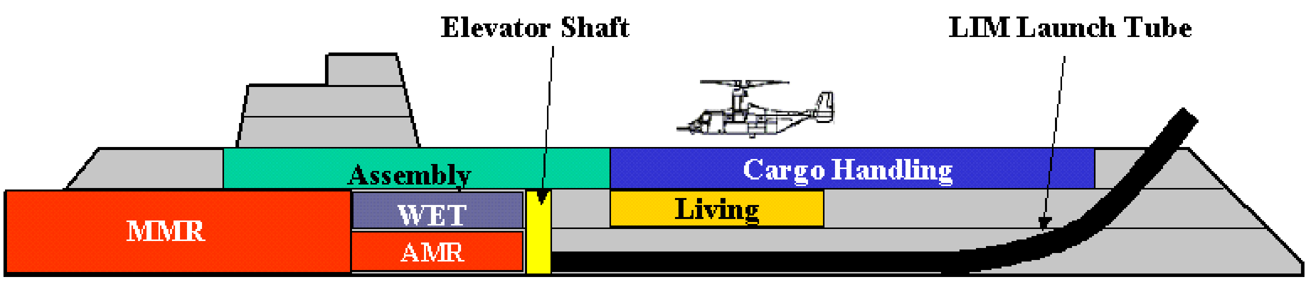
Design Report

Medium Surface Combatant (MSC)

VT Total Ship Systems Engineering



MSC
Ocean Engineering Design Project
AOE 4065/4066
Fall 2009 – Spring 2010
Virginia Tech Team 3

Kevin Flaherty ______________________________

Ed Godfrey ______________________________

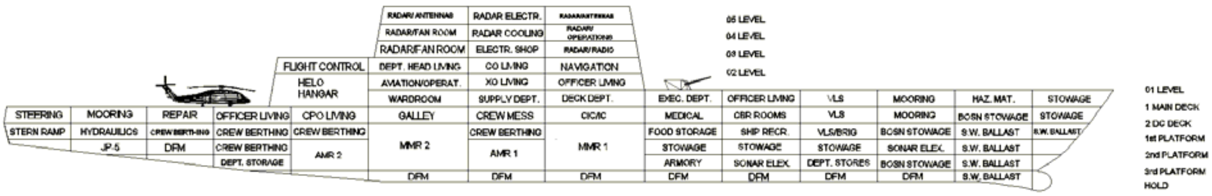
James Kulis ______________________________

Brandon Laing ______________________________

Christopher Ritter ______________________________

Alan Shane – Team Leader ______________________________

Executive Summary



This report describes the Concept Exploration and Development of Medium Surface Combatant for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The MSC requirement is based on the MSC Initial Capabilities Document (ICD) and the Virginia Tech CGX Acquisition Decision Memorandum (ADM), Appendix A and Appendix B.

Concept Exploration trade-off studies and design space exploration are accomplished using a Multi-Objective Genetic Optimization (MOGO) after significant technology research and definition. Objective attributes for this optimization are cost, risk (technology, cost, schedule and performance) and military effectiveness. The product of this optimization is a series of cost-risk-effectiveness frontiers which are used to select alternative designs and define Operational Requirements (ORD1) based on the customer's preference for cost, risk and effectiveness.

MSC is a low cost, low manning, low risk, and good effectiveness. It is an optimization of variant 156 from the non-dominated design frontier. This ship has a flare hull form that transitions into a tumblehome above the waterline to help decrease the radar cross section.

This ship provides modularity as well. This allows the ship to be able to used in a variety of different wartime purposes depending on the package chosen for the task at hand.

Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, propulsion and power system development and arrangement, general arrangements, machinery arrangements, combat system definition and arrangement, seakeeping analysis, cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements in the ORD within cost and risk constraints with additional work required to obtain all information necessary to create a ship that can be widely used.

Ship Characteristic	Value
LWL	193.2 m
Beam	22.9 m
Draft	2.9 m
Lightship weight	14678 MT
Full load weight	17362 MT
Sustained Speed	34 knots
Endurance Range	4550 nm
Propulsion and Power	IPS 4 MT30, 2 LM500 2 Shafts, 2 Propulsors
BHP	107000 kW
Personnel	105
OMOE (Effectiveness)	0.74
OMOR (Risk)	0.1512
Ship Acquisition Cost	$3.25 B
Life-Cycle Cost	$218.5 B

Table of Contents

1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of a Medium Surface Combatant (MSC) for the United States Navy. The MSC requirement is based on the MSC Initial Capabilities Document (ICD), and Virginia Tech MSC Acquisition Decision Memorandum (ADM), Appendix A and Appendix B. This concept design was completed in a two-semester ship design course at Virginia Tech. MSC must perform the following missions:

- Provide surface, air, and subsurface defense. This includes defense around friends, joint forces, and critical bases of operation in CSGs, ESGs, and independent ops.
- Provide Strike and naval surface fire support
- Provide intelligence, surveillance, and reconnaissance
- Provide a sea-based layer of homeland defense

These capabilities can be provided in a coordinated force or individually. The amount of money to build is important so sufficient force numbers can satisfy world-wide issues. In addition to providing the necessary capabilities, manning, rising acquisition, logistics, and energy costs must be addressed with a comprehensive plan including the application of new technologies.

1.2 Design Philosophy, Process, and Plan

Design is creating and making decisions and documenting these decisions in an organized way to support the eventual procurement of material and creation of instructions for production workers to produce a final product that meets the customer's needs. Three different design approaches may be used. The classic design spiral is a point based design. It starts with something that work then is modified until a solution is found. Works well if the starting point is good and the design is complete when you run out of time. The synthesis model based design optimization is a design approach using an algorithm to find the best solution. It generally integrates Design of Experiments, Genetic Algorithms, and Response Surface Methods. The set based design method progressively shrinks a large design space. Details increase with each contraction of design space. It allows different design sub groups to work somewhat independently. To meet these goals a synthesis model design optimization approach is used. The Concept and Requirements Exploration objectives are to provide a consistent format and methodology for making affordable multi-objective acquisition decisions, provide practical and qualitative methods for measuring risk and mission effectiveness, provide an efficient and robust method to search design space for optimal concepts, use the results of the principle analysis codes at earlier stages of design, consider designs and requirements together, and initially consider a very broad range of designs, requirements, cost, and risk. Figure 1 shows the design strategy used. It starts with a broad range of possibilities and narrowed down to a design to move forward with. The level of detail is then expanded for the selected design while the risk is reduced and further specifies what the design will look like. Figure 2 shows the synthesis model design optimization approach. The approach is started with the initial capabilities document to tell what needs to be met. From the capabilities, required operation capabilities are determined. The measures of performance are then determined and an effectiveness model is created. The technologies and risk model are also determined. Many factors are put into the synthesis model to create a balanced ship. Figure 3 shows the VT design spiral used for the project. It graphically shows the overview of the process used for the design project.

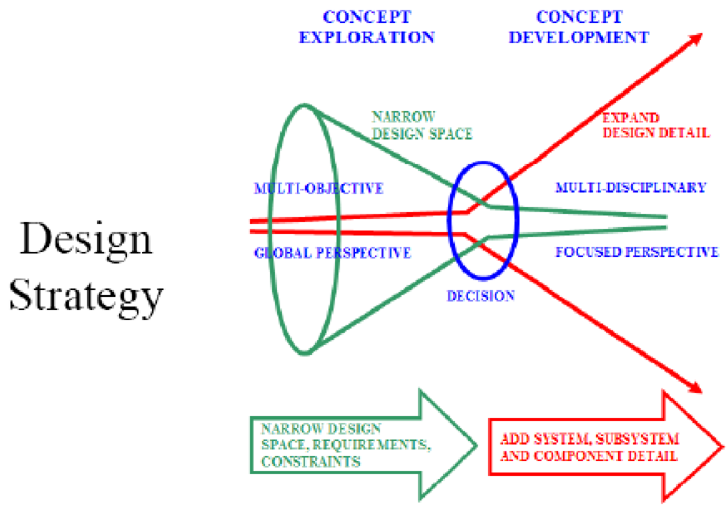


Figure 1 - Design Strategy

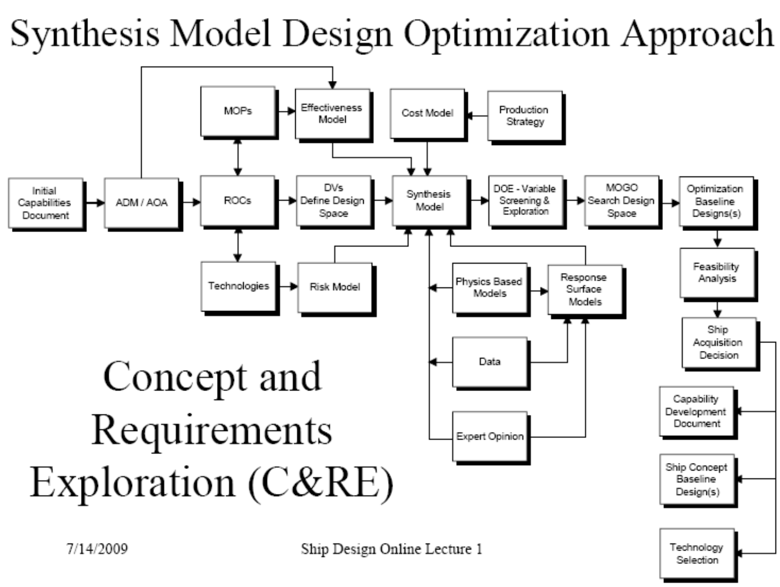


Figure 2 - Concept and Requirements Exploration

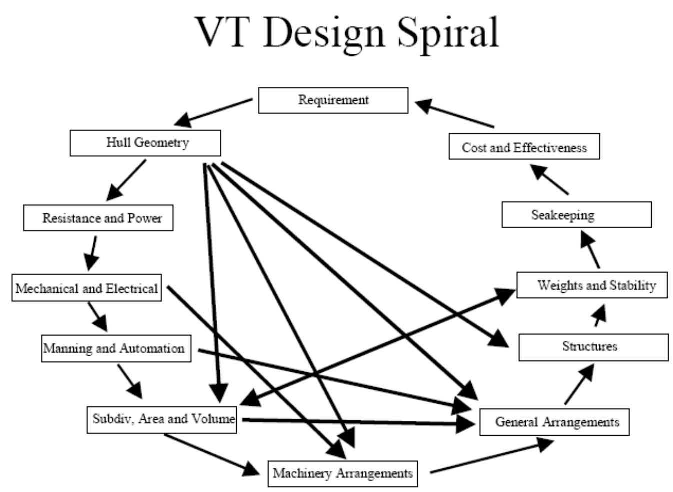


Figure 3 - Virginia Tech Design Spiral

1.3 Work Breakdown

MSC Team 3 consists of six students from Virginia Tech. Each student is assigned areas of work according to his or her interests and special skills as listed in Table 1. Ed Godfrey will specialize in the mission aspect of the ship. James Kulis will specialize in the HM&E and risk aspect of the ship. Brandon Laing will specialize in the combat systems, manning, and cost aspects of the ship. Christopher Ritter will specialize in the weight and space aspects of the ship. Alan Shane will specialize in synthesis, optimization, and feasibility aspects of the ship.

Table 1 - Work Breakdown

Name	Specialization
Ed Godfrey	Mission
James Kulis	HM&E, Risk
Brandon Laing	Combat Systems, Manning & Cost
Kevin Flaherty	Modularity
Christopher Ritter	Space & Weight
Alan Shane	Synthesis, Optimization & Feasibility

1.4 Resources

Computational and modeling tools used in this project are listed in Table 2. Rhino will assist with the arrangement drawings as well as the hull form development. Rhino and HECSALV will assist with the hydrostatics for the ship. The resistance and power will be determined with the assistance of NavCAD. Ship motions will be calculated with the assistance of SWAN. ASSET will assist with the ship synthesis model. Maestro will assist with the structure model.

Table 2 - Tools

Analysis	Software Package
Arrangement Drawings	Rhino
Hull form Development	Rhino
Hydrostatics	Rhino, HECSALV
Resistance/Power	NavCAD
Ship Motions	SWAN, SMP
Ship Synthesis Model	Model Center/ASSET
Structure Model	MAESTRO

2 Mission Definition

The MSC requirement is based on the MSC Initial Capabilities Document (ICD), and Virginia Tech MSC Acquisition Decision Memorandum (ADM), Appendix A and Appendix B with elaboration and clarification obtained by discussion and correspondence with the customer, and reference to pertinent documents and web sites referenced in the following sections.

2.1 Concept of Operations

Provide flexible BMD, NSFS, strike, and multi-mission capability through modularity with different configurations of similar platforms. Full capabilities may be provided in a coordinated force, in support of a larger force, or individually with combinations of inherent multi-mission capabilities and tailored modular capabilities. It is expected that MSCs will operate with Carrier Strike Groups and Expeditionary (Amphibious) Strike Groups providing AAW, ASUW and ASW support. MSC Surface Action Groups (SAGs) will perform various ISR and Strike missions in addition to providing their own AAW, ASUW and ASW defense. ISR missions will include the use of autonomous air surface and subsurface vehicles and LAMPS. Ballistic Missile Defense (BMD). The radar and missile capabilities of some future surface combatants must be greater than the Navy's current Aegis ships. Some multi-mission capabilities may have to be sacrificed to control cost. Conducting BMD operations may require MSCs to operate in a location that is unsuitable for performing one or more other missions. Conducting BMD operations may reduce the ability to conduct air-defense operations against aircraft and cruise missiles due to limits on ship radar capacity. BMD interceptors may occupy ship weapon-launch tubes that might otherwise be used for air-defense, land-attack, or antisubmarine weapons. Maintaining a standing presence of a BMD ship in a location where other Navy missions do not require deployment, and where there is no nearby U.S. home port, can require a total commitment of several ship, to maintain ships on forward deployment. Critical capabilities for BMD-capable ships include high-altitude long-range search and track (LRS&T), and missiles with robust ICBM BMD terminal, mid-course, and potentially boost-phase capability. A ship with both of these is considered an ICBM engage-capable ship. The extent of these capabilities will have a significant impact on the ship's Concept of Operations. BMD requirements may change over time. There is a verified need for major caliber NSFS for the foreseeable future. Deployments will typically be have 6 month duration with underway replenishment, a few port visits, all-weather operations, cluttered air and shipping environments, blue water and littoral, and limited maintenance opportunities. MSCs will typically deploy and return to CONUS.

2.2 Projected Operational Environment (POE) and Threat

MSCs are expected to operate worldwide in open ocean and cluttered, littoral environments - constrained bodies of water, smaller scales relative to open ocean warfare casuing increased difficulty detecting and successfully prosecuting targets. MSC will be designed to function in Sea States 1-7 and survive to SS9. Threats will come from nations with major military capabilities: weapons systems that could be encountered include ballistic missiles, land and surface launched cruise missiles. Threats will also come from smaller nations who support, promote, and perpetrate activities that cause regional instabilities detrimental to international security and/or have the potential development of nuclear weapons - small diesel/electric submarines, land-based air assets, chemical/biological/ radiological weapons, fixed and mobile SAM sites, swarming small boats, and sophisticated sea mines. Threats will not just come from nations but from non-state groups interested in obtaining missiles with nuclear and other payloads or any other types of technologically advanced weapons.

2.3 Specific Operations and Missions

MSC will have four main mission types; CBG (Carrier Battle Group), SAG (Surface Action Group), Independent Operations and Ballistic Missile Defense, and ESG (Expeditionary Strike Group).

2.4 Mission Scenarios

Mission scenarios for the primary BAMFS missions are provided in

Table 3 through 6. A possible SAG 90 day scenario is shown in Table 3. A possible Independent Operations 90 day scenario is shown in Table 4. Table 5 shows a possible CBG 90 day scenario. Table 6 shows a possible ESG 90 day scenario.

Table 3 – SAG 90 Day Scenario

Day	Mission scenario
1-6	Transit with other MSCs and SSCs to area of hostility
6-15	Patrol grid for launch of ballistic missiles
16-17	Detect, engage, and kill incoming anti-ship missile attack
18	Engage Submarines at Medium Range
19	Cruise to 30 nm offshore
20	Insert Navy Seals by Rib
21	Retrieve Navy Seals
22-40	Return to Port, Repair and Replenish
41-54	Cruise back to area of hostility
55-60	Patrol Grid for Area of Hostility
60-65	ISR
66-67	Detect ICBM Launch Against Homeland, Engage and Kill
68-71	Cruise to New Grid
72-76	Patrol Grid for Area of Hostility
77	Sustain damage to radar due to rough seas
78-90	Return to Home Port

Table 4 - Independent Operations 90 Day Scenario

Day	Mission scenario
1-21	SAG transit from CONUS
21-26	Port Call
27	Break off independently, conduct defense against medium boat threat
28-29	Engage submarine threat for SAG defense
30-38	Conduct ASW operations with SAG and SSN
39-45	Port Call, repairs and replenish
46-52	Rejoin SAG
53-54	Engage TBM for allied defense
55-65	Port Call, repairs
66-80	Provide support and surveillance for SAG defense
81-90	Return to Home Port

Table 5 - CBG 90 Day Scenario

Day	Mission scenario
1-21	Leave Port and head to area of hostility with CBG
22-59	ISR
33	Engage missile threat against carrier
40	Launch Cruise Missiles at land target
57	Conduct ASW with LAMPS helo vs. diesel submarine threat
59-63	Port for repairs and replenishment
64	Engage in response to in-port attack by smaller boats
65-71	Rejoin CBG
72-75	ISR
76-80	Counter missile defense against continued aggression
81-90	Return to home port

Table 6 - ESG 90 Day Scenario

Day	Mission scenario
1-21	Leave Port and head to area of hostility with CBG
22-59	ISR
60	Cruise to 15 nm offshore
61-63	Provide support for onshore marines
64	Conduct ASW with LAMPS helo vs. diesel submarine threat
65	ISR
66-73	Port for repairs and replenishment
74-75	Cruise to new grid
76	Practice Launch and Recovery of Marines
77	Cruise to 10 nm offshore
78	Deploy Marines
79	Provide support for onshore marines
80	Recover Marines and cruise to 30 nm offshore
80-82	ISR
82-90	Return to home port

2.5 Required Operational Capabilities

In order to support the missions and mission scenarios described in Section 2.4, the capabilities listed in Table 7 are required. Each of these can be related to functional capabilities required in the ship design, and, if within the scope of the Concept Exploration design space, the ship's ability to perform these functional capabilities is measured by explicit Measures of Performance (MOPs).

Table 7 - List of Required Operational Capabilities (ROCs)

ROCs	Description
AAW 1	Provide anti-air defense
AAW 1.1	Provide area anti-air defense

ROCs	Description
AAW 1.2	Support area anti-air defense
AAW 1.3	Provide unit anti-air self defense
AAW 2	Provide anti-air defense in cooperation with other forces
AAW 5	Provide passive and soft kill anti-air defense
AAW 6	Detect, identify and track air targets
AAW 9	Engage airborne threats using surface-to-air armament
AAW 10	Area BMD
AAW 11	Support ICBMD
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations
AMW 6.3	Conduct all-weather helo ops
AMW 6.4	Serve as a helo hangar
AMW 6.5	Serve as a helo haven
ASU 1	Engage surface threats with anti-surface armaments
ASU 1.1	Engage surface ships at long range
ASU 1.2	Engage surface ships at medium range
ASU 1.3	Engage surface ships at close range (gun)
ASU 1.4	Engage surface ships with large caliber gunfire
ASU 1.5	Engage surface ships with medium caliber gunfire
ASU 1.6	Engage surface ships with minor caliber gunfire
ASU 1.9	Engage surface ships with small arms gunfire
ASU 2	Engage surface ships in cooperation with other forces
ASU 4	Detect and track a surface target
ASU 4.1	Detect and track a surface target with radar
ASU 6	Disengage, evade and avoid surface attack
ASW 1	Engage submarines
ASW 1.1	Engage submarines at long range
ASW 1.2	Engage submarines at medium range
ASW 1.3	Engage submarines at close range
ASW 4	Conduct airborne ASW/recon
ASW 5	Support airborne ASW/recon
ASW 7	Attack submarines with antisubmarine armament
ASW 7.6	Engage submarines with torpedoes
ASW 8	Disengage, evade, avoid and deceive submarines
CCC 1	Provide command and control facilities
CCC 1.6	Provide a Helicopter Direction Center (HDC)
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions

ROCs	Description
CCC 3	Provide own unit Command and Control
CCC 4	Maintain data link capability
CCC 6	Provide communications for own unit
CCC 9	Relay communications
CCC 21	Perform cooperative engagement
FSO 3	Provide support services to other units
FSO 5	Conduct towing/search/salvage rescue operations
FSO 6	Conduct SAR operations
FSO 7	Provide explosive ordnance disposal services
FSO 8	Conduct port control functions
FSO 9	Provide routine health care
FSO 10	Provide first aid assistance
FSO 11	Provide triage of casualties/patients
INT 1	Support/conduct intelligence collection
INT 2	Provide intelligence
INT 3	Conduct surveillance and reconnaissance
INT 8	Process surveillance and reconnaissance information
INT 9	Disseminate surveillance and reconnaissance information
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)
LOG 1	Conduct underway replenishment
LOG 2	Transfer/receive cargo and personnel
LOG 6	Provide airlift of cargo and personnel
MIW 4	Conduct mine avoidance
MIW 6	Conduct magnetic silencing (degaussing, deperming)
MIW 6.7	Maintain magnetic signature limits
MOB 1	Steam to design capacity in most fuel efficient manner
MOB 2	Support/provide aircraft for all-weather operations
MOB 3	Prevent and control damage
MOB 3.2	Counter and control NBC contaminants and agents
MOB 5	Maneuver in formation
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)
MOB 10	Replenish at sea
MOB 12	Maintain health and well being of crew
MOB 13	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support
MOB 16	Operate in day and night environments
MOB 17	Operate in heavy weather
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations
NCO 3	Provide upkeep and maintenance of own unit
NCO 19	Conduct maritime law enforcement operations
SEW 2	Conduct sensor and ECM operations
SEW 3	Conduct sensor and ECCM operations
SEW 5	Conduct coordinated SEW operations with other units
STW 3	Support/conduct multiple cruise missile strikes

3 Concept Exploration

Chapter 3 describes Concept Exploration. Trade-off studies, design space exploration and optimization are accomplished using a Multi-Objective Genetic Optimization (MOGO).

3.1 Trade-Off Studies, Technologies, Concepts and Design Variables

Available technologies and concepts necessary to provide required functional capabilities are identified and defined in terms of performance, cost, risk and ship impact (weight, area, volume, power). Trade-off studies are performed using technology and concept design parameters to select trade-off options in a multi-objective genetic optimization (MOGO) for the total ship design. Technology and concept trade spaces and parameters are described in the following sections.

3.1.1 Hull Form Alternatives

For the hull form selection process Transport Factor Methodology is used to indentify alternative hull-form types.

$$TF = \frac{W_{FL}V_S}{SHP_{TI}} = \frac{(W_{LS} + W_{Fuel} + W_{Cargo})V_S}{SHP_{TI}}$$

$$TF = \frac{(W_{LS} + W_{Cargo})V_S}{SHP_{TI}} + \frac{SFC_E SHP_E \frac{R}{V_E} V_S}{SHP_{TI}}$$

W_{FL} = Full load weight of the ship
W_{LS} = Light ship weight
W_{Fuel} = Ship's fuel weight
W_{Cargo} = Ship's cargo or payload weight
V_S = Sustained speed
V_E = Endurance speed
SHP_{TI} = Total installed shaft horsepower including propulsion and lift systems
R = Range at endurance speed
SFC_E = Specific fuel consumption at endurance speed

Figure 4 - Transport factor equations and variables

Design lanes from previous built ships are used to specify hull-form design parameter ranges. Since the parameters of payload weight, required sustained speed, endurance speed, and range were considered, and the design space limited these factors, in order to achieve our missions and cost threshold an approximate transport factor could be established. A maximum value of 35.4 was calculated for a displacement of 14000 MT, a sustained speed of 35 knots and a SHP of 70 MW. This value suggests a slender displacement monohull. This design offers structural efficiency and, with a wide beam, sufficient deck space for vertical launch systems and a hanger. With the Navy making a move towards reducing radar cross sections of ships and examining tests already complete, a tumblehome design would be desirable. However tests also show that a tumblehome design is not as good for seakeeping. Flare hulls, which are widely tested, show excellent seakeeping ability. So to create the most efficient vessel a hybrid tumblehome/flare monohull design was chosen.

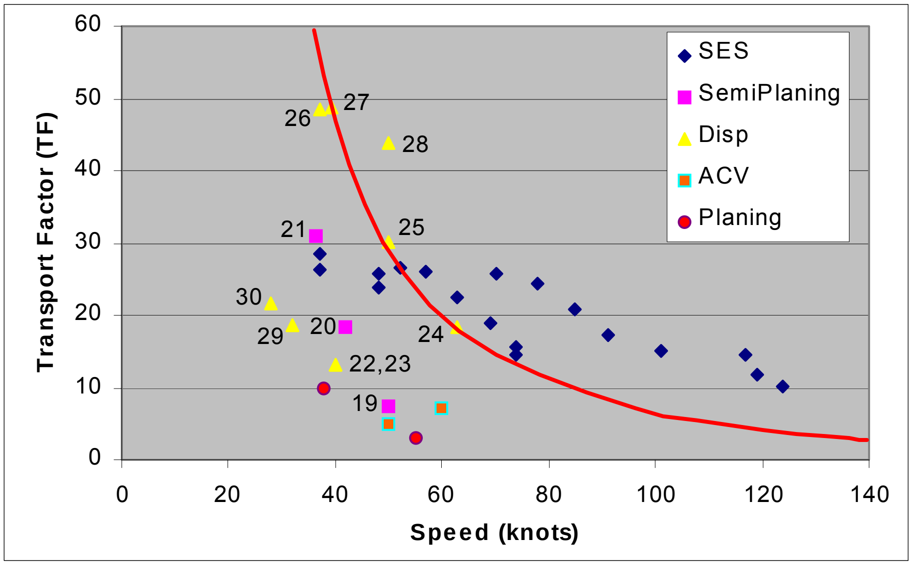


Figure 5 - Graph showing relationship between transport factor and speed for different hull types

Table 8 - Hullform Design Variable Space

Design Variable	Value
L (m)	160 - 210
L/D	11 - 14
L/B	7 - 10
B/T	2.9 - 3.2
C_P	.57 - .63
C_X	.76 - .85

Table 9 - MSC Principal Characteristics

Design Variable	Value
Displacement (MT)	8000-14000
L (m)	172 - 213
B (m)	17.4 - 24.4
D (m)	9.8- 18.3
T (m)	5.5 - 8.5
C_P	.56 -.64
C_X	.75 - .84
C_{rd}	.7 - 1

3.1.2 Propulsion and Electrical Machinery Alternatives

The first step taken to determine the propulsion system for the Medium Surface Combatant (MSC) was to develop machinery general requirements and guidelines. Once this is completed viable machinery alternatives were selected based on guidelines, and an alternative machinery selection hierarchy was developed. Data was then gathered and developed on viable machinery alternatives, these included; manufacturer data, input into ASSET baseline design, and assemble data in propulsion alternative data base (excel file). The ship synthesis propulsion module was then updated to be consistent with the machinery alternatives. The machinery system trade off was performed as part of total ship synthesis and optimization.

3.1.2.1 **Machinery Requirements**

Based on the ADM and Program Manager's inputs, propulsion plant design requirements are summarized as follows:

General Requirements – The ship must have a minimum range of 8000 nautical miles at 20 knots; sustained speed must be achieved in full load, calm water, clean hull, and using no more than 80% MCR.

Sustained Speed and Propulsion Power – The ship must meet a minimum sustained speed of 30 knots with shaft horsepower ranges of 70,000 to 120,000 horsepower with ship service power greater than 10000 kW unless a pulse configuration is used.

Ship Control and Machinery Plant Automation – The ship must comply with ABS ACCU requirements for periodically unattended machinery spaces; auxiliary systems, electric plant, and damage control systems will be continuously monitored from the command control center, main control console, and Chief Engineer's office. The systems will be controlled from the main control console and local controllers.

Propulsion Engine and Ship Service Generator Certification – All equipment should be Navy qualified and grade A shock certified while maintaining a low infrared signature; non-nuclear options only, continuous operation using distillate fuel in accordance with ASTM D975, Grade 2-D; ISO 8217, F-DMA, DFM (NATO Code F-76 and JP-5 (NATO Code F-44).

The propulsion plant selected for the Medium Surface Combatant (MSC) is an integrated power system (IPS). The IPS consists of both primary and secondary power generation modules (PGM, SPGM) and propulsion motor modules (PMM) as directed by the ADM and the Program Manager. **Error! Reference source not found.** shows an example of an IPS. An IPS offers greater flexibility in power availability to all of the ship services, reduces weight, and increases ship efficiency. An IPS also has the ability of zonal distribution which provides greater survivability characteristics than conventional power systems. Zonal survivability ensures loads in undamaged zones do not experience a service interruption. This limits damage propagation to the fewest number of zones. Zonal survivability is demonstrated in **Error! Reference source not found.**.

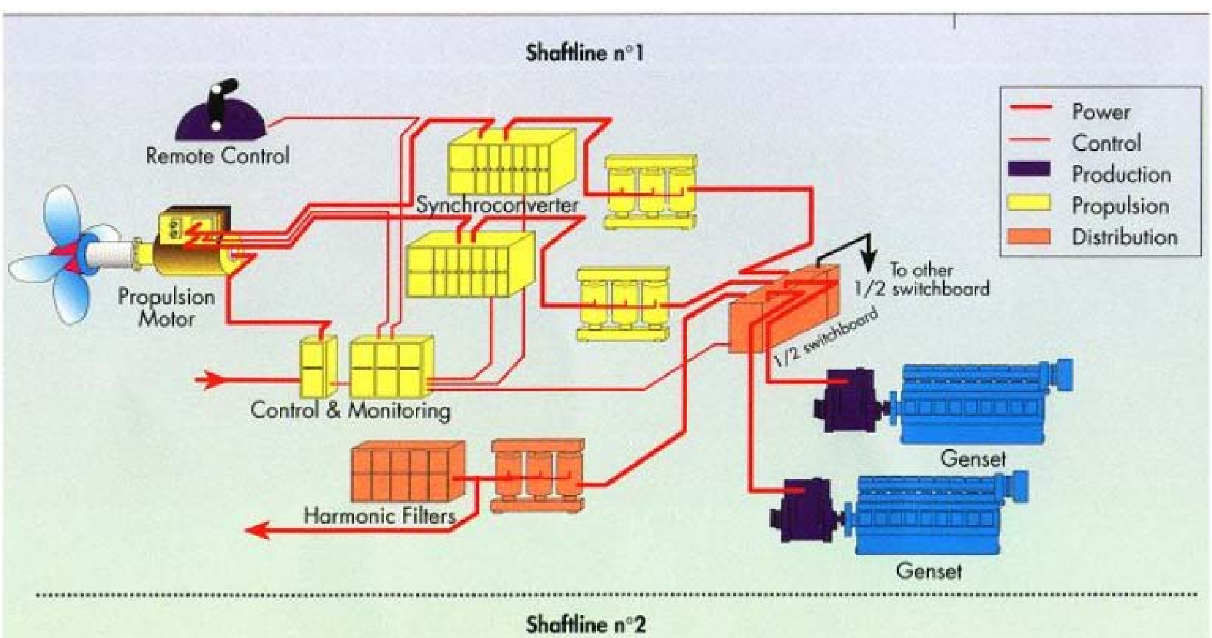


Figure 6 - Example of an Integrated Power System (IPS)

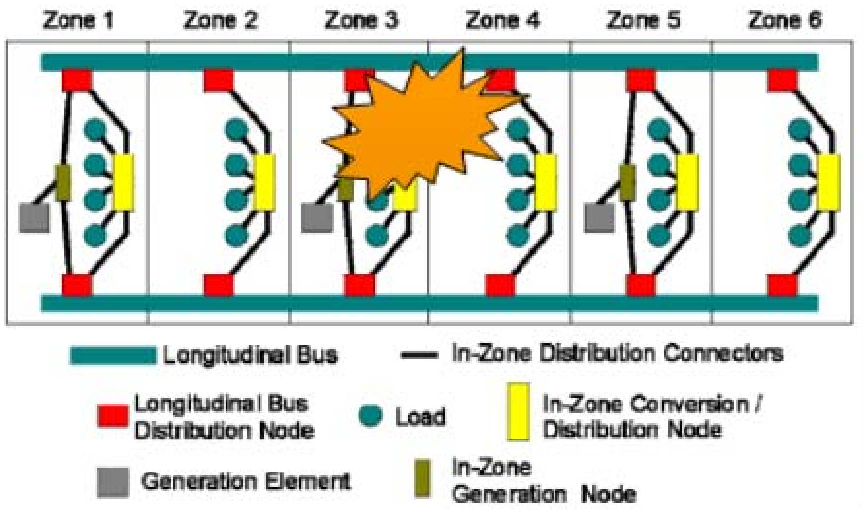


Figure 7 - Example of Zonal Survivability

For the Main Power Generation Module (PGM) only gas turbines were considered. The Power generation module consists of a prime mover, generator and support equipment, and there purpose is to transform power into electrical power. **Error! Reference source not found.** shows an example of a PGM. Gas turbines offer high power to weight ratios, smaller sizes compared to diesels of equivalent power, and lower emissions. The U.S. Navy has increasingly used gas turbines on their ships in both PGMs and SPGMs. The two PGM options for this design are the LM2500+ and the MT30 gas turbine engines. The design team was at a consensus to investigate nuclear options as a feasible alternative; however, the ADM directs that the nuclear option not be considered.

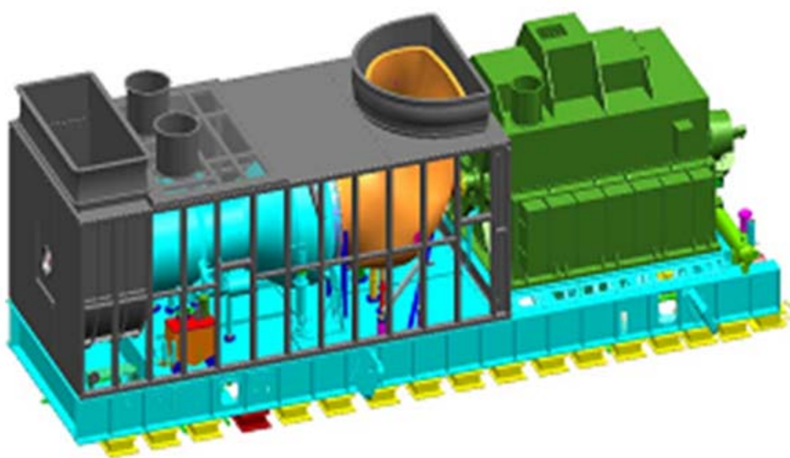


Figure 8 - Example of a Power Generation Module (PGM)

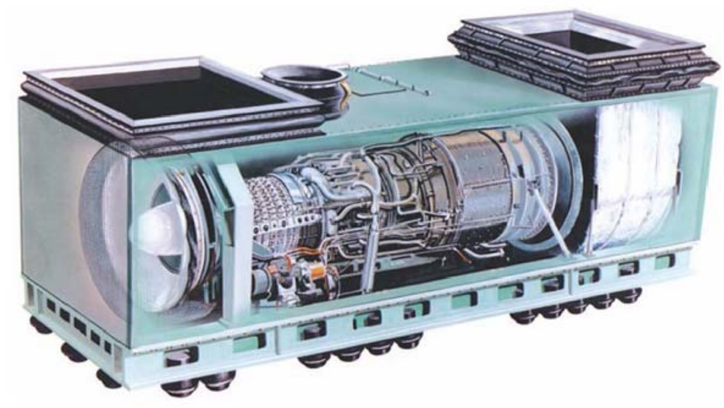


Figure 9 - LM2500+ Gas Turbine Engine

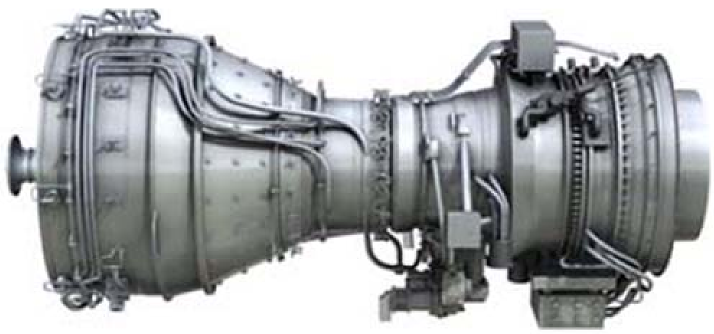


Figure 10 - MT30 Gas Turbine Engine

SPGM options must provide greater fuel efficiency for lower power and speed operations. Gas turbines, diesel engines and fuel cells where considered. Diesels offer fast start up time, lower specific fuel consumption, smaller intakes/uptakes, and greater variety. Two types of diesels were considered in the design. One is a Medium-High speed diesel, seen in **Error! Reference source not found.**, and a Medium-Low speed diesel, seen in **Error! Reference source not found.**. Fuel cells offer high efficiency (35-60%) and also use the ventilation system which doesn't require any dedicated intakes-uptakes saving space in the ship. **Error! Reference source not found.** shows an example of a fuel cell. They do however have slow startup, slow dynamic response, and exhibit an increased risk due to their reasonably new technology.

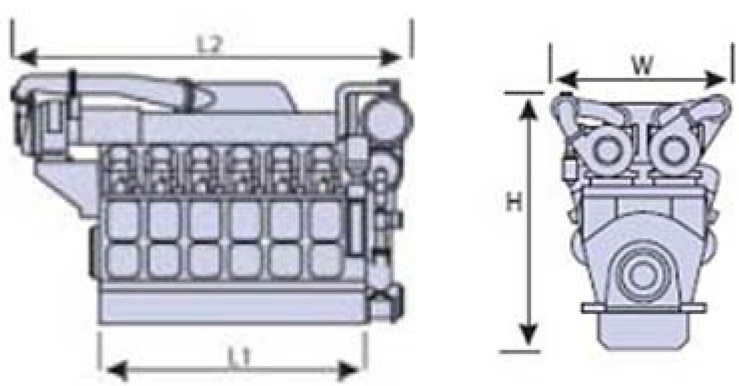


Figure 11 - Example of a Medium-High Speed Diesel

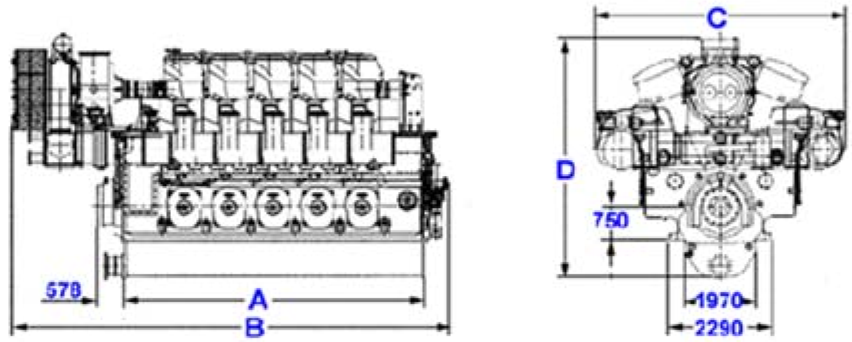
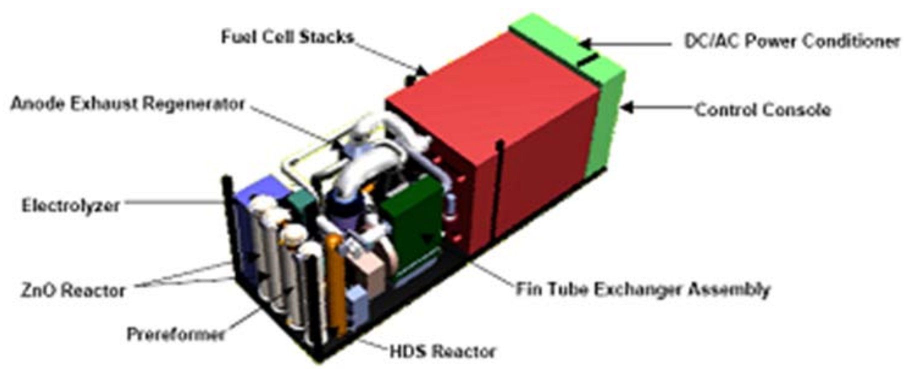


Figure 12 - Example of a Medium-Low Speed Diesel



FuelCell Energy 625kW 450V, 3φ, 60 HZ, MC SSFC Power System

Figure 13 - Example of a Fuel Cell

Propulsion Motor Module (PMM) options considered include two motor types: permanent magnet and advanced induction. The PMM is comprised of a propulsion motor, motor drive, propulsor, and support equipment. There purpose is to convert electricity into propulsion power. **Error! Reference source not found.** shows an example of a propulsion motor module. The advanced induction motor is a proven technology and has a high efficiency, seen in **Error! Reference source not found.**. The drawbacks are it is large and heavy and its efficiencies are still not as high as other motor types. The permanent magnet motor offers lower weight, better efficiency, and is quieter, but at an increased cost and higher risk due to no large scale applications. **Error! Reference source not found.** shows an example of a permanent magnet motor.

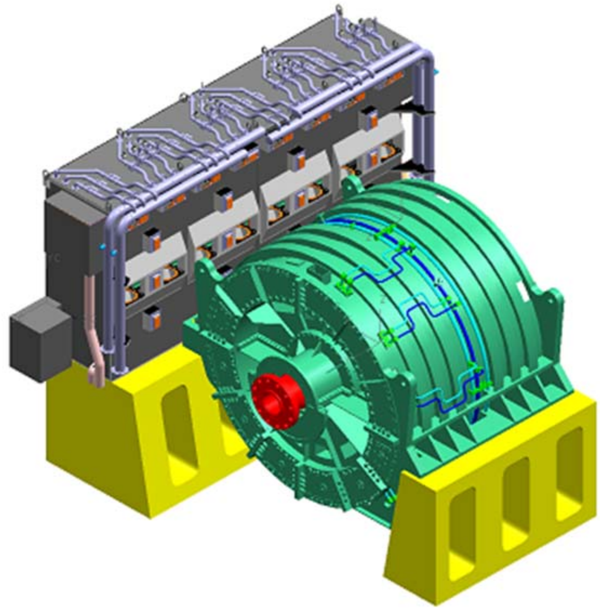


Figure 14 - Example of a propulsion motor module

Figure 15 - Advanced Induction Motor

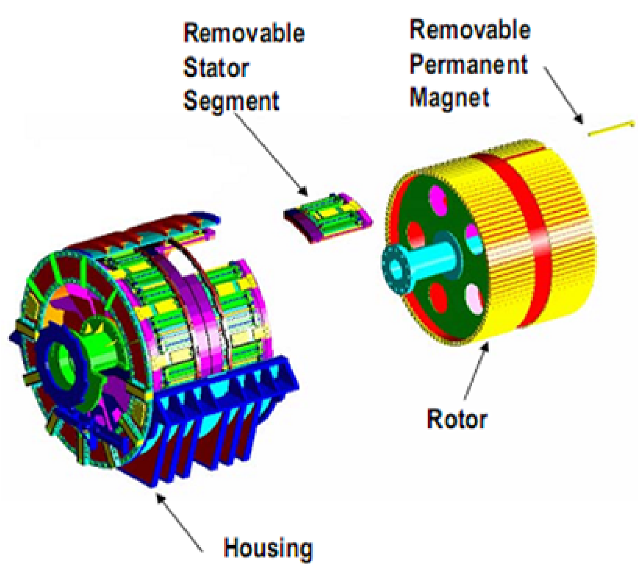


Figure 16 - Permanent Magnet Motor

Three propulsor options were initially considered: fixed-pitch propellers, pods, and a fixed-pitch propeller and a secondary propulsion unit (pod). Fixed pitch propellers have their pitch angle and diameter optimized for cruise speed with a slight decrease in efficiency at sprint speed. Fixed-pitch propellers have an excellent history of survivability, lower machinery, and maintenance requirements. These features combined with an IPS drive system and reversible motor make this design very pleasing. Pods offer excellent maneuvering due to rotational thrust vectoring, but would substantially increase required structure to support the moments and forces created. Survivability and repairs are also questionable because grounding could rip the pod from the hull, internal component or motor repairs would require dry-docking, and a torpedo or underwater explosion could leave all pods in the area of the explosion disabled or unusable. In order to keep costs and risks down while maintaining effectiveness, and after reviewing the mission scenarios which would not require the intense maneuverability provided by a pod system, fixed-pitch propellers were chosen for the design.

Both DC and AC zonal systems are being considered for power distribution, DC systems provide better survivability characteristics and are more fault tolerant than AC systems.

Again, all of these choices were made in an effort to reduce the design space of Medium Surface Combatant while providing reasonable engineering judgment.

3.1.2.2 Machinery Alternatives

Table 10 - Machinery Plant Alternatives

DV #	DV Name	Description	Design Space
10	PGM	Power Generation Module	1=3xLM2500+, AC Synch, 4160 VAC 2=3xLM2500+, AC Synch, 13800 VAC 3=4xLM2500+,AC Synch, 4160 VAC 4=4xLM2500+,AC Synch, 13800 VAC 5=2xMT30, AC Synch, 4160 VAC 6=2xMT30,AC Synch, 13800 VAC 7=3xMT30,AC Synch, 4160 VAC 8=3xMT30,AC Synch, 13800 VAC 9=4xMT30,AC Synch, 4160 VAC 10=4xMT30,AC Synch, 1380 VAC
11	SPGM	Second Power Generation Module	1=NONE 2=2xLM500G, AC Synch (DDG 1000) 3=2xCAT3608 Diesel 4=2xPC 2.5/18 Diesel 5=2xPEM 3 MW Fuel Cells (NSWCCD) 6=2xPEM 4 MW Fuel Cells (NSWCCD) 7=2xPEM 5 MW Fuel Cells (NSWCCD)
12	PROPTYPE	Propeller Type	1= 2 x FPP 2=2 x Pods 3= 1 x FPP+SPU
13	PMM	Propulsion Motor Module Type	1=(AIM) Advanced Induction Motor (DDG 1000) 2=(PMM) Permanent Magnet Motor
14	DIST	Power Distribution Type	1=AC ZEDS 2=DC ZEDS (DDG 1000)

3.1.3 Automation and Manning Parameters

In concept exploration it is difficult to deal with automation manning reductions explicitly, so a ship manning and automation factor is used. This factor represents reductions from "standard" manning levels resulting from automation. The manning factor, C_{AUTO}, varies from 0.5 to 1.0. It is used in the regression based manning equations shown in **Error! Not a valid bookmark self-reference.**. A manning factor of 1.0 corresponds to a "standard" fully-manned ship. A ship manning factor of 0.5 results in a 50% reduction in manning and implies a large increase in automation. The manning factor is also applied using simple expressions based on expert opinion for automation cost, automation risk, damage control performance and repair capability performance. Manning calculations are shown in **Error! Not a valid bookmark self-reference.**. A more detailed manning analysis is performed in concept development.

3.1.3.1 Manpower Reduction

The main goal for any ship design is to reduce the man power to reduce costs. The manpower itself is 60% of the total cost of the Navy's budget. If a restraint can be made at the beginning of the design process a large amount of money can be saved if the manning is reduced. At this time the United States has the largest use of man power for any navy in the world. There are many procedures on a ship that requires the ability to make decisions that a computer would not have the ability to make; for instance standing watch or maintenance. There are three shifts in every day and a man is need for each job. This means that at least 3 men are needed for each job.

3.1.3.2 Enabling Technologies

The emergence of new technologies will help the reduction in man power for a ship. More electronics are being placed so that a single person can do many jobs simultaneously. This also means that jobs that once required lots of pen and paper can be done on a computer much faster. Another major man power job on the ship that is required is repainting so that the ship does not corrode. New corrosion resistant coatings can alleviate much of the time that was spent in turn saving Navy money.

3.1.3.3 Simplified Manning Document

Table 3.1.3.1 shows a typical manning chart for a ship design. Most of the man power goes to weapons and operations. If the ship can have more robotic weapons or new navigation systems the man power can be greatly reduced.

Table 11 - Manning Estimate for Combatant

Departments	Division	Officers	CPO	Enlisted	Total Department	Rationale
	CO/XO	2			2	required
	Department Heads	4				minimum
Executive/Admin	Executive/Admin		1	1	2	CPO to run office, one yeoman, one personnelman
Operations	Communications	1	1	3	21	3 enlisted watch standers (3x1), CPO, officer required
	Navigation and Control		1	3		CPO navigator, 3 enlisted watch standers (3x1)
	Electronic Repair		1	2		minimum for maintenance and expertise
	CIC, EW, Intelligence	1	1	6		6 (3x2) enlisted watch standers
Weapons	Air	2	1	2	24	2 pilots, minimum maintenance and support CPO and enlisted
	Boat and Vehicle		1	3		minimum for maintenance and expertise
	Deck		1	6		minimum for maintenance
	Ordnance/Gunnery		1	2		minimum for maintenance and expertise
	ASW/MCM		1	3		minimum for maintenance and expertise
Engineering	Main Propulsion		1	8	25	minimum for maintenance and expertise, 3x2 enlisted watch standers
	Electrical/IC		1	3		minimum for maintenance and expertise, 3x1 enlisted watch standers
	Auxiliaries		1	3		minimum for maintenance and expertise, 3x1 enlisted watch standers
	Repair/DC		1	6		minimum for maintenance and expertise
Supply	Stores			2	13	minimum for workload and expertise
	Material/Repair		1	2		minimum for workload and expertise
	Mess		1	6		minimum for workload and expertise
	Total	10	16	61	87	
	Accomodations	15	20	70	105	
						assume Condition III, 3 watch sections
						automated bridge
						primary propulsion control on bridge
						accomodations support additional crew for mission packages

3.1.3.4 Building a Manning Model

The steps for determining exactly how many men will be needed are typically a late design process assignment. The steps are:

- Conduct ROC/POE analysis
- Determine the directed manpower requirements (a directed manpower requirements is for a billet that is not directly due to the mission of the ship, the command master chief petty officer billet is an example of a directed billet.)
- Determine watch station requirements
- Develop preventative maintenance levels
- Estimate corrective maintenance workloads
- Apply approved staffing standards
- Conduct on-site workload measurement and analysis
- Consider utility tasking (Special evolutions such as underway replenishment, flight quarters, etc)
- Consider allowances (margins to account for functions not related directly to the missions of the ship. For instance, the time required for set up and stowage of equipment.)
- Conduct a fleet review of the documents.
- Process manpower intensive, slow, and reliant on system experts

One must also look at the typical combat scenario for the ship. Since the Medium Surface combatant will have HELO capability flight operations systems must be installed. Also a larger fire emergency system is needed to handle the JET-A which is onboard.

3.1.3.5 Integrated Simulation Manning Analysis Tool (ISMAT)

ISMAT is a tool that can be used with model center to predict the manning needs for each option considered for the ship. It consists of libraries of known navy equipment and maintenance procedures. The user develops scenarios to test the ability of the crew. Then dynamically allocates a task for each crew member. The allocations are based on taxonomies and on the level of automation prescribed by the user. The four main crew optimization parameters are:

- Cost
- Crew Size
- Variety of jobs/crew ratings
- Workload

Table 12 - ISMAT automation levels shows the ISMAT automation selection options, starting with no automation at the top and full automation on the bottom

Table 12 - ISMAT automation levels

	Roles			
Level of Automation	Monitoring	Generating	Selecting	Implementing
1- Manual Control	Human	Human	Human	Human
2- Action Support	Human/Computer	Human	Human	Human/Computer
3- Batch Processing	Human/Computer	Human	Human	Computer
4- Shared Control	Human/Computer	Human/Computer	Human	Human/Computer
5- Decision Support	Human/Computer	Human/Computer	Human	Computer
6- Blended Decision Making	Human/Computer	Human/Computer	Human/Computer	Computer
7- Rigid System	Human/Computer	Computer	Human	Computer
8- Automated Decision Making	Human/Computer	Human/Computer	Computer	Computer
9- Supervisory Control	Human/Computer	Computer	Computer	Computer
10- Full Automation	Computer	Computer	Computer	Computer

Maintenance levels are also important to consider when running ISMAT.

- Maintenance Level 1: The crew performs all of the maintenance that is listed for each piece of equipment. There is no work done by outside contractors and there is no work that is eliminated due to better technology.
- Maintenance Level 2: The crew performs all tasks except for tasks which have a period of occurrence greater than one year. These tasks may be contracted or eliminated based on their importance to the operation of the ship.
- Maintenance Level 3: The ship performs all monthly tasks and below. Ships generally deploy for 6 months at a time. This will hinder the ability for outside personnel to conduct maintenance on the ship on a monthly, daily, or weekly basis. The quarterly tasks and above can be scheduled around port calls or can be delayed until the ship has returned to port.

All of the inputs are then considered by the manning module, shown in Figure 17, in Model Center and a crew size is determined.

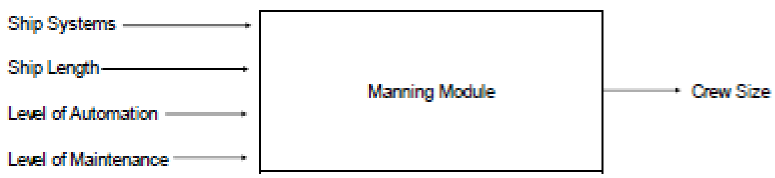


Figure 17 - Manning Module Inputs

The last step is to create a Manning Response Surface Model (RSM) using the manning module data. Personnel are assigned to maintenance tasks based on systems and their department. Personnel are assigned to accomplish the tasks within the scenario from a pool of operators. The RSM is added to the Ship Synthesis Model so that the overall computation time gets reduced.

Table 13 - Response Surface Model for overall Ship Synthesis Program

		Maintenace Level		
		1	2	3
AAW Opton	1	AAWM1	AAWM2	AAWM3
ASuW Options	1	ASuW1M1	ASuW1M2	ASuW1M3
	2	ASuW2M1	ASuW2M2	ASuW3M3
ASW Options	1	ASW1M1	ASW1M2	ASW1M3
	2	ASW2M1	ASW2M2	ASW2M3
Base Option	1	Base1	Base2	Base3
CCC Options	1	CCC1M1	CCC1M2	CCC1M3
	2	CCC2M1	CCC2M2	CCC2M3
Compartment Options	1	COMP1M1	COMP1M2	COMP1M3
	2	COMP2M1	COMP2M2	COMP2M3
	3	COMP3M1	COMP3M2	COMP3M3
GMLS Options	1	GMLSM1	GMLSM2	GMLSM3
NSFS Option	1	NSFSM1	NSFSM2	NSFSM3
PSYS Options	1	PSYS1M1	PSYS1M2	PSYS1M3
	2	PSYS2M1	PSYS2M2	PSYS2M3
	3	PSYS3M1	PSYS3M3	PSYS3M3
SDS Option	1	SDSM1	SDSM2	SDSM3

3.1.3.6 Automation vs. Cost

Figure 18 shows an estimated plot of how automation costs and the manning factor affect each other. The manning factor, C_{AUTO}, varies from 0.5 to 1.0. It is used in the regression based manning equations shown in Figure 19. A manning factor of 1.0 corresponds to a "standard" fully-manned ship. A ship manning factor of 0.5 results in a 50% reduction in manning and implies a large increase in automation. The manning factor is also applied using simple expressions based on expert opinion for automation cost, automation risk, damage control performance and repair capability performance. A standard manning Response Surface model calculation is shown in Figure 19.

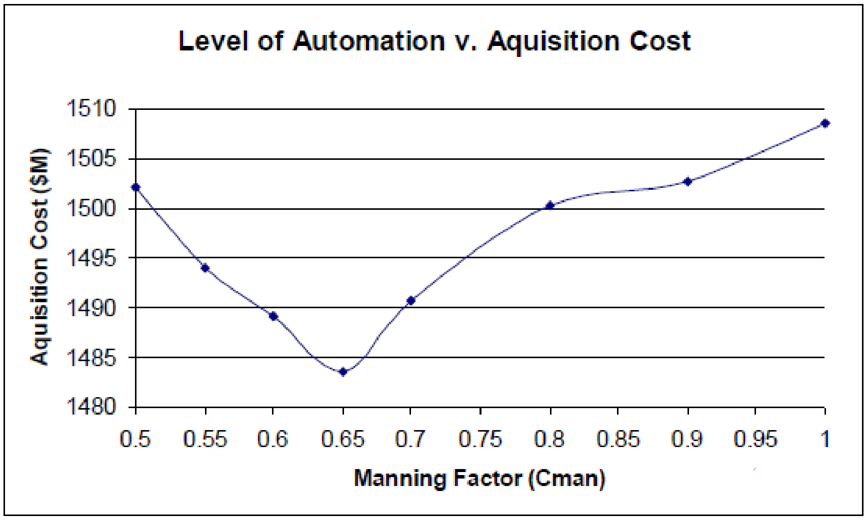


Figure 18

Response Surface Model (RSM)

$$NT = 374.49 + 82.06 * LevAuto - 6.09 * MAINT + 11.29 * LWLComp - 59.85 * LevAuto^2 + 2.08 * PSYS * LWLComp - .147 * PSYS^3 + 8.52 * LevAuto^3 - .294 * ASuW * PSYS * LevAuto + .341 * ASuw * MAINT^2 - .684 * PSYS^2 * LWLComp + .413 * PSYS * LevAuto * CCC - .485 * MAINT * CCC * LWLComp + .210 * CCC * LWLComp^2$$

Figure 19 - "Standard" Manning Calculation

3.1.4 Combat System Alternatives

The medium surface combatant design variable (DVs) include anti air warfare systems with ballistic missile defense (AAW/BMD), anti surface warfare systems (ASUW), anti submarine warfare and mine countermeasures (ASW/MCM), guided missile launch systems (GMLS), helicopter (LAMPS), and command, control, communications, computers and intelligence (CCCCI) .

