Aerospace & Ocean Engineering

Design Report

Small Surface Combatant (SSC)

VT Total Ship Systems Engineering

SSC
Ocean Engineering Design Project
AOE 4065/4066
Fall 2009 – Spring 2010
Virginia Tech Team 4

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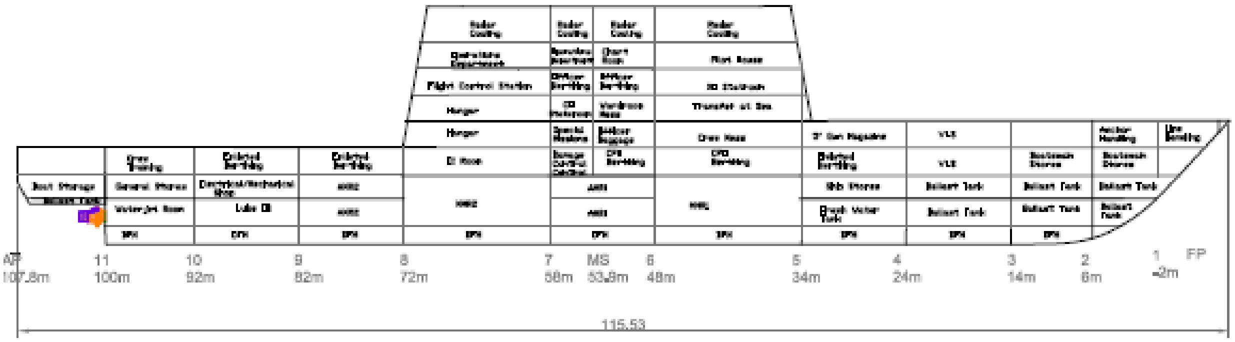
Executive Summary



This report describes the Concept Exploration and Development of small surface combatant (SSC) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The SSC requirement is based on the need for a small, fast littoral ship that has the ability to operate right off the coast. The ship must be light, have the ability to launch and recover helicopters, as well as launch missiles from a vertical launch system.

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.

SSC Small, design 51, is a small littoral combat ship that has a sustained speed of nearly 50 knots. It has the ability to get close to the shoreline where larger ships cannot operate. The ship contains a hangar that can hold 2 SH-60 Seahawk Helicopters, a room dedicated to JP-5 fueling operations, and has a landing pad on the aft deck. The ship itself is armed with a 5 inch deck gun and a vertical launch cluster that can hold up to 10 missiles. Furthermore, the ship has the ability to direct missiles that have been fired by other ships.

Design 51 was selected due to the high overall measure of effectiveness compared to the cost. On a plot comparing OMOE to Cost, the point corresponding to design 51 was on a knee in the curve. It also represented a higher measure of risk compared to others, but the design was still selected due to the high level of effectiveness.

Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, propulsion and power system development and arrangement, general arrangements, machinery arrangements, combat system definition and arrangement, seakeeping analysis,

cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements in the ORD within cost and risk constraints.

Ship Characteristic	Value
LWL	107.85 m
Beam	13.5323 m
Draft	4.391 m
D10	11.48 m
Lightship weight	2467 MT
Full load weight	3298 MT
Sustained Speed	44.1 kn
Endurance Speed	22 kn
Endurance Range	3030 nm
Propulsion and Power	2 Rolls Royce MT-30 GT Engines 2 CAT 3616 Diesel Engines 2 Kamewa Waterjets
BHP	18050 kW
Personnel	69
OMOE (Effectiveness)	0.807
OMOR (Risk)	0.963
Ship Acquisition Cost	$491.31 million
Life-Cycle Cost	$932.2 million
Combat Systems (Modular and Core)	MK XII AIMS IFF, SPY 1-E Radar, MK48 VLS, 2x 50cal Machine Gun, 57MM MK3 Naval Gun Mount, 1x 7M RHIB, Towed Array Tripwire, Mine Avoidance Sonar, capable to store 2x SH-60 helos in hanger, Aviation Magazine

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1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of a Small Surface Combatant (SSC) for the United States Navy. The SSC requirement is based on the SSC Initial Capabilities Document (ICD), and Virginia Tech SSC Acquisition Decision Memorandum (ADM), Appendix A and Appendix B. This concept design was completed in a two-semester ship design course at Virginia Tech. SSC must perform Anti-surface and subsurface warfare, Homeland Defense, ISR, Maritime Interdiction, anti-terrorism protection, provide support for special forces operations, logistics, mine warfare, and anti-air warfare in Carrier Strike Groups (CSGs), Expeditionary Strike Groups (ESGs), Surface Action Groups (SAGs), and Independent Ops (IOs) It must be between 2000 and 8000 MT in displacement and must be cost effective, meaning it must cost less than $300M with an absolute ceiling of $400M. This ship will be placed to perform the missions listed above in open-ocean and littoral waters with high target densities. Therefore, SSC will function in wave heights up to SS7 and survive in SS9.

1.2 Design Philosophy, Process, and Plan

Our design project consists of two main parts: Concept and Requirements Exploration (C&RE) and Required Operational Capabilities (ROCs), or what missions the boat will be carrying out over its lifetime. C&RE provides a consistent format and methodology for making affordable multi-objective acquisition decisions and trade-offs in a non-dominated design space. It also provides practical and quantitative methods for measuring mission effectiveness and risk, as well as methods to search the design space for optimal concepts. C&RE starts with an ICD/ADM which is used to develop detailed CONOPS and Concept Development. ROCs are evaluated to create Measures of Performance (MOP) which are used to evaluate the overall effectiveness of the designs that they create. Using these MOPs, the design team identifies Design Variables (DVs), or the basic characteristics that the ship will need to accomplish all missions requirements set forth by the Navy. A Non-Dominated, design space is then created. This space (graph) allows the design team to pick the most suitable design based on the cost and the Overall Measure of Effectiveness (based on risk and the ROCs). Once the design is picked, the design team can put the details, such as mechanical systems, combat systems, electrical systems and drives, manning, and modularity.

1.3 Work Breakdown

SSC Team 4 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.

Table 1 - Work Breakdown

Name	Specialization
Chaz Henderson	Mission and Mission Effectiveness
Kirsten Talbott	Hull, Mechanical, and Electrical, Risk
Ryan Kneifel	Combat Systems, Manning, Cost
Michael Beynon	Modularity
Christopher Lester	Space and Weight
Jeffrey Martel	Synthesis Model and Optimization

1.4 Resources

Computational and modeling tools used in this project are listed in Table 2.

Table 2 - Tools

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

2 Mission Definition

The SCC requirement is based on the SSC Mission Need Statement (MNS), and Virginia Tech SSC 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 SSC class will be able to operate as a scalable modular family of SSC ships with capabilities sufficient to satisfy the full range of specified SSC capability requirements using interchangeable, networked mission modules, and with the option of more capable AAW sensors and weapons could also be modular, but would be added in construction as a SSC variant or in a major availability using a hull plug, modular deckhouse, or modular mast(s). There variants would be able to contribute significant area AAW support for ESGs or as part of CSGs.

SSC will also be used in support of CSG/ESGs. Two to three SSC ships could be assigned to each strike group with MSCs and a carrier or amphibious ship. Their mission configuration would complement the other strike group combatants. Larger SSCs may be able to contribute to CSG and ESG area AAW defense. Tailored mission configurations could include defense against mine threats, littoral ASW threats, and small boat threats using distributed off-board systems. High speed and agility could provide tactical advantage.

SSC Surface Action Groups (SAGs) will also be utilized. They will operate as a force of networked, dispersed SSCs, providing collective flexibility, versatility and mutual support. SSC and MSC SAGs could provide defense against mine threats, littoral ASW threats, and small boat threats ahead of larger CSGs/ESGs including first-response capability to anti-access crises. High speed and agility should provide a significant tactical advantage.

During SSC Independent Operations, SSC would perform inherent (mobility) mission tasking in known threat environments including defense against mine threats, littoral ASW threats, and small boat threats. Rapid response to contingency mission tasking could provide OTH Targeting, reach-back for mission planning, insertion/extraction of USMC, Army, SOF personnel, and movement of cargo/personnel. SSC could provide ISR ahead of CSG/ESG operations and maritime interdiction/interception operations, overseas or in support of homeland defense, possibly as USCG assets.

Ship deployments could be extended with rotating crews alternately returning to CONUS. Interchangeable, networked mission modules could be changed in 2-3 days, in theater, to support force needs and changing threats. Some SSCs could be configured with more capable AAW sensors and weapons that could also be modular, but require extended availability for upgrade or change-out. Hull plugs, modular deckhouse and modular mast options should be considered for these SSC variants. They would be able to contribute significant area AAW support for ESGs or as part of CSGs.

2.2 Projected Operational Environment (POE) and Threat

SSC will be used for world-wide operation in cluttered, littoral environments or constrained bodies of water with smaller scales relative to open ocean warfare. These environments create an increased difficulty of detecting and successfully prosecuting targets. It will also be used in open ocean environments as part of CSGs and ESGs, so it must be able to withstand Sea States 1 to 9.

The threats that SSC will face are asymmetric, overlapping, and commercially available. They include threats from nations with a major military capability, or the demonstrated interest in acquiring such a capability. Major military capabilities include land, surface, and air launched cruise missiles, diesel submarines, land-attack cruise missiles, and theatre ballistic missiles. It will also face threats from smaller nations who support, promote, and perpetrate activities that cause regional instabilities detrimental to international security and/or have the potential development of nuclear weapons. These threats could be seen in small diesel/electric submarines, land-based air assets, chemical/biological/ radiological weapons, fixed and mobile SAM sites, swarming small boats, and sophisticated sea mines.

2.3 Specific Operations and Missions

The SSC will be capable of performing Underway Replenishment operations, cooperatively detect, engage, and destroy enemy aircraft with nearby AEGIS units, conduct precision missile strikes, engage and kill enemy patrol craft and small boats, perform ISR of the enemy from littoral waters, map and neutralize enemy minefields, avoid or eliminate enemy submarines using LAMPs/Sonar, conduct shore bombardment in support of amphibious assaults with ground troops, destroy incoming enemy cruise missiles, and map enemy coastlines if needed.

2.4 Mission Scenarios

Mission scenarios for the primary SSC missions are provided in Table 3 through Table 6. These missions include the support of SAGs, ESGs, and CSGs as well as Independent Operations (IO).

Table 3 – SAG Mission Scenario

Day	Mission Scenario for Surface Action Group (SAG)
1-8	Transit from Home Port to forward base.
9-12	Refuel and replenish
13-20	Transit from Forward base to area of hostility
21	Avoid/Eliminate enemy submarine
22-26	Cooperatively, with Aegis unit, detect, engage and destroy enemy aircraft
26-27	Execute pre-programmed precision missile strike on inland airfield
28	Conduct precision missile strike on enemy Naval facility
29	Engage and kill enemy patrol crafts with .50-cal machine gun and harpoon missile
30-36	Receive new targeting information and conduct missile strike on update targets
37	Cooperatively, with Aegis unit, detect, engage, and destroy incoming enemy cruise missile on ARG unit
38	Detach from SAG
39-54	Perform ISR of enemy from Littoral Waters (at least 25nm from ESG).
55	Return to SAG
56-60	Receive new targeting information and conduct missile strike on update targets
58-60	Conduct precision strikes in support of ground troops

Table 4 - ESG Mission Scenario for SSC in MCM Configuration

Day	Mission Scenario for Expeditionary Strike Group (ESG) - MCM Configuration
1-8	Transit from Home Port to forward base.
9-12	Refuel and replenish
13-20	Transit from Forward base to area of hostility
21	Avoid/Eliminate enemy submarine
22-26	Map and neutralize enemy minefield to allow access to amphibious landing point
26-27	Execute pre-programmed precision missile strike on inland target
28	Conduct shore bombardment in support of amphibious landing
29	Engage and kill enemy patrol crafts with .50-cal machine gun and harpoon missile
30-36	Receive new targeting information and conduct missile strike on update targets
37	Cooperatively, with Aegis unit, detect, engage, and destroy incoming enemy cruise missile on ESG unit
38	Detach from ESG
38-48	Perform ISR of enemy from littoral waters (at least 25nm from ESG)
43-48	Search for enemy mines. Neutralize them if found.
49	Return to ESG
49-56	Map and neutralize enemy minefield to allow access to second amphibious landing point
56-60	Receive new targeting information and conduct missile strike on update targets
58-60	Conduct precision strikes in support of ground troops

Table 5 - CSG Mission Scenario for SSC in AAW Configuration

Day	Mission Scenario for Carrier Strike Group (CSG) - AAW Configuration
1-8	Transit from Home Port to forward base.
9-12	Refuel and replenish
13-20	Transit from Forward base to area of hostility
21	Search/Eliminate enemy submarine with LAMPs and Sonar
22-26	Cooperatively, with Aegis unit, detect, engage and destroy enemy aircraft
26-27	Execute pre-programmed precision TLAM missile strike on inland airfield
28	Conduct precision missile strike on enemy Naval facility
29	Perform ISR in order to facilitate the launching of aircraft from carrier
30-36	Receive new targeting information and conduct missile strike on update targets
37	Cooperatively, with Aegis unit, detect, engage, and destroy incoming enemy cruise missile on SAG unit
38	Detach from CSG
39-54	Perform ISR of enemy airfield from Littoral Waters (at least 25nm from SAG).
55	Return to CSG
56-60	Receive new targeting information and conduct missile strike on update targets
58-60	Conduct precision strikes in support of ground troops

Table 6 - IO Mission Scenario for SSC in MCM Configuration

Day	Mission Scenario for SSC Independent Operations - MCM Configuration
1-8	Transit from Home Port to forward base.
9-12	Refuel and replenish
13-20	Transit from Forward base to area of hostility
21	Search/Eliminate enemy submarine with LAMPs and Sonar
22-26	Map and neutralize enemy minefield. Conduct ISR
26-27	Execute pre-programmed precision TLAM missile strike on inland airfield
28	Conduct precision missile strike on enemy Naval facility
29	Perform ISR in order to facilitate the launching of aircraft from carrier
30-36	Receive new targeting information and conduct missile strike on update targets
37-44	Map enemy coastline. Neutralize any enemy mines that are found.
45-54	Perform ISR of enemy airfield and naval facility
56-60	Receive new targeting information and conduct missile strike on update targets
58-60	Conduct precision strikes in support of ground troops

2.5 Required Operational Capabilities

In order to support the missions and mission scenarios described in Section 2.3, 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

ROCs	Description
AAW 9	Engage airborne threats using surface-to-air armament
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
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	Provide own unit Command and Control
CCC 3	Maintain data link capability
CCC 4	Provide communications for own unit
CCC 6	Relay communications

ROCs	Description
CCC 9	Perform cooperative engagement
CCC 21	Provide support services to other units
FSO 3	Conduct towing/search/salvage rescue operations
FSO 5	Conduct SAR operations
FSO 6	Provide explosive ordnance disposal services
FSO 7	Conduct port control functions
FSO 8	Provide routine health care
FSO 9	Provide first aid assistance
FSO 10	Provide triage of casualties/patients
FSO 11	Provide medical/surgical treatment for casualties/patients
FSO 12	Provide medical, surgical, post-operative and nursing care for casualties/ patients
FSO 13	Provide medical regulation, transport/evacuation and receipt of casualties and patients
FSO 14	Provide routine and emergency dental care
FSO 16	Support/conduct intelligence collection
INT 1	Provide intelligence
INT 2	Conduct surveillance and reconnaissance
INT 3	Process surveillance and reconnaissance information
INT 8	Disseminate surveillance and reconnaissance information
INT 9	Provide intelligence support for non-combatant evacuation operation (NEO)
INT 15	Transfer/receive cargo and personnel
LOG 2	Provide airlift of cargo and personnel
LOG 6	Conduct mine neutralization/destruction
MIW 3	Conduct mine avoidance
MIW 4	Conduct magnetic silencing (degaussing, deperming)
MIW 6	Maintain magnetic signature limits
MIW 6.7	Steam to design capacity in most fuel efficient manner
MOB 1	Support/provide aircraft for all-weather operations
MOB 2	Prevent and control damage
MOB 3	Counter and control NBC contaminants and agents
MOB 3.2	Maneuver in formation
MOB 5	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)
MOB 7	Replenish at sea
MOB 10	Maintain health and well being of crew
MOB 12	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support
MOB 13	Operate in day and night environments
MOB 16	Operate in heavy weather
MOB 17	Operate in full compliance of existing US and international pollution control laws and regulations
MOB 18	Provide upkeep and maintenance of own unit
NCO 3	Conduct maritime law enforcement operations
NCO 19	Conduct sensor and ECM operations
SEW 2	Conduct sensor and ECCM operations
SEW 3	Conduct coordinated SEW operations with other units
SEW 5	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

To determine possible hull forms, hull characteristics need to be determined based on mission and similar ships. For the small SSC, these characteristics include an approximate full load weight of 2000 to 5000 MT, a range of 3000 to 6000 nautical miles, a total shaft horsepower of 40 to 70 mega-watts, and a sustained speed of 30 to 50 knots. The transport factor is calculated using the chosen hull characteristics. Design lanes are then used to specify hull form design parameter ranges for the design space and the design space is defined.

Based on the mission and similar ships, the small SSC should have smaller combat systems than DDG51, including radar, cooling, missiles, and guns and defense. The small SSC should assist in medium surface combatant (MSC) or multiple SSC ship missions as well as independent operations including mine or small boat threats. It should also have a reasonable sustained speed requirement and a shaft horsepower greater than 74000 hp. Displacement is expected to be between 2000 and 5000 MT.

To calculate the transport factor, the following equation is used:

$$TF=((\Delta\times VS)\div SHP)\times 5.052 kw/MT\times kts$$

where Δ is the full load displacement of the ship, VS is the sustained speed, and SHP is the installed shaft horsepower in kilowatts, including the propulsion and lift systems.

Using a full load weight of 3500 MT, a sustained speed of 40 knots, and a shaft horsepower of 55,000 kW, the transport factor is 12.86. Using **Error! Reference source not found.** and Table 8 - Transport Factor Example
, the transport factor is similar to that of a multihull or semi-planing ship. Using a full load weight of 5000 MT, a sustained speed of 30 knots, and a shaft horsepower of 40,000 kW, the transport factor is 18.95. This is similar to transport factor numbers for a monohull.

There are a few important hull form characteristics to take into consideration when designing an SSC. They include the transport factor, a reduced radar cross-section, the ability to produce multiple ships, good seakeeping, and a high degree of modularity. A reduced radar cross-section can be achieved with a hybrid, enclosed mast and a smaller ship. Modularity and producibility can be increased with a reduced lifetime cost and designing systems to be modular. Good seakeeping can be achieved with a multi-hull while structural efficiency can be achieved with a monohull.

For this project, teams were assigned both displacement monohull and semi-planing hull options. Our team was assigned the semi-planing monohull. The parent ship to our team's semi-planing monohull is the LCS-1 modified to specified design characteristics by linear scaling and adjustment of the deadrise angle. The design space is given in **Error! Reference source not found.**. The length should be between 90 and 110 meters and the beam to draft ratio should be between 3 and 3.4. The length to depth ratio is between 8.5 and 11.5, the length to beam ratio should be between 6.5 and 8, and the deadrise angle should be between 12 and 14 degrees. The small SSC should have a high speed hullform with s sustained speed of 40 to 45 knots in addition to good propulsion space. Finally, the SSC should have reasonable deck space.

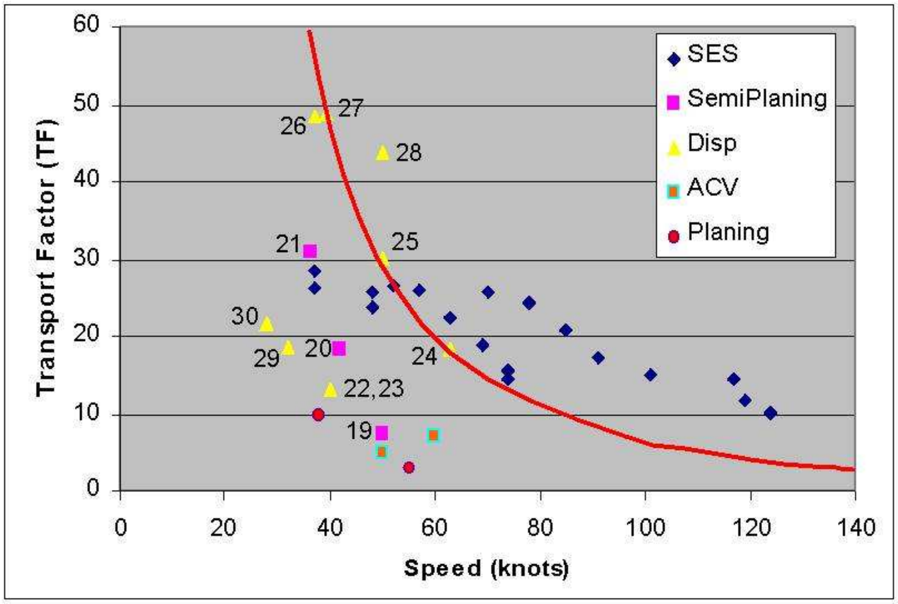


Figure 1 - Transport Factor Plot

Table 8 - Transport Factor Example

Ship or Concept	#	Type	Speed	TF	Power	Range	Payload	Displacement
			(knots)		(SHP)	(n.mi)	(LT)	(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

Table 9 - SSC-small Design Space

L/B	6.5-8	**L (m)**	90-110
L/D	8.5-11.5	**B (m)**	11.25-16.9
B/T	3-3.4	**D (m)**	7.8-12.9
C_P	0.633	**T (m)**	3.3-5.63
C_x	0.778	**β (degrees)**	12-14
C_{rd}	0.7-1.0		

3.1.2 Propulsion and Electrical Machinery Alternatives

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 ship should be Navy qualified. It should comply with American Bureau of Shipping (ABS) standards and requirements, including for periodically unattended machinery spaces. The ship should be designed for continuous operation using distillate fuel in accordance with ASTM D975, Garde 2-D; ISO 8217, F-DMA, DFM (NATO Code F-76) and JP-5 (NATO Code F-44). In addition, it should have a minimum range of 5000 nautical miles at 20 knots.

Sustained Speed and Propulsion Power – There is a sustained speed minimum requirement of 40 knots in full load, calm water, and clean hull conditions using no more than eighty percent of the installed engine rating of the main propulsion engines or motors. The goal speed however is 50 knots in order to provide "just-in-time delivery". The propulsion system alternatives must span 40,000 to 70,000 shaft horsepower (SHP) power range with ship service power greater than 10,000 kilowatts (kW) unless a pulse power configuration is used.

Ship Control and Machinery Plant Automation – An integrated bridge system should be considered which includes integrated navigation, radio communications, interior communications, ship maneuvering equipment and systems, and should comply with the ABS Guide for One Man Bridge Operated (OMBO) Ships. Auxiliary systems, electric plant and damage control systems should be continuously monitored from the SSC, MCC, and Chief Engineer's office, and the systems should be controlled from the MCC and local controllers.

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 grade A shock, non-nuclear, and have a low infrared signature.

3.1.2.2 Machinery Plant Alternatives

The high speed requirements demonstrate a need for high power density. Because of this, only gas turbine engines and epicyclical or planetary reduction gears were considered. The power requirements were satisfied with two to four main engines, each rating 20,000 to 60,000 kW each. The propulsion efficiency at 40-50 knots requires waterjet propulsion. Kamewa S3 Series waterjets will be used. The semi-planing hull provides sufficient room for three or four waterjets. Both mechanical drive and integrated power systems (IPS) were considered. In an IPS configuration, DC Buses, zonal distribution, and permanent magnet motors were used. This provided arrangement and operation flexibility, future power growth, improved fuel efficiency, and survivability with moderate weight and volume penalties.

3.1.3 Automation and Manning Parameters

Manning is the greatest cost over a ships lifetime. The cost of manning is sixty percent of the Navy's budget. The largest expense incurred over a ship's lifetime is the crew. One of the issues with manning is that the manpower on a vessel can be put in harms way. Damage control and firefighting are managed by manpower with a high risk to the personnel. Job enrichment, computer literacy, and response time are all human factors that can cause the death of personnel. Another problem is the background of each sailor. Each background comes with different cultures and traditions that must be addressed in tight living spaces. The manning triad that includes watch standing, maintenance, and damage control requires a significant amount of manning. Recent developments in technology has allowed for a reduction in manpower over most areas of a ship. That said it is important in early design phases to try and reduce the number of personnel on a ship.

