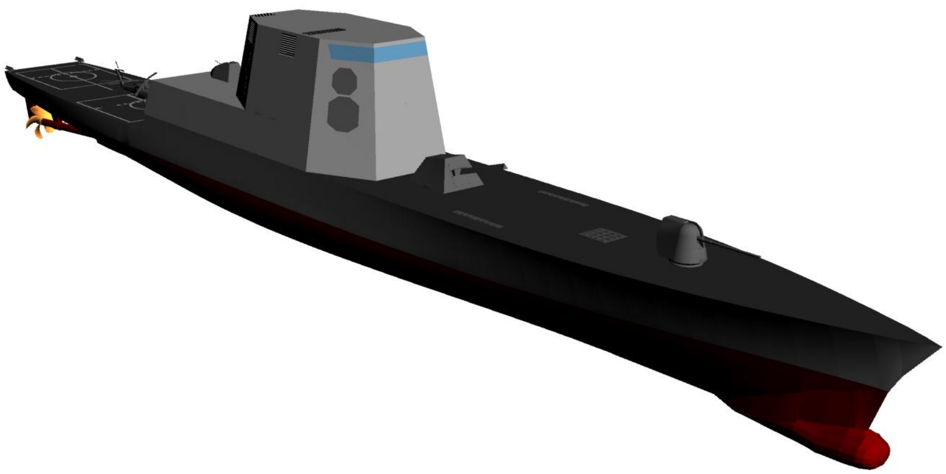
Design Report

Medium Surface Combatant (MSC)



MSC Variant 163
Ocean Engineering Design Project
AOE 4065/4066
Fall 2009 – Spring 2010
Virginia Tech Team 2

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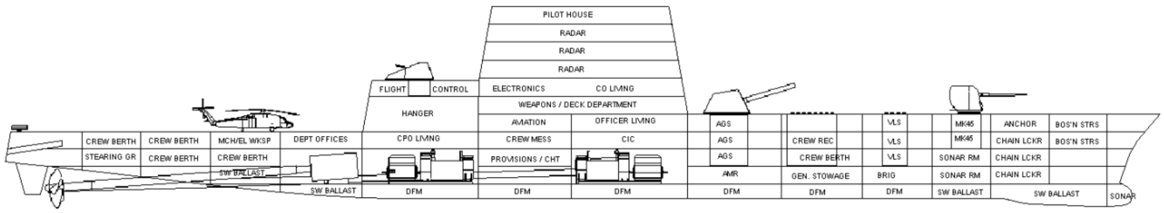
Executive Summary



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

The MSC requirement is based on the MSC Initial Capabilities Document (ICD) and the MSC Acquisition Decision Memorandum.

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 variant 163 is a medium cost, medium risk, and highly effective alternative on the non-dominated frontier.

MCS will address the need for a ship that deals with long range ICBM defense. MSC's ability to adapt to changing mission types will be aided by its large power plant and its full IPS. MSC will provide air, surface, and subsurface defense at sea for joint for friends, joint forces, and critical bases of operation. The ship will also provide the ability for continued surveillance and reconnaissance as well as for a sea-based layer of homeland defense. MSC will also have capabilities to provide to strike and naval surface fire support.

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 improved baseline design satisfies critical operational requirements in the CDD within cost and risk constraints.

Ship Characteristic	Value
LWL	192.059 m
Beam	23 m
Draft	7.93 m
D10	13.1787 m
Lightship weight	13797.716 MT
Full load weight	17876.2 MT
Sustained Speed	32.0107 knots
Endurance Range	6843.845 nm
Propulsion and Power	Full IPS, 2xFPP
BHP	115880 kW
Personnel	174
OMOE (Effectiveness)	0.795668
OMOR (Risk)	0.4440841
Ship Acquisition Cost	$2349 M
Life-Cycle Cost	$3682 M
AAW/BMD/STK	SPY3/VSR+ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA
ASUW	MK110 57mm gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS
CCC	Enhanced CCC, TSCE
GMLS system Alternative	4x4 MK57 VLS or 1xAGS (or rail gun, or directed energy), 64xMK57 PVLS or VLS, Tomahawk WCS

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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 the VirginiaTech 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. The MSC must remain affordable and flexible throughout its expected lifecycle. Several multi-mission capabilities are assessed and achieved through modularity with different configurations of similar MSC platforms. These mission capabilities include Ballistic Missile Defense (BMD), Naval Surface Fire Support (NSFS), and strike operations. The MSC platform must remain adaptable to the application of new technologies and automation to satisfy identified capability gaps in the current and future fleet. An extended 30 year service life is required with demands of flexibility and upgraded capability. The acquisition cost of a single MSC should not exceed $2.4 billion with a lead ship acquisition cost less than $3.6 billion.

1.2 Design Philosophy, Process, and Plan

The design philosophy for the development of MSC is to:

- Provide a consistent format and methodology for making affordable multi-objective acquisition decisions and trade-offs in non-dominated design space.
- Provide practical and quantitative methods for measuring mission effectiveness.
- Provide practical and quantitative methods for measuring risk.
- Provide an efficient and robust method to search design space for optimal concepts – Multi-Objective Genetic Optimization (MOGO).
- Provide an effective framework for transitioning and refining concept development in a multidisciplinary design optimization (MDO).
- Use the results of first-principle analysis codes at earlier stages of design.
- Consider designs and requirements together.
- Initially, consider a very broad range of designs, requirements, cost and risk.

The project begins with Concept Exploration where a very broad range of technologies and ship characteristics are considered as illustrated in Figure 1. The broad design space was narrowed using a multi-objective genetic optimization (MOGO) considering cost, effectiveness and risk. At the completion of the MOGO, an initial baseline design was selected from the non-dominated designs identified by the optimization. Finally the design is developed with added detail in a traditional design spiral process.

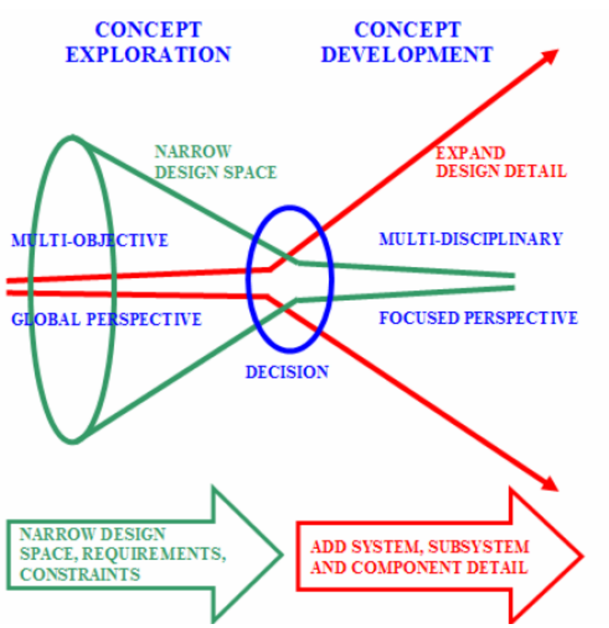


Figure 1: Design Philosophy

Figure 2 shows the process used for Concept Exploration in the MSC design. A detailed mission description was developed from the IRD/ICD and Acquisition Decision Memorandum (ADM). Required Operation Capabilities (ROCs) and Measures of Performance (MOPs) were identified based on this mission description. Alternative technologies (with their associated levels of risk) that potentially enable the required capabilities were identified. An Overall Measure of Effectiveness (OMOE) model was created from the MOPs. Expert opinion was used with the Analytical Hierarchy Process (AHP) to develop MOP weights and Value of Performance (VOP) functions in the OMOE model. Design Variables (DVs) describing the design space were identified from the ROCs and technologies. Overall Measure of Risk (OMOR) and cost models were developed consistent with these technologies and design space. A ship synthesis model was developed from previous models and a Multi-Objective Genetic Optimization (MOGO) was run using this synthesis model to search the design space for non-dominated designs based on Total Ownership Cost (TOC), effectiveness (OMOE), and risk (OMOR). The products from concept and requirements exploration include a Non-Dominated Frontier (NDF) for making the acquisition decision, a Concept Development Document (CDD) specifying specific performance and cost requirements, technology selection, and an initial baseline design including principle characteristics, "single-digit" weights, major Hull Mechanical and Electrical (HM&E) systems, combat systems, and a class "F" cost estimate.

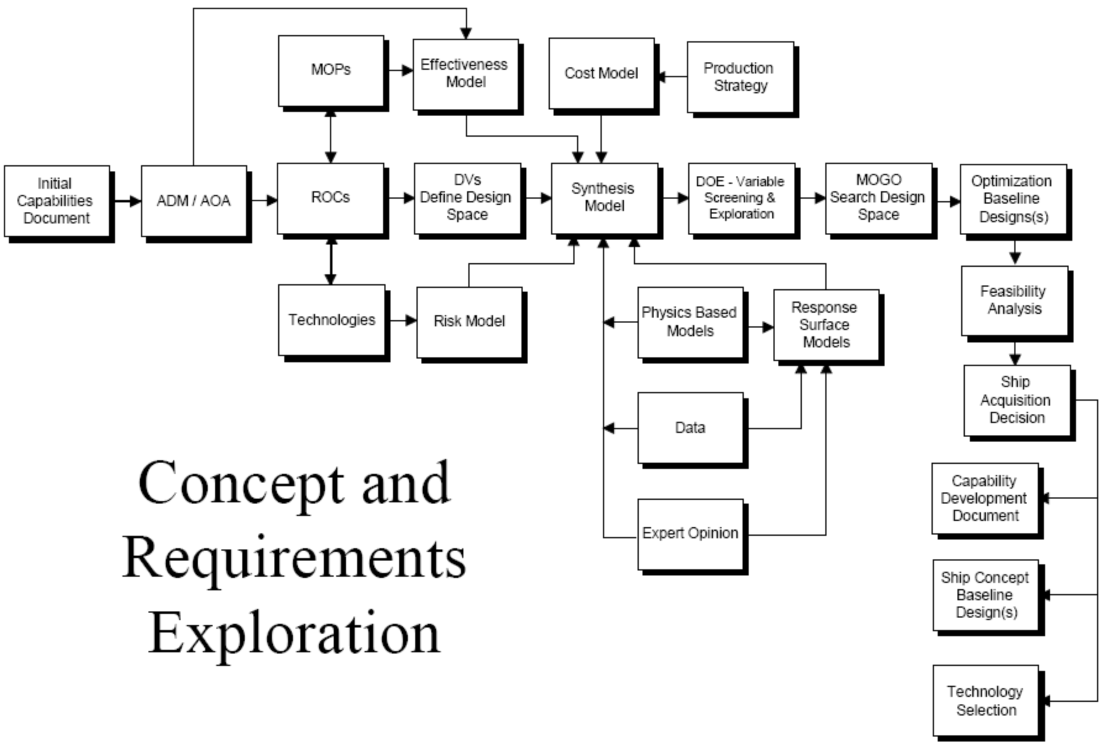


Figure 2 - Concept and requirements exploration process

Concept Development was performed using a more traditional design-spiral approach. Figure 3 shows the design spiral used for MSC. Due to the limited time available for this design project, only a single iteration was completed around the spiral with recommendations for subsequent iterations.

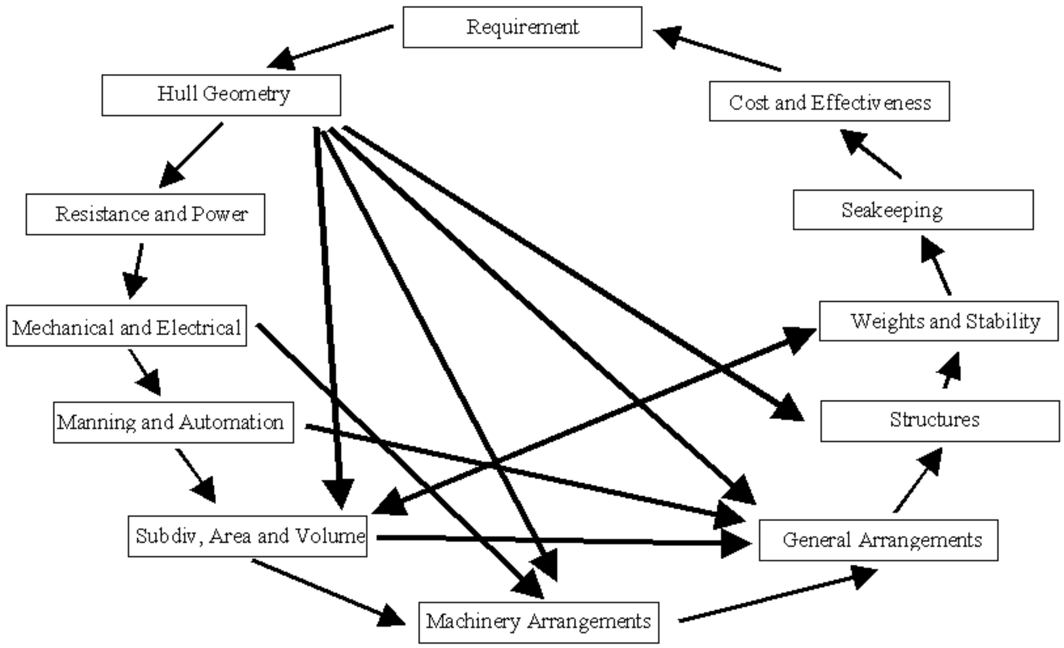


Figure 3 - VT Concept Development Design Spiral

1.3 Work Breakdown

The MSC design procedure is divided into six distinct sections allowing specialized personnel to manage individual aspects of the design. Team 2 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. The mission and mission effectiveness outline the given design variables and maintain the ability to fulfill the design requirements. HM&E and Risk specialty defines the ship arrangement for the required operational capabilities. This specialty is also responsible for electrical layout as well as overall risks associated with each portion of the design. The combat systems, manning, and cost specialty applies the military capabilities such as weapons and damage criteria with the manning necessary to operate all ship functions. Cost is determined based on the upfront research and development procedure, actual construction cost, and maintenance expenses over the ships service life. Modularity focuses on flexibility and mission capability of the MSC by exchanging specific mission packages determined by possible future requirements. The modularity may include weapons, surveillance, or rescue packages. Space and weight categories ensure the design meets tonnage and potential mission package requirements. Space options correlate with the importance of manning, the crew must be able to inhabit the ship for significant durations while maintaining operational proficiency. Optimization occurs throughout the design process to improve mission effectiveness and reduce cost. Finalizing the design is assessed by optimizing its required capabilities.

Table 1 - Work Breakdown

Name	Specialization
Matthew Myers	Mission and Mission Effectiveness
Ashley Loessberg	Hull, Mechanical and Electrical, and Risk (HM&E, Risk)
Donald Clark	Combat Systems, Manning, and Cost
Sean Gwinn	Modularity
Scarlett Abrell	Space and Weight
Skylar Stephens	Synthesis, Optimization, and Feasibility

1.4 Resources

Computational and modeling tools used in this project are listed in Table 2. Each software package is used to develop and analyze specific areas of the design model. ASSET is used to develop a robust surrogate SSSM for concept exploration and to perform an initial feasibility study of the SSSM results. This initial model is utilized in Model Center to achieve preliminary spacing arrangements and further narrow down design options. AutoCAD and RHINO provide methods for the configuration of advanced spacing arrangements and initial structural design. When the ship model is in the detailed design phase it is analyzed in MAESTRO which runs a structural breakdown of the vessel and identifies any local buckling or structural concerns. If any final construction modifications are necessary this is the period where they will occur.

Table 2 - Tools

Analysis	Software Package
Arrangement Drawings	AutoCAD
Hull form Development	Rhino
Hydrostatics	Rhino, HECSALV
Resistance/Power	NavCAD
Ship Motions	SMP
Ship Synthesis Model	MathCad/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

The MSC will provide flexible BMD, NSFS, strike, and multi-mission capability through modularity with different configurations of similar platforms. A full range of multi-mission options are considered which satisfy identified capability gaps. The full capabilities of the MSC platform 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. Force protection and awareness at sea will be provided along with homeland and critical base protection from the sea including BMD. MSC will be capable of conducting BMD operations from advantageous locations at sea that are inaccessible to ground based systems. Persistent Intelligence, Surveillance, and Reconnaissance is accomplished using onboard sensors along with support of manned and unmanned air, surface, and subsurface vehicles. The MSC platform will be deployed with Carrier Battle Groups (CSG), Expeditionary Strike Groups (ESG), and Surface Action Groups (SAG) as well as independent command capabilities.

2.2 Projected Operational Environment (POE) and Threat

The expected operating environment for this platform is all weather conditions. The MSC must remain fully operational in sea states 1-5, and survive up to sea state 9. Mission capabilities must not be sacrificed in open ocean and littoral waters; this includes geographically constrained environments with increased difficulty in detecting and successfully prosecuting targets. Operation in shallow and crowded waters is expected. Weather and geographical constraints also degrade radar picture.

A significant range of threats are expected. Major threats included the launch of long and short range ballistic missiles. Conventional littoral threats including small surface craft, diesel-electric submarines, land based air assets, mines, cruise missiles, and chemical or biological weapons are also of concern. Other fixed or mobile Surface to Air Missiles (SAM) sites and sophisticated sea mines are threats to ISR and littoral operations.

2.3 Specific Operations and Missions

MSC may conduct independent operations such as Ballistic Missile Defense as well as joint operations. The MSC will function with a Carrier Battle Group to engage in Anti-aircraft warfare (AAW) and act as an escort. When part of a Surface Action Group, AAW is expected and Command capabilities possible. During Expeditionary Strike Group missions AAW, Anti-surface Warfare (ASUW), and Anti-Submarine Warfare (ASW) is expected.

2.4 Mission Scenarios

Mission scenarios for the primary MSC missions are provided in Table 3 through Table 6. The Independent Operations, Carrier Battle Group, and Expeditionary Strike Group scenarios occur over 90 day periods with the ship operating independently and as part of a task force. During Independent Operations the MSC maintains intelligence, surveillance, and reconnaissance capabilities while actively engaging hostile threats. With the Carrier Battle Group the MSC provides support and conducts offensive and defensive operations. The Expeditionary Strike Group assesses and engages land and sea based threats while maintaining surveillance in a hostile environment. The Surface Action Group scenario occurs over a 75 day period transiting from port to a forward base. This scenario primarily consists of patrolling hostile waters, actively engaging hostile threats, and assisting Special Forces missions. These scenarios may be extended to accommodate any perceived threats or mission needs with appropriate replenishment and mission packages.

Table 3 – Independent Operations 90 Day Mission

Day	Mission scenario
1-21	SAG transit from CONUS
21-24	Port call, replenish
25-28	ISR
27	Conduct ASUW defense against medium boat threat
28-40	Sit and Wait to Fire/Intercept
41	Detect launch of BM
41	Engage TBM for allied defense
42-45	Conduct SAR
46	UNREP
47-55	Rejoin SAG
51	Multiple AAW threats for SAG defense.
56-63	Repairs / Port call
64-70	Conduct ASW operations with SAG and SSN
69	Engage submarine threat for SAG defense.
70	Emergency evacuation to U.S. Naval base.
71-75	Rejoin SAG
76-78	Joint land attack
79-89	Provide support and surveillance for SAG defense
90+	Port call / Restricted availability

Table 4 – CBG 90 Day Mission

Day	Mission scenario
1-21	CBG leaves port (CONUS); transit to Persian Gulf
22-59	Intelligence, surveillance, and Reconnaissance (ISR)
	Underway Replenishment (UNREP) every 4-6 days
33	Engage missile threat against carrier
40	Launch cruise missiles at land target
57	Conduct Antisubmarine Warfare (ASW) with Light Airborne Multi-Purpose System (LAMPS) helo vs. diesel submarine threat
59-60	Port call for repairs and replenishment
61	Engage in response to in-port attack by several small boats and land-based missiles
62-75	Rejoin CBG
65-89	ISR
70-72	Engage high speed boats using guns and harpoon missiles
75	Search and Rescue (SAR) of crew from damaged destroyer
76-80	Conduct missile defense against continued aggression
80-90	Return transit to home port
90+	Port call/Restricted availability

Table 5 – SAG 75 Day Mission

Day	Mission scenario
1-3	Transit with other MSCs to area of hostility from forward base
4	Detect, engage and kill incoming anti-ship missile attack
5-10	Patrol grid for launch of ballistic missile (BM)
11	Receive tasking for TLAM (subsonic cruise missile) strike
12	Cruise to 25 nm offshore
13	Embark Special Forces by helo
14	Insert Special Forces by RIB
15-25	Patrol grid for launch of BM
26	Detect BM attack against ally; engage and destroy with SM-3
27-29	Cruise to new grid
30	Sustain damage (Radar down) due to SS9
31-44	Cruise back to port for repairs
45-60	Repairs
61-68	Transit back to area of hostility
69	Detect ICBM launch against homeland; engage and kill with KEI
70-71	Cruise to station, 35 nm offshore
72-73	Conduct recon with AAV
74	AAV detects terrorist activity
74	Intelligence indicates high-value target with terrorist cell; conduct TLAM strike and kill target
75-77	Cruise back to forward base
77	Arrive at forward base

Table 6 – ESG 90 Day Mission

Day	Mission scenario
1-21	ESG leaves port (CONUS); transits to area of hostility
22-44	ISR
	UNREP every 4-6 days
32	Detect land based SAM sites
33	Provide Intel to Marines
35	Provide Naval Surface Fire Support (NSFS) for Marines ashore
45-56	Patrol area of hostility
54	Engage suspicious/hostile small craft with guns
57-74	Maintain mine surveillance/detection and provide Intel for ESG
75-89	Cruise back to port
90	Arrive at 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
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	Provide 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
AMW 6.6	Conduct helo air refueling
AMW 12	Provide air control and coordination of air operations
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious operation
AMW 15	Provide air operations to support amphibious operations
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

ROCs	Description
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
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
FSO 12	Provide medical/surgical treatment for 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
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

ROCs	Description
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

The hull form selection process incorporates three steps. In the first step, a transport factor is calculated to identify alternative hull types. The transport factor is given by the following equation:

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

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

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 4shows the transport factor as a function of speed, and the different hull types that are best suited for certain requirements. Table 8 lists different ships and concepts, and the associated transport factors and design variables associated with the design.

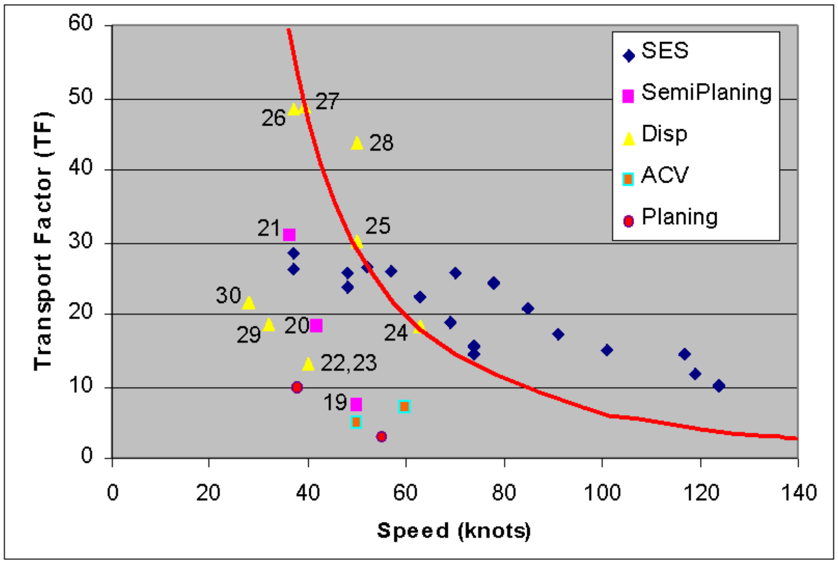


Figure 4 Transport Factor plotted as a function of speed

Table 8 Transport factor and design variables for various ship concepts

Ship or Concept	#	Type	Speed (knots)	TF	Power (SHP)	Range (n.mi)	Payload (LT)	Displacement (LT)
Destriero	19	SP	50	7.32	51675	2000	260	1100
Fastship-Atlantic TG-770 (design)	20	SP (Design)	42	18.33	480000	4800	13600	30480
SOCV (Fastship-Atlantic daughter hull design)	21	SP (Design)	36.5	30.95	320000	4000	10000	39475
Aker Finnyards HSS 1500	22	Disp	40	13.02	95000	500	1300	4500
Aker Finnyards Swath 2000 (design)	23	Disp (Design)	40	13.2	125000	1000	2000	6000
INCAT 130m (design)	24	Disp (Design)	63	18.35	118008	4300	2000	5000
Sumitomo Monohull (design)	25	Disp (Design)	50	30.18	266300	5000	1000	23400
SS United States - As Built	26	Disp	37.25	48.49	240000	10000	5750	45450
SS United States 1997 (design)	27	Disp (Design)	39.5	48.85	240000	10000	5750	43178
1500' Slender Monohull (design)	28	Disp (Design)	50	43.86	525000	10000	20000	67000
DDG51	29	Disp	32	18.72	100000	4500	800	8500
FFG7	30	Disp	28	21.68	40000	6000	350	4500

In the second step, design lanes are used to specify hull-form design parameter ranges for the design. For the MSC, the cruiser and destroyer design lanes shown in Table 9 are used as guidelines for determining hull parameters. The resulting principle characteristics are shown in Table 10.

Table 9 Cruiser/Destroyer Design Lanes

Parameter	Design Lane Value
Displacement	8000-14000 MT
$\Delta/(L/100)^3$ lton/ft^3	43.4-65.6
L/B	7-10
L/D	11-14
B/T	2.9-3.2
C_p	.57-.63
C_x	.76-.85
PANAMAX	
L	294.13 m
B	32.31 m
T	12.04 m
Air Draft	57.91 m

Table 10 Resulting Principle Characteristics

Parameter	Value
L	192.059 m
B	22.996 m
D10	14.57 m
T	7.93 m
C_{rd}	.7824

The third step is selecting a modeling approach. Parameters L, B, D, T, C_p, C_{rd} are defined, and applied to the ASSET DDG-51 boundary curve parents. The Response Surface Models (RSMs) for hull volume, structural weights and EHP(v) are developed by extracting hull data from ASSET in a Design of Experiments (DOE) over the full range of principle characteristics.

MSC characteristics are projected based on mission similar ships. The Ballistic Missile Defense (BMD) combat systems and NSFS combat systems are larger than those on the DDG 51 or CG 52. The MSC is a major combatant involved in worldwide operations, with a range 4,000-8,000 nm, a 75 day SAG endurance and a 90 day CBG endurance. A reasonable sustained speed requirement for these operations is 30-35 knots with an SHP greater than 100,000 hp. The expected displacement for this hull is 8,000-14,000 MT.

Based on these characteristics, the transport factor for this hull ranges between 17.31 and 20.62. These values suggest a slender monohull for the MSC.

Important hull form characteristics include producibility, a high degree of modularity, reduced radar cross section (RCS), structural efficiency, adequate seakeeping performance, a moderate to high speed hullform, and sufficient large object and deck space. Producibility is maintained through the implementation of extensive modularity and by reducing the lifecycle cost. An enclosed mast and a tumblehome or hybrid design reduce the radar cross section. Structural efficiency is obtained in a monohull design, and with devices such as a bulbous bow or a stern flap. Good seakeeping in both open ocean and littoral waters is achieved with a flare or hybrid hull form. Teams are assigned both flare and wave-piercing tumblehome. This team is assigned a hybrid flare design. Large object volume is necessary for a vertical launching system (VLS) or 155mm guns. These two requirements are sufficiently met through a monohull design, especially with a wide beam.

The completion of these three methods yields a monohull design with flare. The design space is summarized using the design lanes of Table 9 above, with a length range of 160 - 210 m.

3.1.2 Propulsion and Electrical Machinery Alternatives

The process for selecting propulsion alternatives includes several steps. The machinery general requirements and guidelines are developed. The viable machinery alternatives are selected based on the guidelines. An alternative machinery selection hierarchy is developed. Manufacturer data and other information on viable machinery alternatives is gathered. A baseline design using ASSET is also an option. The data is assembled in a propulsion alternative database. The ship synthesis propulsion module is updated to be consistent with the machinery alternatives. Machinery system trade off is performed as part of the total ship synthesis and optimization.

3.1.2.1 **Machinery Requirements**

Based on the ADM and Program Manager guidance, pertinent propulsion plant design requirements are summarized as follows:

General Requirements – The alternatives must span a 60-120 MW SHP power range with ship service power greater than 10,000 kW MFLM unless an IPSe power configuration is used. A low IR signature and cruise/boost options are considered for high endurance. Design accounts for 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). IPS with DC Bus, zonal distribution, permanent magnet motors. The design should provide arrangement and operational flexibility, future power growth, improved arrangement and operational flexibility, future power growth, improved fuel efficiency and survivability with moderate weight and volume penalties.

Sustained Speed and Propulsion Power – The minimum sustained speed should be 30 knots in the full load condition, calm water, and clean hull using no more than 80% of the installed engine rating (MCR) of main propulsion engines or motors. The goal speed is 35 knots. The ship must be high speed in order to provide "just-in-time delivery." The minimum range is 8000 nautical miles at 20 knots. The power requirement is satisfied with 2-4 main engines, 20000-36000 kW each. Propulsive Efficiency at 30-35 knots suggests propellers.

Ship Control and Machinery Plant Automation – An integrated bridge system includes integrated navigation, radio communications, interior communications, and ship maneuvering equipment and systems. The system must comply with ABS Guide for One Man Bridge Operated (OMBO) Ships. The ability to continuously monitor auxiliary systems, electric plant and damage control systems from the SCC, MCC and Chief Engineer's office, and control the systems from the MCC and local controllers should be available.

Propulsion Engine and Ship Service Generator Certification – Because of the criticality of propulsion and ship service power to many aspects of the ship's mission and survivability, this equipment shall be non-nuclear. Navy qualified and grade-A shock certified gas turbines are alternatives. A low IR signature is considered. The machinery must comply with ABS ACCU requirements for periodically unattended machinery spaces. Modularity throughout propulsion and auxiliary system is considered.

3.1.2.2 **Machinery Plant Alternatives**

The IPS propulsion system includes the power generation module (PGM), the secondary power generation module (SPGM), the power distribution type (DIST type), propulsion motor module (PMM), and propeller type (PROP type).

Only an integrated power system (IPS) is considered, as shown in Figure 5. A pod-type IPS is shown in Figure 6.

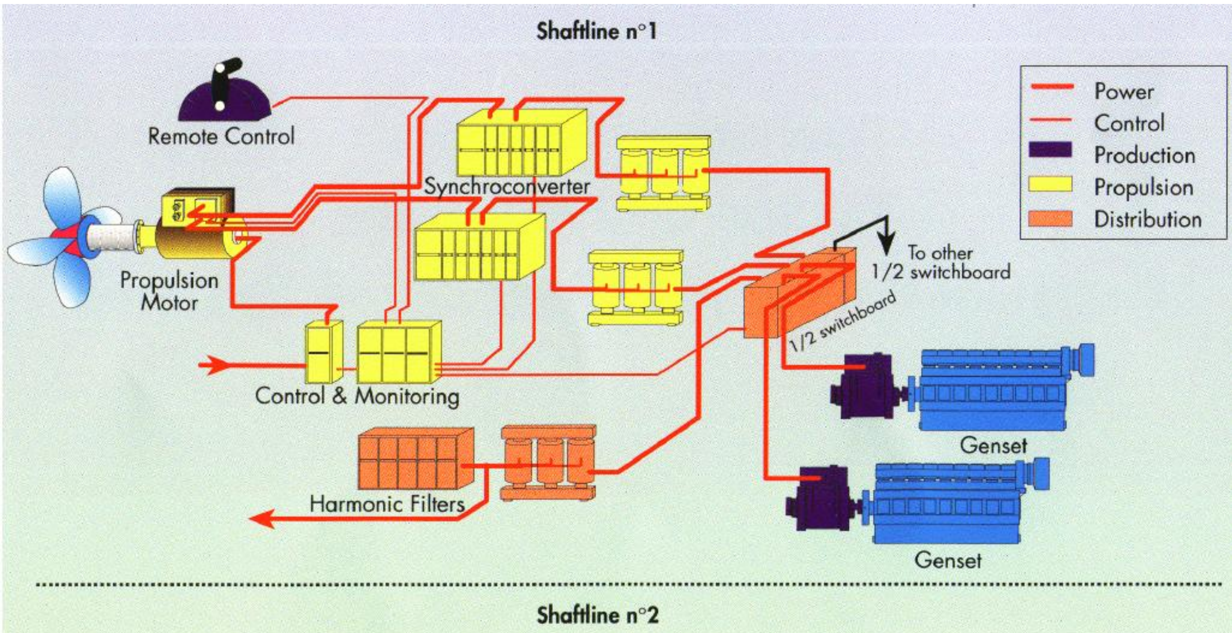


Figure 5 Integrated Power System (IPS)

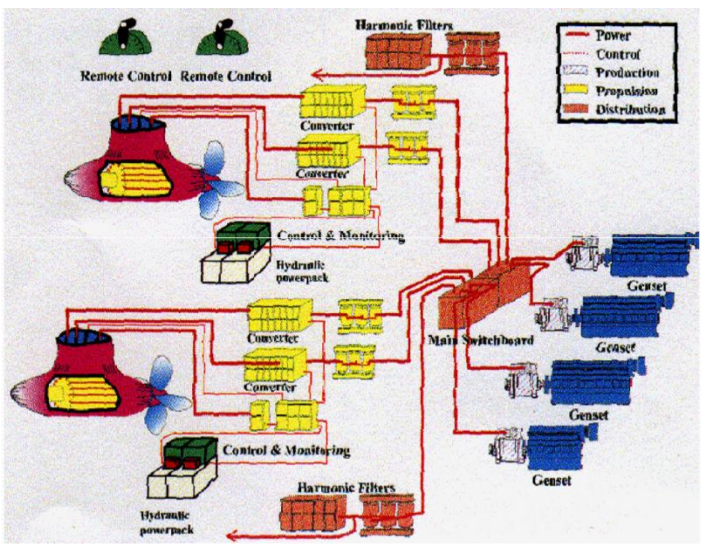
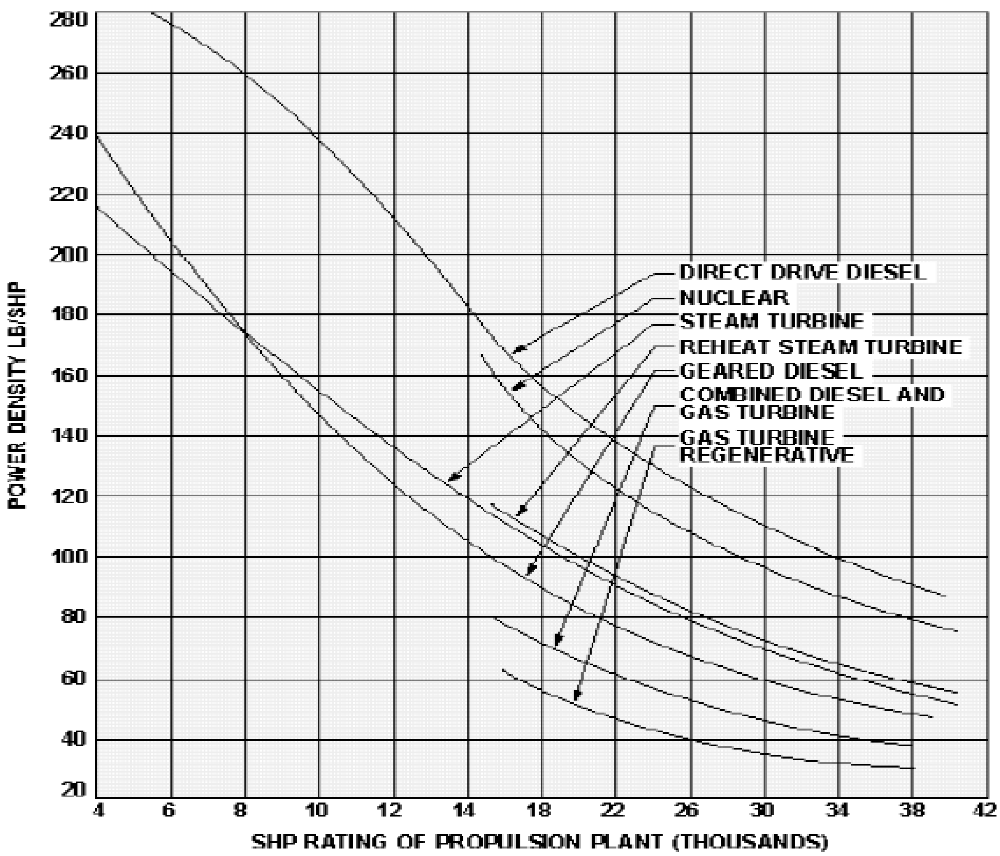


Figure 6 PSYS type IPS

Diesel and gas turbines are considered. Figure 7 shows the performance parameters of diesels and gas turbines. Gas turbines have a greater power density (see), they are lighter and take up less volume, and have lower emissions. See Figure 9 and Figure 10 for gas turbine models. Diesels start faster, are fuel efficient, have smaller intakes and uptakes, and there is a greater variety of models. See Figure 11, Figure 12, and Figure 13 for diesel models.

Data	Medium-speed Diesels	Aero-derivative Gas Turbines	Industrial GT35	Rolls-Royce WR21
Process/cycle	4-stroke	simple cycle	simple cycle	advanced cycle
Construction	trunk piston	two-shaft	two-shaft	two-shaft
Output power range [kW]	500-35000	6000-41000	17000	24000
Output speed [rpm]	300-1000	3600-7000	3300	3600
Fuel type	HFO or MDO	MGO or JP5	MDO or IF30	MGO
Specific fuel rate [g/kW h]*	170-210	240-280	260	200
Specific air rate [kg/kW h]	6-9	10-15		10.5
Specific NOx Emission [g/kW h]	10-18	2-5	2	3
Specific mass [kg/kW]	5-20	1.0-1.4	1.5-2.0	1.8
Specific volume [dm^3/kW]	4-28	2.5-4.5	6.0	4.1
Specific cost [$/kW]	L: 240-360	200-310		515
* ISO standard on MDO	V: 190-310			

Figure 7 Typical Performance Parameters of Medium-Speed Diesel Engines and Marine Gas Turbines



COMPILED FROM VARIOUS SOURCES, INCLUDING *SHIPS AND SHIPBUILDING OF TOMORROW*, SCHÖNKNECKT, LÜSCH, SCHELZEL & OBENHAUS, 1983; *SHIP DESIGN AND CONSTUCTION*, TAGGART, 1980; *MARINE ENGINEERING*, HARRINGTON, 1955 AND MANUFACTURERS DATA

Figure 8 Weight/Power Ratio (1/Power Density)

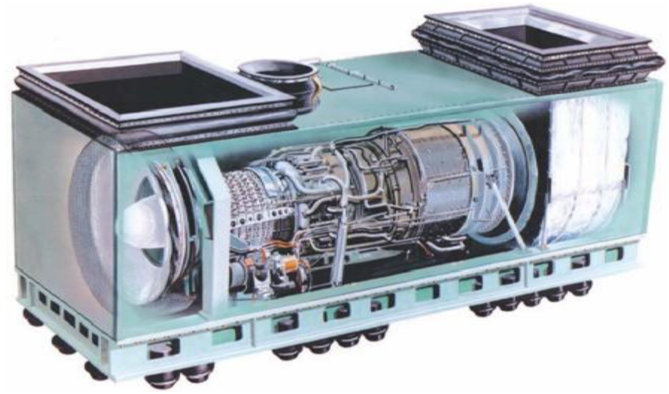
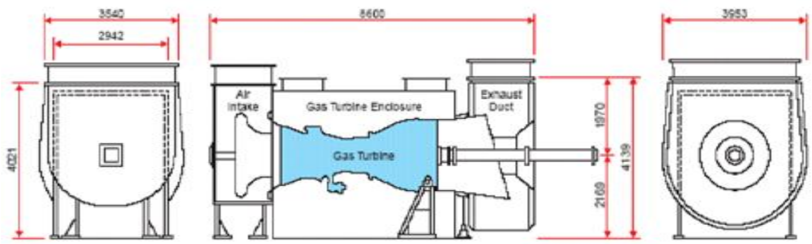


Figure 9 LM2500+ Gas Turbine Engine



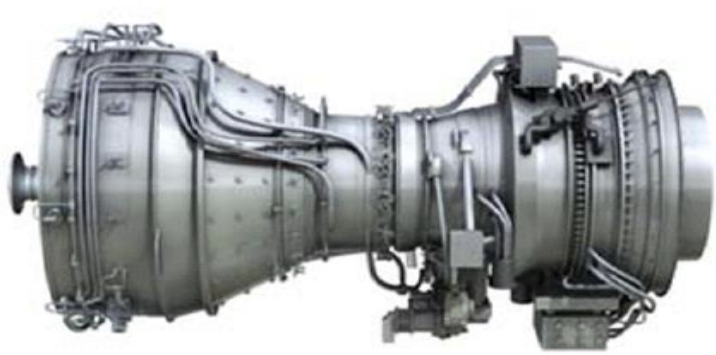


Figure 10 MT30 Gas Turbine Engine

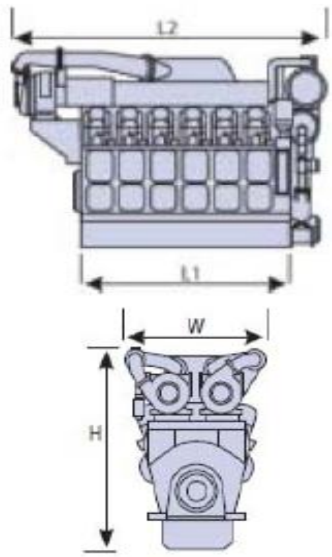
Engine type	Number of cylinders	Speed rpm	Engine output kWb	bhp
12PA6B STC	12	1050	4860	6600
16PA6B STC	16	1050	6480	8800
20PA6B STC	20	1050	8100	11000

CODAD ratings up to 8910 kWb at 1084rpm

Principal dimensions and weights

PA6

Engine type	Weight kg (approx net)	Length L1 mm	Length L2 mm	Width W mm (overall)	Height H mm (overall)
12PA6 STC	22000	3055	4942	2197	3244
16PA6 STC	30000	3975	6133	2197	3415

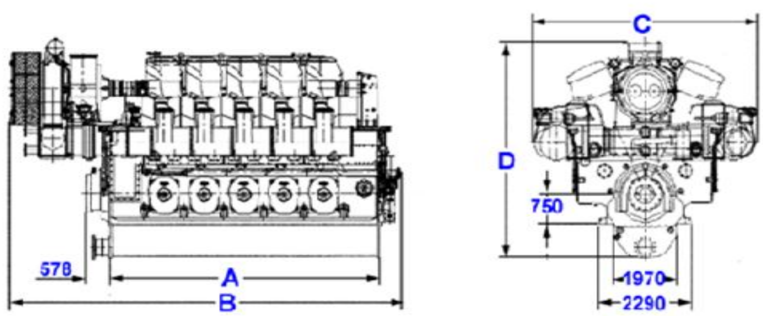


PA6B

Engine type	Weight kg (approx net)	Length L1 mm	Length L2 mm	Width W mm (overall)	Height H mm (overall)
12PA6B STC	26000	3055	5375	2400	3540
16PA6B STC	34000	3975	6295	2400	3540
20PA6B STC	42000	4895	7215	2400	3540

Figure 11 Medium-High Speed Diesel

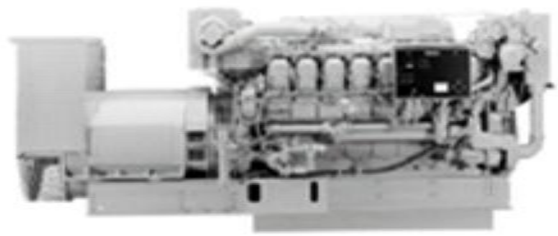
PC4.2B Dimensions



Colt-Pielstick PC4.2B Dimesions (mm) and Ratings (kW)						
CYL.	A	B	C	D	kW (400 / 430 RPM)	TONS
10V	6580	9517	5350	5475	12,500 / 13,250	207
12V	7560	9599	5350	6476	15,000 / 15,900	239
16V	9520	11,795	5690	6396	20,000 / 21,200	302
18V	10,500	13,370	5690	6396	22,500 / 23,850	330

Figure 12 Medium-Low Speed Diesel

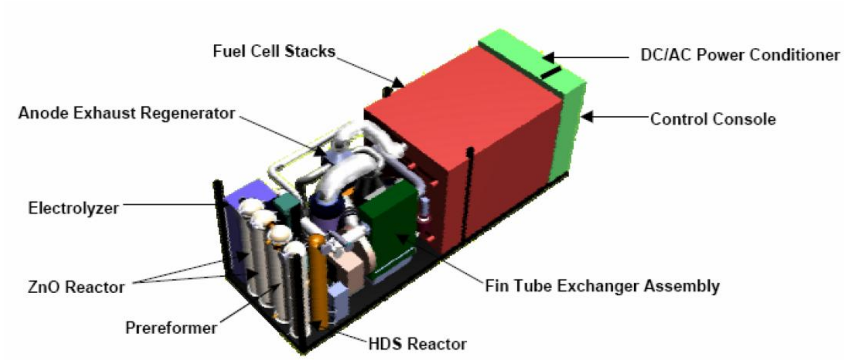
Specifications	
Configurations	Vee 16 cylinder
Cycle	4-Stroke-Cycle-Diesel
Bore x Stroke	170 mm (6.7 in) x 190 mm (7.5 in)
Displacement	69.0 L (4210 cu in)
Governor	Electronic
Aspiration	Turbocharged Aftercooled
LxWxH (mm)	3181 mm x 2144 mm x 2100 mm
LxWxH (in)	125.2 in x 84.4 in x 82.7 in
Weight (Approx. dry)	11354-13538 kg (25030-29845 lb)



Average Fuel Consumption at Rated Speed		
1285 ekW at 1200 rpm	80.5 U.S. gal/hr	304.9 L/hr
1825 ekW at 1800 rpm	125.3 U.S. gal/hr	474.2 L/hr
1180 ekW at 1000 rpm	80.6 U.S. gal/hr	305.2 L/hr
1460 ekW at 1500 rpm	102.2 U.S. gal/hr	387.0 L/hr
1600 ekW at 1500 rpm	111.9 U.S. gal/hr	423.5 L/hr

Figure 13 Caterpillar 3516 High Speed Diesel

Fuel cells (see Figure 14) are highly efficient (35-60%). There are no dedicated intakes or uptakes because they use ventilation. The challenges that come with fuel cells include reforming fuel into hydrogen with an onboard chemical plant and eliminating sulfur from fuels. The fuel cells also have a slow dynamic response. Energy storage is required to balance generation and load. Fuel cells also have a slow startup, which is best used for base-loads.



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

Figure 14 Fuel Cell

The propulsion motor module, shown in Figure 15, includes the propulsion motor, motor drive, propulsor, and support equipment. The module converts electricity into propulsion power.

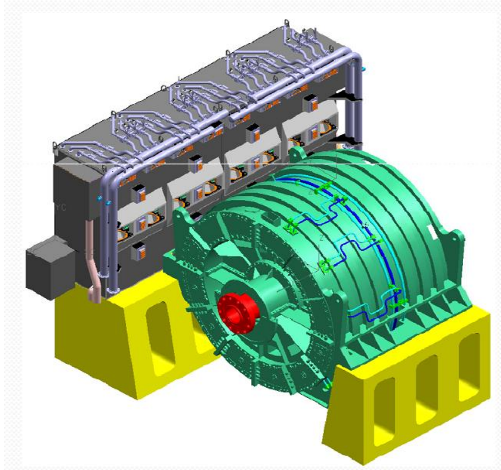


Figure 15 Propulsion Power Module

Table 11 shows the machinery plant alternatives available for the design lanes. Table 12 and Table 13 show the propulsion and power system data for the alternatives. Table 14 shows the options considered for this design.

Table 11 Machinery Plant Alternatives

DV Name	Description	Design Space	
PGM	Power Generation Module	Option 1)	3xLM2500+, 4160VAC, FPP
		Option 2)	3xLM2500+, 13800 VAC, FPP
		Option 3)	2xMT30, 4160VAC, FPP
		Option 4)	2xMT30, 13800 VAC, FPP
		Option 5)	3xMT30, 4160VAC, FPP
		Option 6)	3xMT30, 13800 VAC, FPP
SPGM	Secondary Power Generation Module	Option 1)	NONE
		Option 2)	2xLM500G, AC Synch
		Option 3)	2xCAT3608 Diesel
		Option 4)	2xPC 2.5/18 Diesel
		Option 5)	2xPEM 3 MW Fuel Cells
		Option 6)	2xPEM 4 MW Fuel Cells
		Option 7)	2xPEM 5 MW Fuel Cells
PROPtype	Propulsor Type	Option 1)	2 x FPP
		Option 2)	2 x Pods
DIST Type	Power Distribution Type	Option 1)	AC ZEDS
		Option 2)	DC ZEDS
PMM	Propulsor Motor Module	Option 1)	(AIM) Advanced Induction Motor (DDG 1000)
		Option 2)	(PMM) Permanent Magnet Motor

Table 12 Propulsion and Power System Data

Propulsion Option	PGM Option	Total Propulsion Engine BHP $P_{BPENGTOT}$ (kw)	Endurance Brake Propulsion Power, $P_{bengend}$ (kw)	Endurance Propulsion SFC SFC_{ePE} (kg/kw hr)	Machinery Box Minimum Length L_{MBreq} (m)	Machinery Box Minimum Height H_{MBreq} (m)	Machinery Box Required Volume V_{MBreq} (m^3)
3xLM2500+, 4160VAC, FPP	1	78297	26099	0.226	17.21	7.78	7838
3xLM2500+, 13800 VAC, FPP	2	78297	26099	0.226	17.21	7.78	6532
2xMT30, 4160VAC, FPP	3	72000	36000	0.213	16.50	8.00	6990
2xMT30, 13800 VAC, FPP	4	72000	36000	0.213	16.50	8.00	5825
3xMT30, 4160VAC, FPP	5	108000	36000	0.213	16.50	8.00	8321
3xMT30, 13800 VAC, FPP	6	108000	36000	0.213	16.50	8.00	6934
3xLM2500+, 4160VAC, FPP	1	78297	26099	0.226	17.21	7.78	7838

Table 13 Propulsion and Power System Data (cont.)

Propulsion Option	Basic Propulsion Machinery Weight W_{BM}(MT)	Basic Electric Machinery Weight W_{BME}(MT)	PGM Inlet and Uptake Area A_{PIE}(m^2)	Number of PGMs	Propulsion Engine Type	Super-Conducting PGM	PROPtype
3xLM2500+, 4160VAC, FPP	1074.4	1389.0	84.6	3	48	0	1
3xLM2500+, 13800 VAC, FPP	895.3	1157.5	84.6	3	48	0	1
2xMT30, 4160VAC, FPP	892.4	1380.7	81.0	2	72	0	1
2xMT30, 13800 VAC, FPP	744	1151	81.0	2	72	0	1
3xMT30, 4160VAC, FPP	1062.9	1394.1	121.5	3	72	0	1
3xMT30, 13800 VAC, FPP	886	1162	121.5	3	72	0	1

Table 14 Propulsion Options

PGM	SPGM	Motor	Prop	Dist
2xMT30, AC Synch, 4160 VAC	2xPC 2.5/18 Diesel	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
2xMT30, AC Synch, 4160 VAC	2xPEM 3 MW Fuel Cells (NSWCCD)	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
2xMT30, AC Synch, 4160 VAC	2xPEM 4 MW Fuel Cells (NSWCCD)	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	NONE	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	2xLM500G, AC Synch (DDG 1000)	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	2xCAT3608 Diesel	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	2xPC 2.5/18 Diesel	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	2xPEM 3 MW Fuel Cells (NSWCCD)	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS
3xMT30, AC Synch, 4160 VAC	2xPEM 4 MW Fuel Cells (NSWCCD)	(AIM) Advanced Induction Motor	2 x Pods	AC ZEDS

3.1.3 Automation and Manning Parameters

Manning is a major requirement for a ship to perform specific tasks. Because manning is a primary requirement it is also the largest cost accounting for sixty percent of the Navy's budget. The cost of the ship's crew is the largest expense incurred over the ship's lifetime. There are several concerns associated with manning. Manning puts personnel in harm's way during day to day jobs and in battle situations. Also Firefighting and damage control are performed by manpower with a very high risk to the crew. Computer literacy, reduced response time and job enrichment are human factors are a big responsibility for each sailor. Another issue is the cultural background of each sailor on a ship. Different backgrounds come with different traditions and ethics that must be addressed while aboard. There is also the "manning triad": watch standing, maintenance and damage control. The triad has a high need for manpower. The only method to decrease manning and increase efficiency is to introduce automation into the system. When applied to ships early in their development and throughout their design, human systems (analysis) have the potential to substantially reduce requirements for personnel, leading to significant cost savings.

Automation is the use of computers or machinery to get a task done with fewer personnel. Firefighting may be replaced by automated sprinkler systems, this helps reduce the manpower needed to fight fires on board a ship that reduces the number of personnel in dangerous situations. Maintenance can be made easier for personnel by implementing a system that can monitor the functionality and status of all parts and schedule / flag components due for maintenance. Response time can be reduced with an automated system.

There are many technologies that can help with automation and computers and software are some of the most important. With an automated watch station and personal handhelds, a computer can monitor and control ship automation systems. Watch-standing technology has been improved with GPS, automated route planning, electronic charting and navigation, collision avoidance and electronic log keeping. Video teleconferencing provides a way to access experts without bringing extra personnel on board. Computers can also create and more informative training environment. Hands-on-experience isn't necessary for training on board a ship. Crews can learn the computer systems on shore with programs that can be replayed. These replays can be machinery failure or war situation in which puts the ship in danger. Also with assist of better communication technology and networking, ship logistics will create paperless ships. This allows administration personnel to stay on shore and receive what they need to do their jobs electronically and reduce the extra personnel aboard.

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 Figure 16. 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 Figure 16. A more detailed manning analysis is performed in concept development.

A Manning Response Surface Model (RSM) calculates the manning requirement for the ship in question. Integrated Simulation Manning Analysis Tool (ISMAT) was developed to find personnel scenarios when assigned to maintenance tasks based on systems and their department. The same scenario is used for all designs. ISMAT calculations when optimizing manning based on crew cost. The RSM is used in the overall ship synthesis program instead of ISMAT to reduce computation time. The level of automation also effects cost and risk for the design. The total crew size is calculated as shown in the equation below presented in Figure 16:

$$\begin{aligned} NT = {} & 374.49 + 82.06 * LevAuto - 6.09 * MAINT + 11.29 * LWLComp - 59.85 * LevAuto^2 + 2.08 * PSYS \\ & * LWLComp - 0.147 * PSYS^3 + 8.52 * LevAuto^3 - 0.294 * ASuW * PSYS * LevAuto \\ & + 0.341 * ASuw * MAINT^2 - 0.684 * PSYS^2 * LWLComp + 0.416 * PSYS * LevAuto * CCC \\ & - 0.485 * MAINT * CCC * LWLComp + 0.210 * CCC * LWLComp^2 \end{aligned}$$

Figure 16 "Standard" Manning Calculation

Where NT = Total Crew Size, LevAuto = Level of Automation, MAINT – Maintenance Lever, LWLComp = Length of the Waterline, PSYS = Propulsion System, ASUW = Anti-Surface Warfare, and CCC = Command Control and Communication.

Figure 17 shows the different levels of automation that can be considered in construction a manning model. Level 1 is the least amount of automation and no advanced technology is used to improve the efficiency of a job. A similar list is generated for maintenance, where level 1 is when the crew performs all scheduled system checks and level 4 is when the crew perform daily task but large maintenance jobs are outsourced to contractors. Both level of automation and maintenance are considered in the overall manning model and can be seen in Figure 18.

	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

Figure 17 Level of Automation

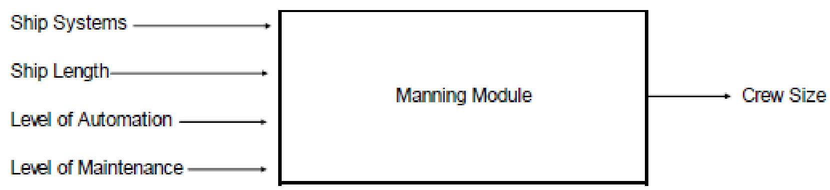


Figure 18 Manning Module flow chart indicating input variables

3.1.4 Combat System Alternatives

The Combat System Alternative section will explore in detail the options and capabilities of each combat system design variable that could be utilized in a any mission situation.

3.1.4.1 AAW

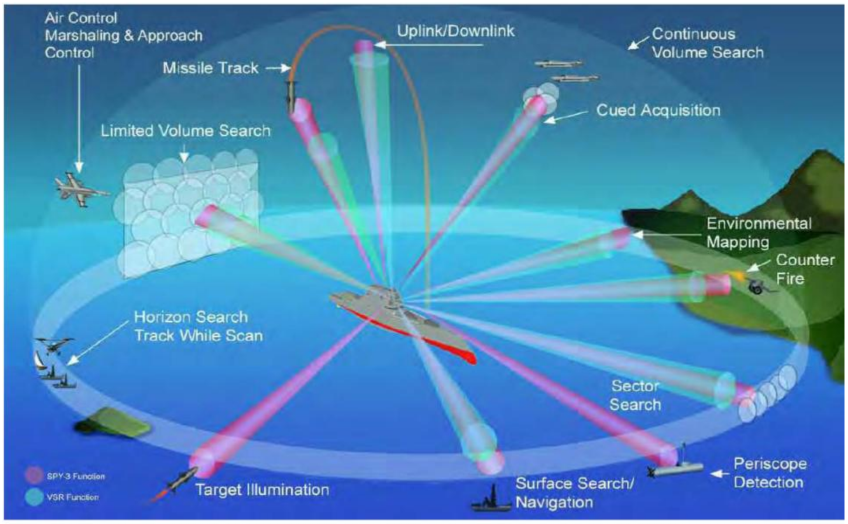
The AAW/BMD options are listed in Table 15, and discussed in the following paragraphs.

Table 15 AAW/BMD Combat Systems Options Table

War fighting System	Options
AAW/BMD	Option 1: SPY3/VSR+++ DBR Option 2: SPY3/VSR++ DBR Option 3: SPY3/VSR+ DBR Option 4: SPY3/VSR DBR All options: AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36 SRBOC w/NULKA.

AN/SPY-3 is a multi-function radar (MFR) that provides X-band capability allowing ships to operate and maintain complex environmental awareness. It detects the most advanced low observable Anti-Ship Cruise Missile (ASCM) threats, and provides fire-control illumination requirements for the Evolved Sea Sparrow Missile (ESSM). AN/SPY-3 supports new ship design requirements for reduced cross-section, limiting different ship signatures to avoid detection. It has a long range 2-D search and limited volume search. AN/SPY-3 meets all horizon search and fire control requirements for the twenty-first century fleet, and supports all BMD missions.

Dual Band Radar (DBR) consists of AN/SPY 3 and the Volume Search Radar (VSR). VSR is an S-Band frequency, 3-D tracking, and long range volume search radar. It can be used for enhanced BMD. DBR is a horizon and volume search radar, which can detect stealthy targets in sea-land battle space. The DBR combines the functionality of the X-Band AN/SPY-3 MFR with an S-Band VSR. It provides low maintenance with no dedicated operator or display console, and supports stealth operations with low radar cross section (RCS) and infrared (IR) signature. BMD capabilities in DBR include the ability to do combat control, including air control, missile tracking, periscope detection, and target illumination, as well as functional details such as environmental mapping and uplink/downlink. Figure 19 provides a visual description. DBR meets next-generation naval radar challenges by performing multiple functions automatically and simultaneously, including detecting and tracking advanced high and low altitude anti-ship cruise missiles.



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

Figure 19 Dual Band Radar (DBR) Capabilities

The Infrared Search and Track (IRST) is a shipboard integrated sensor designed to detect and report low flying ASCMs by their heat plumes. It works by scanning the horizon (plus or minus a few degrees) and can be manually changed to search higher angles. It provides accurate bearing, elevation angle and relative thermal intensity readings.

AN/UPX-36(V) CIFF-SD is the Centralized ID Friend or Foe (CIFF) system. It is a centralized, controller processor-based system that associates different sources of target information. It accepts, processes, correlates and combines sensor inputs into one large track picture while controlling the integration of each IFF system.

The AN/SLQ-32(R) Improved is a Space and Electronic Warfare component that provides early warning of threats. It automatically dispenses chaff decoys, which is part of the MK36 SRBOC and NULKA systems, which are shown in Figure 20. Super Rapid Bloom Off board Countermeasures (SRBOC) is a decoy launching system. NULKA is specifically a rapid response Active Expendable Decoy (AED), which is capable of providing highly effective defense for ships of cruiser size and below against modern radar homing anti-ship missiles.

Figure 20 MK 36 SRBOC and NULKA systems

AEGIS BMD 2014 is an elaboration of the Aegis Weapon System with the AN/SPY-1 radar and Standard missile technologies. The Aegis Ballistic Missile Defense System (Aegis BMD) is a United States Department of Defense Missile Defense Agency program developed to provide defense against ballistic missiles. Aegis BMD (also known as Sea-Based Midcourse) is designed to intercept ballistic missiles post-boost phase and prior to reentry. Future development of the Aegis BMD system includes Launch on Remote capability, upgraded SM-3 avionics and hardware, and an upgraded Aegis Weapon System.

3.1.4.2 ASUW

The ASUW options are listed in Table 16, and discussed in the following paragraphs.

Table 16 ASUW Combat Systems Options Table

War fighting System	Options
ASUW	Option 1: 1xAGS gun Option 2: MK45 5”/62 gun Option 3: MK110 57mm gun all options: 3x30mm CIGS (or small directed energy), FLIR, GFCS

The MK 45 5”/62 gun has a range of over 60 nautical miles with the ERGM rounds. The gun mount is a basic MK 45 gun mount with a 62-caliber barrel, strengthened trunnion supports and a lengthened recoil stroke. It also has an ERGM initialization interface, round identification capability and an enhanced control system. Figure 21 shows the new gun mount shield which reduces overall radar signature, maintenance and production cost.

Figure 21 MK45 5”/62 Gun

The 1xMK110 57 mm gun is capable of firing 2.4 kilogram shells at a rate of 220 rounds per minute. Its range is of nine miles. The MK110 57 mm gun is a multi-purpose, medium caliber gun. The MK110 is shown in Figure 22.

Figure 22 MK110 57 mm Gun

The Mk46 Mod2 3x CIGS (Close-In Gun System) is a two-axis stabilized chain gun that can fire up to 250 rounds per minute. This system uses FLIR to optimize accuracy against small, high-speed surface targets. It can be operated locally at the gun’s turret or fired remotely by a gunner in the ship’s combat station.

Forward Looking Infrared Radar Sensor (FLIR) uses detection of thermal energy to create a picture of the forward surroundings. It can be used at night, in heavy fog and all different types of weather. FLIR is a good investment in military operations for several reasons. It distinguishes heat from a distance of a few miles, which is hard for an enemy to camouflage. It can see through many atmospheric changes (fog, haze, smoke etc.) which is a major benefit for safety reasons and military options. Figure 23 shows the Forward Looking Infrared Radar Sensor.

Figure 23 Forward Looking Infrared Radar Sensor and Operational Images

The AGS gun systems description and supporting figures can be found in Section 3.1.4.4 under GMLS and NSFS. Combining the VLS and AGS was done to allow for a modularity analysis.

MK 86 Gun Fire Control System (GFCS) provides ships of destroyer size and larger with an economical, versatile, lightweight, gun and missile fire control system which is effective against surface and air targets. The Mark 86 fire control system is a substantial improvement over the earlier Mark 68 system that was developed following World War II.

3.1.4.3 **ASW**

The ASW/MCM options are listed in Table 17, and discussed in the following paragraphs.

Table 17 ASW/MCM Combat Systems Options Table

War fighting System	Options
ASW/MCM	Option 1: Dual Frequency Sonar Bow array Option 2: SQS-53C Option 3: SQS-56 sonar All options: Mine avoidance sonar, 2xMK32 SVTT, NIXIE, ISUW

SQS-56 is a hull mounted sonar with digital implementation, system control by a built-in minicomputer and an advanced display system. It is extremely flexible and easy to operate. It also uses active/passive operating capability, as well as preformed beam, digital sonar providing panoramic echo ranging and panoramic passive surveillance. 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.

IUSW is the Integrated Undersea Warfare system. IUSW incorporates two types of sonar arrays in one automated system. The high frequency sonar provides in-stride mine avoidance capabilities, while the medium frequency sonar optimizes anti-submarine and torpedo defense operations. The suite integrates all acoustic undersea warfare systems and subsystems, including the dual frequency bow array, towed array, towed torpedo countermeasures, expendable bathythermograph, data sensor, acoustic decoy launcher, underwater communications, and associated software.

NIXIE is a tow-behind decoy that employs an underwater acoustic projector. It provides deceptive countermeasures against acoustic homing torpedoes and can be used in pairs or singles. Figure 24 illustrates the use and arrangement of NIXIE.

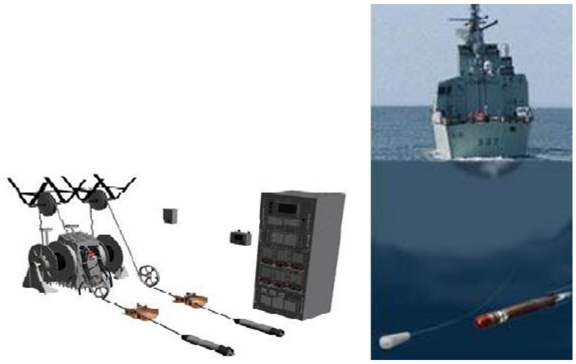


Figure 24 NIXIE countermeasure arrangement and operation

Figure 25 shows the MK32 Surface Vessel Torpedo Tube (SVTT). It is an ASW launching system that pneumatically launches torpedoes over the side. It can handle the MK46 and MK50 torpedoes and is capable of stowing and launching up to three torpedoes under either local control or remote control from an ASW fire control system.

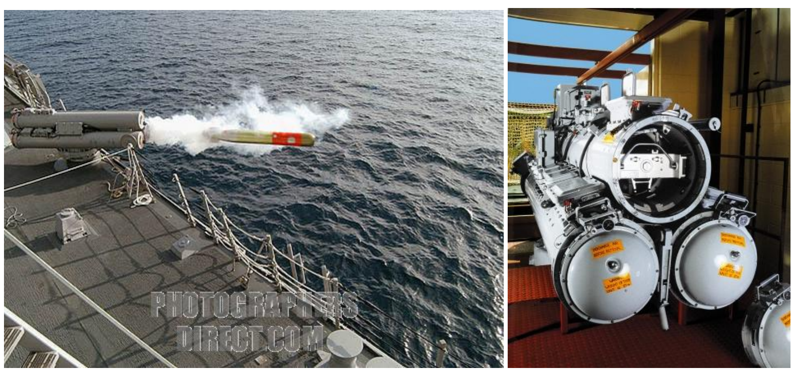


Figure 25 MK32 Surface Vessel Torpedo Tubes

The VANGUARD Mine Avoidance Sonar is a multi-purpose a versatile two frequency active and broadband passive sonar system. It is conceived for use on surface vessels to assist navigation and permit detection of dangerous objects. The system is designed primarily to detect mines but will also be used to detect other moving or stationary underwater objects. Mine Avoidance Sonar can be used as navigation sonar in narrow or dangerous waters. In addition it can complement the sensors on board anchoring surface vessels with regard to surveillance and protection against divers. Figure 26 is an illustration of the mine avoidance sonar.

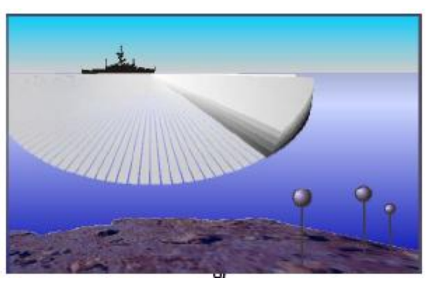


Figure 26 Mine Avoidance Sonar

3.1.4.4 **GMLS/NSFS/STK**

The GMLS/NSFS/SKT options are listed in Table 18 and discussed in the following paragraphs.

Table 18 GMLS /NSFS/ STK Combat Systems Options Table

War fighting System	Options
GMLS/NSFS/STK	Option 1: 4x4 MK57 VLS or 1xAGS, 64xMK57 PVLS or VLS Option 2: 4x4 MK57 VLS or 1xAGS, 56xMK57 PVLS or VLS Option 3: 4x4 MK57 VLS or 1xAGS, 48xMK57 PVLS or VLS Option 4: 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS. All options: Tomahawk WCS

MK 57 VLS may be configured as a peripheral VLS (PVLS) arrangement consisting of fixed, vertical, multi missile canister storage and firing system. MK 57 VLS has the ability to simultaneously prepare missiles in each half of the launcher module which increases reaction time to provide concentrated continuous firepower on multiple threats. Second arrangement option is the traditional cluster array. In the peripheral arrangement, the cells are located around the periphery of the hull, so that in the event of an explosion, the energy is expelled outwards, away from vital ship systems and increasing survivability. Figure 27 shows the PVLS structural setup.

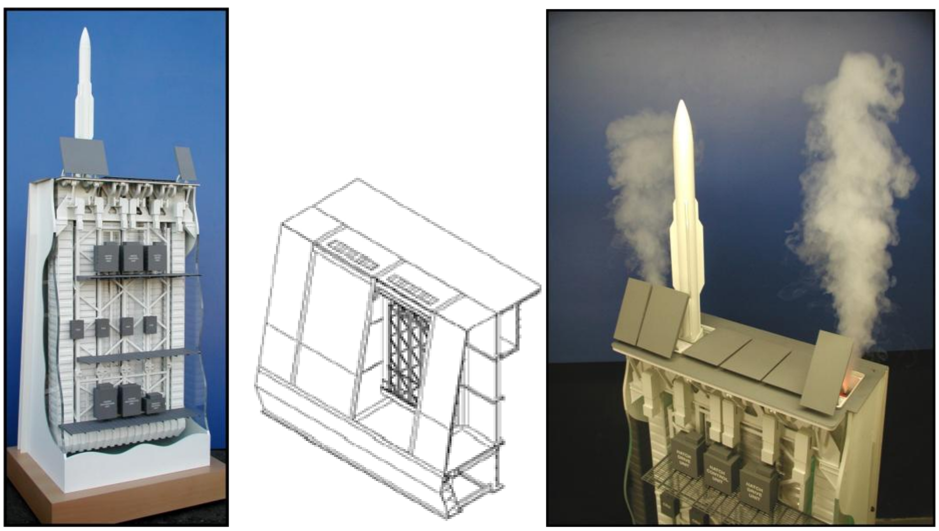


Figure 27 MK57 Peripheral VLS

Figure 28 shows the 155 mm Advanced Gun Systems (AGS). It is a high-volume gun, which sustains fire support of amphibious operations and the joint land battle. AGS fires up to 12 rounds per minute from an automated magazine, storing up to as many as 750 rounds. Firing a round 6.1 inches in diameter, and includes the development of the 155 mm version of the Extended-Range Guided Munitions (ERGM). AGS is a conventional, single barrel, low-signature gun system with fast-reaction, fully stabilized train and elevation capabilities.

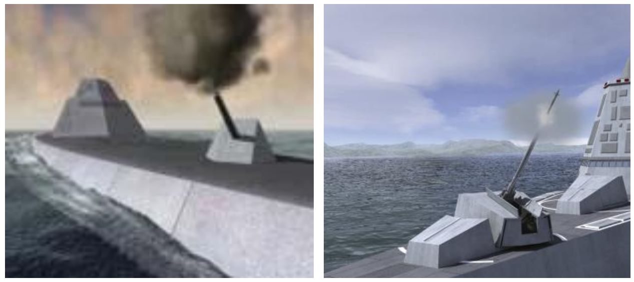


Figure 28 155mm Advanced Gun System

The MK 37 TOMAHAWK Weapon System (TWS) supports the Navy mission of sea control and projection of power with a long range, low altitude attack of land targets with a conventional warhead land strike capability. The TWS provides the capability to attack inland targets in areas where the United States may or may not have sea or air control.

3.1.4.5 CCC

The CCC, CCCI options are listed in Table 19, and discussed in the following paragraphs.

Table 19 CCC Combat Systems Options Table

War fighting System	Options
CCC,CCCI	Option 1: Enhanced CCC Option 2: Basic CCC All options include the Total Ship Computing Environment (TSCE)

Command, Control, Communication (CCC) is an integration of key operational abilities, sensors and radar detection to develop a complete image of the surrounding environment. This introduces Cooperative Engagement Capability (CEC). CEC is a system of hardware and software that allows the sharing of radar data on air targets among ships. Radar data from individual ships of a Battle Group is transmitted to other ships in the group via a line-of-sight, data distribution system (DDS). Each ship uses identical data processing algorithms resident in its cooperative engagement processor (CEP), resulting in each ship having essentially the same display of track information on aircraft and missiles. An individual ship can launch an anti-air missile at a threat aircraft or anti-ship cruise missile within its engagement envelope, based on track data relayed to it by another ship. Program plans include the addition of E-2C aircraft equipped with CEP and DDS, to bring airborne radar coverage plus extended relay capability to CEC. A flow chart of the Total Ship Computing Environment (TSCE) of ship and supporting components is seen in Figure 29.

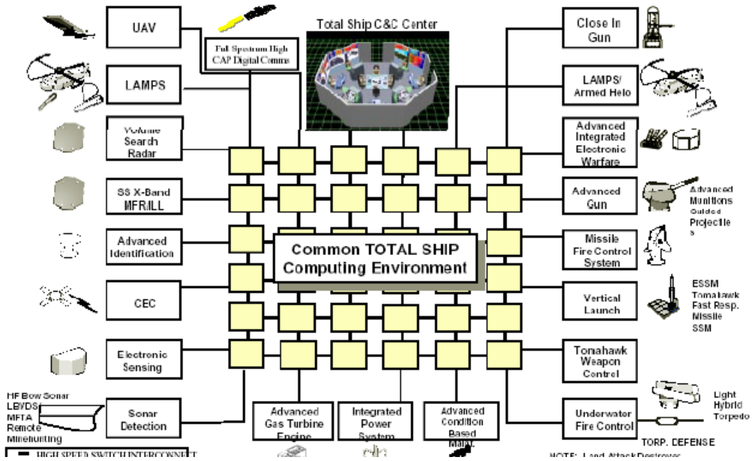


Figure 29 Total Ship Computing Environment

3.1.4.6 **LAMPS**

Table 20 LAMPS Options Table

War fighting System	Options
LAMPS	Option 1: SH-60, Hell Fire Penquin Missiles, Sonobouy, Option 2: SH-60, Hell Fire Penquin Missiles, Sonobouy, Option 3: MKIII in-flight refueling system. All Options Include UVA, MKIII systems

The major component of LAMPS is the SH-60 Seahawk, or LAMPS MK III (Figure 30). It can do a wide range of things, including ASW, ASUW, SPECOPS, cargo lift, and search and rescue. It can deploy sonobuoys, torpedoes (MK46 or MK50) and AGM-119 penguin missiles, as well as house two 7.62 mm machine guns. Figure 31 shows the use of the “Fire and Forget” penguin missiles which are used for multiple target acquisition.