3.1.4.1 AAW/BMD

Table 1 shows the Anti-Air warfare and Ballistic missile defense system options available. Options 1 and 2 are optimal configurations and options 3 and 4 are backup solutions.

Table 14 - AAW Options

Warfighting System	Options
AAW/BMD Develop for Modularity	Option 1) SPY3/VSR+++ DBR; AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 2) SPY3/VSR++ DBR; AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 3) SPY3/VSR+ DBR; AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 4) SPY3/VSR DBR; AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA.

AN/SPY-3 Multi-Function Radar (MFR) - x-band capability allowing the ship to operate and target enemies in high clutter environment; supports BMD. The MFR system meets all horizon search and fire control requirements for the 21st Century Fleet. This system can detect most advanced low observable anti cruise ship missile threats as well as provide fire-control illumination for the Sea Sparrow.

Volume Search Radar (VSR)-uses S-band frequencies for a 3-D tracking system which allows for long range volume search. This system is effective with advanced ballistic missile defense systems. However, the VSR is a large system and requires lots of power and cooling to run effectively which takes away from ship power.

Using both MFR and VSR together in sequence is referred to as dual band radar. The dual band system avoids multi radar track-to-track correlation and has the ability to perform multiple tasks simultaneously. This system replaces 6-10 legacy radar antennas and interfaces with one 6 faced radar system controlled by one system. Dual band allows for detection of stealth targets in sea clutter, and periscopes from submarines. Figure 1 shows the required system components and Figure 2 shows the DBR function.

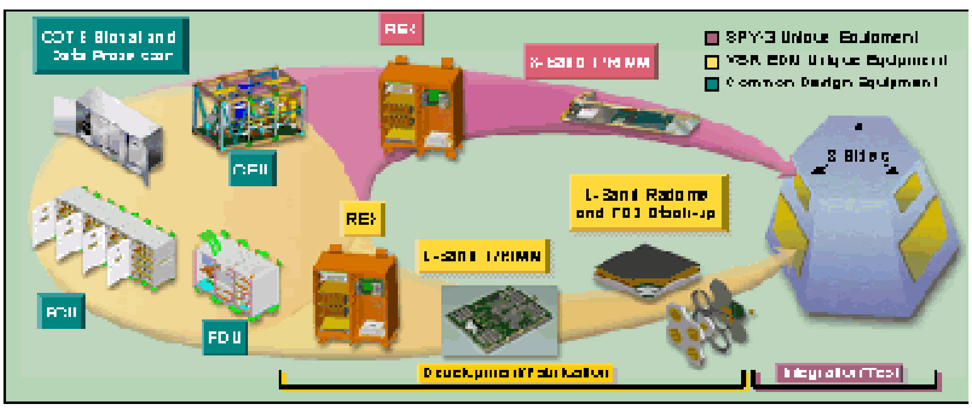
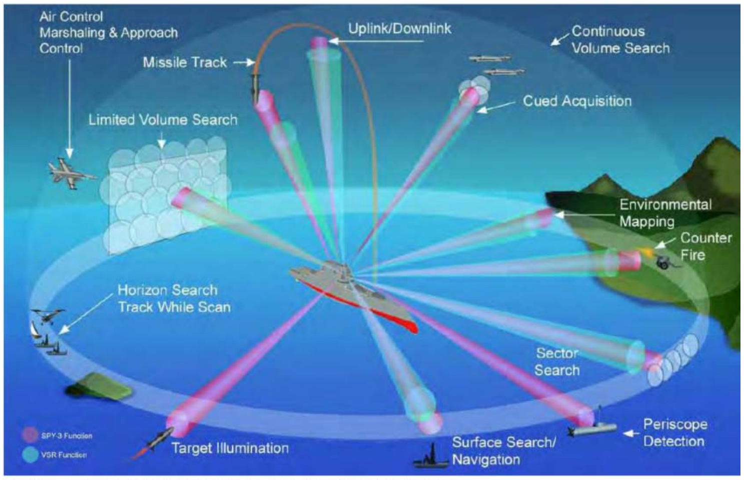


Figure 20 - System Components required for MSR and VSR



The DBR can perform all of these functions simultaneously; many at either X-band or S-band.

Figure 21 - MSR and VSR radar environmental awareness

Infrared Search and Track (IRST) - a shipboard integrator sensor designed to detect and report low flying ASCMs by heat signatures. The system scans the horizon for anomalies and can be manually controlled to receive information on bearing, elevation and thermal intensity.

AN/UPX-36(V) CIFF-SD (Centralized ID Friend or Foe) - The CIFF system is a centralized, controller processor- based system that associates different sources of target information. It identifies an anomaly as a friend or foe.

3.1.4.2 ASUW

Table 2 shows the anti surface warfare systems for the medium surface combatant.

Table 15 - ASUW Options

Warfighting System	Options
ASUW Develop for Modularity	Option 1) 1xAGS or 4x4 MK57 VLS cells (modular) Option 2) MK45 5in;62 gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS Option 3) MK110 57mm gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS

Figure 22 - Advanced Gun System (AGS)

Figure 23 - Mk 5" 62mm gun

Figure 24 - Thermal Imaging and Infrared Detection system (FLIR)

3.1.4.3 ASW

Table 3 shows the anti submarine and mine countermeasure systems. A dual frequency sonar bow array is the goal system for submarine detection.

Table 3 - ASW/MCM Options

Warfighting System	Options
ASW/MCM Develop for Modularity	Option 1) Dual Frequency Sonar Bow array, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 2) SQS-53C Option 3) SQS-56 sonar, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 4) NIXIE, SVTT, Mine Avoidance

Dual Frequency Sonar- Computer-controlled surface-ship sonar (5m), both active and passive operating capabilities providing precise information for ASW weapons control and guidance. The DFS performs direct path ASW search, detection, localization, and tracking from a hull mounted transducer array. The higher power and improved signal processing equipment, first to be linked directly to digital computers, ensures swift, accurate processing of target information. Functions of the system are the detection, tracking, and classification of underwater targets. It can also be used for underwater communications, countermeasures against acoustic underwater weapons, and certain oceanographic recording uses.

SQS-56 – The hull-mounted sonar (1.5m) with digital implementation is a system controlled by a built-in minicomputer, and an advanced display system. This system is extremely flexible and easy to operate. Active/passive, preformed beam, digital sonar providing panoramic echo ranging and panoramic (DIMUS) passive surveillance are options with this sonar option. A single operator can search, track, classify and designate multiple targets from the active system while simultaneously maintaining anti-torpedo surveillance on the passive display.

Nixie- The nixie is a decoy towed behind the ship that employs and underwater acoustic projector which is a deceptive countermeasure for acoustic homing torpedoes.

MK32- The MK32 is a system that pneumatically launches torpedo over the side of ownship. It can handle both MK46 and MK50 torpedoes. Launching from the ASW fire control system, up to three torpedoes can be fired in sequence.

3.1.4.4 GMLS/NSFS/STK

Table 4 shows the options for the guided missile launch and strike systems. Included is a railgun system which may be a module added once the system is perfected.

Table 16 - GMLS/NSFS/STK

Warfighting System	Options
GMLS/NSFS/STK Develop for Modularity	Option 1) 4x4 MK57 VLS or 1xAGS (or rail gun, or directed energy), 64xMK57 PVLS or VLS; Tomahawk WCS Option 2) 4x4 MK57 VLS or 1xAGS,56xMK57 PVLS or VLS; Tomahawk WCS Option 3) 4x4 48 x MC57 Option 4) 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS; Tomahawk WCS

Figure 5 shows the MK57 module for the vertical launch option.

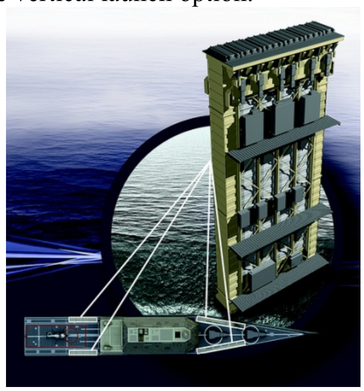


Figure 25 - MK 57 Module

Figure 6 shows the railgun system when technologically available, will be a modular addition.

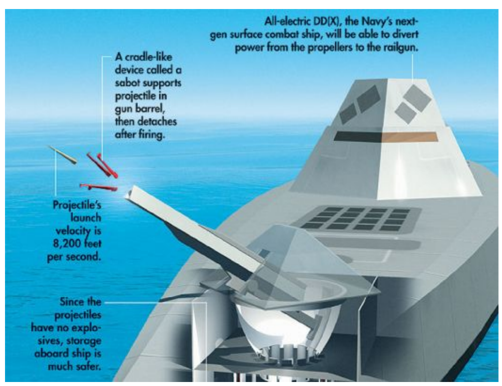


Figure 26 - Proposed Railgun configuration

3.1.4.5 **CCC**

The command, control and communication options are shown in Table 17.

Table 17 - Command, Control, Communications

Warfighting Systems	Options	
CCC Develop For Modularity	Option 1)	TOTAL SHIP COMPUTING ENVIRONMENT, ENHANCED RADIO/EXCOMM, TOMAHAWK WEAPON CONTROL SYSTEM, UNDERWATER COMMUNICATIONS, VISUAL & AUDUBLE SYSTEMS, SECURITY EQUIPMENT SYSTEMS
	Option 2)	TOTAL SHIP COMPUTING ENVIRONMENT, ENHANCED RADIO/EXCOMM, TOMAHAWK WEAPON CONTROL SYSTEM, UNDERWATER COMMUNICATIONS, VISUAL & AUDUBLE SYSTEMS, SECURITY EQUIPMENT SYSTEMS

3.1.4.6 LAMPS

Table 18 shows the HELO options for the MSC.

Table 18 - LAMPS

Warfighting System	Options
LAMPS Develop for Modularity	Option 1) Embarked LAMPS with 2x HELO Option 2) Embarked 1x HELO Option 3) LAMPS Haven

3.1.4.7 MIS/MOD

As shown in Table 19, the mission payload modules for the MSC.

Table 19 - MIS/MOD

Warfighting System	Options
MMOD Develop for Modularity	1. Option 1) 1.5xMSC Mission Payload 2. Option 2) 1xMSC Mission Payload 3. Option 3: 1/2xMSC Mission Payload

3.1.4.8 Combat Systems Payload Summary

In order to trade-off combat system alternatives with other alternatives in the total ship design, combat system characteristics listed in **Error! Reference source not found.** 8 are included in the ship synthesis model data base.

Table 20 - Combat System Ship Synthesis Characteristics

ID	NAME	DV	WTGRP	ID	SingleD	WT (MT)	HD10 (m)	HAREA (m2)	DHAREA (m2)	CRSKW	BATKW
2	155 MM AGS PROTECTION	ASUW	W164	2	100	19	0.86	0	0	0	0
3	155 MM AGS FOUNDATIONS	ASUW	W187	3	100	47	-0.15	0	0	0	0
4	155 MM AGS MAGAZINE SUPPORT	ASUW	W187	4	100	8.4	-13.65	0	0	0	0
5	155 MM AGS STOREROOM PROTECTION	ASUW	W164	5	100	12.75	-8.9	0	0	0	0
6	155 MM AGS GUN MOUNT	ASUW	W711	6	700	44.1	1.35	54.14	0	30	275
7	155 MM AGS ENERGY STORAGE SUBSYSTEM	ASUW	W711	7	700	7.49	-1.9	0	0	0	0
8	155 MM AGS CABLE	ASUW	W711	8	700	2.99	-2.9	0	0	0	0
9	155 MM AGS GUN HANDLING SYSTEM	ASUW	W712	9	700	105	-9.91	0	0	0	0
10	155 MM AGS AMMO PALLETS [304 ROUNDS]	ASUW	WF21	10	20	54.4	-8.65	342	0	0	0
11	155 MM AGS AMMO LOADOUT - 304 ROUNDS	ASUW	WF21	11	20	44.2	-7.9	0	0	0	0
12	SPS-73 SURFACE SEARCH RADAR	ASUW	W451	12	400	0.24	9.02818	0	6.50321	0.2	0.2
13	SMALL ARMS AND PYRO STOWAGE	ASUW	W760	13	700	5.94387	-1.92024	18.8593	0	0	0
14	SMALL ARMS AMMO - 7.62MM + 50 CAL + PYRO	ASUW	WF21	14	20	4.16579	-1.8288	0	0	0	0
15	THERMAL IMAGING SENSOR SYSTEM - TISS	ASUW	W452	15	400	0.13	10.85	0	0	0	1
16	FLIR	ASUW	W452	16	400	0.16	10.8	1	0	0	1.5
17	GFCS	ASUW	W481	17	400	0.762035	-1.8288	0	13.9355	12.3	42.7
18	3 X 30MM CIGS GUN	ASUW	W164	18	100	2.5	1.83	0	0	0	0
19	SWBS 187 2 X 30MM CIGS GUN FOUNDATION	ASUW	W187	19	100	9	4.35	0	0	0	0
20	3 X CIGS SYSTEMS	ASUW	W711	20	700	16.94	4.9	23.84	0	20	40
21	3 X CIGS HOIST EXTENTIONS	ASUW	W711	21	700	0.89	0.1	0	0	0	0
22	3 X CIGS AMMO HOIST	ASUW	W712	22	700	0.45	2.6	0	0	0	0
23	3 X CIGS CASE CAPTURE	ASUW	W712	23	700	4.96	3.57	0	0	0	0
24	3 X 30MM CIGS GUN AMMO	ASUW	WF21	24	20	4.29	-1.5	0	0	0	0
25	2 X 7M RHIB	ASUW	W583	25	500	7	-3	38.02	0	0	0
26	1 X MK110 57MM GUN	ASUW	W710	26	700	18	-1.88976	26.4774	0	36.6	50.2
27	MK110 57MM AMMO - 600 RDS	ASUW	WF21	27	20	16	-8.65632	65.4966	0	0	0
28	MK110 57MM GUN HY-80 ARMOR LEVEL II	ASUW	W164	28	100	10	-2.4384	0	0	0	0
29	1X MK45 5IN/62 GUN	ASUW	W710	29	700	37.3905	-1.88976	26.4774	0	36.6	50.2
30	MK45 5IN AMMO - 600 RDS	ASUW	WF21	30	20	33.6312	-8.65632	65.4966	0	0	0
31	MK45 5IN/62 GUN HY-80 ARMOR LEVEL II	ASUW	W164	31	100	20.5243	-2.4384	0	0	0	0
33	PVLS NON-STRUCTURE FRAG ARMOR 160 CELLS	GMLS	W164	33	100	213.75	-7.68	0	0	0	0
34	PVLS NON-STRUCTURE FRAG ARMOR 128 CELLS	GMLS	W164	34	100	171	-7.68	0	0	0	0
35	PVLS NON-STRUCTURE FRAG ARMOR 96 CELLS	GMLS	W164	35	100	128.25	-7.68	0	0	0	0
36	PVLS FOUNDATIONS 160 CELLS	GMLS	W187	36	100	60.5	-4.65	0	0	0	0
37	PVLS FOUNDATIONS 128 CELLS	GMLS	W187	37	100	48.4	-4.65	0	0	0	0
38	PVLS FOUNDATIONS 96 CELLS	GMLS	W187	38	100	36.3	-4.65	0	0	0	0
39	PVLS COOLING UNIT-VLS MAG 160 CELLS	GMLS	W514	39	500	59.48	-4	0	0	0	0
40	PVLS COOLING UNIT-VLS MAG 128 CELLS	GMLS	W514	40	500	47.58	-4	0	0	0	0
41	PVLS COOLING UNIT-VLS MAG 96 CELLS	GMLS	W514	41	500	35.69	-4	0	0	0	0
42	PVLS COOLING EQUIPMENT OPERATING FLUIDS 160 CELLS	GMLS	W598	42	500	27.47	-4	0	0	0	0
43	PVLS COOLING EQUIPMENT OPERATING FLUIDS 128 CELLS	GMLS	W598	43	500	21.98	-4	0	0	0	0
44	PVLS COOLING EQUIPMENT OPERATING FLUIDS 96 CELLS	GMLS	W598	44	500	16.48	-4	0	0	0	0
45	PVLS 160 CELLS	GMLS	W721	45	700	628.92	-4.33	1900	0	724.6	724.6
46	PVLS 128 CELLS	GMLS	W721	46	700	503.14	-4.33	1520	0	579.68	579.68
47	PVLS 96 CELLS	GMLS	W721	47	700	377.35	-4.33	1140	0	434.76	434.76
48	PVLS MISSLE HANDLING	GMLS	W722	48	700	0.25	14	0	0	0	0
49	PVLS LOADOUT 160 CELLS	GMLS	WF21	49	20	332.375	-3.77	0	0	0	0
50	PVLS LOADOUT 128 CELLS	GMLS	WF21	50	20	265.9	-3.77	0	0	0	0
51	PVLS LOADOUT 96 CELLS	GMLS	WF21	51	20	199.43	-3.77	0	0	0	0
52	KEI LS FOUNDATIONS 8(x4)=32 CELLS	GMLS	W187	52	100	12.1	-4.65	0	0	0	0
53	KEI LS NON-STRUCTURE FRAG ARMOR 8x4 CELLS	GMLS	W164	53	100	42.75	-7.68	0	0	0	0
54	KEI LS COOLING UNIT 8 CELLS	GMLS	W514	54	500	12.69	-4	0	0	0	0
55	KEI LS COOLING EQUIPMENT OPERATING FLUIDS 8x4 CELLS	GMLS	W598	55	500	5.4	-4	0	0	0	0
56	KEI LS 8x4 CELLS	GMLS	W721	56	700	125.8	-4.33	1140	0	434.76	434.76
57	KEI MISSILE LOADOUT 8(x4)=32 CELLS	GMLS	WF21	57	20	66.5	-3.77	0	0	0	0
59	TOTAL SHIP COMPUTING ENVIR SYSTEM	CCC	W412	59	400	73.38	-6.93	763.6	0	435.68	435.68
60	ENHANCED RADIO/EXCOMM	CCC	W441	60	400	51	11.31	0	265	227.89	228.19
61	BASIC RADIO/EXCOMM	CCC	W440	61	400	32.9098	10	0	158	93.3	96.4
62	TOMAHAWK WEAPON CONTROL SYSTEM	CCC	W482	62	400	5.70002	-2.37744	0	0	11.5	11.5
63	UNDERWATER COMMUNICATIONS	CCC	W442	63	400	2.88	-11.22	0	0	0	0
64	VISUAL & AUDIBLE SYSTEMS	CCC	W443	64	400	0.32	-5.46	0	0	0	0
65	SECURITY EQUIPMENT SYSTEMS	CCC	W446	65	400	0.88	-7.27	0	0	0	0
67	DUAL FREQUENCY BOW ARRAY SONAR DOME STRUCTURE	ASW	W165	67	100	22.5	-18.5	0	0	0	0
68	DUAL FREQUENCY BOW ARRAY SONAR ELEX	ASW	W463	68	400	26.73	-11.8	104.2	0	94.3	94.3
69	DUAL FREQUENCY BOW ARRAY SONAR HULL DAMPING	ASW	W636	69	600	10.1	-16.9	0	0	0	0
70	SQS-56 SONAR DOME STRUCTURE	ASW	W165	70	100	7.43	-17.5	0	0	0	0
71	SQS-56 SONAR ELEX	ASW	W462	71	400	5.88	-11.8	126.86	0	19.7	19.7
72	SQS-56 SONAR HULL DAMPING	ASW	W636	72	600	2.01	-16.9	0	0	0	0
73	SQS-53 SONAR DOME STRUCTURE	ASW	W165	73	100	85.7	-18.9	0	0	0	0
74	SQS-53 SONAR ELEX	ASW	W462	74	400	67.4	-11.8	271.7	0	100	100
75	SQS-53 SONAR HULL DAMPING	ASW	W636	75	600	20.1	-16.9	0	0	0	0
76	MINEHUNTING SONAR	ASW	W462	76	400	2.1	-16.5	21	0	3.7	3.7
77	ISUW - INTEGRATED UNDERSEA WARFARE SYS	ASW	W483	77	400	4.87703	-3.3528	0	0	19.5	19.5
78	SQR-19 TACTAS	ASW	W462	78	400	23.6739	-3.6096	43.9431	0	26.6	26.6
79	AN/SLQ-25 NIXIE	ASW	W473	79	400	3.65777	-3.6096	15.9793	0	3	4.2
80	BATHYTHERMOGRAPH	ASW	W465	80	400	2.63	-1.25	0	0	0	0
81	TORPEDO DECOYS	ASW	W473	81	400	5.09	-7.29	46	0	2.4	2.4
82	C+S OPERATING FLUIDS	ASW	W498	82	400	72.31	-16.15	0	0	0	0
83	2X MK32 SVTT ON DECK	ASW	W750	83	700	2.74333	-2.0856	0	0	0.6	1.1
84	6 X MK46 LIGHTWEIGHT ASW TORPEDOES	ASW	WF21	84	20	1.38182	-2.0856	0	0	0	0
86	VOLUME SEARCH RADAR [S BAND]- VSR	AAW	W456	86	400	198	7.5	0	304	2100	2100
87	GLYCOL WATER COOLING SYSTEM FOR VSR	AAW	W532	87	500	54.04	4.5	0	100	1900	1900
88	VOLUME SEARCH RADAR [S BAND]- VSR+	AAW	W456	88	400	256	7.5	0	393	2714	2714
89	GLYCOL WATER COOLING SYSTEM FOR VSR+	AAW	W532	89	500	98.76	4.5	0	183	2300	2300
90	VOLUME SEARCH RADAR [S BAND]- VSR++	AAW	W456	90	400	398	7.5	0	610	4181	4181
91	GLYCOL WATER COOLING SYSTEM FOR VSR++	AAW	W532	91	500	158.13	4.5	0	293	3500	3500
92	VOLUME SEARCH RADAR [S BAND]- VSR+++	AAW	W456	92	400	425	7.5	0	651	4462	4462
93	GLYCOL WATER COOLING SYSTEM FOR VSR+++	AAW	W532	93	500	189.76	4.5	0	352	4200	4200
94	AN/SPY-3 MFR - MULTIPLE MODE RADAR	AAW	W456	94	400	75.71	10.5	0	108.68	382.7	382.7
95	GLYCOL WATER COOLING SYSTEM FOR SPY-3 MFR / EWS	AAW	W532	95	500	22.92	1.43	0	25.14	300	300
96	AEGIS BMD 2014 COMBAT SYSTEM AND CIC	AAW	W411	96	400	17.6183	-1.09728	184.784	0	74.5	74.5
97	CIFF-SD	AAW	W455	97	400	4.47	16.22	0	0	2.7	2.4
98	MK53 NULKA DECOY LAUNCHING SYSTEM - DLS	AAW	WF21	98	20	0.82	-1.4	0	0	0	0
99	MK 36 SRBOC DECOY LAUNCHING SYSTEM - DLS	AAW	WF21	99	20	3.06	1.6	0	0	0	0
100	EWS - ACTIVE ECM - SLQ/32R	AAW	W471	100	400	9.88	1.4	0	6.5	0.32	0.32
101	IRST - INFRARED SENSING & TRACKING	AAW	W459	101	400	0	4.45	0	0	0	0
103	DUAL HELO/UAV DET - 2X SH60R HANGAR UPPER LEVEL 17 X 15.7	LAMPS	NONE	103	100	0	0	0	266.9	0	0
104	DUAL HELO/UAV DET - 2X SH60R HANGAR LOWER LEVEL 17 X 15.7	LAMPS	NONE	104	100	0	0	0	266.9	0	0
105	DUAL HELO/UAV DET - FUEL SYSTEM	LAMPS	W542	105	500	21	-9.84	0	2.77	0	0
106	DUAL HELO/UAV DET - HNDLG/SUPPORT/MAINT/WKSP - AREA ONLY	LAMPS	NONE	106	500	0	0	0	34.1	0	0
107	DUAL HELO/UAV DET - RAST/RAST CONTROL - AREA ONLY	LAMPS	NONE	107	500	0	0	44.4	0	0	0
108	DUAL HELO/UAV DET - HANDLING/SERVICE/STOWAGE - WEIGHT ONLY	LAMPS	W588	108	500	26.04	-1.69	0	0	0	0
109	DUAL HELO/UAV DET - MAGAZINE HANDLING	LAMPS	W712	109	700	0.001	-1.55	0	0	0	0
110	DUAL HELO/UAV DET - MAGAZINE 12-MK46 24-HELLFIRE 6-PENQUIN	LAMPS	WF22	110	20	0.001	-1.5	0	57.46	0	0
111	DUAL HELO/UAV DET - VTUAV	LAMPS	WF23	111	20	3.47	-2	0	0	0	0
112	DUAL HELO/UAV DET - 2X SH60R	LAMPS	WF23	112	20	10.66	-2	0	0	0	0
113	DUAL HELO/UAV DET - SUPPORT/SPARES	LAMPS	WF26	113	20	0	-2	0	158.08	0	0
114	SONOBOUY MAGAZINE STOWAGE - NONE IN PARENT	LAMPS	W713	114	700	0.001	-1.5	0	0	0	0
115	SONOBOUY MAGAZINE - 300 BUOYS - 88 MARKERS	LAMPS	WF22	115	20	0.001	-1.5	0	10.12	0	0
116	SQQ-28 LAMPS MK III ELECTRONICS	LAMPS	W460	116	400	3.51552	0.9144	0	0	5.3	5.5
117	LAMPS MKIII:AVIATION FUEL [JP-5]	LAMPS	WF42	117	40	65.4334	-12.4376	0	0	0	0
118	LAMPS MKIII:HELO IN-FLIGHT REFUEL SYS	LAMPS	W542	118	500	7.72196	-7.572	4.08773	0	1.3	1.3
119	BATHYTHERMOGRAPH PROBES	LAMPS	WF29	119	20	0.21337	-8.56359	0	0	0	0

3.1.5 Modularity Alternatives

Modularity will provide quick and efficient means of system adaptation for an increase in ship availability, functionality, scalability and maintenance and repair. The MSC will primarily integrate MEKO concept modularity into modular combat systems, berthing, logistic systems, and power distribution systems balancing consideration to modules, interfaces, and platforms. Zones will be configured throughout MSC in which modules of specific capabilities will be designated accordingly. Module arrangement within the ship will be done with use of pallets, rafts, containers, and track systems. Each zone should consist of standardized module designs for this purpose. Module design options are presented in the table below and displayed in Figure 27.

Table 21

<table>
<tr><th colspan="6">Modularity Options</th></tr>
<tr><th colspan="2">C4I</th><th colspan="2">HM&E</th><th colspan="2">Habitability</th></tr>
<tr><td>Option 1</td><td>Raft</td><td>Option 1</td><td>MR Deck Rafts</td><td>Option 1</td><td>SMART Tracks</td></tr>
<tr><td>Option 2</td><td>Tracks</td><td>Option 2</td><td>Palletized</td><td>Option 2</td><td>Standard Spaces</td></tr>
<tr><td>Option 3</td><td>Conventional</td><td>Option 3</td><td>Component</td><td>Option 3</td><td>Conventional Spaces</td></tr>
<tr><td></td><td></td><td>Option 4</td><td>Conventional</td><td></td><td></td></tr>
<tr><th colspan="2">Weapons</th><th colspan="4">Sensors/Topside</th></tr>
<tr><td>Option 1</td><td>Max Margin & Interface</td><td>Option 1</td><td>Sensors</td><td></td><td></td></tr>
<tr><td>Option 2</td><td>Min Margin & Interface</td><td>Option 2</td><td>Masts</td><td></td><td></td></tr>
<tr><td>Option 3</td><td>Same Modular Weapon</td><td>Option 3</td><td>Conventional Install</td><td></td><td></td></tr>
<tr><td>Option 4</td><td>Conventional Install</td><td></td><td></td><td></td><td></td></tr>
</table>

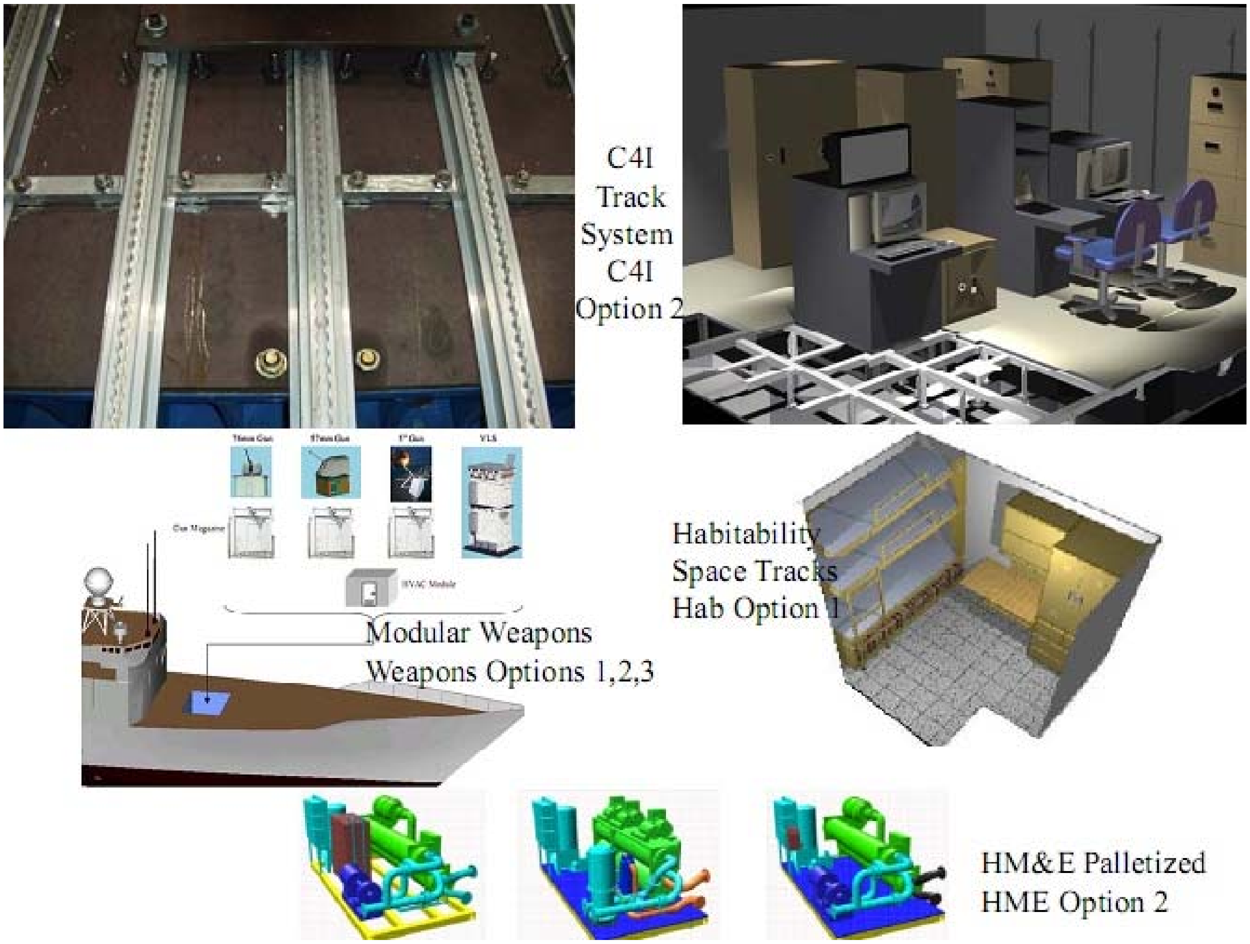


Figure 27 - Modularity Options (Brown 2009)

Track systems allow modules to be mechanically arranged and rearranged between missions (SMART Tracks). C4I and habitat modules can be interchanged using the same system. HM&E modules can be palletized for quick installation and removal. Weapons modules will be open and closed containers with interface. Module arrangement and interface configuration is similar to the MEKO concept depicted in Figure 28.

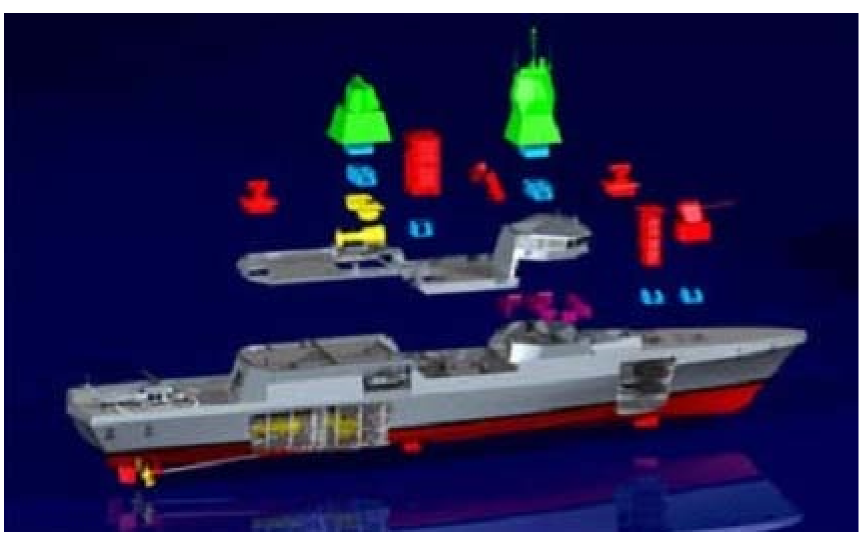


Figure 28 - MEKO Class Ship (Blohm & Voss 2002)

Habitability modularization will be utilized to allow alteration between berthing, C4I space purposes, and cargo containment depending on the mission at focus. Module options for habitability include SMART track systems, and containerization rafts and pallets. C4I modules should be tailored to utilize these same systems. HM&E modules will have the ability to be interchanged to supply needs of modules in conjunction with it. Module packages are a good alternative. Berthing module options are displayed in Figure 29 below.

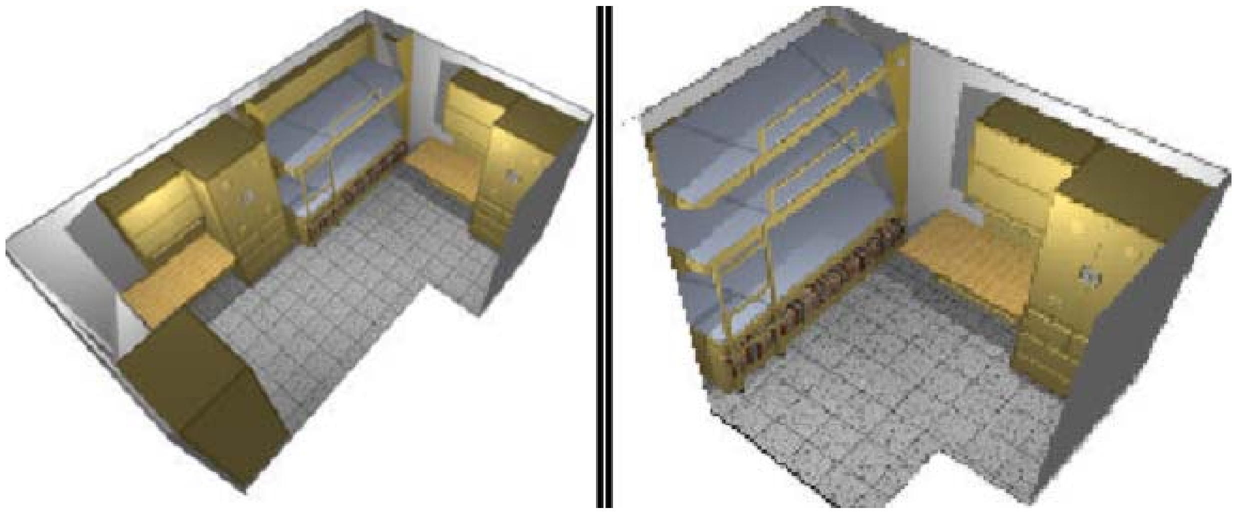


Figure 29 - Berthing Modules

Modular combat systems will provide MSC with its capability to take on a wide range of missions. Installation and removal of open and closed weapon modules will be based on the mission at hand. Interfaces will be open to allow installation of additional electrical, HVAC, water, air, and hydraulic power supply to the weapon installed. Maximum and minimum margin modules and interfaces will be available on MSC to provide compatibility with combat system options. Maximum margin modules and interfaces will allow for potential integration of future technology such as a rail gun. The rail gun module will require modules of 70 ft in length, 40 ft tall and 15 ft wide. Modules will include a power pulse module, magazine, and cooling system displayed in Figure 30. The module will interphase with the IPS 4,160 volt AC bus via a step up transformer to increase the voltage to the required 15,000 volts.

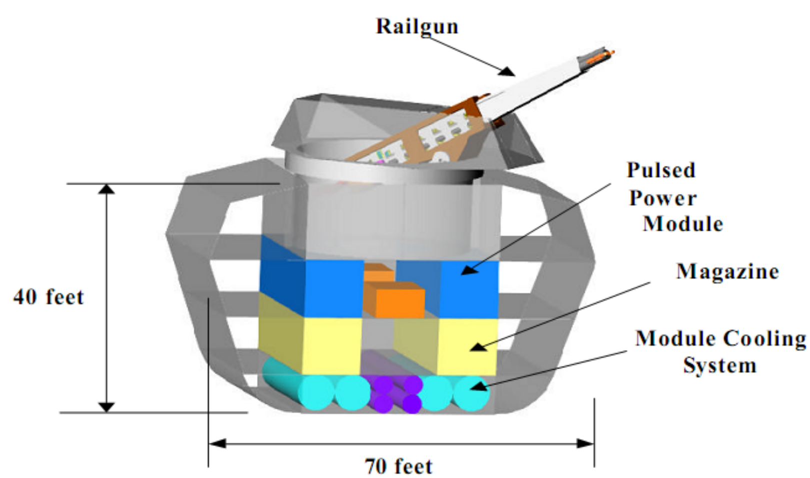


Figure 30 - Rail Gun Module

The rail gun module will be located in the forward combat module with a cost of approximately $100 million.

MSC has the ability to install multifunctional radar and sensors through modular design. Platforms of similar design can be interchanged to acquire SPY 3 and VSR for long range search and track and flexible BMD with forward and aft mast modules.

3.2 Design Space

Table 22 shows the complete design space to be explored as represented by 29 design variables (DVs). The design variables are either continuous variables (options 1-7, 15, 18) or discrete options. Each design variable is intended to represent a design space value that would be consistent with the SAG, BMD, and CSG missions. DVs are hullform options. DVs 10-14 are propulsion and electrical machinery options. DVs 19-24 are combat systems design variables. DVs 25-29 are modularity design variables.

Table 22 - Design Variables (DVs)

DV #	DV Name	Description	Design Space
1	LBP	Length Between Perpendiculars	160-210m
2	LtoB	Length to Beam ratio	7-10
3	LtoD	Length to Depth ratio	11-14
4	BtoT	Beam to Draft ratio	2.9-3.2
5	C_p	Prismatic Coefficient	.57-.63
6	C_x	Sectional Area Coefficient	.76-.85
7	VD	Deckhouse volume	10000-15000 m^3
8	Cdmat	Hull Material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite
9	HULLtype	Hull: Parent	Parent hull
10	PGM	Power Generation Module	1=3xLM2500+, AC Synch, 4160VAC 2=2xMT30, AC Synch, 4160 VAC 3=3xMT30,AC Synch, 4160 VAC 4=3xLM2500+,AC Synch, 13800 VAC 5=2xMT30, AC Synch, 13800 VAC 6=3xMT30,AC Synch, 13800 VAC 7=3xMT30,AC Synch, 4160 VAC 8=3xMT30,AC Synch, 13800 VAC 9=4xMT30,AC Synch, 4160 VAC 10=4xMT30,AC Synch, 1380 VAC
11	SPMG	Second Power Generation Module	1=NONE 2=2xLM500G, AC Synch (DDG 1000) 3=2xCAT3608 Diesel 4=2xPC 2.5/18 Diesel 5=2xPEM 3 MW Fuel Cells (NSWCCD) 6=2xPEM 4 MW Fuel Cells (NSWCCD) 7=2xPEM 5 MW Fuel Cells (NSWCCD)
12	PT	Propeller Type	1= 2 x FPP 2=2 x Pods 3= 1 x FPP+SPU
13	PMMT	Propulsion Motor Module Type	1=(AIM) Advanced Induction Motor (DDG 1000) 2=(PMM) Permanent Magnet Motor
14	PDT	Power Distribution Type	1=AC ZEDS 2=DC ZEDS (DDG 1000)
15	Ts	Provisions duration	60-75 days

16	CPS	Collective Protection System	0 = none, 1 = partial, 2 = full
17	Ndegaus	Degaussing system	0 = none, 1 = degaussing system
18	Cman	Manning reduction and automation factor	0.5 – 0.1
19	AAW/BMD/STK	AAW/SEW system Alternative	Option 1) SPY3/VSR+++ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 2) SPY3/VSR++ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 3) SPY3/VSR+ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 4) SPY3/VSR DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA.
20	ASUW/NFSU	ASUW system alternative	Option 1) MK45 5in;62 gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS Option 2) MK110 57mm gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS
21	ASW/MCM	ASW/MCM system alternative	Option 1) Dual Frequency Sonar Bow array, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option2) SQS-56 sonar, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE
22	C4ISR	C4ISR system alternatives	Option 1) Comm Suite Level A, CTSCE Option 2) Comm Suite Level B, CTSCE
23	GMLS/NSFS/STK	Develop for Modularity	Option 1) 4x4 MK57 VLS or 1xAGS (or rail gun, or directed energy), 64xMK57 PVLS or VLS; Tomahawk WCS Option 2) 4x4 MK57 VLS or 1xAGS,56xMK57 PVLS or VLS; Tomahawk WCS Option 3) 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS; Tomahawk WCS
24	MMOD	Mission Modularity	Option 1) 1.5xLCS Mission Payload; Option 2) 1xLCS Mission Payload; Option 3: 1/2xLCS Mission Payload
25	C4IMO	Modularity Option	Option 1) C4I Raft Option 2) C4I Tracks Option 3) Conventional C4I
26	HMEMOD	Modularity Option	Option 1) MR Deck Rafts Option 2) HM&E Palletized Option 3) HM&E Component Modules Option 4) Conventional HM&E
27	HABMOD	Modularity Option	Option 1) Hab Space Tracks Option 2) Standard Modular Hab Spaces Option 3) Conventional Hab Spaces
28	WPMOD	Modularity Option	Option 1) Maximim Margin and Interfaces Option 2) Minimum Margin and Interfaces Option 3) Same Modular Weapon Option 4) Conventional Weapon Install
29	SENJMOD	Modularity Option	Option 1) Modular Sensors Option 2) Modular Mast Option 3) Conventional Sensor Install

3.3 Ship Synthesis Model

A surrogate ship synthesis model (SSSM) was created in Phoenix Integration's Model Center. This synthesis model consists of multiple modules of FORTRAN code, and multiple response surface models (RSM). Figure 31 shows the model as it appears in Model Center.

The model consists of 13 modules listed below listed below with a brief description. The parts of the model that are not modules are the RSM's. Each of these computes necessary components by varying inputs. These are necessary to have in conjunction with the modules because they calculate and feed important variables to them.

The hull RSM calculates hull characteristics such as hull volume and structural weights using the inputs from the input module. The propulsion RSM calculates the propulsive characteristics; such has the shaft horse power, propulsive coefficient and other powers for the ship. The KW RSM calculates the electric loads. The three RSM's after the electric module calculate variables such as available power, 24 hour average electric load, sustained speed, and weights for various systems. The SSCS RSM's calculate the areas and volumes for the spaces on the ship as well as the manning and automation factors.

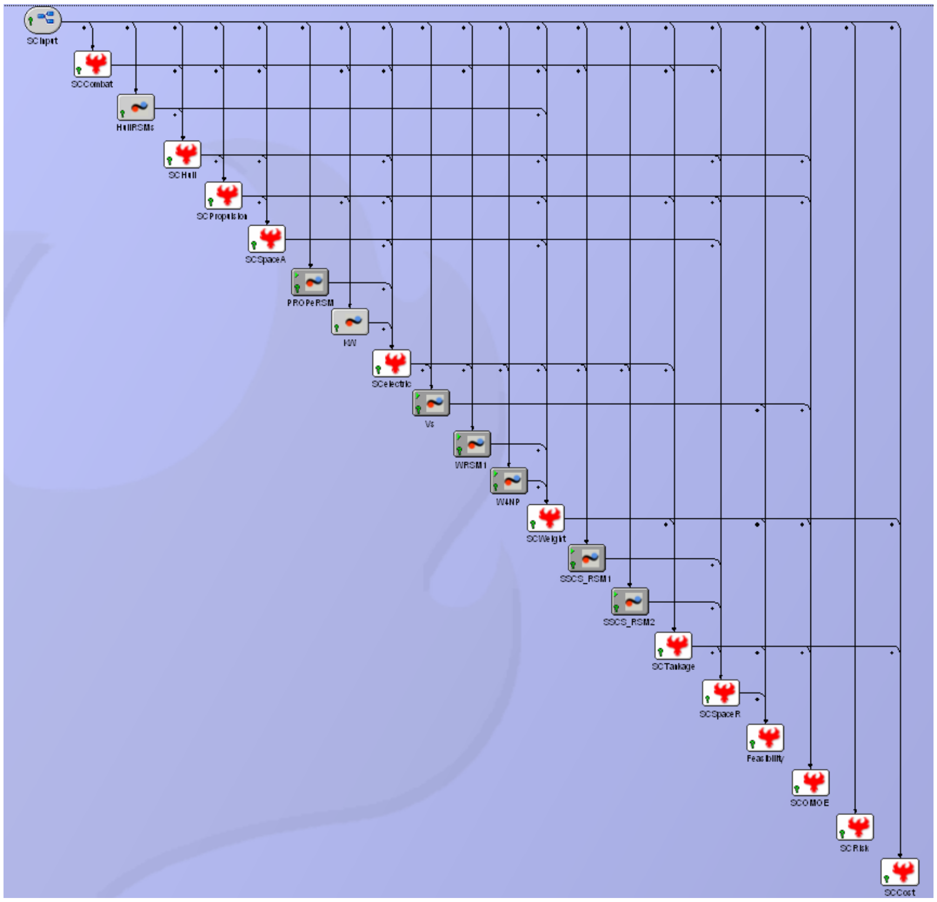


Figure 31 - Ship Synthesis Model in Model Center (MC)

Response Surface Models:

-Hull RSM

Using the Design Variable table, this response surface model will calculate the hull structural weight and the hull volume.

- Propulsion RSM

The propulsion response surface model calculates power for the ship and the propulsive coefficient for the ship.

-Electric Power RSM

The electric response surface model calculates the 24 hour average load for the ship and the maximum functional load with margins.

-Weight RSM

The weight response surface model calculates the associated weights of the ship, such as each SWBS category weights.

-Support RSM's

The support RSM's calculate the associated spaces and volumes for the support areas and auxiliaries.

Modules:
-Input Module
This module stores and distributes design variables and parameters to the necessary modules. It provides a single point of input for the entire model.
-Combat Systems Module
This module calculates ship parameters based upon a combat system option. Each option is a complete data file with varying components in the combat system. Some of the outputs for this model include weight, centers of gravity, electric load, and area necessary for the different systems etc.
-Hull Module
This module uses a parent hull form and simple equations to calculate ship parameters used in later modules. Some of the outputs for this model include total displacement and ship -coefficients etc.
-Propulsion Module
This module calculates the propulsion and power characteristics for the ship. Some of the outputs for this model include required power, areas required and SFC etc.
-Space Available Module
This module estimates the available space on the ship using previous inputs and calculated variables.
-Electric Module
This module estimates the amount of power necessary. This module also does the few manning calculations. This module outputs total electric load, 24 hour average electric load, and total load per generator etc.
-Weight Module
This module calculates the associated weights for the ship by SWBS group. Some of the outputs for this model include weights, vertical center of gravity, deckhouse weight, and stability etc.
-Tankage Module
This module computes the tankage requirements for the ship. Some of the outputs for this model include required areas, required volumes, and required fuel etc.
-Space Required
This module computes the space required for the various systems and the total arrange-able area for this ship.
-Feasibility, OMOE, Risk and Cost Module
These modules compute feasibility, effectiveness, risk and cost, respectively, for each ship design. Each is directly affected by the possible options and variations used in the optimization

3.4 Objective Attributes

3.4.1 Overall Measure of Effectiveness (OMOE)

The overall measure of effectiveness (OMOE) is a single parameter ranging from zero to one. This parameter quantifies the performance of the ship with respect to the specific mission requirements. To determine the value of the OMOE, the following equation is used:

$$OMOE = g\left[VOP_i\left(MOP_i\right)\right] = \sum_i w_i VOP_i\left(MOP_i\right) \tag{1}$$

In equation 1, MOP stands for measure of performance. Measure of performance is a system performance metric in required capabilities which is independent of the mission. VOP stands for value of performance. Value of performance is a figure of merit idex from zero to one specifying a MOP to a mission area for a mission type. The variable *w* is the weighting factor that is applied to the measure of performance and it places more importance on important components with respect to certain missions. Table 13 summarizes each ROC, MOP, and DV. Design variables correspond with ROCs seen in Table 4.

Table 23 - ROC/MOP/DV Summary

ROC	Description	MOP	Related DV	Goal	Threshold
MOB 1	Steam to design capacity in most fuel efficient manner	MOP 13 - Es	LtoB	LtoB=7	LtoB=10
		MOP 13 - Es	LtoD	LtoD=11	LtoD=14
		MOP 13 - Es	BtoT	BtoT=3.2	BtoT=2.9
		MOP 13 - Es	PSYS	PSYS=1	PSYS=8
MOB 2	Support/provide aircraft for all-weather operations	MOP 6 - Magnetic	LAMPS	LAMPS=1	LAMPS=3

MOB 3	Prevent and control damage	MOP 11 - Seakeeping and Stability	LtoB	LtoB=7	LtoB=10
		MOP 11 - Seakeeping and Stability	LtoD	LtoD=11	LtoD=14
		MOP 11 - Seakeeping and Stability	BtoT	BtoT=2.9	BtoT=3.2
		MOP 10 - RCS	VD	VD=5,000m^3	VD=15,000ft^3
		MOP 12 - VUL	Cdmat	Cdmat=1	Cdmat=2 or 3
		MOP 12 - VUL	HULLtype	HULLtype=2	HULLtype=1
		MOP 7 - IR	PSYS	PSYS=1	PSYS=8
MOB 3.2	Counter and control NBC contaminants and agents	MOP 9 - NBC	CPS	Ncps=2	Ncps=0
MOB 5	Maneuver in formation	Required in All Designs			
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	Required in All Designs			
MOB 12	Maintain health and well being of crew	Required in All Designs			
MOB 13	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support	MOP 13 - Es	LtoB	LtoB=7	LtoB=10
		MOP 13 - Es	LtoD	LtoD=11	LtoD=14
		MOP 13 - Es	BtoT	BtoT=3.2	BtoT=2.9
		MOP 13 - Es	PSYS	PSYS=1	PSYS=8
		MOP 12 - Ts	Ts	Ts=75 days	Ts=60 days
MOB 16	Operate in day and night environments	Required in All Designs			
MOB 17	Operate in heavy weather	MOP 11 - Seakeeping and Stability	LtoB	LtoB=7	LtoB=10
		MOP 11 - Seakeeping and Stability	LtoD	LtoD=11	LtoD=14
		MOP 11 - Seakeeping and Stability	BtoT	BtoT=3.2	BtoT=2.9
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations	Required in All Designs			
AAW 1.3	Provide ans Support unit anti-air self defense	MOP 1 - AAW/BMD	AAW/SEW	AAW/SEW=1	AAW/SEW=3
AAW 2	Provide anti-air defense in cooperation with other forces	MOP 1 - AAW/BMD	AAW/SEW	AAW/SEW=1	AAW/SEW=3
		MOP 1 - AAW/BMD	C4ISR	C4I=1	C4I=2
AAW 5	Provide passive and soft kill anti-air defense	MOP 1 - AAW/BMD	AAW/SEW	AAW/SEW=1	AAW/SEW=3
AAW 6	Detect, identify and track air targets	MOP 1 - AAW/BMD	AAW/SEW	AAW/SEW=1	AAW/SEW=3
AAW 9	Engage airborne threats using surface-to-air armament	MOP 1 - AAW/BMD	AAW/SEW	AAW/SEW=1	AAW/SEW=3
ASU 1	Engage surface threats with anti-surface armaments	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
		MOP 2 - ASUW/NSFS	LAMPS	LAMPS=1	LAMPS=3
ASU 1.1	Engage surface ships at long range (gun)	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.2	Engage surface ships at medium range (gun)	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.3	Engage surface ships at close range (gun)	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.4	Enage Surface Ships with large caliper gunfire	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.5	Engage surface ships with medium caliber gunfire	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.6	Engage surface ships with minor caliber gunfire	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 1.9	Engage surface ships with small arms gunfire	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASU 2	Engage surface ships in cooperation with other forces	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
		MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2

ASU 4.1	Detect and track a surface target with radar	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
		MOP 2 - ASUW/NSFS	LAMPS	LAMPS=1	LAMPS=3
ASU 6	Disengage, evade and avoid surface attack	MOP 2 - ASUW/NSFS	ASUW	ASUW=1	ASUW=3
ASW 1.1	Engage submarines at long range	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 1.2	Engage submarines at medium range	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 1.3	Engage submarines at close range	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 4	Conduct airborne ASW/recon	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
		MOP 3 - ASW	ASW/MCM	ASW/MCM=1	ASW/MCM=3
		MOP 3 - ASW	C4ISR	C4ISR=1	C4ISR=2
ASW 5	Support airborne ASW/recon	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
		MOP 3 - ASW	C4ISR	C4ISR=1	C4ISR=2
ASW 7	Attack Submarines with antisubmarine armament	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 7.6	Engage submarines with torpedoes	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 8	Disengage, evade, avoid and deceive submarines	MOP 11 - Vs	LtoB	LtoB=7	LtoB=10
		MOP 11 - Vs	LtoD	LtoD=11	LtoD=14
		MOP 11 - Vs	BtoT	BtoT=3.2	BtoT=2.9
		MOP 11 - Vs	PSYS	PSYS=1	PSYS=8
		MOP 3 - ASW	ASW/MCM	ASW/MCM=1	ASW/MCM=3
MIW 4	Conduct mine avoidance	MOP 3 - ASW	ASW/MCM	ASW/MCM=1	ASW/MCM=3
MIW 6	Conduct Magnetic Silencing	MOP 10 - VUL	Cdmat	Cdmat=2 or 3	Cdmat=1
MIW 6.7	Maintain magnetic signature limits	MOP 10 - VUL	Cdmat	Cdmat=2 or 3	Cdmat=1
CCC 1	Provide command and control facilities	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 1.6	Provide a Helicopter Direction Center	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 2	Coordinate and Control the opertions of the task organization	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 3	Provide own unit Command and Control	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 4	Maintain data link capability	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 6	Provide communications for own unit	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 9	Relay communications	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 21	Perform cooperative engagement	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
SEW 2	Conduct sensor and ECM operations	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=3
SEW 3	Conduct sensor and ECCM operations	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=3
SEW 5	Conduct coordinated SEW operations with other units	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=3
FSO 8	Conduct port control functions	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
		MOP 13 - Vs	LtoB	LtoB=7	LtoB=10
		MOP 13 - Vs	LtoD	LtoD=11	LtoD=14
		MOP 13 - Vs	BtoT	BtoT=3.2	BtoT=2.9
		MOP 13 - Vs	PSYS	PSYS=1	PSYS=8
		MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
FSO 9	Provide routine health care	Required in All Designs			

FSO 10	Provide first aid assistance	Required in All Designs			
FSO 11	Provide triage of causualties and patients	Required in All Designs			
INT 1	Support/conduct intelligence collection	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
INT 2	Provide intelligence	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
INT 3	Conduct surveillance and reconnaissance	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
INT 8	Process Surveillance and reconnaissance information	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
INT 9	Disseminate survillance and reconnaissance information	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
INT 15	Provide intelligence support for non-combat evacuation operation	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
LOG 1	Conduct underway replenishment	Required in All Designs			
LOG 2	Transfer/receive cargo and personnel (CONREP)	Required in All Designs			
LOG 6	Provide airlift of cargo and personnel (VERTREP)	MOP 6 - Magnetic	LAMPS	LAMPS=1	LAMPS=3
NCO 3	Provide upkeep and maintenance of own unit	Required in All Designs			
NCO 19	Conduct maritime law enforcement operations	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
		MOP 11 - Vs	LtoB	LtoB=7	LtoB=10
		MOP 11 - Vs	LtoD	LtoD=11	LtoD=14
		MOP 11 - Vs	BtoT	BtoT=3.2	BtoT=2.9
		MOP 11 - Vs	PSYS	PSYS=1	PSYS=8

Table 14 lists combat system MOPs with the goals and thresholds. The threshold value is the minimum components a ship must have to be able to complete its mission. The goal is the best component to perform the mission.