The use of computers or machinery in place of personnel is automation. Automation can be applied to many areas of a ship. Firefighting can be replaced by automated robot arms for fire suppression. These arms can sense heat or smoke and if used with an automated sprinkler system they can keep personnel away from harm. The response time can be reduced by using an automated system. Without the need for extra personnel during a fire manning is reduced.

Other technologies are available to help reduce manning. Watch standing technology can assist an individual with automated route planning, electronic charting, navigation, collision avoidance and electronic log keeping. Video conferencing allows for the knowledge of expert personnel without having them onboard. Computer systems can be learned on shore rather than having to have hands on experience. These tutorials can be replayed if one forgets exactly how to perform a task. Using these computer systems helps make a ship paperless. It keeps administration personnel on shore while allowing them to perform their duties electronically.

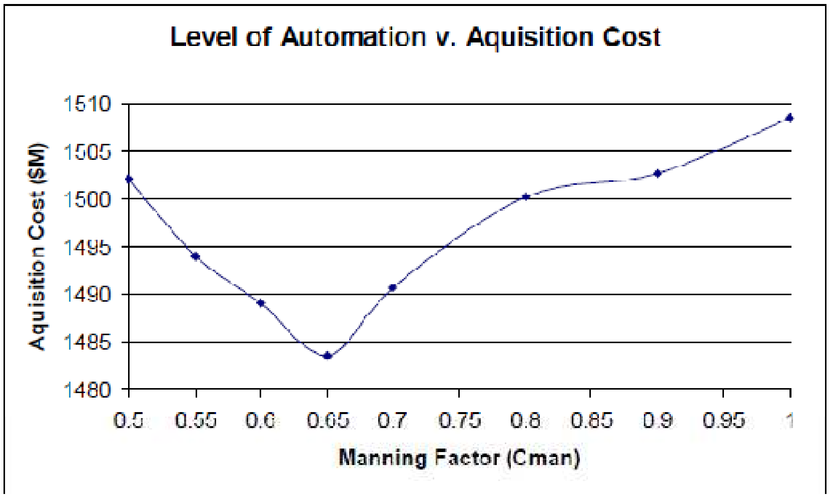


Figure 2 - Automation Cost

A manning factor of 1 signifies a fully manned ship while a manning factor of .5 signifies a half manned ship with half of the manpower simulated by automation. The best solution is a manning of .65 allowing for automation yet having enough personnel available if the automation were to fail.

To build a manning model, guidelines must be used. The U.S. Navy has a guide called a Ship Manpower Document or SMD. The process includes: conducting an ROC/POE analysis, determining a directed manpower requirement, determining watch station requirements, developing preventative maintenance levels, estimating corrective maintenance workloads, applying approved staffing standards, conducting on-site workload measurements and analysis, considering utility tasking, allowing margins, and conducting a fleet review of the documents.

A manning Response Surface Model (RSM) allows for the calculation of required manning. ISMAT (Integrated Simulation Manning Analysis Tool) is used to develop scenarios to test ability of the crew. It dynamically allocates each task to a crew member. A size and make up of crew is optimized for four different goals: cost, crew size, different jobs, and workload. The total crew size is calculated using the formula below:

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

NT = total crew size, *LevAuto* = level of automation, *MAINT* = maintenance level, *LWLComp* = length of the waterline, *PSYS* = propulsion system, *ASUW* = anti-surface warfare, and *CCC* = command, control and communication.

3.1.4 Combat System Alternatives

Combat systems are grouped in sections. These sections include but are not limited to: Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASUW), and Light Airborne Multi-Purpose System (LAMPS).

3.1.4.1 AAW

The Anti-Air Warfare table shows the options that are ideal for this ship. They are described in the following paragraphs.

Warfighting System	Options
AAW/SEW system alternatives	Option 1) AN/SPY- 1E MFR, IRST, 1X MK16 Ram/Searam, MK XII AIMS IFF, Combat-SS21
	Option 2) Seapar MFR, IRST, 1X MK16 Ram/Searam, MK XII AIMS IFF, Combat-SS21
	Option 3) EADS TRS-3D C-Band Radar, IRST, 1X MK16 Ram/Searam, Combat DF, ICMS

AN/SPY-1E is a multi-function phased array radar capable of search, automatic detection, transition to track, tracking of air and surface targets, and missile engagement support.

The SEAPAR is a medium to long-range, 3D multi-beam, volume search radar (VSR) which is suitable for both air surveillance, helicopter guidance, and target designation in the littoral environments. It is designed to be used with the Evolved Sea Sparrow Missiles (ESSM). It is roughly 75% smaller and lighter than Active Phased Array Radars. VSR is an S-band frequency, 3-D tracking, and long range volume search radar. It can be used for enhanced ballistic missile defense (BMD).

EADS TRS 3-D is a multimode, C-band, ship mounted, air and sea surveillance and target acquisition radar. It automatically detects and tracks both surface and airborne fast moving targets serving as stand-alone radar and can be netter with other sensors. It can also detect guided missiles, high speed patrol boats and unmanned aerial vehicles in extreme weather conditions.

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

Combat-SS21 is a network-enabled interoperability, with an open architectural design, and innovative capabilities proven on modern platforms. Its capabilities include anti-submarine warfare, surface warfare, anti-air warfare, mine warfare, special operations, intelligence, homeland defense, surveillance and reconnaissance.

3.1.4.2 **ASUW**

Warfighting Systems	Options
ASUW system alternatives	Option 1) 5IN/62 gun, SPS-73, 1X 30MM CIGS, RHIB, GFCS, Small Arms, 2x50cal Machine gun

	Option 2) SPS-73, 57mm MK3, RHIB, GFCS, Small Arms, 2x50cal Machine gun, IRST
	Option 3) SPS-73, 57mm MK3, RHIB, GFCS, Small Arms, 2x50cal Machine gun

AN/SPS-73 is a short-range, 2-D, surface-search/navigation radar system. At short ranges it can detect low-flying air units and provide surveillance of surface units. It provides contact range and bearing information while enabling quick and accurate determination of ownship position relative to nearby vessels and navigational hazards.

The MK 45 5IN/62 gun has a range of over 60 nautical miles with Extended Range Guided Munitions (ERGM). The gun mount is a basic Mk 45 gun mount with a 62-caliber barrel, strengthened trunnion supports, lengthened recoil stroke, an ERGM initialization interface, round identification capability, and an enhanced control system.

The MK3 Naval 57 mm Gun (Bofors) is capable of firing 2.4 kilogram shells at a rate of 220 rounds per minute at a range of more than 17 kilometres.

The Gun Fire Control System (GFCS) is used to engage surface, air, and shore targets. It can maintain a track file on up to four Surface Direct Fire (SDF) or Anti-air (AA) targets assigned by Command and Decision (C&D), and a maximum of 10 NSFS targets entered at the Gun Console (GC).

The RHIB or Rigid Hull Inflatable Boats are 7 meters longs, weigh 4400 lbs, and have a beam of 9 feet 6 inches and a draft of 13 inches. Using a Cummins 6-cycle, 234 horsepower engine, it can carry up to 18 people.

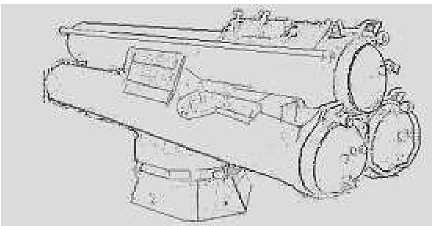
3.1.4.3 **ASW**

The Anti Submarine Warfare options help protect the ship from submarines and other underwater threats. Their purpose is to help detect and defend against a threat. The ASW combat system options are listed in the table below.

Warfighting Systems	Options
ASW system alternatives	Option 1) SQS-56, Nixie, 2xMK 32 Triple Tubes, MK 309 Torpedo FCS, SQQ 89 FCS, NDS 3070 Vanguard
	Option 2) Nixie, 2xMK 32 Triple Tubes, SQQ 89 FCS, MK 309 Torpedo FCS, NDS 3070 Vanguard
	Option 3) Nixie, NDS 7070

The 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 incorporates active/passive operating capability, as well as preformed beam, digital sonar providing panoramic echo ranging and panoramic (DIMUS) 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.

The MK 32 Surface Vessel Torpedo Tube (SVTT) is a ASW launching system which pneumatically launches torpedoes over the side. It can handle the MK-46 and MK-50 torpedoes and stow up to three torpedoes. The torpedo tube launches torpedoes under local control or remote control from an ASW fire control system.



Nixie is a tow-behind decoy that employs an underwater acoustic projector which is towed behind the ship. It provides deceptive countermeasures against acoustic homing torpedoes and can be used in pairs or as singles.

3.1.4.4 LAMPS

Warfighting Systems	Options
LAMPS/helo system alternatives	Option 1) Dual SH-60, hangar
	Option 2) 1 x SH-60, hangar
	Option 3) Flight Deck

A SH-60 Seahawk is capable of ASW, search and rescue, ASUW, special operations, cargo lift, and deploying sonobuoys. It extends the ships radar capabilities. The Seahawk carries either Mk46 or Mk50 torpedoes, two 7.62mm machine guns, and AGM-119 penguin missiles.

Having a flight deck also allows for Vertical Takeoff Unmanned Aircraft Vehicle (VTUAV). It provides an extension of the ships sensors and is suited for high risk missions. It is small in size and stored easily onboard.

3.1.4.5 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 10 are included in the ship synthesis model data base.

Table 10 - Combat System Ship Synthesis Characteristics

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

ROCs	Description
AAW 9	Engage airborne threats using surface-to-air armament
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
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

ROCs	Description
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
FSO 13	Provide medical, surgical, post-operative and nursing care for casualties/ patients
FSO 14	Provide medical regulation, transport/evacuation and receipt of casualties and patients
FSO 16	Provide routine and emergency dental care
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 2	Transfer/receive cargo and personnel
LOG 6	Provide airlift of cargo and personnel
MIW 3	Conduct mine neutralization/destruction
MIW 4	Conduct mine avoidance
MIW 6	Conduct magnetic silencing (degaussing, deperming)
MIW 6.7	Maintain magnetic signature limits
MOB 1	Steam to design capacity in most fuel efficient manner
MOB 2	Support/provide aircraft for all-weather operations
MOB 3	Prevent and control damage
MOB 3.2	Counter and control NBC contaminants and agents
MOB 5	Maneuver in formation
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)
MOB 10	Replenish at sea
MOB 12	Maintain health and well being of crew
MOB 13	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support
MOB 16	Operate in day and night environments
MOB 17	Operate in heavy weather
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations
NCO 3	Provide upkeep and maintenance of own unit
NCO 19	Conduct maritime law enforcement operations
SEW 2	Conduct sensor and ECM operations
SEW 3	Conduct sensor and ECCM operations
SEW 5	Conduct coordinated SEW operations with other units
STW 3	Support/conduct multiple cruise missile strikes

3.1.5 Modularity Alternatives

Modularity is the physical and/or functional grouping of elements of a complex system into building blocks for the purpose of easing construction, integration, installation, removal, and interchangeability. The method of modularity is used primarily to facilitate change. In order to gain the most from mission modules, it is important to consider the modules themselves, their interfaces, and the overall platform.

Through previous uses of mission modularity, there have been several key advantages discovered.

- Acquisition schedule improves by approximately 25%.
- Displacement increases slightly and increases fuel consumption.
- Renovation cost and schedule improve by approximately 25%.
- Evolutionary acquisition capability improves.
- Technology insertion capability improves.
- Systems competition level increases.
- Platform availability improves.
- Fleet effectiveness improves.
- Life cycle cost is 5-11% less than a non-modular ship.

When equipped with the appropriate ASW Mission Package, the SSC will conduct multi-sensor ASW detection, classification, localization, tracking and engagement of submarines throughout the water column in the operating environment. The SSC will have the capability to embark ASW/multi-mission helicopters and unmanned vehicles, and will utilize Undersea Surveillance Systems, environmental models and databases

Lockheed Martin Sea TALON (Tactical Littoral Ocean Network) system successfully completed several significant testing milestones in mid-2006 in its development as an Anti-Submarine Warfare (ASW) mission module for the US Navy's Littoral Combat Ship (LCS). Sea TALON is a unique undersea surveillance system that uses a Remote Towed Active Source (RTAS), a multi-band transducer networked with a Remote Towed Array (RTA), to provide search, detection and localization of quiet submarines. Each array is towed by an unmanned, semi-autonomous, semi-submersible Remote Multi-Mission Vehicle (RMV), an ASW-variant of Lockheed Martin's AN/WLD-1 Remote Minehunting System. The RMV, launched and controlled remotely from a forward-deployed LCS, will provide the Navy's first unmanned, organic, real-time ASW capability, significantly enhancing ship and crew safety.

The SSC will make use of MIW environmental models and databases. The Mission Package will enable SSC to:

- Detect classify and identify surface, moored and bottom mines to permit maneuver or use of selected sea areas.
- Coordinate/support mission planning and execution with Joint and Combined assets in the absence of dedicated MIW command and control platforms. MIW mission planning will include the use of organic and remotely operated sensors. The LCS will exchange MIW tactical information including Mine Danger Areas (MDA), mine locations, mine types, environmental data, bottom maps, off-board system locations, planned search areas and confidence factors.
- Conduct mine reconnaissance.
- Perform bottom mapping.
- Perform minefield break through/punch through operations using off-board systems.
- Perform minesweeping using off-board mission system.
- Conduct precise location and reporting of a full range of MCM contact data. For example: identified mines and non-mine bottom objects.
- Perform mine neutralization.
- Employ, reconfigure, and support MH-60S for MIW operations.
- Embark an EOD detachment.
- Deploy, control, and recover off-board systems, and process data from off-board systems.

The SUW mission package contains several sensor, weapon, and software components packaged in a modular fashion that easily and quickly swaps in and out of the SSC. These components include electro-optical/infrared sensors mounted on a vertical takeoff unmanned air vehicle to provide over-the-horizon detection; 30mm guns to kill close-in targets; four non-line-of-sight launching system (NLOS-LS) container launch units or "missile-in-a-box" systems, with each system containing 15 offensive missiles; and the MH-60R armed helicopter for surveillance and attack missions.

The SUW mission package has software that interfaces with the SSC command and control system to maintain and share situational awareness and tactical control in a coordinated SUW environment. The software supports SUW mission planning, receives and processes the common tactical picture, runs surveillance operations and, if required, initiates offensive actions against surface threats.

Currently, there are several issues associated with mission modularity. The Navy wants modules to be able to be swapped out in a day or less. This will put a strain on the interfaces for each module. They need to able to be quickly detached, removed, and replaced. Other navies around the world have chosen to pursue construction modularity, not mission modularity. This approach puts more emphasis on open architecture for construction modules, than on mission specific modules. This system has seemed to reduce costs more than mission modularity. As a comparison, in the case of the LCS, the anticipated cost of the ship has risen. This though was one of the first attempts at a U.S. Navy mission modular ship, so advances in the process are surely possible.

In order to fully capitalize on the benefits of modularity it is important to consider it in areas applicable to change. This means being able to anticipate future weapon systems. Some areas considered for the SSC are; Rail guns and ADS systems. ADS systems include; CLASS-N, a compact lightweight multi-sensor naval system used for surveillance, target acquisition and as a weapon system director. A second system is the SNS-2, a ship navigation system that is adaptable for an integrated power system. Lastly, C-Eye is a midwave (3-5micron) staring FPA naval thermal imager used for long range day/night observation and target acquisition

In the consideration of modules, there are several key aspects to consider. Prepackaging makes installation and stowage aboard the SSC convenient and quick for mission adaptability. The containers themselves should be analyzed for space and weight saving. The pallets holding each module allow for ease of movement and storage aboard the SSC. The use of unstructured versus structured modules allows for further choices in the mission packages. Enhancement of capability through exchange of a module is very important. It does not make sense to create a mission module that retracts from the capabilities of the ship.
In order to implement modularity the platform should be divided into zones associated with functions. Separate zones for weapons, sensors, electronics, and machinery elements. Then, place module stations within zones. Include necessary interfaces: structural, compressed air, water, and electrical or hydraulic power. And to further benefit the entire fleet, develop rules that guide module design and interfaces within each zone. Below is a figure depicting possible zone configurations:

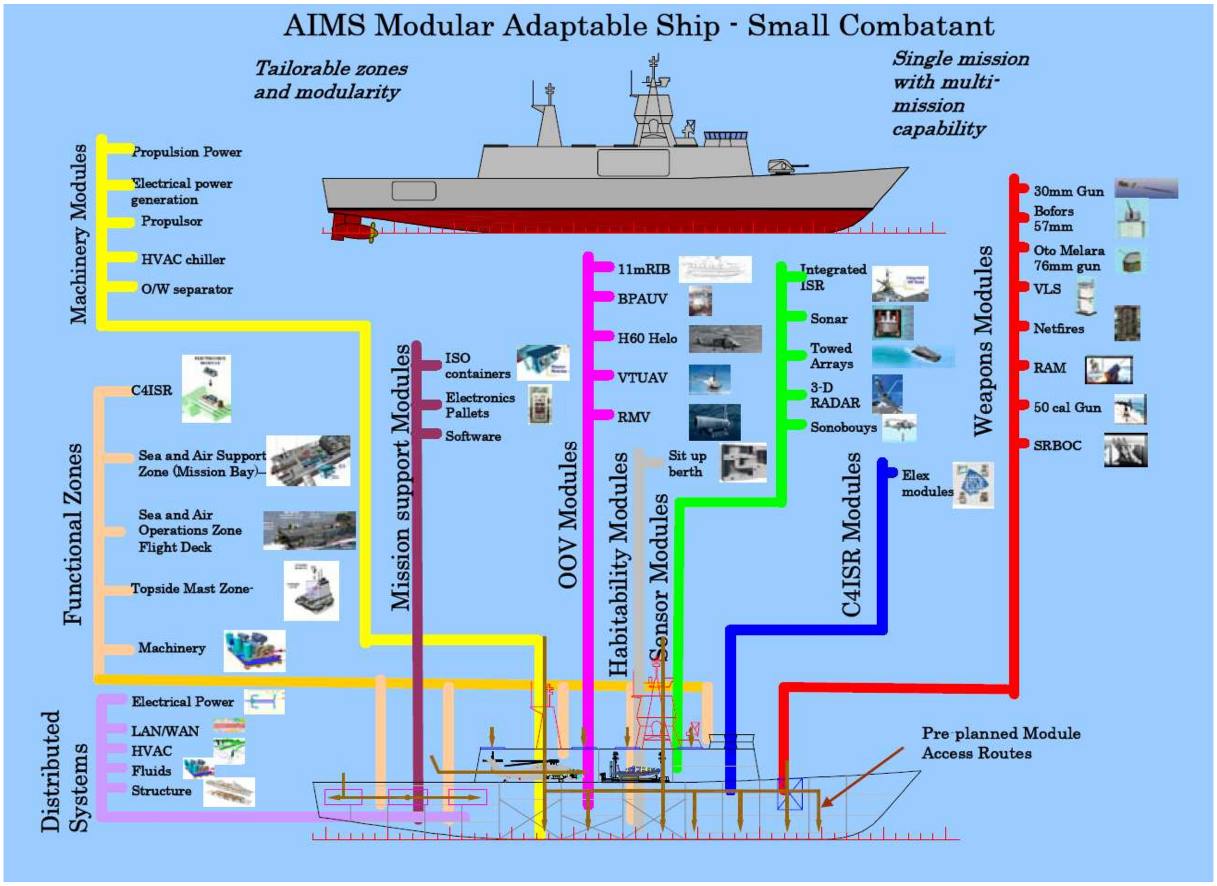


Figure 3 - Modularity System for a SSC

Figure 3 presents a possible schematic for implementing modularity in an SSC. The ship will be divided into sections for each module, not unlike presently used hull sections devoted to various systems. The difference will be that in a modular ship the sections will not be strictly devoted to one particular system. The areas will contain the necessary connections and power supplies for any proposed module. In the figure the colored lines are visual cues demonstrating where modules could be located along with what systems could be implemented in that area. The figure shows how multiple systems could be designed for placement in the ship allowing mission adaptability.

Figure 4 - Example Weapons Module

Figure 4 demonstrates the space saving capabilities of weapons modules. The right image is the weapon system in storage mode. This box could be stored in any easily accessible region of the ship, the optimum location would be where it could quickly be removed for installation. The left image is the weapon system in the process of being installed. The system is taken from its storage location, primed for installation by removing the protective casing, preparing connections, and then dropped into its appropriate location.

In the case of a truly adaptable platform, weight, space and service margins are designed into the platform. Ship services will be larger than normal to accommodate possibly increased demands for future systems. The modular ship services concept will design ship services to be easily upgradable. For example: Instead of one large genset, design ship with up to 4 smaller gensets, with each genset added when needed. The configuration of the spaces will correlate to module dimensions. A possible solution would be to develop a standard grid concept. This would mean space dimensions are multiples of standard modules, and installation and removal routes are designed for easy module installation and removal. Centralized ship service distribution centers could be located in areas where modules are installed. In the long run, removal and installation of modules should have little effect on surrounding structure.

3.2 Design Space

The Design Variables (DVs) are variables that are changed from design to design in order to find the optimal design for the necessary capabilities for a given mission or mission package. They include the general characteristics of the ship, propulsion systems, manning and sustainability considerations, as well as the necessary war-fighting packages. They are used to develop the Measures of Performance (MOPs) and the Values of Performance (VOPs).

Table 11 - Design Variables (DVs)

DV #	DV Name	Description	Design Space
1	LWL	Length at Waterline	90-110m
2	LtoB	Length to Beam ratio	6.5-8m
3	LtoD	Length to Depth ratio	8.5-12m
4	BtoT	Beam to Draft ratio	3-3.4m

5	VD	Deckhouse volume	4000-8000m^3
6	Cdmat	Hull Material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite
8	PSYS	Propulsion system alternative	Option 1) 4WJ (2x30MW, 2x6.5MWsteer), 2xLM2500, 2xCAT3616, 4xCAT3508B Option 2) 4WJ (2x35MW, 2x6MWsteer), 2xMT30, 2xSEMT16PA, 4xCAT3508B Option 3) 3WJ (2x30MW, 1x13MWsteer), 2xLM2500, 1xCAT3616, 4xCAT3508B Option 4) 3WJ (2x35MW, 1x12MWsteer), 2xMT50, 1xSEMT16PA6B, 4xCAT3508B Option 5) 3WJ (2x30MW, 1x6MWsteer, 1MW SPU), 2xLM2500, 1xCAT3616, 2xCAT3508B Option 6) 3WJ (2x35MW, 1x6MWsteer, 1MW SPU), 2xMT50, 1xSEMT16PA6B, 2xCAT3508B
9	Ts	Provisions duration	14 - 28 days
10	CPS	Collective Protection System	0 = none, 1 = partial, 2 = full
11	Ndegaus	Degaussing system	0 = none, 1 = degaussing system
12	Cman	Manning reduction and automation factor	0.5 – 0.1
13	AAW/SEW	AAW/SEW system Alternative	Option 1) Sea Giraffe AMB radar, 1xMK16, Ram/Searam, Mk XII AIMS IFF Option 2) Seapar MFR, 1xMK16, Ram/Searam, MK XII AIMS IFF Option 3) EADS TRS-3D C-Band Radar, 1xMK16, Ram/Searam, Combat DF
14	ASUW	ASUW system alternative	Option 1) SPS-73, 1x30mm CIG, 57mm MK3
15	ASW/MCM	ASW/MCM system alternative	Option 1) SQS-56, Nixie, 2xMK 32 Triple Tubes, MK 309 Torpedo FCS, SQQ 89 FCS Option 2) SQS-56, Nixie, 2xMK 32 Triple Tubes, SQQ 89 FCS
16	C4ISR	C4ISR system alternatives	Option 1) Comm Suite Level A, CTSCE Option 2) Comm Suite Level B, CTSCE
17	LAMPS	LAMPS system alternatives	Option 1) Dual SH-60 Option 2) SH-60

3.3 Ship Synthesis Model

The Ship Synthesis Model is responsible for making sure that the design of the ship is feasible. The design must be balanced by making sure the weight and displacement are equal, the volume, space, electrical power and stability of the ship are adequate. The main concern is to make sure that the ship will be able to meet the requirements set for it in performance, cost, risk, and effectiveness. An engineering analysis is needed to be performed in order to verify these requirements, and the ship synthesis model aids in this process. The ship synthesis model is made up of modules and file wrappers that represent each design requirement and their codes, which will determine the design attributes of the ship. Figure 5 below shows the flowchart for the ship synthesis model, and each module is described thereafter.