Figure 30 SH60 Seahawk

Figure 31 SH60 Seahawk firing a AGM-119 penguin missile

3.1.4.7 MMOD: Mission Modularity

The MMOD options are listed in Table 21 and discussed in the following paragraphs.

Table 21 Mission Modularity Combat System Variables

War fighting System	Options
MMOD	Option 1: 1.5xLCS Mission Payload Option 2: 1xLCS Mission Payload Option 3: 1/2xLCS Mission Payload

The LCS mission packages include ASW, ASUW and ISR options. These package arrangements can be added, removed, or modified for a particular mission. The full LCS package consists of 2 unmanned surface vehicles, which work in tandem for wide area detection. USVs may also deploy a towed variant of Airborne Low-Frequency Sonar (ALFS). One MH-60R helo with MK54 torpedoes, ALFS, and sonobuoys which were mentioned in section 3.1.4.6. Three Firescout Vertical Takeoff Unmanned Air Vehicles (VTUAV) for data relay. Two AN/WLD-1 Remote Mine hunting Vehicles (RMV) with multifunction towed arrays. The package also consists of an Extended Echo Ranging (EER) acoustic sensor system and torpedo countermeasures. Figure 32 shows this complete package option.

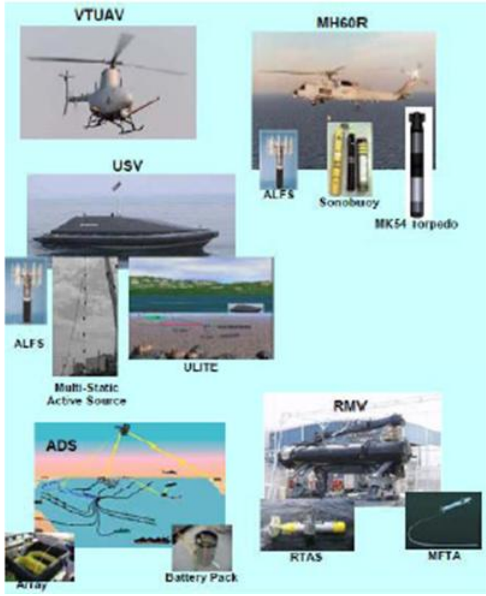


Figure 32 LCS Mission Package

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 Table 22are included in the ship synthesis model data base.

Table 22 Combat System Ship Synthesis Characteristics

ID	NAME	DV	WTGRP	SingleD	WT (MT)	HD10 (m)	HAREA (m2)	DHAREA (m2)	CRSKW	BATKW
86	VOLUME SEARCH RADAR [S BAND]- VSR	AAW	W456	400	198	7.5	0	304	2100	2100
87	GLYCOL WATER COOLING SYSTEM FOR VSR	AAW	W532	500	54.04	4.5	0	100	1900	1900
88	VOLUME SEARCH RADAR [S BAND]- VSR+	AAW	W456	400	256	7.5	0	393	2714	2714
89	GLYCOL WATER COOLING SYSTEM FOR VSR+	AAW	W532	500	98.76	4.5	0	183	2300	2300
90	VOLUME SEARCH RADAR [S BAND]- VSR++	AAW	W456	400	398	7.5	0	610	4181	4181
91	GLYCOL WATER COOLING SYSTEM FOR VSR++	AAW	W532	500	158.13	4.5	0	293	3500	3500
92	VOLUME SEARCH RADAR [S BAND]- VSR+++	AAW	W456	400	425	7.5	0	651	4462	4462
93	GLYCOL WATER COOLING SYSTEM FOR VSR+++	AAW	W532	500	189.76	4.5	0	352	4200	4200
94	AN/SPY-3 MFR - MULTIPLE MODE RADAR	AAW	W456	400	75.71	10.5	0	108.68	382.7	382.7
95	GLYCOL WATER COOLING SYSTEM FOR SPY-3 MFR / EWS	AAW	W532	500	22.92	1.43	0	25.14	300	300
96	AEGIS BMD 2014 COMBAT SYSTEM AND CIC	AAW	W411	400	17.6183	-1.09728	184.784	0	74.5	74.5
97	CIFF-SD	AAW	W455	400	4.47	16.22	0	0	2.7	2.4
98	MK53 NULKA DECOY LAUNCHING SYSTEM - DLS	AAW	WF21	20	0.82	-1.4	0	0	0	0
99	MK 36 SRBOC DECOY LAUNCHING SYSTEM - DLS	AAW	WF21	20	3.06	1.6	0	0	0	0
100	AIEWS - ACTIVE ECM -	AAW	W471	400	9.88	1.4	0	6.5	0.32	0.32

ID	NAME	DV	WTGRP	SingleD	WT (MT)	HD10 (m)	HAREA (m2)	DHAREA (m2)	CRSKW	BATKW
	SLQ/32R									
101	IRST - INFRARED SENSING & TRACKING	AAW	W459	400	0	4.45	0	0	0	0
12	SPS-73 SURFACE SEARCH RADAR	ASUW	W451	400	0.24	9.02818	0	6.50321	0.2	0.2
13	SMALL ARMS AND PYRO STOWAGE	ASUW	W760	700	5.94387	-1.92024	18.8593	0	0	0
14	SMALL ARMS AMMO - 7.62MM + 50 CAL + PYRO	ASUW	WF21	20	4.16579	-1.8288	0	0	0	0
16	FLIR	ASUW	W452	400	0.16	10.8	1	0	0	1.5
17	GFCS	ASUW	W481	400	0.762035	-1.8288	0	13.9355	12.3	42.7
18	3 X 30MM CIGS GUN	ASUW	W164	100	2.5	1.83	0	0	0	0
19	SWBS 187 3 X 30MM CIGS GUN FOUNDATION	ASUW	W187	100	9	4.35	0	0	0	0
20	3 X CIGS SYSTEMS	ASUW	W711	700	16.94	4.9	23.84	0	20	40
21	3 X CIGS HOIST EXTENTIONS	ASUW	W711	700	0.89	0.1	0	0	0	0
22	3 X CIGS AMMO HOIST	ASUW	W712	700	0.45	2.6	0	0	0	0
23	3 X CIGS CASE CAPTURE	ASUW	W712	700	4.96	3.57	0	0	0	0
24	3 X 30MM CIGS GUN AMMO	ASUW	WF21	20	4.29	-1.5	0	0	0	0
25	2 X 7M RHIB	ASUW	W583	500	7	-3	38.02	0	0	0
26	1 X MK110 57MM GUN	ASUW	W710	700	18	-1.88976	26.4774	0	36.6	50.2
27	MK110 57MM AMMO - 600 RDS	ASUW	WF21	20	16	-8.65632	65.4966	0	0	0
28	MK110 57MM GUN HY-80 ARMOR LEVEL II	ASUW	W164	100	10	-2.4384	0	0	0	0
29	1X MK45 5IN/62 GUN	ASUW	W710	700	37.3905	-1.88976	26.4774	0	36.6	50.2
30	MK45 5IN AMMO - 600 RDS	ASUW	WF21	20	33.6312	-8.65632	65.4966	0	0	0
31	MK45 5IN/62 GUN HY-80 ARMOR LEVEL II	ASUW	W164	100	20.5243	-2.4384	0	0	0	0
67	DUAL FREQUENCY BOW ARRAY SONAR DOME STRUCTURE	ASW	W165	100	22.5	-18.5	0	0	0	0
68	DUAL FREQUENCY BOW ARRAY SONAR ELEX	ASW	W463	400	26.73	-11.8	104.2	0	94.3	94.3
69	DUAL FREQUENCY BOW ARRAY SONAR HULL DAMPING	ASW	W636	600	10.1	-16.9	0	0	0	0
70	SQS-56 SONAR DOME STRUCTURE	ASW	W165	100	7.43	-17.5	0	0	0	0
71	SQS-56 SONAR ELEX	ASW	W462	400	5.88	-11.8	126.86	0	19.7	19.7
72	SQS-56 SONAR HULL DAMPING	ASW	W636	600	2.01	-16.9	0	0	0	0
73	SQS-53 SONAR DOME STRUCTURE	ASW	W165	100	85.7	-18.9	0	0	0	0
74	SQS-53 SONAR ELEX	ASW	W462	400	67.4	-11.8	271.7	0	100	100
75	SQS-53 SONAR HULL DAMPING	ASW	W636	600	20.1	-16.9	0	0	0	0
76	MINEHUNTING SONAR	ASW	W462	400	2.1	-16.5	21	0	3.7	3.7
77	ISUW - INTEGRATED UNDERSEA WARFARE SYS	ASW	W483	400	4.87703	-3.3528	0	0	19.5	19.5
78	SQR-19 TACTAS	ASW	W462	400	23.6739	-3.6096	43.9431	0	26.6	26.6
79	AN/SLQ-25 NIXIE	ASW	W473	400	3.65777	-3.6096	15.9793	0	3	4.2
80	BATHYTHERMOGRAPH	ASW	W465	400	2.63	-1.25	0	0	0	0
81	TORPEDO DECOYS	ASW	W473	400	5.09	-7.29	46	0	2.4	2.4
82	C+S OPERATING FLUIDS	ASW	W498	400	72.31	-16.15	0	0	0	0
83	2X MK32 SVTT ON DECK	ASW	W750	700	2.74333	-2.0856	0	0	0.6	1.1
84	6 X MK46 LIGHTWEIGHT ASW TORPEDOES	ASW	WF21	20	1.38182	-2.0856	0	0	0	0
59	TOTAL SHIP COMPUTING ENVIRONMENT	CCC	W412	400	73.38	-6.93	763.6	0	435.68	435.68
60	ENHANCED RADIO/EXCOMM	CCC	W441	400	51	11.31	0	265	227.89	228.19
61	BASIC RADIO/EXCOMM	CCC	W440	400	32.9098	10	0	158	93.3	96.4
62	TOMAHAWK WEAPON CONTROL SYSTEM	CCC	W482	400	5.70002	-2.37744	0	0	11.5	11.5
63	UNDERWATER	CCC	W442	400	2.88	-11.22	0	0	0	0

ID	NAME	DV	WTGRP	SingleD	WT (MT)	HD10 (m)	HAREA (m2)	DHAREA (m2)	CRSKW	BATKW
	COMMUNICATIONS									
64	VISUAL & AUDIBLE SYSTEMS	CCC	W443	400	0.32	-5.46	0	0	0	0
65	SECURITY EQUIPMENT SYSTEMS	CCC	W446	400	0.88	-7.27	0	0	0	0
33	PVLS NON-STRUCTURE FRAG ARMOR 64 CELLS	GMLS	W164	100	213.75	-7.68	0	0	0	0
34	PVLS NON-STRUCTURE FRAG ARMOR 56 CELLS	GMLS	W164	100	171	-7.68	0	0	0	0
35	PVLS NON-STRUCTURE FRAG ARMOR 48 CELLS	GMLS	W164	100	128.25	-7.68	0	0	0	0
36	PVLS FOUNDATIONS 64 CELLS	GMLS	W187	100	60.5	-4.65	0	0	0	0
37	PVLS FOUNDATIONS 56 CELLS	GMLS	W187	100	48.4	-4.65	0	0	0	0
38	PVLS FOUNDATIONS 48 CELLS	GMLS	W187	100	36.3	-4.65	0	0	0	0
39	PVLS COOLING UNIT-VLS MAG 64 CELLS	GMLS	W514	500	59.48	-4	0	0	0	0
40	PVLS COOLING UNIT-VLS MAG 56 CELLS	GMLS	W514	500	47.58	-4	0	0	0	0
41	PVLS COOLING UNIT-VLS MAG 48 CELLS	GMLS	W514	500	35.69	-4	0	0	0	0
42	PVLS COOLING EQUIPMENT OPERATING FLUIDS 64 CELLS	GMLS	W598	500	27.47	-4	0	0	0	0
43	PVLS COOLING EQUIPMENT OPERATING FLUIDS 56 CELLS	GMLS	W598	500	21.98	-4	0	0	0	0
44	PVLS COOLING EQUIPMENT OPERATING FLUIDS 48 CELLS	GMLS	W598	500	16.48	-4	0	0	0	0
45	PVLS 64 CELLS	GMLS	W721	700	628.92	-4.33	1900	0	724.6	724.6
46	PVLS 56 CELLS	GMLS	W721	700	503.14	-4.33	1520	0	579.68	579.68
47	PVLS 48 CELLS	GMLS	W721	700	377.35	-4.33	1140	0	434.76	434.76
48	PVLS MISSLE HANDLING	GMLS	W722	700	0.25	14	0	0	0	0
49	PVLS LOADOUT 64 CELLS	GMLS	WF21	20	332.375	-3.77	0	0	0	0
50	PVLS LOADOUT 56 CELLS	GMLS	WF21	20	265.9	-3.77	0	0	0	0
51	PVLS LOADOUT 48 CELLS	GMLS	WF21	20	199.43	-3.77	0	0	0	0
2	155 MM AGS PROTECTION	ASUW	W164	100	19	0.86	0	0	0	0
3	155 MM AGS FOUNDATIONS	ASUW	W187	100	47	-0.15	0	0	0	0
4	155 MM AGS MAGAZINE SUPPORT	ASUW	W187	100	8.4	-13.65	0	0	0	0
5	155 MM AGS STOREROOM PROTECTION	ASUW	W164	100	12.75	-8.9	0	0	0	0
6	155 MM AGS GUN MOUNT	ASUW	W711	700	44.1	1.35	54.14	0	30	275
7	155 MM AGS ENERGY STORAGE SUBSYSTEM	ASUW	W711	700	7.49	-1.9	0	0	0	0
8	155 MM AGS CABLE	ASUW	W711	700	2.99	-2.9	0	0	0	0
9	155 MM AGS GUN HANDLING SYSTEM	ASUW	W712	700	105	-9.91	0	0	0	0
10	155 MM AGS AMMO PALLETS [304 ROUNDS]	ASUW	WF21	20	54.4	-8.65	342	0	0	0
11	155 MM AGS AMMO LOADOUT - 304 ROUNDS	ASUW	WF21	20	44.2	-7.9	0	0	0	0
103	DUAL HELO/UAV DET - 2X SH60R HANGAR UPPER LEVEL 17 X 15.7	LAMPS	NONE	100	0	0	0	266.9	0	0
104	DUAL HELO/UAV DET - 2X SH60R HANGAR LOWER LEVEL 17 X 15.7	LAMPS	NONE	100	0	0	0	266.9	0	0
105	DUAL HELO/UAV DET - FUEL SYSTEM	LAMPS	W542	500	21	-9.84	0	2.77	0	0
106	DUAL HELO/UAV DET - HNDLG/SUPPORT/MAINT/ WKSP - AREA ONLY	LAMPS	NONE	500	0	0	0	34.1	0	0
107	DUAL HELO/UAV DET -	LAMPS	NONE	500	0	0	44.4	0	0	0

ID	NAME	DV	WTGRP	SingleD	WT (MT)	HD10 (m)	HAREA (m2)	DHAREA (m2)	CRSKW	BATKW
	RAST/RAST CONTROL - AREA ONLY									
108	DUAL HELO/UAV DET - HANDLING/SERVICE/STOWAGE - WEIGHT ONLY	LAMPS	W588	500	26.04	-1.69	0	0	0	0
109	DUAL HELO/UAV DET - MAGAZINE HANDLING	LAMPS	W712	700	0.001	-1.55	0	0	0	0
110	DUAL HELO/UAV DET - MAGAZINE 12-MK46 24-HELLFIRE 6-PENQUIN	LAMPS	WF22	20	0.001	-1.5	0	57.46	0	0
111	DUAL HELO/UAV DET - VTUAV	LAMPS	WF23	20	3.47	-2	0	0	0	0
112	DUAL HELO/UAV DET - 2X SH60R	LAMPS	WF23	20	10.66	-2	0	0	0	0
113	DUAL HELO/UAV DET - SUPPORT/SPARES	LAMPS	WF26	20	0	-2	0	158.08	0	0
114	SONOBOUY MAGAZINE STOWAGE - NONE IN PARENT	LAMPS	W713	700	0.001	-1.5	0	0	0	0
115	SONOBOUY MAGAZINE - 300 BUOYS - 88 MARKERS	LAMPS	WF22	20	0.001	-1.5	0	10.12	0	0
116	SQQ-28 LAMPS MK III ELECTRONICS	LAMPS	W460	400	3.51552	0.9144	0	0	5.3	5.5
117	LAMPS MKIII:AVIATION FUEL [JP-5]	LAMPS	WF42	40	65.4334	-12.4376	0	0	0	0
118	LAMPS MKIII:HELO IN-FLIGHT REFUEL SYS	LAMPS	W542	500	7.72196	-7.572	4.08773	0	1.3	1.3
119	BATHYTHERMOGRAPH PROBES	LAMPS	WF29	20	0.21337	-8.56359	0	0	0	0

3.1.5 Modularity Alternatives

There are a few options to add to the ship to make its systems modular; weapons systems, mast systems, deck track systems and HVAC systems. It is up to the size of the ship and the effectiveness of the systems to determine if it's applicable.

The MSC is able to take full advantage of the modular weapons systems. The PVLS system, seen in Figure 33, is made up of 4 cells that can be swapped and interchanged easily with other cells depending on mission and intended use of the ship. The Mk41 cell can also be interchanged with other closed and open containers depending mission and intent of use. Each cell area has an "allowed volume" which can give larger cells the room they need when replacing a smaller system.

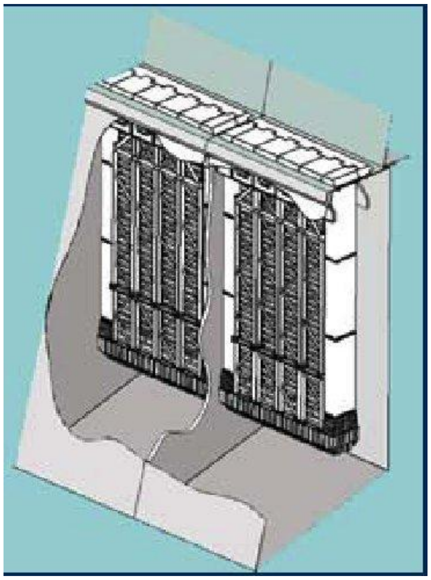


Figure 33 PVLS Cell

The modular mast system doesn't apply to the MSC due to the size of the ship. On a larger class ship the ability to completely replace the mast and radar system is limited. The mast on larger ships goes down directly into the bowels of the ship and would be inefficient to refit for mission. The only way to do this would to be to have a smaller mast and radar system, but that would limit the larger ships' ability to operate properly. Figure 34 shows the modular mast option 2. This mast is meant for 3 to 4 ton ships and cannot be use on the MSC. The MSC is 4 to 6 times as large, so it would not be practical for our ships needs.

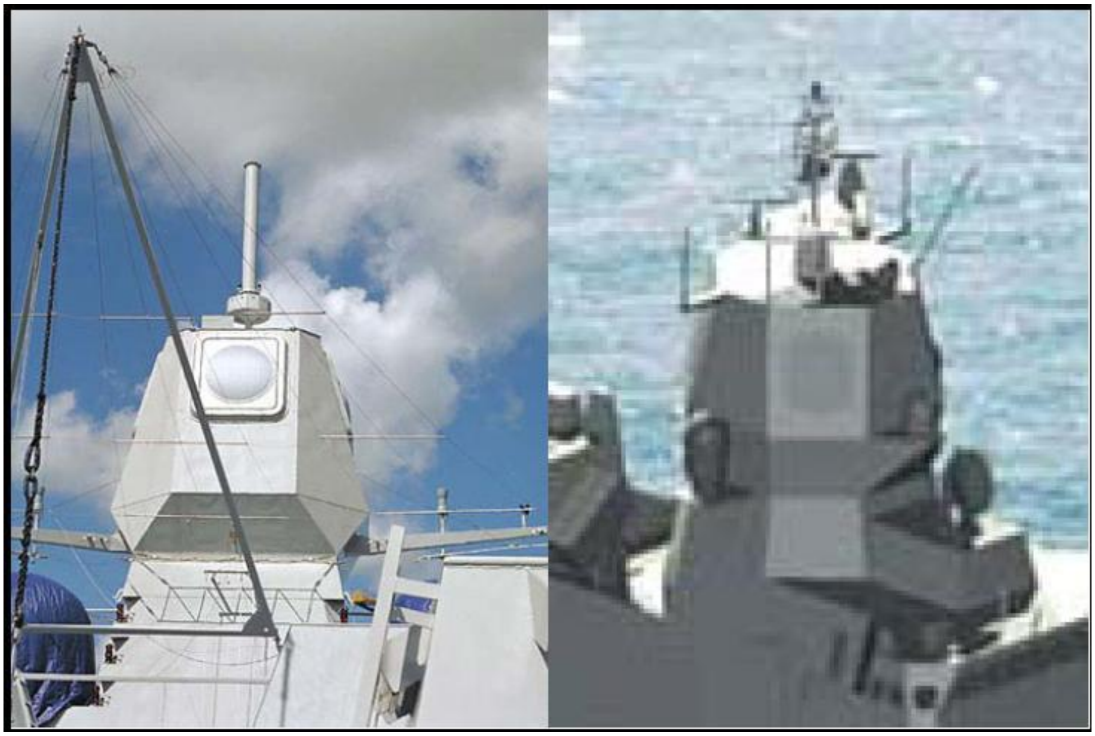


Figure 34 Modular Mast (Sensor Option 2)

The intent of the modular HVAC is to make sure that all parts are interchangeable. This allows for faster repairs and upgrades for refitting. Screws, nuts and bolts all need to be universal, so there can be no specialized parts. This also means the overhead and under-floor systems need to match.

A modular platform is also essential in avoiding costly and time consuming repairs. The MSC can switch out whole modules and the ship could be refitted for multiple tasks. Our ship could take full advantage of this to accommodate new missions on the fly. For example, a mission that requires the ship to have a greater range would be doable by removing whole modules or replacing them with lighter ones, thus making the ship more fuel efficient. Figure 35 shows how a ship may be made to accommodate different platforms and change them out for other missions.

Figure 35 Modularity Platform

In our MSC we will have modular implementation zones. They will be in designated areas for certain types of modules. These areas include weapons, sensors, electronics, and machinery elements for each zone. From these zones we will have stations such as structural, compressed air, water, and electrical or hydraulic power. Rules will be implemented for each zone to make sure the right stations and modules are appropriately used.

In our design we also have Design Variables shown in Table 23which details the options for modularity spaces on the ship.

Table 23 Modularity Design Variables

Modular System	Options
C4I	Option 1: C4I Raft Option 2: C4I Tracks Option 3: Conventional C4I
HM&E	Option 1: MR Deck Rafts Option 2: HM&E Palletized Option 3: HM&E Component Modules Option 4: Conventional HM&E
Habitability	Option 1: Hab Space Tracks Option 2: Standard Modular Hab Spaces Option 3: Conventional Hab Spaces
Weapons	Option 1: Maximum Margin and Interfaces Option 2: Minimum Margin and Interfaces Option 3: Same Modular Weapon Option 4: Conventional Weapon Install
Sensors/Topside	Option 1: Modular Sensors Option 2: Modular Mast Option 3: Conventional Sensor Install

Some of the modules that can be included on an MSC class ship include container, pallet, and structured modules. These all have the benefits of ease of maintenance, reduced cost, and improved availability. On top of that these modules have standardized components which helps in all of these areas.

Other than these few systems, modularity has not developed too many alternatives to what you can put on a larger class ship. Some of the smaller ships have the option of the modular mast and some other systems, but when it comes to an MSC your choices are limited.

3.2 Design Space

Table 24 presents the complete design space to be explored as represented by 29 design variables (DVs). The design variables consist of two categories; continuous variables (options 1-8, 11, 14), or discrete options. Each variable is intended to represent a design space value for the medium surface combatant mission. Design variables 1-9 are hullform options discussed in section 3.1.1. DVs 15-19 are combat system options as discussed in section 3.1.4.

Table 24 - Design Variables (DVs)

DV #	DV Name	Description	Design Space
1	LBP	Length between Perpendiculars	180-200 meters
2	LtoB	Length to Beam ratio	7.5-8.5
3	LtoD	Length to Depth ratio	11-14
4	BtoT	Beam to Draft ratio	2.8-3.0
5	Cp	Prismatic Coefficient	0.57 - 0.63
6	Cx	Maximum Section Coefficient	0.76 - 0.85
7	Crd	Raised Deck Coefficient	0.7 - 0.8
8	VD	Deckhouse volume	10,000-15,000m^3
9	Cdmat	Hull Material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite
10	PGM	Propulsion system alternative and Power Generation Module (PGM)	Option 1) 3xLM2500+,4160VAC, FPP Option 2) 3xLM2500+,13800VAC, FPP Option 3) 4xLM2500+,4160VAC, FPP Option 4) 4xLM2500+,13800VAC, FPP Option 5) 2xMT30, 4160VAC, FPP Option 6) 2xMT30, 13800VAC, FPP Option 7) 3xMT30, 4160VAC, FPP Option 8) 3xMT30, 13800VAC, FPP Option 9) 4xMT30, 4160VAC, FPP Option 10) 4xMT30, AC Synch, 13800VAC
11	Ts	Provisions duration	60 - 75 days
12	CPS	Collective Protection System	0 = none, 1 = partial, 2 = full
13	Ndegaus	Degaussing system	0 = none, 1 = degaussing system
14	Cman	Manning reduction and automation factor	0.5 – 0.1
15	AAW/BMD/STK	AAW/BMD/STK system Alternative	Option 1) SPY3/VSR+++ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 2) SPY3/VSR++ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 3) SPY3/VSR+ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 4) SPY3/VSR DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA
16	ASUW	ASUW system alternative	Option 1) 1xAGS gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS Option 2) MK45 5"/62 gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS Option 3) MK110 57mm gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS
17	ASW/MCM	ASW/MCM system alternative	Option 1) Dual Frequency Sonar Bow array, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 2) SQS-53C sonar, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 3) SQS-56 sonar, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE
18	CCC, CCI	CCC, CCI system alternatives	Option 1) Enhanced CCC, TSCE Option 2) Basic CCC, TSCE

DV #	DV Name	Description	Design Space
19	GMLS	GMLS system Alternative	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, 48xMK57 PVLS or VLS, Tomahawk WCS Option 4) 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS, Tomahawk WCS
20	MMOD	MMOD system Alternative	Option 1) 1.5xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs Option 2) 1xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs Option 3) 1/2xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs
21	SPGM	Secondary Power Generation Module (SPGM)	Option 1) NONE Option 2)2xLM500G, AC Synch Option 3)2xCAT3608 Diesel Option 4)2xPC 2.5/18 Diesel Option 5)2xPEM 3 MW Fuel Cells Option 6)2xPEM 4 MW Fuel Cells Option 7)2xPEM 5 MW Fuel Cells
22	PROPtype	Propeller Type	Option 1) 2 x FPP (Fixed Pitch Propeller) Option 2) 2 x Pods
23	PMM	Propulsion Motor Module Type	Option 1) (AIM) Advanced Induction Motor (DDG 1000) Option 2) (PMM) Permanent Magnet Motor
24	DISTtype	Power Distribution Type	Option 1) AC ZEDS Option 2) DC ZEDS (DDG 1000)
25	C4IMOD	C$I system alternative	Option 1) C4I Raft Option 2) C4I Tracks Option 3) Conventional C4I
26	HMEMOD	HM&E system alternatives	Option 1) MR Deck Rafts Option 2) HM&E Palletized Option 3) HM&E Component Modules Option 4) Conventional HM&E
27	HABMOD	Habitability system alternatives	Option 1) Hab Space Tracks Option 2) Standard Modular Hab Spaces Option 3) Conventional Hab Spaces
28	WPMOD	Weapons system alternatives	Option 1) Maximum Margin and Interfaces Option 2) Minimum Margin and Interfaces Option 3) Same Modular Weapon Option 4) Conventional Weapon Install
29	SNSMOD	Sensors/Topside system alternatives	Option 1) Modular Sensors Option 2) Modular Mast Option 3) Conventional Sensor Install
30	LAMPS		Option 1) SH-60, Hell Fire Penquin Missiles, Sonobouy, UVA, MKIII systems Option 2) MKIII in-flight refueling system, UVA, MKIII systems

3.3 Ship Synthesis Model

The primary function of the ship synthesis model is to balance or ensure that there is a balanced ship design. There is a balanced ship design when displacement equals weight, there is sufficient volume and space, there is sufficient electrical power, and there is adequate stability. It is important to balance the ship because it is ensures that the design is feasible. One is interested in a ship's threshold caps in performance and whether or not the ship is cost and risk acceptable. These parameters are assessed by performing an engineering analysis on perspective ship designs and the ship synthesis model aids in this process. The ship synthesis model is made up of several modules that represent different design criteria and help to determine the appropriate ship. The model flowchart can be seen below in Figure 36 and the description of these modules subsequently follows.

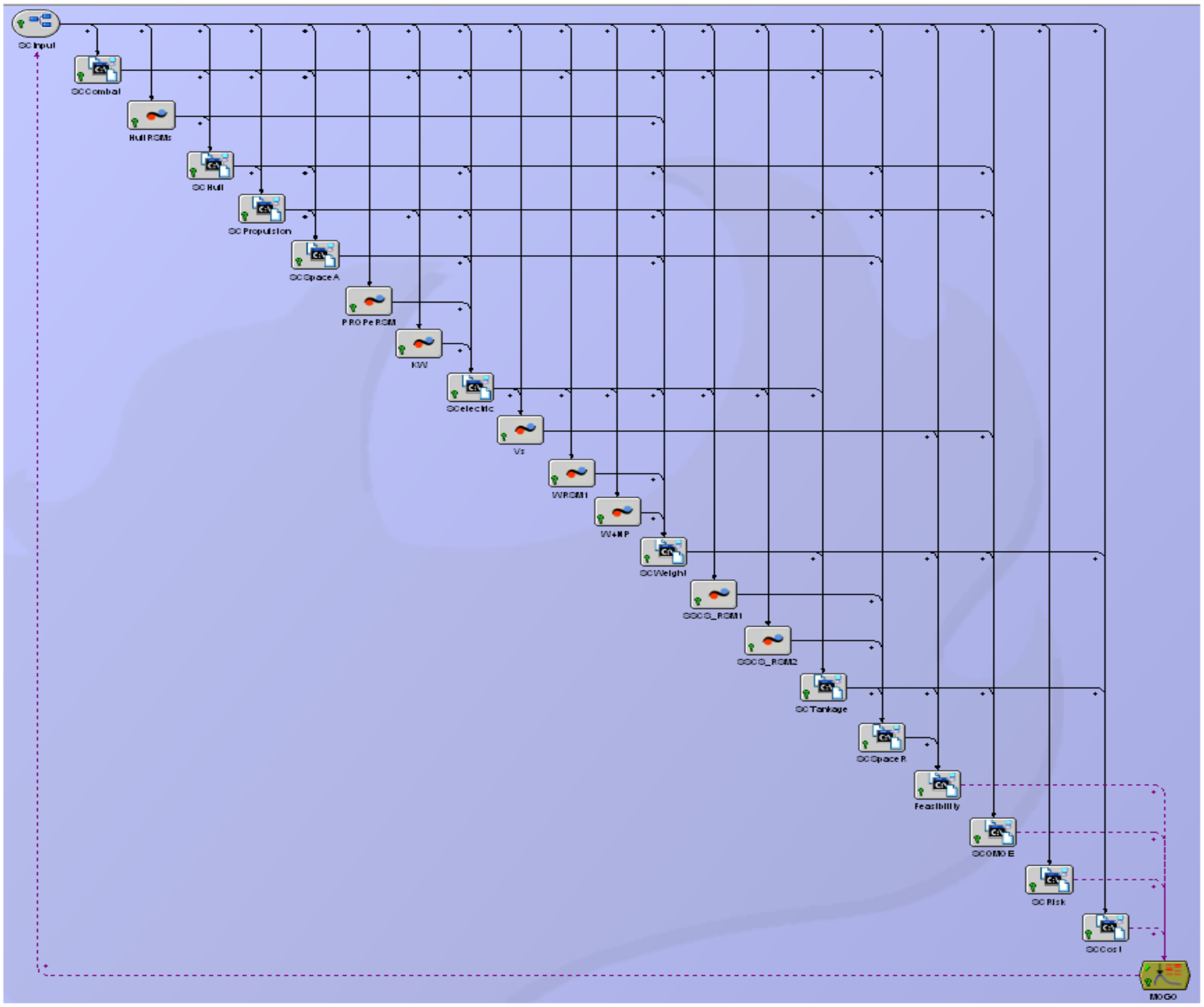


Figure 36 - Ship Synthesis Model in Model Center (MC)

Each module is represented by an actual computer code, written in FORTRAN that calculates the output variables given the necessary input variables. The input and output are managed and interconnected in the Model Center environment. One can run an optimization and Model Center will manage all the inputs and outputs by linking them and ensuring they are updated. Model Center provides the connections needed in order to run individual modules together as a unit.

The combat systems module calculates payload characteristics. This module outputs payload weight, the payload vertical center of gravity, the variable payload weight, the variable payload vertical center of gravity, the payload structure weight, the payload CCC weight, the payload auxiliaries weight, the payload outfit weight, the payload weapons weight, the payload SWBS 100, 400, 500, 600, and 700 vertical center of gravities, the helo miscellaneous weights, the expendable ordnance weight, the sonar type, the payload required deckhouse CCC area, the payload required deckhouse armament area, the payload required hull CCC area, the payload required hull armament area, the payload electric power required, the payload deckhouse area required, the payload hull area required, the depth at station 10, the number of officers, the number of enlisted, the total crew, and additional accommodations.

The propulsion module calculates characteristics as delta from baseline. It calculates propulsion and generator system characteristics. This module outputs the propulsive coefficient, the sum of the number of engines multiplied by the power available for all engines online at sustained speed, the SEC engine SFC or the main engine SFC, the maximum engine or motor height plus one meter, the machinery space volume from SWBS 200, the SEC engine power available and/or one main engine power available, the number of propellers, the database PGM engine number, the database SPGM engine number, and the number of PGMs.

The input module is not a calculation module and does not use a FORTRAN code. It takes user input or input from the MOGO and distributes them to the other modules as required. The input module is a single point of input for the overall module and feeds the data in one place to all the other modules.

The hull module is a FORTRAN code that does some simple calculations associated with the hull form given input and provides output values that are used by the other modules. The inputs for the module are length on the waterline, beam, depth at station 10, draft, prismatic coefficient, maximum section coefficient, and a sonar dome type. The module uses these primary inputs to calculate to surface area, sonar dome surface area, volume of the sonar dome, volume full load displaced volume of ship, the waterplane coefficient, volumetric coefficient, the beam to draft ratio, and the block coefficient.

The space module parametrically extracts some characteristics of a hull form for which there is not a full 3d shape. However, some requirements and other rules can be used to give a hull form shape consistent with what is needed based on t he principle characteristics of the hull form. The module calculates volume machinery box required, volume of the hull total, the cubic number, the total volume of the entire ship, the height of the machinery box, the minimum depth at station 10, and the average depth of the hull form from baseline to deck edge from bow to stern. It also calculates space available on the ship by using input variables from the input module, the hull module, and the propulsion module.

The electric module primarily calculates power requirements for the design. The size of the ship, combat systems, and the propulsion systems are important in determining these requirements. The module also does a simple calculation for manning because this is a convenient place to perform it. The module calculates electrical load and auxiallry machinery room volume.

The resistance module calculates the hull resistance based on the inputs using the Holtrop Mennen method. It also calculates required shaft horsepower endurance, sustained speed, and the propeller diameter.

The weight module calculates the total weight and organizes the weights by SWBS number. It also calculates weights in each weight group in single digit groups (100 to 700), calculates loads such as fuel, water, and lube oil, and also calculates vertical centers of gravity. The module calculates KG overall, KB overall, and from those it is possible to obtain GM (height of the metacenter above the center of gravity). It is then possible to obtain an estimate of the stability and the stiffness in roll based on that waterplane. It is then possible to calculate the weight of ship and the vertical center of gravity and ultimately the stability of the ship.

The tankage module calculates tankage requirements based on DDS 200-1. This module outputs total tankage volume, fuel volume, endurance range from endurance fuel calculation, the gallons per year used assuming 2000 hours per year operation (propulsion operation), and average effective brake horsepower.

The space required module calculates and estimates the space requirements. These measurements are necessary to ensure that the ship is balanced and thus feasible. Available volume and area should be equal to or exceed the requirement. The module calculates total deckhouse required area, available deckhouse area, total required volume, and total available volume.

The feasibility module is where all the balance related parameters that have already been calculated related to space, weight, and minimum or threshold performance requirements are reconciled. It outputs the total arrangeable area, the feasibility ratio, the deckhouse area feasibility ratio, the sustained speed feasibility ratio, the endurance speed feasibility ratio, the electric power feasibility ratio, the minimum and maximum GM/B feasibility ratio, the hull depth feasibility ratio, and the endurance range feasibility ratio.

The cost module calculates lead and follow acquisition cost and life cycle cost. The module outputs lead ship acquisition cost, the average follow ship acquisition cost, the follow ship total ownership cost, the discounted life cycle fuel cost (30 years), and the discounted life cycle manning cost (30 years).

The OMOE module calculates the ship overall measure of effectiveness. The module assesses the performance of all the input systems and determines the overall value for performance.

The risk module calculates the overall measure of risk. The module assesses the risk of all the input systems and determines the overall risk of the ship design.

Several Response Surface Models (RSMs) were created as part of the Ship Synthesis model. RSMs are parametric models that represent more complex workings of a simulation or experimental data. RSMs were incorporated into the Ship Synthesis Model in order to represent entities of the ship that required a more detailed regression type analysis. This regression model can more accurately predict the dependency of these entities on their continuous variables.

Hull RSMs for hull volume and hull and bare hull structural weight were derived as functions of the length between perpendiculars, the beam, the depth at station 10, the draft at the design waterline, the block coefficient, and the prismatic coefficient. The dependency of the hull volume RSM on these variables can be seen in Figure 37. The hull volume RSM is very dependent on the length between perpendiculars. Figure 36 shows that the hull RSM provides input for the FORTRAN hull module and the FORTRAN space module.

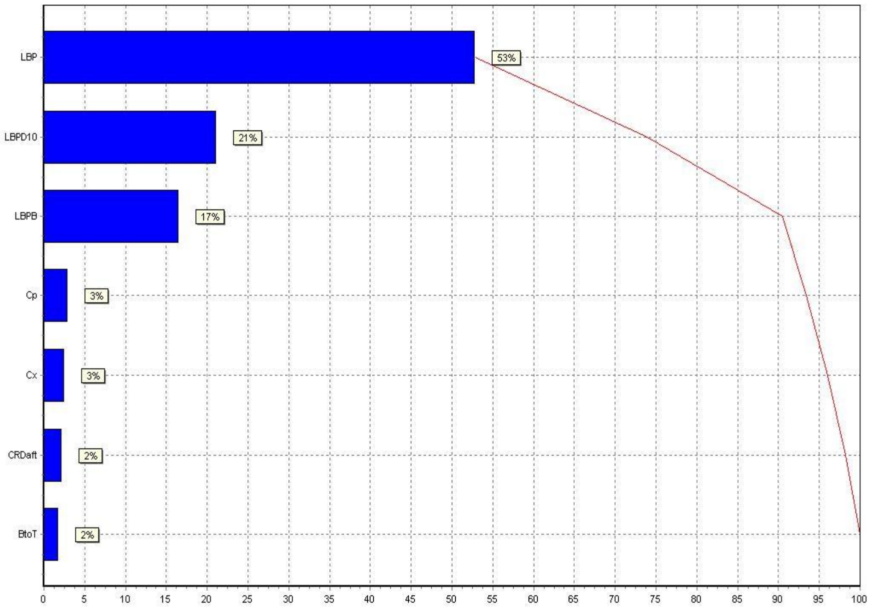


Figure 37 Hull Volume RSM

Figure 38 shows the heavy dependence of the SSCS (Ship Space Classification System) 1150 (IC) RSM on the LBP and LBPB. All of the other continuous variables shown in the figure have a small effect on the model. The SSCS 1150 (IC) RSM uses output from previous modules and produces output for the FORTRAN space module.

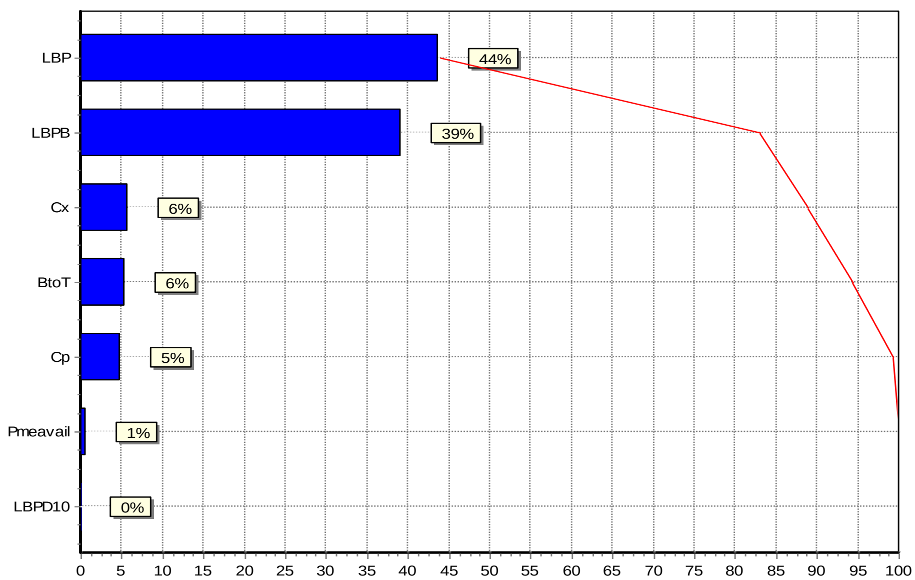


Figure 38 SSCS 1150 (IC) RSM

Figure 39 shows that the SCSS 2000 (Human Support) RSM is essentially completely dependent on the length between perpendiculars. This RSM uses output from previous modules in order to produce output for the FORTRAN space module.

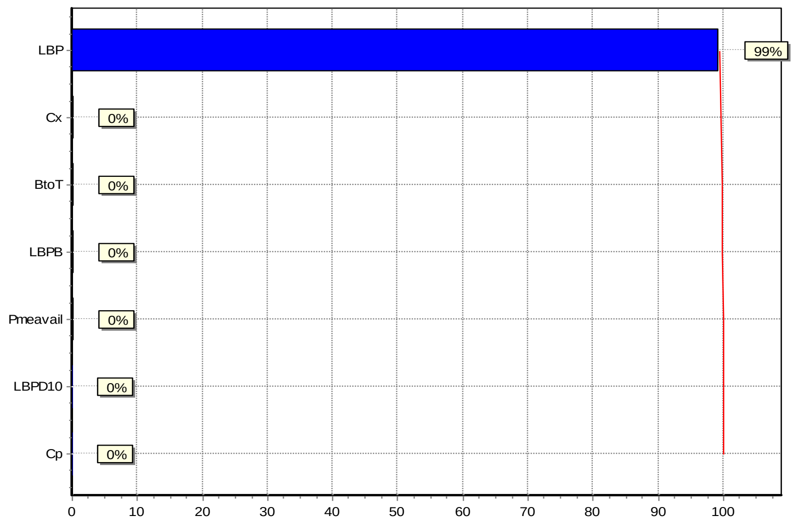


Figure 39 SCSS 2000 (Human Support) RSM

Figure 40 shows the dependencies for the SCSS 3000 (Ship Support) RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN space module.

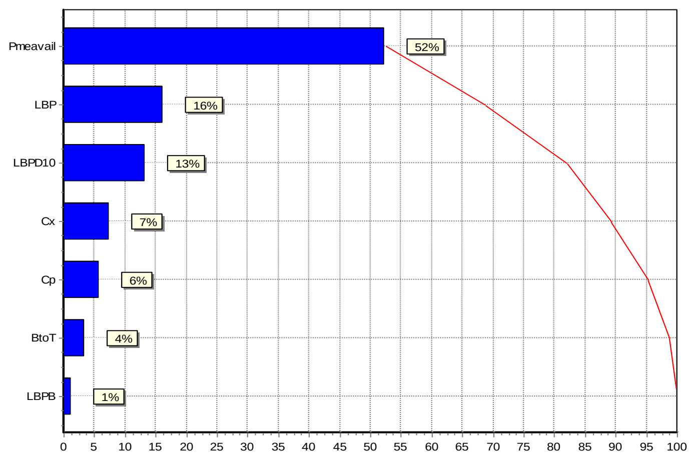


Figure 40 SCSS 3000 (Ship Support) RSM

Figure 41 shows the dependencies for the SCSS 4300 (Auxiliaries) RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN space module.

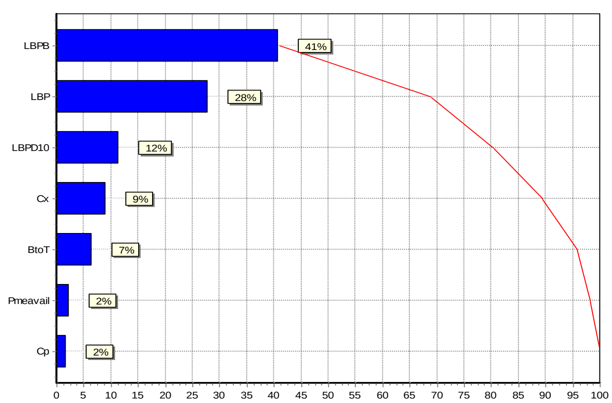


Figure 41 SCSS 4300 (Auxiliaries) RSM

Figure 42 shows the dependencies for the KWmflm RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN electric module.

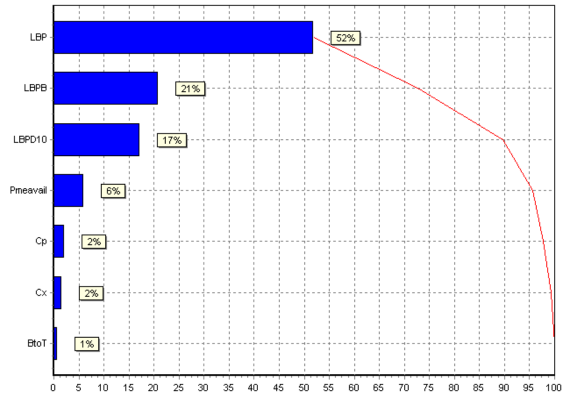


Figure 42 KWmflm RSM

Figure 43 shows the dependencies for the KW24 RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN electric module.

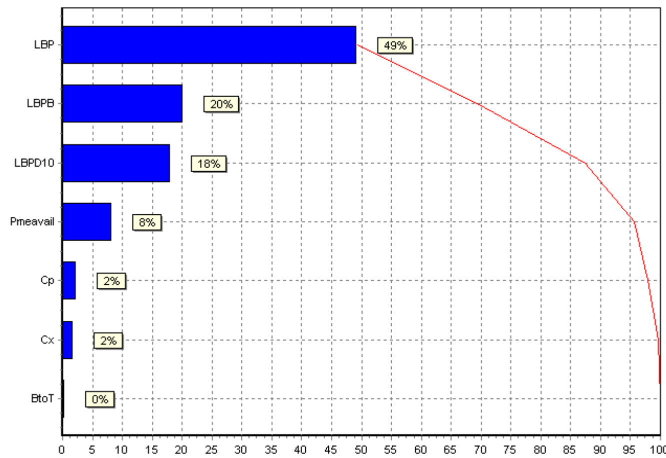


Figure 43 KW24

Figure 44 shows that the W320 RSM is almost completely dependent on the length between perpendiculars. This RSM uses output from previous modules in order to produce output for the FORTRAN weight module.

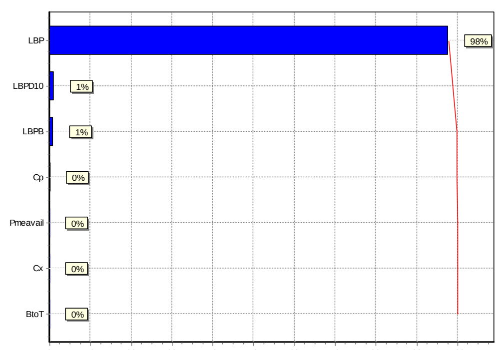


Figure 44 W320 RSM

Figure 45 shows the dependencies for the W330 RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN weight module.

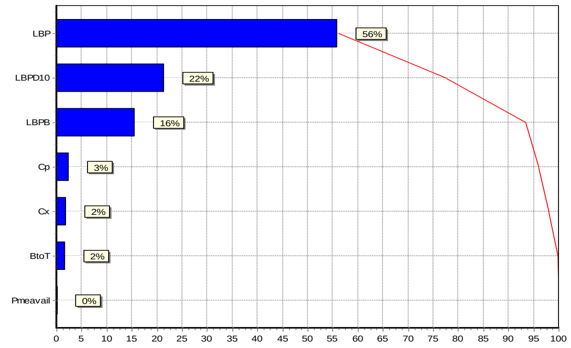


Figure 45 W330 RSM

Figure 46 shows the dependencies for the W4NP RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN weight module.

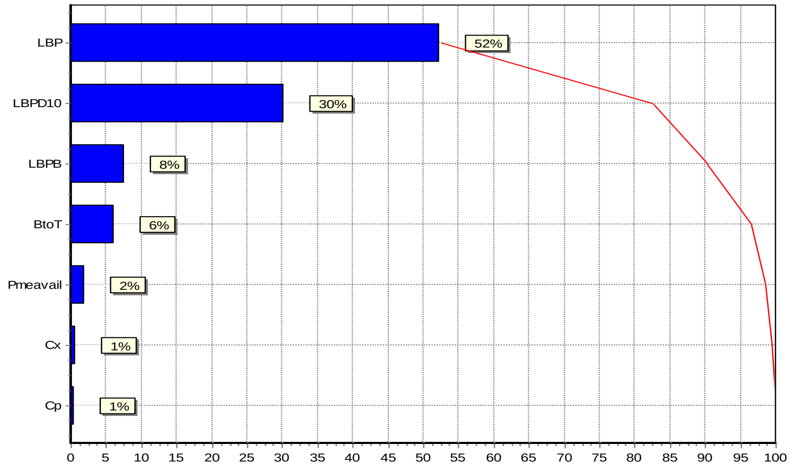


Figure 46 W4NP RSM

Figure 47 shows the dependencies for the W5 RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN weight module.

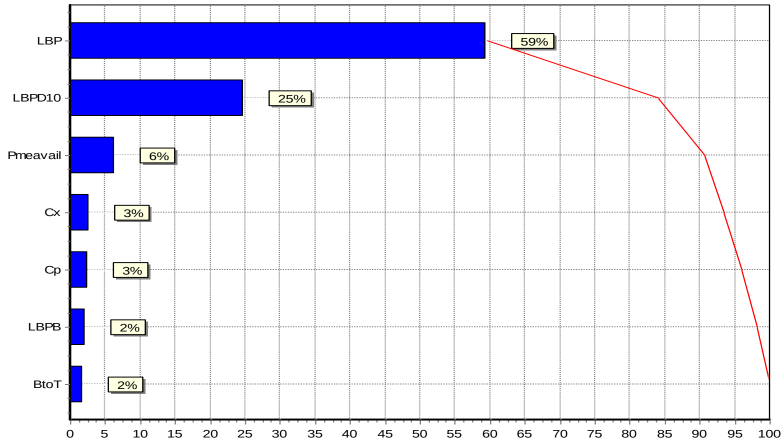


Figure 47 W5 RSM

Figure 48 shows the dependencies for the W6 RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN weight module.

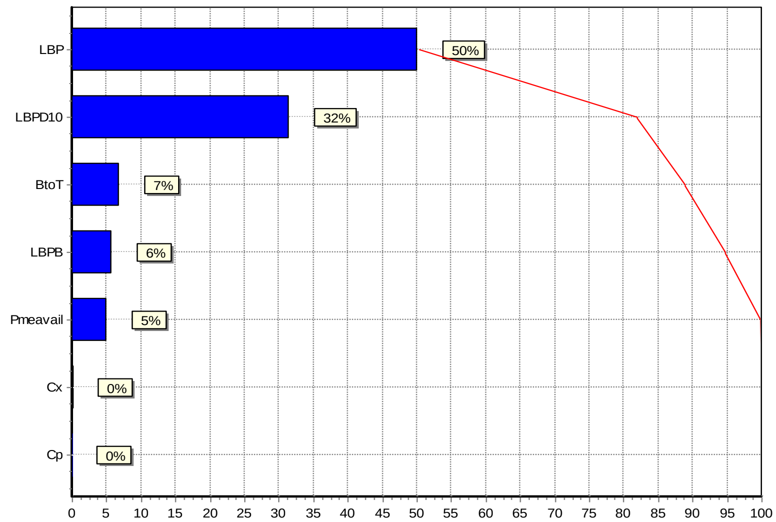


Figure 48 W6 RSM

Figure 49 shows the dependencies for the Effective Horsepower RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN electric module.

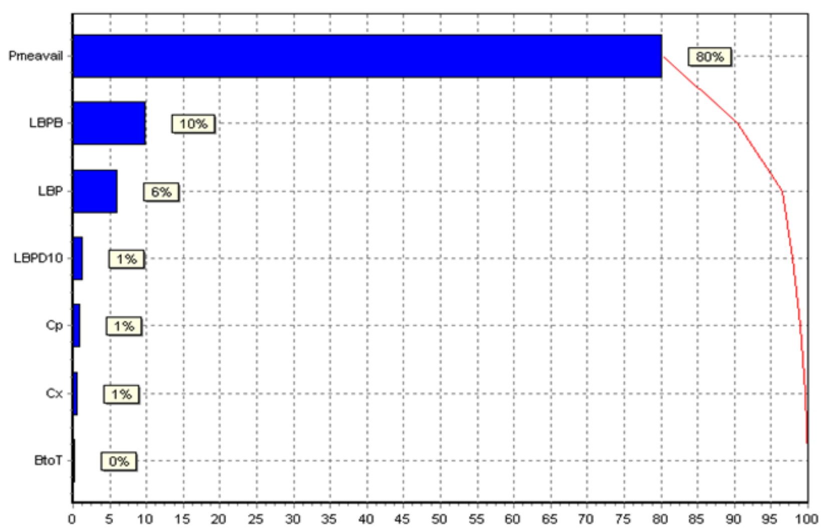


Figure 49 Effective Horsepower RSM

Figure 50 shows the dependencies for the Propulsive Coefficient RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN electric module.

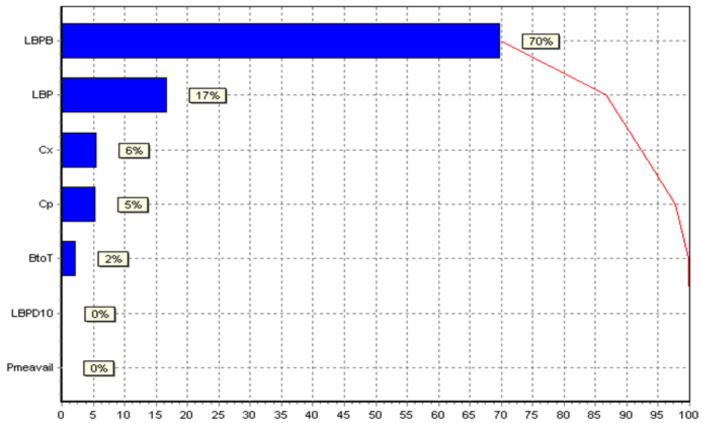


Figure 50 Propulsive Coefficient RSM

Figure 51 shows the dependencies for the Sustained Speed RSM. This RSM uses output from previous modules in order to produce output for the FORTRAN feasibility module and the FORTRAN OMOE module.

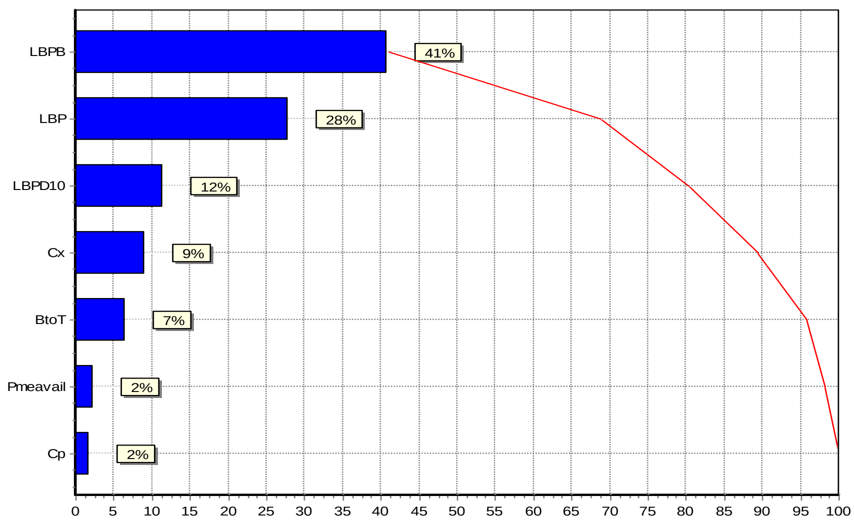


Figure 51 Sustained Speed RSM

3.4 Objective Attributes

3.4.1 Overall Measure of Effectiveness (OMOE)

The overall measure of effectiveness (OMOE) is a parameter that quantifies the performance of a ship with respect to specific mission requirements with a value of zero to one. The following equation is used to assess the value of the OMOE.

$$OMOE = g\left[VOP_i\left(MOP_i\right)\right] = \sum_i w_i VOP_i\left(MOP_i\right)$$

Here MOP is measure of performance; it is a system performance metric for the MSCs required capabilities which is independent of mission type. VOP is value of performance which is a merit index ranging from zero to one specifying a MOP value to a mission area for a mission type. *w* is a weighting factor to be applied to the MOP which places more importance on components with respect to certain mission types and capabilities.

Considerations used to determine the OMOE are specific MOPs, the current and future defense policy and goals, and threats which the MSC are expected to encounter. The operating environment, either littoral or open ocean are also critical of the MSCs sea keeping characteristics, stability, and combat operations. Mission scenarios and specific mission duties are also considered when assessing the OMOE.

Ideally a detailed simulation of war game scenarios allows the prediction of measures of effectiveness for a matrix of ship performance inputs. This defines a mathematical relationship between the MOPs and output effectiveness by applying a regression analysis to the simulation results. The accuracy for this analysis depends on modeling detailed interactions of complex human and physical systems to a broad range of variables and conditions including the ship MOPs.

An alternative to calculating the OMOE is use of an expert opinion to integrate the diverse range of inputs and assess the utility of ship MOPs for a given scenario. Methods of this alternative include Multi-Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP), Multi-Attribute Value Theory (MAVT), Additive MAVT, or a combination of two or more of these techniques. The approach used in calculating the MOP weights and value functions to assemble the OMOE function for the MSC are a blend all four of these methods influenced heavily by the Analytical Hierarchy Process. AHP organizes the criteria in a natural hierarchy by goals, attributes of the respective goal, sub-attributes, and alternatives to achieve the specific goal. The AHP quantifies aspects of the MSC capabilities by pairwise comparison to calculate MOP weights. The VOPs for each OMOE metric are then defined by value functions.

Table 25 summaries each ROC, MOP, and DVs. The design variables correspond with their respective MSC ROCs presented in Table 7. The Analytical Hierarchy Process (AHP) is used to calculate the weighting factors to break up the OMOE into different missions that the MSC will perform. In each mission type (mobility, survivability, war fighting), areas essential to the mission are listed with respective MOPs.

Table 25 - ROC/MOP/DV Summary

ROC	Description	MOP	Related DV	Goal	Threshold
MOB 1	Steam to design capacity in most fuel efficient manner	MOP 15 - Es	LtoB	LtoB=8.5	LtoB=7.5
		MOP 15 - Es	LtoD	LtoD=11	LtoD=14
		MOP 15 - Es	BtoT	BtoT=3.0	BtoT=2.8
		MOP 15 - Es	PSYS	PSYS=1	PSYS=8
MOB 2	Support/provide aircraft for all-weather operations	MOP 8 - Magnetic	LAMPS	LAMPS=1	LAMPS=3
MOB 3	Prevent and control damage	MOP 11 - Seakeeping and Stability	LtoB	LtoB=8.5	LtoB=7.5
		MOP 11 - Seakeeping and Stability	LtoD	LtoD=14	LtoD=11
		MOP 11 - Seakeeping and Stability	BtoT	BtoT=2.8	BtoT=3.0
		MOP 10 - RCS	VD	VD=15,000 m^3	VD=10,000 m^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
		MOP 12 - VUL	Ndegaus	Ndegaus=1	Ndegaus=0
		MOP 12 - VUL	Cman	Cman=0.1	Cman=0.5
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			

ROC	Description	MOP	Related DV	Goal	Threshold
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 15 - Es MOP 15 - Es MOP 15 - Es MOP 15 - Es MOP 14 - Ts	LtoB LtoD BtoT PSYS Ts	LtoB=8.5 LtoD=11 BtoT=3.0 PSYS=1 Ts=21 days	LtoB=7.5 LtoD=14 BtoT=2.8 PSYS=8 Ts=14 days
MOB 16	Operate in day and night environments	Required in All Designs			
MOB 17	Operate in heavy weather	MOP 11 - Seakeeping and Stability MOP 11 - Seakeeping and Stability MOP 11 - Seakeeping and Stability	LtoB LtoD BtoT	LtoB=7.5 LtoD=14 BtoT=2.8	LtoB=8.5 LtoD=11 BtoT=3.0
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations	Required in All Designs			
AAW 1.3	Provide unit anti-air self defense	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
AAW 2	Provide anti-air defense in cooperation with other forces	MOP 1 - AAW MOP 1 - AAW	AAW/BMD/STK CCC, CCCI	AAW/BMD/STK=1 CCC, CCCI=1	AAW/BMD/STK=4 CCC, CCCI=2
AAW 5	Provide passive and soft kill anti-air defense	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
AAW 6	Detect, identify and track air targets	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
AAW 9	Engage airborne threats using surface-to-air armament	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
ASU 1	Engage surface threats with anti-surface armaments	MOP 2 - ASUW MOP 2 - ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 1.3	Engage surface ships at close range (gun)	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=2
ASU 1.5	Engage surface ships with medium caliber gunfire	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=2
ASU 1.6	Engage surface ships with minor caliber gunfire	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=2
ASU 1.9	Engage surface ships with small arms gunfire	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=2
ASU 2	Engage surface ships in cooperation with other forces	MOP 2 - ASUW MOP 4 - CCC, CCCI	ASUW CCC, CCCI	ASUW=1 CCC, CCCI=1	ASUW=2 CCC, CCCI=2

ROC	Description	MOP	Related DV	Goal	Threshold
ASU 4.1	Detect and track a surface target with radar	MOP 2 - ASUW MOP 2 - ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 6	Disengage, evade and avoid surface attack	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=2
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 MOP 3 - ASW MOP 3 - ASW	LAMPS ASW/MCM CCC, CCCI	LAMPS=1 ASW/MCM=1 CCC, CCCI=1	LAMPS=3 ASW/MCM=3 CCC, CCCI=2
ASW 5	Support airborne ASW/recon	MOP 3 - ASW MOP 3 - ASW	LAMPS CCC, CCCI	LAMPS=1 CCC, CCCI=1	LAMPS=3 CCC, CCCI=2
ASW 8	Disengage, evade, avoid and deceive submarines	MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs MOP 3 - ASW	LtoB LtoD BtoT PSYS ASW/MCM	LtoB=8.5 LtoD=11 BtoT=3.0 PSYS=1 ASW/MCM=1	LtoB=7.5 LtoD=14 BtoT=2.8 PSYS=8 ASW/MCM=3
MIW 4	Conduct mine avoidance	MOP 3 - ASW	ASW/MCM	ASW/MCM=1	ASW/MCM=3
MIW 6.7	Maintain magnetic signature limits	MOP 12 - VUL MOP 12 - VUL	Cdmat Ndegaus	Cdmat=2 or 3 Ndegaus=1	Cdmat=1 Ndegaus=0
CCC 1	Provide command and control facilities	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
CCC 3	Provide own unit Command and Control	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
CCC 4	Maintain data link capability	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
CCC 6	Provide communications for own unit	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
CCC 9	Relay communications	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
CCC 21	Perform cooperative engagement	MOP 4 - CCC, CCCI	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2
SEW 2	Conduct sensor and ECM operations	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
SEW 3	Conduct sensor and ECCM operations	MOP 1 - AAW	AAW/BMD/STK	AAW/BMD/STK=1	AAW/BMD/STK=4
FSO 6	Conduct SAR operations	MOP 5 - FSO/NCO	LAMPS	LAMPS=1	LAMPS=3
FSO 8	Conduct port control functions	MOP 5 - FSO/NCO MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs MOP 2 - ASUW MOP 5 - FSO/NCO	CCC, CCCI LtoB LtoD BtoT PSYS ASUW LAMPS	CCC, CCCI=1 LtoB=8.5 LtoD=11 BtoT=3.0 PSYS=1 ASUW=1 LAMPS=1	CCC, CCCI=2 LtoB=7.5 LtoD=14 BtoT=2.8 PSYS=8 ASUW=2 LAMPS=3
FSO 9	Provide routine health care	Required in All Designs			
FSO 10	Provide first aid	Required in All			

ROC	Description	MOP	Related DV	Goal	Threshold
	assistance	Designs			
INT 1	Support/conduct intelligence collection	MOP 6 - MCM MOP 6 - MCM	LAMPS CCC, CCCI	LAMPS=1 CCC, CCCI=1	LAMPS=3 CCC, CCCI=2
INT 2	Provide intelligence	MOP 6 - MCM MOP 6 - MCM	LAMPS CCC, CCCI	LAMPS=1 CCC, CCCI=1	LAMPS=3 CCC, CCCI=2
INT 3	Conduct surveillance and reconnaissance	MOP 6 - MCM MOP 6 - MCM	LAMPS CCC, CCCI	LAMPS=1 CCC, CCCI=1	LAMPS=3 CCC, CCCI=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 8 - 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 MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs MOP 13 - Vs	ASUW LtoB LtoD BtoT PSYS	ASUW=1 LtoB=8.5 LtoD=11 BtoT=3.0 PSYS=1	ASUW=2 LtoB=7.5 LtoD=14 BtoT=2.8 PSYS=8

Table 26 contains MOP summary with goal and threshold values for the MSC. Threshold values are the minimum level of components required that are necessary for the ship to perform its mission. Goal values are typically the most cost prohibitive but represent the best components for a given mission. Figure 52 shows the hierarchy for three different mission types. Figure 53 shows the hierarchy for three different mission types.

Table 26 - MOP Table

MOP#	MOP	Goal	Threshold	Related DV
1	AAW/BMD	AAW/BMD/STK=1 CCC, CCCI=1	AAW/BMD/STK=3 CCC, CCCI=2	AAW/BMD/STK option CCC, CCCI option
2	ASUW/NSFS	ASUW=1 Mod SUW=1 LAMPS=1 CCC, CCCI=1	ASUW=2 Mod SUW=5 LAMPS=1 CCC, CCCI=2	ASUW option Mod SUW option LAMPS option CCC, CCCI option
3	ASW	ASW/MCM=1 Mod MIW/MCM=1 Mod ASW=1 LAMPS=1 CCC, CCCI=1	ASW/MCM=3 Mod MIW/MCM=6 Mod ASW=4 LAMPS=1 CCC, CCCI=2	ASW/MCM option Mod MIW/MCM option Mod ASW option LAMPS option CCC, CCCI option
4	CCC, CCCI	CCC, CCCI=1	CCC, CCCI=2	CCC, CCCI option
5	MODUPG	C4I=1 HM&E=1	C4I=3 HM&E=4	C4I option HM&E option
6	STK	GMLS=1 C4I=1	GMLS=4 C4I=2	GMLS option C4I option
7	IR	SPGM=2	SPGM=1	SPGM option
8	Magnetic	Degaussing=1	Degaussing=2	Degaussing option

9	NBC	Ncps=2	Ncps=0	CPS option
10	RCS	VD=10,000	VD=15,000	Deckhouse volume,m^3
11	Seakeeping and Stability	HullTYPE=1	HullTYPE=0	Hullform LtoB LBP
12	VUL (Vulnerability)	Cdmat=1 Degaus=1 Cman=0.5	Cdmat=3 Degaus=0 Cman=0.1	Ship material Degaussing Cman
13	Vs (Sustained Speed)	35	30	knots
14	Ts (Provisions)	75	60	days
15	Es (Endurance range at 20 kt)	8000	4000	nm
16	Surge	25 0	20 2	knots refuels
17	Acoustic signature	SPGM=1,3	SPGM=2,4,5,6	SPGM Option

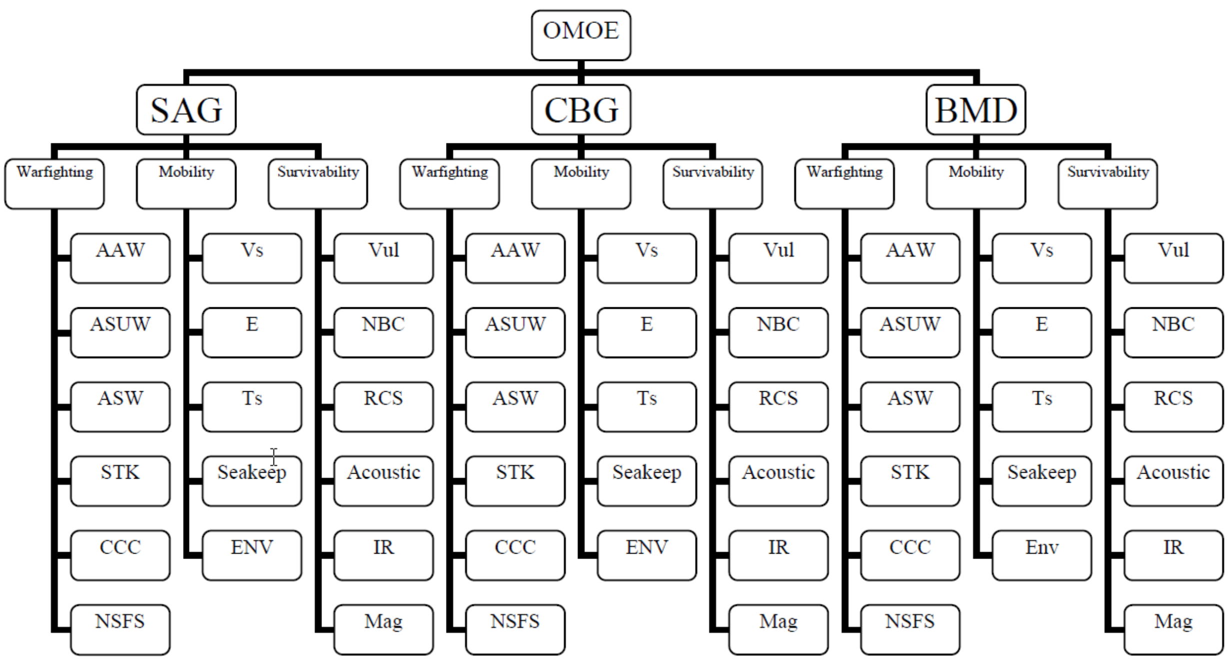


Figure 53 OMOE Hierarchy

Figure 54 shows the value of each MOP weight calculated with pairwise comparison by the AHP. Appendix C lists the pairwise comparison results of each MOP. The result of pairwise comparison shows that the highest regarded MOP is AAW/BMD which is a primary strike and defense purpose of the MSC. Several other war fighting systems (ASUW/NSFS, ASW/MCM, STK, CCC/ISR) hold relatively higher values which is also in line with the intended use of the MSC. While combat operating capabilities are the primary focus of this design all supporting characteristics maintain an adequate degree of weight in the OMOE. Provisions duration shows the lowest MOP weight which is consistent with the specified mission capabilities of the MSC. Typical mission scenarios involve the MSC as part of a CBG, SAG, or ESG where underway replenishment is readily available. These VOP functions are used to calculate the value of performance for each MOP.

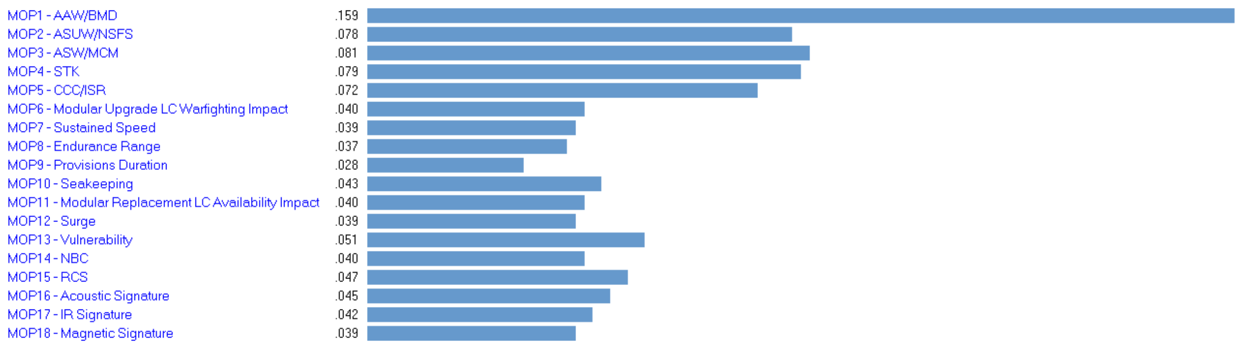


Figure 54 Bar Chart Showing MOP Weights

3.4.2 Overall Measure of Risk (OMOR)

A certain level of risk is inherent in any design. An Overall Measure of Risk (OMOR) allows the designer to compare competing designs to choose with the best combination of allowable risk and design variables. There are three types of risk: performance, cost and scheduling risks. The performance risk measures the effect of the design variable not meeting performance TLRs. The cost risk accounts for development and acquisition cost overruns. The schedule risk accounts for the impact of schedule delays on the program. The risk is calculated as the product of the probability that failure will occur (P_i), as described in Table 28, and the consequence of failure (C_i) as described in Table 29. The overall measure of risk equation, seen below, combines each of the three risk types for each design variable to create hierarchy weights.