Table 24 - MOP Table

MOP#	MOP	Goal	Threshold	Related DV
1	AAW/BMD	AAW/SEW=1 C4I=1	AAW/SEW=3 C4I=2	AAW/SEW option C4I option
2	ASUW/NSFS	ASUW=1 Mod SUW=1 LAMPS=1 C4I=1	ASUW=3 Mod SUW=5 LAMPS=3 C4I=2	ASUW option Mod SUW option LAMPS option C4I option
3	ASW	ASW/MCM=1 Mod MIW/MCM=1 Mod ASW=1 LAMPS=1 C4I=1	ASW/MCM=3 Mod MIW/MCM=6 Mod ASW=4 LAMPS=3 C4I=2	ASW/MCM option Mod MIW/MCM option Mod ASW option LAMPS option C4I option
4	C4ISR	C4I=1	C4I=2	C4I option
5	IR	AAW/SEW=1	AAW/SEW=3	AAW/SEW option
6	Magnetic	LAMPS=1	LAMPS=3	LAMPS option
7	NBC	Ncps=2	Ncps=0	CPS option
8	RCS	VD=5000	VD=15,000	Deckhouse volume, m^3

9	Seakeeping and Stability	McC = 40	McC = 30	Hullform LBP LtoB
10 11	VUL (Vulnerability) Vs (Sustained Speed)	Cdmat=1 35	Cdmat=3 30	Ship material knots
12	Ts (Provisions)	75	60	days
13	Es (Endurance range at 20 kt)	8000	4000	nm
14	Acoustic signature	PSYS=3,4,7,8	PSYS=1,2,5,6	PSYS Option

To determine the weighting factors, and analytical hierarchy process (AHP) is used. This breaks up the OMOE into different missions that the ship will perform. The hierarchy breaks up the OMOE into different missions that the ship will perform, SAG, BMD, and CSG. In each mission type, areas important to the mission are listed and under them are the MOPs that are relevant to those areas. Figure 3 shows the hierarchy. AHP uses pairwise comparison to calculate the MOP weights. Figure 4 shows the value of each MOP weight. The result of the pairwise comparison shows that the most important MOP is AAW/BMD and the least important MOP is the ships Magnetic Signature.

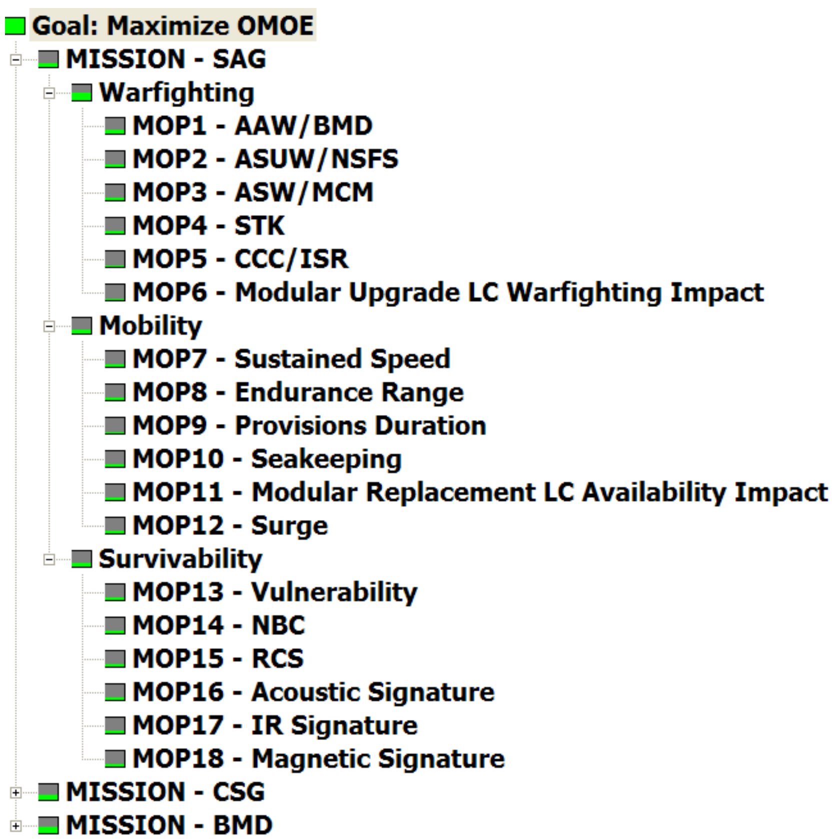


Figure 32 - OMOE Hierarchy

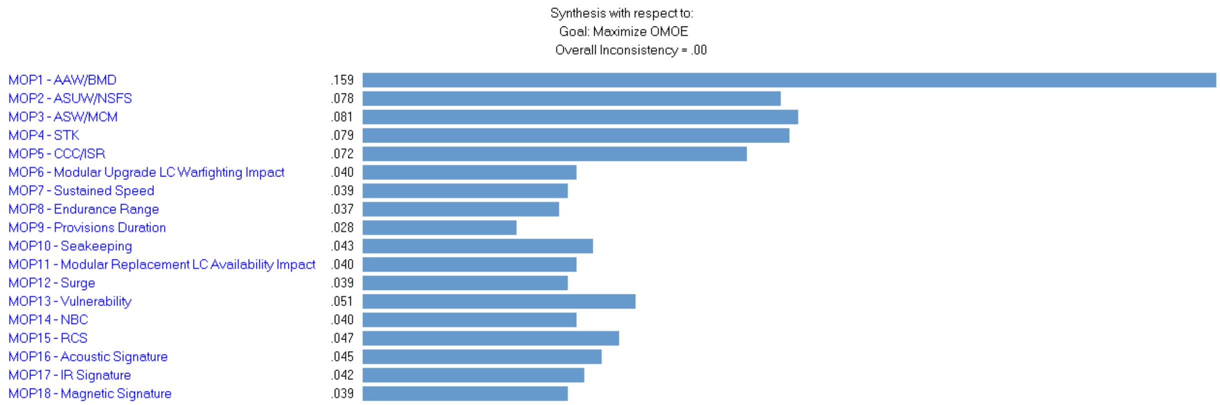


Figure 33 - Bar Chart Showing MOP Weights

3.4.2 Overall Measure of Risk (OMOR)

To calculate the ships OMOR, risk events associated with specific design variables unable to meet required capabilities, schedule, and cost are identified. Performance risks are any risks that may cause a decrease in ship performance. Cost risks are risks that will likely increase the cost to construct and operate the ship over the course of the ships life. Schedule risks are risks that could increase the production time of a ship.

For each risk event the probability of occurrence, P_i, and the consequence of the occurrence, C_i, are estimated. Table 25 shows the probability chart used to determine the value for the likelihood the risk event will occur. Table 26 shows the consequence value given the magnitude of the impact on performance, schedule or cost. The overall measure of risk can be calculated using the risk register and the calculation below. The constants W_{perf}, W_{cost}, W_{sched} are the weighting factors of risks for performance, cost, and scheduling. They are found using pair-wise comparison and the sum of them should equal 1.

$$OMOR = W_{perf} \sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{\cos t} \sum_j w_j P_j C_j + W_{sched} \sum_k w_k P_k C_k$$

Table 25 - Event Probability Estimate

Probability	What is the Likelihood the Risk Event Will Occur?
0.1	Remote
0.3	Unlikely
0.5	Likely
0.7	Highly likely
0.9	Near Certain

Table 26 - Event Consequence Estimate

Consequence Level	Given the Risk is Realized, What Is the Magnitude of the Impact? Performance	Schedule	Cost
0.1	Minimal or no impact	Minimal or no impact	Minimal or no impact
0.3	Acceptable with some reduction in margin	Additional resources required; able to meet need dates	<5%
0.5	Acceptable with significant reduction in margin	Minor slip in key milestones; not able to meet need date	5-7%
0.7	Acceptable; no remaining margin	Major slip in key milestone or critical path impacted	7-10%

0.9	Unacceptable	Can’t achieve key team or major program milestone	>10%

Table 27 shows the risk register compiled for this design. It is used to provide detailed information about the probability of risk. Each risk event is listed with its corresponding design variable and its design variable option that contains the risk. It also gives reason to why the risk will occur and the impact on performance, cost and scheduling.

The risk equation will return a value between zero and one. A zero value corresponds to no risk to performance, schedule, or cost while other values represent either some failure, lateness, or extra cost. Having risk is not necessarily a bad thing. Knowing the impact of different systems on the entire ship and especially the outcome on performance, cost, or scheduling can be lessened with proper planning.

Table 27 - Risk Register

SWBS	Risk Type	Related DV #	DV Options	DV Description	Risk Event Ei	Event #	Pi	Ci	Ri
1	Performance	DV8	3	Deckhouse Material	Composite Material producability Problems	1	0.5	0.6	0.3
1	Performance	DV8	3	Deckhouse Material	Materials fire performance doesn't meet performance predictions	2	0.3	0.5	0.15
1	Schedule	DV8	3	Deckhouse Material	Material schedule delays impact program	3	0.3	0.5	0.15
1	Cost	DV8	3	Deckhouse Material	Material development and acquisition cost overruns	4	0.3	0.6	0.18
2	Performance	DV10	1-6	Propulsion Systems	IPS Development and Implementation	5	0.4	0.6	0.24
2	Schedule	DV10	1-6	Propulsion Systems	IPS schedule delays impact program	6	0.3	0.4	0.12
2	Cost	DV10	1-6	Propulsion Systems	IPS development and acquisition cost overruns	7	0.3	0.5	0.15
2	Performance	DV11	5-7	Secondary Propulsion Systems	Fuel cells don't meet performance TLRs	8	0.4	0.6	0.24
2	Schedule	DV11	5-8	Secondary Propulsion Systems	Fuel Cells schedule delays impact program	9	0.3	0.35	0.11
2	Cost	DV11	5-9	Secondary Propulsion Systems	Fuel Cells development and acquisition cost overruns	10	0.3	0.5	0.15
2	Performance	DV14	.5	Manning reduction and automation	Automation systems doesn't meet performance TLRs	11	0.4	0.45	0.18
2	Schedule	DV14	.5	Manning reduction and automation	Automation system schedule delays impact program	12	0.3	0.3	0.09
2	Cost	DV14	.5	Manning reduction and automation	Automation system development and acquisition cost overruns	13	0.4	0.6	0.24
4	Performance	DV15	1-4	AAW Systems	SPY3/VSR development and implementation	14	0.3	0.5	0.15
4	Schedule	DV15	1-4	AAW Systems	SPY3/VSR schedule delays impact program	15	0.3	0.5	0.15
4	Cost	DV15	1-4	AAW Systems	SPY3/VSR development and acquisition cost overruns	16	0.3	0.7	0.21
4	Performance	DV19	1-3	Advance Gun System	AGS development and implementation	17	0.3	0.5	0.15
4	Schedule	DV19	1-3	Advance Gun System	AGS schedule delays impact program	18	0.3	0.5	0.15
4	Cost	DV19	1-3	Advance Gun System	AGS development and acquisition cost overruns	19	0.3	0.7	0.21

3.4.3 Cost

The components of cost included in our cost model can be seen in Figure 34. The total lead ship acquisition cost is a combination of both the end cost and the delivery cost. This is considered the Life Cycle Cost (LCC). The life cycle cost is "the direct total cost to the government of acquisition and ownership of a system over its useful life. It includes the cost of development, acquisition, operations, support, and where applicable, disposal." The LCC can be seen in Figure 36.

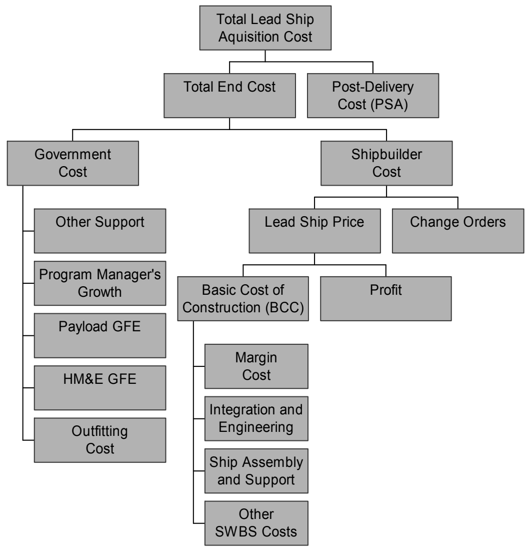


Figure 34 - Naval Ship Acquisition Cost Components

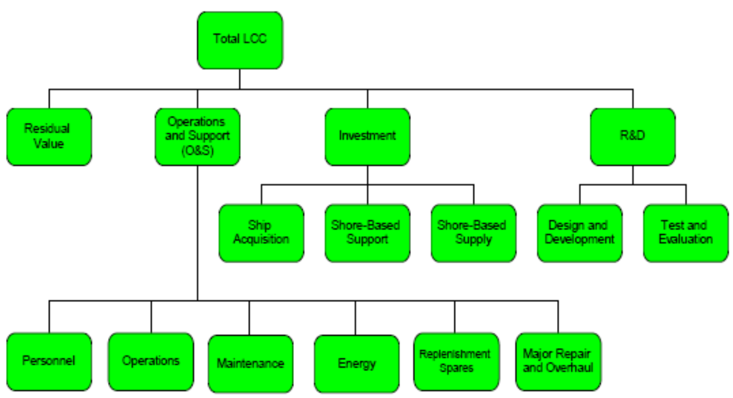


Figure 35 - Total Life Cycle Cost

Figure 36 shows that most of the entire cost for a combatant is mission personnel. This is significant because the families of the men and women aboard are also taken care of. The goal is to minimize the amount of personnel while still maintaining an effective ship so that overall cost can be reduced. This is accomplished through automation and computer systems.

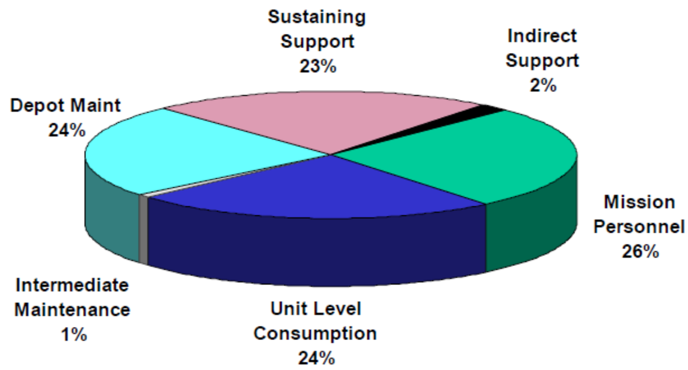


Figure 36 - Typical Combatant O & S Costs

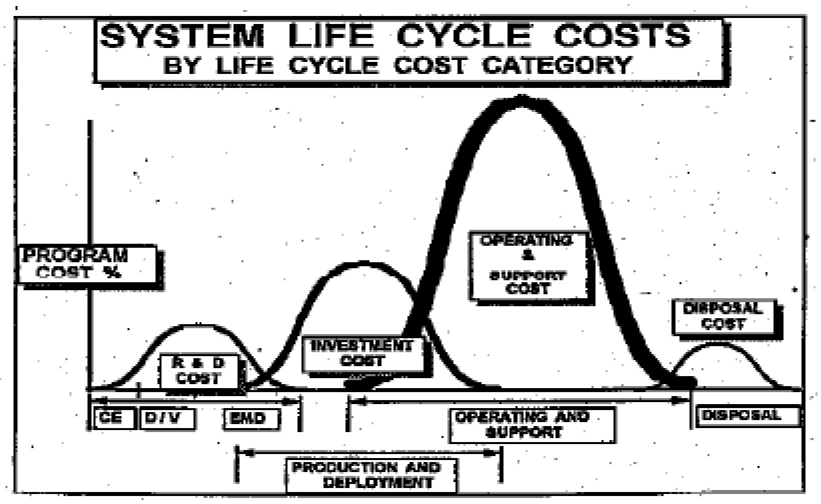


Figure 37 - Nominal Cost Distribution

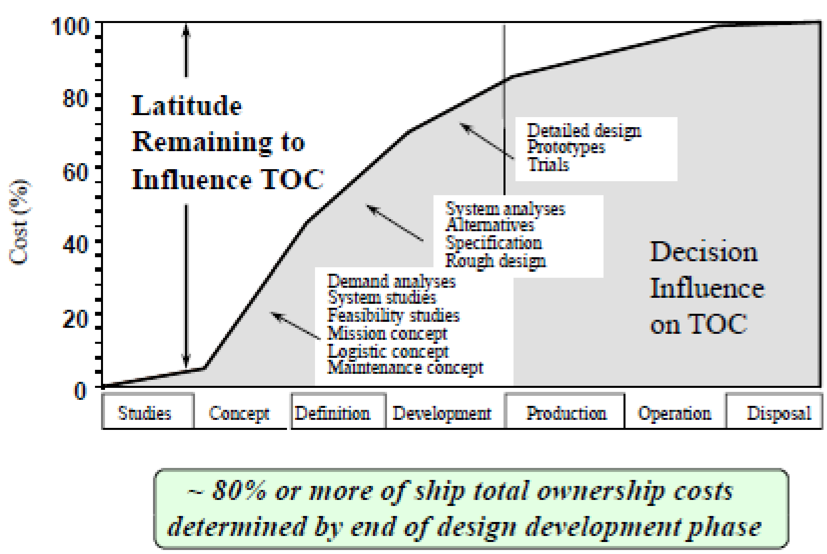


Figure 38 - Design Leverage on Total Ownership Cost

There are many methods to estimate the cost of a ship and its crew for the working life. The model chosen for this Medium Surface Combatant is the parametric model.

3.4.3.1 Parametric Model

The parametric model uses statistics to use like elements. They are estimates based on performance or design characteristics like propulsion requirements. It assumes that the performance is independent and the cost is dependent. This is the most used system for early cost estimation because it can be done with just knowing basic characteristics of the ship. The ADLV Fortran code will be utilized with the Ship Work Breakdown structure (SWBS) to compute cost estimation. The SWBS is shown in Figure 39.

SWBS	COMPONENT
100	HULL STRUCTURES
200	PROPULSION PLANT
300	ELECTRIC PLANT
400	COMMAND, CONTROL+SURVEILLANCE
500	AUXILIARY SYSTEMS
600	OUTFIT+FURNISHING
700	ARMAMENT
800	INTEGRATION AND ENGINEERING
900	SHIP ASSEMBLY AND SUPPORT
F00	LOADS
F10	CREW
F20	MISSION RELATED EXPENDABLES+SYS
F30	STORES
F40	LIQUIDS, PETROLEUM BASED
F50	LIQUIDS, NON-PETRO BASED
M25	FUTURE GROWTH MARGIN

Figure 39 - Ship Work Breakdown Structure

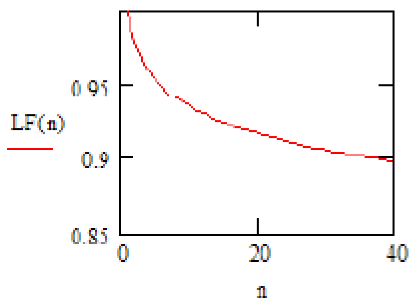
3.4.3.2 Cost Model Inputs

The cost model has a variety of inputs which are defined by design requirements. They are representative of the SWBS criteria. The list below shows most of the input variables for a cost model:

- Endurance Speed
- Endurance Range
- Fuel volume
- SWBS 100-700
- Marginal weight
- Light ship weight
- Ordinance weights
- Fuel used yearly
- Crew
- Profit margin
- Number of ships to be built

The number of ships to be built input is very important because the more ships that are built, the less it will cost over the life cycle of the ships. These are known as follow ships. The follow ships are part of a learning factor and Figure 40 shows this.

Learning Rate: $R_L := .98$ (for every doubling of number of units) $LF(n) := R_L^{\frac{\ln(n)}{\ln(2)}}$ $n := 1..N_S$



Average Follow Ship Learning Cost Factor:

$$F_{LAV} := \frac{\sum_{n=2}^{N_S} LF(n)}{N_S - 1} \qquad F_{LAV} = 0.921$$

Ship N_S/2 Learning Cost Factor: $F_l := LF\left(\frac{N_S}{2}\right)$ $F_l = 0.916$

Figure 40 - Follow Ship Learning Factor

3.5 Multi-Objective Optimization

The Multi-Objective Genetic Optimization, or MOGO, is performed in Model Center using the Darwin Optimization tool plug-in. This optimization tool and method are chosen over others because this genetic algorithm based optimization has both continuous variables and discrete variables. Other methods do not handle discrete variables well, if at all. A flow chart for this MOGO is shown in Figure 8. The objective attributes for this optimization are life cycle cost of the ship, the risk involved, and the military effectiveness of the ship. In the optimizer, the constraints considered are all taken from the feasibility portion of the Ship Synthesis Model. Finally, the design variables are all the input variables used in the ship synthesis model. Once tolerances and bounds are set for their respective variables, the Darwin genetic algorithm optimization is set to run for the optimization results.

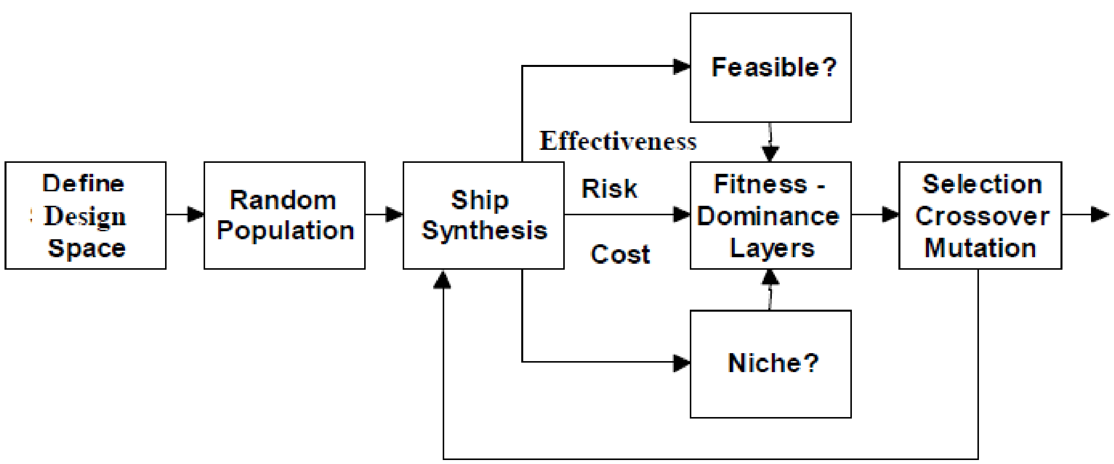


Figure 41 - Multi-Objective Genetic Optimization (MOGO)

In the first generation of designs, the optimizer randomly defines a large number of balanced ships using the ship synthesis model to weigh cost, risk and effectiveness for each design. The second generation of optimization is the single analysis of the non-dominated design. This is chosen from the optimization results analyzed in the first MOGO run and from plots like Figure 10. The "best" design is then chosen from the customer's preference for the variables cost, risk and effectiveness.

3.6 Optimization Results and Initial Baseline Design (Variant 156)

Figure 9 shows the 3D Non-Dominated Frontier for the results weighing the Overall Measure of Risk, OMOR, the Overall Measure of Effectiveness, OMOE, and Cost.

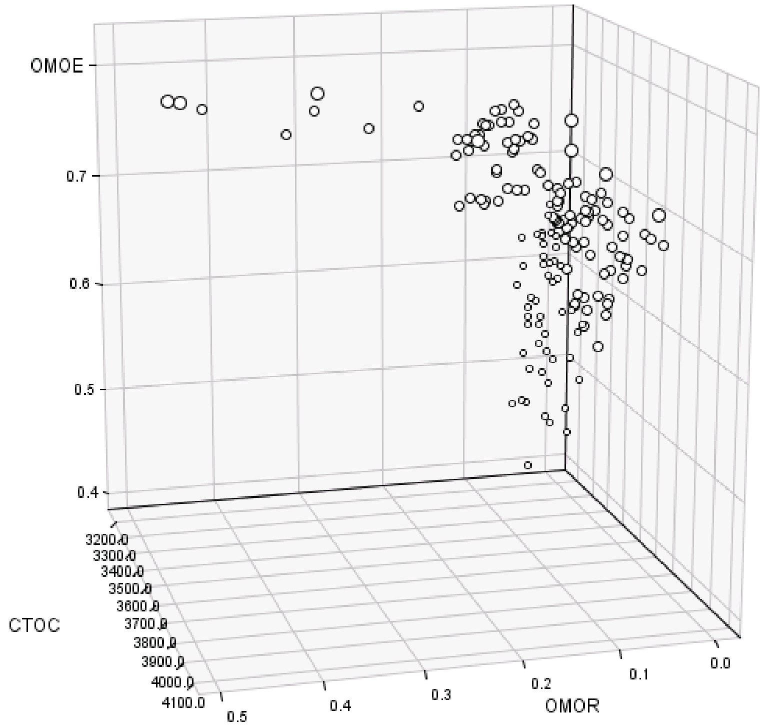


Figure 42 – 3D Non-Dominated Frontier

Perhaps an easier way to review the results is to look at Figure 10, the 2D Non-Dominated Frontier where OMOE is plotted vs. Cost but with a color variant to show the optimization of the OMOR variable. Every point on these plots represent a feasible non-dominated ship design with its respective objective attributes. "Knees" in the plot are distinct inconsistencies in the curves where large improvements in effectiveness occur for a minimal increase in cost. The "knees" in the graph represent designs that should be looked at or at least discussed as a candidate for the "best" design. For example, Point 1 shows a possible "knee" in the plot as there is little increase in cost but a high measure of effectiveness. Point 1 has an OMOE of 0.79 and an OMOR of 0.49.

The higher risk frontiers represent an increase in the use of higher risk alternatives. As can be seen in Figures 9 and 10, these high risk frontiers increase OMOR as well as OMOE. This is what causes the positive slope throughout this 2D Non-Dominated Frontier plot. It makes sense that an increase in effectiveness and an increase in risk lead to in an increase in cost, as generally more things are added to the ship to support this.

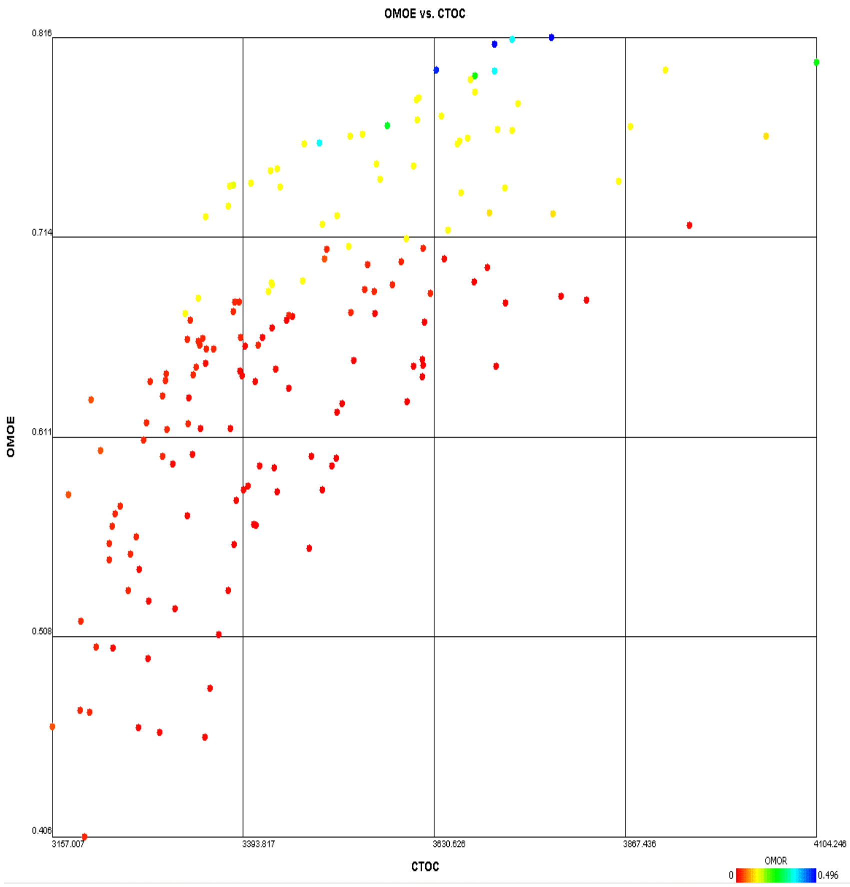


Figure 43 – 2D Non-Dominated Fromtier

3.7 Baseline Design

Using design 156 from the non dominated design frontier, a single objective optimization was preformed. From the MOGO, the baseline design had a cost of 2273 million, after the first single objective optimization the cost was reduced to 2258, the second optimization came out with a cost of 2263 million, which is more than the first but still 10 million less than the original design. Also to be noted from table 18, the ability to increase in size, while still decreasing in cost. Figure 44 shows the cost as a function of run number for the first single objective optimization.

Figure 44 Cost Optimization Run 1

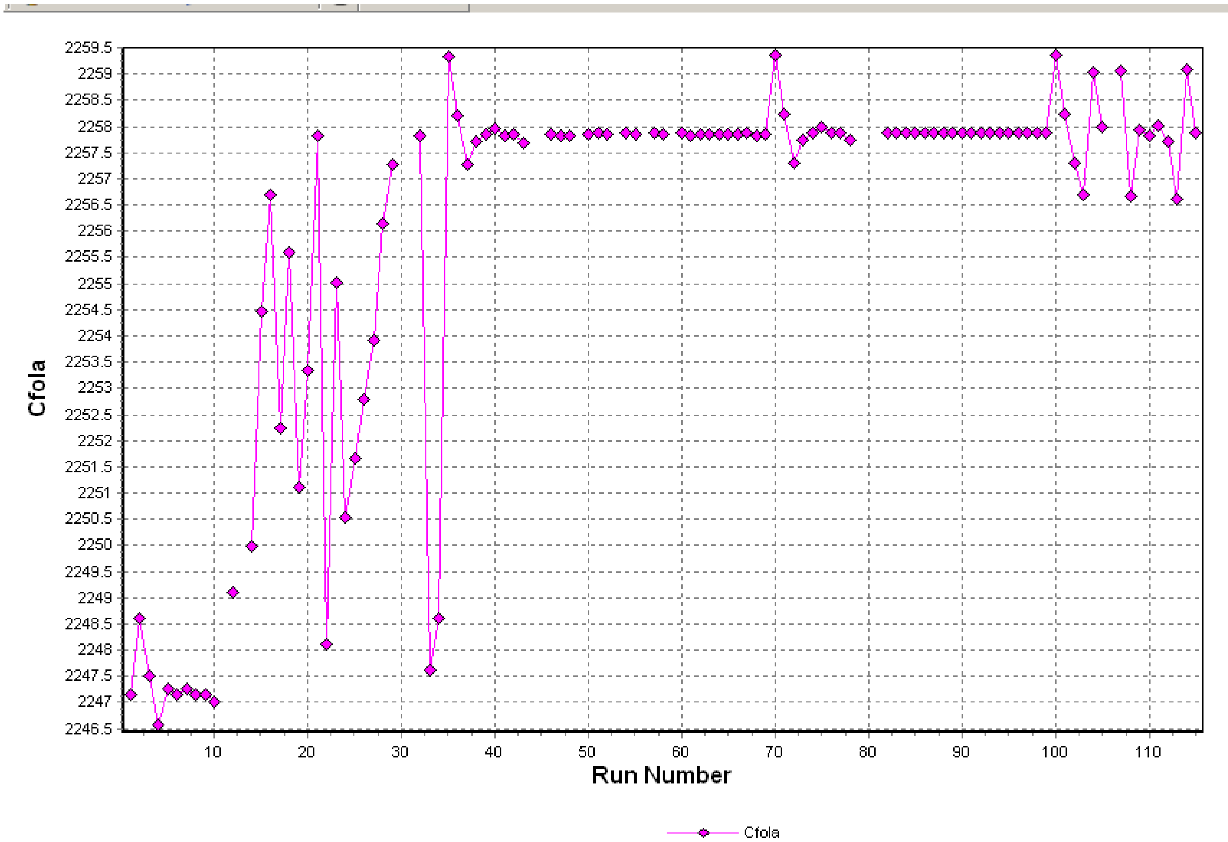


Table 28 – Baseline Design Variables Summary

Design Variable	Description	Trade-off Range	Initial Baseline (Variant 156)	Improved Baseline
1	Length Between Perpendiculars	160-210m	193.05	193.695
2	Length to Beam ratio	10-Jul	8.182	8.42
3	Length to Depth ratio	14-Nov	12.426	12.5
4	Beam to Draft ratio	2.9-3.2	2.9525	2.90474
5	Prismatic Coefficient	.57-.63	0.59419	0.58428
6	Sectional Area Coefficient	.76-.85	0.83543	0.82311
7	Deckhouse volume	5000-15000 m^3	10497	10100
8	Power Generation Module	1=3xLM2500+, AC Synch, 4160VAC 2=2xMT30, AC Synch, 4160 VAC 3=3xMT30,AC Synch, 4160 VAC 4=3xLM2500+,AC Synch, 13800 VAC 5=2xMT30, AC Synch, 13800 VAC 6=3xMT30,AC Synch, 13800 VAC	10	10
9	Second Power Generation Module	1=NONE 2=2xLM500G, AC Synch (DDG 1000) 3=2xCAT3608 Diesel 4=2xPC 2.5/18 Diesel 5=2xPEM 3 MW Fuel Cells (NSWCCD) 6=2xPEM 4 MW Fuel Cells (NSWCCD) 7=2xPEM 5 MW Fuel Cells (NSWCCD)	2	2
10	Propeller Type	1= 2 x FPP 2=2 x Pods 3= 1 x FPP+SPU	1	1
11	Propulsion Motor Module Type	1=(AIM) Advanced Induction Motor (DDG 1000) 2=(PMM) Permanent Magnet Motor	1	1
12	Power Distribution Type	1=AC ZEDS 2=DC ZEDS (DDG 1000)	1	1
13	Provisions duration	60-75 days	61	61
14	Collective Protection System	0 = none, 1 = partial, 2 = full	1	1
15	Degaussing system	0 = none, 1 = degaussing system	1	1
16	Manning reduction and automation factor	0.5 – 0.1	0.5976	0.60904
17	AAW/SEW system Alternative	Option 1) SPY3/VSR+++ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 2) SPY3/VSR++ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 3) SPY3/VSR+ DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA. Option 4) SPY3/VSR DBR; EGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA.	3	3

18	ASUW system alternative	Option 1) MK45 5in;62 gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS Option 2) MK110 57mm gun; 3x30mm CIGS (or small directed energy), small arms and pyrolocker, FLIR, 1x7m RHIB, GFCS	2	2
19	ASW/MCM system alternative	Option 1) Dual Frequency Sonar Bow array, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option2) SQS-56 sonar, ISUW; Mine avoidance sonar, 2xMK32 SVTT, NIXIE	4	4
20	Develop for Modularity	Option 1) 4x4 MK57 VLS or 1xAGS (or rail gun, or directed energy), 64xMK57 PVLS or VLS; Tomahawk WCS Option 2) 4x4 MK57 VLS or 1xAGS,56xMK57 PVLS or VLS; Tomahawk WCS Option 3) 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS; Tomahawk WCS	2	2
21	Mission Modularity	Option 1) 1.5xLCS Mission Payload; Option 2) 1xLCS Mission Payload; Option 3: 1/2xLCS Mission Payload	2	2
22	Modularity Option	Option 1) C4I Raft Option 2) C4I Tracks Option 3) Conventional C4I	2	2
23	Modularity Option	Option 1) MR Deck Rafts Option 2) HM&E Palletized Option 3) HM&E Component Modules Option 4) Conventional HM&E	2	2
24	Modularity Option	Option 1) Hab Space Tracks Option 2) Standard Modular Hab Spaces Option 3) Conventional Hab Spaces	2	2
25	Modularity Option	Option 1) Maximim Margin and Interfaces Option 2) Minimum Margin and Interfaces Option 3) Same Modular Weapon Option 4) Conventional Weapon Install	3	3
26	Modularity Option	Option 1) Modular Sensors Option 2) Modular Mast	1	1

Table 29 - Baseline Weights and Vertical Center of Gravity Summary

Group	Weight	VCG
SWBS 100	7381.31	
SWBS 200	1480.36	
SWBS 300	1922.35	
SWBS 400	936.412	

SWBS 500	1575.88	
SWBS 600	769.38	
SWBS 700	465.477	
Loads	458.843	
Lightship	14531.18	
Lightship w/Margin	15984.3	8.91239
Full Load w/Margin	17362.8	

Table 30 – Baseline Design Area Summary

Area	Required	Available
Total-Arrangeable Area	8389.97	12425.6
Hull Arrangeable Area	39154.66	44722.9
Deck House Arrangeable Area	30149.71	37829.43

Table 31 – Concept Exploration Electric Power Summary

Group	Description	Power
KW_{MFLM}	Max. Functional Load w/Margins	16700
KW_{24}	24 Hour Electrical Load	8560

Table 32 - MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Value of Performance
MOP 1	AAW/BMSD	0.874918
MOP 2	ASUW/NSFS	0.851404
MOP 3	ASW/MCM	0.583843
MOP 4	STK	0.881497
MOP 5	CCC/ISR	1
MOP 6	Modular Upgrade LC Warfighting Impact	0.673961
MOP 7	Sustained Speed	0.9816632
MOP 8	Endurance Range	0
MOP 9	Provisions duration	0.5088
MOP 10	Seakeeping	0.5
MOP 11	Modular Replacement LC Availability (Time to Repair) Impact	0.724874
MOP 12	Mission Modularity	0.845
MOP 13	Vulnerability	0.683447
MOP 14	NBC	0.845
MOP 15	RCS	1
MOP 16	Acoustic Signature	0.165
MOP 17	IR Signature	0
MOP 18	Magnetic Signature	1
MOP 19	Overall Measure of Effectiveness	0.7194714
MOP 20	Overall Measure of Risk	0.15041
MOP 21	AAW/BMSD	0.874918
MOP 22	ASUW/NSFS	0.851404
MOP 23	ASW/MCM	0.583843
OMOE	STK	0.881497
OMOR	CCC/ISR	1

Table 33 - Baseline Design Principal Characteristics

Characteristic	Baseline Value
Hull form	Flare w/tumblehome
Δ (MT)	17363
LWL (m)	193.2
Beam (m)	22.9
Draft (m)	7.87
D10 (m)	15.46
W1 (MT)	7381
W2 (MT)	1490
W3 (MT)	1922
W4 (MT)	936.4
W5 (MT)	1576
W6 (MT)	769.4
W7 (MT)	456.4
Wp (MT)	1797
Lightship Displacement (MT)	14678
Full Load Displacement Δ (MT)	17363
KG (m)	8.81
GM/B=	2.25
Propulsion system	IPS
AAW system	Option 3
ASW system	Option 4
ASUW system	Option 2
CCC system	Option 1
Total Officers	35
Total Enlisted	70
Total Manning	105
Lead-Ship Acquisition Cost	$3.25 billion
Follow-Ship Acquisition Cost	$2.713 billion
Life Cycle Cost	$218.5 billion

3.8 ASSET Feasibility Study

After completing the single objective optimization in Model Center, we ran the ship in ASSET to check its feasibility. The following characteristics in **Error! Reference source not found.** were determined and compared, showing that the ship was feasible.

Table 34 Improved Baseline / ASSET Design Principal Characteristics

Characteristic	Improved Baseline	ASSET Feasibility Study
Hull form	Flare w/tumblehome	Flare
Δ (MT)	17363	16300
LWL (m)	193.2	193.2
Beam (m)	22.9	22.95
Draft (m)	7.87	7.59
D10 (m)	15.46	15.46
W1 (MT)	7381	6400.6

W2 (MT)	1490	2251.8
W3 (MT)	1922	857.9
W4 (MT)	936.4	726.2
W5 (MT)	1576	1574.4
W6 (MT)	769.4	970.9
W7 (MT)	456.4	472.9
Wp (MT)	1797	1719
Lightship Displacement (MT)	14678	13254
Full Load Displacement D (MT)	17363	16300
KG (m)	8.81	9.06
GM/B=	2.25	2.53
Propulsion system	IPS	IPS
AAW system	Option 3	Option 3
ASW system	Option 4	Option 4
ASUW system	Option 2	Option 2
CCC system	Option 1	Option 1
Number of SPARTAN's	0	0
Number of VTUAV's	1	1
Number of LAMPS	2	2
Total Officers	35	23
Total Enlisted	70	68
Total Manning	105	91
Lead-Ship Acquisition Cost	$3.25 billion	$3.413 billion
Follow-Ship Acquisition Cost	$2.713 billion	$2.263 billion
Life Cycle Cost	$218.5 billion	$256.4 billion

4 Concept Development (Feasibility Study)

Concept Development of ASC follows the design spiral in sequence after Concept Exploration. In Concept Development the general concepts for the hull, systems and arrangements are developed. These general concepts are refined into specific systems and subsystems that meet the ORD requirements. Design risk is reduced by this analysis and parametrics used in Concept Exploration are validated.

4.1 Hull Form and Deck House (or Sail)

Using a DDG-51 parent hullform from ASSET a hybrid flare/tumblehome hull design was chosen to maximize stability while minimizing radar cross section. At 3 meters above the waterline the hull is angled inward at 10 degrees, which is conducive to reducing radar cross section and is shown in **Figure 45 Front View of MSC showing 10 degree inward angle**. This angle is currently being utilized on LPD-17 and will be on the DDG 1000.

Figure 45 Front View of MSC showing 10 degree inward angle

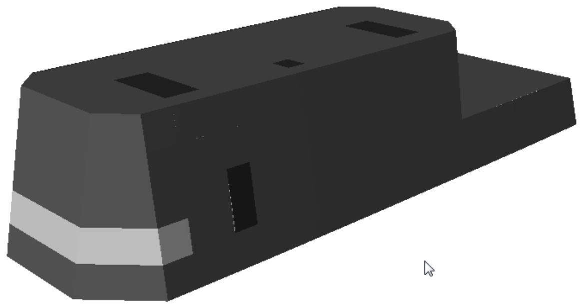
Table 35 Hull Characterisitcs

LWL	193.76
B	22.9
T	7.86
D_{10}	14.4
Δ	16012
C_x	.8

4.1.1 Deck House

The deckhouse is composite constructed with a volume of 16,000 cubic meter and continues with the 10 degree inward angle. It is comprised of 5 decks which have a HELO hanger, aviation control center, CO berthing, and navigation. The bridge is located low on the deckhouse to allow room for the large SPY-3/VSR+++DBR radar and cooling towers on the upper decks. The intake vents are located on the port and starboard sides of the deckhouse wall. The exhaust vents are located on the very top of the deckhouse. Figure 46shows the deckhouse design.

Figure 47 MSC Deckhouse



4.2 Preliminary Arrangement (Cartoon)

The preliminary arrangements and layout of MSC were made from consideration of necessary volumes and surface areas required for the equipment, machinery and structures expected to exist on the ship. Figure and Figure 49 are, respectively, profile and plan views of the preliminary arrangements of machinery rooms, exhausts, and weapons systems.

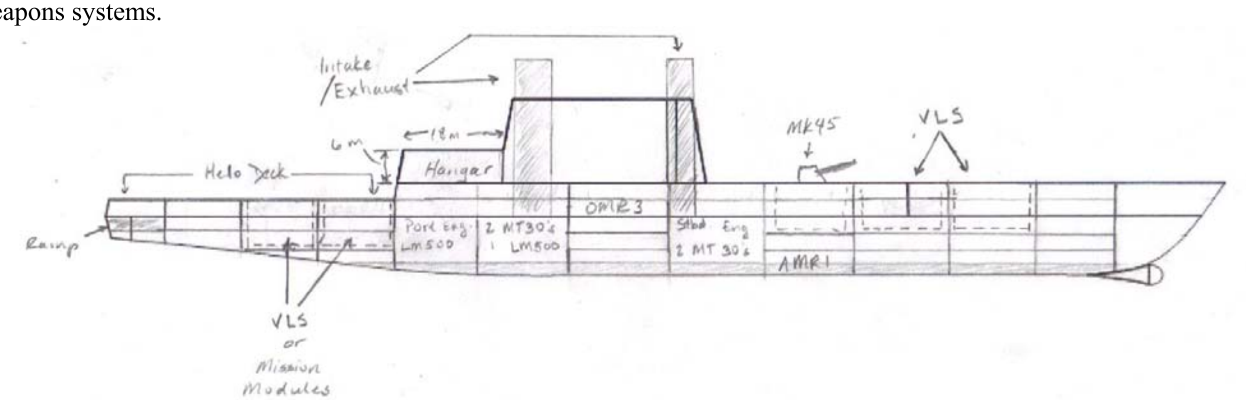


Figure 48 Preliminary Arrangements - Profile View

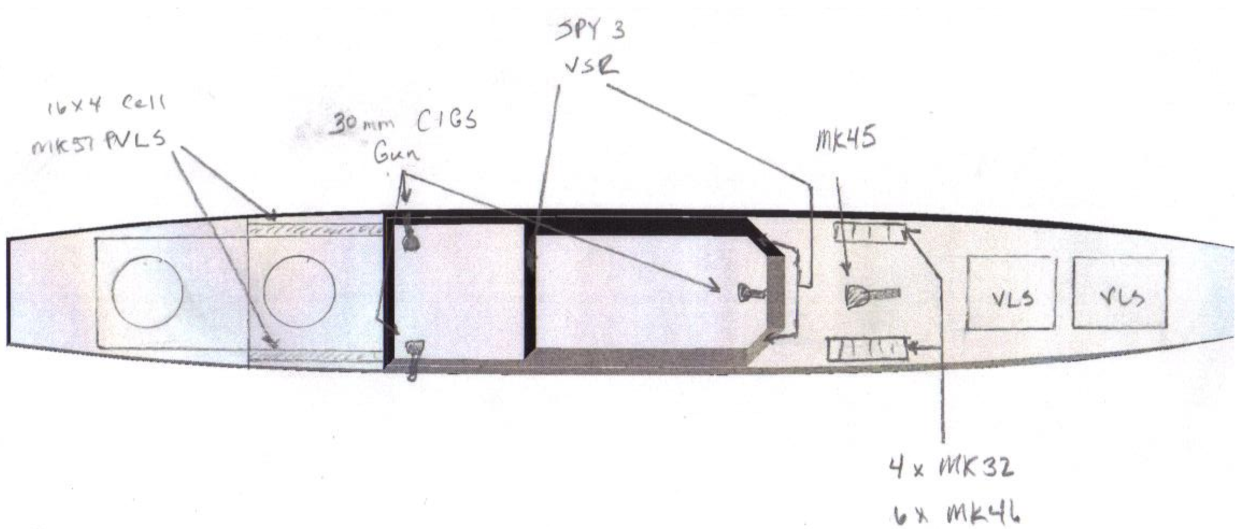


Figure 49 Preliminary Arrangements Plan View

4.3 Design for Production

Production of the hybrid hull, MSC was a continuous consideration throughout the design process. It will be done using a strategy of modular construction techniques. The ship is broken down into units or blocks such as follows:

- Bow/Stern – 1000/4000 – more curvature and transition to transverse stiffening
- Hull Cargo – 2000
- Machinery – 3000 – difficult distributed systems and outfitting
- On-board – 5000 – actually defines construction stage – electrical wiring, etc.
- Special – 6000 – requires high skill – electronics, CS, accommodations

Blocks must be installed above the relative deck by 10 cm and aft of transverse bulkheads (TBHD) by 25 cm. Stiffeners must be placed on the forward side of the TBHD. The blocks will extend between transverse bulkheads while maintaining a TBHD spacing less than plate length (50') and a block width under 10 m. All blocks, with exceptions of wing tanks/spaces and in bow tankage, will be one deck high. Blocks must be no more than 100 MT.

Special processes and specifications expected are maximum use of outfit package units and ATC modules, wire-brushing in lieu of blasting of erection butts and seams, one-sided welding with ceramic backing tape when joining units. Sleeve couplings will be used to join piping and prefabricated plates with piping welded to it for bulkhead penetrations will be used. Weld-through primer will be used and retention of CFE and GFE paint will be maximized. Below, is the unit/block breakdown of the MSC.

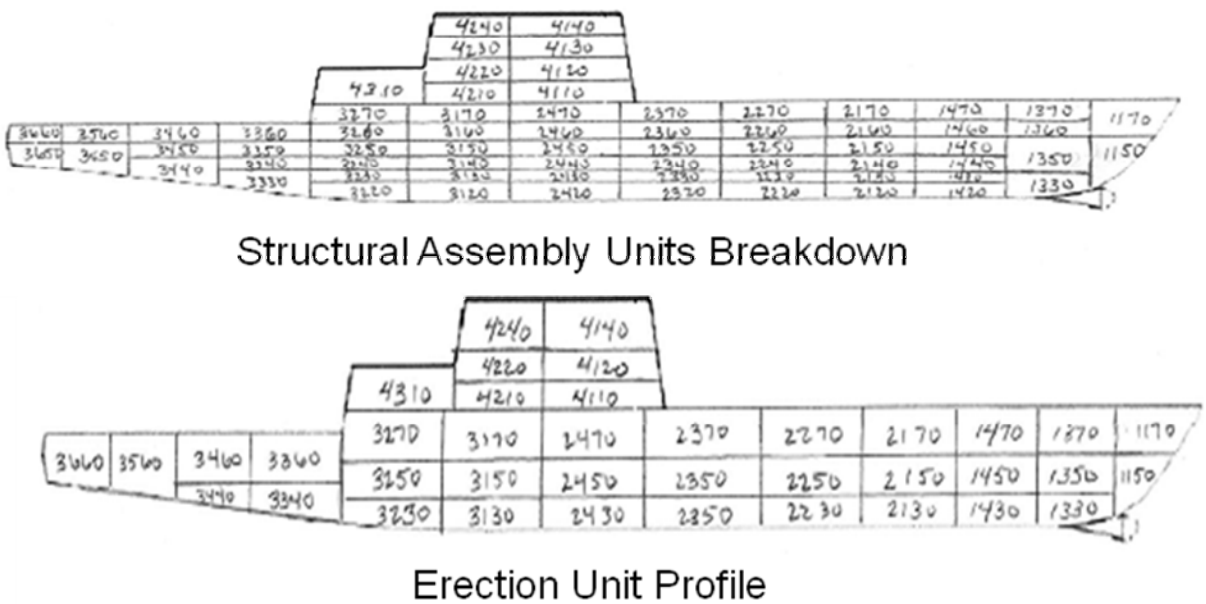


Figure 50 Unit/Block Breakdown

The approximated times of installation for these blocks are presented in Table 36 below and the overall design schedule is presented in Table 37 below.

Table 36 Claw Chart

Week	3500	3400	3300	3200	3100/3120	4600/2400	2300	4400/2200	4200/2100	4100/1400	1300	1200	1100
1					3120	2410							
2				3230		2420							
3						Gen#2	2320						
4			3330						2210				
5			Gen #3						2220				
6		3440			3130								
7						2430	2330						
8						ER#2		2230					
9			3350						2120				
10				3250					Gen#1				
11	3540									1420			
12					3150			ER#1					
13						2450			2130				
14							2350			1430			
15						4600					1310		
16								2250				1210	
17							PACKC		2150				
18								4400		1450			
19									4210		1330		
20										4110	1340		
21									4230		1350		
22	SShaft									4130		1260	
23	Pshaft								4240				1150
24									4250				1160
25	3510								4260				

Table 37 Design Schedule

Event	Description	Duration (Months)	MBD
1	Award Contract	0	66
2	Detail Design	38	65
3	Material Procurement	472	64
4	MFG/Production Planning	40	63
5	Lofting	21	57
6	Start Construction	0	48
7	Structual Fab Assembly	24	48
8	Lay Keel	0	42
9	Structural Erection	20	42
10	Machinery Installation	30	41
11	Piping Installation	32	37
12	Elect/Elex Installation	30	36
13	HVAC Installation	28	34
14	Tanl/Void Closeouts	16	25
15	Stern Release	0	24
16	Systems Testing	20	23
17	Launch	0	21
18	On-board Outfitting	14	19
19	Compartment Closeouts	14	17
20	Drydocking	1	14
21	Inclining	0	13
22	Dock Trials	0	7
23	Builder's Trials	0	5
24	Acceptance Trials	0	3
25	Delivery	0	0

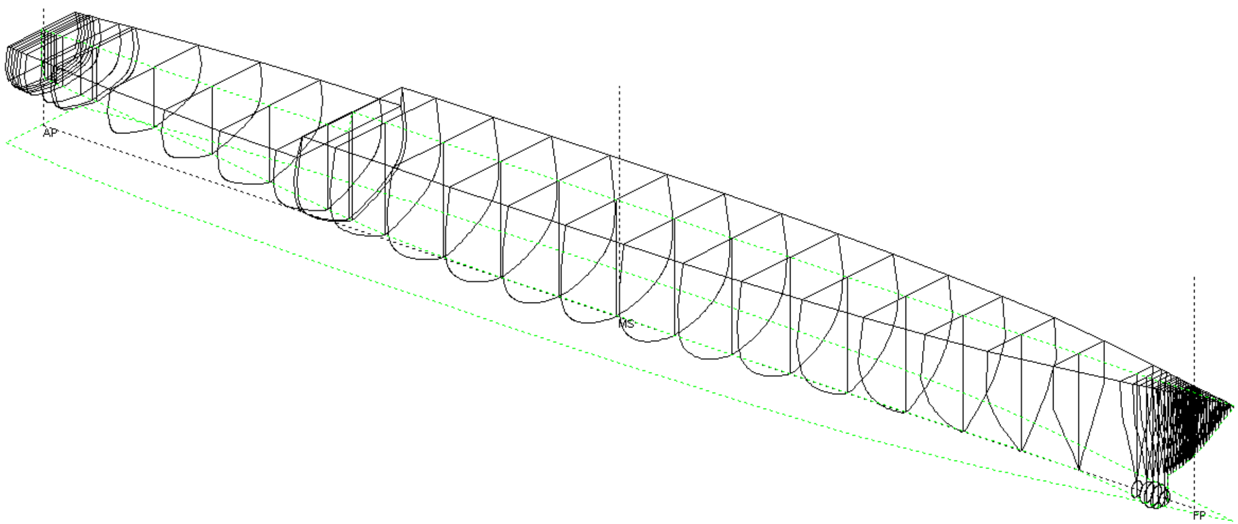
4.4 Subdivision

Primary subdivision was done with the program HecSalv. Rhino was used to model sections of the ship's hull that were then input into HecSalv. The ship particulars were input and then the bulkhead locations and deck heights were determined to provide adequate stability and workspace. Then tanks for diesel marine fuel, JP-5 Fuel, lube oil, waste oil, salt water ballast, fresh water, and sewage were placed throughout the ship. Full load and minimum operating conditions were then modeled and the preliminary assessment of intact stability based on DDS079-2 was carried out.

4.4.1 Hullform in HECSALV

Rhino sections were used to model the starboard side of the hull and were then input into HecSalv. The sections were cleaned up and simplified and then mirrored to form the whole ship. Figure 51 Rhino Sections in HecSalv shows the hull in HecSalv.

Figure 51 Rhino Sections in HecSalv



4.4.2 Transverse Subdivision, Floodable Length and Preliminary Tankage

The number of transverse bulkhead and decks were determined by ASSET. Table 38 shows the location of the transverse bulkheads measured aft from the forward perpendicular. Table 39 shows the deck heights measured from the keel of the ship. Figure 52 Transverse Bulkheads and Decks location in HecSalv shows the transverse bulkheads and decks locations on the ship in HecSalv.

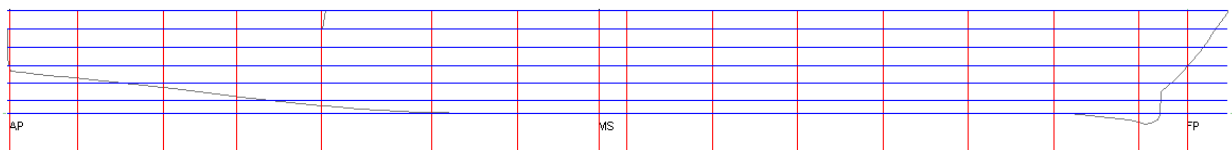
Table 38: Transverse Bulkhead Locations

Name	Long m-FP	Name	Long m-FP
FP	0	MS	96.585A
TBHD 1	8.000A	TBHD 8	110.000A
TBHD 2	22.000A	TBHD 9	124.000A
TBHD 3	36.000A	TBHD 10	142.000A
TBHD 4	50.000A	TBHD 11	156.000A
TBHD 5	64.000A	TBHD 12	168.000A
TBHD 6	78.000A	TBHD 13	182.000A
TBHD 7	92.000A	AP	193.17A

Table 39: Deck Heights

Name	Vert m-BL
Keel	0
Inner Bottom	2
Deck 4	4.8
Deck 3	7.6
Deck 2 (DC)	10.5
Deck 1 (Main)	13.5
01 Level	16.5

Figure 52 Transverse Bulkheads and Decks location in HecSalv



The bulkhead locations were input to satisfy three compartment flooding i.e. if a hole in the ship spans three compartments the ship would still be able to float. To test if the bulkhead locations would satisfy this condition the Floodable Length applet was used in HecSalv. The floodable length was modeled with four different permeability conditions i.e. the percentage of how much water would occupy the compartment. The four conditions were as followed; 95% permeability, 90% permeability, 85% permeability, and 80% permeability. Figure 53 Floodable Length Curve shows the result of the test and verifies a three compartment ship and in some sections a four compartment ship.

