	0	15	0
	503		CHT Systems	12.65	410	5186.5	0	0	25	316.25
	504		Damage Control Systems							
		504.1	DC Equipment	5	400	2000	0	0	35	175
		504.2	Fire Main Piping	127.13	410	52123.3	0	0	35	4449.55
		504.3	Fire Pumps	6	400	2400	0	0	20	120
		504.4	AFFF Systems	46.59	500	23295	0	0	45	2096.55
		504.5	Halon Systems	5	400	2000	0	0	45	225
	505		Fuel Transfer Systems							
		505.1	Aviation	5.6	620	3472	0	0	70	392
		505.2	Generators			0				
		505.3	Interceptor			0				
		505.4	Refuel-At-Sea	33.22	600	19932	0	0	75	2491.5
	506		Steering Systems	20	800	16000	0	0	40	800
	507		Refrigeration Systems							
		507.1	Food Storage	2	150	300	0	0	40	80
		507.2	Cryogenics			0	0	0	5	0
		507.3	Air Conditioning	8	410	3280	0	0	35	280
			507.3.1 Crew Spaces			0				
			507.3.2 Equipment Cooling			0				
	508		Galley Systems	5	150	750	0	0	67	335
	509		Fresh water Distribution Systems	2	400	800	0	0	35	70
	510		Recovery Assist Secure and Traverse System	30.83	720	22197.6	0	0	68	2096.44
	511		Anchor	5	30	150	0	0	68	340
	512		Capstans	3.5	50	175	0	0	70	245
	513		Anchor Chain	10	50	500	0	0	32	320
	514									
Group 500 Total				**368.53**		**450.00**		**0.00**		**44.70**
600			**Outfit and Furnishings**							
	601		Living Quarters	20	200	4000	0	0	55	1100
	602		Messing	5	200	1000	0	0	67	335
	603		Heads	5	200	1000	0	0	55	275
	604		Lounge Spaces	5	410	2050	0	0	55	275



605		Aviation							
	605.1	Aircraft	17.2	620	10664	0	0	80	1376
	605.2	PUK	5	630	3150	0	0	90	450
606		Exercise/Training Spaces	5	500	2500	0	0	80	400
Group 600 Total			**62.20**		**391.70**		**0.00**		**67.70**
700		**Combat Systems**							
701		Ammunition	5	400	2000	0	0	70	350
702		Ammunition Handling Equipment	2	400	800	0	0	70	140
703		AAW Systems	12.2	350	4270	0	0	70	854
704		ASUW Systems	0	0	0	0	0	0	0
705		ASW Systems	0	0	0	0	0	0	0
706		EW Systems	0.4	250	100	0	0	75	30
707		TACAN	0.1	330	33	0	0	145	14.5
708		60-400 HZ Conversion	1.5	330	495	0	0	82	123
Group 700 Total			**21.20**		**363.11**		**0.00**		**71.30**
800		**Mission Bay**							
801		Interceptors	600	410	246000	0	0	44	26400
802		Dollies	30	410	12300	0	0	44	1320
803		Mules	4	220	880	0	0	44	176
804		Overhead Hoist	12	680	8160	0	0	80	960
805		Bay Door	7.1	610	4331	0	0	44	312.4
Group 800 Total			**653.10**		**415.97**		**0.00**		**44.66**
		TOTAL WEIGHT ESTIMATE		**Weight**	**18645.63**				
				LCG	**415.12**				
				VCG	**30.57**				
				TCG	**0.00**				

Figure 163. TSUNAMI Group Weights and Centers estimation

IV. LOAD DISTRIBUTION DIAGRAM

Structural analysis and development of the scantlings are discussed in another portion of this appendix. However, the development of the load distribution diagram came from the placement of the heavy items, including the previously mentioned machinery, Interceptors and tanks. To model this in a usable format, a spreadsheet was developed in which loads were distributed in one-foot increments. This allowed for an extremely accurate estimate of the load curve, which was in turn able to be applied to the calm water and wave loading curves to develop load distribution, shear force, and bending moment diagrams. This information provided the starting point for the structural analysis of the MTR ship. Included below are the loading diagram, shear force diagram, and bending moment diagrams for calm water.

For the hogging and sagging conditions, the team chose to model the ship in extremes. Rather than compute the response of the vessel in a trochoidal wave with peaks or troughs at the forward and aft perpendiculars, the ship was modeled in hog as a hull girder with the entire ship's displacement concentrated as weights at the extremities (100 feet in from the bow and stern), and the entire buoyant force applied at midships. The process was reversed for sag, with weights applied at midships and the buoyant force applied at the extremities. This resulted in the maximum possible bending force conceivable for the ship, well beyond what may be expected in an operational environment.

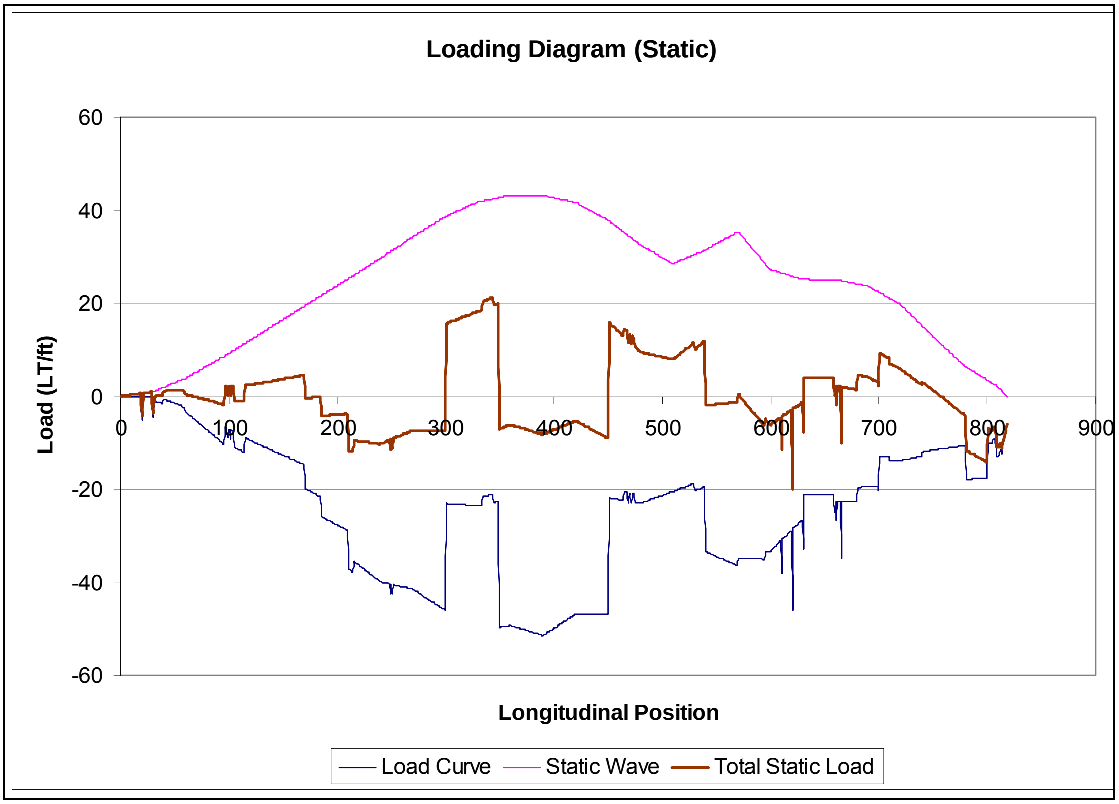


Figure 164. Static Loading Diagram for calm seas

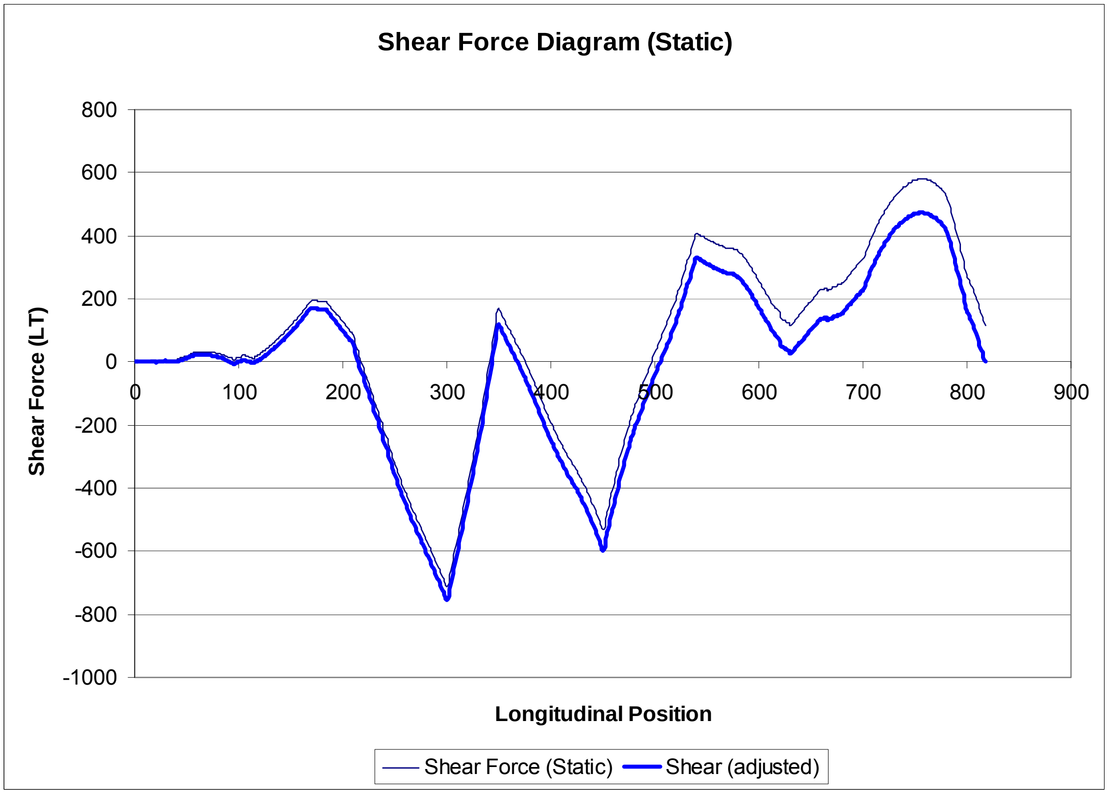


Figure 165. Shear Force Diagram for calm seas

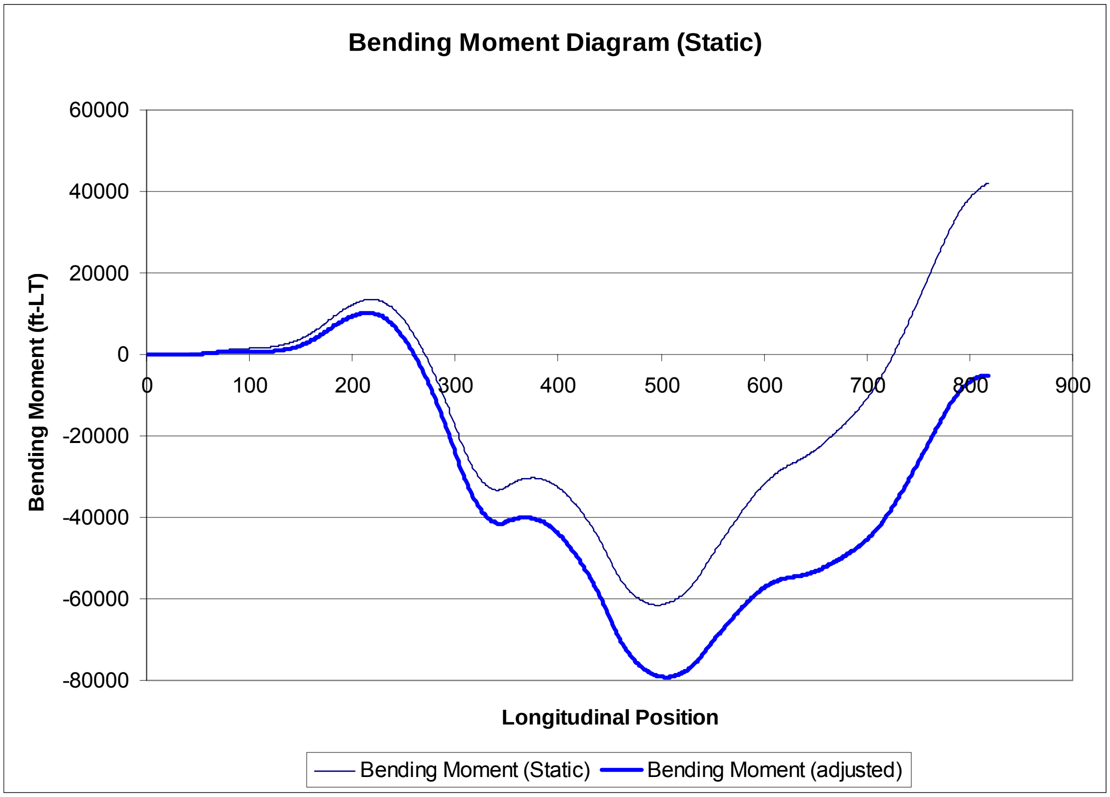


Figure 166. Bending Moment Diagram for calm seas

V. ARRANGEMENT DRAWINGS

A. GENERAL DESCRIPTION

The deck arrangement drawings were developed in AutoCAD^{TM} in three dimensions. The three-dimensional view is similar to the damage control plates in common use on current Navy warships and is an easy way to provide a sense of depth to a drawing and eliminate the need to insert two-dimensional symbology. In addition, as the external bulkheads are angled at 26.5 degrees, the slope of the exterior shows more accurately in three dimensions, helping to explain why some of the spaces appear in more than one deck drawing. Complex exterior curvature was simplified slightly in these drawings where space arrangement would not be compromised. Detailed deck arrangements are provided for the 01 Level, Main Deck, Mission Bay, and Main Engineering Spaces. In addition, a profile cutaway drawing depicting major equipment and tankage was developed. The drawings utilize the skin of the MTR ship as drawn in Rhino Marine^{TM}, imported into AutoCAD^{TM} using the .dxf format. This format allowed file sharing between the two programs, even allowing for modifications to be made after importation. Deck outlines were also developed this way, eliminating the need to reproduce complex curves in both programs.

B. DECK ARRANGEMENTS

1. 01 Level

The 01 Level is the top deck of the ship not considered aloft. It is divided into two sections. The forward section starts at frame 212. The Pilothouse and bridge wings span the entire beam of the ship, providing an enormous space from which to control the ship. Like any ship with a wide beam, however, this is necessary for the safety of navigation, and interior volume is thankfully not at a premium on this ship. Immediately behind the Pilothouse in the forward superstructure, two ladder wells are positioned against the outboard bulkheads. These ladder wells are also mirrored at the far end of the forward superstructure. Inboard of the ladder wells are matching passageways, leading to CIC on the starboard side and the Commanding Officer’s Cabin to port. Inboard of the passageway to starboard is the ship’s chart room, with a head inboard of the port side passageway. CIC is also spacious, 60 feet long by 40 feet wide. This space is plenty large enough to coordinate the employment of Interceptors and manage shipboard flight and combat operations.

The after superstructure slopes up gradually from the Main Deck below, providing the Main Deck spaces in this region of the ship a high ceiling. At the start of the helicopter hangars, however, a 20-foot-wide section between the two-level hangar spaces is utilized for officer’s berthing, storage, and office space, and the after end of this space houses the Helicopter Control Tower, jutting out from the superstructure and providing a commanding view of the Flight Deck below. Figure 4 depicts the arrangement of the 01 Level.

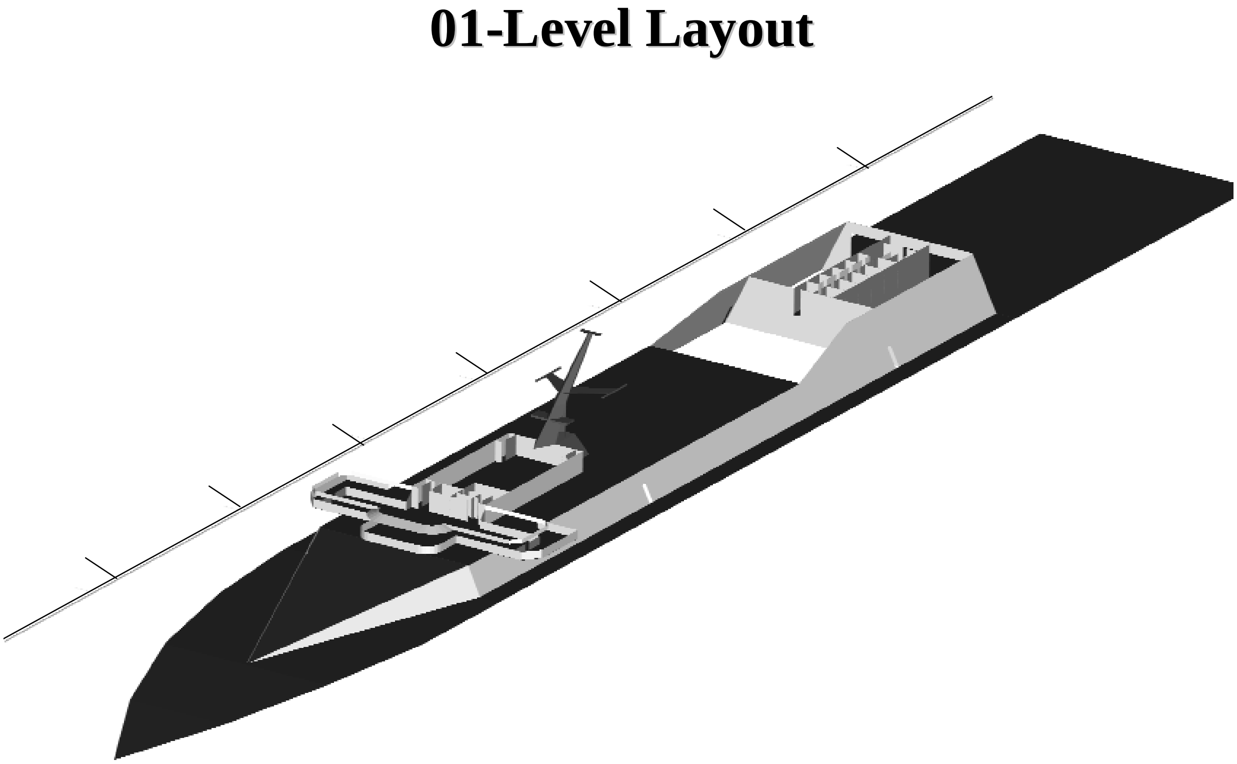

01-Level Layout

Figure 167. 01 Level Arrangements

2. Main Deck

The Main Deck is the nerve center of the TSUNAMI. By far the largest deck in terms of usable square footage, a lot of spaces are crammed into this busy area. Forward, the Forecastle slopes downward as mentioned earlier for the view from the Bridge. The slope starts at frame 210, however, so that the bow of the ship is actually slightly below the location of most of the 1st Deck. This slope, as well as the extreme angle of the forward superstructure, also impacts the spaces forward. The deck is open forward of frame 185, affording the living spaces one deck down an impressively tall ceiling. Within the superstructure, much of the Main Deck is utilized as living space. Two continuous passageways span from the ladder wells marking the start of the deck all the way aft to the Crew Training and Fitness Center (CTFC), a two-deck-tall space spanning the entire beam of the superstructure and more than 30 feet longitudinally. A centerline passageway also runs forward and aft, but is broken by major spaces such as the Wardroom and CCS. Due to the long length of the Main Deck (the superstructure runs from frame 100 all the way aft to frame 614), five athwart ships passageways are also included, as well as a pass-through between the two helicopter hangars. Vertical access to the decks below is limited by the presence of the Mission Bay, but pairs of ladder wells are located both forward and aft leading to the 1st Deck below.

Major spaces on the Main Deck abound. Immediately forward of the Flight Deck are the two helicopter hangars, each 25 feet tall, 75 feet long, and with a doorway 20 feet wide. Centered between the hangars are equipment and office spaces, with a large space set aside as an armory and magazine. Forward of the hangars is the CTFC. This space is desired for the MTR mission so that the boarding teams can maintain good physical condition and practice climbing, etc in the 25-foot-tall space. Forward of the CTFC is CCS. This space is positioned just forward of the CTFC for quick access to the external doors and the ladder wells located just outside of the superstructure at the after end of the hangars. Forward of CCS is a large, four-room Common Office Complex (COC). Each room within the COC is roughly 400 square feet, providing ample workspace for ship's crew or for training. Farther forward, the Wardroom and Wardroom Lounge are positioned beneath the CIC. The 30 foot by 35 foot Wardroom is designed for feeding a large officer/rider contingent, and the lounge is a separate space just aft, allowing for the dining section to be a more formal affair, or a suitable briefing location. Completing the arrangements on this deck are 99 staterooms and 15 heads, not including the separate head and stateroom for the Executive Officer, located immediately forward of the

Wardroom Pantry. Each stateroom is 10 feet square, easily able to accommodate two officers, though most will only require single occupancy. Heads are designed to be large enough to hold a sink, two urinals, a toilet stall, and three shower stalls each. Figure 5 below depicts this detailed arrangement.

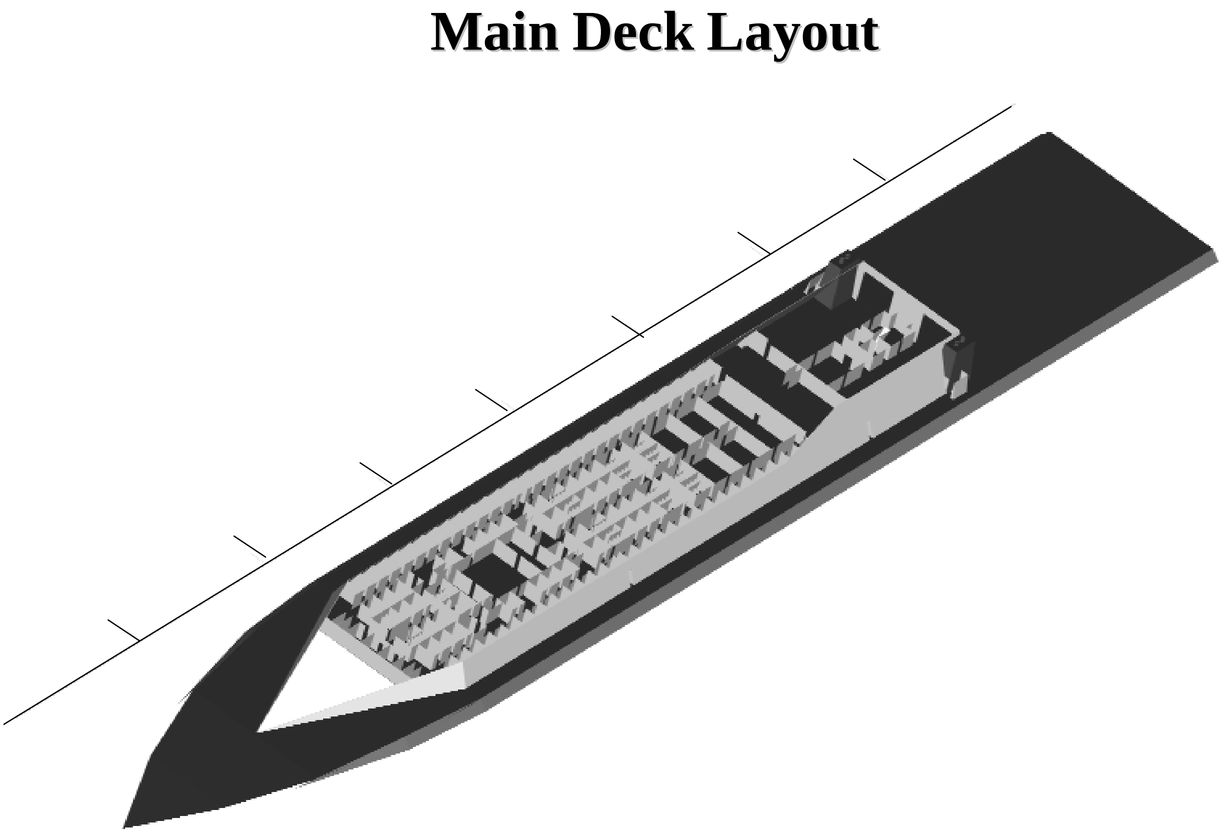


Figure 168. Main Deck Arrangements

3. Mission Bay

As was previously mentioned, the Mission Bay dominated the design of the ship. Taking up three decks and the majority of the center hull, the Mission Bay deserves attention as a separate entity. Starting at frame 210, the Mission Bay is essentially a rectangular box 390 feet long, 120 feet wide, and 36 feet tall. At the top of the space, the overhead angles inward at 45 degrees. The size of the bay was determined by the selection of the interceptor. At 118 feet in length and a 30 foot beam, the bay is built to hold six Wally Power 118’ yachts on self-propelled pallets. The center lane of the bay is used to transit Interceptors forward and aft, so the bay needs to be wider than three pallets. The Mission Bay door, located at the after end of the bay, opens 10 feet above the design waterline to the hoist area at the stern of the ship between the side hulls. A pallet transits out of the bay on rails lining the side hull struts, dictating the width of the pallets, and therefore the width of the bay. Figure 6 depicts the internal layout of the Mission Bay, showing six Interceptors within the space stowed in the fully loaded condition. The stanchions depicted in the figure are directly above watertight bulkheads. In an ideal configuration, the Mission Bay will be completely open, though first iteration calculations indicated that stanchions may be required to maintain the structural integrity of this large space.

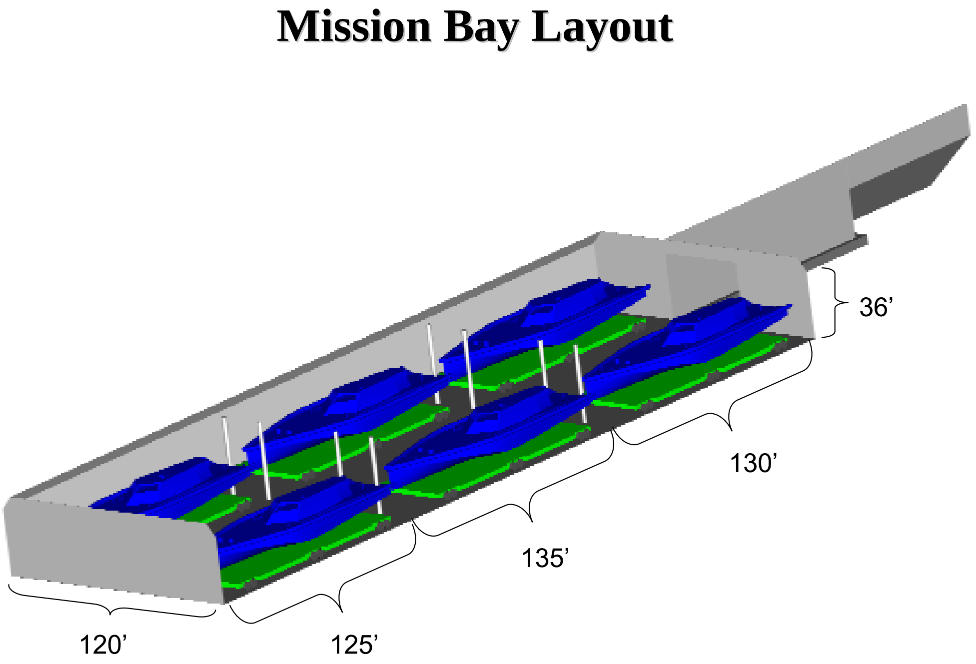


Figure 169. Mission Bay Arrangements

4. Main Engine Rooms

The Main Engine Rooms on the MTR ship are positioned above the DWL aft of the Mission Bay. The all-electric ship configuration allowed for power generation to be removed from the propellers, providing flexibility in placement. The MER spaces were chosen for their proximity to the motors (so that power cables are as short as possible), convenience to the Main Deck and CCS, and also for the proximity to the Flight Deck (for intakes and exhaust). The MER spaces are enormous, with each space comfortably fitting an MT-30 gas turbine engine, generator, and four static frequency converters for power generation and propulsion. The watertight spaces below are also easily accessible, with vertical access through the struts to the side hulls. MER #1 (starboard side) also holds a small room at the forward inboard corner for controlling Interceptor launch and retrieval operations. Steering gear fits easily in the stern-most compartments low down in the MER lower levels, while the upper two decks are reserved for the bulky equipment (note that the generators and gas turbine engines penetrate the MER upper levels). The forward sections of the MER lower levels are roomy enough for fire pumps, fuel service systems, and a variety of other engineering subsystems. A small (four-foot) bilge deck rests beneath the lower levels, a likely location for oily waste and lube oil service tanks. Figure 7 depicts the arrangement of the Main Engine Rooms, with some bulkheads cut out for clarity.

Main Engine Room Layout

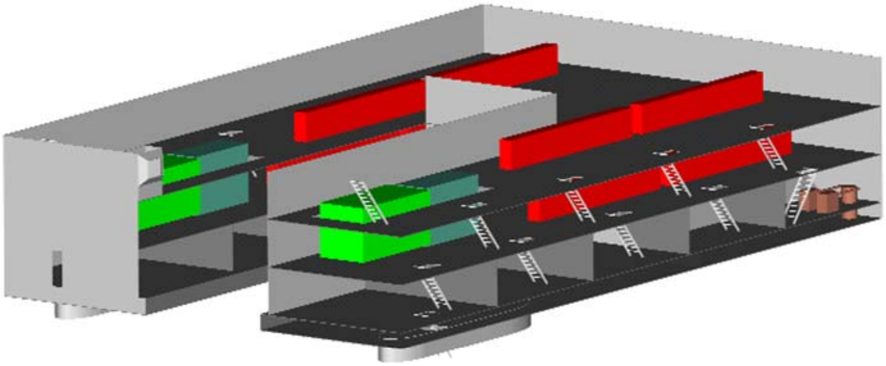


Figure 170. Main Engine Room Arrangements

1. Profile Cut-away

The last major arrangement drawing produced for this project is a profile cut-away view of the ship's major equipment and tanks. This view provides a thorough understanding of the longitudinal separation between spaces, shows the location of watertight bulkheads, and is perhaps the clearest way to grasp the size of the Mission Bay relative to the rest of the ship. A brief description is warranted for each of the useful aspects of this drawing.

The first noticeable aspect of the profile view is the locations of watertight bulkheads. Floodable length calculations revealed that the ship was not susceptible to large changes in draft, with the lowest floodable length (about 150 feet) located about one quarter of the ship's length aft of the forward perpendicular. For this reason, standardized bulkhead spacing was chosen at 40-foot increments for the entire forward section of the ship. Beneath the Mission Bay (the location of the margin line in the amidships area), the bulkhead spacing spreads out to 45 feet as the floodable length is much higher here, and the spacing was convenient for the locations of the Mission Bay stanchions. Astern of the Mission Bay, the bulkhead spacing above the side hulls is 40 feet, while the watertight bulkheads within the side hulls themselves are spaced at 30 feet. This configuration allows the MTR ship to flood any three compartments without danger of sinking below the margin line. Figures 171 and 172 show the bulkhead configurations within the ship.

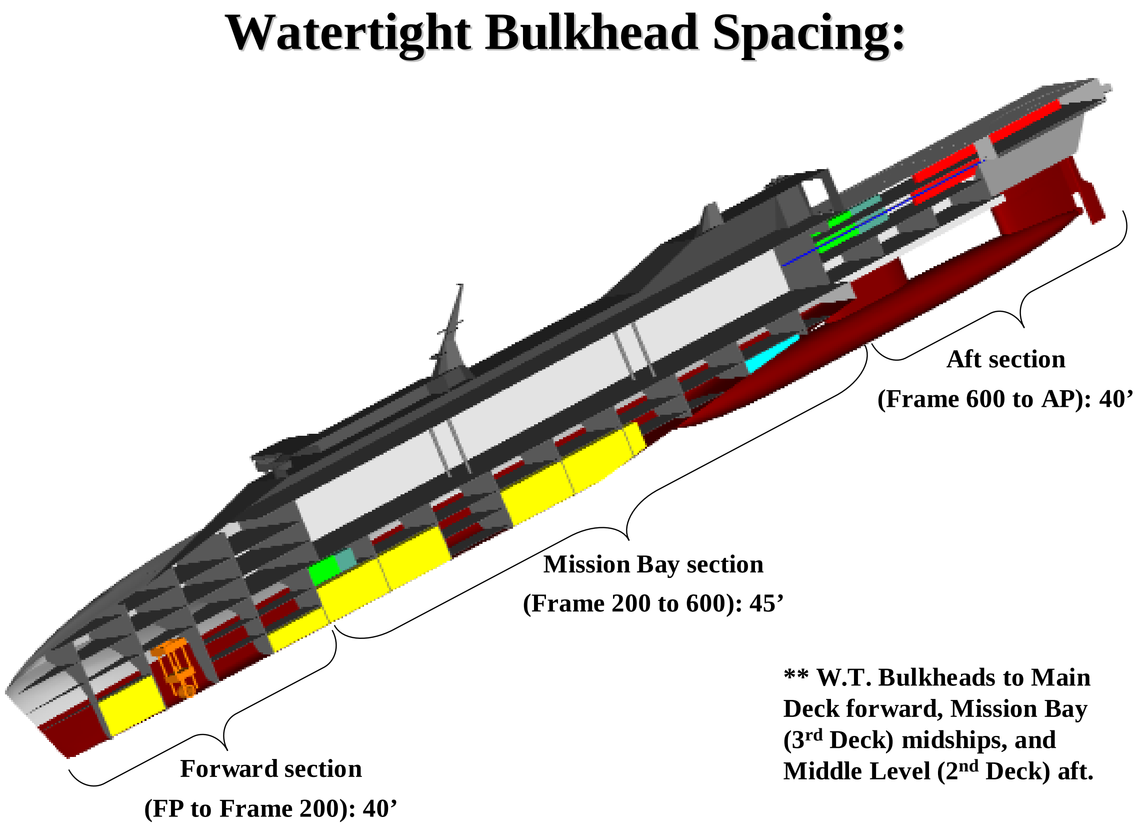


Figure 171. Center hull watertight bulkhead spacing

Side Hull Bulkhead Spacing

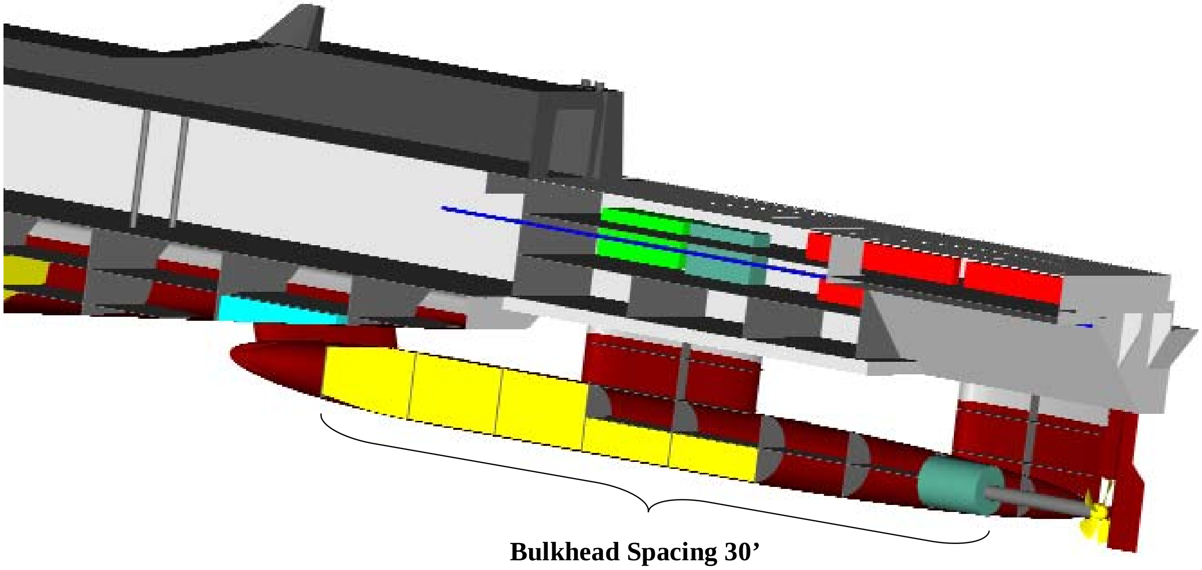


Figure 172. Side hull watertight bulkhead spacing

Another important aspect of the profile drawing is that it shows the longitudinal separation of major equipment and tanks within the hull. Propulsion systems are located at the extremities of the ship, with the twin screws aft and the APU forward (the center of thrust for the APU is at frame 100, over 300 feet from the ship’s LCG). Power systems are also distributed longitudinally, with the Auxiliary Engine Room located just beneath the Mission Bay on the Fourth Deck and the two Main Engine Rooms aft of the Mission Bay. Fuel tanks are also distributed throughout the ship’s length, with much of the tankage actually located within the side hulls. Figure 10 outlines these locations graphically.

Major Engineering Equipment and Tankage

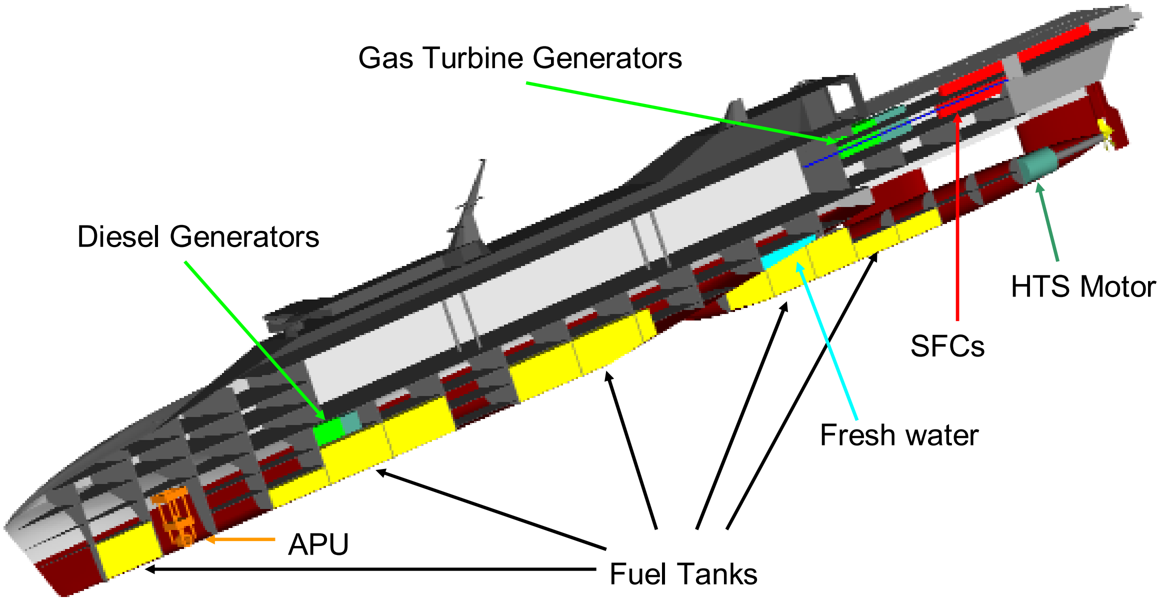


Figure 173. Locations of major equipment shown in profile cut-away

VI. STRUCTURE AND SCANTLINGS

A. INITIAL SECTION MODULUS CALCULATIONS

The maximum bending moments were determined in the previously described loading condition analysis. Under static conditions the maximum bending moment was -79,214 ft-LT which was rounded to -80,000 ft-LT for analysis. The maximums for hogging and sagging were similar as the extreme models used had the loading and buoyant force locations reversed. Those values were 3,653,781 ft-LT and -3,653,781 ft-LT respectively.

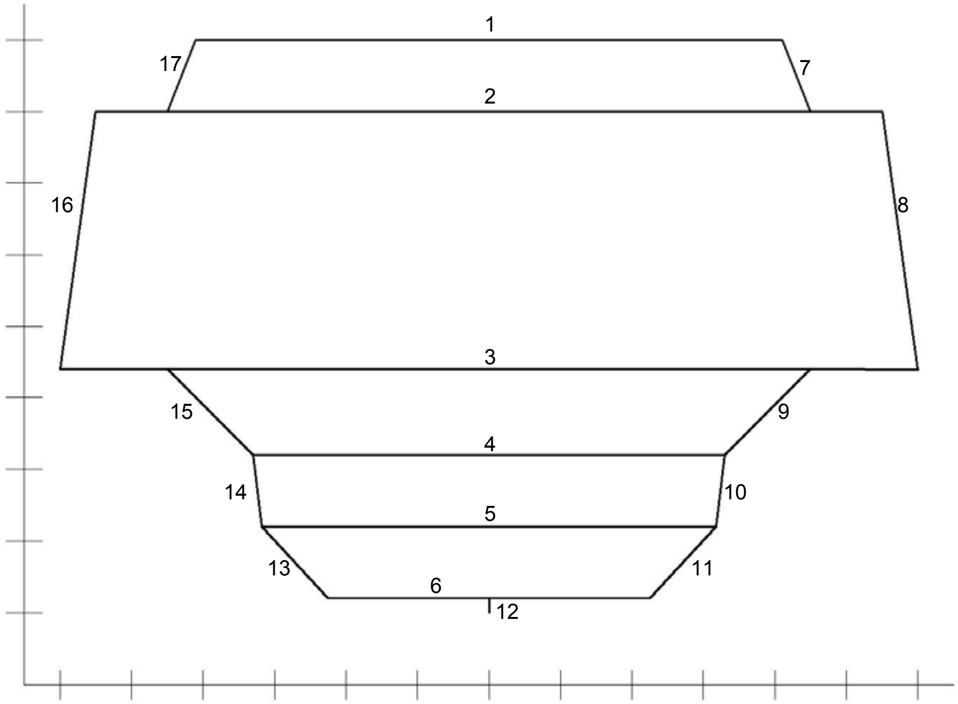
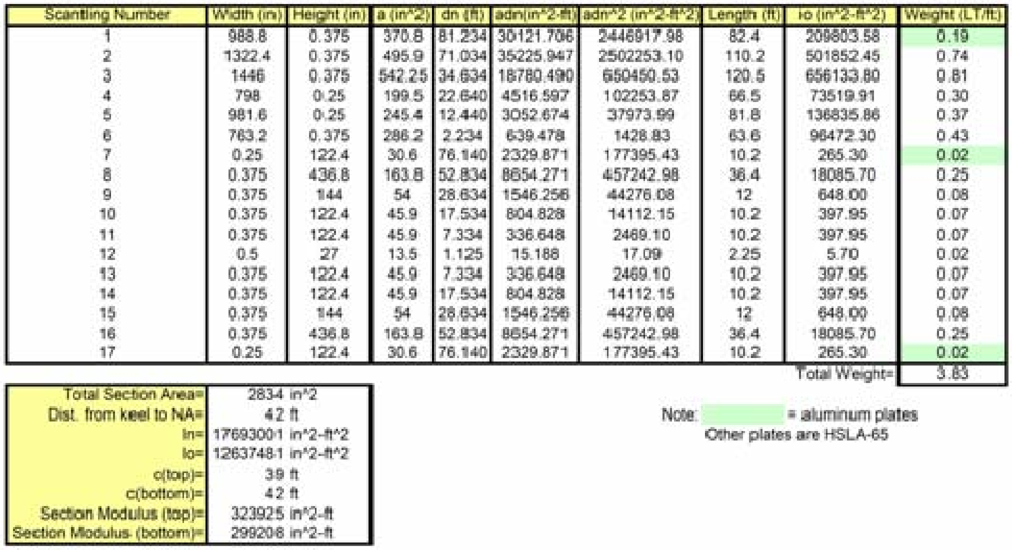


Figure 174. Simplified midships section. Each increment is 10ft

This simplified midships section was then used to compute the section modulus. The following table shows the Microsoft Excel sheet that was used to find the section modulus.



Scantling Number	Width (in)	Height (in)	a (in^2)	dn (ft)	adn(in^2-ft)	adn^2 (in^2-ft^2)	Length (ft)	io (in^2-ft^2)	Weight (LT/ft)
1	988.8	0.375	370.8	81.234	30121.706	2446917.98	82.4	209803.58	0.19
2	1322.4	0.375	495.9	71.034	35225.947	2502253.10	110.2	501852.45	0.74
3	1446	0.375	542.25	34.634	18780.490	650450.53	120.5	656133.80	0.81
4	798	0.25	199.5	22.640	4516.597	102253.87	66.5	73519.91	0.30
5	981.6	0.25	245.4	12.440	3052.674	37973.99	81.8	136835.86	0.37
6	763.2	0.375	286.2	2.234	639.478	1428.83	63.6	96472.30	0.43
7	0.25	122.4	30.6	76.140	2329.871	177395.43	10.2	265.30	0.02
8	0.375	436.8	163.8	52.834	8654.271	457242.98	36.4	18085.70	0.25
9	0.375	144	54	28.634	1546.256	44276.08	12	648.00	0.08
10	0.375	122.4	45.9	17.534	804.828	14112.15	10.2	397.95	0.07
11	0.375	122.4	45.9	7.334	336.648	2469.10	10.2	397.95	0.07
12	0.5	27	13.5	1.125	15.186	17.09	2.25	5.70	0.02
13	0.375	122.4	45.9	7.334	336.648	2469.10	10.2	397.95	0.07
14	0.375	122.4	45.9	17.534	804.828	14112.15	10.2	397.95	0.07
15	0.375	144	54	28.634	1546.256	44276.08	12	648.00	0.08
16	0.375	436.8	163.8	52.834	8654.271	457242.98	36.4	18085.70	0.25
17	0.25	122.4	30.6	76.140	2329.871	177395.43	10.2	265.30	0.02
								Total Weight=	3.83

Total Section Area=	2834 in^2
Dist. from keel to NA=	42 ft
In=	17693001 in^2-ft^2
Io=	12637481 in^2-ft^2
c(top)=	39 ft
c(bottom)=	42 ft
Section Modulus (top)=	323925 in^2-ft
Section Modulus (bottom)=	299208 in^2-ft

Note: 🟩 = aluminum plates
Other plates are HSLA-65

Figure 175. Section Modulus calculation

The maximum bending moments were then used with this data to find the maximum compressive and tensile stresses applied to the hull. The hogging and sagging conditions yielded 11.3 LT/in^2 in the deck (tensile and compressive respectively) and 12.2 LT/in^2 in the keel (compressive and tensile respectively) which resulted in a 2.376 factor of safety. The static condition had 0.25 LT/in^2 compressive stress in the deck and 0.27 LT/in^2 in the keel yielding a safety factor of 109.