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

Table 27 Risk Register

SWBS	Risk Type	Related DV #	DV Options	DV Description	Risk Event Ei	Event #	Pi	Ci	Ri
2	Performance	DV11	5,6,7,8	VSR+	Does not meet performance TLRs	1	0.4	0.4	0.16
2	Schedule	DV11	5,6,7,8	VSR+	Schedule delays impact program	2	0.3	0.4	0.12
2	Cost	DV11	5,6,7,8	VSR+	Development and acquisition cost overruns	3	0.3	0.7	0.21
4	Performance	DV17	1	SPY-3	Does not meet performance TLRs	4	0.4	0.5	0.2
4	Schedule	DV17	1	SPY-3	Schedule delays impact program	5	0.3	0.35	0.105
4	Cost	DV17	1	SPY-3	Development and acquisition cost overruns	6	0.3	0.65	0.195
	Performance	DV12	1	Propulsion system alternative power generation module	Does not meet performance TLRs	7	0.4	0.7	0.28
	Schedule	DV12	1	Propulsion system alternative power generation module	Schedule delays impact program	8	0.3	0.6	0.18
	Cost	DV12	1	Propulsion system alternative power generation module	Development and acquisition cost overruns	9	0.3	0.6	0.18
7	Performance	DV22	1	VLS/PVLS	Does not meet performance TLRs	10	0.4	0.4	0.16
7	Schedule	DV22	1	VLS/PVLS	Schedule delays impact program	11	0.3	0.3	0.09

7	Cost	DV22	1	VLS/PVLS	Development and acquisition cost overruns	12	0.3	0.6	0.18
	Performance	DV21	1	LAMPS	Does not meet performance TLRs	13	0.4	0.65	0.26
	Schedule	DV21	1	LAMPS	Schedule delays impact program	14	0.3	0.5	0.15
	Cost	DV21	1	LAMPS	Development and acquisition cost overruns	15	0.3	0.6	0.18
	Performance	DV24	1	Secondary Power generation module	Does not meet performance TLRs	16	0.4	0.4	0.16
	Schedule	DV24	1	Secondary Power generation module	Schedule delays impact program	17	0.3	0.3	0.09
	Cost	DV24	1	Secondary Power generation module	Development and acquisition cost overruns	18	0.3	0.6	0.18

Table 28 - 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 29 - 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%

3.4.3 Cost

The cost model utilized is a weight based cost model, which uses parametric equations to correlate weight and other parameters to overall cost. The inputs used to derive the cost model are as follows; propulsion system type and power, endurance range and speed, deck house material, fuel volume, SWBS weight groups (100-700), crew size, profit margin, inflation rate, number of ships to be built, and base year for cost calculation. The inflation factor is calculated, and then the cost for each SWBS group 100-700 is recalculated for each followship. This calculation is done by multiplying the weight of the group by a unique complexity factors. This total is multiplied by margin weight and added to the SWBS 800 and 900 costs to come up with the lead ship basic construction cost. Added to this cost are the government costs, profits, and delivery cost, change order cost, to produce the finial lead ship acquisition cost. Figure 55 shows the naval ship acquisition cost components.

Some key components within the operation stated include inflation rate, followship, life cycle cost. Inflation rate is important in determining the approximate overall cost of each ship. Calculated by taking the number of years between the time in which an initial estimate was made and a given year in the future. Inflation approximations are crucial in developing budgets for follow ships and life cycle cost. Follow ship acquisition cost depend on the number of ships to build and how fast they can be built. Follow ships are generally cheaper due to the reduced engineering/design cost, and ignoring the initial production cost since it was included in the lead ship.

In the end the main concern is life cycle cost. This is the direct total cost to the government of acquisitions and ownership of a system over its useful life. It included the cost of development, acquisitions, operation, support, and where applicable, disposal.

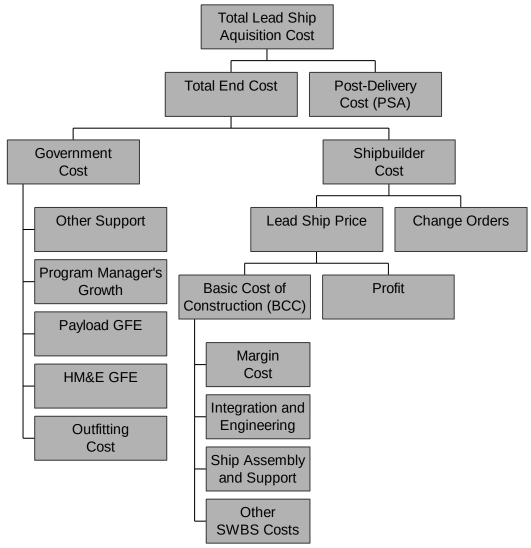


Figure 55 - Naval Ship Acquisition Cost Components

3.5 Multi-Objective Optimization

Model Center is used to perform the Multi-Objective Genetic Optimization (MOGO) through the use of the Darwin optimization plug-in. The objectives for this optimization are effectiveness, risk, and cost; which are discussed in Section 3.4. Quantitative objective functions are developed for each optimization objective before performing the optimization. Cost is already quantitative, while an overall measure of effectiveness (OMOE) and overall measure of risk (OMOR) are used to quantify effectiveness and risk. Model Center is set to minimize risk and cost while maximizing the effectiveness. Figure 56 is a flow chart showing the MOGO process. The constraints are determined from the error functions in the Feasibility subdirectory. The design variables come from the variables in the SCInput Module subdirectory. The optimizer defines a random set of 200 balanced ships to populate the first generation. The ship synthesis model, described in Section 3.3, is used to calculate each ship's measure of effectiveness, measure of risk, and cost. Each design is then assigned a fitness level and ranked according to the design's dominance in the optimization objectives. Designs are penalized for bunching, known as a niche, or for infeasibility before being randomly selected to populate the second generation. These randomly selected designs are weighted to ensure higher selection probabilities for ships with higher fitness levels. Twenty-five percent of the second generation's designs are selected to swap some of their design variable values, known as crossover. A small percentage of randomly selected design variable values are selected for mutation, which replaces it with a new random value. Each generation of ships are spread across the effectiveness/cost/risk three-dimensional design space. After several hundred generations of evolution, a non-dominated frontier forms a surface of designs with the highest effectiveness for a given cost and risk. Figure 60 shows the non-dominated frontier. The optimal design is determined by preferences for effectiveness, cost, and risk.

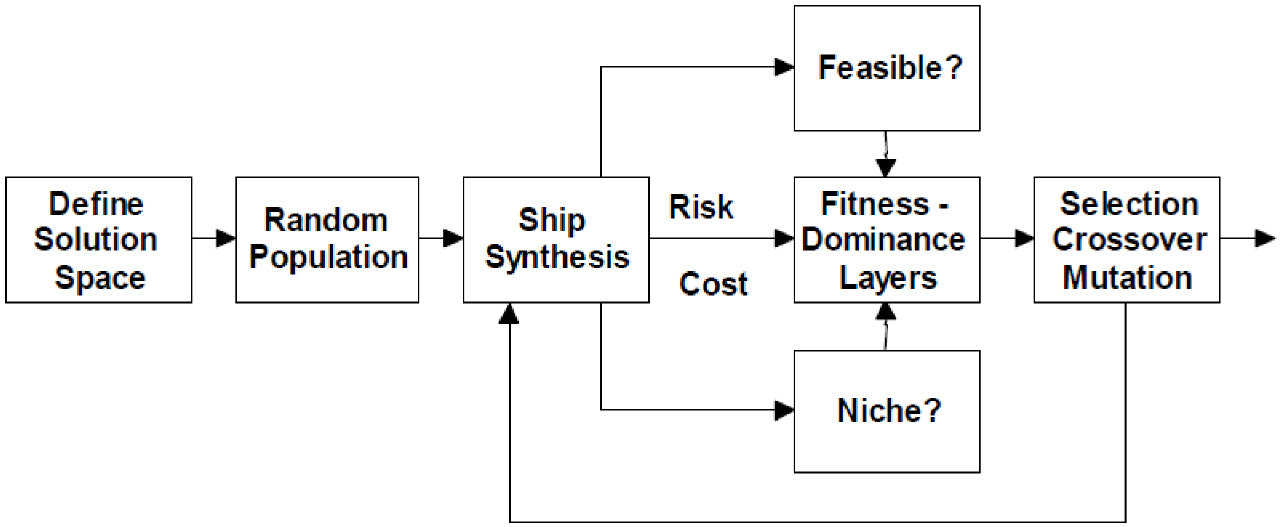


Figure 56 - Multi-Objective Genetic Optimization (MOGO)

Figure 57 lists the objectives used for the MOGO. The OMOR and CTOC are minimized and the OMOE is maximized. Figure 58 shows the constraints and their lower and upper bounds used for the MOGO. Figure 59 shows the continuous and discrete variables and their bounds used in running the MOGO.

Objective	Value	Goal
MSCwFlare.SCRisk.OMOR	0.0	minimize
MSCwFlare.SCCost.CTOC	3819.492	minimize
MSCwFlare.SCOMOE.OMOE	0.680901	maximize

Figure 57 Objectives

Constraint	Value	Lower Bound	Upper Bound
MSCwFlare.Feasibility.Eta	0.3419716	0.01	1.0
MSCwFlare.Feasibility.Evs	0.1167124	0.01	1.0E30
MSCwFlare.Feasibility.Egmmin	0.296925	0.01	2.0
MSCwFlare.Feasibility.Egmmax	0.3083067	0.01	2.0
MSCwFlare.Feasibility.Ee	0.7580796	0.01	1.0E30

Figure 58 Constraints

Variable	Type	Value	Single Analysis	Lower Bound	Upper Bound	Edit
MSCwFlare.SCInput.LWL	continuous	197.15	165.0	160.0	210.0	...
MSCwFlare.SCInput.LtoB	continuous	8.299	8.183	7.0	10.0	...
MSCwFlare.SCInput.LtoD	continuous	12.37	11.425	11.0	14.0	...
MSCwFlare.SCInput.BtoT	continuous	3.0076	3.1154	2.9	3.2	...
MSCwFlare.SCInput.Cp	continuous	0.5734	0.61068	0.57	0.63	...
MSCwFlare.SCInput.Cx	continuous	0.83894	0.8216	0.76	0.85	...
MSCwFlare.SCInput.Crd	continuous	0.7955	0.7112	0.6	0.8	...
MSCwFlare.SCInput.VD	continuous	10918.0	7997.0	10000.0	15000.0	...
MSCwFlare.SCInput.CMan	continuous	1.0	0.9476	0.5	1.0	...
MSCwFlare.SCInput.PGM	discrete	10	1			...
MSCwFlare.SCInput.SPGM	discrete	2	1			...
MSCwFlare.SCInput.DISTtype	discrete	1	1			...
MSCwFlare.SCInput.PMM	discrete	1	1			...
MSCwFlare.SCInput.PROPtype	discrete	1	1			...
MSCwFlare.SCInput.Ts	discrete	63	60			...
MSCwFlare.SCInput.Ncps	discrete	2	0			...
MSCwFlare.SCInput.AAW	discrete	4	1			...
MSCwFlare.SCInput.ASUW	discrete	2	1			...
MSCwFlare.SCInput.ASW	discrete	1	1			...
MSCwFlare.SCInput.CCC	discrete	1	1			...
MSCwFlare.SCInput.GMLS	discrete	2	1			...
MSCwFlare.SCInput.LAMPS	discrete	1	1			...
MSCwFlare.SCInput.MISMOD	discrete	2	1			...
MSCwFlare.SCInput.C4IMOD	discrete	2	1			...
MSCwFlare.SCInput.HMEMOD	discrete	3	1			...
MSCwFlare.SCInput.HABMOD	discrete	2	1			...
MSCwFlare.SCInput.WEAPMOD	discrete	3	1			...
MSCwFlare.SCInput.SENSMOD	discrete	1	1			...

Figure 59 Design Variables

3.6 Optimization Results and Initial Baseline Design (Variant 163)

The design selected for Team 2 is Design 163. Figure 60 and Figure 61 show the non-dominated frontier for effectiveness, cost, and risk produced by the multi-objective genetic optimization. The plot shows the OMOE for a given cost ship design. The OMOR is displayed by color, red being the lowest risk and blue the highest. Designs that are most attractive to the customer are often those that occur at extremes of the frontier, or at knees in the curve. The knees in the curve represent a significant increase in effectiveness with a minimal increase in cost or risk.

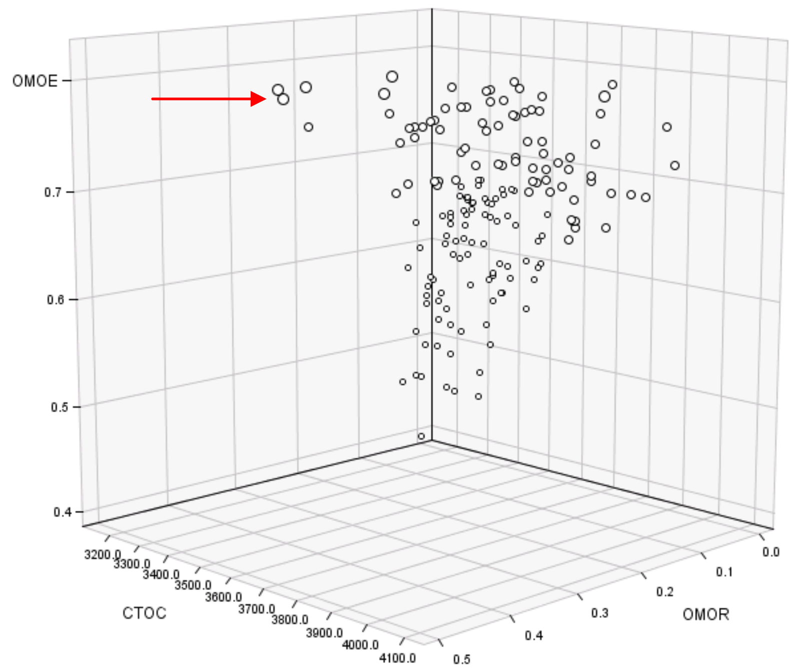


Figure 60 – 3D Non-Dominated Frontier (Variant 163 identified with red arrow)

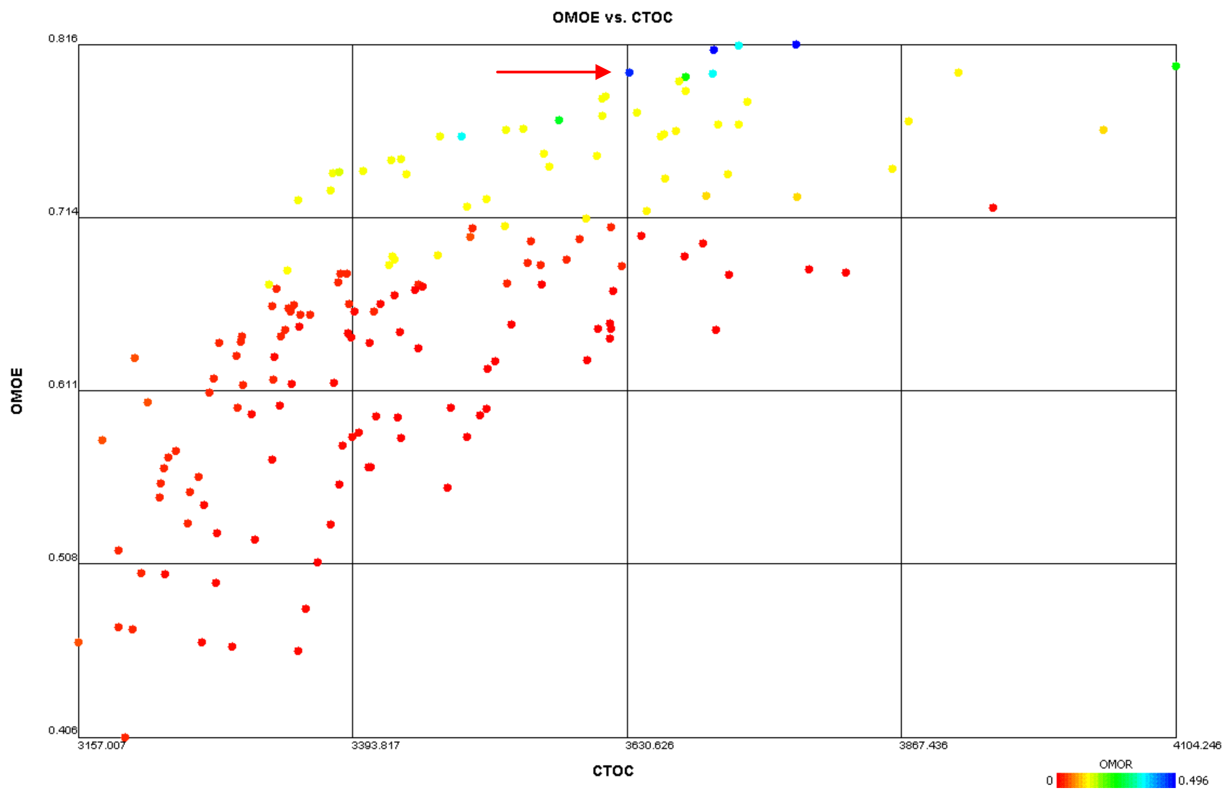


Figure 61 – 2D Non-Dominated Frontier (Variant 163 identified with red arrow)

The design selected for Team 2 is Design 163. MSC 163 is the high end design with low risk compared to similarly priced ships. The design has a high OMOE of 0.799, and a low OMOR of 0.455. Table 30 is a comparison table of some of the considered designs. It shows the OMOE, CTOC, OMOR, and some design variables for each design. MSC 100 is an example of a ship at a knee in the curve with the highest OMOE in its low cost range. MSC 164 has the highest OMOE in the same price range as the selected MSC163.

Table 30 Comparison Table

Design	Chosen Design MSC 163	High End MSC 164	Low Cost MSC 100
OMOE	0.79942	0.8161696	0.6389542
CTOC	3633.19	3776.627	3278.801
OMOR	0.45525	0.4913337	0.043042999
SPGM	2	2	1
Prop Type	1	1	1
DISTtype	2	1	1
PMM	1	2	1
Ts	74	74	73
Ncps	2	1	0
AAW	3	3	4
ASUW	2	2	2
ASW	3	1	4
CCC	1	1	1
GMLS	1	1	2
LAMPS	1	1	1
PGM	8	10	10
LWL	194.45	196.09	191.63
LtoB	8.294	8.115	8.1
LtoD	12.418	12.412	12.168
BtoD	2.9594	2.9197	2.9499
Cp	0.59588	0.60924	0.58958
Cx	0.84657	0.8264	0.83365
Crd	0.7824	0.7935	0.7603
VD	11326	10723	11603
CMan	0.6664	0.6972	0.6388
MISMOD	2	1	1
C4IMOD	2	2	2
HMEMOD	3	2	2
HABMOD	1	3	2
WEAPMOD	2	3	3
SENSMOD	2	1	1

3.7 Improved Baseline Design – Single Objective Optimization

Design 163 was chosen from the Multi-objective Genetic Optimization. A gradient optimizer was then used inside of Model Center to perform a single objective optimization on Design 163. The follow ship acquisition cost was chosen as the variable to be optimized and thus minimized. The results from Design 163 were loaded into the model and the gradient optimizer was added into the model. The gradient optimizer was set to only change the variables listed under Design Variables as seen in Figure 62. Constraints were then added to the gradient optimizer as seen in Figure 62. The optimizer was then run, and the results can be seen in Figure 63. This figure shows that the cost was reduced in a systematic fashion and finally converged to a cost value smaller than the original cost value. The constraints of the gradient optimizer were then changed and run again. The results from this optimization can be seen in Figure 64. Again, it can be seen that the optimizer produced a ship with a lower acquisition cost. The last ship tested was used to generate a modified baseline design and many of these updated characteristics can be seen in Table 31 through Table 36.

Table 31 shows that all the discrete variables remained the same after the optimization. However, all the continuous variables listed in Table 31 were changed by the gradient optimizer to produce the more cost effective ship. Table 32 shows the weight by SWBS section and details the lightship and full load displacements with margins. Table 33 shows the improved area baseline summary. This table of areas shows that the ship is feasible with respect to area requirements because the available area exceeds the required area.

Table 34 gives values for the maximum functional load with margins and the 24 hour electrical load.

Table 35 gives values of overall performance and Table 36 gives an overview of the improved baseline characteristics.

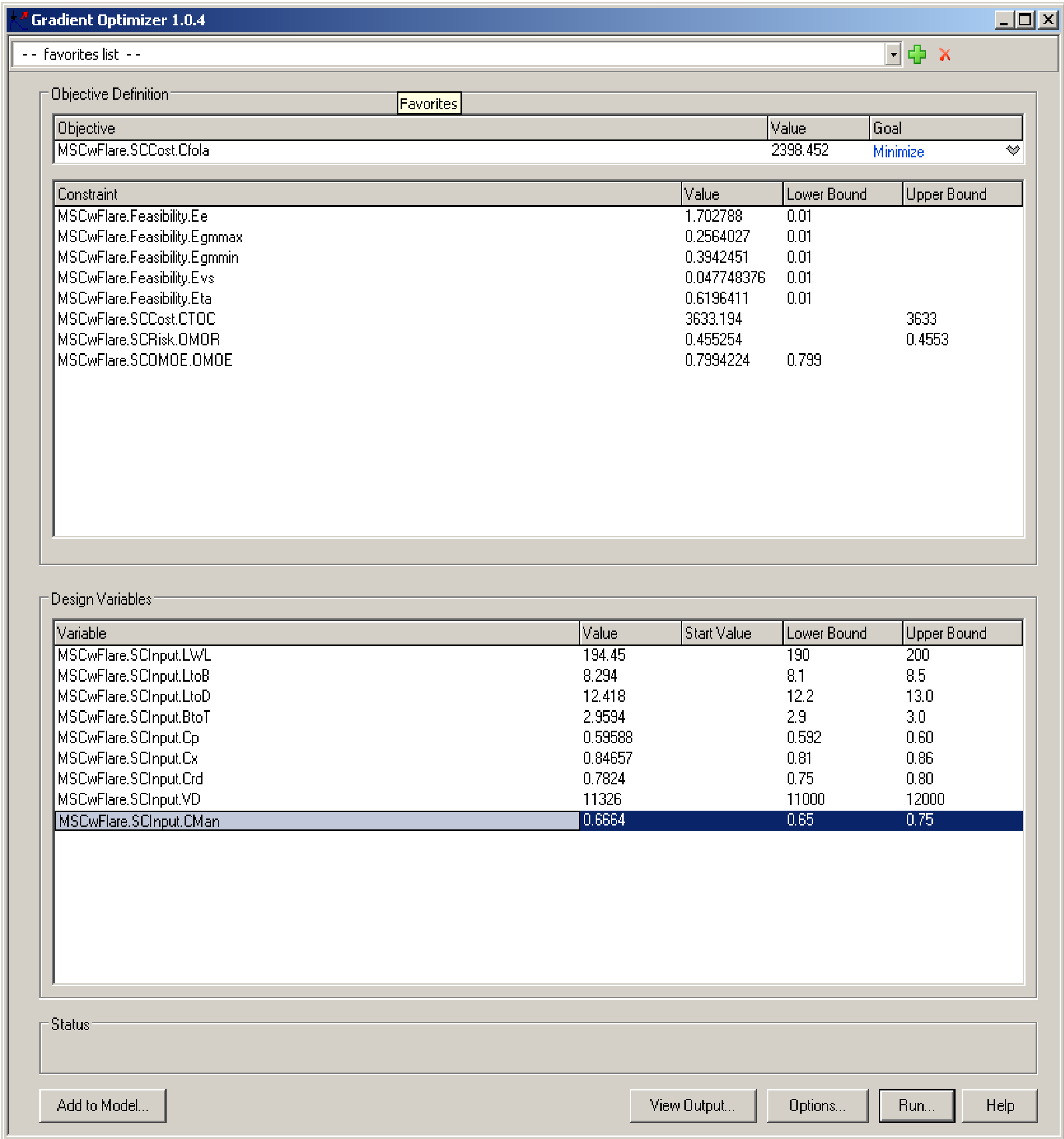


Figure 62 Gradient Optimizer Constraints and Design Variables

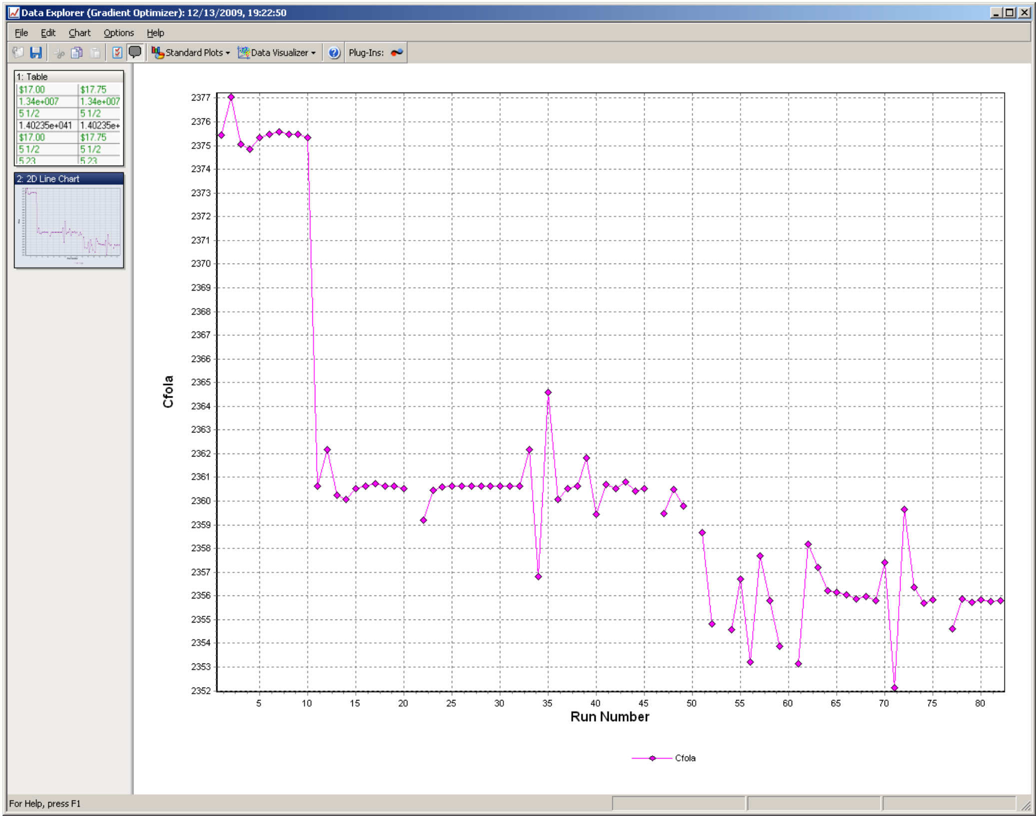


Figure 63 Results from First Gradient Optimization

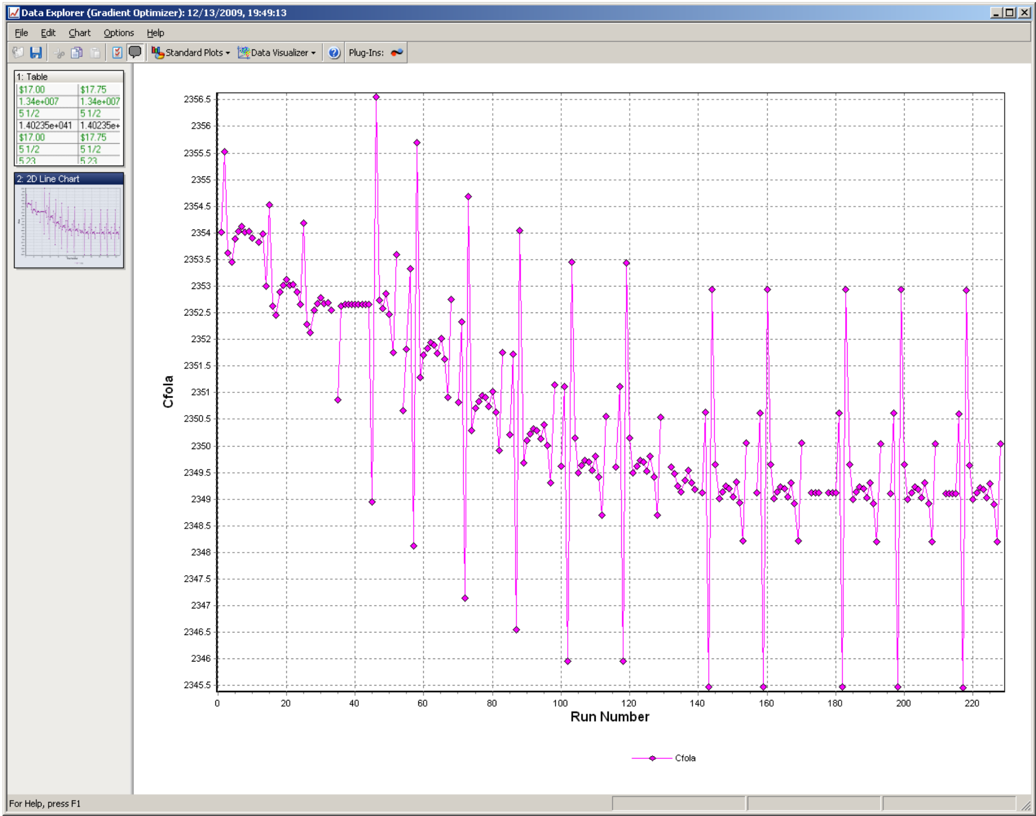


Figure 64 Results from Second Gradient Optimization

Table 31 Design Variables Summary

DV #	DV Name	Description	Design Space
1	LBP	Length between Perpendiculars	180-200 meters
2	LtoB	Length to Beam ratio	7.5-8.5
3	LtoD	Length to Depth ratio	11-14
4	BtoT	Beam to Draft ratio	2.8-3.0
5	Cp	Prismatic Coefficient	0.57 - 0.63
6	Cx	Maximum Section Coefficient	0.76 - 0.85
7	Crd	Raised Deck Coefficient	0.7 - 0.8
8	VD	Deckhouse volume	10,000-15,000m^3
9	Cdmat	Hull Material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite
10	PGM	Propulsion system alternative and Power Generation Module (PGM)	Option 1) 3xLM2500+,4160VAC, FPP Option 2) 3xLM2500+,13800VAC, FPP Option 3) 4xLM2500+,4160VAC, FPP Option 4) 4xLM2500+,13800VAC, FPP Option 5) 2xMT30, 4160VAC, FPP Option 6) 2xMT30, 13800VAC, FPP Option 7) 3xMT30, 4160VAC, FPP Option 8) 3xMT30, 13800VAC, FPP Option 9) 4xMT30, 4160VAC, FPP Option 10) 4xMT30, AC Synch, 13800VAC
11	Ts	Provisions duration	60 - 75 days
12	CPS	Collective Protection System	0 = none, 1 = partial, 2 = full
13	Ndegaus	Degaussing system	0 = none, 1 = degaussing system
14	Cman	Manning reduction and automation factor	0.5 – 0.1
15	AAW/BMD/STK	AAW/BMD/STK system Alternative	Option 1) SPY3/VSR+++ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 2) SPY3/VSR++ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 3) SPY3/VSR+ DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA Option 4) SPY3/VSR DBR, AEGIS BMD 2014, IRST, CIFF-SD, AIEWS, MK36SRBOC w/NULKA
16	ASUW	ASUW system alternative	Option 1) 1xAGS gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS Option 2) MK45 5"/62 gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS Option 3) MK110 57mm gun, 3x30mm CIGS (or small directed energy), small arms and pyro locker, FLIR, 1x7m RIB, GFCS
17	ASW/MCM	ASW/MCM system alternative	Option 1) Dual Frequency Sonar Bow array, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 2) SQS-53C sonar, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE Option 3) SQS-56 sonar, ISUW, Mine avoidance sonar, 2xMK32 SVTT, NIXIE
18	CCC, CCI	CCC, CCI system alternatives	Option 1) Enhanced CCC, TSCE Option 2) Basic CCC, TSCE
19	GMLS	GMLS system Alternative	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, 48xMK57 PVLS or VLS, Tomahawk WCS Option 4) 4x4 MK57 VLS or 1xAGS, 40xMK57 PVLS or VLS, Tomahawk WCS
20	MMOD	MMOD system Alternative	Option 1) 1.5xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs

DV #	DV Name	Description	Design Space
			Option 2) 1xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs Option 3) 1/2xLCS Mission Payload, SPARTANs, VTUAVs, UAVs, RIBs
21	SPGM	Secondary Power Generation Module (SPGM)	Option 1) NONE Option 2)2xLM500G, AC Synch Option 3)2xCAT3608 Diesel Option 4)2xPC 2.5/18 Diesel Option 5)2xPEM 3 MW Fuel Cells Option 6)2xPEM 4 MW Fuel Cells Option 7)2xPEM 5 MW Fuel Cells
22	PROPtype	Propeller Type	Option 1) 2 x FPP (Fixed Pitch Propeller) Option 2) 2 x Pods
23	PMM	Propulsion Motor Module Type	Option 1) (AIM) Advanced Induction Motor (DDG 1000) Option 2) (PMM) Permanent Magnet Motor
24	DISTtype	Power Distribution Type	Option 1) AC ZEDS Option 2) DC ZEDS (DDG 1000)
25	C4IMOD	C$I system alternative	Option 1) C4I Raft Option 2) C4I Tracks Option 3) Conventional C4I
26	HMEMOD	HM&E system alternatives	Option 1) MR Deck Rafts Option 2) HM&E Palletized Option 3) HM&E Component Modules Option 4) Conventional HM&E
27	HABMOD	Habitability system alternatives	Option 1) Hab Space Tracks Option 2) Standard Modular Hab Spaces Option 3) Conventional Hab Spaces
28	WPMOD	Weapons system alternatives	Option 1) Maximum Margin and Interfaces Option 2) Minimum Margin and Interfaces Option 3) Same Modular Weapon Option 4) Conventional Weapon Install
29	SNSMOD	Sensors/Topside system alternatives	Option 1) Modular Sensors Option 2) Modular Mast Option 3) Conventional Sensor Install
30	LAMPS		Option 1) SH-60, Hell Fire Penquin Missiles, Sonobouy, UVA, MKIII systems Option 2) MKIII in-flight refueling system, UVA, MKIII systems

Table 32 Improved Baseline Weights and Vertical Center of Gravity Summary

Group	Weight
SWBS 100	7148.27 MT
SWBS 200	1273.25 MT
SWBS 300	1815.09 MT
SWBS 400	979.236 MT
SWBS 500	1576.76 MT
SWBS 600	721.255 MT
SWBS 700	504.648 MT
Loads	2417.19 MT
Lightship	13797.716 MT
Lightship w/ Margin	15176.87 MT
Full Load w/ Margin	17594.06 MT with KG=8.06424 m

Table 33 Improved Area Baseline Summary

Area	Required	Available
Total-Arrangeable	92344.17 m^2	114043.4 m^2
Hull	41307.86 m^2	74300.95 m^2
Deckhouse	28812.85 m^2	39742.43 m^2

Table 34 Improved Baseline Electric Power Summary.

Group	Description	Power
KW_{MFLM}	Max. Functional Load w/ Margins	17964.72
KW_{24}	24 Hour Electrical Load	8355.059

Table 35 Improved Baseline MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Value of Performance
MOP 1	AAW/BMD	0.92746
MOP 2	ASUW/NSFS	0.851404
MOP 3	ASW	0.83641
MOP 4	CCC, CCCI	1
MOP 5	MODUPG	0.546488
MOP 6	STK	1
MOP 7	IR	0
MOP 8	Magnetic	1
MOP 9	NBC	1
MOP 10	RCS	0.9878407
MOP 11	Seakeeping and Stability	0.5
MOP 12	VUL (Vulnerability)	0.884128
MOP 13	Vs (Sustained Speed)	0.6017283
MOP 14	Ts (Provisions)	0.975
MOP 15	Es (Endurance range at 20 kt)	0.740298
MOP 16	Surge speed	0.6017283
MOP 17	Acoustic signature	0.165
MOP 18	NMOD	0.845
MOP 19	MODMAINT	0.754625

Table 36 Improved Baseline

Characteristic	Improved Baseline
Hull form	Flare
Δ (MT)	17594.06
LWL (m)	192.059
Beam (m)	23
Draft (m)	7.93
D10 (m)	13.1787
Displacement to Length Ratio, $C_{\Delta L}$ (MT/m^3)	93.482
Beam to Draft Ratio, C_{BT}	2.9
W1 (MT)	7148.27
W2 (MT)	1273.25
W3 (MT)	1815.09
W4 (MT)	979.236
W5 (MT)	1576.76
W6 (MT)	721.255
W7 (MT)	504.648
Wp (MT)	2417.19
Lightship Δ (MT)	13797.716
KG (m)	8.06424
GM/B=	0.1
Propulsion system	Option 8
ASW system	Option 3
ASUW system	Option 2
AAW system	Option 3
Average deck height (m)	3
Total Officers	33
Total Enlisted	141
Total Manning	174
Number of SPARTANs	0
Number of VTUAVs	0
Number of LAMPS	1
Ship Acquisition Cost	2349.103
Life Cycle Cost	3628.034

3.8 ASSET Feasibility Study

The ship modeling and synthesis tool, ASSET, is utilized to study the feasibility of the ship design chosen through the optimization method. ASSET contains modules which perform the calculations to measure feasibility. The modules work in junction with the data input Editor. The Editor is a database containing where all ship characteristics. ASSET is first populated with variables from the parents' hull of this design, a standard DDG baseline ship from the ASSET databank.

Next, principle hullform characteristics from the single objective re-optimization of the chosen ship design are input and the ASSET hullform modules are performed. The DDG-51 parent hullform is referenced and modified to generate an optimized model.

Next, ASSET's Editor is populated with the Design 163 variable values, such as combat systems and machinery options. Payloads and Adjustments are specified in ASSET according to combat options chosen in optimization. Deck and bulkhead spacing, as well as machinery room location, propulsion type, and many other details must be specified by the operator. All of this information is used by ASSET's modules to perform necessary calculations and produce reports. Each of ASSET's modules are first run one at a time, in order, and adjustments are made to variables in the Editor until the modules are running properly and without errors. The Machinery Wizard is run to include specific engine specification and requirements to ensure an accurately generated model. Once all of the modules are running correctly, ASSET "synthesis" is run until all modules converge to a single feasible point. Successful convergence implies a feasible design.
After ASSET successfully converges, results are compared to the calculated results from the Model Center optimization and confirmed to be within acceptable margins of one another. Figure 65 shows the Hull Geometry Module isometric view of the hullform. Figure 66 shows the body plan view from the same module. Figure 67 shows the profile view from the Deckhouse Module. The Machinery Module profile view is shown in Figure 68.

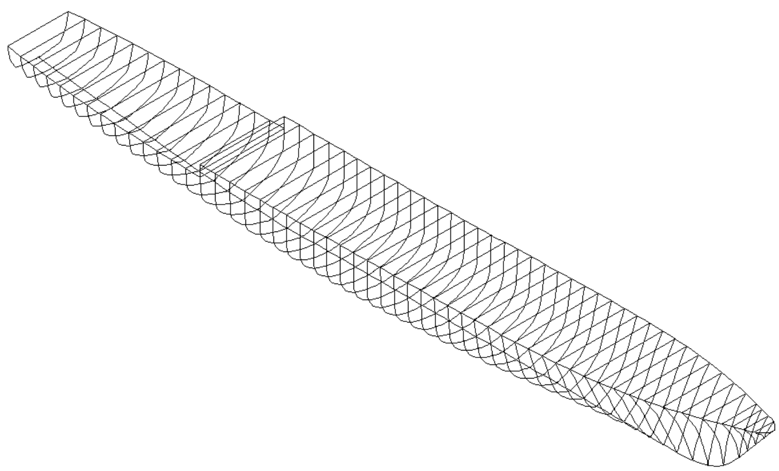


Figure 65 – ASSET Design 163 Isometric Hullform View

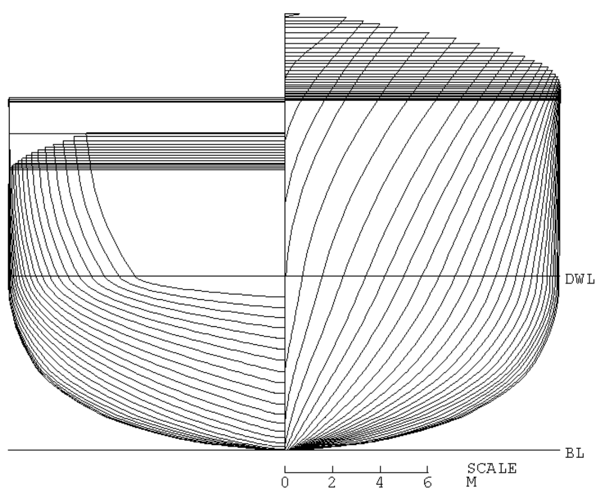


Figure 66 - Asset Design 163 Body Plan View

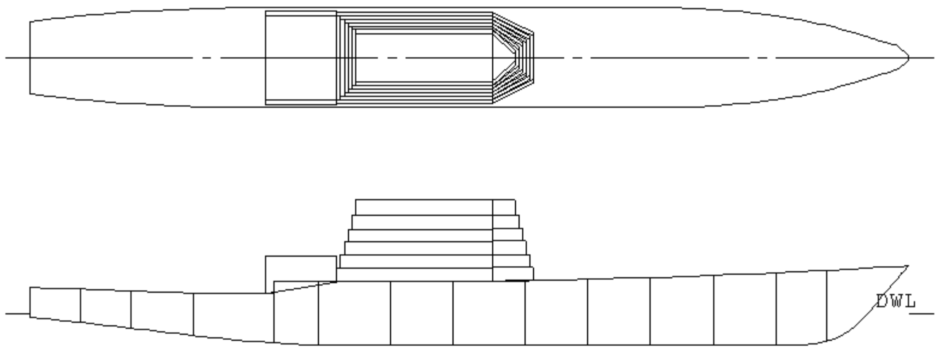


Figure 67 - Asset Design 163 Deckhouse Module Profile View

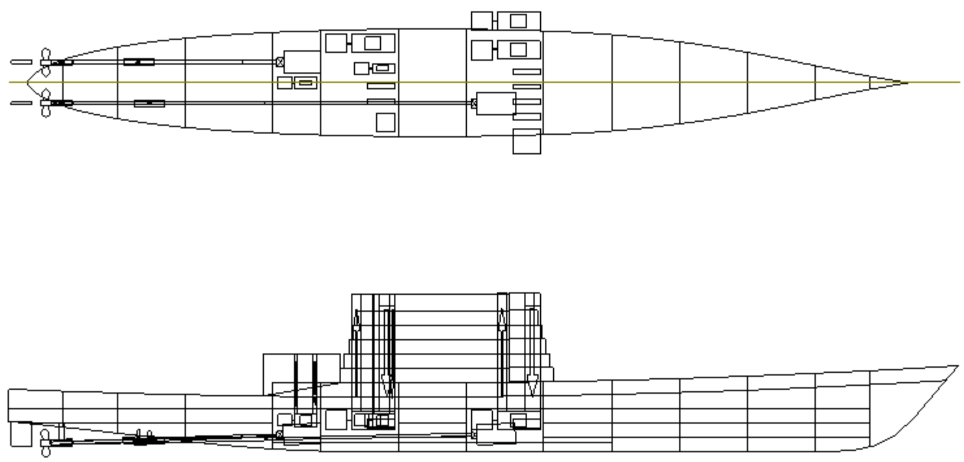


Figure 68 - ASSET Design 163 Machinery Module Profile View

The results of ASSET modeling are shown below in Table 37. Some of the results included in the Principal Characteristics include basic ship specification, SWBS weights, manning, and area and volume calculations. The results of the ASSET study utilizing design 163 characteristics serve as the Final Baseline Design.

Table 37 - ASSET Design Summary

```
  PRINCIPAL CHARACTERISTICS - M          WEIGHT SUMMARY - MTON
LBP                            192.1    GROUP 1 - HULL STRUCTURE   6528.0
HULL LOA                       201.3    GROUP 2 - PROP PLANT       1903.2
BEAM, DWL                       23.0    GROUP 3 - ELECT PLANT       852.0
DEPTH @ STA 10                  14.6    GROUP 4 - COMM + SURVEIL    799.5
DRAFT TO KEEL DWL                7.2    GROUP 5 - AUX SYSTEMS      1465.5
DRAFT TO KEEL LWL                7.2    GROUP 6 - OUTFIT + FURN     934.7
FREEBOARD @ STA 3                9.0    GROUP 7 - ARMAMENT          373.2
GMT                              3.6    ----------------------------------
CP                             0.598    SUM GROUPS 1-7            12856.1
CX                             0.818    DESIGN MARGIN              1285.6
                                        ----------------------------------
                                        LIGHTSHIP WEIGHT          14141.7
SPEED(KT):  MAX= 33.6  SUST= 32.0       LOADS                      2158.3
ENDURANCE:  4738.4 NM AT 20.0 KTS       ----------------------------------
                                        FULL LOAD DISPLACEMENT    16300.0
TRANSMISSION TYPE:               IPS    FULL LOAD KG:  M              7.9
MAIN ENG: 3 GT       @ 36000.0 KW
SEC ENG:  2 GT       @  3940.0 KW       MILITARY PAYLOAD WT- MTON  1452.7
SHAFT POWER/SHAFT:     43162.6 KW       USABLE FUEL WT - MTON      1631.9
PROPULSORS: 2 - FP         -  5.8 M  DIA

PD GEN:   6 DC-BUS   @  5000.0 KW
                                                 OFF  CPO   ENL    TOTAL
24-HR LOAD                    8335.3    MANNING   23   23    89      135
MAX MARG ELECT LOAD          16352.3    ACCOM     26   26    98      150

    REQUIRED AREA SUMMARY - M2              AVAILABLE AREA SUMMARY - M2
OTHER AREA            -      9289.      HULL AREA             -      8851.
SUPERSTRUCTURE AREA   -      3966.      SUPERSTRUCTURE AREA   -      4403.
----------------------------------      ----------------------------------
TOTAL AREA            -     13254.      TOTAL AREA            -     13254.

    REQUIRED VOLUME SUMMARY - M3            AVAILABLE VOLUME SUMMARY - M3
OTHER VOLUME          -     41751.      HULL VOLUME           -     41804.
SUPERSTRUCTURE VOLUME -     11897.      SUPERSTRUCTURE VOLUME -     13944.
----------------------------------      ----------------------------------
TOTAL VOLUME          -     53648.      TOTAL VOLUME          -     55748.
```

Table 38 shows the comparison between the SSSM optimization and ASSET results. The ASSET generated model closely replicates the optimized design from Model Center. Most characteristics were found to be within an acceptable 10% margin and no serious differences were encountered. Upon reaching this point, Design 163 is validated as an acceptable model and utilized throughout the remainder of the design. Table 39 shows the entire Improved Baseline derived from ASSET with the key weapon and machinery components that were included in the Editor to generate the new baseline model.

Table 38 - SSSM & ASSET Comparison

	SSSM	ASSET
Sustained Speed (knts)	32.0	32.0
Endurance Range (nm)	6843.8	4738.4
Total Required Area (m^2)	8579	9289
Total Available Area (m^2)	10594	8851
Maximum Functional Load with Margins (KW)	17964	16352.3
Average 24 Hour Electric Load (KW)	8355	8335.3
Full Load Displacement (MT)	17876.2	16027.97
Usable Fuel Weight (MT)	1863.169	1631.9
KG (m)	8.06	7.76
LCG (m)	NA	99.33
GM (m)	3.13	3.76

Table 39 - Improved Baseline with Key Components

	Value	Units
AAW	VSR+, AN/SPY-3 MFR , AEGIS BMD 2014, CIFF-SD, MK53 Nulka Decoy Launching System, MK 36 SRBOC Decoy Launching System, IRST	
ASuw	SPS-73 Surface Search Radar, TISS, FLIR, GFCS, 3 X 30MM CIGS GUN, 2 X 7M RHIB, 1X MK45 5IN/62 GUN	
ASW	SQS-56 Sonar, Minehunting Sonar, AN/SLQ-25 NIXIE, 2X MK32 SVTT 6 X MK46	
CCC	Total Ship Computing Environment, Enhanced RADIO/EXCOMM, Tomahawk Weapon Control System, Underwater Communications	
LAMPS	2X SH60R, SQQ-28 LAMPS MK III Electronics, Hellfire, Sonobouy	
GMLS	155 MM AGS, MK57 PVLS/VLS 32 CELLS	
MMod	1/2X LCS Mission Package	
Displ, Full Load	17876.2	MT
L	192.1	m
B	23.0	m
T	7.93	m
D10	14.57	m
KG	8.06	m
KB	4.68	m
Vol Total	52087.4	m^3
Vol Deckhs	11076.2	m^3
IPS	3 x MT 30 2 x LM500	PGM SPGM
Prop	2 x FPP	
Total Power Inst	97915.3	kW
kWmflm	17964	kW
Sustained Speed	32.01	Kt
Endurance Speed	20	Kt
Range at Endr	6843.8	Nm
Provisions	74	Days
Fuel Capacity	1863.2	MT
Officers	23	
Enlisted	89	
Total Crew	135	
Lead ship acquisition cost	$3,550	Million $
Follow ship acq cost	$2,350	Million $
Follow ship total owner cost	$3,630	Million $

4 Concept Development (Feasibility Study)

Concept Development of MSC 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 Hullform and Deck House

4.1.1 Hullform

The DDG-51 parent hullform is imported directly from ASSET to RHINO 3D. Within this modeling workspace a practical hullform is generated. A series of initial steps must be completed on the hull before further analysis can be performed. Some of the changes implemented include creating a bulbous bow to improve wave drag, and creating housing for the sonar dome. These can be seen in Figure 69. The other alteration implemented on the hull is to apply a fine mesh over the surface of the hull. This fine mesh allows for a cleaner, more detailed final product. Figure 70 shows the final rendered hull.

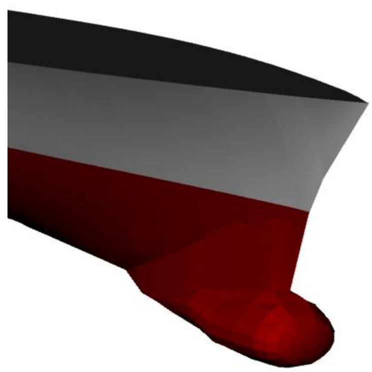


Figure 69 - Bulbous Bow Modeled

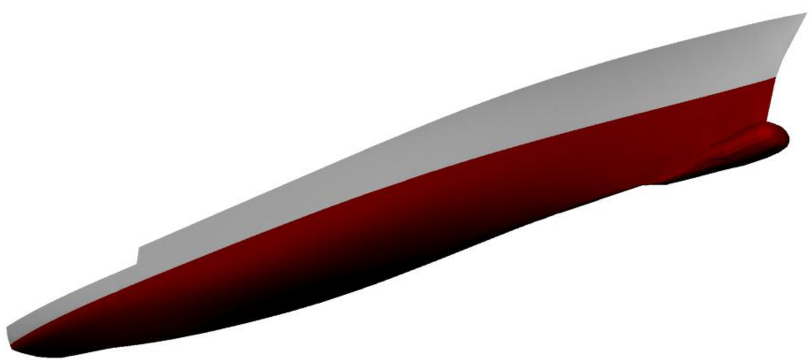


Figure 70 - 3D Modeled Hull

After the hull is generated and all modifications are completed, a hydrostatic study is executed. ORCA3D is used to perform this analysis. ORCA3D is an add-on of RHINO and uses the current 3D model to generate curves of form and right arm curves. ORCA is also used to create sections and lines drawings. To complete the needed hydrostatic calculations, the following baseline design characteristics shown in Table 23 are used. Hydrostatic data can be seen in the following figures. Figure 71 shows the righting arm curves. Figure 72 illustrates buoyancy centers vs. draft. Area values can be seen in Figure 73. Figure 74 shows coefficient values, and Figure 75 provided sectional area curve data. Figure 76 illustrates the 2D lines drawings created in ORCA3D.

Table 40 - Baseline Characteristics

Displacement	17954 MT
LWL	192.059 m
B	22.996 m
T	7.93 m
D10	14.5735 m
Cp	0.81838
Cx	0.59834
Crd	0.70874
Topside flare	
Sonar Dome	

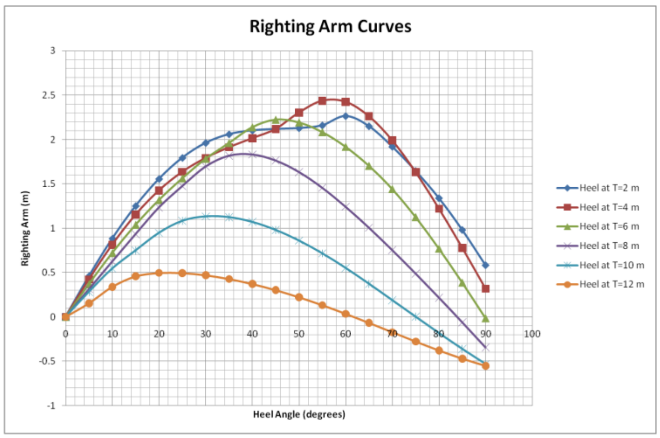


Figure 71- Righting Arm Curves

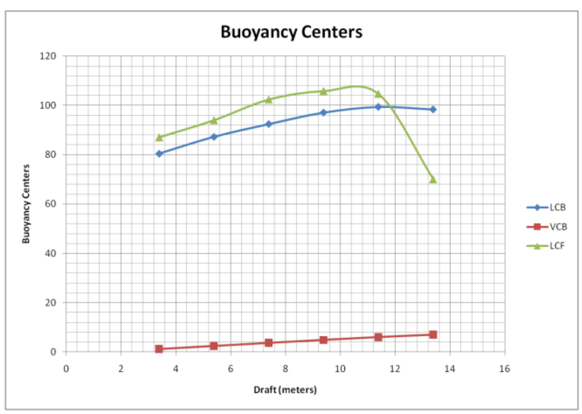


Figure 72 - Buoyancy Centers vs. Draft

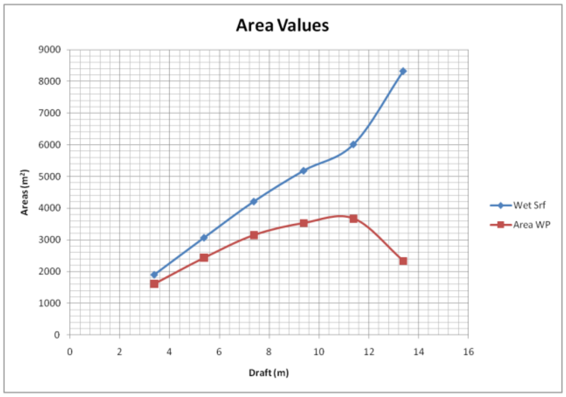


Figure 73 - Area Values

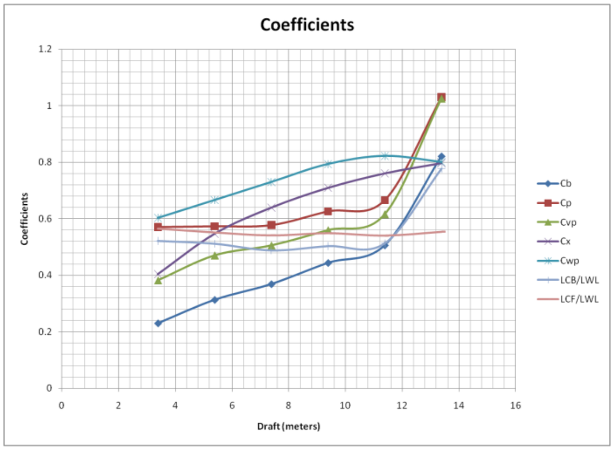


Figure 74 – Coefficients

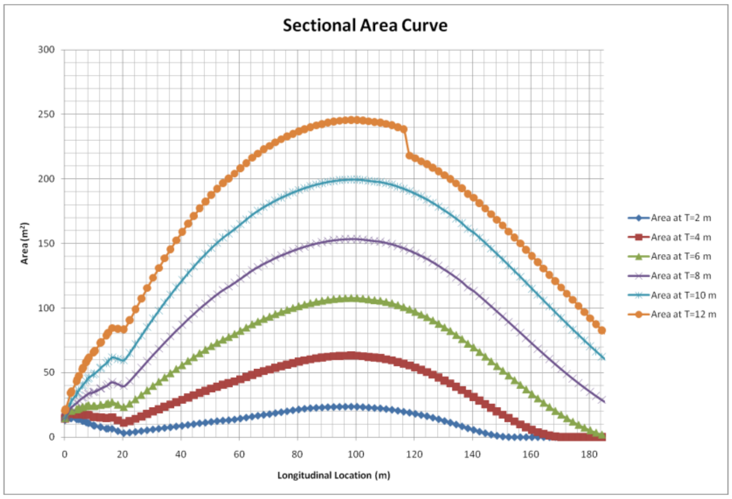


Figure 75 - Sectional Area Curve

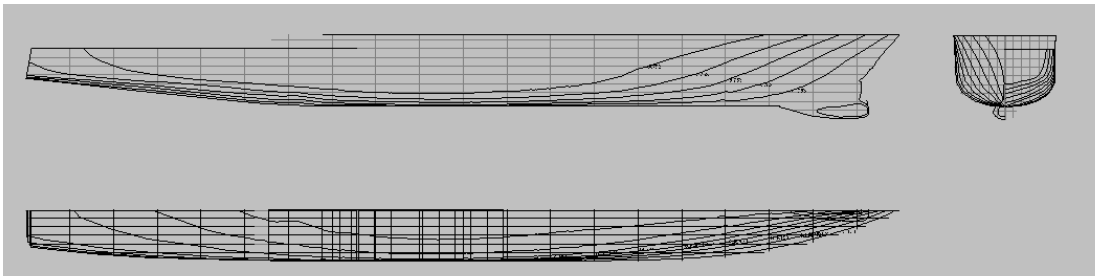


Figure 76 – Lines Drawing

4.1.2 Deckhouse

Upon exporting the ASSET model data into RHINO, a preliminary deckhouse shape is presented. A 3D model is created using this initial outline with known deckhouse areas and volumes. To accommodate the U.S. Navy's efforts to build and design ships with a smaller radar cross section, the sides of the deckhouse are tapered ten degrees. To allow for optimal decreased radar signature, conventional radar instrumentation has been replaced by the SPY3/VSR arrays on four sides of the deckhouse. This effort to minimize cross section is also extended to the design of the close in gun system (CIGS) positioned aft of the deckhouse on top of the hanger. Figure 77 shows the deckhouse and all components integrated in a simple flat surface structure. Figure 78 shows the large hanger bay with large flight control station.

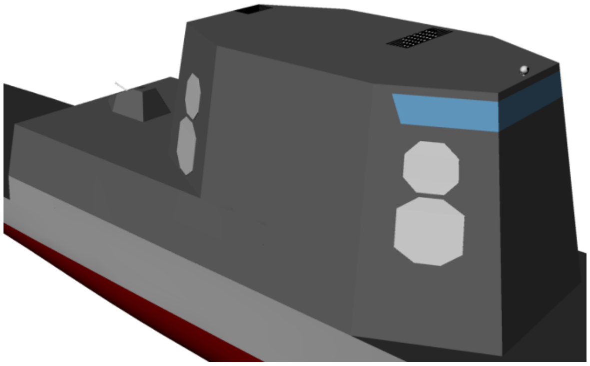


Figure 77 – Deckhouse Forward

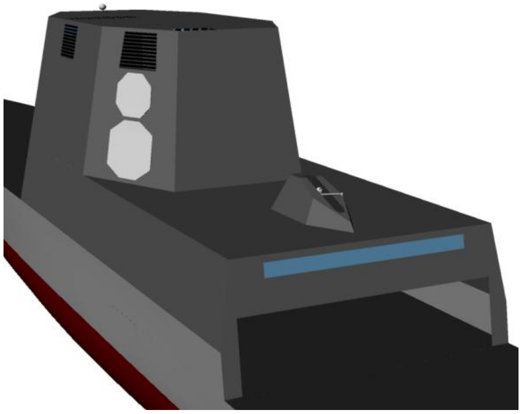


Figure 78 - Deckhouse Aft

4.2 Preliminary Arrangement (Cartoon)

The goal of preliminary arrangement is to ensure all necessary objects fit in the ship and all required volumes and areas are accounted for. By defining primary subdivisions, decks, and transverse bulkheads, the locations of tanks and critical spaces can be considered. In addition, stability, trim, radar cross section, machinery alignment with shaft and prop, damage stability, large object arrangements, engine intake and exhaust, structural efficiency, survivability, topside and overall function can be considered. The preliminary cartoon is a guide, for more detailed CAD work later.

The large objects that are accounted for in the initial cartoon consist of weapon system, tanks and machinery rooms. These items can be seen in Figure 79. Figure 80 is generated post CAD production and shows how the preliminary cartoon views aided in assembling a more complex 3D model. Figure 81 illustrates which surfaces and locations of the ship are considered modular spaces.

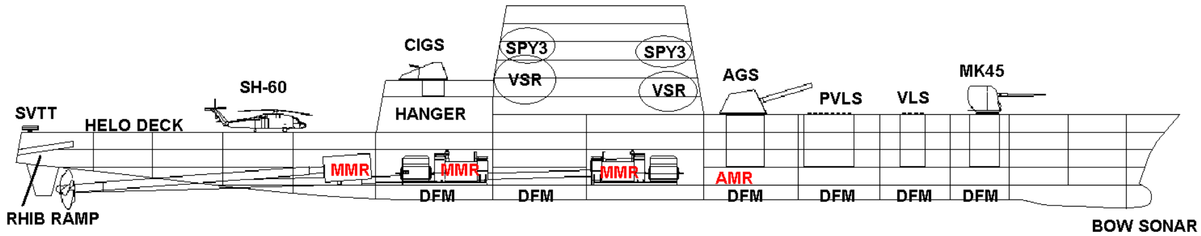


Figure 79 - Profile Cartoon View

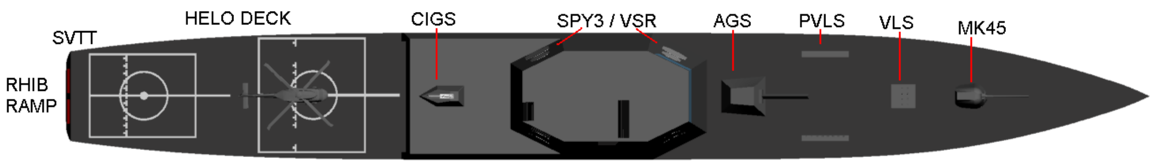


Figure 80 - Topside Arrangement

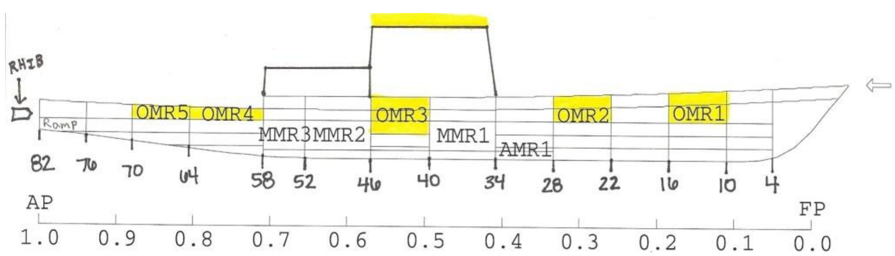


Figure 81 - Modularity Cartoon

4.3 Design for Production

The ideal build strategy for the MSC is to create a highly producible hull form. Wherever possible, flat plates and straight frames are used in place of contoured members. Single curvature plating is used to create most contours, and in circumstances which double curvature plates are required only slight contours are used. The deckhouse is constructed with flat plates and straight frames to maximize producibility. The implementation of a flat weather deck and a lengthy parallel midbody also aids in the ease of construction. The most complicated section of the ship is the bulbous bow, which has a constant elliptical cross-section. These designs are shown in Figure 82.

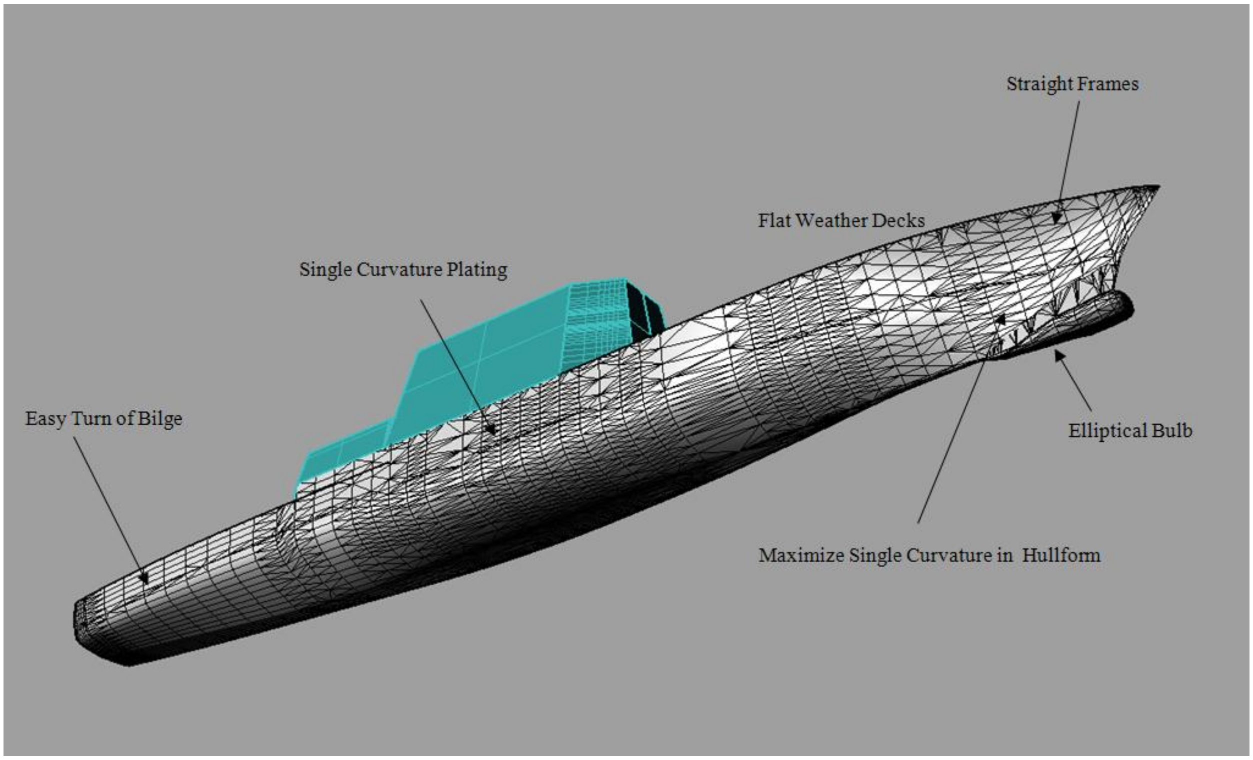


Figure 82 - MSC Producible Hullform Features

Modular construction techniques are utilized in order to produce the hull form quickly and efficiently. A preliminary structural assembly breakdown, seen in Figure 83, indicates the general group classifications and zones of the vessel through a division of the ship in separate blocks. Each block has an average width of 12-14 meters, and maximum weight of 100 MT. Blocks in the bow are given classification numbers in the 1000s where there is more curvature. 2000 level classifications indicate hull cargo areas, 3000 level classifications designate machinery rooms and distributed systems and outfitting. The 4000 level classification is assigned to the deckhouse and hanger areas. In more detailed unit breakdowns, which is not shown here, the 5000 level is reserved for on-board construction stages such as electrical wiring and plumbing spread throughout the ship. The 6000 level is reserved for special electronics and accommodations requiring a high degree of construction skill.

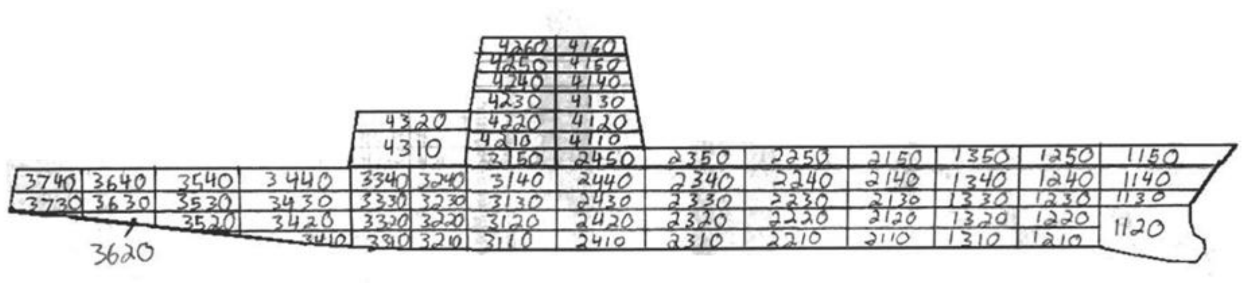


Figure 83– Structural Assembly Units Breakdown

These individual blocks are assembled into continuous larger sections called grand blocks which are then ready for final assembly, shown in the erection unit profile in Figure 84. To expedite construction during final assembly, sleeve couplings are used to join piping extending from one block to the next. One-sided welding of plating with ceramic backing tape is permitted when joining blocks, and primer is allowed to maximize the retention of the paint weld-through.

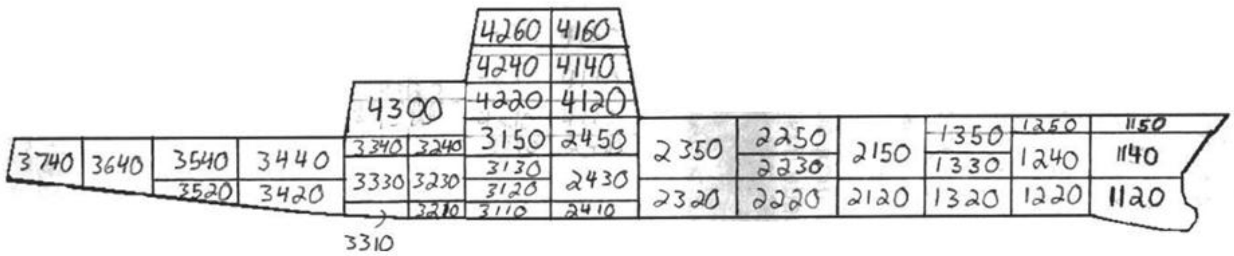


Figure 84 – Erection Unit Profile

The claw chart is shown in Table 41. It displays the construction schedule of blocks in the erection unit profile by week. Assembly begins approximately at amidships directly beneath the deckhouse with the expansion of construction longitudinally and vertically. During certain weeks main structural construction is slowed to install main machinery room equipment and shafting. The master construction schedule, seen in Table 42, indicates the duration of time necessary to complete each phase in the design, construction, and delivery process. It is a comprehensive view to maintain an on time work flow.

Table 41 – Claw Chart

Week	3700	3600	3500	3400	4400/ 3300	4300/ 3200	4200/ 3100	4100/ 2400	2300	2200	2100	1300	1200	1100
1							3110	2410						
2						3210		2430						
3							3120	Gen#2						
4					3310		3130		2320					
5						3230				2220				
6						Gen#3		2450						
7					3330						2120			
8				3420				ER#2						
9							3150		2350					
10			3520								Gen#1			
11					3340	3240								
12										ER#1		1320		
13				3440						2230				
14			3540										1220	
15										2250				
16		3640												
17									PACKC		2150			
18								4120				1330		
19							4220							1120
20												1350		
21	3740												1240	
22			SShaft					4140						
23			Pshaft											1140
24							4240						1250	
25						4300								1150
26							4260	4160						

Table 42 – Master Construction Schedule

Event	Description	Duration (Months)	Months Before Delivery (MBD)
1	Award Contract	0	66
2	Detail Design	38	65
3	Material Procurement	42	64
4	MFG/Production Planning	40	63
5	Lofting	21	57
6	Start Construction	0	48
7	Structural Fabrication 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	Dry-docking	1	14
21	Inclining	0	13
22	Dock Trails	0	7
23	Builder's Trials	0	5
24	Acceptance Trials	0	3
25	Delivery	0	0

4.4 Subdivision

The primary subdivision and tankage is developed using Rhino and HECSALV. The ship particulars are entered into the HECSALV Ship Project Editor and the Rhino file containing the hull offsets is imported into HECSALV. With transverse bulkheads and decks placed in HECSALV, a floodable length curve is generated. The bulkheads and decks are adjusted such that the ship meets the 3 compartment standard. The ASSET Space Module Report results and Model Center results are used to determine the amount of fuel, JP-5, fresh water, ballast, lube oil, sewage, dirty oil, and cargo tanks needed and then tanks are located in the ship. With the ship subdivided and tanks placed, multiple loading conditions are analyzed to determine the stability characteristics.

4.4.1 Hullform in HECSALV

The ship particulars, listed in Table 43 are entered in HECSALV Ship Project Editor and then the port side of the hullform created in Rhino is exported into the HECSALV file in sections. Each port side section, shown in Figure 85, is simplified by removing points that are within 50 mm of each other. After each half section is simplified, it is then mirrored to create the starboard side. The original and mirrored sections are shown in Figure 86. Once the ship is imported, it is located in HECSALV so that the forward and aft perpendiculars are correctly defined. Using the offsets that are imported into HECSALV, the deck edge is chosen and the margin line is placed three inches below the deck edge. This is shown by the red line in Figure 87.