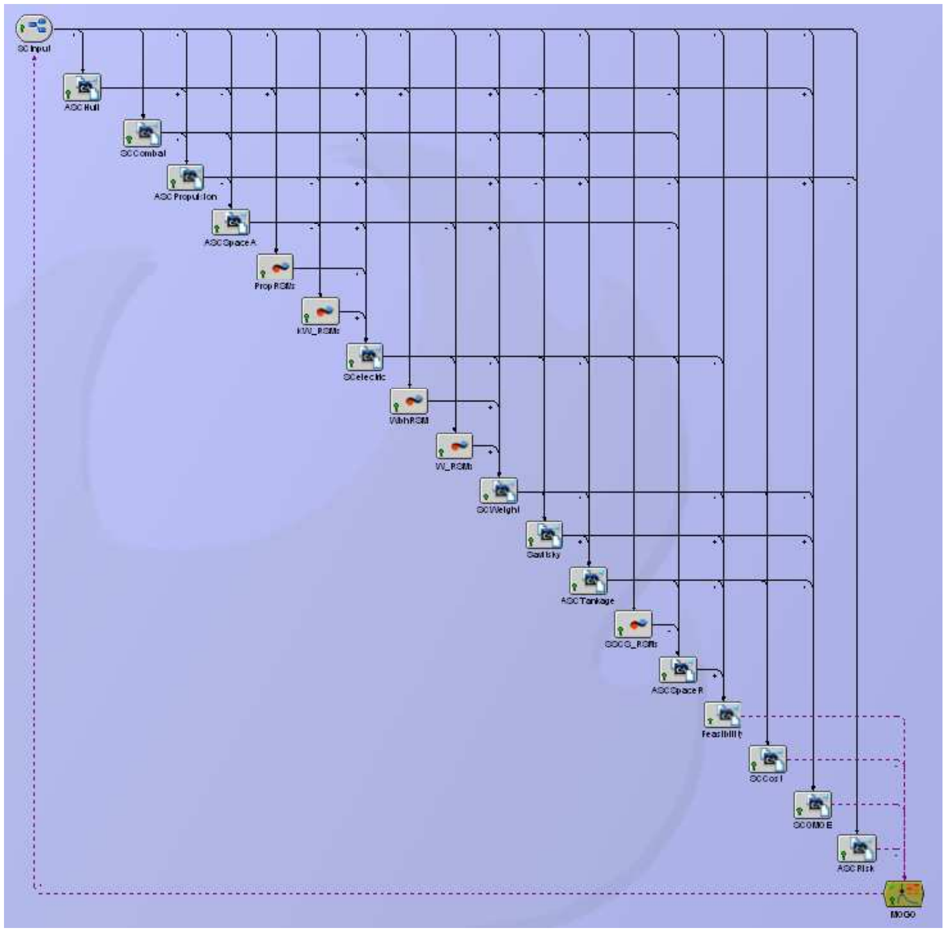


Figure 5 - Ship Synthesis Model in Model Center (MC)

Each of these modules is composed of FORTRAN computer code that will calculate the output variables based on the given input variables. Both the input and output variables are linked in Model Center. Model Center will manage all of these inputs and outputs together so long as everything is linked together properly. Once linked together, the entire synthesis model will run correctly and will produce a ship that will meet all of the constraints set in the input module.

The first module that is seen is the Input module. This module is not FORTRAN code, but rather a list of all of the input parameters needed to run the synthesis model. The list is comprised of integers and doubles that are all given values based on the ASSET baseline design, and those values are then subsequently linked to each module following. Without this input file, the synthesis module would not be able to run.

The ASCHull module is the first of the FORTRAN codes that is run, and it performs calculations that are associated with the hull of the ship. It takes inputs for waterline length, beam, depth at station 10, draft, and maximum section coefficient. These inputs are then run through the code and surface area, volume of the full load displacement, waterplane coefficient, volumetric coefficient, beam to draft ratio, and block coefficient.

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

The propulsion module then calculates the characteristics as delta from the baseline. This module calculates the propulsion and generator system characteristics. Then the module outputs the propulsive coefficient, 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 main engine power available, number of propellers, database PGM engine number, the database SPGM engine number, and number of PGMs.

Following this, the space available module calculates the amount of space that is available for use based on the characteristics of the hull form. It calculates the available volume for the machinery box, total hull, cubic number, minimum depth at station 10, and the average depth of the hull form from deck edge to the baseline the entire length of the ship. It calculates this based on inputs from the Input module, hull module, and propulsion module.

The electric module calculates the required power for the ship design. The ship size, combat systems, and propulsion are important factors that go into determination of electrical requirements. It calculates the electrical load as well as auxiliary machinery room volume. This module also performs the manning calculation.

The weight module calculates the weight and organizes weight based on SWBS number. This module calculates loads such as the water, fuel, and lube oil, vertical center of gravity, and weights in each single digit group (100-700). It also calculates overall KG, KB and from those values is able to calculate GM. It is also able to give an estimate of the stiffness and stability in roll based on the waterplane. From there, it is possible to calculate the weight and finally the stability of the ship.

The Savitsky module calculates the resistance of the ship by using the Savitsky method. It also calculates performance parameters such as required endurance shaft horsepower, sustained speed, and diameter of the propeller.

The tankage module calculates the requirements for the ship's tankage. This outputs the total tankage volume, endurance range from endurance fuel calculation, gallons per year used, fuel volume, and average effective break horsepower.

The space required module estimates the required space needed on the ship based on calculations for systems volume requirements. This is to ensure that the design is adequate to have these systems installed on board. Its main goal is to ensure that the required volume and area are less than the available space modules calculated volume and area. This module calculates the required deckhouse area, available deckhouse area, total required volume, and available required volume.

The feasibility module is responsible for checking the calculated parameters such as space, weight, and minimum performances to ensure that the ship meets design requirements. It will output the feasibility ratio, electric power feasibility ratio, deckhouse area feasibility ratio, minimum and maximum GM/B feasibility ratio, endurance range feasibility ratio, hull depth feasibility ratio, and total area available to be arranged.

The cost module calculates the lead, follow acquisition, and lifecycle costs for the ship. This module outputs the lead ship cost, average follow ship acquisition cost, discounted lifecycle fuel cost over 30 years, follow ship total ownership cost, and discounted life cycle manning cost over 30 years.

The OMOE module calculates the overall measurement of effectiveness for the ship. It analyzes the performance of each aspect of the ship and assigns it a value based on its performance. Certain attributes are more effective than others in improving ships performance, based on criteria set up before the design process begins. Newer technologies generally offer better effectiveness than older designs.

The risk module is responsible for calculating the overall measure of risk. This module analyzes the risks of each aspect in the design and determines how it will affect the risk of the entire ship. New technologies and higher automated systems are generally considered to be higher risk than the older technologies that have been proven over many years.

In addition, Response Surface Models were created and linked in to all of the other modules in order to complete the ship synthesis model. A Response Surface Model is a methodology that uses a Design of Experiments to obtain an optimal response. This RSM uses statistical models to approximate reality. In this ship synthesis model, there are 5 RSMs that are used: Prop, KW, Wbh, W, and SSCS. To create these RSMs, the baseline design is opened in ASSET, Model Center is opened with the MC/ASSET Interface model, and the DOE tool is selected. Then, the specific RSM attribute is selected and design variables are changed to match the design specified. 3 level full factorial DOEs are then run for each RSM, and the RSMs are finally constructed using the RSM toolkit. Once the RSMs are constructed, they are added into the ship synthesis model and linked.

Figure 6, below, shows the inner workings of one of the RSMs, the Hull Volume RSM. Figure 7 shows this data in a graphical form.

HullVolume - Response Surface 6

Stepwise Regression (cubic)
Response Transformation: Z=Y (None)
Fin = 0.20
Fout = 0.20

SOURCE	DF	SS	MS	F	Fsig(%)
REGRESSION	20	0.2062940E+12	0.1031470E+11	0.1453832E+04	0.0000
RESIDUAL ERROR	708	0.5023144E+10	0.7094837E+07		
TOTAL	728	0.2113172E+12			

PREDICTOR	COEF	scaledCOEF	STDERR
Constant	-.8822090E+06		
LBP	0.1471941E+05	0.1411793E+02	0.1244424E+01
LBPB*LBPB	0.8373671E+04	0.1025344E+02	0.3152540E+01
LBPD10*LBPD10	0.5943020E+04	0.1483506E+02	0.3113959E+01
LBP*LBPB	-.1483900E+04	-.2367981E+02	0.3079458E+01
LBP*LBPD10	-.1361306E+04	-.3013453E+02	0.3313235E+01
LBPB*LBPD10	0.1115600E+05	0.1390246E+02	0.1970154E+01
LBP*LBP*LBP	-.2075512E+00	-.2167855E+02	0.1017965E+01
LBPB*LBPB*LBPB	-.5149918E+03	-.8154237E+01	0.2139970E+01
LBPD10*LBPD10*LBPD10	0.3373968E+03	0.1660056E+02	0.2216044E+01
LBP*LBP*LBPB	0.9849564E+00	0.4019020E+01	0.1741826E+01
LBP*LBP*LBPD10	0.9852076E+01	0.5827886E+02	0.1893853E+01
LBP*LBP*Cp	0.8652837E+00	0.1989682E+00	0.6178166E-01
LBP*LBP*CRDaft	0.2868319E+00	0.8244469E-01	0.6178166E-01
LBP*LBPB*LBPB	0.6850855E+02	0.1671532E+02	0.1388706E+01
LBP*LBPB*LBPD10	-.1547301E+02	-.4026238E+01	0.7854370E+00
LBP*LBPD10*LBPD10	-.9730184E+02	-.4901099E+02	0.1612632E+01
LBPB*LBPB*LBPD10	-.6286865E+03	-.1102314E+02	0.9979565E+00
LBPB*LBPD10*LBPD10	0.1303835E+03	0.3225609E+01	0.1056065E+01
LBPB*Cp*CRDaft	-.2696369E+04	-.9920413E-01	0.5581320E-01
Cp*Cx*CRDaft	0.4089293E+05	0.7997238E-01	0.1032136E-01

DATA FOR RESPONSE VARIABLE (Y)

S = 0.2663613E+04
Yavg = 0.5357663E+05
CoV = 4.97%

R-Sq = 97.62%
R-Sq(adj) = 97.56%

Figure 6 - Hull Volume RSM

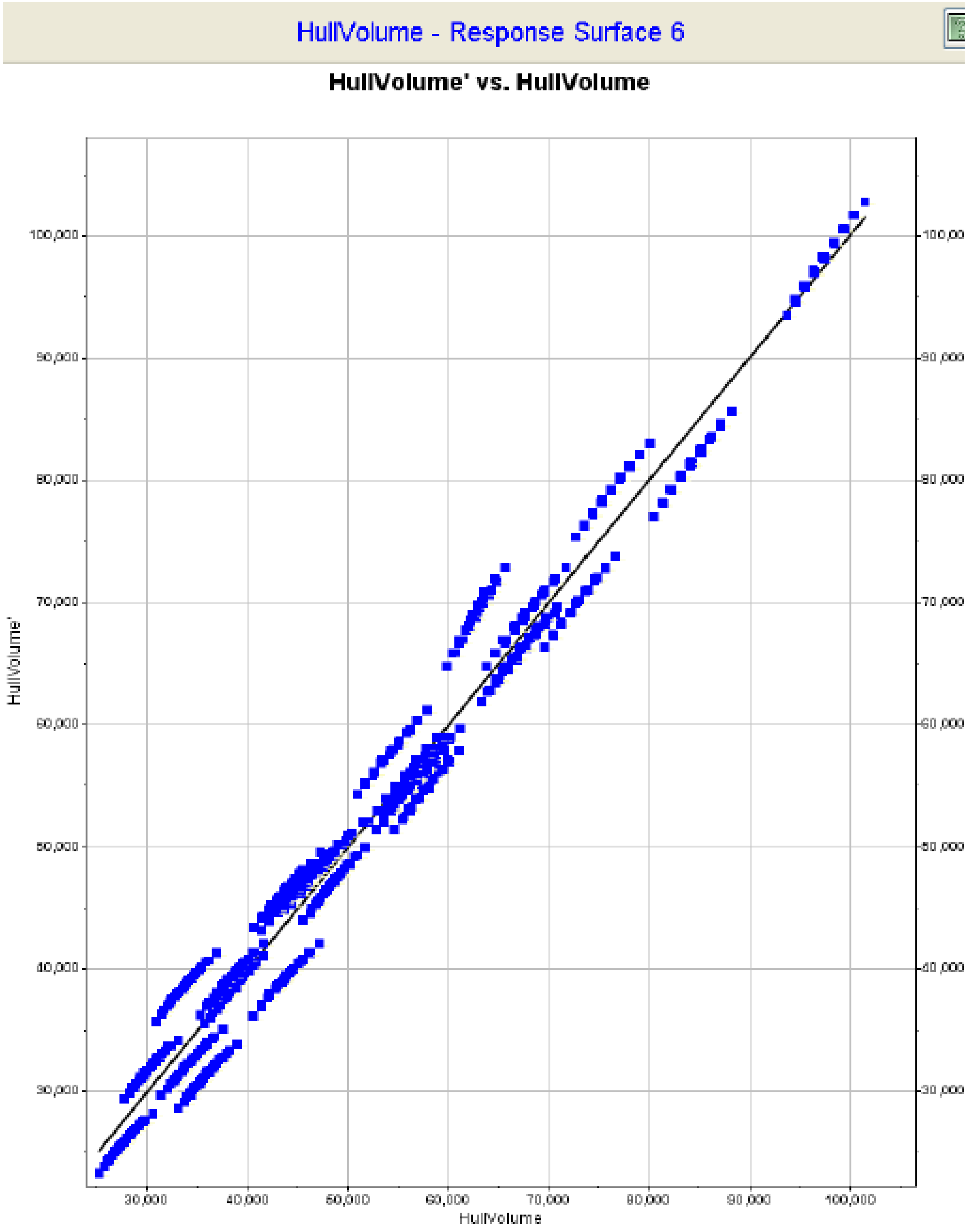


Figure 7 - Hull Volume RSM in Graphical Form

3.4 Objective Attributes

3.4.1 Overall Measure of Effectiveness (OMOE)

The Overall Measure of Effectiveness (OMOE) is a single overall figure of merit index (0-1.0) describing ship effectiveness for specified missions. In order to calculate the OMOE, we take our Measures of Performance (MOPs), which are ship or system performance metrics in required capabilities that are independent of the mission (speed, range, number of missiles), and our Values of Performance (VOP), which are figure of merit indices (0-1.0) specifying the value of a specific MOP to a specific mission area for a specific mission type, and insert these values into the following equation:

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

Ideally, war-gaming simulations would be used to predict measures of effectiveness for the matrix of ship performance inputs (DOE) in a series of probabilistic scenarios. A regression analysis (RSM) would then be applied to the results in order to define the mathematical relationship between the input ship MOPs and output effectiveness. However, due to constraints, we used expert opinion to integrate these diverse inputs and assess the value or utility of ship MOPs for a given mission, force, and threat. These values are detailed in Tables 12 and 13.

Table 12 - 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=10	LtoB=7
		MOP 15 - Es	LtoD	LtoD=17.8	LtoD=10.75
		MOP 15 - Es	BtoT	BtoT=3.2	BtoT=2.8
		MOP 15 - Es	PSYS	PSYS=1	PSYS=6
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=7	LtoB=10
		MOP 11 - Seakeeping and Stability	LtoD	LtoD=10.75	LtoD=17.8
		MOP 11 - Seakeeping and Stability	BtoT	BtoT=2.8	BtoT=3.2
		MOP 10 - RCS	VD	VD=200,000ft3	VD=140,000ft3
		MOP 12 - VUL	Cdmat	Cdmat=1	Cdmat=2 or 3
		MOP 7 - IR	PSYS	PSYS=1	PSYS=6
		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			
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=10 LtoD=17.8 BtoT=3.2 PSYS=1 Ts=21 days	LtoB=7 LtoD=10.75 BtoT=2.8 PSYS=6 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 LtoD=10.75 BtoT=2.8	LtoB=10 LtoD=17.8 BtoT=3.2
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/SEW	AAW/SEW=1	AAW/SEW=4
AAW 2	Provide anti-air defense in cooperation with other forces	MOP 1 - AAW MOP 1 - AAW	AAW/SEW C4ISR	AAW/SEW=1 C4I=1	AAW/SEW=4 C4I=2
AAW 5	Provide passive and soft kill anti-air defense	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=4
AAW 6	Detect, identify and track air targets	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=4
AAW 9	Engage airborne threats using surface-to-air armament	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=4
ASU 1	Engage surface threats with anti-surface armaments	MOP 2 - ASUW MOP 2 - ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=3 LAMPS=3
ASU 1.3	Engage surface ships at close range (gun)	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
ASU	Engage surface	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3

1.5	ships with medium caliber gunfire				
ASU 1.6	Engage surface ships with minor caliber gunfire	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
ASU 1.9	Engage surface ships with small arms gunfire	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
ASU 2	Engage surface ships in cooperation with other forces	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
		MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
ASU 4.1	Detect and track a surface target with radar	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
		MOP 2 - ASUW	LAMPS	LAMPS=1	LAMPS=3
ASU 6	Disengage, evade and avoid surface attack	MOP 2 - ASUW	ASUW	ASUW=1	ASUW=3
ASW 1.3	Engage submarines at close range	MOP 3 - ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 4	Conduct airborne ASW/recon	MOP 3 - ASW MOP 3 - ASW MOP 3 - ASW	LAMPS ASW/MCM C4ISR	LAMPS=1 ASW/MCM=1 C4ISR=1	LAMPS=3 ASW/MCM=4 C4ISR=2
ASW 5	Support airborne ASW/recon	MOP 3 - ASW MOP 3 - ASW	LAMPS C4ISR	LAMPS=1 C4ISR=1	LAMPS=3 C4ISR=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=10 LtoD=17.8 BtoT=3.2 PSYS=1 ASW/MCM=1	LtoB=7 LtoD=10.75 BtoT=2.8 PSYS=6 ASW/MCM=4
MIW 4	Conduct mine avoidance	MOP 3 - ASW	ASW/MCM	ASW/MCM=1	ASW/MCM=4
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 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 3	Provide own unit Command and Control	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC	Maintain data	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2

4	link capability				
CCC 6	Provide communications for own unit	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 9	Relay communications	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
CCC 21	Perform cooperative engagement	MOP 4 - C4ISR	C4ISR	C4ISR=1	C4ISR=2
SEW 2	Conduct sensor and ECM operations	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=4
SEW 3	Conduct sensor and ECCM operations	MOP 1 - AAW	AAW/SEW	AAW/SEW=1	AAW/SEW=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	C4ISR LtoB LtoD BtoT PSYS ASUW LAMPS	C4ISR=1 LtoB=10 LtoD=17.8 BtoT=3.2 PSYS=1 ASUW=1 LAMPS=1	C4ISR=2 LtoB=7 LtoD=10.75 BtoT=2.8 PSYS=6 ASUW=3 LAMPS=1
INT 1	Support/conduct intelligence collection	MOP 6 - MCM MOP 6 - MCM	LAMPS C4ISR	LAMPS=1 C4ISR=1	LAMPS=3 C4ISR=2
INT 2	Provide intelligence	MOP 6 - MCM MOP 6 - MCM	LAMPS C4ISR	LAMPS=1 C4ISR=1	LAMPS=3 C4ISR=2
INT 3	Conduct surveillance and reconnaissance	MOP 6 - MCM MOP 6 - MCM	LAMPS C4ISR	LAMPS=1 C4ISR=1	LAMPS=3 C4ISR=2
LOG 1	Conduct underway replenishment	Required in All Designs			
LOG 2	Transfer/receive cargo and personnel (CONREP)	Required in All Designs			
LOG 6	Provide airlift of cargo and personnel (VERTREP)	MOP 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	ASUW	ASUW=1	ASUW=3

		MOP 13 - Vs	LtoB	LtoB=10	LtoB=7
		MOP 13 - Vs	LtoD	LtoD=17.8	LtoD=10.75
		MOP 13 - Vs	BtoT	BtoT=3.2	BtoT=2.8
		MOP 13 - Vs	PSYS	PSYS=1	PSYS=6

Table 13 - MOP Table

MOP#	MOP	Goal	Threshold	Related DV
1	AAW	AAW/SEW=1 C4I=1	AAW/SEW=3 C4I=2	AAW/SEW option C4I option
2	ASUW/NSFS	ASUW=1 Mod SUW=1 LAMPS=1 C4I=1	ASUW=1 Mod SUW=5 LAMPS=2 C4I=2	ASUW option Mod SUW option LAMPS option C4I option
3	ASW/MCM	ASW/MCM=1 Mod MIW/MCM=1 Mod ASW=1 LAMPS=1 C4I=1	ASW/MCM=2 Mod MIW/MCM=6 Mod ASW=4 LAMPS=2 C4I=2	ASW/MCM option Mod MIW/MCM option Mod ASW option LAMPS option C4I option
4	C4ISR	C4I=1	C4I=2	C4I option
5	MISMOD	LAMPS=1	LAMPS=2	LAMPS option
6	MCM	LAMPS=1 C4I=1	LAMPS=2 C4I=2	LAMPS option C4I option
7	IR	SPGM=1	SPGM=0	SPGM Option
8	Magnetic	Ndegaus=1	Ndegaus = 0	Degaussing Option
9	NBC	Ncps=2	Ncps=0	CPS option
10	RCS	VD=4000	VD=8000	Deckhouse volume, m^3
11	Seakeeping and Stability	LtoB=8 LtoD=12 BtoD=3.4	LtoB=6.5 LtoD=8.5 BtoD=3	LtoB LtoD BtoD
12	VUL (Vulnerability)	Cdmat=1	Cdmat=3	Ship material
13	Vs (Sprint Speed)	50	40	knots
14	Ts (Provisions)	28	14	days
15	Es (Endurance range at 18 kt)	6000	3000	nm
16	Draft	3	5	m
17	Acoustic signature	PSYS=3,4	PSYS=1,2,5,6	PSYS Option