B. MIDSHIPS STRUCTURAL CONFIGURATION

Since the MTR ship's center hull is long and narrow, but also must support torsion from the side hulls and topside structure, the decision was made to frame the ship with a combination of longitudinal and transverse structure. Transverse web framing is spaced at six-foot intervals throughout most of the ship, except for the webs on either side of the watertight bulkheads beneath the Mission Bay stanchions. Those web frames are five feet apart for additional support. Stringers are longitudinal, and have spacing between 18 and 24 inches, depending upon location within the ship. Plating thicknesses are also dependent upon depth relative to the DWL. In all cases, the steel used as the basis for structural calculations is HSLA-65 (High Strength, Low-Alloy) steel, with a yield strength of 65000 psi. The calculations were conducted by a spreadsheet. Each section of the spreadsheet is described in detail below.

1. Plating Thickness

The first portions of the spreadsheet test plating thicknesses for ultimate strength, membrane stresses, shear stress, and buckling, varying plating thickness by 1/16th inch intervals and assuming a static head which accounts for a minimum of sea state five, but is never less than four feet (a four-foot static head is applied to the deck and shear strakes, despite the fact that they will likely never be submerged). Spreadsheet calculations for plate stresses were developed in accordance with chapter nine (small deflection theory, membrane stresses, and plates loaded beyond the elastic limit) of Ship Structural Design; A Rationally-Based, Computer-Aided Optimization Approach by Owen F. Hughes (Hughes, pp. 332-350). Plating is separated into five sections, covering the bottom, lower side, middle side, upper side (shear strake), and deck.

2. Longitudinal Stringers

Longitudinal stringers are also developed in sections, though only bottom, deck, and side sections were analyzed. Here, the critical tests were for proportionality of the beams analyzed and for the required strength ratio as described in chapter 11 of Hughes (Hughes, pp. 390-400). In all cases, the stringers used turned out to have the same dimensions, a T-section with a web depth of six inches and thickness of 0.5 inches, and a flange width of four inches with a thickness of 0.25 inches. To provide additional structural rigidity in the Mission Bay, the stringers corresponding to deck heights for the First and Second Decks are increased in size to correspond to the web frames in those locations.

3. Transverse Framing

Transverse frames were divided into four sections corresponding to the deck, upper and lower sides, and bottom frames. The criteria for these beams were developed from class notes and a project for the Ship Structures course (EN358) at the United States Naval Academy from 1999. The criteria compare the geometry of the analyzed beams to the geometry of the chosen longitudinal stringers for proportionality, and also check for a required section modulus based on the combined properties of the plate and stiffeners.

4. Center Vertical Keel and Center Deck Girder

The two major backbones of the framing are designed around a similar concept. The calculation, also based on class notes and project results from the Naval Academy, is based on proportionality of the beam, the geometry of the space covered (particularly the watertight bulkhead spacing), required section modulus based on other structure, and a maximum expected bending moment based on the rest of the structure.

B. STRUCTURE SUMMARY

The chosen scantlings in each case were the smallest (lightest) structures conforming to the criteria checks listed. A single-sheet summary and a midships section structural drawing were produced to describe each of these pieces within the ship. More detailed analysis of the Mission Bay and side hulls will be required in the second iteration of the design spiral, however, this first cut at structure for the midships section provides a strong baseline for the rest of the MTR ship. Figure 11 depicts the scantlings graphically, while the tables following show the calculations described above in greater detail.

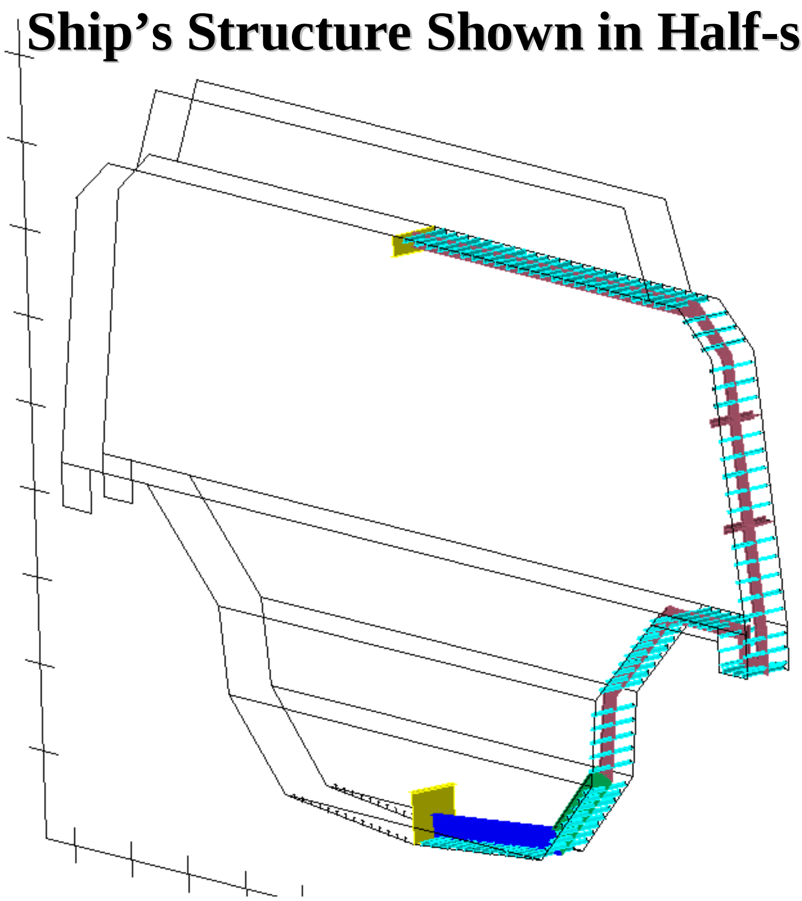
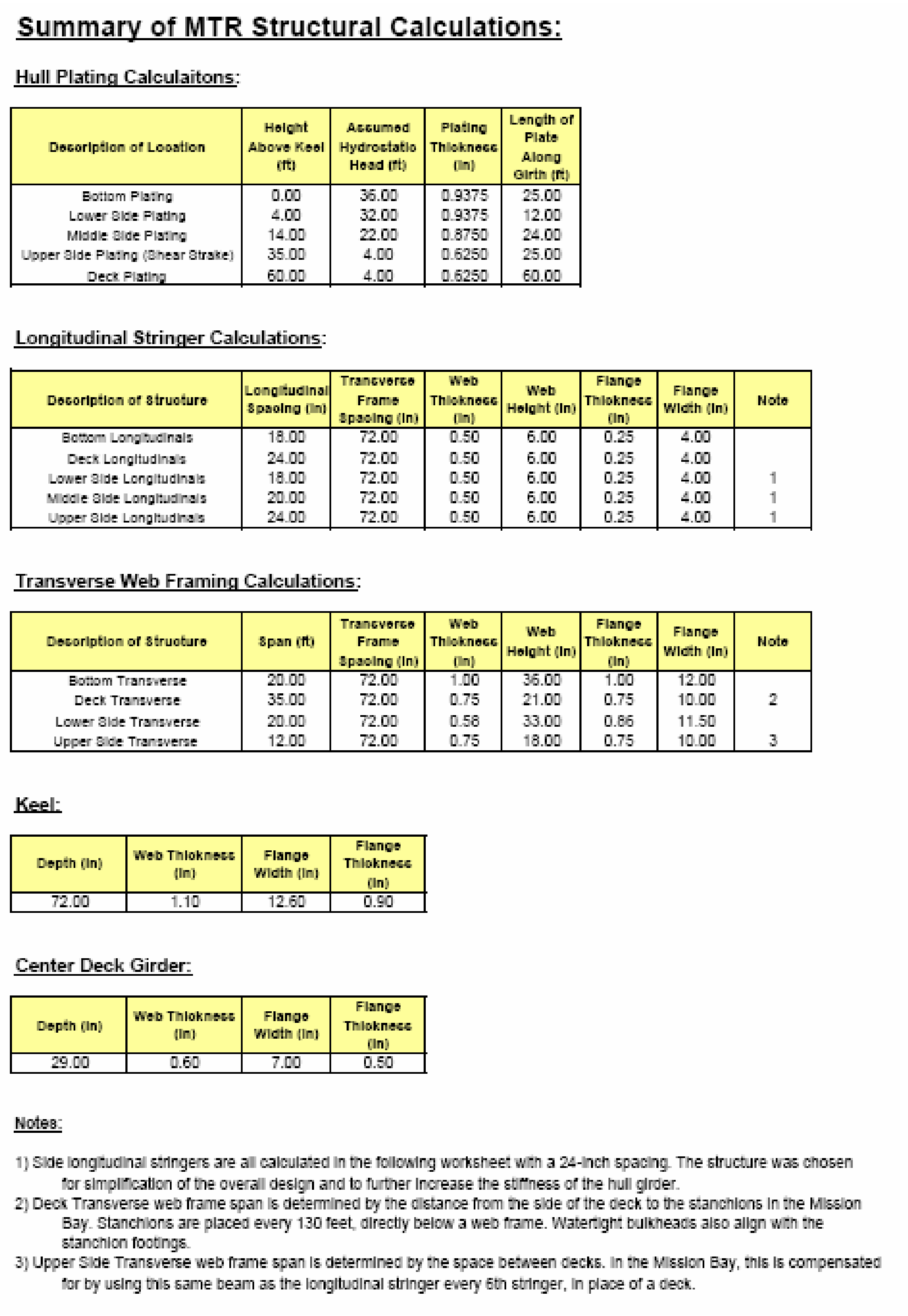


Figure 176. Half-section drawing of structural framing



Summary of MTR Structural Calculations:

Hull Plating Calculaitons:

Description of Location	Height Above Keel (ft)	Assumed Hydrostatic Head (ft)	Plating Thickness (in)	Length of Plate Along Girth (ft)
Bottom Plating	0.00	36.00	0.9375	25.00
Lower Side Plating	4.00	32.00	0.9375	12.00
Middle Side Plating	14.00	22.00	0.8750	24.00
Upper Side Plating (Shear Strake)	35.00	4.00	0.6250	25.00
Deck Plating	60.00	4.00	0.6250	60.00

Longitudinal Stringer Calculations:

Description of Structure	Longitudinal Spacing (in)	Transverse Frame Spacing (in)	Web Thickness (in)	Web Height (in)	Flange Thickness (in)	Flange Width (in)	Note
Bottom Longitudinals	18.00	72.00	0.50	6.00	0.25	4.00	
Deck Longitudinals	24.00	72.00	0.50	6.00	0.25	4.00	
Lower Side Longitudinals	18.00	72.00	0.50	6.00	0.25	4.00	1
Middle Side Longitudinals	20.00	72.00	0.50	6.00	0.25	4.00	1
Upper Side Longitudinals	24.00	72.00	0.50	6.00	0.25	4.00	1

Transverse Web Framing Calculations:

Description of Structure	Span (ft)	Transverse Frame Spacing (in)	Web Thickness (in)	Web Height (in)	Flange Thickness (in)	Flange Width (in)	Note
Bottom Transverse	20.00	72.00	1.00	36.00	1.00	12.00	
Deck Transverse	35.00	72.00	0.75	21.00	0.75	10.00	2
Lower Side Transverse	20.00	72.00	0.56	33.00	0.86	11.50	
Upper Side Transverse	12.00	72.00	0.75	18.00	0.75	10.00	3

Keel:

Depth (in)	Web Thickness (in)	Flange Width (in)	Flange Thickness (in)
72.00	1.10	12.60	0.90

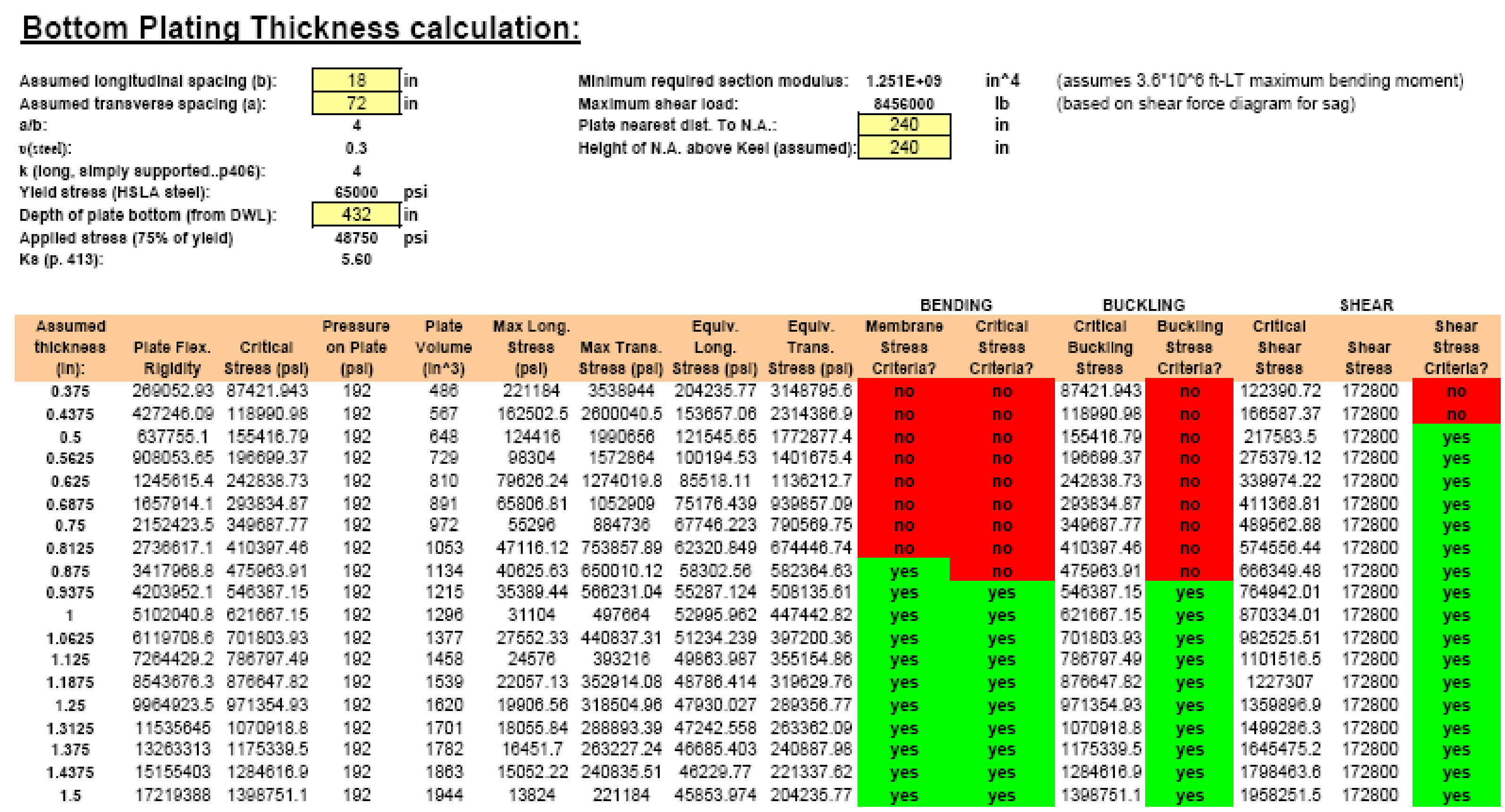
Center Deck Girder:

Depth (in)	Web Thickness (in)	Flange Width (in)	Flange Thickness (in)
29.00	0.60	7.00	0.50

Notes:

1) Side longitudinal stringers are all calculated in the following worksheet with a 24-inch spacing. The structure was chosen for simplification of the overall design and to further increase the stiffness of the hull girder.
2) Deck Transverse web frame span is determined by the distance from the side of the deck to the stanchions in the Mission Bay. Stanchions are placed every 130 feet, directly below a web frame. Watertight bulkheads also align with the stanchion footings.
3) Upper Side Transverse web frame span is determined by the space between decks. In the Mission Bay, this is compensated for by using this same beam as the longitudinal stringer every 6th stringer, in place of a deck.

Figure 177. Summary of Structural Scantlings



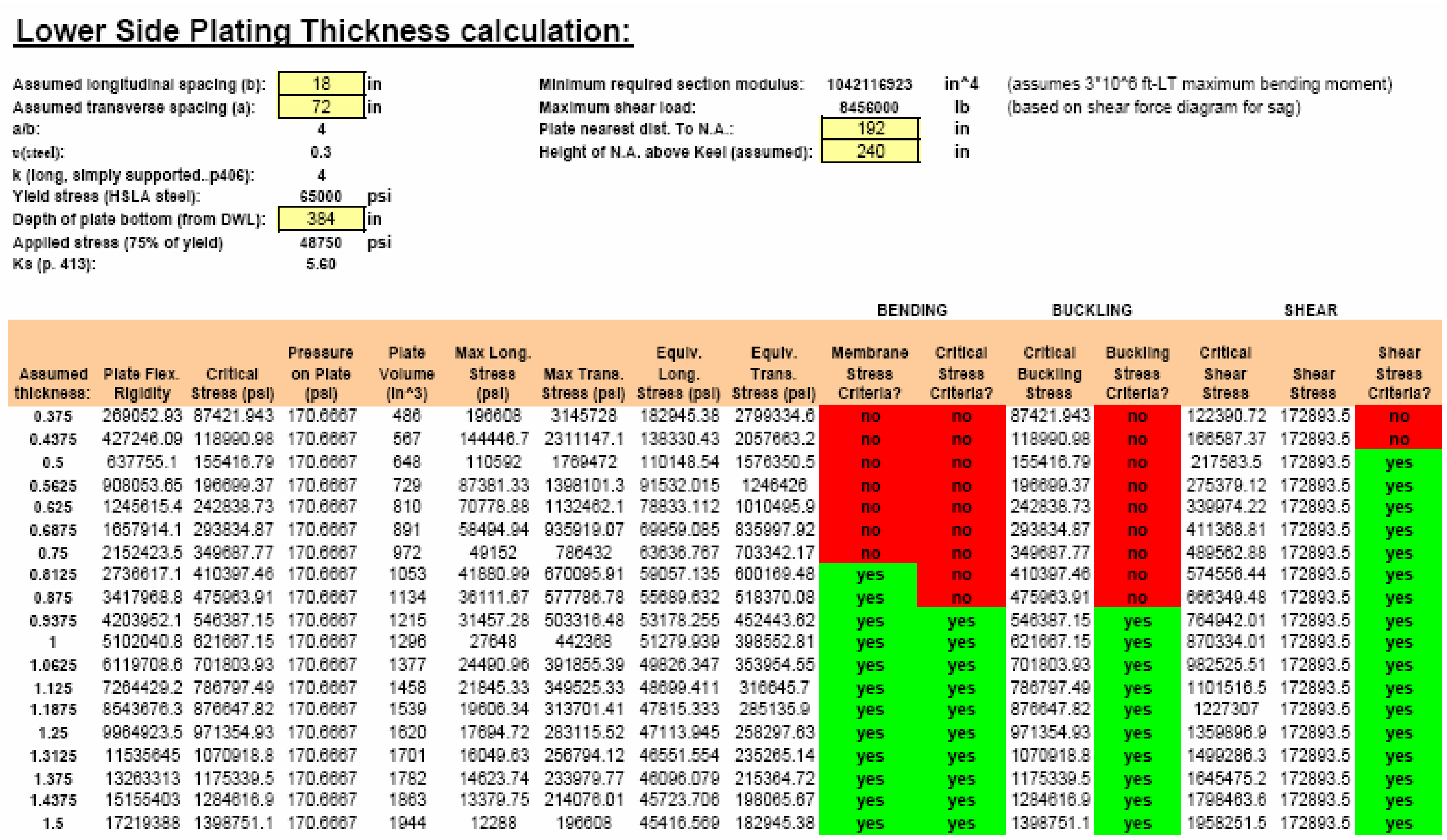
Bottom Plating Thickness calculation:

Assumed longitudinal spacing (b): 18 in
Assumed transverse spacing (a): 72 in
a/b: 4
υ(steel): 0.3
k (long, simply supported..p406): 4
Yield stress (HSLA steel): 65000 psi
Depth of plate bottom (from DWL): 432 in
Applied stress (75% of yield) 48750 psi
Ks (p. 413): 5.60

Minimum required section modulus: 1.251E+09 in^4 (assumes 3.6*10^6 ft-LT maximum bending moment)
Maximum shear load: 8456000 lb (based on shear force diagram for sag)
Plate nearest dist. To N.A.: 240 in
Height of N.A. above Keel (assumed): 240 in

									BENDING		BUCKLING			SHEAR	
Assumed thickness (in):	Plate Flex. Rigidity	Critical Stress (psi)	Pressure on Plate (psi)	Plate Volume (in^3)	Max Long. Stress (psi)	Max Trans. Stress (psi)	Equiv. Long. Stress (psi)	Equiv. Trans. Stress (psi)	Membrane Stress Criteria?	Critical Stress Criteria?	Critical Buckling Stress	Buckling Stress Criteria?	Critical Shear Stress	Shear Stress	Shear Stress Criteria?
0.375	269052.93	87421.943	192	486	221184	3538944	204235.77	3148795.6	no	no	87421.943	no	122390.72	172800	no
0.4375	427246.09	118990.98	192	567	162502.5	2600040.5	153657.06	2314386.9	no	no	118990.98	no	166587.37	172800	no
0.5	637755.1	155416.79	192	648	124416	1990656	121545.65	1772877.4	no	no	155416.79	no	217583.5	172800	yes
0.5625	908053.65	196699.37	192	729	98304	1572864	100194.53	1401675.4	no	no	196699.37	no	275379.12	172800	yes
0.625	1245615.4	242838.73	192	810	79626.24	1274019.8	85518.11	1136212.7	no	no	242838.73	no	339974.22	172800	yes
0.6875	1657914.1	293834.87	192	891	65806.81	1052909	75176.439	939857.09	no	no	293834.87	no	411368.81	172800	yes
0.75	2152423.5	349687.77	192	972	55296	884736	67746.223	790569.75	no	no	349687.77	no	489562.88	172800	yes
0.8125	2736617.1	410397.46	192	1053	47116.12	753857.89	62320.849	674446.74	no	no	410397.46	no	574556.44	172800	yes
0.875	3417968.8	475963.91	192	1134	40625.63	650010.12	58302.56	582364.63	yes	no	475963.91	no	666349.48	172800	yes
0.9375	4203952.1	546387.15	192	1215	35389.44	566231.04	55287.124	508135.61	yes	yes	546387.15	yes	764942.01	172800	yes
1	5102040.8	621667.15	192	1296	31104	497664	52995.962	447442.82	yes	yes	621667.15	yes	870334.01	172800	yes
1.0625	6119708.6	701803.93	192	1377	27552.33	440837.31	51234.239	397200.36	yes	yes	701803.93	yes	982525.51	172800	yes
1.125	7264429.2	786797.49	192	1458	24576	393216	49863.987	355154.86	yes	yes	786797.49	yes	1101516.5	172800	yes
1.1875	8543676.3	876647.82	192	1539	22057.13	352914.08	48786.414	319629.76	yes	yes	876647.82	yes	1227307	172800	yes
1.25	9964923.5	971354.93	192	1620	19906.56	318504.96	47930.027	289356.77	yes	yes	971354.93	yes	1359896.9	172800	yes
1.3125	11535645	1070918.8	192	1701	18055.84	288893.39	47242.558	263362.09	yes	yes	1070918.8	yes	1499286.3	172800	yes
1.375	13263313	1175339.5	192	1782	16451.7	263227.24	46685.403	240887.98	yes	yes	1175339.5	yes	1645475.2	172800	yes
1.4375	15155403	1284616.9	192	1863	15052.22	240835.51	46229.77	221337.62	yes	yes	1284616.9	yes	1798463.6	172800	yes
1.5	17219388	1398751.1	192	1944	13824	221184	45853.974	204235.77	yes	yes	1398751.1	yes	1958251.5	172800	yes

Figure 178. Bottom Plating Calculations



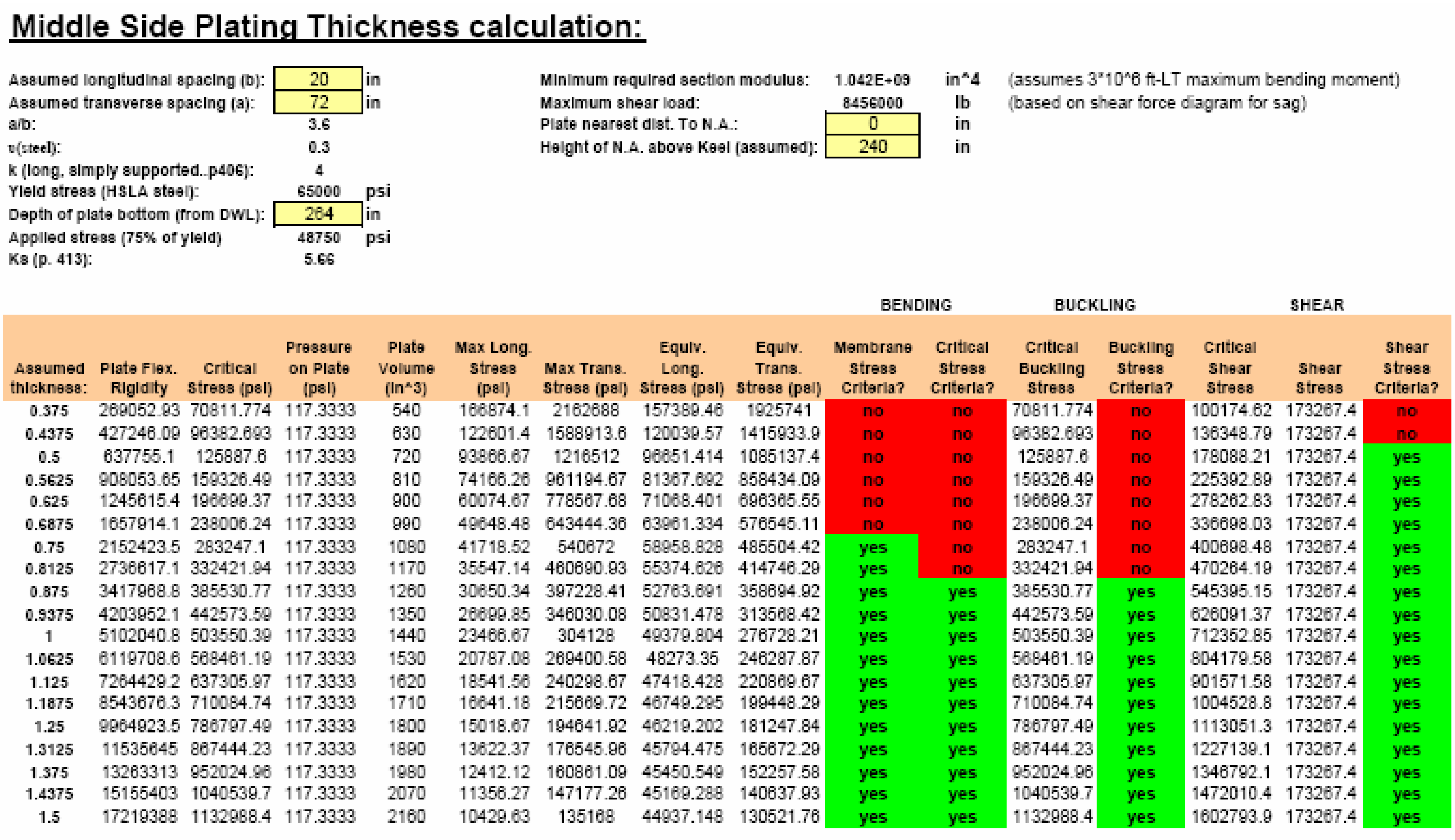
Lower Side Plating Thickness calculation:

Assumed longitudinal spacing (b): 18 in
Assumed transverse spacing (a): 72 in
a/b: 4
υ(steel): 0.3
k (long, simply supported..p406): 4
Yield stress (HSLA steel): 65000 psi
Depth of plate bottom (from DWL): 384 in
Applied stress (75% of yield) 48750 psi
Ks (p. 413): 5.60

Minimum required section modulus: 1042116923 in^4 (assumes 3*10^6 ft-LT maximum bending moment)
Maximum shear load: 8456000 lb (based on shear force diagram for sag)
Plate nearest dist. To N.A.: 192 in
Height of N.A. above Keel (assumed): 240 in

									BENDING		BUCKLING		SHEAR		
Assumed thickness:	Plate Flex. Rigidity	Critical Stress (psi)	Pressure on Plate (psi)	Plate Volume (in^3)	Max Long. Stress (psi)	Max Trans. Stress (psi)	Equiv. Long. Stress (psi)	Equiv. Trans. Stress (psi)	Membrane Stress Criteria?	Critical Stress Criteria?	Critical Buckling Stress	Buckling Stress Criteria?	Critical Shear Stress	Shear Stress	Shear Stress Criteria?
0.375	269052.93	87421.943	170.6667	486	196608	3145728	182945.38	2799334.6	no	no	87421.943	no	122390.72	172893.5	no
0.4375	427246.09	118990.98	170.6667	567	144446.7	2311147.1	138330.43	2057663.2	no	no	118990.98	no	166587.37	172893.5	no
0.5	637755.1	155416.79	170.6667	648	110592	1769472	110148.54	1576350.5	no	no	155416.79	no	217583.5	172893.5	yes
0.5625	908053.65	196699.37	170.6667	729	87381.33	1398101.3	91532.015	1246426	no	no	196699.37	no	275379.12	172893.5	yes
0.625	1245615.4	242838.73	170.6667	810	70778.88	1132462.1	78833.112	1010495.9	no	no	242838.73	no	339974.22	172893.5	yes
0.6875	1657914.1	293834.87	170.6667	891	58494.94	935919.07	69959.085	835997.92	no	no	293834.87	no	411368.81	172893.5	yes
0.75	2152423.5	349687.77	170.6667	972	49152	786432	63636.767	703342.17	no	no	349687.77	no	489562.88	172893.5	yes
0.8125	2736617.1	410397.46	170.6667	1053	41880.99	670095.91	59057.135	600169.48	yes	no	410397.46	no	574556.44	172893.5	yes
0.875	3417968.8	475963.91	170.6667	1134	36111.67	577786.78	55689.632	518370.08	yes	no	475963.91	no	666349.48	172893.5	yes
0.9375	4203952.1	546387.15	170.6667	1215	31457.28	503316.48	53178.255	452443.62	yes	yes	546387.15	yes	764942.01	172893.5	yes
1	5102040.8	621667.15	170.6667	1296	27648	442368	51279.939	398552.81	yes	yes	621667.15	yes	870334.01	172893.5	yes
1.0625	6119708.6	701803.93	170.6667	1377	24490.96	391855.39	49826.347	353954.55	yes	yes	701803.93	yes	982525.51	172893.5	yes
1.125	7264429.2	786797.49	170.6667	1458	21845.33	349525.33	48699.411	316645.7	yes	yes	786797.49	yes	1101516.5	172893.5	yes
1.1875	8543676.3	876647.82	170.6667	1539	19606.34	313701.41	47815.333	285135.9	yes	yes	876647.82	yes	1227307	172893.5	yes
1.25	9964923.5	971354.93	170.6667	1620	17694.72	283115.52	47113.945	258297.63	yes	yes	971354.93	yes	1359896.9	172893.5	yes
1.3125	11535645	1070918.8	170.6667	1701	16049.63	256794.12	46551.554	235265.14	yes	yes	1070918.8	yes	1499286.3	172893.5	yes
1.375	13263313	1175339.5	170.6667	1782	14623.74	233979.77	46096.079	215364.72	yes	yes	1175339.5	yes	1645475.2	172893.5	yes
1.4375	15155403	1284616.9	170.6667	1863	13379.75	214076.01	45723.706	198065.67	yes	yes	1284616.9	yes	1798463.6	172893.5	yes
1.5	17219388	1398751.1	170.6667	1944	12288	196608	45416.569	182945.38	yes	yes	1398751.1	yes	1958251.5	172893.5	yes

Figure 179. Lower Side Plating Calculations



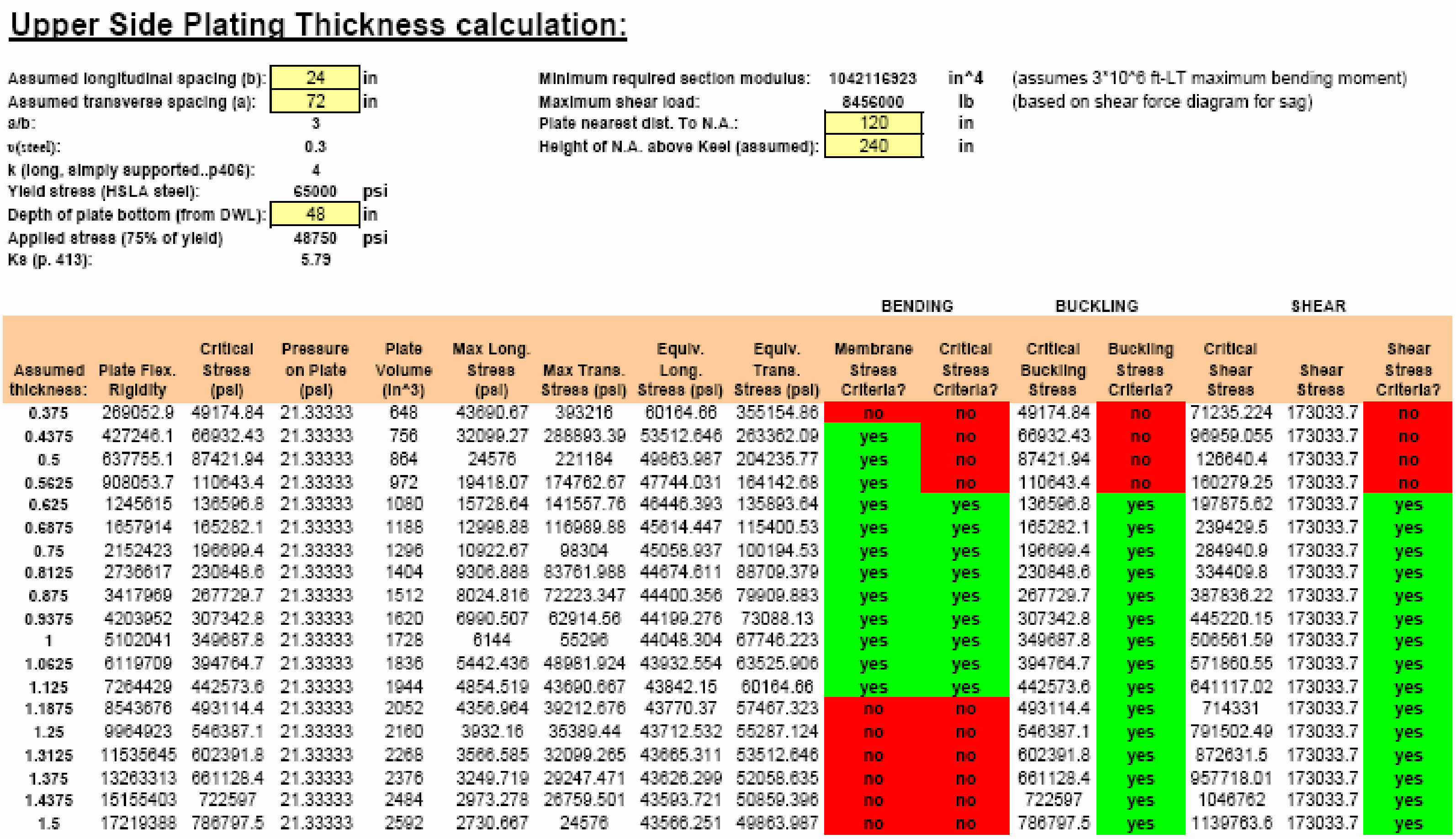
Middle Side Plating Thickness calculation:

Assumed longitudinal spacing (b):	20	in
Assumed transverse spacing (a):	72	in
a/b:	3.6	
υ(steel):	0.3	
k (long, simply supported..p406):	4	
Yield stress (HSLA steel):	65000	psi
Depth of plate bottom (from DWL):	264	in
Applied stress (75% of yield)	48750	psi
Ks (p. 413):	5.66	

Minimum required section modulus:	1.042E+09	in^4	(assumes 3*10^6 ft-LT maximum bending moment)
Maximum shear load:	8456000	lb	(based on shear force diagram for sag)
Plate nearest dist. To N.A.:	0	in	
Height of N.A. above Keel (assumed):	240	in	

									BENDING		BUCKLING		SHEAR		
Assumed thickness:	Plate Flex. Rigidity	Critical Stress (psi)	Pressure on Plate (psi)	Plate Volume (in^3)	Max Long. Stress (psi)	Max Trans. Stress (psi)	Equiv. Long. Stress (psi)	Equiv. Trans. Stress (psi)	Membrane Stress Criteria?	Critical Stress Criteria?	Critical Buckling Stress	Buckling Stress Criteria?	Critical Shear Stress	Shear Stress	Shear Stress Criteria?
0.375	269052.93	70811.774	117.3333	540	166874.1	2162688	157389.46	1925741	no	no	70811.774	no	100174.62	173267.4	no
0.4375	427246.09	96382.693	117.3333	630	122601.4	1588913.6	120039.57	1415933.9	no	no	96382.693	no	136348.79	173267.4	no
0.5	637755.1	125887.6	117.3333	720	93866.67	1216512	96651.414	1085137.4	no	no	125887.6	no	178088.21	173267.4	yes
0.5625	908053.65	159326.49	117.3333	810	74166.26	961194.67	81367.692	858434.09	no	no	159326.49	no	225392.89	173267.4	yes
0.625	1245615.4	196699.37	117.3333	900	60074.67	778567.68	71068.401	696365.55	no	no	196699.37	no	278262.83	173267.4	yes
0.6875	1657914.1	238006.24	117.3333	990	49648.48	643444.36	63961.334	576545.11	no	no	238006.24	no	336698.03	173267.4	yes
0.75	2152423.5	283247.1	117.3333	1080	41718.52	540672	58958.828	485504.42	yes	no	283247.1	no	400698.48	173267.4	yes
0.8125	2736617.1	332421.94	117.3333	1170	35547.14	460690.93	55374.626	414746.29	yes	no	332421.94	no	470264.19	173267.4	yes
0.875	3417968.8	385530.77	117.3333	1260	30650.34	397228.41	52763.691	358694.92	yes	yes	385530.77	yes	545395.15	173267.4	yes
0.9375	4203952.1	442573.59	117.3333	1350	26699.85	346030.08	50831.478	313568.42	yes	yes	442573.59	yes	626091.37	173267.4	yes
1	5102040.8	503550.39	117.3333	1440	23466.67	304128	49379.804	276728.21	yes	yes	503550.39	yes	712352.85	173267.4	yes
1.0625	6119708.6	568461.19	117.3333	1530	20787.08	269400.58	48273.35	246287.87	yes	yes	568461.19	yes	804179.58	173267.4	yes
1.125	7264429.2	637305.97	117.3333	1620	18541.56	240298.67	47418.428	220869.67	yes	yes	637305.97	yes	901571.58	173267.4	yes
1.1875	8543676.3	710084.74	117.3333	1710	16641.18	215669.72	46749.295	199448.29	yes	yes	710084.74	yes	1004528.8	173267.4	yes
1.25	9964923.5	786797.49	117.3333	1800	15018.67	194641.92	46219.202	181247.84	yes	yes	786797.49	yes	1113051.3	173267.4	yes
1.3125	11535645	867444.23	117.3333	1890	13622.37	176545.96	45794.475	165672.29	yes	yes	867444.23	yes	1227139.1	173267.4	yes
1.375	13263313	952024.96	117.3333	1980	12412.12	160861.09	45450.549	152257.58	yes	yes	952024.96	yes	1346792.1	173267.4	yes
1.4375	15155403	1040539.7	117.3333	2070	11356.27	147177.26	45169.288	140637.93	yes	yes	1040539.7	yes	1472010.4	173267.4	yes
1.5	17219388	1132988.4	117.3333	2160	10429.63	135168	44937.148	130521.76	yes	yes	1132988.4	yes	1602793.9	173267.4	yes

Figure 180. Middle Side Plating Calculations



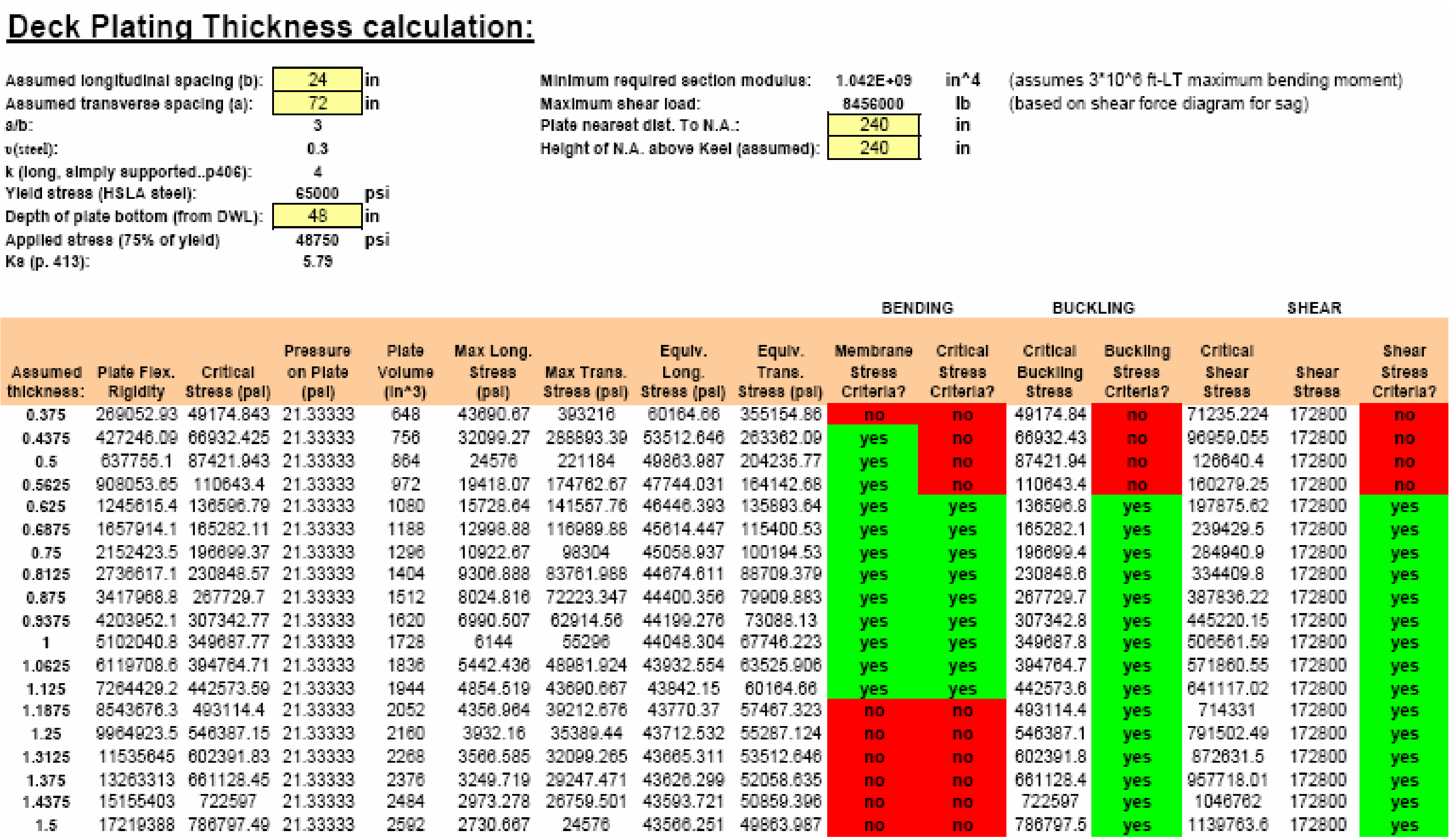
Upper Side Plating Thickness calculation:

Assumed longitudinal spacing (b): 24 in
Assumed transverse spacing (a): 72 in
a/b: 3
ν(steel): 0.3
k (long, simply supported..p406): 4
Yield stress (HSLA steel): 65000 psi
Depth of plate bottom (from DWL): 48 in
Applied stress (75% of yield) 48750 psi
Ks (p. 413): 5.79

Minimum required section modulus: 1042116923 in^4 (assumes 3*10^6 ft-LT maximum bending moment)
Maximum shear load: 8456000 lb (based on shear force diagram for sag)
Plate nearest dist. To N.A.: 120 in
Height of N.A. above Keel (assumed): 240 in