Table 43 - Ship Particulars Used for HECSALV

Particulars	LBP (m)	192.056
	Depth (m)	14.00
	Beam (m)	22.996
	LOA (m)	194.929
Longitudinal Bounds	Aft (m-MS)	95.883A
	Fwd (m-MS)	99.046F
Vertical Bounds	Lower (m-BL)	-1.150
	Upper (m-BL)	16.467
Transverse Bounds	Port (m-CL)	11.698P
	Stbd (m-CL)	11.698S
Other	Keel Thick (mm)	0.0
	Design Keel Draft (m)	7.93

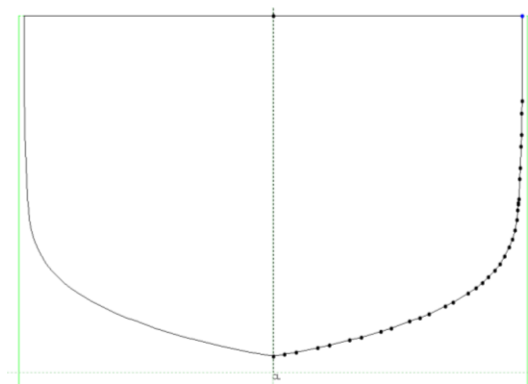


Figure 85 – Simplified Hullform Section

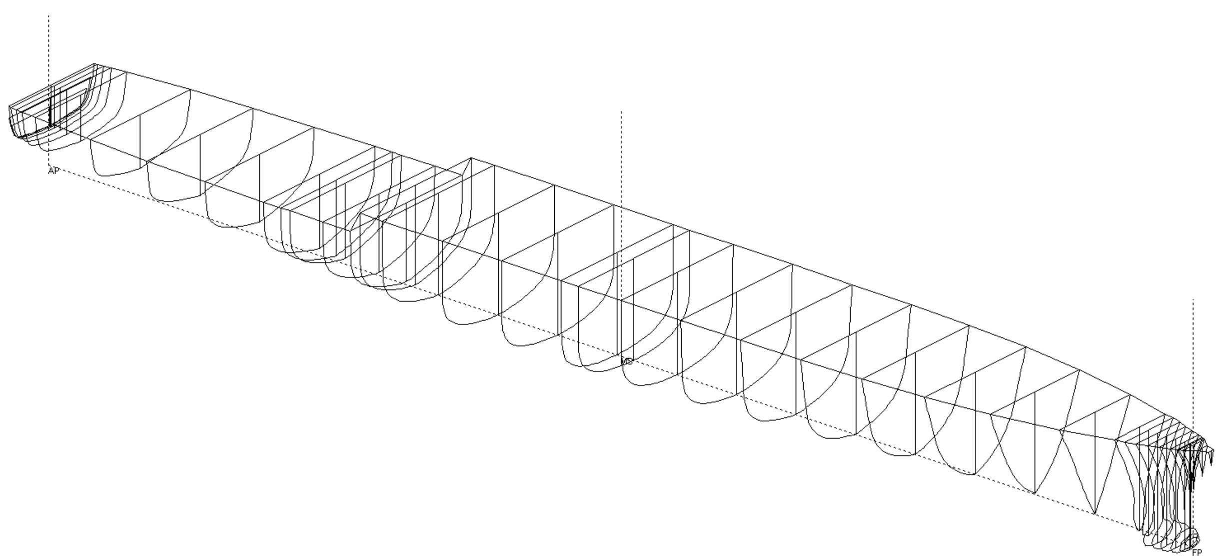


Figure 86 - Hullform Sections in HECSALV

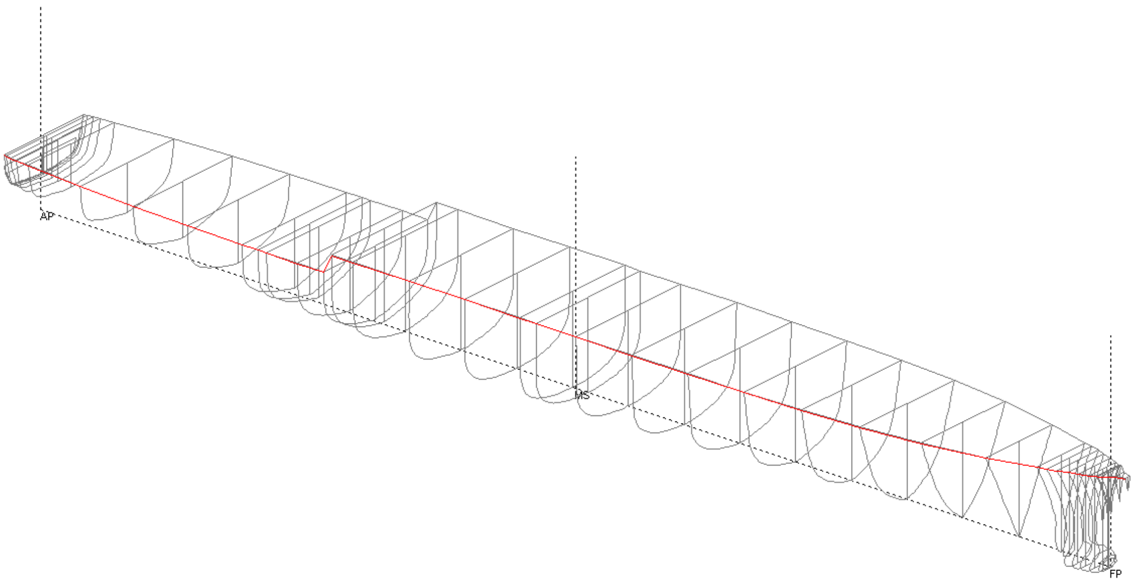


Figure 87 - Margin Line along the Length of the Ship

4.4.2 Transverse Subdivision, Floodable Length and Preliminary Tankage

The first step in subdividing the ship is locating the decks. The inner bottom has a height of 2.5 m and each deck above it is spaced 3 m apart. Figure 88 shows the deck spacing and Table 44 lists each deck and its height above the baseline. Next, the ship is subdivided transversely. The bulkheads are placed around the deckhouse and machinery rooms to ensure the correct spacing and locations, and are then spaced out over the remaining length of the ship. The bulkhead locations are shown in Figure 89 and Table 45 lists each bulkhead and its distance aft of the forward perpendicular.

A floodable length curve is generated based upon the transverse bulkhead locations and permeabilities of 0.95, 0.90, 0.85, and 0.80. Figure 90 shows the floodable length curve over the length of the ship for each permeability, and the triangles show the damage length if three compartments were damaged, where the damage length is 0.15*LBP.

The ASSET Space Module Report is used to determine the amounts of fuel, water, ballast, and other items needed. Then tanks are created in HECSALV to accommodate the correct volume for each item needed. Figure 91 shows the ship with each type of compartment outlined in a different color. Table 46 lists the compartment use and the corresponding color along with capacity and location characteristics.

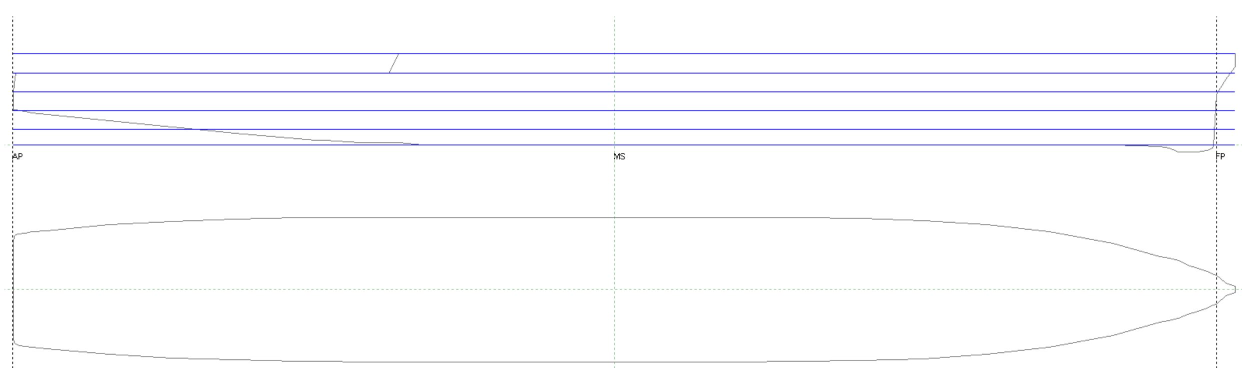


Figure 88 - Location of Decks

Table 44 - Vertical Spacing of Each Deck Above the Baseline

Name	Vert (m-BL)
Baseline	0.0
Keel	0.0
Inner Bottom	2.5
Deck 3	5.5
Deck 2	8.5
Deck 1	11.5
01 Level	14.5

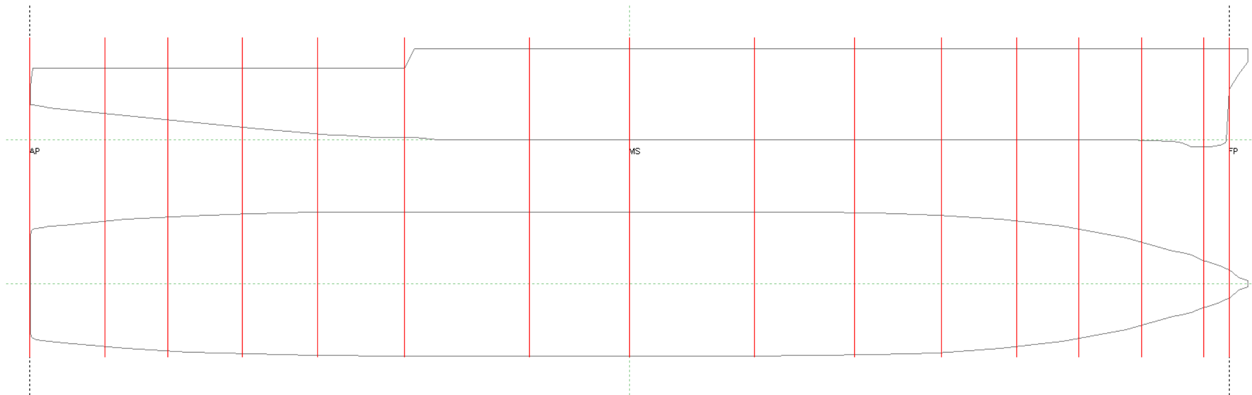


Figure 89 - Transverse Bulkhead Locations

Table 45 - Transverse Bulkhead Location Relative to Amidships

Name	Long (m-MS)
FP	96.028F
1	92.028F
2	82.028F
3	72.028F
4	62.028F
5	50.028F
6	36.028F
7	20.028F
8	0.028F
9	15.972A
10	35.972A
11	49.972A
12	61.972A
13	73.972A
14	83.972A
AP	96.028A

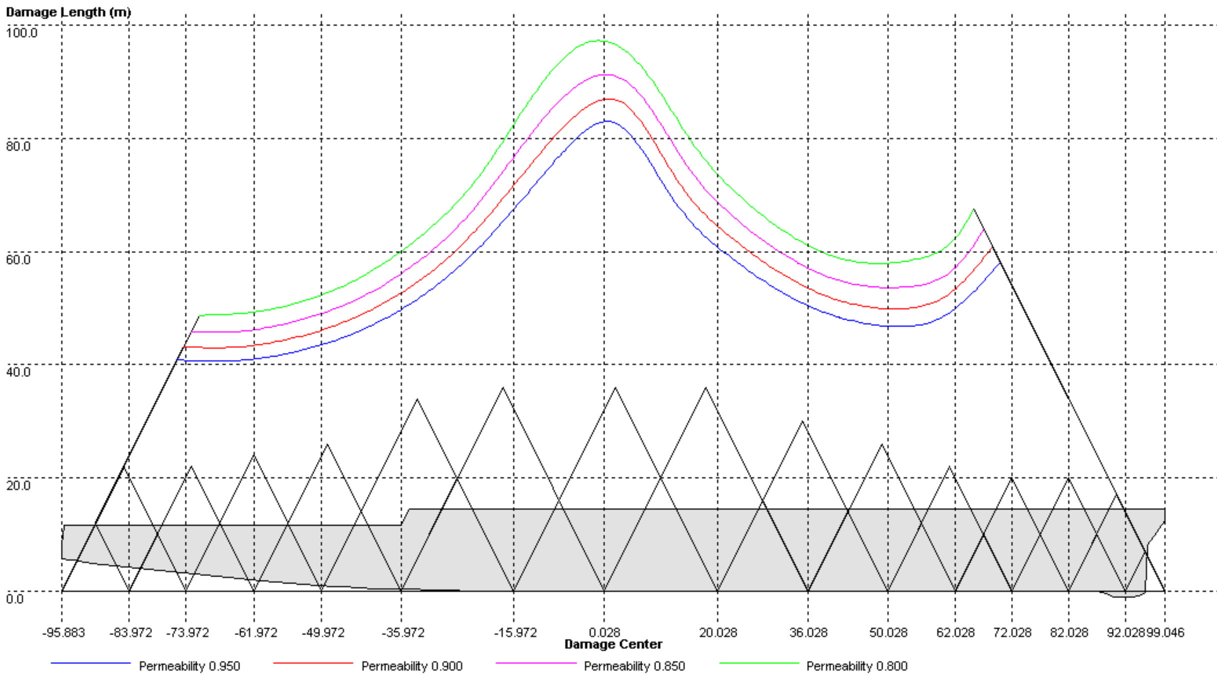


Figure 90- Floodable Length Curve with Three Compartment Damage Stability

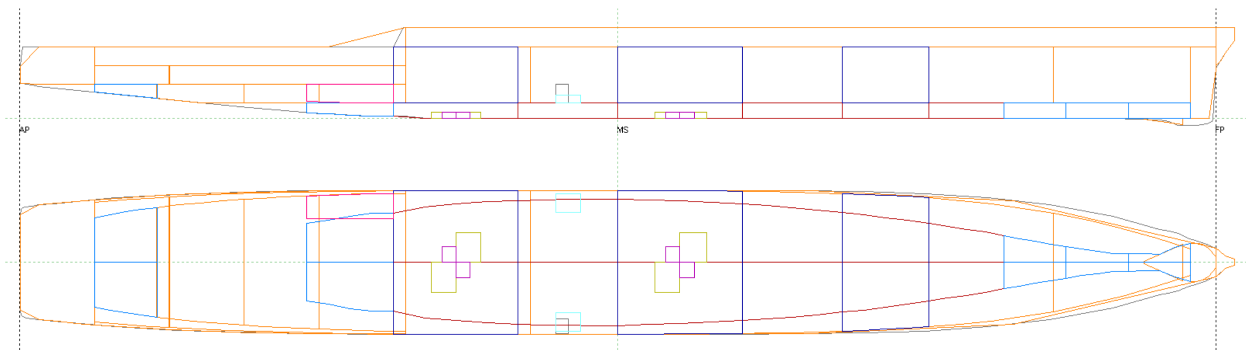


Figure 91 - Compartments Classified According to Table 23

Table 46 - Compartment Subdivision and Characteristics

Name	Color	Capacity Perm (m^3)	LCG (m-MS)	VCG (m-BL)	TCG (m-CL)	Free Surface Slack (m^4)	Free Surface 98% Full (m^4)
Unassigned		26,186	2.695A	9.081	0.0	258,748	43,594
Sewage		11	8.972A	4.165	10.023S	2	2
Fuel (DFM)		2,656	8.678A	1.536	0.002S	10,631	2,315
Waste Oil		58	5.945A	0.585	0.071P	150	28
Lube Oil		20	7.206A	0.537	0.006S	12	4
Fresh Water		25	7.969A	3.163	0.0	17	6
SW Ballast		587	12.254A	2.542	0.0	1,615	334
Machinery		9,932	3.803F	7.121	0.0	51,258	19,487
JP5		100	42.506A	4.35	8.479P	65	31

4.4.3 Loading Conditions and Preliminary Stability Analysis

Three loading conditions are used for the stability analysis, full load, minimum operations, and lightship. The full load conditions listed in Table 47 are used for the still water, hogging, and sagging analysis. Figure 92 shows the profile view with the still water wave shown in blue. The stability is checked using HECSALV and the stability, trim, draft and strength calculations are listed in Table 48. The wind heel curve is also generated using HECSALV. The wind heel curve for the full load still water condition, which can be seen in Figure 93, shows that the ship is stable. Data related to the wind heel curve is listed in Table 49. Figure 94 shows the shear force and bending moment diagrams for the full load still water condition.

Table 47 - Full Load Still Water Condition

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT
Light Ship	15,177	8.060	1.972A	0	---
Constant	0	0	1.972A	0	0
Sewage	0	---	---	---	---
Fuel (DFM)	1,774	1.489	8.486F	0.002S	3,204
Waste Oil	0	---	---	---	---
Lube Oil	17	0.514	7.206A	0.006S	7
Fresh Water	25	3.163	7.969A	0.000P	0
SW Ballast	0	---	---	---	---
JP5	77	4.292	42.489A	8.456P	39
Misc. Weights	525	0.0	0.0	0.0	0.0
Displacement	17,594	7.126	1.048A	0.037P	3,250

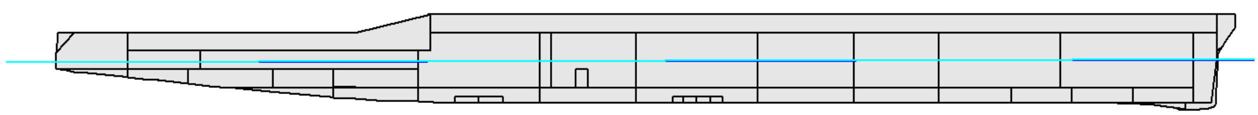


Figure 92 - Still Water Condition

Table 48 - Stability, Trim, Draft, and Strength Summaries for the Full Load Still Water Condition

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KMt (m)	11.9	LCF Draft (m)	6.854	Draft at A.P (m)	6.67	Shear	626 MT at 56.972 A m-MS
VCG (m)	7.126	LCB (m-MS)	1.044 A	Draft at M.S. (m)	6.876	Bending Moment	31,660 H m-MT at 18.293 m-MS
GMt (Solid) (m)	4.774	LCF (m-MS)	10.124A	Draft at F.P (m)	7.083		
FSc (m)	0.185	MT1cm (m-MT/cm)	434	Draft at Aft Marks (m)	6.873		
GMt (Corrected) (m)	4.589	Trim (m-F)	0.413	Draft at Mid Marks (m)	7.079		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	7.286		

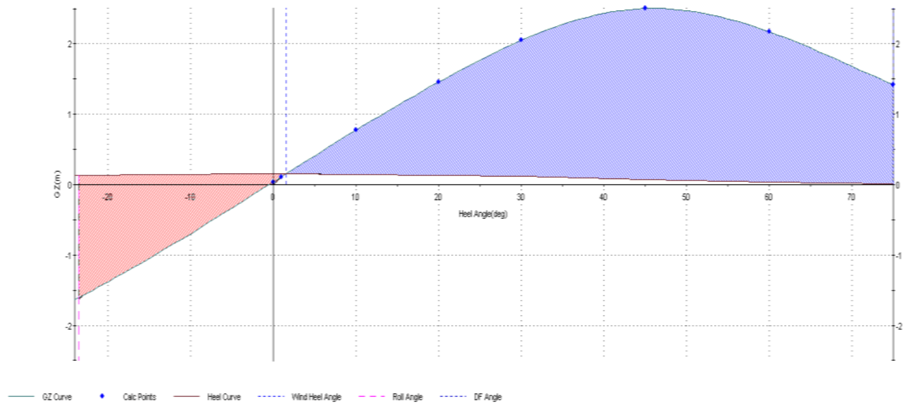


Figure 93 - Wind Heel Curve for Full Load Still Water Condition

Table 49 - Calculated Wind Heel Values for Full Load Still Water Condition

Parameter	Units	Value	Required
Wind Heel	deg	1.6	---
Wind Heeling Arm Lw	m	0.152	---
Maximum Righting Arm Ratio		0.06	0.6
Capsizing Area A2	m-rad	0.41	---
Righting Area A1	m-rad	2.17	0.57
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.507	---
Angle at Max GZ	deg	45.9	---
Projected Sail Area	m^2	1,879.03	---
Vertical Arm ABL	m	11.768	---
Heeling Arm at 0 deg	m	0.152	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area – BL	m	16.660	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

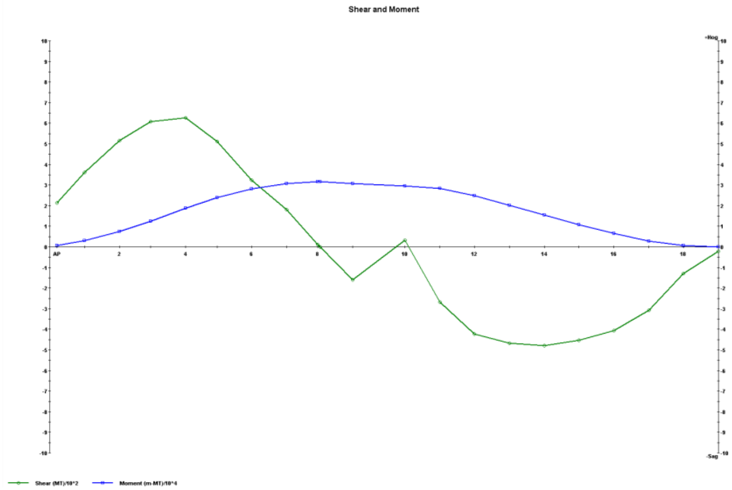


Figure 94 - Shear and Moment Diagram for Full Load Still Water Condition

Next the full load hogging and sagging conditions are checked. The same parameters listed in Table 47 for the still water condition are used for the hogging and sagging cases.

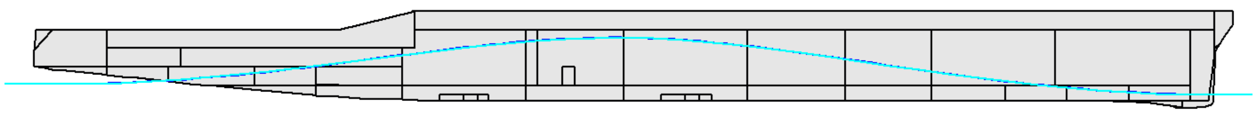


Figure 95 shows the hogging case with the crest of the wave located in the middle of the ship. The height of the wave is equal to sixty percent of the square root of the ship length. The calculations for the full load hogging condition are summarized in Table 50 and the shear force and bending moment are shown in Figure 96.

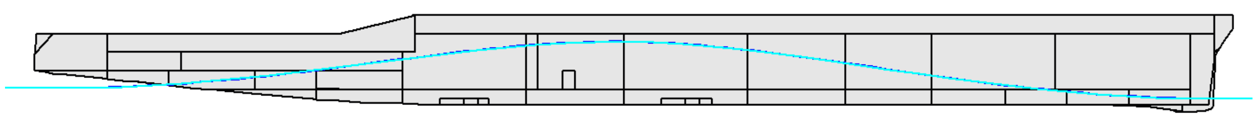


Figure 95 - Hogging Condition

Table 50 - Stability, Trim, Draft, and Strength Summaries for the Full Load Hogging Condition

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KMt (m)	10.961	LCF Draft (m)	6.037	Draft at A.P (m)	6.894	Shear	-2,327 MT at 36.028 F m-MS
VCG (m)	7.126	LCB (m-MS)	1.064A	Draft at M.S. (m)	6.025	Bending Moment	127,450H m-MT at 5.238A m-MS
GMt (Solid) (m)	3.834	LCF (m-MS)	1.423	Draft at F.P (m)	5.155		
FSc (m)	0.185	MT1cm (m-MT/cm)	235	Draft at Aft Marks (m)	6.039		
GMt (Corrected) (m)	3.65	Trim (m-F)	1.739	Draft at Mid Marks (m)	5.170		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	4.300		

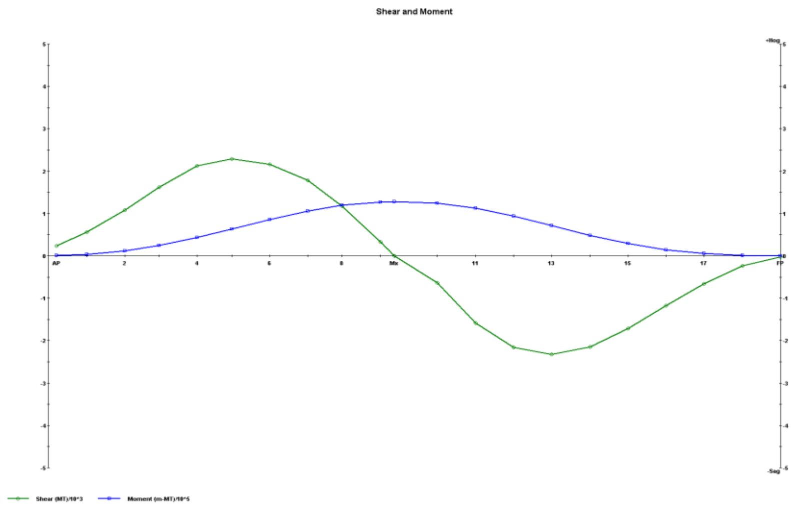


Figure 96 - Shear and Moment Diagrams for Full Load Hogging Condition

Figure 97 shows the sagging case with the trough of the wave located in the middle of the ship. The calculations for the full load sagging condition are summarized in Table 51 and the shear force and bending moment are shown in Figure 98.

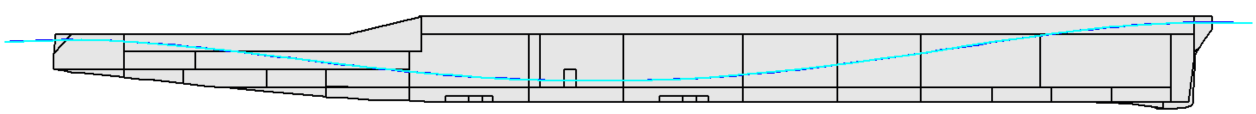


Figure 97 - Full Load Sagging Condition

Table 51 - Stability, Trim, Draft, and Strength Summaries for the Full Load Sagging Condition

Stability Calculations		Trim Calculation		Drafts		Strength Calculation	
KMt (m)	12.827	LCF Draft (m)	7.721	Draft at A.P (m)	6.324	Shear	-1,697 MT at 47.972A m-MS
VCG (m)	7.126	LCB (m-MS)	1.011A	Draft at M.S. (m)	7.830	Bending Moment	97,384S m-MT at 2.650A m-MS
GMt (Solid) (m)	5.701	LCF (m-MS)	6.929A	Draft at F.P (m)	9.335		
FSc (m)	0.185	MT1cm (m-MT/cm)	520	Draft at Aft Marks (m)	7.805		
GMt (Corrected) (m)	5.516	Trim (m-F)	3.011	Draft at Mid Marks (m)	9.310		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	10.816		

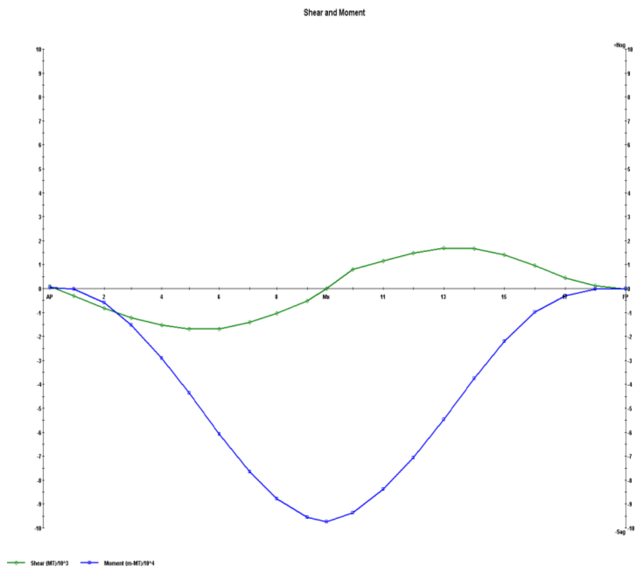


Figure 98 - Shear and Moment Diagrams for Full Load Sagging Condition

The parameters for the minimum operations for the still, hogging, and sagging waves are listed in Table 52. Table 53 shows the stability, trim, draft, and strength summaries for the minimum operations still water condition. Table 54 summarizes the values associated with the wind heel curve shown in Figure 99. Figure 100 is the shear force and bending moment curve for the ship in still water at the minimum operating condition.

Table 52 - Min OP Still Water Condition

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT
Light Ship	15,177	8.060	1.972A	0	---
Constant	0	0	1.972A	0	0
Sewage	11	4.165	8.972A	10.023S	0
Fuel (DFM)	616	0.791	8.591F	0.001S	4,101
Waste Oil	28	0.369	5.940A	0.067P	140
Lube Oil	9	0.305	7.204A	0.007S	11
Fresh Water	16	2.963	7.967A	0.00P	15
SW Ballast	0	---	---	---	---
JP5	27	3.441	42.015A	8.015P	22
Misc. Weights	186	0.00	0.00	0.00	0.00
Displacement	16,070	7.655	1.631A	0.006P	4,289

Table 53 - Stability, Trim, Draft, and Strength Summaries for the Min OP Still Water Condition

Stability Calculations		Trim Calculation		Drafts		Strength Calculation	
KMt (m)	12.221	LCF Draft (m)	6.450	Draft at A.P (m)	6.502	Shear	805 MT at 56.972A m-MS
VCG (m)	7.655	LCB (m-MS)	1.636A	Draft at M.S. (m)	6.443	Bending Moment	44,702H m-MT at 10.463A m-MS
GMt (Solid) (m)	4.566	LCF (m-MS)	10.497A	Draft at F.P (m)	6.384		
FSc (m)	0.267	MT1cm (m-MT/cm)	422	Draft at Aft Marks (m)	6.444		
GMt (Corrected) (m)	4.299	Trim (m-A)	0.118	Draft at Mid Marks (m)	6.385		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	6.327		

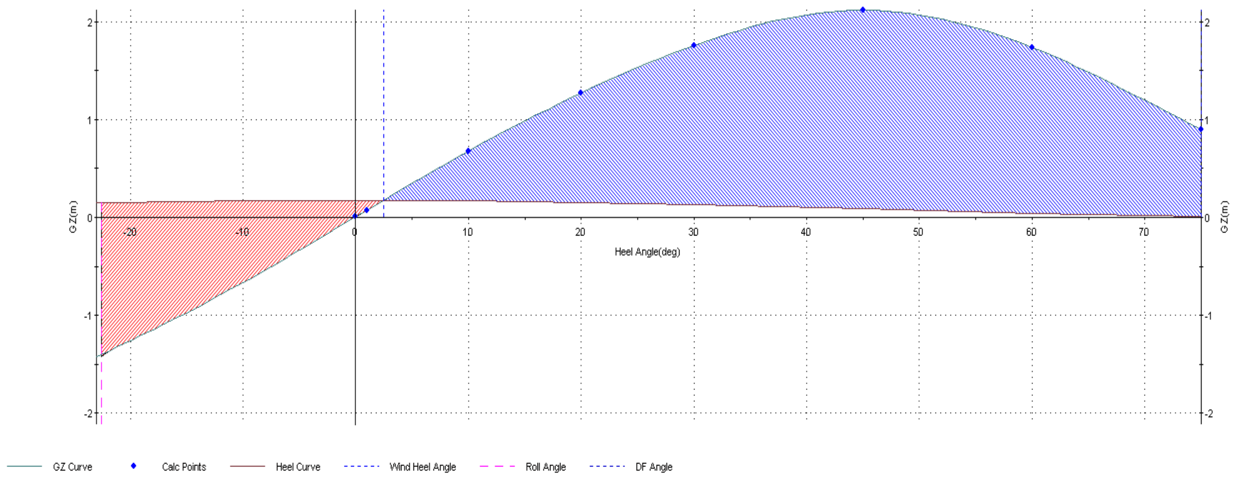


Figure 99 - Wind Heel Curve for Min OP Still Water Condition

Table 54 - Calculated Wind Heel Values for Min Op Still Water Condition

Parameter	Units	Value	Required
Wind Heel	deg	2.5	---
Wind Heeling Arm Lw	m	0.175	---
Maximum Righting Arm Ratio		0.08	0.6
Capsizing Area A2	m-rad	0.37	---
Righting Area A1	m-rad	1.76	0.57
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.119	---
Angle at Max GZ	deg	45.0	---
Projected Sail Area	m^2	1,969.87	---
Vertical Arm ABL	m	11.572	---
Heeling Arm at 0 deg	m	0.175	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area – BL	m	16.700	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

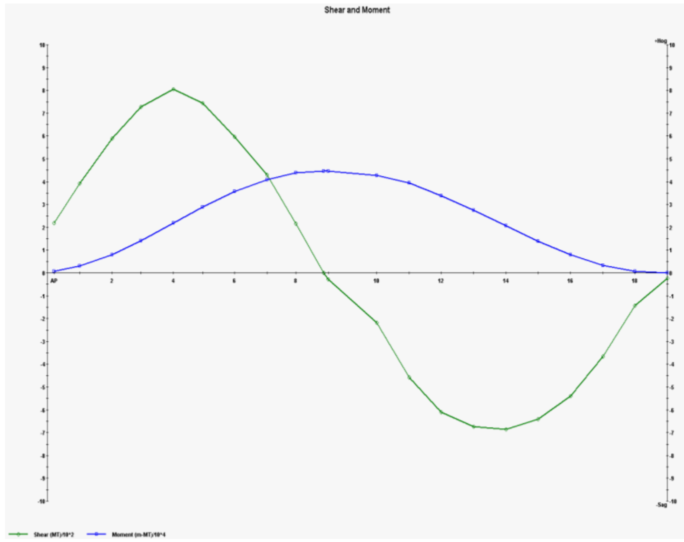


Figure 100 - Shear and Moment Diagrams for Min OP Still Water Condition

The stability for the minimum operations load is also tested with an applied hogging wave and a sagging wave. Table 55 lists the characteristics when the ship encounters a hogging wave, and Figure 101 shows the shear force and bending moment that the ship will experience from the wave. Table 56 lists the calculated values for the ship when it experiences a sagging wave and Figure 102 shows the shear force and bending moment caused by the wave.

Table 55 - Stability, Trim, Draft, and Strength Summaries for the Min OP Hogging Condition

Stability Calculations		Trim Calculation		Drafts		Strength Calculation	
KMt (m)	11.102	LCF Draft (m)	5.532	Draft at A.P (m)	6.600	Shear	-2,457 MT at 36.028F m-MS
VCG (m)	7.655	LCB (m-MS)	1.655A	Draft at M.S. (m)	5.517	Bending Moment	137,423H m-MT at 3.689A m-MS
GMt (Solid) (m)	3.447	LCF (m-MS)	1.291A	Draft at F.P (m)	4.434		
FSc (m)	0.267	MT1cm (m-MT/cm)	216	Draft at Aft Marks (m)	5.535		
GMt (Corrected) (m)	3.180	Trim (m-A)	2.166	Draft at Mid Marks (m)	4.453		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	3.370		

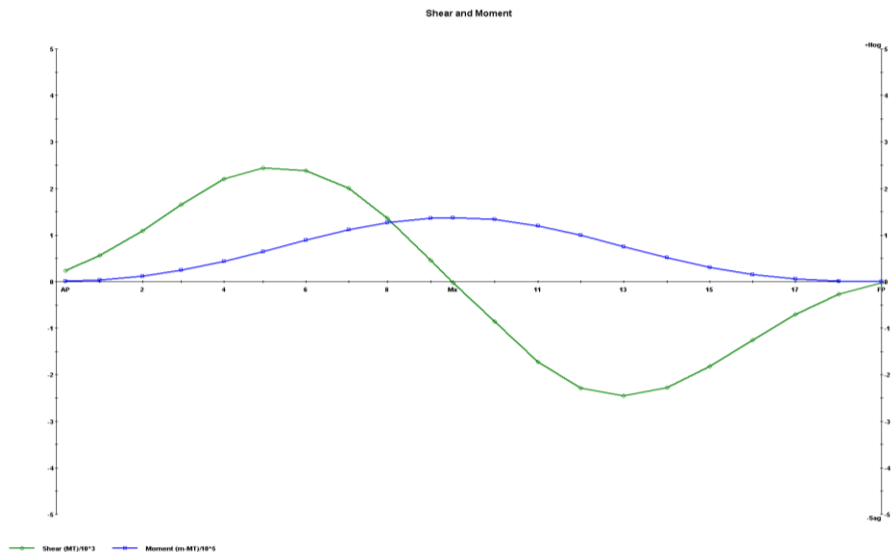


Figure 101 - Shear and Moment Diagram for Min OP Hogging Condition

Table 56 - Stability, Trim, Draft, and Strength Summaries for the Min OP Sagging Condition

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KMt (m)	13.058	LCF Draft (m)	7.326	Draft at A.P (m)	6.098	Shear	1,448 MT at 36.028F m-MS
VCG (m)	7.655	LCB (m-MS)	1.587A	Draft at M.S. (m)	7.429	Bending Moment	79,863S m-MT at 2.937A m-MS
GMt (Solid) (m)	5.403	LCF (m-MS)	7.447A	Draft at F.P (m)	8.760		
FSc (m)	0.267	MT1cm (m-MT/cm)	509	Draft at Aft Marks (m)	7.407		
GMt (Corrected) (m)	5.137	Trim (m-A)	2.662	Draft at Mid Marks (m)	8.738		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	10.069		

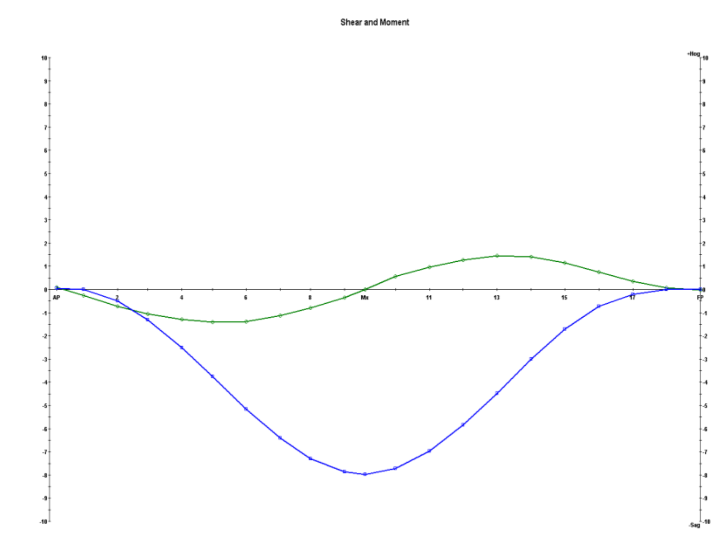


Figure 102 - Shear and Moment Diagram for Min OP Sagging Condition

The last scenario tested is the lightship in still water. Table 57 lists the conditions for lightship and Table 58 lists the stability, trim, draft, and strength values calculated for the lightship scenario. Figure 103 shows that the ship is stable and Table 59 lists the values associated with the wind heel curve. Figure 104 shows the shear force and bending moment that the ship will experience while in still water with only the lightship load.

Table 57 - Lightship Still Water Condition

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT
Light Ship	15,177	8.060	1.972A	0.00	---
Constant	0.00	0.00	1.972A	0.00	0.00
Sewage	0.00	---	---	---	---
Fuel (DFM)	0.00	---	---	---	---
Waste Oil	0.00	---	---	---	---
Lube Oil	0.00	---	---	---	---
Fresh Water	0.00	---	---	---	---
SW Ballast	0.00	---	---	---	---
JP5	0.00	---	---	---	---
Misc. Weights	0.00	---	---	---	---
Displacement	0.00	---	---	---	---

Table 58 - Stability, Trim, Draft, and Strength Summaries for the Lightship Still Water Condition

Stability Calculations		Trim Calculation		Drafts		Strength Calculation	
KMt (m)	12.430	LCF Draft (m)	6.210	Draft at A.P (m)	6.399	Shear	913 MT at 56.972A m-MS
VCG (m)	8.060	LCB (m-MS)	1.986A	Draft at M.S. (m)	6.187	Bending Moment	53,236H m-MT at 7.257A m-MS
GMt (Solid) (m)	4.370	LCF (m-MS)	10.691A	Draft at F.P (m)	5.975		
FSc (m)	0.000	MT1cm (m-MT/cm)	414	Draft at Aft Marks (m)	6.190		
GMt (Corrected) (m)	4.370	Trim (m-A)	0.424	Draft at Mid Marks (m)	5.978		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	5.766		

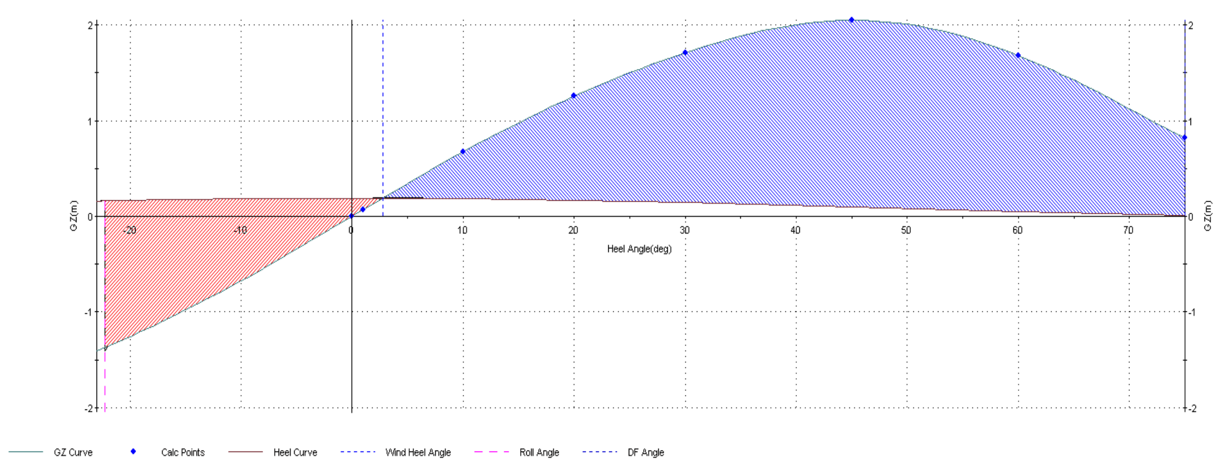


Figure 103 - Wind Heel Curve for Lightship Still Water Condition

Table 59 - Calculated Wind Heel Values for Lightship Still Water Condition

Parameter	Units	Value	Required
Wind Heel	deg	2.7	---
Wind Heeling Arm Lw	m	0.189	---
Maximum Righting Arm Ratio		0.09	0.6
Capsizing Area A2	m-rad	0.37	---
Righting Area A1	m-rad	1.69	0.49
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.050	---
Angle at Max GZ	deg	45.1	---
Projected Sail Area	m^2	2,019.13	---
Vertical Arm ABL	m	11.443	---
Heeling Arm at 0 deg	m	0.190	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area – BL	m	16.700	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

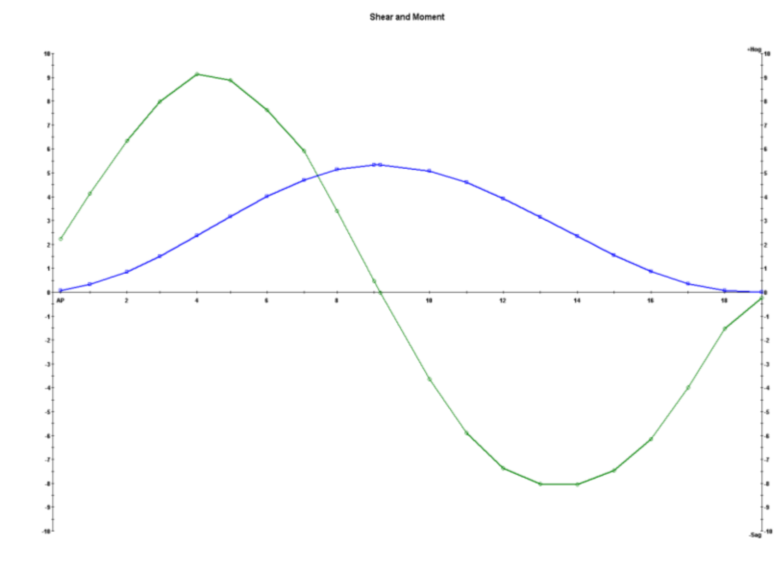


Figure 104 - Shear and Moment Diagram for Lightship Still Water Condition

4.5 Structural Design and Analysis

4.5.1 Procedure

MAESTRO, a course-mesh finite element solver, is used to analyze the structural integrity of the ship. An iterative process is implemented in order to properly scale the ship's scantlings. Initial materials, structural geometry and scantlings are obtained from ASSET and then entered into a component catalog in MAESTRO. ASSET and RHINO are used to determine endpoints and represent the ship geometry in MAESTRO. The model is then loaded with data from HECSALV and evaluated. Evaluation in MAESTRO determines if the scantlings are acceptable. Scantling dimensions are changed in an iterative process until an acceptable adequacy is obtained.

4.5.2 Geometry, Components and Materials

A port side of the entire length of the ship with transverse symmetry is modeled in MAESTRO and can be seen in Figure 110. Sixteen modules are created, separated by transverse bulkheads and pieced together under one substructure. ASSET produces data that can be used to create geometry endpoints in MAESTRO, but the ship geometry created in ASSET has changed too much at this point, and this method is inadequate. Instead, Orca 3D in Rhino is used to create a wireframe of the ship by adding waterlines, buttocks, and sections. This wireframe model is then imported into MAESTRO as an IDF file as seen in Figure 106. Construction lines are created in MAESTRO and used to generate endpoints that described the geometry of the ship, using the wireframe as a guide. The original ASSET midship endpoint locations can be seen in Figure 107. This suggestion of endpoint locations is modified by deleting ID4 (inner deck 4), adding more points to define the curvature and shape, and renumbering the points to establish a logical order to be entered into MAESTRO. The result of these modifications can be seen in Figure 108. This process of redefining the endpoints is used for every module modeled in MAESTRO.

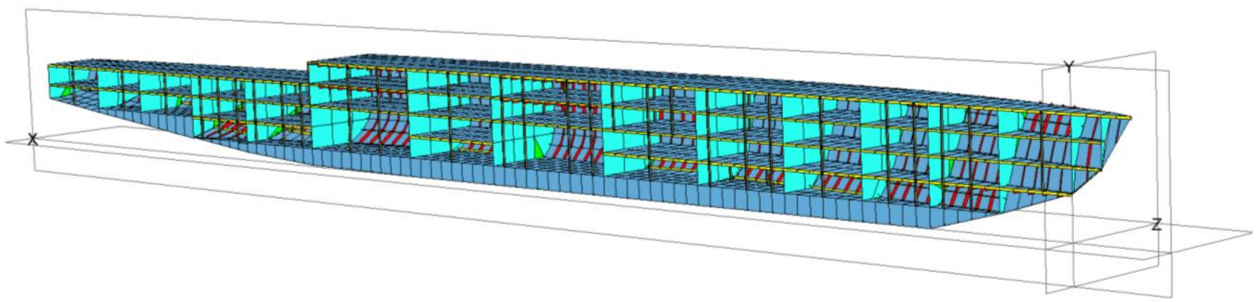


Figure 105 - MAESTRO Model

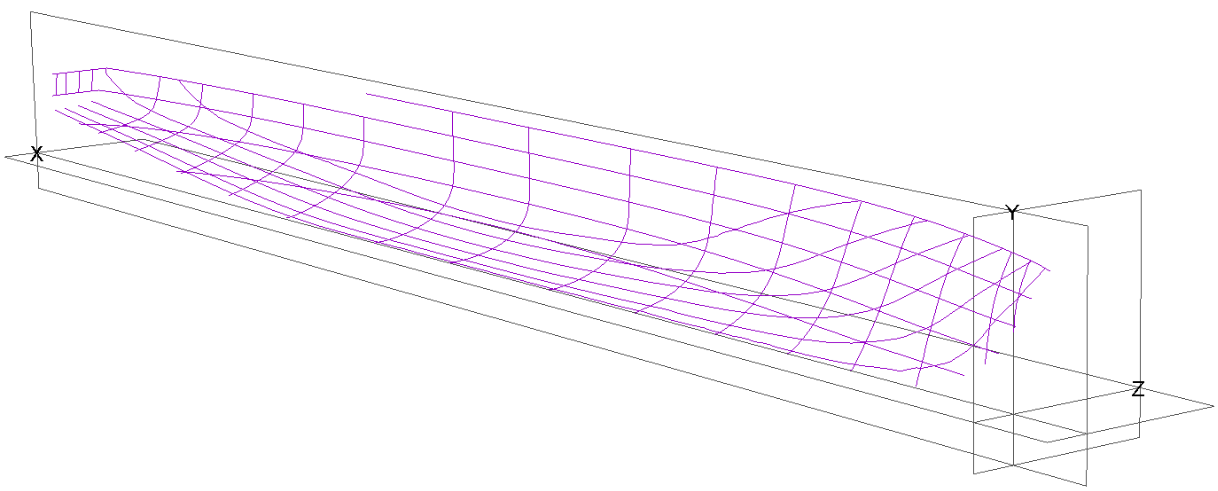


Figure 106 - Wireframe Model in MAESTRO

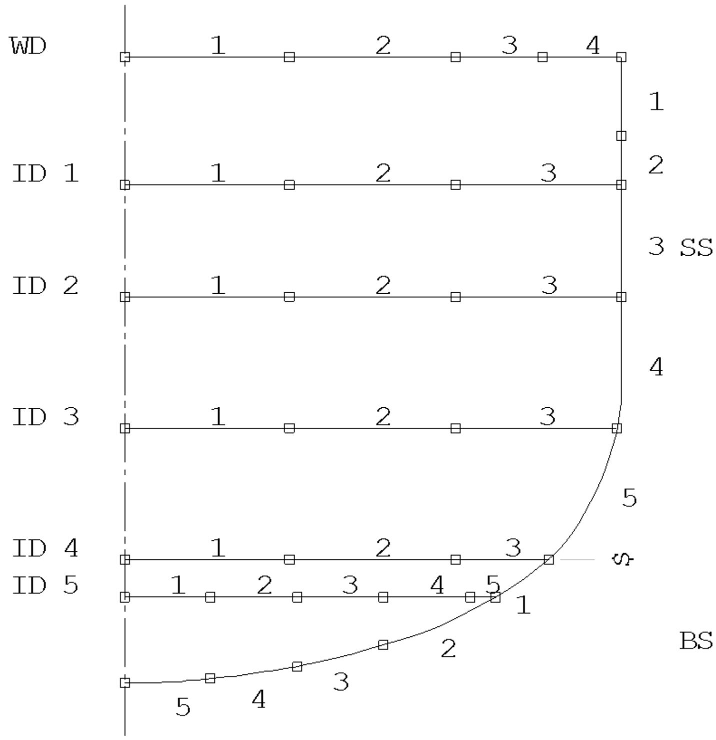


Figure 107 - ASSET Endpoint Locations

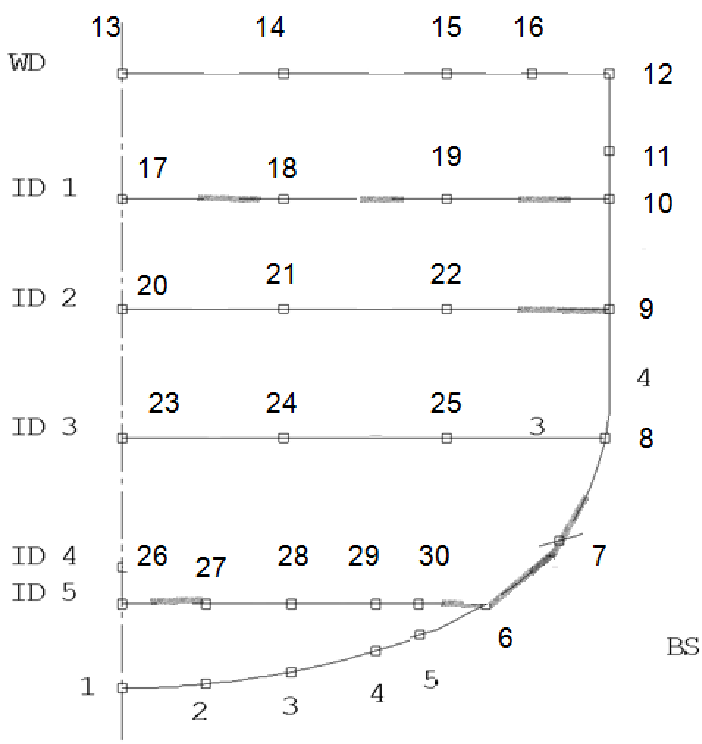


Figure 108 - Modified Endpoint Locations

Data from ASSET is used as a preliminary design for the structural geometry of the ship. Plate thicknesses, frame and girder dimensions, stiffener layouts, and material properties are used to create the component catalog. HSLA80 steel is used for all parts of the ship. It's properties can be seen below in Figure 109.

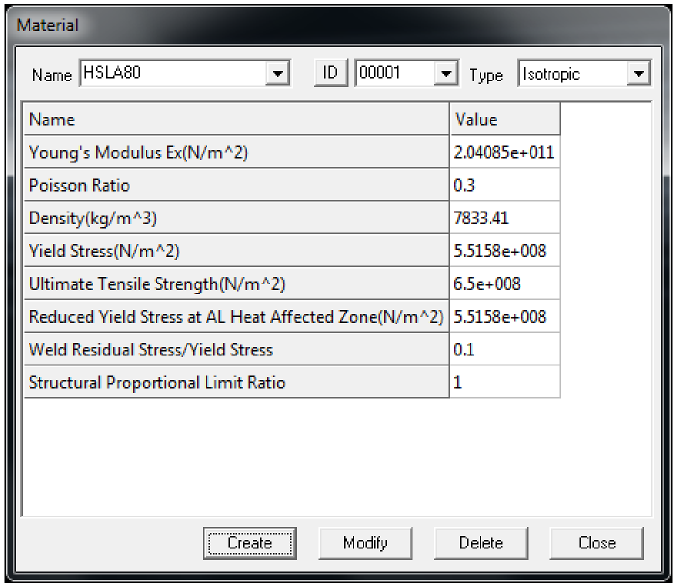


Figure 109 - Material Properties in MAESTRO

A table of plate thicknesses with corresponding plate location can be seen below in Table 60. Beam properties for frames, girders, and stiffeners can be seen below in Table 61.

Table 60 - Plate Thickness

Name	Thickness (m)
Weather Deck Segments	0.015875
Bottom Shell Segments 1 and 2	0.015875
Bottom Shell Segment 3	0.0206375
Bottom Shell Segment 4	0.0333375
Bottom Shell Segment 5	0.0460375
Side Shell Segment 1	0.015875
Side Shell Segments 2-5	0.0127
Internal Deck 1 All Segments	0.0103187
Internal Deck 2 All Segments	0.009525
Internal Deck 3 All Segments	0.0111125
Internal Deck 4 All Segments	0.0127
Transverse Bulkhead Segments	0.0111125

Table 61 - Beam Properties

Name	Web Height	Web Thickness (m)	Flange Width (m)	Flange Thickness (m)
Bottom Shell Frame Segment 1	0.202946	0.00635	0.1016	0.007874
Bottom Shell Frame Segment 2	0.557565	0.007144	0.4953	0.0127
Bottom Shell Frame Segment 3	1.364	0.008731	0.4953	0.0127
Bottom Shell Frame	2	0.011906	0.4953	0.0127

Name	Web Height	Web Thickness (m)	Flange Width (m)	Flange Thickness (m)
Segment 4				
Bottom Shell Frame Segment 5	2.5	0.0127	0.4953	0.0127
Bottom Shell Girder Segment 1	2.5	0.014827	0.4953	0.0127
Bottom Shell Girder Segment 2	2	0.014827	0.4953	0.0127
Bottom Shell Girder Segment 3	1.61363	0.0127	0.4953	0.0127
Bottom Shell Girder Segment 4	1.11452	0.0127	0.4953	0.0127
Bottom Shell Girder Segment 5	0.332179	0.015875	0.332179	0.0127
Bottom Shell Stiffener Segment 1	0.17653	0.004572	0.0762	0.00635
Bottom Shell Stiffener Segments 2-4	0.177546	0.004572	0.127	0.007874
Bottom Shell Stiffener Segment 5	0.201422	0.00635	0.0762	0.009398
Side Shell Frame Segment 1	0.126746	0.004572	0.0508	0.007874
Side Shell Frame Segment 2	0.124968	0.004572	0.0508	0.007874
Side Shell Frame Segment 3	0.253238	0.00635	0.1016	0.010922
Side Shell Frame Segment 4	0.304038	0.007874	0.1778	0.013462
Side Shell Frame Segment 5	0.454914	0.01922	0.1524	0.014986
Side Shell Stiffener Segments 1-2	0.124968	0.003048	0.0762	0.004572
Side Shell Stiffener Segment 3	0.126746	0.004572	0.0508	0.007874
Side Shell Stiffener Segment 4	0.152146	0.004572	0.0508	0.007874
Side Shell Stiffener Segment 5	0.177546	0.004572	0.0762	0.007874
Internal Deck 1 Frame All Segments	0.252222	0.00635	0.0762	0.009398
Internal Deck 2 Frame All Segments	0.17653	0.004572	0.0762	0.00635
Internal Deck 3 Frame All Segments	0.17653	0.004572	0.0762	0.00635
Internal Deck 4 Frame All Segments	0.099568	0.003048	0.0508	0.004572
All Internal Deck Stiffener All Segments	0.099568	0.003175	0.0508	0.004775
Internal Deck 1 Girder All Segments	0.227838	0.00635	0.0762	0.010922
Internal Deck 2 Girder All Segments	0.253746	0.00635	0.127	0.007874
Internal Deck 3 Girder All Segments	0.3048	0.007874	0.2286	0.013462
Internal Deck 4 Girder All Segments	0.304038	0.007874	0.254	0.013462
Side Shell Girder Segment 1	0.126746	0.004572	0.0508	0.007874
Side Shell Girder Segment 2	0.124968	0.007874	0.0508	0.013462
Side Shell Girder Segment 3	0.253238	0.00635	0.1016	0.010922
Side Shell Girder Segment 4	0.304038	0.007874	0.1778	0.013462
Side Shell Girder Segment 5	0.454914	0.007874	0.2286	0.013462

Name	Web Height	Web Thickness (m)	Flange Width (m)	Flange Thickness (m)
Weather Deck Girder All Segments	0.304038	0.007874	0.1524	0.013462
Weather Deck Frame All Segments	0.252222	0.00635	0.0762	0.009398
Weather Deck Stiffener All Segments	0.124968	0.003048	0.0762	0.004572
Transverse Bulkhead Frame	0.304038	0.007874	0.2286	0.013462
For Failing Stiffener	0.201422	0.012	0.0762	0.018
Null Frame Set	0	0	0	0

Strake elements are used to represent stiffened panels and longitudinal floors, compound elements are used to model transverse floors, and quads and tris are used to produce the transverse bulkheads. The completed midship module can be seen in Figure 110 with the MAESTRO elements labeled.

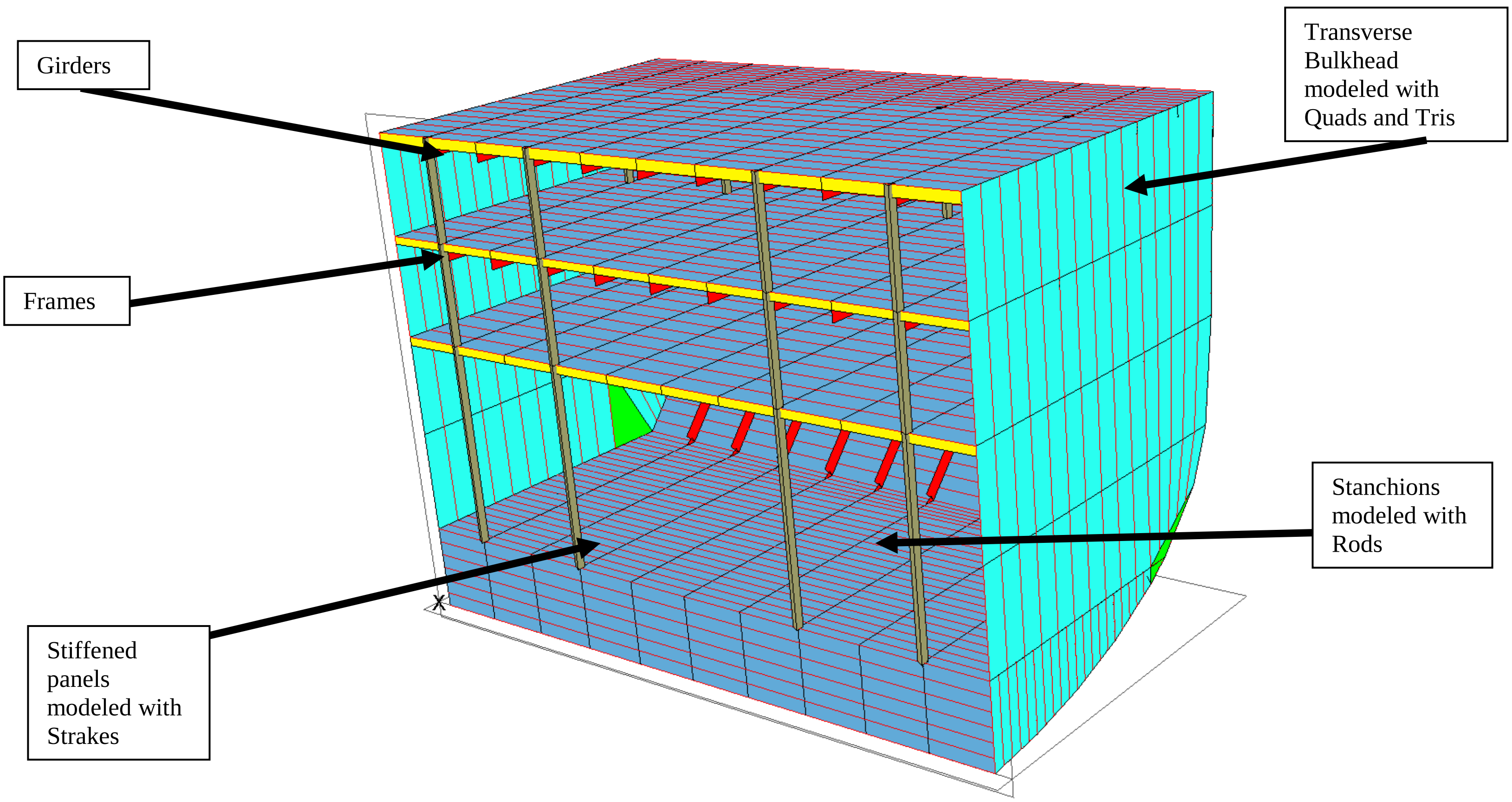


Figure 110 - Midship Module with MAESTRO Elements

Figure 111 shows the two main machinery room modules connected by a third module. Note that the main machinery rooms span two decks and are thus given extra stanchions for structural integrity.

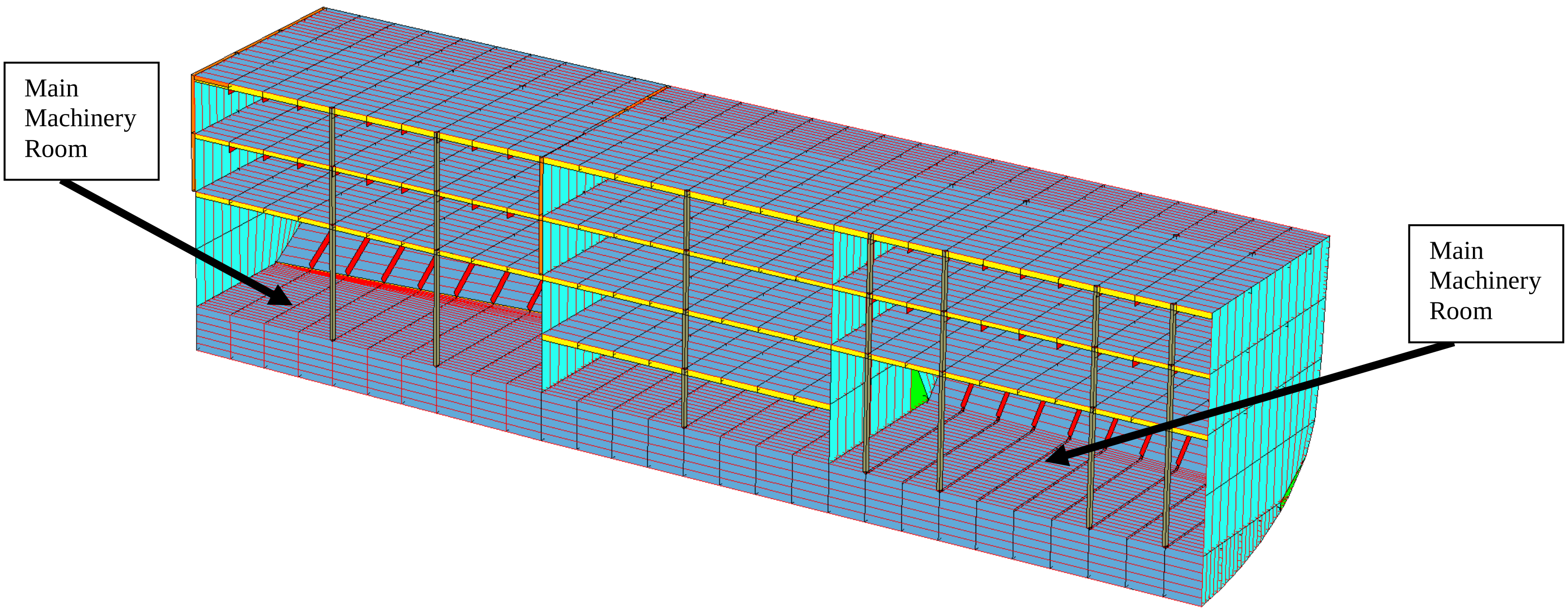


Figure 111 - Main Machinery Room Modules

4.5.3 Loads

Six different load cases are developed in order to study the structural adequacy of the ship. A still water condition, a hogging wave condition, and a sagging wave condition are each paired both with a full load condition and a minimum operation condition. The wave height for both the hogging and sagging is 8.33 meters, which is about a sea state 7. The full load condition equates to 95% permeability for the DFM tanks and the minimum operations condition equates to 33% permeability for the DFM tanks. The location of the DFM tanks modeled in MAESTRO can be seen in Figure 112 as red elements.

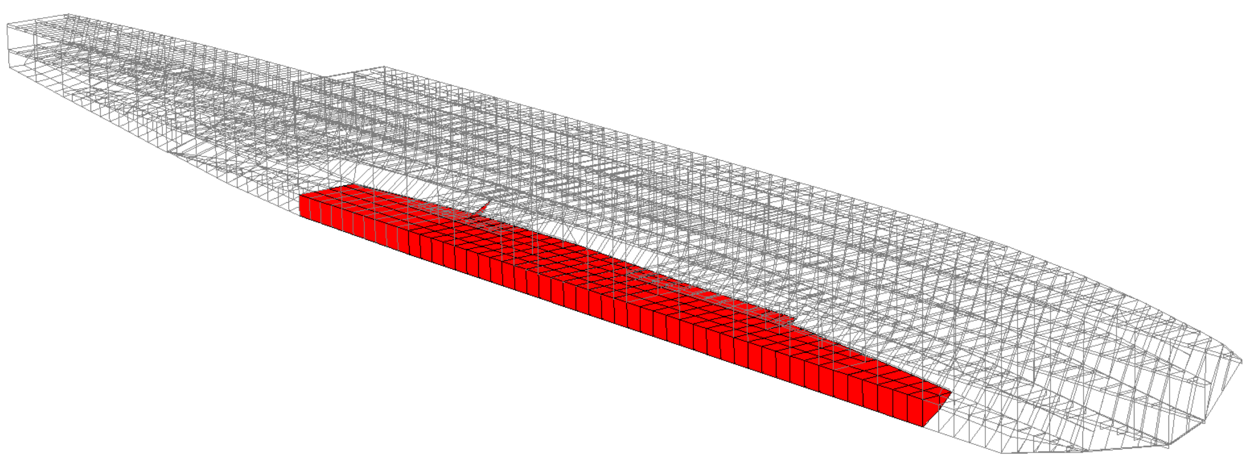


Figure 112 - DFM Tanks in MAESTRO Model

The lightship distribution from HECSALV is then used to estimate the weight of each module used in the model. This distribution can be seen below in Figure 113.

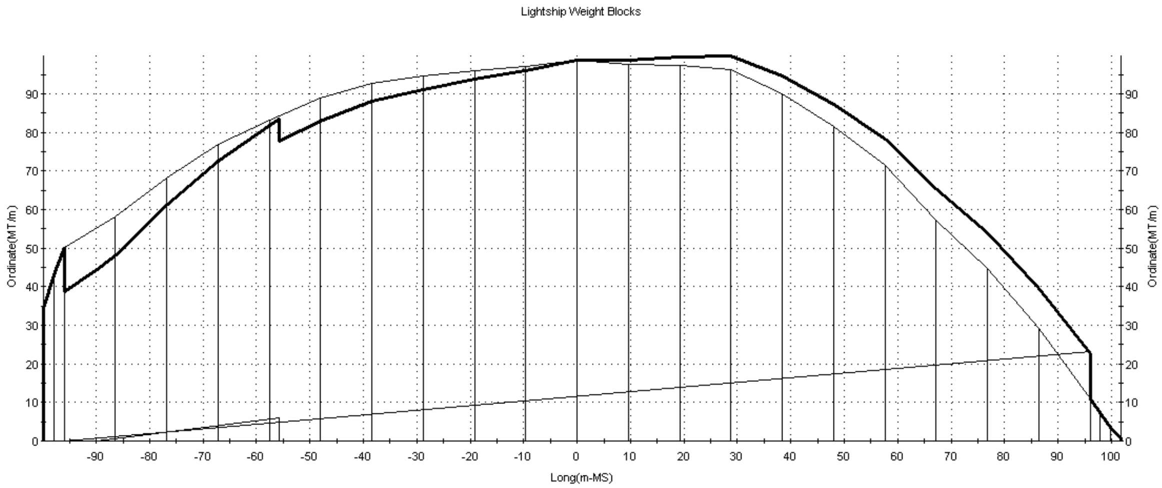


Figure 113 - Lightship Distribution

The still water condition, the hogging wave condition, and the sagging wave condition are added to the model after the tank loads and the lightship distribution loads are modeled. These three wave conditions used for full load and minimum operations can be seen in Figure 114 - Figure 116.

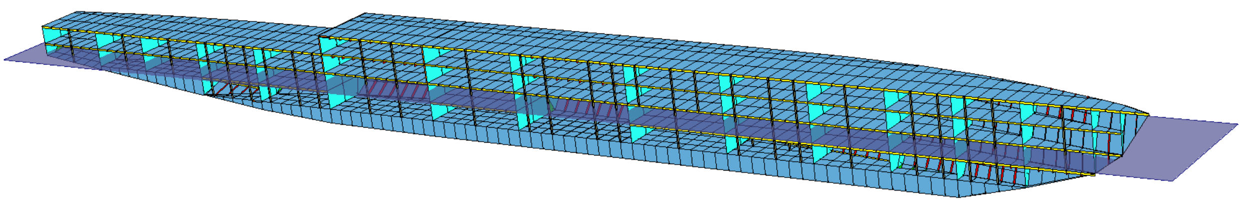


Figure 114 - Still Water Condition

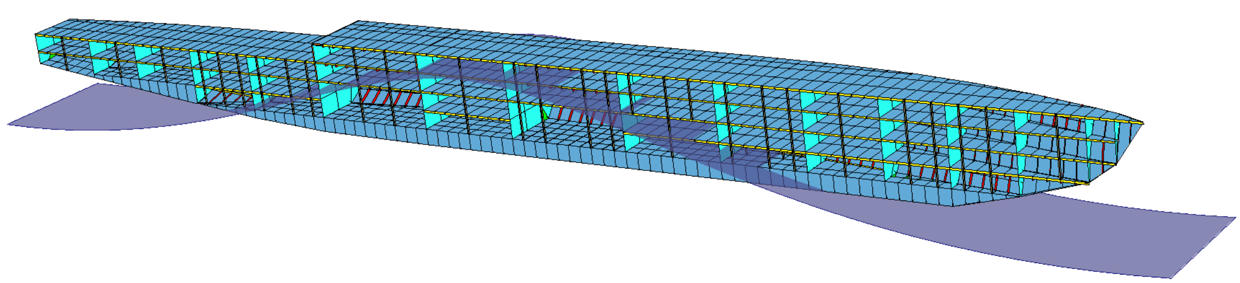


Figure 115 - Hogging Wave Condition

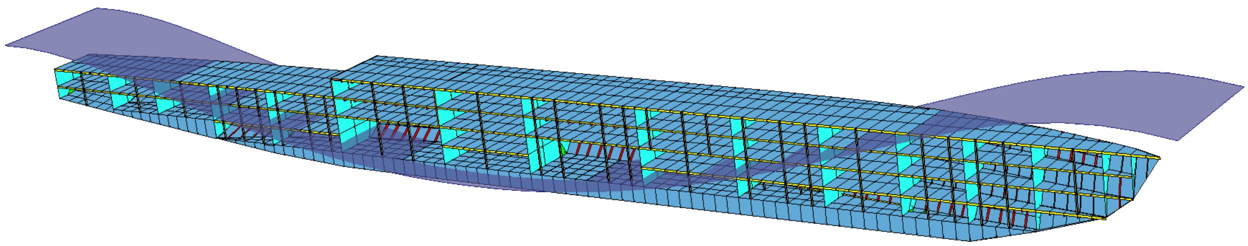


Figure 116 - Sagging Wave Condition

The three wave conditions are defined using the wave amplitude, the pitch angle, and the emersion. The model is balanced for all load cases to ensure that the emersion value in MAESTRO is equal to the negative value of the draft, -7.93 meters. Before the evaluation is conducted in MAESTRO, it is necessary to constrain the model in all six degrees of freedom. The model specified port-starboard symmetry and therefore the center-plane restraints of no roll, sway, or yaw are automatically supplied. Heave, pitch, and surge are prevented by adding two Y-restraints at the ends of the model and one X-restraint at the mid-length of the ship close to the neutral axis so as not to interfere with hull girder bending. The added restraints can be seen below in Figure 117 as magenta elements.

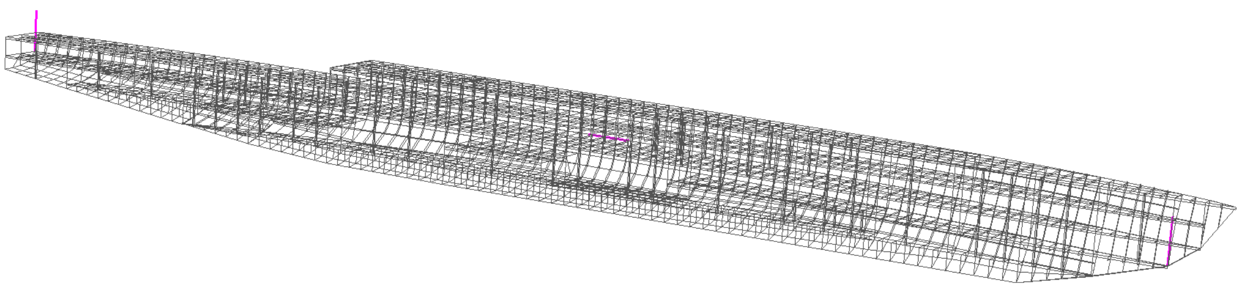


Figure 117 - Model Restraints

Several aspects of the model are tested before the evaluation is conducted in order to ensure that the ship has been properly modeled. A wetted element test, a plate stiffener side test, and a plate pressure side test are all run and the results can be seen in Figure 118 - Figure 120. The wetted elements test shows that the model accurately accounts for the bottom shell and side shell as wetted elements. The plate stiffener side test and the plate pressure side test both show that the normal direction is modeled correctly as denoted by the magenta elements.