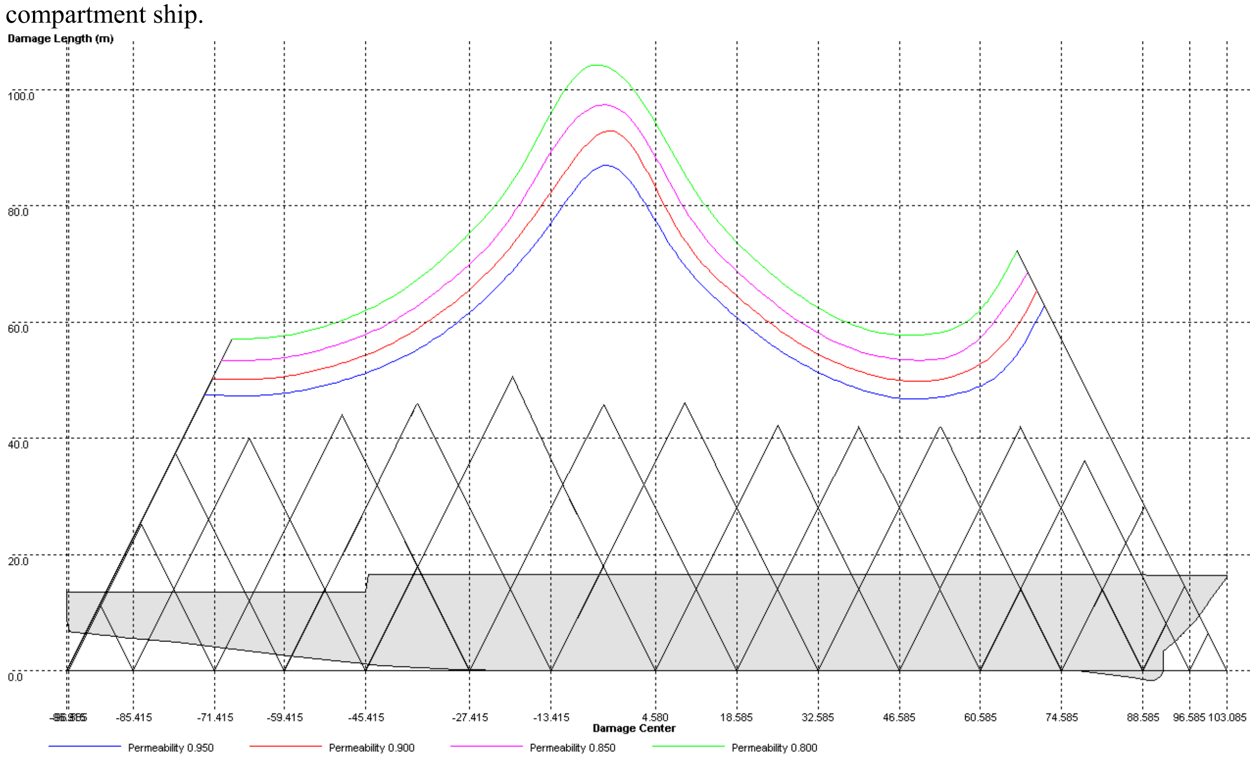


Figure 53 Floodable Length Curve

The tankage for the ship was determined using the ASSET baseline design. The first step was placing the Diesel Fuel Marine (DFM) tanks. Since these were the biggest tanks and needed to be easily accessible to the engines they were placed in the inner bottom spanning the entire ship. Next the JP-5 tanks and were placed in wing tanks under the helo deck. Salt water ballast tanks were placed as far forward and aft as possible to allow maximum trim capabilities. The lube oil and waste oil were placed in the inner bottom inside the DFM tanks under the machinery rooms to provide easy access. Fresh water and sewage tanks were placed near crew berthing for efficiency. Figure 54 shows the tanks location throughout the ship in a color coded format. Table 40 lists the tanks, their color code, volumes and locations.

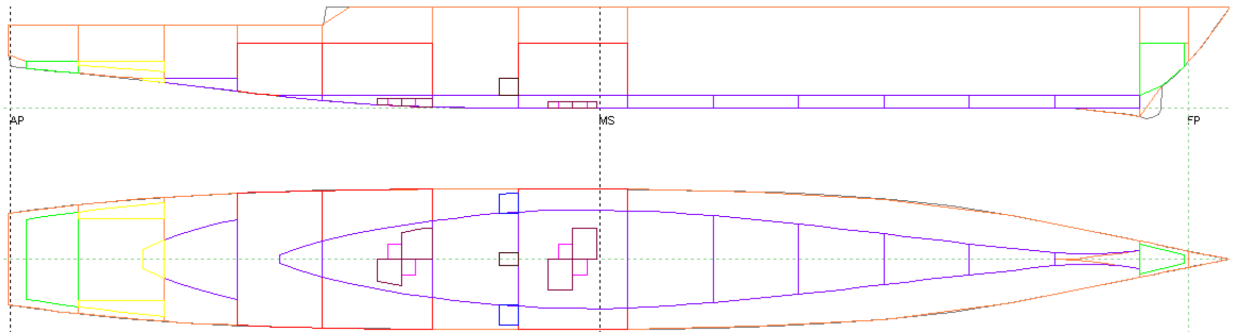


Figure 54: Ship with complete primary tankage

Table 40: Tank Definition

Name	Color	Capacity Perm m^3	100% Full Center LCG m-FP	VCG m-BL	TCG m-CL	Free Surface Slack m^4	98% Full m^4
General Space		34,157	92.539A	10.31	0.000S	130,273	44,210
Machinery Rooms		7,873	123.916A	6.669	0.000P	47,926	15,957
Fuel (DFM)		1,587	90.097A	1.44	0.010S	12,674	2,021
Lube Oil		21	115.489A	0.771	0.047S	12	5
Fresh Water		31	111.480A	3.771	0.000P	16	8
SW Ballast		193	121.879A	7.396	0.000P	1,441	203
JP-5 Fuel		43	172.724A	6.849	0.000P	35	10
Waste Oil		55	114.613A	0.819	.312P	140	26
Sewage		16	111.5A	3.4	0.000S	2	2

4.4.3 Loading Conditions and Preliminary Stability Analysis

Three loading conditions were used to test the ship's stability, lightship, Full Load, and Navy's Minimum Operation condition. In the light ship condition all the tanks remained empty. This condition was to verify that the ship would float and is stable. For full load the DFM, JP-5 Fuel, and lube oil tanks were filled 95% full while fresh water was filled 100% full and the rest remained empty. One condition for this loading was no salt water ballast could be used to trip the ship and the trim of the ship must be less than one meter. The Navy's minimum operation condition called for the DFM, JP-5 Fuel, lube oil, and fresh water tanks to be filled 33% full and the rest to remain empty. Wind heel angles were also calculated for each loading condition. For these calculations the wind speed was set at 100 mph and the sail area of the ship to be 5000 meters squared. The following figures illustrate the results of the tests for the three loading conditions.

Light Ship

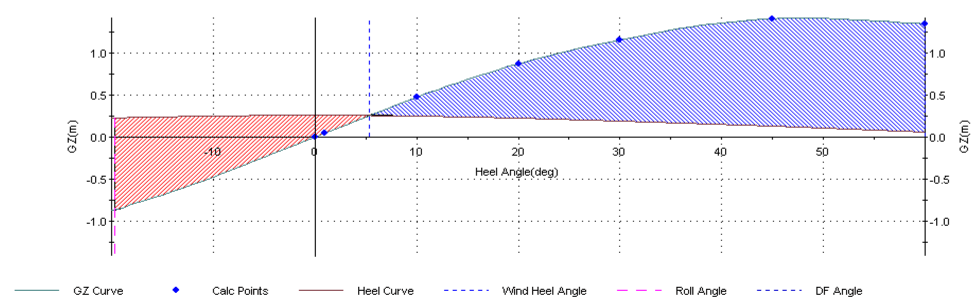
Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	15,984	9.250	96.585A	0.000	----
Constant	0	0.000	96.585A	0.000	0
Lube Oil	0	----	----	----	----
Fresh Water	0	----	----	----	----
SW Ballast	0	----	----	----	----
Fuel (DFM)	0	----	----	----	----
JP-5 Fuel	0	----	----	----	----
Waste Oil	0	----	----	----	----
Sewage	0	----	----	----	----
Misc. Weights	0	----	----	----	----
Displacement	15,984	9.250	96.585A	0.000	0

Stability Calculation			Trim Calculation		
KMt	12.207	m	LCF Draft	7.483	m
VCG	9.250	m	LCB	96.576A	m-FP
GMt (Solid)	2.957	m	LCF	106.316A	m-FP
FSc	0.000	m	MT1cm	399	m-MT/cm
GMt (Corrected)	2.957	m	Trim	0.268	m-F
			List	0.0	deg
Specific Gravity	1.0250				
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	7.631	m	Shear	2,256	MT at 142.000A m-FP
Draft at M.S.	7.497	m	Bending Moment	112,188H	m-MT at 99.161A m-FP
Draft at A.P.	7.363	m			
Draft at FwdMarks	7.631	m			
Draft at Mid Marks	7.497	m			
Draft at AftMarks	7.363	m			

Figure 55: Light ship stability calculations

Light Ship



Parameter	Units	Value	Required
Wind Heel	deg	5.3	---
Wind Heeling Arm Lw	m	0.256	---
Maximum Righting Arm Ratio		0.18	0.6
Capsizing Area A2	m-rad	0.26	---
Righting Area A1	m-rad	0.87	0.36
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.413	---
Angle at Max. GZ	deg	47.7	---
Projected Sail Area	m2	2,415.24	---
Vertical Arm ABL	m	13.748	---
Heeling Arm at 0 deg.	m	0.258	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.0	
Reference Draft	m	0.000	
Projected Sail Area	m2	5,000.00	
Vertical Center of Sail Area -BL	m	20.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

Figure 56: Light ship wind heel calculations

Full Load

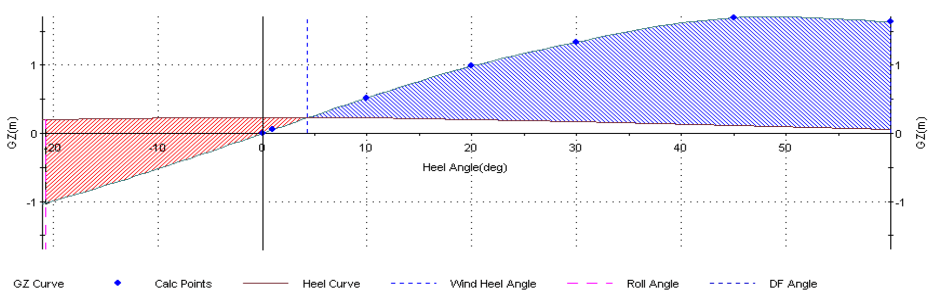
Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	15,984	9.250	96.585A	0.000	----
Constant	0	0.000	96.585A	0.000	0
Lube Oil	18	0.747	115.488A	0.047S	8
Fresh Water	31	3.771	111.480A	0.000	0
SW Ballast	0	----	----	----	----
Fuel (DFM)	1,252	1.403	90.091A	0.011S	3,438
JP-5 Fuel	71	6.859	173.439A	0.000P	0
Waste Oil	0	----	----	----	----
Sewage	0	----	----	----	----
Misc. Weights	8	0.000	96.585A	0.000	0
Displacement	17,363	8.652	96.477A	0.001S	3,446

Stability Calculation			Trim Calculation		
KMt	12.044	m	LCF Draft	7.870	m
VCG	8.652	m	LCB	96.461A	m-FP
GMt (Solid)	3.392	m	LCF	106.160A	m-FP
FSc	0.198	m	MT1cm	412	m-MT/cm
GMt (Corrected)	3.193	m	Trim	0.641	m-F
			List	0.0S	deg
Specific Gravity	1.0250				
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	8.223	m	Shear	2,143	MT at 142.000A m-FP
Draft at M.S.	7.902	m	Bending Moment	105,222H	m-MT at 99.307A m-FP
Draft at A.P.	7.581	m			
Draft at FwdMarks	8.223	m			
Draft at Mid Marks	7.902	m			
Draft at AftMarks	7.581	m			

Figure 57: Full load stability calculations

Full Load



Parameter	Units	Value	Required
Wind Heel	deg	4.3	---
Wind Heeling Arm Lw	m	0.229	---
Maximum Righting Arm Ratio		0.13	0.6
Capsizing Area A2	m-rad	0.29	---
Righting Area A1	m-rad	1.07	0.40
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.709	---
Angle at Max. GZ	deg	48.5	---
Projected Sail Area	m2	2,336.95	---
Vertical Arm ABL	m	13.951	---
Heeling Arm at 0 deg.	m	0.230	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.0	
Reference Draft	m	0.000	
Projected Sail Area	m2	5,000.00	
Vertical Center of Sail Area -BL	m	20.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

Figure 58: Full load wind heel calculations

Min Op

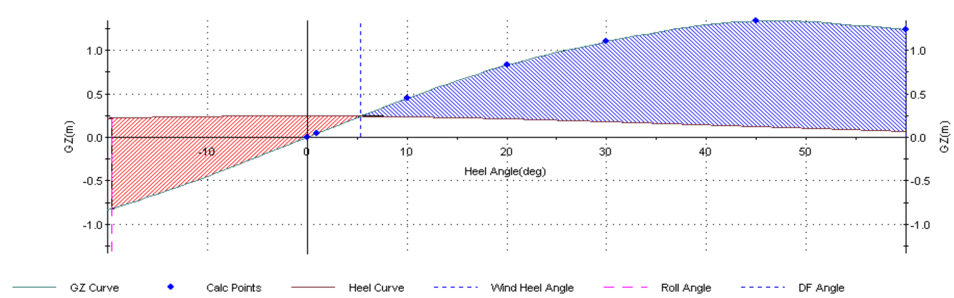
Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	15,984	9.250	96.585A	0.000	----
Constant	0	0.000	96.585A	0.000	0
Lube Oil	6	0.420	115.461A	0.048S	11
Fresh Water	20	3.395	111.474A	0.000	12
SW Ballast	0	----	----	----	----
Fuel (DFM)	435	0.854	89.986A	0.030S	5,479
JP-5 Fuel	23	6.365	172.318A	0.000P	35
Waste Oil	0	----	----	----	----
Sewage	0	----	----	----	----
Misc. Weights	0	----	----	----	----
Displacement	16,468	9.014	96.544A	0.001S	5,536

Stability Calculation			Trim Calculation		
KMt	12.148	m	LCF Draft	7.620	m
VCG	9.014	m	LCB	96.532A	m-FP
GMt (Solid)	3.134	m	LCF	106.270A	m-FP
FSc	0.336	m	MT1cm	404	m-MT/cm
GMt (Corrected)	2.798	m	Trim	0.402	m-F
			List	0.0S	deg
Specific Gravity	1.0250				
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	7.841	m	Shear	2,215	MT at 142.000A m-FP
Draft at M.S.	7.640	m	Bending Moment	109,680H	m-MT at 99.118A m-FP
Draft at A.P.	7.439	m			
Draft at FwdMarks	7.841	m			
Draft at Mid Marks	7.640	m			
Draft at AftMarks	7.439	m			

Figure 59: Minimum operating stability calculations

Min Op



Parameter	Units	Value	Required
Wind Heel	deg	5.4	---
Wind Heeling Arm Lw	m	0.246	---
Maximum Righting Arm Ratio		0.18	0.6
Capsizing Area A2	m-rad	0.25	---
Righting Area A1	m-rad	0.82	0.35
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.340	---
Angle at Max. GZ	deg	46.6	---
Projected Sail Area	m2	2,387.58	---
Vertical Arm ABL	m	13.820	---
Heeling Arm at 0 deg.	m	0.248	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.0	
Reference Draft	m	0.000	
Projected Sail Area	m2	5,000.00	
Vertical Center of Sail Area -BL	m	20.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

Figure 60: Minimum operating wind heel calculations

When examining the results we find that the ship trims well in all loading conditions such that the salt water ballast isn't used even in the minimum operation condition and the maximum change in trim is .64 meters which is very small along a 200 meter ship. The wind heel calculations all yielded pretty similar values but the value was smaller than expected.

4.5 Structural Design and Analysis

MAESTRO is a finite-element program used to analyze the structural effectiveness of ships. MAESTRO stands for **M**ETHOD for **A**NALYSIS, **E**VALUATION, and **STR**UCTURAL **O**PTIMIZATION. It is for rationally-based design of large and complex thin-walled structures. MAESTRO can calculate ship-based loading, finite element analysis, structural evaluation, optimization, and fine mesh analysis.

The materials and component definition was determined from ASSET. Other structural information such as frame spacing and stiffener spacing was also determined from ASSET. The hull was determined in combination with ASSET and Rhino, where changes were made to the baseline model. It was then input into MAESTRO using structural node points. The points, defined at the bulkhead locations were entered into MAESTRO to create a panel.

In MAESTRO, general loads like Stillwater, hogging and sagging conditions, tankage, hull weight, and other hull loads were entered. The way MAESTRO determines if an element is adequate enough is to calculate its strength ratio and then normalizing it to where values would fall between -1 and +1. If an element has an adequacy value less than 0 it is failing and if it has a value of 1 it is overdesigned. The equations and variables for the adequacy calculation can be seen in Figure 61.

Strength Ratio: $$R = \frac{\gamma Q}{Q_L}$$

Adequacy Parameter: $$g(R) = \frac{1 - \gamma R}{1 + \gamma R}$$

γ Factor of Safety
Q Measured Load
Q_L Limit Load

Figure 61: MAESTRO adequacy equations and variables

The model was tested and MAESTRO gave results on the stress locations and plate adequacy within the structure to determine if the hull is structurally efficient. The structural Design Process is shown in Figure 62.

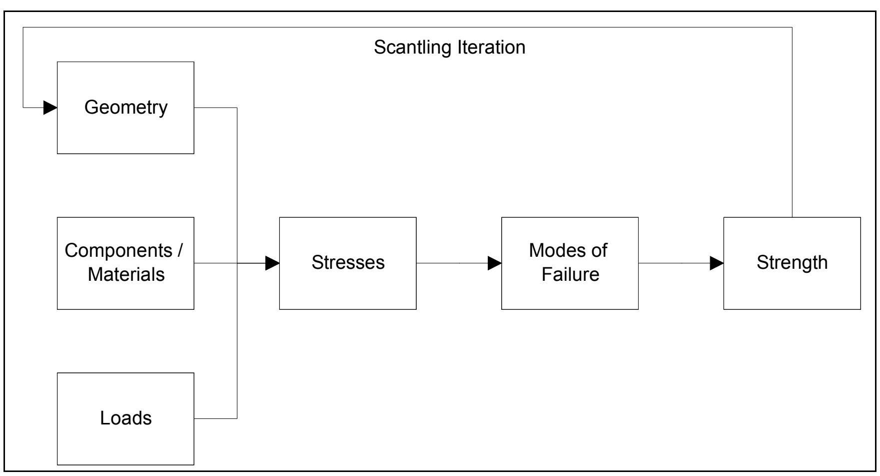


Figure 62: Structural Design Process

4.5.1 Geometry, Components and Materials

From a combination of ASSET and Rhino, all materials, nodes, and structural components were determined from the structures module. The structure was built starting from midship and working forward then continuing aft of midship using 15 modules. Each module consists of smaller strakes that are defined by the node points and can contain frames, stiffeners, and girders. The completed Finite Element model is shown in Figure 63.

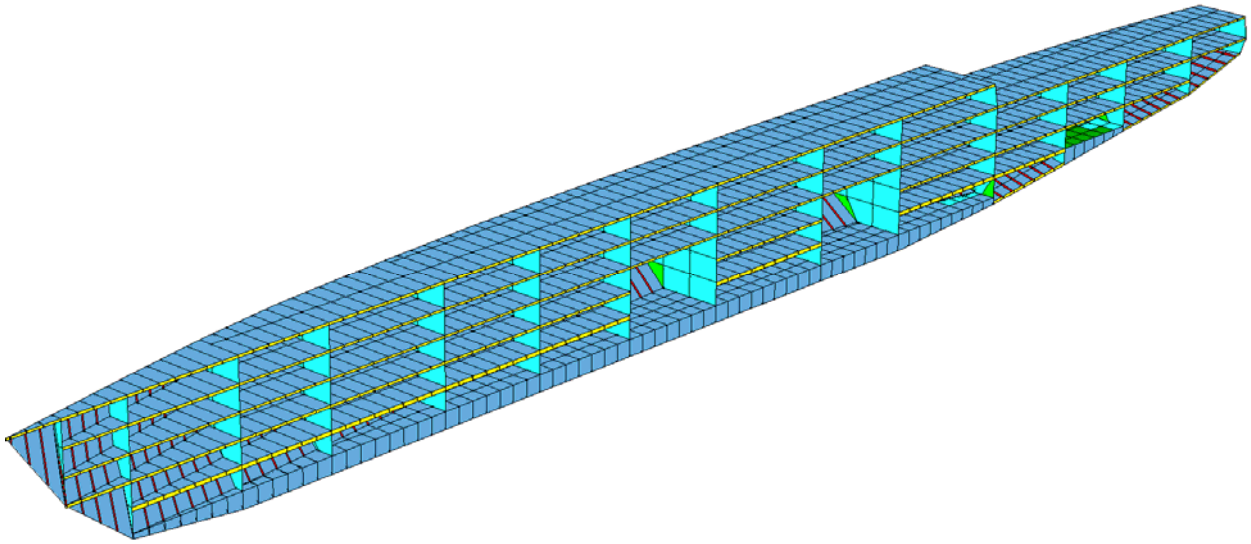


Figure 63: Complete Finite Element Model

The structural model has many details in it including girders, frames, and stiffeners. Figure 64 shows the skeletal structure of the model including the girders, frames, and bulkheads.

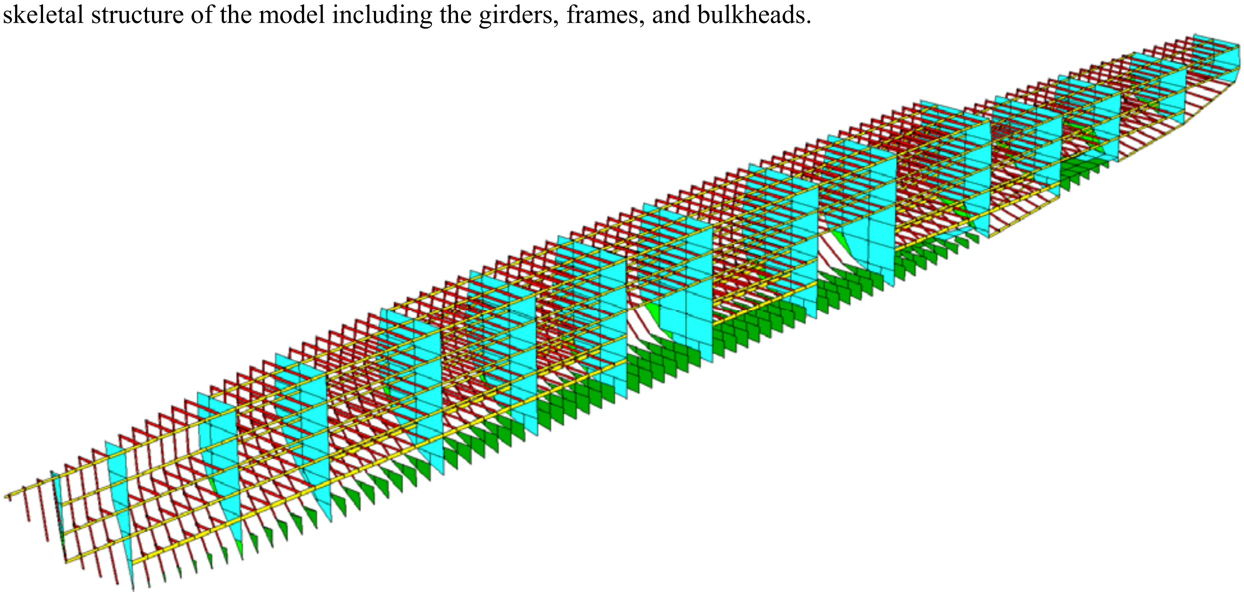


Figure 64: Skeletal Structure

Figure 65 shows all the different plate thicknesses used in the model, each color representing a different thickness.

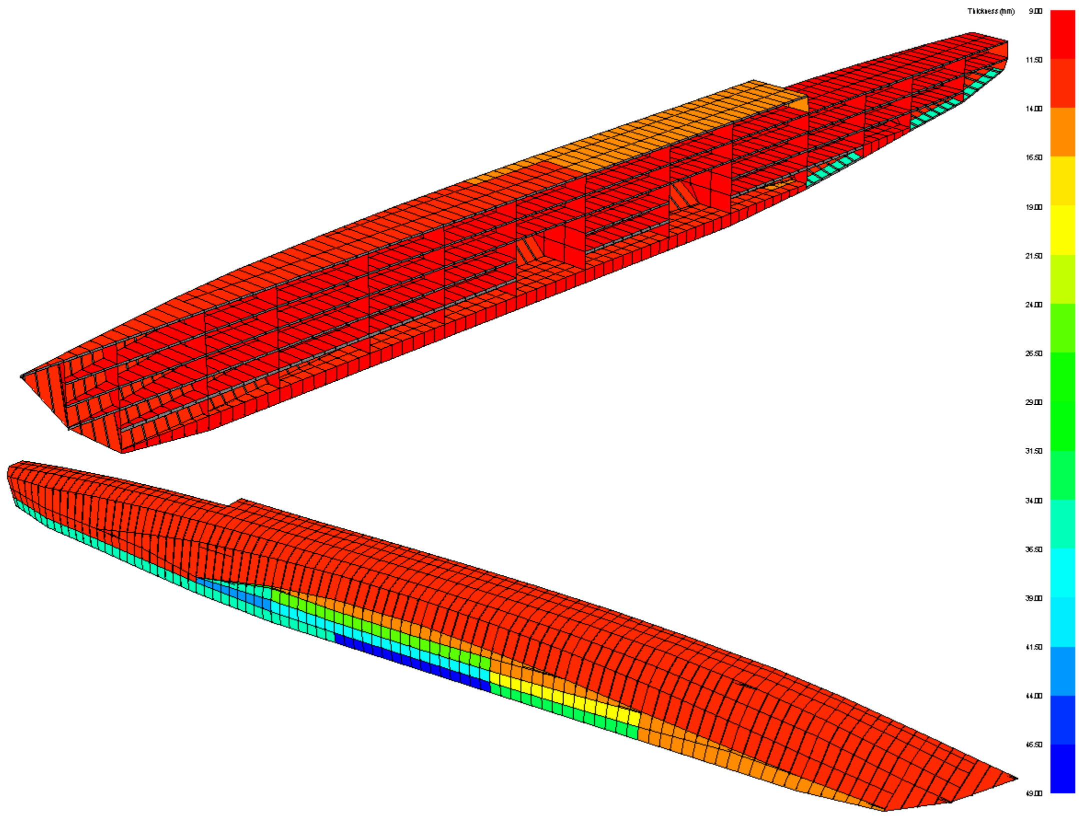


Figure 65: Plate Thicknesses

Figure 66 shows the mid ship sections drawing. All of the dimensions are in millimeters and the material throughout the ship is HY 80.

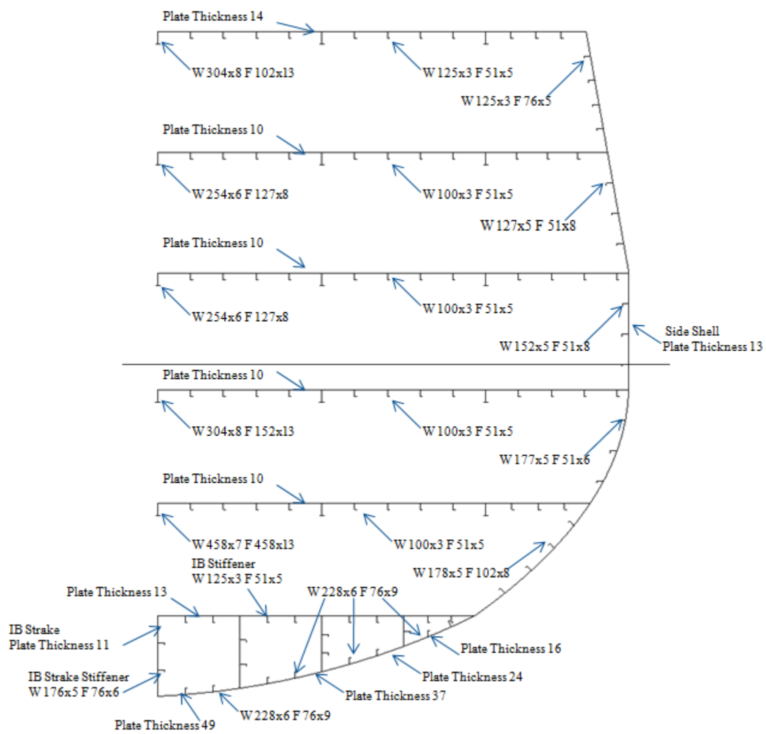


Figure 66: Midship section drawing

4.5.2 Loads

The ship was loaded for full load and minimum operating conditions.. Loading included tankage, ship self weight, and environmental loads. The tanks were created as volumes and entered as being 95% full. Each module was also given a self weight, which is the projected lightship weight of each module. The values were obtained from the Hecsalv model using the lightship weight tool.   The weights are presented in Table 41. Figure 67 shows the gross weight of the ship under full load.

Table 41: Module Weights

Compartment	Weight (kg)
Bow - TBHD 1	23000
TBHD 1- TBHD 2	523500
TBHD 2 - TBHD 3	576500
TBHD 3 - TBHD 4	639500
TBHD 4 - TBHD 5	701500
TBHD 5 - TBHD 6	733000
TBHD 6 - TBHD 7	723500
TBHD 7 - TBHD 8	878000
TBHD 8 - TBHD 9	630500
TBHD 9 - TBHD 10	642000
TBHD 10 - TBHD 11	625500
TBHD 11 - TBHD 12	946500
TBHD 12 - TBHD 13	607000
TBHD 13 - Stern	185500

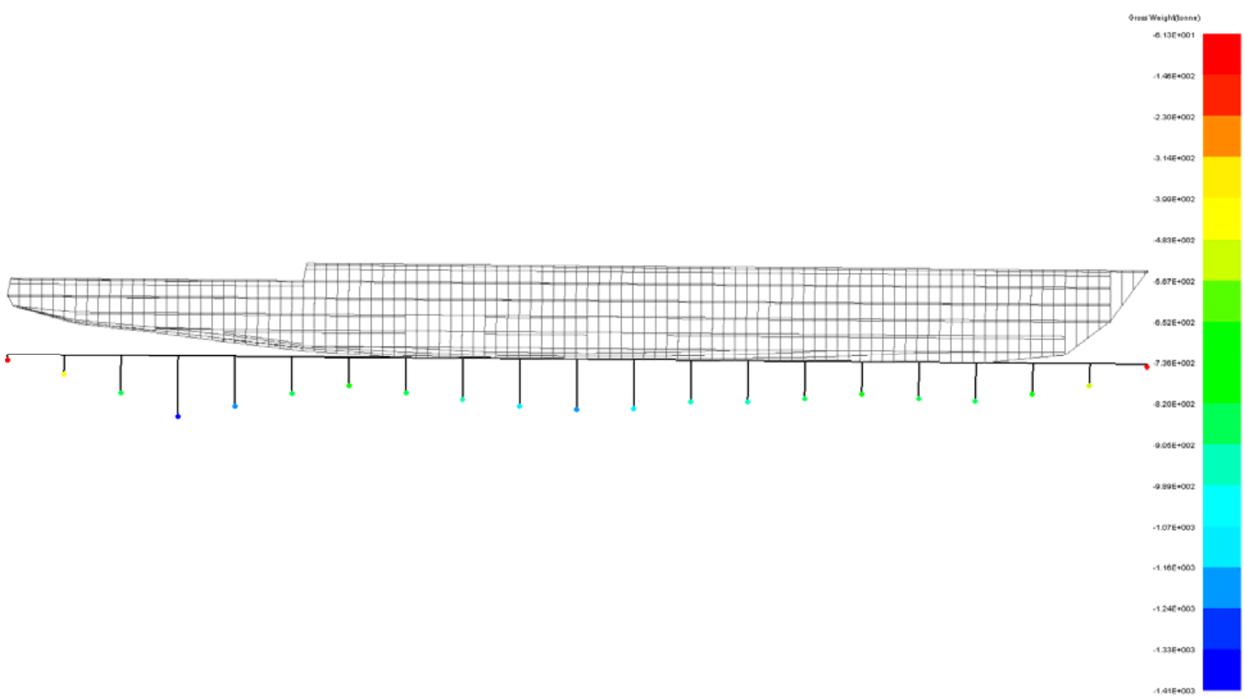


Figure 67: Gross weight of ship when fully loaded

The final loading conditions are the environmental, which includes a stillwater, hogging, and sagging conditions. The wave amplitude on the conditions is 4.17 m giving an overall wave height of 8.34 m which equates to a Seat State of 7. The MAESTRO program uses a balancing algorithm to balance the model with emersion in the conditions. A picture of these loading conditions is shown in **Figure 68**.

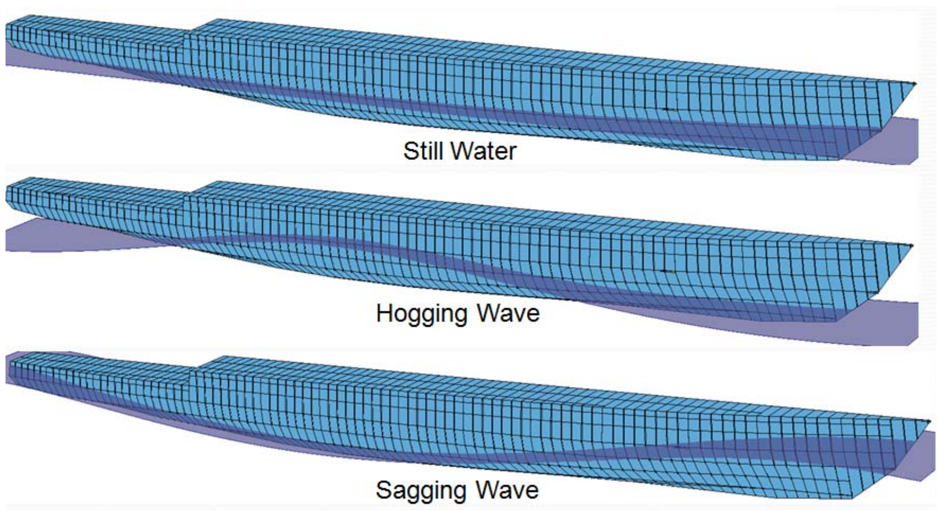
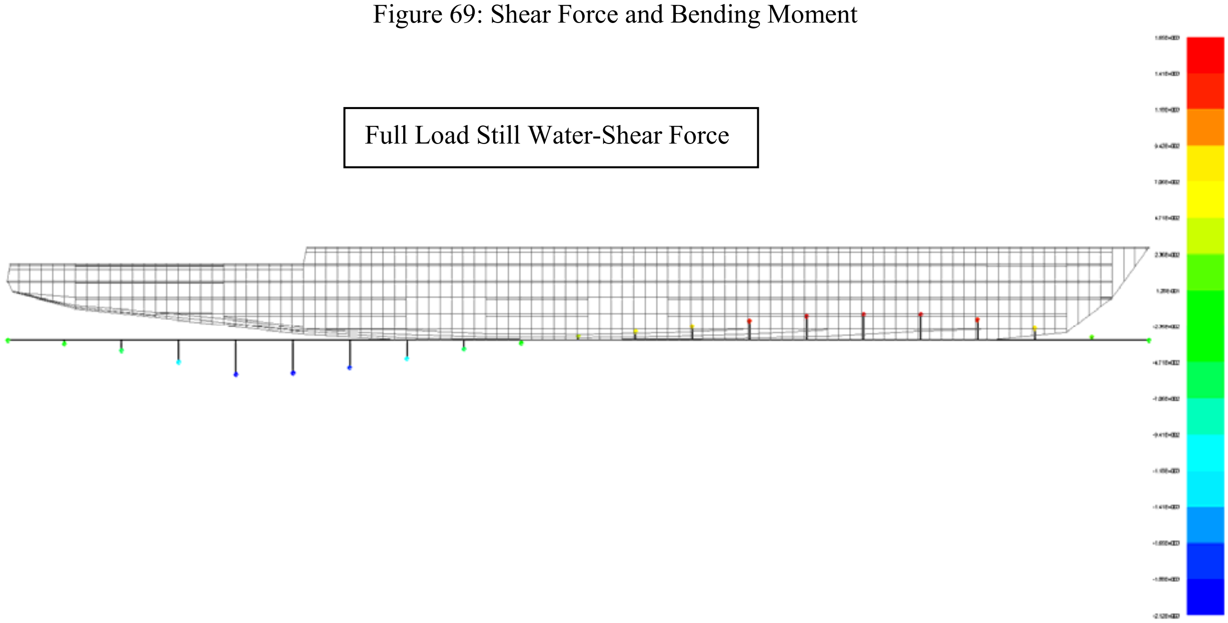
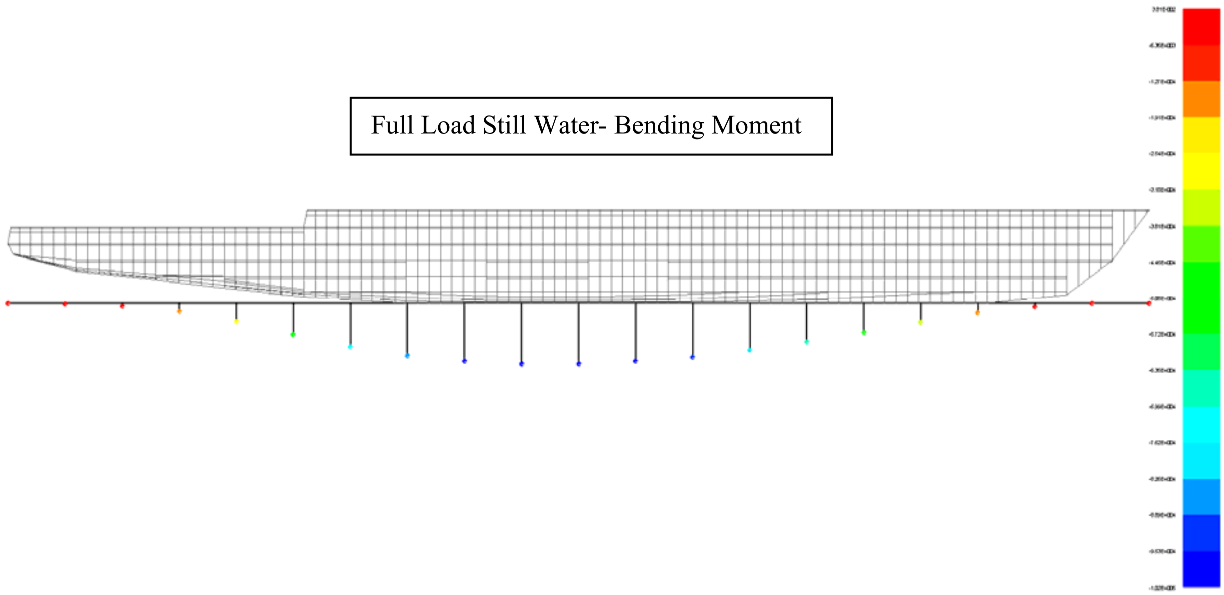


Figure 68: Loading Conditions

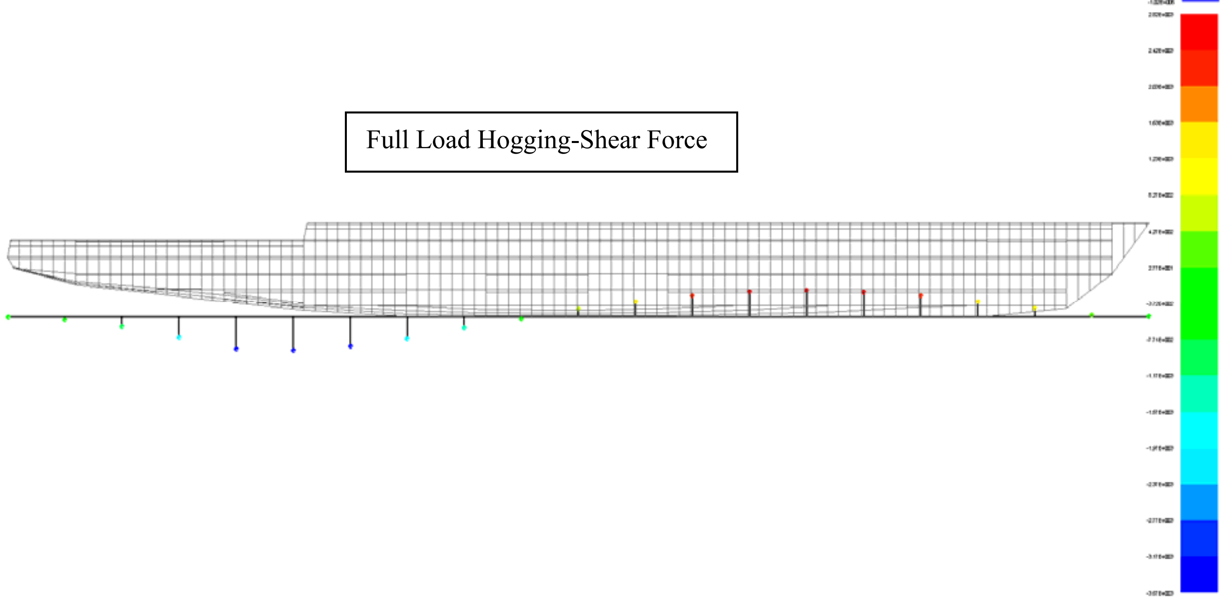
Under the loading conditions shear force and bending moment calculations can be produced. The can be seen in **Error! Not a valid bookmark self-reference.**. The shear force is in units of tonne and the bending moment is in units of tonne*m.