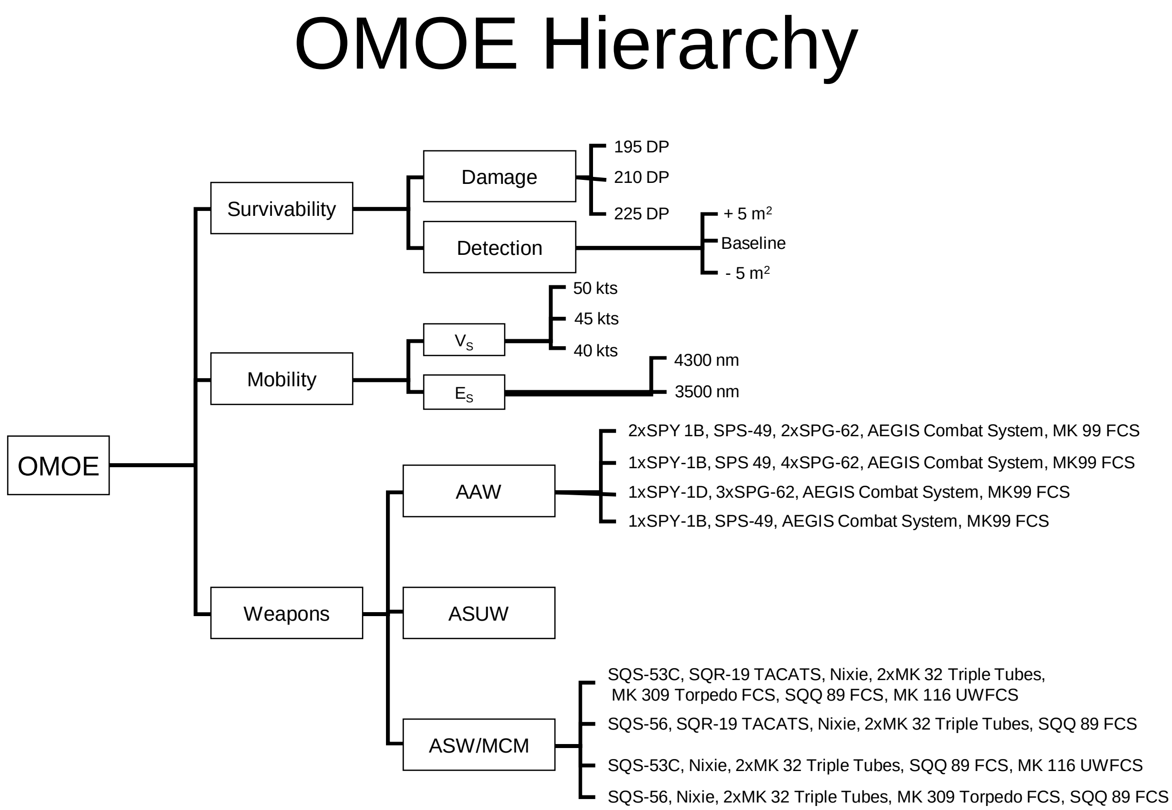


Figure 8 - OMOE Hierarchy

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

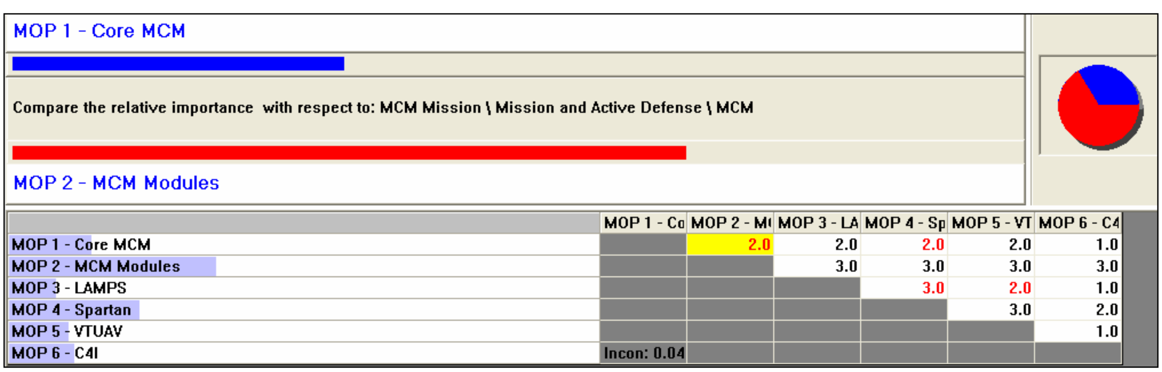


Figure 9 - AHP Pairwise Comparison

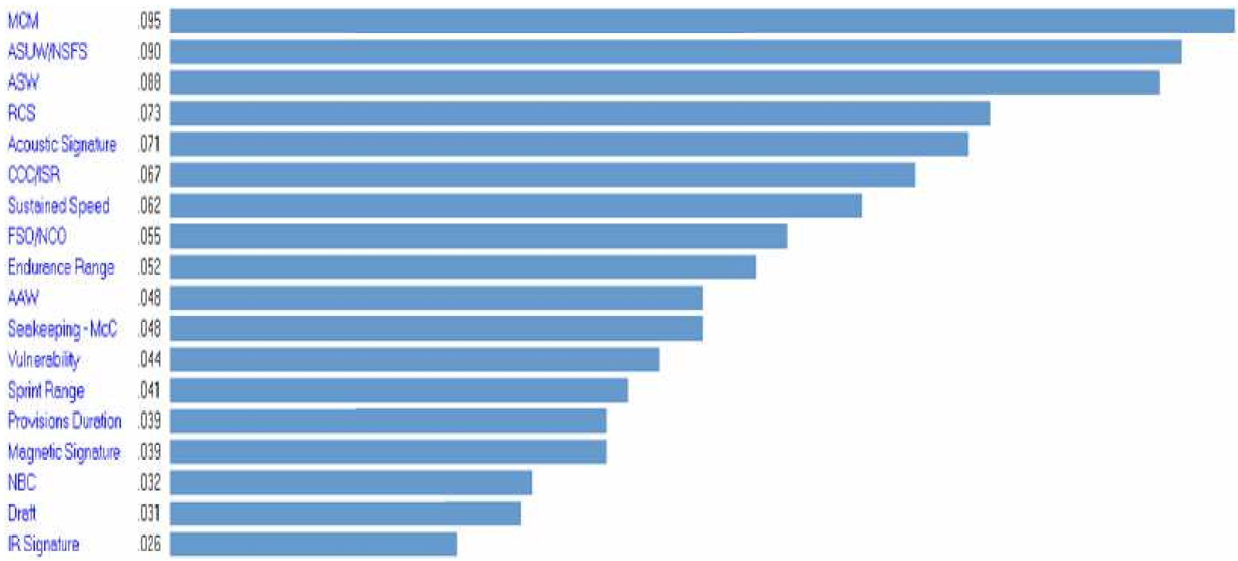


Figure 10 - Bar Chart showing MOP Weights

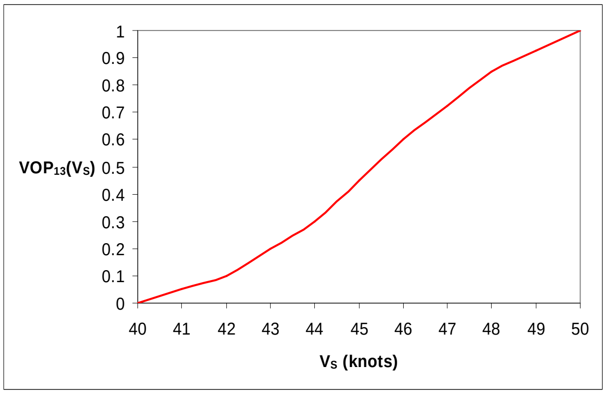


Figure 11 - Value of Performance Function for Sprint (Sustained) Speed

3.4.2 Overall Measure of Risk (OMOR)

The Overall Measure of Risk (OMOR) is very important in ship design. Knowing the OMOR for a specific design and certain technology choices helps designers make an informed decision regarding the technology choices and the amount of risk they are willing to accept. Using the equation below, a quantitative overall measure of risk can be determined for a specific design with certain technology selections. Three types of risks are considered when determining the value for the overall measure of risk. They include performance, cost, and schedule. To begin, risk events associated with specific design variables, required capabilities, schedule, and cost must be identified. Next, the probability of occurrence, P_i, and the consequence of occurrence, C_i, for each event should be estimated using Table 4 and Table 5. The risk for each event should be calculated next by multiplying P_i and C_i together. The weights of each type of risk should also be estimated. Finally, using the equation below, the OMOR can be calculated.

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

Table 10 - Risk Register

SWBS	Risk Type	Related DV #	DV Options	DV Description	Risk Event Ei	Risk Description	Event #	Pi	Ci	Ri
1	Performance	5	2	Hull Material Type	Implementation problems	USN lack of experience with aluminum	1	0.5	0.7	0.35
1	Performance	5	3	Hull Material Type	Implementation problems	USN lack of experience with advanced composite	2	0.5	0.7	0.35
1	Performance	6	1,2	Hullform	Unable to accurately predict seakeeping performance	lack of data available for planing hulls	3	0.5	0.5	0.25
1	Performance	6	1,2	Hullform	unable to accurately predict resistance performance	lack of data available for planing hulls	4	0.4	0.5	0.2
2	Performance	7	2	Integrated Power System	Develop and use of new IPS system	new equipment and systems will have reduced reliability	5	0.4	0.4	0.16
2	Cost	7	2	Integrated Power System	Development and integration of new IPS systems will have cost	unexpected problems with new equipment and systems	6	0.3	0.6	0.18
2	Schedule	7	2	Integrated Power System	Development and integration of new IPS systems will be behind schedule	unexpected problems with new equipment and systems	7	0.3	0.3	0.09
4	Performance	11	0.5-1.0	Manning and Automation Factor	Development and integration of automation systems	equipment and systems will have reduced reliability	8	0.3	0.7	0.21
4	Cost	11	0.5-1.0	Manning and Automation Factor	Development and integration of automation systems will have cost overruns	unexpected problems with new equipment and systems	9	0.4	0.4	0.16

4	Schedule	11	0.5-1.0	Manning and Automation Factor	Development and integration of automation systems will be behind schedule	unexpected problems with new equipment and systems	10	0.4	0.4	0.16
7	Performance	14	4	MCM Alternative	Development of new technologies and integration of modules	new equipment and systems will have unknown reliability	11	0.4	0.6	0.24
7	Performance	12	1	VTUAV Alternative	Development of new technologies	new technologies will have only been used in test runs, never real situations and therefore will have reduced reliability	12	0.3	0.5	0.15
7	Performance	13	3	SPARTAN Alternative	Development of new technologies	new technologies will have only been used in test runs, never real situations and therefore will have reduced reliability	13	0.2	0.3	0.06

Table 15 - 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 16 - 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%

OMOR = 3.568055556

3.4.3 Cost

There are many things to consider in the cost of a ship. The life cycle cost of a ship is significantly different from the acquisition cost because it also includes the ownership of the ship over its useful life span. The life cycle cost of the ship includes but is not limited to development, acquisition, operations, support, logistics, and disposal costs. A parametric method is used in calculating cost. It is a statistical method using “like” elements to relate weight and other parameters to cost. In a cost model the following inputs are used: power and propulsion system, deck house material, speed and endurance range, fuel volume, SWBS weight groups 100-700, number of personnel, profit margin, inflation rate, number of ships to be built, and base year for cost calculations. Using the inflation factor the cost for each SWBS group 100-700 is calculated. The weight of each group is multiplied by complexity factors. This total is then multiplied by margin weight and added to SWBS 800, 900 costs to end up with a lead ship basic construction cost. Adding change order costs, government costs, and delivery costs produces a final acquisition cost for the lead ship. The quality of the cost estimate is important but usually a class D estimate of within 20% is adequate. Building more ships is cost effective because the lead ship is more expensive due to design costs. It also requires more effort from the shipyard because each time they build a new ship they “learn” how to put it together. When building multiple ships the shipyard will learn to build each ship more efficiently. A learning factor helps estimate the cost of the follow ships.

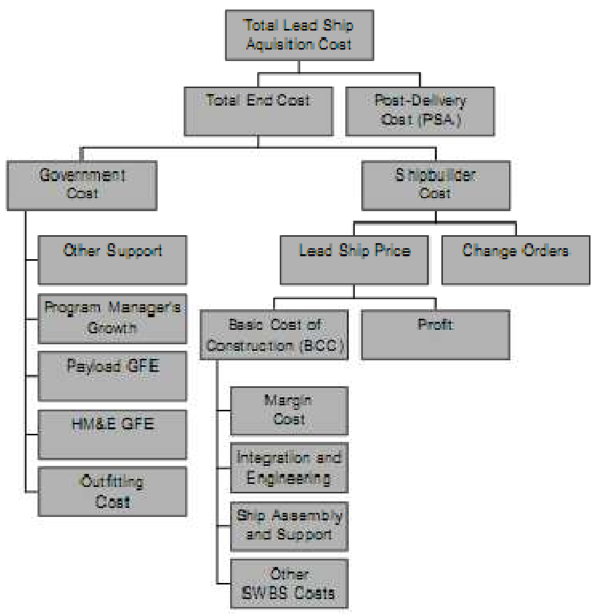
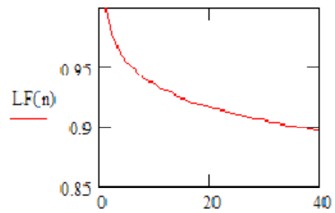


Figure 12 - Naval Ship Acquisition Cost Components

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



Average Follow Ship Learning Cost Factor:

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

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

Figure 13 - Learning Factor

3.5 Multi-Objective Optimization

The Multi-Objective Genetic Optimization (MOGO) is a process where multiple objectives are chosen and are optimized. For this design, the objectives are Cost, Effectiveness, and Risk. Cost and Risk are minimized and Effectiveness is maximized. The constraints are based on feasibility. The Darwin input screens are used to specify the MOGO parameters. The first section of the Darwin optimizer contains the objectives that are to be evaluated. The second section contains system constraints. The third section takes into account all desired design variables.

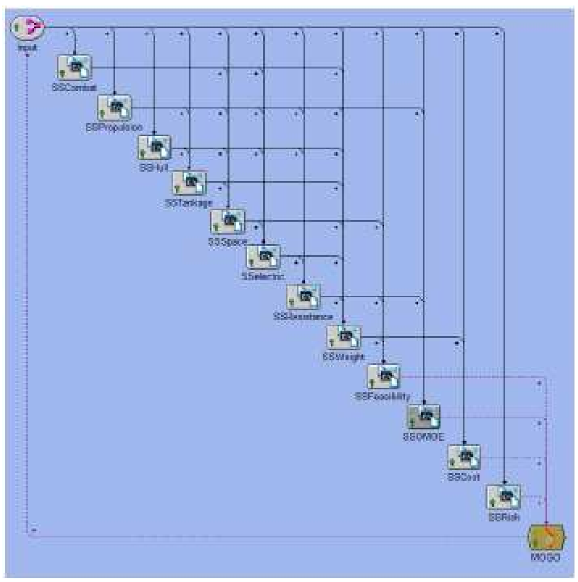


Figure 14 - Multi-Objective Genetic Optimization (MOGO)

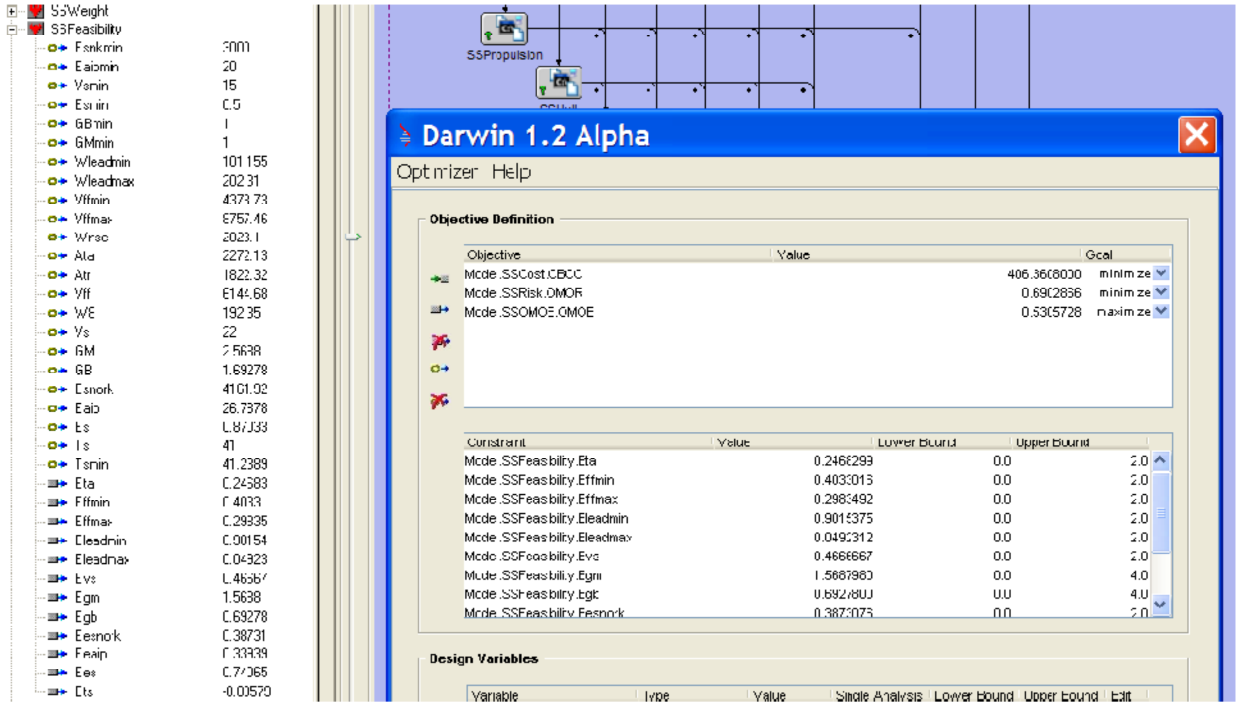


Figure 15 - Darwin Optimizer Objectives and Constraints

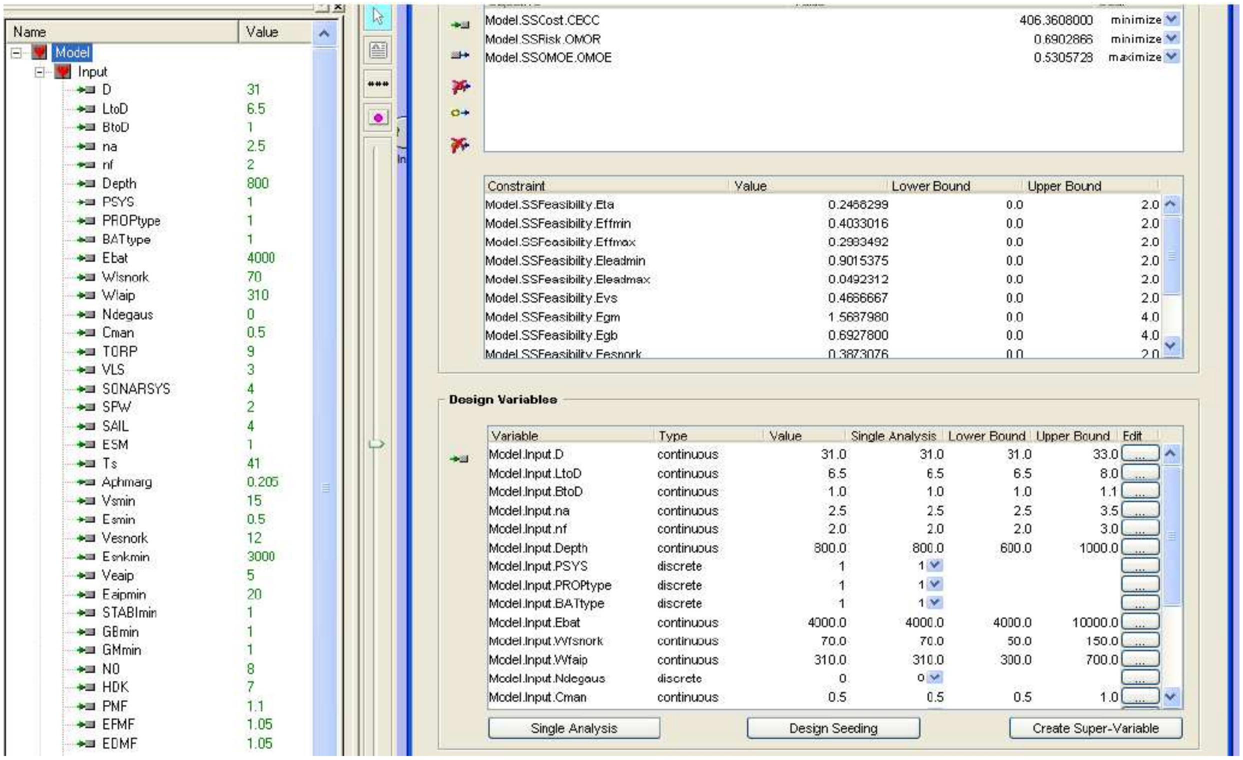


Figure 16 - Darwin Optimizer Design Variables

3.6 Optimization Results and Initial Baseline Design (Variant 51)

The non-dominated frontier presented in Figure 17 show the relationship between cost, effectiveness, and risk. Figures 17 and 18 show that the most effective designs are some of the cheapest; however, those designs are high risk. For the purposes of this design, high risk designs are more likely to be looked at. It is interesting to note that as cost increases, the overall effectiveness and risk decreases. The designs that will be used in this report will be those that fall in the range of high risk, high effectiveness, and low cost.

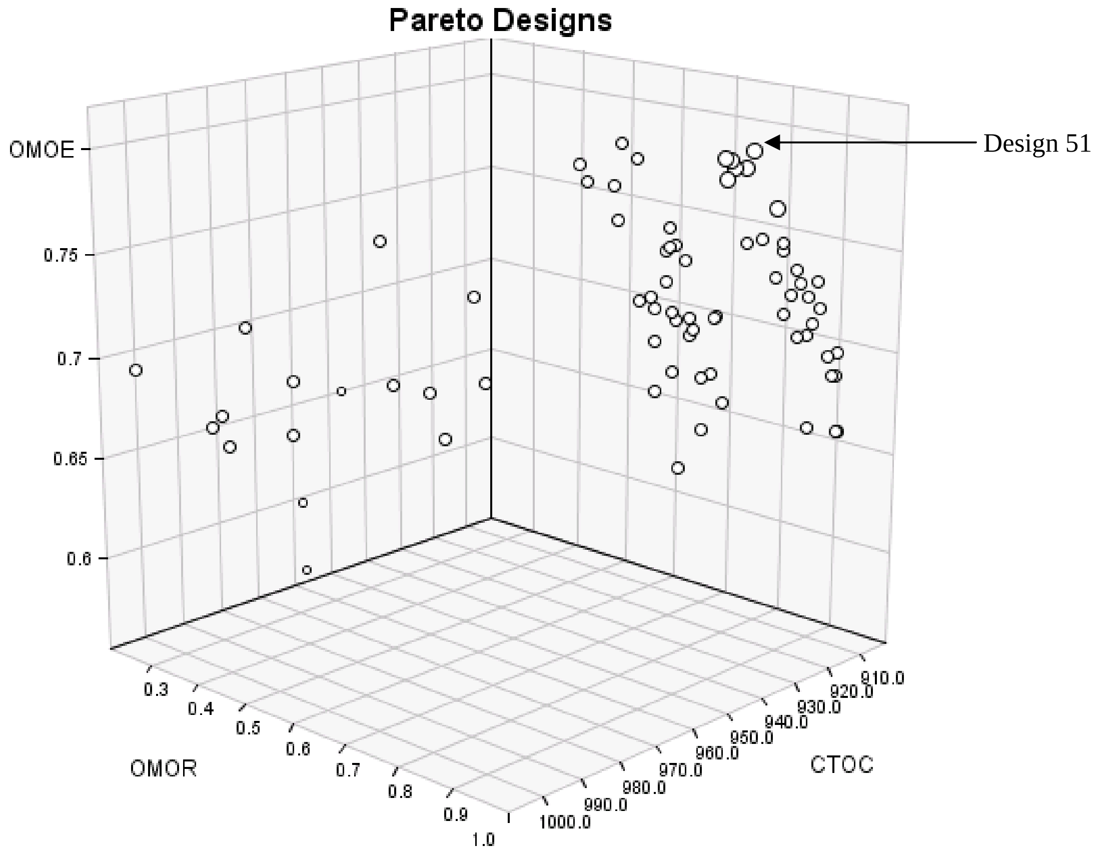


Figure 17 - 3D Non-Dominated Frontier

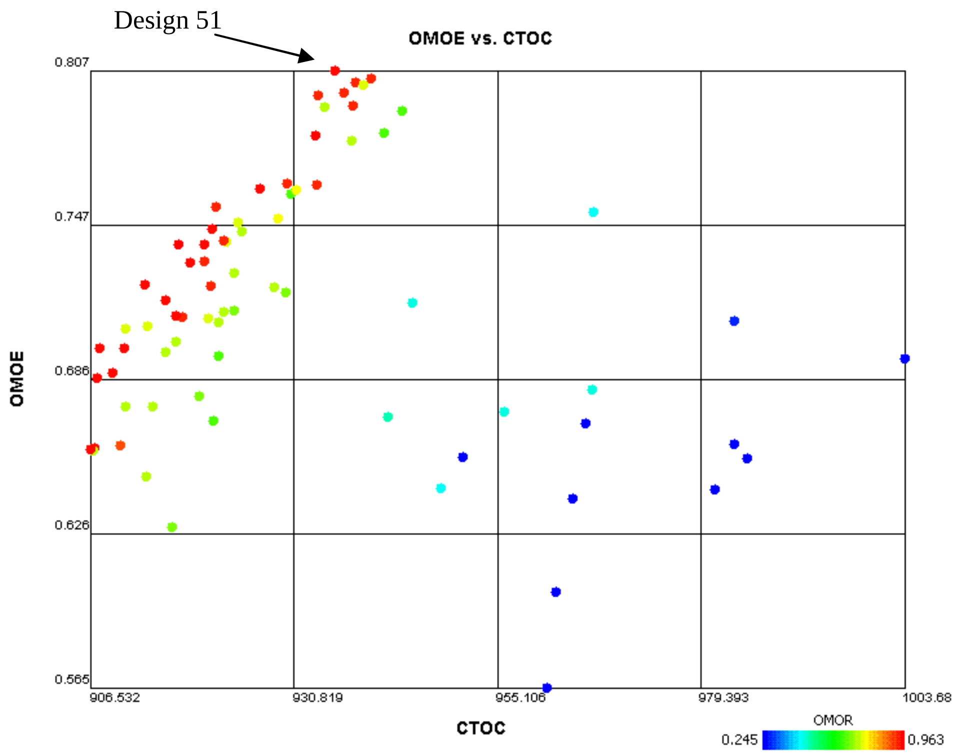


Figure 18 - 2D Non-Dominated Frontier

3.7 Improved Baseline Design – Single Objective Optimization

Design 51 was chosen to be further optimized using Model Center's gradient optimizer tool. This tool allows the fine tuning of continuous design variables in order to maximize or minimize a certain characteristic, usually cost, or OMOE. In our single objective optimization, cost was chosen two be minimized, while putting constraints on other variables in order to keep them within required values. Generally, other cost and risk variables were given upper bounds equal to their current values obtained from the Multi-Objective optimization. The Single Objective Optimizer was successful in creating a better design than Design 51. The cost was reduced from $952.6 million to $921.7 million for the initial ship, and the follow up acquisition ship cost was reduced from $387 million to $381 million. These cost savings come from making the ship smaller, from 108m to 106m in length, increasing the length to beam ratio resulting in a skinnier ship, and increasing the length to depth making a ship which has less volume under the surface. In addition, the manning factor was increased, which results in less automation. This cuts down on the need to purchase expensive machinery, and can use simpler technologies that are operated by ship personnel.