									BENDING		BUCKLING		SHEAR		
Assumed thickness:	Plate Flex. Rigidity	Critical Stress (psi)	Pressure on Plate (psi)	Plate Volume (in^3)	Max Long. Stress (psi)	Max Trans. Stress (psi)	Equiv. Long. Stress (psi)	Equiv. Trans. Stress (psi)	Membrane Stress Criteria?	Critical Stress Criteria?	Critical Buckling Stress	Buckling Stress Criteria?	Critical Shear Stress	Shear Stress	Shear Stress Criteria?
0.375	269052.9	49174.84	21.33333	648	43690.67	393216	60164.66	355154.86	no	no	49174.84	no	71235.224	173033.7	no
0.4375	427246.1	66932.43	21.33333	756	32099.27	288893.39	53512.646	263362.09	yes	no	66932.43	no	96959.055	173033.7	no
0.5	637755.1	87421.94	21.33333	864	24576	221184	49863.987	204235.77	yes	no	87421.94	no	126640.4	173033.7	no
0.5625	908053.7	110643.4	21.33333	972	19418.07	174762.67	47744.031	164142.68	yes	no	110643.4	no	160279.25	173033.7	no
0.625	1245615	136596.8	21.33333	1080	15728.64	141557.76	46446.393	135893.64	yes	yes	136596.8	yes	197875.62	173033.7	yes
0.6875	1657914	165282.1	21.33333	1188	12998.88	116989.88	45614.447	115400.53	yes	yes	165282.1	yes	239429.5	173033.7	yes
0.75	2152423	196699.4	21.33333	1296	10922.67	98304	45058.937	100194.53	yes	yes	196699.4	yes	284940.9	173033.7	yes
0.8125	2736617	230848.6	21.33333	1404	9306.888	83761.988	44674.611	88709.379	yes	yes	230848.6	yes	334409.8	173033.7	yes
0.875	3417969	267729.7	21.33333	1512	8024.816	72223.347	44400.356	79909.883	yes	yes	267729.7	yes	387836.22	173033.7	yes
0.9375	4203952	307342.8	21.33333	1620	6990.507	62914.56	44199.276	73088.13	yes	yes	307342.8	yes	445220.15	173033.7	yes
1	5102041	349687.8	21.33333	1728	6144	55296	44048.304	67746.223	yes	yes	349687.8	yes	506561.59	173033.7	yes
1.0625	6119709	394764.7	21.33333	1836	5442.436	48981.924	43932.554	63525.906	yes	yes	394764.7	yes	571860.55	173033.7	yes
1.125	7264429	442573.6	21.33333	1944	4854.519	43690.667	43842.15	60164.66	yes	yes	442573.6	yes	641117.02	173033.7	yes
1.1875	8543676	493114.4	21.33333	2052	4356.964	39212.676	43770.37	57467.323	no	no	493114.4	yes	714331	173033.7	yes
1.25	9964923	546387.1	21.33333	2160	3932.16	35389.44	43712.532	55287.124	no	no	546387.1	yes	791502.49	173033.7	yes
1.3125	11535645	602391.8	21.33333	2268	3566.585	32099.265	43665.311	53512.646	no	no	602391.8	yes	872631.5	173033.7	yes
1.375	13263313	661128.4	21.33333	2376	3249.719	29247.471	43626.299	52058.635	no	no	661128.4	yes	957718.01	173033.7	yes
1.4375	15155403	722597	21.33333	2484	2973.278	26759.501	43593.721	50859.396	no	no	722597	yes	1046762	173033.7	yes
1.5	17219388	786797.5	21.33333	2592	2730.667	24576	43566.251	49863.987	no	no	786797.5	yes	1139763.6	173033.7	yes

Figure 181. Upper Side Plating Calculations



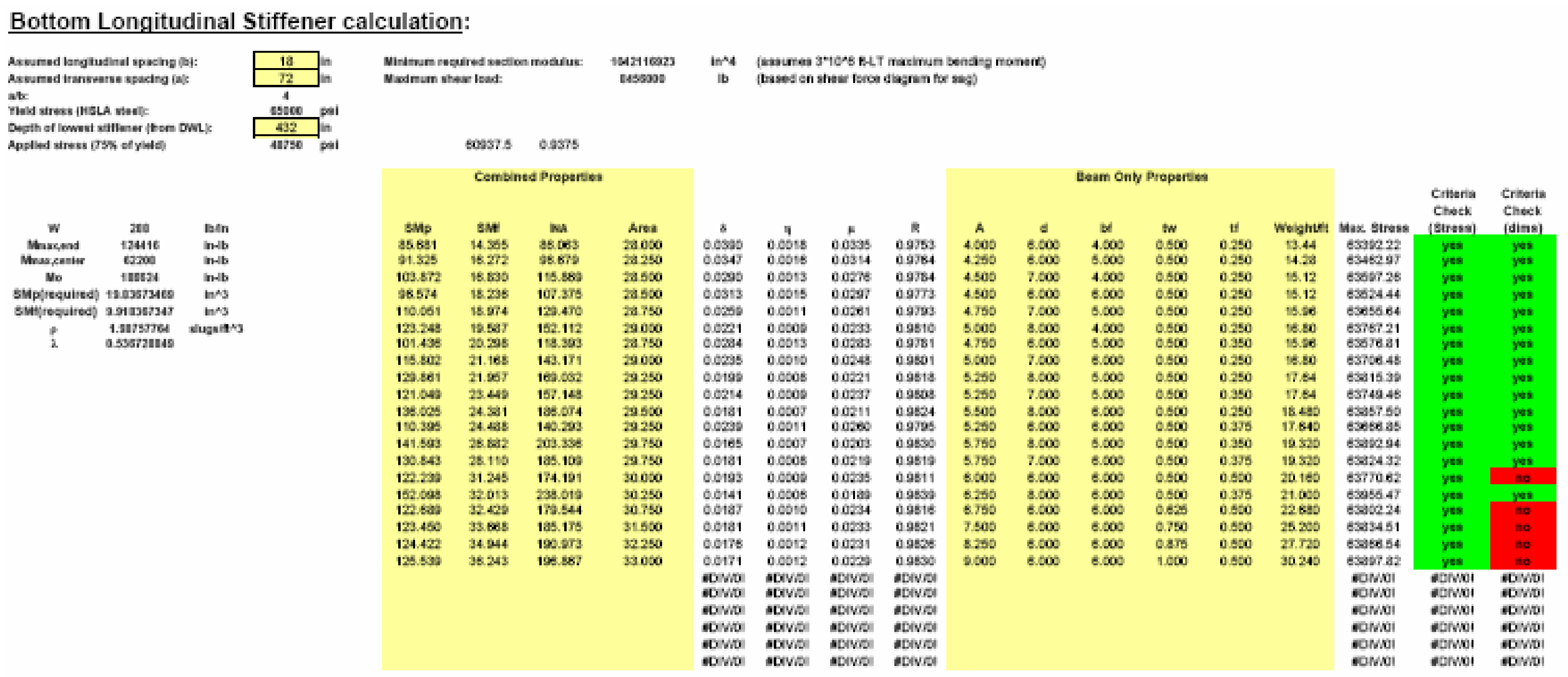
Deck Plating Thickness calculation:

Assumed longitudinal spacing (b): 24 in
Assumed transverse spacing (a): 72 in
a/b: 3
ν(steel): 0.3
k (long, simply supported..p406): 4
Yield stress (HSLA steel): 65000 psi
Depth of plate bottom (from DWL): 48 in
Applied stress (75% of yield) 48750 psi
Ks (p. 413): 5.79

Minimum required section modulus: 1.042E+09 in^4 (assumes 3*10^6 ft-LT maximum bending moment)
Maximum shear load: 8456000 lb (based on shear force diagram for sag)
Plate nearest dist. To N.A.: 240 in
Height of N.A. above Keel (assumed): 240 in

									BENDING		BUCKLING		SHEAR		
Assumed thickness:	Plate Flex. Rigidity	Critical Stress (psi)	Pressure on Plate (psi)	Plate Volume (in^3)	Max Long. Stress (psi)	Max Trans. Stress (psi)	Equiv. Long. Stress (psi)	Equiv. Trans. Stress (psi)	Membrane Stress Criteria?	Critical Stress Criteria?	Critical Buckling Stress	Buckling Stress Criteria?	Critical Shear Stress	Shear Stress	Shear Stress Criteria?
0.375	269052.93	49174.843	21.33333	648	43690.67	393216	60164.66	355154.86	no	no	49174.84	no	71235.224	172800	no
0.4375	427246.09	66932.425	21.33333	756	32099.27	288893.39	53512.646	263362.09	yes	no	66932.43	no	96959.055	172800	no
0.5	637755.1	87421.943	21.33333	864	24576	221184	49863.987	204235.77	yes	no	87421.94	no	126640.4	172800	no
0.5625	908053.65	110643.4	21.33333	972	19418.07	174762.67	47744.031	164142.68	yes	no	110643.4	no	160279.25	172800	no
0.625	1245615.4	136596.79	21.33333	1080	15728.64	141557.76	46446.393	135893.64	yes	yes	136596.8	yes	197875.62	172800	yes
0.6875	1657914.1	165282.11	21.33333	1188	12998.88	116989.88	45614.447	115400.53	yes	yes	165282.1	yes	239429.5	172800	yes
0.75	2152423.5	196699.37	21.33333	1296	10922.67	98304	45058.937	100194.53	yes	yes	196699.4	yes	284940.9	172800	yes
0.8125	2736617.1	230848.57	21.33333	1404	9306.888	83761.988	44674.611	88709.379	yes	yes	230848.6	yes	334409.8	172800	yes
0.875	3417968.8	267729.7	21.33333	1512	8024.816	72223.347	44400.356	79909.883	yes	yes	267729.7	yes	387836.22	172800	yes
0.9375	4203952.1	307342.77	21.33333	1620	6990.507	62914.56	44199.276	73088.13	yes	yes	307342.8	yes	445220.15	172800	yes
1	5102040.8	349687.77	21.33333	1728	6144	55296	44048.304	67746.223	yes	yes	349687.8	yes	506561.59	172800	yes
1.0625	6119708.6	394764.71	21.33333	1836	5442.436	48981.924	43932.554	63525.906	yes	yes	394764.7	yes	571860.55	172800	yes
1.125	7264429.2	442573.59	21.33333	1944	4854.519	43690.667	43842.15	60164.66	yes	yes	442573.6	yes	641117.02	172800	yes
1.1875	8543676.3	493114.4	21.33333	2052	4356.964	39212.676	43770.37	57467.323	no	no	493114.4	yes	714331	172800	yes
1.25	9964923.5	546387.15	21.33333	2160	3932.16	35389.44	43712.532	55287.124	no	no	546387.1	yes	791502.49	172800	yes
1.3125	11535645	602391.83	21.33333	2268	3566.585	32099.265	43665.311	53512.646	no	no	602391.8	yes	872631.5	172800	yes
1.375	13263313	661128.45	21.33333	2376	3249.719	29247.471	43626.299	52058.635	no	no	661128.4	yes	957718.01	172800	yes
1.4375	15155403	722597	21.33333	2484	2973.278	26759.501	43593.721	50859.396	no	no	722597	yes	1046762	172800	yes
1.5	17219388	786797.49	21.33333	2592	2730.667	24576	43566.251	49863.987	no	no	786797.5	yes	1139763.6	172800	yes

Figure 182. Deck Plating Calculations



Bottom Longitudinal Stiffener calculation:

Assumed longitudinal spacing (b):	18	in
Assumed transverse spacing (a):	72	in
a/b:	4	
Yield stress (HSLA steel):	65000	psi
Depth of lowest stiffener (from DWL):	432	in
Applied stress (75% of yield)	48750	psi

Minimum required section modulus:	1042116923	in^4	(assumes 3*10^8 ft-LT maximum bending moment)
Maximum shear load:	8456000	lb	(based on shear force diagram for sag)

60937.5 0.9375

W	288	lb/in
Mmax,end	124416	in-lb
Mmax,center	62208	in-lb
Mo	186624	in-lb
SMp(required)	19.03673469	in^3
SMf(required)	9.918367347	in^3
ρ	1.98757764	slugs/ft^3
λ	0.536728849	

Combined Properties								Beam Only Properties							Criteria Check (Stress)	Criteria Check (dims)
SMp	SMf	INA	Area	δ	η	μ	R	A	d	bf	tw	tf	Weight/ft	Max. Stress		
85.681	14.355	85.063	28.000	0.0390	0.0018	0.0335	0.9753	4.000	6.000	4.000	0.500	0.250	13.44	63392.22	yes	yes
91.325	16.272	98.679	28.250	0.0347	0.0016	0.0314	0.9764	4.250	6.000	5.000	0.500	0.250	14.28	63462.97	yes	yes
103.872	16.830	115.889	28.500	0.0290	0.0013	0.0276	0.9784	4.500	7.000	4.000	0.500	0.250	15.12	63597.26	yes	yes
98.574	18.236	107.375	28.500	0.0313	0.0015	0.0297	0.9773	4.500	6.000	6.000	0.500	0.250	15.12	63524.44	yes	yes
110.051	18.974	129.470	28.750	0.0259	0.0011	0.0261	0.9793	4.750	7.000	5.000	0.500	0.250	15.96	63655.64	yes	yes
123.248	19.587	152.112	29.000	0.0221	0.0009	0.0233	0.9810	5.000	8.000	4.000	0.500	0.250	16.80	63767.21	yes	yes
101.436	20.298	118.393	28.750	0.0284	0.0013	0.0283	0.9781	4.750	6.000	5.000	0.500	0.350	15.96	63576.81	yes	yes
115.802	21.168	143.171	29.000	0.0235	0.0010	0.0248	0.9801	5.000	7.000	6.000	0.500	0.250	16.80	63706.48	yes	yes
129.861	21.957	169.032	29.250	0.0199	0.0008	0.0221	0.9818	5.250	8.000	5.000	0.500	0.250	17.64	63815.39	yes	yes
121.049	23.449	157.148	29.250	0.0214	0.0009	0.0237	0.9808	5.250	7.000	5.000	0.500	0.350	17.64	63749.46	yes	yes
136.025	24.381	186.074	29.500	0.0181	0.0007	0.0211	0.9824	5.500	8.000	6.000	0.500	0.250	18.480	63857.50	yes	yes
110.395	24.488	140.293	29.250	0.0239	0.0011	0.0260	0.9795	5.250	6.000	6.000	0.500	0.375	17.640	63666.85	yes	yes
141.593	26.882	203.336	29.750	0.0165	0.0007	0.0203	0.9830	5.750	8.000	5.000	0.500	0.350	19.320	63892.94	yes	yes
130.843	28.110	185.109	29.750	0.0181	0.0008	0.0219	0.9819	5.750	7.000	6.000	0.500	0.375	19.320	63824.32	yes	yes
122.239	31.245	174.191	30.000	0.0193	0.0009	0.0235	0.9811	6.000	6.000	6.000	0.500	0.500	20.160	63770.62	yes	no
152.098	32.013	238.019	30.250	0.0141	0.0005	0.0189	0.9839	6.250	8.000	6.000	0.500	0.375	21.000	63955.47	yes	yes
122.689	32.429	179.544	30.750	0.0187	0.0010	0.0234	0.9816	6.750	6.000	6.000	0.625	0.500	22.680	63802.24	yes	no
123.450	33.868	185.175	31.500	0.0181	0.0011	0.0233	0.9821	7.500	6.000	6.000	0.750	0.500	25.200	63834.51	yes	no
124.422	34.944	190.973	32.250	0.0176	0.0012	0.0231	0.9826	8.250	6.000	6.000	0.875	0.500	27.720	63866.54	yes	no
125.539	36.243	196.887	33.000	0.0171	0.0012	0.0229	0.9830	9.000	6.000	6.000	1.000	0.500	30.240	63897.82	yes	no
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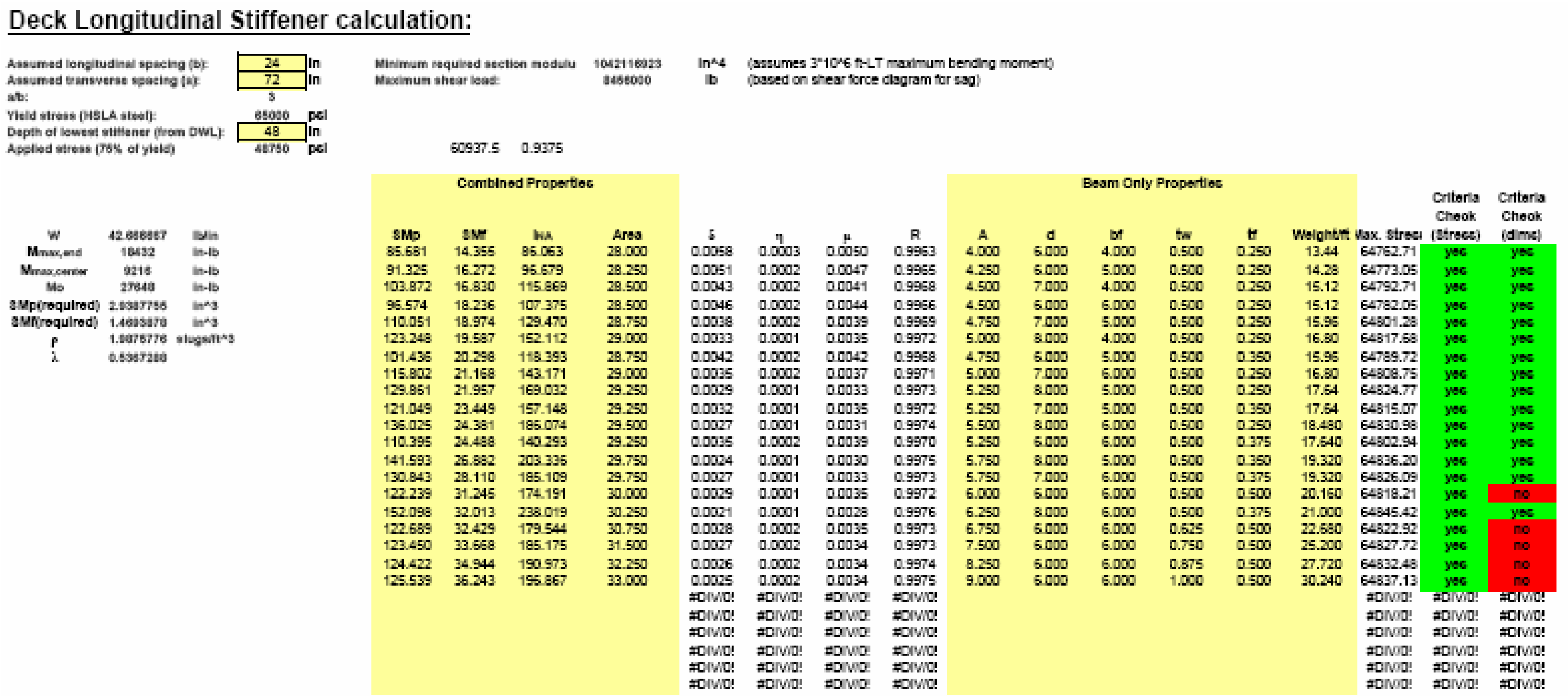
Figure 183. Bottom Longitudinal Calculations



Deck Longitudinal Stiffener calculation:

Assumed longitudinal spacing (b):	24	in	Minimum required section modulu	1042116923	in^4	(assumes 3*10^6 ft-LT maximum bending moment)
Assumed transverse spacing (a):	72	in	Maximum shear load:	8466000	lb	(based on shear force diagram for sag)
a/b:	3					
Yield stress (HSLA steel):	65000	psi				
Depth of lowest stiffener (from DWL):	48	in				
Applied stress (75% of yield)	48750	psi	60937.5	0.9375		

W	42.666667	lb/in
$M_{max,end}$	18432	in-lb
$M_{max,center}$	9216	in-lb
Mo	27648	in-lb
SMp(required)	2.0387756	in^3
SMf(required)	1.4693878	in^3
ρ	1.9876776	slugs/ft^3
λ	0.5367280	

Combined Properties								Beam Only Properties							Criteria Check	Criteria Check
SMp	SMf	I_{NA}	Area	δ	η	μ	R	A	d	bf	tw	tf	Weight/ft	Max. Stres	(Stress)	(dims)
85.681	14.355	86.063	28.000	0.0058	0.0003	0.0050	0.9963	4.000	6.000	4.000	0.500	0.250	13.44	64762.71	yes	yes
91.325	16.272	96.679	28.250	0.0051	0.0002	0.0047	0.9965	4.250	6.000	5.000	0.500	0.250	14.28	64773.05	yes	yes
103.872	16.830	115.869	28.500	0.0043	0.0002	0.0041	0.9968	4.500	7.000	4.000	0.500	0.250	15.12	64792.71	yes	yes
96.574	18.236	107.375	28.500	0.0046	0.0002	0.0044	0.9966	4.500	6.000	6.000	0.500	0.250	15.12	64782.05	yes	yes
110.051	18.974	129.470	28.750	0.0038	0.0002	0.0039	0.9969	4.750	7.000	5.000	0.500	0.250	15.96	64801.28	yes	yes
123.248	19.587	152.112	29.000	0.0033	0.0001	0.0035	0.9972	5.000	8.000	4.000	0.500	0.250	16.80	64817.68	yes	yes
101.436	20.298	118.393	28.750	0.0042	0.0002	0.0042	0.9968	4.750	6.000	5.000	0.500	0.350	15.96	64789.72	yes	yes
115.802	21.168	143.171	29.000	0.0035	0.0002	0.0037	0.9971	5.000	7.000	6.000	0.500	0.250	16.80	64808.75	yes	yes
129.861	21.957	169.032	29.250	0.0029	0.0001	0.0033	0.9973	5.250	8.000	5.000	0.500	0.250	17.64	64824.77	yes	yes
121.049	23.449	157.148	29.250	0.0032	0.0001	0.0035	0.9972	5.250	7.000	5.000	0.500	0.350	17.64	64815.07	yes	yes
136.025	24.381	186.074	29.500	0.0027	0.0001	0.0031	0.9974	5.500	8.000	6.000	0.500	0.250	18.480	64830.98	yes	yes
110.395	24.488	140.293	29.250	0.0035	0.0002	0.0039	0.9970	5.250	6.000	6.000	0.500	0.375	17.640	64802.94	yes	yes
141.593	26.882	203.336	29.750	0.0024	0.0001	0.0030	0.9975	5.750	8.000	5.000	0.500	0.350	19.320	64836.20	yes	yes
130.843	28.110	185.109	29.750	0.0027	0.0001	0.0033	0.9973	5.750	7.000	6.000	0.500	0.375	19.320	64826.09	yes	yes
122.239	31.245	174.191	30.000	0.0029	0.0001	0.0035	0.9972	6.000	6.000	6.000	0.500	0.500	20.160	64818.21	yes	no
152.098	32.013	238.019	30.250	0.0021	0.0001	0.0028	0.9976	6.250	8.000	6.000	0.500	0.375	21.000	64845.42	yes	yes
122.689	32.429	179.544	30.750	0.0028	0.0002	0.0035	0.9973	6.750	6.000	6.000	0.625	0.500	22.680	64822.92	yes	no
123.450	33.668	185.175	31.500	0.0027	0.0002	0.0034	0.9973	7.500	6.000	6.000	0.750	0.500	25.200	64827.72	yes	no
124.422	34.944	190.973	32.250	0.0026	0.0002	0.0034	0.9974	8.250	6.000	6.000	0.875	0.500	27.720	64832.48	yes	no
125.539	36.243	195.867	33.000	0.0025	0.0002	0.0034	0.9975	9.000	6.000	6.000	1.000	0.500	30.240	64837.13	yes	no
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				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!
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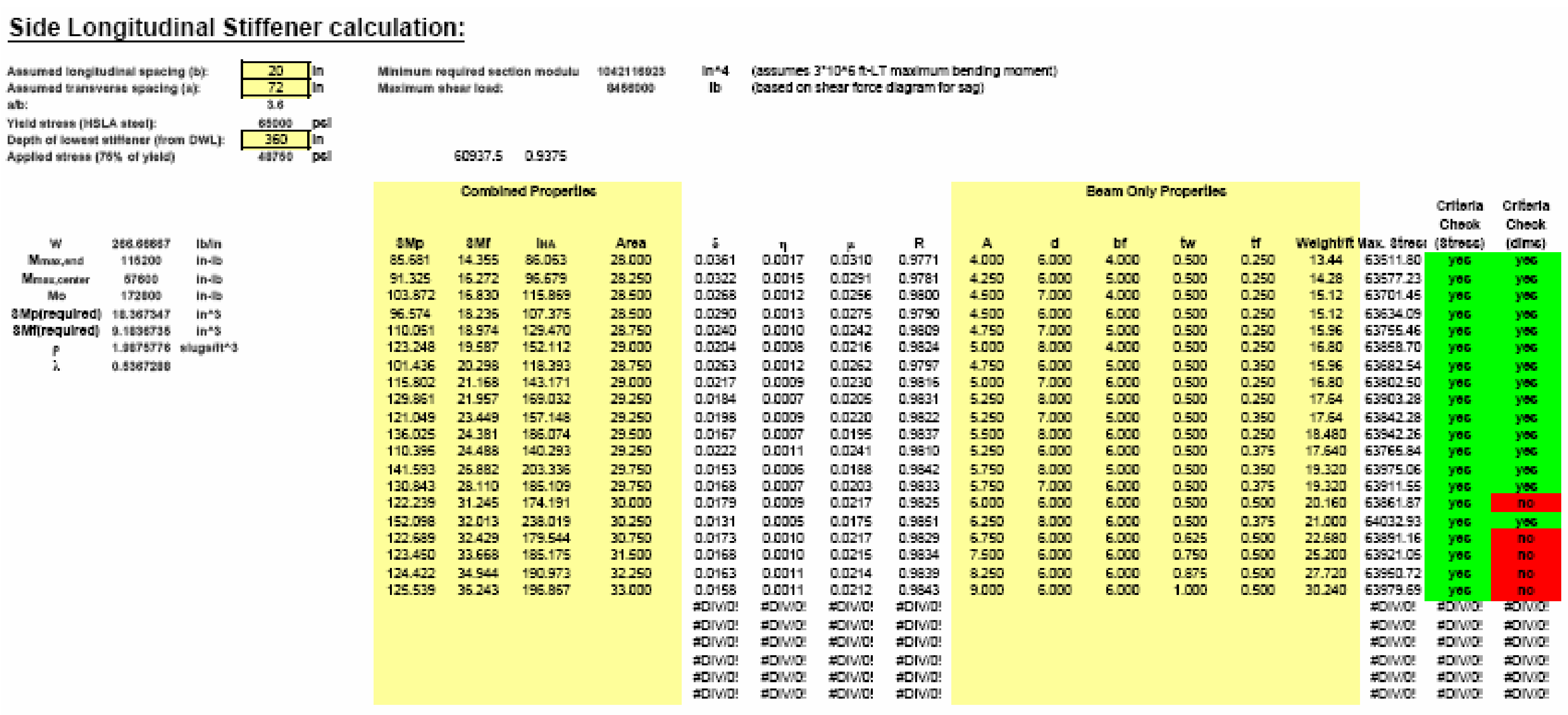
Figure 184. Deck Longitudinal Calculations



Side Longitudinal Stiffener calculation:

Assumed longitudinal spacing (b):	20	in
Assumed transverse spacing (a):	72	in
a/b:	3.6	
Yield stress (HSLA steel):	65000	psi
Depth of lowest stiffener (from DWL):	360	in
Applied stress (75% of yield)	48750	psi

Minimum required section modulu	1042116923	in^4	(assumes 3*10^6 ft-LT maximum bending moment)
Maximum shear load:	8456000	lb	(based on shear force diagram for sag)

60937.5 0.9375

W	266.66667	lb/in
$M_{max,end}$	115200	in-lb
$M_{max,center}$	57600	in-lb
Mo	172800	in-lb
SMp(required)	18.367347	in^3
SMf(required)	9.1836735	in^3
ρ	1.9875776	slugs/ft^3
λ	0.5367288	

Combined Properties								Beam Only Properties							Criteria Check	Criteria Check
SMp	SMf	I_{NA}	Area	δ	η	μ	R	A	d	bf	tw	tf	Weight/ft	Max. Stress	(Stress)	(dims)
85.681	14.355	86.063	28.000	0.0361	0.0017	0.0310	0.9771	4.000	6.000	4.000	0.500	0.250	13.44	63511.80	yes	yes
91.325	16.272	96.679	28.250	0.0322	0.0015	0.0291	0.9781	4.250	6.000	5.000	0.500	0.250	14.28	63577.23	yes	yes
103.872	16.830	115.869	28.500	0.0268	0.0012	0.0256	0.9800	4.500	7.000	4.000	0.500	0.250	15.12	63701.45	yes	yes
96.574	18.236	107.375	28.500	0.0290	0.0013	0.0275	0.9790	4.500	6.000	6.000	0.500	0.250	15.12	63634.09	yes	yes
110.051	18.974	129.470	28.750	0.0240	0.0010	0.0242	0.9809	4.750	7.000	5.000	0.500	0.250	15.96	63755.46	yes	yes
123.248	19.587	152.112	29.000	0.0204	0.0008	0.0216	0.9824	5.000	8.000	4.000	0.500	0.250	16.80	63858.70	yes	yes
101.436	20.298	118.393	28.750	0.0263	0.0012	0.0262	0.9797	4.750	6.000	5.000	0.500	0.350	15.96	63682.54	yes	yes
115.802	21.168	143.171	29.000	0.0217	0.0009	0.0230	0.9816	5.000	7.000	6.000	0.500	0.250	16.80	63802.50	yes	yes
129.861	21.957	169.032	29.250	0.0184	0.0007	0.0205	0.9831	5.250	8.000	5.000	0.500	0.250	17.64	63903.28	yes	yes
121.049	23.449	157.148	29.250	0.0198	0.0009	0.0220	0.9822	5.250	7.000	5.000	0.500	0.350	17.64	63842.28	yes	yes
136.025	24.381	186.074	29.500	0.0167	0.0007	0.0195	0.9837	5.500	8.000	6.000	0.500	0.250	18.480	63942.26	yes	yes
110.396	24.488	140.293	29.250	0.0222	0.0011	0.0241	0.9810	5.250	6.000	6.000	0.500	0.375	17.640	63765.84	yes	yes
141.593	26.882	203.336	29.750	0.0153	0.0006	0.0188	0.9842	5.750	8.000	5.000	0.500	0.350	19.320	63975.06	yes	yes
130.843	28.110	185.109	29.750	0.0168	0.0007	0.0203	0.9833	5.750	7.000	6.000	0.500	0.375	19.320	63911.55	yes	yes
122.239	31.245	174.191	30.000	0.0179	0.0009	0.0217	0.9825	6.000	6.000	6.000	0.500	0.500	20.160	63861.87	yes	no
152.098	32.013	238.019	30.250	0.0131	0.0005	0.0175	0.9851	6.250	8.000	6.000	0.500	0.375	21.000	64032.93	yes	yes
122.689	32.429	179.544	30.750	0.0173	0.0010	0.0217	0.9829	6.750	6.000	6.000	0.625	0.500	22.680	63891.16	yes	no
123.450	33.668	185.175	31.500	0.0168	0.0010	0.0215	0.9834	7.500	6.000	6.000	0.750	0.500	25.200	63921.05	yes	no
124.422	34.944	190.973	32.250	0.0163	0.0011	0.0214	0.9839	8.250	6.000	6.000	0.875	0.500	27.720	63950.72	yes	no
125.539	36.243	196.867	33.000	0.0158	0.0011	0.0212	0.9843	9.000	6.000	6.000	1.000	0.500	30.240	63979.69	yes	no
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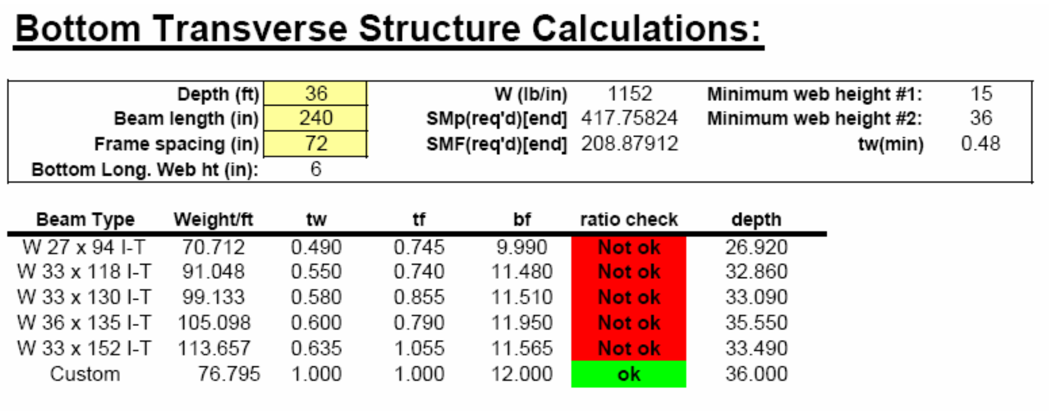
				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!
				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!
				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!
				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!
				#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!							#DIV/0!	#DIV/0!	#DIV/0!

Figure 185. Side Longitudinal Calculations

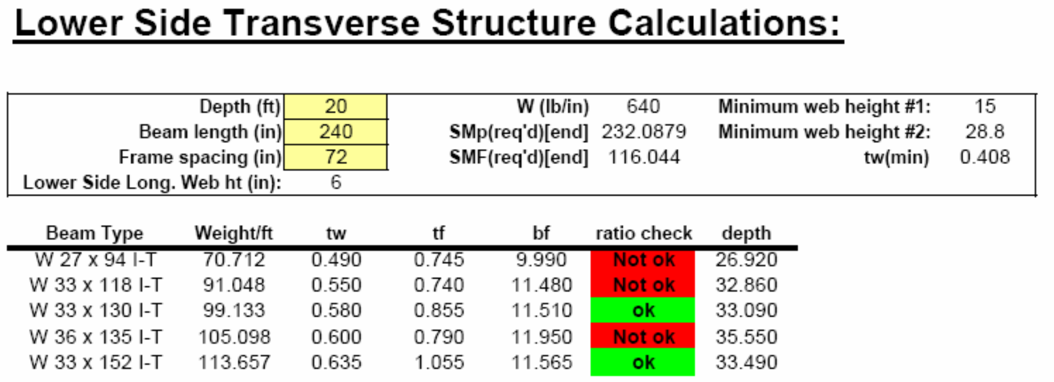


Bottom Transverse Structure Calculations:

Depth (ft)	36	**W (lb/in)**	1152	**Minimum web height #1:**	15
Beam length (in)	240	**SMp(req'd)[end]**	417.75824	**Minimum web height #2:**	36
Frame spacing (in)	72	**SMF(req'd)[end]**	208.87912	**tw(min)**	0.48
Bottom Long. Web ht (in):	6				

Beam Type	Weight/ft	tw	tf	bf	ratio check	depth
W 27 x 94 I-T	70.712	0.490	0.745	9.990	Not ok	26.920
W 33 x 118 I-T	91.048	0.550	0.740	11.480	Not ok	32.860
W 33 x 130 I-T	99.133	0.580	0.855	11.510	Not ok	33.090
W 36 x 135 I-T	105.098	0.600	0.790	11.950	Not ok	35.550
W 33 x 152 I-T	113.657	0.635	1.055	11.565	Not ok	33.490
Custom	76.795	1.000	1.000	12.000	ok	36.000

Figure 186. Bottom Transverse Calculations

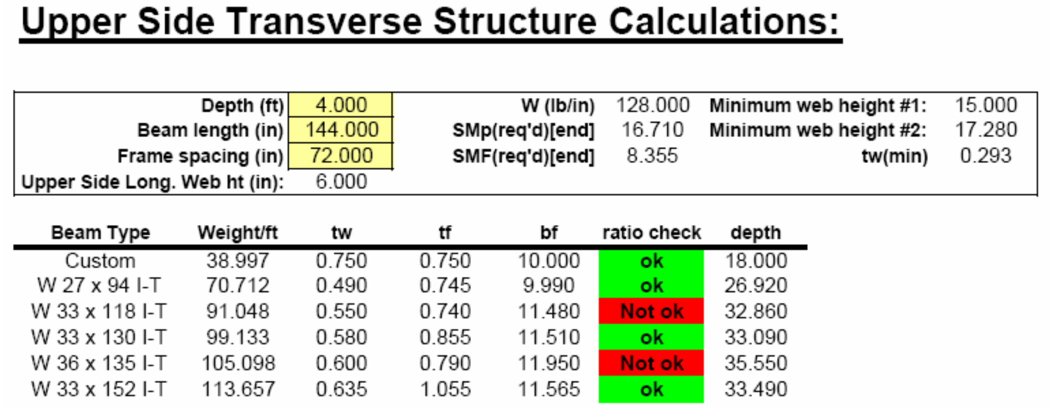


Lower Side Transverse Structure Calculations:

Depth (ft)	20	**W (lb/in)**	640	**Minimum web height #1:**	15
Beam length (in)	240	**SMp(req'd)[end]**	232.0879	**Minimum web height #2:**	28.8
Frame spacing (in)	72	**SMF(req'd)[end]**	116.044	**tw(min)**	0.408
Lower Side Long. Web ht (in):	6				

Beam Type	Weight/ft	tw	tf	bf	ratio check	depth
W 27 x 94 I-T	70.712	0.490	0.745	9.990	Not ok	26.920
W 33 x 118 I-T	91.048	0.550	0.740	11.480	Not ok	32.860
W 33 x 130 I-T	99.133	0.580	0.855	11.510	ok	33.090
W 36 x 135 I-T	105.098	0.600	0.790	11.950	Not ok	35.550
W 33 x 152 I-T	113.657	0.635	1.055	11.565	ok	33.490

Figure 187. Lower Side Transverse Calculations

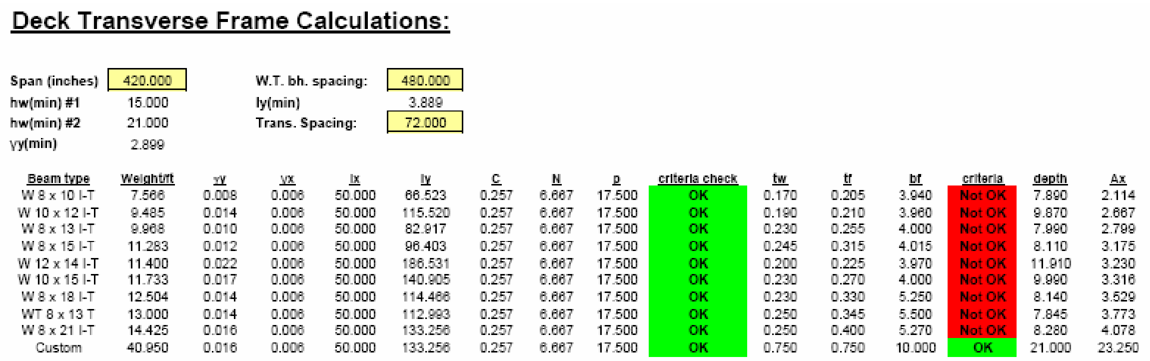


Upper Side Transverse Structure Calculations:

Depth (ft)	4.000	**W (lb/in)**	128.000	**Minimum web height #1:**	15.000
Beam length (in)	144.000	**SMp(req'd)[end]**	16.710	**Minimum web height #2:**	17.280
Frame spacing (in)	72.000	**SMF(req'd)[end]**	8.355	**tw(min)**	0.293
Upper Side Long. Web ht (in):	6.000				

Beam Type	Weight/ft	tw	tf	bf	ratio check	depth
Custom	38.997	0.750	0.750	10.000	ok	18.000
W 27 x 94 I-T	70.712	0.490	0.745	9.990	ok	26.920
W 33 x 118 I-T	91.048	0.550	0.740	11.480	Not ok	32.860
W 33 x 130 I-T	99.133	0.580	0.855	11.510	ok	33.090
W 36 x 135 I-T	105.098	0.600	0.790	11.950	Not ok	35.550
W 33 x 152 I-T	113.657	0.635	1.055	11.565	ok	33.490

Figure 188. Upper Side Transverse Calculations

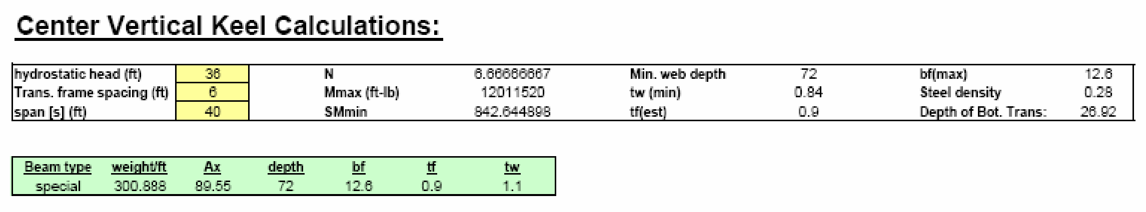


Deck Transverse Frame Calculations:

Span (inches)	420.000	W.T. bh. spacing:	480.000
hw(min) #1	15.000	Iy(min)	3.889
hw(min) #2	21.000	Trans. Spacing:	72.000
yy(min)	2.899		

Beam type	Weight/ft	yy	yx	Ix	Iy	C	N	p	criteria check	tw	tf	bf	criteria	depth	Ax
W 8 x 10 I-T	7.566	0.008	0.006	50.000	66.523	0.257	6.667	17.500	OK	0.170	0.205	3.940	Not OK	7.890	2.114
W 10 x 12 I-T	9.485	0.014	0.006	50.000	115.520	0.257	6.667	17.500	OK	0.190	0.210	3.960	Not OK	9.870	2.667
W 8 x 13 I-T	9.968	0.010	0.006	50.000	82.917	0.257	6.667	17.500	OK	0.230	0.255	4.000	Not OK	7.990	2.799
W 8 x 15 I-T	11.283	0.012	0.006	50.000	96.403	0.257	6.667	17.500	OK	0.245	0.315	4.015	Not OK	8.110	3.175
W 12 x 14 I-T	11.400	0.022	0.006	50.000	186.531	0.257	6.667	17.500	OK	0.200	0.225	3.970	Not OK	11.910	3.230
W 10 x 15 I-T	11.733	0.017	0.006	50.000	140.905	0.257	6.667	17.500	OK	0.230	0.270	4.000	Not OK	9.990	3.316
W 8 x 18 I-T	12.504	0.014	0.006	50.000	114.466	0.257	6.667	17.500	OK	0.230	0.330	5.250	Not OK	8.140	3.529
WT 8 x 13 T	13.000	0.014	0.006	50.000	112.993	0.257	6.667	17.500	OK	0.250	0.345	5.500	Not OK	7.845	3.773
W 8 x 21 I-T	14.425	0.016	0.006	50.000	133.256	0.257	6.667	17.500	OK	0.250	0.400	5.270	Not OK	8.280	4.078
Custom	40.950	0.016	0.006	50.000	133.256	0.257	6.667	17.500	OK	0.750	0.750	10.000	OK	21.000	23.250

Figure 189. Deck Transverse Calculations

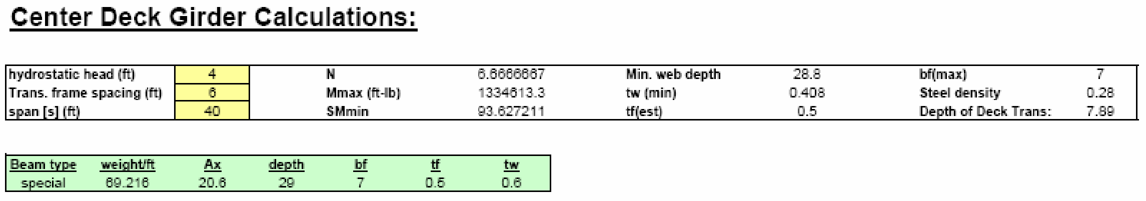


Center Vertical Keel Calculations:

hydrostatic head (ft)	36	N	6.66666667	Min. web depth	72	bf(max)	12.6
Trans. frame spacing (ft)	6	Mmax (ft-lb)	12011520	tw (min)	0.84	Steel density	0.28
span [s] (ft)	40	SMmin	842.644898	tf(est)	0.9	Depth of Bot. Trans:	26.92

Beam type	weight/ft	Ax	depth	bf	tf	tw
special	300.888	89.55	72	12.6	0.9	1.1

Figure 190. Keel Calculations



Center Deck Girder Calculations:

hydrostatic head (ft)	4	N	6.6666667	Min. web depth	28.8	bf(max)	7
Trans. frame spacing (ft)	6	Mmax (ft-lb)	1334613.3	tw (min)	0.408	Steel density	0.28
span [s] (ft)	40	SMmin	93.627211	tf(est)	0.5	Depth of Deck Trans:	7.89

Beam type	weight/ft	Ax	depth	bf	tf	tw
special	69.216	20.6	29	7	0.5	0.6

Figure 191. Center Deck Girder Calculations

LIST OF REFERENCES

1) Focht, Eric M.; “Mechanical Properties Evaluation of ASTM A945 (HSLA-65) Steels (Progress Report).” CASI HC A03/MF A01; 1996.

2) Hughes, Owen F.; <u>Ship Structural Design: A Rationally-Based, Computer-Aided Optimization Approach</u>; The Society of Naval Architects and Marine Engineers; Jersey City, NJ; 1988.

3) DeMeyer, Donnelley, and Haskell; “Midships Section Design”; Unpublished class notes and project spreadsheets for EN358 course at The United States Naval Academy; Annapolis, MD; 1999.

4) ERN\special\tsse\Library\Software\Programs\Surface\Rammstein; Rammstein group weights and centers estimation database (in TSSE Library); No copyright or publication date available; Accessed in August and September of 2006.