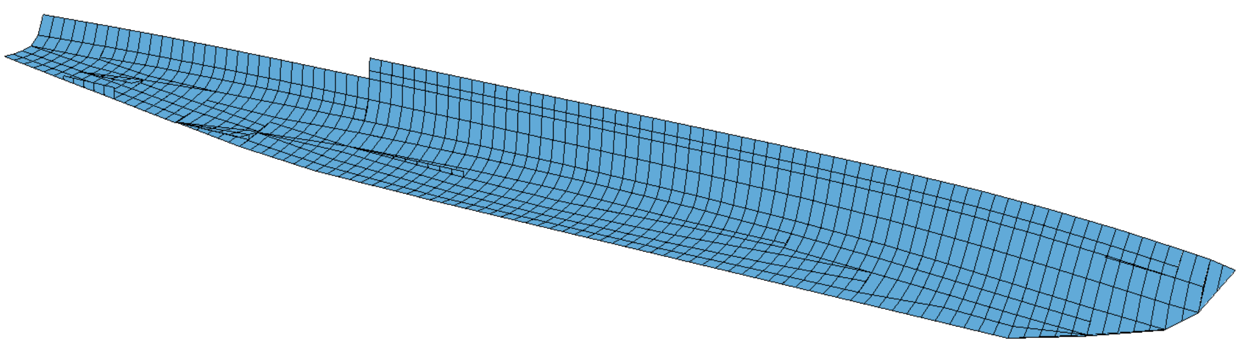


Figure 118 - Wetted Elements Test

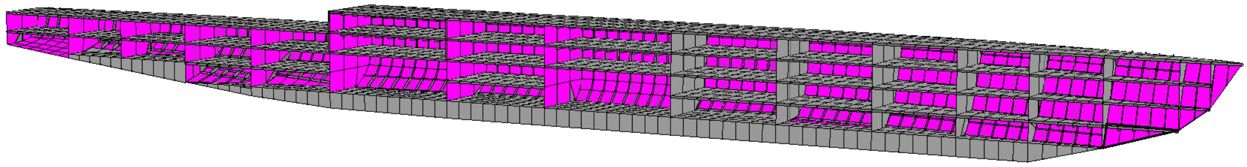


Figure 119 - Plate Stiffener Side Test

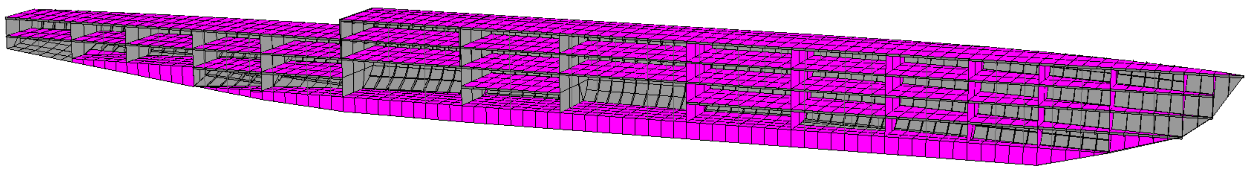


Figure 120 - Plate Pressure Side Test

The evaluation is run after the model passes all the tests, and weight, buoyancy, shear force, bending moment, and adequacy data are acquired. The total weight in MAESTRO is determined to be 17,417 MT. This value gives confidence that the weight has been properly modeled. The shear force and bending moment curves for the full load hogging wave produced with HECSALV can be seen in Figure 121 and the same curves produced with MAESTRO can be seen in Figure 122 - Figure 123. The trends shown in the shear force and bending moment curves is very similar for the HECSALV and MAESTRO results. This again gives confidence that the loads have been accurately represented in the MAESTRO model.

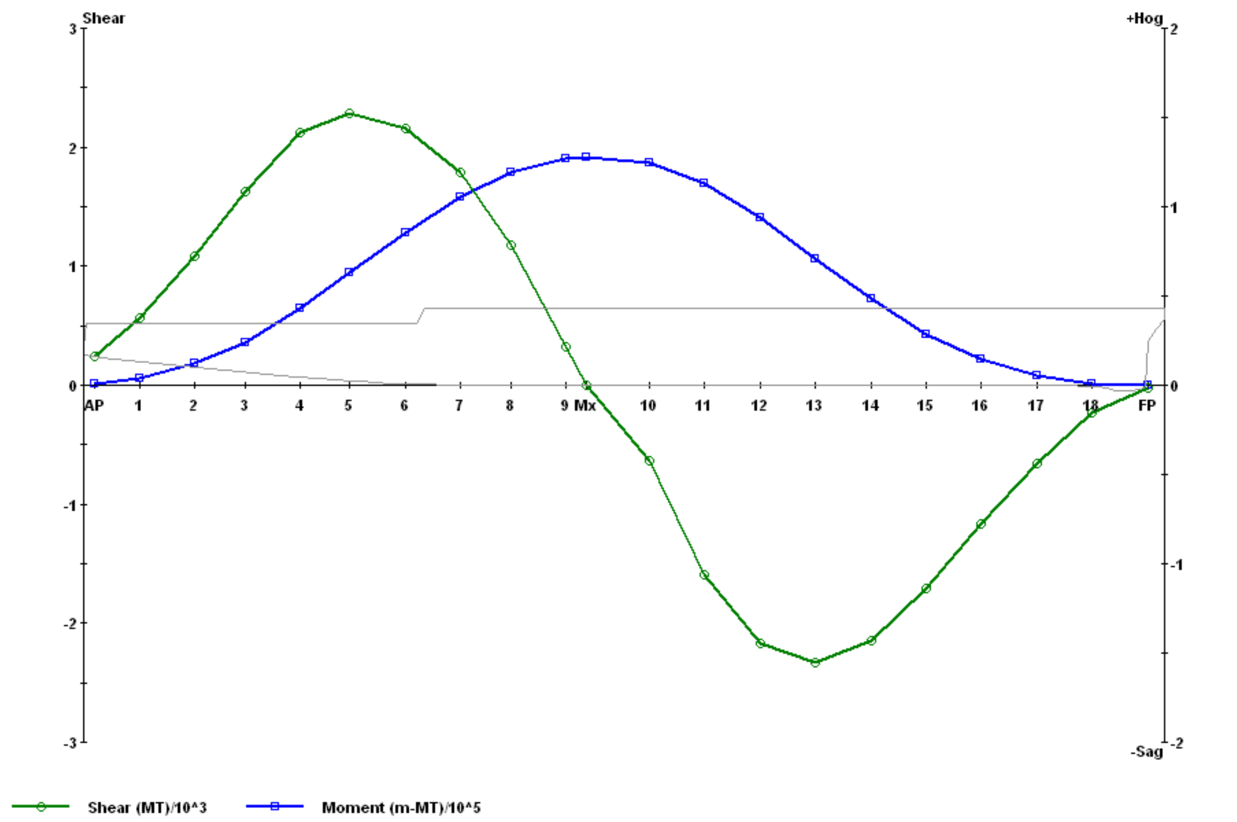


Figure 121 - HECSALV Hogging Wave Shear Force and Bending Moment Diagram

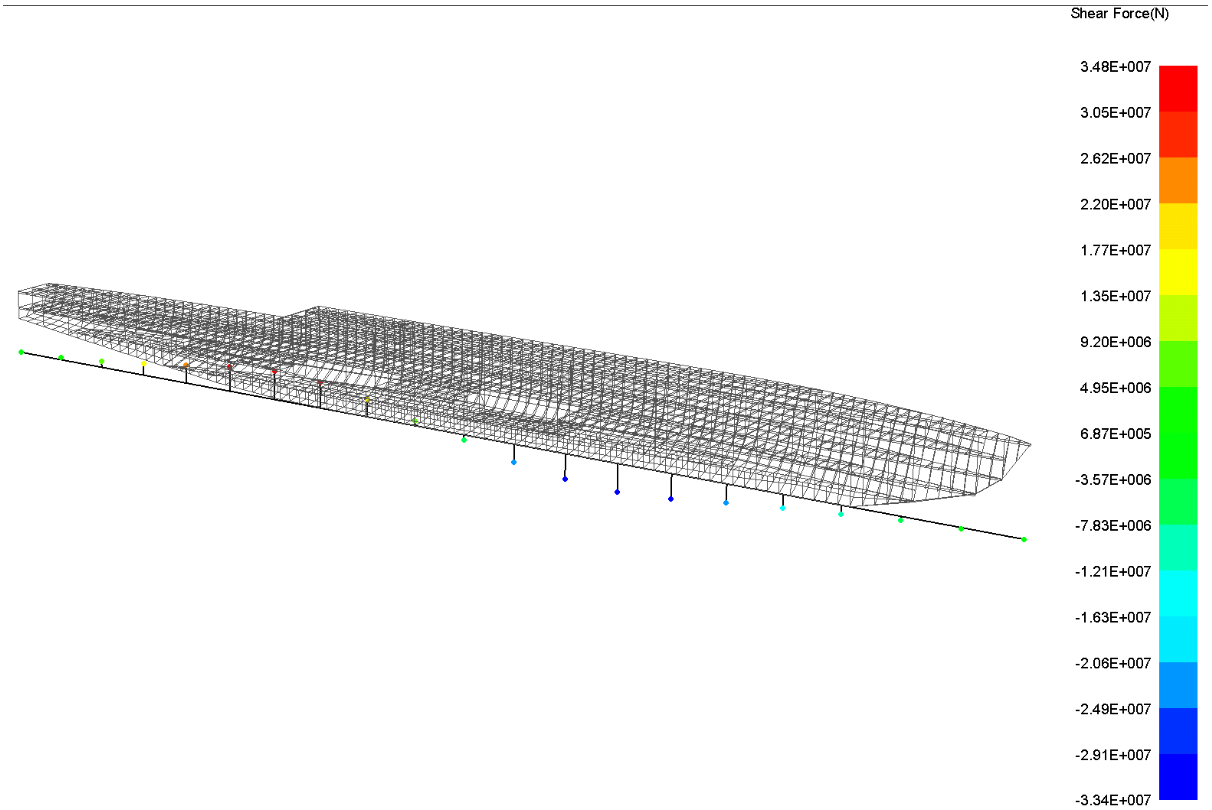


Figure 122 - MAESTRO Hogging Wave Shear Force Diagram

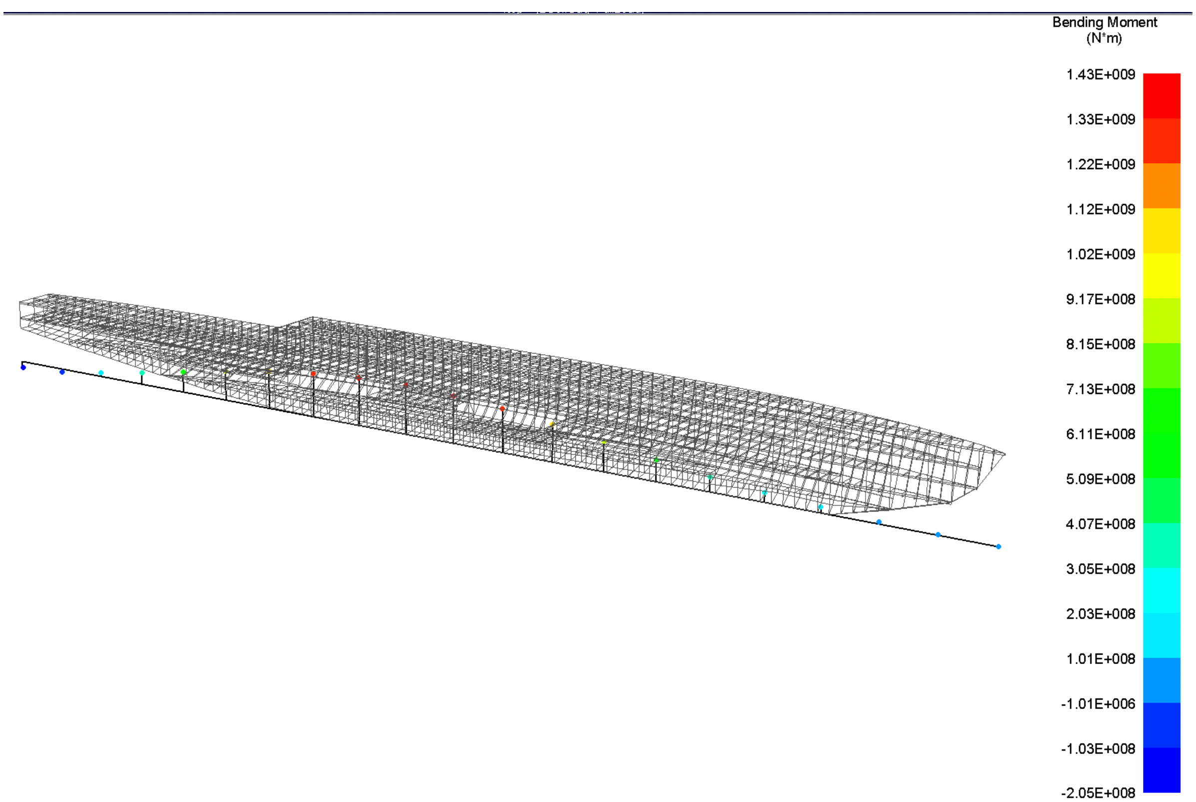


Figure 123 - MAESTRO Hogging Wave Bending Moment Diagram

Stress contours are generated after running the MAESTRO evaluation. Von Mises Stress contours for all three wave conditions at full load can be seen below in Figure 124 - Figure 126.

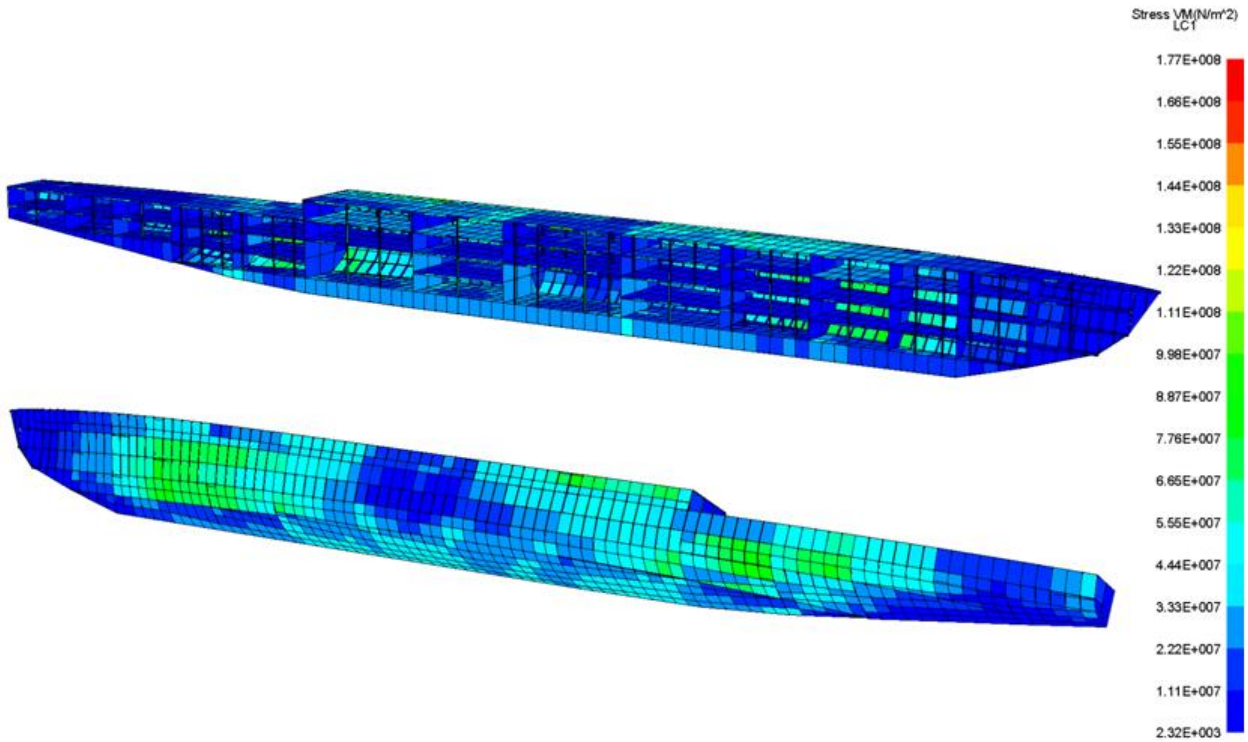


Figure 124 - Still Water Von Mises Stress

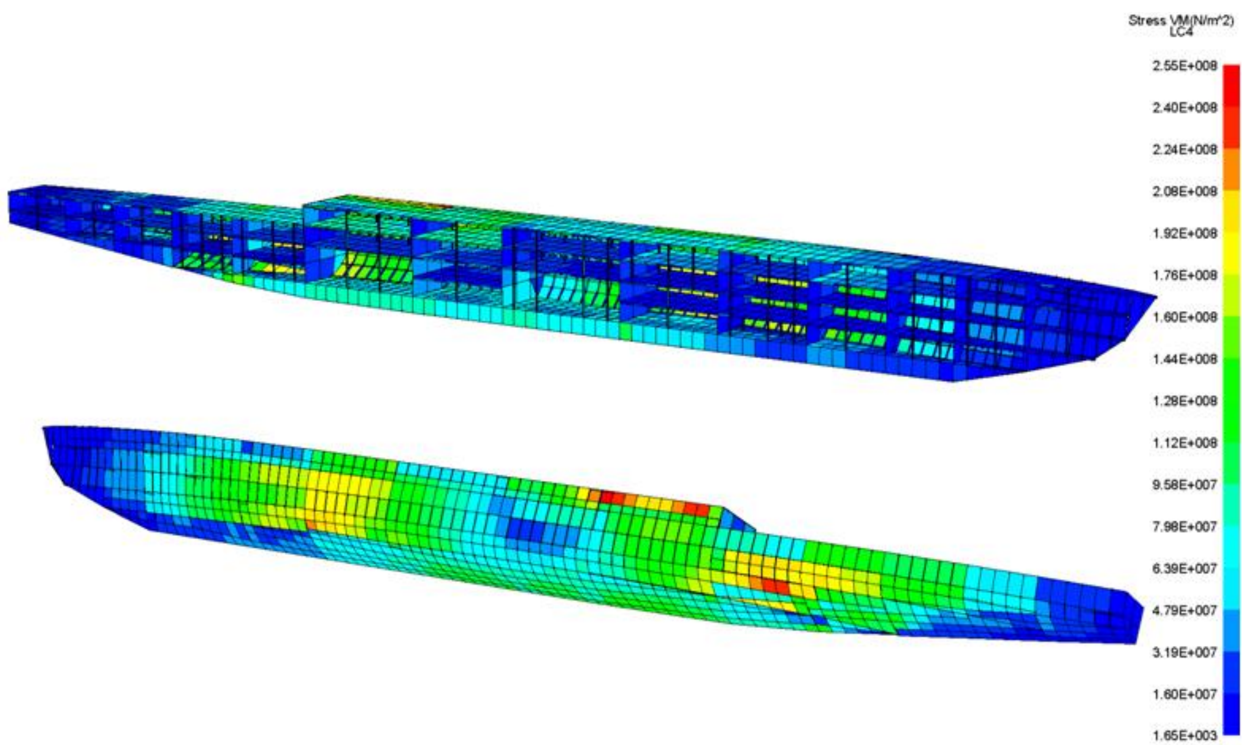


Figure 125 - Hogging Wave Von Mises Stress

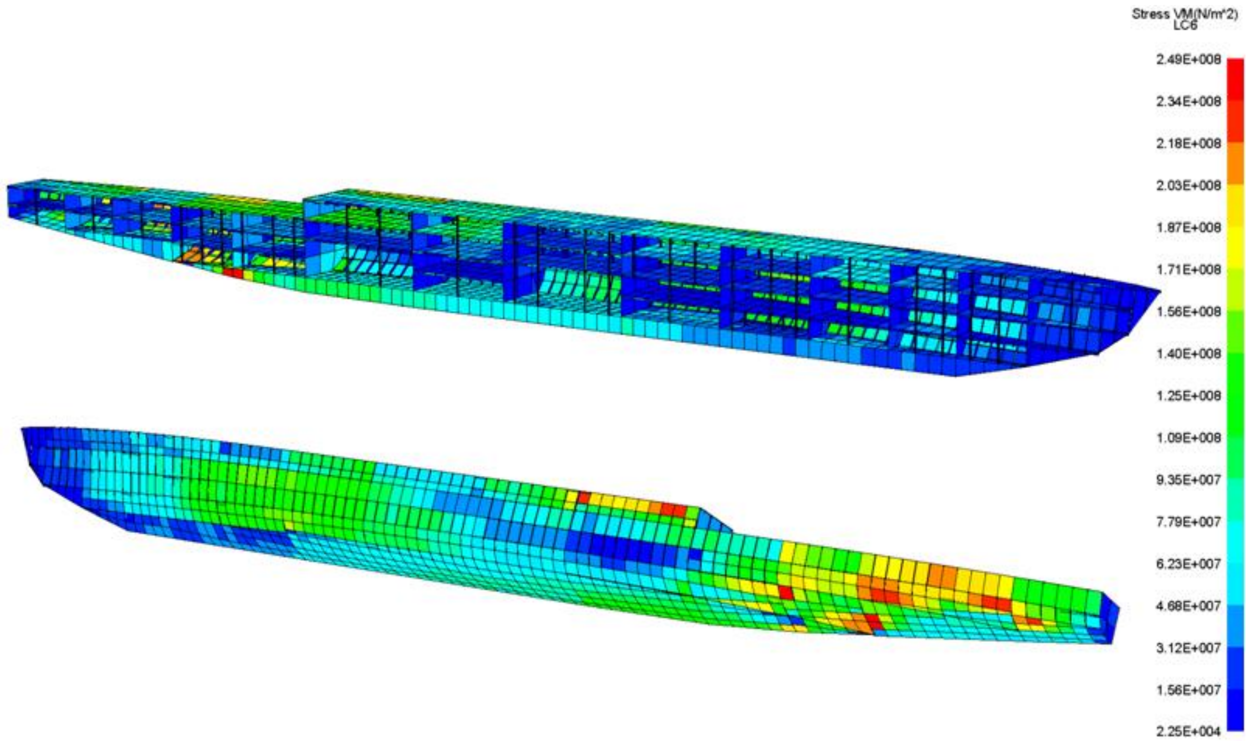


Figure 126 - Sagging Wave Von Mises Stress

4.5.4 Adequacy

The MAESTRO model is tested for adequacy of structural design. The MAESTRO Solver calculates stresses in the panels in order to compare the values to a limit state criteria. MAESTRO defines the limit state based upon the strength ratio, r, where r is equal to $(\gamma Q)/Q_L$. MAESTRO then defines an adequacy parameter, g, where g is equal to (1-r)/(1+r). The adequacy parameter varies from -1 to +1 and a value of zero denotes the optimum adequacy for the particular limit state. Positive values near 1 indicate that the response of the structure is over-designed, and negative values indicate the response of the structure is inadequate for the specified limit state. Adequacy results are returned for all six load cases. Full load adequacy for still water, hogging, and sagging data can be seen below in Figure 127 - Figure 129. Figure 127 shows that most of the structure is over-designed for the still water case because most values of the limit state tend towards values greater than 0.5. However, Figure 128 shows that the structure takes on values closer to the limit state value in the hogging wave full load condition. All adequacy values are still equal to or greater than 0.05, and the model contains fewer elements that are overdesigned than in the still water case. The sagging case shown in Figure 129 shows a similar adequacy condition as compared to the one shown in the hogging case. All adequacy parameters are still above 0.05. Therefore, the structure is adequate in all loading conditions analyzed.

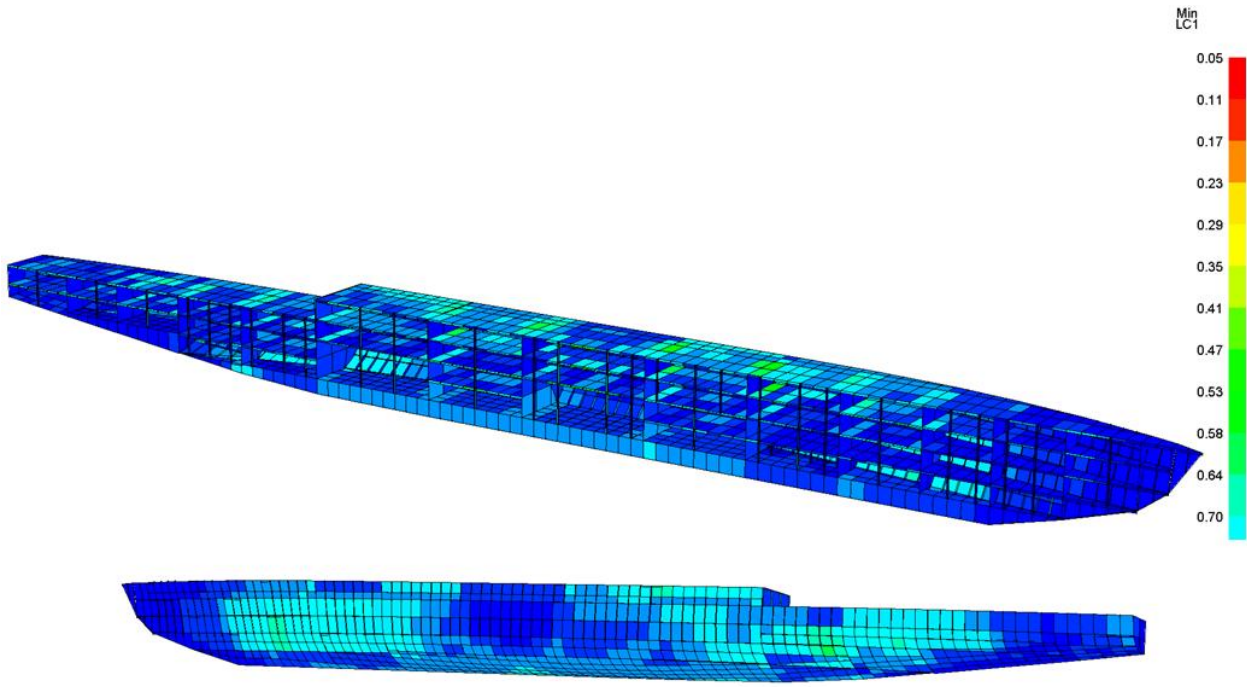


Figure 127 - Minimum Adequacy for Still Water

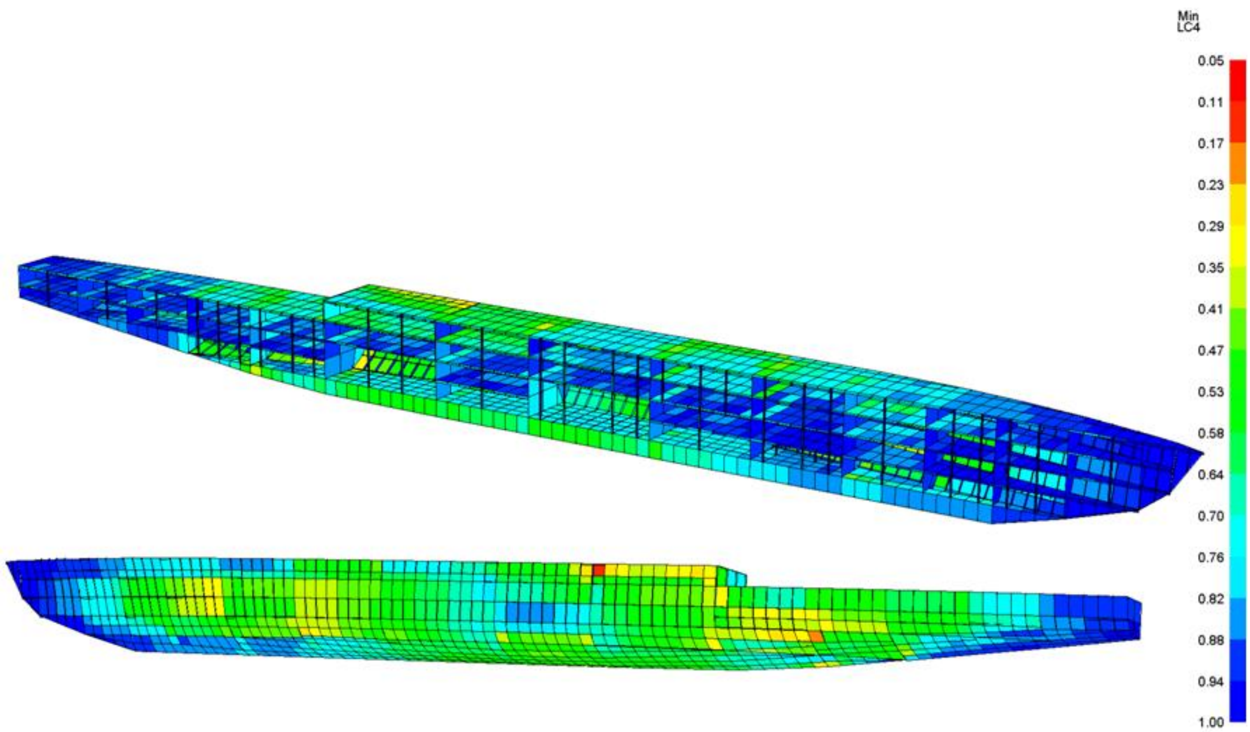


Figure 128 - Minimum Adequacy for Hogging Wave

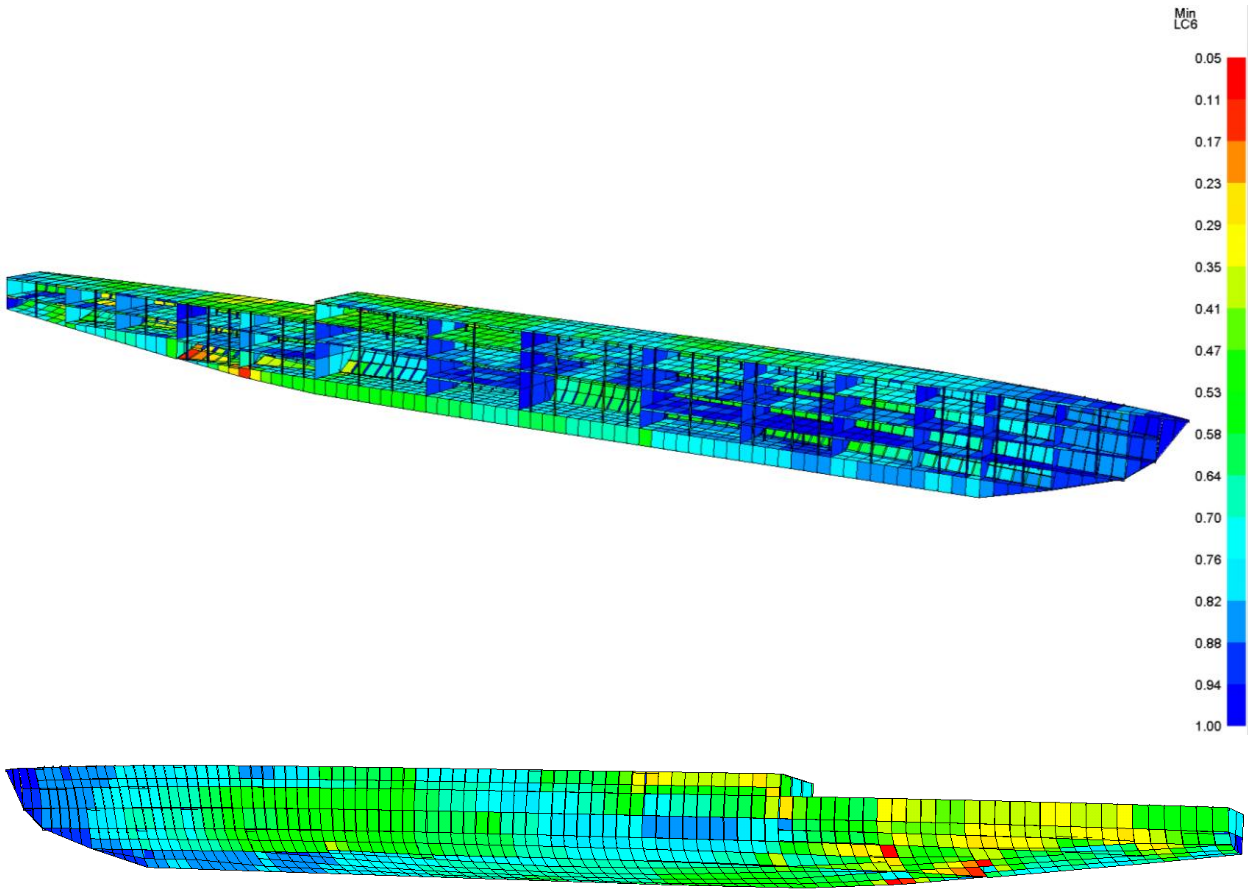


Figure 129 - Minimum Adequacy for Sagging Wave

4.5.5 Revisions and Final Structural Design

The data for ship scantlings provided by ASSET is used as a preliminary design. However, during the evaluation process it is determined that these scantlings are often inadequate under the six loading conditions tested. Plate buckling, panel collapse, yielding, and tripping are some of the modes of failure present. Creating extra stiffeners, thicker plating, larger frames, and larger girders are methods used to prevent these modes of failure. Plate thicknesses and frames given by ASSET are determined to be too small in some places. Larger plate thicknesses are needed for longitudinal and transverse floors and also in the decks in the midship module. Edge stiffeners are needed in longitudinal and transverse floors. Thicker plating is also needed for the bottom shell in the aft-most portion of the ship. A summary of final plate thicknesses can be seen in Figure 130. A maximum plate thickness of 46 mm is used as seen in the dark blue shaded areas of Figure 130. A minimum frame thickness of 4.8 mm, a minimum web height of 100 mm, and a minimum flange height of 50 mm is used. As shown previously, the new design is evaluated and meets minimum requirements for adequacy. This plating is on the heavy side, and future work would attempt to decrease this maximum thickness to a value below 40 mm.

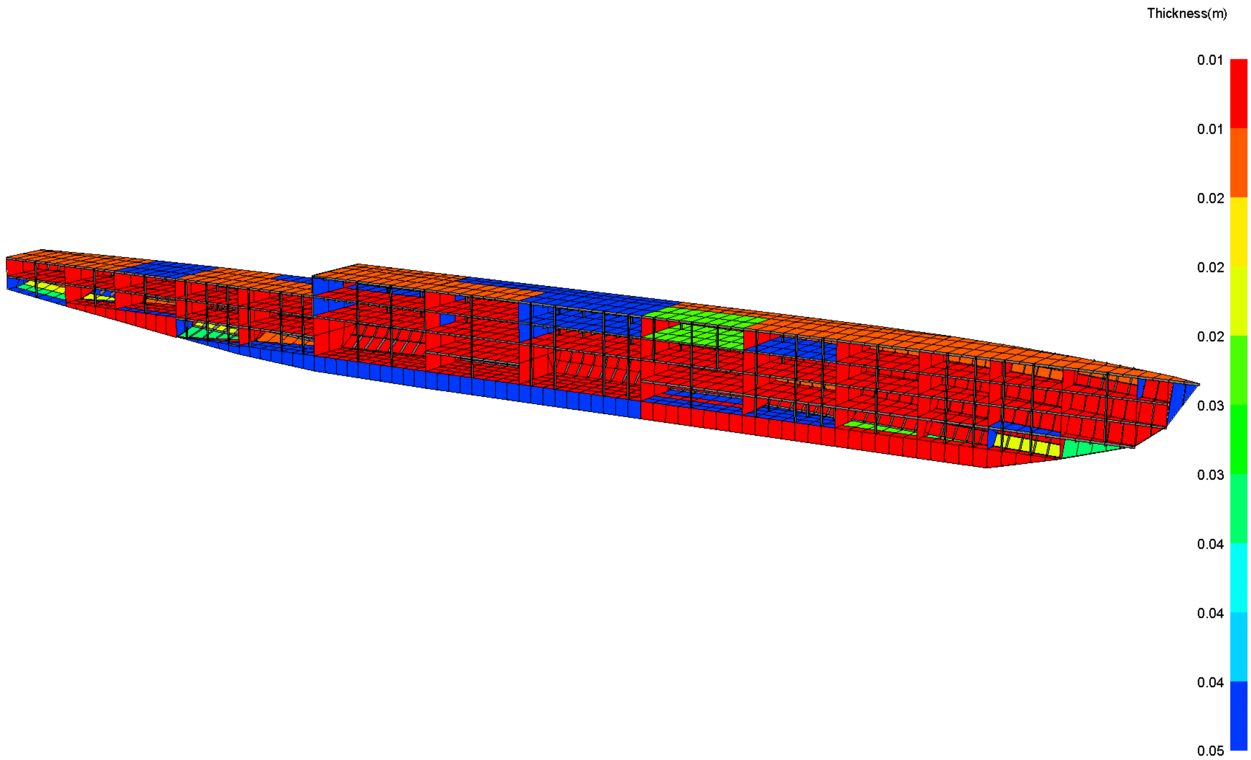


Figure 130 - Final Plate Thicknesses for MAESTRO Model (meters)

4.6 Power and Propulsion

4.6.1 Resistance

In NavCad a variety of resistance calculations from wind, seas, bare hull resistance and other miscellaneous factors are calculated. NavCad is a computer aided design program that allows the user to input hullform and environmental characteristic to then output the ships resistance as it moves at a variety of speeds. These speeds are chosen by the user and inserted into the given NavCad conditions table seen in Figure 131. The other inputs needed to run the resistance analysis are the hullform characteristics, appendage characteristics and the behavior of the environment (i.e. sea state). For the hullform, length between perpendiculars, beam, and bare displacement are a few examples of what is needed, as seen in Figure 132. For the appendage tab, any protrusions or additions the ships bare hull are inserted and taken into account to accommodate for their drag. However, due to the ship design and what is available in ASSET, not all the appendage cells are filled out. The area of the front dome is not known and therefore left blank. The rudders, shafts, bilge keels and skeg are also inserted as seen in Figure 133. Finally the environment tab is completed with information about the ship's sailing conditions. Figure 134 shows a sea state of two is chosen to represent relatively calm seas. The ship's hullform areas are also inserted to account for how the wind affects the ship's movement.

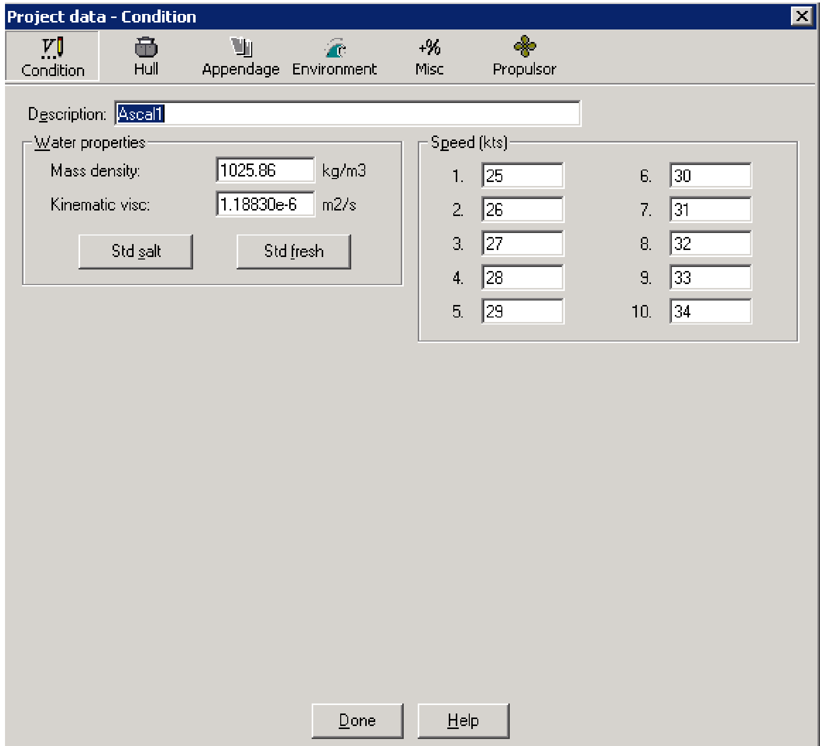


Figure 131 - NavCad Conditions

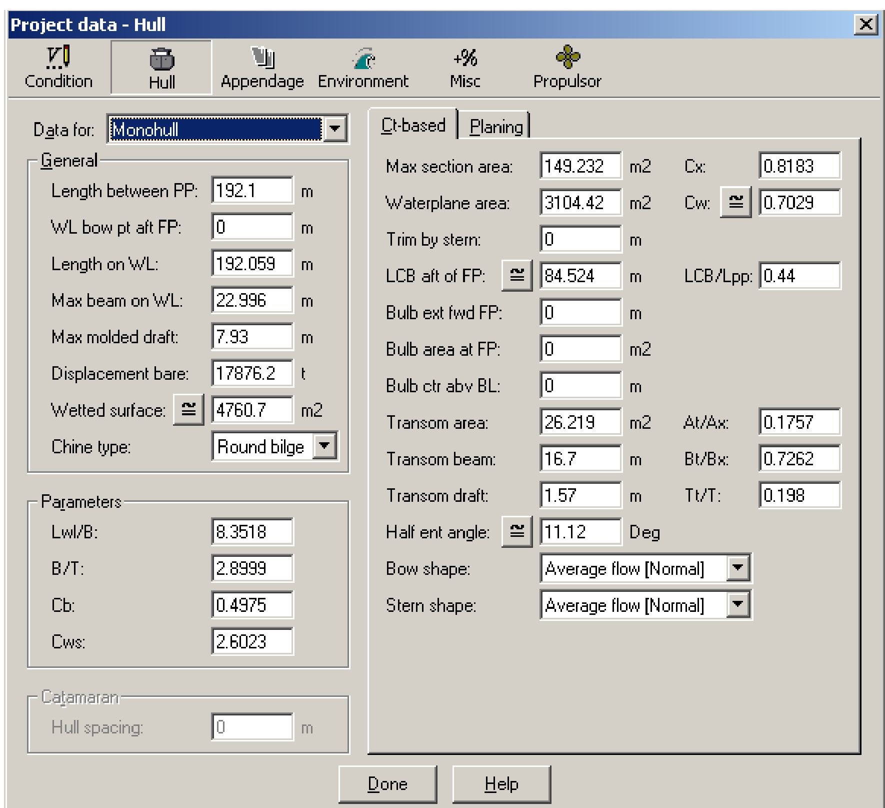


Figure 132 - NavCad Hullform Characteristics

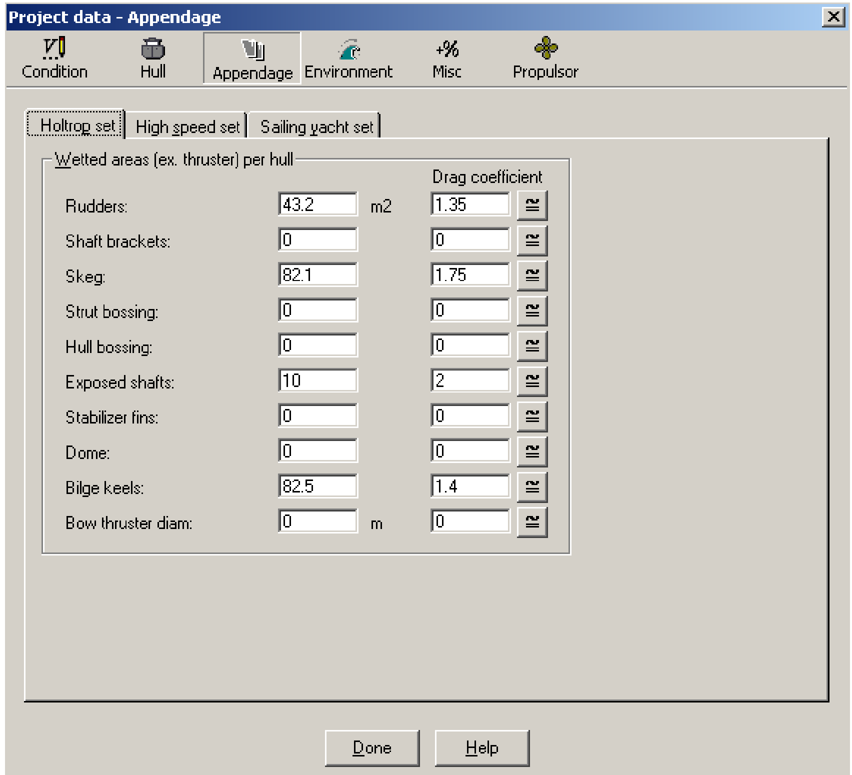


Figure 133 - NavCad Appendage Characteristics

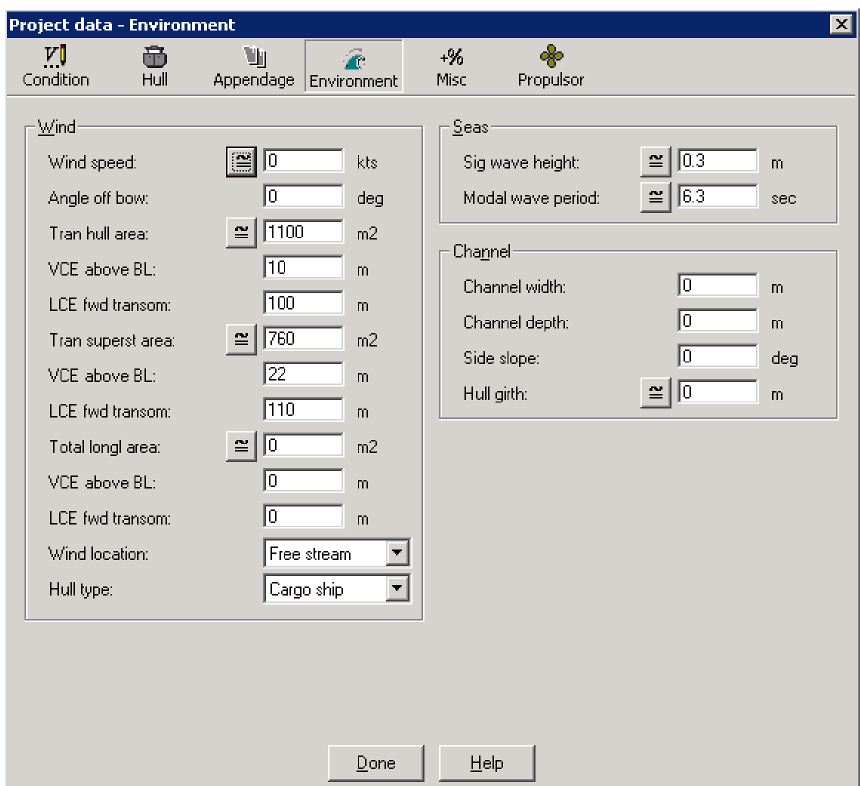


Figure 134 - Environment Characteristics

After all values are inserted a resistance analysis is generated for both endurance and sustained speed. This gives an outlook of how the ship will behave at these velocities. Figure 135 and Figure 136 illustrates the five resistance curves NavCad outputs for endurance and sustained speed.

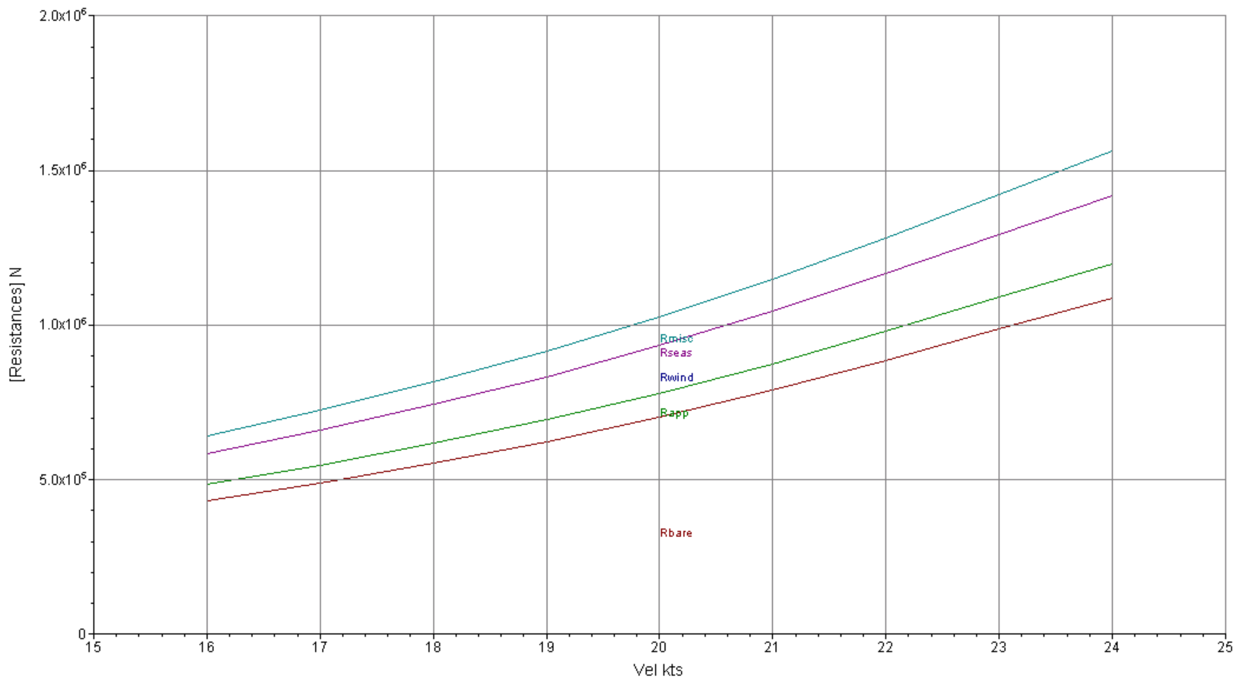


Figure 135 - Resistance Analysis Endurance Speed

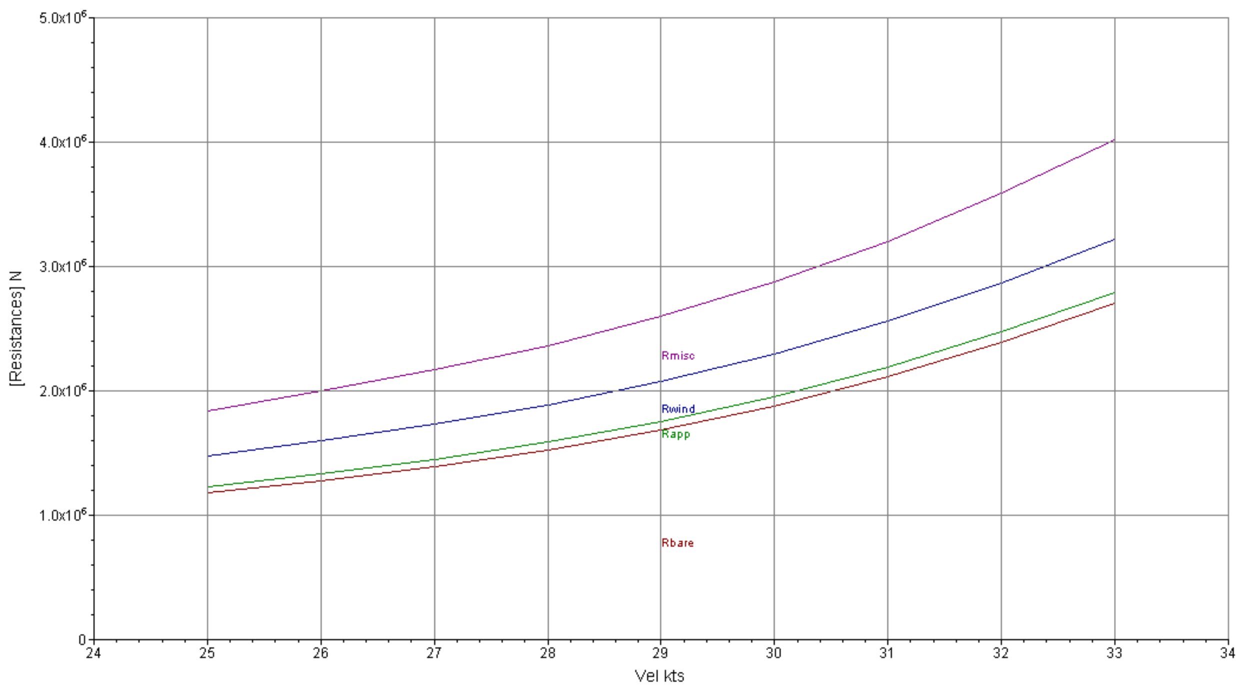


Figure 136 - Resistance Analysis Sustained Speed

4.6.2 Propulsion Analysis – Endurance Range and Sustained Speed

The endurance range and sustained speed are critical to know when assessing ships capabilities. By including data on the ships three MT 30 engines and two backup LM500 diesel generators a detailed propulsion analysis can be derived. The Engine data is placed in the grid in Figure 137 and divided over the two shafts to simulate power distribution. The total engine RPM is also shown with this configuration at endurance speed. At sustained speed in Figure 138 all engines are enabled, allowing for a dramatic increase in power at peak RPM.

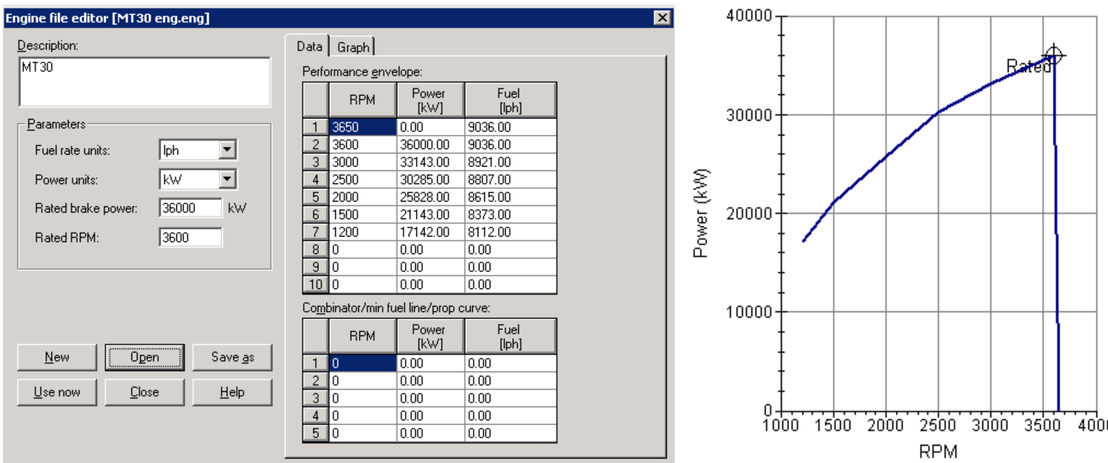


Figure 137 - MT30 Plus LM500 Split Between Two Shafts

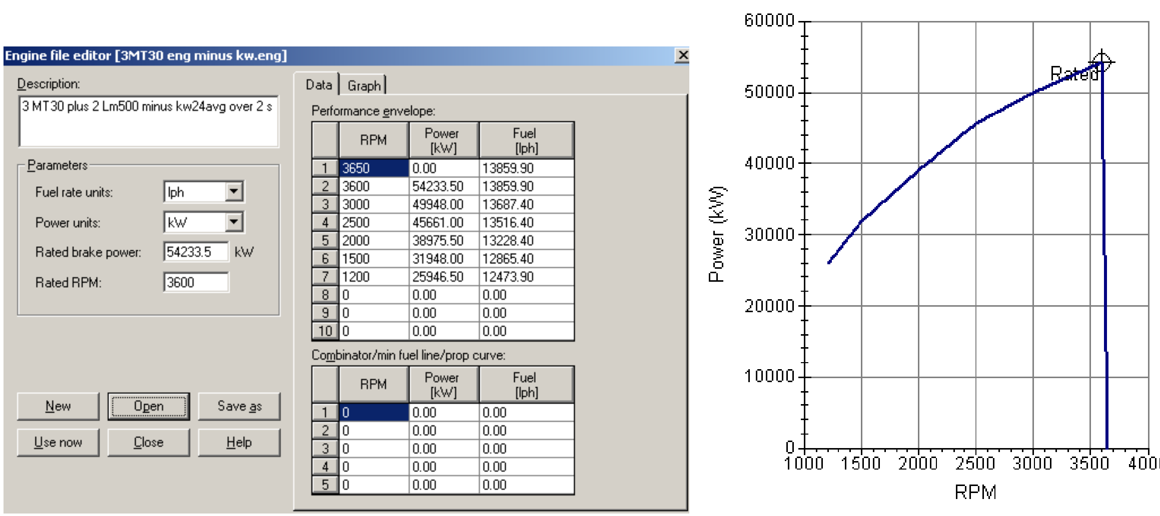


Figure 138 - Three MT30 Plus Two LM500's Split Between Two Shafts

The propeller data acquired from ASSET is included as seen in Figure 139. The propulsion sizing is then used to adjust the expanded area ratio and the pitch based on the diameter of the propeller (Figure 140). The engine file, seen above, is imported and the gear and shaft efficiency are set at 92% and 98% respectively. The gear ratio is derived by running the program and changing the ratio until the highest velocity in the range corresponds to peak RPM as demonstrated in Figure 142 and Figure 143. To change from Endurance range to sustained speed the user must change the margins from 10% to 25%, shown in Figure 141. From these graphs sustained velocity as well as endurance speed range can be visually demonstrated confirming the theoretical numbers given in ASSET. The resulting outputs from NavCad were then put into MATHCAD to calculate the fuel consumption and range of the ship at sustained speed (Figure 144). The resulting fuel usage at each speed can be seen in Figure 145. Figure 146 through Figure 151 show the other graphical outputs from NavCad. Total power, OPC versus velocity and brake horsepower are a few of the graphs in that series.

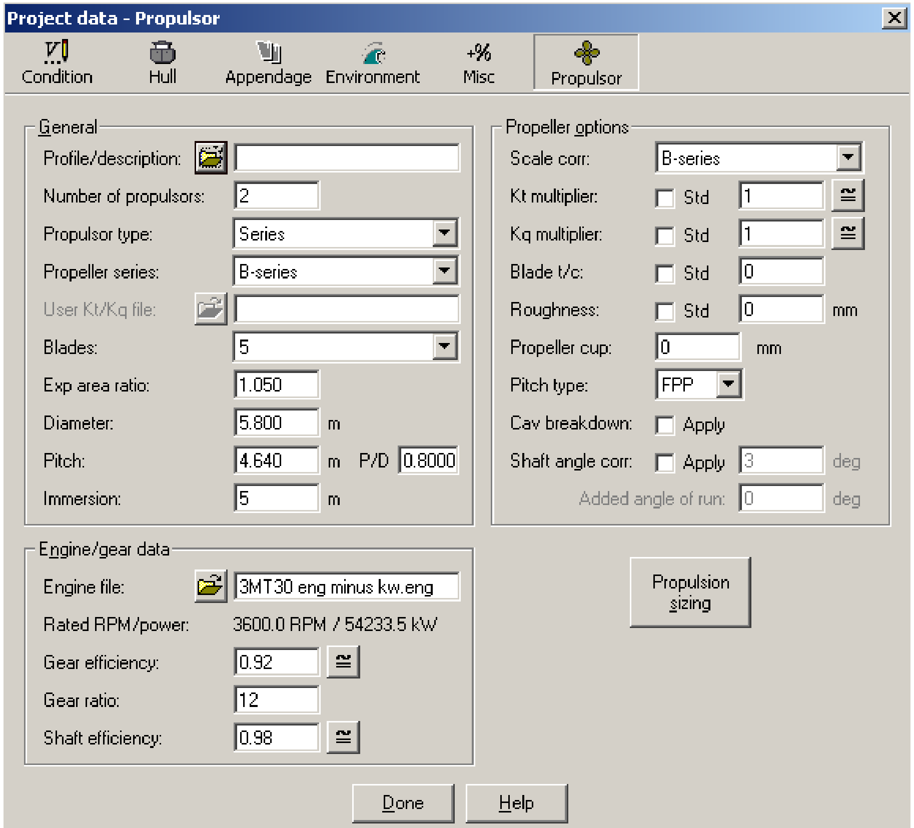


Figure 139 - Propulsion Characteristics

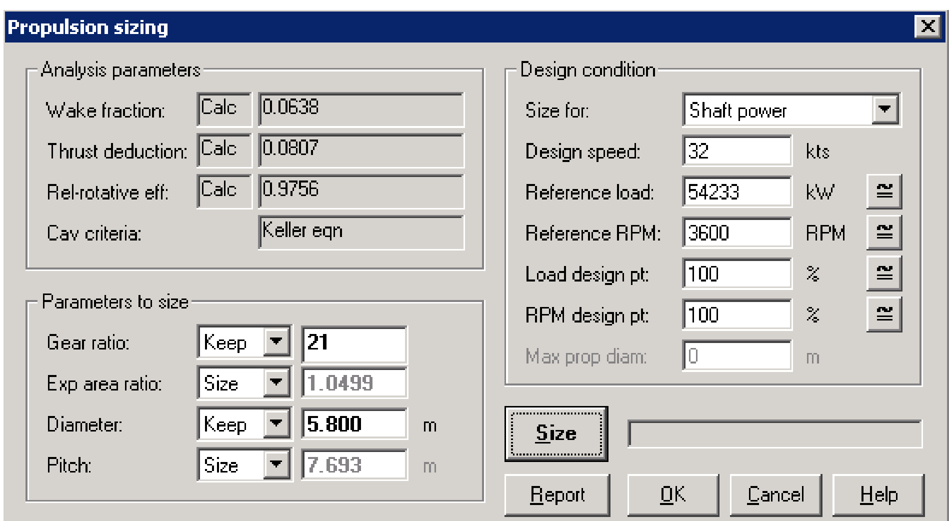


Figure 140- Propulsion sizing

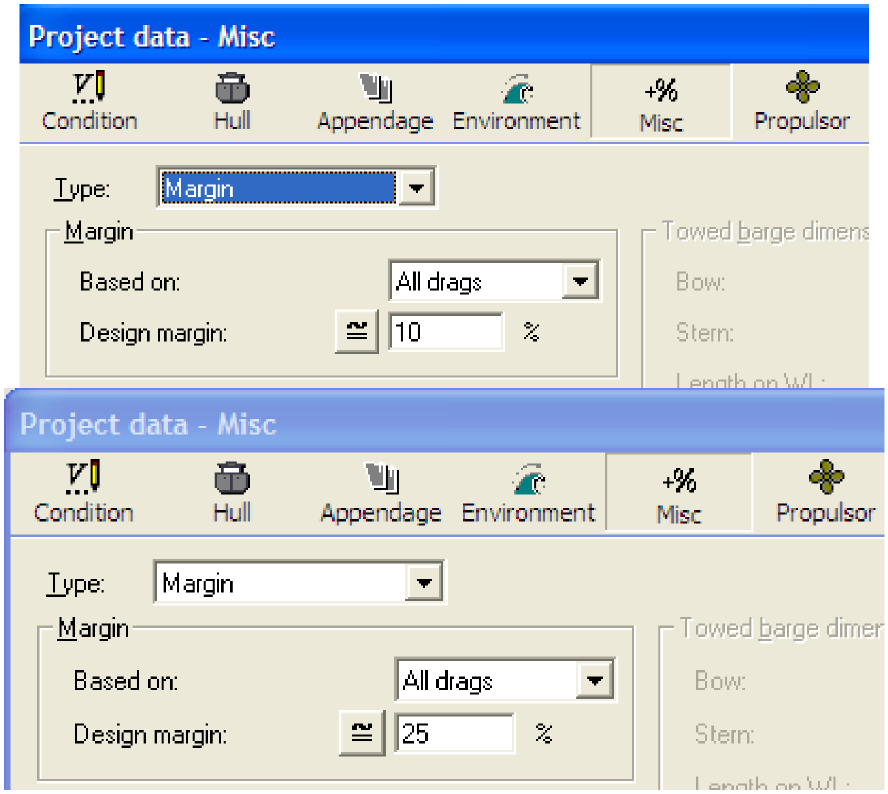


Figure 141- Margins

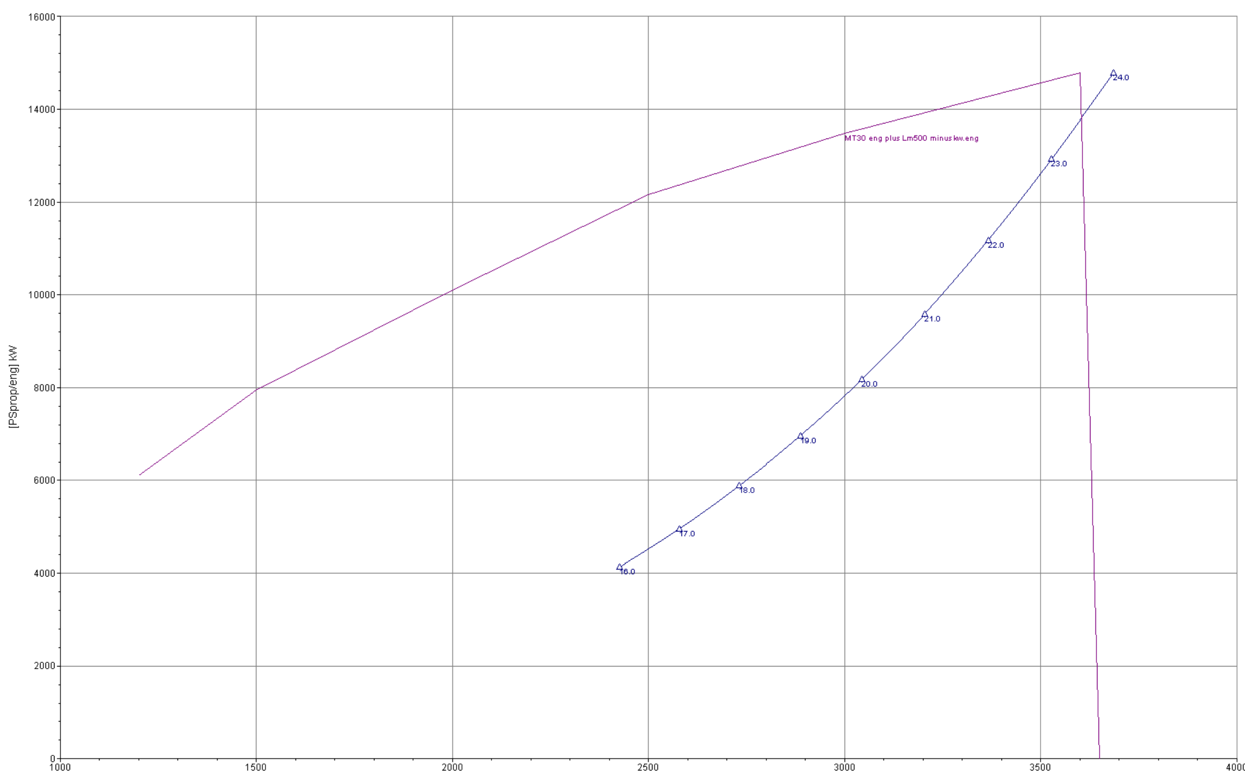


Figure 142 - Endurance Speed Proposer Analysis

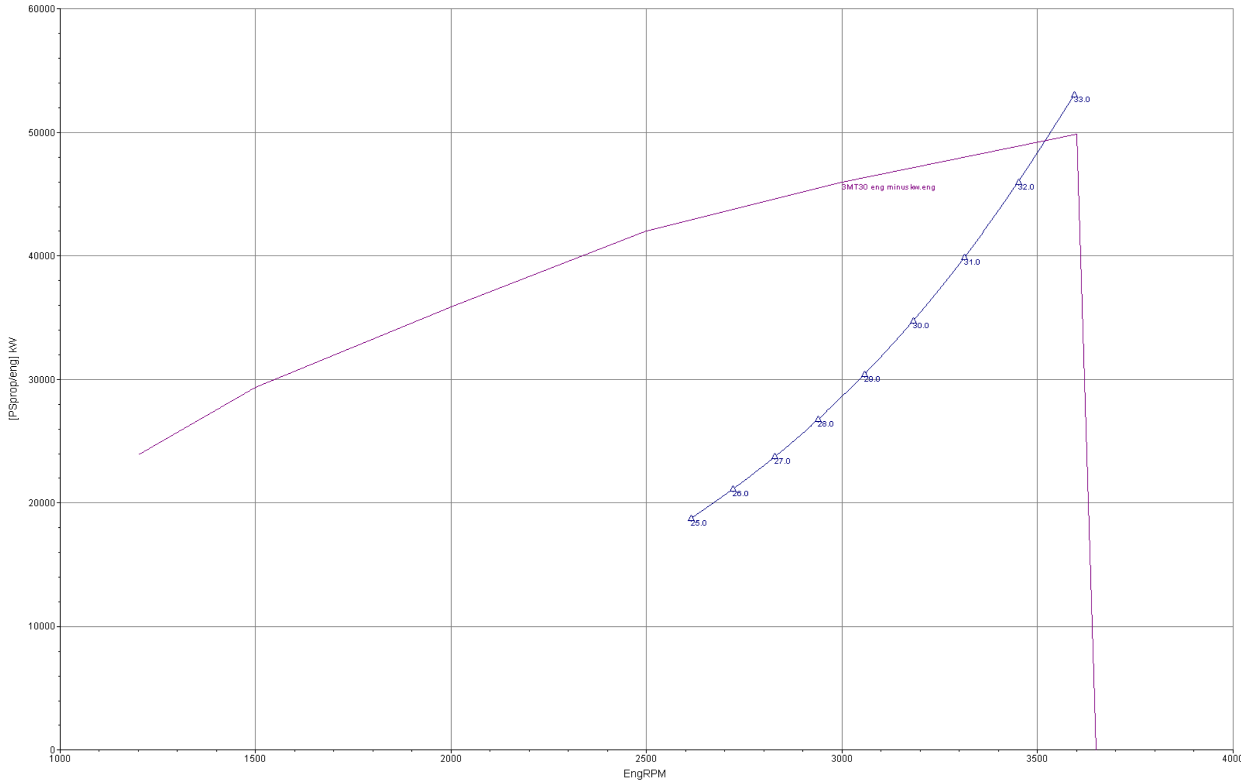


Figure 143 - Sustained Speed Proposer Analysis

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

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

$V_e := 20 \cdot knt$ $N_E := 2$ $BHP_{PGM} := 36000 \cdot kW$ $BHP_{ePGM} := 11753 \cdot kW$ $GPH_{eENG} := 735.3 \cdot \frac{gal}{hr}$

From HECSALC tankage: $V_{F41} := 2656 \cdot m^3$

From SSSM at cruise condition:

$KW_{24AVG} := 8355 \cdot kW$

Conversion of units:

$GPH_{eprop} := N_E \cdot GPH_{eENG}$ $GPH_{eprop} = 1471 \cdot \frac{gal}{hr}$ $SFC_{ePGM} := \frac{GPH_{eprop}}{\delta_F \cdot BHP_{ePGM}}$ $SFC_{ePGM} = 0.641 \cdot \frac{lbf}{hp \cdot hr}$

$SFC_g := SFC_{ePGM}$ for IPS

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

Correction for instrumentation inaccuracy and machinery design changes:

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

Figure 144- MATHCAD Inputs

Vel [kts]	Fn	Fv	Press [kPa]	MinBAR	%Cav	%CavPeak	PropRn	Kt/J2	Kq/J3	Cth	Cp	Fuel/eng [gph]	TransEff	EngLoad%
16	0.190	0.516	11.7	0.2349	0.0	0.0	5.82e07	0.1592	0.03986	0.4054	0.001189	418.0	174.79	35
17	0.202	0.548	13.3	0.2588	0.0	0.0	6.19e07	0.1596	0.03984	0.4065	0.001188	482.9	154.87	40
18	0.213	0.581	15.0	0.2849	0.0	0.0	6.56e07	0.1605	0.03993	0.4087	0.001191	558.6	137.81	46
19	0.225	0.613	16.8	0.3134	0.0	0.0	6.93e07	0.1618	0.04011	0.4120	0.001196	642.0	123.13	53
20	0.237	0.645	18.9	0.3448	0.0	0.0	7.31e07	0.1636	0.04041	0.4167	0.001205	735.3	110.28	60
21	0.249	0.678	21.1	0.3799	0.0	0.0	7.69e07	0.1663	0.04089	0.4234	0.001219	842.6	98.836	69
22	0.261	0.710	23.6	0.4186	0.0	0.0	8.08e07	0.1694	0.04148	0.4314	0.001237	961.6	88.761	78
23	0.273	0.742	26.3	0.4589	0.0	0.0	8.46e07	0.1721	0.04198	0.4383	0.001252	1088.9	80.235	88
24	0.284	0.774	28.8	0.4988	0.0	0.0	8.84e07	0.1736	0.04223	0.4422	0.001259	---	73.24	0

Figure 145- Fuel Consumption at Endurance Speed

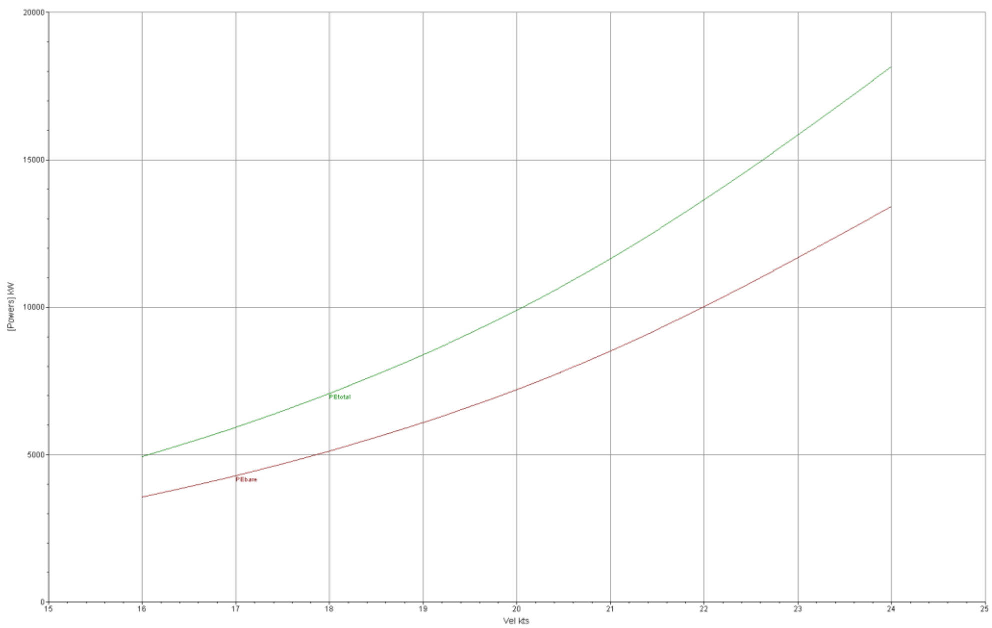


Figure 146- Endurance Total Power

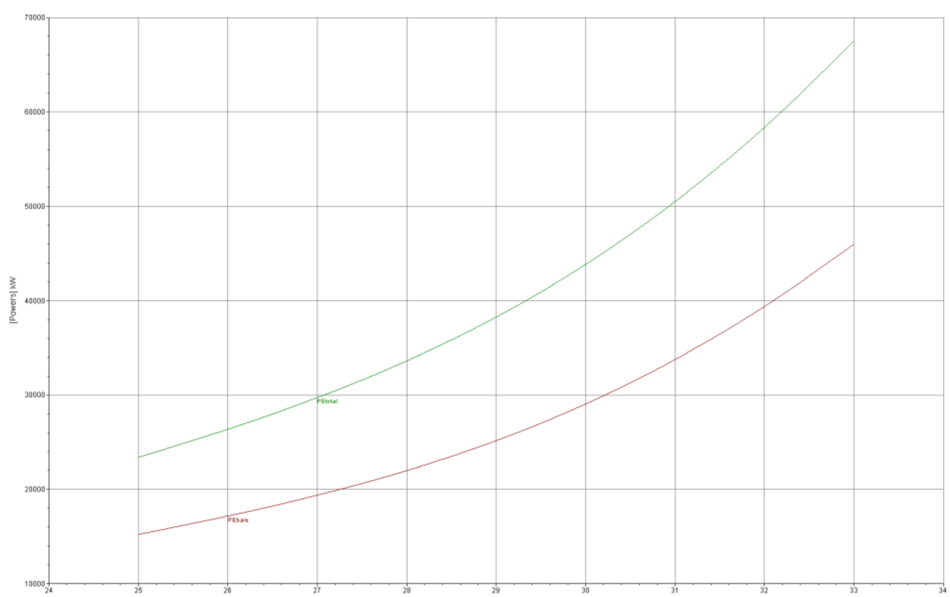


Figure 147- Sustained Total Power

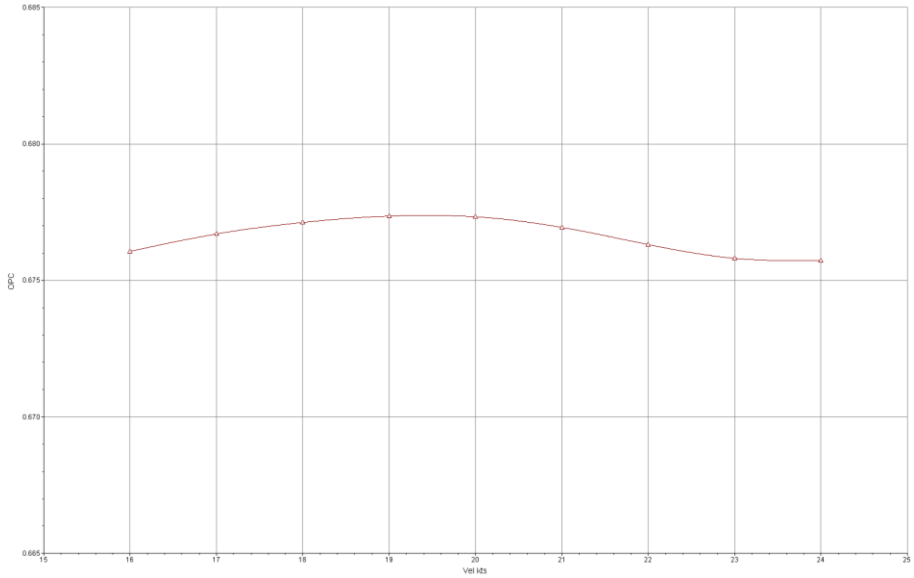


Figure 148- Endurance OPC

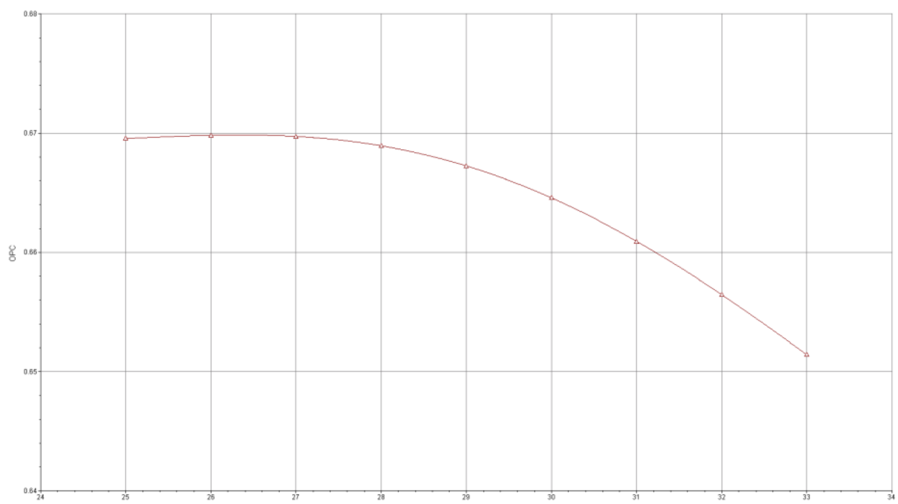


Figure 149- Sustained OPC

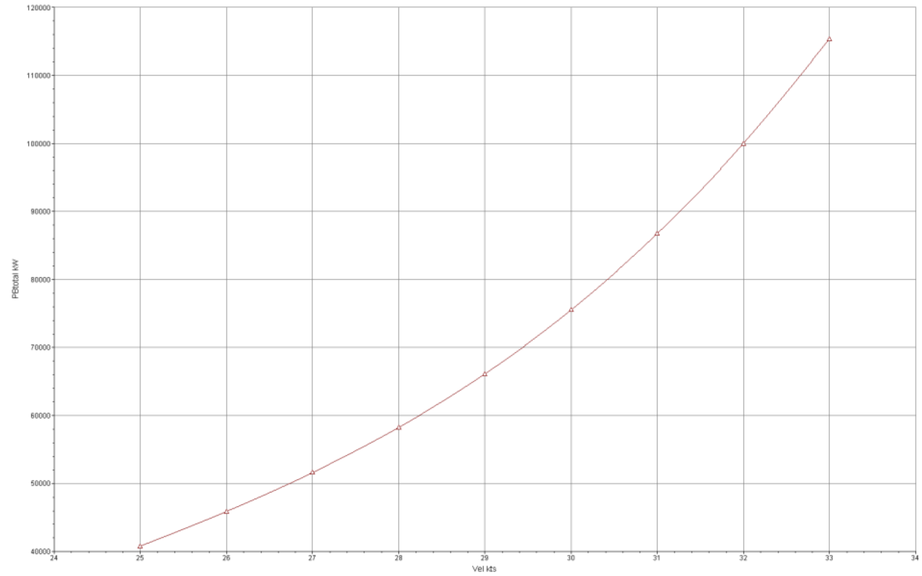


Figure 150- Sustained BHP

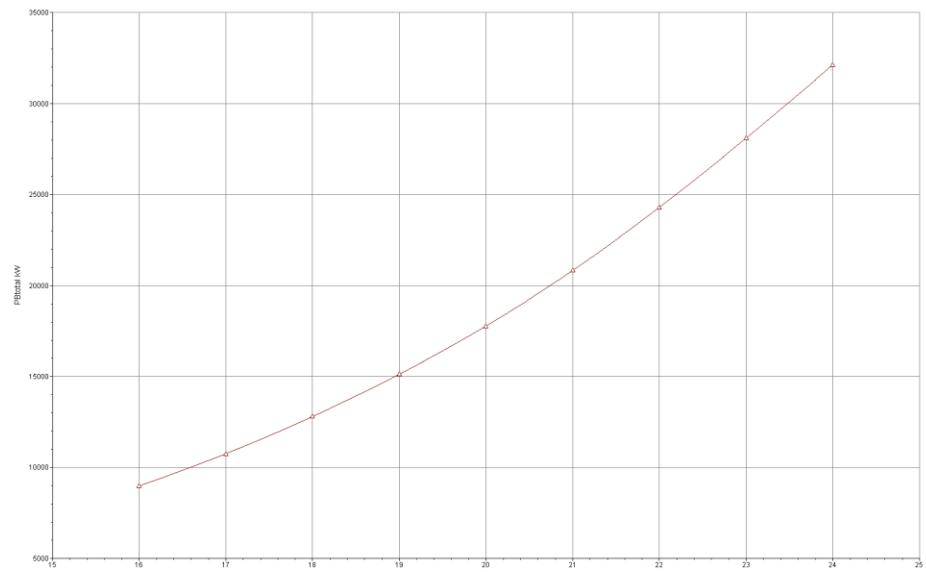


Figure 151- Endurance BHP

4.6.3 Electric Load Analysis (ELA)

Table 62 - 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	590	0.00	0	0.00	0	1.00	590	0.30	177	0.00	0
	200	Propulsion	105421		102650		21084		2310		0		373
		Propulsion Direct	101405	1.00	101405	0.20	20281	0.02	2204	0.00	0	0.00	359
		Propulsion Support	4016	0.31	1245	0.20	803	0.03	106	0.00	0	0.00	14
	300	Electric	1872	0.25	468	0.25	465	0.19	357	0.40	749	0.15	281
	400	CCC	14519		8133		8064		728		4		3460
		Combat Systems	14479	0.56	8108	0.56	8039	0.05	724	0.00	0	0.24	3460
		Miscellaneous	40	0.63	25	0.63	25	0.10	4	0.10	4	0.00	0
	500	Auxiliary	10149		2538		3726		2150		362		1098
	510	Climate Control	7097	0.25	1774	0.40	2847	0.25	1774	0.00	0	0.09	657
	520	Sea Water Systems	532	0.25	133	0.30	157	0.29	156	0.40	213	0.34	181
	530	Fresh Water System	485	0.25	121	0.61	296	0.25	121	0.00	0	0.28	134
	540	Fuel Handling	1491	0.25	373	0.17	253	0.03	51	0.10	149	0.00	0
	550	Air System	159	0.25	40	0.26	42	0.26	42	0.00	0	0.00	0
	560	Ship Control Systems	370	0.25	92	0.34	126	0.00	0	0.00	0	0.34	126
	590	Special Purpose Systems	15	0.34	5	0.33	5	0.40	6	0.00	0	0.00	0
	600	Services	610	0.10	61	0.16	96	0.10	64	0.40	244	0.01	4
	700	Weapons	1503	0.34	511	0.15	232	0.13	189	0.00	0	0.24	365
		Total Required	134664		114361		33667		6388		1536		5581
		24 Hour Average	8335		46772		14228		2833		1064		2409
Number	**Generator**	**Rating (kW)**	**Average Connected (kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(kW)**	**Online**	**(KW)**
3	MT30	36000.0	108000	3	108000	1	36000	0	0	0	0	0	0
2	LM500	3800.0	7600	2	7600	1	3800	2	7600	1	3800	2	7600
	Total		115600		115600		39800		7600		3800		7600
			Available Power		1239		6133		1212		2264		2019

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) (or Ship Service Power) and Electrical Distribution

The one-line diagram is a simple schematic for power distribution on the ship. The IPS (integrated powered system) enables a ship's electrical loads, such as pumps and lighting, to be powered from the same electrical source as the propulsion system. As shown in this schematic in Figure 152, the IPS contains switchboards, PGM's (power generation modules) and PCM's (power conversion modules). Together they make up the ship's electrical distribution (Figure 153). The PCM's come off the primary switchboards in the MMR's (main machinery rooms) and connect to the buses. Each bus is 4160 volts at 60 Hz. The MT30's and LM500's are both interconnected to the system to provide the main source of power for all ship systems.