The tables following show the Design Variables of the ship and their final values for the optimized results:

Table 17 - Design Variables Summary

Design Variable	Description	Trade-off Range	Initial Baseline (Variant 51)	Improved Baseline
LWL	Waterline Length	90-110	108.75	106.839
CMan	Manning factor	0.7-0.8	0.788	0.8
LtoB	Length to Beam	6.5-8	7.978	8
VD	Volume Displacement	5000-6000	5755	5612.83
LtoD	Length to Depth	8.5-11.5	10.473	10.2827
Beta	Deadrise Angle	12-14	13.578	14
Ccg		.35-.45	0.3643	0.3801
Crd		0.6-0.7	0.619	0.65

Table 18 – Improved Baseline Weights and Vertical Center of Gravity Summary

Group	Weight	VCG
SWBS 100	0.01	10.4355
SWBS 200	557.7	3.84
SWBS 300	144.7	6.07
SWBS 400	72.0192	11.6869
SWBS 500	9.88	9.4649
SWBS 600	0.01	10.4355
SWBS 700	22.5	10.7846
Loads		
Lightship	2480.63	5.77355
Lightship w/Margin		
Full Load w/Margin		

Table 19 – Improved Baseline Area Summary

Area	Required	Available
Total-Arrangeable		
Hull		
Deck House		

Table 20 – Improved Baseline Electric Power Summary

Group	Description	Power
SWBS 200	Propulsion	
SWBS 300	Electric Plant, Lighting	
SWBS 430, 475	Miscellaneous	
SWBS 521	Firemain	
SWBS 540	Fuel Handling	
SWBS 530, 550	Miscellaneous Auxiliary	
SWBS 561	Steering	
SWBS 600	Services	
CPS	CPS	
KW_{NP}	Non-Payload Functional Load	
KW_{MFLM}	Max. Functional Load w/Margins	
KW_{24}	24 Hour Electrical Load	

Table 21 – Improved Baseline MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Value of Performance
MOP 1		
MOP 2		
MOP 3		
MOP 4		
MOP 5		
MOP 6		
MOP 7		
MOP 8		
MOP 9		
MOP 10		
MOP 11		
MOP 12		
MOP 13		
MOP 14		
MOP 15		
MOP 16		
MOP 17		
MOP 18		
MOP 19		
MOP 20		
MOP 21		
MOP 22		
MOP 23		
OMOE	Overall Measure of Effectiveness	
OMOR	Overall Measure of Risk	

Table 22 – Improved Baseline / ASSET Design Principal Characteristics

Characteristic	Improved Baseline	ASSET Feasibility Study
Hull form	Planing Hull	
Δ (MT)		
LWL (m)	107.593	
Beam (m)	13.4639	
Draft (m)	4.44	
D10 (m)	10.4355	
Displacement to Length Ratio, $C_{\square L}$ (lton/ft^3)		
Beam to Draft Ratio, C_{BT}		
W1 (MT)	660.389	
W2 (MT)	733.621	
W3 (MT)	116.449	
W4 (MT)	97.4935	
W5 (MT)	466.585	
W6 (MT)	158.083	
W7 (MT)	22.4952	
Wp (MT)		
Lightship Δ (MT)	2480.63	
KG (m)	5.77355	
GM/B=	0.09113	
Propulsion system		
Engine inlet and exhaust		
MCM system		
ASW system		
ASUW system		
AAW system		
Average deck height (m)		
Hangar deck height (m)		
Total Officers	19	
Total Enlisted	50	
Total Manning	69	
Number of SPARTANs	0	
Number of VTUAVs	1	
Number of LAMPS	2	
Ship Acquisition Cost	386.645	
Life Cycle Cost	546.76	

4 Concept Development (Feasibility Study)

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

4.1 Hull Form and Deck House

The objective of hull form and deck house design is to model the improved baseline characteristics, to minimize drag on the hull form, to deliver a producible hull form, to determine if the hull is capable of supporting required propulsion and mission systems, to shape and position the deck house in order to support mission systems, provide for engine inlet and exhaust, and topside arrangements, and to design the hull for proper sea keeping.

These objectives are accomplished by creating a rough hull form that conforms to ASSET baseline characteristics in Rhino. The rough draft created in Rhino is then cleaned up (the hull surface is lofted, a transom is added, the bow is modified/fixed, and a deckhouse is added). Hydrostatic analysis is conducted in ORCA3D, which generates curves of form and a righting arm curve. Finally, a 2-D drawing (lines drawing) is created to demonstrate the final hull form and deck house.

4.1.1 Hull Form

Table 23 – Baseline Design

Characteristic	Value
Displacement	2700 MT
LWL	110.5 m
B	12.9 m
T	3.34 m
D10	8.73 m
Cp	0.57
Cx	0.8
Crd	0.85
Hull	Flare
Bulb/Sonar Dome	No
Deckhouse	Tumblehome
DKHS Vol.	7050 m^3

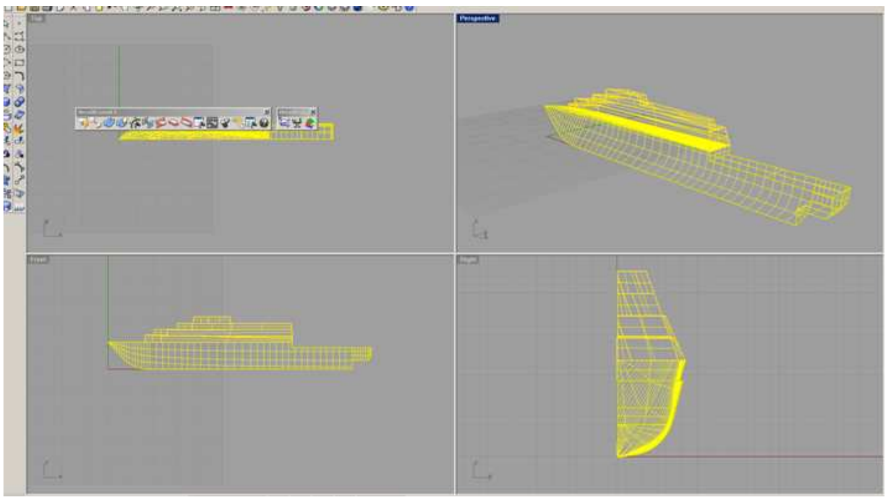


Figure 19 - Hull Form Modified in Rhino

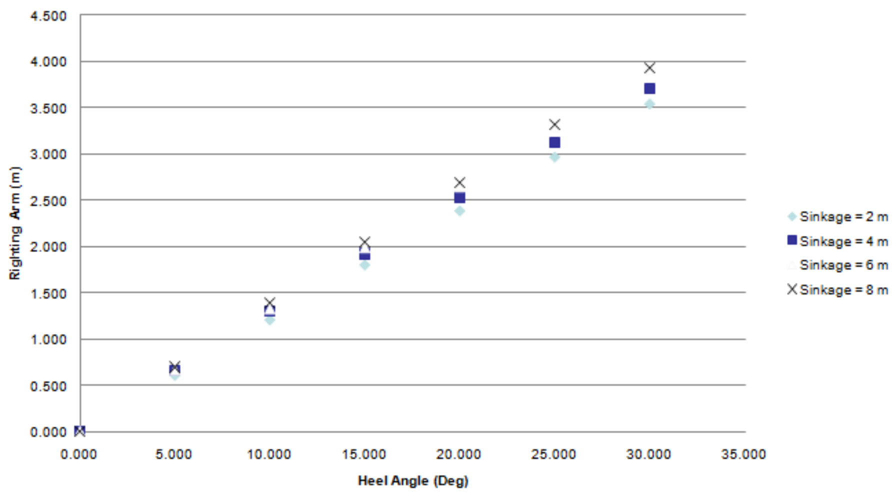


Figure 20 - Righting Arm Curve

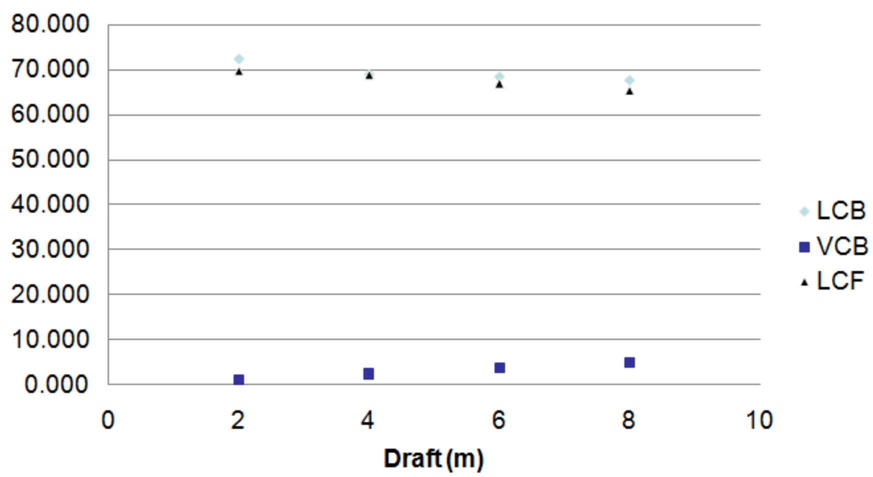


Figure 21 - Buoyancy Centers

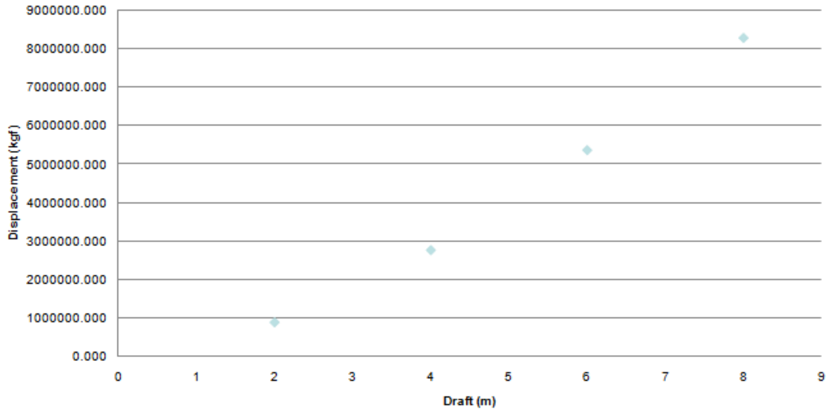


Figure 22 - Displacement

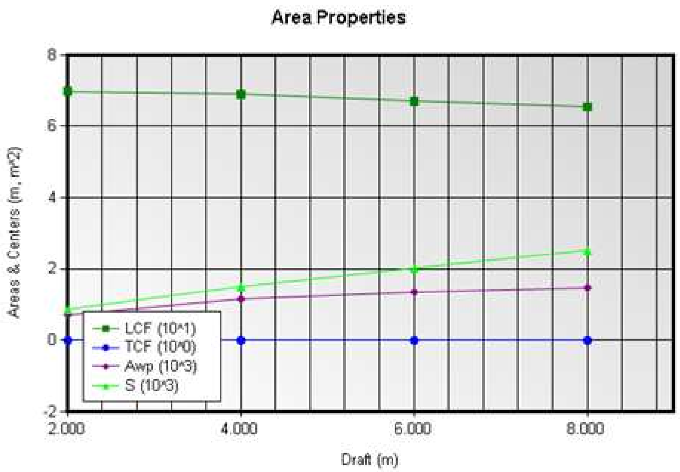


Figure 23 - Areas

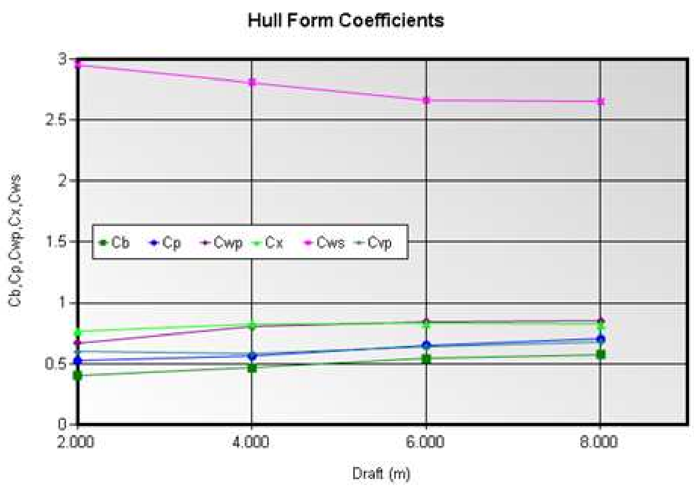


Figure 24 - Coefficients

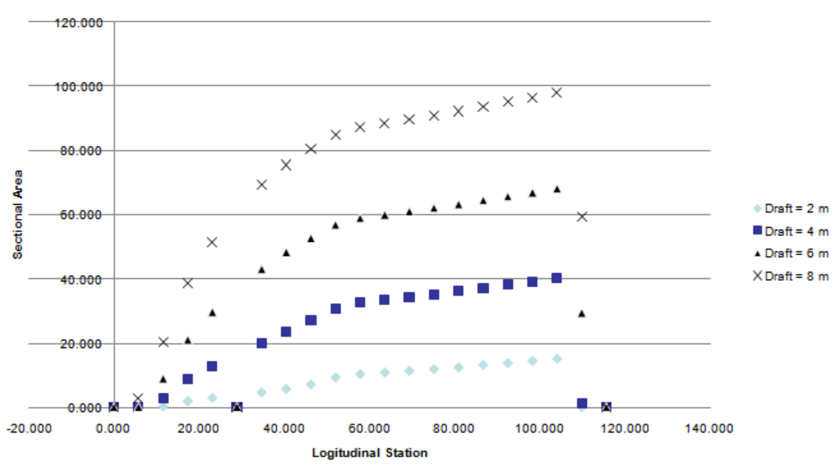


Figure 25 - Sectional Area

4.1.2 Deck House

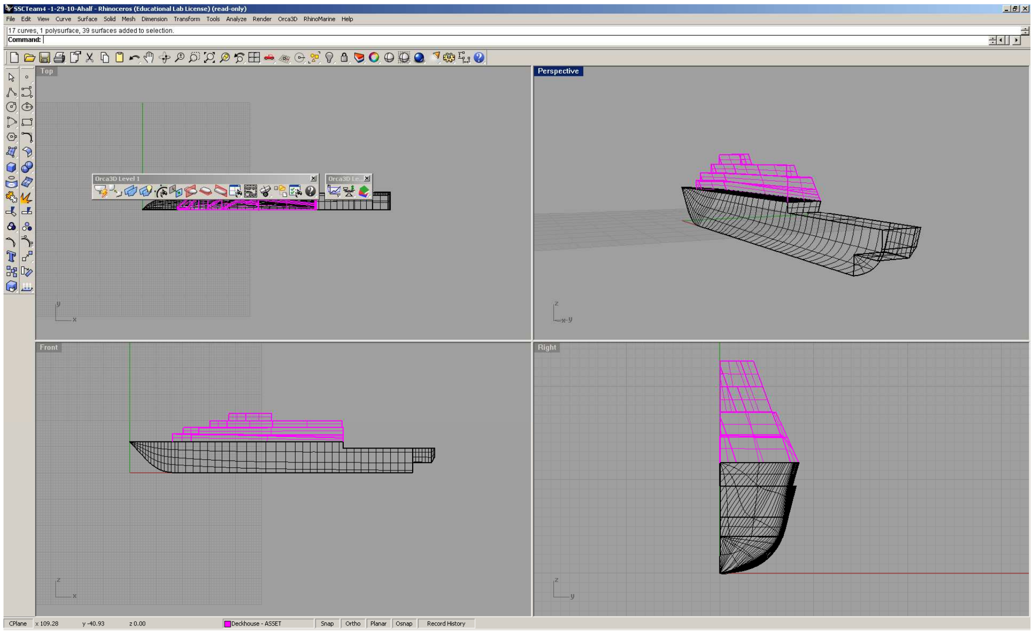


Figure 26 - Deckhouse and Sections in Rhino

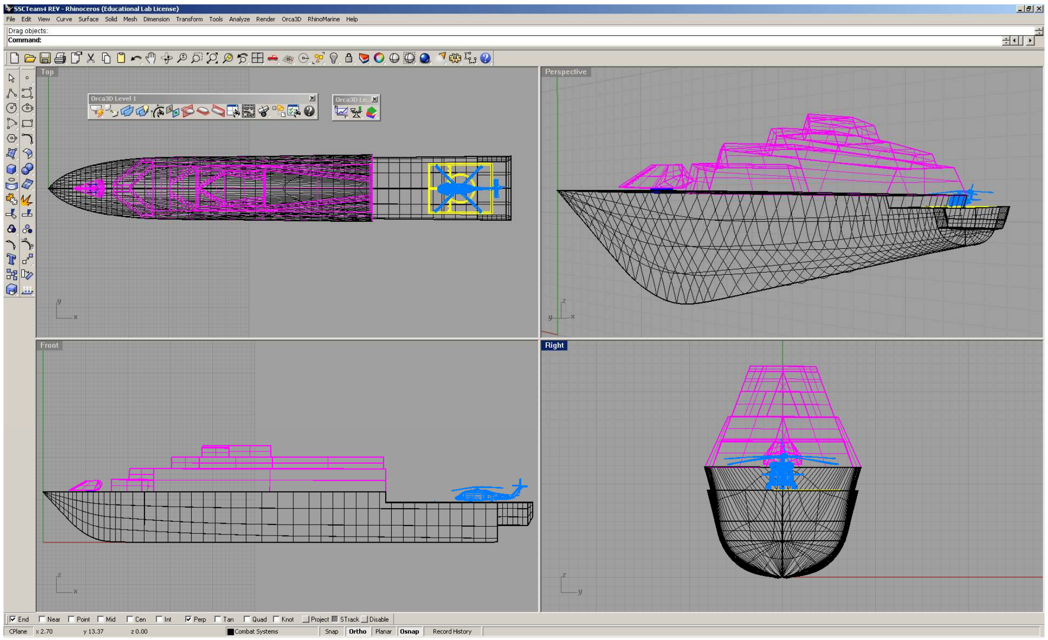


Figure 27 - Hull and Deckhouse (Rhino)

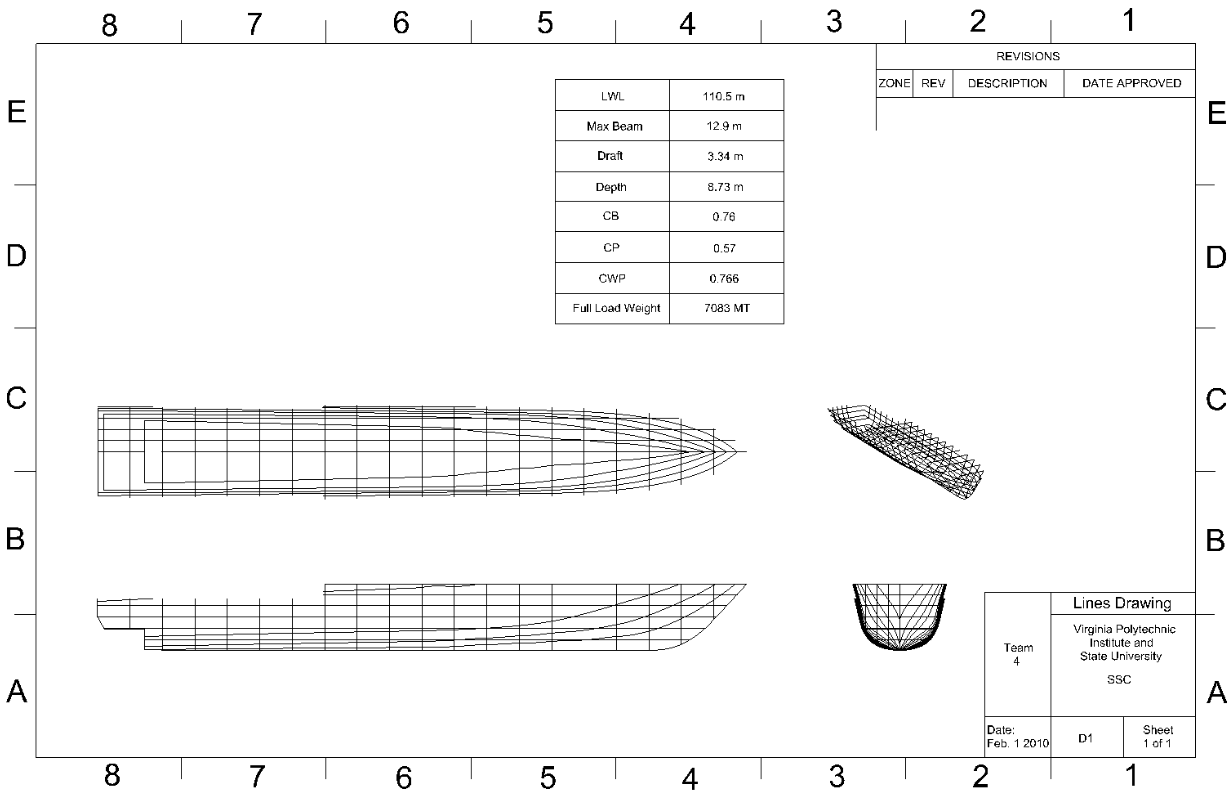


Figure 28 - Lines Drawing

4.2 Preliminary Arrangement (Cartoon)

The objective of preliminary arrangements is to ensure that all necessary volume, area, and large objects fit inside the ship, to define the primary subdivision (including transverse bulkheads and decks), to locate tanks and primary spaces, to consider stability, trim, radar cross section, machinery alignment with shaft and waterjets, damage stability, large object arrangements, engine intake and exhaust, structural efficiency, survivability, topside and overall function, to make a preliminary arrangement cartoon to guide more detailed CAD, and to have a preliminary plan on where objects will go in the ship.

These objectives are accomplished by printing the hull and deckhouse profile and deck plan views from Rhino. Then the tables for required area and volume are built based off of the baseline synthesis model. Finally, sketches are made on the profile and plan views. Primary subdivision with numbering is shown. Eleven transverse bulkheads (TBHDs) are spaced an even multiple of frames apart with frame spacing at 2.5m (longer spaces near midships and smaller near ends at 14m and 10 m respectively). Topside arrangement, mission specs, machinery spaces, inlet/exhaust trunks, and all tanks are included.