APPENDIX D (ELECTRICAL)

TABLE OF CONTENTS

I. ELECTRICAL GENERATION

A. INTEGRATED POWER SYSTEM

In keeping with the Navy's goal of building all electric ships, we have chosen the Integrated Power System (IPS) to be the power system for the MTR mother ship. There are many advantages to the IPS. Chief among these advantages is efficiency. All of the electrical generators for the IPS feed one distribution system. In addition, all of the prime movers onboard the ship (i.e. gas turbines and diesel generators) are coupled to these electrical generators. Therefore, the energy produced by the ship can be distributed and scaled. Any prime mover can produce electrical power for use by any of the ship's loads, to include the ship's largest load- propulsion. Additionally, only the amount of power needed for current operations is produced. By adjusting how many prime movers are running at any one time, you can make sure that they are running close to their maximum capacity, where they are the most efficient.

A very simple, notional IPS system is shown in Figure 188. From the figure, it is apparent that power generated is shared by all of the loads of the ship to include; propulsion, weapons systems, auxiliaries and hotel loads. If more power is needed (i.e. high speed ops) then more generators are brought online. This is in contrast to today's ships where there are separate prime movers for electrical generation and for propulsion. At low-speeds and/or low electrical loads, these prime movers are most likely operating below their capacity. We introduce efficiency and flexibility in our system by operating near capacity for the online generators and sharing power.

Additionally, by using electric propulsion motors, other advantages are gained. For example, the prime movers for the electrical generators and the propulsion motors do not need to be co-located. There is no longer a need for reduction gears, controllable pitch propellers (CPP) and all of the auxiliary system that come with these components.[1]

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[1] Unknown, "Marine Electric Drive Overview," USNA 200

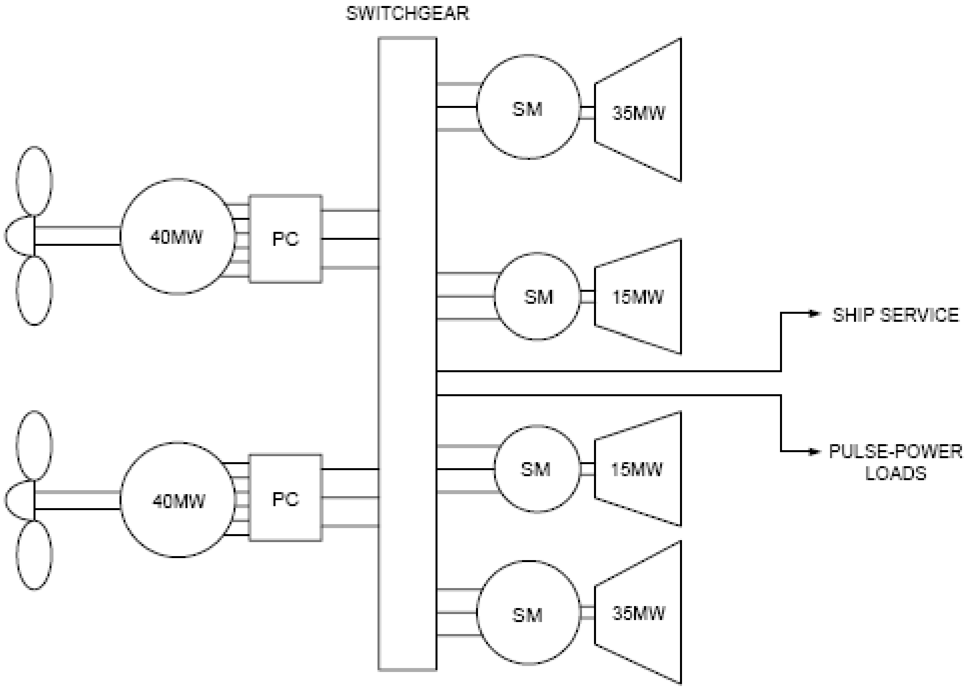

Figure 192. Notional Integrated power System[2]

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[2] Unknown, “Marine Electric Drive Overview,” USNA 200

II. PRIME MOVERS

A. PRIME MOVER ALTERNATIVES

1. General Electric LM2500[3]

The LM2500 gives you the following advantages:

- High efficiency while operating at conservative metal temperatures
- Corrosive-resistant metals and coatings
- Ease of handling/quick change out to optimize availability

Specifications:

Output (Shp):	33,600
Specific Fuel Consumption (lb/shp-hr):	0.373
Thermal Efficiency:	37%
Heat Rate (BTU/shp-hr):	6,860
Exhaust Gas Flow (lb/sec):	155
Exhaust Gas Temp (°F):	1,051
Power Turbine Speed (rpm):	3,600
Weight (lb):	0,300
Length (m):	6.52
Height (m):	2.04

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[3] http://www.geae.com/engines/marine/lm2500.html

2. General Electric LM2500+[4]

It is designed to achieve reliability equal to the precedent setting reliability, 99.6%, of the LM2500. Its high efficiency, reliability, and installation flexibility make it ideal for a wide variety of marine power generation and mechanical drive applications.

Specifications:

Output (Shp):	40,5
Specific Fuel Consumption (lb/shp-hr):	0.35
Thermal Efficiency:	39%
Heat Rate (BTU/shp-hr):	6,52
Exhaust Gas Flow (lb/sec):	189
Exhaust Gas Temp (°F):	965
Power Turbine Speed (rpm):	3,600
Weight (lb):	11,545
Length (m):	6.7
Height (m):	2.04

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[4] http://www.geae.com/engines/marine/lm2500+.html

3. General Electric LM6000[5]

It provides the power and unprecedented efficiency needed by users at an installed cost that is competitive with any gas turbine. The LM6000 is suitable for a variety of Marine Applications including fast ferry and high speed cargo ship applications.

Specifications:

Output (Shp):	57,330
Specific Fuel Consumption (lb/shp-hr):	0.329
Thermal Efficiency:	42%
Heat Rate (BTU/shp-hr):	6,060
Exhaust Gas Flow (lb/sec):	273
Exhaust Gas Temp (°F):	853
Power Turbine Speed (rpm):	3,600
Weight (lb):	18,010
Length (m):	7.3
Height (m):	2.5

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[5] http://www.geae.com/engines/marine/lm6000.html

4. Rolls Royce Marine Spey[6]

- Integrated Propulsion module with minimum of interferences
- Full blackout running capability
- NBCD containment
- Shock Resistance
- No torque limitations
- Power turbines installed for life of ship

Engine Specifications		
Compressor Stages	LP	5
	HP	11
Turbine Stages	LP	2
	HP	2
	PT	2
Shaft Speed rev/min	LP	8000
	HP	12070
	PT	5500
Combustion System	Cannular	10 Combustors
Number of shafts	2 plus	free power turbine
Performance		
Power	MW	19.5
	Bhp	26150
Intake	kg/sec	65.7
Exhaust	kg/sec	66.9
Exhaust temperature	Celsius	490

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[6] http://www.rolls-royce.com/marine/downloads/pdf/gasturbine/spey_naval.pdf

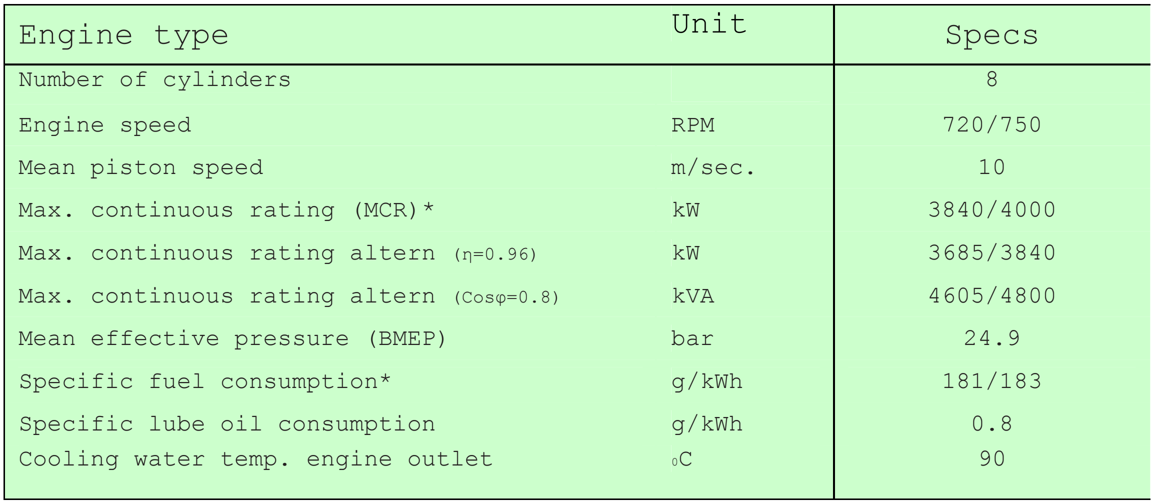
5. Rolls Royce MT-30

- High efficiency twin spool, high pressure ratio gas turbine
- Low vibration unit, resiliently mounted
- Integrated Engine Management System
- On engine condition monitoring

Engine Specifications		
Compressor Stages	LP	8
	HP	6
Turbine Stages	LP	1
	HP	1
	PT	4
PT Speed (nominal)	Alternator	3600
	Mech. drive	3300
Performance		
Power	MW	36
Specific Fuel Consumption	kg/Kw-hr	.21
Exhaust temperature	Celsius	466

6. Rolls Royce B32:40L8A

The rolls Royce Bergen B32:30 is a combination of high performance and cost effective operations. The Rolls Royce Bergen line has been in production for close to 60 years.



Engine type	Unit	Specs
Number of cylinders		8
Engine speed	RPM	720/750
Mean piston speed	m/sec.	10
Max. continuous rating (MCR)*	kW	3840/4000
Max. continuous rating altern (η=0.96)	kW	3685/3840
Max. continuous rating altern (Cosφ=0.8)	kVA	4605/4800
Mean effective pressure (BMEP)	bar	24.9
Specific fuel consumption*	g/kWh	181/183
Specific lube oil consumption	g/kWh	0.8
Cooling water temp. engine outlet	$_{0}$C	90

Figure 193. Technical Specs

B. PRIME MOVER SELECTION

The prime mover selected was the Rolls Royce MT-30 for the HTS 40 MW Generators. This was chosen based on the fact that this engine is currently the model being used by American Superconductor for testing.

III. ELECTRIC MOTORS

A. ELECTRIC MOTOR DRIVES

An electric drive consists of a power converter connected to a propulsion motor. The power converter, also referred to as the electric motor drive, converts a fixed-amplitude, fixed-frequency set of AC voltages from an AC generator into a variable-amplitude, variable-frequency set of output voltages required to control the speed of the AC motor. This is usually done by converting the AC from the generator output to DC, and then back to the AC required by the propulsion motor.

ABB Inc. produces motor drives of varying capacities for various applications. By utilizing multiple motor drives, the required output can be produced for our Electric Drive Motors (EDM's). The below chart shows how four 9MW motor drives can be combined to produce the required power for a 34MW electric motor. By stacking these motor drives together, a relatively compact and lightweight unit can be produced, figure 190 shows a typical layout for one of these drives.

Motor Drives

Model	MW	Weight	Length	Height	Depth
ACS6000	9	4.312	4.9	2.9	1.5

4 X 9MW per motor X 2 motors - (8 / 72MW)
= 40M (135 ft) of space needed, weighing 35 Tons.

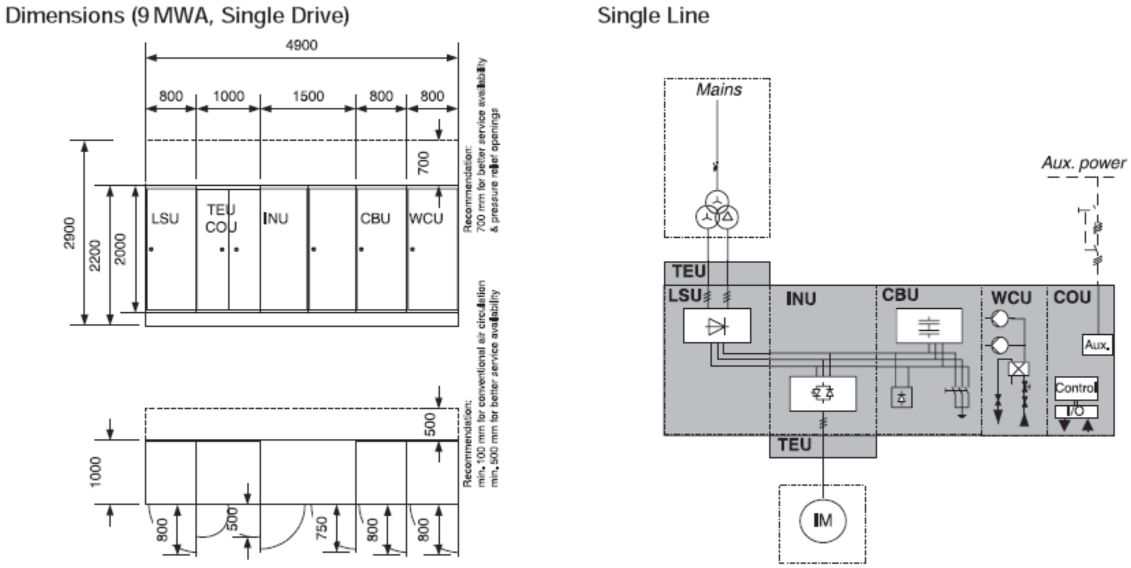


Figure 194. Dimensional layout of a 9 MWA Motor drive[7]

B. ELECTRIC PROPULSION MOTORS

1. Conventional Motors

a. History

Electric drive for ships is not a new concept. It has been around since the early 20th century. Interestingly, the first aircraft carrier was electric drive. Back in 1913, the collier Jupiter was converted with the first electric drive and renamed the Langley. In between World War I and II, 5 battleships, 2 carriers and over 50 other vessels used electric drive. Additionally, due to a shortage of reduction gears (not needed for electric drive) over 500 vessels were outfitted with electric drive during World War II.

On the contrary, IPS is a new concept. During the early days of electric drive, there was no "sharing" of power between the ship's loads and the electric propulsion motors. There were separate electrical systems. Instead of converting power using modern power converters, the generators for propulsion were separate and their output voltage was varied for the propulsion motors.

After World War II, electric drive went out of favor with the availability of double reduction gears. The reduction gears offered lower weight and volume with

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[7] ABB Inc., Drive ACS 6000 Marine Data Sheet Rev. B, 2005

increased efficiency when compared to the existing electric drive technology. But, during the past 30 years, the commercial sector has been shifting back to electric drive. The U.S. Navy has discovered the benefits of electric drive combined with an IPS system and has chosen this system for the Zumwalt-class (DD1000) destroyer.[8]

b. PODS

PODS are a very popular form of conventional motor widely used in the maritime industry today (especially cruise liners). The POD is a way of packaging the motor in a convenient and versatile self-contained unit. The POD has a swivel base (usually overhead) which allows it to be maneuvered in almost any direction. Figure 193 illustrates the typical POD architecture. Figure 194 is an example of how ubiquitous the use of PODS is today.

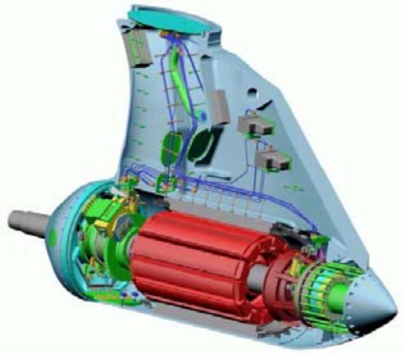

Figure 195. Graphical depiction of a POD[9]

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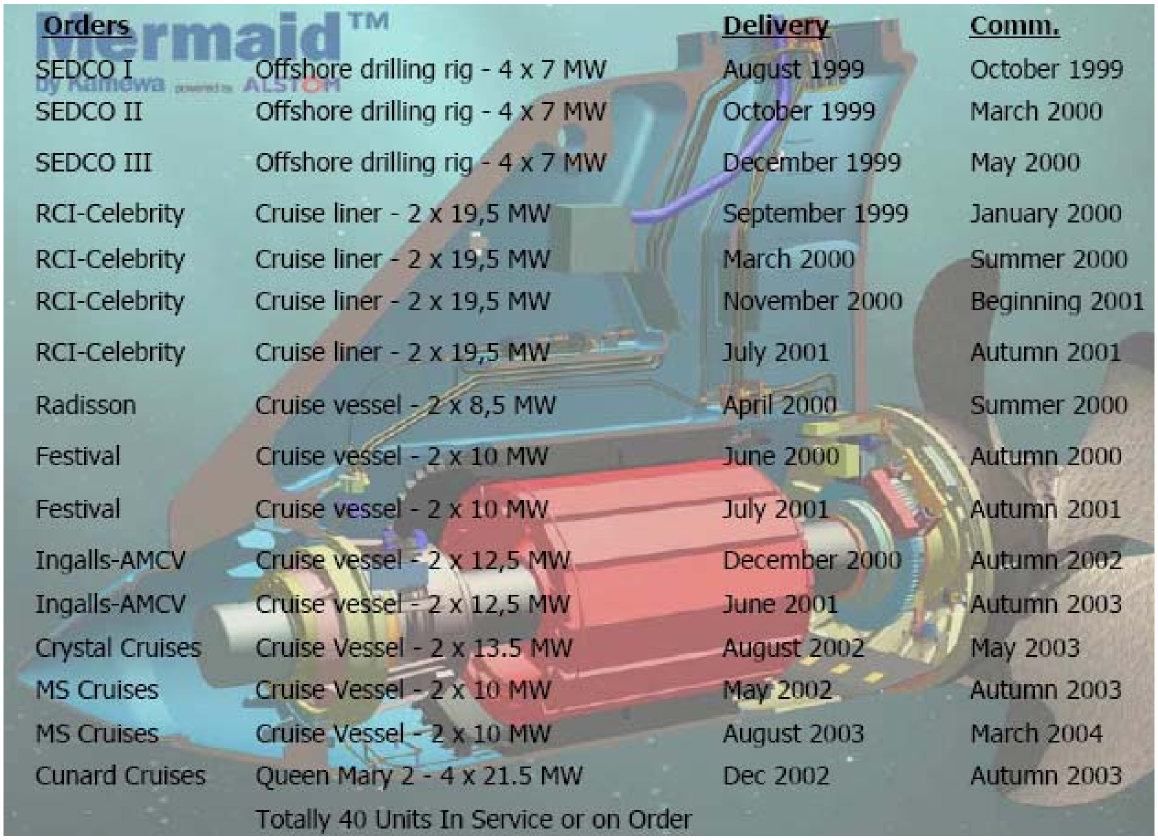
[8] Unknown, "Marine Electric Drive Overview," USNA 2004

[9] Alstom Inc., Naval Research Advisory Brief, August 2001



Orders		Delivery	Comm.
SEDCO I	Offshore drilling rig - 4 x 7 MW	August 1999	October 1999
SEDCO II	Offshore drilling rig - 4 x 7 MW	October 1999	March 2000
SEDCO III	Offshore drilling rig - 4 x 7 MW	December 1999	May 2000
RCI-Celebrity	Cruise liner - 2 x 19,5 MW	September 1999	January 2000
RCI-Celebrity	Cruise liner - 2 x 19,5 MW	March 2000	Summer 2000
RCI-Celebrity	Cruise liner - 2 x 19,5 MW	November 2000	Beginning 2001
RCI-Celebrity	Cruise liner - 2 x 19,5 MW	July 2001	Autumn 2001
Radisson	Cruise vessel - 2 x 8,5 MW	April 2000	Summer 2000
Festival	Cruise vessel - 2 x 10 MW	June 2000	Autumn 2000
Festival	Cruise vessel - 2 x 10 MW	July 2001	Autumn 2001
Ingalls-AMCV	Cruise vessel - 2 x 12,5 MW	December 2000	Autumn 2002
Ingalls-AMCV	Cruise vessel - 2 x 12,5 MW	June 2001	Autumn 2003
Crystal Cruises	Cruise Vessel - 2 x 13.5 MW	August 2002	May 2003
MS Cruises	Cruise Vessel - 2 x 10 MW	May 2002	Autumn 2003
MS Cruises	Cruise Vessel - 2 x 10 MW	August 2003	March 2004
Cunard Cruises	Queen Mary 2 - 4 x 21.5 MW	Dec 2002	Autumn 2003
	Totally 40 Units In Service or on Order		

Figure 196. PODS in use today[10]

c. *Advanced Induction Motor*

The DD1000 Zumwalt-class Destroyer will use these motors as part of an overall IPS system.[11] Seeing that the Navy has already decided to put these motors into the DD1000 program of record, they have been deemed technically mature. Selected for use in the Navy's latest ship, the Advanced Induction Motor (AIM) produced by Alstom Inc., represents the latest in mature, conventional motor technology.

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[10] Alstom Inc., Naval Research Advisory Brief, August 2001

[11] Unknown, "Marine Electric Drive Overview," USNA 2004

Figure 197. Alstom 19MW Advanced Induction Motor[12]

d. *Superconducting Motors*

A lot of time and money has been put into researching superconductors lately. The Office of Naval Research (ONR) has more than one contractor looking in to this technology. The great thing about high-temperature superconducting (HTS) wire is that it can carry up to 140 times more current than comparable copper wire (same size and weight). Carrying more current translates to a greater flux density; a greater corresponding magnetic field; and thus, more torque in a motor built with HTS wire. As shown in Figure 199 and 200, HTS motors can be up to 1/3 the weight and ½ the size of their copper-based counterparts at the same power ratings. This is due not only to the reduced size of the wires, but due to the increased current carrying capacity of the wires.

As shown in Figure 198, the other great advantage of HTS motors is that they operate more efficiently than copper motors across the entire motor load spectrum. The motors can be operated at low loads (e.g. during slow speed ops) without a great loss in efficiency.

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[12] Unknown, "Marine Electric Drive Overview," USNA 2004

By having smaller and lighter motors, it opens up a lot more possibilities as to where we can place them on the ship. Also, these smaller motors free up space and weight for other "nice to have" pieces of equipment that may not have been viable beforehand.

The term "high temperature superconducting" is a relative term; since the conductors in these motors still must remain quite cool (140°K, -130°C). The "high temperature" is as compared to other superconducting technologies where the conductors are kept at near absolute zero temperatures (4°K, -266°C). In our case, these higher temperatures are maintained with little difficulty. The cryogenics involved for each motor consist of a refrigeration system on the order of the size of a 5-foot file cabinet. The typical system would have two, one for backup. The amount of power drawn by these cooling systems is negligible.

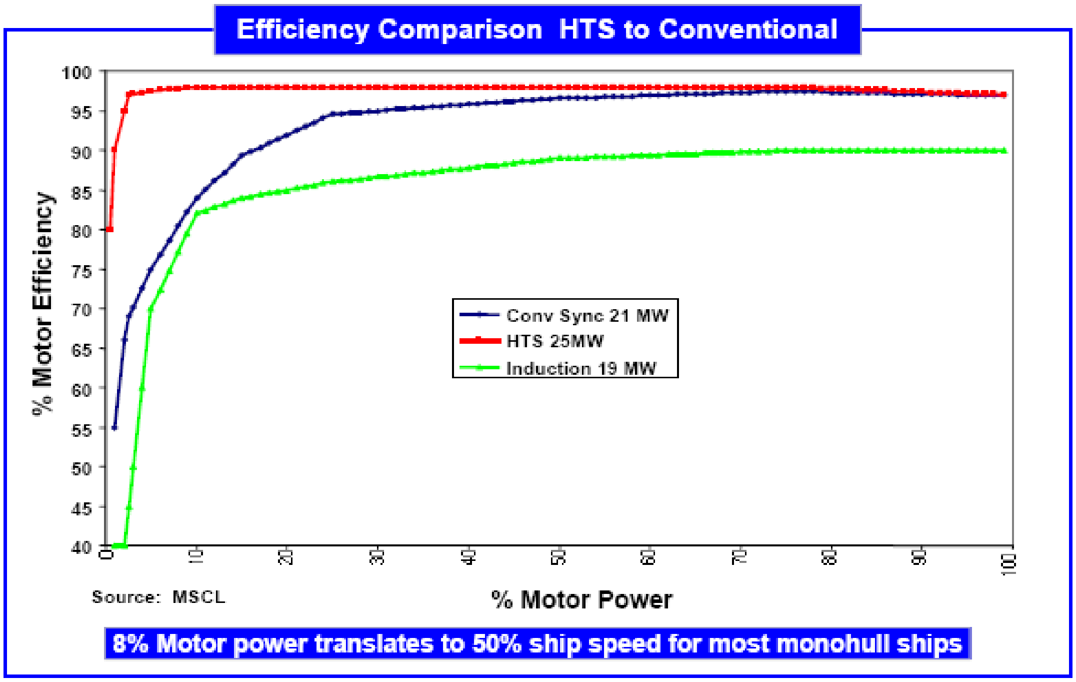

Figure 198. Efficiency advantage of HTS versus conventional motors[13]

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[13] "Optimal Electric Ship Propulsion Solution," Marine Reporter, 2002

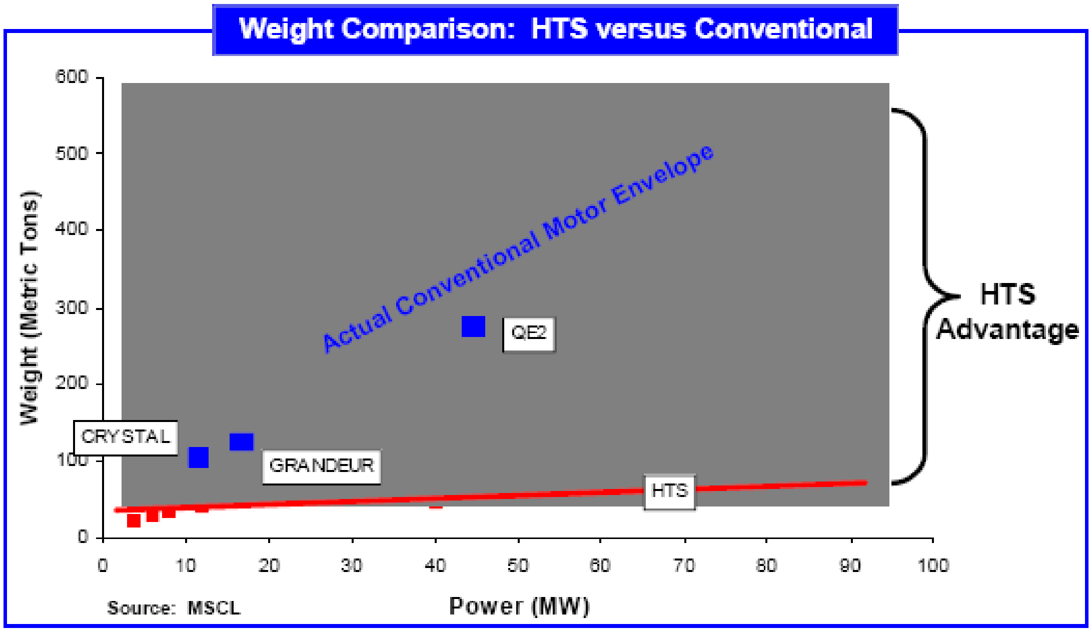

Figure 199. Comparing HTS and conventional motors: weight versus power[14]

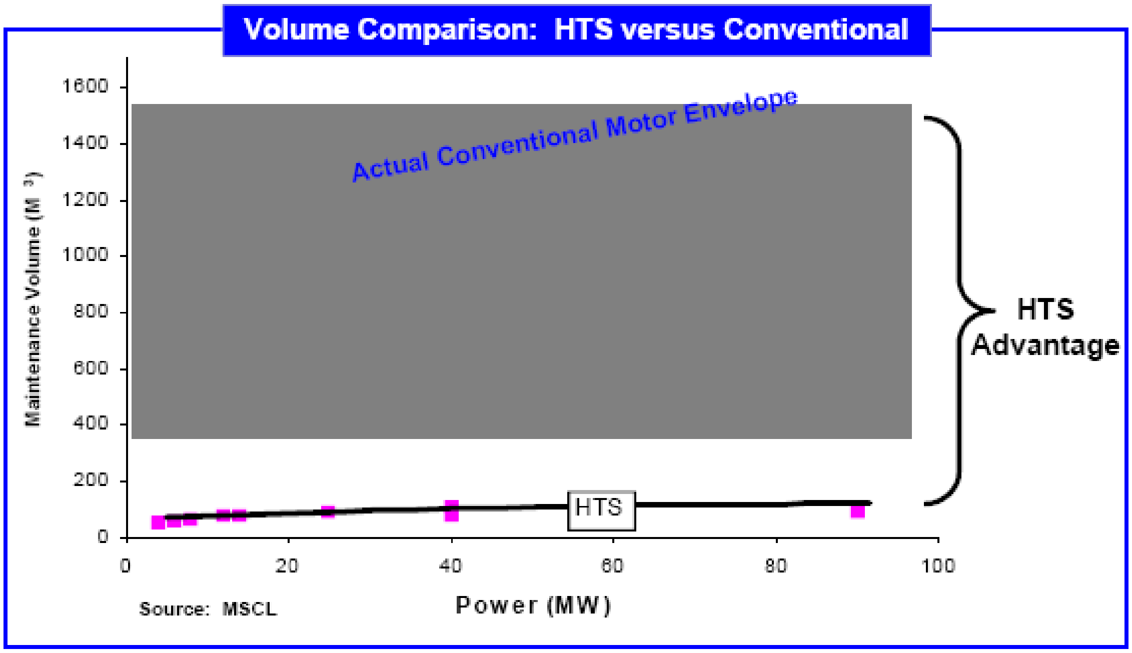

Figure 200. Comparing HTS and conventional motors: size versus power[15]

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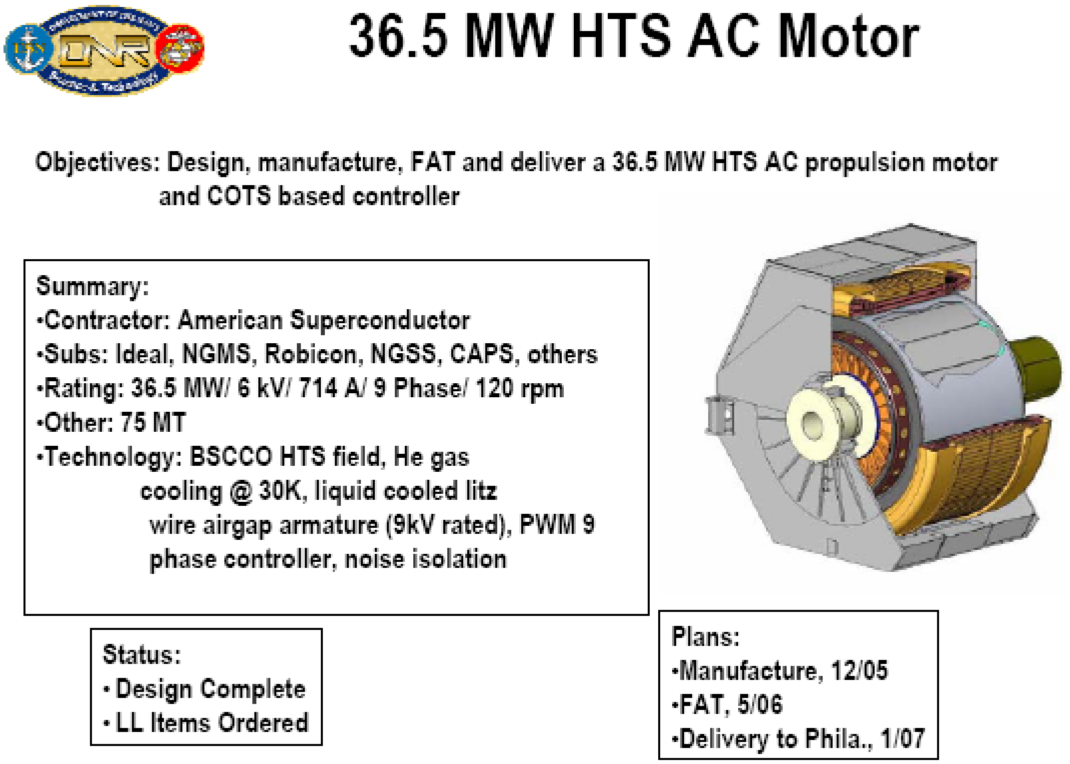
[14] "Optimal Electric Ship Propulsion Solution," Marine Reporter, 2002

[15] "Optimal Electric Ship Propulsion Solution," Marine Reporter, 2002

e. High-Temperature Superconducting (HTS) AC Synchronous Motor

Under development by American Superconductor in conjunction with ONR, the HTS AC Synchronous Motor is the most mature of the superconducting motor technologies. Their 34MW motor has successfully competed advanced testing milestones and is due to be delivered, operational to the U.S. Navy in late 2006. This motor has all of the advantages discussed above with respect to superconducting motors.

As depicted in the figure below, the expected size of the American Superconductor HTS AC Synchronous Motor is 15ft in diameter and 15 ft long.



36.5 MW HTS AC Motor

Objectives: Design, manufacture, FAT and deliver a 36.5 MW HTS AC propulsion motor and COTS based controller

Summary:
- **Contractor: American Superconductor**
- **Subs: Ideal, NGMS, Robicon, NGSS, CAPS, others**
- **Rating: 36.5 MW/ 6 kV/ 714 A/ 9 Phase/ 120 rpm**
- **Other: 75 MT**
- **Technology: BSCCO HTS field, He gas cooling @ 30K, liquid cooled litz wire airgap armature (9kV rated), PWM 9 phase controller, noise isolation**

Status:
- **Design Complete**
- **LL Items Ordered**

Plans:
- **Manufacture, 12/05**
- **FAT, 5/06**
- **Delivery to Phila., 1/07**

Figure 201. 36.5 MW HTS AC Motor [16]

f. Superconducting DC Homopolar Motor

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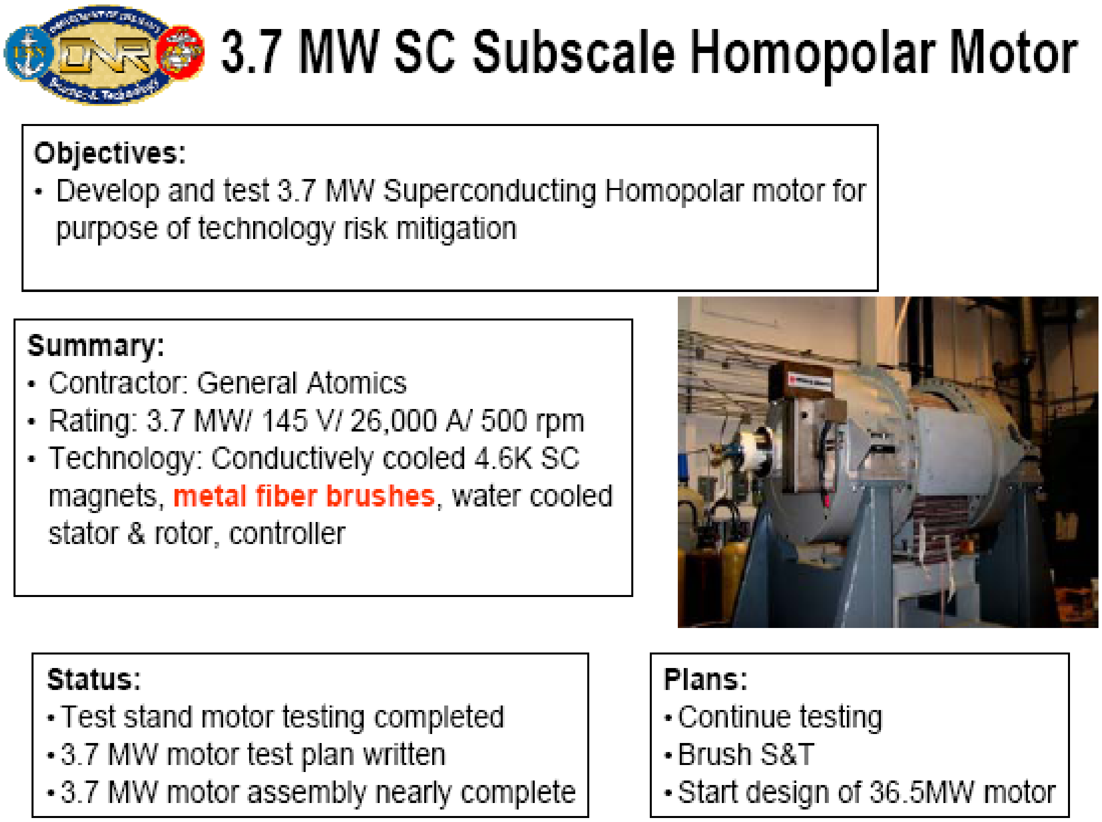
[16] Peterson, Lynn, “ONR Motors and Drives Program Review,” 11/14/2005

Another technology currently undergoing research is the Superconducting DC Homopolar motor. This DC motor would integrate well with a DC zonal distribution system. In a configuration such as this, the power conversion is much simpler; since the ship's system and the motor are both DC, and therefore no frequency conversion is required Figure 202 provides further details on the subscale motor.

The DC Homopolar motor is not an HTS system and thus requires a more robust cooling system. Even so, the cooling system is not expected to be a major source of contention.

This motor is not as far along in the development process. A 3.7MW motor has been developed and a 30+ MW motor is under development.

Given our relatively short timeline (5 years) to implement the MTR system, coupled with our choice of an AC Zonal Distribution System and HTS generators, the HTS AC synchronous motor more closely meets our needs.



3.7 MW SC Subscale Homopolar Motor

Objectives:
- Develop and test 3.7 MW Superconducting Homopolar motor for purpose of technology risk mitigation

Summary:
- Contractor: General Atomics
- Rating: 3.7 MW/ 145 V/ 26,000 A/ 500 rpm
- Technology: Conductively cooled 4.6K SC magnets, **metal fiber brushes**, water cooled stator & rotor, controller

Status:
- Test stand motor testing completed
- 3.7 MW motor test plan written
- 3.7 MW motor assembly nearly complete

Plans:
- Continue testing
- Brush S&T
- Start design of 36.5MW motor

Figure 202. Superconducting DC Homopolar Motor[17]

E. CONCLUSION

As shown in the above discussion, a propulsion system which couples the scalable electric motor drives with an HTS AC Synchronous motor provides the best combination for the MTR mothership’s needs. This system represents a blend of advanced and proven technologies which meet the timeline requirements of the MTR project.

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[17] Peterson, Lynn, “ONR Motors and Drives Program Review,” 11/14/2005

III. ELECTRICAL GENERATION

A. INTRODUCTION

Based on the loading requirements of the ships propulsion motors the logical choice for power generation was to use High Temperature Superconducting (HTS) Power Generation. The major advantage to the HTS generators are the high power output compared to traditional Electrical Generators. Additionally, the HTS Generator is the primary choice of power Generation for the DDX.

Conventional generators have been continually developing over the past several decades, but conventional generators simply cannot provide the Megawatts of power required without the drawback of significantly added weight and size. The thermal efficiency and small size of the HTS Generators make them the logical choice.

Currently, American Super Conductor Inc is developing a 40 MW Generator that will be more than adequate based on our power and weight requirements. The figure below shows the vital features of this HTS Generator.

Rating	Amperage	50 MVA
	Power	40 MW
	Line Voltage	6.6 KV
	RPM	3600
	Frequency	60 Hz
Cooling	Description	3 Cold Heads.4 compressors.
	Weight	260 lbs
Dimension	Frame Diameter	1.82 m
	Length over bearings	3.88 m
Total Weight		~75,000 lb

Figure 203. Preliminary Specification for the HTS Generator

The figure above represents only preliminary numbers for the HTS Generator. It is still in testing phases.

IV. AC DISTRIBUTION SYSTEM

The major design decision for choosing the electrical plant was between whether or not to choose the conventional distribution system or to use the Zonal distribution system that is being used on the DDXG-79 and LPD-17 Class.

The advantage of the conventional electrical distribution system is primarily proven reliability. This electrical plant has proven itself over the years. It would be an excellent choice for our ship based on this alone. However, the AC Zonal distribution will provide all the power requirements of the conventional distribution system with the added benefit of providing additional redundancy in the event of battle damage.

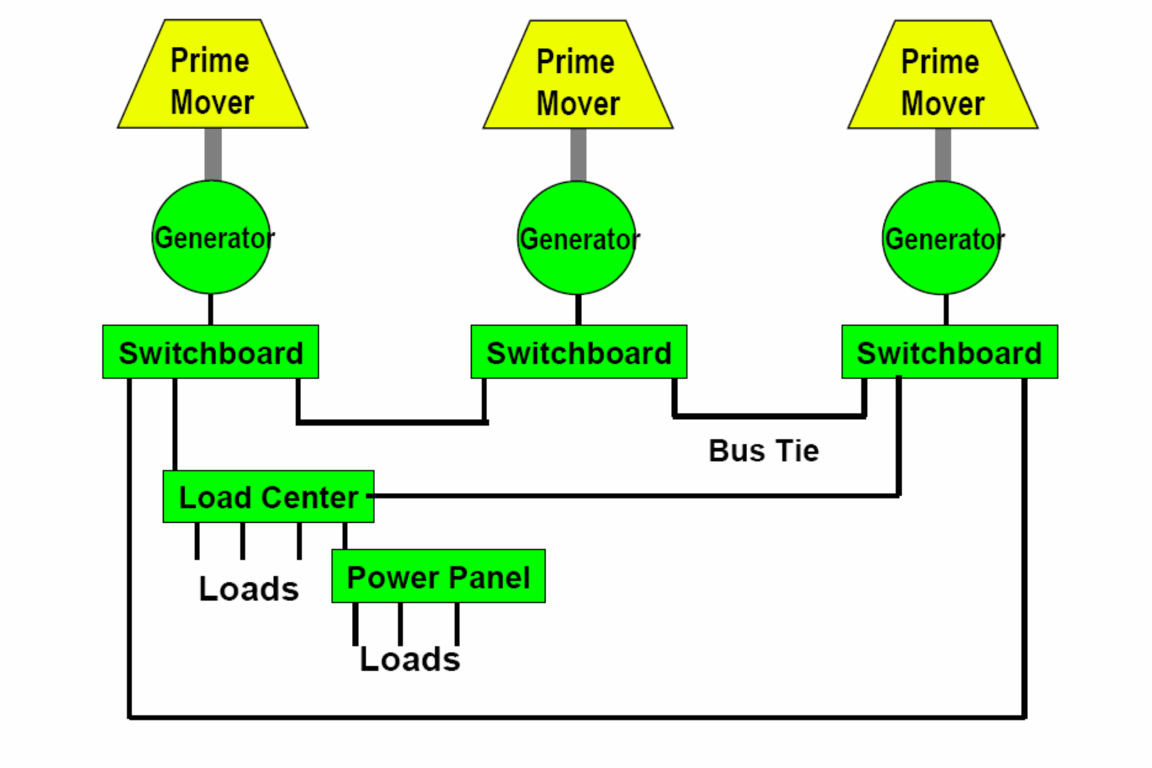

Figure 204. Conventional Distribution

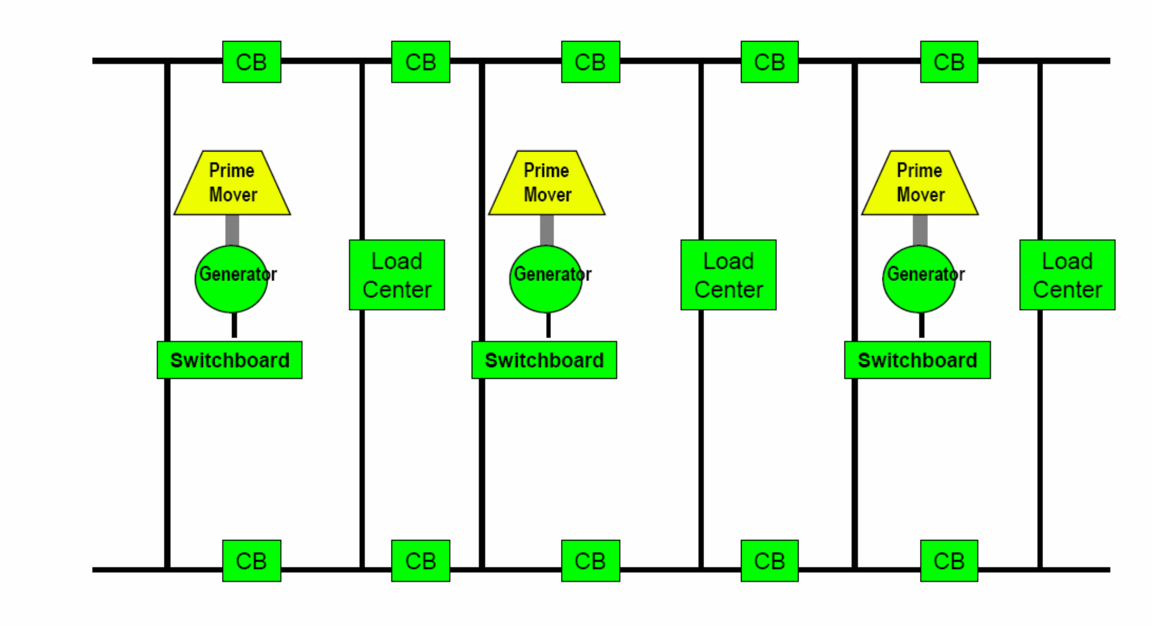

Figure 205. AC Zonal Distribution System

The key concept with any electrical distribution system is to provide alternate paths to vital components throughout the ship. Depending on the importance of the electrical subsystem to the ship's mission will determine the number of available back up methods to the component. Typical loads that have historical significance as vital load are combat systems, damage control, and ship's propulsion. The AC zonal distribution system inherently solves the problem of reliability as a fundamental feature of the design.