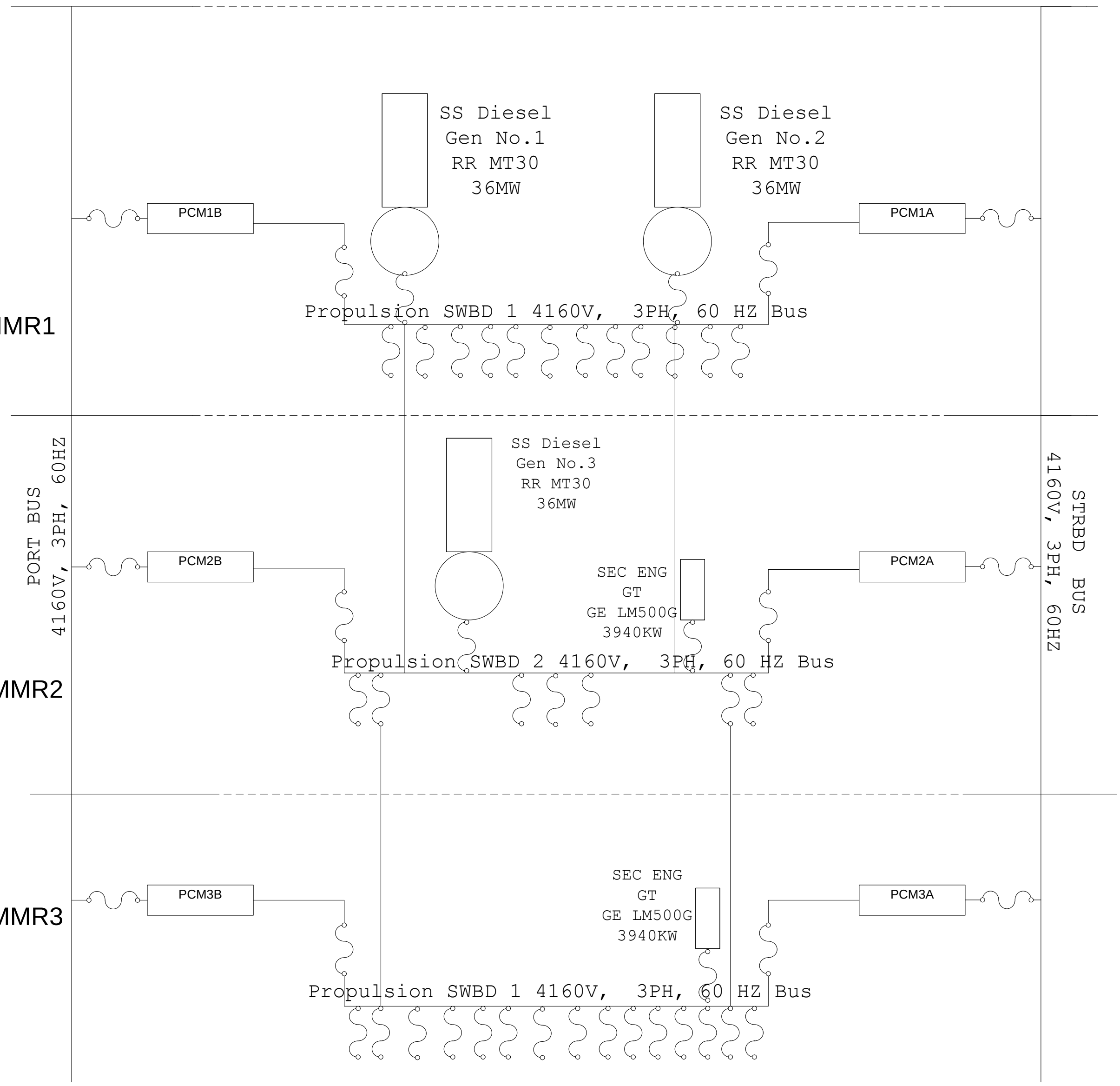


Figure 152 - One-Line Electrical Diagram

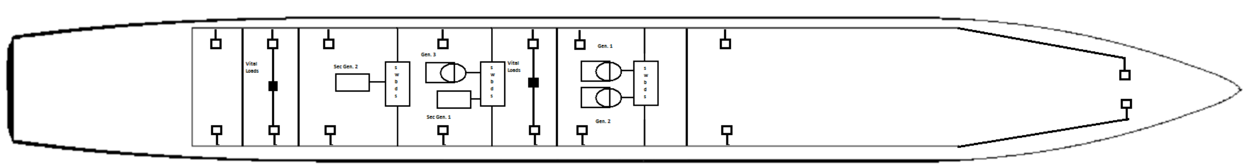


Figure 153 -Electrical Distribution

4.7.2 Service and Auxiliary Systems

Service and auxiliary systems are a part of the ships fuel, air, and water systems. The main components for these systems can be found in the SWBS 500 area and are labeled in the MEL in Appendix D. They are an intricate and important group of systems that provide habitability throughout the ship. Components such as the HVAC (heating ventilation and cooling) are powered by the IPS like any other system and are integrated into the electrical distribution.

4.7.3 Main and Auxiliary Machinery Spaces and Machinery Arrangement

Each MMR and AMR (auxiliary machinery room) in comprised of the necessary systems to allow propulsion, habitability and mission operation. The ships machinery reside on the fourth, third and second decks as shown in Figure 154. An example of one of the MMR’s in Figure 155 shows the PGM’s alongside many of the crucial ship systems such as the pump for the fuel tanks and the service tanks that go alongside it (numbers 28 & 29). The AMR in Figure 156 shows a machinery room without any PGM’s or PCM’s but still holds many important ship systems such as the water pumps and refrigeration systems. All machinery rooms can access each other via ladders located against bulkheads and transverse bulkheads and are shown in Figure 157through Figure 164. The ship engines take up most of the room and require the space of three platforms so that they have clearance to operate. Inlet and exhaust ducts are inserted based on engine location in the MMR and then funneled through the deckhouse. This is all done in the RHINO program as shown in MMR1 and MMR2 in Figure 165 and Figure 166. The machinery rooms are some of the most important areas on the ship and their management is crucial for smooth efficient operation.

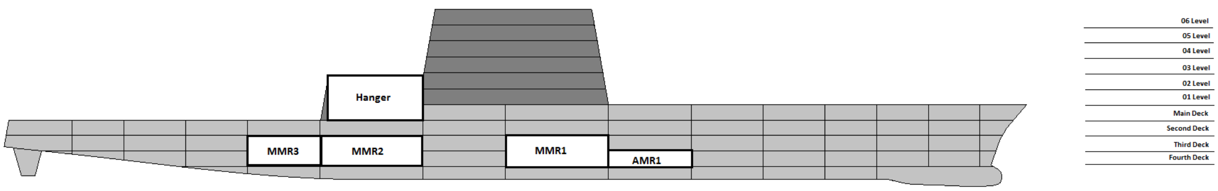


Figure 154 - Machinery Arrangement

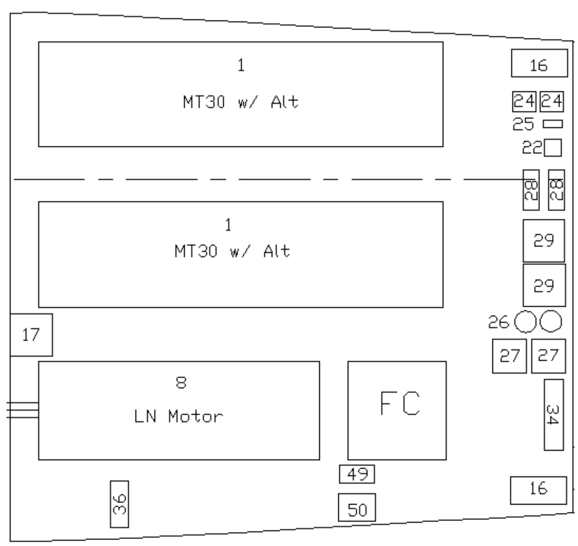


Figure 155 - MMR 1 3rd Platform

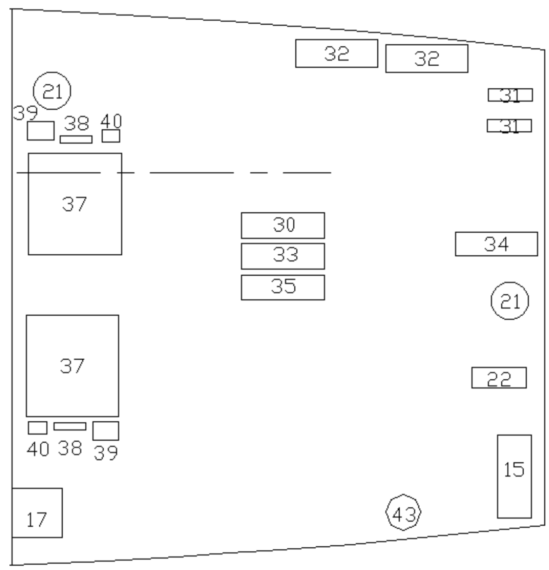


Figure 156 – AMR1 Third Platform

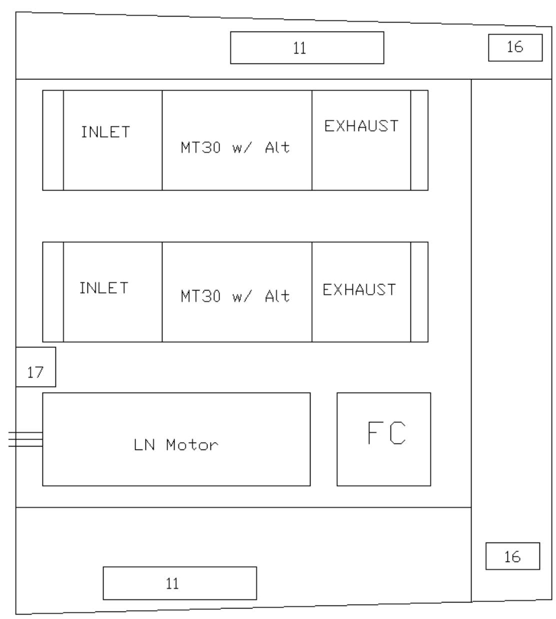


Figure 157 - MMR 1 First Platform

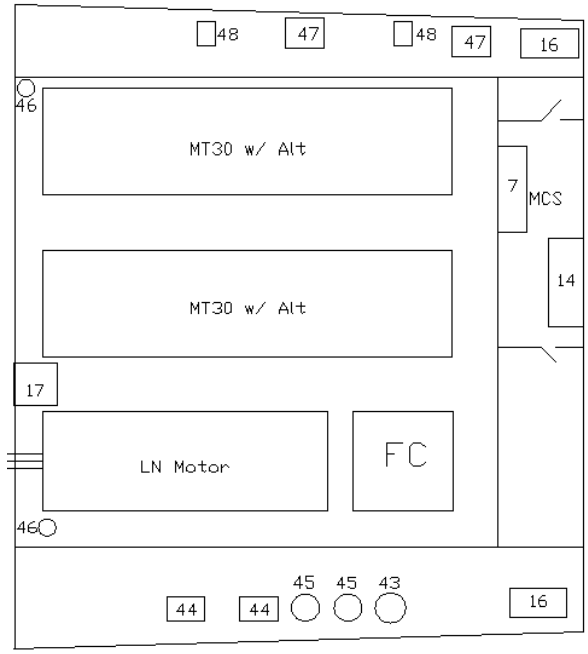


Figure 158 - MMR 1 Second Platform

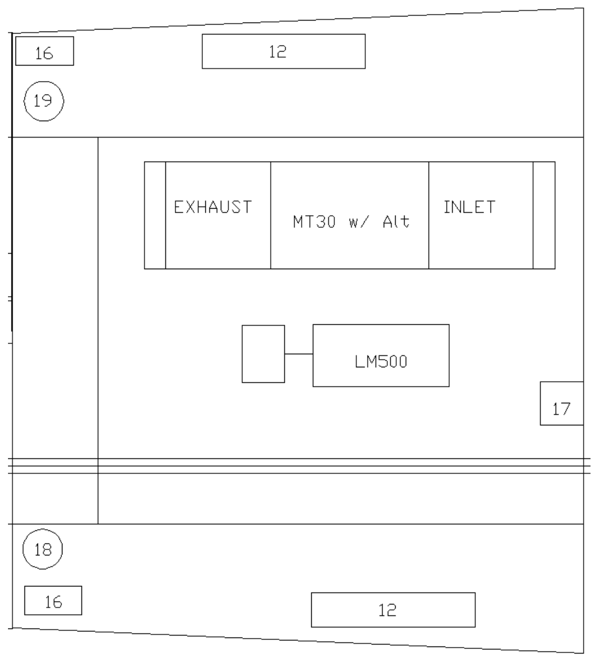


Figure 159 – MMR2 First Platform

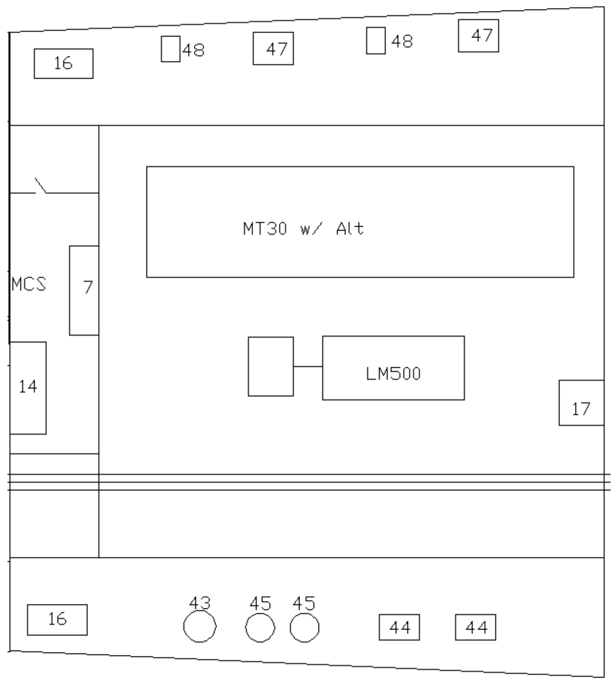


Figure 160- MMR2 Second Platform

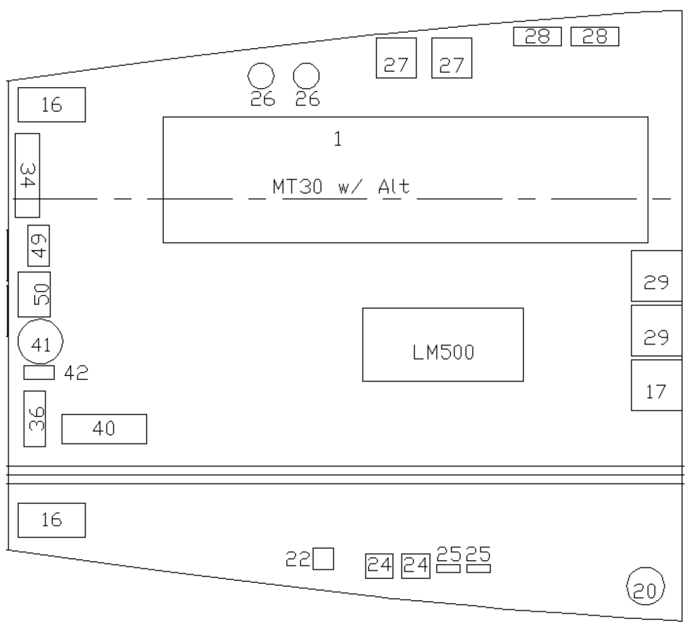


Figure 161- MMR 2 Third Platform

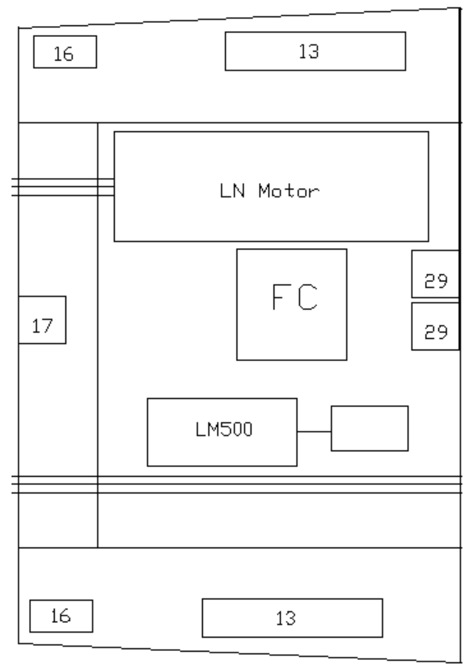


Figure 162 -MMR3 First Platform

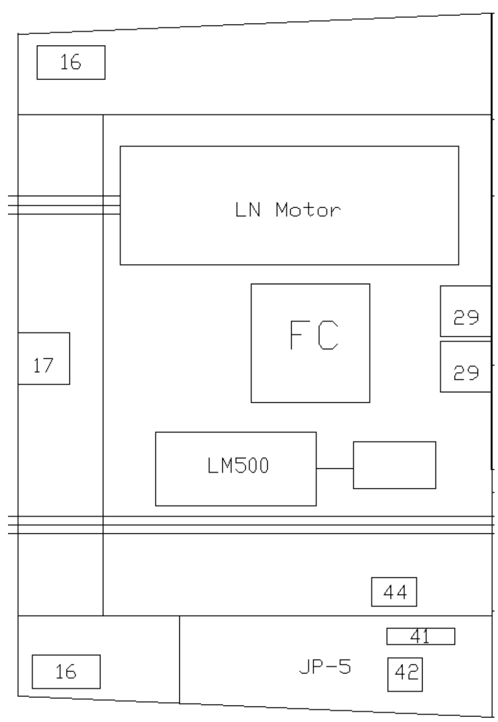


Figure 163 -MMR3 Second Platform

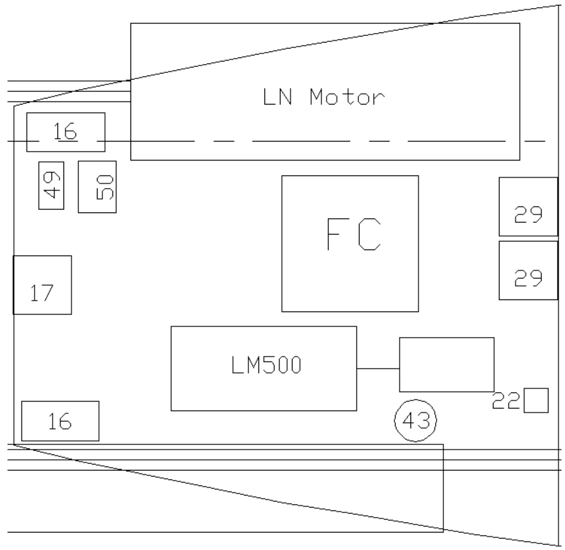


Figure 164- MMR3 Third Platform

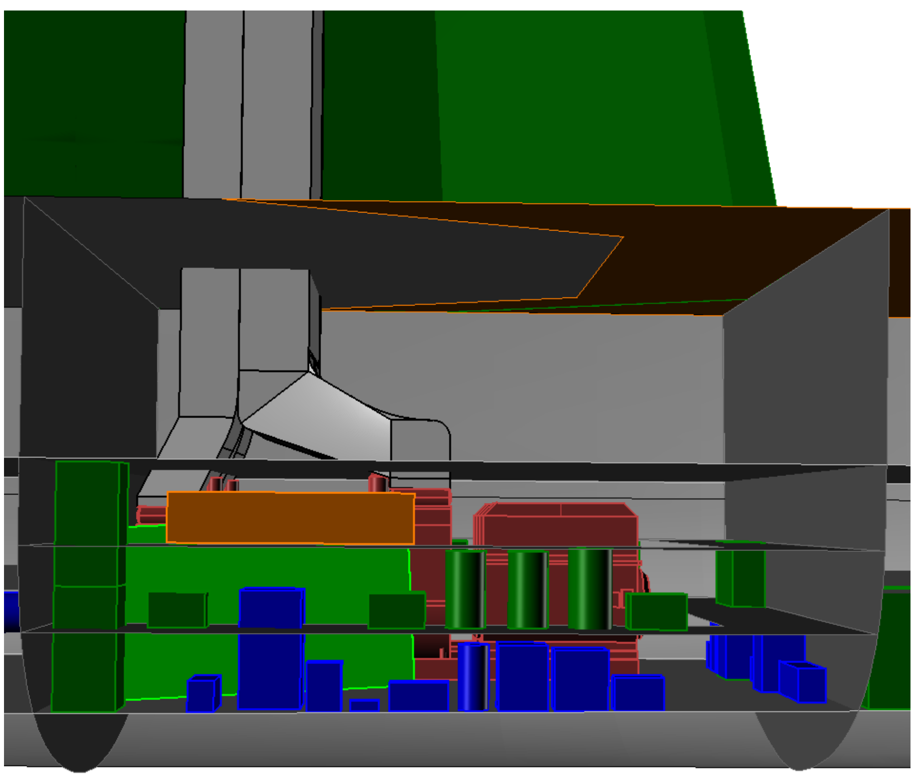


Figure 165 -MMR1 Rhino

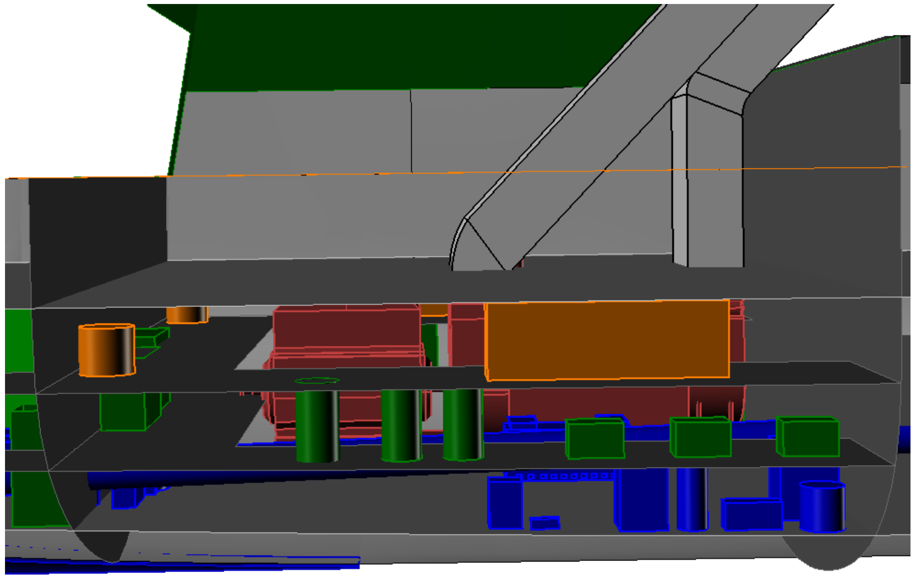


Figure 166- MMR2 Rhino

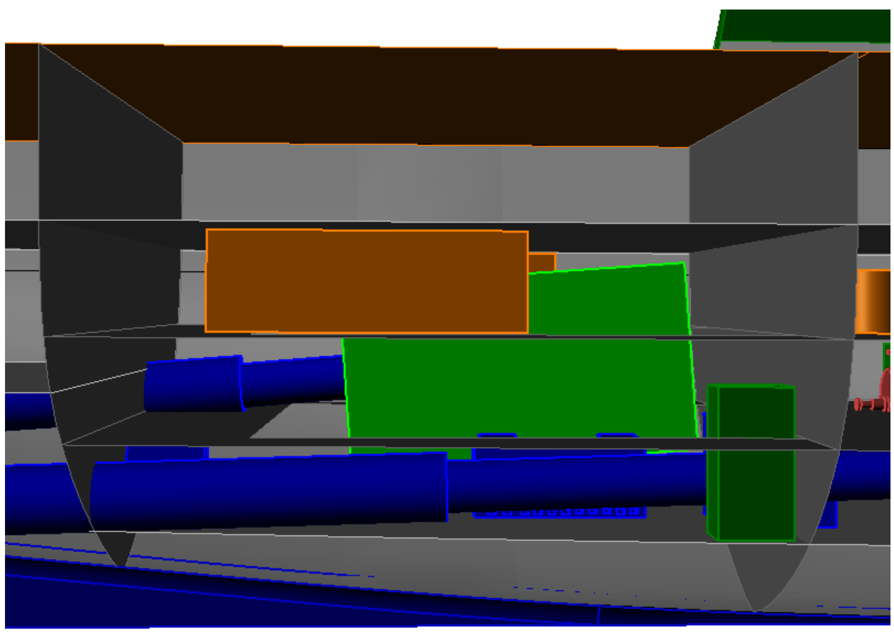


Figure 167 – MMR3 in Rhino

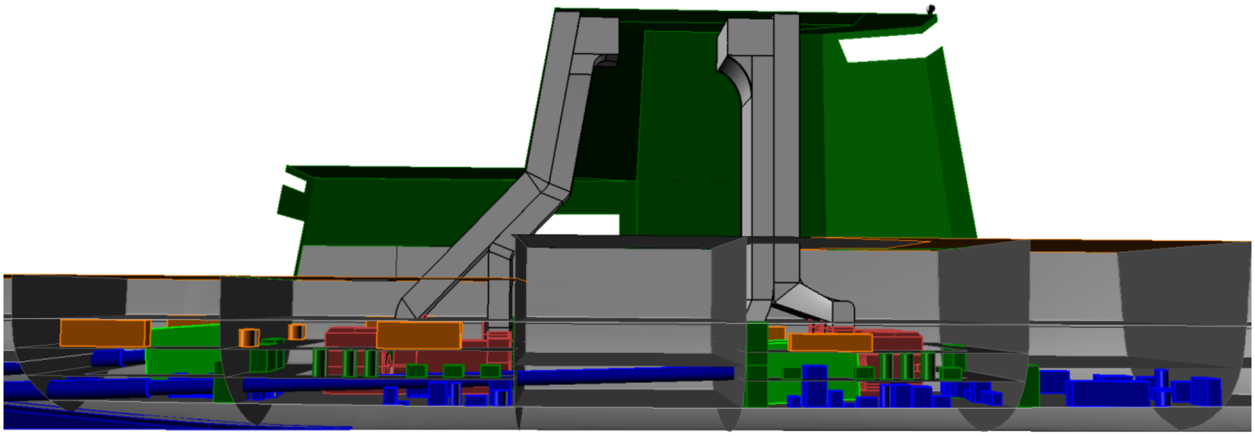


Figure 168- Rhino Profile View

4.8 Manning

Through advanced automation and unmanned systems, the total ship manning requirement for the MSC has been reduced considerably from current naval craft of comparable size. The total manning breakdown is presented in Table 63 with 5 separate department divisions outlined in Figure 169. This chart is constructed to allow for three watch sections, an automated bridge, and the primary propulsion control to be located on the bridge. Overall, the MSC is capable of accommodating 25 officers, 25 chief petty officers, and 100 enlisted men for a total crew of 150 sailors. Table 64 indicates the necessary number of accommodation spaces and respective sizes for each area. A minimum area of 730 m^2 is required for habitable and sanitary spaces for the crew. The area for each space is proven acceptable for a surface ship of this size by prior naval vessels.

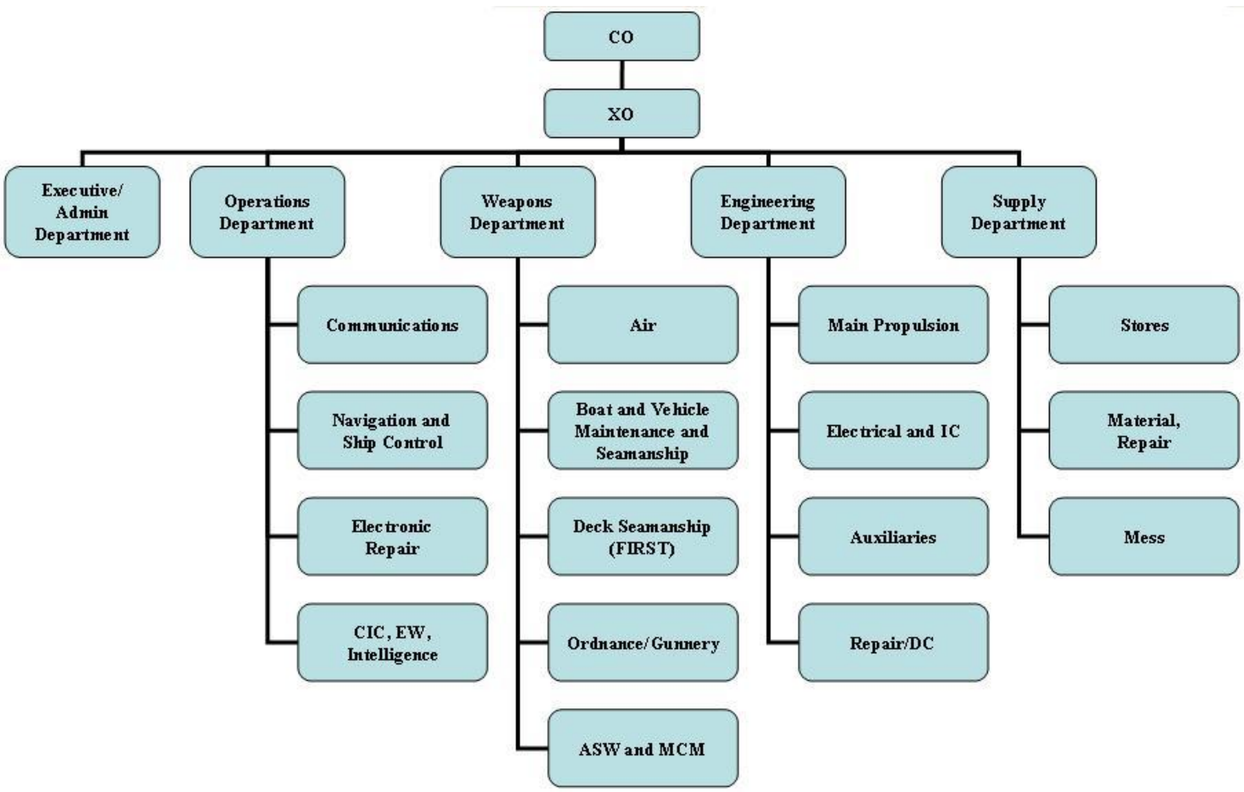


Figure 169 -Surface Ship Manning Organization

Table 63 -Manning Summary

Departments	Division	Officers	CPO	Enlisted	Total Department	Rationale
	CO/XO	2			2	required
	Department Heads	4			4	minimum
Executive/Admin	Executive/Admin		1	1	2	CPO to run office, one personnel man
Operations	Communications	1	1	6	31	3 enlisted watch standers (3x1), CPO, officer required
	Navigation & Control	1	1	5		CPO navigator, 3 enlisted watch standers (3x1)
	Electronic Repair	1	1	6		minimum for maintenance and expertise
	CIC, EW, Intelligence	1	1	6		6 (3x2) enlisted watch standers
Weapons	Air	2	1	6	42	2 pilots, minimum maintenance and support CPO and enlisted
	Boat & Vehicle		1	8		minimum for maintenance and expertise
	Deck	1	1	8		minimum for maintenance
	Ordinance/Gunnery	1	1	4		minimum for maintenance and expertise
	ASW/MCM	1	1	6		minimum for maintenance and expertise
Engineering	Main Propulsion	1	2	10	43	minimum for maintenance and expertise 3x2 enlisted watch standers
	Electrical/IC	1	1	10		minimum for maintenance and expertise 3x1 enlisted watch standers
	Auxiliaries	1	1	7		minimum for maintenance and expertise 3x1 enlisted watch standers
	Repair/DC	1	1	7		minimum for maintenance and expertise
Supply	Stores		1	2	11	minimum for workload and expertise
	Material/Repair		1	2		minimum for workload and expertise
	Mess		1	4		minimum for workload and expertise
	Total	19	18	98	135	
	Accommodations	25	25	100	150	

Table 64 -Manning Accommodation Space

Item	Accommodation Quantity	Per Space	Number of Spaces	Area Each (m^2)	Total Area (m^2)
CO	1	1	1	20	20
XO	1	1	1	15	15
Flag Officer	1	1	1	10	10
Department Head	4	1	4	10	40
Other Officer	12	2	6	10	60
CPO	18	6	3	20	60
Enlisted	98	15	7	20	140
Officer Sanitary	19	6	3	40	120
CPO Sanitary	18	6	3	30	90
Enlisted Sanitary	98	15	7	25	175
Total			36		730

A great deal of enabling technologies are incorporated into the design and construction of MSC to achieve this low manning requirement. Computers with automated software aid in typical everyday tasks such as watch standing.

Automated route planning with collision avoidance systems operate in parallel with global positioning systems and electronic charting and navigation (ECDIS). Varieties of smart sensors monitor equipment within the ship and provide information to the crew via large flat panel displays. This improves efficiency where needed with diminished crew size, and reliability of machinery and automated systems.

The use of condition based maintenance is effectively used to further reduce standing crew size. This also has the advantage of reducing lifetime costs and minimizing ship systems downtime. During construction of the vessel a more costly self-priming paint coating is used. Long term costs and maintenance decrease, however, as these paints have a 300% improvement in life expectancy and require half the time for the initial coating. These paints also have an added benefit of a 50% reduction in volatile organic compounds (VOC's).

4.9 Space and General Arrangements

HECSALV, Rhino and AutoCAD are used to generate and assess subdivision and arrangements. HECSALV is used for tankage, deck and transcerse bulkhead locations. Rhino is used for the 3-D geometry, and AutoCAD is used to construct 2-D drawings of the inboard and outboard profiles, and deck and platform plans.

When considering general arrangements, three priorities must be maintained: function, survivability and maintainability. Spaces may not be filled based strictly on availability. Consideration must be given to those three criteria to create a practical and useable arrangement. A profile showing the internal arrangements is shown in Figure 170and Figure 171.

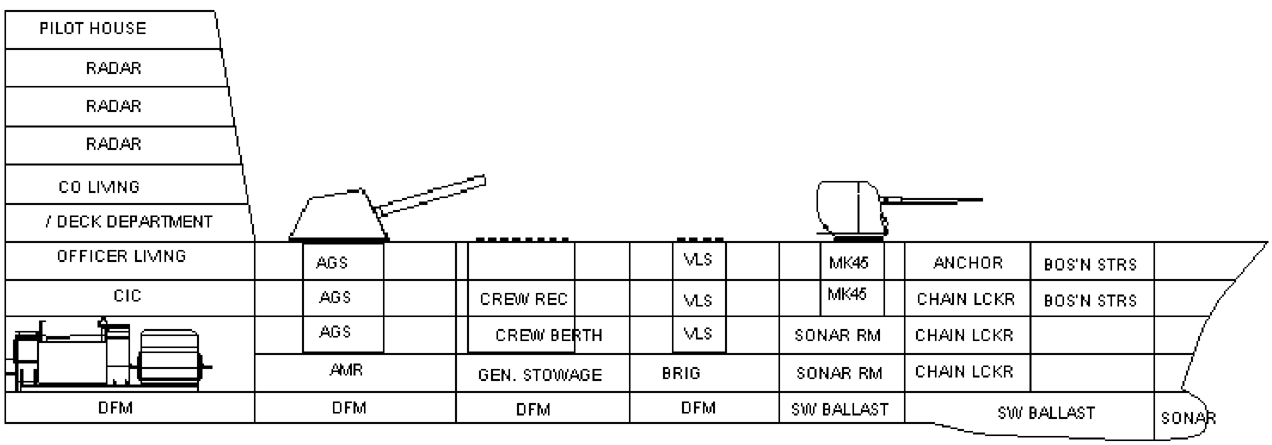


Figure 170 Profile View Showing Arrangements (Forward)

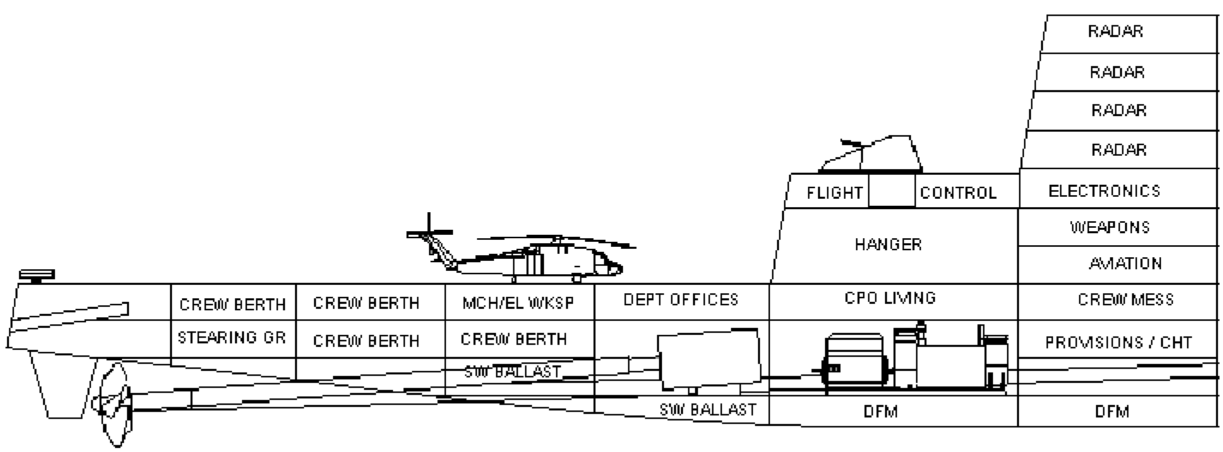


Figure 171 Profile View Showing Arrangements (Aft)

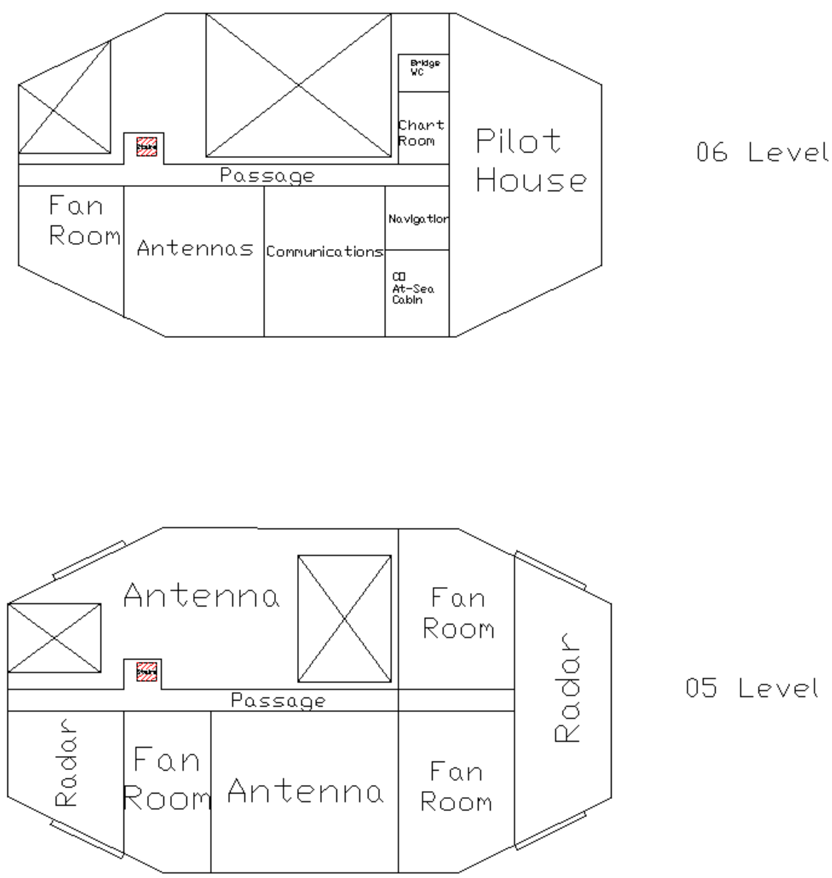
4.9.1 Internal Arrangements

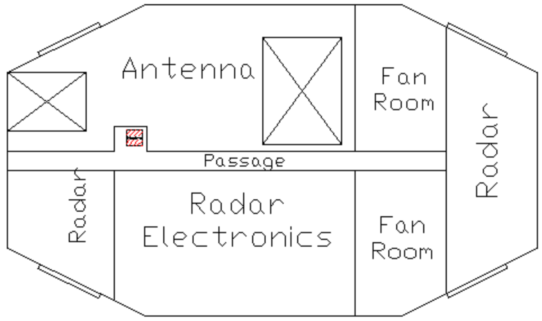
The MSC internal arrangements are divided into four categories: Mission Support, Human Support, Ship Support and Ship Machinery System. The spaces are filled according to the SSCS. The low value real estate is tilled first – tanks in hull curvature and voids. The large object spaces such as machinery rooms are added next. The machinery arrangements were outlined in Section 4.7.3. Finally, the remaining areas are filled according to location priority, functionality, preference, maintainability and survivability.

Mission support include all of the mission-critical spaces, including electronics, communications, weapons, and aviation support. Human support includes all living spaces for all crew members. This includes berthing, mess, recreation, and stores, along with all personal support including dental, medical and laundry. Ship support includes all systems necessary to keep the ship afloat. This includes damage control, ship administration, anchor handling, maintenance support, stowage and tanks. Ship machinery system includes all machinery and supporting structures.

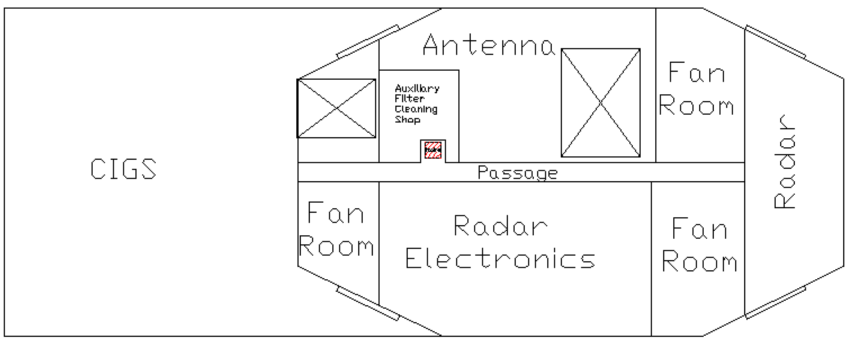
A few things should be noted in the arrangements. All passageways are a minimum 36 inches, with a majority actually a roomy 48 inches. There are two fore and aft passages on the DC Deck (Second Deck), one each on port and starboard. Vertical access trunks are provided from the DC passageways to other levels. There are no access openings below the DC Deck. Detailed arrangement drawings can be seen in Figure 172. Table 65 lists the capacity for each tank. See Section 4.7 for detailed machinery room arrangements.

Figure 172 Internal Arrangements

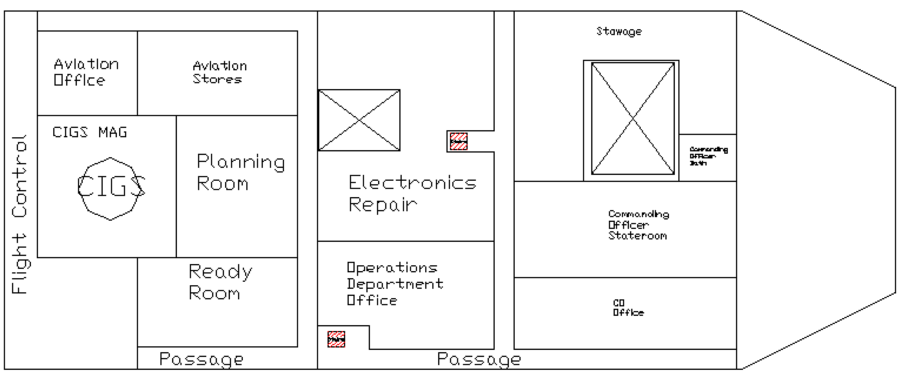




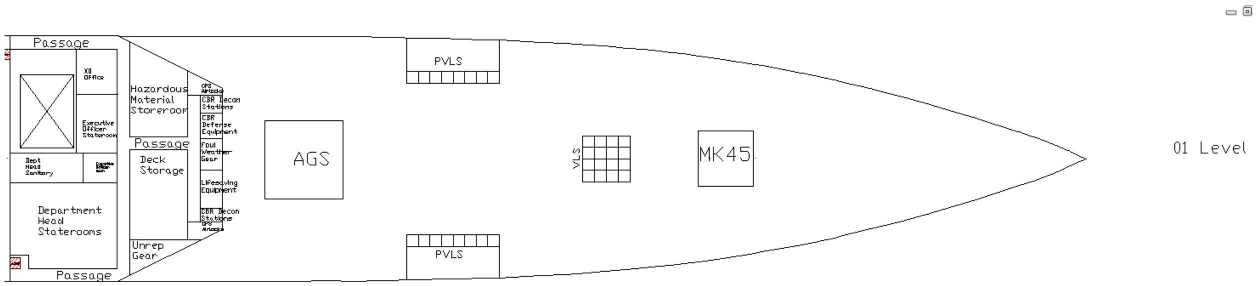
04 Level

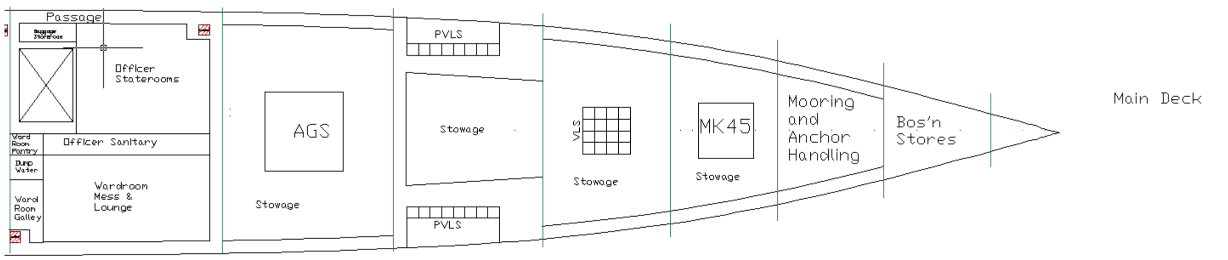


03 Level

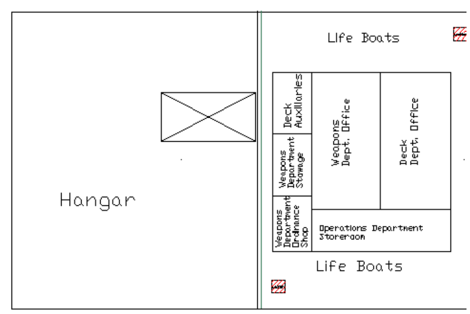


02 Level

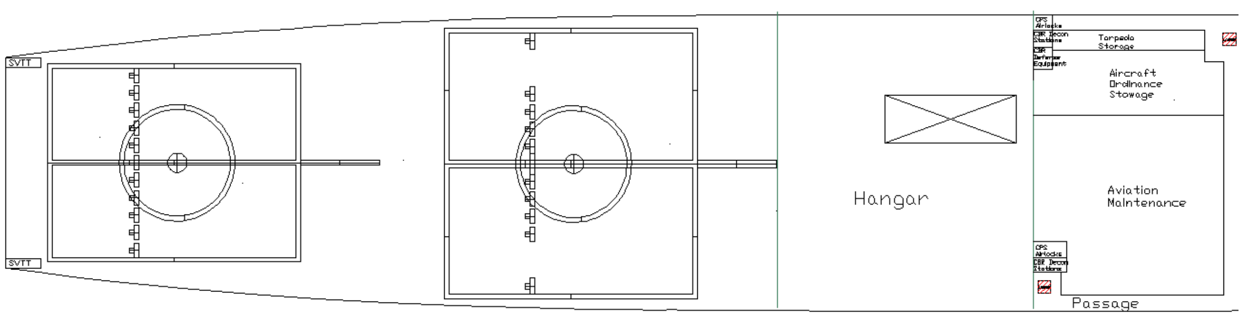




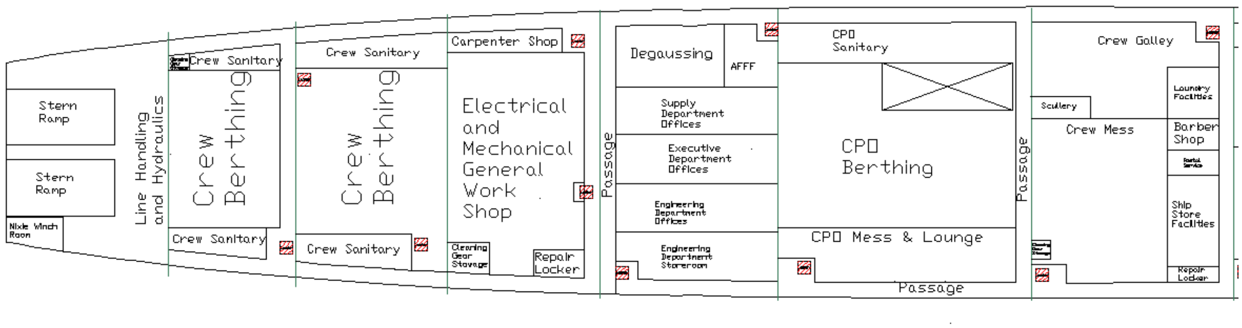
01 Level



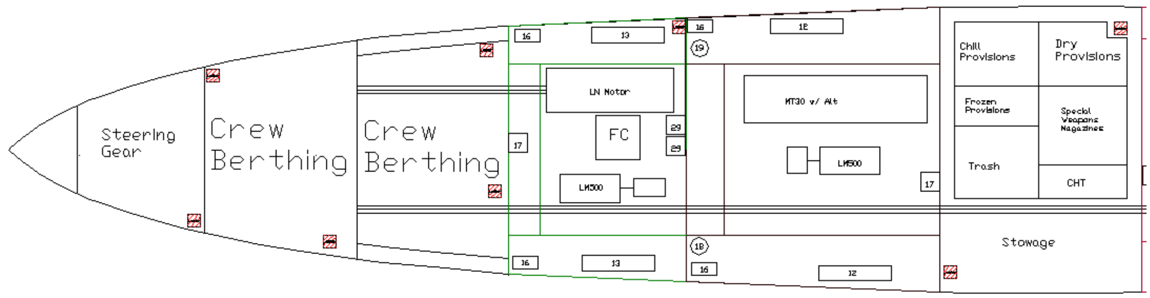
Main Deck

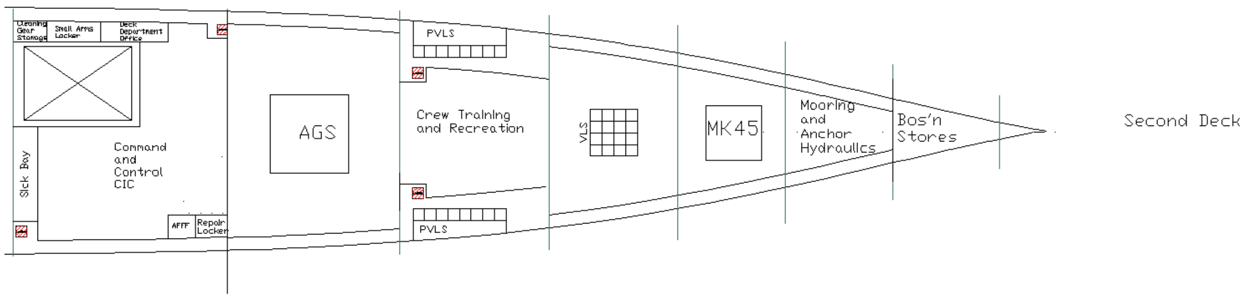


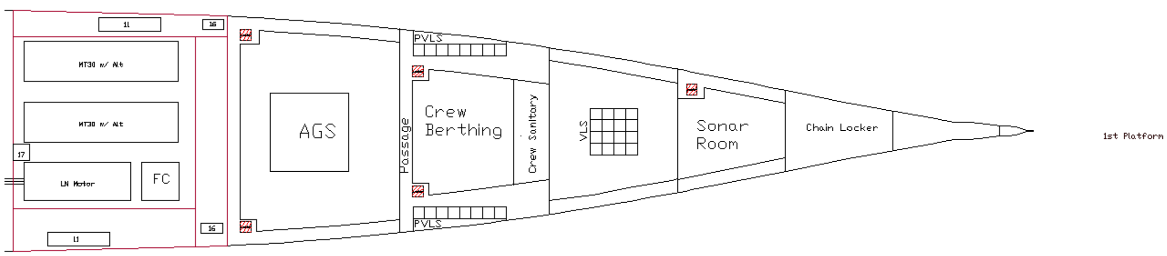
Second Deck



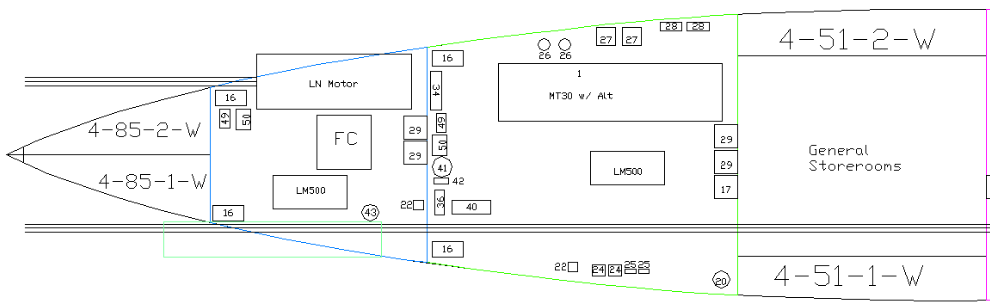
1st Platform



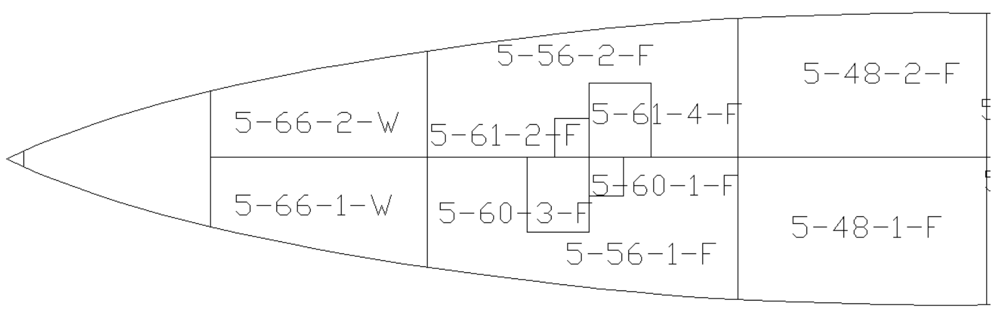


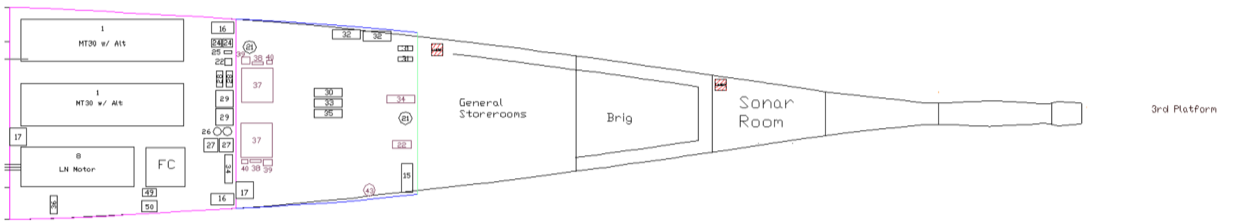


3rd Platform



Inner Bottom





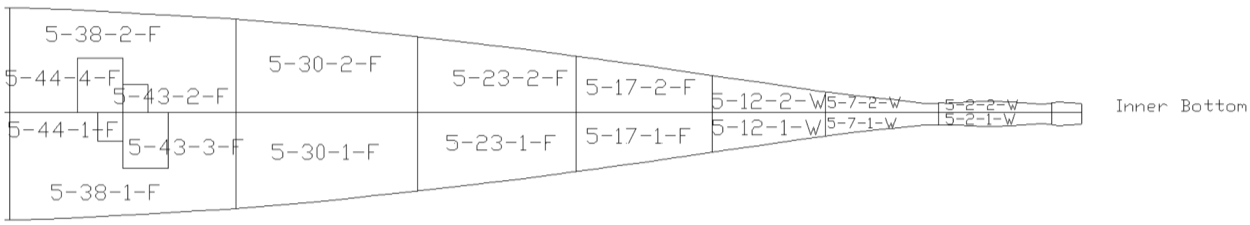


Table 65 Tank Capacity Plan

Tank	Capacity (m^3)	Tank	Capacity (m^3)
4-50-3-Q	11	5-60-1-F	5
5-48-2-F	281	5-61-2-F	5
5-48-1-F	281	5-44-1-F	5
5-38-1-F	318	5-43-2-F	5
5-38-2-F	318	4-51-2-W	12
5-56-2-F	270	4-51-1-W	12
5-56-1-F	271	5-7-2-W	22
5-30-2-F	221	5-7-1-W	22
5-30-1-F	221	4-85-2-W	82
5-23-2-F	148	4-85-1-W	82
5-23-1-F	148	5-66-2-W	111
5-17-2-F	90	5-66-1-W	111
5-17-1-F	90	5-2-2-W	33
5-44-4-F	16	5-2-1-W	33
5-43-3-F	16	5-12-2-W	44
5-60-3-F	12	5-12-1-W	44
5-61-4-F	14	4-66-2-F	100

4.9.2 Living Arrangements

Initial living space estimates are taken from the ASSET reports and the ship synthesis model. The manning estimate is then used to refine these requirements. See section 3.2 for estimates for required living areas, distributed among the crew.

The CO's quarters are situated on the 02 level, with the XO and department heads' quarters on the 01 level just below. All of the CPO living spaces are on the main deck, along with the officer's mess and lounge. The enlisted living spaces are all on the second deck or below, arranged mostly at the stern with some near the bow, leaving the midship sections open for mission and ship support. All crew berthing is split male and female, with separate berthing and sanitary spaces. The crew recreational facility is located forward on the second deck. Figure 173 shows the typical arrangements for crew mess and berthing areas onboard. Notice that the seating and racks are situated fore-and-aft to make the pitching ship motions more comfortable for the crew.

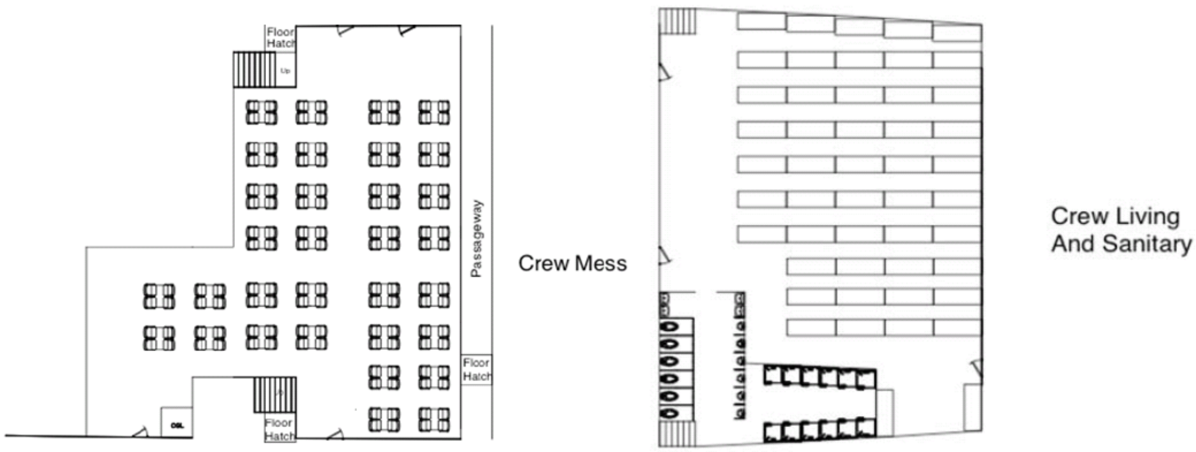


Figure 173 Typical Crew Mess and Berthing

4.9.3 External Arrangements

A major design requirements is minimal radar cross section. This must be considered when creating the topside design. For the MSC, all radars are flat panels on the deckhouse. PVLS and VLS systems are flush with the deck. Guns are even encased in minimal-cross-section enclosures. Ship anchors are stored internally, keeping the deck free and clear. Figure 174 shows the topside design for the MSC.

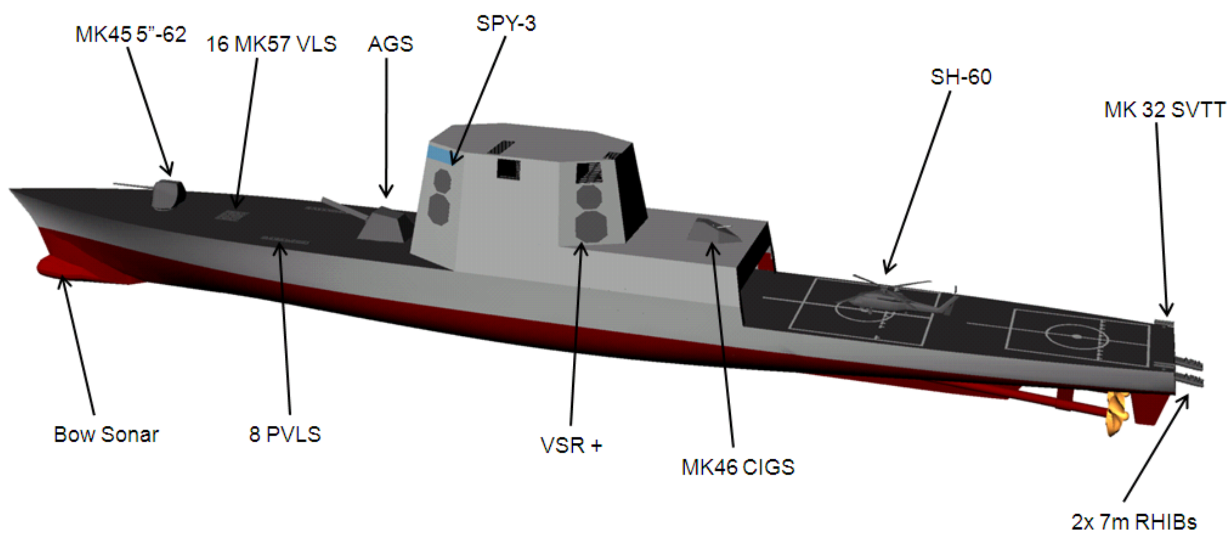


Figure 174 Topside Design

The SVTT torpedo tubes are mounted at the stern, with torpedo stowage inside the hangar. Below the SVTTs are the two 7m RHIBs. The ship supports two SH-60 Seahawk helicopters, and sports two landing pads. The MK-46 CIGS is mounted aft of the deckhouse on the hangar. The VSR+ radar is mounted on the aft-facing corners of the deckhouse. The SPY-3 is located on the forward-facing corners of the deckhouse. The bridge is located above the radars to maintain complete visibility and control on the ship. The AGS is located on the stern deck just forward of the deckhouse. Forward of that gun are the 16 VLS launch tubes, arranged in two rows of 8 cells along the side of the hull. The other 16 cells are clustered together forward of the PLVS tubes. The MK-45 5”-62 is situated rathers forward on the stern deck. This location keeps the gun far enough away from the AGS so as not to interfere with the rotation of the turret from port to starboard. This topside arrangement also facilitates survivability. Should one compartment be damaged in an attack, there is a non-adjacent compartment that may be unharmed and can still maintain functionality.

4.9.4 Area and Volume

Initial space requirements and availability in the ship are determined in the ship synthesis module. The ASSET Space Module Reports include the area and volume requirements for spaces throughout the hull. These volume and area requirements are listed in Appendix F. They are used to allocate spaces within the hull.

4.10 Weights, Loading and Stability

4.10.1 Lightship Weights

ASSET parametrics and the ship synthesis model are used to determine the weights of each SWBS group as well as the vertical and longitudinal centers of gravity. These values are used to calculate the overall center of gravity and the mass moments of the ship. The vertical and longitudinal centers of gravity obtained from ASSET are compared to the locations in the general and machinery arrangements and adjusted when performing the stability analysis. The tank volumes and densities from HECSALV are used when calculating the full load and minimum operating condition characteristics. Table 66 summarizes the SWBS groups for the lightship condition. The complete weights spreadsheet is provided in Appendix E.

Table 66 - Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m- BL)	LCG (m- FP)
100	6654.3	7.52	95.33
200	1919.7	6.19	117.11
300	843.3	8.26	101.15
400	412.4	31.53	106.4
500	1277.4	9.04	69.07
600	827.1	7.94	94.84
700	303.6	9.95	0.00
Margin	1223.78	8.42	94.38
Total (LS)	13461.58	8.42	94.38

Table 67 - Lightship Weight Summary

4.10.2 Loads and Loading Conditions

The full load condition, as stated in DDS 079-1, includes the lightship weights plus the full allowance of ammunition, ship's force, general stores, and all other items aboard. The full load condition also includes all liquid tanks at 95% capacity, with the exception of the ballast tanks. The tanks are adjusted so the trim remains between 0 and 0.1m aft. A summary of the weights for the full load condition is provided in Table 68.