Figure 69: Shear Force and Bending Moment

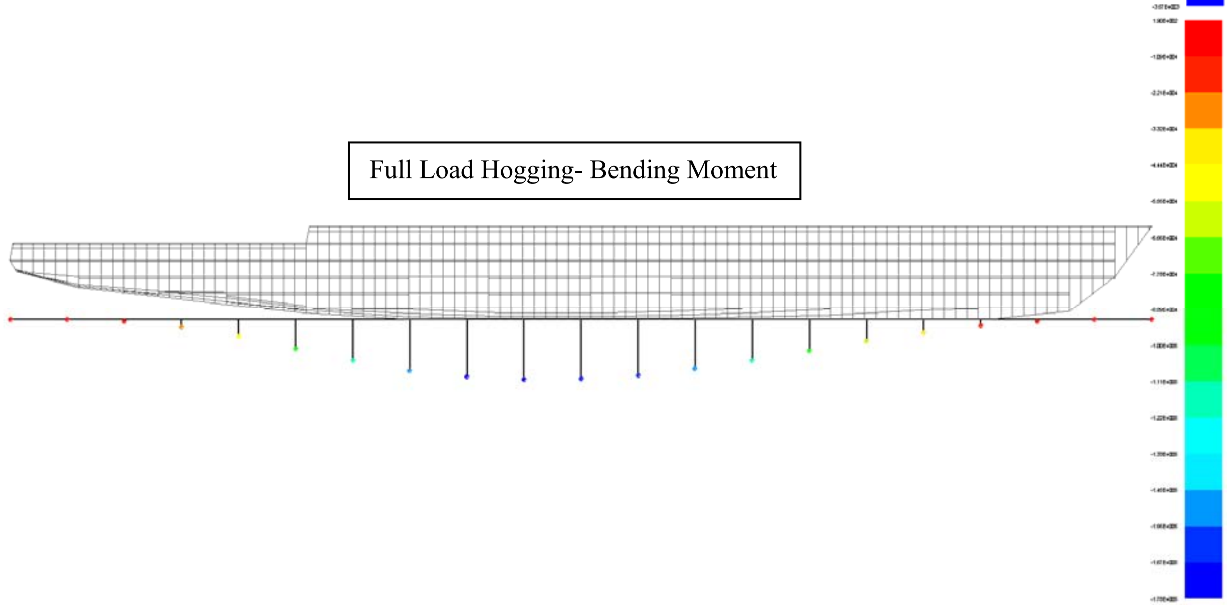




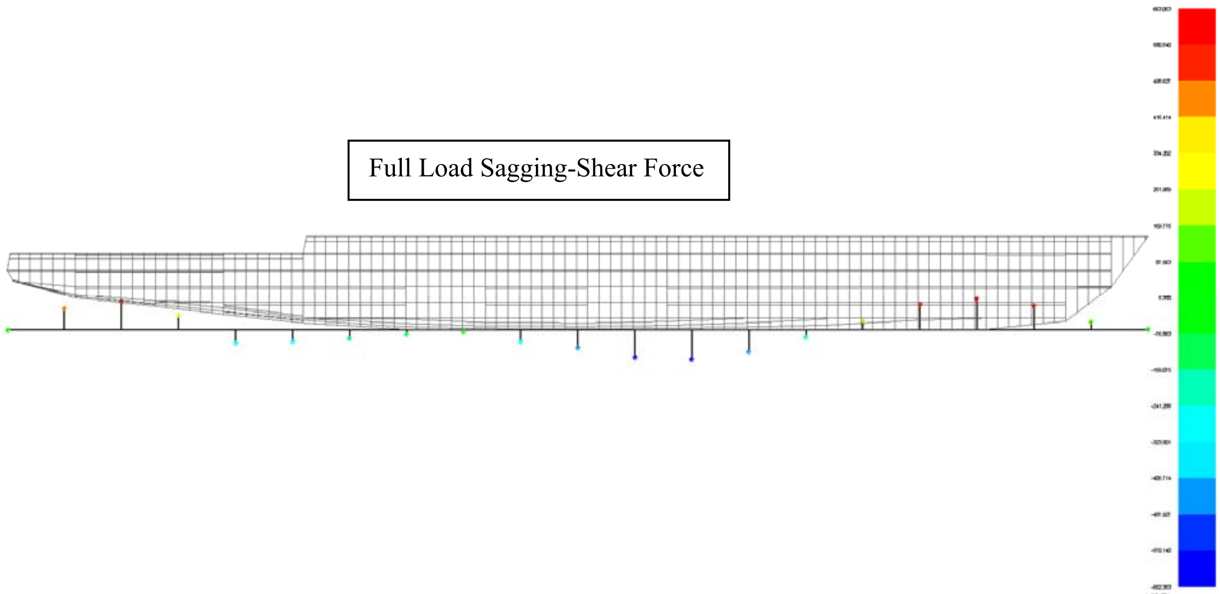
Full Load Still Water- Bending Moment



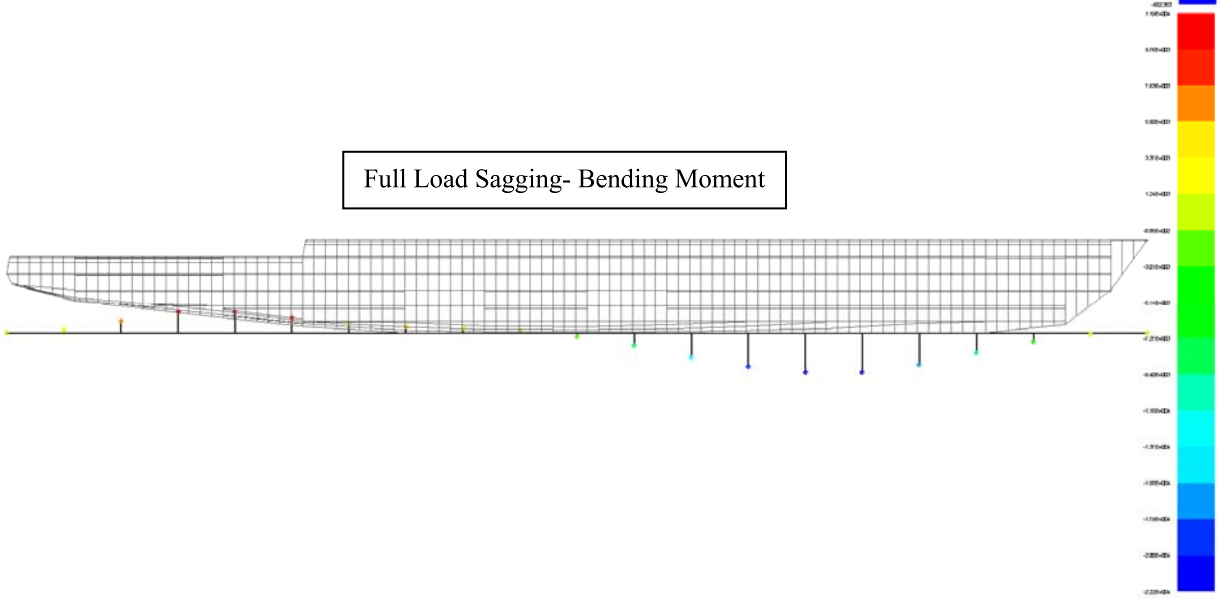
Full Load Hogging-Shear Force



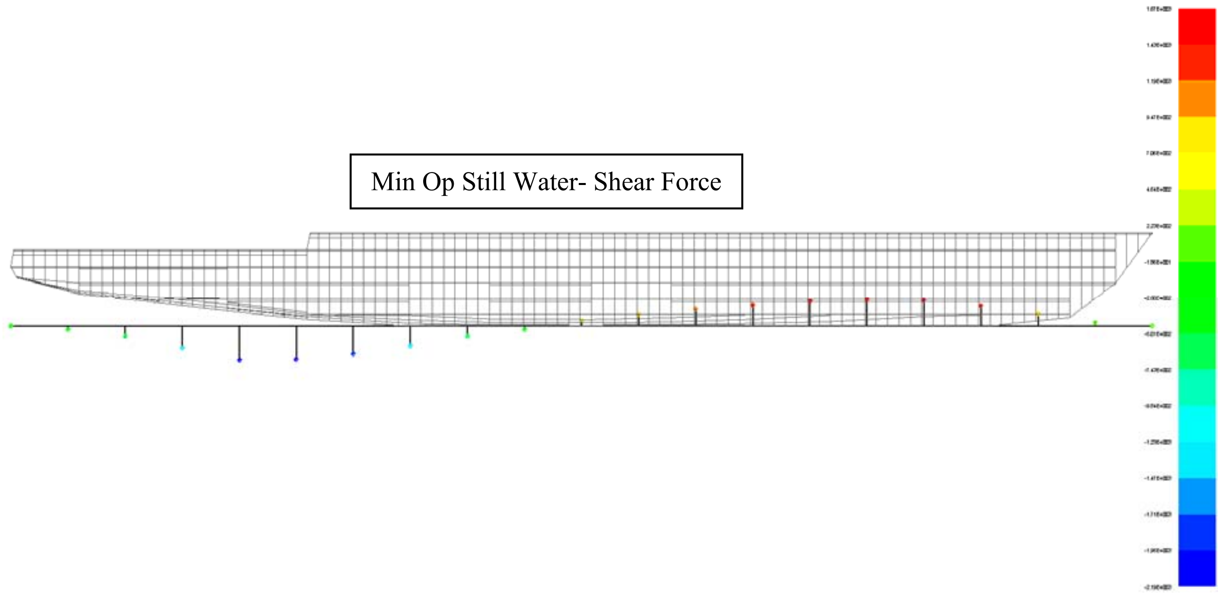
Full Load Hogging- Bending Moment

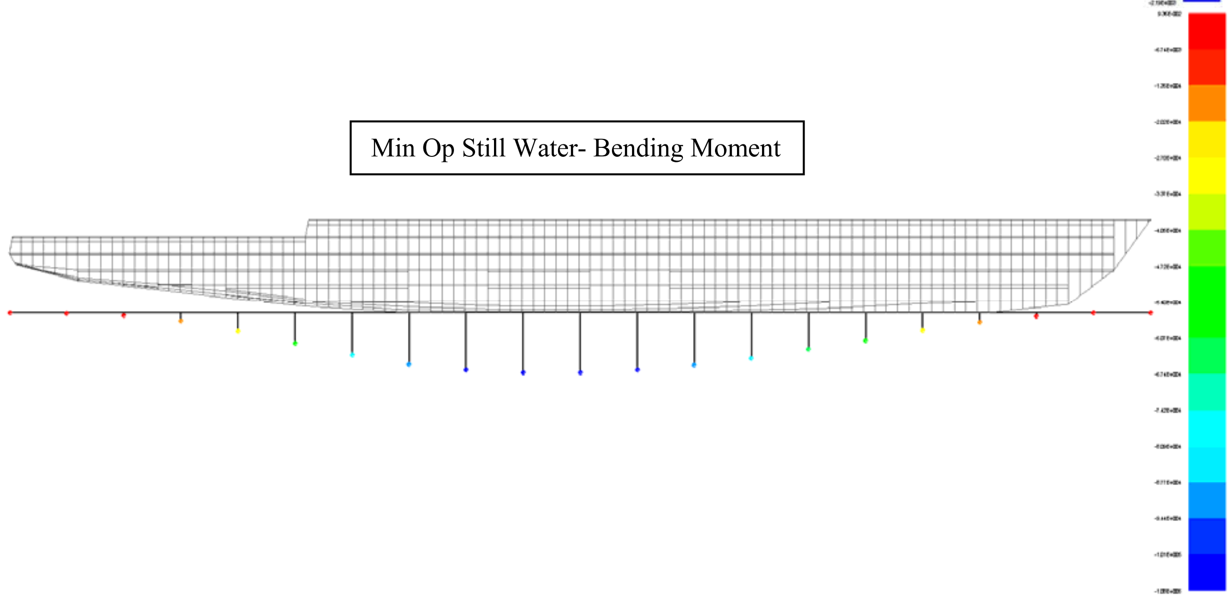


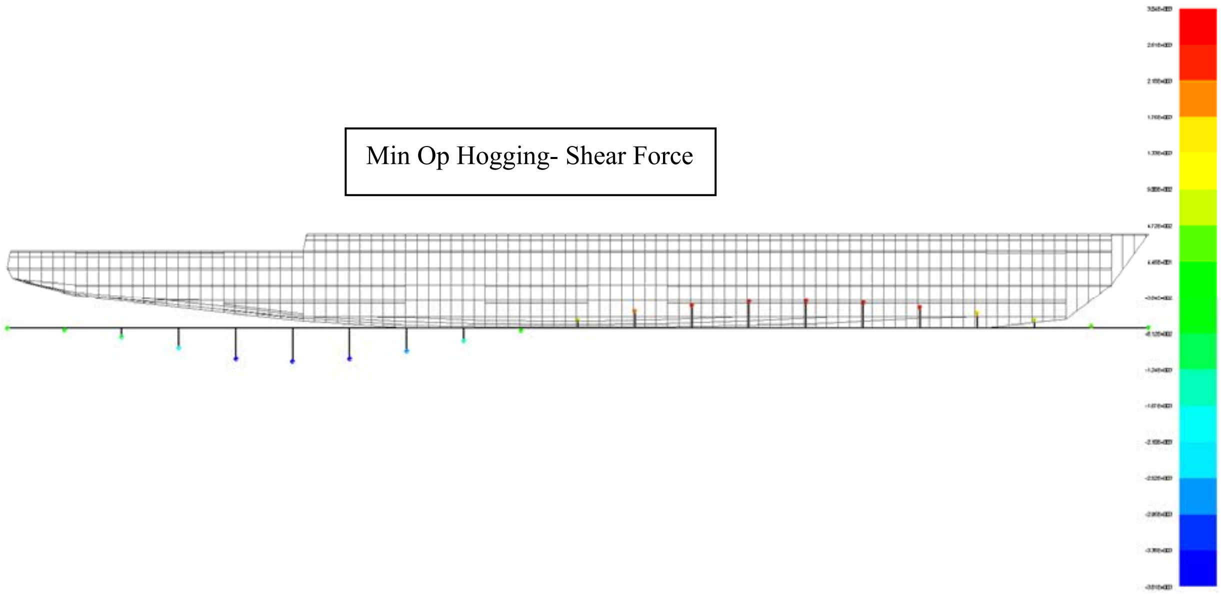
Full Load Sagging-Shear Force

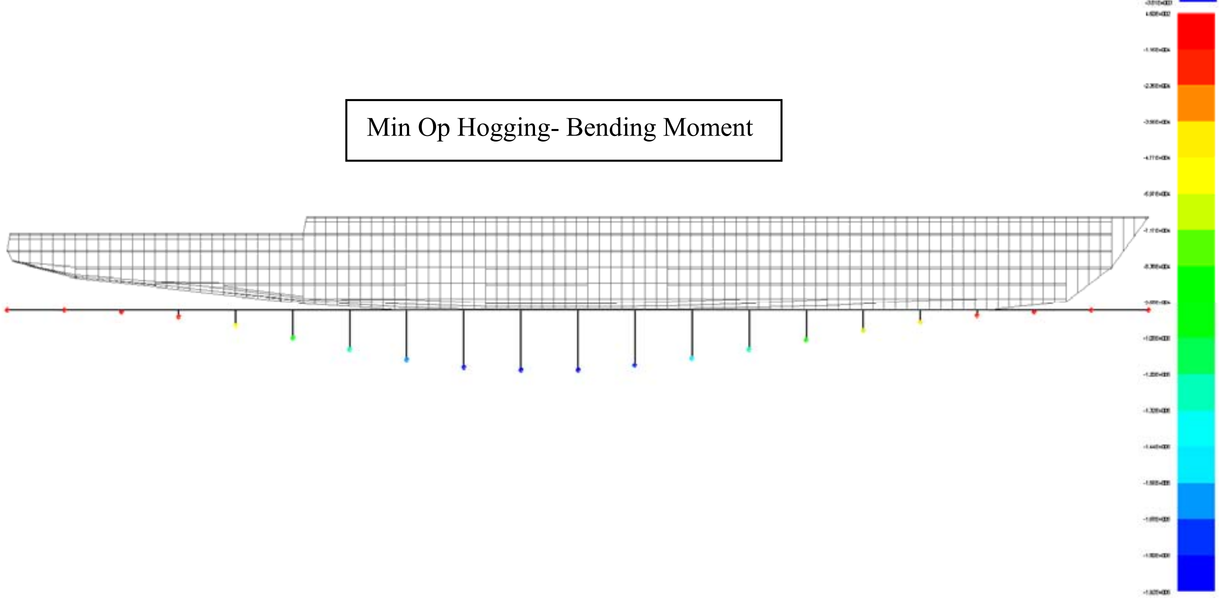


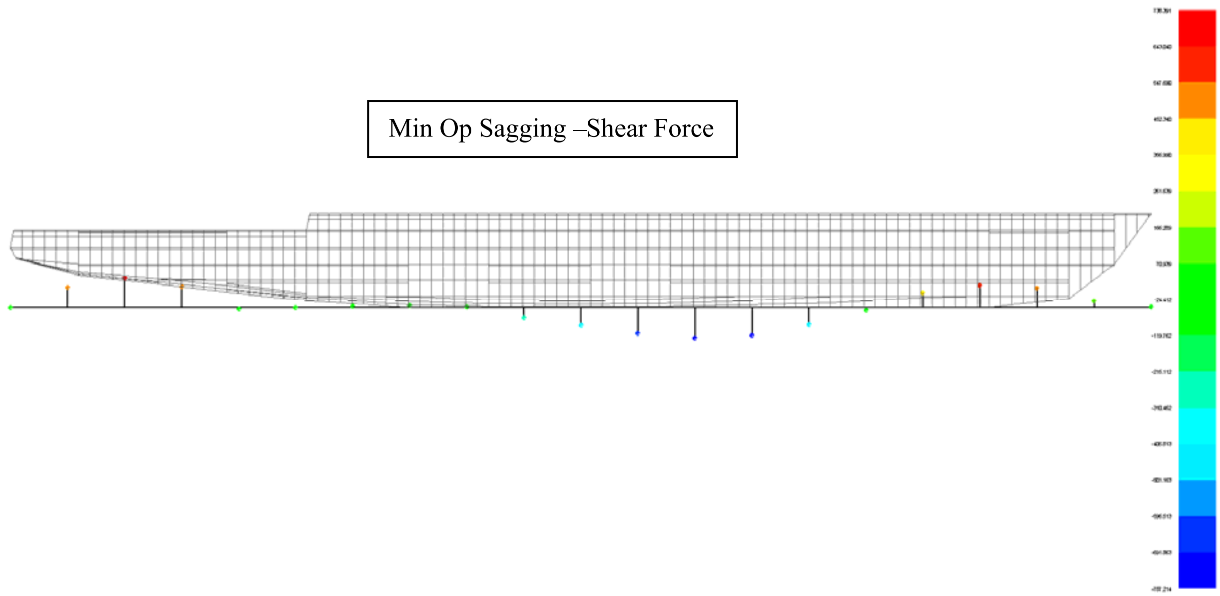
Full Load Sagging- Bending Moment

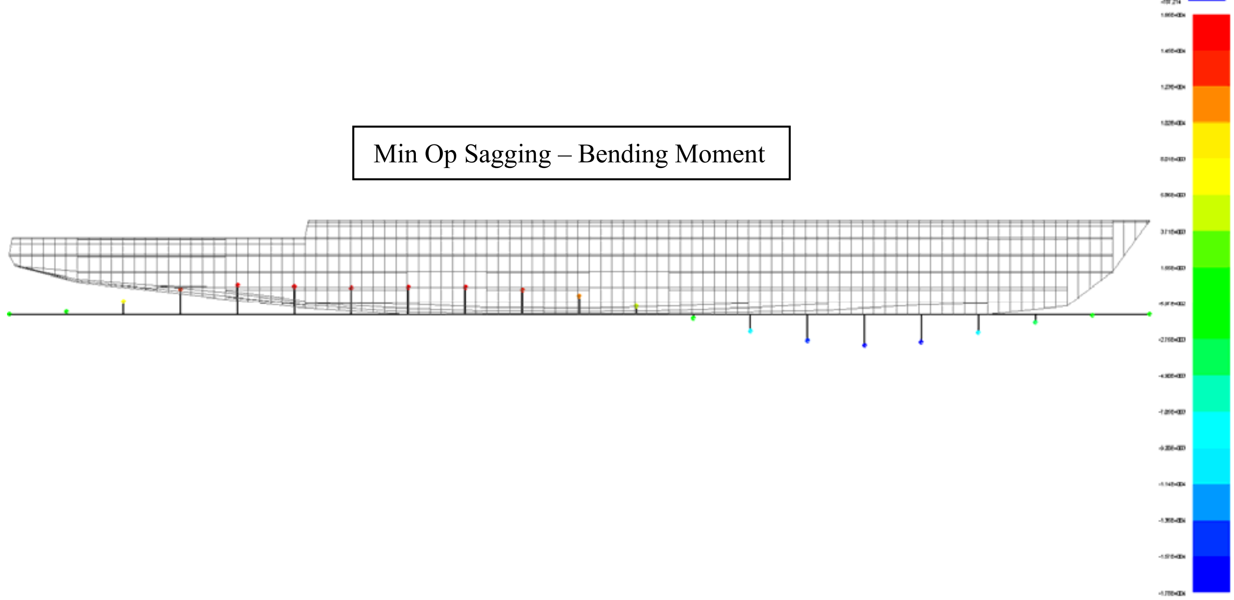

Min Op Still Water- Shear Force


Min Op Still Water- Bending Moment


Min Op Hogging- Shear Force


Min Op Hogging- Bending Moment

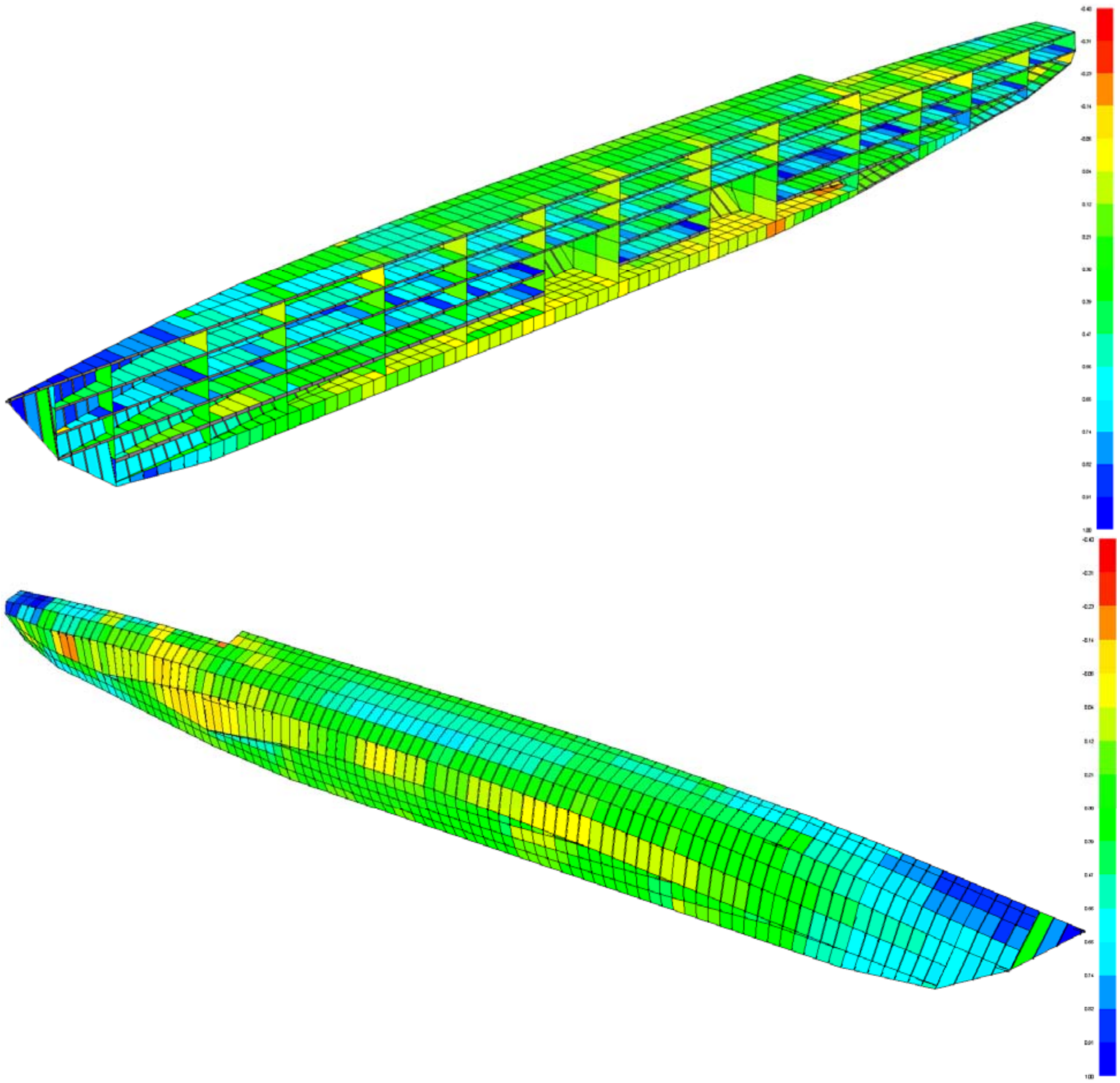




4.5.3 Adequacy

The MAESTRO modeler has an installed adequacy algorithm. This function determines if a plate in a certain area will fail under the caused stresses. Areas that failed are then redesigned and entered until all the areas will not fail. Figure 70 shows the adequacy of the plates in all loading conditions. Figure 71 shows the adequacy of all the beam elements in all loading conditions

Figure 70: Adequacy of Plates



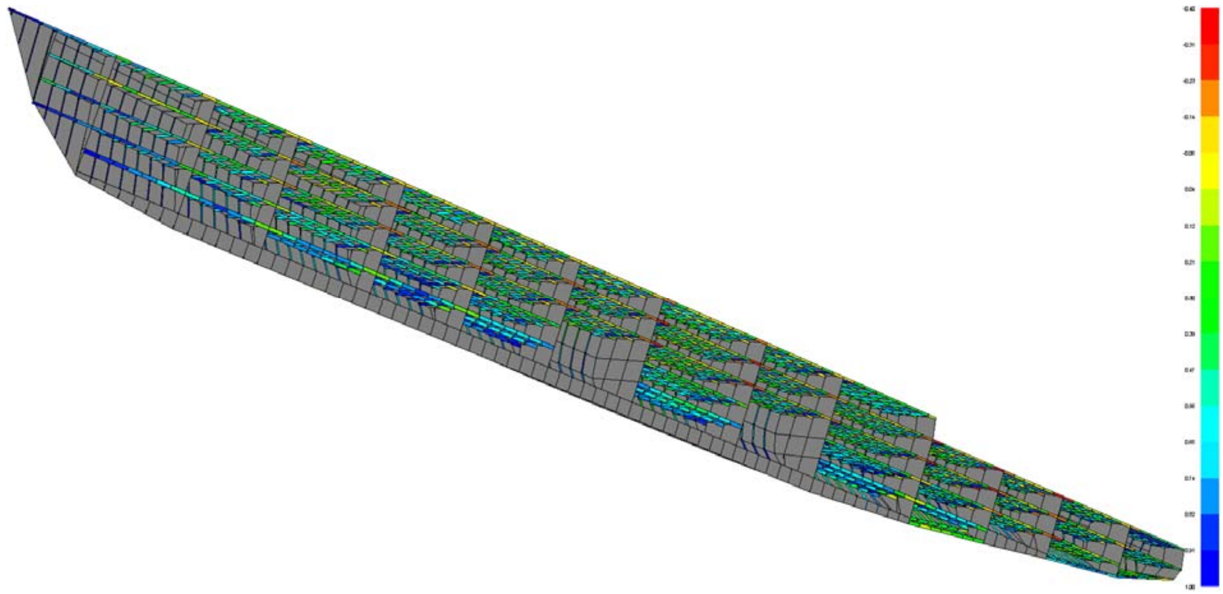


Figure 71: Adequacy of Bar Elements

4.5.4 Revisions and Final Structural Design

The structural work done this far is only the first iteration around the design spiral. With further iterations panels that are failing can be modified not to fail and panels that are over designed can be scaled back to save material and lessen cost. Also with further iterations brackets can be added where girders meet up with transverse bulkheads to lessen the stress on connection.

4.6 Power and Propulsion

The structural work done this far is only the first iteration around the design spiral. With further iterations panels that are failing can be modified not to fail and panels that are over designed can be scaled back to save material and lessen cost. Also with further iterations brackets can be added where girders meet up with transverse bulkheads to lessen the stress on connection.

This MSC has an integrated propulsion system (IPS) which converts power from 4 MT30 gas turbine engines and 2 LM500. The IPS drives two 6 meter diameter fixed pitch propellers.

4.6.1 Resistance

The resistance calculations were performed by NAVCAD using the Holtrop-Mennon method. Hullform data including LBP, draft, wetted surface, max section area, and water plane area are necessary inputs for adequate resistance results. Appendage data is also needed. The endurance resistances were calculated for a range of speeds from 10- 25 knots and sustained speed resistance ranged from 15 knots to 37 knots. Figure 72 and Figure 73 show the resistance plots.

Figure 72 Endurance Speed Resistance

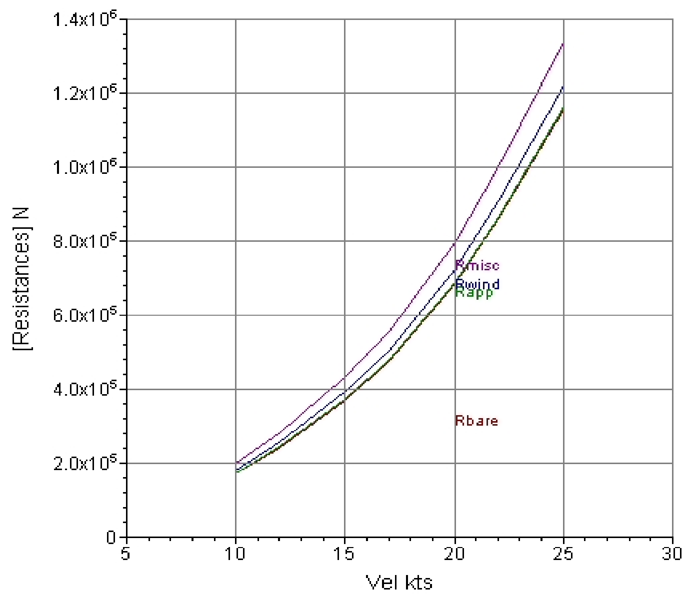
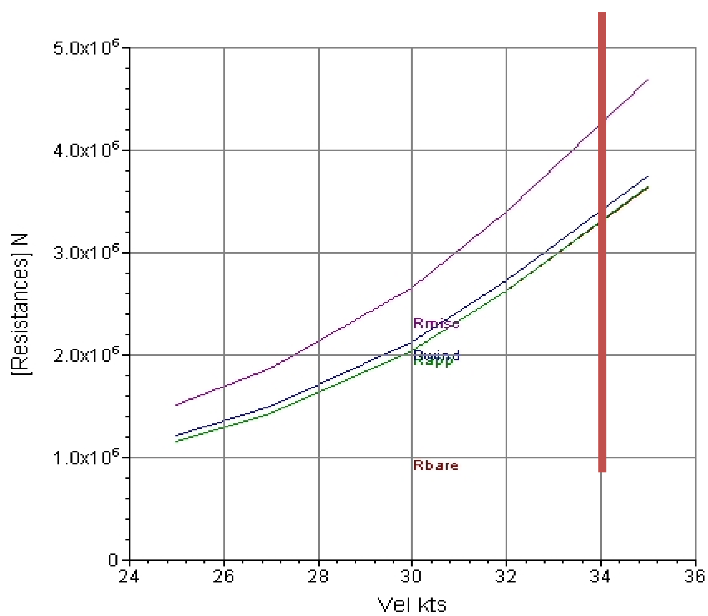


Figure 73 Sustained Speed Resistance



The effective horsepower was also calculated for the endurance and sustained speed ranges and are shown in Figure 74 and Figure 75**.**

Figure 74 Endurance Speed Effective Horsepower

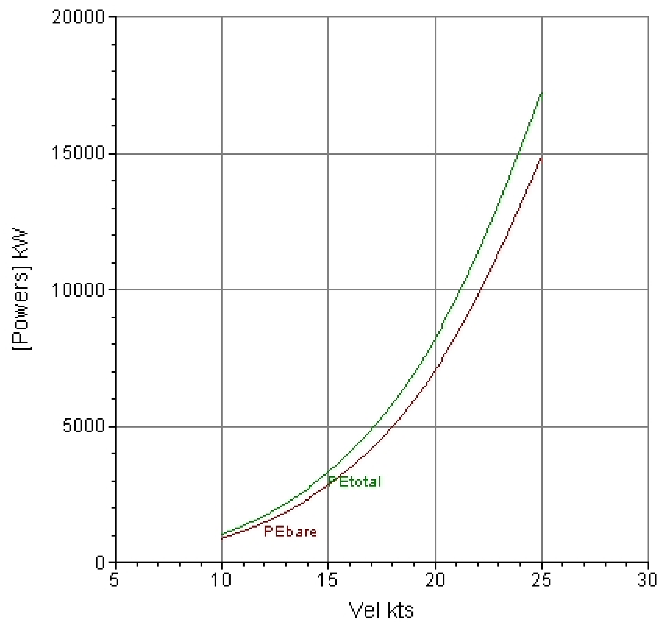
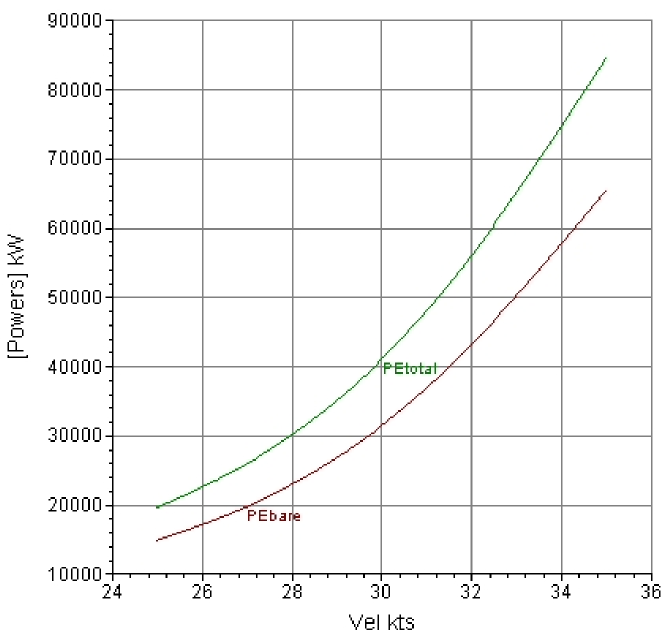


Figure 75 Sustained Speed Effective Horsepower



4.6.2 Propulsion Analysis – Endurance Range and Sustained Speed

Continuing with the calculations made in NAVCAD from the resistance the propulsion was calculated. Assuming 98% transmission efficiency and a 92% motor, generator and frequency efficiency endurance propulsion and sustained speed propulsion were found. The ship has a KW_{24AVG} of 8700 KW which must be compensated for when calculating propulsion characteristics. Endurance speed requires that only one MT30 and on LM500 be on the line the power curve had to be adjusted to fit the power scheme which is shown in Figure 76. Since this is IPS there is a single variable reduction gear which can be altered to maximize efficiency and performance.

Figure 76 Endurance Speed Engine Characteristics per shaft

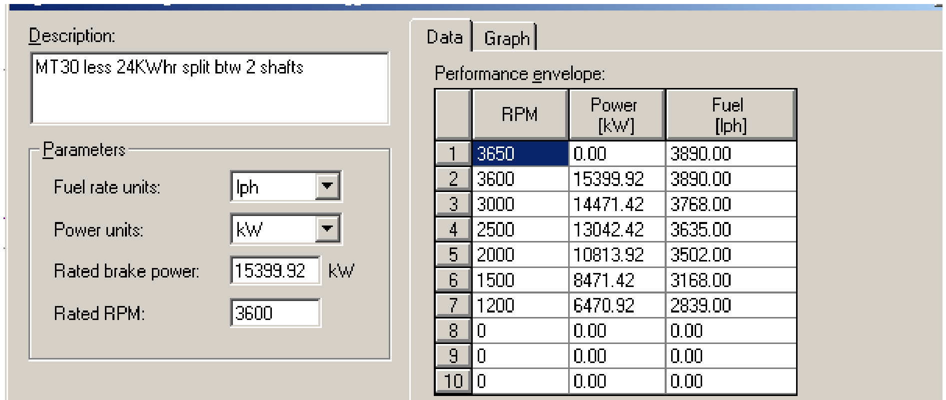


Figure 77 Sustained Speed Engine Characteristics per shaft

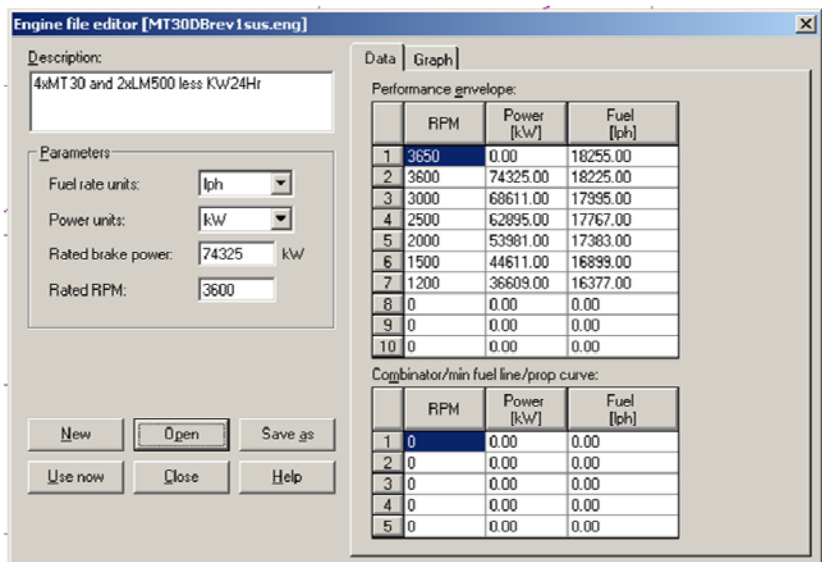


Figure 78 and Figure 79 shows the endurance and sustained speed propulsion curves with adjusted IPS gearing for that specific scenario. Endurance speed required a gearing of 23 at an RPM of 115 and the sustained speed required a ratio of 12 with an RPM of 160.

Figure 78 Endurance Speed Engine Characteristics per shaft (gear ratio 23)

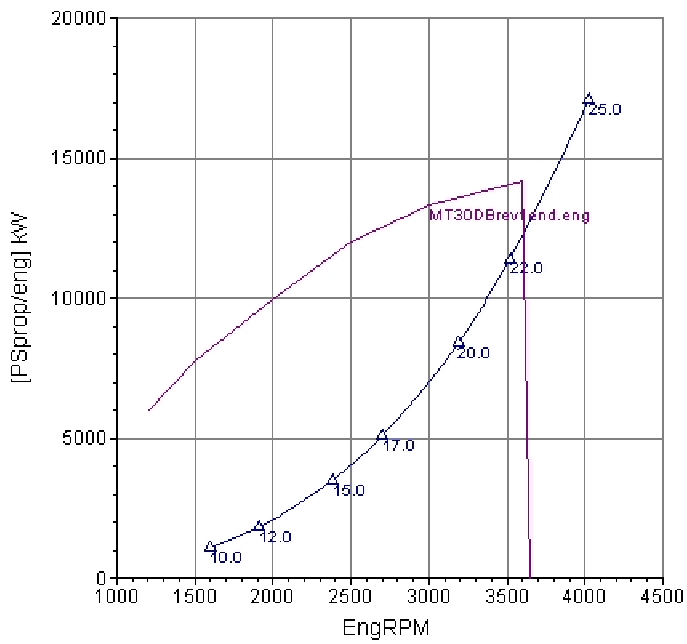
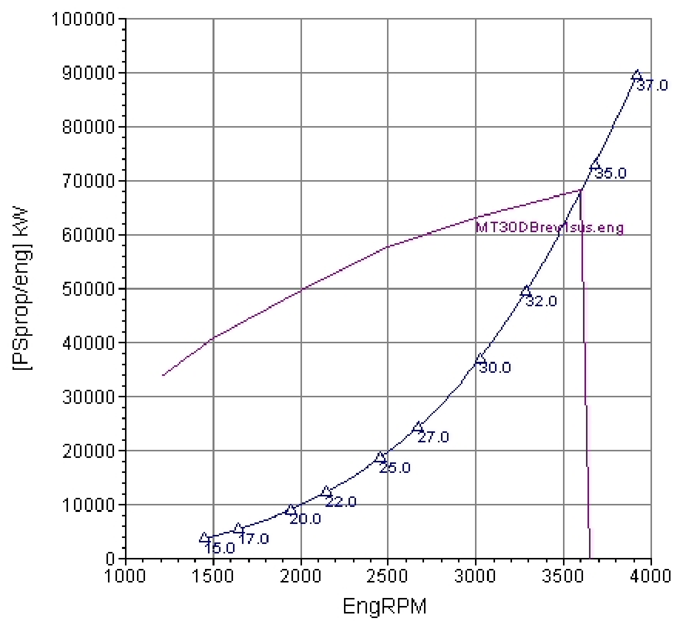


Figure 79 Endurance Speed Engine Characteristics per shaft (gear ratio 23)



Finally using Math CAD an endurance range value was found to be 4550 nm with 603.6 g/h. The code used can be seen below in Figure 80.

Figure 80 MathCAD code used to find Endurance Range of 4550 nm

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{ePGM}$ $FR_{SP} = 0.347 \cdot \frac{lbf}{hp \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years:

$FR_{AVGp} := 1.05 \cdot FR_{SP}$ $FR_{AVGp} = 0.365 \cdot \frac{lbf}{hp \cdot hr}$

Calculate the endurance range for the specified fuel tank volume - for Ship Service Power - IPS:

Correction for instrumentation inaccuracy and machinery design changes:

$f_{g1} := f_1$ $f_{g1} = 1.03$

Specified fuel rate: $FR_{SPg} := f_{g1} \cdot SFC_g$ $FR_{SPg} = 0.347 \cdot \frac{lbf}{hp \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years:

$FR_{AVGg} := 1.05 \cdot FR_{SPg}$ $FR_{AVGg} = 0.365 \cdot \frac{lbf}{hp \cdot hr}$

Tailpipe allowance: $TPA := 0.95$

$knt \equiv 1.69 \cdot \frac{ft}{sec}$ $mile \equiv knt \cdot hr$ $lton \equiv 2240 \cdot lbf$ $nm := knt \cdot hr$ $MT := g \cdot 1000 \cdot kg$ $\delta_F := 43.6 \cdot \frac{ft^3}{lton}$

From NAVCAD for propulsion only at endurance speed (IPS):

$V_e := 20 \cdot knt$ $N_E := 2$ $BHP_{PGM} := 36000 \cdot kW$ $BHP_{ePGM} := 18344 \cdot kW$ $GPH_{eENG} := 603.6 \cdot \frac{gal}{hr}$

From HECSALC tankage: $V_{F41} := 1587 \cdot m^3$

From SSSM at cruise condition:

$KW_{24AVG} := 8700 \cdot kW$

Conversion of units:

$GPH_{eprop} := N_E \cdot GPH_{eENG}$ $GPH_{eprop} = 1207 \cdot \frac{gal}{hr}$ $SFC_{ePGM} := \frac{GPH_{eprop}}{\delta_F \cdot BHP_{ePGM}}$ $SFC_{ePGM} = 0.337 \cdot \frac{lbf}{hp \cdot hr}$

$SFC_g := SFC_{ePGM}$ for IPS

Calculate the endurance range for the specified fuel tank volume - for Propulsion:

Correction for instrumentation inaccuracy and machinery design changes:

$$f_1 := \begin{cases} 1.04 & \text{if } BHP_{ePGM} + KW_{24AVG} \le \frac{1}{3} \cdot BHP_{PGM} \\ 1.02 & \text{if } BHP_{ePGM} + KW_{24AVG} \ge \frac{2}{3} \cdot BHP_{PGM} \\ 1.03 & \text{otherwise} \end{cases} \qquad f_1 = 1.02$$

Usable Fuel (volume allowance for expansion, 5%, and tank internal structure, 2%) and Endurance Range

$$W_{F41} := \frac{V_{F41}}{1.02 \cdot 1.05 \cdot \delta_F} \qquad W_{F41} = 1219 \cdot MT$$

$$E := \frac{W_{F41} \cdot V_e \cdot TPA}{BHP_{ePGM} \cdot FR_{AVGp} + \frac{KW_{24AVG}}{.8} \cdot FR_{AVGg}} \qquad E = 4550 \cdot nm$$

4.6.3 Electric Load Analysis (ELA)

Table 42 - Electric Load Analysis Summary

			Connected Load	Battle		Cruise		Anchor		In Port		Emergency	
	SWBS	**Description**	**(kW)**	**Power Factor**	**(kW)**	**Power Factor**	**(kW)**	**Power Factor**	**(kW)**	**Power Factor**	**(kW)**	**Power Factor**	**(KW)**
	100	Deck Machinery	790	0.00	0	0.000	0	1.0	790	0.3	237	0.0	0
	200	Propulsion	140487		138473		21783		0		0		587
		Propulsion Direct	137550	1.00	137550	0.155	21319	0.0	0	0.0	0	0.0	0
		Propulsion support	2937	0.31	923	0.158	464	0.0	0	0.0	0	0.2	587
	300	Electric	1841	0.25	454	0.294	542	0.1	346	0.4	736	0.1	276
	400	CCC	11842		7226		3344		1601		234		1440
		Combat Systems	9498	0.63	5984	0.281	2671	0.1	1340	0.0	0	0.1	1323
		Miscellaneous	2343	0.53	1242	0.287	673	0.1	260	0.1	234	0.1	117
	500	Auxiliary	3106		6067		3292		2991		1007		616
	510	HVAC	1685	0.34	573	1.637	2759	1.4	2442	0.4	674	0.2	283
	520	Sea Water Systems	554	0.34	189	0.292	162	0.3	163	0.3	166	0.3	188
	530	Fresh Water System	485	0.34	164	0.600	291	0.6	291	0.3	145	0.3	145
	540	Fuel Handling	215	0.34	73	0.170	37	0.2	51	0.1	22	0.0	0
	550	Air System	167	0.34	57	0.264	44	0.3	44	0.0	0	0.0	0
	600	Services	224	0.10	59	0.360	81	0.2	50	0.1	22	0.0	0
	700	Weapons	3701	0.34	382	0.329	1217	0.3	1188	0.0	0	0.0	0
		Total Required	161991		152661		30259		6965		2237		2919
		24 Hour Average	150193		144421		25499		2994		1337		1686
Number	**Generator**	**Rating (kW)**	**Average Connected (kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(KW)**
4	MT30	36000.0	144000	4	144000	1.000	36000	0	0	0	0	0	0
2	LM500	4470.0	8940	2	8940	1.000	4470	2	8940	1	4470	2	8940
	Total		152940		152940		40470		8940		4470		8940
			Available Power		279		10211		1975		2233		6021

Table 42 - Electric Load Analysis Summary displays the required power for each system of the ship in different operating conditions along with the available power for each condition.

4.7 Mechanical and Electrical Systems and Machinery Arrangements

Mechanical and electrical systems are selected based on mission requirements, standard naval requirements for combat ships, and expert opinion. The Machinery Equipment List (MEL) of major mechanical and electrical systems includes quantities, dimensions, weights, and locations. The complete MEL is provided in Appendix D.

4.7.1 Integrated Power System (IPS) and Electrical Distribution

Following is the basic schematic of power generation and distribution of the MSC. It is an integrated power system with primary and secondary power generation modules (PGM and SPGM). DC busses are used in this system with 1000 V DC. The PGM's produce 36 MW each at 13800 V A.C. while the SPGM's provide 5.3 MW at 1000 V D.C.

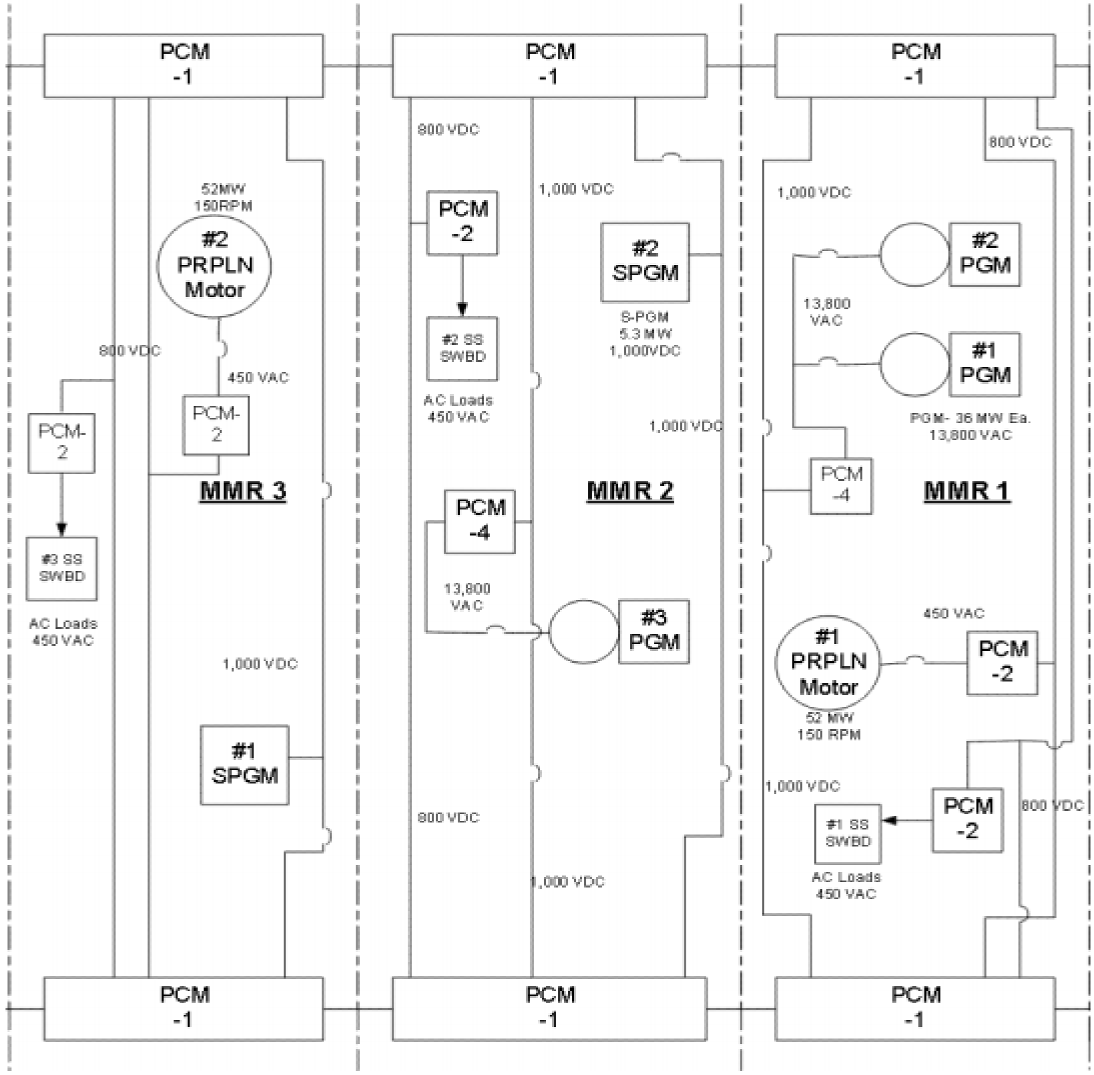


Figure 81 - One-Line Electrical Diagram

4.7.2 Service and Auxiliary Systems

All service and auxiliary systems were determined by the Ship Synthesis Model based on ship capacity, functions, and mission conditions. A connected load of about 4000 kW is required for these systems which entail the following:

- Fuel oil service and transfer
- Lube oil service and transfer
- Salt Water Cooling
- Air Conditioning and Refrigeration
- Firemain, Bilge, Ballast
- Potable Water
- JP-5 Service and Transfer
- Compressed Air
- Steering Gear Hydraulics
- Environmental

Components of these systems along with their specifications are provided in the Machinery Equipment List (MEL) in Appendix D. They are also shown in the machinery arrangement drawings in 4.7.3 on page 88.

4.7.3 Main and Auxiliary Machinery Spaces and Machinery Arrangement

Two main machinery rooms and two auxiliary machinery rooms exist on the MSC. The machinery was arranged in Rhino where it was positioned in consideration to exhausts and intakes, shaft positions, bulkhead and deck locations with respect to machinery sizes. Similar systems were positioned in generally the same proximity. Electrical systems are positioned on higher decks while water systems were placed lower in the ship. Main engines are on the bottom deck for low centers of gravity. The machinery rooms ended up being fairly tight due to our flare hull. Though, arrangements were done in a manner to obtain best maneuverability and functionality in machinery rooms as far as maintenance and survivability. Figures below display our final arrangements in 3-D models from Rhino as well as 2-D plan view drawings of each machinery room.

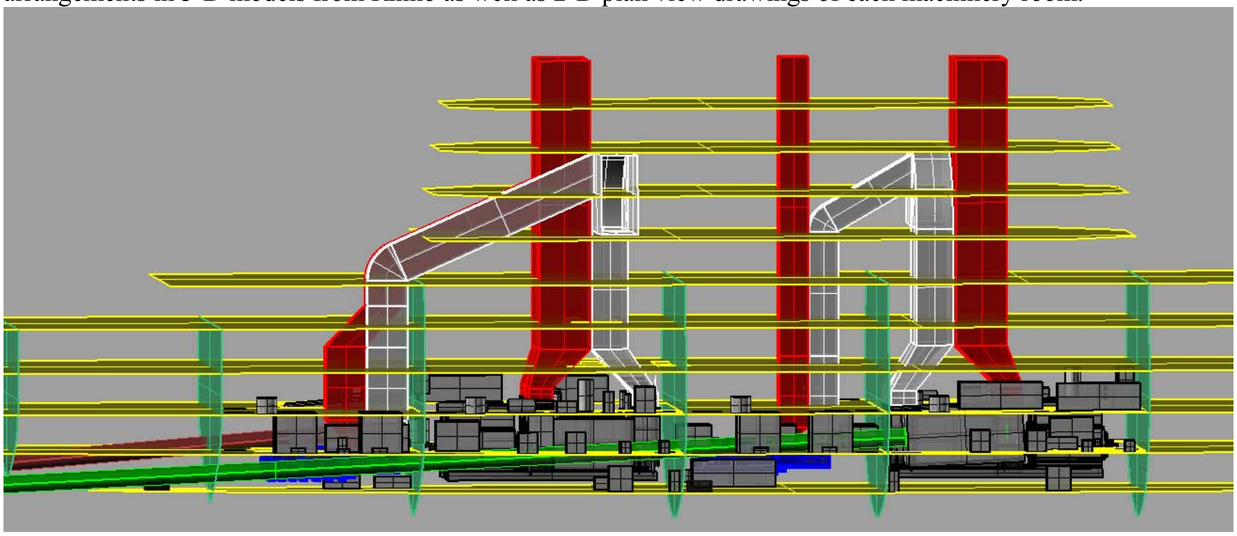


Figure 82 Machinery Arrangements in Rhino

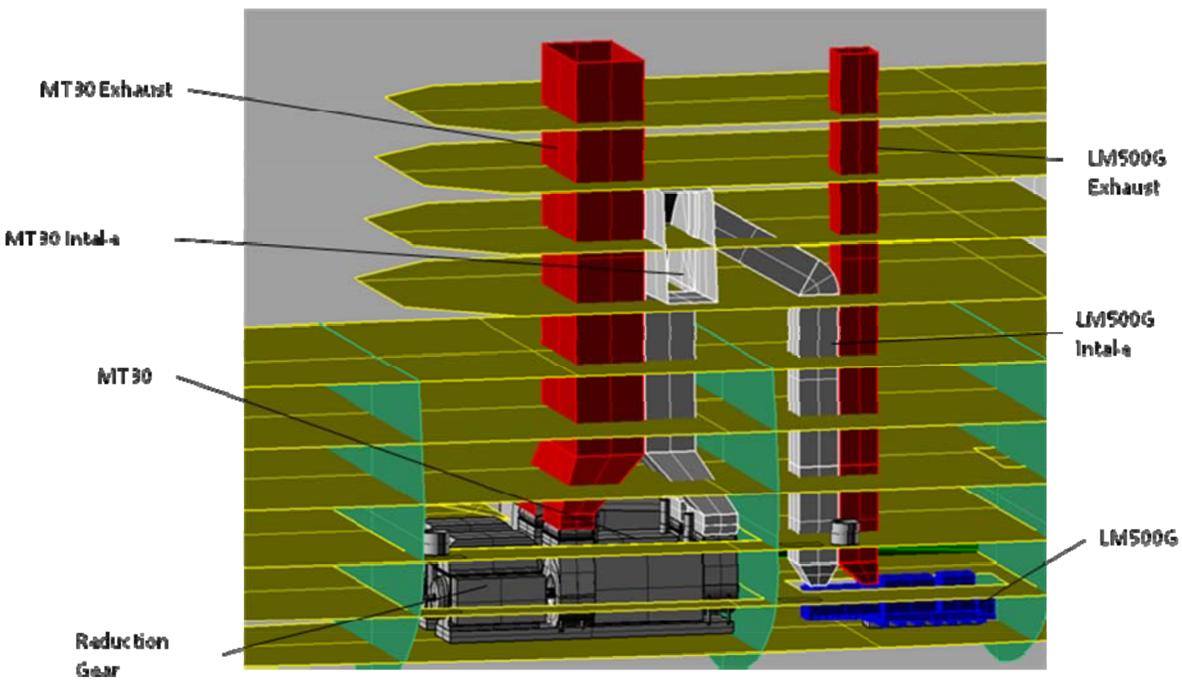


Figure 83 MMR 1 - Looking Inboard from Port side

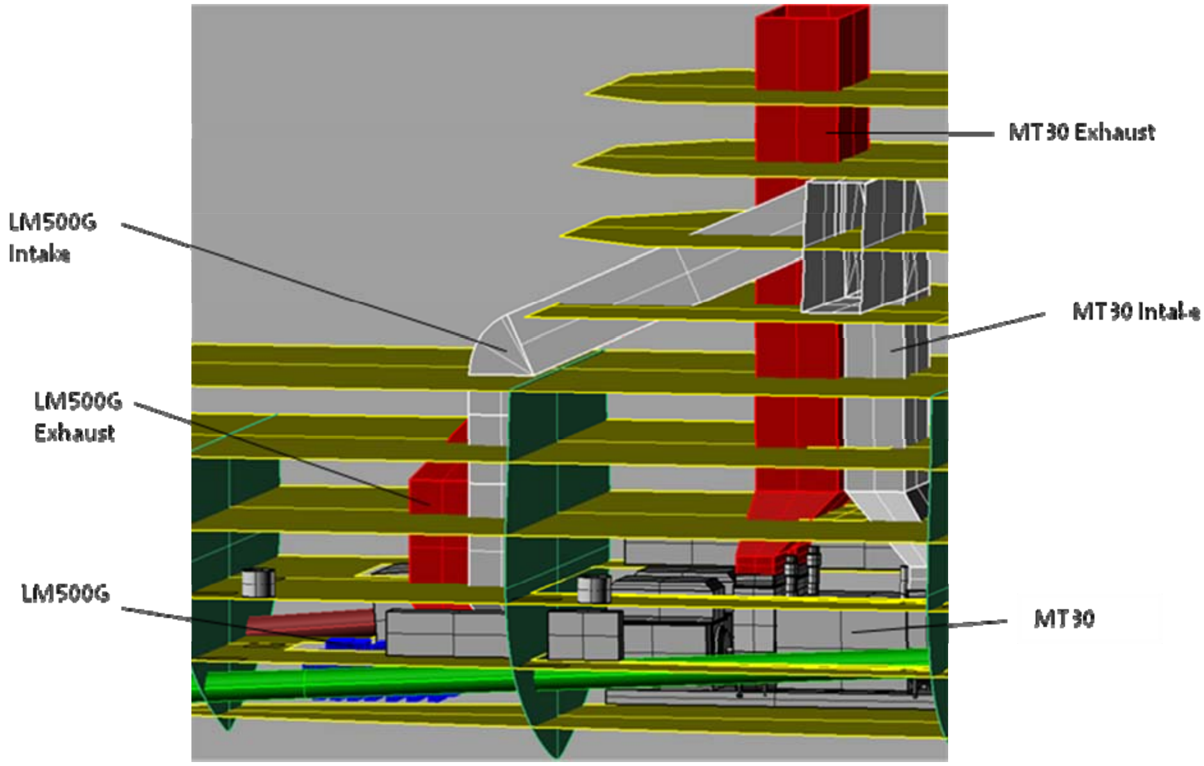


Figure 84 MMR2 - Looking Inboard from Starboard Side

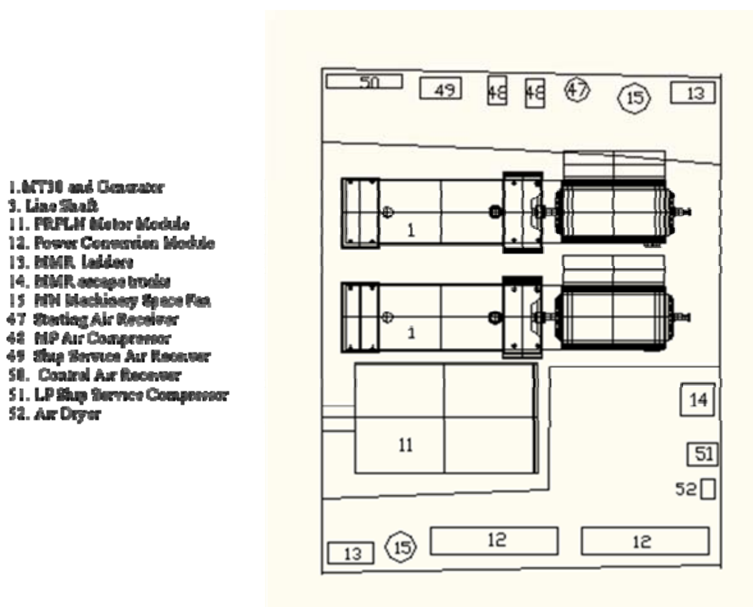


Figure 85 1st Platform MMR 1

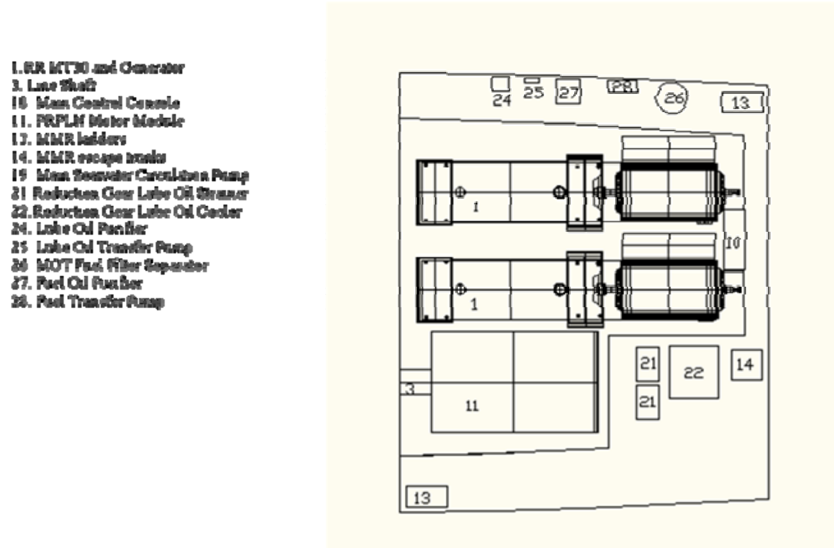


Figure 86 2nd Platform MMR 1

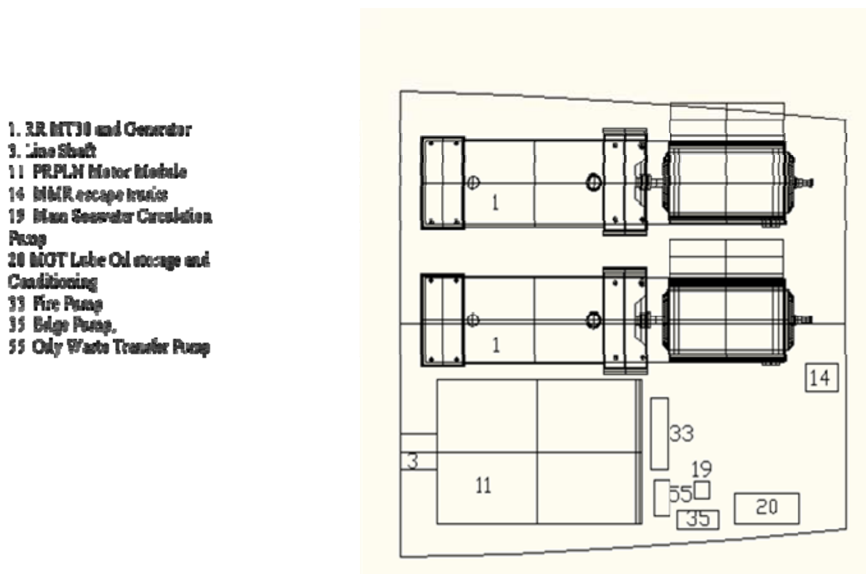


Figure 87 3rd Platform of MMR 1

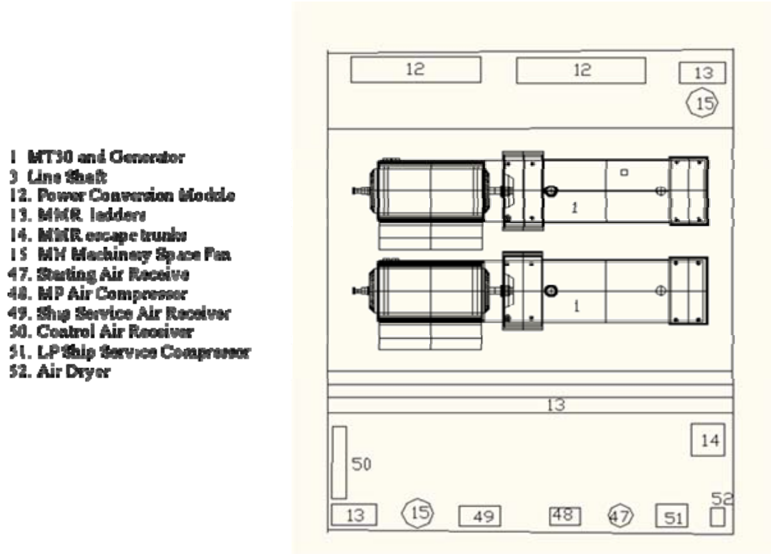


Figure 88 1st Platform MMR 2

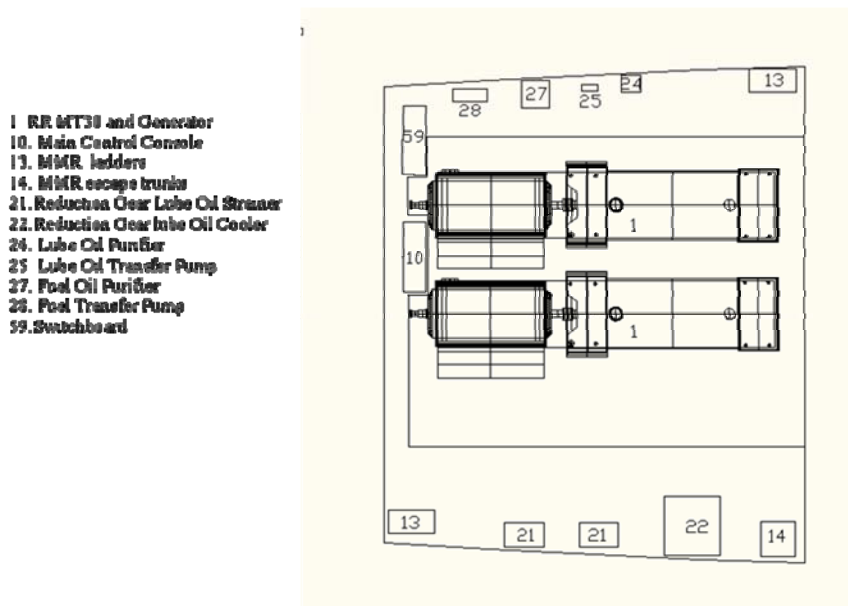


Figure 89 2nd Platform MMR 2

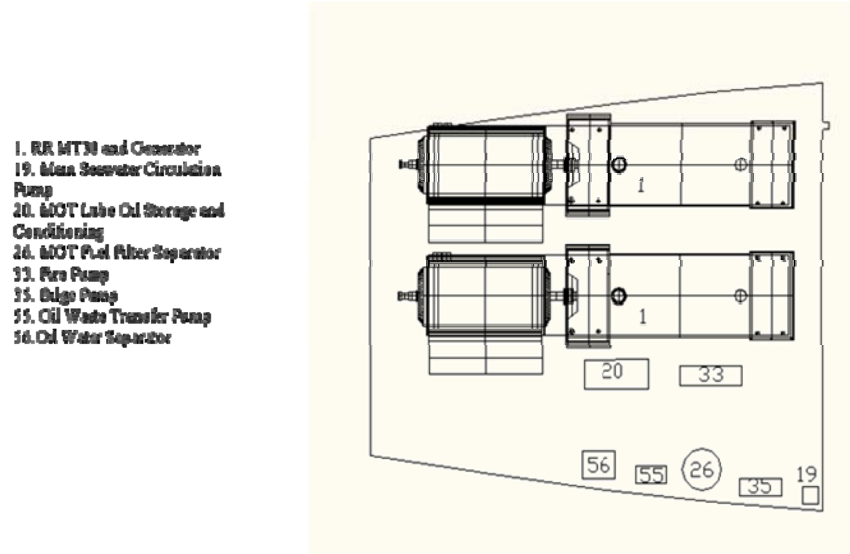


Figure 90 3rd Platform of MMR 2

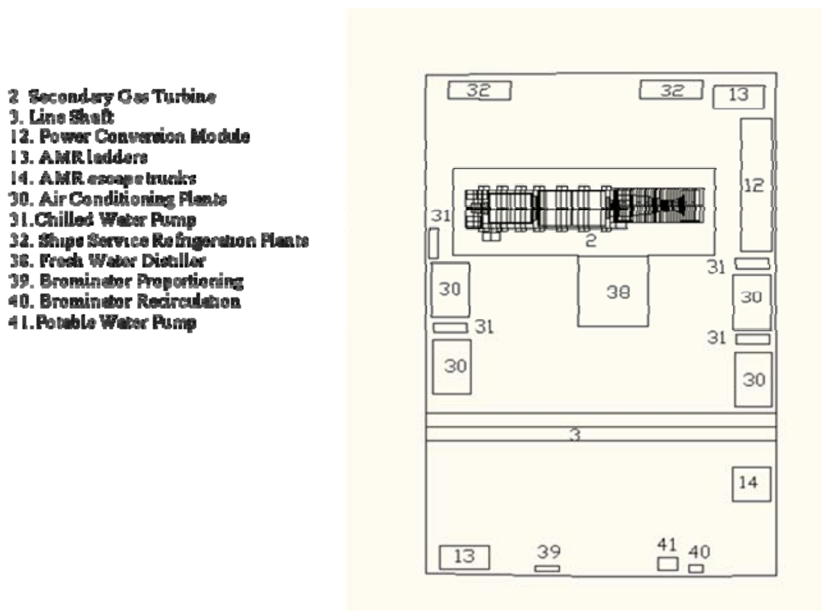


Figure 91 2nd Platform AMR 1

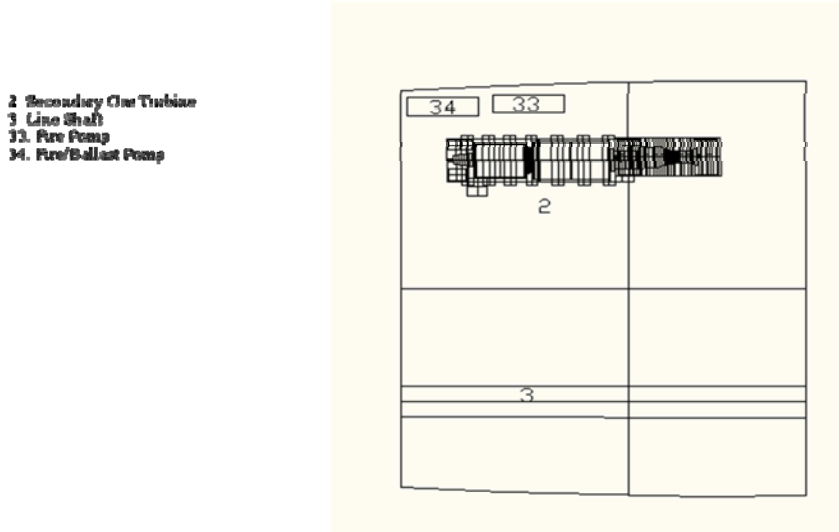


Figure 92 3rd Platform of AMR 1

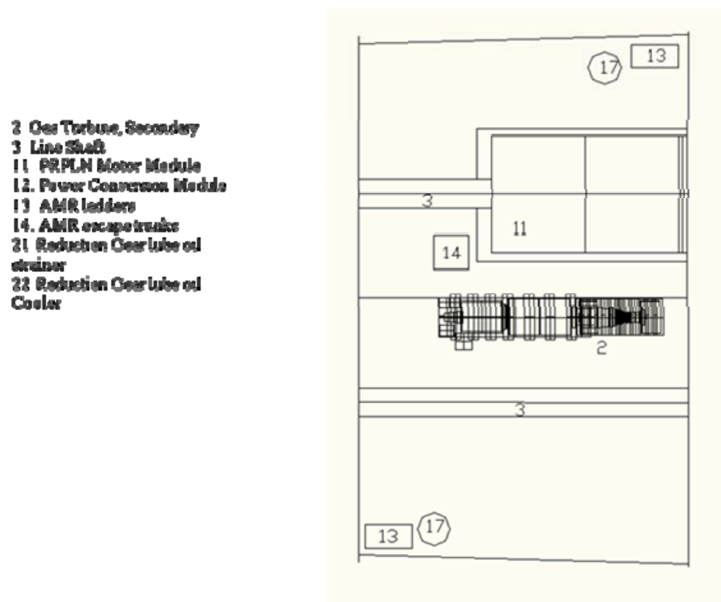


Figure 93 2nd Platform AMR 2

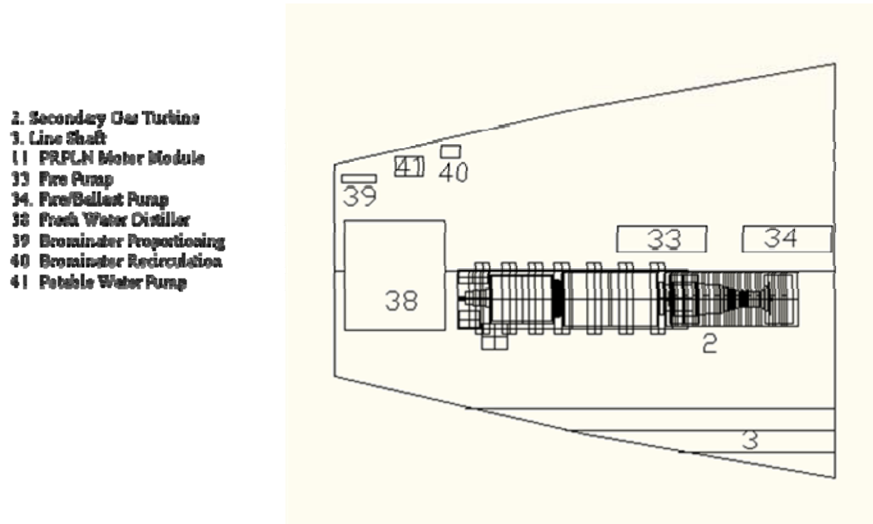


Figure 94 3rd Platform AMR 2

4.8 Manning

Manning is determined by first developing a hierarchy chart and table to assign personnel to divisions and departments. Estimates from concept exploration are used as a goal, and are adjusted if necessary. Feasibility is then validated. The following is a the manning organization by department and division:

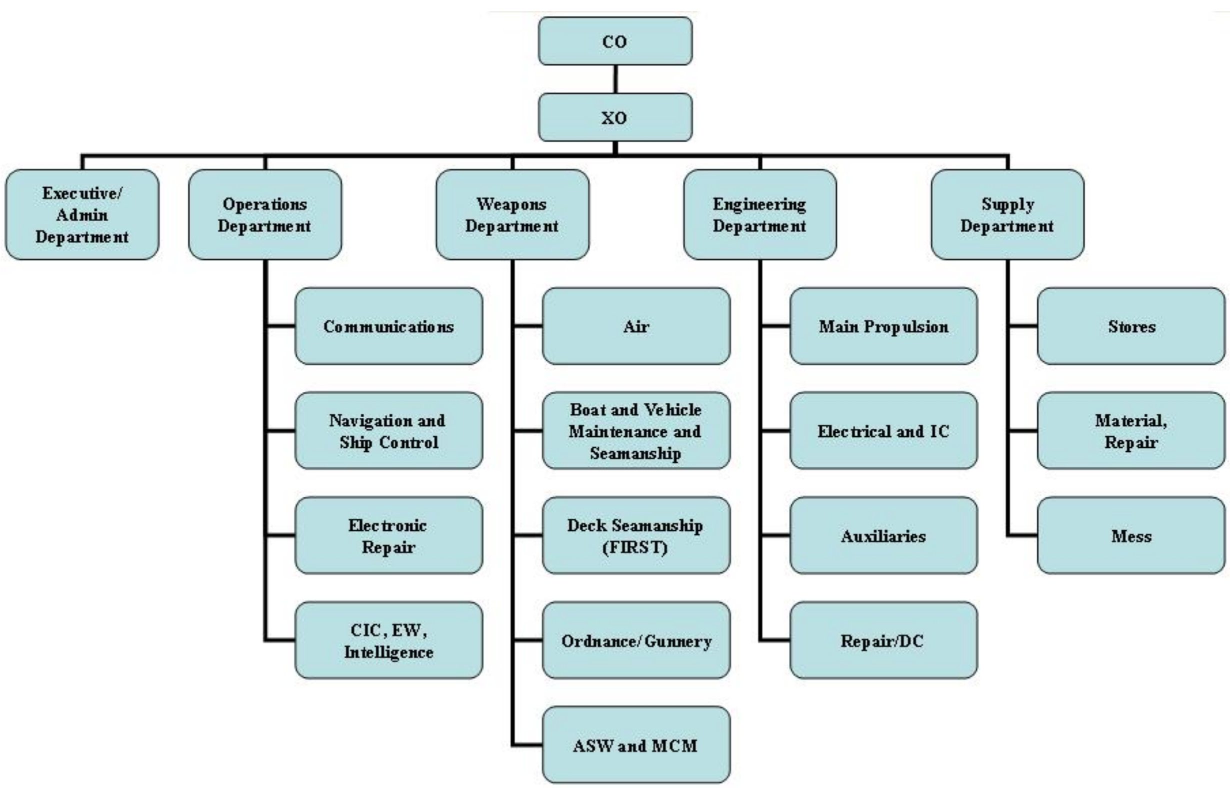


Figure 95 - Manning Organization by Department and Division

Once the final estimate is determined, the manning organization by department and division is used to ascertain how many crew belong in each department. The crew numbers were allocated by department and then refined by comparison of manning to other similar ships and by the MSC's mission. The following is an estimate of manning division by department with a total at the bottom:

Table 43 Manning Estimates by Department and Division

Departments	Division	Officers	CPO	Enlisted	Total Department
	CO/XO	2			2
	Department Heads	4			
Executive/Admin	Executive/Admin		1	1	2
Operations	Communications	1	1	3	21
	Navigation & Control		1	3	
	Electronic Repair		1	2	
	CIC, EW, Intelligence	1	1	6	
Weapons	Air	2	1	2	24
	Boat & Vehicle		1	3	
	Deck		1	6	
	Ordinance/Gunnery		1	2	
	ASW/MCM		1	3	
Engineering	Main Propulsion		1	8	25
	Electrical/IC		1	3	
	Auxiliaries		1	3	
	Repair/DC		1	6	
Supply	Stores			2	13
	Material/Repair		1	2	
	Mess		1	6	
	Total	10	16	61	87
	Accommodations	**15**	**20**	**70**	**105**

The MSC has accommodations for 105 crew with room for 25 officers. The final manning estimate is lower than a traditional ship of this size because numerous technological advances. The more automated systems and processes, the less manning required. Technology such as video teleconferencing, GPS, Electronic Charting and Navigation (ECDIS), automated mess, Integrated Condition Assessment System (ICAS), etc. The ship is paperless, meaning things are communicated electronically. There is an automated bridge and automated route planning is utilized. These advances require less crew.