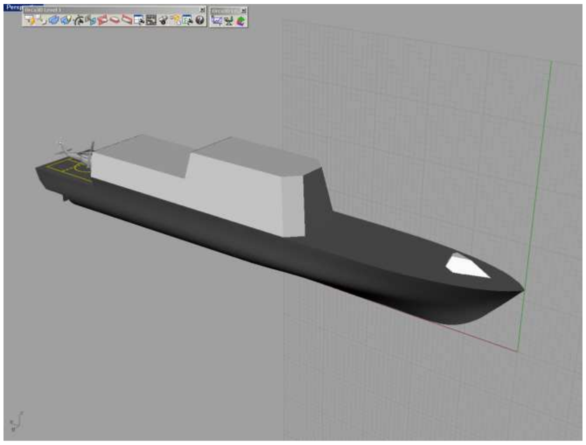


Figure 29 - Hullform and Deckhouse (Rhino)

Table 24 – Required Areas and Volumes

Parameter	Value	Description
VD	4497.39 m^3	[deckhouse volume]
Vtk	977.015 m^3	[total tankage volume]
Vaux	834.153 m^3	[auxiliary machinery space volume]
Vht	11038.6 m^3	[total hull volume]
Vmb	2512 m^3	[propulsion machinery box volume]
ADPR	971.82 m^2	[required deckhouse payload area]
AHPR	682.418 m^2	[required hull or deckhouse payload area]
Ahie	138.88 m^2	[required hull propulsion inlet and exhaust area]
Adie	416.64 m^2	[required deckhouse propulsion inlet and exhaust area]
Ts	17	[endurance days]
CN	4.76155	[hull cubic number]
NT	46	[total crew]
NO	13	[number of officers]
NA	0	[number of additional accomodations]
Adr	2205.06 m^2	[total deckhouse required area]
Ada	2199.16 m^2	[available deckhouse area]
Atr	4296.16 m^2	[total required arrangeable area]
Ata	4342.71 m^2	[total available arrangeable area]

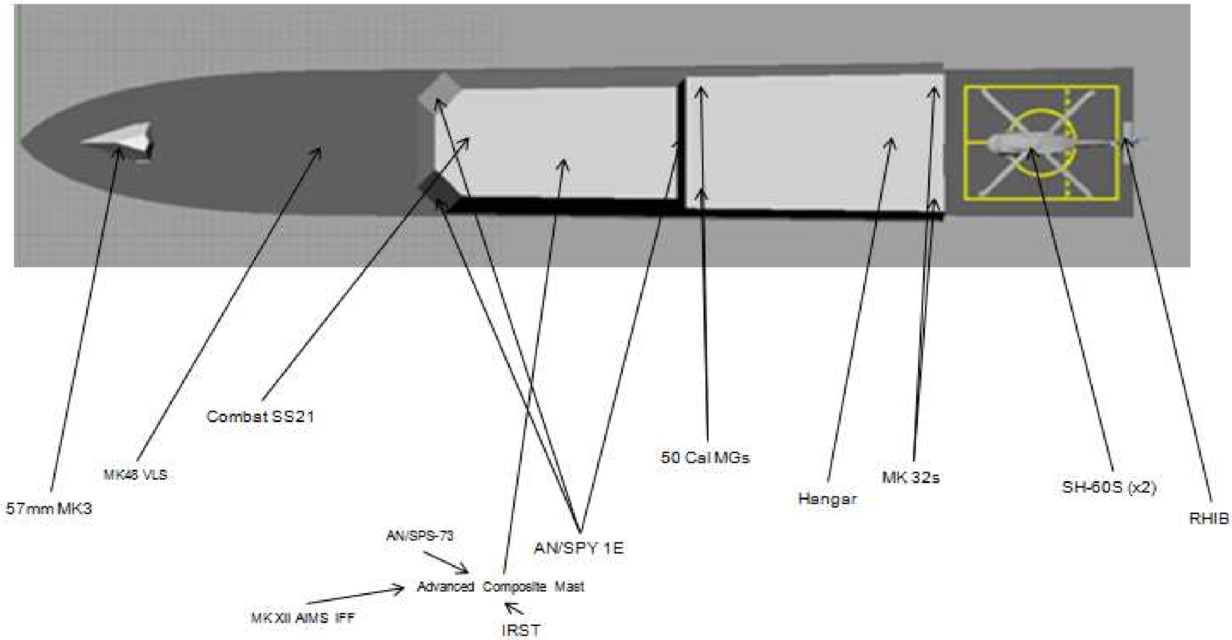


Figure 30 - Topside Arrangement

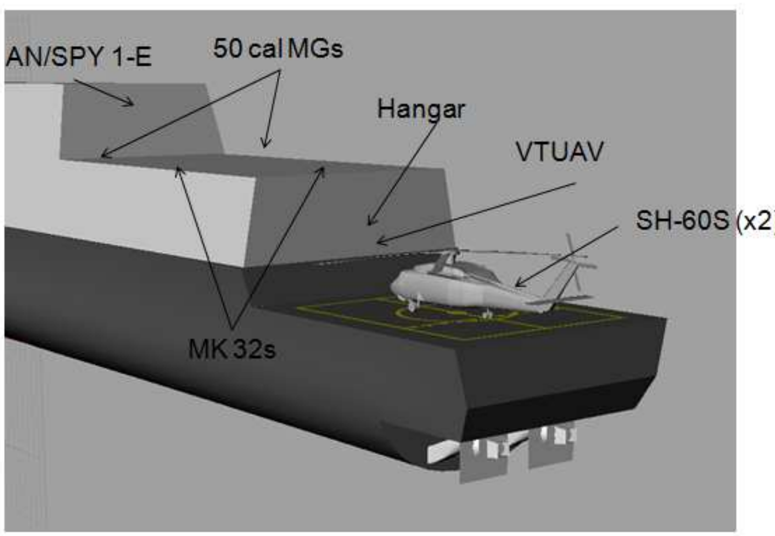


Figure 31 - Combat Systems (Stern)

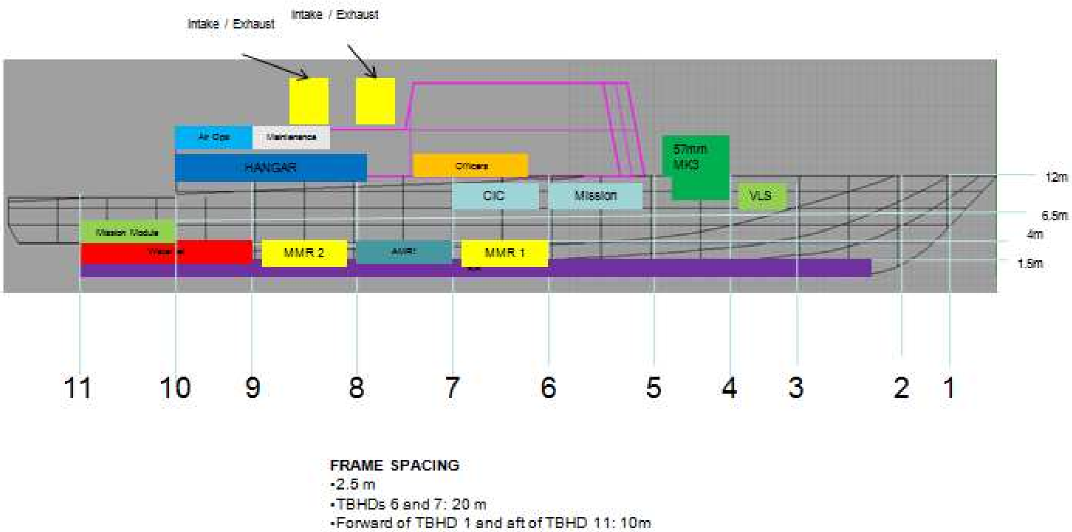


Figure 32 – Cartoon

Small Surface Combatant (Aluminum Variant)

LENGTH AT WATERLINE	110.5m
BEAM	12.9m
DEPTH AT STATION 10	8.73m
DRAFT	3.34m
DECKHOUSE VOLUME	7050m^3

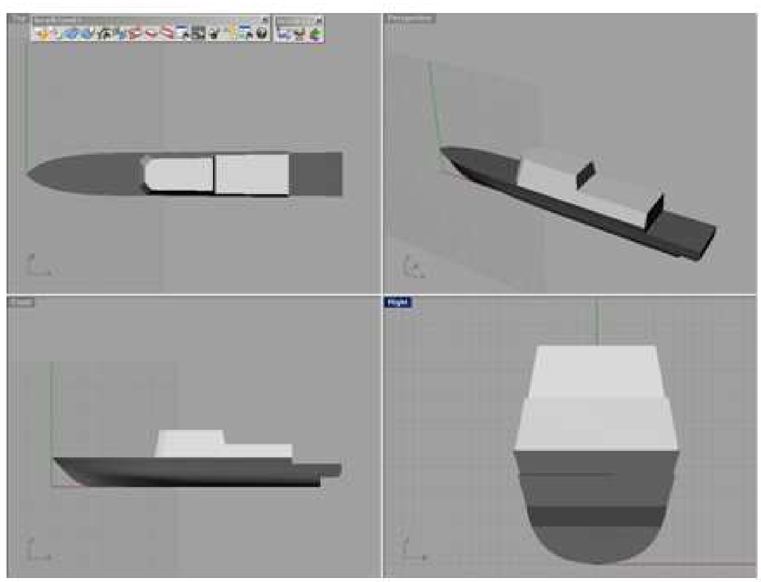


Figure 33 - Basic Characteristics

4.3 Design for Production

Designing of a ship for production requires some thought. Beginning with a build strategy it is important to be able to have producible hull form structures. General group classifications are designated to different sections of the ship. The bow/stern is classified as 1000/3000 levels and generally contains more curvature and transition to transverse stiffening. Sections that carry cargo in the hull are designated 2000 and machinery as 5000. On-board electrical wiring is categorized in the 6000 sections. Special accommodations, combat systems, and high skill areas have a 4000 level designation.

Shipyards have begun to assemble ships in block sections. Each block requires a certain criteria. Blocks are generally sectioned between transverse bulkheads with a maximum width of ten meters and a maximum weight of 100MT. Stiffeners and airlocks are placed on the forward side of the bulkhead.

When a ship goes into production, it is generally built beginning with the lowest center block and works its way out. The blocks are assembled in a way such that the blocks are not required to be inserted in between two previously installed blocks. This helps in ensuring that the fitment is correct.

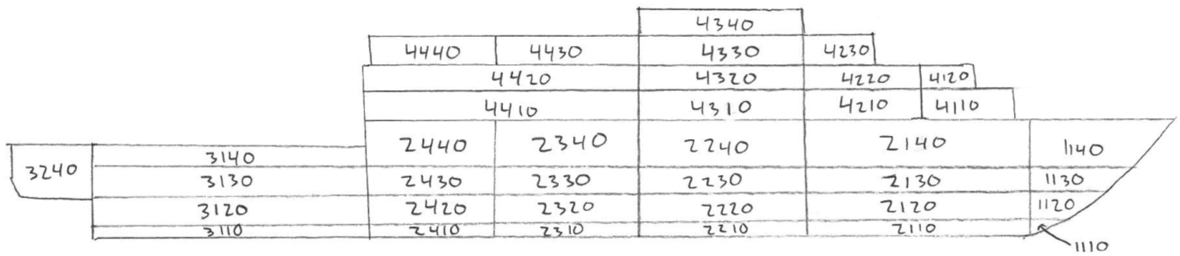


Figure 34 - Claw Diagram

Table 25 – Claw Chart

Week	3240	3100	2400	2300	4400	2200	2100	4300	4200	4100	1100
1			2410	2310							
2		3110		2320							
3		3120	2420								
4			2430	2330							
5		3130		2340							
6		3140	2440								
7	3240					2210					
8						2220	2110				
9							2120				1110
10						2230					1120
11							2130				1130
12						2240	2140				
13					4410						1140
14					4420			4310			
15								4320	4210		
16									4220	4110	
17					4440					4120	
18					4430			4330			
19								4340	4230		

4.4 Subdivision

4.4.1 Hullform in HECSALV

Based on the ASSET parameters and provided offsets, a hullform was constructed in Rhino. The model was constructed to fit the offsets as accurately as possible while also designing options for a deckhouse. Due to the short length of the SSC and the need for a spacious flight deck, the deckhouse shape and size became variables in need of iteration. A simple, tapered deckhouse was chosen to minimize radar cross section while also maximizing usable space. The deckhouse was not necessary for analysis in the HECSALV software, however, it was important to have a general idea of the above deck arrangement in order to properly locate machinery rooms with inlets and exhaust in mind.

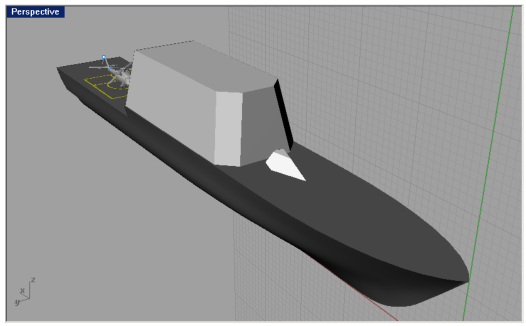


Figure 35 - Final hull shape in Rhino

Once the model was finalized in Rhino, it was imported into the HECSALV ship project editor by opening the Rhino-exported .dxf file and defining design particulars for the general shape of the hull.

HECSALV

Particulars

Particulars	LBP	m	107.849
	Depth	m	11.810
	Beam	m	13.532
	LOA	m	115.530
Long Bounds	Aft	m-FP	108.700A
	Fwd	m-FP	6.830F
Vert Bounds	Lower	m-BL	0.000
	Upper	m-BL	11.819
Trans Bounds	Port	m-CL	8.363P
	Stbd	m-CL	8.363S
Other	Keel Thick	mm	0.0
	Design Keel Draft	m	4.391

ASSET Improved Baseline	
LBP	107.849
Depth	11.81
Beam	13.5323
LOA	115.53
Draft	4.391

Figure 36 - Design Particulars in HECSALV compared to ASSET baseline

While the functionality between Rhino and HECSALV is useful, it is not without flaws. The offsets exported from Rhino did not automatically match the input format needed by HECSALV. The sections used to describe the hull had to be redefined in some positions while also adding extra sections to define more complex geometries. These added sections were needed at the aft of the ship in order to better describe the waterjet transom.

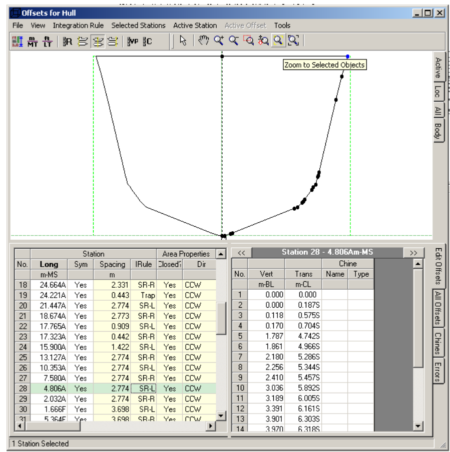


Figure 37 - Example of an offset section in HECSALV

Once the sections were correctly oriented and defined, the deck edge was established by defining a margin line 3 inches below the design deck edge. With the sections and deck edge properly defined the hull was ready for analysis. Based on the below figure, the completed ship has a displacement of 3,493 MT which is slightly larger than the ASSET improved baseline design value of 3,297 MT. The increased displacement is caused by the shape of the SSC deck. In the original ASSET design, the deck tapered along the length of the ship. In the final design it was decided to keep the deck at a constant height in order to simplify stability analysis, provide a flat flight deck for aircraft, and increase usable space.

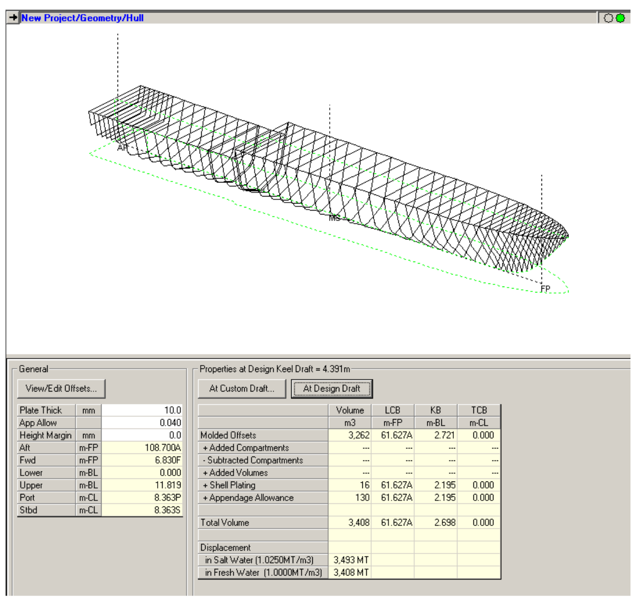
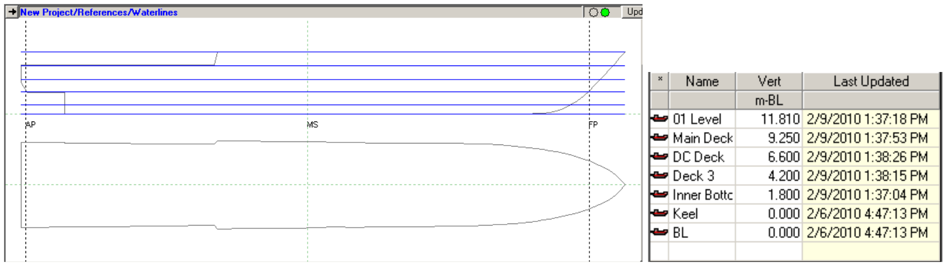


Figure 38 - Final Hull Design in HECSALV

4.4.2 Transverse Subdivision, Floodable Length and Preliminary Tankage

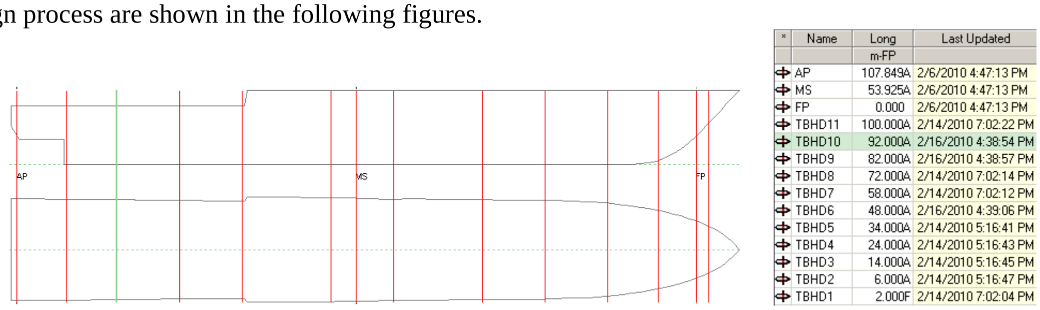
The next step in the subdivision process was to define deck locations and transverse bulkheads. The deck locations were chosen based on a desire for 5 decks along with guidelines for deck heights. The inner bottom was initially the governing point in choosing these locations. There needed to be enough space to provide room for fuel, while also not limiting the needed headroom in above decks. The following figure describes the chosen deck heights.



*	Name	Vert	Last Updated
		m-BL	
	01 Level	11.810	2/9/2010 1:37:18 PM
	Main Deck	9.250	2/9/2010 1:37:53 PM
	DC Deck	6.600	2/9/2010 1:38:26 PM
	Deck 3	4.200	2/9/2010 1:38:15 PM
	Inner Bottc	1.800	2/9/2010 1:37:04 PM
	Keel	0.000	2/6/2010 4:47:13 PM
	BL	0.000	2/6/2010 4:47:13 PM

Figure 39 - Deck Heights in HECSALV

With the deck heights chosen and defined, the next step was to establish the transverse bulkhead locations. These dimensions were governed by the various compartment sizes needed for ship components, along with maintaining an acceptable floodable length. These design goals were further constrained by the waterjet transom. This feature posed a potential problem for flooding in case of damage. It was remedied by shortening the distance between bulkheads in this vicinity, made possible by moving the machinery rooms forward in the ship. The results of this design process are shown in the following figures.



*	Name	Long	Last Updated
		m-FP	
	AP	107.849A	2/6/2010 4:47:13 PM
	MS	53.925A	2/6/2010 4:47:13 PM
	FP	0.000	2/6/2010 4:47:13 PM
	TBHD11	100.000A	2/14/2010 7:02:22 PM
	TBHD10	92.000A	2/16/2010 4:38:54 PM
	TBHD9	82.000A	2/16/2010 4:38:57 PM
	TBHD8	72.000A	2/14/2010 7:02:14 PM
	TBHD7	58.000A	2/14/2010 7:02:12 PM
	TBHD6	48.000A	2/16/2010 4:39:06 PM
	TBHD5	34.000A	2/14/2010 5:16:41 PM
	TBHD4	24.000A	2/14/2010 5:16:43 PM
	TBHD3	14.000A	2/14/2010 5:16:45 PM
	TBHD2	6.000A	2/14/2010 5:16:47 PM
	TBHD1	2.000F	2/14/2010 7:02:04 PM

Figure 40 - Transverse Bulkhead Locations

These dimensions provided ample space for machinery and support areas while also falling within acceptable limits on a floodable length curve. The orange lines on the figure below demonstrate the floodable length.

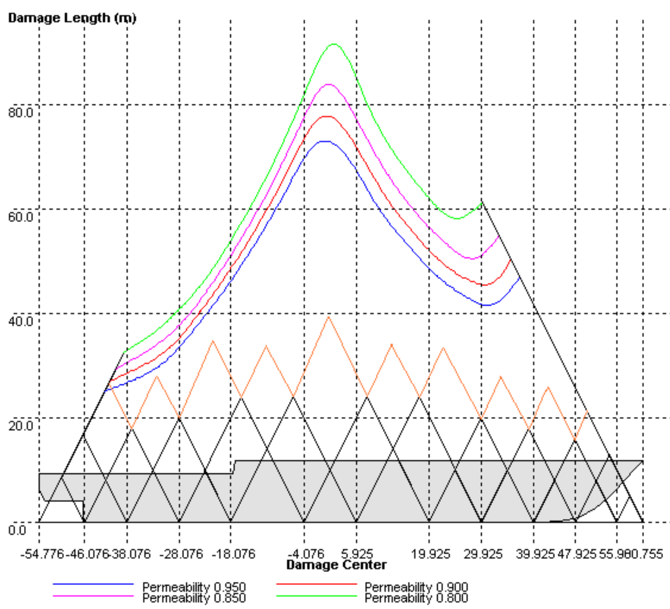


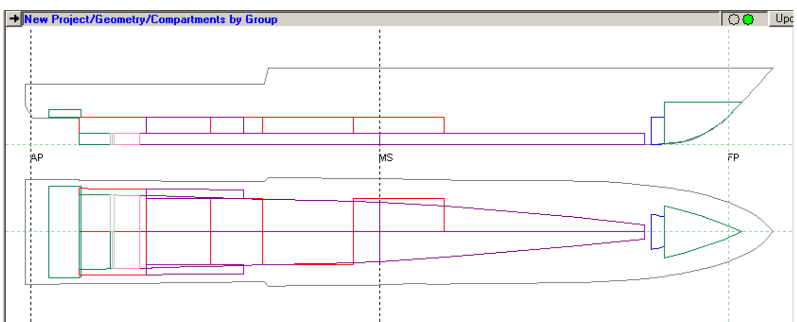
Figure 41 - Floodable Length Curve

Once the bulkhead locations and deck heights were defined and found to be acceptable, preliminary tankage was designed. The tankage requirements for the SSC were formed based on the ASSET improved baselines’ tankage report. These requirements along with space designated for the various functions in the final design are outlined via the following figure.

	ASSET Rqmt (m^3)	Tankage Capacity (m^3)
JP-5	73.6	74
Endurance Fuel	614.1	624
Ballast	264.1	267
Freshwater	17.5	18
Dirty Oil	4.4	6
Sewage	1.1	2

Figure 42 - Improved Baseline Tankage requirements vs. Final Design Tankage

Because the fuel requirement was by far the largest, it was located first. The inner bottom of the SSC provided room for the main diesel fuel, as well as oil and waste tanks. The JP-5 fuel, needed for any aircraft used by the SSC, was placed in wing tanks above the inner bottom. This allowed there to still be space for machinery, while also keeping the JP-5 near the hangar where it would be needed. After the fuel, the next largest tankage demand was the ballast tanks. These were placed in 3 different locations, with the main goal being to keep the ballast as far from midship as possible, in order to maximize their potential to adjust trim. With these demands met, the last step was to place the freshwater tank. It was placed behind the forward ballast tank in order to be close to habitation spaces. The locations described can be seen in the following figure. The colors in the top image correspond to the tank type listed in the table below it.