In the zonal distribution system pictured in Figure 201, the two main power buses (top and bottom) will run along the port and starboard portion of the ship, where each zone, covers, a portion of the ship. This automatically provides a backup power supply to each and every component of the ship. Additionally, vertical separation of these buses will provide additional redundancy if damage was done to an entire deck.

Another major benefit to the AC Zonal distribution systems is the cost savings. In a traditional radial power distribution system, feeder cables had to be run for the closest switchboard to the load center in order to provide power. With the zonal distribution, the simplified installation of two large main buses can be integrated from the beginning of the design process and standardized as well to minimize testing and production cost.

In order to estimate the weight of the AC zonal distribution system on our ship design. The baseline estimates for the DDX was used and scaled up to the size of our ship to give us a rough estimate of the total weight. Figure 206 shows the result of these calculations.

Weight of AC Zonal (LBS)	
Shore Power (Station)	8000 (Bkrs, Etc)
SSDS Bus Cabling (Ship Service Distribution)	138,054
Power Conversion (IPC)	96,000 (12 * 4 Tons Each)
Power Conversion (NON IPC)	186,542
In Zone Distribution	137,636
In Zone Cabling	84,527
400 Hz	44,316
Total:	**695,075**

Figure 206. Estimated Weight of the AC Zonal Distribution

A diagram of the AC zonal distribution system for MTR is shown in Figure 203. There are 2 primary power sources total for the distribution system. Each 40 MW Generator will supply power to either the Port or Starboard Bus. Additionally, either bus can be supplied by and Diesel Generator in the event of the failure of either of the Main Generators or whenever the Main Generators are not needed (i.e. In Port/At Anchor)

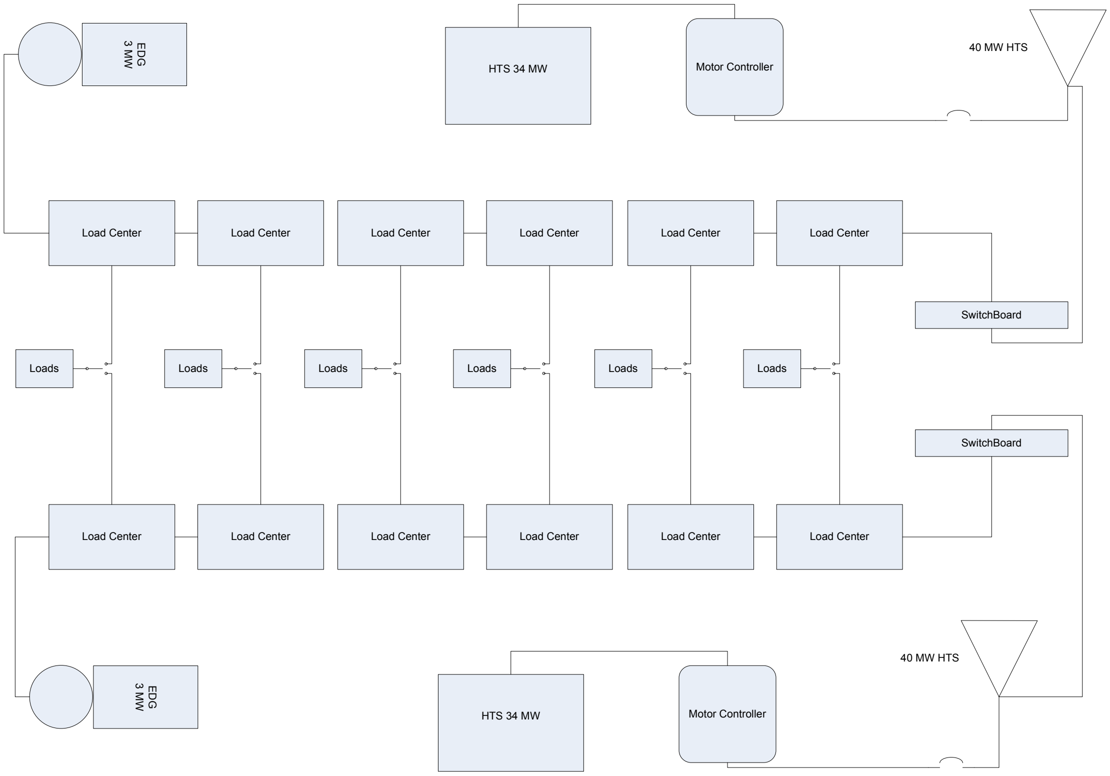

Figure 207. AC Zonal Distribution for MTR Ship Design

V. SUMMARY

Once the design decision to go with the Electric Drive ship was made by the group, the choices for power generation became limited. HTS generators were the obvious choice based on power density. Another viable option was the high speed permanent magnet generators. However, in the end, these generators proved to be far too unpredictable for the short time horizon of our ship design (< 5 years).

The choice for the electric drive motor for the most part coincided with the choice of power generation. Once the decision was made to use the HTS for generation, it makes sense to use a similar technology for propulsion. Overall, since the maintenance would be similar, the decision would result in reduced manning. The major drawback to the HTS motors for propulsion will be the fact the technology is relatively new and untested. This may cause unexpected maintenance costs in the future.

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APPENDIX E (COMBAT SYSTEMS)

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I. THREAT ENVIRONMENT

The modern day threat environment includes a large range of scenarios. .The lowest scale threat comes from individuals or individual terrorist cells. A medium level threat comes from terrorists that are state sponsored or covert operations carried out by national governments, which allows increased funding and access to more sophisticated weaponry. Finally, there is the threat of direct action by nation states cumulating in possible persecution by regular military forces.

The operational area for the MTR ship will be 7th Fleet AOR. The concept of operations has the MTR ship home port in Japan with operations in the Northern Pacific Ocean. Specific threat assessments are provided for port/choke point transits. Currently, there is a high level of confidence in the safety of operating out of Japan. The international waters of operations are sufficiently far from continental areas that will preclude all, but the largest scale threats or threats directed from the contact of interest. In the future, it is possible that less funded terrorist cells or states will obtain the ability to power project S Navy, it can be envisioned that the appropriate proportional response can be easily adapted. Certainly, if necessary, navy surface combatants can be used to augment protection of the MTR ship should the combatant commander deem necessary.

Being a US Navy ship, the MTR ship will be considered a target like any other. There are two competing factors working towards the probability of it being selected as a target. First, the MTR ship is not a major combatant ship, therefore would probably not be considered a high value unit by an adversary. However, being a non-combatant, it could be assumed that it would be a soft target as opposed to a cruiser or aircraft carrier, so an attack would have a higher perceived chance of success.

A. THREATS

1. Combat Swimmers

Probability: Likely Severity: High

A known tactic used by both terrorist cells and special forces personnel. The swimmers can attack the hull via several methods including attaching limpet mines to the hull to fouling the running gear with netting or chains. This threat is mainly to a pier side ship and can be countered by heavy lighting, sonar, hull armor, small boat patrols, and stand-off netting.

2. Mines

Probability: Likely Severity: High

Mines are one of the cheapest weapons that can be produced and are fielded by almost all enemy combatants. This threat is typically encountered in chokepoints or while entering/leaving port. It can be countered by small boat escort, hull armor, mine detection gear, hull design considerations (fiberglass, non-magnetic) and channel sweeping.

3. Mortar Attack

Probability: Average Severity: Medium

Mortars can be used to perform a standoff attack when a ship is in port or very close to land. This method of attack requires is a ballistic trajectory and specific targeting with a smaller warhead will cause less damage. Increasing standoff range to as maximum as possible can help deter attacks, while increasing hull and topside protection will increase survivability.

4. RPG Attack

Probability: Likely Severity: Medium

Like mines, RPGs are proliferated throughout the world. Although best used against helicopters and mechanized ground equipment, it is still able to inflicted moderate damage to a warship. It can be countered by incorporating large standoff distances and physical armor protection.

5. Low Slow Flier
   Probability: Average Severity: High

This threat exists from a small aircraft, laden with explosives ramming the ship such as in a kamikaze attack. Active defense against this attack would be crew-served weapons, backed up by survivability concerns from topside explosions/penetration.

6. Small Boat Attack
   Probability: Likely Severity: High

A known tactic for both terrorist cells and nation-states, small boats present a large threat pier side or in areas where the ship is unable to maneuver. Having organic small boats to shoulders off attackers and larger crew-served weapons can deter attackers.

7. CBR attack
   Probability: Low Severity: High

The mode of delivery of these types of weapons could fall in the above categories or could be package. Theses devices attack only the crew and the defenses include CBR gear and airtight integrity within zones of the hull. In addition, counter measure wash down systems and decontamination chambers can help minimize the consequences of an attack.

8. Unmanned Vehicles
   Probability: Likely Severity: Medium

Just as the United States ramps up its use of unmanned vehicles for surveillance and attack, so are its adversaries. This allows a large standoff distance for the attacker and a small target to detect and destroy. It would be suspected that the deliverable payload would be smaller, so that defenses would include those the same for mortars or RPGs.

9. Large Boat Attack
   Probability: Low Severity: High

Like the low, slow flier scenario it is possible that adversaries would use a hijacked merchant ship (LNG would be worse case) to use as a ram to the MTR ship. In open ocean, the MTR ship has the ability to maneuver so this threat is minimized, but pier side or in restricted maneuvering the threat exists. Short of sinking the hijacked ship before collision, there is no way to stop it. Therefore, survivability concerns considered to minimize this threat include the use of double hulls and water tight integrity.

10. Information Warfare

Probability: Medium Severity: Low

As command and control for the ship becomes more complicated, its vulnerability to attack also increases. This type of attack may have an infinite stand-off distance if the ship has connectivity into satellite or land based networks. The approach to counteract this threat can be two fold. First, the systems can be designed to minimize susceptibility, such as encryption. Another alternative is to not use these advanced networks and stick to older style systems for communication and information transfer that are not accessible by computer attack.

B. CONCLUSIONS

Defense design for all of these threats falls into three categories. First, the ship can be designed for survivability. Many of the threats are one hit events, so if the ship can survive the initial encounter with minimal impact it can still complete its mission or at a minimum transit for repair. Second, the ship can be equipped with the ability to make threats standoff. This may be part of a concept of operations involving assets that are both inorganic and embarked elements. Third, active offensive capability can be used to destroy known threats before they reach engagement range. Although the first two categories are primarily passive in nature, the third requires command and control to make real time identification and engagement decisions. All of the types will impact design choices for ship engineering, manning, and operations.

II. WEAPON SYSTEMS: AIR DEFENSE

The MTR ship is relatively a base of operations from which to launch interceptors and helicopters. It however, still needs a self protection capability. These weapons are chosen based on the threat analysis. For the primary mission, the MTR ship will encounter several merchant ships which may or may not be help by terrorists. It is not unreasonable to assume that an organization could place a ship to ship missile on board a merchant. For this analysis we will assume that a hostile merchant ship can be outfitted with four Styx missiles. This is instance is not likely as explained by the threat analysis, but is not impossible to accomplish. The characteristics of the Styx missile are given below.

- Speed: Mach 0.9
- Range: 45 NM
- Active Radar: L-band (1 GHz) + IR Seeker

For air defense, the MTR ship will adopt a standard layered depth strategy utilizing the Phalanx close in weapons system (CIWS) and Rolling Airframe Missile (RAM). These are placed on the ship such that a minimum of one of each of these systems can align to the threat vector. This weapon numbering is justified as follows:

It is assumed that only one merchant ship would be firing on the MTR ship in a stream raid (10 sec interval) along a common threat axis.

Given the following assumptions:

- Range at detection: 25 NM – based on height of 48E to radar horizon
- Time to reach MTR ship: 148 seconds
- Range of RAM: ~ 9 NM
- Speed of RAM: ~ Mach 2.0
- Flight time to 1st intercept: 24 secs
- Enemy Missile range at first launch: 14 NM
- Maximum number of RAM engagements assuming shoot/look/shoot tactic: 3 (given 2 sec BDA decision time)

Number of missiles needed: 12 (3 shots times 4 incoming missiles) one MK 49 RAM launcher (21 missiles) can handle this. However, this weapon system is susceptible to the stream raid tactic, since the first missile may mask further out missiles. The RAM will track the target along the azimuth and bearing it is fired on and successive missiles may be mask by the first missile or its debris. Assuming a P_k of 0.8 for the RAM this gives a 99.2% probability of kill of the incoming missile. Successive missiles will trail the lead missile in 1.7NM intervals and therefore will not be able to be engaged until the first missile is destroyed. Even assuming the first missile is destroyed with the first shot, the second missile will already be at 11 NM and will only be able to be engaged twice with the RAM lowering the P_k to 96%. The probability of hitting the first three missiles on their first RAM engagement is 51.2%, therefore the use of a second weapons system is required, in the case of the MTR ship – Phalanx.

The most restrictive area is to the stern where the flight deck makes it difficult to place centerline weapons. Therefore, one weapon system of each type is placed directly below the flight deck at the corners of the transom. This will provide the two weapon coverage to the stern of the ship. The forward weapons are mounted offset on the foc'sle (Phalanx) and centerline above the pilot house (RAM). This will provide weapon two weapon coverage to all areas except the 135 degree cutout astern. Therefore, on the beam, the ship will have three weapon coverage from 10 degrees to 135 relative.

A. WEAPON SYSTEMS: FORCE PROTECTION

When operating at sea, the best tactic to use for ship defense will be maneuverability and speed. However, in restricted waters, such as entering and exit port, the ship will not be able to maneuver and self defense weapons are needed. A specific threat to design to is very difficult as any combinations of boats, aircraft, swimmers, mines, etc could be creatively employed. Therefore, weapons are placed on the ship to provide a mount at approximately 200 ft intervals. This will provide 3 mount sites per ship side to be filled by twin mounted 50 caliber machine guns. It is hoped that this volume of fire, along with support from air and sea borne assets will be sufficient to deter attacks.

B. COMMUNICATIONS AND DATA LINKS

The MTR will perform its primary mission with interceptors over the horizon, in order to facilitate communications requirements a robust system was mirrored off of the San Antonio Class warship. Since the boarding teams are assumed to have satellite connectivity equipment for communications the MTR class ship will utilize the WSC-6 communications system. The ship will have SHF connectivity for increased bandwidth for internet to allow for greater data transfer between shore and possibly inceptor teams if, for instance, digital pictures need to be sent through the chain of command. The ship will also use HF whips, AS-3226, and WSC-3 radios to back up the primary satellite communications and allow for other ships in the fleet and foreign countries to operate with the ship in secondary missions.

In order to pass tactical data through the fleet this class of ship will utilize Link-11, Link-16, and Link-22 (if available). The tactical picture could be anchored by the MTR ship since it has a high mast height giving Link-11 ships the best possible line of sight. Again, the ability of this ship to have Link will make it an asset for the fleet in secondary missions and foreign navy exercises.

Along with the surface tactical picture, MTR will be capable of hawklink for use with MH-60 helicopters. Again, adding to the robust communications from above along with the sharing of information through Link-11 and Link-16; the hawklink advantage increases the fidelity of the system to keep an accurate maritime picture.

For communications between civilian and suspected merchant traffic the ship will utilize bridge-to-bridge (BTB) radios.

C. AVIONICS

Due to large distances involved in the boarding concept of operations it is desirable to have organic aviation assets for support. This is supported by the opinions given through the questionnaire distributed. It allows an incredible range of support for the interceptors to include personal, equipment, and medical transfer services in addition to being the primary offensive weapon for disabling fire on a suspect merchant vessel.

D. CONCEPT OF OPERATIONS

During a typical mission, it would be expected that the airborne assets will assist in boarding's by ID, protection, and equipment transport. It is assumed that an airborne asset can be aloft for a four our mission. During the first day of operations, it is assumed that one asset would need to be available for 16 hours (four flights) and a second would need to be available for 12 hours (three flights). During the subsequent six days, the asset would be available for three flights a day for a total of 25 flights. In addition, it is assumed that one asset would be up for force protection for port transits, raising the total number of mission flights to 27.

These missions are centered around the mothership and are of medium range in nature (100-150 nm). An alternative, long range mission can be preformed by offering transport of personnel and equipment from a land base. For the primary mission, this is assumed to be from Yokosuka or Honolulu out to 2000nm (midway distance along the northern trade route).

E. ALTERNATIVES

Due to large size of the mother ship needed to support mission requirements in high sea states, there is ample room for avionics support – flight deck, hangar bay, armory, radars, communications and workshops. Because of the flight deck space, any aircraft can be considered for the MTR ship. However, the choices were limited to current operational aircraft in the Navy's inventory to standardize training and supply. The aircraft considered are listed below:

- MH-60
- OV-22
- CH-46
- CH-53

From these, the CH-53 and CH-46 models were eliminated as older models that are eventually being replaced by the OV-22. The following tables compare and contrast the Osprey to the MH-60 series aircraft.

Attribute	**MH-60**	**V-22**
Footprint	**H x L x W (ft)**	**H x L x W**
Folded	17' x 41' 4 " x 8'	18' 1" x 63' x 18' 5"
Unfolded	17' x 64' 10" x 53' 8"	22' 1" x 57' 4" x 84' 7"
Weight	23,000 lbs	VTOL 47,500 STOL 55,000 Self Deploy 60,500
Speed (max)	180 knots	240 knots
Range	450 nm	500 nm 2100 nm Self Deploy (w/ refuel)
Armament	Several variants available – considered a standard load out of 4 Hellfire missiles + M-60 machine guns.	(2) .50 cal

Figure 208. Osprey to the MH-60 series aircraft

As seen in the table, both the V-22 and the MH-60 are appropriate aircraft for use in the Maritime Strategy. The following table is compares and contrasts the attributes listed above to the requirement of the MTR study, as seen in the table below, the MH-60 is the flexible aircraft of choice. If the MTR interceptors become modular in the sense of the Littoral Combat Ship, the MH-60 aircraft is the appropriate fit interface between the missions.

Attribute	MH-60	V-22
Footprint	-Much smaller footprint allows for extra helos	-Large wingspan could prove dangerous in sea state 5
Weight	-Half the weight of a V-22	
Speed	-Much slower	-Greater speed for fast recovery and assistance if needed
Range	-Equivalent	-Equivalent for interceptor operations. Much greater for transport.
Armament	-MH-60 allows for various armament for MTR responsibilities -MH-60 is also the aircraft of choice for LCS missions, as such, could fit the MTR secondary missions well	-Only to .50 cal guns will not suffice for MTR

Figure 209. Osprey to the MH-60 series aircraft

F. CONCLUSIONS

The addition of two MH-60 helicopters to the mother ship provides a wide range of operational capabilities. The two primary missions will be mother ship support and force protection. Secondary missions include SAR.

III. RADAR CROSS SECTION

An analysis of the radar cross section of the clean hull was performed to form a baseline to which it could be compared to other ships of similar size. As a large ship, from which to conduct operations, it is not necessary to achieve the low radar cross sections that can be achieved through the use of advanced materials such as PCS and other materials. It is still useful, however to understand if there are specific vulnerabilities to the ship if it is tracked by either active homing missiles or surface search radars.

The Lucern Hammer program was used to conduct monostatic analysis of the clean –hull representation produced with the Rhino program. The incident radiation is taken at 0.17 degrees to simulate a ship's radar location 150ft above the ocean and at a range of 10NM not taking into account he curvature of the earth or an incoming missile that is not necessarily sea skimming. Three different frequencies were run. The first is at 1GHz to represent the standard L band radar used on Styx missiles. The second and third frequencies at 3 GHz and 10 GHz represent the two bands of frequencies produced by common navigational radars.

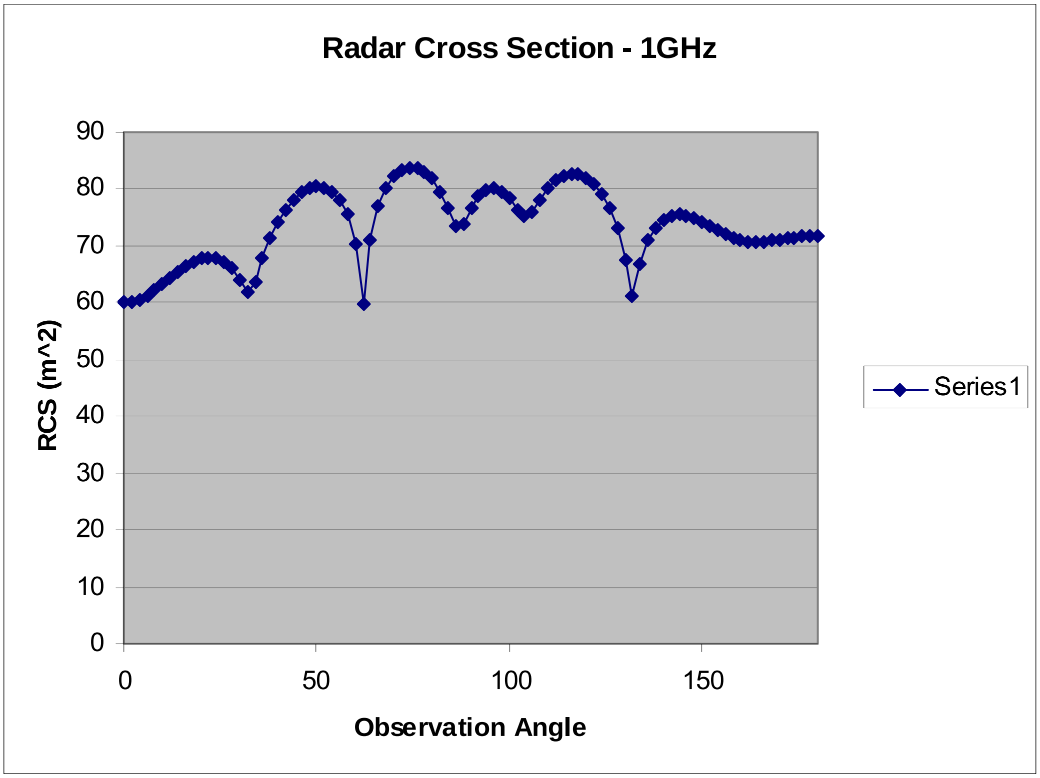

Figure 210. Radar Cross Section 1 GHz

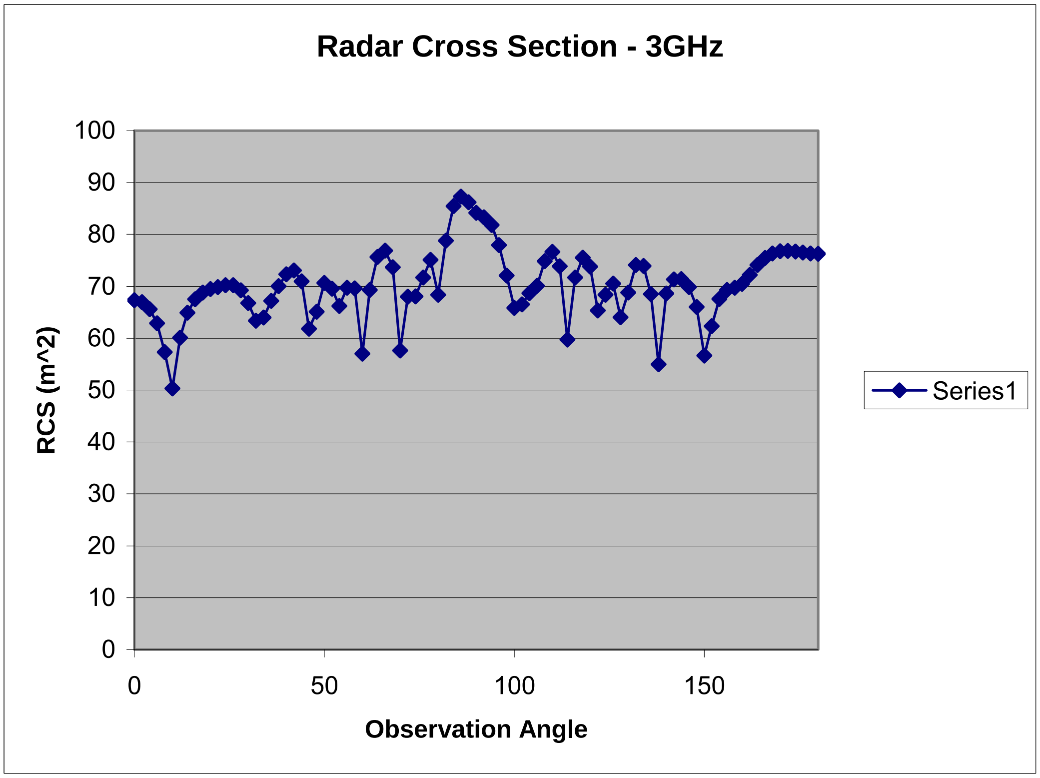

Figure 211. Radar Cross Section 3GHz

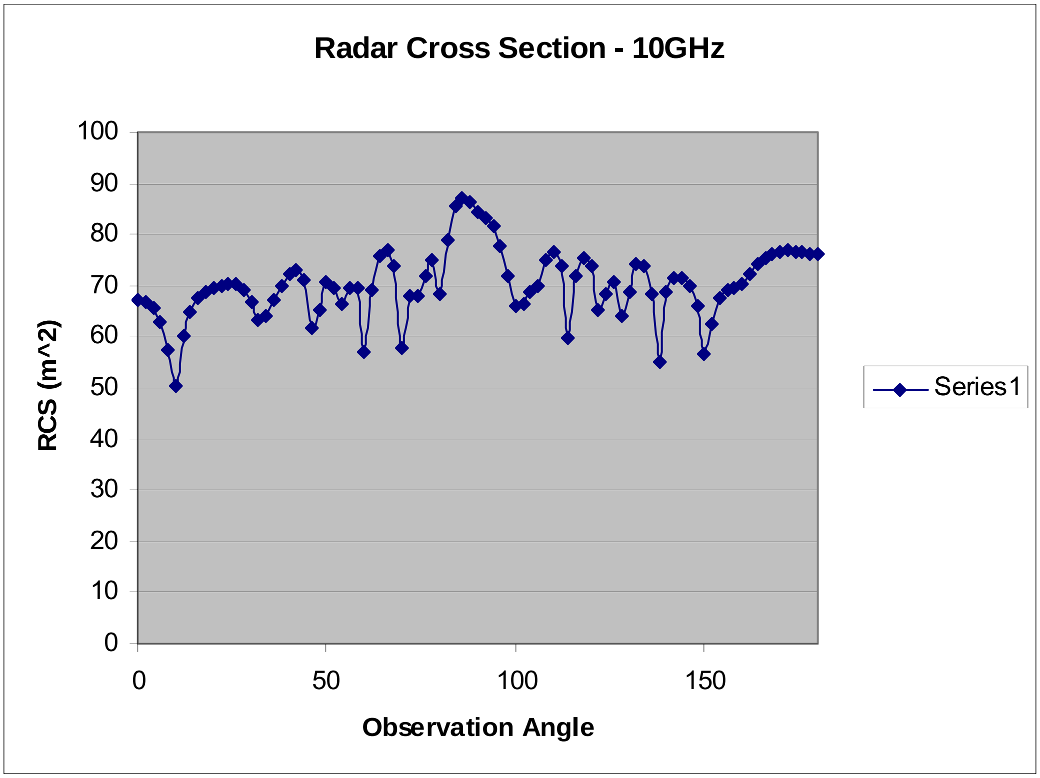

Figure 212. Radar Cross Section 10 GHz

A. CONCLUSIONS

The design of the clean hull provides an excellent basis to build up a minimal radar cross section from. As expected, there is a slight rise in the radar cross section as the beam is approached due to the basically a long, flat plate that the ship would present directly at the beam. Certainly, the fully designed ship will have a much larger cross section as objects such as lifelines, antenna wires, hatches, etc are added to the outside of the ship, but this data gives the absolute lower bound from which to build-up from. The relatively small increase in radar cross section along the observation angle does show that for the clean hull ship there is really no preferential attack angle or vulnerability axis.

APPENDIX F (PROPULSION)

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I. SYSTEM OVERVIEW

The unique hull form of TSUNAMI presented the Hull and Mechanical design team with a very challenging problem in selecting a propulsion system that would provide enough thrust to achieve the objective maximum speed of 30 knots while still being efficient enough at a cruising speed of 20 knots to meet the 10,000 nautical mile range threshold. The tri-hybrid hull provided three acceptable possibilities for propulsion placement: the after ends of the center and side hulls. The forward ends of the side hulls were also considered, but were deemed unacceptable due to the close proximity of the moon pool and the inefficiency expected to result from the prop wash having to go around the side hulls.

The side hulls were seen as the best choice for placing propulsion units as their wash would be well aft of the moon pool, provided that enough thrust could be generated to maintain the required 20 knot speed of advance. If necessary, additional thrust from propulsors in the center hull could be used to augment the side hull units to achieve the 30 knot maximum speed as interceptor launching operations would not be conducted in those conditions. The next challenge was how much propulsive power could be squeezed into the side hulls and whether direct mechanical drive or electric drive would be most appropriate way to create that power.

II. ELECTRIC VERSUS DIRECT DRIVE

The dimensions of the side hulls reduced the feasible direct drive options down to either a single gas turbine or a pair of gas turbine engines per side hull. Diesel engines of equivalent power were too bulky to fit into the side hulls. The gas turbine option was not much better as they would require vast volumes of intake air and exhaust gasses to be routed through the struts attaching the side hulls to the ship plus the probable need for using reduction gear. Initial resistance calculations (see Appendix B) showed that approximately 30 knots could be achieved on the power provided by two large gas turbine engines (one per side hull) which reduced the magnitude of the uptake problem, but this arrangement would still present daunting maintenance issues especially if any major turbine components ever had to be replaced.

The use of electric drive in the side hulls eliminated the uptake and reduction gear problems while significantly reducing the maintenance issues as most marine motors are designed for use in externally mounted pods and therefore require little periodic maintenance. Electric motors also allowed the prime movers generating the electricity to be placed in more convenient locations and provided much more flexibility in prime mover selection which permitted tailoring the power generated to the power required to produce thrust at different speeds. This power matching significantly decreases fuel consumption rates as the most efficient prime mover(s) can be selected for the power required under a given operating condition.

Improved fuel efficiency combined with the arrangement flexibility provided by electric drive drove the design team to choose it over direct drive options. High Temperature Superconducting (HTS) motors and generators produced by American Superconductors were selected for this system. Details of why HTS motors and generators won out over other types can be found in Appendix D (Electrical).

III. GENERATOR PRIME MOVERS

With the selection of electric drive for the propulsion units, options for prime mover selection that were unsuitable due to the confined spaces in the side hulls were back on the table for consideration. The three leading contenders were gas turbines, diesel engines, a nuclear fired steam plant or some combination of these.

A. NUCLEAR

Nuclear power seemed at first to be an attractive option. The nearly unlimited range provided by such a system would have been a great benefit for TSUNAMI that would have allowed not only a single seven day search mission to be completed without re-supply, but several in succession limited only by how much fuel could be carried for the interceptors and support aircraft. The factor that eliminated the nuclear steam plant from consideration was the very short time periods expected prior to getting underway dictated by the concept of operations. Having to go from complete shut down to underway with only a few hours notice is not feasible with current nuclear plants.

B. DIESEL

Large diesel engines were the next likely option as their fuel consumption rates are significantly lower than comparable gas turbine engines. However, diesels of this size are quite heavy. For example, the S.E.M.T. Pielstick model PC 4.2 B rated at 26.5 MW weighs 360 metric tons (t) compared to only 22 t for a Rolls Royce MT30 gas turbine (including the enclosure) [1,2]. This limited the diesels to being placed as low as possible in the hull to achieve an acceptable center of gravity for the ship. The only spaces available that would allow low placement are either forward or below the mission bay. Placement below the mission bay would require very long and circuitous uptake and exhaust ducts to avoid the mission bay which spans the entire beam of the ship. Placement forward of the mission bay would simplify this problem, but would require running cables capable of carrying approximately 80 MW of power nearly the entire length of the ship. This length of cable would also be detrimental to efficiency as the resistance of these cables increases with length.

C. GAS TURBINE

The relatively light weight of gas turbines allows them to be placed directly above the side hulls without seriously impacting TSUNAMI's center of gravity. This permits large volume uptakes of relatively short length (approximately 40 feet) to be routed nearly vertically aft of the mission bay along the after end of the superstructure while at the same time providing for short cable runs from the generators to the frequency conversion units and then down the struts to the motors in the side hulls. These benefits outweighed the cost of the relatively high fuel consumption rates as long as enough fuel could be carried to meet the range requirements.

The two gas turbines capable of meeting the power required to sustain 24 knots were General Electric's LM6000 and Rolls Royce's MT30 [2,3]. The fuel required to run these engines for 7 days at 24 knots was computed as well as that of the LM2500+ as it was only 13% overloaded and had poorer fuel consumption which allowed for a more conservative estimate [4]. The results, found in Table 1, showed that TSUNAMI had sufficient volume available to meet these fuel requirements plus a considerable margin. The fuel consumption rates used in the table are maximum efficiency values which we thought was appropriate as all three engines are loaded to at least 80% at 24 knots.

	LM6000	**LM2500+**	**MT30**
Engine Loading:	80%	113%	95%
Fuel Consumption Rate:	0.329 lb/shp-hr 0.00555 ft^3/shp-hr	0.354 lb/shp-hr 0.00597 ft^3/shp-hr	0.310 lb/shp-hr 0.00523 ft^3/shp-hr
Required Fuel Volume:	126910 ft^3 949355 gallons	136554 ft^3 1021494 gallons	119581 ft^3 894529 gallons
Weight of Fuel:	3360 LT	3615 LT	3166 LT

Figure 213. Gas Turbine Fuel Requirements

D. MT30 SELECTION

The initial look at fuel consumption indicated that the MT30 was the best choice for meeting power requirements for both cruising and maximum sustained speed conditions, but this had to be confirmed using fuel consumption rates other than one fixed at maximum efficiency to ensure that the MT30 retained its advantage throughout the power band.

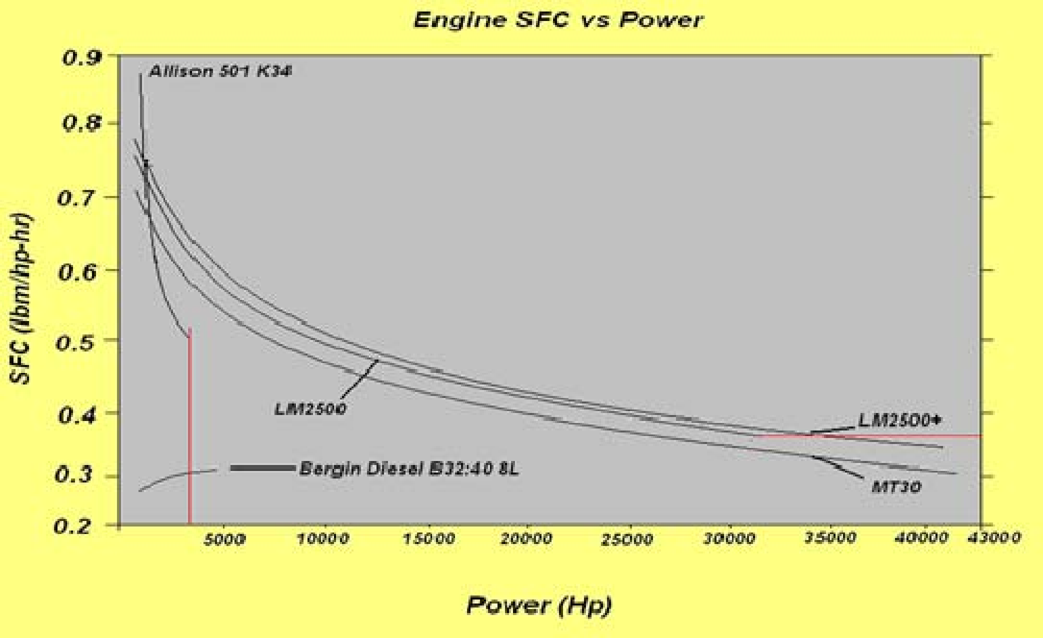


Figure 214. Specific Fuel Consumption for various engines (from ONR).

The above graph was provided by the Office of Naval Research which tested many of the engines we were interested in under US Navy standard conditions (100°F with 4 and 6 inches of water inlet and exhaust losses at sea level). This supported the initial results in favor of the MT30. As an added advantage, Rolls Royce publishes all pertinent weights and volume specifications for both the engine and the associated enclosure which greatly simplified our engine room arrangements.

IV. AUXILIARY POWER

In order to avoid the poor low power fuel efficiency inherent to gas turbine engines, a power source other than the main MT30 gas turbine engines was deemed necessary. Having auxiliary power generators provides much better fuel efficiency at lower speeds and allows an extra level of redundancy to be built into the system. We examined two options to meet this requirement: a small gas turbine generator and a diesel generator.

The standard small gas turbine generator currently in use by the US Navy is the Allison model 501-K34. This engine is compact, available as a complete unit with the enclosure and generator included, and rated to generate up to 2.50 MW sustained [5]. The diesel engine we looked at was the Bergen model B32:40 8L. This engine is also available as a complete unit, and, although it has a higher sustained power generation rating of up to 3.84 MW and weighs just over twice as much as the Allison, it has nearly the same footprint as the Allison [6].

Once again, the fuel efficiency (also shown in Fig. 1) was the driving factor and we chose to use a pair of Bergen diesel engines. The Bergen diesels also have the advantage of not requiring as much air flow as the Allison engines which would have been an issue given the location of the auxiliary engine space low and forward in the ship. This auxiliary engine space location also helped mitigate the disadvantage of the Bergen engines having twice the mass of the Allison engines. The conventional generators that come standard with the complete Bergen power generation package were not replaced with HTS generators because we did not feel the advantages of the HTS generators were worth installing another set of high temperature cryogenic plants in this case.

V. PROPULSOR SELECTION

Water jets and conventional screws were considered for propulsor selection. Water jets were very attractive, at first, for use on the center hull when we thought thrust in excess of what could be provided by the side hulls was going to be required to achieve 30 knots. This was due to their lack of external appendages that would disrupt the flow of water forward of the interceptor launch/retrieval area and create a larger wake. This extra thrust was found to be unnecessary.

Water jets were also compared to conventional screws for use in the side hulls. It quickly became apparent that although water jets can have peak efficiencies on par with screws, they are very inefficient at the low end of their designed power band and cease producing usable thrust at all below this power band. We attempted to overcome this by mixing large and small water jets on each side hull, but this also was not efficient and was deemed overly complex.

Several different conventional screw designs of the Wageningen B-series were compared using the Propeller Optimization Program (version 1.5) from the University of Michigan. Screws of four, five and six blades were optimized for a diameter of 6.09 meters (just under the narrow diameter of the side hulls to keep the navigational draft of the ship at 34 feet) at a 20 knot speed of advance with 24 knots of thrust being produced (again reflecting the sea state five requirement). Fixed pitch was used for all comparisons due to its higher open water efficiency and the ability of the HTS motors to reverse rotational direction. This also eliminated the need for complex pitch control equipment being installed in the confines of the side hulls. The most efficient screw was a five bladed propeller with a diameter of 6.09 meters and pitch of 6.5 meters operating at 108 revolutions per minute. This screw also had good open water efficiency at all speeds never going below 67% until below two knots.

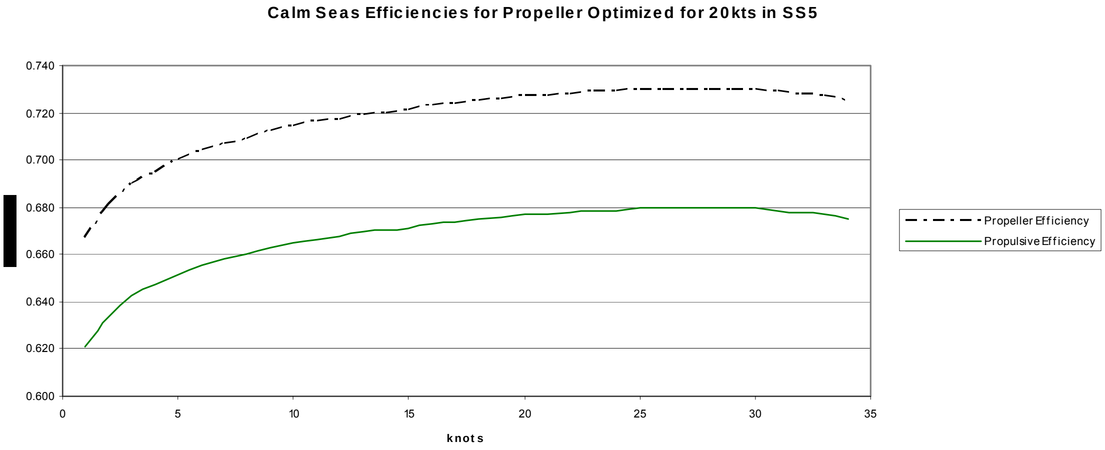
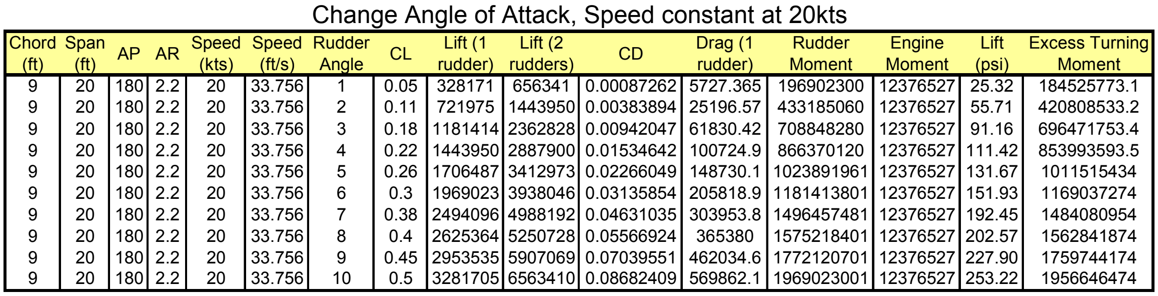


Figure 215. Propeller and propulsive efficiencies

VI. RUDDER CALCULATIONS

Having determined that one screw per side hull was sufficient to propel TSUNAMI at all required speeds, we had to ensure that the turning moment created by the loss of a screw or motor on one side could be overcome by the ships rudder. If rudders could not provide sufficient compensating force, two screws per side hull would have to be installed to allow the ship to continue its mission or make it back to port albeit with a diminished top speed.

This proved unnecessary. As seen in Table 2, the turning moment generated by only having one engine functioning is overcome by the rudders with less than a degree of rudder angle. Lift and drag forces in the table are in pounds force. All moments are in pound feet.



Change Angle of Attack, Speed constant at 20kts

Chord (ft)	Span (ft)	AP	AR	Speed (kts)	Speed (ft/s)	Rudder Angle	CL	Lift (1 rudder)	Lift (2 rudders)	CD	Drag (1 rudder)	Rudder Moment	Engine Moment	Lift (psi)	Excess Turning Moment
9	20	180	2.2	20	33.756	1	0.05	328171	656341	0.00087262	5727.365	196902300	12376527	25.32	184525773.1
9	20	180	2.2	20	33.756	2	0.11	721975	1443950	0.00383894	25196.57	433185060	12376527	55.71	420808533.2
9	20	180	2.2	20	33.756	3	0.18	1181414	2362828	0.00942047	61830.42	708848280	12376527	91.16	696471753.4
9	20	180	2.2	20	33.756	4	0.22	1443950	2887900	0.01534642	100724.9	866370120	12376527	111.42	853993593.5
9	20	180	2.2	20	33.756	5	0.26	1706487	3412973	0.02266049	148730.1	1023891961	12376527	131.67	1011515434
9	20	180	2.2	20	33.756	6	0.3	1969023	3938046	0.03135854	205818.9	1181413801	12376527	151.93	1169037274
9	20	180	2.2	20	33.756	7	0.38	2494096	4988192	0.04631035	303953.8	1496457481	12376527	192.45	1484080954
9	20	180	2.2	20	33.756	8	0.4	2625364	5250728	0.05566924	365380	1575218401	12376527	202.57	1562841874
9	20	180	2.2	20	33.756	9	0.45	2953535	5907069	0.07039551	462034.6	1772120701	12376527	227.90	1759744174
9	20	180	2.2	20	33.756	10	0.5	3281705	6563410	0.08682409	569862.1	1969023001	12376527	253.22	1956646474

Figure 216. Excess turning moment created by rudders at varying angles

The rudders are 20 ft tall by 9 ft wide giving a total surface area for both rudders of 360 ft^2. This size was derived by taking the three separate submerged hulls and running rudder estimation calculations on each using the equations found in Gilmer and Johnson's *Introduction to Naval Architecture* [7] and then adding the resulting areas together. The rudders on TSUNAMI are actually larger than this because these calculations only reflect the rudder area in the wash of the screws. If the extra 64 ft^2 of area per rudder is included the total surface area comes to 488 ft^2. The design team felt that this extra area would be beneficial since the rudder estimation calculations could not account for the increase in directional stability expected to be created by the side hull struts.