Table 68 - Weight Summary: Full Load Condition

Item	Weight (MT)	VCG (m- BL)	LCG (m- FP)
Lightship w/Margin	12975.5	7.49	98.9
Ships Force	16.9	10.61	90.3
Total Weapons Loads	304.0	8.61	95.0
Provisions	152.0	7.01	96.0
General Stores	38.0	7.93	88.3
Diesel Fuel Marien	2095.0	2.21	87.3
JP-5	77.0	4.29	138.9
Lubricating Oil	17.0	0.51	87.1
SW Ballast	0.0	0.00	0.00
Fresh Water	25.0	3.16	103.9
Total	15721	6.70	97.4

The Minimum Operating (Min Op) condition corresponds to a condition after a period at sea. Ammunition, provisions, stores, and fuel are at one third of full capacity and the fresh water is at two thirds of its full capacity. The ballast tanks are filled to maintain trim between 0 and 0.5m aft. The values for the minimum operating condition are listed in Table 69.

Table 69 - Weight Summary: Min Op Condition

Item	Weight (MT)	VCG (m- BL)	LCG (m- FP)
Lightship	12975.5	7.49	98.9
Ships Force	16.9	10.61	90.3
Total Weapons	101.3	8.61	95.0
Provisions	50.7	7.01	96.0
General Stores	12.7	7.93	88.3
Diesel Fuel	616.0	2.21	87.3
JP-5	77.0	4.29	138.9
Lubricating Oil	9.0	0.51	87.1
Waste Oil	28	0.37	102.1
Sewage	11	4.1651	105.1
SW Ballast	194.0	1.46	20.2
Fresh Water	16.0	3.16	103.9
Total	14182	7.08	97.3

4.10.3 Final Hydrostatics and Intact Stability

The hydrostatic properties are analyzed using the HECSALV software suite. The section geometry is imported from RHINO into the HECSALV Ship Project Editor. Tankage and lightship distribution are established in the Ship Project Editor. Bulkheads are arranged so that the ship meets the three compartment standard which is checked using the floodable length curve, discussed in Section 4.4. The miscellaneous values that were not known for the initial calculations are entered and the intact stability and damaged stability are reanalyzed in HECSALV and the Damaged Stability Module. Intact stability is calculated in accordance with the U.S. Navy Design Sheet DDS 079-1. The damaged conditions are calculated for multiple scenarios with a damage length of 15% LWL or greater, which corresponds to three compartments. The three worst scenarios, maximum trim forward and aft, and maximum heel, are modeled in HECSALV.

In each condition, trim, stability, righting arm, and strength summary data are calculated. All conditions are assessed using DDS 079-1 stability standards for beam winds with rolling. There are two criteria which must be fulfilled in order to have satisfactory intact stability: (1) 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, and (2) 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).

The trim, stability, righting arm, and strength summary data are shown below for the full load, minimum operations, and lightship conditions. Table 70 through Table 75 and Figure 175through Figure 180 summarize the data for each condition.

Table 70 - Full Load Trim and Stability Summary

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KMt (m)	12.3	LCF Draft (m)	6.357	Draft at A.P (m)	6.385	Shear	544 MT at 66.972 A m-MS
VCG (m)	6.677	LCB (m-MS)	1.289A	Draft at M.S. (m)	6.353	Bending Moment	24500 H m-MT at 28.293A m-MS
GM_t (Solid) (m)	5.606	LCF (m-MS)	10.412A	Draft at F.P (m)	6.322		
FS_c (m)	0.248	MT1cm (m-MT/cm)	419	Draft at Aft Marks (m)	6.354		
GM_t (Corrected) (m)	5.358	Trim (m-A)	0.063	Draft at Mid Marks (m)	6.322		
Specific Gravity	1.025	List (deg)	0.5P	Draft at Fwd Marks (m)	6.291		

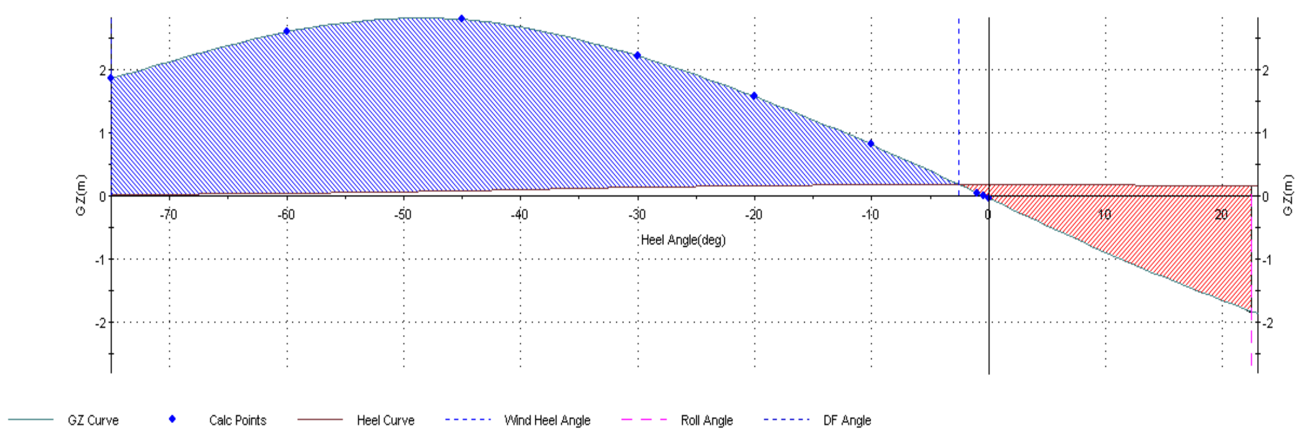


Figure 175 - Full Load Righting Arm Curve

Table 71 - Full Load Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Heel	deg	2.5	---
Wind Heeling Arm	m	0.179	---
Maximum Righting Arm Ratio		0.06	0.6
Capsizing Area A2	m-rad	0.44	---
Righting Area A1	m-rad	2.46	0.61
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.828	---
Angle at Max GZ	deg	48.5	---
Projected Sail Area	m^2	1,979.44	---
Heeling Arm at 0 deg	m	0.179	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area –BL	m	16.660	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

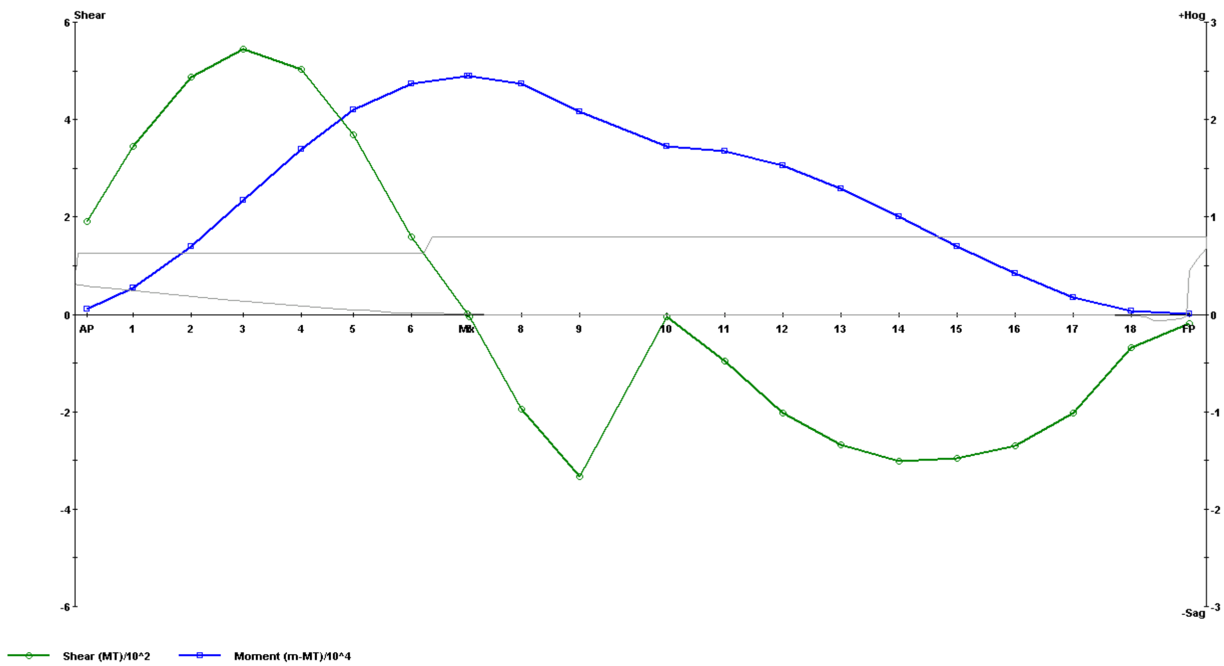


Figure 176 - Strength Summary for Full Load Condition

In the full load condition both DDS 079-1 criteria are met. (1) The maximum heeling arm ratio is 0.06 which is below the limit of 0.6 and (2) the area A1 is greater than 0.62, which is 1.4 times the area A2. The intact stability is satisfactory in the full load condition.

Table 72 - Min Op Trim and Stability Summary

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KM_t (m)	12.634	LCF Draft (m)	5.941	Draft at A.P (m)	6.104	Shear	744 MT at 56.972 A m-MS
VCG (m)	7.084	LCB (m-MS)	1.205A	Draft at M.S. (m)	5.921	Bending Moment	40343H m-MT at 14.816A m-MS
GM_t (Solid) (m)	5.549	LCF (m-MS)	10.448A	Draft at F.P (m)	5.738		
FS_c (m)	0.306	MT1cm (m-MT/cm)	404	Draft at Aft Marks (m)	5.924		
GM_t (Corrected) (m)	5.243	Trim (m-A)	0.366	Draft at Mid Marks (m)	5.741		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	5.558		

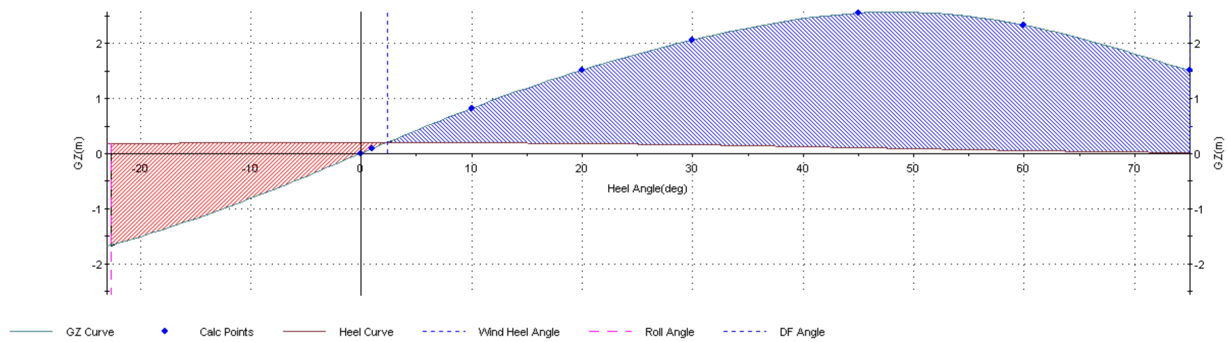


Figure 177 - Min Op Righting Arm Curve

Table 73 - Min Op Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Heel	deg	2.4	---
Wind Heeling Arm	m	0.208	---
Maximum Righting Arm Ratio		0.08	0.6
Capsizing Area A2	m-rad	0.44	---
Righting Area A1	m-rad	2.22	0.61
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.575	---
Angle at Max GZ	deg	48.2	---
Projected Sail Area	m^2	2070.17	---
Heeling Arm at 0 deg	m	0.208	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area –BL	m	16.7	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

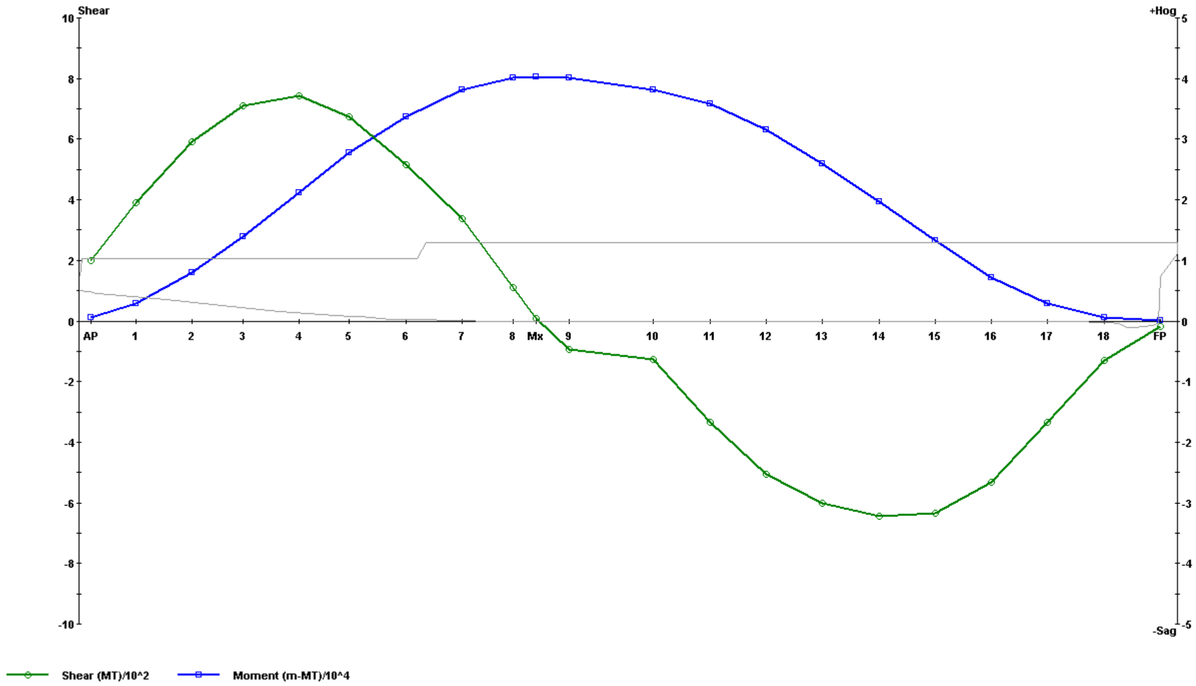


Figure 178 - Strength Summary for Min Op Condition

In the minimum operations condition both DDS 079-1 criteria are met. (1) The maximum heeling arm ratio is 0.08 which is below the limit of 0.6 and (2) the area A1 is greater than 0.62, which is 1.4 times the area A2. The intact stability is satisfactory in the minimum operations condition.

Table 74 - Lightship Trim and Stability Summary

Stability Calculations		Trim Calculations		Drafts		Strength Calculations	
KMt (m)	13.143	LCF Draft (m)	5.618	Draft at A.P (m)	6.443	Shear	818 MT at 56.972 A m-MS
VCG (m)	7.490	LCB (m-MS)	5.146A	Draft at M.S. (m)	5.502	Bending Moment	47207H m-MT at 13.036A m-MS
GM_t (Solid) (m)	5.653	LCF (m-MS)	11.893A	Draft at F.P (m)	4.560		
FS_c (m)	0.000	MT1cm (m-MT/cm)	394	Draft at Aft Marks (m)	5.517		
GM_t (Corrected) (m)	5.653	Trim (m-A)	1.883	Draft at Mid Marks (m)	4.576		
Specific Gravity	1.025	List (deg)	0.0	Draft at Fwd Marks (m)	3.635		

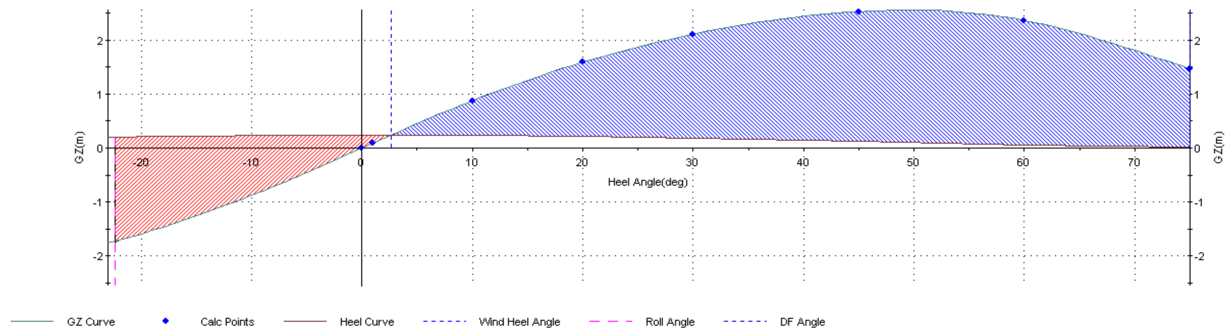


Figure 179 - Lightship Righting Arm Curve

Table 75 - Lightship Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Heel	deg	2.6	---
Wind Heeling Arm	m	0.236	---
Maximum Righting Arm Ratio		0.09	0.6
Capsizing Area A2	m-rad	0.46	---
Righting Area A1	m-rad	2.23	0.64
Angle Limiting Area	deg	75.0	---
Maximum Righting Arm	m	2.556	---
Angle at Max GZ	deg	49.6	---
Projected Sail Area	m^2	2150.72	---
Heeling Arm at 0 deg	m	0.237	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100	
Reference Draft	m	0.00	
Projected Sail Area	m^2	2,428	
Vertical Center of Sail Area –BL	m	16.7	
Factor f where $p=f*V^2$ (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

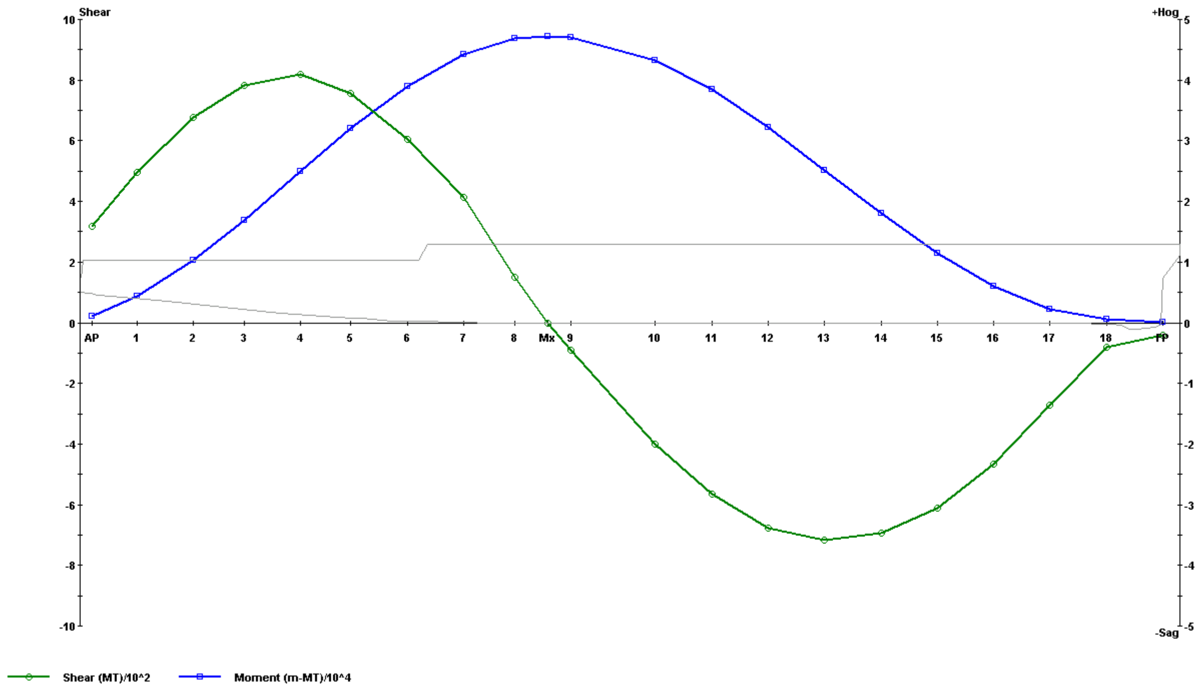


Figure 180 - Strength Summary for Lightship Condition

In the lightship condition both DDS 079-1 criteria are met. (1) The maximum heeling arm ratio is 0.09 which is below the limit of 0.6 and (2) the area A1 is greater than 0.64, which is 1.4 times the area A2. The intact stability is satisfactory in the lightship condition.

4.10.4 Damage Stability

To assess the damage that can be withstood, thirty two individual damage cases are modeled in the HECSALV Damaged Stability Module. For each scenario, three compartments are flooded, which is equal to or greater than the 15% LWL damage criteria required by the DDS 079-1. The DDS 079-1 criteria for righting arm and area ratio as discussed before also applies for damage stability.

Damage Case 6 is shown in Figure 181. This is the worst case for forward trim, which occurs during the full load condition. The damage length is 46m, which is above the 15% LWL damage criteria. The three compartments include flooding one of the main machinery rooms and the auxiliary machinery room. This case gives a draft at the FP of 10.85m and it causes the ship to trim 4.92m forward. The righting arm and heeling arm curve is shown in Figure 182 with the data analyzed in Table 76.

Figure 181 - Extreme Case Forward Trim

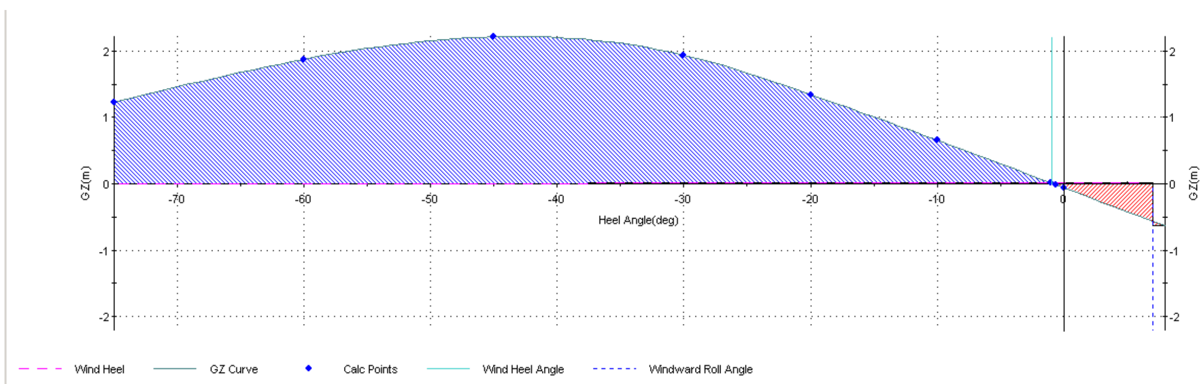


Figure 182 - Righting Arm Curve for Extreme Case of Forward Trim

Table 76 - Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Speed	knots	40.22	40.22
Windward Roll Angle	deg	8.0	8.0
Angle of List of Loll	deg	0.8	15.0
Wind Heel	deg	1.0	---
GZ_{Max} Margin	m	2.218	0.082
Area A1	m-rad	1.07	0.01
Area Ratio A1/A2		26.97	1.4
Freeboard to Margin Line	m	3.507	0.000
Longitudinal GM	m	325.315	---
Calculation Parameters			
Wind Heeling Arm	m	0.011	---
Angle at Max GZ	deg	43.1	---
Capsizing Area A2	m-rad	0.04	---

Parameter	Units	Value	Required
Righting Area A1	m-rad	1.07	---
Angle Limiting Area A1	deg	45.0	---
Projected Sail Area	m^2	1000.24	---
Vertical Arm ABL	m	10.981	---
Heeling Arm at 0 deg	m	0.011	---
Factor f where $p=f*V^2$ (lb/ft^2)		0.0040	---
Wind Pressure	bar	0.00	---

Damage Case 11 is shown in Figure 183 which is the worst case for aft trim. The worst case of aft trim occurs during the full load condition. The damage length is 38m, which is above the 15% LWL damage criteria. The flooding of the three aft compartments causes a trim of 3.47m aft and a draft of 8.79m at the aft perpendicular. The data for the righting arm curve in Figure 184 is summarized in Table 77.

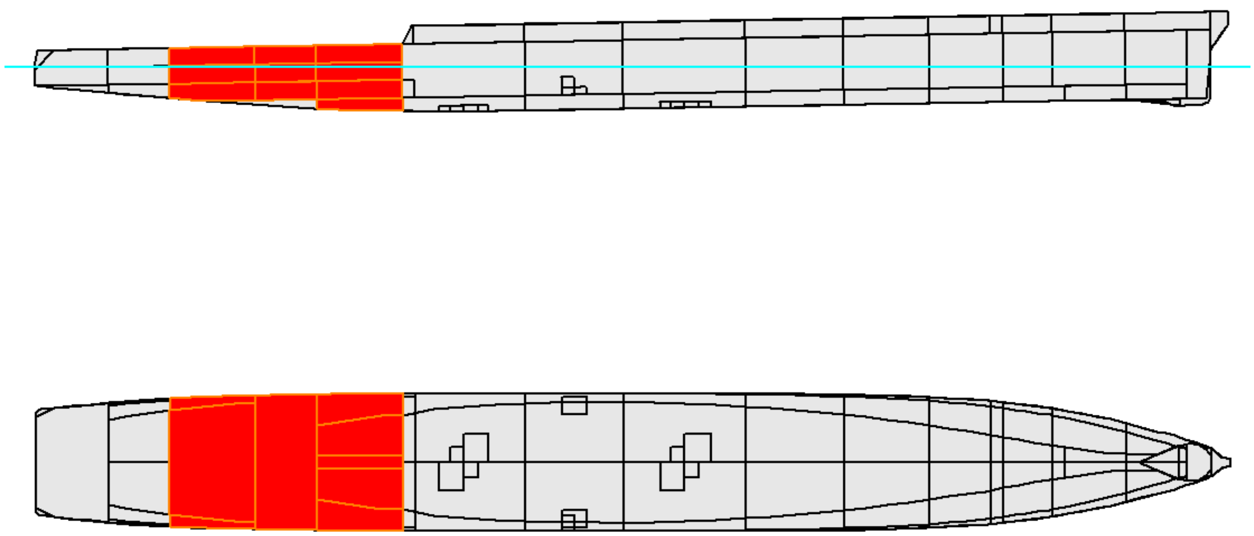


Figure 183 - Extreme Case of Aft Trim

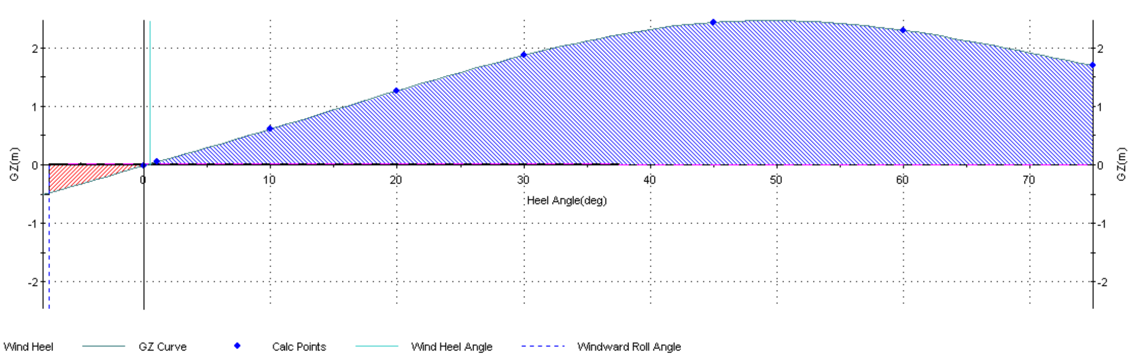


Figure 184 - Righting Arm Curve for Extreme Case of Aft Flooding

Table 77 - Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Speed	knots	40.22	40.22
Windward Roll Angle	deg	8.0	8.0
Angle of List of Loll	deg	0.2	15.0
Wind Heel	deg	0.5	---
GZ_{Max} Margin	m	2.474	0.083
Area A1	m-rad	1.06	0.01
Area Ratio A1/A2		30.56	1.4
Freeboard to Margin Line	m	2.605	0.000
Longitudinal GM	m	321.259	---
Calculation Parameters			
Wind Heeling Arm	m	0.015	---
Angle at Max GZ	deg	49.4	---
Capsizing Area A2	m-rad	0.03	---
Righting Area A1	m-rad	1.06	---
Angle Limiting Area A1	deg	45.0	---
Projected Sail Area	m^2	1258.58	---
Vertical Arm ABL	m	10.394	---
Heeling Arm at 0 deg	m	0.015	---
Factor f where $p=f*V^2$ (lb/ft^2)		0.0040	---
Wind Pressure	bar	0.00	---

The worst case for heel is damage case 8 in the minimum operations loading condition. The damage length is 56m, which is above the 15% LWL damage criteria. The three flooded compartments take out both main machinery rooms, shown in Figure 185. Table 78 summarizes the data for the righting arm curve in Figure 186.

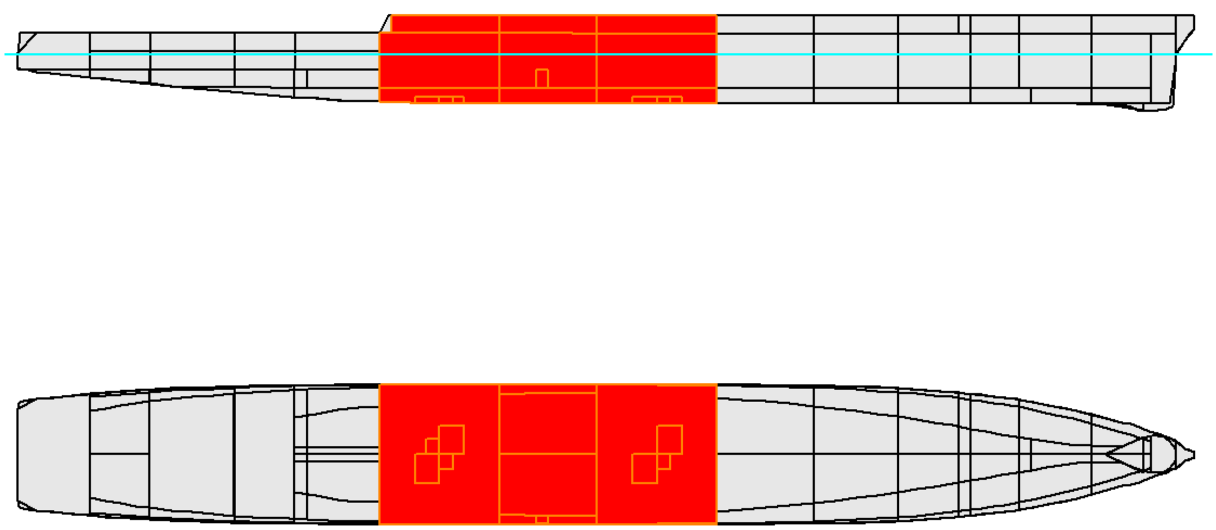


Figure 185 - Extreme Case of Heel

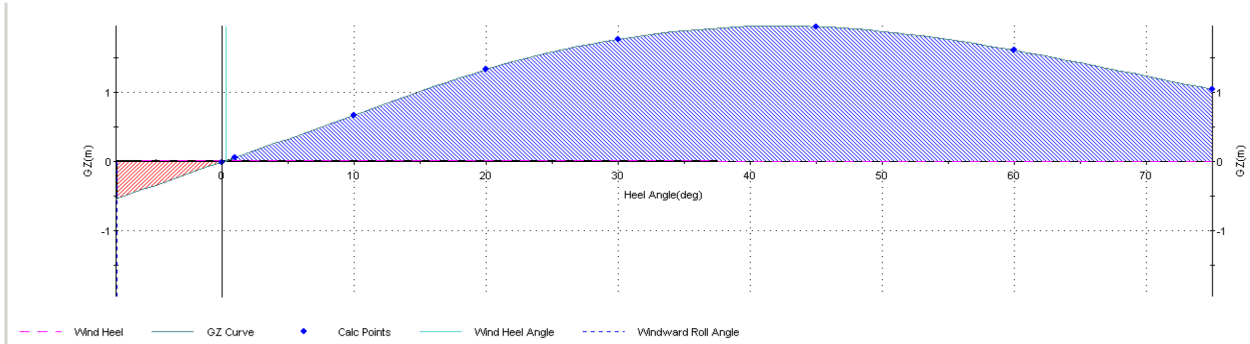


Figure 186 - Righting Arm Curve for Extreme Case of Heel

Table 78 - Righting Arm and Heeling Arm Data

Parameter	Units	Value	Required
Wind Speed	knots	39.37	39.37
Windward Roll Angle	deg	8.2	8.2
Angle of List of Loll	deg	0.1	15.0
Wind Heel	deg	0.3	---
GZ_{Max} Margin	m	1.958	0.083
Area A1	m-rad	1.00	0.01
Area Ratio A1/A2		25.30	1.4
Freeboard to Margin Line	m	3.407	0.000
Longitudinal GM	m	383.672	---
Calculation Parameters			
Wind Heeling Arm	m	0.013	---
Angle at Max GZ	deg	42.2	---
Capsizing Area A2	m-rad	0.04	---
Righting Area A1	m-rad	1.00	---
Angle Limiting Area A1	deg	45.0	---
Projected Sail Area	m^2	1071.82	---
Vertical Arm ABL	m	10.981	---
Heeling Arm at 0 deg	m	0.013	---
Factor f where $p=f*V^2$ (lb/ft^2)		0.0040	---
Wind Pressure	bar	0.00	---

4.11 Seakeeping, Maneuvering and Control

In order to evaluate the seakeeping characteristics of the vessel, two main programs are used. First, HECSMP is used to generate basic input files. These files are further modified and run in Visual SMP (Ship Motions Prediction) to create speed-polar plots for limiting responses at a range of sea-states. These responses are compared to the limit definitions and identified for each sea-state response. The MSC is evaluated at sea-states 4-7, with significant wave heights of 1.88, 3.25, 5, and 7.5 meters respectively. The limiting criteria for the MCS is presented in Table 79. Figure 187 through Figure 202 show the speed-polar plots for the MSC in a range of cases.

Table 79 – Selected Seakeeping Limit Criteria

Application	SeaState	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°							
4.) VLS Launch	6	NA		3°						
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°							
9.) Bow Sonar	6	NA	15°							
10.) Bow Sonar	6	NA		5°						
11.) Gun	5	NA	7.5°							
12.) Gun	5	NA		7.5°						
13.) Gun	5	CG			1 m/s					
14.)Torpedo Launch	5	NA	7.5°							
15.) UNREP	5	NA	4°							
16.) UNREP	5	NA		1.5°						
17.) Helo	5	NA	5°							
18.) Helo	5	NA		3°						
19.) Helo	5	Landing			2 m/s					
20.) Personnel	7	NA	8°							
21.) Personnel	7	NA		3°						
22.) Personnel	7	Bridge						0.4g		

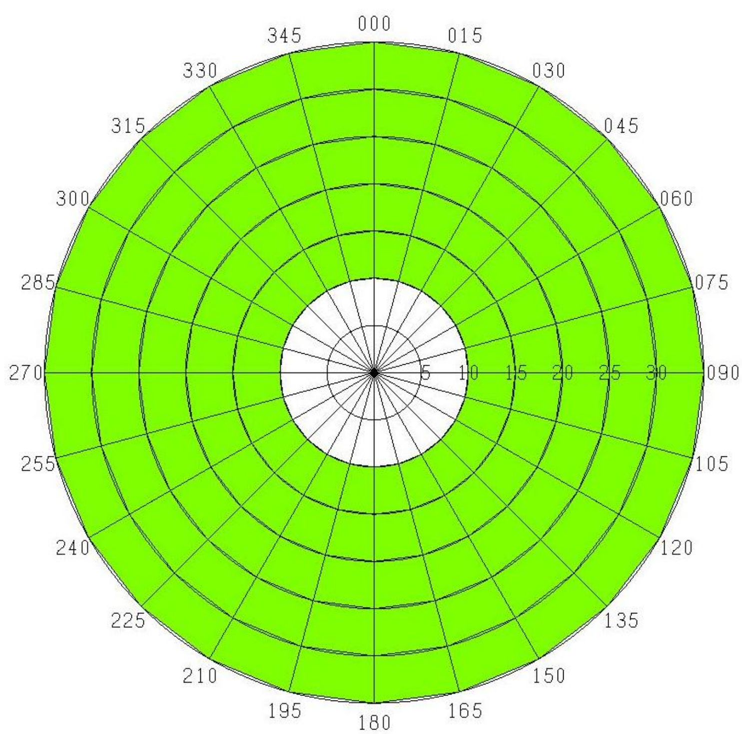


Figure 187 - Bow Wetness Limit (30/hr, SS7)

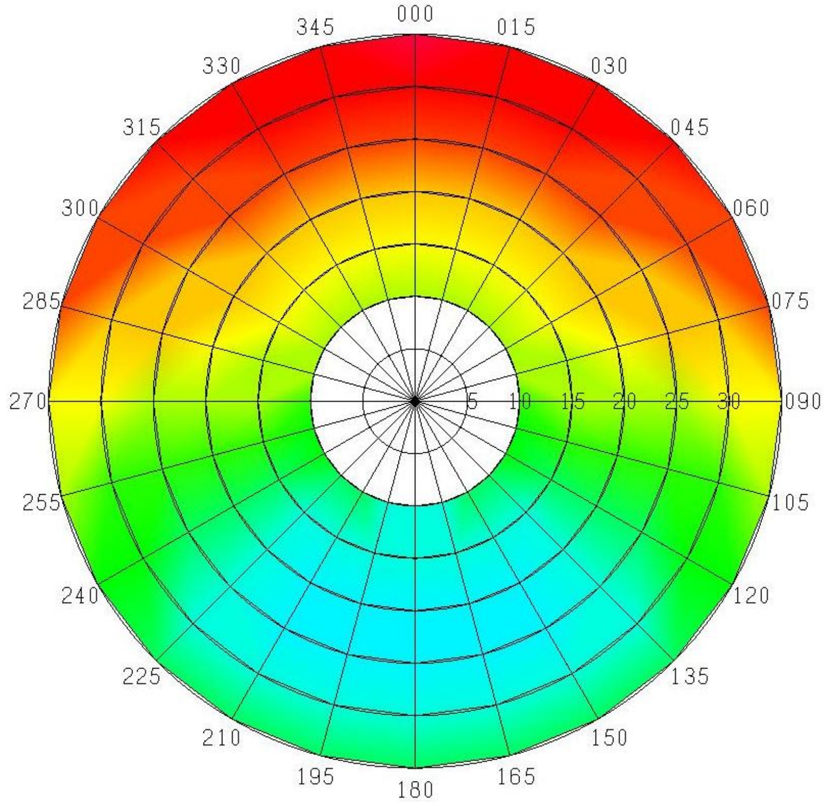


Figure 188 - Keel Slam Limit (20/hr, SS7)

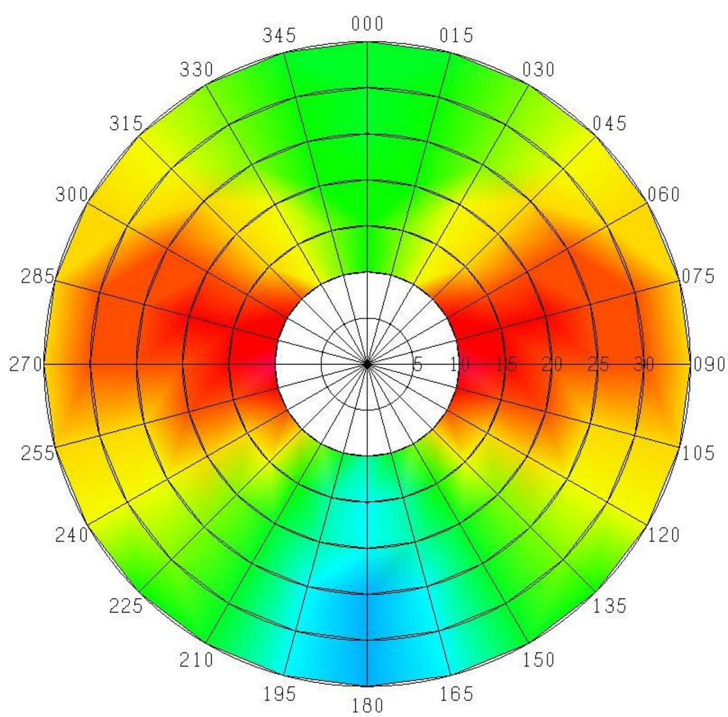


Figure 189 -VLS Launch Roll (17.5°, SS6)

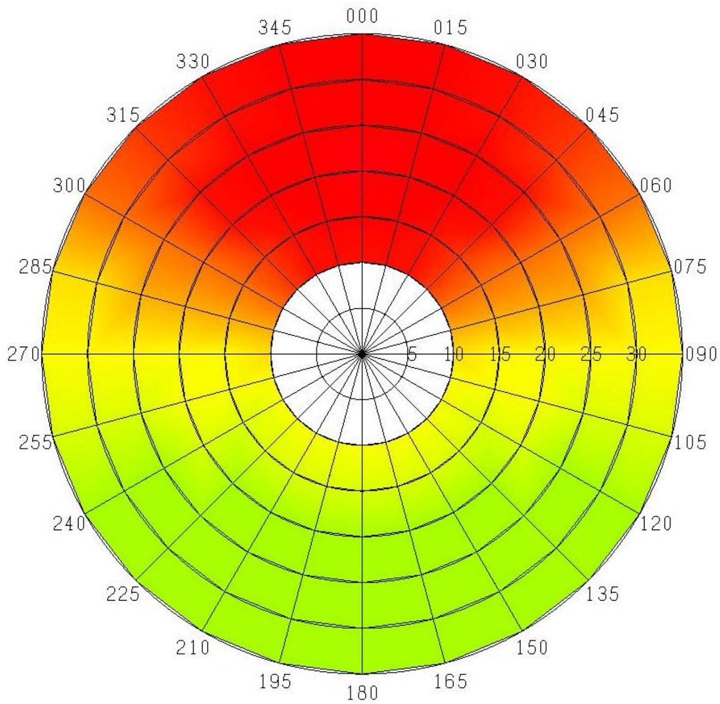


Figure 190 - VLS Launch Pitch (3^o, SS6)

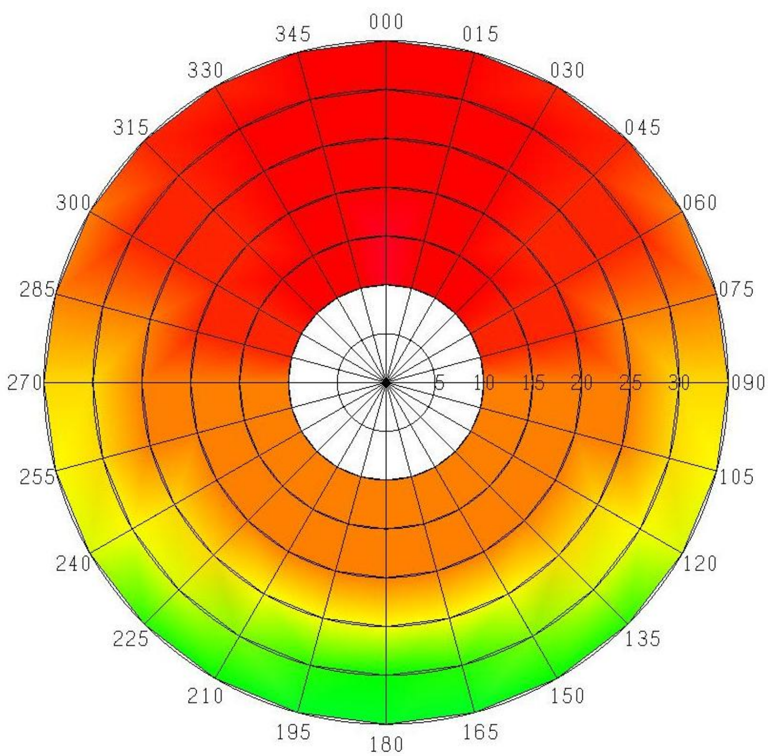


Figure 191 - VLS Launch Longitudinal Acceleration (0.3g, SS6)

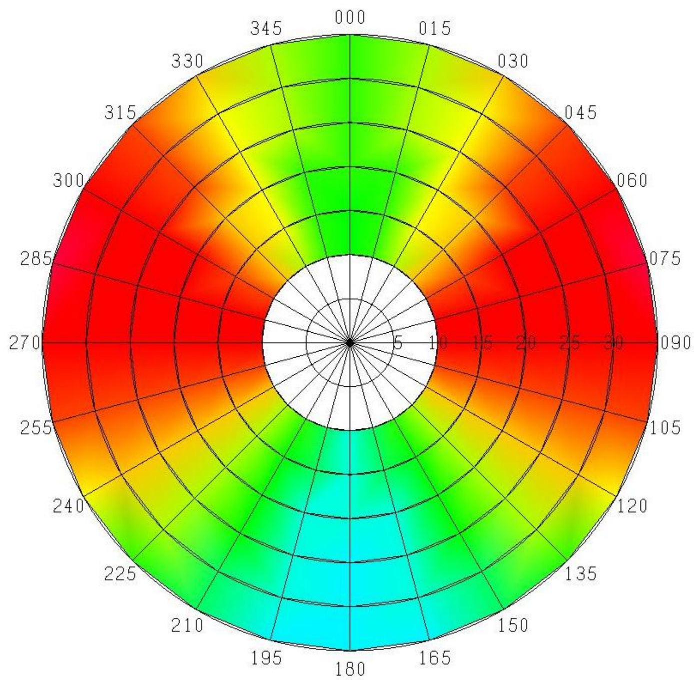


Figure 192 - VLS Launch Lateral Acceleration (0.7g, SS6)

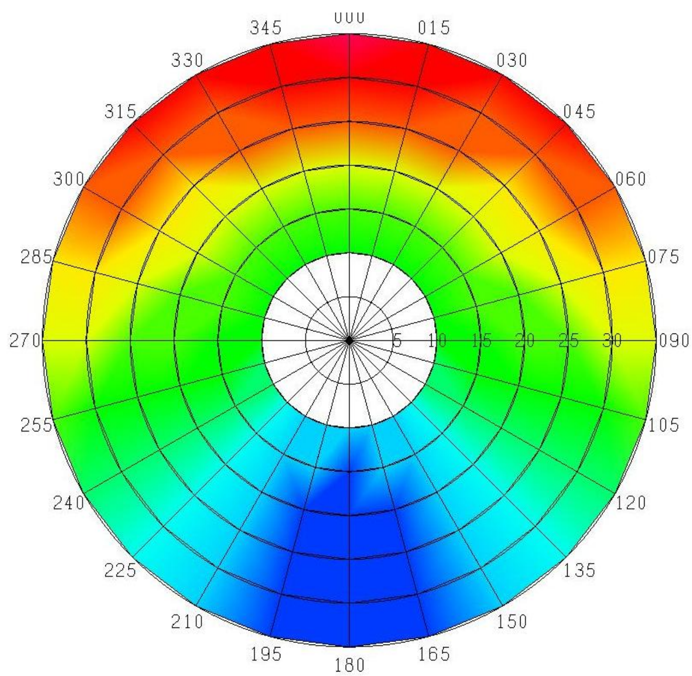


Figure 193 -VLS Launch Vertical Acceleration (0.6g, SS6)

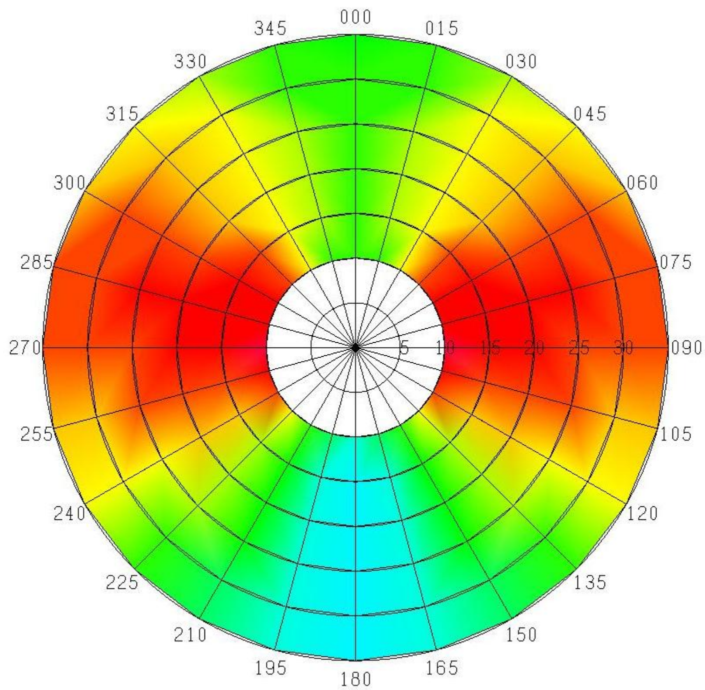


Figure 194 - Radar Roll (25°, SS7)

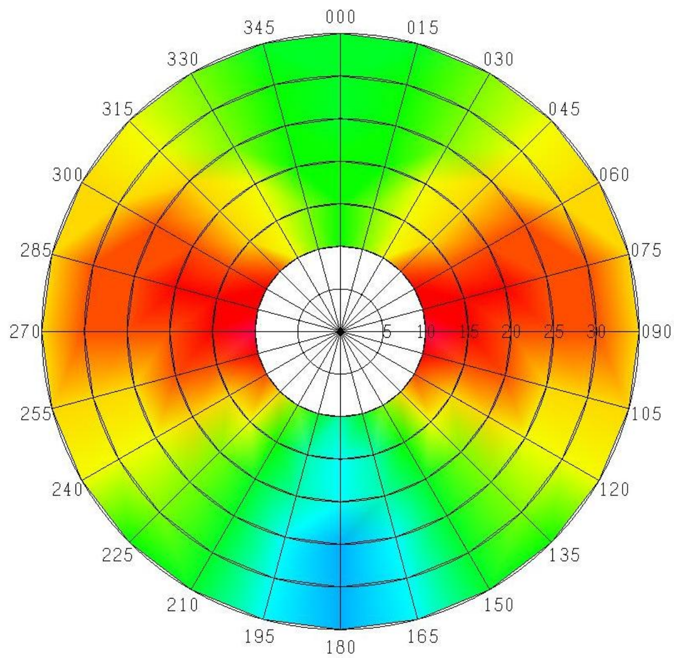


Figure 195 -Bow Sonar Roll (15°, SS6)

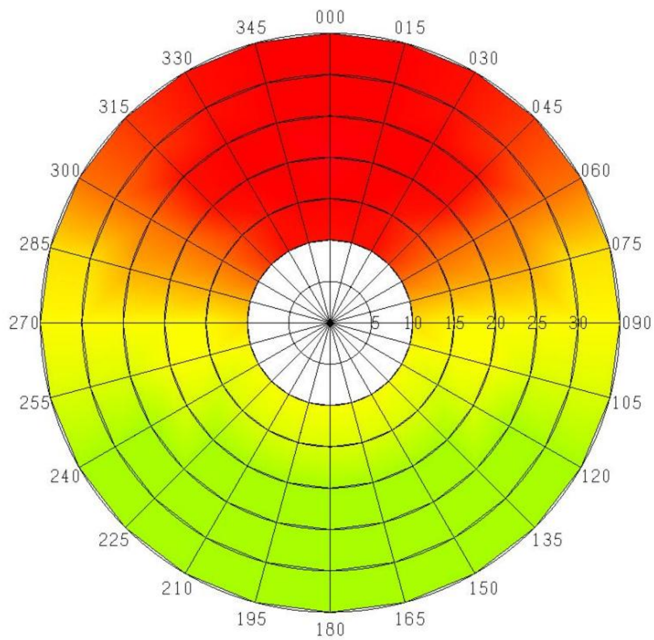


Figure 196 -Bow Sonar Pitch (5°, SS6)

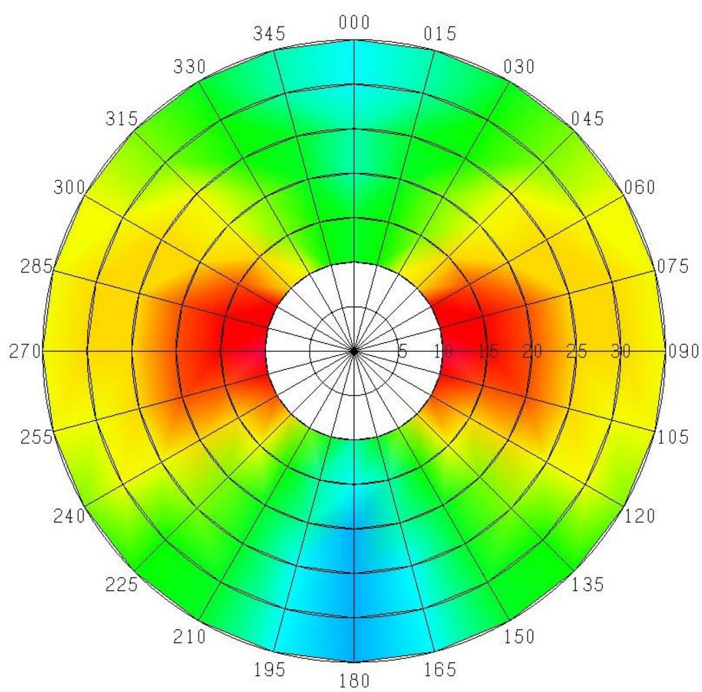


Figure 197 - Gun Roll (7.5°, SS5)

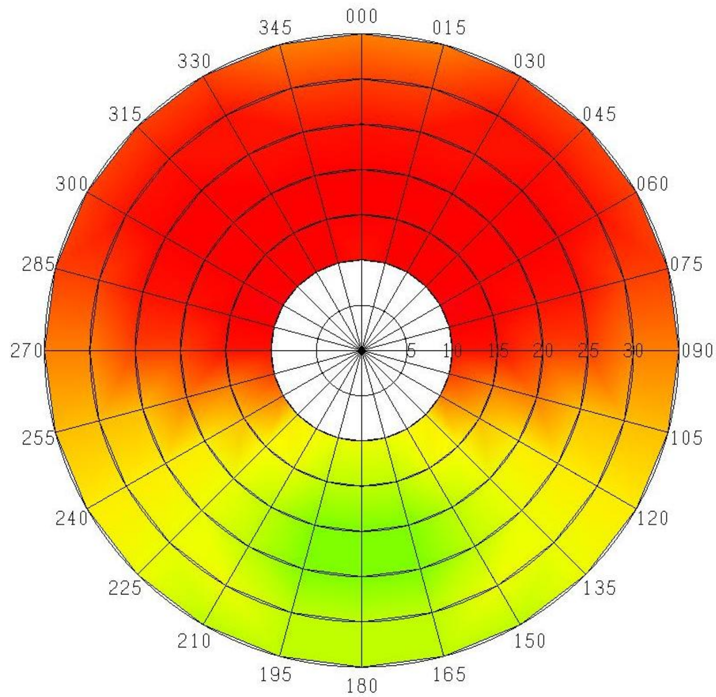


Figure 198 - Gun Pitch (7.5°, SS5)

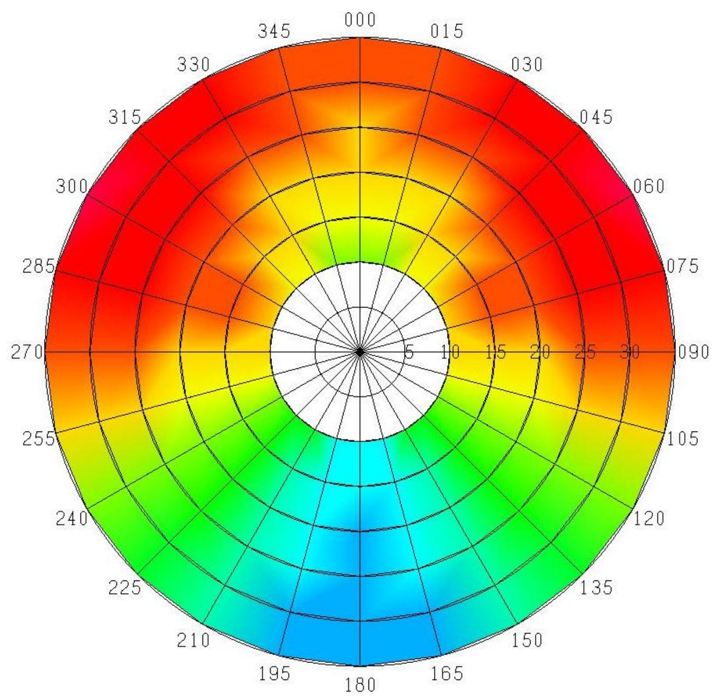


Figure 199 - Gun Vertical Velocity (1 m/s, SS5)

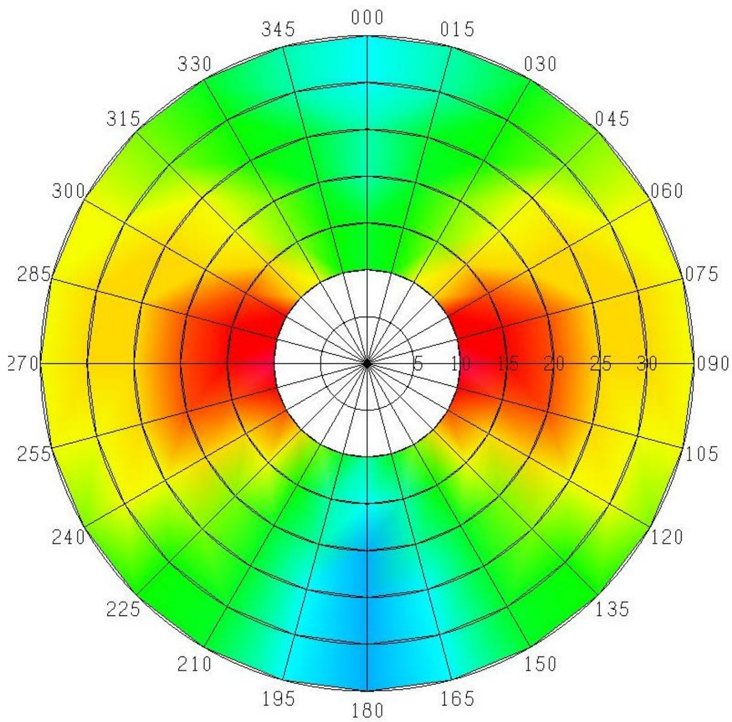


Figure 200 - Torpedo Launch Roll (7.5°, SS5)

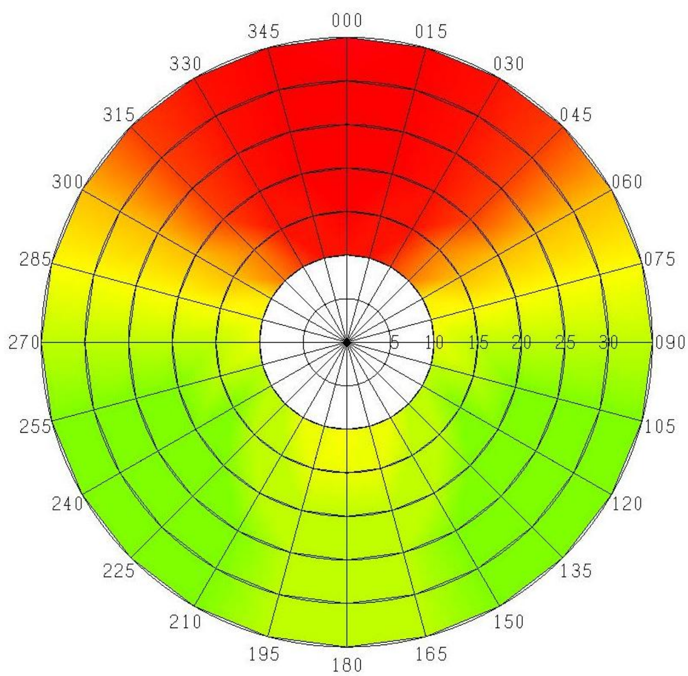


Figure 201 - Helo L&R Pitch (3°, SS5)

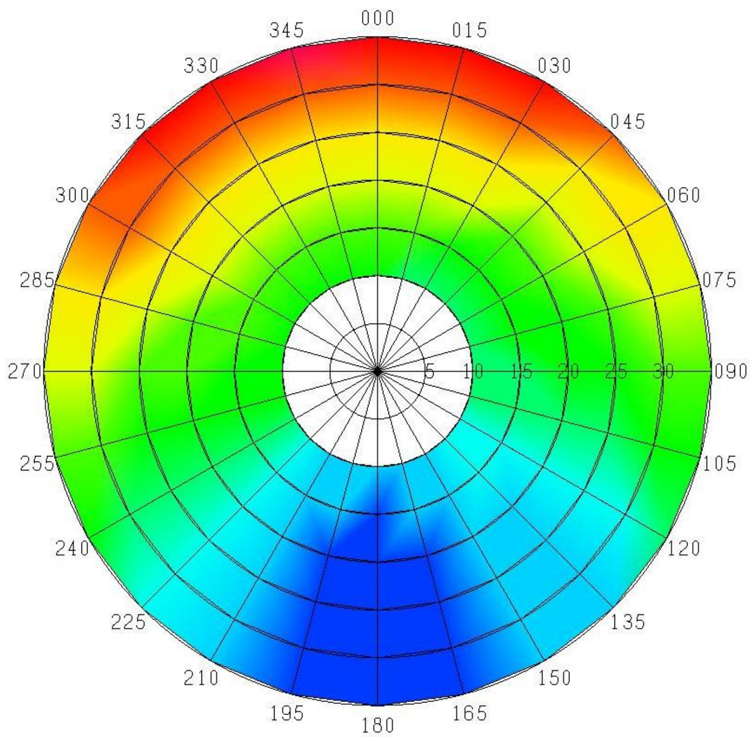


Figure 202 - Helo L&R Velocity (2 m/s, SS5)

The summary for the MSC capabilities at various sea states, through an analysis of the speed-polar plots, is presented in Table 80. Several systems are still fully operational at sustained speed in sea state 7. Generally the limiting factor for the MSC is personnel in sea state 7, and a limited degree of combat and UNREP capabilities in beam seas.

Table 80 – Seakeeping Limit Assessment

Criteria	SeaState Threshold	Assessment
1.) Bow Wetness (submergence/hr)	7	Fully Operational
2.) Keel Slam (Slam/hr)	7	Limited to beam and following seas
3.) VLS Launch (Roll)	6	Fully Operational
4.) VLS Launch (Pitch)	6	Exceeds limit in head seas
5.) VLS Launch (Long 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	Exceeds limit in beam seas less than 20 knots
12.) Gun (Pitch)	5	Fully Operational
13.) Gun (Vertical Velocity)	5	Limited to beam and following seas
14.) Torpedo Launch (Roll)	5	Exceeds limit in beam seas less than 20 knots
15.) UNREP (Roll)	5	Exceeds limit in beam seas less than 20 knots
16.) UNREP (Pitch)	5	Limited to beam and following seas
17.) Helo (Roll)	5	Exceeds limit in beam seas less than 20 knots
18.) Helo (Pitch)	5	Fully Operational
19.) Helo (Vertical Velocity)	5	Exceeds limit in head seas over 25 knots
20.) Personnel (Roll)	7	Exceeds limit in beam seas
21.) Personnel (Pitch)	7	Exceeds limit in head seas
22.) Personnel (Vertical Acceleration)	7	Exceeds limit in head seas over 25 knots
23.) Overall		Limited operational envelope for specified SSs

4.12 Cost and Risk Analysis

The cost model for the MSC includes estimates for both lead and follow ships. Factors taken into consideration include rough SWBS weight estimates, endurance range, and brake horsepower. Figure 203 shows the SWBS weight breakdown for the MSC. Figure 204 shows the total SWBS cost. Although the SWBS 300 group is not the heaviest, it accounts for the largest percentage of the cost out of all the groups. This is to be expected since it includes the electric plant.

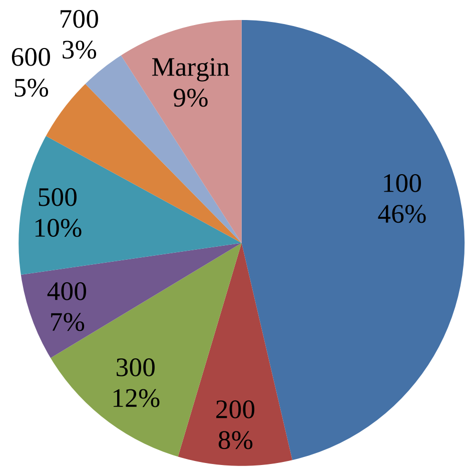


Figure 203 SWBS Weight Breakdown

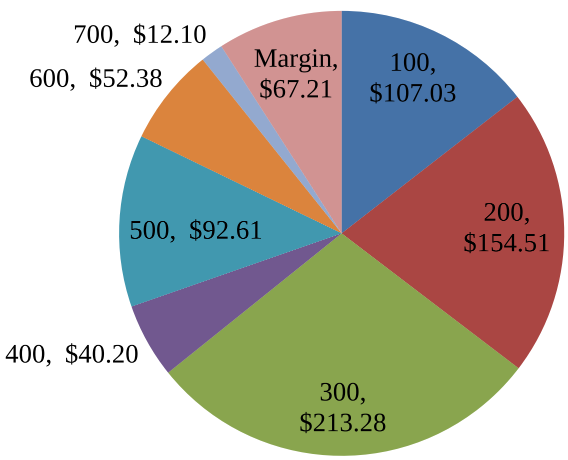


Figure 204 Total SWBS Costs in Millions of US Dollars

The estimate is broken down into government and shipbuilder portions. Table 81 lists the shipbuilder and government estimates. The estimate also includes items such as R&D and operations and support. The discounted and undiscounted life cycle costs are listed in Table 82. A limit of $3.6 Billion is given in the improved baseline for the lead ship. The estimate for the MSC lead ship is $3.55 Billion. A limit of $2.4 Billion is given in the improved baseline for the follow-ship. The cost estimate gives $2.383 Billion for the MSC follow-ship. The costs fall under the limit and are there-for acceptable. The complete cost model can be seen in Appendix G.

Table 81 Cost Estimate (In Million $)

	Follow Ship Cost	Leadship
SWBS	$ 630.42	$ 739.32
800	$ 290.05	$ 483.42
900	$ 42.07	$ 68.92
Total Construction	$ 1,110.00	$ 1,292.00
Profit	$ 111.02	$ 129.17
Shipbuilder Price	$ 1,221.00	$ 1,421.00
Change Orders	$ 97.70	$ 170.50
Total Shipbuilder Portion	**$ 1,319.00**	**$ 1,591.00**
Other Support	$ 30.53	$ 35.52
Program Manager's Growth	$ 61.06	$ 142.08
Payload GFE	$ 804.24	$ 1,624.59
HM&E GFE	$ 24.43	$ 28.42
Outfitting	$ 48.85	$ 56.83
Total Gov't Portion	**$ 969.10**	**$ 1,887.00**
Total Shipbuilder Portion	$ 1,319.00	$ 1,591.00
Total Gov't Portion	$ 969.10	$ 1,887.00
Total Ship End Cost	$ 2,288.00	$ 3,479.00
Post Delivery Cost	$ 61.06	$ 71.04
Total Ship Acquisition Cost	**$ 2,349.00**	**$ 3,550.00**
Average FS Ship Acquisition Cost	$ 2,393.00	

Table 82 Additional Cost Estimates

Life Cycle Costs	Undiscounted	Discounted
R&D Costs	$ 3,121.00	$ 3,021.00
Investment	$ 53,852.00	$ 18,053.00
Operations and Support	$ 50,126.00	$ 4,562.00
Residual Value	$ 2,719.00	$ 38.50
Total	$ 104,379.00	$ 25,598.00

5 Conclusions and Future Work

5.1 Assessment

Table 83 compares the CDD KPPs to the performance of the baseline designs. Most weapons and defense goals are met in the final baseline, if not exceeded. The endurance range did not approach the threshold. The sustained and endurance speeds meet the threshold values. The crew size is substantially lower to the threshold, thanks to the many design factors discussed throughout. The final baseline draft is the threshold value.

Table 83 - Compliance with Operational Requirements

Technical Performance Measure	CCD KPP (Threshold)	Original Goal	Improved Baseline	Final Baseline
AAW	SPY-3 (3 panel), Aegis MK 99 FCS	SPY-3 (3 panel), Aegis BMD 2014	SPY-3 (3 panel), Aegis BMD 2014	SPY-3 (3 panel), Aegis BMD 2014
ASUW/NSFS	MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker	AGS(155mm), MK45 5"-62 gun, MK46 (30mm) CIGS, FLIR, 2 RHIBs, Small Arms Locker	AGS(155mm), MK45 5"-62 gun, MK46 (30mm) CIGS, FLIR, 2 RHIBs, Small Arms Locker	AGS(155mm), MK45 5"-62 gun, MK46 (30mm) CIGS, FLIR, 2 RHIBs, Small Arms Locker
ASW	SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar	SQS-56, 2xMK32 SVVT, NIXIE, ISUW, mine avoidance sonar	SQS-56, 2xMK32 SVVT, NIXIE, ISUW, mine avoidance sonar	SQS-56, 2xMK32 SVVT, NIXIE, ISUW, mine avoidance sonar
CCCC	Enhanced CCCC	Enhanced CCCC	Enhanced CCCC	Enhanced CCCC
LAMPS	LAMPS Haven (flight deck, refueling, rearming), SQQ-28	LAMPS Haven, SQQ-28, UVA, 2 x SH60	LAMPS Haven, SQQ-28, UVA, 2 x SH60	LAMPS Haven, SQQ-28, UVA, 2 x SH60
GMLS	64 cells, MK 41 VLS	32 cells, MK57 VLS & PVLS	32 cells, MK57 VLS & PVLS	32 cells, MK57 VLS & PVLS
LCS Modules	Spartan, VTUAV	VTUAV	VTUAV	VTUAV
Hull	Flared Tumblehome	Flared	Flared	Flared
Power and Propulsion	2 shaft IPS sxMT30, 2xLM500G, AC, synchronous	2 shaft IPS, 2xMT30, 3xLM500	2 shaft IPS, 2xMT30, 3xLM500	2 shaft IPS, 2xMT30, 3xLM500
Endurance Range (nm)	8913 nm	6844 nm	6844 nm	6844 nm
Sustained Speed (knots)	35 knots	32 knots	32 knots	32 knots
Endurance Speed (knots)	20 knots	20 knots	20 knots	20 knots
Stores Duration (days)	45-60	90	90	90
Collective Protection System	full	full	full	Full
Crew Size	296	135	135	135
Maximum Draft (m)	7.922	7.922	7.922	7.922
Vulnerability (Hull Material)	Steel	Steel	Steel	Steel
Ballast/fuel system	Clean, separate ballast tanks	Clean, separate ballast tanks	Clean, separate ballast tanks	Clean, separate ballast tanks
Degaussing System	Yes	Yes	Yes	Yes

5.2 Future Work

The next cycle around the design spiral would include many changes to specific design aspects due to later lessons learned. One overlooked design flaw is that the torpedo launchers, aft helo pad and stern ramps are all in close proximity to each other. It may prove difficult to man all these areas at one time. The crew may also be too small from a survivability perspective. If there is any loss or crew disability, then all necessary ship functions may not be performed in a critical time.

For stability reasons, the deckhouse could be designed shorter. This would also lower the bridge. If the motions are still too large at the bridge for comfort, then bridge may be lowered in the deckhouse. The crew berthing above the propeller shafts may be a poor design decision due to the noise levels in that area. These spaces may be rearranged to provide more crew comfort. The inner bottom may be too large at 2.5 meters tall. Deck space may be opened by shortening the inner bottom and replacing the lost tankage space with wing tanks in the machinery rooms. Finally, future work in structures would attempt to decrease the maximum plate thickness to a value below 40 mm. Continued work would ensure a more continuous change in plate thicknesses across the weather deck. Continued work in this area would include modeling deck loading and its impact on the structural integrity of the ship. Future work could also look into modeling the stress concentration due to the VLS and the MK-45 gun.

5.3 Conclusions

The MSC design presented in this report is a functional, cost effective and adequate solution to the capability gaps in the ADM. The design fits all of the mission requirements, and often surpasses them. The LAMPS capability, PVLS/VLS, AGS and RHIB support allow for the performance of a variety of missions. The design does not exceed the budget, although it does have more advanced designs than expected. The MSC is designed for the future, thanks to the modularity concepts implemented throughout. It is also designed with efficiency in mind, thanks to the enabling technologies and superior automation capabilities. The MSC is a model of a sustainable class of US Navy ships that will bridge the fleet between outdated hulls of the past and the as-yet-undiscovered advancements of the future.

6 References

1. Brown, A.J., “Ship Design Notes”, Virginia Tech AOE Department, 2009.

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

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

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Appendix C– Capabilities Development Document (CDD)

UNCLASSIFIED

CAPABILITY DEVELOPMENT DOCUMENT

FOR

Medium Surface Combatant (MSC)
VT Team 2

1 Capability Discussion

The Initial Capabilities Document (ICD) for this CDD was issued by the Virginia Tech Acquisition Authority on 21 August 2009. The overarching capability gaps addressed by this ICD are: 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 Block IA and IB do not fly fast enough to offer a substantial capability for intercepting ICBMs. A faster-flying version of the SM-3, the Block II/IIA, is being developed. Despite the improved capabilities of Block II/IIA, MSC will require a more robust ICBM defense missile capability. Possibilities include a system using a modified version of the Army's Patriot Advanced Capability-3 (PAC-3) interceptor or a system using a modified version of the SM-6 Extended Range Active Missile (SM-6 ERAM) air defense missile being developed by the Navy. The MSC will also include the advanced AEGIS system onboard.

A significant capability gap addressed by the ICD is to provide a robust sea-based terminal and/or boost phase ICBM defense platform. Specific capability gaps and requirements in this ICBMD platform are shown below:

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	LRS&T Radar	SPY-3 X-band radar; S-Band VSR	Big!
2	BMD Missile Cells	SM-3/MK-57 VLS only	KEI and SM-3/MK-57 VLS
3	BMD Missile Capacity	96 SM-3	128 SM-3
4	BMD Platform Mobility	30 knt, full SS4, 4000 nm, 60 days	34 knt, full SS5, 6000 nm, 75 days
5	Affordable Sustainability and Upgrade	Component Modularity	System Modularity
6	Platform Passive Susceptibility	DDG-51 signatures	DDG1000 signatures
7	Platform Vulnerability and Recoverability	AFSS	AFSS
8	Platform Self and Area Defense, Other Multi-Mission	CIGS, LAMPS haven, TSCE	1xAGS, IUSW, SOF and ASUW stern launch, Embarked LAMPS/AAV w/hangar, TSCE

2 Analysis Summary

An Acquisition Decision Memorandum issued on 24 August 2009 by the Virginia Tech Acquisition Authority directed Concept Exploration and Analysis of Alternatives (AoA) for a Modular Ballistic Missile Defense Cruiser with emphasis on providing ICBM and TBM defense. Required core capabilities are AAW/BMD and blue/green water ASW. The platforms must be highly producible, maintainable and upgradable through significant modularization, minimizing the time from concept to delivery and maximizing system commonality with MSC. The platforms must operate within current logistics support capabilities. Inter-service and Allied C^4/I (inter-operability) must be considered. The new ship must have minimum manning.

Concept Exploration was conducted from 2 September 2009 through 11 December 2009. A Concept Design and Requirements Review was conducted on 20 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 2, 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.