4.9 Space and General Arrangements

Once manning is estimated, space for each necessity in the ship is determined. Crew accommodation space is estimated from similar naval ships and the general requirements for space needed for each respective crew member.

The SSCS from ASSET is used for tentative space arrangement dimensions. HECSALV and Rhino are used to generate and assess subdivision and arrangements. HECSALV is used for primary subdivision, tank arrangements and loading. Rhino is used for the 3-D geometry and to construct 2-D drawings of the inboard and outboard profiles, deck and platform plans, detailed drawings of berthing, sanitary, and messing spaces. A profile showing the internal arrangements of the MSC is shown in Figure 96.

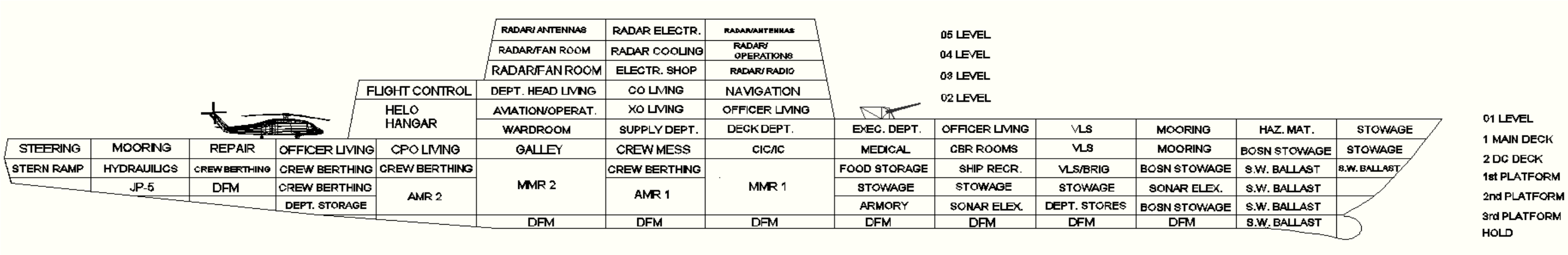
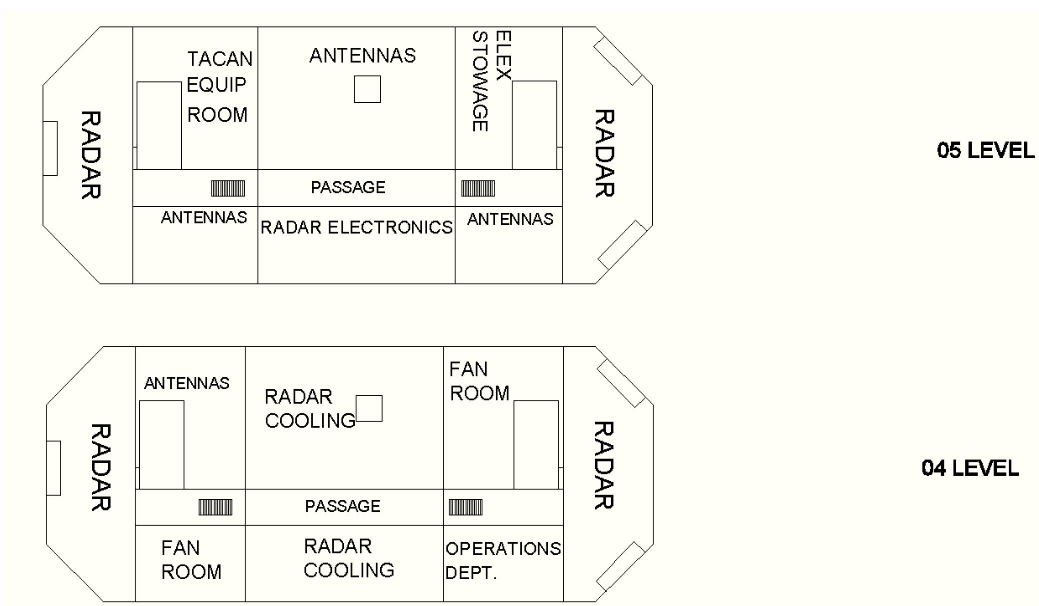


Figure 96 - Profile View Showing Arrangements

4.9.1 Internal Arrangements

The deckhouse was designed first because of the large number of complex systems and technical spaces needed to fit in such small spaces. Antenna and radar rooms were allocated first because of their importance. There are fan rooms on the 04 and 03 levels of the deckhouse and radar cooling on the 04 level to keep the electronics at a decent, operating temperature. The radio is lower on the deckhouse, on the 03 level, right above the bridge and navigation room on the 02 level. The CO cabin and living area is quite spacious and is located close to the bridge for easy access and adjacent to the department heads. Through all levels of the deckhouse, there is a center passageway as opposed to the traditional starboard and port passageways. This was done in an effort to save space and material as well as provide easy access to both sides of the deckhouse from the main center passageway. Flight control, aviation stores, aviation planning, and the aviation office are conveniently located above and around the hangars on the Helicopter of 01 Level. The deckhouse levels are shown in Figure 97and Figure 98.

Figure 97 Deckhouse Arrangements, 05, 04, 03 Levels



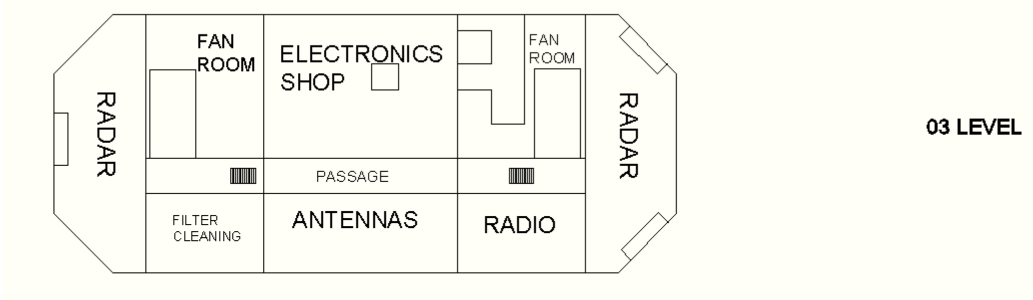
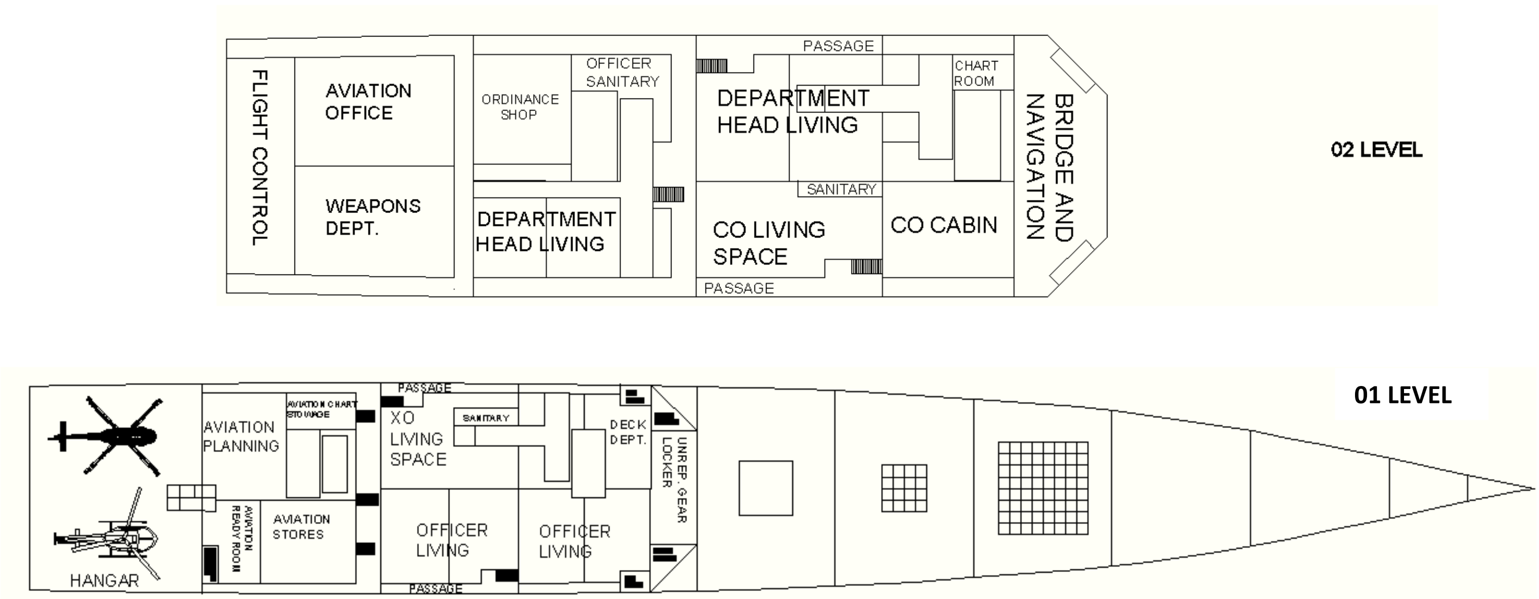


Figure 98 Deckhouse and Helo Deck Arrangements, 02 and 01 Levels



The main deck and damage control deck are predominately for weapons and storage in the forward sections. The VLS, PVLS, and MK45 weapon systems extend from the 01 Level through the 1 Main Deck and the 2 DC Deck. Midships on the 1 Main Deck are the separate departments; deck, executive, and supply. The helicopter hangars are on the aft end of the 1 Main Deck. The 2 DC Deck houses the officers and CPO in the aft end as well as provides the crew mess and galley. The 2 Damage Control Deck has 3 repair stations and 3 fire-fighting stations scattered around it with one forward, one midships, and one aft. The 1 Main Deck and 2 DC Deck are shown in Figure 99 and Figure 100.

Figure 99 Forward Plan View of 1 Main Deck and 2 DC Deck

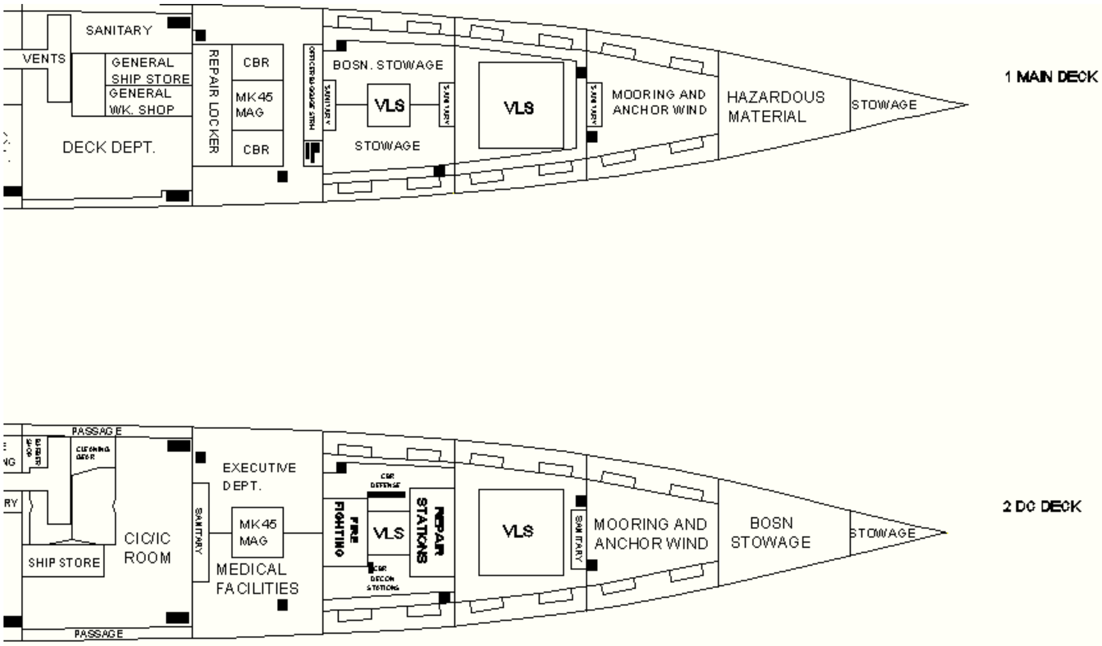
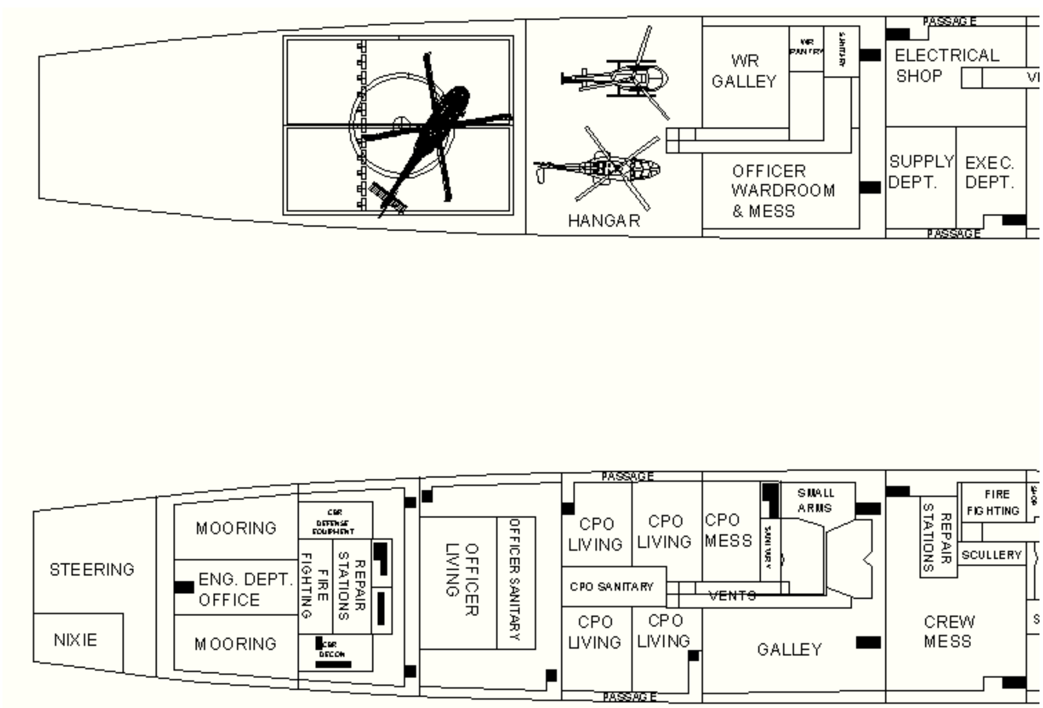


Figure 100 Aft Plan View of 1 Main Deck and 2 DC Deck



The next figures, Figure 101 and Figure 102, show the 1st, 2nd, and 3rd platforms. The 1st platform is the last deck for the VLS, PVLS, and MK 45 weapons systems as well as the last deck for machine rooms 1 and 2. In the aft end of the 1st platform there is predominately crew berthing with some other items far aft like hydraulics and the JP-5 pump room for the aviation equipment two decks higher. On the lowest platforms there is mainly stowage and tankage as well as the space consuming machine and auxiliary machine rooms. The SW ballast tanks cover the far forward compartments on the 1st and 2nd platforms. The two aft auxiliary machinary rooms extend from the 3rd platform up through the 2nd platform. The sonar electronics for the ship are located on the forward end of the 2nd and 3rd platforms.

Figure 101 Forward Plan Views of 1st, 2nd, 3rd Platforms

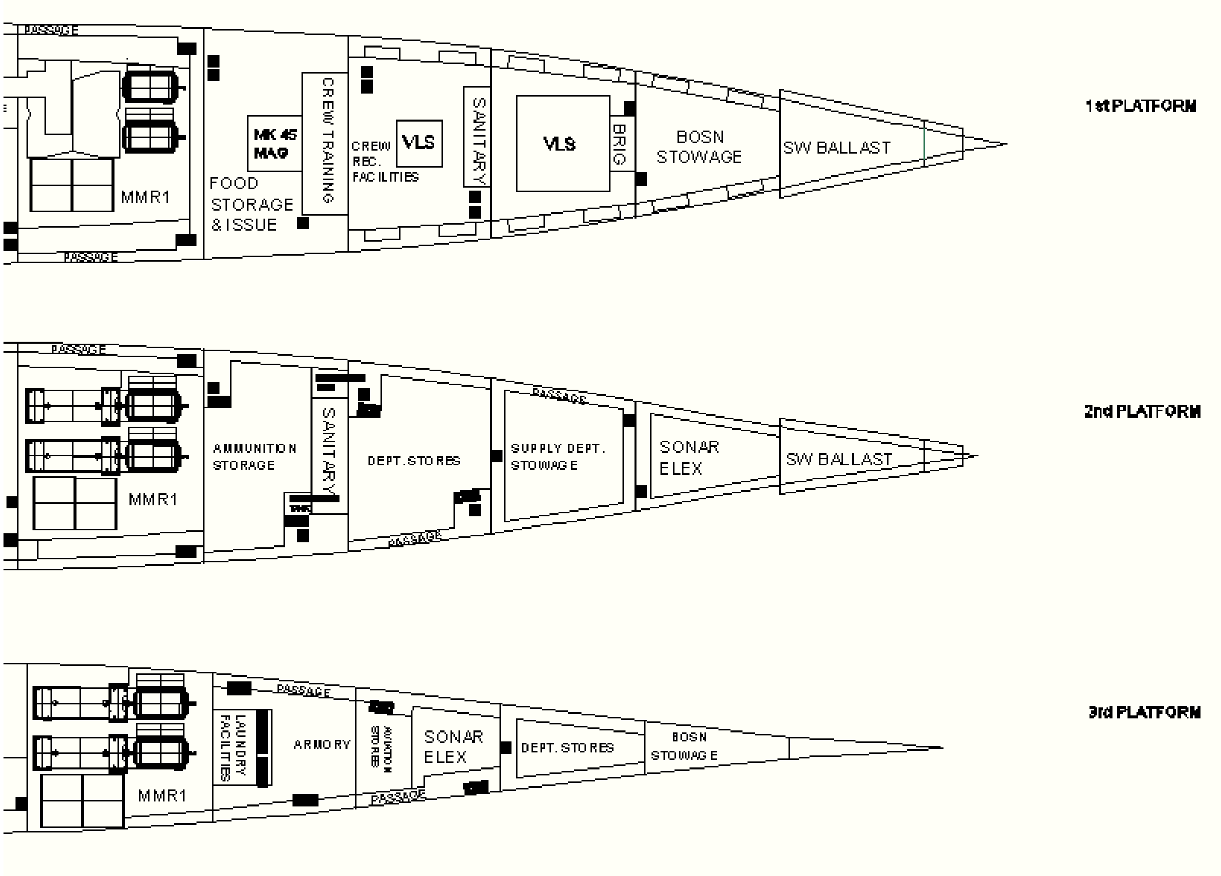
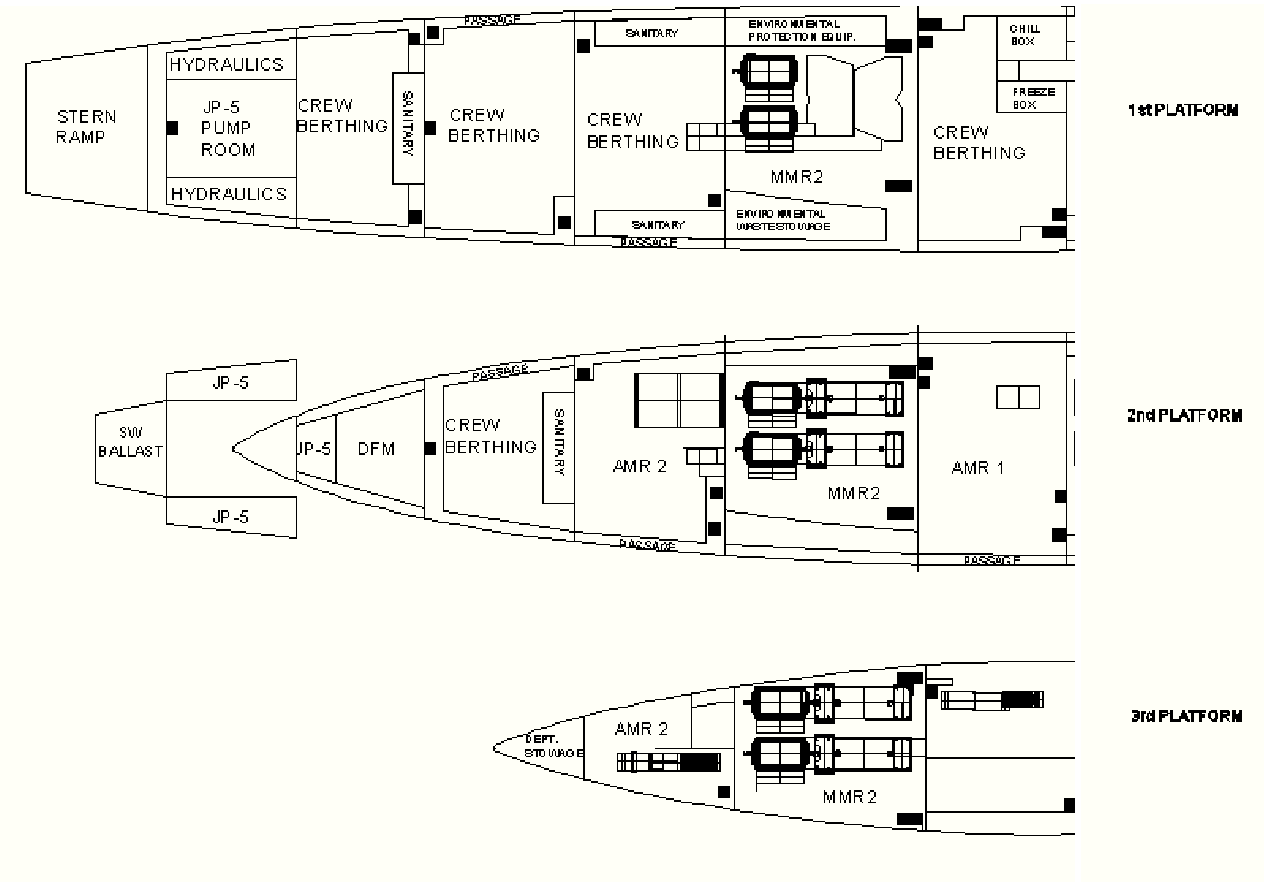


Figure 102 Aft Plan Views of 1st, 2nd, 3rd Platforms



4.9.2 Living Arrangements

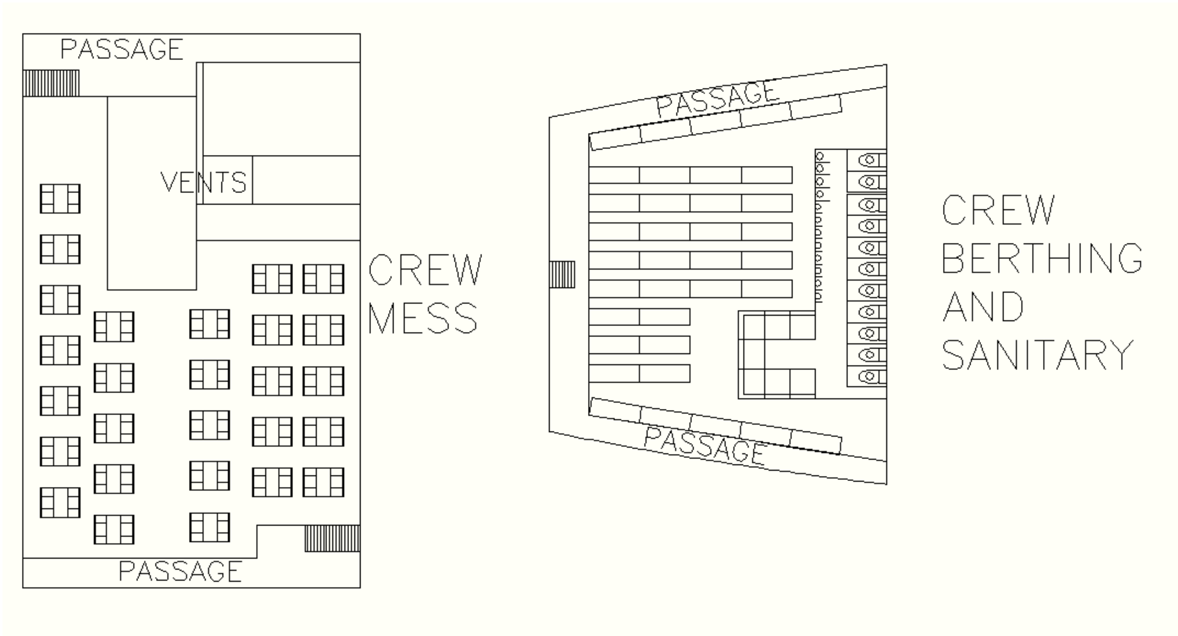
The living arrangements were determined by first acquiring the necessary room for each type of crew from typical crew berthing sizes and similar naval ships. This is shown in the following table on accommodation space:

Table 44 Accommodation Space

Item	Accomodation Quantity	Per Spac e	Number of Spaces	Area Each (m2)	Total Area (m2)
CO	1	1	1	37.3	37.3
XO	1	1	1	13.9	13.9
Department Head	4	1	4	11.6	46.5
Other Officer	9	2	5	12.5	62.5
CPO	20	5	4	13.64	54.56
Enlisted	70	25	3	49.9	149.7
Officer Sanitary	15	7	2	7	14.0
CPO Sanitary	20	5	4	4	16.0
Enlisted Sanitary	70	25	3	9.3	27.9
Total			**27**		**422.36**

Crew berthing and sanitary arrangements were difficult on this MSC because of the tumblehome and flare design. The flare cuts down on the space in the lower decks and compartments where enlisted crew would normally live. The officers and crew were kept away from the VLS and MK weapons systems for safety. Crew berthing is on the aft end of the ship on Platforms 1 and 2. Officers and department heads live higher in the ship on the 2 DC deck and on the 01 and 02 levels of the deckhouse. An example of a crew mess arrangements as well as a crew berthing and sanitary arrangement is exhibited in Figure 103.

Figure 103 Crew Mess and Berthing/Sanitary Arrangements



4.9.3 External Arrangements

The external arrangements on the MSC are not too involved because mostly everything is internal. This allows the ship to be more stealth oriented. A less complicated external arrangement leads to a smaller radar signature. The main focus on external arrangements was radar cross section, weapons systems, and aircraft operations. The MK45 gun can be seen from this profile view. Something taken into consideration was limiting visibility by placing the MK45 directly in front of the bridge. It was determined the MK45 should not affect viewing out of the bridge. The 1 Main Deck holds the Helo Deck markings and the hangar. The aft end of the 1 Main Deck is devoted to the helicopters and other aviation. The radar is mostly located internally in the forward and aft end of the top 3 levels of the deckhouse. Not seen from a profile view are the VLS and PVLS weapons systems. They are not necessarily included in the external arrangements until they are utilized. The VLS and PVLS are labeled on this view in Figure 104.

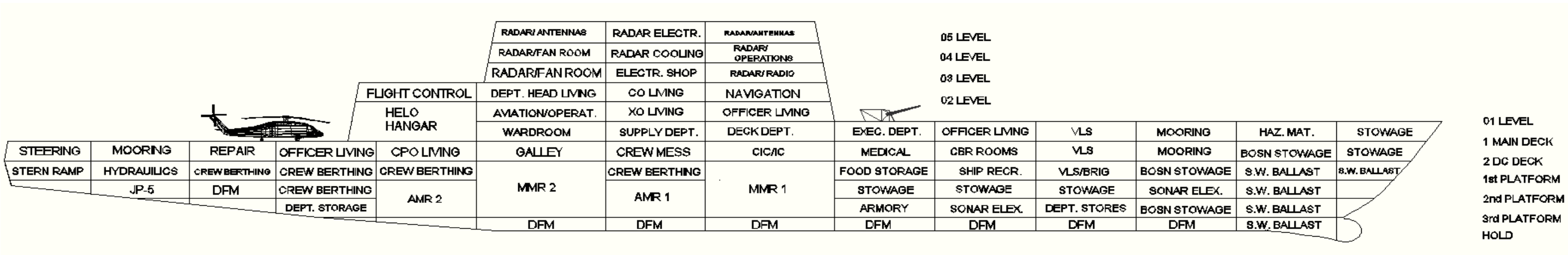


Figure 104 Profile View of External Arrangements

4.9.4 Area and Volume

The SSCS from ASSET is used to generate estimates of space and area and volume. The following is a table showing tentative values of area and volume outputted for the surface ship from ASSET. These exact values were not used, but were good references while determining the spacing and area arrangement for the MSC.

Table 45 SSCS from ASSET Space Estimates

SSCS	GROUP	VOLUME (m3)	AREA (m2)
	TOTAL AVAILABLE	8532	13956
	TOTAL REQUIRED	7471	13865
1	MISSION SUPPORT	86.1	5489
1.1	COMMAND,COMMUNICATION+SURV		124.2
1.11	EXTERIOR COMMUNICATIONS		5.9
1.111	RADIO		
1.113	VISUAL COM		5.9
1.12	SURVEILLANCE SYS		
1.121	SURFACE SURV (RADAR)		
1.122	UNDERWATER SURV (SONAR)		
1.13	COMMAND+CONTROL		73.6
1.131	COMBAT INFO CENTER		
1.132	CONNING STATIONS		73.6
1.1321	PILOT HOUSE		66.5
1.1322	CHART ROOM		7.1
1.14	COUNTERMEASURES		

1.141	ELECTRONIC		
1.142	TORPEDO		
1.143	MISSILE		
1.15	INTERIOR COMMUNICATIONS		124.2
1.16	ENVIORNMENTAL CNTL SUP SYS		
1.2	WEAPONS		
1.21	GUNS		
1.214	AMMUNITION STOWAGE		
1.22	MISSILES		
1.24	TORPEDOS		
1.26	MINES		
1.3	AVIATION	86.1	554.2
1.32	AVIATION CONTROL		20.4
1.321	FLIGHT CONTROL		9.3
1.3212	HELO FLIGHT CONTROL		9.3
1.321201	HELICOPTER CONTROL STATION		9.3
1.322	NAVIGATION		11.1
1.32202	TACAN EQUIP RM		11.1
1.323	OPERATIONS		
1.33	AVIATION HANDLING		
1.34	AIRCRAFT STOWAGE		533.8
1.342	HELICOPTER HANGAR		
1.35	AVIATION ADMINISTRATION		8.4
1.353	AIR WING		8.4
1.353	AVIATION OFFICE		8.4
1.36	AVIATION MAINTENANCE		17.6
1.361	AIRFRAME SHOPS		5.9
1.36106	BATTERY SHOP		5.9
1.369	ORGANIZATIONAL LEVEL MAINTENANCE		11.6
1.36905	HELICOPTER SHOP		11.6
1.37	AIRCRAFT ORDINANCE		
1.374	STOWAGE		
1.38	AVIATION FUEL SYS	86.1	
1.381	JP-5 SYSTEM	86.1	
1.3813	AVIATION FUEL	86.1	
1.39	AVIATION STORES		21.4
1.391	AVIATION CONSUMABLES		21.4
1.3911	SD STOREROOM		21.4
1.391102	AVIATION STORE RM		21.4
1.8	SPECIAL MISSIONS		
1.9	SM ARMS,PYRO+SALU BAT		8.3
1.91	SM ARMS (LOCKER)		6.2
1.94	ARMORY		2.1

2	HUMAN SUPPORT		835.0
2.1	LIVING		415.0
2.11	OFFICER LIVING		195.2
2.111	BERTHING		176.1
2.1111	SHIP OFFICER		176.1
2.1111101	COMMANDING OFFICER CABIN		31.8
2.1111104	COMMANDING OFFICER STATEROOM		18.6
2.1111206	EXECUTIVE OFFICER STATEROOM		13.9
2.111123	DEPARTMENT HEAD STATEROOM		11.6
2.1111302	OFFICER STATEROOM (DBL)		150.5
2.1114	AVIATION OFFICER		
2.112	SANITARY		19.1
2.1121	SHIP OFFICER		19.1
2.1121101	COMMANDING OFFICER BATH		4.6
2.1121201	EXECUTIVE OFFICER BATH		2.8
2.1121303	OFFICER		16.4
2.1124	AVIATION OFFICER		
2.12	CPO LIVING		86.8
2.121	BERTHING		66.4
2.1211	SHIP CPO		20.3
2.122	SANITARY		20.3
2.13	CREW LIVING		120.2
2.131	BERTHING		99.9
2.1311	SHIP CREW		99.9
2.131101	LIVING SPACE		99.9
2.132	SANITARY		20.3
2.133	RECREATION		
2.14	GENERAL SANITARY FACILITIES		4.6
2.142	BRIDGE WASHRM & WC		2.3
2.143	DECK WASHRM WR & WC		2.3
2.144	ENGINEERING WR & WC		2.3
2.15	SHIP RECREATION FAC		4.9
2.16	TRAINING		3.3
2.16002	RECOGNITION TRAINING LKR		3.3
2.2	COMMISSARY		227.4
2.21	FOOD SERVICE		133.8
2.211	WARDROOM MESSRM & LOUNGE		55.7
2.212	CPO MESSROOM AND LOUNGE		55.7
2.213	CREW MESSROOM		22.3
2.22	COMMISSARY SERVICE SPACES		55.3
2.222	GALLEY		38.6
2.22201	COMMANDING OFFICER GALLEY		10.7
2.2222	WARD ROOM GALLEY		9.8
2.2224	CREW GALLEY		18.0
2.223	WARDROOM PANTRY		7.4
2.224	SCULLERY		9.3
2.22403	CREW SCULLERY		9.3

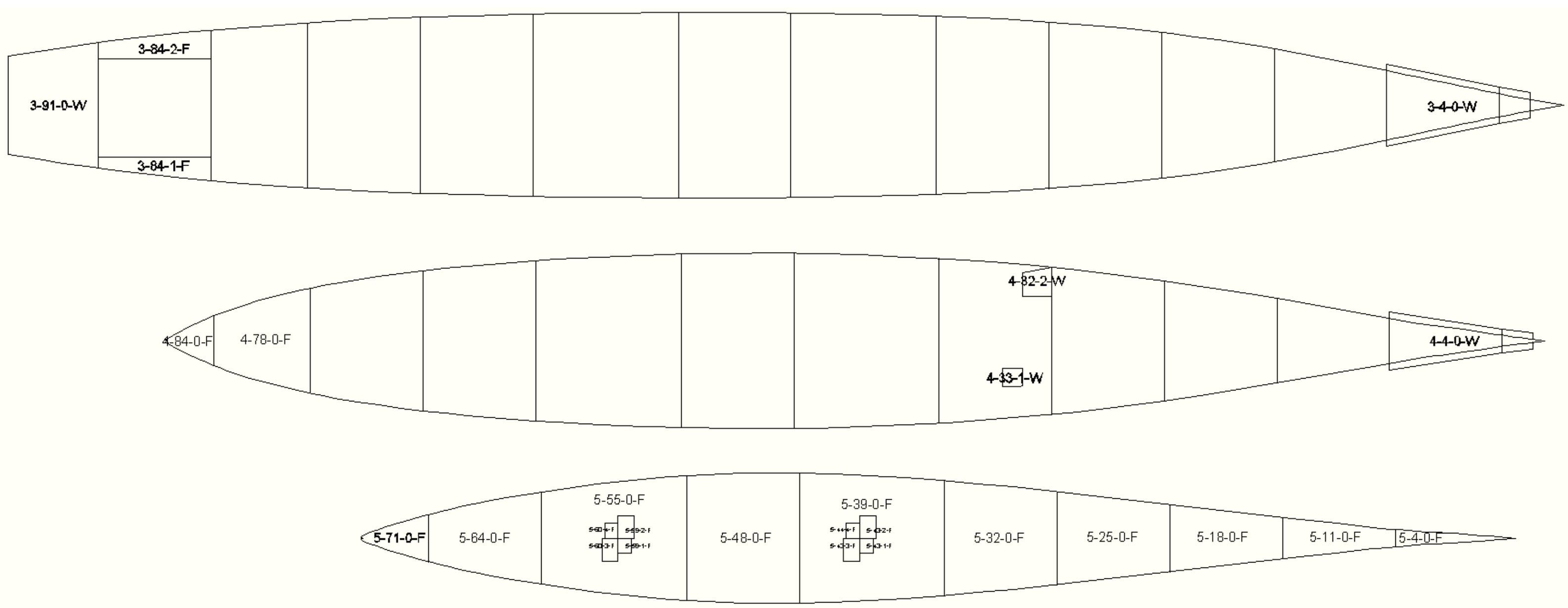
2.23	FOOD STORAGE+ISSUE		38.3
2.231	CHILL PROVISIONS		12.5
2.232	FROZEN PROVISIONS		8.2
2.233	DRY PROVISIONS		17.6
2.3	MEDICAL+DENTAL		30.6
2.31	MEDICAL FACILITIES		18.1
2.31007	DIET PANTRY		6.5
2.31012	MEDICAL TREATMEN ROOM		6.3
2.31023	MEDICAL UTILITY RM		5.2
2.34	MEDICAL AND DENTAL STOWAGE		12.5
2.341	MEDICAL		12.5
2.34103	MEDICAL LOCKER		1.4
2.34104	BATTLE DRESSING STRM		11.1
2.4	GENERAL SERVICES		24.4
2.41	SHIP STORE FACILITIES		12.3
2.42	LAUNDRY FACILITIES		12.1
2.44	BARBER SERVICE		
2.46	POSTAL SERVICE		
2.47	BRIG		
2.5	PERSONNEL STORES		19.9
2.51	BAGGAGE STOREROOMS		7.2
2.52	MESSROOM STORES		9.1
2.55	FOUL WEATHER GEAR		0.8
2.56	LINEN STOWAGE		2.2
2.6	CBR PROTECTION		58.5
2.61	CBR DECON STATIONS		
2.62	CBR DEFENSE EQUIPMENT		12.3
2.63	CPS AIRLOCKS		46.2
2.7	LIFESAVING EQUIPMENT		1.9
3	SHIP SUPPORT	7028.8	4321.4
3.1	SHIP CNTL SYS (STEERING)		125.3
3.11	STEERING GEAR		125.3
3.12	ROLL STABILIZATION		
3.15	STEERING CONTROL		
3.2	DAMAGE CONTROL		105.8
3.21	DAMAGE CNTRL CENTRAL		
3.22	REPAIR STATIONS		59.8
3.25	FIRE FIGHTING		46.1
3.3	SHIP ADMINISTRATION		86.7
3.301	GENERAL SHIP		7.3
3.302	EXECUTIVE DEPT		16.7
3.303	ENGINEERING DEPT		10.2
3.304	SUPPLY DEPT		8.5
3.305	DECK DEPT		4.4
3.306	OPERATIONS DEPT		39.5
3.307	WEAPONS DEPT		
3.5	DECK AUXILIARIES		72.9

3.51	ANCHOR HANDLING		65.0
3.52	LINE HANDLING		16.6
3.53	TRANSFER-AT-SEA		7.9
3.54	SHIP BOATS STOWAGE		
3.6	SHIP MAINTENANCE		268.3
3.61	ENGINEERING DEPT		172.9
3.611	AUX (FILTER CLEANING)		24.4
3.612	ELECTRICAL		57.5
3.613	MECH (GENERAL WK SHOP)		80.8
3.614	PROPULSION MAINTENANCE		10.2
3.62	OPERATIONS DEPT (ELECT SHOP)		82.0
3.63	WEAPONS DEPT (ORDINANCE SHOP)		13.4
3.64	DECK DEPT (CARPENTER SHOP)		
3.7	STOWAGE		916.6
3.71	SUPPLY DEPT		640.9
3.711	HAZARDOUS MATL (FLAM LIQ)		75.6
3.713	GEN USE CONSUM+REPAIR PART		483.4
3.714	SHIP STORE STORES		19.2
3.715	STORES HANDLING		62.7
3.72	ENGINEERING DEPT		15.9
3.73	OPERATIONS DEPT		22.2
3.74	BOATSWAIN STORES		196.5
3.75	WEAPONS DEPT		14.2
3.76	EXEC DEPT (MASTER-AT-ARMS STOR)		16.4
3.78	CLEANING GEAR STOWAGE		10.6
3.8	ACCESS		2083.6
3.82	INTERIOR		2083.6
3.821	NORMAL ACCESS		2063.9
3.822	ESCAPE ACCESS		19.7
3.9	TANKS	7028.8	25.1
3.91	SHIP PROP SYS TNKG	6479.3	
3.9111	ENDUR FUEL TANK (INCL SERVICE)	6479.3	
3.914	FEEDWATER TNKG		
3.92	BALLAST TNKG		
3.93	FRESH WATER TNKG	15.8	
3.94	POLLUTION CNTRL TNKG		25.1
3.941	SEWAGE TANKS		0.4
3.942	OILY WASTE TANKS		24.7
3.95	VOIDS	533.7	
4	SHIP MACHINERY SYSTEM		2559.1

4.1	PROPULSION SYSTEM		1008.3
4.142	COMBUSTION AIR (INTAKE)		385.0
4.143	EXHAUST		623.3
4.144	CONTROL		87.3
4.3	AUX MACHINERY		1119.6
4.33	ELECTRICAL		120.2
4.331	POWER GENERATION		95.4
4.334	DEGAUSSING		24.9
4.34	POLLUTION CONTROL SYSTEMS		7.1
4.341	SEWAGE		4.7
4.342	TRASH		2.4
4.35	MECHANICAL SYSTEMS		35.5
4.36	VENTILATION SYSTEMS		341.2

The tankage assessment was taken from these numbers and distributed in the bottom of the ship accordingly. The tanks were placed according to where their liquid was necessary. Figure 105 shows the Tankage Capacity Plan for the MSC.

Figure 105 Tankage Capacity Plan



The tanks are labeled as the deck number, how far from forward they begin, where the tanks are compared to the centerline and what the tanks hold. Each tank is labeled and categorized in Table 1Table 46.

Table 46 Tankage Labels and Volumes

Tank #	Type	Vol. (m3)	Cap. (gal)	Tank #	Type	Vol. (m3)	Cap. (gal)	Tank #	Type	Vol. (m
5-4-0-F	DFM	36	9510	5-71-0-F	DFM	9	2378	4-4-0-W	S.W. BALLAST	
5-11-0-F	DFM	54	14265	5-43-1-F	LUBE OIL	5	1321	4-32-2-W	FRESH WATER	
5-18-0-F	DFM	102	26946	5-43-2-F	WASTE OIL	14	3698	4-33-1-W	FRESH WATER	
5-25-0-F	DFM	155	40947	5-44-3-F	LUBE OIL	5	1321	4-78-0-F	DFM	
5-32-0-F	DFM	213	56269	5-44-4-F	WASTE OIL	14	3698	4-84-0-F	JP-5	
5-39-0-F	DFM	265	70006	5-59-1-F	LUBE OIL	6	1585	3-4-0-W	S.W. BALLAST	
5-48-0-F	DFM	323	85328	5-59-2-F	WASTE OIL	10	2642	3-84-1-F	JP-5	
5-55-0-F	DFM	232	61288	5-60-3-F	LUBE OIL	5	1321	3-84-2-F	JP-5	
5-64-0-F	DFM	108	26530	5-60-4-F	WASTE OIL	18	4755	3-91-0-W	S.W. BALLAST	

4.10 Weights, Loading and Stability

Ship weights are grouped by their respective SWBS number. When weights were not given from the manufacturer information, ASSET parametrics and the ship synthesis model were used. The VCGs and LCGs of the different weights are determined from the machinery arrangements and the general ship. The mass moments and lightship center of gravity is calculated using these values. A summary of lightship weights and centers of gravity by SWBS number is shown below. The entire weights spreadsheet is shown in Appendix E.

Table 47 - Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m-Abv BL)	LCG (m-Aft FP)
100	5190.3	9.84	99.58
200	2252.9	7.47	112.37
300	853.4	9.17	101.63
400	725.9	18.46	92.75
500	1551.6	11.0	108.40
600	961.9	7.8	96.35
700	472.9	11.07	95.85
Margin	1200.89	9.86	104.14
Total (LS)	132209.79	9.86	104.14

4.10.1 Loads and Loading Conditions

DDS 079-1 defines the full load condition to include the lightship weights and the full allowance of variable loads and cargo. This includes all liquid tanks at 95% full, ammunition, provisions for endurance, ship's force, and miscellaneous cargo. The minimum operating condition refers to a condition after the ship has spent some time at sea. Provisions, fuel, ammunition, and stores are considered to be at one third capacity. A summary of the weights for the full load condition are provided in Table 48 . A summary for the minimum operating condition is provided in Table 49.

Table 48

	FULL LOAD CONDITION	Weight(MT)	VCG	LCG
F00	LOADS	3090	3.17437	91.49262
F10	SHIPS FORCE	12.3	11.3	90.82
F11	OFFICERS	4.2	11.3	90.82
F12	NON-COMMISSIONED OFFICERS	3.4	11.3	90.82
F13	ENLISTED MEN	4.7	11.3	90.82
F20	MISSION RELATED EXPENDABLES+SYS	393.4	10.52	96.62
F21	SHIP AMMUNITION	262.3	9.5	65
F23	ORD DEL SYS (AIRCRAFT)	14.1	13.46	120
F30	STORES	21.4	11.42075	69.90654
F31	PROVISIONS+PERSONNEL STORES	17.9	11.434	65
F32	GENERAL STORES	3.5	11.353	95
F40	LIQUIDS, PETROLEOM BASED	2647.5	1.975222	91.03335
F41	DIESEL FUEL MARINE	2565.9	2	90

F42	JP-5	65.4	1	130
F46	LUBRICATING OIL	16.1	2	98
F50	LIQUIDS, NON-PETRO BASED	15.4	3.73	70
F52	FRESH WATER	15.4	3.73	70

Table 49

	MINIMUM OPERATING CONDITION	Weight (MT)	VCG	LCG
F00	LOADS	1005.5	2.881119	100.1323
F10	SHIPS FORCE	12.3	11.3	90.82
F11	OFFICERS	4.2	11.3	90.82
F12	NON-COMMISSIONED OFFICERS	3.4	11.3	90.82
F13	ENLISTED MEN	4.7	11.3	90.82
F20	MISSION RELATED EXPENDABLES+SYS	92.13333	9.702012	96.62
F21	SHIP AMMUNITION	87.43333	9.5	96.62
F23	ORD DEL SYS (AIRCRAFT)	4.7	13.46	96.62
F30	STORES	7.133333	11.42075	110
F31	PROVISIONS+PERSONNEL STORES	5.966667	11.434	110
F32	GENERAL STORES	1.166667	11.353	110
F40	LIQUIDS, PETROLEOM BASED	883.6667	1.973972	100.4338
F41	DIESEL FUEL MARINE	855.3	2	100
F42	JP-5	23	1	105
F46	LUBRICATING OIL	5.366667	2	150
F47	SEA WATER	0	0	0
F50	LIQUIDS, NON-PETRO BASED	10.26667	3.73	110
F52	FRESH WATER	10.26667	3.73	110

4.10.2 Final Hydrostatics and Intact Stability

The hydrostatic properties of the ship were analyzed using the HECSALV software suite. The section geometry was imported from RHINO into the HECSALV Ship Project Editor. The ship's loads were balanced then the intact stability and damaged stability were analyzed in HECSALV and the Damaged Stability Module. Intact stability was calculated in accordance with the U.S. Navy Design Sheet DDS 079-1. Trim, stability and righting arm data were calculated for each condition. All conditions were assessed using DDS 079-1 stability standards for beam winds with rolling. The magnitude of the heeling arm at the intersection of the righting arm and
wind heel arm curves must be less than six-tenths of the maximum GZ to be acceptable and the area under the righting arm curve and above the heeling arm curve (A1) must be greater than 1.4 times the area under the heeling arm curve and above the righting arm curve (A2). In both cases the criteria is met. The intact stability is satisfactory for both conditions. Table 50 shows the full load trim and stability summary and Table 50 shows the full load righting arm curve. Table 51 shows the MinOp trim and stability summary and Figure 107 MinOp Load Righting Arm Curve shows the MinOp righting arm curve.