Name	Color	Capacity Perm m3	100% Full Center LCG m-FP	VCG m-BL	TCG m-CL	Free Surface Slack m4	98%Full m4	Last Updated
Unassigne		0	53.900A	0.000	0.000	0	0	2/14/2010 5:01:59 PM
Machinery		830	77.116A	3.012	0.081S	1,009	402	2/14/2010 5:01:59 PM
Fuel (DFM)		662	62.432A	1.392	0.000P	1,035	260	2/14/2010 5:01:59 PM
Lube Oil		48	93.011A	1.150	0.000P	357	54	2/14/2010 5:01:59 PM
Fresh Wat		18	11.085A	2.876	0.000P	18	8	2/14/2010 5:01:59 PM
SW Ballast		258	57.064A	3.974	0.016S	1,680	250	2/14/2010 5:01:59 PM
Waste		5	95.250A	1.146	0.734P	13	3	2/14/2010 5:01:59 PM
Misc. Tank		0	53.900A	0.000	0.000	0	0	2/14/2010 5:01:59 PM
Constant		0	53.900A	0.000	0.000	0	0	2/14/2010 5:01:59 PM

Figure 43 - Preliminary Tankage

The final design exceeded the demands of the ASSET Improved Baseline, while also leaving space available for propulsion systems and shafts.

4.4.3 Loading Conditions and Preliminary Stability Analysis

Once the preliminary tankage was established, it was necessary to analyze the ship's stability in various loading conditions. These conditions were governed by the U.S. Navy distributed document, DDS 079-1, which outlines the requirements for the stability and buoyancy of U.S. Naval surface ships. This design required an analysis of two different loading conditions; full load, and minimum operating conditions. These conditions are described by the following two tables.

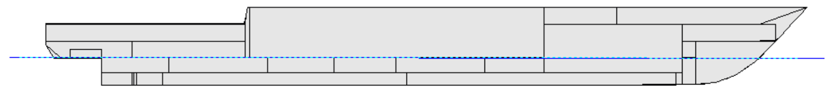
Table 26 - Full Load Condition per DDS 079-1

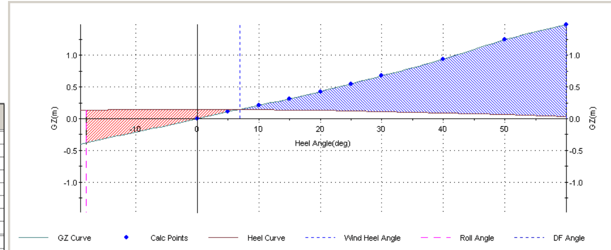
ITEM	LOADS
Crew and effects	Wartime complement
Provisions and personnel stores	Complement * # of days endurance. Quantities not to exceed available capacity. 30 day limit on chill stores. Medical and troop stores in normal amounts.
General Stores	All stores other than personnel stores which are consumable. Based on Design Characteristics.
Ammunition	Full allowance of ammunition with maximum quantities in ready-service stowage and remainder in magazines. For missiles and torpedoes, least favorable quantity and disposition is assumed.
Lube Oil	Storage tanks are 95% full, settling tanks are empty.
Reserve feed and Fresh water	All tanks 100% full.
Diesel Oil (other than for propulsion)	All tanks 95% full. Overflow tanks filled as necessary for endurance. Contaminated oil settling tanks (COST) are empty.
Aviation or vehicle fuel	All tanks are 95% full.
Airplanes and aviation stores	Full design complement of aircraft, empty. Full allowance of repair parts and stores. Distribution of aircraft shall be most unfavorable from stability standpoint.
Cargo	Includes all items of ammunition, stores, provisions, fuel water, etc. which are normally carried for issue to other activities.
Propulsion fuel	All tanks 95% full.
Anti-roll tanks	Operating level
Sewage Holding Tanks (CHT)	Empty
Water ballast tanks	Empty

Table 27 - MinOp Load Condition per DDS 079-1

ITEM	LOADS
Crew and effects	Same as Full Load
Provisions and personnel stores	One-third of Full Load
General Stores	One-third of Full Load
Ammunition	One-third of full-load ammunition with maximum quantities in ready-service stowages and remainder in magazines. For missiles and torpedo least favorable quantity and disposition is assumed.
Lube Oil	One-third full load
Reserve feed and Fresh water	Two-thirds full load
Diesel Oil (other than for propulsion)	One-half full load on ships below destroyer size; one-third full load on larger ships.
Aviation or vehicle fuel	One-third of full load. Compensating fuel sea water ballast (or ballast water in empty tanks) is taken as remainder the load.
Airplanes and aviation stores	Same as full load.
Cargo	No cargo for ships whose normal function requires that they unload all cargo. For ships such as tenders and replenishment types which do not normally unload completely, assume one-third of full load cargo.
Propulsion fuel	One-third full load with remaining tanks loaded in accordance with liquid loading instructions.
Anti-roll tanks	Operating level
Sewage Holding Tanks (CHT)	Full
Water ballast tanks	Empty*

With the loading conditions known, it was necessary to decide upon a design longitudinal center of gravity for the ship. This location is important because it governs the trim of the SSC. In order to have a trim less than 0.1 meters, the design requires the longitudinal center of gravity exist at 61.5 meters aft of the forward perpendicular. Combining the loading condition with the design longitudinal center of gravity allowed an analysis of the SSC's stability through the use of another one of HECSALV's functions. The results of this analysis are shown by the following figures.





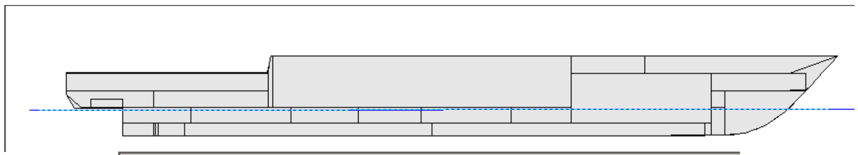
Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	2,467	6.750	61.500A	0.000	----
Constant	0	0.000	61.500A	0.000	0
Fuel (DFM)	549	1.442	63.354A	0.000P	404
Lube Oil	41	1.118	93.036A	0.000P	103
SW Ballast	0	----	----	----	----
Fresh Water	18	2.876	11.110A	0.000P	0
Waste	0	----	----	----	----
Misc. Weights	400	6.000	53.925A	0.000	0
Displacement	3,475	5.739	61.025A	0.000P	508

Stability Calculation			Trim Calculation		
KMt	7.381	m	LCF Draft	4.376	m
VCG	5.739	m	LCB (even keel)	61.627A	m-FP
GMt (Solid)	1.642	m	LCF	61.459A	m-FP
FSc	0.146	m	MT1cm	88	m-MT/cm
GMt (Corrected)	1.496	m	Trim	0.239	m-F
			List	0.0	deg
Specific Gravity	1.0250				
Hull calcs from tables			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	4.512	m	Shear	-170	MT at 58.050A m-FP
Draft at M.S.	4.392	m	Bending Moment	2,267H	m-MT at 70.050A m-FP
Draft at A.P.	4.273	m			
Draft at FwdMarks	4.893	m			
Draft at Mid Marks	4.784	m			
Draft at AftMarks	4.674	m			

Parameter	Units	Value	Required
Wind Heel	deg	6.9	---
Wind Heeling Arm Lw	m	0.147	---
Maximum Righting Arm Ratio		0.1	0.6
Capsizing Area A2	m-rad	0.11	---
Righting Area A1	m-rad	0.64	0.16
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.479	---
Angle at Max. GZ	deg	60.0	---
Projected Sail Area	m2	604.78	---
Vertical Arm ABL	m	7.196	---
Heeling Arm at 0 deg.	m	0.149	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.0	
Reference Draft	m	0.000	
Projected Sail Area	m2	600.00	
Vertical Center of Sail Area -BL	m	10.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

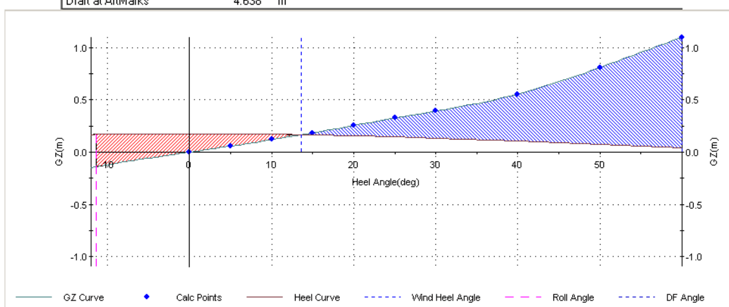
Figure 44 - Full Load Condition Stability Results



Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	2,467	6.750	61.500A	0.000	----
Constant	0	0.000	61.500A	0.000	0
Fuel (DFM)	191	0.913	63.467A	0.000P	308
Lube Oil	14	0.630	93.041A	0.000P	161
SW Ballast	0	----	----	----	----
Fresh Water	12	2.373	11.113A	0.000S	11
Waste	7	1.146	95.330A	0.011P	0
Misc. Weights	400	6.000	53.925A	0.000	0
Displacement	3,091	6.234	60.670A	0.000P	479

Stability Calculation			Trim Calculation		
KMt	7.256	m	LCF Draft	4.057	m
VCG	6.234	m	LCB (even keel)	61.817A	m-FP
GMt (Solid)	1.022	m	LCF	60.178A	m-FP
FSc	0.155	m	MT1cm	76	m-MT/cm
GMt (Corrected)	0.866	m	Trim	0.469	m-F
			List	0.0	deg
Specific Gravity	1.0250				
Hull calcs from tables			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	4.319	m	Shear	-187	MT at 58.050A m-FP
Draft at M.S.	4.085	m	Bending Moment	3,120H	m-MT at 70.050A m-FP
Draft at A.P.	3.850	m			
Draft at FwdMarks	5.069	m			
Draft at Mid Marks	4.853	m			
Draft at AftMarks	4.638	m			



Parameter	Units	Value	Required
Wind Heel	deg	13.6	---
Wind Heeling Arm Lw	m	0.167	---
Maximum Righting Arm Ratio		0.15	0.6
Capsizing Area A2	m-rad	0.07	---
Righting Area A1	m-rad	0.36	0.09
Angle Limiting Area	deg	60.0	---
Maximum Righting Arm	m	1.095	---
Angle at Max. GZ	deg	60.0	---
Projected Sail Area	m2	637.98	---
Vertical Arm ABL	m	7.042	---
Heeling Arm at 0 deg.	m	0.176	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.0	
Reference Draft	m	0.000	
Projected Sail Area	m2	600.00	
Vertical Center of Sail Area -BL	m	10.000	
Factor f where p = f*V^2 (lb/ft^2)		0.0035	
Roll Angle	deg	25.0	

Figure 45 - MinOp Load Condition Stability Results

These results are based on the SSC lightship in still water.

4.5 Structural Design and Analysis

MAESTRO was used to model the SSC and load it with waves under different conditions, including full load and minimum operating conditions. It is a coarse-mesh finite element solver that can evaluate individual modes of failure. **Error! Reference source not found.**46 shows the iterative process that drives the structural design of the small SSC.

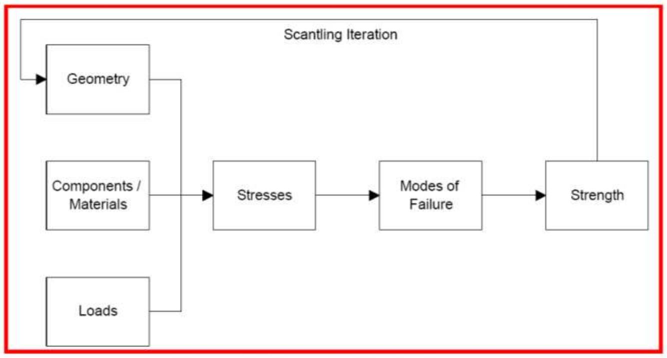


Figure 46 - Structural Design Process

4.5.1 Geometry, Components and Materials

The entire starboard side of the ship was modeled and is illustrated in **Error! Reference source not found.**47. To begin, materials, geometry, and scantlings were taken from ASSET's Structural Modules, shown in Figure 48. The only material used was Aluminum-5456. Properties of Aluminum-5456 were entered into MAESTRO and are shown in Table 28. Next, all of the different sized beams and plates were entered into MAESTRO for further use. Also added were the different stiffener sizes and arrangements. ASSET's Structural Modules also included a picture with endpoint locations. Shown in Figure 49 is an example of the midship section endpoint locations.

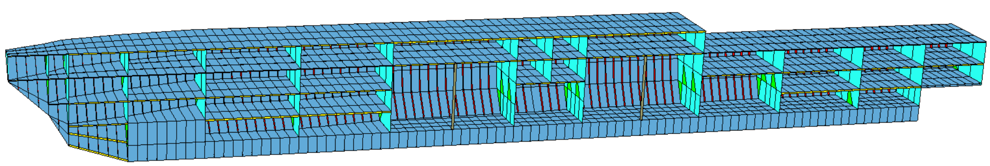


Figure 47 - MAESTRO Model

```
     ASSET/MONOSC V5.3.0 - HULL STRUCT MODULE -  2/27/2010 22:42.17
           DATABANK-ASSET2009RSMBASELINES-1.BNK  SHIP-SSCSML

PRINTED REPORT NO. 3 - WEATHER DECK
DECK MTRL TYPE-AL 5456
STRINGER PLATE MTRL TYPE-AL 5456
                                          SHELL     STRINGER PLATE
  MODULUS OF ELASTICITY, MPA            68947.6       68947.6
  DENSITY, KG/M3                        2657.27       2657.27
  YIELD STRENGTH, MPA                    179.26        179.26
  MAX PRIMARY STRENGTH, MPA               69.50         69.50
  ALLOWABLE WORKING STRENGTH, MPA        144.79        144.79
HULL LOADS IND-BM CONSTANT
                              MAX       MIN
STIFFENER SPACING, MM       609.60    609.60
STRINGER PLATE WIDTH, M       1.83
SEGMENT GEOMETRY
      --------NODE COORD, M -------------------SCND. LOAD, M --
  SEG      YIB      ZIB      YOB      ZOB        HEAD1    HEAD2
   1       0.00    10.48     2.59    10.48        2.54
   2       2.59    10.48     5.17    10.48        2.54
   3       5.17    10.48     6.01    10.48        2.51
   4       6.01    10.48     7.84    10.48        2.52
SEGMENT SCANTLINGS
        ----------------SCANTLINGS OF STIFFENED PLATES-----------------
        ----- STIFFENER GEOMETRY (MM) -----
           WEB     FLANGE     WEB     FLANGE   CATLG NO.OF  PLATE   SPACING
  SEG    HEIGHT    WIDTH   THKNESS  THKNESS    NO   STIFF TK, MM     MM
  -----------------------------------------------------------------------
   1 *E  69.672   76.200    4.775    6.528     1     4     9.5250   517.16
   2 *E  69.672   76.200    4.775    6.528     1     4    10.3187   517.16
   3 *E  69.672   76.200    4.775    6.528     1     1    10.3187   417.68
   4 *E  69.672   76.200    4.775    6.528     1     4    10.3187   457.20
   NOTE: *E STANDS FOR EXTRUDED SHAPE
```

Figure 48 - ASSET Structural Model

Table 28 - Properties of Aluminum 5456

Material	AL 5456
Young's Modulus (N/m^2)	6.895x10^{10}
Poisson Ratio	0.33
Density (kg/m^3)	2.657
Yield Stress (N/m^2)	2x10^8
Ultimate Tensile Strength (N/m^2)	2.69x10^8

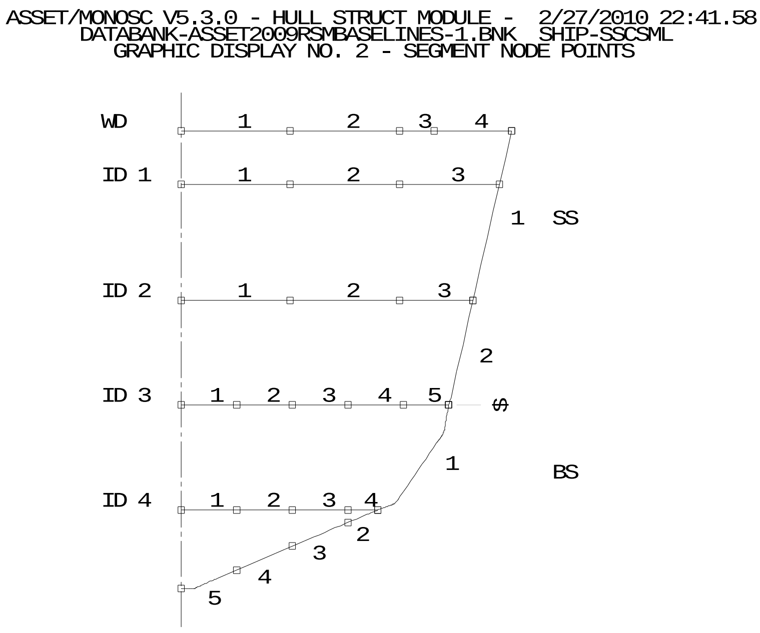


Figure 49 - Midship Section Endpoint Locations from ASSET

The ASSET structural modules were run at each bulkhead location to obtain specific geometry and components for each section. Each section was then built using this information. Endpoints were connected with strakes that represented individual plates. Some strakes had girders depending on where in the section the plate was located. Transverse bulkheads were added to each section using quad and tri elements between endpoints. Longitudinal and transverse floors in the inner bottom were created using compounds made of quad and tri elements that extend the length of each section. Stanchions were added in the machinery rooms using rod elements. Stanchion properties are shown in Table 29.

Table 29 - Stanchion Properties

Stanchions	Outside Diameter (mm)	Wall Thickness (mm)	Material
All	304.8	25.4	AL 5456

Using HECSALV as a reference, the tank locations for diesel fuel marine (DFM) and ballast water tanks were modeled in MAESTRO as well. This was done by creating volume groups. Each tank's volume group was created by selecting the bounding edges of the tanks in the volume group dialog box.

The completed MAESTRO model is illustrated in Figure 47.

4.5.2 Loads

Before loads could be applied, restraints needed to be added to the model. The model had port-starboard symmetry, supplying centerline constraints of roll, sway, and yaw automatically. It was therefore only necessary to prevent heave, pitch, and surge. To add these restraints, two y-restraints were added at the ends and one x-restraint was added at midships near the model's neutral axis. The neutral axis placement prevented the restraint from interfering with hull girder bending.

Next, the model's self weight needed to be added to MAESTRO. This information was obtained from the HECSALV strength summary report and added into a mass group in MAESTRO. Each module of the model was a transverse bulkhead and had its own mass. In total, there were 14 mass groups created in MAESTRO, some modules containing more than one station. The table used as reference from HECSALV is shown in Table 30.

Table 30 - Lightship Weight Distribution

No.	Long	Ordinate
	m-FP	MT/m
1	3.235F	0.0000
2	3.235F	3.3454
3	2.157F	3.9850
4	1.078F	4.7979
5	0.000	5.6107
6	0.000	6.1020
7	5.392A	10.1170
8	10.785A	13.4971
9	16.177A	16.1843
10	16.177A	13.9683
11	21.570A	17.2676
12	26.962A	19.6431
13	32.355A	21.6146
14	37.747A	23.0664
15	43.140A	23.2482
16	48.532A	23.2568
17	53.925A	23.4964
18	59.317A	23.0431
19	64.709A	22.7631
20	70.102A	22.3676
21	75.494A	21.8566
22	80.887A	20.8838
23	85.201A	19.7822
24	85.201A	61.5446
25	86.279A	58.9163
26	91.672A	45.6018
27	97.064A	31.7100
28	102.457A	17.4718
29	104.343A	12.6919
30	107.849A	11.4590
31	107.849A	11.9502
32	108.927A	10.2761
33	110.006A	8.1977
34	110.006A	0.0000

There were a total of six load cases tested in MAESTRO. They consisted of a combination of waves and loading conditions. The waves tested included stillwater, hogging, and sagging while the different loads cases were full-load and minimum operating conditions. Each load case had an emersion originally set to the draft of the ship. The waves were trochoidal and included Froude-Krylov effects. The wave length was set to the length between perpendiculars of the ship. The amplitude was determined using the following equation:

$$Amp = \frac{0.6 * \sqrt{LBP}}{2}$$

The stillwater cases did not have a wave, only emersion. The hogging cases' phase angle was set to 180^o while the sagging cases' was set to 0^o. All six cases were specified to include the mass groups created previously to represent the model's self weight. The full load cases included the volume groups with the DFM tanks full 95 percent and the ballast tanks completely full. The lightship cases included the DFM tanks 33 percent full and the ballast tanks 66 percent full.

Since the model was the entire length of the ship, there was not a need to add a bending moment or shear force to the load cases. **Error! Reference source not found.**50 shows the model with an applied sagging wave, Figure 51 shows an applied hogging wave, and Figure 52**Error! Reference source not found.** shows a stillwater case.

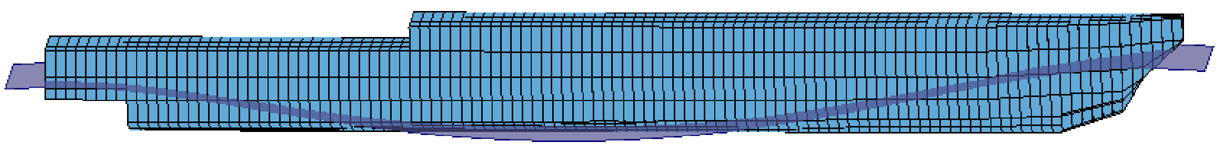


Figure 50 - Model with Sagging Wave

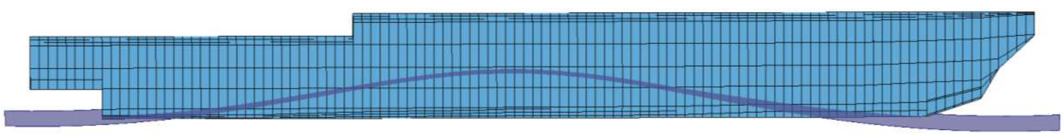


Figure 51 - Model with Hogging Wave

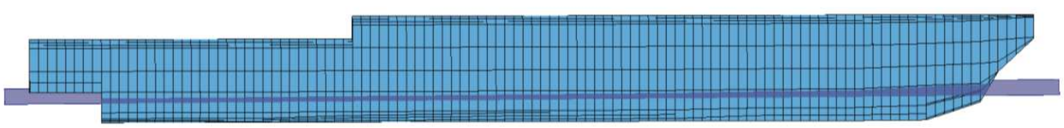


Figure 52 - Model in Stillwater

4.5.3 Adequacy

To test the strength of the model after the loads were applied, the adequacy of the plates was analyzed. MAESTRO has a Scalable Solver that compares stress for each of the panels and beams for different failure modes to create a strength ratio, r. To evaluate the adequacy of scantlings, an adequacy parameter is defined as follows:

$$adequacy\ parameter = \frac{1 - r}{1 + r}$$

Originally, the plates were not adequate enough in many places to support the load from the waves. Many plates required an increased number of stiffeners or larger stiffeners, sometimes both. This showed that the sizes provided by ASSET were a rough estimate at the beginning and further analysis needed to be done to obtain the correct sizes. After some tweaking, the plates all met the specified adequacy parameter number of -0.33 or less. Figures 53 and 54 show the plate adequacy for the full load hogging wave case. This was the worst case out of the six cases evaluated. The red areas represent an adequacy parameter value of -0.22, which was acceptable for the first design.