VII. POWER VS. SPEED

Taking the resistance calculations derived in Appendix B, we generated a graph of shaft horsepower (SHP) requirements over the range of speeds we expect TSUNAMI to be able to achieve. These values were adjusted for generator, motor and propulsive efficiencies as well as electrical transmission losses. The results are listed in Table 3.

knots	ft/sec	EHP	SHP	Prop. Eff.	Prplsve. Eff.	RPM	SHP w/ Losses	MW w/ Losses
1	1.69	2.31	3.56	0.667	0.621	5.9	3.96	0.003
2	3.38	17.13	26.35	0.681	0.634	11.7	28.70	0.021
3	5.06	55.39	85.22	0.690	0.642	17.4	91.62	0.068
4	6.75	127.52	196.18	0.695	0.647	23.1	209.39	0.156
5	8.44	243.63	374.81	0.700	0.652	28.7	397.19	0.296
6	10.13	413.63	636.35	0.704	0.655	34.3	670.52	0.500
7	11.81	647.28	995.82	0.707	0.658	39.9	1044.83	0.779
8	13.50	954.28	1468.13	0.709	0.660	45.5	1536.04	1.145
9	15.19	1344.42	2068.34	0.712	0.663	51.1	2154.91	1.607
10	16.88	1827.86	2812.09	0.714	0.665	56.7	2921.57	2.179
11	18.57	2415.46	3716.09	0.716	0.667	62.3	3849.98	2.871
12	20.25	3119.19	4798.76	0.717	0.668	67.9	4964.72	3.702
13	21.94	3952.45	6080.69	0.719	0.669	73.5	6273.50	4.678
14	23.63	4930.24	7584.98	0.720	0.670	79.1	7814.61	5.827
15	25.32	6069.27	9337.34	0.721	0.671	84.8	9606.68	7.164
16	27.00	7387.90	11366.00	0.723	0.673	90.5	11661.51	8.696
17	28.69	8905.40	13700.61	0.724	0.674	96.2	14037.40	10.468
18	30.38	10643.50	16374.61	0.725	0.675	102.0	16754.00	12.493
19	32.07	12630.94	19432.21	0.726	0.676	107.8	19855.05	14.806
20	33.76	14893.85	22913.61	0.727	0.677	113.7	23380.01	17.434
21	35.44	17434.57	26822.41	0.727	0.677	119.6	27368.36	20.409
22	37.13	20235.24	31131.14	0.728	0.678	125.5	31721.16	23.654
23	38.82	23294.80	35838.15	0.729	0.679	131.4	36467.29	27.194
24	40.51	26657.99	41012.30	0.729	0.679	137.3	41732.27	31.120
25	42.20	30411.86	46787.47	0.730	0.680	143.3	47543.61	35.453
26	43.88	34667.42	53334.50	0.730	0.680	149.3	54196.45	40.414
27	45.57	39544.35	60837.47	0.730	0.680	155.6	61820.67	46.100
28	47.26	45157.98	69473.82	0.730	0.680	162.1	70596.59	52.644
29	48.95	51603.68	79390.27	0.730	0.680	168.7	80673.31	60.158
30	50.63	58939.14	90675.60	0.730	0.680	175.6	92141.02	68.710
31	52.32	67170.01	103338.48	0.729	0.679	182.6	105152.60	78.412
32	54.01	76245.43	117300.66	0.728	0.678	189.6	119523.84	89.129
33	55.70	86134.46	132514.55	0.727	0.677	196.7	135211.80	100.827
34	57.39	97514.15	150021.77	0.725	0.675	204.1	153497.65	114.463

Transmission Eff.:	0.98
Gen. & Motor Eff.:	0.98
Hull Efficiency:	1.00
Rotative Efficiency:	0.95
Shaft Trans. Eff.:	0.98

Figure 217. SHP efficiency calculations

This data was then used to generate a graph of megawatts required versus ship's speed and the power outputs of the installed electrical generators overlaid upon it. Figure 3 shows how the MT30's power output makes for a superb match to the required power for cruising speed. The top speed shown with all engines online has 2 MW reserved for ship's electrical power loads. Specific numbers for power generation are in Table 4.

	MW for 1 engine	MW for 2 engines	SHP for 1 engine	SHP for 2 engines
MT30	36.00	72.00	48276.80	96553.60
Bergen B32:40L8A	3.84	7.68	5149.50	10299.00
Total (2 MW reserved)		77.68		104152.60

Figure 218. Power generation totals

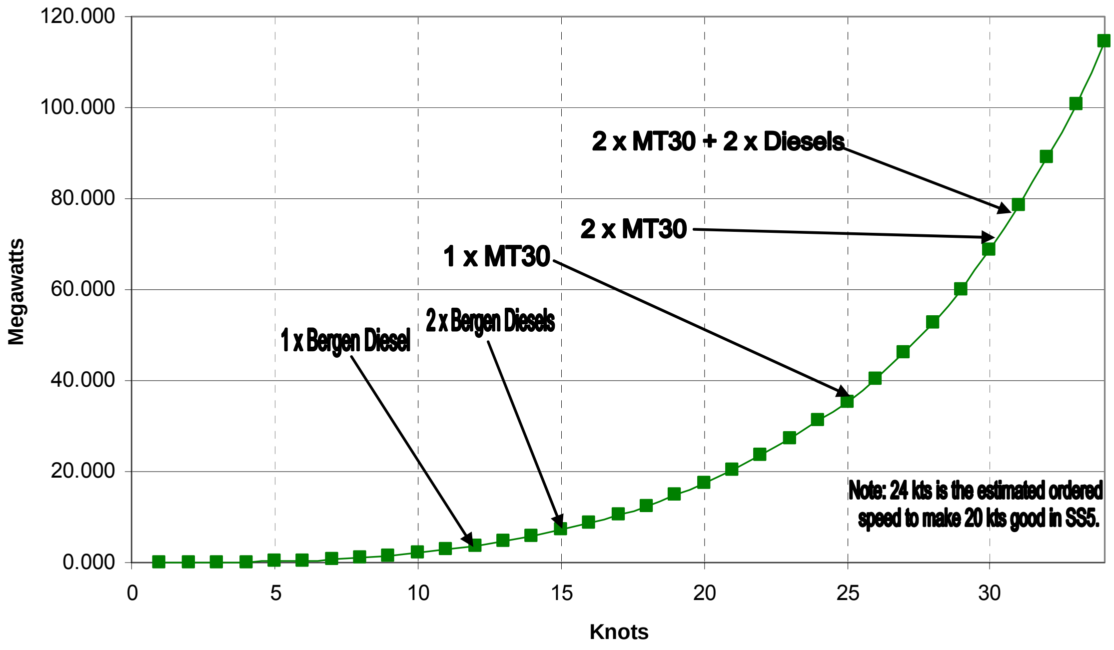


Figure 219. Generated power vs. ship’s speed

VIII. MANEUVERING THRUSTER

Two factors combined to motivate the design team to install a maneuvering thruster in the bow of TSUNAMI: the large amount of sail area, and the need to get underway on very short notice. The first factor is self explanatory. The second is derived from the concept of operations and the desire to not be required to depend on tugboat availability to complete our mission.

The first option considered was a tunnel thruster. The sharp bow design of the center hull seemed to be an ideal location for a simple tunnel thruster, but the drag that would be caused by the tunnel at high speeds was a cause for concern. We thought we could solve this problem by installing retractable doors (similar to the doors on submarine torpedo tubes) to close the tunnel when the thruster was not in use, but that level of complexity detracted from the tunnel thruster's major advantage of simplicity.

The design team then looked at retractable thrusters and chose a steerable model produced by Wärtsilä. The Wärtsilä LIPS model 250 thruster is rated at 2 MW, provides 360° vectoring and is retractable to minimize drag at high speeds [8]. This can also serve as an emergency propulsion unit capable of driving the ship at 9 knots. Though the unit is so large that it cannot be placed as far forward in the hull as a tunnel thruster could, the LIPS 250 is powerful enough to overcome this reduction in moment arm as it can produce over 78,000 pounds of thrust.

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APPENDIX G (L & R BAY)

TABLE OF CONTENTS

I. INTRODUCTION

The operational analysis of alternative in the preliminary stages of the systems engineering project showed the need for a 95 ton, 28ft beam, and 120 foot long interceptor. Based on this result, conventional launching and recovery systems were ruled out. Such designs as a sling arm davit or ramp were deemed too hazardous by initial surveys conducted by the TSSE group. Additionally, based on recent analysis of movable overhead hoist systems, the hoist designers believed a vertical stationary hoisting system with movable pallets over a moon pool would be the simplest and most effective means of launch and recovery.

II. HOIST SYSTEM LOCATION

A. OVERVIEW

A number of launch and recovery locations were considered for the problem of operating the launch and recovery system on the mothership in sea state 5 including: craned off from the main deck, ramped or hoisted from within an internal bay on the side of the ship, externally moored to the side of the ship, dropped from under the outrigger (such as a missile on an aircraft wing), and upon a submersible deck such as a heavy lift ship. The arrangement and type of the launch and recovery system was also opened up to the suggestions of a select group of students and faculty through a TSSE MTR survey. Further detail of the interceptor hoist selection process is covered in the Mission Bay Appendix of this report.

B. MAIN DECK CRANE SYSTEM

The main deck crane operation system is the basis for the mothership concept of converting a Maritime Sealift Command ship for the purpose of launching interceptors to various targets. It would be considered a relatively low cost conversion since systems already in place. The simplicity of the design would be familiar to sailors requiring little to no additional training.

Figure 220. Military Sealift Crane Operations

The operations currently conducted by the MSC do not launch boats over 10 tons. The fundamental disadvantage of this design is its inability to sustain launch and recovery of 100 ton interceptors which can sustain operations in environmental conditions at or greater that Sea State 5. Further calculations of the typical roll motion of a Navy Military Sealift Command type vessel show the immediate development of a negative metacentric height assuming the pendulating interceptor is lifted from the water with adequate clearance to prevent hitting the hull of the mothership.

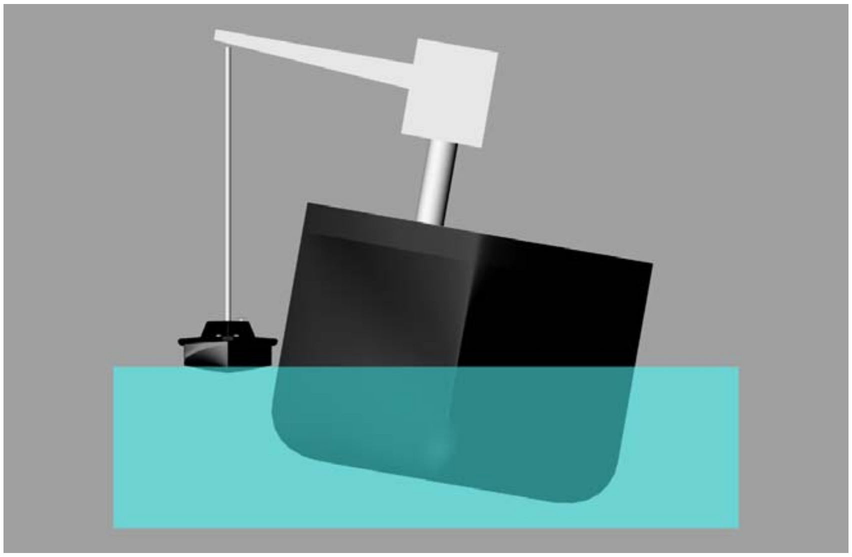


Figure 221. Crane Handling of Interceptor with +10 degree roll

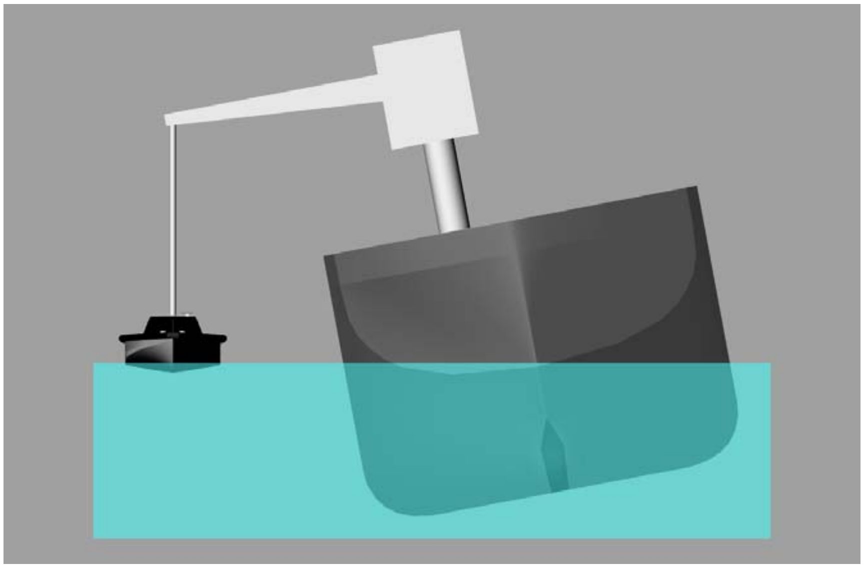


Figure 222. Crane Handling of Interceptor with -10 degree roll

In a Sea State 5 conditions, there is no doubt the large sea lift command ships can maintain stability with their cargo securely fasten to the deck, however, rarely is a MSC conducting crane operations in such environments. To understand the gravity of the dangers of crane operations, the interceptor is modeled as a point mass at the end of a massless cable. We define the following variables:

- θ = angle of pendulum (0=vertical)
- R = 60ft: length of cable to bring interceptor to the main deck
- T = 200,000 lbs: tension in cable
- m = 6212 lbm: mass of interceptor
- g = 32.2 ft/sec^2: gravitational constant

Using the equation of motion for the pendulum using Newton's second law for motion about a fixed axis,

$$\tau = I\,\alpha$$

- τ = net torque
- I = rotational inertia
- $\alpha = \theta''$= angular acceleration

The rotational inertia about the pivot on the crane is

$I = m\,R^2$

Torque can be calculated as the vector cross product of the position vector and the force. The magnitude of the torque due to gravity works out to be $\tau = -R\,m\,g\sin\theta$.

$$\theta'' = -\,{}^{g}\!/_{R}\,\sin\theta$$

Assuming a frequency of:

$$\frac{1}{2\pi}\sqrt{g/R}$$

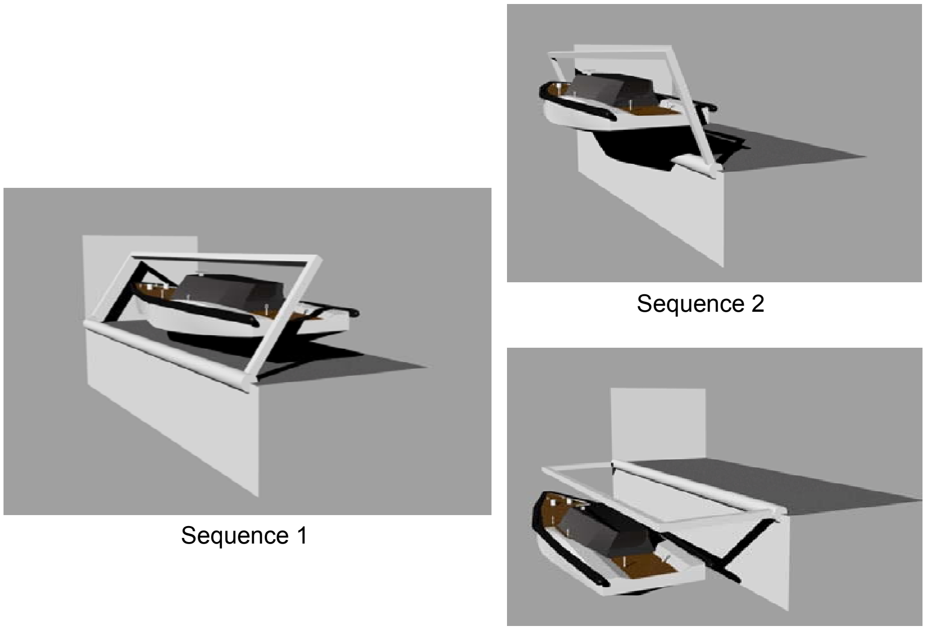
With only a 10 degree roll applied to the ship, due to the large dimensions required to pull the interceptor to the main deck, the interceptor will translate 45 feet laterally, and 32 feet vertically in the period of the wave. This situation would make loading the interceptor from a crane seriously dangerous to all personnel. Unless multiple cranes are positioned to mitigate the forces exerted on the interceptor, this type of loading is not feasible. The use of two large cranes for interceptor hoisting is the only feasible fit on board current ships. To mitigate any swing laterally, a third 100 ton crane must be positioned to create a “Trapezoidal” cable configuration. This arrangement would have to come from an additional ship (i.e. ship on either side of the interceptor) or an overhead archway configuration.

C. SIDE RAMP SYSTEM

Initial concept design considered a boat slip or ramp secured to the sides of the mothership. Further consideration was ruled out due to the assumption that any vessel would be subject to excessive list and would experience roll periods that would hinder recovery of interceptors.

D. COUNTER BALANCE SIDE DAVIT

A standard davit system was ruled out based on the excessive weights that would be required by the interceptors required by the concept of operations. An alternative design to the standard davit was considered where the weight of the interceptor would be supported through a rotating counter balance davit arm.



Sequence 1

Sequence 2

Sequence 3

Figure 223.   Counter Balance Side Launch Davit

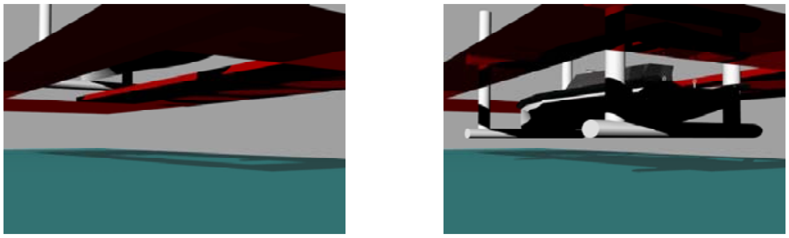
Further study of this design shows an excessive amount of clearance is required for the counter balance davit to swing through from a safe distance from the ship to a secure location on the deck. In order to accommodate the clearance requirement, a hoist or pulley system may be implemented. However, further analysis shows that, as with side launch of previously discussed forms, the roll of the ship in Sea State 5 is too excessive for safe and continuous operations.

E. WET MOORING (DRAGGING)

Using the mothership for towing of the interceptor vessels to the Rendezvous position is ruled out due to the possibility of encountering environmental conditions more severe than that required for continued mission operations and the continuous risks involved with prolonged towing operations. Additionally, the towing configuration would restrict mothership speed of advance due to the possibility of swamping the interceptors.

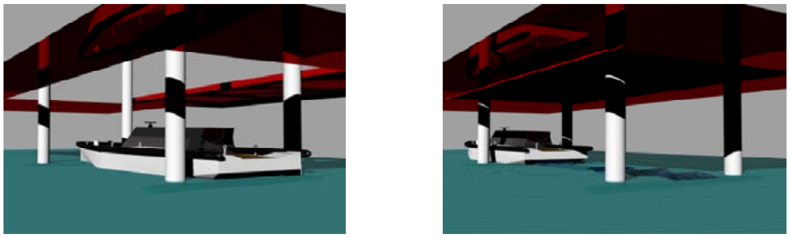
F. BOMBAY DROP SYSTEM

The Bombay drop system is a concept much like that used for the lowering of research vehicles from current configurations of Small Waterplane Area Twin Hull (SWATH) ships. However, due to the limited dimensions and payload capacity of the SWATH, it alone could not be considered for the mission. This type of configurations could not be implemented in a trimaran design due to the low clearance under the outriggers. This type of configuration would require designing the outriggers of the trimaran 35 feet above the waterline, then require and additional 40 feet for interceptor storage. A height of 80 feet above the waterline was considered excessive and would lead to stability problems. Additionally, it was deemed too restrictive to store interceptors on the top deck of a ship if this type of configuration was used in a Tsunami hull.



1. Door Opens

2. Lower Hoist



3. Undock Interceptor

4. Interceptor Underway

Figure 224. Bombay Drop System

H. STERN RAMP SYSTEM

The stern ramp has proven to be very effective in the past. One concern for us was that the ramp itself would have to be lowered while still maintaining headway. The size of the ramp necessary to hold a 100 ton interceptor would create exceptionally high amounts of drag. The second concern was could we make a ramp that was able to hold this much weight and with stand the drag force exerted on it. We felt that other options could prove more beneficial for us.

I. AMPHIBIOUS WET WELL DECK

The amphibious type wet well deck was not used due to the shallow draft required of vehicles entering the well deck. Due to the nature of the mission, an interceptor with sufficient draft, i.e. to sustain operations in Sea State 5, must be used. This would require a vessel with a draft in excess of 7ft. Current Amphibious ship configurations have a well deck sill entrance depth of 4.5 to 6ft.

Additionally, embarkation landing craft into the well deck of the amphibious ship is restricted to;

- When the ship is at anchor.
- When the ship is underway with bare steerageway.
- When the ship is moored.

These restrictions, due to limited sill clearance, severely limit operational envelopes and rule out amphibious ships and more specifically, wet well deck systems from use for Maritime Threat Response.

III. TYPE OF HOIST SYSTEM

A. OVERHEAD TRANSLATING HOIST SYSTEM

Many overhead systems that are in use currently have many problems with translation. The bending moments created on the overhead rails, that span considerable lengths, are excessive due to the twisting created by various sea states. For this reason we again wanted to search for a better answer.

B. OVERHEAD STATIONARY HOIST SYSTEM

This system provides what we feel is the best answer. The system lifts from overhead, thus avoiding the drag problem of dropping a ramp in the water while moving. The system does not translate and avoids the problem of having to move while overcoming a twist in the track.

Currently there is a smaller version of the system that we chose on private yacht. The interceptors will have to have a hard system for the lifting slings. The evolution of moving the interceptors once lifted is addressed later in the report.

Figure 225. Paul Allen's Octopus

The picture of the yacht, Octopus, is owned Paul Allen. The picture and some of the work was completed by Roodberg. The over head system in the TSUNAMI would need to be modified from the above version to accommodate the excessive weights. There are various companies that make these lifts of this magnitude. Roodberg and Marine Travelift are two that we attempted to contact for information on various systems.

IV. MISSION BAY PALLET SYSTEMS

A. RAIL SYSTEM

The pallet system that we chose is designed and manufactured by Marine travel lift. We wanted a system that moved on the deck to avoid tripping hazards and to avoid a problem if there was a mechanical failure with a desk system. With a desk system, a problem could result in a signal point of failure, the pallets become grid locked. With our traversing pallet system we were able to build in some redundancy. The pallet itself has multiple wheels, the driving source is interchangeable, and the pallet has all wheel steering. These pallets come in various sizes to accommodate the end user. They are also available for custom design. To ease the process we are using a COTS air bladder as the suspension system on the pallet. This air bladder design eliminates the need for exact position on the pallet as in traditional boat trailers.

B. TURNTABLE "CD-CHANGER" SYSTEM

1. Concept

One possibility for storing, deploying, and retrieving a multiple of interceptors would be to utilize a rotating horizontal plate, either circular or rectangular in nature, resembling a compact disk (CD) changer. This method would involve a large rotating plate, circular or rectangular, where multiple interceptors would reside and be internally moved to sequentially position interceptors for deployment and retrieval. A typical launch and recovery sequence might occur as follows:

2. Launch

i) Horizontal plate is rotated to place interceptor of choice in desired position at top of stern ramp

ii) Crew embarks

iii) Interceptor is eased down stern ramp via engagement hook connected to bow of interceptor

iv) Once interceptor in water, engine is started

v) Engagement hook is released, and interceptor departs on mission

3. Recovery

i) Interceptor approaches stern ramp

ii) Interceptor bow latches on to engagement hook on stern ramp

iii) Engine is stopped once interceptor stern clear of water

iv) Interceptor is pulled up ramp to its own spot in rotating horizontal plate (circular or rectangular)

v) Crew disembarks

vi) Horizontal plate is rotated as necessary to allow other interceptors to be deployed/retrieved

V. CONCEPTUALIZED LAUNCH AND RECOVERY

Critical to the success of MTR mission, the ship required to perform the mission must be able to load and unload multiple boats equipped with personnel and detection devices used to search merchant shipping while underway. In order to accomplish this task without interfering with shipping transit times, the MTR Con-OPS requires no more than a 12 hour delay of the merchant ship in question. This significantly reduces the ability of a ship's crew to launch and recover intercept vessels regularly. This also restricted the actual type of interceptor used for MTR. The MTR requirements generated an interceptor approximately 120ft long with a 28ft beam. An approximate total weight of the interceptor is 95 tons. Additionally, the requirements impose operation in sea state five.

A number of launch and recovery locations were considered for this problem including: from the main deck, from within a bay on the side of the ship, from under the outrigger (such as a missile on an aircraft wing), and upon a submersible deck. The arrangement of launch and recovery was also offered to the TSSE MTR survey. The most popular means of launch and recovery was from the stern of the ship.

In addition to the location, the device to which the interceptor is recovered is critical to design. The weight of the interceptor and complexity of the launch/recovery problem required the hoisting equipment to be integral to the design of the ship. Some of the devices considered will be addressed in other sections. It had been determined by the TSSE team that a FIXED overhead hoist would be used to lower and raise the interceptor out of the sea, and a pallet with rollers on the deck would be used translate the ship into a securing area.

Due the desired location of the launch and recovery of the interceptor and the decision for a fixed overhead hoisting harness in an arch type of arrangement would be required for the TSSE mothership. Additionally, it was recognized that it would be prudent to not keep the interceptor suspended any lengthy amount of time. Thus, it was necessary to design the stern of the ship in such a way that would allow for the interceptor to translate in the water under the hoist harness, be lifted to a specified height in which the pallet may roll under the interceptor, bridging the loading bay allowing the interceptor to be lowered onto it and released from the harness.

VIII. SYSTEM LAYOUT

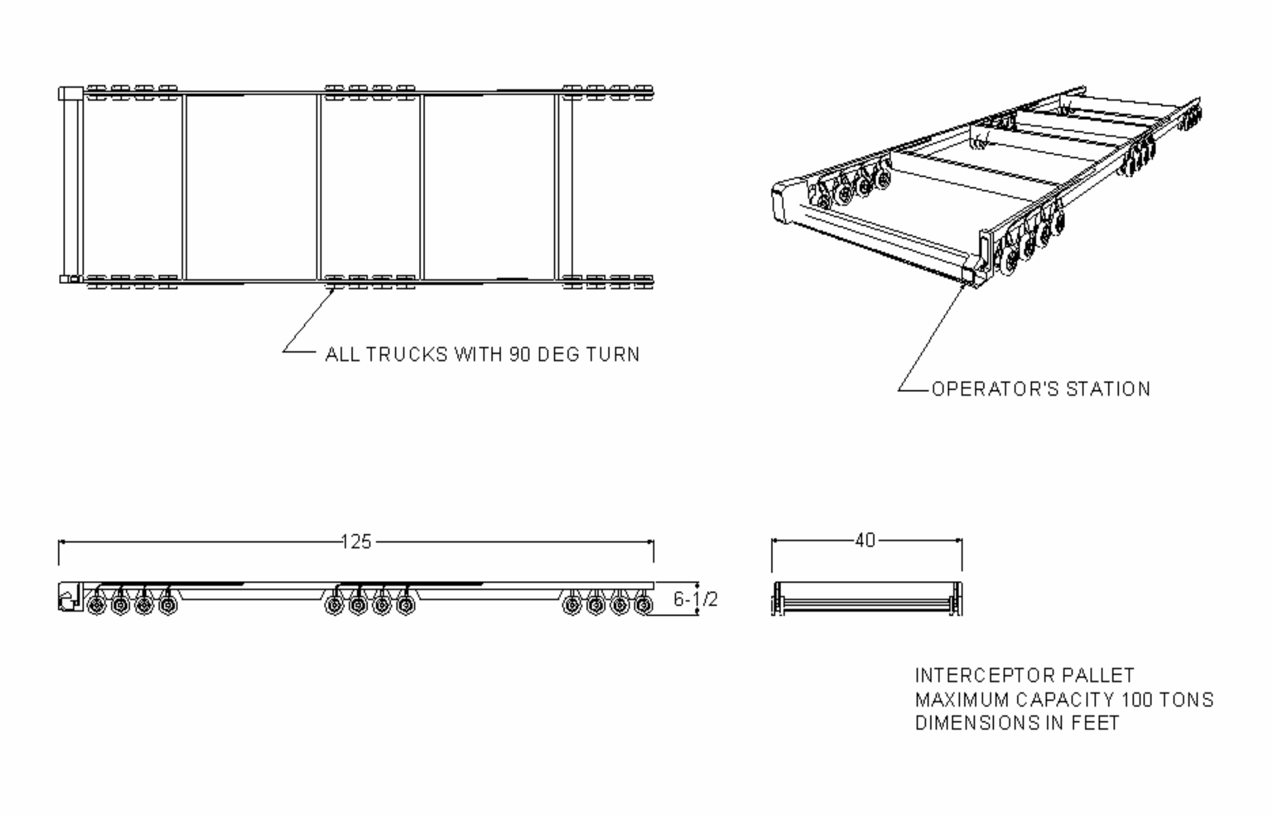


Figure 226. Interceptor Pallet Three View Drawings

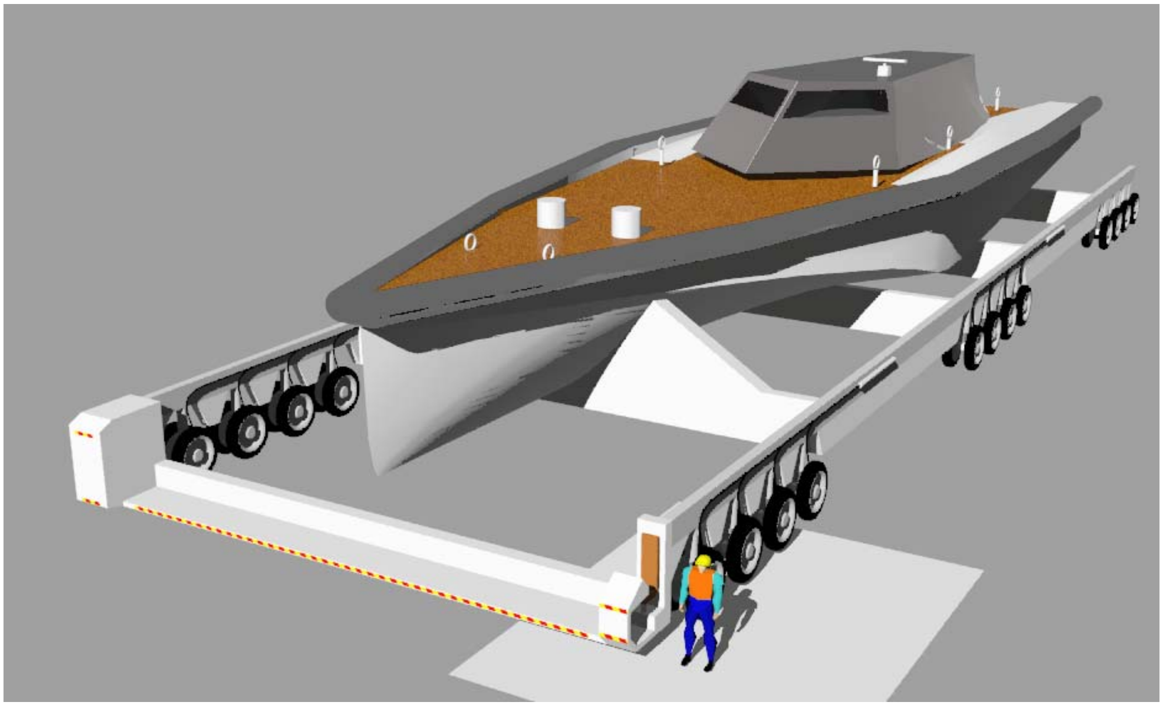


Figure 227. Conceptual Drawing of Interceptor Pallet System

X. RISK ASSESSMENT LAUNCH AND RECOVERY

A. INTRODUCTION

The complexity of the mothership concept requires the implementation of a unique hoist and storage system. The concept of carrying 100 ton ships in the hold of a carrier and launching them at sea is acknowledged to be a risky endeavor. It is the purpose of this section to analyze and assess the level of risk associated involved with this design.

B. PROCEDURE OUTLINE

This section walks the reader through a brief outline of the interceptor recovery procedure envisioned by the design team.

1. MODE 1: Interceptor Approach

1. Mothership at Station Speed and Course; Interceptor Pilot request permission to make approach
2. Interceptor Pilot is granted permission to make his approach on the Mothership.
    - 2.1. Interceptor is aligned behind the mothership and increases speed to make the approach to the open archway of the stern.
    - 2.2. Hoist Operator on Mothership deploys the Towing cable to the stern on ship using an overhead control system and track guided payout mechanism.
    - 2.3. When Interceptor is aligned with stern, Hoist Operator lowers the remotely controlled Sea Painter with buoy from the overhead payout mechanism.
3. Interceptor Pilot maneuvers vessel to draw Sea Painter over bow and allow Interceptor deck hand to feed Sea Painter into high speed capstan
4. While Interceptor is kept on station, Deck hand takes in Sea Painter which is attached to tow cable.
    - 4.1. Once Tow cable is on deck, Deck hand attaches Cable Eye, to Remotely Released Tow Connection.
5. When signaled by Deck Hand, Interceptor pilot slowly reduces engine power and allows the tow cable to take up the strain.
6. Once Tow cable has full strain, Pilot takes engines to idle.

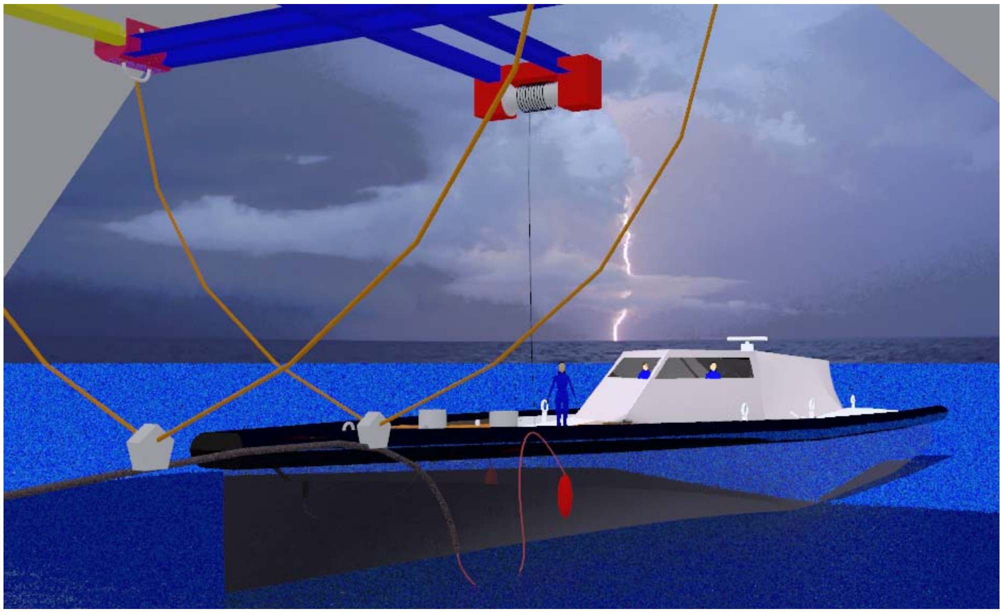


Figure 228. Overhead Sea Painter and Tow Cable Payout Mechanism

2. MODE 2: Interceptor in Tow

1. Interceptor is under Mothership control.
    1.1. Pilot maintains engines at idle in the event of emergency break away or change course.
2. Hoist Control Officer verifies proper tension on towing cable, from Stress Monitoring Panel in Hoist Control Booth.
3. Hoist Operator draws Interceptor into Hoist Bay using Remote Tow Cable Control Console in Hoist Control Booth.
4. Interceptor is drawn into the bay directly under overhead Hoist.
    4.1. Tension on Tow Cable is automatically adjusted by accelerometers on the Tow mechanism

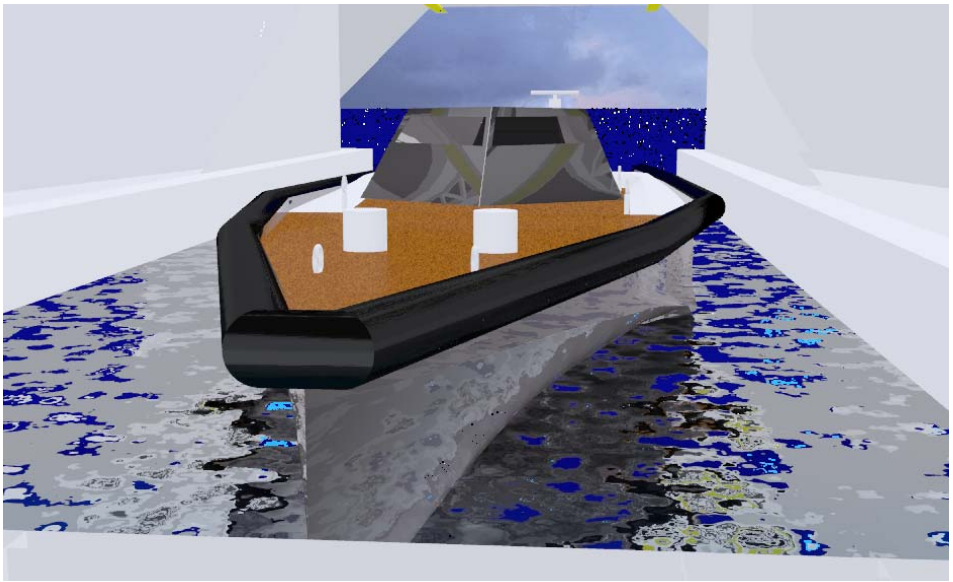


Figure 229. Interceptor in Tow inside the Hoist Bay of the Tsunami ship

3. MODE 3: Interceptor Hoisting

1. While the interceptor is maintained in position by the Hoist Operator and automatic systems, the Hoist Operator lowers the Eight Hoist Cables
2. When the hoist cables are lowered into position, the Deck hands onboard the interceptor attach the cables to the hard points on the interceptor deck.
3. Each cable hoist has an individual accelerometer and strain meter to hoist at the optimum speed.
4. The Hoist Operator, in the Hoist Control Booth, actuates the Lifts to take up strain and increases strain to hoists the Interceptor from the water.
5. Hoist speed is increased to relatively quickly draw interceptor several feet up.
6. Interceptor is hoisted to a maximum height and secured.
7. Tow cable is slacked and removed from Interceptor. Overhead Tow Cable supports detached and Tow Cable is drawn into ship.

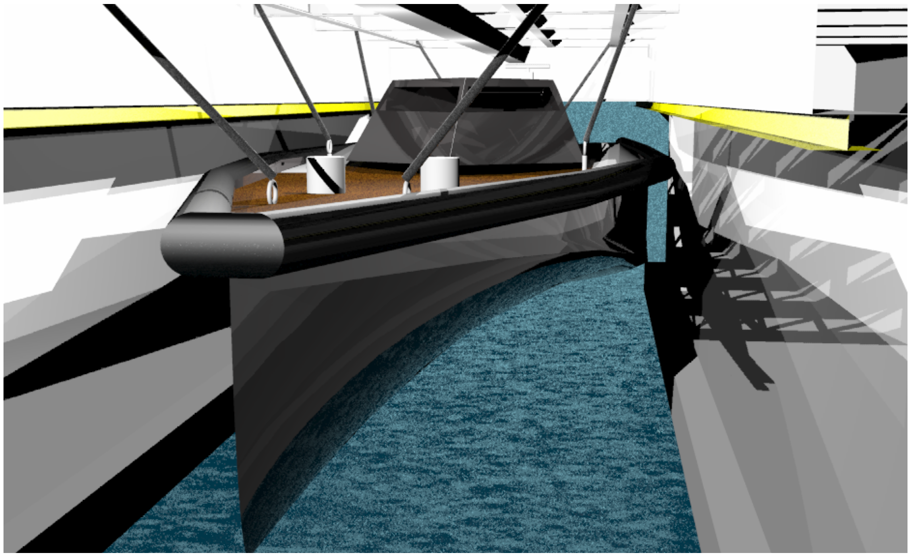


Figure 230. Hoisting Interceptor over Pallet

4. MODE 4: Pallet Drop

1. The Pallet is rolled out over the Hoist Bay and under the interceptor.
2. Pallet is locked in position.
3. Interceptor is lowered to just above Pallet Hard point, Inflatable supports are fully pressurized to required support pressure using compressor.
4. Interceptor is lowered completely onto pallet; pressure on pallet is transmitted to Hoist Control Booth via Wireless LAN.
5. Interceptor is tied down to pallet from personnel on pallet with deck hands on interceptor

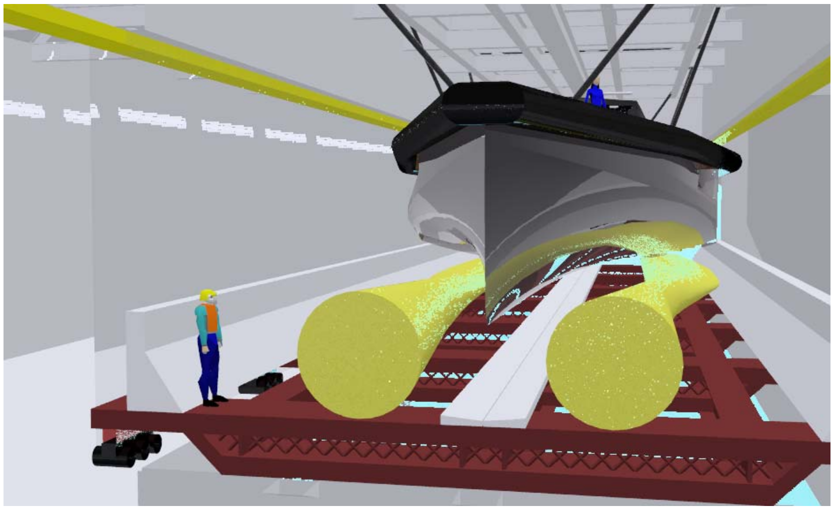


Figure 231. Hoisting Interceptor onto Mission Bay Pallet

5. MODE 5: Pallet Translation

1. Pallet locks are released through multiple safety switches operated by Hoist Control Booth and Mission Bay Personnel
2. Pallet rolls into mission bay, once clear of the Hoist Bay; Mission Bay doors may be closed.
3. Pallet is positioned laterally to designated storage area.
4. Pallet Dollies are rotated to align rollers laterally
5. Pallet Operator translates vehicle into the stowage area.

Figure 232. Rolling Interceptor Pallet into the Mission Bay

6. MODE 6: Stowage and Securing

1. Once pallet is in position, Brakes are set.
2. Pallet and interceptor are secured to mission bay deck through hard points on Deck and on hull on interceptor by Bay Personnel
3. Trim and list of Ship Automatically compensated through automated system.

C. RISK ASSESSMENT

Each mode of operation is assessed individually to control the level of complexity of the analysis.