Table 50 Full Load Trim and Stability Summary

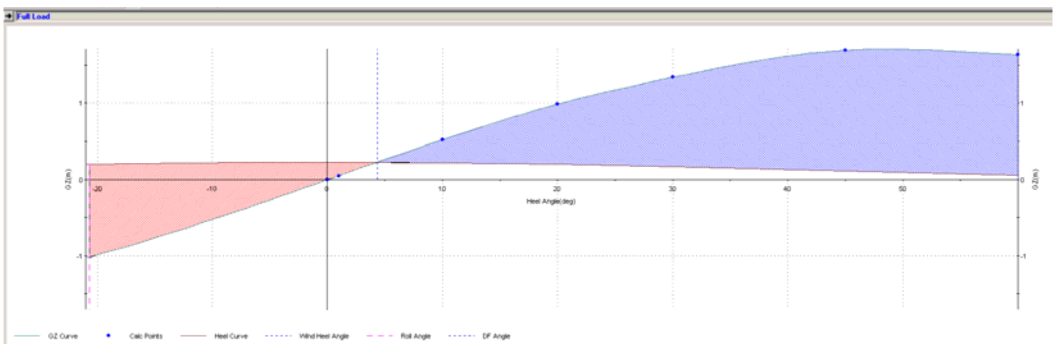
Full Load

Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	15,984	9.250	96.585A	0.000	----
Constant	0	0.000	96.585A	0.000	0
Lube Oil	18	0.747	115.488A	0.047S	8
Fresh Water	31	3.771	111.480A	0.000	0
SW Ballast	0	----	----	----	----
Fuel (DFM)	1,252	1.403	90.091A	0.011S	3,438
JP-5 Fuel	71	6.859	173.439A	0.000P	0
Waste Oil	0	----	----	----	----
Sewage	0	----	----	----	----
Misc. Weights	8	0.000	96.585A	0.000	0
Displacement	17,363	8.652	96.477A	0.001S	3,446

Stability Calculation			Trim Calculation		
KMt	12.044	m	LCF Draft	7.870	m
VCG	8.652	m	LCB	96.461A	m-FP
GMt (Solid)	3.392	m	LCF	106.160A	m-FP
FSc	0.198	m	MT1cm	412	m-MT/cm
GMt (Corrected)	3.193	m	Trim	0.641	m-F
			List	0.0S	deg
Specific Gravity	1.0250		TPcm	36	MT/cm
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculation		
Draft at F.P.	8.223	m	Shear	2,143	MT at 142.000A m-FP
Draft at M.S.	7.902	m	Bending	105,222H	m-MT at 99.307A m-FP
Draft at A.P.	7.581	m			
Draft at FwdMarks	8.223	m			
Draft at Mid Marks	7.902	m			
Draft at AftMarks	7.581	m			

Figure 106 Full Load Righting Arm Curve



U.S. Navy DDS079-1: Beam Wind and Rolling	Units	Value	Required
Wind Heel	deg	4.3	---
Wind Heeling Arm Lw	m	0.229	---
Maximum Righting Arm Ratio		0.13	0.60
Capsizing Area A2	m-rad	0.28	---
Righting Area A1	m-rad	1.07	0.40
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.709	---
Angle at Max. GZ	deg	48.5	---
Projected Sail Area	m2	2,336.95	---
Heeling Arm at 0 deg.	m	0.230	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.00	
Reference Draft	m	0.000	
Projected Sail Area	m2	5,000.00	
Vertical Center of Sail Area -BL	m	20.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

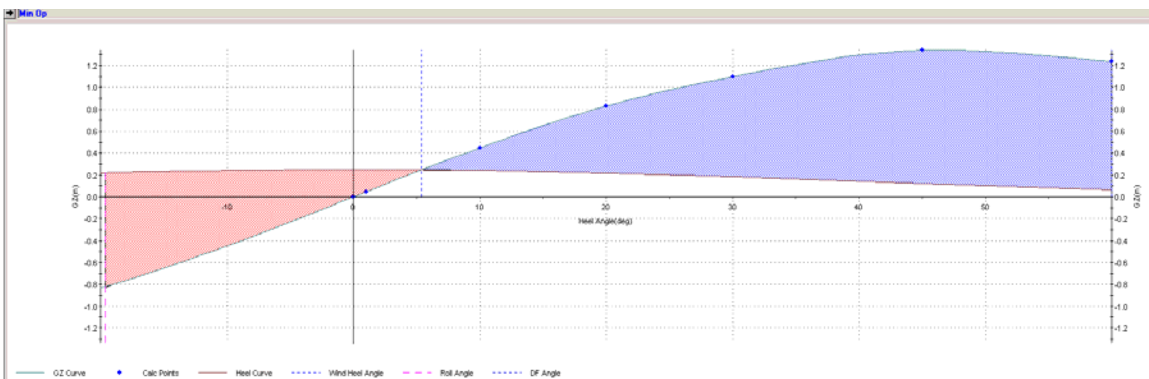
Table 51 MinOp Trim and Stability Summary

Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	15,984	9.250	96.585A	0.000	----
Constant	0	0.000	96.585A	0.000	0
Lube Oil	6	0.420	115.461A	0.048S	11
Fresh Water	20	3.395	111.474A	0.000	12
SW Ballast	0	----	----	----	----
Fuel (DFM)	435	0.854	89.986A	0.030S	5,479
JP-5 Fuel	23	6.365	172.318A	0.000P	35
Waste Oil	0	----	----	----	----
Sewage	0	----	----	----	----
Misc. Weights	0	----	----	----	----
Displacement	16,468	9.014	96.544A	0.001S	5,536

Stability Calculation			Trim Calculation		
KMt	12.148	m	LCF Draft	7.620	m
VCG	9.014	m	LCB	96.532A	m-FP
GMt (Solid)	3.134	m	LCF	106.270A	m-FP
FSc	0.336	m	MT1cm	404	m-MT/cm
GMt (Corrected)	2.798	m	Trim	0.402	m-F
			List	0.0S	deg
Specific Gravity	1.0250		TPcm	35	MT/cm
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculation		
Draft at F.P.	7.841	m	Shear	2,215	MT at 142.000A m-FP
Draft at M.S.	7.640	m	Bending	109,680H	m-MT at 99.118A m-FP
Draft at A.P.	7.439	m			
Draft at FwdMarks	7.841	m			
Draft at Mid Marks	7.640	m			
Draft at AftMarks	7.439	m			

Figure 107 MinOp Load Righting Arm Curve



U.S. Navy DDS079-1: Beam Wind and Rolling	Units	Value	Required
Wind Heel	deg	5.4	---
Wind Heeling Arm Lw	m	0.246	---
Maximum Righting Arm Ratio		0.18	0.60
Capsizing Area A2	m-rad	0.25	---
Righting Area A1	m-rad	0.82	0.34
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.340	---
Angle at Max. GZ	deg	46.6	---
Projected Sail Area	m2	2,307.50	---
Heeling Arm at 0 deg.	m	0.248	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.00	
Reference Draft	m	0.000	
Projected Sail Area	m2	5,000.00	
Vertical Center of Sail Area -BL	m	20.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

4.10.3 Damage Stability

To assess the vulnerability of the ship to damage, twenty-six individual damage cases were modeled in the HECSALV Damaged Stability Module. The full load condition as well as the MinOp condition were analyzed. These cases involved three and four compartment flooding to the waterline determined by the creating damage scenarios with a 15% LWL damage event on the starboard side. The ship is largely symmetrical in loading and tankage so it was safe to consider only damage to the starboard side. The results from the 26 individual cases is shown in Table 52 HECSALV Damage Stability Results. Draft one in the MinOp condition and Draft 2 in the Full Load Condition.

Table 52 HECSALV Damage Stability Results

#	Draft	Status	Case	Intact			Damaged			Case
				T AP	T FP	GMt	T AP	T FP	Heel	
				m	m	m	m	m	deg	
1	1	1	1	7.439	7.841	2.798	7.385	7.947	0.0	Case 1
2	1	1	2	7.439	7.841	2.798	7.377	7.964	0.0	Case 2
3	1	1	3	7.439	7.841	2.798	7.349	8.022	0.0	Case 3
4	1	1	4	7.439	7.841	2.798	7.381	7.959	0.0	Case 4
5	1	1	5	7.439	7.841	2.798	7.330	8.103	0.0	Case 5
6	1	1	6	7.439	7.841	2.798	7.298	8.234	0.0	Case 6
7	1	1	7	7.439	7.841	2.798	7.302	8.340	0.0	Case 7
8	1	1	8	7.439	7.841	2.798	7.464	8.418	0.0	Case 8
9	1	1	9	7.439	7.841	2.798	8.058	8.938	0.0	Case 9
10	1	1	10	7.439	7.841	2.798	7.958	8.660	0.0	Case 10
11	2	1	1	7.581	8.223	3.193	7.521	8.343	0.0	Case 1
12	2	1	2	7.581	8.223	3.193	7.512	8.360	0.0	Case 2
13	2	1	3	7.581	8.223	3.193	7.485	8.417	0.0	Case 3
14	2	1	4	7.581	8.223	3.193	7.520	8.346	0.0	Case 4
15	2	1	5	7.581	8.223	3.193	7.475	8.479	0.0	Case 5
16	2	1	6	7.581	8.223	3.193	7.444	8.607	0.0	Case 6
17	2	1	7	7.581	8.223	3.193	7.450	8.712	0.0	Case 7
18	2	1	8	7.581	8.223	3.193	7.610	8.789	0.0	Case 8
19	2	1	9	7.581	8.223	3.193	8.227	9.339	0.0	Case 9
20	2	1	10	7.581	8.223	3.193	8.126	9.067	0.0	Case 10
21	1	1	11	7.439	7.841	2.798	7.447	7.854	0.0	Case 11
22	2	1	11	7.581	8.223	3.193	7.589	8.236	0.0	Case 11
23	1	1	12	7.439	7.841	2.798	7.454	7.854	0.2	Case 12
24	2	1	12	7.581	8.223	3.193	7.596	8.236	0.2	Case 12
25	1	1	13	7.439	7.841	2.798	7.549	7.885	0.0	Case 13
26	2	1	13	7.581	8.223	3.193	7.690	8.267	0.0	Case 13
27	1	1	14	7.439	7.841	2.798	8.234	8.126	-0.2	Case 14
28	2	1	14	7.581	8.223	3.193	8.404	8.517	-0.2	Case 14
29	1	1	15	7.439	7.841	2.798	9.557	7.984	0.0	Case 15
30	2	1	15	7.581	8.223	3.193	9.784	8.373	0.0	Case 15
31	1	1	16	7.439	7.841	2.798	8.646	7.701	0.0	Case 16
32	2	1	16	7.581	8.223	3.193	8.831	8.082	0.0	Case 16
33	1	1	17	7.439	7.841	2.798	7.457	7.838	0.0	Case 17
34	2	1	17	7.581	8.223	3.193	7.598	8.220	0.0	Case 17
35	1	1	18	7.439	7.841	2.798	8.348	7.494	0.0	Case 18
36	2	1	18	7.581	8.223	3.193	8.527	7.867	0.0	Case 18
37	1	1	19	7.439	7.841	2.798	8.436	7.450	0.0	Case 19
38	2	1	19	7.581	8.223	3.193	8.615	7.823	0.0	Case 19
39	1	1	20	7.439	7.841	2.798	9.295	7.016	0.0	Case 20
40	2	1	20	7.581	8.223	3.193	9.528	7.367	0.0	Case 20
41	1	1	21	7.439	7.841	2.798	9.353	6.982	0.5	Case 21
42	2	1	21	7.581	8.223	3.193	9.586	7.334	0.4	Case 21
43	1	1	22	7.439	7.841	2.798	8.145	7.469	0.4	Case 22
44	2	1	22	7.581	8.223	3.193	8.322	7.837	0.3	Case 22
45	1	1	23	7.439	7.841	2.798	8.100	7.487	0.0	Case 23
46	2	1	23	7.581	8.223	3.193	8.278	7.855	0.0	Case 23
47	1	1	24	7.439	7.841	2.798	8.021	7.481	0.0	Case 24
48	2	1	24	7.581	8.223	3.193	8.206	7.840	0.0	Case 24
49	1	1	25	7.439	7.841	2.798	8.150	7.390	-0.4	Case 25
50	2	1	25	7.581	8.223	3.193	8.334	7.751	-0.3	Case 25
51	1	1	26	7.439	7.841	2.798	8.337	7.264	-0.4	Case 26
52	2	1	26	7.581	8.223	3.193	8.518	7.627	-0.3	Case 26

The three worst damage conditions were then analyzed. The results showed that of the three determined extreme damage situations, 2 of the conditions were with the full load conditions. The flooded figure and the respective righting arms are shown below. Figure 108 Full Load Damage Condition shows flooding just aft of midships in the full load condition. Figure 110 Full Load Damage Condition shows flooding farther aft than before also in the full load condition. Figure 112 MinOp Damage Condition shows the same damage condition as the previous figure but in the MinOp condition.

Figure 108 Full Load Damage Condition

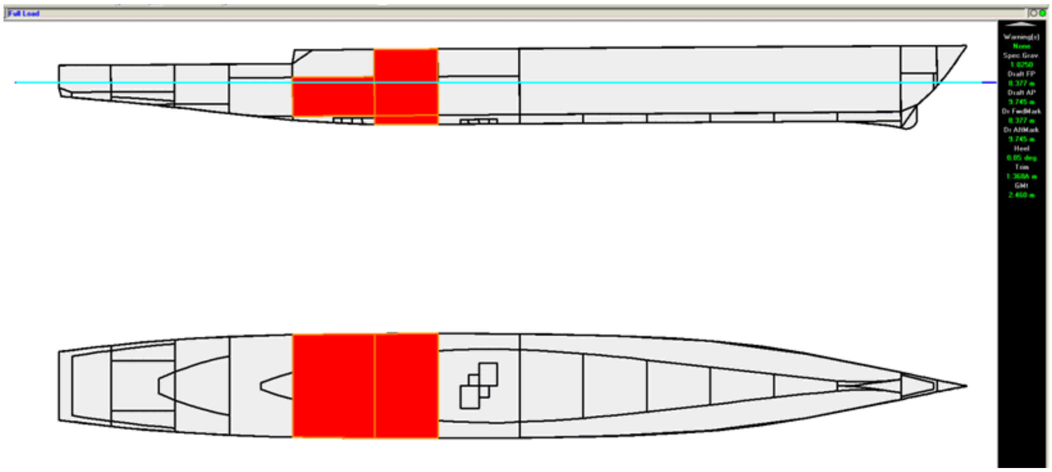


Figure 109 Full Load Damage Condition Righting Arm

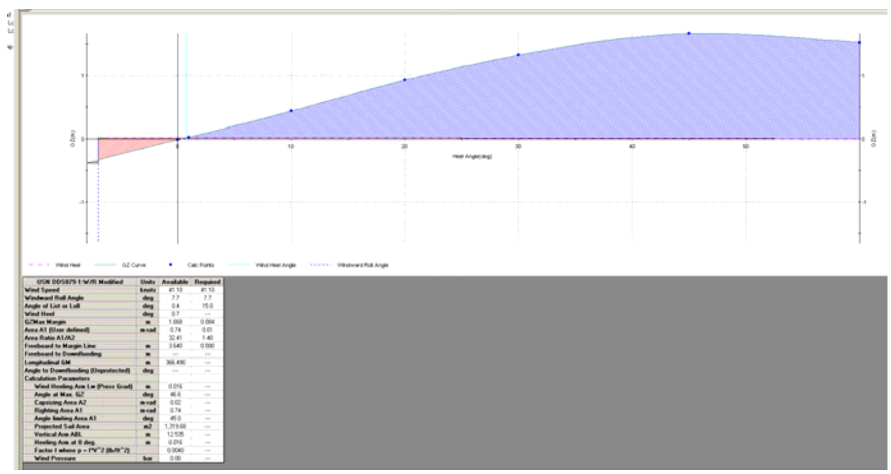


Figure 110 Full Load Damage Condition

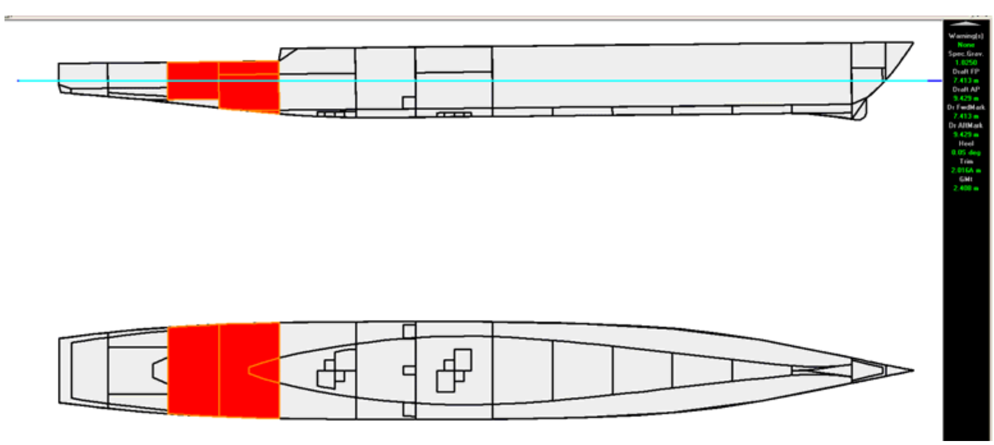


Figure 111 Full Load Damage Condition Righting Arm

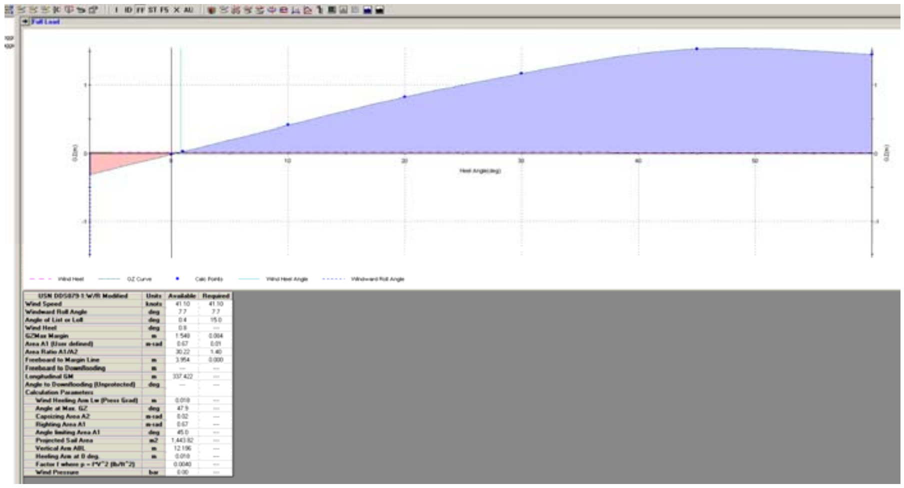


Figure 112 MinOp Damage Condition

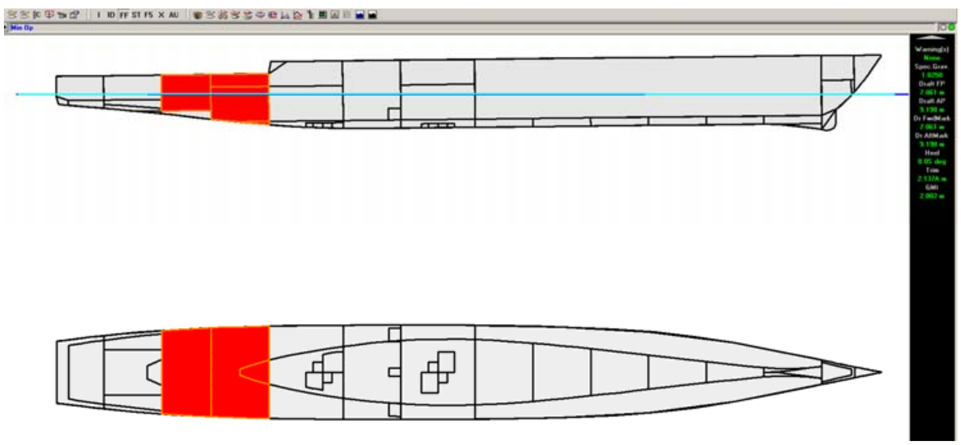
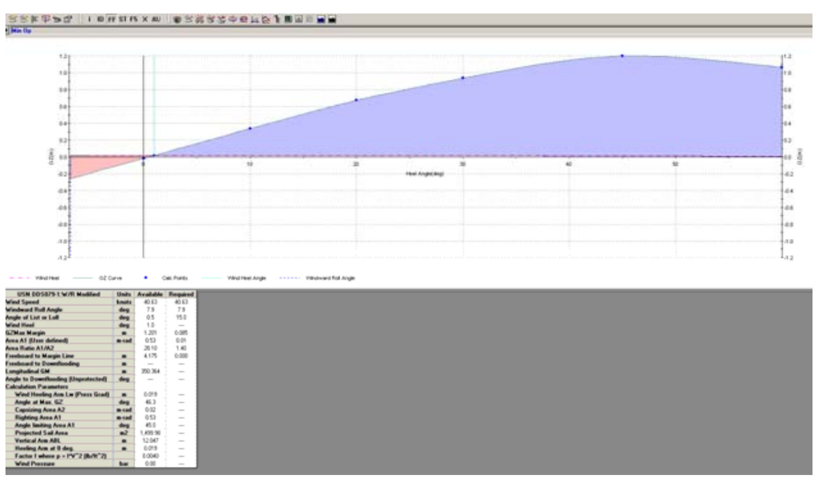


Figure 113 MinOp Damage Condition Righting Arm



4.11 Seakeeping, Maneuvering and Control

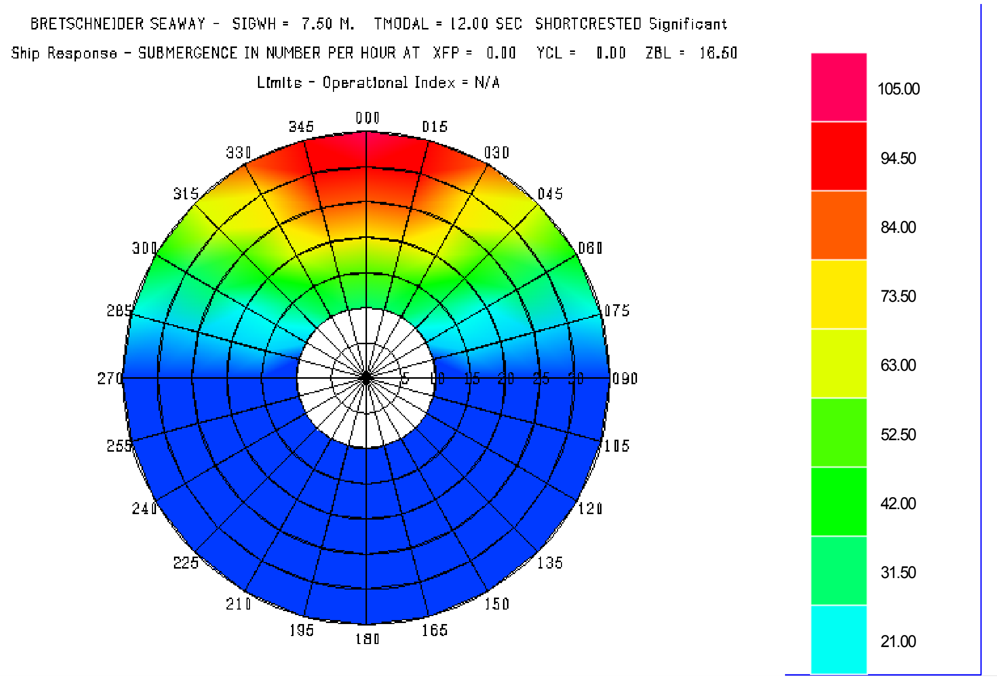
To get the seakeeping, maneuvering and control HECSALV and SMP were used. Using the offsets created in HecSalv that can be seen in section 4.4.1, a pre-SMP processor was used to import the offsets, loads, sea-states, responses, motion points and relative points. Once this file was saved and executer, it would create an input file that was to be used in SMP, after some editing of the file. The next step was to input the appendages onto the model, such as the bilge keel, the skeg and the rudders. After the appendages were loaded, the irregular wave input file had to be adjusted in SMP to edit the general information used as well as the ship responses used. Then, the speed polar files, each of the testing conditions, had to be input into SMP. Once the conditions were input, it is possible to see the contour plots showing the seakeeping aspects for the ship at each testing condition.

The limiting criteria for the ship can be seen below in Table 53.

Table 53 Selected Seakeeping Limiting Criteria

Application	Sea State	Location	Roll	Pitch	V Vel	L Acc	T Acc	V Acc	Slam	Wet
1. Bow Wetness	7	Bow Sta 0								30/hr
2. Keel Slam	7	Keel Sta 3							20/hr	
3. VLS Launch	6	NA	17.5 deg							
4. VLS Launch	6	NA		3 deg						
5. VLS Launch	6	CG				0.3g				
6. VLS Launch	6	CG					0.7g			
7. VLS Launch	6	CG						0.6g		
8. Radar	7	NA	25 deg							
9. Bow Sonar	6	NA	15 deg							
10. Bow Sonar	6	NA		5 deg						
11. Gun	5	NA	7.5 deg							
12. Gun	5	NA		7.5 deg						
13. Gun	5	CG			1 m/s					
14. Torpedo Launch	5	NA	7.5 deg							
15. UNREP	5	NA	4 deg							
16. UNREP	5	NA		1.5 deg						
17. Helo	5	NA	5 deg							
18. Helo	5	NA		3 deg						
19. Helo	5	Landing			2 m/s					
20. Personnel	7	NA	8 deg							
21. Personnel	7	NA		3 deg						
22. Personnel	7	Bridge						0.4g		

Some of the contour plots for the testing conditions can be seen below, with a color scale on the right. For each of the cases with the same sea state, only one image is provided, because they have the same output. The difference between each case is only the limit that can be sustained when underway.



c

Figure 114 Case 1 Bow wetness at Sea–State 7

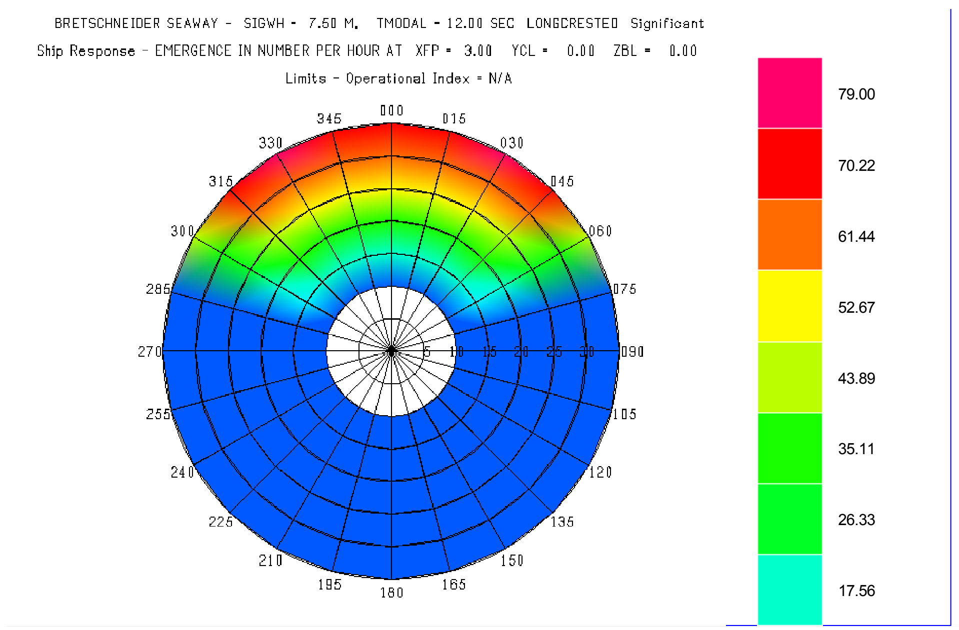


Figure 115 Case 2 Keel Slamming at Sea-State 7

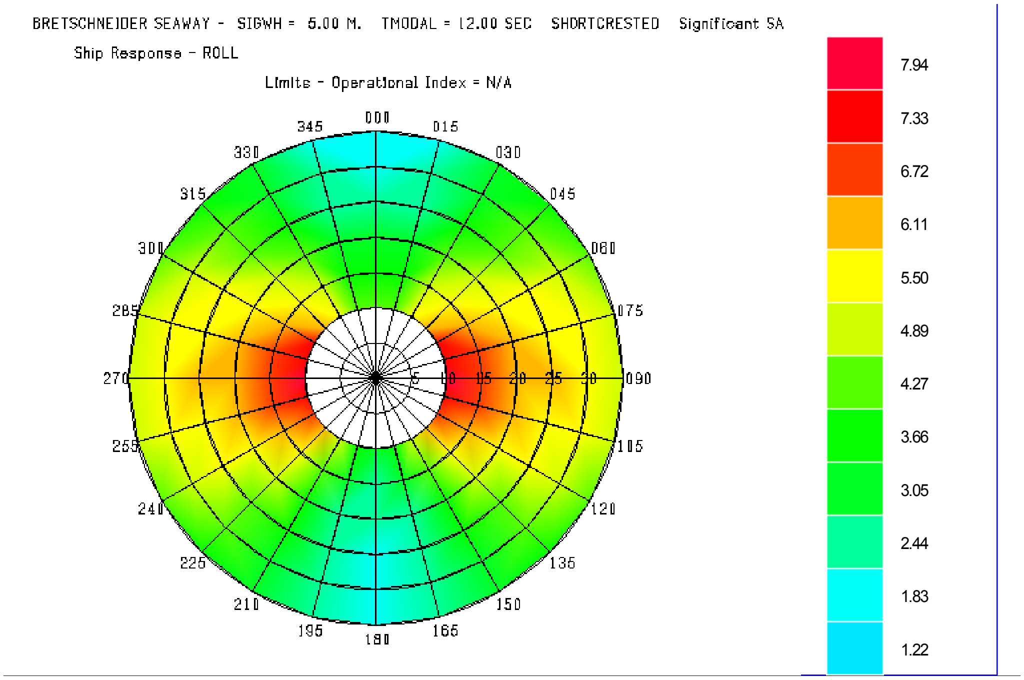


Figure 116 Cases 3, 9 Roll for VLS Launch and Bow Sonar at Sea-State 6

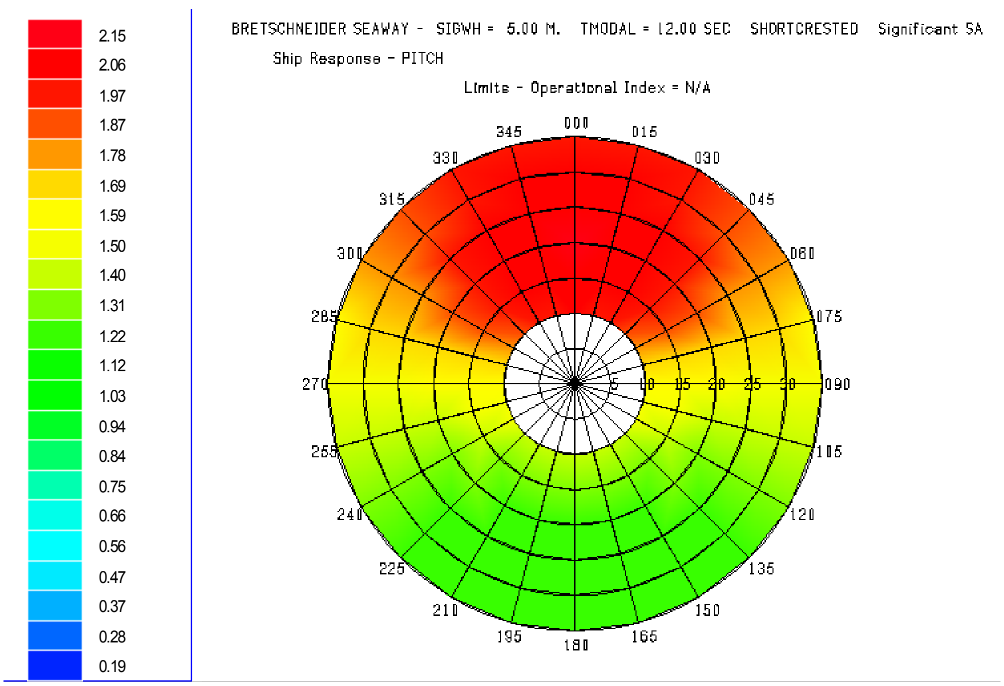


Figure 117 Cases 4, 10 Pitch for VLS Launch and Bow Sonar at Sea-State 6

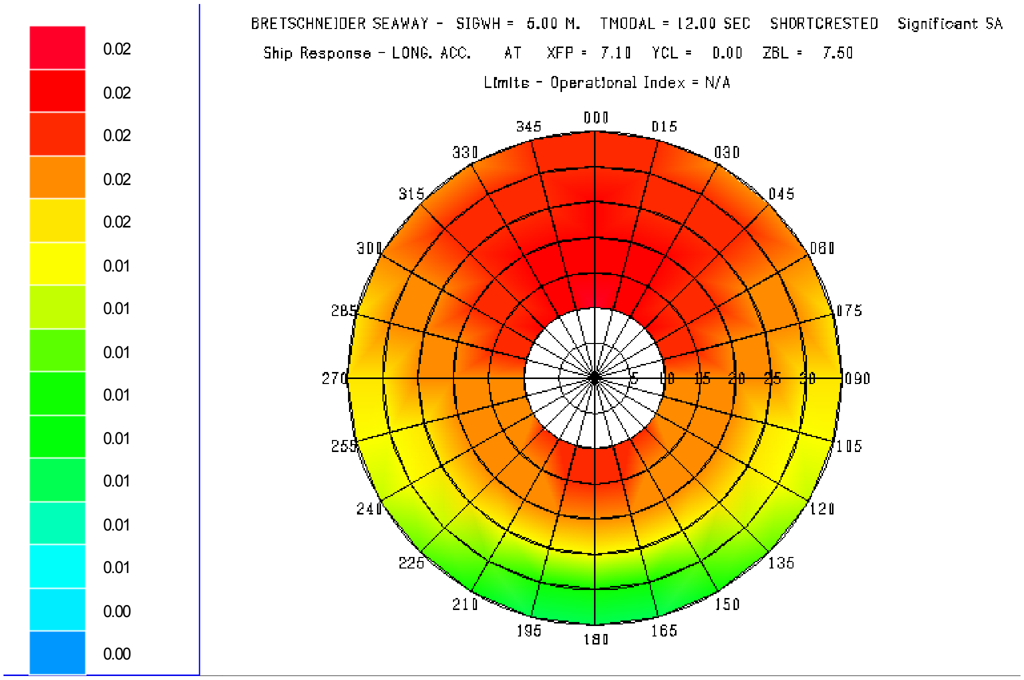


Figure 118 Case 5 Longitudinal Acceleration for VLS Launch at Sea-State 6

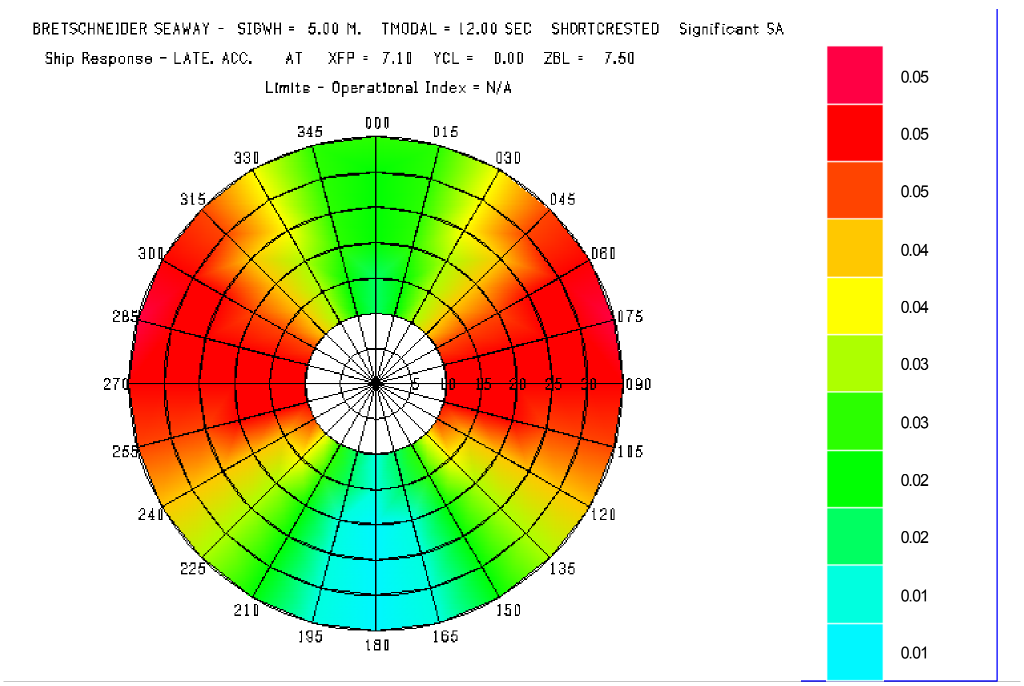


Figure 119 Case 6 Lateral Acceleration for VLS Launch at Sea-State 6

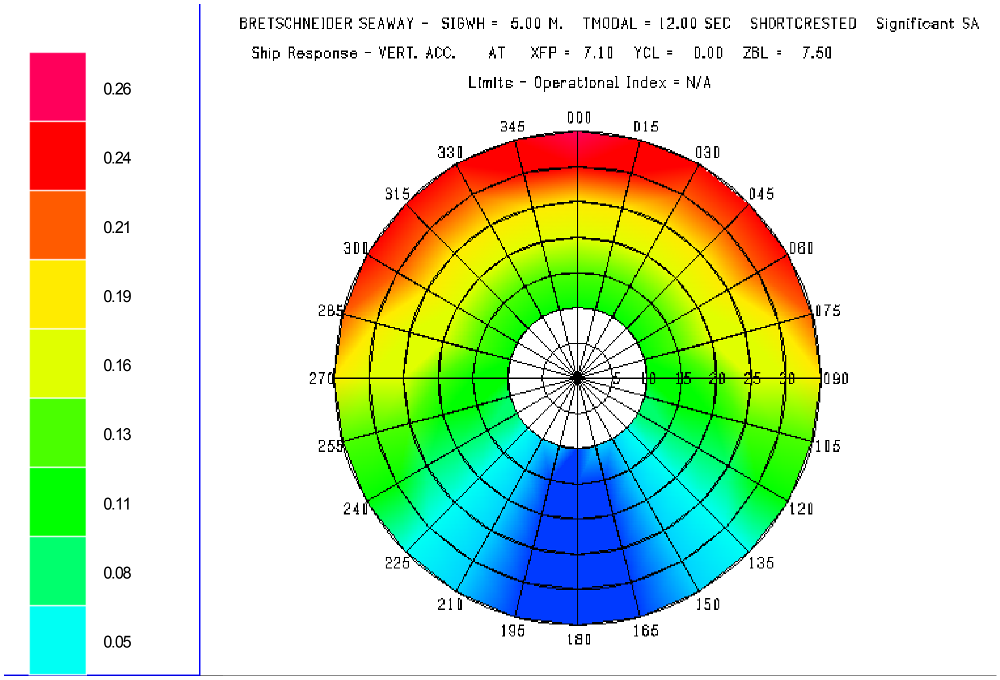


Figure 120 Case 7 Vertical Acceleration for VLS Launch at Sea-State 6

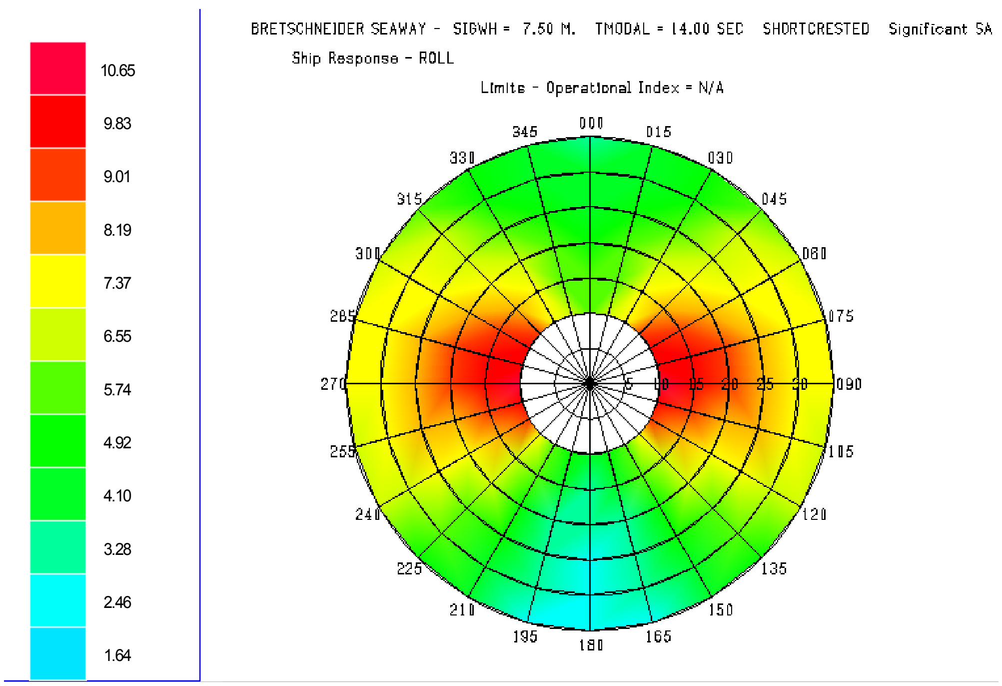


Figure 121 Cases 8, 20 Roll for Sonar and Personnel at Sea-State 7

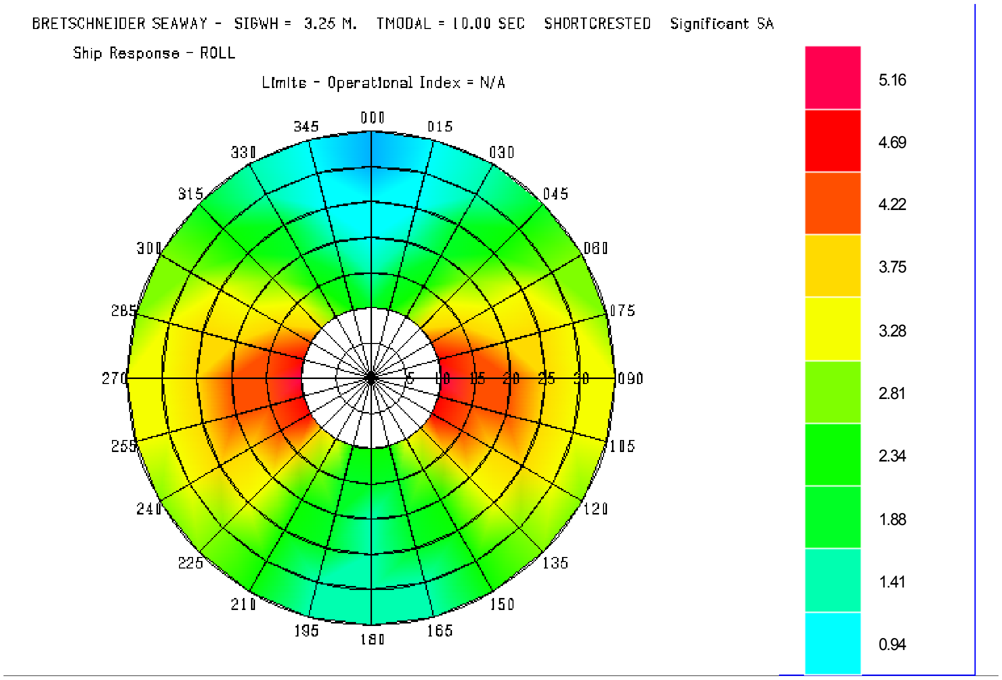


Figure 122 Cases 11, 14, 15 and 17 Roll for the Gun, Torpedo Launch, UNREP and Helo Operations at Sea-State 5

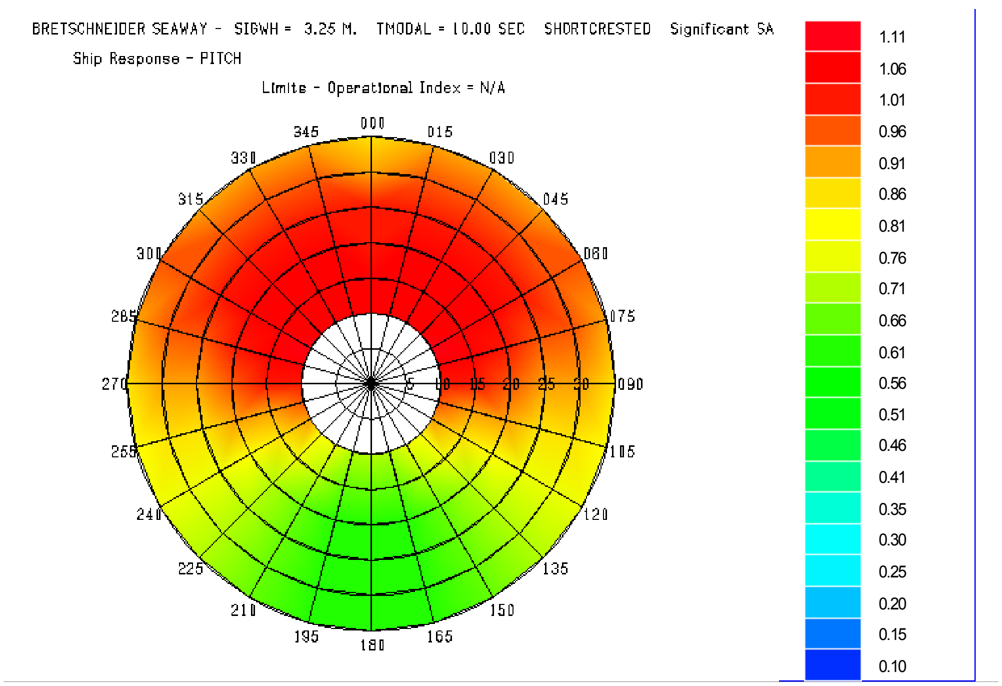


Figure 123 Cases 12 16, 18 Pitch for the Gun, UNREP, and Helo Operations at Sea-State 5

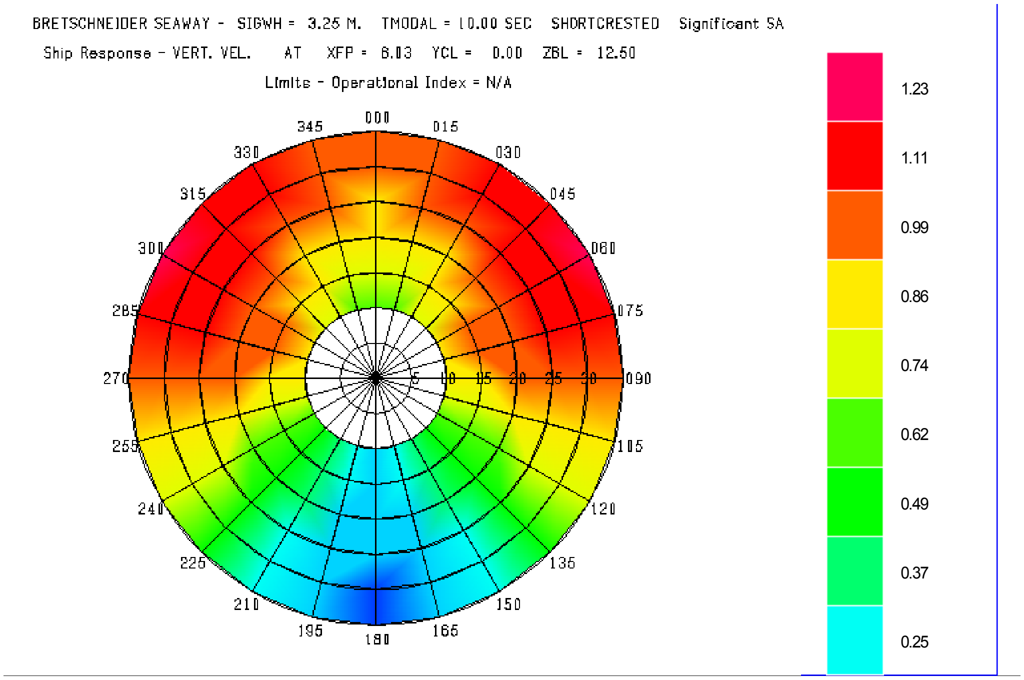


Figure 124 Cases 13 and 19 Vertical Velocity for the Gun and Helo Operations at Sea State 5

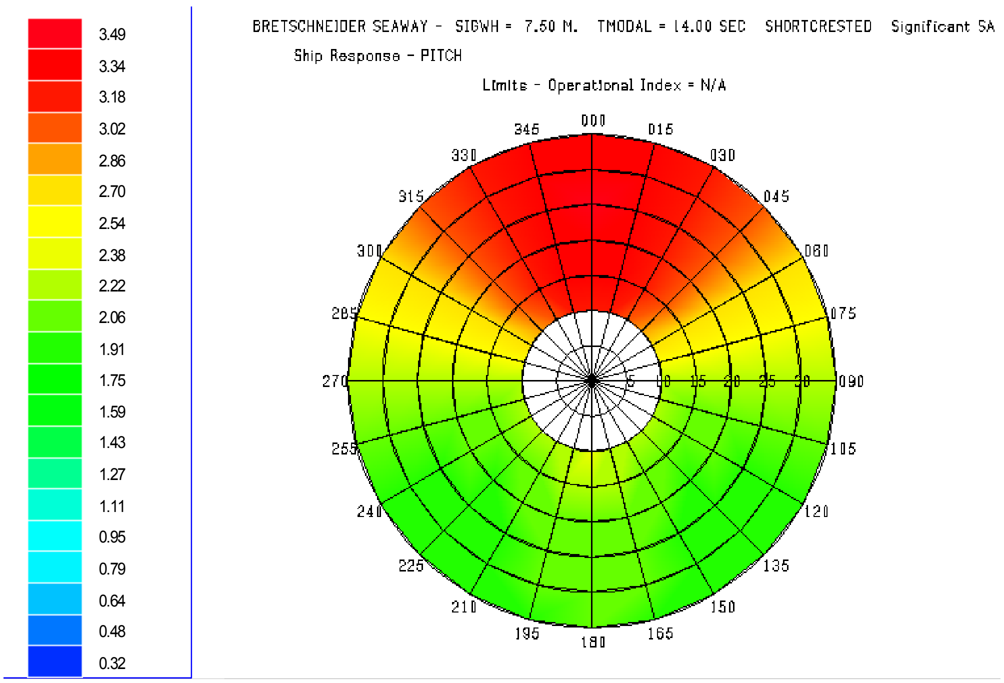


Figure 125 Case 21 Pitch for Personnel at Sea-State 7

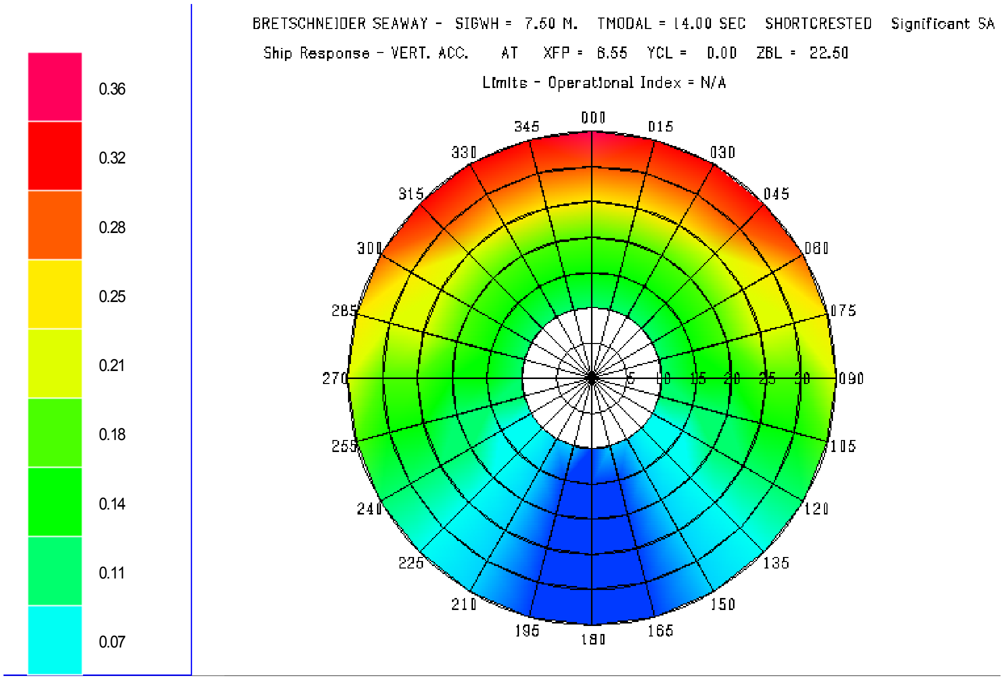


Figure 126 Case 22 Vertical Acceleration for Personnel at Sea-State 7

For each of the cases, the areas of operation can be seen below in Table 54.

Table 54 Seakeeping Limiting Criteria and Areas of Operation

Application	Sea State Threshold	Assessment
1. Bow Wetness (submergence/hr)	7	Limited to beam and following seas
2. Keel Slam (Slam/hr)	7	Limited to beam and following seas
3. VLS Launch (Roll)	6	Fully Operational
4. VLS Launch (Pitch)	6	Fully Operational
5. VLS Launch (Longitudinal Acceleration)	6	Fully Operational
6. VLS Launch (Lateral Acceleration)	6	Fully Operational
7. VLS Launch (Vertical Acceleration)	6	Fully Operational
8. Radar (Roll)	7	Fully Operational
9. Bow Sonar (Roll)	6	Fully Operational
10. Bow Sonar (Pitch)	6	Fully Operational
11. Gun (Roll)	5	Fully Operational
12. Gun (Pitch)	5	Fully Operational
13. Gun (Vertical Velocity)	5	Exceeds limit in head and beam seas of 20 knots
14. Torpedo Launch (Roll)	5	Fully Operational
15. UNREP (Roll)	5	Exceeds limit in beam seas less than 25 knots
16. UNREP (Pitch)	5	Fully Operational
17. Helo (Roll)	5	Fully Operational
18. Helo (Pitch)	5	Fully Operational
19. Helo (Vertical Velocity)	5	Fully Operational
20. Personnel (Roll)	7	Exceeds limit in beam seas less than 25 knots

21. Personnel (Pitch)	7	Exceeds limit in head seas
22. Personnel (Vertical Acceleration)	7	Fully Operational

4.12 Cost and Risk Analysis

As part of the multi-objective optimization performed, cost was estimated for both lead and follow ship using parametric mathematical models. These models use the estimates of weights for different SWBS groups, along with other variables to estimate a cost of basic construction. Other variables considered were ships service life, total number of ships produced, base fiscal year with accounted inflation, crew, and total engine power. Estimates for government costs, change orders, shipbuilder profit, and several other capital-consuming costs were added to determine final cost estimates. The total cost estimate and cost breakdown for the lead ship as well as the follow ship are shown in Table 55. The total government portion cost along with the breakdown of costs for the lead and follow ships are shown in Table 56. The total cost estimates along with a general breakdown of costs are shown in Table 57. The undiscounted vs. discounted costs for the life time of the ship are shown in Table 58.

Table 55

	Follow Ship Cost	Lead Ship Cost
SWBS	760.85	809.42
800	84.179	275.202
900	53.831	57.267
Total FS Construction	898.86	1141.89
Profit	89.886	114.189
Shipbuilder Price	988.75	1256
Change Orders	100.486	150.729
Total Shipbuilder Portion	1089.24	1406.729

Table 56

	Follow Ship Cost	Lead Ship Cost
Other Support	24.719	31.402
Programs Managers Growth	49.437	125.607
Payload GFE	1441	1549
HM&E GFE	19.775	25.121
Outfitting	39.55	50.243
Total Gov't Portion	1574.481	1781.373

Table 57

	Follow Ship Cost	Lead Ship Cost
Total Shipbuilder Portion	1089.24	1406.729
Total Gov't Portion	1574.481	1781.373
Total Lead Ship End Cost	2663.72	3188.102
Post Delivery Cost	49.437	62.804
Total Lead Ship Acquisition Cost	2713.15	3250.906
Average Ship Acquisition Cost	2630	

Table 58

	Undiscounted	Discounted
R&D Costs	2747	2,659
Investment	98,622	29,153
Operations and Support	122,000	5,911
Residual Value	5,070	19
Total	218,500	37,705

5 Conclusions and Future Work

5.1 Assessment

Table 59 - Compliance with Operational Requirements

Technical Performance Measure	CCD KPP (Threshold)	Original Goal	Improved Baseline	Final Baseline
AAW/BMD	AAW/SEW=3	AAW/SEW=1	3	3
ASUW/NSFS	ASUW=3	ASUW=1	2	2
C4ISR	C4I=2	C4I=1	2	2
Vs (Sustained Speed)	30	35	32	32
Ts (Provisions)	60	75	61	61
Vs (Sustained Speed)	30	35	32	32
Es (Endurance range at 20 kt)	4000	8000	4550	4550

5.2 Future Work

Adjust Preliminary Tankage and Structures
Adjust Arrangements
Damage Stability

5.3 Conclusions

This hybrid/tumblehome medium surface combatant is the best of all worlds when risk and cost are used as the primary sources motivating the ship design. The flared hull allows for a very stable ship in many different sea states because of the large beam at the waterline. Above the waterline a radar cross section reducing tumblehome was utilized so this ship has the best of all worlds. This MSC has fairly high lead ship costs, but its modularity capabilities allow it to perform effectively for the life of the ship making it well worth it. As new technologies become available they can be installed and utilized quickly.

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Appendix A – Initial Capabilities Document (ICD)

UNCLASSIFIED

INITIAL CAPABILITIES DOCUMENT

FOR A

Medium Surface Combatant (MSC)

1 PRIMARY JOINT FUNCTIONAL AREAS

- Force and Homeland Protection - The range of military application for this function includes: force protection and awareness at sea; and protection of homeland and critical bases from the sea.
- Intelligence, Surveillance and Reconnaissance (ISR) - The range of military application for this function includes: onboard sensors; and support of manned and unmanned air, surface and subsurface vehicles.
- Power Projection - The range of military application for this function includes strike warfare and naval surface fire support.

Operational timeframe considered: 2018-2070. This extended timeframe demands flexibility in upgrade and capability over time.

2 REQUIRED FORCE CAPABILITY(S)

- Provide air, surface and subsurface defense around friends, joint forces and critical bases of operations at sea including BMD (multi-mission).
- Provide a sea-based layer of homeland defense, particularly BMD.
- Provide persistent surveillance and reconnaissance.
- Provide strike and naval surface fire support.

These capabilities may be provided as a coordinated force, in support of a larger force, or individually with combinations of inherent multi-mission capabilities and tailored modular capabilities. Affordability is a critical issue which must enable sufficient force numbers to satisfy world-wide commitments consistent with national defense policy. In addition to providing necessary capabilities, rising acquisition, manning, logistics support, maintenance and energy costs must be addressed with a comprehensive plan including the application of new technologies, automation, modularity, and a necessary rational compromise of full multi-mission capabilities in all platforms.

3 CONCEPT OF OPERATIONS SUMMARY

Ballistic Missile Defense (BMD). Current Aegis ships are being configured to intercept short and medium-range BM threats, but can not counter long-range intercontinental ballistic missiles that could target the US from China, North Korea and Iran. Current ships are also fully multi-mission ships. The radar and missile capabilities of some future surface combatants must be greater than the Navy's current Aegis ships. Some multi-mission capabilities may have to be sacrificed to control cost. Conducting BMD operations may require MSCs to operate in a location that is unsuitable for performing one or more other missions. Conducting BMD operations may reduce the ability to conduct air-defense operations against aircraft and cruise missiles due to limits on ship radar capacity. BMD interceptors may occupy ship weapon-launch tubes that might otherwise be used for air-defense, land-attack, or antisubmarine weapons. Maintaining a standing presence of a BMD ship in a location where other Navy missions do not require deployment, and where there is no nearby U.S. home port, can require a total commitment of several ships, to maintain ships on forward deployment. Critical capabilities for BMD-capable ships include high-altitude long-range search and track (LRS&T), and missiles with robust ICBM BMD terminal, mid-course, and potentially boost-phase capability. A ship with both of these is considered an ICBM engage-capable ship. The extent of these capabilities will have a significant impact on the ship's Concept of Operations. BMD requirements may change over time.