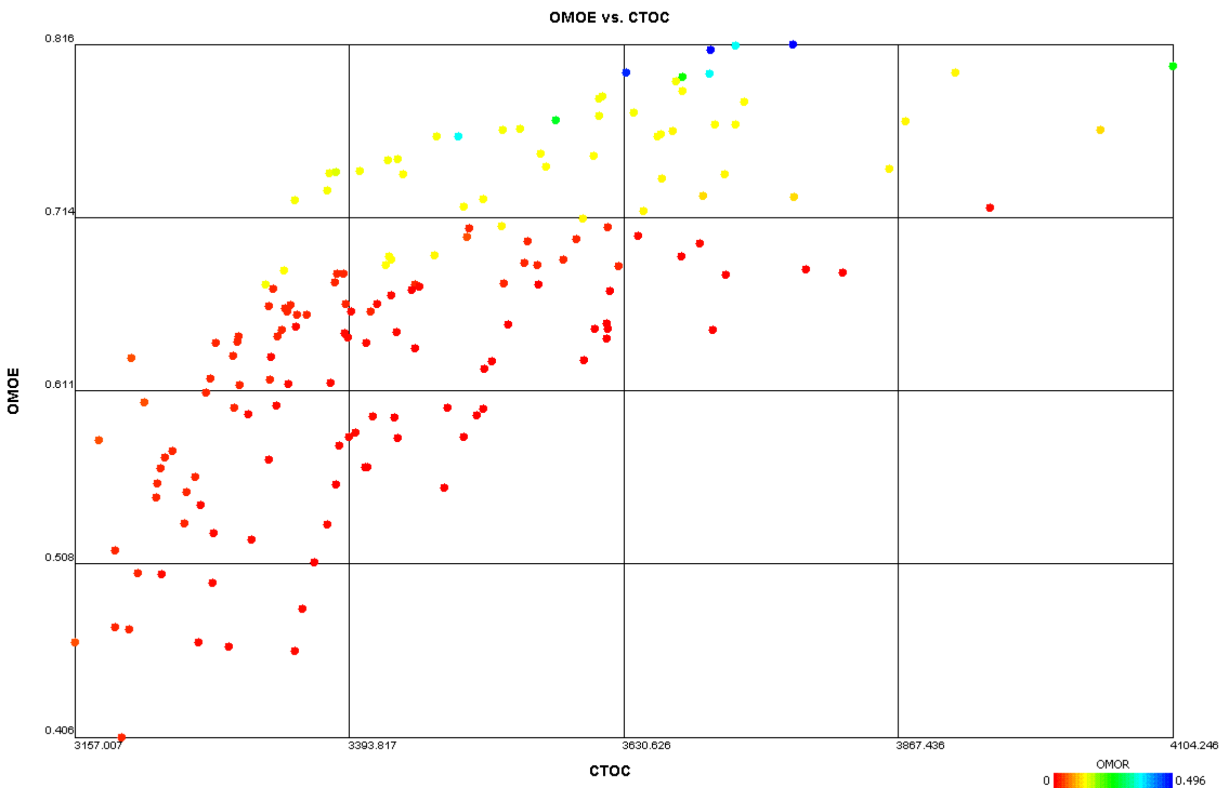


Figure 1 – CGXmod Non-Dominated Frontier

3 Concept of Operations Summary

The range of military operations for the functions in this ICD includes: force application from the sea; force application, protection and awareness at sea; and protection of homeland and critical bases from the sea. Timeframe considered: 2018-2050. This extended timeframe demands flexibility in upgrade and capability over time. The 2001 Quadrennial Defense Review identifies seven critical US military operational goals. These are: 1) protecting critical bases of operations; 2) assuring information systems; 3) protecting and sustaining US forces while defeating denial threats; 4) denying enemy sanctuary by persistent surveillance, 5) tracking and rapid engagement; 6) enhancing space systems; and 7) leveraging information technology.

These goals and capabilities must be achieved with sufficient numbers of ships for worldwide and persistent coverage of all potential areas of conflict, vulnerability or interest.

Potential strengths of MSC are: the ability to conduct BMD operations from advantageous locations at sea that are inaccessible to ground-based systems, the ability to operate in forward locations in international waters without permission from foreign governments, and the ability to readily move to new locations. MSC can operate over the horizon from observers ashore, making it less visible and less provocative. MSC can readily move to respond to changing demands for BMD capabilities or to evade detection and targeting by enemy forces, and could do so without placing demands on other assets.

Potential limitations of a MSC are: possible conflicts with performing other ship missions, and vulnerability to attack when operating in forward locations. Typical cruiser multi-mission capabilities and self-defense capabilities may have to be traded to control cost. MSC may require other surface combatant and submarine support to operate safely in high-risk environments. Conducting BMD operations may require MSC 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.

Naval forces must also be able to support non-combatant and maritime interdiction operations in conjunction with national directives. They must be flexible enough to support peacetime missions yet be able to provide instant wartime response should a crisis escalate.

Expected operations for MSC include:

- Independent Ballistic Missile Defense (BMD)
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
- Escort (CSG, ESG, MCG, Convoy)
  - Provide Area AAW, ASW and ASUW defense
- SAG (Surface Action Group)
  - With CGs, DDGs and/or LCSs
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
  - Support BMD (w/ queuing)
  - Provide MCM and additional ISR/ASW/ASUW w/ mission modules
  -

4 Threat Summary

Ballistic missiles armed with WMD payloads pose a strategic threat to the United States. Threat can come from both state and non-state groups. Non-state groups are interested in obtaining missiles and nuclear or other payloads; however they do not match the quality or quantity of the United States. Warning time of deployment, safety, accuracy and reliability of missiles also pose a threat to the United States. 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. Also, the emerging ballistic missile powers to hide their activities from the U.S. and to create deception about the pace, scope and direction also creates a threat.

Since many potentially unstable nations are located on or near geographically constrained (littoral) bodies of water, the tactical picture will be on 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. Many encounters may occur in shallow water which increases the difficulty of detecting and successfully prosecuting targets. Platforms chosen to support and replace current assets must have the capability to dominate all aspects of the littoral environment.

The platform or system must be capable of operating in the following environments:

- Open ocean (sea states 0 through 9) and littoral, fully operational through SS5
- 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 Battle Group
- All-Weather Independent operations

5 System Capabilities and Characteristics Required for the Current Development Increment

Key Performance Parameter (KPP)	Development Threshold or Requirement
AAW	SPY-3 (3 panel), Aegis MK 99 FCS
ASUW/NSFS	MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
ASW	SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar
CCCC	Enhanced CCCC
LAMPS	LAMPS Haven (flight deck, refueling, rearming), SQQ-28
SDS	SLQ-32(V) 3, SRBOC, NULKA, ESSM
GMLS	64 cells, MK 41 VLS
LCS Modules	Spartan, VTUAV
Hull	Flared Tumblehome
Power and Propulsion	2 shaft IPS sxMT30, 2xLM500G, AC, synchronous
Endurance Range (nm)	8913 nm
Sustained Speed (knots)	35 knots
Endurance Speed (knots)	20 knots
Stores Duration (days)	45-60
Collective Protection System	full
Crew Size	296
RCS (m^3)	3459
Maximum Draft (m)	7.922
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 $2.4B ($FY2012) with a lead ship acquisition cost less than $3.6B. It is expected that 18 ships of this type will be built with IOC in 2018.

Appendix D – Machinery Equipment List (MEL)

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION	SWBS #	REMARKS	DIMENSIONS LxWxH (m)
System: Main Engines and Transmission								
1	3	PGM	Rolls Royce MT30 w/generator	36MW	MMR	234	Includes Acoustic Enclosure	9.18x3.84x3.78
2	2	Shaft, Motors		50MW	MMR	241	Includes Thrust Bearing, Clutch, Turning Gear, Shaft Brake	2.89x4.41x3.38
3	2	Shaft, Line	530 mm (OD), 380 mm (ID)	-	various	243	ABS Grade 2 Steel, calculate size and weight	0.6m D, L as reqd
4	3	Bearing, Line Shaft	Journal	575 mm Line Shaft	various	244	Calculate number required and locate	1 x .125 x .125
5	2	Main Engine Exhaust Duct	Rolls Royce MT30	141.2 kg/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out stack	8.7 m2
6	2	Main Engine Inlet Duct	Rolls Royce MT30	65 kg/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	12.4 m2
7	2	Console, Main Control	Main Propulsion	NA	MMR Engineering Operation Station (EOS)	252	MMR 2nd or upper level in EOS looking down on RG	3x1x2
System: Power Generation and Distribution								
8	2	SPGM	GE LM500G	3940 kW, 480 V, 3 phase, 60 Hz, 0.8 PF	MMR	311	Includes enclosure, 2nd or upper level, orient F&A	4.76 x 2.16 x2.99
9	2	Exhaust Duct	GE LM500G	16.5 kg/sec	MMR, AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out stack	1.1 m2
10	2	Inlet Duct	GE LM500G	15 kg/sec	MMR, AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	2.2 m2
11	2	PCM	Power Conversion Module	4160V	AMR		First Leve AMR	5.72x1.22x1.83
12	2	PCM	Power Conversion Module	4160V	AMR		First Leve AMR	5.72x1.22x1.83
13	2	PCM	Power Conversion Module	4160V	AMR		First Leve AMR	5.72x1.22x1.83
14	3	Switchboard, Propulsion	Generator Control Power Distribution	-	MMR EOS	324	MMR upper level in EOS	3.096 x 1.220 x 2.286
15	1	Switchboard, Emergency Ships	Generator Control Power Distribution	-	AMR EOS	324	AMR upper level	2.5x1x2
16	6	MMR and AMR ladders	Inclined ladders		MMR,AMR		May have single or double inclined ladders between levels	1.0x2.0
17	6	MMR and AMR escape trunks	Vertical ladders with fire tight doors at each level		MMR, AMR		One per space in far corners, bottom to main deck	1.5x1.5
18	3	MN Machinery Space Fan	Supply	94762 m^3/hr	FAN ROOM	512	above, outside MMR	1.118 (H) x 1.384 (dia)
19	3	MN Machinery Space Fan	Exhaust	91644 m^3/hr	MMR	512	Upper level in corners	1.118 (H) x 1.384 (dia)
20	2	Aux Machinery Space Fan	Supply	61164 m^3/hr	FAN ROOM	512	above, outside AMR	1.092 (H) x 1.118 (dia)
21	2	Aux Machinery Space Fan	Exhaust	61164 m^3/hr	AMR	512	Upper level in corners	1.092 (H) x 1.118 (dia)

System: Salt Water Cooling								
22	3	Pump, Main Seawater Circ	Centrifugal, Vertical, Motor Driven	230 m^3/hr @ 2 bar	MMR	256	P&S MMR lower level near hull and ME	.622 x .622 x 1.511
System: Lube Oil Service and Transfer								
23	2	Assembly, MGT Lube Oil Storage and Conditioning	Includes Oil Storage and Cooler	NA	MMR	262	next to each engine	1.525 x 2.60 x 1.040
24	2	Purifier, Lube Oil	Centrifugal, Self Cleaning, Partial Discharge Type	1.1 m^3/hr	MMR	264	next to LO transfer pump, 2nd or upper level MMR	.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	next to LO purifier	.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	next to FO purifiers	1.6 (L) x.762 (dia)
27	2	Purifier, Fuel Oil	Self Cleaning, Centrifugal, Partial Discharge Type	7.0 m^3/hr	MMR	541	2nd or upper level MMR	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	next to FO purifiers	1.423 x .559 x .686
29	2	Fuel Oil Service Tanks			MMR		lower level MMR P&S	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	either level, side by side	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	next to AC plants	1.321 x .381 x .508
32	2	Refrig Plants, Ships Service	R-134a	4.3 ton	AMR	516	either level, side by side	2.464 x .813 x 1.5
System: Salt Water: Firemain, Bilge, Ballast								
33	6	Pump, Fire	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	VARIOUS	521	lower levels	2.490 x .711 x .864
34	1	Pump, Fire/Ballast	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	AMR	521	lower levels	2.490 x .711 x .864
35	2	Pump, Bilge	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	MMR	529	lower levels	1.651 x .635 x 1.702
36	1	Pump, Bilge/Ballast	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	AMR	529	lower levels	1.651 x .635 x .737
System: Potable Water								
37	2	Distiller (Brominator), Fresh Water	Distilling Unit	76 m^3/day (3.2 m^3/hr)	AMR	531	lower or 2nd level	2.794 x 3.048 x 2.794
38	2	Brominator	Proportioning	1.5 m^3/hr	AMR	531	next to distillers	.965 x .203 x .406
39	2	Pump, Potable Water	Centrifugal, Horizontal, Motor Driven	22.7 m^3/hr @ 4.8 bar	AMR	533	next to distillers	.787 x .559 x .356
40	2	Brominator, fuel pump	Recirculation	5.7 m^3/hr	AMR	533	next to distillers	.533 x.356 x 1.042
System: JP-5 Service and Transfer								
41	2	Filter/Separ., JP-5 Transfer	Static, Two Stage	17 m^3/hr	JP-5 PUMP ROOM	542	in JP-5 pump room	.457 (L) x 1.321 (dia)
42	2	Filter/Separ., JP-5 Service	Static, Two Stage	22.7 m^3/hr	JP-5 PUMP ROOM	542	in JP-5 pump room	.407 (L) x 1.219 (dia)
System: Compressed Air								
43	2	Receiver, Starting Air	Steel, Cylindrical	2.3 m^3	AMR	551	near ME, compressors and bulkhead	1.067 (dia) x 2.185 (H)
44	2	Compressor, MP Air	Reciprocating Motor Driven, Water Cooled	80 m^3/hr FADY @ 30 bar	MMR	551	2nd or upper level	1.334 x .841 x .836
45	1	Receiver, Ship Service Air	Steel, Cylindrical	1.7 m^3	MMR	551	near ME, compressors and bulkhead	1.830 (H) x .965 (dia)
46	1	Receiver, Control Air	Steel, Cylindrical	1 m^3	MMR	551	near ME, compressors and bulkhead	3.421 (H) x .610 (dia)
47	2	Compressor, Air, LP Ship Service	Reciprocating, Rotary Screw	8.6 bar @ 194 SCFM	MMR	551	2nd or upper level	1.346 x 1.067 x 1.829
48	2	Dryer, Air	Refrigerant Type	250 SCFM	MMR	551	near LP air compressors	.610 x .864 x 1.473
System: Environmental								
49	2	Pump, Oily Waste Transfer	Motor Driven	12.3 m^3/hr @ 7.6 bar	MMR	593	lower level	1.219 x .635 x .813
50	2	Separator, Oil/Water	Coalescer Plate Type	2.7 m^3/hr	MMR	593	lower level near oily waste transfer pump	1.321 x .965 x 1.473

Appendix E - Weights and Centers

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
	FULL LOAD WEIGHT + MARGIN	16786.08	7.64	128219.19	94.00	1577853.51	0.00	0
	MINOP WEIGHT + MARGIN	15856.73	7.82	124029.34	94.25	1494471.17	0.00	0.00
	LIGHTSHIP WEIGHT + MARGIN	13461.58	8.42	113360.01	94.38	1270537.40	0.00	0.00
	LIGHTSHIP WEIGHT	12237.80	8.42	103054.55	94.38	1155034.00	0.00	0.00
	MARGIN	1223.78	8.42	10305.46	94.38	115503.40	0.00	0.00
100	HULL STRUCTURES	6654.30	7.52	50064.27	95.33	634369.42	0.00	0.00
110	SHELL + SUPPORTS	2422.80	4.76	11529.92	90.04	218148.91	0.00	0.00
111	PLATING	1128.80	6.50	7337.20	91.42	103194.90		0.00
113	INNER BOTTOM	169.50	2.00	339.00	99.19	16812.71		0.00
114	SHELL APPENDAGES	63.00	2.00	126.00	126.75	7985.25		0.00
115	STANCHIONS	40.10	7.29	292.33	96.03	3850.80		0.00
116	LONGIT FRAMING	609.90	0.57	347.64	80.51	49103.05		0.00
117	TRANSV FRAMING	411.70	7.50	3087.75	90.39	37213.56		0.00
120	HULL STRUCTURAL BULKHDS	470.70	8.51	4005.66	94.22	44349.35	0.00	0.00
122	TRANSV STRUCTURAL BULKHDS	361.50	8.51	3076.37	94.22	34060.53		0.00
123	TRUNKS + ENCLOSURES	109.20	8.51	929.29	94.22	10288.82		0.00
130	HULL DECKS	1810.90	10.34	18716.51	96.00	173846.40	0.00	0.00
131	MAIN DECK	569.30	12.09	6882.84	109.30	62224.49		0.00
132	2ND DECK	359.80	8.97	3227.41	106.20	38210.76		0.00
133	3RD DECK	289.80	5.97	1730.11	103.00	29849.40		0.00
134	4TH DECK	150.80	2.97	447.88	100.00	15080.00		0.00
136	01 HULL DECK	441.20	14.57	6428.28	70.52	31113.42		0.00
140	HULL PLATFORMS/FLATS	469.20	5.36	2513.80	91.73	43039.72	0.00	0.00
141	1ST PLATFORM	268.00	4.50	1206.00	99.71	26722.28		0.00
142	2ND PLATFORM	201.20	6.50	1307.80	81.11	16319.33		0.00
150	DECK HOUSE STRUCTURE	203.90	21.81	4447.06	94.91	19352.15	0.00	0.00
160	SPECIAL STRUCTURES	303.70	9.43	2864.86	116.27	35311.20	0.00	0.00
161	CASTINGS+FORGINGS+EQUIV WELDMT	159.10	4.62	735.04	134.75	21438.73		0.00
163	SEA CHESTS	6.60	2.53	16.70	96.03	633.80		0.00
164	BALLISTIC PLATING	42.10	8.14	342.69	96.03	4042.86		0.00
165	SONAR DOMES	7.40	-2.93	-21.68	96.03	710.62		0.00
167	HULL STRUCTURAL CLOSURES	117.00	10.98	1284.66	96.03	11235.51		0.00
168	DKHS STRUCTURAL CLOSURES	12.30	21.81	268.26	94.91	1167.39		0.00
169	SPECIAL PURPOSE CLOSURES+STRUCT	15.10	15.84	239.18	96.03	1450.05		0.00
170	MASTS+KINGPOSTS+SERV PLATFORM	2.10	32.30	67.83	110.43	231.90	0.00	0.00
171	MASTS, TOWERS, TETRAPODS	2.10	32.30	67.83	110.43	231.90		0.00
180	FOUNDATIONS	689.70	5.74	3955.88	106.26	73287.52	0.00	0.00
182	PROPULSION PLANT FOUNDATIONS	393.80	3.39	1334.98	108.27	42636.73		0.00
183	ELECTRIC PLANT	32.00	5.22	167.04	92.55	2961.60		0.00
184	COMMAND+SURVEILLANCE FDNS	30.90	12.74	393.67	88.93	2747.94		0.00
185	AUXILIARY SYSTEMS FOUNDATIONS	122.60	9.31	1141.41	117.91	14455.77		0.00
186	OUTFIT+FURNISHINGS FOUNDATIONS	18.20	7.57	137.77	90.77	1652.01		0.00
187	ARMAMENT FOUNDATIONS	92.10	8.48	781.01	95.83	8825.94		0.00
190	SPECIAL PURPOSE SYSTEMS	281.30	6.98	1962.76	95.28	26802.26	0.00	0.00
196	MILL TOLERANCE	181.40	7.17	1300.64	95.28	17283.79		0.00

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
197	WELDING AND RIVETS	90.20	7.17	646.73	95.28	8594.26		0.00
198	FREE FLOODING LIQUIDS	9.80	1.57	15.39	95.25	933.45		0.00
200	PROPULSION PLANT	1919.70	6.19	11885.94	117.11	224810.51	0.00	0.00
230	PROPULSION UNITS	1151.60	4.98	5734.97	106.85	123048.46	0.00	0.00
234	GAS TURBINES	172.30	6.56	1130.29	99.77	17190.37		0.00
235	ELECTRIC PROPULSION	979.30	4.71	4612.50	108.10	105862.33		0.00
240	TRANSMISSION+PROPULSOR SYSTEMS	450.00	2.35	1057.50	156.84	70578.00	0.00	0.00
243	SHAFTING	271.50	2.43	659.75	152.74	41468.91		0.00
244	SHAFT BEARINGS	85.00	2.94	249.90	139.87	11888.95		0.00
245	PROPULSORS	93.40	1.61	150.37	184.18	17202.41		0.00
250	SUPPORT SYSTEMS, UPTAKES	284.40	17.25	4905.90	96.85	27544.14	0.00	0.00
251	COMBUSTION AIR SYSTEM	86.90	16.49	1432.98	91.85	7981.77		0.00
252	PROPULSION CONTROL SYSTEM	36.00	9.47	340.92	99.77	3591.72		0.00
256	CIRC + COOL SEA WATER SYSTEM	5.80	5.25	30.45	121.00	701.80		0.00
259	UPTAKES (INNER CASING)	155.70	19.91	3099.99	98.06	15267.94		0.00
260	PROPUL SUP SYS- FUEL, LUBE OIL	8.30	4.88	40.50	98.55	817.97	0.00	0.00
264	LUBE OIL HANDLING		4.88	0.00	98.55	0.00		0.00
290	SPECIAL PURPOSE SYSTEMS	25.40	5.79	147.07	111.10	2821.94	0.00	0.00
298	OPERATING FLUIDS	16.30	2.44	39.77	115.24	1878.41		0.00
299	REPAIR PARTS + TOOLS	9.10	11.77	107.11	103.71	943.76		0.00
300	ELECTRIC PLANT, GENERAL	843.30	8.26	6963.87	101.15	85302.70	0.00	0.00
310	ELECTRIC POWER GENERATION	162.30	5.86	951.08	92.55	15020.87	0.00	0.00
311	SHIP SERVICE POWER GENERATION	160.20	5.83	933.97	92.55	14826.51		0.00
313	BATTERIES+SERVICE FACILITIES	2.00	8.45	16.90	92.55	185.10		0.00
320	POWER DISTRIBUTION SYS	608.40	8.60	5232.24	102.00	62056.80	0.00	0.00
321	SHIP SERVICE POWER CABLE	567.00	8.48	4808.16	101.79	57714.93		0.00
323	CASUALTY POWER CABLE SYS	7.60	11.41	86.72	101.79	773.60		0.00
324	SWITCHGEAT+PANELS	33.80	9.83	332.25	105.63	3570.29		0.00
330	LIGHTING SYSTEM	54.90	12.48	685.15	100.90	5539.41	0.00	0.00
331	LIGHTING DISTRIBUTION	29.60	11.94	353.42	101.79	3012.98		0.00
332	LIGHTING FIXTURES	25.40	13.10	332.74	99.87	2536.70		0.00
390	SPECIAL PURPOSE SYS	17.70	5.39	95.40	151.73	2685.62	0.00	0.00
399	REPAIR PARTS+SPECIAL TOOLS	17.70	5.39	95.40	151.73	2685.62		0.00
400	COMMAND+SURVEILLANCE	412.40	31.53	13004.62	106.40	43880.49	0.00	0.00
410	COMMAND+CONTROL SYS	73.40	9.00	660.60	85.59	6282.31	0.00	0.00
412	DATA PROCESSING GROUP	73.40	7.64	560.78	96.03	7048.60		0.00
420	NAVIGATION SYS	21.20	27.00	572.40	93.65	1985.38	0.00	0.00
421	NON-ELECT NAVIGATION AIDS	1.70	19.84	33.73	75.87	128.98		0.00
422	ELECTRICAL NAVIGATION AIDS	7.00	19.84	138.88	112.16	785.12		0.00
423	ELECTRONIC NAVIGATION AIDS, RADIO	1.90	19.84	37.70	67.36	127.98		0.00
424	ELECTRONIC NAVIG AIDS, ACOUSTIC	1.40	19.84	27.78	51.32	71.85		0.00
426	ELECTRICAL NAVIGATION SYS	7.00	19.84	138.88	54.56	381.92		0.00
427	INERTIAL NAVIGATION SYS	2.10	19.84	41.66	74.52	156.49		0.00
430	INTERIOR COMMUNICATIONS	65.40	11.74	767.80	109.03	7130.56	0.00	0.00
431	SWITCHBOARDS FOR I.C. SYSTEMS	6.50	11.74	76.31	109.03	708.70		0.00

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
432	TELEPHONE SYSTEMS	20.30	11.74	238.32	109.03	2213.31		0.00
433	ANNOUNCING SYSTEMS	12.40	11.74	145.58	109.03	1351.97		0.00
434	ENTERTAINMENT + TRAINING SYS	5.20	11.74	61.05	109.03	566.96		0.00
435	VOICE TUBES+MESSAGE PASSING SYS	0.30	11.74	3.52	109.03	32.71		0.00
436	ALARM, SAFETY, WARNING SYSTEMS	9.80	11.74	115.05	45.63	447.17		0.00
437	INDICATING, ORDER, METERING SYS	9.20	11.74	108.01	109.03	1003.08		0.00
438	INTEGRATED CONTROL SYSTEMS	1.30	11.74	15.26	109.03	141.74		0.00
439	RECORDING + TELEVISION SYSTEMS	0.40	11.74	4.70	109.03	43.61		0.00
440	EXTERIOR COMMUNICATIONS	55.10	29.13	1604.80	92.76	5111.28	0.00	0.00
441	RADIO SYSTEMS	51.00	31.00	1581.00	96.03	4897.53		0.00
442	UNDERWATER SYSTEMS	2.90	5.00	14.50	33.97	98.51		0.00
443	VISUAL + AUDIBLE SYSTEMS	0.30	9.11	2.73	96.03	28.81		0.00
446	SECURITY EQUIPMENT SYSTEMS	0.90	7.30	6.57	96.03	86.43		0.00
450	SURF SURVEILLANCE SYS (RADAR)	0.50		0.00		0.00	0.00	0.00
451	SURFACE SEARCH RADAR	0.20		0.00		0.00		0.00
452	AIR SEARCH RADAR (2D)	0.30		0.00		0.00		0.00
460	UNDERWATER SURVEILLANCE SYSTEMS	14.10	7.21	101.66	96.03	1354.02	0.00	0.00
462	PASSIVE SONAR	8.00		0.00		0.00		0.00
465	BATHYTHERMOGRAPH	2.60	2.60	6.76	96.03	249.68		0.00
470	COUNTERMEASURES	80.50	9.87	794.44	152.43	12270.46	0.00	0.00
473	TORPEDO DECOYS	8.80	8.80	77.44	96.03	845.06		0.00
475	DEGAUSSING	71.70	10.00	717.00	159.35	11425.40		0.00
480	FIRE CONTROL SYS	10.60	10.60	112.36	96.03	1017.92	0.00	0.00
482	MISSILE FIRE CONTROL SYSTEMS	5.70	5.70	32.49	96.03	547.37		0.00
483	UNDERWATER FIRE CONTROL SYSTEMS	4.90	4.90	24.01	96.03	470.55		0.00
490	SPECIAL PURPOSE SYS	91.60	91.60	8390.56	95.29	8728.56	0.00	0.00
491	ELCTRNC TEST,CHKOUT,MONITR EQPT	5.90	5.90	34.81	91.21	538.14		0.00
493	NON-COMBAT DATA PROCESSING SYS	8.50	8.50	72.25	93.99	798.92		0.00
498	C+S OPERATING FLUIDS	72.30	72.30	5227.29	96.03	6942.97		0.00
499	REPAIR PARTS+SPECIAL TOOLS	4.90	4.90	24.01	91.49	448.30		0.00
500	AUXILIARY SYSTEMS, GENERAL	1277.40	9.04	11549.88	69.07	88227.42	0.00	0.00
510	CLIMATE CONTROL	265.20	12.81	3397.21	105.63	28013.08	0.00	0.00
511	COMPARTMENT HEATING SYSTEM	13.10	12.93	169.38	105.63	1383.75		0.00
512	VENTILATION SYSTEM	128.00	14.51	1857.28	105.63	13520.64		0.00
513	MACHINERY SPACE VENT SYSTEM	36.10	15.10	545.11	105.63	3813.24		0.00
514	AIR CONDITIONING SYSTEM	85.60	9.44	808.06	105.63	9041.93		0.00
516	REFRIGERATION SYSTEM	2.10	7.49	15.73	105.63	221.82		0.00
517	AUX BOILERS+OTHER HEAT SOURCES	0.30	8.83	2.65	105.63	31.69		0.00
520	SEA WATER SYSTEMS	171.60	8.65	1484.34	105.63	18126.11	0.00	0.00
521	FIREMAIN+SEA WATER FLUSHING SYS	107.40	9.16	983.78	105.63	11344.66		0.00
523	WASHDOWN SYSTEM	7.40	10.92	80.81	105.63	781.66		0.00
526	SCUPPERS+DECK DRAINS	0.90	20.50	18.45	105.63	95.07		0.00
528	PLUMBING DRAINAGE	12.90	15.95	205.76	105.63	1362.63		0.00
529	DRAINAGE+BALLASTING SYSTEM	43.00	9.83	422.69	105.63	4542.09		0.00
530	FRESH WATER SYSTEMS	75.70	4.84	366.39	105.63	7996.19	0.00	0.00
531	DISTILLING PLANT	4.70	8.80	41.36	105.63	496.46		0.00
532	COOLING WATER	14.10	7.35	103.64	105.63	1489.38		0.00

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
533	POTABLE WATER	20.60	14.68	302.41	105.63	2175.98		0.00
534	AUX STEAM + DRAINS IN MACH BOX	36.30	9.86	357.92	105.63	3834.37		0.00
540	FUELS/LUBRICANTS,HANDLING+STORAGE	97.40	6.10	594.14	105.63	10288.36	0.00	0.00
541	SHIP FUEL+COMPENSATING SYSTEM	75.10	6.32	474.63	105.63	7932.81		0.00
542	AVIATION+GENERAL PURPOSE FUELS	21.00	4.73	99.33	105.63	2218.23		0.00
545	TANK HEATING	1.30	1.81	2.35	105.63	137.32		0.00
550	AIR,GAS+MISC FLUID SYSTEM	151.50	9.37	1419.56	105.63	16002.95	0.00	0.00
551	COMPRESSED AIR SYSTEMS		8.32	0.00	105.63	0.00		0.00
555	FIRE EXTINGUISHING SYSTEMS	82.80	10.25	848.70	105.63	8746.16		0.00
560	SHIP CNTL SYS	170.30	5.03	856.61	5.03	856.61	0.00	0.00
561	STEERING+DIVING CNTL SYS	51.10	8.10	413.91	8.10	413.91		0.00
562	RUDDER	119.20	3.72	443.42	3.72	443.42		0.00
570	UNDERWAY REPLENISHMENT SYSTEMS	48.90	11.17	546.21	83.00	4058.70	0.00	0.00
571	REPLENISHMENT-AT-SEA SYSTEMS	31.40	10.89	341.95	10.89	341.95		0.00
572	SHIP STORES+EQUIP HANDLING SYS	17.40	11.67	203.06	11.67	203.06		0.00
580	MECHANICAL HANDLING SYSTEMS	159.10	10.71	1703.96	10.71	1703.96	0.00	0.00
581	ANCHOR HANDLING+STOWAGE SYSTEMS	100.60	8.82	887.29	8.82	887.29		0.00
582	MOORING+TOWING SYSTEMS	24.30	14.20	345.06	14.20	345.06		0.00
583	BOATS,HANDLING+STOWAGE SYSTEMS	8.20	10.00	82.00	109.22	895.60		0.00
588	AIRCRAFT ELEVATORS	26.00	12.88	334.88	12.88	334.88		0.00
590	SPECIAL PURPOSE SYSTEMS	137.70	8.58	1181.47	8.58	1181.47	0.00	0.00
593	ENVIRONMENTAL POLLUTION CNTL SYS	20.20	5.31	107.26	5.31	107.26		0.00
598	AUX SYSTEMS OPERATING FLUIDS	103.50	9.29	961.52	9.29	961.52		0.00
599	AUX SYSTEMS REPAIR PARTS+TOOLS	13.90	8.02	111.48	8.02	111.48		0.00
600	OUTFIT+FURNISHING,GENERAL	827.10	7.94	6566.60	94.84	78443.47	0.00	0.00
610	SHIP FITTINGS	23.50	2.56	60.16	114.78	2697.33	0.00	0.00
611	HULL FITTINGS	6.50	9.22	59.93	102.71	667.62		0.00
612	RAILS,STANCHIONS+LIFELINES	15.00		0.00	123.54	1853.10		0.00
613	RIGGING+CANVAS	2.00		0.00	89.13	178.26		0.00
620	HULL COMPARTMENTATION	175.30	9.26	1623.28	91.40	16022.42	0.00	0.00
621	NON-STRUCTURAL BULKHEADS	70.60	15.53	1096.42	82.58	5830.15		0.00
622	FLOOR PLATES+GRATING	74.50	6.22	463.39	102.86	7663.07		0.00
623	LADDERS	12.90	7.29	94.04	87.77	1132.23		0.00
624	NON-STRUCTURAL CLOSURES	14.30	12.46	178.18	81.60	1166.88		0.00
625	AIRPORTS,FIXED PORTLTS, WINDOWS	3.10	1.52	4.71	77.35	239.79		0.00
630	PRESERVATIVES+COVERINGS	387.80	7.18	2784.40	86.58	33575.72	0.00	0.00
631	PAINTING	113.40	5.65	640.71	91.33	10356.82		0.00
633	CATHODIC PROTECTION	5.70	2.13	12.14	99.80	568.86		0.00
634	DECK COVERINGS	78.10	7.75	605.28	84.80	6622.88		0.00
635	HULL INSULATION	151.10	8.72	1317.59	91.09	13763.70		0.00
636	HULL DAMPING	15.80	1.30	20.54	12.22	193.08		0.00
637	SHEATHING	14.30	9.43	134.85	86.12	1231.52		0.00
638	REFRIGERATION SPACES	9.30	5.79	53.85	88.94	827.14		0.00
640	LIVING SPACES	32.60	11.93	389.02	112.89	3680.31	0.00	0.00
641	OFFICER BERTHING+MESSING	10.60	15.00	159.00	92.38	979.23		0.00
642	NON-COMM OFFICER B+M	5.30	13.00	68.90	109.03	577.86		0.00
643	ENLISTED PERSONNEL B+M	13.30	10.00	133.00	132.43	1761.32		0.00

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
644	SANITARY SPACES+FIXTURES	1.80	7.29	13.12	81.44	146.59		0.00
645	LEISURE+COMMUNITY SPACES	1.50	10.00	15.00	143.54	215.31		0.00
650	SERVICE SPACES	11.70	7.30	85.40	98.11	1147.86	0.00	0.00
651	COMMISSARY SPACES	6.00	7.00	42.00	109.23	655.38		0.00
652	MEDICAL SPACES	1.60	9.00	14.40	96.64	154.62		0.00
654	UTILITY SPACES	0.90		0.00		0.00		0.00
655	LAUNDRY SPACES	2.70	10.00	27.00	104.29	281.58		0.00
656	TRASH DISPOSAL SPACES	0.50	4.00	2.00	112.54	56.27		0.00
660	WORKING SPACES	82.20	9.56	785.45	124.69	10249.26	0.00	0.00
661	OFFICES	11.90	7.79	92.70	83.44	992.94		0.00
662	MACH CNTL CENTER FURNISHING	2.70	6.72	18.14	106.68	288.04		0.00
663	ELECT CNTL CENTER FURNISHING	4.00	9.65	38.60	59.63	238.52		0.00
664	DAMAGE CNTL STATIONS	29.00	10.00	290.00	90.73	2631.17		0.00
665	WORKSHOPS,LABS,TEST AREAS	34.60	10.00	346.00	176.26	6098.60		0.00
670	STOWAGE SPACES	105.40	7.45	785.23	96.03	10121.56	0.00	0.00
671	LOCKERS+SPECIAL STOWAGE	14.30	10.89	155.73	96.03	1373.23		0.00
672	STOREROOMS+ISSUE ROOMS	91.10	6.91	629.50	96.03	8748.33		0.00
690	SPECIAL PURPOSE SYSTEMS	8.60	6.24	53.66	110.35	949.01	0.00	0.00
698	OPERATING FLUIDS	0.50	7.38	3.69	77.35	38.68		0.00
699	REPAIR PARTS+SPECIAL TOOLS	8.20	6.18	50.68	112.17	919.79		0.00
700	ARMAMENT	303.60	9.95	3019.37	0.00	0.00	0.00	0.00
710	GUNS+AMMUNITION	152.90	10.00	1529.00	35.26		0.00	
711	GUNS	10.50	12.39	130.10	96.03			
712	AMMUNITION HANDLING	105.00	4.66	489.30	96.03			
720	MISSLES+ROCKETS	125.80	10.00	1258.00	53.68			
721	LAUNCHING DEVICES	125.80	11.00	1383.80	195.87			
750	TORPEDOES	2.70	12.49	33.72	135.52		0.00	
760	SMALL ARMS+PYROTECHNICS	8.90	12.86	114.45	83.43			
761	SMALL ARMS+PYRO LAUNCHING DEV	1.00	13.26	13.26	48.57			
763	SMALL ARMS+PYRO STOWAGE	1.90	10.00	19.00	95.53			
790	SPECIAL PURPOSE SYSTEMS	13.30	6.33	84.19	83.41		0.00	
798	ARMAMENT OPERATING FLUIDS	3.40	9.07	30.84	22.57			
799	ARMAMENT REPAIR PART+TOOLS	9.90	5.41	53.56	104.09			
	FULL LOAD CONDITION							
F00	LOADS	3324.50	4.47	14859.18	92.44	307316.11	0.00	0.00
F10	SHIPS FORCE	16.90	10.61	179.31	90.27	1525.56		0.00
F11	OFFICERS	4.20	10.61	44.56	90.27	379.13		0.00
F12	NON-COMMISSIONED OFFICERS	3.40	10.61	36.07	90.27	306.92		0.00
F13	ENLISTED MEN	9.30	10.61	98.67	90.27	839.51		0.00
F20	MISSION RELATED EXPENDABLES+SYS	151.90	7.01	1064.82	96.03	14586.96		0.00
F21	SHIP AMMUNITION	137.80	6.43	886.05	96.03	13232.93		0.00
F23	ORD DEL SYS (AIRCRAFT)	14.10	12.57	177.24	96.03	1354.02		0.00
F30	STORES	38.00	7.93	301.34	103.71	3940.98		0.00
F31	PROVISIONS+PERSONNEL STORES	31.90	7.77	247.86	103.71	3308.35		0.00
F32	GENERAL STORES	6.10	8.79	53.62	103.71	632.63		0.00
F40	LIQUIDS, PETROLIUM BASED	3095.00	4.27	13215.65	92.14	285173.30		0.00

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F41	DIESEL FUEL MARINE	3017.10	4.32	13033.87	92.04	277693.88		0.00
F42	JP-5	65.40	2.14	139.96	96.03	6280.36		0.00
F46	LUBRICATING OIL	12.50	4.37	54.63	96.03	1200.38		0.00
F47	SEA WATER	754.28	4.30	3243.38	96.00	72410.40		
F50	LIQUIDS, NON-PETRO BASED	22.70	4.32	98.06	92.04	2089.31		0.00
F52	FRESH WATER	22.70	4.32	98.06	92.04	2089.308		0
	MINIMUM OPERATING CONDITION							
F00	LOADS	2395.15	4.45	10669.33	93.49	223933.78	0.00	0.00
F10	SHIPS FORCE	16.90	10.61	179.31	90.27	1525.56		0.00
F21	SHIP AMMUNITION	55.12	6.43	354.42	96.03	5293.17		0.00
F22	ORD DEL SYS AMMO			0.00		0.00		0.00
F23	ORD DEL SYS (AIRCRAFT)	14.10	12.57	177.24	96.03	1354.02		0.00
F31	PROVISIONS+PERSONNEL STORES	10.63	7.77	82.62	103.71	1102.78		0.00
F32	GENERAL STORES	2.03	8.79	17.87	103.71	210.88		0.00
F41	DIESEL FUEL MARINE	1508.55	4.32	6516.94	92.04	138846.94		0.00
F42	JP-5	21.80	2.14	46.65	96.03	2093.45		0.00
F46	LUBRICATING OIL	4.17	4.37	18.21	96.03	400.13		0.00
F47	SEA WATER	754.28	4.30	3243.38	96.00	72410.40		0.00
F52	FRESH WATER	7.57	4.32	32.69	92.04	696.44		0.00

Appendix F – SSCS Space Summary

SSCS	GROUP	VOLUME (m^3)	AREA (m^2)	Typical Associated Spaces	Typical Locations
	TOTAL AVAILABLE	55748	13254		
	TOTAL REQUIRED		13254		
1	MISSION SUPPORT	86.1	4781		
1.1	COMMAND, COMMUNICATION + SURV		79.7		
1.11	EXTERIOR COMMUNICATIONS		5.9		
1.111	RADIO			Communications	high in deckhouse, often behind chart room
1.113	VISUAL COM		5.9	Signal Bridge	external, top of deckhouse
1.12	SURVEILLANCE SYS				
1.121	SURFACE SURV (RADAR)			Electronics Spaces, Radar and Radar Cooling Rooms	deckhouse behind radars
1.122	UNDERWATER SURV (SONAR)			Sonar Rooms (2 or 3), TACTASS Winch Room	sonar rooms low towards bow
					just below deck fwd of transom
1.13	COMMAND+CONTROL		73.7		
1.131	COMBAT INFO CENTER			CIC	below deck house centerline on DC deck or low in deckhouse
1.132	CONNING STATIONS		73.7	bridgewings or aft of deckhouse	external to hull/deckhouse
1.1321	PILOT HOUSE		66.7	Pilot House	Forward space on upper level of deck house
1.1322	CHART ROOM		7.1	Chart Room	behind pilot house on upper level of deck house
1.14	COUNTERMEASURES				
1.141	ELECTRONIC			deck sensors	external on deck
1.142	TORPEDO			Nixie Winch Room	just below deck fwd of transom
1.143	MISSILE			deck launchers	external on deck
1.15	INTERIOR COMMUNICATIONS		124.2	IC Room	DC deck midships
1.16	ENVIORNMENTAL CNTL SUP SYS			Environmental Protection Equipment Room, Environmental Waste Stowage, Sewage Treatment Room, Collection Holding and Transfer (CHT) Room and Tank	under or adjacent to galley, berthing, heads
1.2	WEAPONS				
1.21	GUNS				
1.214	AMMUNITION STOWAGE			Gun Magazines	fwd, below weather deck, 3 levels
1.22	MISSILES			Vertical Missile Launchers (VLS)	fwd, aft, peripheral below weather decks, 3 levels
1.24	TORPEDOS			Torpedo Stowage and Launchers	midship on deck and below
1.26	MINES			Special Weapons Magazines	midships below 2nd deck
1.3	AVIATION	86.1	554.2		
1.32	AVIATION CONTROL		20.4		
1.321	FLIGHT CONTROL		9.3	Flight Control Station	above hangar overlooking
1.322	NAVIGATION		11.1	Aviation Planning Rm	above/fwd of hangar

SSCS	GROUP	VOLUME (m³)	AREA (m²)	Typical Associated Spaces	Typical Locations
1.323	OPERATIONS			Aviation Ready Room	above/fwd of hangar
1.33	AVIATION HANDLING			RAST Winch Room, Hangar stowage area	below/forward flight deck
1.34	AIRCRAFT STOWAGE		533.8		
1.342	HELICOPTER HANGAR			Hangar	aft end of deckhouse, 2 decks
1.35	AVIATION ADMINISTRATION		8.4		
1.353	AVIATION OFFICE		8.4	Aviation Office	above/fwd of hangar
1.36	AVIATION MAINTENANCE		17.6	Aviation Shops	above/fwd of hangar
1.37	AIRCRAFT ORDINANCE				
1.374	STOWAGE			Aircraft ordinance Magazine(s)	
1.38	AVIATION FUEL SYS	86.1			
1.381	JP-5 SYSTEM	86.1		JP-5 Pumprooms	Just above inner bottom, below flight deck/hangar
1.3813	AVIATION FUEL	86.1		JP-5 Tanks	inner bottom below fwd flight deck
1.39	AVIATION STORES		21.4		
1.8	SPECIAL MISSIONS			Modular System Stowage Spaces	fwd or below hangar
1.9	SM ARMS,PYRO+SALU BAT		10	Small Arms Locker	fwd, below 2nd deck
2	HUMAN SUPPORT		1038		
2.1	LIVING		57.2		
2.11	OFFICER LIVING		54.8		
2.111	BERTHING		50.2		
2.1111	SHIP OFFICER		50.2		
2.11111	COMMANDING OFFICER STATEROOM		18.6	CO Stateroom, CO At-Sea Cabin	Main deck or 01/02 Level in DH
2.111121	EXECUTIVE OFFICER STATEROOM		13.9	XO Stateroom	Main deck or second deck midship, near administrative office
2.111123	DEPARTMENT HEAD STATEROOM		46.5	Department Head Staterooms (singles)	Often main deck or 01 Level in DH
2.11113	OFFICER STATEROOM (DBL)		125.4	Officer Staterooms (mostly doubles, 1 or 2 4-person OK)	Officer's Country (1 or 2) 01 level or main deck near ward room
2.1114	AVIATION OFFICER				
2.112	SANITARY		4.6		
2.1121	SHIP OFFICER		4.6		
2.11211	COMMANDING OFFICER BATH		4.6	CO WR, WC & SH, At-Sea WC	adjacent CO berthing
2.11212	EXECUTIVE OFFICER BATH		2.8	XO WR, WC & SH	adjacent XO berthing
2.11213	OFFICER		16.4	Officer WCs, WR & SH	near officer/DH berthing
2.1124	AVIATION OFFICER				
2.12	CPO LIVING		86.8		
2.121	BERTHING		66.4	CPO Berthing	sleeping and lounge, 2nd deck
2.122	SANITARY		20.3	CPO WC	adjacent CPO berthing
2.13	CREW LIVING		234.1		
2.131	BERTHING		195.7	Crew Berthing	below 2nd deck, usually 2 levels, 3 or 4 locations
2.132	SANITARY		38.4	Crew WCs	adjacent berthing or above on 2nd deck

SSCS	GROUP	VOLUME (m^3)	AREA (m^2)	Typical Associated Spaces	Typical Locations
2.133	RECREATION			Crew Recreation	small area in berthing
2.14	GENERAL SANITARY FACILITIES		2.3		
2.142	BRIDGE WASHRM & WC		2.3	Bridge WC	adjacent bridge
2.15	SHIP RECREATION FAC		6.3	Crew Recreation Room	2nd deck or below
2.16	TRAINING		3.3	Crew Training	2nd deck or below
2.2	COMMISSARY		282.5		
2.21	FOOD SERVICE		154.6		
2.211	WARDROOM MESSRM & LOUNGE		55.7	Wardroom Mess	main deck or 01 level near officer country
2.212	CPO MESSROOM AND LOUNGE		55.7	CPO Mess and Lounge	adjacent CPO berthing, near crew mess
2.213	CREW MESSROOM		43.1	Crew Mess	2nd deck midship
2.22	COMMISSARY SERVICE SPACES		59.6		
2.222	GALLEY		42.8		
2.2222	WARD ROOM GALLEY		9.8	WR Galley	adjacent wardroom
2.2224	CREW GALLEY		22.3	Crew Gally	adjacent crew mess
2.223	WARDROOM PANTRY		7.4	WR Pantry	adjacent wardroom galley
2.224	SCULLERY		9.3	Scullery	adjacent crew mess
2.23	FOOD STORAGE+ISSUE		68.4		
2.231	CHILL PROVISIONS		22.4	Chill Box	adjacent or below crew mess
2.232	FROZEN PROVISIONS		14.6	Freeze Box	adjacent or below crew mess
2.233	DRY PROVISIONS		31.4	Dry Provision SR	adjacent or below crew mess
2.3	MEDICAL+DENTAL		34.1	Sick Bay	2nd deck fwd midships
2.4	GENERAL SERVICES		34.6		
2.41	SHIP STORE FACILITIES		18.2	Ship Store	2nd deck aft midships
2.42	LAUNDRY FACILITIES		12.1	Laundry	below 2nd deck aft
2.44	BARBER SERVICE			Barber Shop	2nd deck or below aft
2.46	POSTAL SERVICE		4.3	Ship Post office	2nd deck midships
2.47	BRIG			Brig	below 2nd deck forward
2.5	PERSONNEL STORES		20.5		
2.51	BAGGAGE STOREROOMS		7.2	Officer baggage storeroom	near/below officer country
2.55	FOUL WEATHER GEAR		1.1	Bosn Stores, Foul Weather Gear Locker	
2.6	CBR PROTECTION		62.6		
2.61	CBR DECON STATIONS			Decon Stations	main deck with weather access
2.62	CBR DEFENSE EQUIPMENT		16.3	CBR stowage	near decon stations
2.63	CPS AIRLOCKS		46.2	Airlocks	between CBR zones and weather access
2.7	LIFESAVING EQUIPMENT		1.9	life jacket stowage	near deck access
3	SHIP SUPPORT	4890	4250		
3.1	SHIP CNTL SYS (STEERING)		124.8		
3.11	STEERING GEAR		124.8	After Steering	2nd deck or below above rudders
3.12	ROLL STABILIZATION				
3.15	STEERING CONTROL				
3.2	DAMAGE CONTROL		106		
3.21	DAMAGE CNTRL CENTRAL			DC Central	2nd deck, midship
3.22	REPAIR STATIONS		59.8	Repair Lockers	3 ea, 2nd deck, fwd/midship/aft
3.25	FIRE FIGHTING		46.2	Fire Fighting Stations	2nd deck above MMRs, AMRs

SSCS	GROUP	VOLUME (m^3)	AREA (m^2)	Typical Associated Spaces	Typical Locations
3.3	SHIP ADMINISTRATION		137.2		
3.301	GENERAL SHIP		14	Ship's Office	2nd deck midship
3.302	EXECUTIVE DEPT		32.1	Ship's Office	3rd deck midship
3.303	ENGINEERING DEPT		19.7	Engineering Office	aft midship 2nd deck or below
3.304	SUPPLY DEPT		16.4	Supply Office	fwd midship 2nd deck or below
3.305	DECK DEPT		8.5	Deck Department Office	main deck, deckhouse
3.306	OPERATIONS DEPT		46.5	Operations Department Office	01 level or above deckhouse
3.307	WEAPONS DEPT			Weapons Department Office	01 level or above deckhouse
3.5	DECK AUXILIARIES		16.6		
3.51	ANCHOR HANDLING		65	Anchor Windlass Room and Chain Lockers	just below weather deck in bow with hydraulics below and chain hausers connecting to chain lockers below near keel
3.52	LINE HANDLING			Line Handling Stations / Capstans	on deck or room/station in bow and stern just below weather deck with hydraulics below
3.53	TRANSFER-AT-SEA		7.9	Unrep Stations	p/s deckhouse opening on weather deck
3.54	SHIP BOATS STOWAGE			Boat davits or boat ramp aft	on weather deck near midships or side hatches, or ramp in transom
3.6	SHIP MAINTENANCE		283.3		
3.61	ENGINEERING DEPT		173.3		
3.611	AUX (FILTER CLEANING)		24.4	Filter Cleaning Shop	deckhouse
3.612	ELECTRICAL		57.6	Electrical Shop	2nd deck or below aft midships
3.613	MECH (GENERAL WK SHOP)		81	Work Shop	2nd deck or below aft midships
3.62	OPERATIONS DEPT (ELECT SHOP)		96.5	Electronics Repair Shop	deckhouse 01 level or above
3.63	WEAPONS DEPT (ORDINANCE SHOP)		13.5	Ordnance Shop	near/above hangar
3.64	DECK DEPT (CARPENTER SHOP)			Carpenter Shop	2nd deck or below aft midships
3.7	STOWAGE		789.7		
3.71	SUPPLY DEPT		554.7		
3.711	HAZARDOUS MATL (FLAM LIQ)		64.4	Flamable Liquid/Paint Storeroom	deckhouse opening on weather deck
3.713	GEN USE CONSUM+REPAIR PART		412	General Storerooms	below 2nd deck
3.714	SHIP STORE STORES		16.4	General Storerooms	below 2nd deck
3.72	ENGINEERING DEPT		13.5	Engineering Storage	near shops, below 2nd deck
3.73	OPERATIONS DEPT		18.9	Operations Storage	deckhouse near Electric Shop
3.74	BOATSWAIN STORES		167.5		2nd deck forward
3.75	WEAPONS DEPT		12.1	Weapons Dept Stowage	near Ordnance Shop
3.78	CLEANING GEAR STOWAGE		9	Cleaning Gear Lockers	6-8 around ship, 2nd deck
3.8	ACCESS		656.9		
3.82	INTERIOR		2047		
3.821	NORMAL ACCESS		650.5	Passageways	2nd deck and above, port and starboard or single centerline
3.822	ESCAPE ACCESS		6.5	Escape trunks	MMRs, AMRs, manned spaces 2nd access
3.9	TANKS	4890	16.2		

SSCS	GROUP	VOLUME (m^3)	AREA (m^2)	Typical Associated Spaces	Typical Locations
3.91	SHIP PROP SYS TNKG	4338			
3.9111	ENDUR FUEL TANK (INCL SERVICE)	2169		DFM Tanks and Service Tanks	mostly inner bottom, service tanks in MMRs, AMRs w/SSGs above IB
3.914	FEEDWATER TNKG			Feedwater Tanks	Near aux boiler if there is one
3.92	BALLAST TNKG			Ballast Tanks, Peak Tank	bottom, bow and stern
3.93	FRESH WATER TNKG	23.2		Fresh Water Tanks	near AMRs, wings or IB separated from fuel
3.94	POLLUTION CNTRL TNKG		16.2		
3.941	SEWAGE TANKS		0.6	Sewage/Holding Tanks	below crew berthing/heads
3.942	OILY WASTE TANKS		15.7	Oily Waste Tanks	IB below MMRs, AMRs
3.95	VOIDS	529.3		Voids	various against hull
4	SHIP MACHINERY SYSTEM		2555		
4.1	PROPULSION SYSTEM		733.9	MMRs, Motor Rooms	
4.142	COMBUSTION AIR (INTAKE)		287.1	Intakes	Up from engines, through deckhouse to sides of ship 03 level or above
4.143	EXHAUST		446.8	Exhaust	Up from engines, through deckhouse
4.2	PROPULSOR & TRANSMISSION SYST				
4.23	WATERJET ROOMS			WJ Rooms	
4.23001	PROP SHAFT ALLEY			Shaft Alleys	between MMRs or motors along shaft to hull exit
4.3	AUX MACHINERY		166.8	AMRs and MMRs	
4.33	ELECTRICAL		118.3		
4.331	POWER GENERATION			AMRs and MMRs	
4.334	DEGAUSSING		22.9	Degaussing Room	2nd deck or below near electrical shop
4.34	POLLUTION CONTROL SYSTEMS		10.5	Environmental Protection Equipment Room, Environmental Waste Stowage, Sewage Treatment Room, Collection Holding and Transfer (CHT) Room and Tank	under or adjacent to galley, berthing, heads
4.36	VENTILATION SYSTEMS		166.8	Fan Rooms (8-12+)	deckhouse on skin or just below weatherdeck

.

Appendix G - Simplified Cost Model MathCAD File

$Mdol := 1coul$

$Bdol := 1000 \cdot Mdol$

$lton := 2240 \cdot lb$ $Kdol := \frac{Mdol}{1000}$

$hp := \frac{33000 \cdot ft \cdot lb}{min}$ $dol := \frac{Kdol}{1000}$

SIMPLIFIED COST MODEL

FFSHI

1. Single Digit Weight Summary: $i1 := 100, 200 .. 700$

$W_{100} := 7035.4 lton$ $W_{400} := 963.7793 lton$ $W_{500} := 1551.863 lton$

$W_{200} := 1253.145 lton$ $W_{420} := 23.03 lton$ $W_{600} := 709.8662 lton$ $W_{F_{20}} := 280.4989 lton$

$W_{300} := 1786.43 lton$ $W_{430} := 70.863 lton$ $W_{700} := 496.6795 lton$ $W_{F_{23}} := 13.877 lton$ [helo]

$N_{HELO} := 2$

Weight margin: $W_M := 1379.716 lton$

2. Additional charcteristics:

Lightship:

$W_{LS} := \sum_{i1} W_{i1} + W_M$ $W_{LS} = 1.518 \times 10^4 \cdot lton$

Costed Military Payload: (helo and helo fuel weight not included)

$W_{MP} := \left(\left(W_{400} + W_{700}\right)\right)$ $W_{MP} = 1.46 \times 10^3 \cdot lton$

Installed Propulsion Power: $P_{SUM} := 155397 \cdot hp$

Manning: (crew + air detachment + staff)

Officers: $N_{C_1} := 19$ CPO's: $N_{C_2} := 18$ Enlisted: $N_{C_3} := 98$

Ship Service Life: $L_S := 30$ Initial Operational Capability: $Y_{IOC} := 2018$

Total Ship Acquisition: $N_S := 18$ Production Rate (per year): $R_P := 3$

3. Inflation:

Base Year: $Y_B := 2013$ $iy := 1 .. Y_B - 1981$

Average Inflation Rate (%): $R_I := 3.$
(from 1981)

$F_I := \prod_{iy} \left(1 + \frac{R_I}{100}\right)$ $F_I = 2.575$

4. Lead Ship Cost:

a. Lead Ship Cost - Shipbuilder Portion:

SWBS costs: (See Enclosure 1 for K_N factors); includes escalation estimate $KM1 := 1.0929$

Structure $K_{N1} := \frac{1.2 \cdot Mdol}{lton^{.772}}$ $C_{L_{100}} := .03395 \cdot F_I \cdot K_{N1} \cdot KM1 \left(W_{100}\right)^{.772}$ $C_{L_{100}} = 107.032 \cdot Mdol$

$KM2 := 1.01$

+ Propulsion $K_{N2} := \frac{2.04 \cdot Mdol}{hp^{.808}}$ $C_{L_{200}} := .00186 \cdot F_I \cdot K_{N2} \cdot KM2 \, P_{SUM}^{0.808}$ $C_{L_{200}} = 154.505 \cdot Mdol$

$KM3 := 1.01$

+ Electric $K_{N3} := \frac{1.2 \cdot Mdol}{lton^{.91}}$ $C_{L_{300}} := .07505 \cdot F_I \cdot K_{N3} \cdot KM3 \left(W_{300}\right)^{.91}$ $C_{L_{300}} = 213.281 \cdot Mdol$

+ Command, Control, Surveillance

$KM4 := 1.050$

$$K_{N4} := \frac{1.973338 \cdot Mdol}{lton^{.617}} \quad C_{L_{400}} := .10857 \cdot F_I \cdot K_{N4} \cdot KM4 \left(W_{400}\right)^{.617} \quad C_{L_{400}} = 40.203 \cdot Mdol$$

(less payload GFM cost)

$KM5 := 1.01$

+ Auxiliary

$$K_{N5} := \frac{1.2 \cdot Mdol}{lton^{.782}} \quad C_{L_{500}} := .09487 \cdot F_I \cdot K_{N5} \cdot KM5 \left(W_{500}\right)^{.782} \quad C_{L_{500}} = 92.613 \cdot Mdol$$

$KM6 := 1$

+ Outfit

$$K_{N6} := \frac{1.2 \cdot Mdol}{lton^{.784}} \quad C_{L_{600}} := .09859 \cdot F_I \cdot K_{N6} \cdot KM6 \left(W_{600}\right)^{.784} \quad C_{L_{600}} = 52.375 \cdot Mdol$$

$KM7 := 1.02$

+ Armament

$$K_{N7} := \frac{1.2 \cdot Mdol}{lton^{.987}} \quad C_{L_{700}} := .00838 \cdot F_I \cdot K_{N7} \cdot KM7 \left(W_{700}\right)^{.987} \quad C_{L_{700}} = 12.102 \cdot Mdol$$

(Less payload GFM cost)

+ Margin Cost:

$$C_{LM} := \frac{W_M}{W_{LS} - W_M} \cdot \left(\sum_{i1} C_{L_{i1}}\right) \qquad C_{LM} = 67.211 \cdot Mdol$$

+ Integration/Engineering: (Lead ship includes detail design engineering and plans for class)

$$K_{N8} := \frac{10. \cdot Mdol}{Mdol^{1.099}} \quad C_{L_{800}} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099} \quad C_{L_{800}} = 483.422 \cdot Mdol$$

+ Ship Assembly and Support: (Lead ship includes all tooling, jigs, special facilities for class)

$$K_{N9} := \frac{2.0 \cdot Mdol}{Mdol^{.839}} \quad C_{L_{900}} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839} \quad C_{L_{900}} = 68.915 \cdot Mdol$$

= Total Lead Ship Construction Cost (BCC):

$$C_{LCC} := \sum_{i1} C_{L_{i1}} + C_{L_{800}} + C_{L_{900}} + C_{LM} \qquad C_{LCC} = 1.292 \times 10^3 \cdot Mdol$$

+ Profit:

$F_P := .10 \qquad C_{LP} := F_P \cdot C_{LCC} \qquad C_{LP} = 129.166 \cdot Mdol$

= Lead Ship Price:

$P_L := C_{LCC} + C_{LP} \qquad P_L = 1.421 \times 10^3 \cdot Mdol$

+ Change Orders:

$C_{LCORD} := .12 \cdot P_L \qquad C_{LCORD} = 170.499 \cdot Mdol$

= Total Shipbuilder Portion:

$C_{SB} := P_L + C_{LCORD} \qquad C_{SB} = 1.591 \times 10^3 \cdot Mdol$

b. Lead Ship Cost - Government Portion

Other support: $C_{LOTH} := .025 \cdot P_L$ $C_{LOTH} = 35.521 \cdot Mdol$

+ Program Manager's Growth: $C_{LPMG} := .1 \cdot P_L$ $C_{LPMG} = 142.082 \cdot Mdol$ $W_{MP} = 1.46 \times 10^3 \cdot lton$

+ Ordnance and Electrical GFE:
(Military Payload GFE)

$C_{LMPG} := 1624.59491 Mdol$ (or incl actual cost if known)

+ HM&E GFE (boats, IC): $C_{LHMEG} := .02 \cdot P_L$ $C_{LHMEG} = 28.416 \cdot Mdol$

+ Outfittimg Cost : $C_{LOUT} := .04 \cdot P_L$ $C_{LOUT} = 56.833 \cdot Mdol$

= Total Government Portion:

$C_{LGOV} := C_{LOTH} + C_{LPMG} + C_{LMPG} + C_{LHMEG} + C_{LOUT}$ $C_{LGOV} = 1.887 \times 10^3 \cdot Mdol$

c. Total Lead Ship End Cost: (Must always be less than appropriation)

* Total End Cost:

$C_{LEND} := C_{SB} + C_{LGOV}$ $C_{LEND} = 3.479 \times 10^3 \cdot Mdol$

d. Total Lead Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{LPDEL} := .05 \cdot P_L$ $C_{LPDEL} = 71.041 \cdot Mdol$

= Total Lead Ship Acquisition Cost: $C_{LA} := C_{LEND} + C_{LPDEL}$ $C_{LA} = 3.55 \times 10^3 \cdot Mdol$

5. Follow-Ship Cost:

Learning Rate/Factor: $R_L := .98$ $F := .9350906$ (for N_s/2 ship) $F = 0.935$

a. Follow Ship Cost - Shipbuilder Portion

$C_{F_{i1}} := 1.125509F \cdot C_{L_{i1}}$ $C_{FM} := 1.125509F \cdot C_{LM}$ $C_{FM} = 70.736 \cdot Mdol$

$$C_{F_{800}} := \frac{.204 \cdot Mdol}{Mdol^{1.099}} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099} \quad C_{F_{800}} = 290.053 \cdot Mdol$$

$$\frac{C_{F_{i1}}}{Mdol} = \begin{pmatrix} 112.647 \\ 162.609 \\ 224.468 \\ 42.311 \\ 97.47 \\ 55.123 \\ 12.736 \end{pmatrix}$$

$C_{F_{900}} := 1.125509 \cdot .58F \cdot C_{L_{900}}$ $C_{F_{900}} = 42.067 \cdot Mdol$

Total Follow Ship Construction Cost: (BCC)

$$C_{FCC} := \sum_{i1} C_{F_{i1}} + C_{F_{800}} + C_{F_{900}} + C_{FM} \qquad C_{FCC} = 1.11 \times 10^3 \cdot Mdol$$

+ Profit:

$F_P := .1$ $C_{FP} := F_P \cdot C_{FCC}$ $C_{FP} = 111.022 \cdot Mdol$

= Follow Ship Price:

$P_F := C_{FCC} + C_{FP}$ $P_F = 1.221 \times 10^3 \cdot Mdol$

+ Change Orders:

$C_{FCORD} := .08 \cdot P_F$ $C_{FCORD} = 97.699 \cdot Mdol$

= Total Follow Ship Shipbuilder Portion:

$C_{FSB} := P_F + C_{FCORD}$ $C_{FSB} = 1.319 \times 10^3 \cdot Mdol$

b. Follow Ship Cost - Government Portion

Other support: $C_{FOTH} := .025 \cdot P_F$ $C_{FOTH} = 30.531 \cdot Mdol$

+ Program Manager's Growth: $C_{FPMG} := .05 \cdot P_F$ $C_{FPMG} = 61.062 \cdot Mdol$

number of helo's: $N_{HELO} = 2$

+ Ordnance and Electrical GFE:
(Military Payload GFE)

$$C_{FMPG} := 1.125509 \cdot 19 \cdot \frac{Mdol}{lton} \cdot W_{MP} \cdot F_I$$

$C_{FMPG} = 804.235 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{FHMEG} := .02 \cdot P_F$ $C_{FHMEG} = 24.425 \cdot Mdol$

+ Outfittimg Cost: $C_{FOUT} := .04 \cdot P_F$ $C_{FOUT} = 48.85 \cdot Mdol$

= Total Follow Ship Government Cost:

$$C_{FGOV} := C_{FOTH} + C_{FPMG} + C_{FMPG} + C_{FHMEG} + C_{FOUT} \qquad C_{FGOV} = 969.103 \cdot Mdol$$

c. Total Follow Ship End Cost: (Must always be less than SCN appropriation)

* Total Follow Ship End Cost:

$$C_{FEND} := C_{FSB} + C_{FGOV} \qquad C_{FEND} = 2.288 \times 10^{3} \cdot Mdol$$

d. Total Follow Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{FPDEL} := .05 \cdot P_F \qquad C_{FPDEL} = 61.062 \cdot Mdol$

= Total Follow Ship Acquisition Cost: $C_{FA} := C_{FEND} + C_{FPDEL} \qquad C_{FA} = 2.349 \times 10^{3} \cdot Mdol$

AVERAGE SHIP ACQUISITION COST:

$$C_{AV} := \frac{\frac{C_{FA} - C_{FMPG}}{F} \cdot (N_S - 1)^{\frac{\ln(2 \cdot R_L)}{\ln(2)}} + (N_S - 1) \cdot C_{FMPG} + C_{LA}}{N_S}$$

$$C_{AV} = 2.393 \times 10^{3} \cdot Mdol$$

6. Life Cycle Cost:

a. Research and development

Ship design and development:

$$C_{SDD} := 1.1\cdot\left(.571\cdot\frac{C_{FSB}}{F} + .072\cdot C_{LMPG}\right) \qquad C_{SDD} = 1.015\times 10^{3}\cdot Mdol$$

+ Ship test and evaluation

$$C_{STE} := 1.2\cdot\left(.499\cdot\frac{C_{FSB}}{F} + .647\cdot C_{LMPG}\right) \qquad C_{STE} = 2.106\times 10^{3}\cdot Mdol$$

= Total Ship R&D Cost:

$$C_{RD} := C_{SDD} + C_{STE} \qquad C_{RD} = 3.121\times 10^{3}\cdot Mdol$$

b) Investment (less base facilities, unrep, etc)

Ship Expected Total Shipbuilding Program Cost:

$$C_{SPE} := C_{AV}\cdot N_S \qquad C_{SPE} = 43.082\cdot Bdol$$

+ Support Equipment (shore-based)

ship: $C_{SSE} := .15\cdot C_{SPE}$ $\qquad C_{SSE} = 6.462\cdot Bdol$

+ Spares and repair parts (shore supply)

ship: $C_{ISS} := .1\cdot C_{SPE}$ $\qquad C_{ISS} = 4.308\cdot Bdol$

= Total Investment Cost: $C_{INV} := C_{SPE} + C_{SSE} + C_{ISS}$

$$C_{INV} = 53.852\cdot Bdol$$

c) Operations and Support (total service life, base year dollars)

Personnel (Pay and Allowances)

$$C_{PAY} := F_I\cdot\left[.026184\cdot N_{C_1} + .01151\cdot\left(N_{C_2} + N_{C_3}\right)\right]\cdot N_S\cdot L_S\cdot Mdol \qquad C_{PAY} = 2.548\cdot Bdol$$

$$C_{TAD} := F_I\cdot\left(N_{C_1} + N_{C_2} + N_{C_3}\right)\cdot N_S\cdot L_S\cdot 2.6\cdot 10^{-6}\cdot Mdol \qquad C_{TAD} = 0.488\cdot Mdol$$

$$C_{PERS} := C_{PAY} + C_{TAD} \qquad C_{PERS} = 2.549\cdot Bdol$$

+ Operations:

Operating hours/year: $H := 2500\cdot hr$

$$C_{OPS} := N_S\cdot L_S\cdot\left[F_I\cdot Kdol\cdot\left[188. + 2.232\cdot\left(N_{C_1} + N_{C_2} + N_{C_3}\right) - \frac{H}{26.9\cdot hr}\right] + \frac{C_{AV}}{769.2} + \frac{C_{FMPG}}{196}\right]$$

$$C_{OPS} = 4.447\cdot Bdol$$

+ Maintenance

$$C_{MTC} := N_S\cdot L_S\cdot\left[F_I\cdot Kdol\cdot\left[2967 + 4.814\cdot\left(N_{C_1} + N_{C_2} + N_{C_3}\right) - \frac{H}{3.05\cdot hr}\right] + \frac{C_{AV}}{156.25}\right]$$

$$C_{MTC} = 12.161\cdot Bdol$$

+ Energy

Fuel Rate: $W := 3.0 \cdot \frac{lton}{hr}$ $C_{FUEL} := .9 \cdot \frac{dol}{gal}$

$$C_{EGY} := N_S \cdot L_S \cdot C_{FUEL} \cdot \frac{H}{6.8 \cdot \frac{lb}{gal}} \cdot W \qquad C_{EGY} = 1.201 \cdot Bdol$$

+ Replenishment Spares

$$C_{REP} := C_{ISS} \cdot \frac{L_S - 4}{4} \qquad C_{REP} = 28.003 \cdot Bdol$$

+ Major Support (COH, ROH):

$$C_{MSP} := N_S \cdot L_S \cdot \left[698. + 5.988 \cdot \left(N_{C_1} + N_{C_2} + N_{C_3}\right) - \frac{H}{10.36 \cdot hr}\right] \cdot Kdol \cdot F_I + .0022 \cdot C_{AV}$$

$$C_{MSP} = 1.764 \cdot Bdol$$

= Total Operation and Support Cost: $C_{OAS} := C_{PERS} + C_{OPS} + C_{MTC} + C_{EGY} + C_{REP} + C_{MSP}$

$$C_{OAS} = 50.126 \cdot Bdol$$

d. Residual Value:

$$RES := .5 \cdot C_{SPE} \cdot \left(1 - \frac{2}{L_S}\right)^{L_S} \qquad RES = 2.719 \cdot Bdol$$

e. Total Program

* Total Life Cycle Cost (Undiscounted): $C_{LIFE} := C_{RD} + C_{INV} + C_{OAS} - RES$

$$C_{LIFE} = 104.379 \cdot Bdol$$

7. Discounted Life Cycle Cost:

Discount Rate: $R_D := .1$

a. Discounted R&D:

Length of R&D Phase: $L_{RD} := 13$

end: $E_{RD} := Y_{IOC} + 2 - Y_B$ $E_{RD} = 7$ (normalized to base year)

start: $B_{RD} := E_{RD} - L_{RD} + 1$ $B_{RD} = -5$

$$F_{DRD} := \frac{\sum_{y = B_{RD}}^{E_{RD}} \frac{1}{(1 + R_D)^y}}{L_{RD}} \qquad F_{DRD} = 0.968$$

$C_{DRD} := F_{DRD} \cdot C_{RD}$ $C_{DRD} = 3.021 \times 10^{3} \cdot Mdol$

b. Discounted Investment:

start: $B_{INV} := E_{RD} + 1$ $B_{INV} = 8$

end: $E_{INV} := B_{INV} + \frac{N_S - 1}{R_P}$ $E_{INV} = 13.667$

$L_{INV} := E_{INV} - B_{INV} + 1$ $L_{INV} = 6.667$

$$F_{DINV} := \frac{\displaystyle\sum_{y = B_{INV}}^{Floor(E_{INV}, 1)} \frac{1}{(1 + R_D)^{y}}}{L_{INV}} \qquad F_{DINV} = 0.335$$

$C_{DINV} := F_{DINV} \cdot C_{INV}$ $C_{DINV} = 18.053 \cdot Bdol$

c. Discounted O&S:

start: $B_{OAS} := E_{INV} + 1$ $B_{OAS} = 14.667$

end: $E_{OAS} := B_{OAS} + L_S - 1$ $E_{OAS} = 43.667$

$L_{OAS} := E_{OAS} - B_{OAS} + 1$ $L_{OAS} = 30$

$$F_{DOAS} := \frac{\displaystyle\sum_{y = Floor(B_{OAS}, 1)}^{Floor(E_{OAS}, 1)} \frac{1}{(1 + R_D)^{y}}}{L_{OAS}} \qquad F_{DOAS} = 0.091$$

$C_{DOAS} := F_{DOAS} \cdot C_{OAS}$ $C_{DOAS} = 4.562 \cdot Bdol$

d. Discounted Residual Value:

$$RES_D := RES \cdot \left(\frac{1}{1 + R_D}\right)^{E_{OAS}+1} \qquad RES_D = 38.503 \cdot Mdol$$

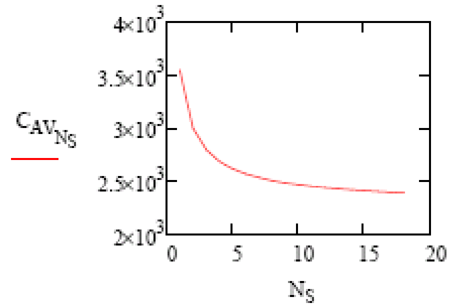
e. Total Discounted Life Cycle Cost:

$C_{DLIFE} := C_{DRD} + C_{DINV} + C_{DOAS} - RES_D$ $C_{DLIFE} = 25.598 \cdot Bdol$

LEARNING CURVE:

$N_S := 1 .. 18$

$$C_{AV_{N_S}} := \frac{\frac{C_{FA} - C_{FMPG}}{F} \cdot (N_S - 1)^{\frac{\ln(2 \cdot R_L)}{\ln(2)}} + (N_S - 1) \cdot C_{FMPG} + C_{LA}}{N_S}$$



$C_{LA} = 3.55 \times 10^{3} \cdot Mdol$

$C_{FA} = 2.349 \times 10^{3} \cdot Mdol$