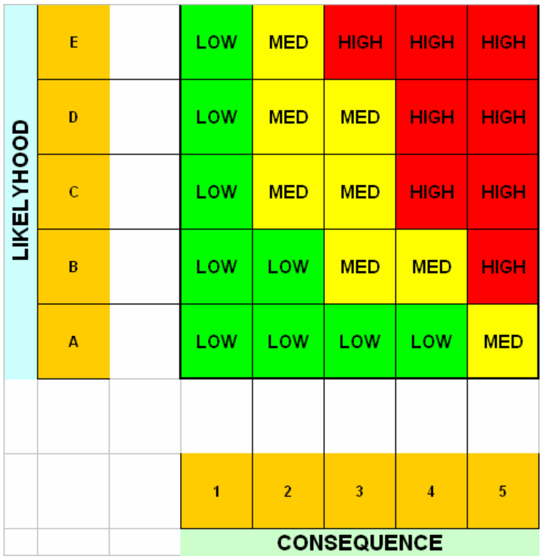
Mission Phase: Launch and Recovery

PROBABILITY	
A	remotely possible
B	Unlikely
C	Likely
D	Highly likely
E	Near Certainty

CONSEQUENCE		
1	Minimal	0%
2	Acceptable with Some reduction in margin	<A%
3	Acceptable with significant reduction	A-7%
4	Acceptable no remainimg margin	7-10%
5	Unacceptable	>10%

		RISK ASSESMENT																		
		PROBABILITY						**CONSEQUENCE**						**RISK**						**Number Per System**
		Modes of Operation						**Modes of Operation**												
800 **MISSION BAY SUB-SYSTEMS**		**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	
802 **Pallet System**																				
802.1 **Dolly**																				14
802.1.1	Wheels	A	A	A	A	B	A	1	1	1	2	1	4	L	L	L	L	L	L	3
802.1.2	Bearings	A	A	A	A	A	A	1	1	1	2	5	1	L	L	L	L	M	L	3
802.1.3	axle	A	A	A	A	A	A	1	1	1	2	5	1	L	L	L	L	M	L	3
802.1.4	steering	A	A	A	A	A	A	1	1	1	2	1	1	L	L	L	L	L	L	4
802.2 **Prime Mover**																				4
802.2.1	lateral electric pulley sys	A	A	A	A	A	A	1	1	1	1	5	1	L	L	L	L	M	L	1
802.2.2	longutidinal mule	A	A	A	A	A	A	1	1	1	1	4	1	L	L	L	L	M	L	1
802.2.3	Control System	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	2
802.3 **Main Frame**																				1
802.3.1	Inflatable Support	A	A	A	B	B	B	1	1	1	1	1	1	L	L	L	L	L	L	6
802.3.2	Solid Frame	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
802.4 **Locking & Securing Systems**																				1
802.4.1	Guide Rail	A	A	A	A	A	A	1	1	1	1	2	1	L	L	L	L	L	L	2
802.4.2	Brake system	A	A	A	B	B	B	1	1	1	4	4	1	L	L	L	M	M	L	14
802.4.3	Interceptor Tie-down Sys	A	A	A	B	A	A	1	1	1	1	1	1	L	L	L	L	L	L	8
802.4.4	Deck Anchor Sys	A	A	A	A	A	A	1	1	1	2	1	1	L	L	L	L	L	L	8
802.4.5	Lateral Cable Securing	A	A	A	A	A	A	1	1	1	1	5	1	L	L	L	L	M	L	8
804 **Hoist System**																				
804.1 **Hoist machinery**																				2
804.1.1	Electrical/Control	A	A	A	A	A	A	1	1	4	4	1	1	L	L	L	L	L	L	4
804.1.2	Mechanical	A	A	A	A	A	A	1	1	1	4	1	1	L	L	L	L	L	L	4
804.1.3	Operator Error	A	A	B	B	A	A	1	1	1	1	1	1	L	L	L	L	L	L	2
804.1.4	Electrical/Motor	A	A	A	A	A	A	1	1	1	3	1	1	L	L	L	L	L	L	4
804.1.5	Motion Sensors	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	4
803 **Tow Cable System**																				
803.1 **Winch Machinery**																				1
803.1.1	Payout Mechanism	A	A	A	A	A	A	2	2	1	1	1	1	L	L	L	L	L	L	2
803.1.2	Electrical/Control	A	A	A	A	A	A	2	1	1	3	1	1	L	L	L	L	L	L	1
803.1.3	Electrical/Motor	A	A	A	A	A	A	2	1	1	3	1	1	L	L	L	L	L	L	1
803.1.4	Cable	A	A	A	A	A	A	2	2	1	3	1	1	L	L	L	L	L	L	1
803.2 **Interceptor Connection**																				2
803.2.1	Latch / Hooking	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
803.2.2	Structural	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805 **Mission Bay Support Systems**																				
805.1 **Stability**																				
805.1.1	Ballasting System	A	A	A	A	A	A	1	1	1	1	3	2	L	L	L	L	L	L	2
805.1.2	Roll Detection System	A	A	A	A	A	A	1	1	1	1	3	1	L	L	L	L	L	L	2
805.1.3	Pallet Position Monitoring	A	A	A	A	A	A	1	1	1	2	2	1	L	L	L	L	L	L	2
805.1.4	Weather Warning	D	D	A	A	A	A	2	2	1	1	1	1	M	M	L	L	L	L	2
805.2 **Communications**																				
805.2.1	Voice	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	2
805.2.2	Visual	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805.2.3	Computer / LAN	A	A	A	A	A	A	1	1	1	1	3	1	L	L	L	L	L	L	2
805.3 **Auxiliary**																				
805.3.1	Repair Truck / Hoist	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805.3.2	Mission Bay Doors	A	A	A	B	B	B	1	1	1	1	1	1	L	L	L	L	L	L	2
805.3.3	Deck Drainage System	A	A	A	A	B	B	1	1	1	1	2	1	L	L	L	L	L	L	2
805.3.4	Ventilation Systems	A	A	A	A	A	A	1	1	1	1	1	3	L	L	L	L	L	L	2
805.3.5	Interceptor Replenishment Sys	A	A	A	A	A	A	1	4	1	1	1	1	L	L	L	L	L	L	1
805.4 **Damage Control**																				
805.4.1	Fire Detection	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805.4.2	Smoke / Fire Boundary	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805.4.3	Flooding Containment / Removal	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	1
805.4.4	Toxic Atmosphere	A	A	A	A	A	A	1	1	2	1	1	1	L	L	L	L	L	L	1
805.4.5	Pallet Securing	A	A	A	A	A	A	1	1	1	1	1	1	L	L	L	L	L	L	

Figure 233. Mothership Mission Bay and Hoist Sub-system Risk Analysis



LIKELYHOOD

E	LOW	MED	HIGH	HIGH	HIGH
D	LOW	MED	MED	HIGH	HIGH
C	LOW	MED	MED	HIGH	HIGH
B	LOW	LOW	MED	MED	HIGH
A	LOW	LOW	LOW	LOW	MED
	1	2	3	4	5

CONSEQUENCE

Figure 234. Navy Risk Evaluation Assessment Guide

D. EXPLANATION OF MODERATE RISKS

1. Mode 1 and 2: Approach and Tow

The moderate risks associated with mode 1 fall under the weather warning sub-system 805.1.4. Weather conditions are typically heavily weighted in risk assessments. In especially the cases for Mode 1 and Mode 2, the interceptor and mothership are in close proximity to each other while in the water. Sudden changes in currents, winds, or waves may cause a loss of control of either vessel. Weather changes can never be fully predicted, as such, the design of the Tsunami ship provides substantial stability and significantly dampened roll period, as discussed in previous sections, for sustained recovery of interceptors.

2. Mode 3: Hoist Operations

No sub-systems in mode 3 have a risk greater that Low.

3. Mode 4: Pallet Drop

The moderate risks associated with mode 4 involve the pallet braking systems. If this sub-system of the pallet becomes in-operative at critical locations, a serious degradation of the mission bay system occurs. A total loss of the braking system may result in a stuck pallet or runaway pallet. In either case quadruple backup systems are in place to ensure positive control of the pallets at all times. Although the severity of failure is high, the probability of occurrence is low. Additionally, redundant systems are in place to provide substantial backup.

4. Mode 5: Pallet Translation

The moderate risks associated with pallet translations sensitive to pallet sub-systems specifically. Due to the single door for interceptor loading and unloading, the event of a pallet getting stuck in a critical location is very severe. However, I most instances the probability of occurrence is low. In addition, numerous redundancies are called out for each pallet system, such as the braking systems, prime mover, and dolly sub-systems. Each pallet is to have 14 dollies (7 on each side). Of those 14 dollies 2 on each side can catastrophically fail. In the event of failure, an onboard operator will disengage the dolly and continue pallet operation.

5. Mode 6: Stowage and Securing

No moderate levels of risk are associated with the storage and securing mode of operation.

XI. COMPUTER RENDERING SYSTEMS USED

The following computer programs were used in the development of the MTR Tri-hybrid hull:

RENDERING:	SOLIDWORKS
	RHINOCEROS 3.0
	AUTOSHIP
ANALYSIS:	RHINOMARINE
	AUTOSHIP
	EXCEL
	MATLAB 7.0

APPENDIX H (MTR SURVEY)

MARITIME THREAT RESPONSE SURVEY

Please indicate your background. Check all that apply:

☐Professor ☐ Naval Aviation ☐ Surface Warfare Qualified
☐ Surface Warfare Non-Qualified ☐ Submarine
☐ USMC ☐ USA ☐ USAF ☐ EDO Qualified
☐ Other ____

Maritime Threat Response Survey

You have been given this survey to assist the Maritime Threat Response (MTR) TSSE Group in making critical decisions and influence the design of the system being generated. We ask you use your experience and subjectivity in answering the questions. Although some questions may seem like there is an obvious answer. Please consider each question fully, since major design decisions may depend on your answer. Again, we are calling upon your experience and subjectivity in filling out this questionnaire.

Background:

The MTR system's objective is to carry out boarding of merchant vessels suspected of malicious intent (WMD, Al Qaeda cells, using the ship as a weapon) leaving Singapore or Hong Kong en route to San Francisco. There are approximately 20 Vessels of Interest (VOIs) that will leave from these Asian ports over a 24 hour period. This means the spread between the first ship and the last ship could be as large as 500 miles. The MTR system must intercept the VOIs' track in order to board and search VOIs in a 7 day period without slowing the merchant's speed of advance (expected to be 20 knots).

The system is comprised of motherships carrying smaller waterborne interceptors that will be utilized to intercept and transfer search teams aboard VOIs. Furthermore, aviation support (Helos and/or Ospreys) will be available to move equipment, extra gear, and complete other extraneous missions. The combined system must be able to board and search all 20 ships in 7 days without slowing the merchant's speed of advance. Furthermore, the system is designed to be carried out in Sea State 5 (12 foot wave height, 9 second period) for a worst case weather situation. The picture below is conceptually how the system will be organized. As you can see, the system will require multiple motherships in order to cover all 20 VOIs leaving Hong Kong or Singapore.

Each interceptor will carry 24 boarding team personnel to carry out the search mission on the VOIs. These teams are not expected to be as highly trained as the Navy SEALS nor can they be considered helpless in the event of a hostile VOI crew. As of now, the search crews are expected to do a 2-section (12-hour-on/12-hour-off) rotation.

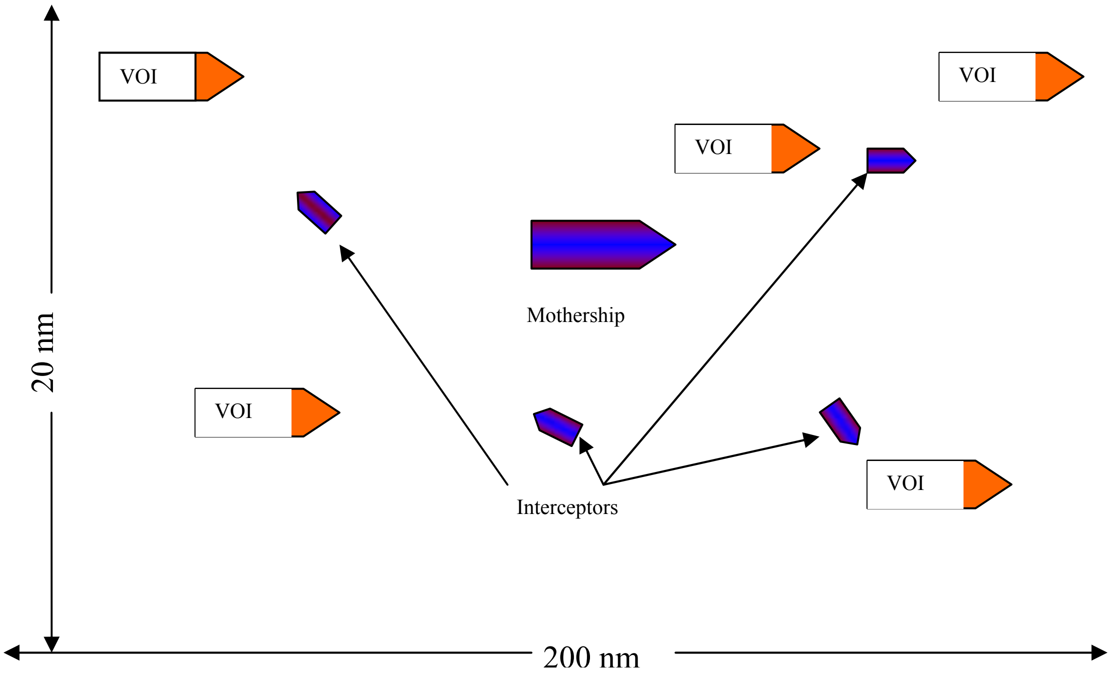


Figure 235. Operation Box

Purpose:

We are asking you to fill in the questionnaire below. Some questions are yes/no format and others are subjective asking you about certain attributes if you were the Captain or Boat Officer. The first part of the questionnaire will ask you about the Concept of Operations, then the mothership, and finally the Interceptor.

Concept of Operations: These questions pertain to how the system will be utilized and how certain functions are best employed. Use your best judgment having the background from above to make your choices below.

1a. Do you think it is reasonable to leave search teams onboard a VOI for 12 hours without the presence of an interceptor or mothership in the immediate vicinity?

☐ Yes ☐ No

Comments:

____

____

1b. If Yes to above, in case of emergency, how much time lag is acceptable for the mothership to assist the Boarding Team in case of an emergency? (Medical, Emergency Egress, etc)

☐ Less than 30 minutes by aircraft. ☐ Less than 30 minutes by interceptor

☐ Less than 1 hour by aircraft ☐ Less than 1 hour by interceptor

☐ Less than three hours by aircraft of interceptor

Comments:

____

____

2a. In your opinion after reviewing the above picture, what is an acceptable distance for a MOTHERSHIP to be from a vessel being searched **with** an interceptor consistently alongside the VOI while a search team is onboard?

☐ 0-20 nm ☐ 0-50 nm ☐ 0-100 nm ☐ 0-150 nm ☐ > 150 nm

Comments:

____

____

2b. In your opinion after reviewing the above picture, what is an acceptable distance for a MOTHERSHIP to be from a vessel being searched **without** an interceptor continually alongside the VOI while a search team is onboard?

☐ 0-20 nm ☐ 0-50 nm ☐ 0-100 nm ☐ 0-150 nm ☐ > 150 nm

Comments:

____

____

3. Referring to the picture above, there are 5 VOIs that could be as far as 150nm from the mothership, an acceptable ratio of interceptor:VOI is:

☐ 1:1 ☐ 1:2 ☐ 1:3 ☐ 1:4 ☐1:5

Comments:

____

____

4. The system will have aviation support, as such, the boarding team members could have their equipment moved via helicopter, however, high winds might make this approach unusable. Furthermore, there might not be a perfect ergonomic spot on the VOI to drop the cargo. On the other hand, bringing the equipment on the interceptor might require rigging to pull the equipment up from over the side from a height of 100 ft, or, to carry the equipment up an accommodation ladder at the expense of the boarding team's time to search. As a boarding officer, I would prefer to deliver my equipment on an interceptor vice a helicopter recognizing there are difficulties in both approaches?

○	○	○	○	○	○	○
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Comments:

5. The MTR Concept is designed to not slow the speed of commerce or put a delay in the delivery of commerce. However, given a 14 day transit from the Asian ports to San Francisco, how many hours delay would you consider acceptable to place on these VOIs?

☐ 6 ☐ 12 ☐ 18 ☐ > 24 ☐ No delay is acceptable

Comments:

6. Given that the interceptor could weigh between 50 – 100 tons, and the sea state could be as adverse as sea state 5. Would a stern ramp system be capable to launch/recover interceptors or side launched through a series of cranes?

☐ Stern ramp is preferred ☐ Craning the interceptors is preferred.
☐ Either way could lead to disastrous events. ☐ Either way is acceptable

Comments:

7. As a Captain of a mothership, do you think it is wise to have a single mothership capable of carrying more than 5 interceptors, within reason, to search 5 VOIs at once?

☐ Yes ☐ No

Comments:

8. Are you willing to leave your team unattended onboard a VOI? In other words, are you comfortable leaving a boarding team alone for 7 days or have the presence of the interceptor on the horizon?

☐ Yes ☐ No

Comments:

9. I would feel most comfortable (Circle one):

a. With an interceptor alongside the merchant at all times.
b. With an interceptor able to assist at regular intervals (12 hour interval)
c. With an interceptor "on call" at short notice (roughly 3-4 hours)
d. Without an interceptor alongside except for initial boarding, departing, or during an emergency.

Comments:

10. If the option was available to be towed behind the VOI, I would tie my interceptor up to the ship.

○	○	○	○	○	○	○
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Comments:

Mothership: The following questions apply to the mothership. This ship's purpose is to support/move the interceptors to a position such that the search missions can proceed. This ship will be considered the center point of the system capable of carrying sufficient food, parts, equipment for the missions and enough fuel for itself, the interceptors, and any aviation support.

1. In the event of sea state five (significant wave height of 12 ft), I am willing to accept the risk and launch my interceptors to complete the boarding mission.

○	○	○	○	○	○	○
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Comments:

2. As Captain of my ship, I prefer stability in high sea state (able to withstand up to Sea State 5 without significant damage or crew discomfort) at the expense of range.

○	○	○	○	○	○	○
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Comments:

3. In order to complete the mission, I would prefer having a mothership capable of launching and recovering interceptors in all sea states and weather conditions at the expense of maintaining relative position amongst the interceptors. This means that the mothership may have to slow to 5 knots for 1 hour, while the VOI's continue to proceed at 20 knots.

○	○	○	○	○	○	○
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Comments:

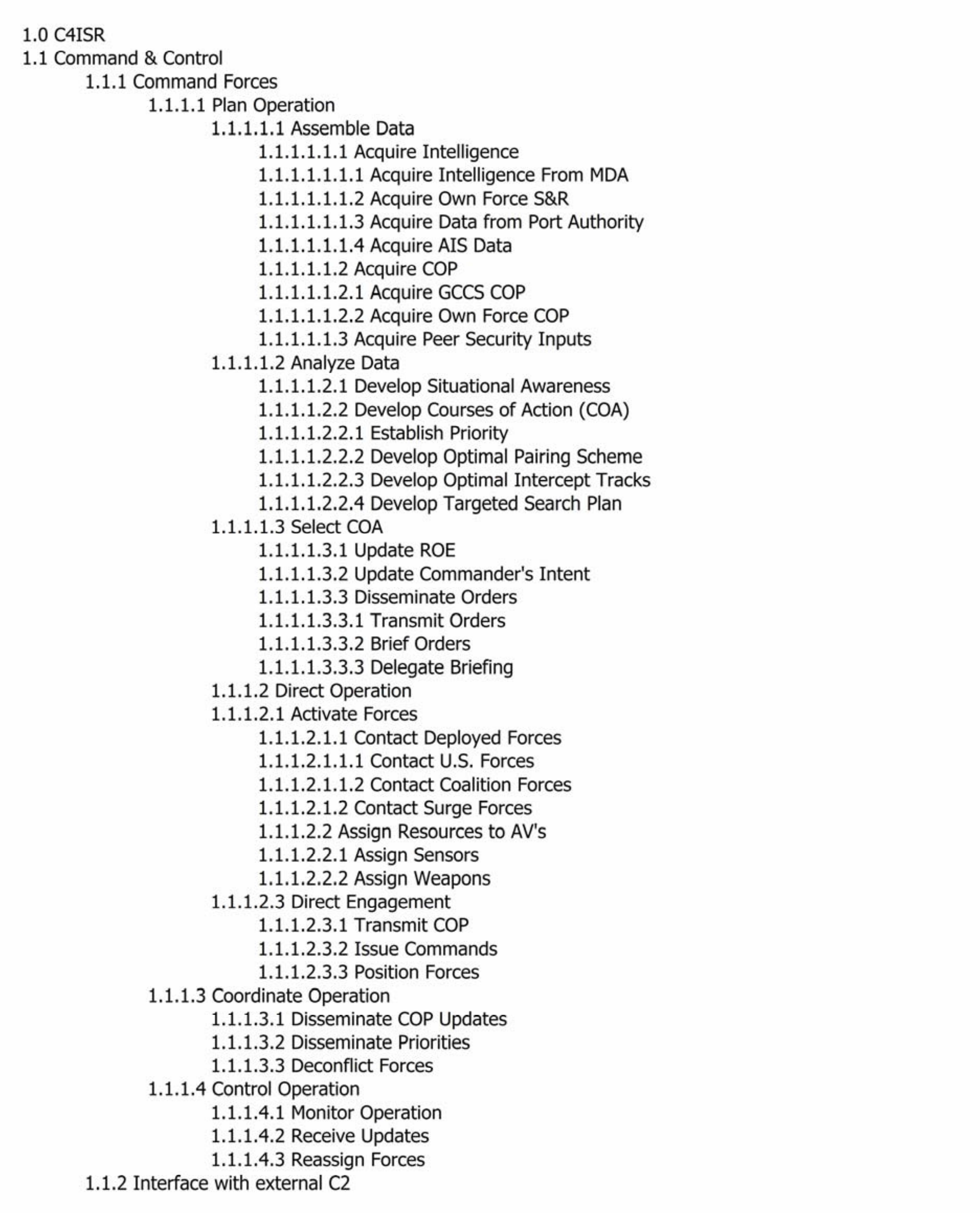
4. We are considering two different methods of launching/recovering interceptors from the mothership. One is to utilize a stern ramp system and the other is an over side using heavy crane lift system. Knowing the complication caused by weather and sea states up to sea state 5, what would you be more comfortable with:

○	○	○	○	○
Side Launch		Equally effective		Stern Launch

Comments:

APPENDIX I (SEA 9)

SEA-9 FUNCTIONAL REQUIREMENTS DECOMPOSITION



- 1.0 C4ISR
- 1.1 Command & Control
  - 1.1.1 Command Forces
    - 1.1.1.1 Plan Operation
      - 1.1.1.1.1 Assemble Data
        - 1.1.1.1.1.1 Acquire Intelligence
        - 1.1.1.1.1.1.1 Acquire Intelligence From MDA
        - 1.1.1.1.1.1.2 Acquire Own Force S&R
        - 1.1.1.1.1.1.3 Acquire Data from Port Authority
        - 1.1.1.1.1.1.4 Acquire AIS Data
        - 1.1.1.1.1.2 Acquire COP
        - 1.1.1.1.1.2.1 Acquire GCCS COP
        - 1.1.1.1.1.2.2 Acquire Own Force COP
        - 1.1.1.1.1.3 Acquire Peer Security Inputs
      - 1.1.1.1.2 Analyze Data
        - 1.1.1.1.2.1 Develop Situational Awareness
        - 1.1.1.1.2.2 Develop Courses of Action (COA)
        - 1.1.1.1.2.2.1 Establish Priority
        - 1.1.1.1.2.2.2 Develop Optimal Pairing Scheme
        - 1.1.1.1.2.2.3 Develop Optimal Intercept Tracks
        - 1.1.1.1.2.2.4 Develop Targeted Search Plan
      - 1.1.1.1.3 Select COA
        - 1.1.1.1.3.1 Update ROE
        - 1.1.1.1.3.2 Update Commander's Intent
        - 1.1.1.1.3.3 Disseminate Orders
        - 1.1.1.1.3.3.1 Transmit Orders
        - 1.1.1.1.3.3.2 Brief Orders
        - 1.1.1.1.3.3.3 Delegate Briefing
      - 1.1.1.2 Direct Operation
      - 1.1.1.2.1 Activate Forces
        - 1.1.1.2.1.1 Contact Deployed Forces
        - 1.1.1.2.1.1.1 Contact U.S. Forces
        - 1.1.1.2.1.1.2 Contact Coalition Forces
        - 1.1.1.2.1.2 Contact Surge Forces
        - 1.1.1.2.2 Assign Resources to AV's
        - 1.1.1.2.2.1 Assign Sensors
        - 1.1.1.2.2.2 Assign Weapons
      - 1.1.1.2.3 Direct Engagement
        - 1.1.1.2.3.1 Transmit COP
        - 1.1.1.2.3.2 Issue Commands
        - 1.1.1.2.3.3 Position Forces
    - 1.1.1.3 Coordinate Operation
      - 1.1.1.3.1 Disseminate COP Updates
      - 1.1.1.3.2 Disseminate Priorities
      - 1.1.1.3.3 Deconflict Forces
    - 1.1.1.4 Control Operation
      - 1.1.1.4.1 Monitor Operation
      - 1.1.1.4.2 Receive Updates
      - 1.1.1.4.3 Reassign Forces
  - 1.1.2 Interface with external C2

    - 1.1.2.1 Interface with Higher Authority
        - 1.1.2.1.1 Request Permission to Act
        - 1.1.2.1.2 Receive Permission to Act
        - 1.1.2.1.3 Provide Status Updates
    - 1.1.2.2 Interface with Coalition C2
        - 1.1.2.2.1 Coordinate Operations
        - 1.1.2.2.2 Transmit Information
        - 1.1.2.2.3 Receive Information
    - 1.1.2.3 Interface with GCCS
        - 1.1.2.3.1 Receive GCCS Data
        - 1.1.2.3.2 Provide GCCS Updates
    - 1.1.2.4 Interface with MDA
        - 1.1.2.4.1 Receive Intelligence Data
        - 1.1.2.4.2 Request Intelligence Updates
        - 1.1.2.4.3 Request aAdditional Intelligence Data
- 1.2 Communicate - Provide Onshc Network
    - 1.2.1 Provide VOX / Data
        - 1.2.1.1 Transmit Voice, Data, Imagery
        - 1.2.1.2 Receive Voice, Data, Imagery
    - 1.2.2 Network MTR nodes
        - 1.2.2.1 Provide Sufficient Nodes
        - 1.2.2.2 Provide Robust Network
        - 1.2.2.3 Minimize Downtime
        - 1.2.2.4 Provide Redundancy
        - 1.2.2.5 Minimize Data Corruption
        - 1.2.2.6 Minimize Nodal Failures
        - 1.2.2.7 Reroute Transmissions around Failed Nodes
    - 1.2.3 Receive MDA Intelligence
        - 1.2.3.1 Maintain Link with MDA
        - 1.2.3.2 Collect, Prioritize, Fuse Information
        - 1.2.3.3 Disseminate Information
- 1.3 Compute
- 1.3.1 Information Assurance
    - 1.3.1.1 Provide Confidentiality
        - 1.3.1.1.1 Support Multi-Security Level Login
        - 1.3.1.1.2 Personnel & Physical Security
        - 1.3.1.1.3 Provide Discrete Access / Mandatory Access Control
        - 1.3.1.1.4 High Assurance System
        - 1.3.1.1.5 Harden System
            - 1.3.1.1.5.1 Software Patches
            - 1.3.1.1.5.2 Turn off Unwanted Services
        - 1.3.1.1.6 Prevent Unauthorized User from Accessing Data While in Transmission
        - 1.3.1.1.7 Prevent Unauthorized User from Accessing Data in Storage
        - 1.3.1.1.8 Separate Classified Data Storage Area
    - 1.3.1.2 Provide Integrity
        - 1.3.1.2.1 Prevent Unknown Data Modification
        - 1.3.1.2.2 Perform Audit Check for Changes to Data
    - 1.3.1.3 Provide Authenticity
        - 1.3.1.3.1 Ensure the User/Data are Authentic
        - 1.3.1.3.2 Provide Authentication by Password, Token,

Biometric

- 1.3.1.3.3 Provide Authentication by Key, PKI
- 1.3.1.4 Provide Availability
  - 1.3.1.4.1 Provide Timely Response to Data
  - 1.3.1.4.2 Provide Redundant System for Synchronization, Backup and Disaster Recovery
  - 1.3.1.4.3 Provide Non-single Point of Failure
- 1.3.1.5 Network Security
  - 1.3.1.5.1 Employ Defense in Depth Strategy

- 1.3.2 Data Fusion
  - 1.3.2.1 Data Association
    - 1.3.2.1.1 Filter Iirrelevant Data
    - 1.3.2.1.2 Categorize Relationship to Scenario
  - 1.3.2.2 Data Analysis
    - 1.3.2.2.1 Refine data - Classification & Identification Using Rule-based prediction
    - 1.3.2.2.2 Refine/update Situation - Deploy Function Status with current traffic
  - 1.3.2.3 Threat Assessment Based on Scenarios
  - 1.3.2.4. Automate Processes & Collaborative Tools
  - 1.3.2.5 Request for Data Recollection
  - 1.3.2.6 Collaborative Feedback
    - 1.3.2.6.1 Provide Reasoning Engine
    - 1.3.2.6.2 Predict Scenario Occurrence
  - 1.3.2.7 Provide "No-MDA" Function
- 1.4 Provide Intelligence
  - 1.4.1 Form Overall Operational Picture
  - 1.4.2 Analyze Operation Needs of Individual Functional Teams
  - 1.4.3 Provide Customized COP Overlays to Teams

- 2.0 Prepare the Battlespace
  - 2.1 Activate Security Measures
    - 2.1.1 Prepare Critical Infrastructure
      - 2.1.1.1 Heighten HSAS
        - 2.1.1.1.1 Initiate Command to DHS to Heighten HSAS
        - 2.1.1.1.2 Receive Compliance that HSAS Has Been heightened
      - 2.1.1.2 Upgrade/augment Existing Security Forces
        - 2.1.1.2.1 Notify Gas Line Personnel on or Near Piers
        - 2.1.1.2.2 Add Security Teams Onboard Essential Boat traffic
        - 2.1.1.2.3 Upgrade/Augment Security Teams at Points of interest
    - 2.1.2 Activate Preplanned Operation Orders
      - 2.1.2.1 Place Specialized Teams on Alert
        - 2.1.2.1.1 Contact Specialized Teams
        - 2.1.2.1.2 Assemble Specialized Teams
        - 2.1.2.1.3 Activate Specialized Teams
      - 2.1.2.2 Get USCG to Activate Specific MARSEC Plan
      - 2.1.2.3 Restrict Non-Essential Boat Traffic
        - 2.1.2.3.1 Initiate Command to USCG to Post a Notice to Mariners

- 2.1.2.3.2 Receive Compliance that "Notice to Mariners" Has Been Posted
- 2.1.2.3.3 Activate Boat Traffic Restriction Teams

- 2.2 Assemble Forces
  - 2.2.1 Activate Required Personnel
    - 2.2.1.1 Decide Team Composition
    - 2.2.1.2 Contact all Necessary Personnel
    - 2.2.1.2 Muster Personnel
  - 2.2.2 Issue Equipment
    - 2.2.2.1 Gather Specialized Equipment
    - 2.2.2.2 Provide Arms and Protective Gear
  - 2.2.3 Prepare Deployment Platforms
    - 2.2.3.1 Set Mission Specific Configurations
- 2.3 Deploy Forces
  - 2.3.1 Embark Deployment Platforms
  - 2.3.2 Move Deployment Platforms into Position
  - 2.3.3 Move Teams to Attacking Vessel
    - 2.3.3.1 Gather Teams for Debarkation of Deployment Platforms
    - 2.3.3.2 Provide Teams with a Means of Transport to the Attacking Vessel
  - 2.3.4 Recover Teams from Attacking Vessel
    - 2.3.4.1 Gather Teams for Debarkation of Attacking Vessel
    - 2.3.4.2 Provide Teams with a Means of Transport to the Platforms

- 3.0 Find/ Fix Threat
  - 3.1 Detect Threat
    - 3.1.1 Scan Area of Interest
      - 3.1.1.1 Scan Mechanically
        - 3.1.1.1.1 Position Automated Scan Device
      - 3.1.1.2 Scan Manually
        - 3.1.1.2.1 Position Search Crew Member
        - 3.1.1.2.2 Conduct Layout Specific Search
    - 3.1.2 Process Data from Scan
      - 3.1.2.1 Process Mechanically
      - 3.1.2.2 Process Manually
  - 3.2 Identify Threat
    - 3.2.1 Analyze Data On-Site
      - 3.2.1.1 Analyze Mechanically
      - 3.2.1.2 Analyze Manually
    - 3.2.2 Analyze Data Off-Site
      - 3.2.2.1 Analyze Mechanically
      - 3.2.2.2 Analyze Manually
    - 3.2.3 Quantify Threat
      - 3.2.3.1 Quantify Mechanically
      - 3.2.3.2 Quantify Manually
  - 3.3 Assess Threat
    - 3.3.1 Determine Intent
      - 3.3.1.1 Observe Declarations
      - 3.3.1.2 Observe Actions
    - 3.3.2 Determine Damage Potential
      - 3.3.2.1 Solicit Intelligence
      - 3.3.2.2 Determine Destructive Potential

3.3.2.3 Determine Execution Time

4.0 Finish Threat
4.1 Use Non-lethal measures
4.1.1 Guard HVU from Internal Threat
4.1.1.1 Guard Control Spaces
4.1.1.2 Guard Crew
4.1.2 Guard HVU from External Threat
4.1.2.1 Escort HVU with Other Units
4.1.2.2 Place Forces on HVU
4.1.3 Warn
4.1.3.1 Use Visual
4.1.3.2 Use Auditory
4.1.4 Conduct Non-lethal Weapon Engagement
4.1.4.1 Use Anti-Personnel NLW
4.1.4.1.1 Target
4.1.4.1.2 Fire Weapon
4.1.4.1.3 Assess Engagement
4.1.4.2 Use Anti-Vehicle NLW
4.1.4.2.1 Target
4.1.4.2.2 Fire Weapon
4.1.4.2.3 Assess Engagement
4.1.5 Shoulder
4.1.6 Tow Disabled Vessel
4.1.7 Conduct SAR
4.2 Use Lethal Measures
4.2.1 Disable
4.2.1.1 Target
4.2.1.2 Fire Weapon
4.2.1.3 Assess Engagement
4.2.2 Sink/Destroy
4.2.2.1 Detect/Track
4.2.2.2 Classify
4.2.2.3 Target
4.2.2.4 Fire Weapon
4.2.2.5 Assess Engagement
4.2.3 Recapture
4.2.3.1 Board AV
4.2.3.2 Secure Control Spaces

5.0 Sustain
5.1 Support Units
5.1.1 Deliver Consumables to Units
5.1.1.1 Deliver to Military Ships
Deliver to Non-Military Ships
5.1.2 Refuel Platforms
5.1.2.1 Refuel Ships
5.1.2.2 Refuel Boats
5.1.2.3 Refuel Aircraft
5.1.3 Provide Manning for Sustained Operations
5.1.3.1 Receive Manning Reports
5.1.3.2 ID Manning Deficiencies

    - 5.1.3.3 Locate Manning Sources
      - 5.1.3.4 Transport Manning to Units
      - 5.1.3.4.1 Transport Manning to Military Units at Sea
        - 5.1.3.4.2 Transport Manning to Non-Military Units at Sea
        - 5.1.3.4.3 Transport Manning to Military Units Inport
  - 5.1.4 Provide Barracks
    - 5.1.4.1 Provide Barracks for Units Onboard Military Ships at Sea
    - 5.1.4.2 Provide Barracks for Units Onboard Non-Military Ships at Sea
    - 5.1.4.3 Provide Barracks for Units Inport
- 5.2 Maintain Units
    - 5.2.1 Identify Maintenance Deficiencies
    - 5.2.1.1 Receive Unit Capability Reports
    - 5.2.1.2 Asses System Capability
    - 5.2.1.3 Correct System Deficiency
  - 5.2.2 Provide Non-Depot Level Maintenance
    - 5.2.2.1 Identify Components
    - 5.2.2.2 Stock Spares
    - 5.2.2.3 Replace Components
  - 5.2.3 Time to Provide Depot Level Maintenance
        - Identify Pre-scheduled Depot-Level Maintenance
        - Enable Unit Rotation
          - 5.2.3.2.1 Identify Unit Replacements
          - 5.2.3.2.2 Schedule Unit Turnover

APPENDIX J (SYSTEM ENGINEERING DESIGN PROCESS)

SYSTEMS ENGINEERING DESIGN PROCESS

4 Processes

4.1 Acquisition and Supply

4.1.1 Supply

4.1.1.1 Product Supply

4.1.2 Acquisition

4.2.1.2 Product Acquisition
4.2.1.3 Supplier Performance

4.2 Technical Management

4.2.1 Planning

4.2.1.1 Process Implementation Strategy

ID stakeholders, source documents, software, process approaches
ID progress assessment metrics/reporting req's
Prepare, document, make available
List of tasks, work breakdown structure

4.2.1.2 Technical Effort Definition

ID tasks/appropriate contraints/performance measures
Establish information database
Determine risk management strategy
Program metrics (cost, sked compliance, performance, risks, critical path)
Product metrics (MOE achievement, KPP, complexity, req's traceability, design changes)
Cost objectives

4.2.1.3 Schedule and Organization

Calendar-based sked
Event-based sked
ID resource req's/staffing needs
Team/organizational structure

4.2.1.4 Technical Plans

Engineering
Risk management
Technical review
Verification (testing)
Validation (testing)

4.2.1.5 Work Directives

Work packages (SOW, SOO, TWP)
Work authorizations

4.2.2 Assessment

4.2.2.1 Progress Against Plans and Schedules

Monitor progress/make appropriate changes
Determine risk/ID need to correct variances
Record rationale for decisions/assumptions made

4.2.2.2 Progress Against Requirements

Monitor progress/make appropriate changes
Determine risk/ID need to correct variances
Record rationale for decisions/assumptions made

4.2.2.3 Technical Reviews

- ID/review objectives and req's cited
- Determine progress against event-based plan
- Establish technical review board, agenda, speakers
- Technical review pkg, presentation pkg
- Formal review
- Minutes, resolve action items, final sign-off, close-out

4.2.3 Control

4.2.3.1 Outcomes Management

- Capture outcomes, description of methods/tools used, decisions/assumptions, lessons learned
- Configuration management
- Change management
- Interface management
- Risk management
- Data/document management
- Information database

4.2.3.2 Information Dissemination

- Technical progress
- Technical planning
- Approved/controlled req's
- Techical reviews
- Design data/schema
- Lessons learned
- Changes

4.3 System Design--convert agreed-upon req's into set of realizable products to satisfy stakeholder req's

4.3.1 Requirements Definition

4.3.1.1 Acquirer Requirements

- ID, collect, and prioritize acquirer's system req's
- Ensure completeness/consistency of set of collected acquirer req's
- Record set of acquirer req's

4.3.1.2 Other Stakeholder Requirements

- ID/collect other stakeholders' end product req's
- ID/collect other stakeholders' enabling product req's
- ID/collect other stakeholders' external constraints
- Ensure completeness/consistency of other stakeholders' req's
- Record set of other stakeholder req's

4.3.1.3 System Technical Requirements

- Establish req'd rules, priorities, inputs, outputs, states, modes, configs
    - that affect/influence other tasks
- Operational req's
    - utilization environment and factors, natural or induced, that can affect end product performance
    - events to which end products must respond
    - physical and functional interfaces, system boundaries and interactions
    - what system end products must be able to accomplish
    - functional requirements serve to translate operational need into system capabilities

- Performance req's (how well each functional requirement must be accomplished)
    - performance expectations for each functional requirement
    - MOP

    - key performance parameters (KPP) from selected MOP's--key indicators of end product/ system performance
- Human interface req's
    - roles
    - design constraints, conflicts of interest
    - Cost/cost drivers??
    - ID/resolve requirements that have questionable utility or have unacceptable risk of not being satisfied
    - resolve identified conflicts between the requirements

4.3.2 Solution Definition

4.3.2.1 Logical Solution Representations

- Select/implement analysis approach (functional, object-oriented, structured, information modeling)
- Establish sets of logical solution representations
    - trade-off analyses
    - ID/define interfaces
    - analyzing behahaviors
    - ID/define states and modes
    - ID/define timelines
    - ID/define data and control flows
    - analyze failure modes/define failure effects
- Assign system technical req's
- ID, define, validate derived technical requirement statements
- Ensure completeness/consistency of logical solution representations
- Record logical solution representations/derived technical req's

4.3.2.2 Physical Solution Representations

- Analyze logical solution representation sets, assigned system and derived technical req's
- Assign representations to appropriate physical entities
- Generate/evaluate alternative physical representations
- Select preferred physical solution
- Ensure selected physical solution representation consistency
- Record outcomes

4.3.2.3 Specified Requirements

- Fully characterized design solution
- Ensure design solution consistency
- Specify requirements
- Record design solution and related specified requirements
- Establish projects for development of enabling products

4.4 Product Realization

4.4.1 Implemetation

4.4.1.1 Implementation

4.4.2 Transition to Use

4.5 Technical Evaluation

4.5.1 System Analysis

4.5.1.1 Effective Analysis
4.5.1.2 Trade-off Analysis
4.5.1.3 Risk Analysis

4.5.2 Requirements Validation

4.5.2.1 Requirements Statements Validation
4.5.2.2 Acquirer Requirements Validation

- 4.5.2.3 Other Stakeholder Requirements Validation
- 4.5.2.4 System Technical Requirements Validation
- 4.5.2.5 Logical Solution Representations Validation

4.5.3 System Verification

- 4.5.3.1 Design Solution Verification
- 4.5.3.2 End Product Verification
- 4.5.3.3 Enabling Products Readiness

4.5.4 End Products Validation

- 4.5.4.1 System Technical Req's

APPENDIX K (WALLY POWER BOAT)

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I. INTERCEPTOR: WALLYPOWER 118

A. SELECTION

The Wallypower 118 was first considered as a possible interceptor in the very first analysis of alternatives when the initial mothership/interceptor combinations were being considered. At that point, it was originally paired with the modified containership. As the team worked towards a design concept, the 118 became a proxy representing the "high speed displacement" class. It filled this role capably as the team's research was unable to find a more suitable example. Once the high speed displacement type of interceptor was chosen for the final design concept, the team decided to upgrade the 118 from proxy to full fledged selection due to the time constraints preventing designing a more optimal high speed displacement interceptor and because the 118 was relatively close to optimal already.

B. SPECIFICATIONS

The high speed displacement hull was chosen because of its endurance, ability to sprint, berthing capacity and relatively small overall size. The 118's attributes are shown in the table below.

Length	118 ft
Beam	26 ft 3 in
Draft	4 ft 1 in
Displacement (Diesel Configuration)	75 tons
Sprint Speed (Diesel Configuration)	45 kts, Sea State V
Berthing (modified)	27
Cruise (20kts) Endurance (Diesel Config.)	3900 nm
Propulsion (Diesel Configuration)	2 3,650-hp MTU 16V 4000s w/KaMeWa waterjets
Cost (Diesel Configuration, unmodified)	$16.55 million

Figure 236. Wallypower 118 Attributes (After Ref. 1.)

Although a faster version with three gas turbines combined with two smaller diesels exists, the cruise endurance is significantly less and the boat is much heavier. Figures 1 through 3 represent the unmodified version with the alternate propulsion system.

Figure 237. Starboard Bow (Ref. 2.)

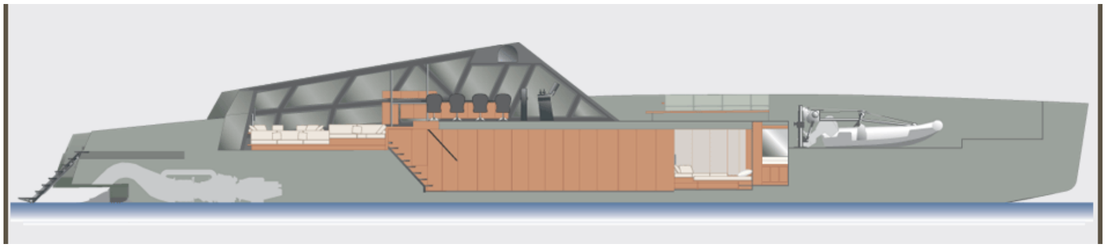

Figure 238. Interior Profile (Ref. 2.)

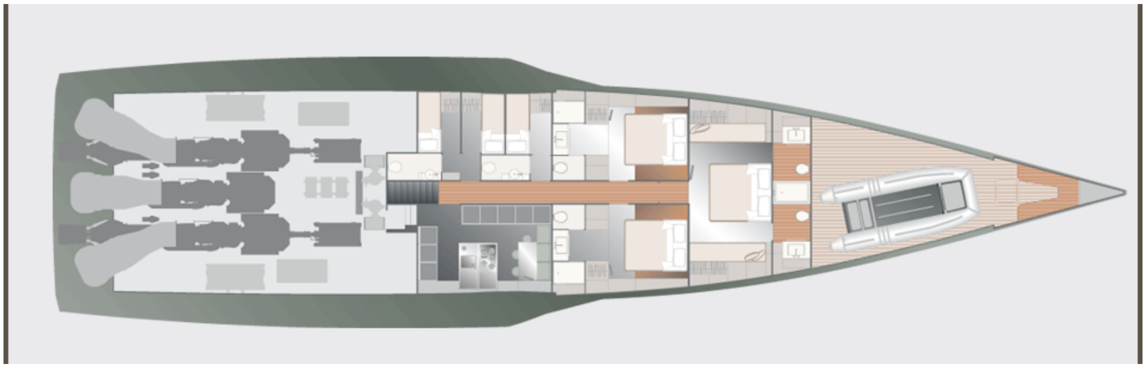

Figure 239. Interior Deck (Ref. 2.)

B. MODIFICATIONS

Because the Wallypower 118 was designed for independent trans-Atlantic voyages, the boat is remarkably prepared for the interceptor mission as is. However, there are several changes that must be made prior to use in that mission. First of all, the 118 is a luxury yacht and so the primary modification to be made is the removal of the individual staterooms, galley and office spaces to be replaced by bunk berthing. Food will be provided as airplane style pre-prepared meals that will only require heating. As a weight saving measure, the hull is fiberglass and carbon fiber with a carbon/honeycomb deck. These materials present a potential problem when lifting the boat so the pick points for lifting will need to be reinforced. Finally, the tender well shown in figure 4 could be converted into a protected gun/grenade launcher mount to give the 118 an offensive and defensive capability.

Figure 240. Potential Protected Armament Location (Ref. 2.)

C. OTHER SOLUTIONS

Purchasing the Wallypower 118 as a Commercial Off the Shelf (COTS) item fit the requirements of this project. However, designing a new high speed displacement vessel should not be overlooked. American boat builders have significant experience in this area and the designs currently being built for military riverine operations are certainly a good example of this expertise. Additionally, considering that the nominal number of MTR systems is four and there are six interceptors per system, a design and build order of 24 interceptors would definitely benefit from economy of scale cost savings.

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2. Wally. (2006) *Wallypower 118 Specifications*. Retrieved November 01, 2006, from http://www.wally.com/jumpCh.asp?idChannel=1&idUser=0&idLang=IT.

APPENDIX L (COST ANALYSIS)

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I. COST ESTIMATION

A. METHODOLOGY

Given that the design is in its earliest stages, the only appropriate methodologies available are the analogy and parametric methods. The LPD 17 was used for the system comparison in the analogy technique. Because only basic and broad cost data was obtainable, a comparison was made for overall program acquisition cost to check the work performed in the parametric method. For the parametric process, cost estimating relationships (CER) were taken from a project involving the CVN(x). A modified and limited work breakdown structure was utilized to group and organize the different classes of CERs. The CERs were based on weight and converted both labor man-hours and material costs from expected system weights. Many weights were estimated based on comparisons with the LPD 17 which is similar in length and volume if not exactly matching in mission. Where individual costs were known, such as the MT30 gas turbines or the Wallypower 118s, these costs were plugged directly into the analysis.