Major Caliber Naval Surface Fire Support. There is a verified need for major caliber NSFS for the foreseeable future. DDG1000 was to provide this capability with the Advanced Gun System (AGS), but affordability issues may limit the number of these ships that can be built. An alternative strategy is required for placing one or two AGS on other MSCs, possibly as a modular system, and possibly without full multi-mission capability. These ships would operate with and ahead of marine amphibious task groups to prepare for and support marines operating from the sea.

CSGs, ESGs and SAGs. It is expected that MSCs will continue to operate with Carrier Strike Groups and Expeditionary (Amphibious) Strike Groups providing AAW, ASUW and ASW support. MSC Surface Action Groups (SAGs) will perform various ISR and Strike missions in addition to providing their own AAW, ASUW and ASW defense. ISR missions will include the use of autonomous air surface and subsurface vehicles and LAMPS.

Deployments will typically be have 6 month duration with underway replenishment, a few port visits, all-weather operations, cluttered air and shipping environments, blue water and littoral, and limited maintenance opportunities. MSCs will typically deploy and return to CONUS.

4 CAPABILITY GAP(S)

The overarching capability gap addressed by this ICD is to provide demanding surface combatant capabilities in affordable medium surface combatant (MSC) ships (8000-14000 MT). All capabilities may not be met in all MSCs at all times, but may be distributed over multiple ships at different times. Specific capability gaps and requirements include:

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	LRS&T Radar	SPY-3 X-band radar; S-Band VSR	SPY-3 X-band radar; large S-Band VSR
2	Missile Capacity	96 SM-3	192 SM-3
3	NSFS – Major Gun(s)	1 5in/62	2 AGS
4	Platform Mobility	30knt, full SS4, 4000 nm, 60 days	35knt, full SS5, 6000 nm, 75 days
5	Platform Passive Susceptibility	DDG-51 signatures	DDG1000 signatures
6	Platform Self and Area Defense, Other Multi-Mission	CIGS, LAMPS haven, TSCE, 5m passive sonar	IUSW, SOF and ASUW stern launch, CIGS, Embarked LAMPS/ AAV w/hangar, TSCE

5 THREAT AND OPERATIONAL ENVIRONMENT

Ballistic missiles armed with WMD payloads pose a strategic threat to the United States. This is not a distant threat. A new strategic environment now gives emerging ballistic missile powers the capacity, through a combination of domestic development and foreign assistance, to acquire the means to strike the U.S. within about five years of a decision to acquire such a capability. During several of those years, the U.S. might not be aware that such a decision had been made. Available alternative means of delivery can shorten the warning time of deployment nearly to zero. The threat is exacerbated by the ability of both existing and emerging ballistic missile powers to hide their activities from the U.S. and to deceive the U.S. about the pace, scope and direction of their development and proliferation programs.

Twenty-first-century threats to the United States, its deployed forces, and its friends and allies differ fundamentally from those of the Cold War. An unprecedented number of international actors have now acquired – or are seeking to acquire – ballistic and other types of missiles. These include not only states, but also non-state groups interested in obtaining missiles with nuclear or other payloads. The spectrum encompasses the missile arsenals already in the hands of Russia and China, as well as the emerging arsenals of a number of hostile states. The character of this threat has also changed. Unlike the Soviet Union, these newer missile possessors do not attempt to match U.S. systems, either in quality or in quantity. Instead, their missiles are designed to inflict major devastation without necessarily possessing the accuracy associated with the U.S. and Soviet nuclear arsenals of the Cold War.

The warning time that the United States might have before the deployment of such capabilities by a hostile state, or even a terrorist actor, is eroding as a result of several factors, including the widespread availability of technologies to build missiles and the resulting possibility that an entire system might be acquired. Would-be possessors do not have to engage in the protracted process of designing and building a missile. They could purchase and assemble components or reverse-engineer a missile after having purchased a prototype, or immediately acquire a number of assembled missiles. Even missiles that are primitive by U.S. standards might suffice for a rogue state or terrorist organization seeking to inflict extensive damage on the United States.

A successfully launched short or long range ballistic missile has a high probability of delivering its payload to its target compared to other means of delivery. Emerging powers therefore see ballistic missiles as highly effective deterrent weapons and as an effective means of coercing or intimidating adversaries, including the United States. The basis of most missile developments by emerging ballistic missile powers is the Soviet Scud missile and its derivatives. The Scud is derived from the World War II-era German V-2 rocket. With the external help now readily available, a nation with a well-developed, Scud-based ballistic missile infrastructure would be able to achieve first flight of a long range missile, up to and including intercontinental ballistic missile (ICBM) range (greater than 5,500 km), within about five years of deciding to do so. During several of those years the U.S. might not be aware that such a decision had been made. Early production models would probably be limited in number. They would be unlikely to meet U.S. standards of safety, accuracy and reliability. But the purposes of these nations would not require such standards. A larger force armed with scores of missiles and warheads and meeting higher operational standards would take somewhat longer to test, produce and deploy. But meanwhile, even a few of the simpler missiles could be highly effective for the purposes of those countries.

The extraordinary level of resources North Korea and Iran are now devoting to developing their own ballistic missile capabilities poses a substantial and immediate danger to the U.S., its vital interests and its allies. While these nations' missile programs may presently be aimed primarily at regional adversaries, they inevitably and inescapably engage the vital interests of the U.S. as well. Their targeted adversaries include key U.S. friends and allies. U.S. deployed forces are already at risk from these nations' growing arsenals. Each of these nations places a high priority on threatening U.S. territory, and each is even now pursuing advanced ballistic missile capabilities to pose a direct threat to U.S. territory.

Since many potentially unstable nations are located on or near geographically constrained (littoral) bodies of water, the tactical picture may be at smaller scales relative to open ocean warfare. Threats in such an environment include: (1) technologically advanced weapons - cruise missiles like the Silkworm and Exocet, land-launched attack aircraft, fast gunboats armed with guns and smaller missiles, and diesel-electric submarines; and (2) unsophisticated and inexpensive passive weapons – mines (surface, moored and bottom), chemical and biological weapons. Encounters may occur in shallow water which increases the difficulty of detecting and successfully prosecuting targets.

The sea-based environment includes:

- Open ocean (sea states 0 through 9) and littoral
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture
- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather

6 FUNCTIONAL SOLUTION ANALYSIS SUMMARY

a. Ideas for Non-Materiel Approaches (DOTMLPF Analysis).

- Increase reliance on foreign BMD support (Japan, etc.) to meet the interests of the U.S.

b. ***Ideas for Materiel Approaches***

- Army/Air Force BMD assets
- Design and build new large (25000 lton) nuclear CGNX for BMD and/or NSFS
- Design and build modified LPD-17 for BMD or NSFS
- Upgrade and extend service life of CG-52 ships with increased BMD or NSFS capability
- Design and build a scalable modular family of new BMD, NSFS, strike or CBG MSC ships with flexible multi-mission capabilities.
- Design and build new DDG or CGX BMD/NSFS ship with maximum DDG1000 commonality

7 FINAL RECOMMENDATIONS

a. Non-material solutions are not consistent with national policy.

b. The secondary mission for this ship is CBG AAW and escort. The LPD-17 option does not support CBG requirements.

c. CG-52 ships do not have sufficient stability, margin or large object space to support robust BMD radar and missile requirements.

d. A new DDG or CGX ship with maximum DDG1000 commonality or a CGNX are not affordable in sufficient numbers to support force requirements.

e. The option of a new scalable Medium Surface Combatant (MSC) ship with flexible BMD, NSFS, strike and multi-mission capability through modularity with different configurations of similar platforms should be explored. A full range of multi-mission options satisfying identified capability gaps from threshold to goal should be considered. Follow-ship acquisition cost should not exceed $2B ($FY2013). Trade-offs should be made based on total ownership cost (including cost of upgrade), effectiveness (including flexibility) and risk.

Appendix B– Acquisition Decision Memorandum (ADM)

Virginia Tech

Aerospace and Ocean Engineering

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

215 Randolph Hall
Mail Stop 0203, Blacksburg, Virginia 24061
Phone # 540-231-6611 Fax: 540-231-9632

August 24, 2009

From: Virginia Tech Naval Acquisition Executive
To: MSC Design Teams

Subject: ACQUISITION DECISION MEMORANDUM FOR a Medium Surface Combatant

Ref: (a) Virginia Tech MSC Initial Capabilities Document (ICD), 14 August 2009

1. This memorandum authorizes concept exploration of a single material alternative proposed in Reference (a) to the Virginia Tech Naval Acquisition Board on 14 August 2007. Additional material and non-material alternatives supporting this mission may be authorized in the future.

2. Concept exploration is authorized for a Medium Surface Combatant (MSC), 8000-14000 MT, consistent with the functional capabilities specified in Reference (a), with particular emphasis on life cycle affordability and flexible achievement of BMD, NSFS, strike and multi-mission capability through modularity with different configurations of similar platforms. A full range of multi-mission options satisfying identified capability gaps from threshold to goal should be considered. Affordability is a critical issue in order to enable sufficient force numbers to satisfy world-wide commitments consistent with national defense policy. Rising acquisition, manning, logistics support, maintenance and energy costs must be addressed with a comprehensive plan including the application of new technologies, automation, modularity, and a necessary rational compromise of full multi-mission capabilities in single ships.

3. Follow-ship acquisition cost should not exceed $2B ($FY2013) with a lead ship acquisition cost less than $3.0B. Trade-offs should be made based on total ownership cost (including cost of upgrade), effectiveness (including flexibility) and risk. It is expected that 30 ships of this type will be built with IOC in 2018, and a 40 year service life. This extended service life demands flexibility in upgrade and capability over time through modularity.

A.J. Brown
VT Acquisition Executive

Appendix C– Capabilities Development Document (CDD)

UNCLASSIFIED

CAPABILITY DEVELOPMENT DOCUMENT

FOR A

Medium Surface Combatant (MSC) VT Team 3

1 Capability Discussion.

The Initial Capabilities Document (ICD) for this CDD was issued by the Virginia Tech Acquisition Authority on 14 August 2009. These capabilities are provided as a coordinated force, in support of a larger force, or individually with combinations of inherent multi-mission capabilities and tailored modular capabilities. Affordability is a critical issue which must enable sufficient force numbers to satisfy world-wide commitments consistent with national defense policy. In addition to providing necessary capabilities, rising acquisition, manning, logistics support, maintenance and energy costs must be addressed with a comprehensive plan including the application of new technologies, automation, modularity, and a necessary rational compromise of full multi-mission capabilities in all platforms.

A significant capability gap addressed by the ICD is to provide a demanding surface combatant capabilities in affordable medium surface combatant (MSC) ships (8000-14000 MT). All capabilities may not be met in all MSCs at all times, but may be distributed over multiple ships at different times. Specific capability gaps and requirements in the MSC include:

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	LRS&T Radar	SPY-3 X-band radar; S-Band VSR	SPY-3 X-band radar; large S-Band VSR
2	Missile Capacity	96 SM-3	192 SM-3
3	NSFS – Major Gun(s)	1 5in/62	2 AGS
4	Platform Mobility	30 knt, full SS4, 4000 nm, 60 days	35 knt, full SS5, 6000 nm, 75 days
5	Platform Passive Susceptibility	DDG-51 signatures	DDG1000 signatures
6	Platform Self and Area Defense, Other Multi-mission	CIGS, LAMPS haven, TSCE, %m passive sonar	IUSW, SOF and ASUW stern launch, CIGS, Embarked LAMPS/AAV w/hanger, TSCE

2 Analysis Summary.

An Acquisition Decision Memorandum issued on 14 August 2009 by the Virginia Tech Acquisition Authority directed Concept Exploration for a Medium Surface Combatant (MSC), 8000-14000 MT, consistent with the functional capabilities specified in Reference (a), with particular emphasis on life cycle affordability and flexible achievement of BMD, NSFS, strike and multi-mission capability through modularity with different configurations of similar platforms. A full range of multi-mission options satisfying identified capability gaps from threshold to goal should be considered. Affordability is a critical issue in order to enable sufficient force numbers to satisfy world-wide commitments consistent with national defense policy. Rising acquisition, manning, logistics support, maintenance and energy costs must be addressed with a comprehensive plan including the application of new technologies, automation, modularity, and a necessary rational compromise of full multi-mission capabilities in single ships.

Concept Exploration was conducted from 2 September 2009 through 15 December 2009. A Concept Design and Requirements Review was conducted on 19 January 2010. This CDD presents the baseline requirements approved in this review.

Available technologies and concepts necessary to provide required functional capabilities were identified and defined in terms of performance, cost, risk and ship impact (weight, area, volume, power). Trade-off studies were performed using technology and concept design parameters to select trade-off options in a multi-objective genetic optimization (MOGO) for the total ship design. The result of this MOGO was a non-dominated frontier, Figure 1. This frontier includes designs with a wide range of risk and cost, each having the highest effectiveness for a given risk and cost. Preferred designs are often "knee in the curve" designs at the top of a large increase in effectiveness for a given cost and risk, or designs at high and low extremes. The design selected for Virginia Tech Team 3, and specified in this CDD, is a low-cost and low-risk design chosen from Figure 1. Selection of a point on the non-dominated frontier specifies requirements, technologies and the baseline design.

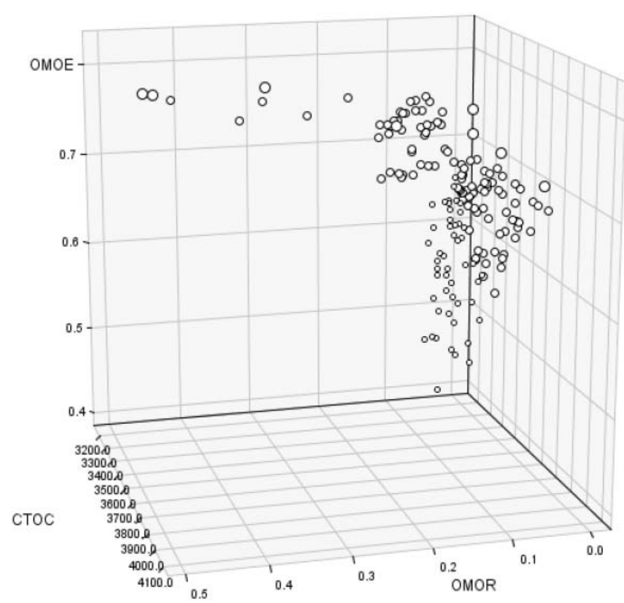

Figure 1 – MSC Non-Dominated Frontier

3 Concept of Operations Summary

Provide flexible BMD, NSFS, strike, and multi-mission capability through modularity with different configurations of similar platforms. Full capabilities may be provided in a coordinated force, in support of a larger force, or individually with combinations of inherent multi-mission capabilities and tailored modular capabilities.

CSGs, ESGs and SAGs. It is expected that MSCs will continue to operate with Carrier Strike Groups and Expeditionary (Amphibious) Strike Groups providing AAW, ASUW and ASW support. MSC Surface Action Groups (SAGs) will perform various ISR and Strike missions in addition to providing their own AAW, ASUW and ASW defense. ISR missions will include the use of autonomous air surface and subsurface vehicles and LAMPS.

Ballistic Missile Defense (BMD). Current Aegis ships are being configured to intercept short and medium-range BM threats, but can not counter long-range intercontinental ballistic missiles. Current ships are also fully multi-mission ships. The radar and missile capabilities of some future surface combatants must be greater than the Navy's current Aegis ships. Some multi-mission capabilities may have to be sacrificed to control cost. Conducting BMD operations may require MSCs to operate in a location that is unsuitable for performing one or more other missions. Conducting BMD operations may reduce the ability to conduct air-defense operations against aircraft and cruise missiles due to limits on ship radar capacity. BMD interceptors may occupy ship weapon-launch tubes that might otherwise be used for air-defense, land-attack, or antisubmarine weapons. Maintaining a standing presence of a BMD ship in a location where other Navy missions do not require deployment, and where there is no nearby U.S. home port, can require a total commitment of several ships, to maintain ships on forward deployment. Critical capabilities for BMD-capable ships include high-altitude long-range search and track (LRS&T), and missiles with robust ICBM BMD terminal, mid-course, and potentially boost-phase capability. A ship with both of these is considered an ICBM engage-capable ship. The extent of these capabilities will have a significant impact on the ship's Concept of Operations. BMD requirements may change over time.

Major Caliber Naval Surface Fire Support. There is a verified need for major caliber NSFS for the foreseeable future. DDG1000 was to provide this capability with the Advanced Gun System (AGS), but affordability issues may limit the number of these ships that can be built. An alternative strategy is required for placing one or two AGS on other MSCs, possibly as a modular system, and possibly without full multi-mission capability. These ships would operate with and ahead of marine amphibious task groups to prepare for and support marines operating from the sea.

Deployments will typically be have 6 month duration with underway replenishment, a few port visits, all-weather operations, cluttered air and shipping environments, blue water and littoral, and limited maintenance opportunities. MSCs will typically deploy and return to CONUS.

4 Threat Summary

Ballistic missiles armed with WMD payloads pose a strategic threat to the United States. This is not a distant threat. A new strategic environment now gives emerging ballistic missile powers the capacity, through a combination of domestic development and foreign assistance, to acquire the means to strike the U.S. within about five years of a decision to acquire such a capability. During several of those years, the U.S. might not be aware that such a decision had been made. Available alternative means of delivery can shorten the warning time of deployment nearly to zero. The threat is exacerbated by the ability of both existing and emerging ballistic missile powers to hide their activities from the U.S. and to deceive the U.S. about the pace, scope and direction of their development and proliferation programs. Twenty-first-century threats to the United States, its deployed forces, and its friends and allies differ fundamentally from those of the Cold War. An unprecedented number of international actors have now acquired – or are seeking to acquire – ballistic and other types of missiles. These include not only states, but also non-state groups interested in obtaining missiles with nuclear or other payloads. The spectrum encompasses the missile arsenals already in the hands of Russia and China, as well as the emerging arsenals of a number of hostile states. The character of this threat has also changed. Unlike the Soviet Union, these newer missile possessors do not attempt to match U.S. systems, either in quality or in quantity. Instead, their missiles are designed to inflict major devastation without necessarily possessing the accuracy associated with the U.S. and Soviet nuclear arsenals of the Cold War. The warning time that the United States might have before the deployment of such capabilities by a hostile state, or even a terrorist actor, is eroding as a result of several factors, including the widespread availability of technologies to build missiles and the resulting possibility that an entire system might be acquired. Would-be possessors do not have to engage in the protracted process of designing and building a missile. They could purchase and assemble components or reverse-engineer a missile after having purchased a prototype, or immediately acquire a number of assembled missiles. Even missiles that are primitive by U.S. standards might suffice for a rogue state or terroristorganization seeking to inflict extensive damage on the United States. A successfully launched short or long range ballistic missile has a high probability of delivering its payload to its target compared to other means of delivery. Emerging powers therefore see ballistic missiles as highly effective deterrent weapons and as an effective means of coercing or intimidating adversaries, including the United States. The basis of most missile developments by emerging ballistic missile powers is the Soviet Scud missile and its derivatives. The Scud is derived from the World War II-era German V-2 rocket. With the external help now readily available, a nation with a well-developed, Scud-based ballistic missile infrastructure would be able to achieve first flight of a long range missile, up to and including intercontinental ballistic missile (ICBM) range (greater than 5,500km), within about five years of deciding to do so. During several of those years the U.S. might not be aware that such a decision had been made. Early production models would probably be limited in number. They would beunlikely to meet U.S. standards of safety, accuracy and reliability. But the purposes of these nations would not require such standards. A larger force armed with scores of missiles and warheads and meeting higher operational standards would take somewhat longer to test, produce and deploy. But meanwhile, even a few of the simpler missiles could be highly effective for the purposes of those countries. The extraordinary level of resources North Korea and Iran are now devoting to developing their own ballistic missile capabilities poses a substantial and immediate danger to the U.S., its vital interests and its allies. While these nations' missile programs may presently be aimed primarily at regional adversaries, they inevitably and inescapably engage the vital interests of the U.S. as well. Their targeted adversaries include key U.S. friends and allies. U.S. deployed forces are already at risk from these nations' growing arsenals. Each of these nations places a high priority on threatening U.S. territory, and each is even now pursuing advanced ballistic missile capabilities to pose a direct threat to U.S. territory. Since many potentially unstable nations are located on or near geographically constrained (littoral) bodies of water, the tactical picture may be at smaller scales relative to open ocean warfare. Threats in such an environment include: (1) technologically advanced weapons - cruise missiles like the Silkworm and Exocet, land-launched attack aircraft, fast gunboats armed with guns and smaller missiles, and diesel-electric submarines; and (2) unsophisticated and inexpensive passive weapons – mines (surface, moored and bottom), chemical and biological weapons. Encounters may occur in shallow water which increases the difficulty of detecting and successfully prosecuting targets.

The sea-based environment includes:

- Open ocean (sea states 0 through 9) and littoral
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture
- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather

5 System Capabilities and Characteristics Required for the Current Development Increment.

Key Performance Parameter (KPP)	Development Threshold or Requirement
AAW	Volume Search Radar [S BAND], GLYCOL WATER COOLING SYSTEM FOR VSR, AN/SPY-3 MFR, GLYCOL WATER COOLING SYSTEM, AEGIS BMD 2014 COMBAT SYSTEM AND CIC, CIFF-SD, MK53 NULKA DECOY LAUNCHING SYSTEM, MK 36 SRBOC DECOY LAUNCHING SYSTEM, EWS - ACTIVE ECM - SLQ/32R, IRST - INFRARED SENSING & TRACKING
ASUW/NSFS	SPS-73 SURFACE SEARCH RADAR, SMALL ARMS AND PYRO STOWAGE, SMALL ARMS AMMO - 7.62MM + 50 CAL + PYRO, THERMAL IMAGING SENSOR SYSTEM – TISS, FLIR, GFCS, 3 X 30MM CIGS GUN, SWBS 187 2 X 30MM CIGS GUN FOUNDATION, 3 X CIGS SYSTEMS, 3 X CIGS HOIST EXTENTIONS, 3 X CIGS AMMO HOIST, 3 X CIGS CASE CAPTURE, 3 X 30MM CIGS GUN AMMO, 2 X 7M RHIB, 1X MK45 5IN/62 GUN, MK45 5IN AMMO - 600 RDS, MK45 5IN/62 GUN HY-80 ARMOR LEVEL II
ASW	MINEHUNTING SONAR, AN/SLQ-25 NIXIE, BATHYTHERMOGRAPH, TORPEDO DECOYS, 4X MK32 SVTT ON DECK, 6 X MK46 LIGHTWEIGHT ASW TORPEDOES
CCC	TOTAL SHIP COMPUTING ENVIR SYSTEM, ENHANCED RADIO/EXCOMM, TOMAHAWK WEAPON CONTROL SYSTEM, UNDERWATER COMMUNICATIONS, VISUAL & AUDIBLE SYSTEMS, SECURITY EQUIPMENT SYSTEMS
LAMPS	2X SH60R HANGAR UPPER LEVEL 17 X 15.7, 2X SH60R HANGAR LOWER LEVEL 17 X 15.7, DUAL HELO/UAV DET - FUEL SYSTEM, HNDLG/SUPPORT/MAINT/WKSP, RAST/RAST CONTROL, HANDLING/SERVICE/STOWAGE, MAGAZINE HANDLING, MAGAZINE 12-MK46 24-HELLFIRE 6-PENQUIN, VTUAV, 2X SH60R, SUPPORT/SPARES, SONOBOUY MAGAZINE STOWAGE, SONOBOUY MAGAZINE - 300 BUOYS - 88 MARKERS, SQQ-28 LAMPS MK III ELECTRONICS, LAMPS MKIII:AVIATION FUEL [JP-5]
SDS	SLQ-32(V) 3, SRBOC, NULKA, ESSM
GMLS	64 cells, MK 41 VLS
LCS Modules	Spartan, VTUAV
Hull	Flared Tumblehome
Power and Propulsion	4 x MT30, 13800 VAC, FPP 2 x LM500G, 2 x FPP
Endurance Range (nm)	3068 nm
Sustained Speed (knots)	34.1 knots
Endurance Speed (knots)	20 knots
Stores Duration (days)	61
Collective Protection System	full
Crew Size	91
RCS (m^3)	3459
Maximum Draft (m)	7.87
Vulnerability (Hull Material)	Steel
Ballast/fuel system	Clean, separate ballast tanks
Degaussing System	Yes
McCreight Seakeeping Index	15.5

KG margin (m)	19.53
Propulsion power margin (design)	10%
Propulsion power margin (fouling and seastate)	25% (0.8 MCR)
Electrical margins	5%
Net Weight margin (design and service)	10%

6 Program Affordability.

According to the ADM the average follow-ship acquisition cost shall not exceed $2.0B ($FY2012) with a lead ship acquisition cost less than $3.0B. It is expected that 30 ships of this type will be built with IOC in 2018, and a 40 year service life.

Appendix D – Machinery Equipment List (MEL)

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION	SWBS #	DIMENSIONS LxWxH (m)
System: Main Engines and Transmission							
1	4	PGM	RR MT30 and Generator	36MW	MMR	234	9.18 x 3.84 x 3.78
2	2	SPGM	GE LM500G and Generator	4MW	MMR	234	4.76 x 2.16 x 2.99
3	2	Shaft, Line	740 mm (OD)	-	various	243	0.74m D, 44 m port L, 93 m stbd L
4	6	Bearing, Line Shaft	Journal	740 mm Line Shaft	various	244	1 x .125 x .125
5	2	Unit, MGT Hydraulic Starting	HPU with Pumps and Reservior	14.8 m^3/hr @ 414 bar	MMR	556	2x2x2
6	4	Main Engine Exhaust Duct	RR MT30	141 kg/sec	MMR and up	234	8.7 m2
7	4	Main Engine Inlet Duct	RR MT30	9.14 m/sec	MMR and up	234	3.24 m2
8	2	Secondary Engine Exhaust Duct	GE LM500G	29 kg/sec	MMR and up	234	3.9 m2
9	2	Secondary Engine Inlet Duct	GE LM500G	6.10 m/sec	MMR and up	234	3.8 m2
10	2	Console, Main Control	Main Propulsion	NA	MMR Engineering Operation Station (EOS)	252	3x1x2
System: Power Generation and Distribution							
11	2	PRPLN Motor Module	MIL AIM 52T 15A	52 MW	MMR	234	8.02 x 4.73 x 4.37
12	6	Power Conversion Module	IPS PCM4-5000	5 MW	MMR	234	5.72 x 1.22 x 1.83
13	8	MMR and AMR ladders	Inclined ladders		MMR,AMR	600	1.0x2.0
14	4	MMR and AMR escape trunks	Vertical ladders with fire tight doors at each level		MMR, AMR	600	1.5x1.5
15	4	MN Machinery Space Fan	Supply	94762 m^3/hr	FAN ROOM	512	1.118 (H) x 1.384 (dia)
16	4	MN Machinery Space Fan	Exhaust	91644 m^3/hr	MMR	512	1.118 (H) x 1.384 (dia)
17	4	Aux Machinery Space Fan	Supply	61164 m^3/hr	FAN ROOM	512	1.092 (H) x 1.118 (dia)
18	4	Aux Machinery Space Fan	Exhaust	61164 m^3/hr	AMR	512	1.092 (H) x 1.118 (dia)

System: Salt Water Cooling							
19	2	Pump, Main Seawater Circ	Centrifugal, Vertical, Motor Driven	230 m^3/hr @ 2 bar	MMR	256	.622 x .622 x 1.511
System: Lube Oil Service and Transfer							
20	2	Assembly, MGT Lube Oil Storage and Conditioning	Includes Oil Storage and Cooler	NA	MMR	262	1.525 x 2.60 x 1.040
21	6	Strainer, Reduction Gear Lube Oil	Duplex	200 m^3/hr	MMR	262	1.68 x 1.073 x 1.105
22	3	Cooler, Reduction Gear Lube Oil	Plate Type	NA	MMR	262	2.362 x 2.57 x 1.067
23	2	Pump, Reduction Gear Lube Oil Service	Pos. Displacement, Horizontal, Motor Driven	200 m^3/hr @ 5 bar	MMR	262	2.337 x .660 x. 660
24	2	Purifier, Lube Oil	Centrifugal, Self Cleaning, Partial Discharge Type	1.1 m^3/hr	MMR	264	.830 x .715 x 1.180
25	2	Pump, Lube Oil Transfer	Pos. Displacement, Horizontal, Motor Driven	4 m^3/hr @ 5 bar	MMR	264	.699 x .254 x .254
System: Fuel Oil Service and Transfer							
26	2	Filter Separator, MGT Fuel	2-Stage, Static, 5 Micron	30 m^3/hr	MMR	541	1.6 (L) x.762 (dia)
27	2	Purifier, Fuel Oil	Self Cleaning, Centrifugal, Partial Discharge Type	7.0 m^3/hr	MMR	541	1.2 x 1.2 x 1.6
28	2	Pump, Fuel Transfer	Gear, Motor Driven	45.4 m^3/hr @ 5.2 bar	MMR	541	1.423 x .559 x .686
29	2	Fuel Oil Service Tanks			MMR		size for 4 hours at endurance speed
System: Air Conditioning and Refrigeration							
30	4	Air Conditioning Plants	150 Ton, Centrifugal Units	150 ton	AMR	514	2.353 x 1.5 x 1.5
31	4	Pump, Chilled Water	Centrifugal, Horizontal, Motor Driven	128 m^3/hr @4.1 bar	AMR	532	1.321 x .381 x .508
32	4	Refrig Plants, Ships Service	R-134a	4.3 ton	AMR	516	2.464 x .813 x 1.5
System: Salt Water: Firemain, Bilge, Ballast							
33	4	Pump, Fire	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	VARIOUS	521	2.490 x .711 x .864

34	2	Pump, Fire/Ballast	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	AMR	521	2.490 x .711 x .864
35	2	Pump, Bilge	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	MMR	529	1.651 x .635 x 1.702
36	2	Pump, Bilge/Ballast	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	AMR	529	1.651 x .635 x .737
37	2	Station, AFFF	Skid Mounted	227 m^3/hr @3.8 bar	above MMR	555	2.190 x 1.070 x 1.750
System: Potable Water							
38	2	Distiller, Fresh Water	Distilling Unit	76 m^3/day (3.2 m^3/hr)	AMR	531	2.794 x 3.048 x 2.794
39	2	Brominator	Proportioning	1.5 m^3/hr	AMR	531	.965 x .203 x .406
40	2	Brominator	Recirculation	5.7 m^3/hr	AMR	533	.533 x.356 x 1.042
41	2	Pump, Potable Water	Centrifugal, Horizontal, Motor Driven	22.7 m^3/hr @ 4.8 bar	AMR	533	.787 x .559 x .356
System: JP-5 Service and Transfer							
42	2	Pump, JP-5 Transfer	Rotary, Motor Driven	11.5 m^3/hr @ 4.1 bar	JP-5 PUMP ROOM	542	1.194 x.483 x .508
43	2	Pump, JP-5 Service	Rotary, Motor Driven	22.7 m^3/hr @ 7.6 bar	JP-5 PUMP ROOM	542	1.194 x .483 x .508
44	1	Pump, JP-5 Stripping	Rotary, Motor Driven	5.7 m^3/hr @ 3.4 bar	JP-5 PUMP ROOM	542	.915 x .381 x .381
45	2	Filter/Separ., JP-5 Transfer	Static, Two Stage	17 m^3/hr	JP-5 PUMP ROOM	542	.457 (L) x 1.321 (dia)
46	2	Filter/Separ., JP-5 Service	Static, Two Stage	22.7 m^3/hr	JP-5 PUMP ROOM	542	.407 (L) x 1.219 (dia)
System: Compressed Air							
47	2	Receiver, Starting Air	Steel, Cylindrical	2.3 m^3	MMR	551	1.067 (dia) x 2.185 (H)
48	3	Compressor, MP Air	Reciprocating Motor Driven, Water Cooled	80 m^3/hr FADY @ 30 bar	MMR	551	1.334 x .841 x .836
49	2	Receiver, Ship Service Air	Steel, Cylindrical	1.7 m^3	MMR	551	1.830 (H) x .965 (dia)
50	2	Receiver, Control Air	Steel, Cylindrical	1 m^3	MMR	551	3.421 (H) x .610 (dia)
51	2	Compressor, Air, LP Ship Service	Reciprocating, Rotary Screw	8.6 bar @ 194 SCFM	MMR	551	1.346 x 1.067 x 1.829
52	2	Dryer, Air	Refrigerant Type	250 SCFM	MMR	551	.610 x .864 x 1.473
System: Steering Gear Hydaulics							

53	2	Hydraulic Pump and Motor	Steering Gear		aft Steering Gear Room	561	0.5x0.8x0.8
54	1	Hydraulic Steering Ram	Steering Gear		aft Steering Gear Room	561	1.2x8.5x1.5
System: Environmental							
55	2	Pump, Oily Waste Transfer	Motor Driven	12.3 m^3/hr @ 7.6 bar	MMR	593	1.219 x .635 x .813
56	2	Separator, Oil/Water	Coalescer Plate Type	2.7 m^3/hr	MMR	593	1.321 x .965 x 1.473
57	1	Unit, Sewage Collection	Vacuum Collection Type w/ Pumps	28 m^3	SEWAGE TREATMENT ROOM	593	2.642 x 1.854 x 1.575
58	1	Sewage Plant	Biological Type	225 people	SEWAGE TREATMENT ROOM	593	1.778 x 1.092 x 2.007
59	1	Switchboard	IPS System	NA	MMR	234	3x1x2

Appendix E - Weights and Centers

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment
	FULL LOAD WEIGHT + MARGIN	16299.79	8.59	140015.65	103.36	1684730.91
	MINOP WEIGHT AND MARGIN	14215.29	9.36	133103.81	110.94	1577049.53
	LIGHTSHIP WEIGHT + MARGIN	13209.79	9.86	130206.84	104.14	1375683.52
	LIGHTSHIP WEIGHT	12008.90	9.86	118369.86	104.14	1250621.38
	MARGIN	1200.89	9.86	11836.99	104.14	125062.14
100	HULL STRUCTURES	5190.30	9.84	51085.92	99.58	516839.81
110	SHELL + SUPPORTS	1236.20	5.96	7367.75	94.56	116895.07
111	PLATING	913.30	6.18	5644.19	93.18	85101.29
114	SHELL APPENDAGES	66.90	2.18	145.84	129.50	8663.55
115	STANCHIONS	11.50	7.73	88.90	96.62	1111.13
116	LONG FRAMING	33.30	0.32	10.66	81.16	2702.63
117	TRANSV FRAMING	211.10	6.99	1475.59	91.06	19222.77
120	HULL STRUCTURAL BULKHDS	486.60	9.26	4505.92	94.86	46158.88
122	TRANSV STRUCTURAL BULKHDS	373.70	9.26	3460.46	94.86	35449.18
123	TRUNKS + ENCLOSERS	112.90	9.26	1045.45	94.86	10709.69
130	HULL DECKS	1222.50	13.15	16075.88	96.23	117641.18
131	MAIN DECK	501.70	12.95	6497.02	108.97	54670.25
132	2ND DECK	314.80	10.49	3302.25	106.10	33400.28
136	01 HULL DECK	406.00	15.46	6276.76	72.85	29577.10
140	HULL PLATFORMS/FLATS	402.40	6.44	2591.46	97.48	39225.95
141	1ST PLATFORM	236.40	7.59	1794.28	104.22	24637.61
142	2ND PLATFORM	166.00	4.79	795.14	87.89	14589.74
150	DECK HOUSE STRUCTURE	347.90	22.70	7897.33	105.53	36713.89
160	SPECIAL STRUCTURES	394.10	8.83	3479.90	114.54	45140.21
161	CASTING+FORGING+EQUIV WELDMT	168.90	4.95	836.06	137.44	23213.62
163	SEA CHESTS	7.20	2.66	19.15	96.62	695.66
164	BALLISTIC PLATING	129.70	9.92	1286.62	96.62	12531.61
167	HULL STRUCTURAL CLOSURES	52.20	11.81	616.48	96.62	5043.56
168	DKHS STRUCTURAL CLOSERS	18.90	22.70	429.03	105.53	1994.52
169	SPECIAL PURPOSE CLOSERS+STRUCT	17.30	16.87	291.85	96.62	1671.53
170	MASTS+KINGPOSTS+SERV PLATFORM	1.00	34.97	34.97	111.11	111.11
171	MASTS, TOWERS, TETRAPODS	1.00	34.97	34.97	111.11	111.11
180	FOUNDATIONS	854.50	7.96	6801.82	105.97	90551.37
182	PROPULSION PLANT FOUNDATIONS	426.90	3.80	1622.22	109.05	46553.45
183	ELECTRIC PLANT FOUNDATIONS	32.00	5.57	178.24	92.37	2955.84
184	COMMAND+SURVEILLANCE FDNS	66.10	18.53	1224.83	93.22	6161.84
185	AUXILIARY SYSTEMS FOUNDATIONS	149.00	11.04	1644.96	117.61	17523.89
186	OUTFIT+FURNISHING FOUNDATIONS	21.20	7.82	165.78	93.65	1985.38
187	ARMAMENT FOUNDATIONS	159.30	12.34	1965.76	96.50	15372.45
190	SPECIAL PURPOSE SYSTEMS	245.10	9.51	2330.90	99.56	24402.16
196	MILL TOLERANCE	159.40	9.86	1571.68	99.56	15869.86
197	WELDING AND RIVETS	75.20	9.86	741.47	99.56	7486.91
198	FREE FLOODING LIQUIDS	10.60	1.68	17.81	99.56	1055.34
200	PROPULSION PLANT	2252.90	7.47	16840.16	112.37	253154.06

230	PROPULSION UNITS	1297.20	5.45	7073.35	100.05	129785.10
234	GAS TURBINES	217.00	6.96	1510.32	100.30	21765.10
235	ELECTRIC PROPULSION	1080.20	5.15	5563.03	100.00	108020.00
240	TRANSMISSION+PROPULSOR SYSTEMS	484.60	2.69	1302.30	157.26	76208.88
243	SHAFTING	291.60	2.75	801.90	152.84	44568.14
244	SHAFT BEARINGS	91.60	3.26	298.62	140.42	12862.47
245	PROPULSORS	101.40	1.99	201.79	185.19	18778.27
250	SUPPORT SYSTEMS, UPTAKES	431.60	19.04	8217.74	101.18	43671.02
251	COMBUSTION AIR SYSTEM	129.10	18.23	2353.49	96.83	12500.75
252	PROPULSION CONTROL SYSTEM	39.00	10.05	391.95	100.30	3911.70
256	CIRC+COOL SEA WATER SYSTEM	6.30	5.57	35.09	121.74	766.96
259	UPTAKES (INNER CASTING)	257.20	21.14	5437.21	103.00	26491.60
260	PROPUL SUP SYS- FUEL, LUBE OIL	9.40	4.88	45.87	12.38	116.33
264	LUBE OIL HANDLING	9.40	4.88	45.87	12.38	116.33
290	SPECIAL PURPOSE SYSTEMS	30.10	6.67	200.89	112.05	3372.74
298	OPERATING FLUIDS	19.10	2.44	46.60	115.94	2214.45
299	REPAIR PARTS + TOOLS	11.10	13.90	154.29	104.35	1158.29
300	ELECTRIC PLANT, GENERAL	853.40	9.17	7828.02	101.63	86734.60
310	ELECTRIC POWER GENERATION	162.30	6.22	1009.88	92.31	14982.41
311	SHIP SERVICE POWER GENERATION	160.20	6.18	990.04	92.37	14797.67
313	BATTERIES +SERVICE FACILITIES	2.00	9.92	19.84	92.37	184.74
320	POWER DISTRIBUTION SYS	612.90	9.51	5829.84	102.63	62897.90
321	SHIP SERVICE POWER CABLE	570.50	9.35	5334.18	102.41	58424.91
323	CASUALTY POWER CABLE SYS	8.60	12.28	105.61	102.41	880.73
324	SWITCHGEAR+PANELS	33.80	11.54	390.05	106.28	3592.26
330	LIGHTING SYSTEM	60.20	14.71	885.35	101.44	6106.41
331	LIGHTING DISTRIBUTION	29.80	14.02	417.80	102.41	3051.82
332	LIGHTING FIXTURES	30.40	15.38	467.55	100.48	3054.59
390	SPECIAL PURPOSE SYS	18.00	5.72	102.96	152.66	2747.88
399	REPAIR PARTS+SPECIAL TOOLS	18.00	5.72	102.96	152.66	2747.88
400	COMMAND+SURVEILLANCE	725.90	18.46	13399.37	92.75	67328.85
410	COMMAND+CONTROL SYS	91.00	9.66	878.84	95.00	8645.00
411	DATA DISPLAY GROUP	17.60	14.36	252.74	95.00	1672.00
412	DATA PROCESSING GROUP	73.40	8.53	626.10	95.00	6973.00
420	NAVIGATION SYS	24.20	23.59	570.88	85.00	2057.00
421	NON-ELECTRIC NAVIGATION AIDS	2.00	23.59	47.18	85.00	170.00
422	ELECTRICAL NAVIGATION AIDS	8.00	23.59	188.72	85.00	680.00
423	ELECTRICAL NAVIG AIDS, RADIO	2.20	23.59	51.90	85.00	187.00
424	ELECTRICAL NAVIG AIDS, ACOUSTIC	1.60	23.59	37.74	85.00	136.00
426	ELECTRICAL NAVIGATION SYS	8.00	23.59	188.72	85.00	680.00
427	INTERNAL NAVIGATION SYSTEM	2.40	23.59	56.62	85.00	204.00
428	NAVIGATION CONTROL MONITORING	0.00	23.59	0.00	85.00	0.00
430	INTERIOR COMMUNICATIONS	74.60	12.50	932.50	86.86	6479.76
431	SWITCHBOARDS FOR I.C. SYSTEMS	7.50	12.50	93.75	84.00	630.00
432	TELEPHONE SYSTEMS	23.10	12.50	288.75	87.60	2023.56
433	ANNOUNCING SYSTEMS	14.20	12.50	177.50	81.87	1162.55
434	ENTERTAINMENT + TRAINING SYS	6.00	12.50	75.00	90.24	541.44
435	VOICE TUBES+MESSAGE PASSING SYS	0.30	12.50	3.75	47.23	14.17
436	ALARM, SAFETY, WARNING SYSTEMS	11.20	12.50	140.00	92.91	1040.59

437	INDICATING, ORDER, METERING SYS	10.40	12.50	130.00	99.74	1037.30
438	INTEGRATED CONTROL SYSTEMS	1.50	12.50	18.75	53.10	79.65
439	RECORDING + TELEVISION SYSTEMS	0.40	12.50	5.00	82.44	32.98
440	EXTERIOR COMMUNICATIONS	55.10	25.20	1388.52	96.62	5323.76
441	RADIO SYSTEMS	51.00	26.77	1365.27	93.00	4743.00
442	UNDERWATER SYSTEMS	2.90	4.24	12.30	96.62	280.20
443	VISUAL + AUDIBLE SYSTEMS	0.30	10.00	3.00	96.62	28.99
446	SECURITY EQUIPMENT SYSTEMS	0.90	8.19	7.37	96.62	86.96
450	SURF SURVEILLANCE SYS (RADAR)	336.70	23.75	7996.73	96.62	32531.95
451	SURFACE SEARCH RADAR	0.20	24.49	4.90	96.62	19.32
452	AIR SEARCH RADAR	0.30	26.28	7.88	96.62	28.99
455	INDENTIFICATION SYSTEMS	4.50	31.68	142.56	96.62	434.79
456	MULTIPLE MODE RADAR	331.70	23.64	7841.39	96.62	32048.85
460	UNDERWATER SURVEILLANCE SYSTEMS	8.20	4.24	34.76	55.38	454.11
462	PASSIVE SONAR	2.10	-1.04	-2.18	96.62	202.90
465	BATHYTHERMOGRAPH	2.60	14.21	36.95	96.62	251.21
470	COUNTERMEASURES	96.20	11.12	1069.45	83.42	8024.88
471	ACTIVE + ACTIVE/PASSIVE ECM	9.90	16.86	166.91	96.62	956.54
473	TORPEDO DECOYS	8.80	9.97	87.74	96.62	850.26
475	DEGAUSSING	77.60	10.50	814.80	80.13	6218.09
480	FIRE CONTROL SYS	6.50	13.15	85.48	96.62	628.03
481	GUN FIRE CONTROL SYSTEMS	0.80	13.63	10.90	95.00	76.00
482	MISSILE FIRE CONTROL SYSTEMS	5.70	13.08	74.56	96.62	550.73
490	SPECIAL PURPOSE SYS	33.40	13.24	442.22	95.34	3184.36
491	ELCTRNC TEST, CHKOUT, MONITR EQPT	13.10	17.75	232.53	94.41	1236.77
493	NON-COMBAT DATA PROCESSING SYS	9.70	7.10	68.87	97.29	943.71
499	REPAIR PARTS + SPECIAL TOOLS	10.70	13.28	142.10	94.70	1013.29
500	AUXILIARY SYSTEMS, GENERAL	1551.60	11.00	17072.06	108.40	168188.17
510	CLIMATE CONTROL	283.90	14.77	4192.33	99.85	28347.86
511	COMPARTMENT HEATING SYSTEM	15.10	14.76	222.88	106.28	1604.83
512	VENTILATION SYSTEM	148.60	16.55	2459.33	96.00	14265.60
513	MACHINERY SPACE VENT SYSTEM	47.30	16.09	761.06	100.00	4730.00
514	AIR CONDITIONING SYSTEM	70.80	10.32	730.66	106.28	7524.62
516	REFRIGERATION SYSTEM	1.80	8.55	15.39	106.28	191.30
517	AUX BOILERS+OTHER HEAT SOURCES	0.30	10.07	3.02	105.00	31.50
520	SEA WATER SYSTEMS	195.00	9.30	1812.95	106.28	20724.60
521	FIREMAIN+SEA WATER FLUSHING SYS	132.40	9.86	1305.46	106.28	14071.47
523	WASHDOWN SYSTEM	7.40	21.34	157.92	106.28	786.47
526	SCUPPERS+DECK DRAINS	0.70	18.20	12.74	106.28	74.40
528	PLUMBING DRAINAGE	8.80	11.22	98.74	106.28	935.26
529	DRAINAGE+BALLASTING SYSTEM	45.70	5.21	238.10	106.28	4857.00
530	FRESH WATER SYSTEMS	214.40	15.54	3331.23	100.09	21458.85
531	DISTILLING PLANT	3.20	7.83	25.06	106.28	340.10
532	COOLING PLANT	146.30	18.94	2770.92	106.28	15548.76
533	POTABLE WATER	23.40	11.25	263.25	50.00	1170.00
534	AUX STEAM + DRAINS IN MACH BOX	41.40	6.57	272.00	106.28	4399.99
540	FUELS/LUBRICANTS,HANDLING+STORAGE	119.30	6.71	800.91	119.58	14266.16
541	SHIP FUEL+COMPENSATING SYSTEM	76.00	7.40	562.40	103.00	7828.00
542	AVIATION+GENERAL PURPOSE FUELS	42.00	5.62	236.04	150.00	6300.00
545	TANK HEATING	1.30	1.90	2.47	106.28	138.16
550	AIR,GAS+MISC FLUID SYSTEM	177.60	10.67	1894.16	106.28	18875.33

551	COMPRESSED AIR SYSTEM	83.10	9.50	789.45	106.28	8831.87
555	FIRE EXTINGUISHING SYSTEM	94.50	11.69	1104.71	106.28	10043.46
560	SHIP CNTL SYS	191.80	5.40	1035.72	190.41	36520.64
561	STEERING+DIVING CNTL SYS	57.50	8.52	489.90	180.00	10350.00
562	RUDDER	134.30	4.07	546.60	190.41	25572.06
570	UNDERWAY REPLENISHMENT SYSTEMS	44.50	12.10	538.26	94.53	4206.52
571	REPLENISHMENT-AT-SEA SYSTEMS	28.30	11.83	334.79	106.28	3007.72
572	SHIP STORES+EQUIP HANLING SYS	16.20	12.56	203.47	74.00	1198.80
580	MECHANICAL HANDLING SYSTEMS	177.20	11.30	2002.30	45.54	8069.40
581	ANCHOR HANDLING+STOWAGE SYSTEMS	110.00	9.27	1019.70	33.00	3630.00
582	MOORING+TOWING SYSTEMS	26.80	15.13	405.48	33.00	884.40
583	BOATS,HANDLING+STOWAGE SYSTEMS	14.50	15.11	219.10	30.00	435.00
588	AIRCRAFT HANDLING, SERVICE, STOWAGE	26.00	13.77	358.02	120.00	3120.00
590	SPECIAL PURPOSE SYSTEMS	147.90	9.90	1464.21	106.28	15718.81
593	ENVIRONMENTAL POLLUTION CNTL SYS	20.00	5.58	111.60	106.28	2125.60
598	AUX SYSTEMS OPERATING FLUIDS	110.70	10.80	1195.56	106.28	11765.20
599	AUX SYSTEMS REPAIR PARTS+TOOLS	17.10	9.15	156.47	106.28	1817.39
600	OUTFIT+FURNISHING,GENERAL	961.90	7.80	7498.29	96.35	92679.03
610	SHIP FITTINGS	26.10	2.62	68.38	125.15	3266.42
611	HULL FITTINGS	7.50	9.16	68.70	106.32	797.40
612	RAILS, STANCHIONS+LIFELINES	16.30			137.36	2238.97
613	RIGGING+CANVAS	2.30			99.10	227.93
620	HULL COMPARTMENTATION	197.40	9.87	1948.34	93.36	18429.26
621	NON-STRUCTURAL BULKHEADS	80.60	13.35	1076.01	85.48	6889.69
622	FLOORS PLATES+GRATING	80.50	6.70	539.35	103.97	8369.59
623	LADDERS	15.10	7.24	109.32	90.85	1371.84
624	NON-STRUCTURAL CLOSURES	16.30	13.28	216.46	84.46	1376.70
625	AIRPORTS, FIXED PORTLTS, WINDOWS	4.90	1.52	7.45	86.00	421.40
630	PRESERVATIVES+COVERING	442.60	7.22	3195.57	89.59	39652.53
631	PAINTING	129.50	5.61	726.50	94.53	12241.64
633	CATHODIC PROTECTION	5.80	2.13	12.35	100.87	585.05
634	DECK COVERINGS	101.80	7.71	784.88	87.78	8936.00
635	HULL INSULATION	172.60	8.67	1496.44	94.29	16274.45
636	HULL DAMPING	14.90	2.05	30.55		0.00
637	SHEATHING	12.10	9.38	113.50	89.15	
638	REFRIGERATION SPACES	5.80	5.75	33.35	92.06	
640	LIVING SPACES	25.20	7.93	199.72	87.56	2206.52
641	OFFICER BERTHING+MESSING	10.60	9.94	105.36	95.00	1007.00
642	NON-COMM OFFICER B+M	5.30	7.73	40.97	85.00	450.50
643	ENLISTED PERSONNEL B+M	6.80	5.40	36.72	70.00	476.00
644	SANITARY SPACES+FIXTURES	1.40	7.24	10.14	84.30	118.02
645	LEISURE+COMMUNITY SPACES	1.00	6.53	6.53	155.00	155.00
650	SERVICE SPACES	8.00	7.23	57.87	81.72	653.77
651	COMMISSARY SPACES	4.20	7.24	30.41	92.39	388.04
652	MEDICAL SPACES	1.10	8.17	8.99	65.00	71.50
654	UTILITY SPACES	0.50	8.24	4.12	81.47	40.74
655	LAUNDRY SPACES	1.90	5.97	11.34	65.00	123.50
656	TRASH DISPOSAL SPACES	0.40	7.53	3.01	75.00	30.00
660	WORKING SPACES	91.90	7.37	677.40	128.42	11801.49
661	OFFICES	10.10	7.74	78.17	155.00	1565.50
662	MACH CNTL CENTER FURNISHING	3.10	7.24	22.44	92.39	286.41

663	ELECT CNTL CENTER FURNISHING	4.00	9.59	38.36	61.72	246.88
664	DAMAGE CNTL STATIONS	33.20	7.78	258.30	96.00	3187.20
665	WORKSHOPS, LABS, TEST AREAS	41.50	6.75	280.13	157.00	6515.50
670	STOWAGE SPACES	160.70	8.02	1288.81	96.62	15526.83
671	LOCKERS+SPECIAL STOWAGE	21.80	11.72	255.50	96.62	2106.32
672	STOREROOMS+ISSUE ROOMS	138.90	7.44	1033.42	96.62	13420.52
690	SPECIAL PURPOSE SYSTEMS	10.00	6.22	62.20	114.22	1142.20
698	OPERATING FLUIDS	0.50	7.62	3.81	80.06	40.03
699	REPAIR PARTS + SPECIAL TOOLS	9.50	6.14	58.33	116.10	1102.95
700	ARMAMENT	472.90	11.07	4646.03	95.85	472.90
710	GUNS+AMMUNITION	220.20	8.74	1924.35	57.25	12606.00
711	GUNS	72.40	17.11	1238.76	75.00	5430.00
712	AMMUNITION HANDLING	110.40	6.21	685.58	65.00	7176.00
720	MISSLES+ROCKETS	220.40	11.14	2455.61	60.00	13218.00
721	LAUNCHING DEVICES	220.10	11.13	2449.71	60.00	13206.00
722	MISSILE+ROCKET, GUID CAP HAND SYS	0.20	29.46	5.89	60.00	12.00
750	TORPEDOES	5.50	13.37	73.54	0.00	0.00
760	SMALL ARMS+PYROTECHNICS	9.10	4.95	45.02	21.31	193.96
761	SMALL ARMS+PYRO LAUNCHING DEV	1.00	14.07	14.07	50.28	50.28
763	SMALL ARMS+PYRO STOWAGE	2.20	14.07	30.95	65.31	143.68
790	SPECIAL PURPOSE SYSTEMS	17.70	8.33	147.52	82.47	1459.78
798	ARMAMENT OPERATING FLUIDS	5.30	11.62	61.59	23.36	123.81
799	ARMAMENT REPAIR PART+TOOLS	12.40	6.93	85.93	107.74	1335.98
	FULL LOAD CONDITION					
F00	LOADS	3090.00	3.17	9808.80	91.49	282712.19
F10	SHIPS FORCE	12.30	11.30	138.99	90.82	1117.09
F11	OFFICERS	4.20	11.30	47.46	90.82	381.44
F12	NON-COMMISSIONED OFFICERS	3.40	11.30	38.42	90.82	308.79
F13	ENLISTED MEN	4.70	11.30	53.11	90.82	426.85
F20	MISSION RELATED EXPENDABLES+SYS	393.40	10.52	4138.57	96.62	38010.31
F21	SHIP AMMUNITION	262.30	9.50	2491.85	65.00	17049.50
F23	ORD DEL SYS (AIRCRAFT)	14.10	13.46	189.79	120.00	1692.00
F30	STORES	21.40	11.42	244.40	69.91	1496.00
F31	PROVISIONS+PERSONNEL STORES	17.90	11.43	204.67	65.00	1163.50
F32	GENERAL STORES	3.50	11.35	39.74	95.00	332.50
F40	LIQUIDS, PETROLEOM BASED	2647.50	1.98	5229.40	91.03	241010.80
F41	DIESEL FUEL MARINE	2565.90	2.00	5131.80	90.00	230931.00
F42	JP-5	65.40	1.00	65.40	130.00	8502.00
F46	LUBRICATING OIL	16.10	2.00	32.20	98.00	1577.80
F50	LIQUIDS, NON-PETRO BASED	15.40	3.73	57.44	70.00	1078.00
F52	FRESH WATER	15.40	3.73	57.44	70.00	1078.00
	MINIMUM OPERATING CONDITION					
F00	LOADS	1005.50	2.88	2896.96	100.13	100683.01
F10	SHIPS FORCE	12.30	11.30	138.99	90.82	1117.09
F11	OFFICERS	4.20	11.30	47.46	90.82	381.44
F12	NON-COMMISSIONED OFFICERS	3.40	11.30	38.42	90.82	308.79
F13	ENLISTED MEN	4.70	11.30	53.11	90.82	426.85
F20	MISSION RELATED EXPENDABLES+SYS	92.13	9.70	893.88	96.62	8901.92

F21	SHIP AMMUNITION	87.43	9.50	830.62	96.62	8447.81
F23	ORD DEL SYS (AIRCRAFT)	4.70	13.46	63.26	96.62	454.11
F30	STORES	7.13	11.42	81.47	110.00	784.67
F31	PROVISIONS+PERSONNEL STORES	5.97	11.43	68.22	110.00	656.33
F32	GENERAL STORES	1.17	11.35	13.25	110.00	128.33
F40	LIQUIDS, PETROLEOM BASED	883.67	1.97	1744.33	100.43	88750.00
F41	DIESEL FUEL MARINE	855.30	2.00	1710.60	100.00	85530.00
F42	JP-5	23.00	1.00	23.00	105.00	2415.00
F46	LUBRICATING OIL	5.37	2.00	10.73	150.00	805.00
F47	SEA WATER	0.00	0.00	0.00	0.00	0.00
F50	LIQUIDS, NON-PETRO BASED	10.27	3.73	38.29	110.00	1129.33
F52	FRESH WATER	10.27	3.73	38.29	110.00	1129.33

Appendix F – SSCS Space Summary