Various methods to represent shipbuilding economies of scale were implemented as well. A learning curve of 90% was used to represent the cost savings incurred as additional ships of the class are built although this factor was less important for the small four ship TSUNAMI class. Other factors such as shipyard profit, overhead and growth margins were also included. Finally, costs were adjusted from the 1991 dollars used in the model to today dollars in 2006.

Besides the basic assumptions made in utilizing a parametric approach and the estimations that were required for expected weights, additional considerations regarding operation of the class were needed. It was previously mentioned that only four ships would be required for the MTR mission (allowing one system to be in maintenance at any given time). Also important is the expected service life, 30 years, which accounts for the large life cycle cost. The actual operation or mission to be executed is another vital variable. The MTR primary mission should only occur a maximum of three times a year. This mission uses the smallest manning profile but expends the most fuel as it is cruising at high speeds for almost the entire mission duration. Secondary missions such as counter drug operations require greater manning but expend much less fuel as the mothership will spend a great deal of time at low speeds.

Representative spreadsheets used in the analysis are listed in this appendix.

B. RESULTS

The results of the analysis are shown below.

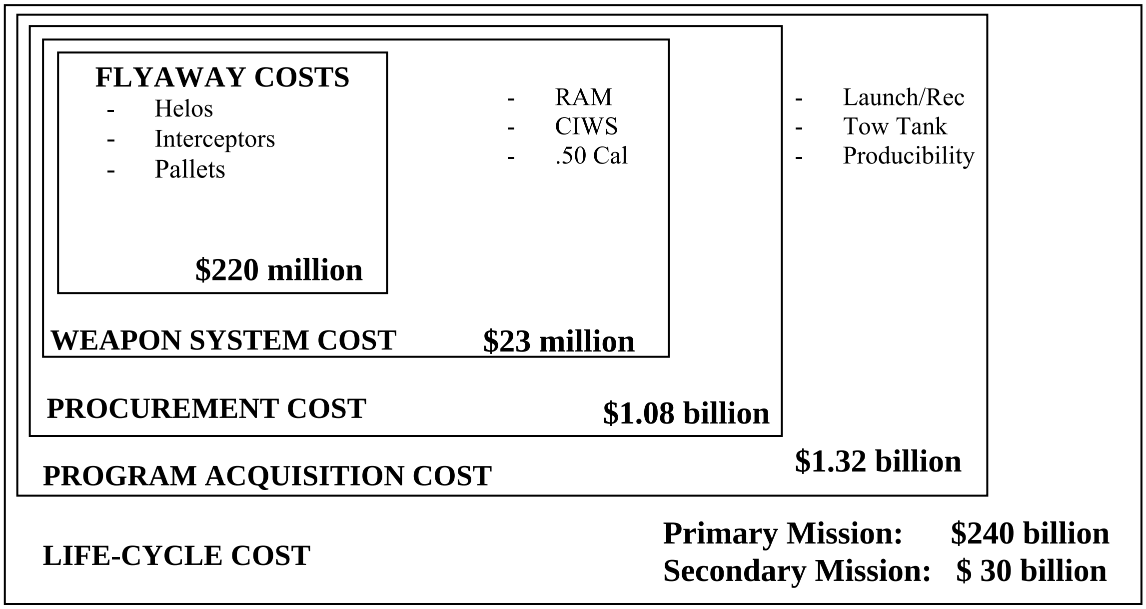
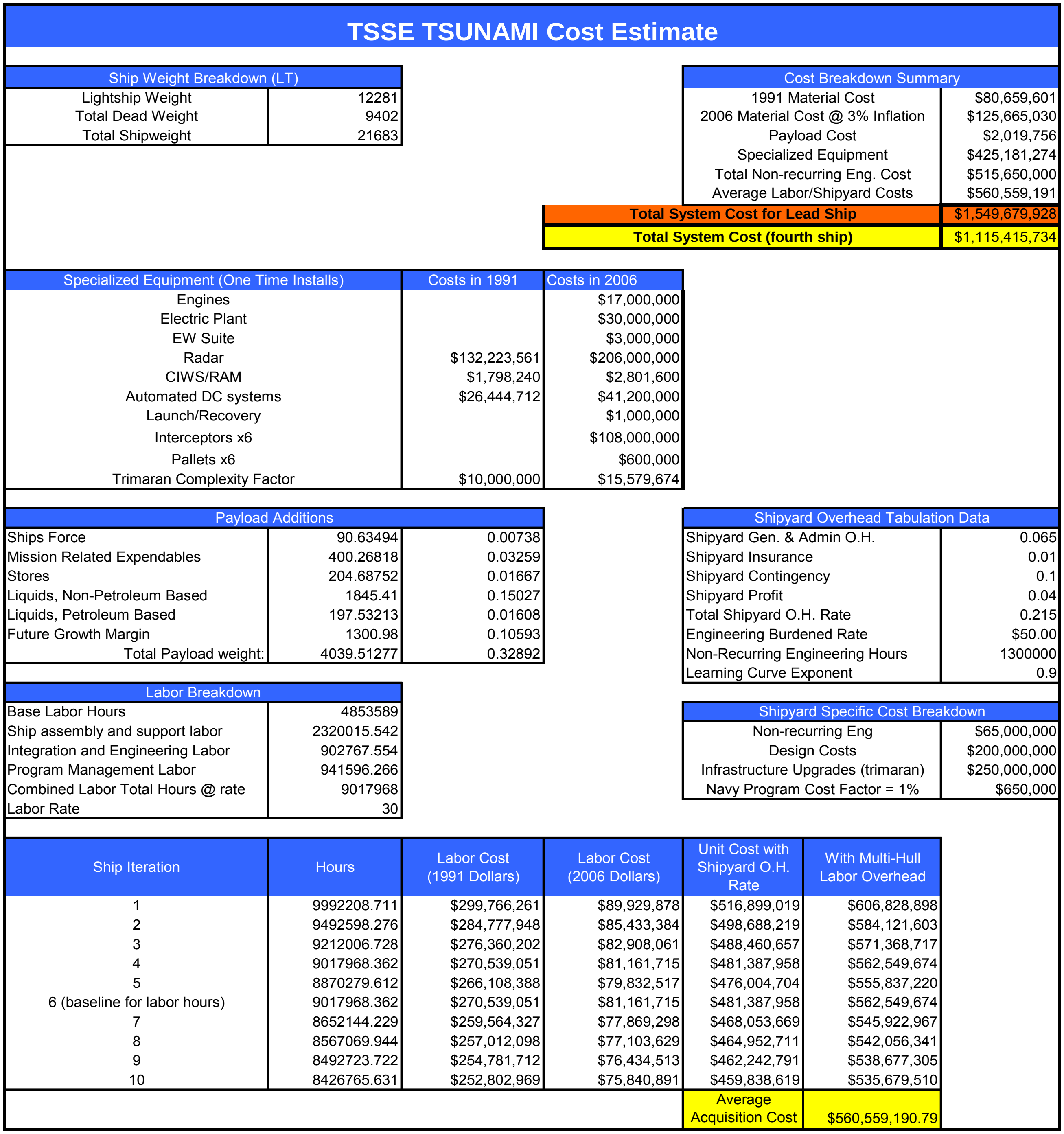


Figure 241. Average Single TSUNAMI System Cost (Construct 4 Systems)

These numbers represent the cost of an average ship system for a production run of four systems. The program acquisition cost of $1.32 billion is slightly higher than the comparable LPD-17 average ship cost of $1.2 billion (12 ship productions run) but close enough to show that the parametric estimation is a reasonable assessment. Considerable additional research dollars are allocated for three key new elements of the design. They are the launch and recovery system, resistance study of the hull form through tow tank analysis and the required study for the producibility of trimaran hull.

It is interesting to consider the differences between the primary and secondary ship mission life-cycle costs. The primary mission's cost is much higher despite operating almost half of the time of the secondary mission. The key distinction is the fuel burn rates required for the high speed cruising versus the low speed loitering. Even the cost of additional personnel for the secondary mission, $1139million versus $936million, and the additional maintenance that comes with twice the operating time does not even come close to closing the gap.



TSSE TSUNAMI Cost Estimate

Ship Weight Breakdown (LT)	
Lightship Weight	12281
Total Dead Weight	9402
Total Shipweight	21683

Cost Breakdown Summary	
1991 Material Cost	$80,659,601
2006 Material Cost @ 3% Inflation	$125,665,030
Payload Cost	$2,019,756
Specialized Equipment	$425,181,274
Total Non-recurring Eng. Cost	$515,650,000
Average Labor/Shipyard Costs	$560,559,191
Total System Cost for Lead Ship	$1,549,679,928
Total System Cost (fourth ship)	$1,115,415,734

Specialized Equipment (One Time Installs)	Costs in 1991	Costs in 2006
Engines		$17,000,000
Electric Plant		$30,000,000
EW Suite		$3,000,000
Radar	$132,223,561	$206,000,000
CIWS/RAM	$1,798,240	$2,801,600
Automated DC systems	$26,444,712	$41,200,000
Launch/Recovery		$1,000,000
Interceptors x6		$108,000,000
Pallets x6		$600,000
Trimaran Complexity Factor	$10,000,000	$15,579,674

Payload Additions		
Ships Force	90.63494	0.00738
Mission Related Expendables	400.26818	0.03259
Stores	204.68752	0.01667
Liquids, Non-Petroleum Based	1845.41	0.15027
Liquids, Petroleum Based	197.53213	0.01608
Future Growth Margin	1300.98	0.10593
Total Payload weight:	4039.51277	0.32892

Shipyard Overhead Tabulation Data	
Shipyard Gen. & Admin O.H.	0.065
Shipyard Insurance	0.01
Shipyard Contingency	0.1
Shipyard Profit	0.04
Total Shipyard O.H. Rate	0.215
Engineering Burdened Rate	$50.00
Non-Recurring Engineering Hours	1300000
Learning Curve Exponent	0.9

Labor Breakdown	
Base Labor Hours	4853589
Ship assembly and support labor	2320015.542
Integration and Engineering Labor	902767.554
Program Management Labor	941596.266
Combined Labor Total Hours @ rate	9017968
Labor Rate	30

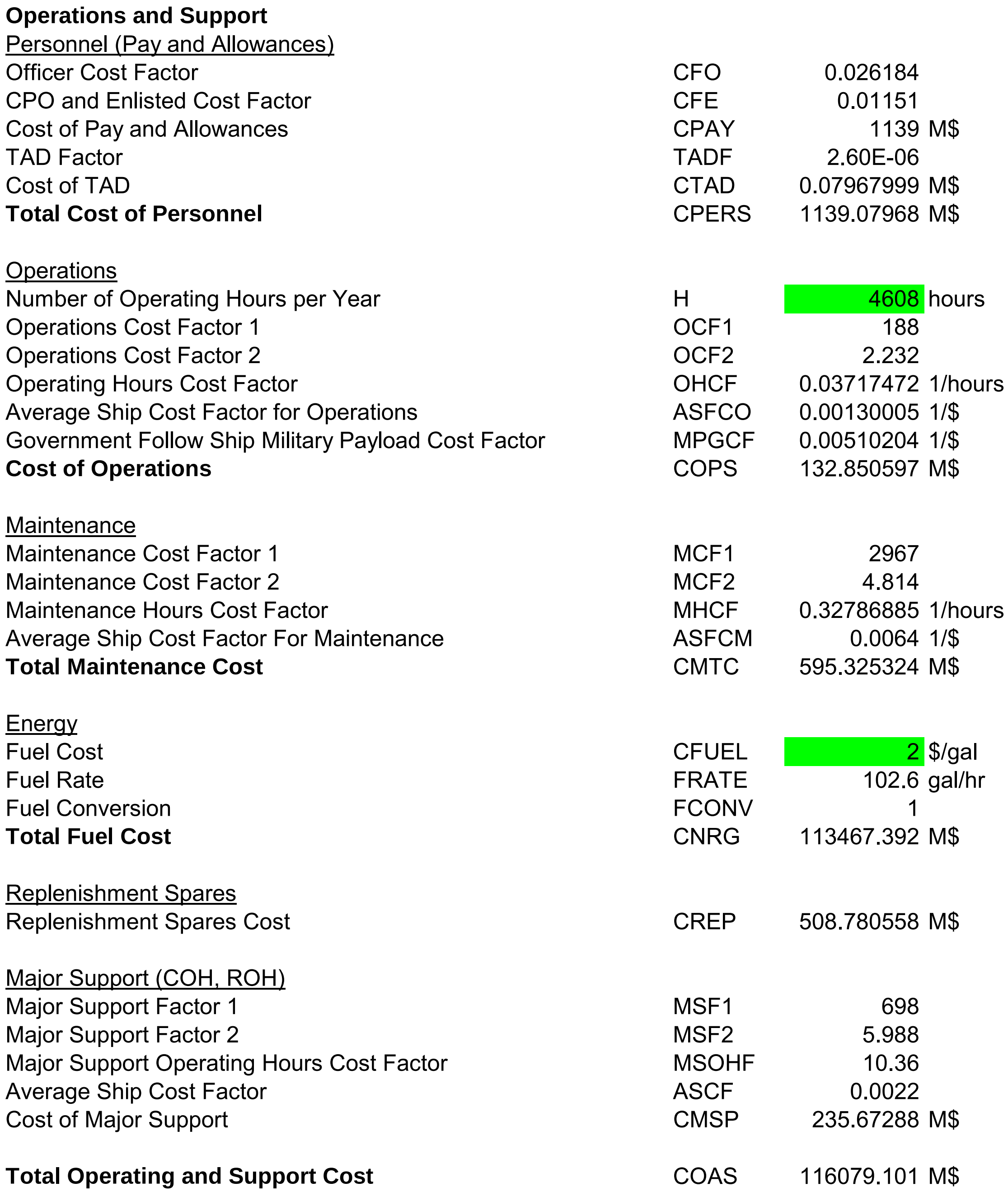
Shipyard Specific Cost Breakdown	
Non-recurring Eng	$65,000,000
Design Costs	$200,000,000
Infrastructure Upgrades (trimaran)	$250,000,000
Navy Program Cost Factor = 1%	$650,000

Ship Iteration	Hours	Labor Cost (1991 Dollars)	Labor Cost (2006 Dollars)	Unit Cost with Shipyard O.H. Rate	With Multi-Hull Labor Overhead
1	9992208.711	$299,766,261	$89,929,878	$516,899,019	$606,828,898
2	9492598.276	$284,777,948	$85,433,384	$498,688,219	$584,121,603
3	9212006.728	$276,360,202	$82,908,061	$488,460,657	$571,368,717
4	9017968.362	$270,539,051	$81,161,715	$481,387,958	$562,549,674
5	8870279.612	$266,108,388	$79,832,517	$476,004,704	$555,837,220
6 (baseline for labor hours)	9017968.362	$270,539,051	$81,161,715	$481,387,958	$562,549,674
7	8652144.229	$259,564,327	$77,869,298	$468,053,669	$545,922,967
8	8567069.944	$257,012,098	$77,103,629	$464,952,711	$542,056,341
9	8492723.722	$254,781,712	$76,434,513	$462,242,791	$538,677,305
10	8426765.631	$252,802,969	$75,840,891	$459,838,619	$535,679,510
				Average Acquisition Cost	$560,559,190.79

Figure 242. Cost Estimate Spreadsheet Summary

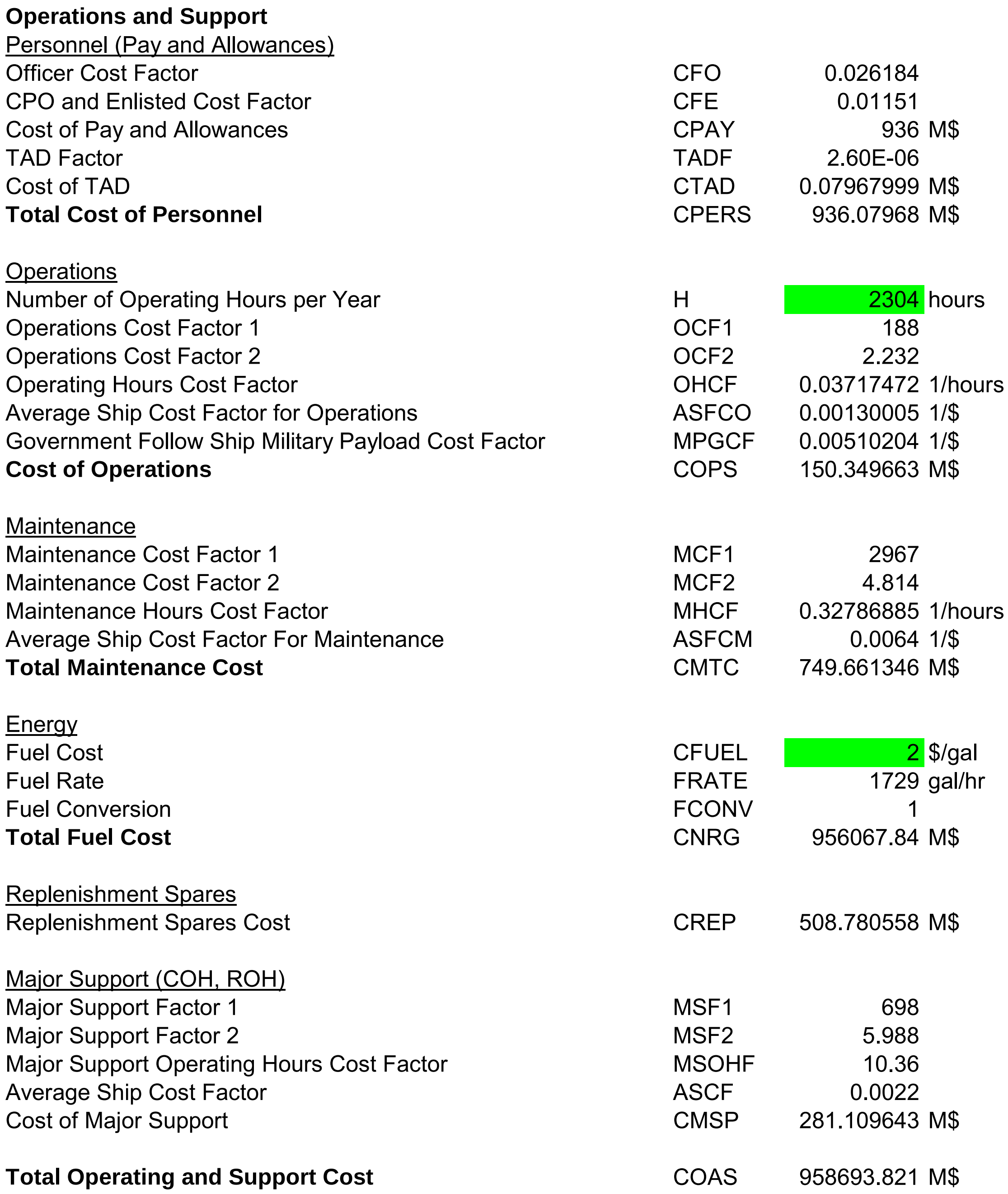
Description	WT (LT)	Wt/Tot	MATERIAL CER	MATERIAL COSTS	LABOR CER	LABOR HOURS
HULL STRUCTURE	12000	0.97712	1181	$14,172,000	316	3792000
MAST	15	0.00122	6183	$92,745	316	4740
SEA WATER PIPING	160	0.01303	4758	$761,280	164	26240
	12175.0	0.99137		$15,026,025		3822980
COMB.AIR SYSTEM	50	0.00407	288	$14,400	412	20600
UPTAKES	5	0.00041	288	$1,440	412	2060
PROP.SEA WATER COOLING	80	0.00651	288	$23,040	412	32960
BOW THRUSTER 1	18	0.00147	144	$2,592	209	3762
Props and Shafts	80	0.00651	144	$11,520	209	16720
HTS Motor	10	0.00081	80000	$800,000	209	2090
CCS	5	0.00041	288	$1,440	162	810
Main 1	50	0.00407	36916	$1,845,800	1412	70600
Main 2	50	0.00407	36916	$1,845,800	1412	70600
Diesel Room	30	0.00244	36916	$1,107,480	1412	42360
	378.0	0.03078		$5,653,512		262562
Frequency Converters	100	0.00814	98329	$9,832,900	1294	129400
SS POWER CABLE	200	0.01629	788	$157,600	471	94200
LIGHTING SYSTEMS	80	0.00651	5450	$436,000	1329	106320
AC MOTOR 1	80	0.00651	650	$52,000	4	320
SWDs	9	0.00073	98329	$884,961	1294	11646
Fan Rooms	10	0.00081	14545	$145,450	1882	18820
	479.0	0.03900		$11,508,911		360706
SRBOC 1	1	0.00008	150000	$150,000	235	235
SRBOC 2	1	0.00008	150000	$150,000	235	235
BRIDGE	3	0.00024	150000	$450,000	235	705
CHARTROOM	1	0.00008	150000	$150,000	235	235
CIC	10	0.00081	150000	$1,500,000	235	2350
RADIO IT	5	0.00041	150000	$750,000	235	1175
MAGAZINE	5	0.00041	150000	$750,000	235	1175
C/S OFFICE	6	0.00049	150000	$900,000	235	1410
PRI FLY	6	0.00049	150000	$900,000	235	1410
RADAR/SENSOR	38	0.00309	150000	$5,700,000	235	8930
	76.0	0.00619	150000	$11,400,000	235	17860
VENTILATION SYSTEMS	100	0.00814	32868	$3,286,800	494	49400
FIREMAIN AND FLUSHING	100	0.00814	50705	$5,070,500	679	67900
COMPRESSED AIR SYSTEMS	80	0.00651	70265	$5,621,200	647	51760
FIRE EXTINGUISHING SYS.	90	0.00733	50705	$4,563,450	679	61110
AUX.SYS.OP.FLUIDS	40	0.00326	42125	$1,685,000	271	10840
CHT CMPT	28	0.00228	70265	$1,967,420	647	18116
AFT CHT TANK	30	0.00244	70265	$2,107,950	647	19410
	468.0	0.03811		$24,302,320		278536
COSAL SR	25	0.00204	55033	$1,375,825	882	22050
LAUNDRY	10	0.00081	26174	$261,740	135	1350
SUPPLY OFFICE	4	0.00033	27376	$109,504	292	1168
DRY PROV	12	0.00098	86901	$1,042,812	12	144
REFRG.STR.	17	0.00138	86901	$1,477,317	12	204
CONVEYOR	4	0.00033	35511	$142,044	694	2776
REPAIR SHOP	8	0.00065	27376	$219,008	292	2336
ANCHOR	20	0.00163	55033	$1,100,660	882	17640
CHAIN LOCKER	10	0.00081	86901	$869,010	12	120
SMALL ARMS	1	0.00008	27376	$27,376	292	292
POST OFFICE	1	0.00008	27376	$27,376	292	292
SHIP OFFICE	2	0.00016	27376	$54,752	292	584
MED.ROOM	2	0.00016	27376	$54,752	292	584
O.F.BERTH.	5	0.00041	29677	$148,385	1235	6175
GYM	8	0.00065	29677	$237,416	1235	9880
REPAIR LOCKER 1	5	0.00041	27376	$136,880	292	1460
STORAGE	4	0.00033	86901	$347,604	12	48
RHIB	3	0.00024	35511	$106,533	694	2082
GALLEY	5	0.00041	26174	$130,870	135	675
MESS DECK	6	0.00049	26174	$157,044	135	810
ENLISTED BERTH.	10	0.00081	29677	$296,770	1235	12350
CPO BERTHING	5	0.00041	29677	$148,385	1235	6175
CO SR	2	0.00016	29677	$59,354	1235	2470
S/R GROUP	4	0.00033	29677	$118,708	1235	4940
W/R	2	0.00016	29677	$59,354	1235	2470
CARDIO	2	0.00016	29677	$59,354	1235	2470
	177.0	0.01441		$8,768,833		101545
HELO	40	0.00326	100000	$4,000,000	235	9400
	40.0	0.00326		$4,000,000		9400

Figure 243. Example of Material Weight CER Analysis



Operations and Support			
Personnel (Pay and Allowances)			
Officer Cost Factor	CFO	0.026184	
CPO and Enlisted Cost Factor	CFE	0.01151	
Cost of Pay and Allowances	CPAY	1139	M$
TAD Factor	TADF	2.60E-06	
Cost of TAD	CTAD	0.07967999	M$
Total Cost of Personnel	CPERS	1139.07968	M$
Operations			
Number of Operating Hours per Year	H	4608	hours
Operations Cost Factor 1	OCF1	188	
Operations Cost Factor 2	OCF2	2.232	
Operating Hours Cost Factor	OHCF	0.03717472	1/hours
Average Ship Cost Factor for Operations	ASFCO	0.00130005	1/$
Government Follow Ship Military Payload Cost Factor	MPGCF	0.00510204	1/$
Cost of Operations	COPS	132.850597	M$
Maintenance			
Maintenance Cost Factor 1	MCF1	2967	
Maintenance Cost Factor 2	MCF2	4.814	
Maintenance Hours Cost Factor	MHCF	0.32786885	1/hours
Average Ship Cost Factor For Maintenance	ASFCM	0.0064	1/$
Total Maintenance Cost	CMTC	595.325324	M$
Energy			
Fuel Cost	CFUEL	2	$/gal
Fuel Rate	FRATE	102.6	gal/hr
Fuel Conversion	FCONV	1	
Total Fuel Cost	CNRG	113467.392	M$
Replenishment Spares			
Replenishment Spares Cost	CREP	508.780558	M$
Major Support (COH, ROH)			
Major Support Factor 1	MSF1	698	
Major Support Factor 2	MSF2	5.988	
Major Support Operating Hours Cost Factor	MSOHF	10.36	
Average Ship Cost Factor	ASCF	0.0022	
Cost of Major Support	CMSP	235.67288	M$
Total Operating and Support Cost	COAS	116079.101	M$

Figure 244. Example of Secondary Mission Operating Costs



Operations and Support			
Personnel (Pay and Allowances)			
Officer Cost Factor	CFO	0.026184	
CPO and Enlisted Cost Factor	CFE	0.01151	
Cost of Pay and Allowances	CPAY	936	M$
TAD Factor	TADF	2.60E-06	
Cost of TAD	CTAD	0.07967999	M$
Total Cost of Personnel	CPERS	936.07968	M$
Operations			
Number of Operating Hours per Year	H	2304	hours
Operations Cost Factor 1	OCF1	188	
Operations Cost Factor 2	OCF2	2.232	
Operating Hours Cost Factor	OHCF	0.03717472	1/hours
Average Ship Cost Factor for Operations	ASFCO	0.00130005	1/$
Government Follow Ship Military Payload Cost Factor	MPGCF	0.00510204	1/$
Cost of Operations	COPS	150.349663	M$
Maintenance			
Maintenance Cost Factor 1	MCF1	2967	
Maintenance Cost Factor 2	MCF2	4.814	
Maintenance Hours Cost Factor	MHCF	0.32786885	1/hours
Average Ship Cost Factor For Maintenance	ASFCM	0.0064	1/$
Total Maintenance Cost	CMTC	749.661346	M$
Energy			
Fuel Cost	CFUEL	2	$/gal
Fuel Rate	FRATE	1729	gal/hr
Fuel Conversion	FCONV	1	
Total Fuel Cost	CNRG	956067.84	M$
Replenishment Spares			
Replenishment Spares Cost	CREP	508.780558	M$
Major Support (COH, ROH)			
Major Support Factor 1	MSF1	698	
Major Support Factor 2	MSF2	5.988	
Major Support Operating Hours Cost Factor	MSOHF	10.36	
Average Ship Cost Factor	ASCF	0.0022	
Cost of Major Support	CMSP	281.109643	M$
Total Operating and Support Cost	COAS	958693.821	M$

Figure 245. Example of Primary Mission Operating Costs

APPENDIX M (PENDULATION ANALYSIS)

In the pendulation analysis a sinusoid wave motion was applied to the athwart ships direction to determine what type of general motion the interceptor would display. The model was designed in solid works and transferred into NASTRAN. The amplitude was one meter and the period time was varied at five, ten and fifteen seconds. The length of the wire rope cable s was also varied from the maximum extensions to the shortest assumed position.

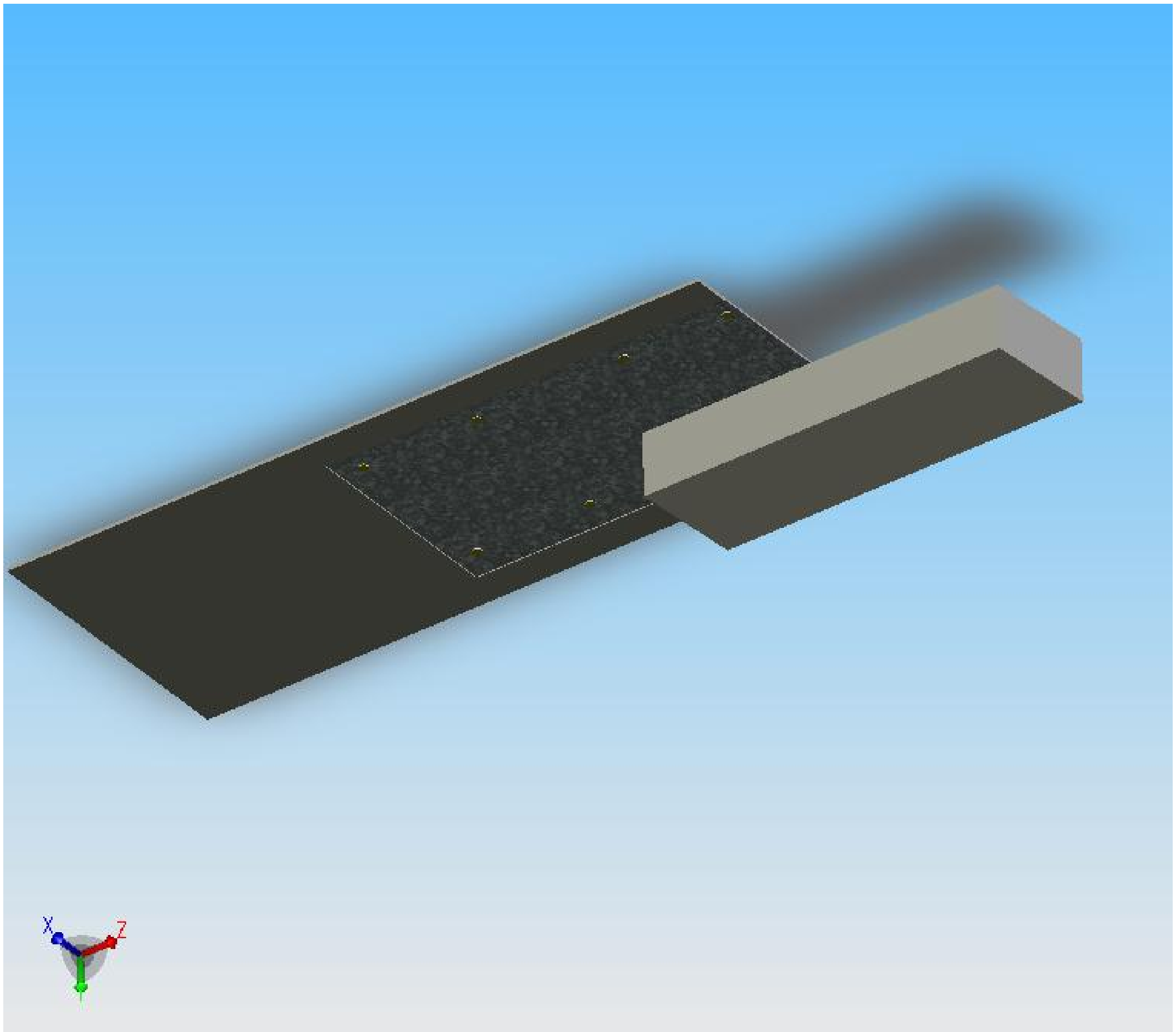


Figure 246. SolidWorks picture of the Ship and Interceptor

The block represents the Wally interceptor and the flat plat represents the overhead with in the TSUNAMI. The Wally has been given the correct dimensions and weight assignment to match the commercial design.

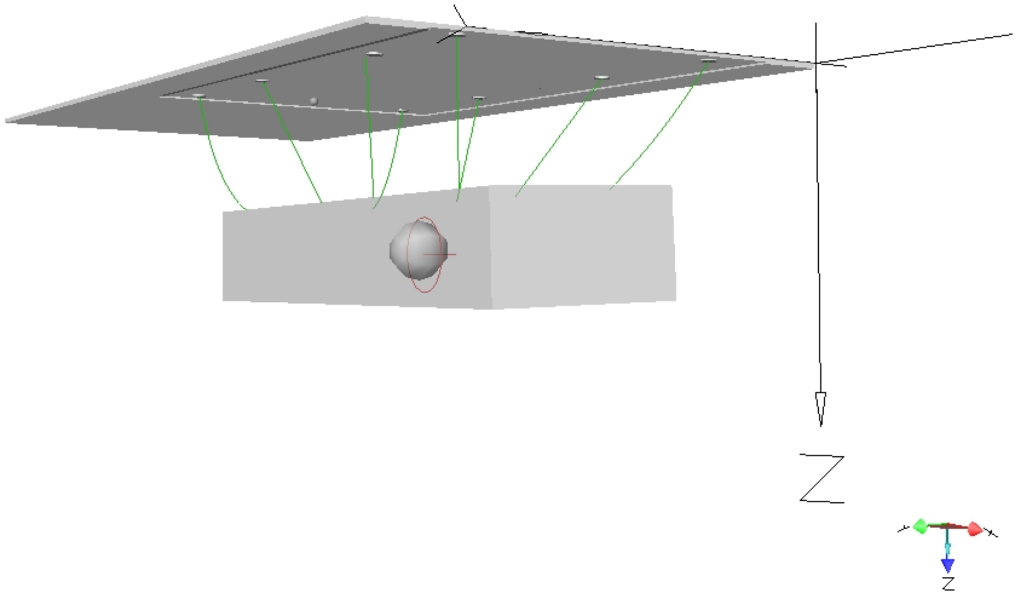


Figure 247. NASTRAN photo of the model

In NASTRAN the sin wave was applied to the overhead plate that represents the TSNUMI ship. Four attached wire ropes were attached. The number is for redundancy, due to the excessive amount of weight of a Wally.

The several meters were used in this assessment, to include: position of the Wally, velocity of the Wally and tensions of the different lines. The lines in there maximum extensions were 25.5 feet and in the shortest position 14.5 feet.

TENSION AVERAGE			
	5	10	15
25 feet	225,000	225,000	230,000
15 feet	175,000	175,000	165,000
MEASUREMENTS IN LBF			

TENSION MAX			
	5	10	15
25 feet	9,000,000	600,000	500,000
15 feet	225,000	200,000	170,000
MEASUREMENTS IN LBF			

Figure 248. Tension measurements of the wire ropes

The trend, as indicated by the above chart, depicts a drop in max tensions with an increase in period. This type of response was expected. The wave action contributes less as the period gets longer, for the same wave height. Another observation was that in the maximum extension wire ropes, the tension varied throughout the ropes. In the shorter length the tension was even distributed among all the ropes. The overall take away is that in either configuration the tensions are high and the system used will need to be very robust to hand the stresses induced by the speed of the TSUNAMI and the weight of the interceptors.

Irregardless of the applied sinusoid wave period, the Wally respond similar in all cases for the short ropes. The Wally moved only in the athwart ship direction. This indicates some stability in the other directions. This stability is in inherent to the design of the lifting shape, a double trapezoid. The ropes form a “V” shape in both directions.

In the long or extended ropes there is more movement as expected. In this position, the Wally moves again in the athwart ship direction primarily, and slightly, in contrast, in the vertical direction. The noticeable difference is that as the period increase so does the period of movement but not the excursion distances of the Wally. In the shortened rope set up the Wally moved less as a function of the wave period. In order to obtain a actual amount of movement more analysis would have to be completed.

To over come some of the motion stress a spreader bar could be inserted in the lifting system. The payout is that the system itself becomes less stable. A second possible solution would be to lower the lifting rack, over head system, in order to decrease the distances and simultaneously putting an angle on the overhead beams so that align to be directly over the lift. This idea is similar to the commercial yacht design by Roodberg. The last design consideration to have the lifting beams actual run on hydraulics. This eliminates the stress from the overhead rigging system and places the movement stress on eh beams. Here the payout is in space, the size of the hydraulics would be very substantial.

APPENDIX N (MANNING)

TABLE OF CONTENTS

I. INTRODUCTION

The manning profile was developed to minimize manning and thus operating costs without adversely affecting mission accomplishment and ship survivability. Current “reduced manning” concepts, team member operational experience and different mission requirements were the primary drivers for the final manning profile. This profile incorporated the needs for different watch section organizations and the overall need for maintainers and subject matter experts. It also recognizes the need for additional surge manning for missions more dangerous than the primary Maritime Threat Response (MTR) mission.

Total system crew to execute the MTR mission is 327. This number includes the ship’s crew of 122, aviation detachment of 25, interceptor crews of 36 and the Department of Energy (DOE) inspection teams of 144. The assumptions utilized to achieve this number and the limitations associated with this small crew size will be discussed next.

II. MANNING PROFILE DEVELOPMENT

A. MISSION REQUIREMENTS AND SURGE CAPACITY

The threat assessment for the primary MTR mission requires a minimum defensive manning, essentially only that required for force protection. Thus, although the ship carries robust defensive systems such as CIWS and RAM, there would be no need to man these systems during the typical mission profile. Therefore, the combat systems department is drastically undermanned in comparison to a standard navy warship. The lack of hostile threat also reduces the need for a robust damage control capacity. Damage control requirements are consequently limited to actions that may be encountered during peacetime steaming such as fire and flooding due to equipment failures, flooding due to grounding or collision and main space fires. These scenarios reduce the standard repair locker manning. The reduction of damage control manning is a significant reducer for the overall manning.

The addition of secondary missions increases the manning requirements. It is expected that a system would not be tasked from an MTR mission to a secondary mission without some time allowance for training and refitting. During this time, additional crew would be brought onboard and trained to the ship specifics. Remember that the ship utilizes all standard navy weapon systems. This way, crew could be surged from the general population without the requirement to maintain a TSUNAMI specific crew pool.

The missions of standard maritime interdiction operations and counter drug operations would not result in additional repair team requirements. Additional combat systems manning would, however, be required to improve the air tracking capabilities.

The missions of riverine operations and amphibious operations support would result in the greatest manning increase. The combat systems department would need to increase in order to man and maintain all defensive weapons and additional damage control personnel may be required to be available for the increased hostile threat.

B. REDUCED MANNING INITIATIVES

Experimentation with reduced manning initiatives are very active in today's fleet and considering the five year timeline for initial capability of this system, it is expected that even greater reduction of manning from today's standards can be expected. However, the manning profile did not take these potential savings into account. Rather it primarily recognized the savings in damage control requirements allowed through the use of automatic fire suppression devices and remote monitoring tools. Given that the engineering equipment is remarkably similar to that of the Littoral Combat Ship (LCS), the LCS manning profile was used as the lowest achievable number. The high number was taken from a Oliver Hazard Perry class frigate that had been optimized for the lowest possible crew size acceptable without the use of reduced manning equipment. One team member had extensive experience with the measures taken to reduce that crew size.

Other initiatives outside of the engineering and damage control arena include the doubling up of bridge watch stations such as combining the quartermaster and boatswain mate of the watch positions and the reduction of lookouts. The initiative most relied on, however, was the concept of remote maintenance, outsourced ship preservation, advanced paints and materials and off-ship administration. Although an 800 foot ship will require a lot more care than the smaller LCS, the manning was not relatively increased due to the expectation that ships crew would be exempt from many of today's maintenance tasks.

C. DEPARTMENT NUMBERS

The following sections outline the crew size requirements per department to execute the primary MTR mission. Department numbers provide an excess of personnel when manning various watch conditions as seen in Table 1. It is therefore possible to further reduce department manning. Additional reduction would have to be verified through initial class sea trials and by validating the innovative new operations such as high speed rear launch and recovery of interceptors.

1. Interceptors

Interceptor manning was based on the crew size recommended by the manufacturer. Each interceptor will carry two three man watch teams consisting of boat officer, helmsman and engineer. Teams will stand two section watches while operating. Maximum expected duration of each mission is seven days. Because interceptors are not required to maintain close station while escorting vessels of interest, fatigue levels are expected to be manageable. Additionally, most missions will not require operation of all six teams thus allowing an opportunity for crew rest. Total crew size for six interceptors is thus 36.

2. Aviation Detachment

The standard complement for two embarked MH-60 helicopters was utilized to determine the total number of 25.

3. Department of Energy Inspection Teams

Each inspection team of 24 members contains two watch teams of 12. Like the interceptors, the teams are expected to stand two section watches for the seven day mission duration. Composition of these teams was given to the SEA9 group from Lawrence Livermore Laboratory. Total size for six teams is 144.

4. Engineering

Total department size is 26 including officers and chiefs. This number is slightly higher than the LCS due to the greater dispersion of equipment and requirement for more independent operations at greater distances from supporting personnel and facilities.

5. Operations and Combat Systems

Manning requirements for these departments are driven by the need to man only basic detect and classification operations. The larger number of personnel is devoted to launch and recovery operations for the interceptors. Due to the redundancy and simplicity of the launch and recovery system, manpower was limited to only basic operators and limited supervision. Total number is 49.

6. Supply

Reduced manning and maintenance also reduce the requirement for supply personnel. Additionally, messing for the operating interceptors will be provided by heated airplane style meals thus further reducing the supply manning requirements. Total number is 11.

D. WATCH STATIONS

Watch station manning was developed using operational experience and with consideration to previously mentioned reduced manning initiatives. However, there is not a significant reduction over current manning profiles. The only radically different concept may be the size of the watch team in relation to the size of the ship. Table 1 outlines nominal watch sections for general quarters, peacetime steaming and launching and recovering of interceptors.

	Condition 1	Condition II (Intercept Ops)	Condition IV
	1 Section	3 Section	4 Section
STATION	POSITION		
PILOTHOUSE	EXECUTIVE OFFICER		
	OOD	1	1
	JOOD	1	1
	NAVIGATOR		
	QMOW	1	1
	BMOW		
	SCC OPERATOR/HELMSMAN	1	1
LOOKOUTS	FORWARD LOOKOUT (JL)		
	AFT LOOKOUT (JL)	1	1
CIWS	REMOTE CONTROL PANEL OPERATOR		
	LOCAL CONTROL PANEL OPERATOR		
	POIC/RELOADER		
	LOADER		
RAMS	REMOTE CONTROL PANEL OPERATOR		
	LOCAL CONTROL PANEL OPERATOR		
SCAT TEAM	Mount 01-50 CAL		
	Mount 02-50 CAL		
	Mount 03-50 CAL		
	Mount 04-50 CAL		
	Mount 05-50 CAL		
	Mount 06-50 CAL		
	Mount 07-50 CAL		
	Mount 08-50 CAL		
AIR NAV / ECM ROOM	CSOSS TECHNICIAN (SPS-55)		
	CSOSS TECHNICIAN (SLQ-32)		
SWITCH GEAR ROOM	SWBD MONITOR (5JV)		
Diesel/BowThruster	ASM		
	SWBD MONITOR (5JV)		
	OIL KING		
MER 1	LOP OPERATOR/ PSM (2JV)	1	1
	PSM		
MER 2	LOP OPERATOR/ PSM (2JV)	1	1
	PSM		
HOIST OPS	HOIST SUPERVISOR	1	
	HOIST OPERATOR	1	
	DECK SAFETY	1	
	DECK HANDS	1	
	DECK HANDS	1	
	PALLET OPERATOR	1	
	PALLET OPERATOR	1	
	PALLET SAFETY	1	
	ELECTRICIAN		
AVIATION OPS	Supervisor	1	
	Flight Deck Crew	1	
	Flight Deck Crew	1	

CIC	WEAPONS CONTROL OFFICER		
(WEPS CONTROL)	WCC 1 OPERATOR #1 (2JP)		
CIC (EW)	SUPERVISOR (SLQ-32(V)5 (SIDEKICK)		
	DCC OPERATOR		
	TECH OPERATOR		
RADIO CENTRAL	RADIO CENTRAL SUPERVISOR	1	1
	SATELLITE COMMUNICATION OPERATOR		
	TELETYPE OPERATOR / TAPE CUTTER		
	BROADCAST OPERATOR		
	TRANSMITTER OPERATOR		
BATTLE DRESS	MEDICAL TECHNICIAN		
	MEDICAL TECHNICIAN		
	MEDICAL TECHNICIAN		
	STRETCHER BEARER		
	STRETCHER BEARER		
BATTLE MESSING	SHIPS COOK (GALLEY)		
	SHIPS COOK (GALLEY)		
EMERGENCY ISSUE	STOCK CONTROL SUPERVISOR		
CCS	SUPERVISOR		
	EOOW	1	1
	EPCC	1	1
DCC	DAMAGE CONTROL ASSISTANT		
	PLOTTER		
	TALKER (2JZ)		
	TALKER (1JV) BRIDGE		
(FIRE / FLOODING)	RLO		
	PLOT		
	2JZ P/T		
	MSGR		
	OSL		
	INV #1		
	INV #2		
	ELEC		
	TM LDR		
	#1 NOZ		
	#1 HOSE		
	#1 PLUG		
	#2 NOZ		
	#2 HOSE		
	#2 PLUG		
	HOSE		
	HOSE		
	BDRY		
	BDRY		
	BDRY		
	BDRY		
	AC/OVER		
	AC/OVER		
	ATMOS TEST		
	D/W TM		
	D/W TM		
	SHORE TM		
	SHORE TM		
	SHORE TM		
	PIPE/PLUG		
	PIPE-PLUG		
	UTILITYMAN		
	UTILITYMAN		
	UTILITYMAN		
	UTILITYMAN		
	SOUNDING		

Figure 249. Watch Stations

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