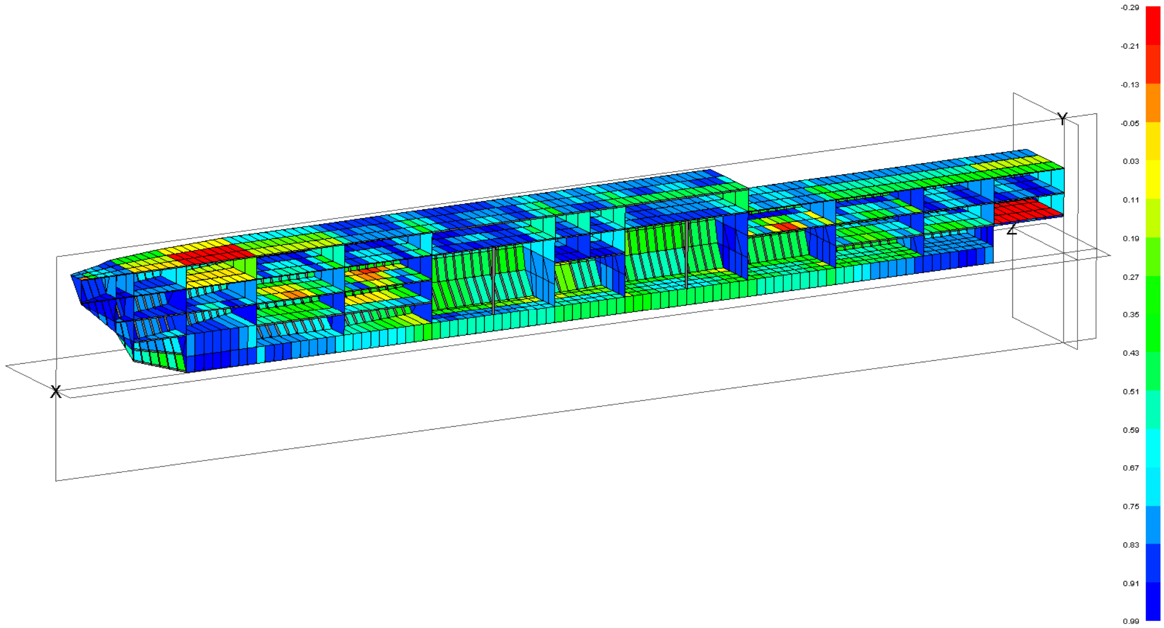


Figure 53 - Plate Adequacy for Full Load Hogging Wave Case (Conventional View)

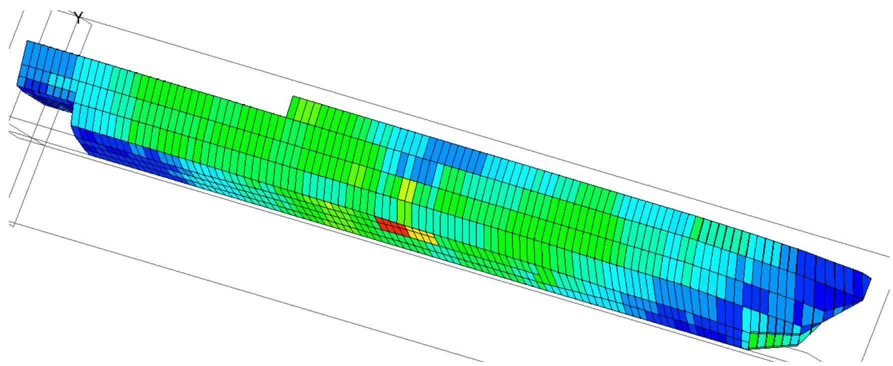


Figure 54 - Plate Adequacy for Full Load Hogging Wave Case (Alternate View)

4.5.4 Revisions and Final Structural Design

Revisions to the current design would include changing almost all of the plates. Some of the plates are over-designed and the design would benefit from making them less thick, removing some of the stiffeners, or making the stiffeners smaller. Additionally, the plates that are above an adequacy parameter value of 0, such as the red plates above with a value of -0.22, should be stiffened more or the stiffener size increased.

From a production standpoint, there is a varied size of plates, stiffeners, and girders. Many of the plate thicknesses and the stiffeners should be made to standard sizes for easier manufacturing. In addition, items that are similar in size should be changed to the same size. This again would make production easier due to more uniform sizes for plates, stiffeners, and frames then what is currently in the design.

4.6 Power and Propulsion

The objective of the power and propulsion module is to calculate the resistance in NavCad using the Holtrop method for endurance speed and the Savitsky method for sustained speed, to select an appropriate water jet and model its location and characteristics, to model the driving engines, to perform propulsion analysis in NavCad at endurance and sustained speeds, to determine sustained speed, and to calculate endurance range in MathCad.

These objectives are accomplished by first determining the location of the water jets (this includes distance from the baseline, the angle of the shaft, and shaft diameter). Resistance is then calculated. After completing the resistance module, engine and water jet data are input into NavCad, which then determines the engine operating conditions, the optimum reduction gear (RG) ratio, and the sustained and endurance speeds.

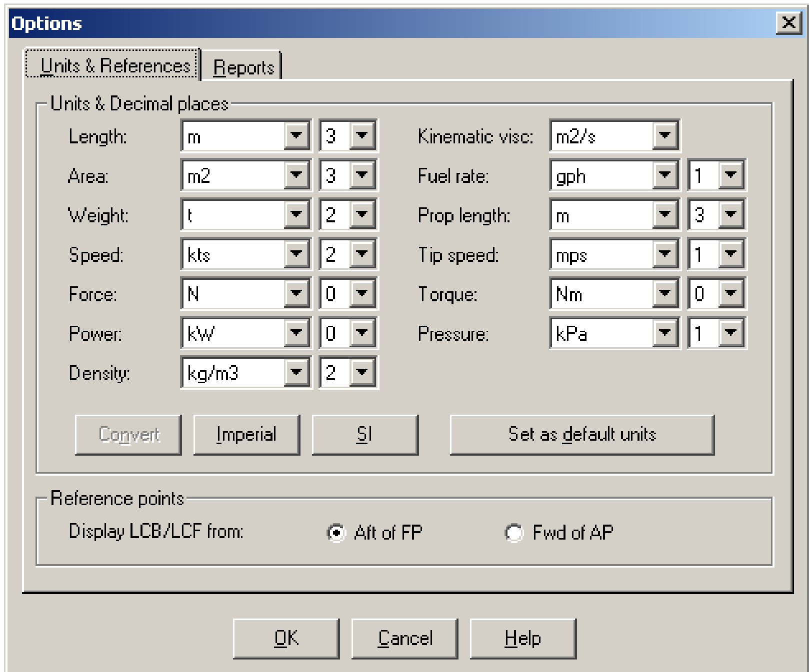


Figure 55 - NavCad Inputs (Units)

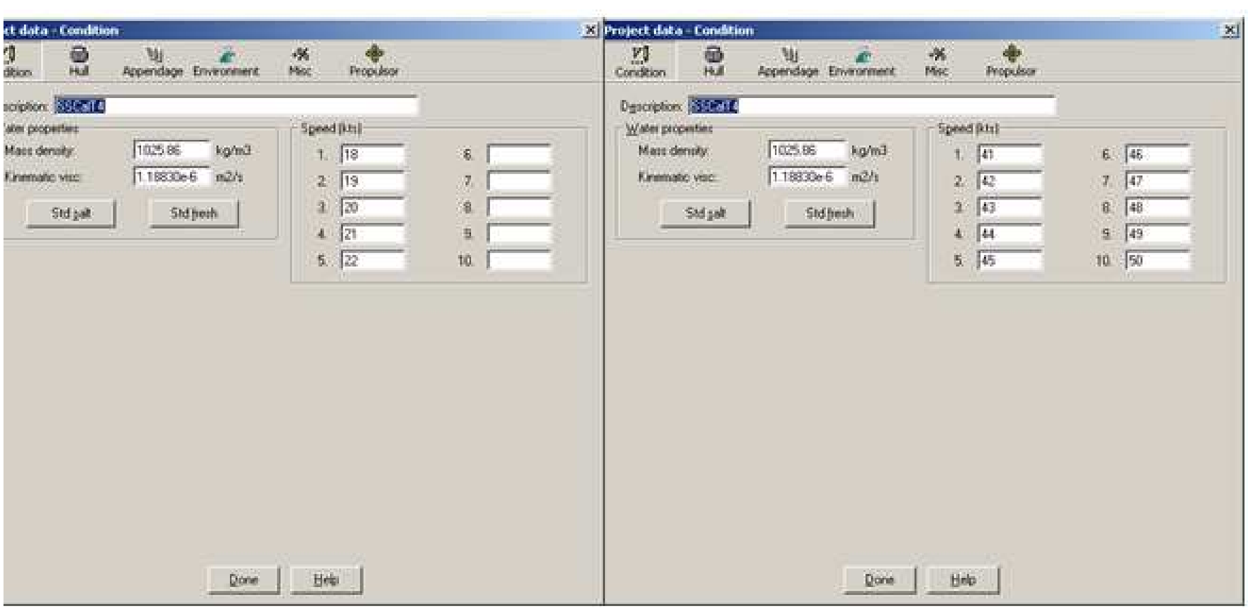


Figure 56 - NavCad Inputs (Condition)

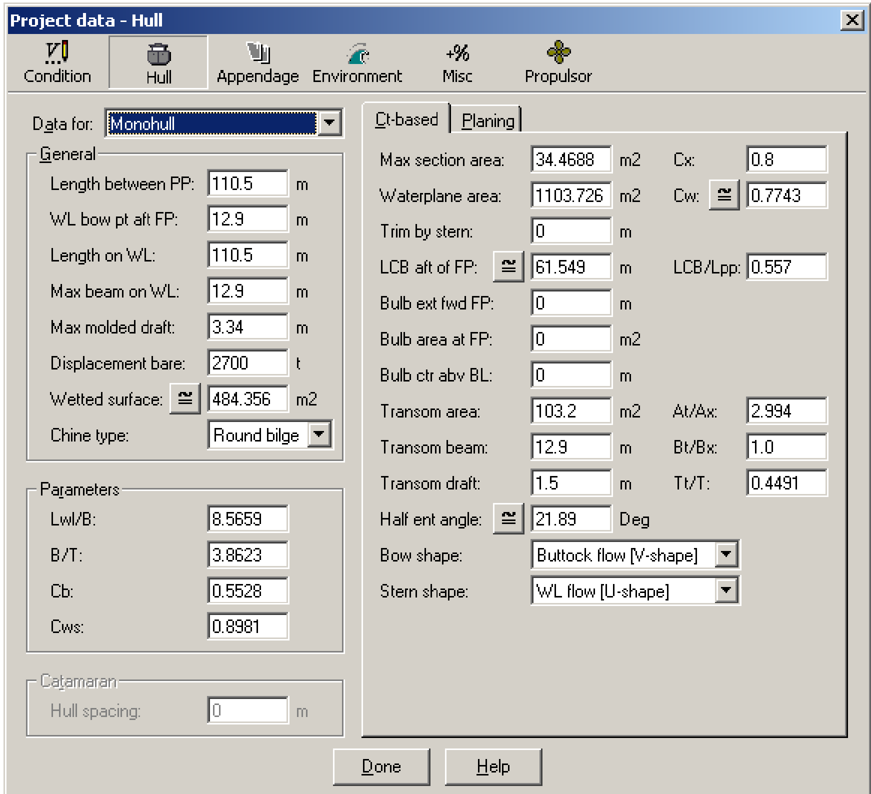


Figure 57 - NavCad Inputs (Hullform - Displacement)

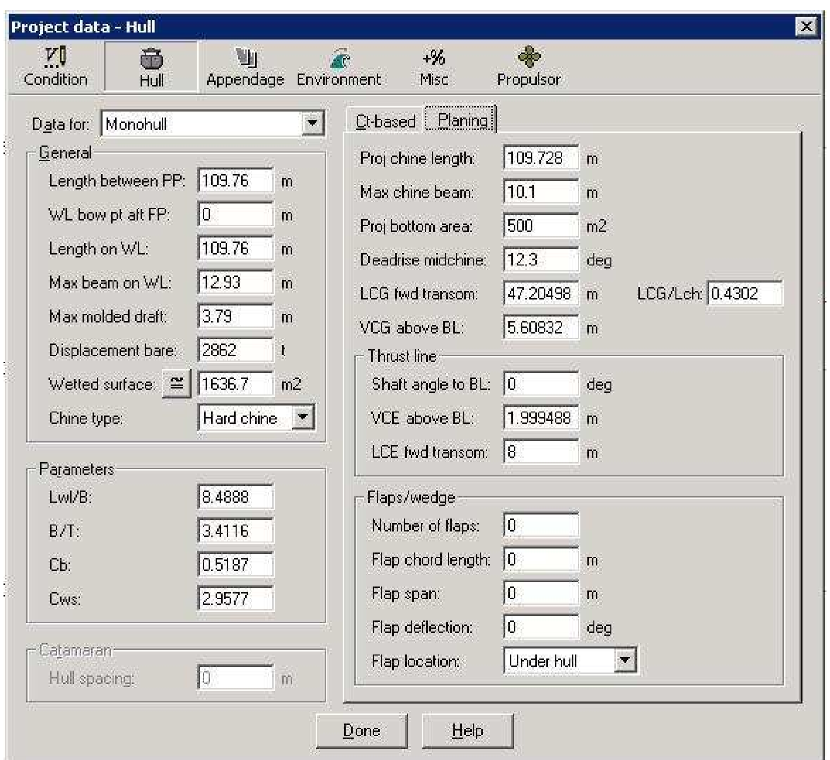


Figure 58 - NavCad Inputs (Hullform - Planing)

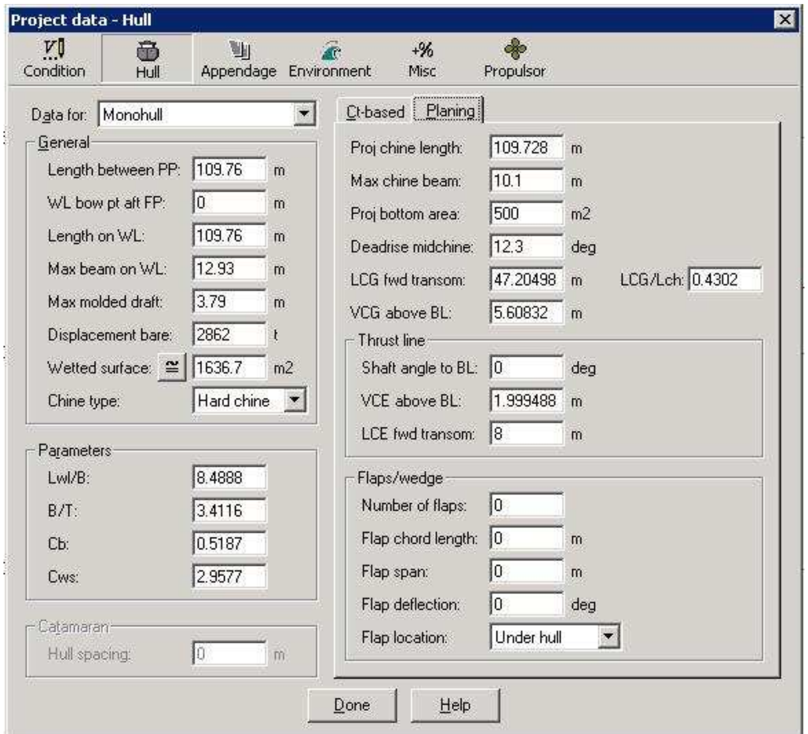


Figure 59 - NavCad Inputs (Environment)

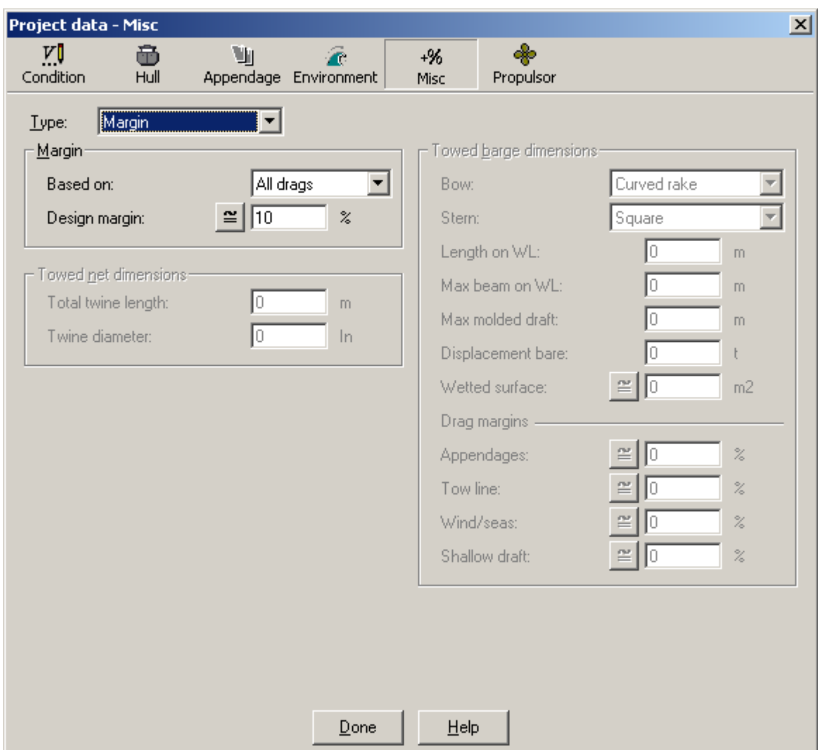


Figure 60 - NavCad Inputs (Endurance Margin)

4.6.1 Resistance

The Resistance module uses the Holtrop-Mennen method to calculate the total ship resistance at endurance speed and the Savitsky planing method for sustained speed. The endurance speed of SSC is 22 knots. The sustained speed of SSC is 50 knots. These methods approximate the bare hull viscous surface friction drag and the wave-making mass movement drag. The total resistance is a sum of the viscous drag (uses ITTC estimates and friction), wave-making drag (force to move a mass of water around the hull), appendage drag (drag of the propeller and other appendages), bulb drag (zero for SSC), and transom drag. The power is calculated and includes a 10% margin at endurance speed and a 25% margin at sustained speed. The effective horsepower (EHP) required is a sum of the power needed to overcome total bare hull resistance, appendage resistance, and air resistance.

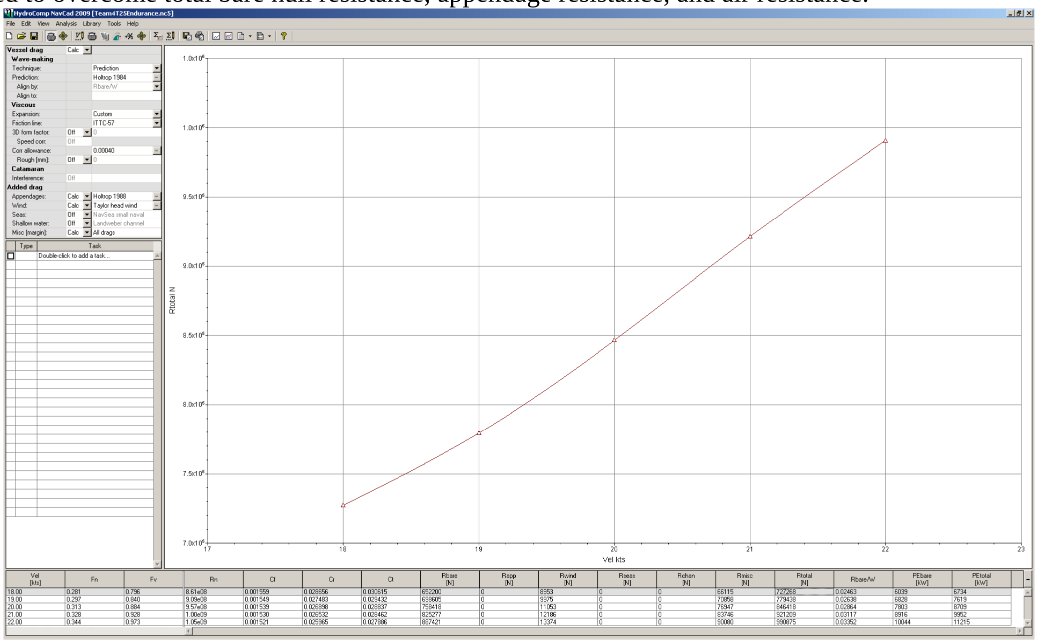


Figure 61 - Holtrop Resistance

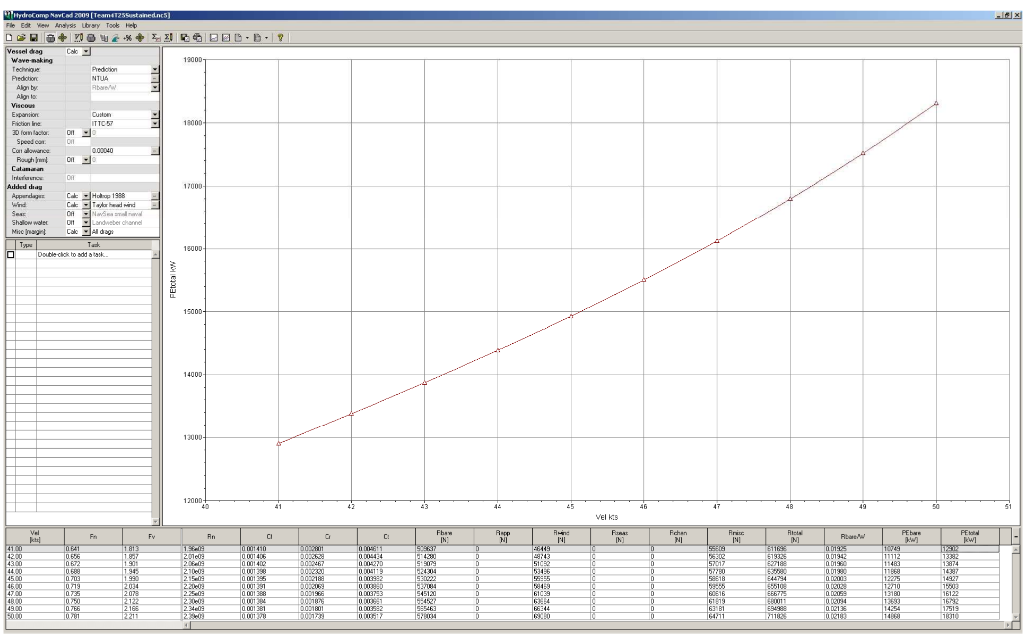
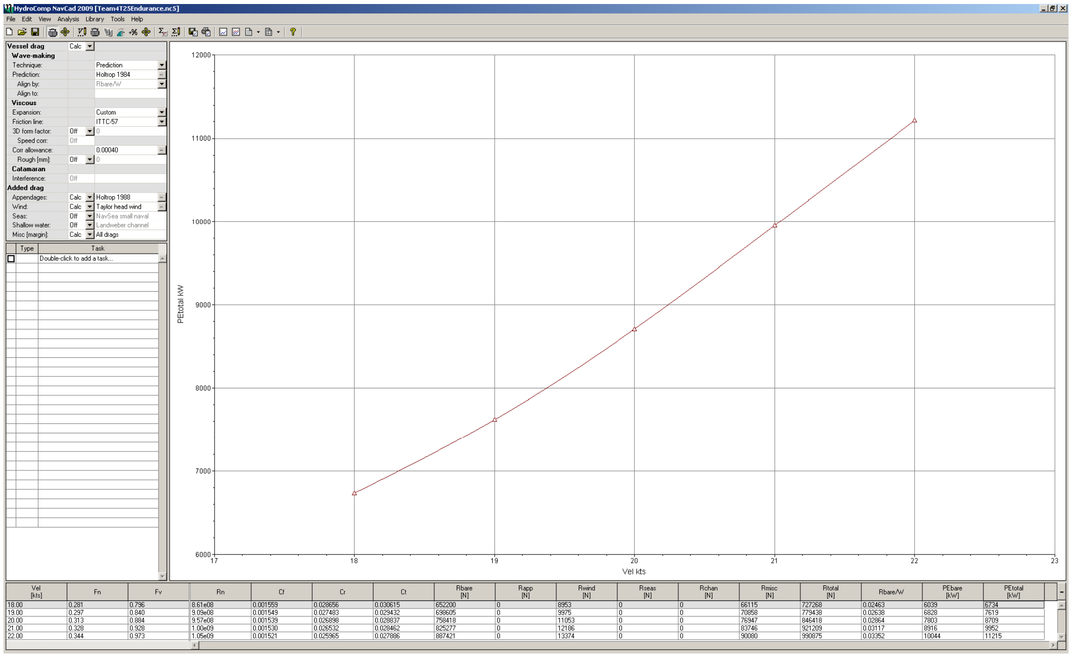


Figure 62 - Sustained Speed EHP



Vel [kts]	Fn	Fv	Rn	Cf	Cr	Ct	Rbare [N]	Rapp [N]	Rwind [N]	Rseas [N]	Rchan [N]	Rmisc [N]	Rtotal [N]	Rbare/W	PEbare [kW]	PEtotal [kW]
18.00	0.281	0.796	8.61e08	0.001559	0.028656	0.030615	652200	0	8953	0	0	66115	727268	0.02463	6039	6734
19.00	0.297	0.840	9.09e08	0.001549	0.027483	0.029432	698605	0	9975	0	0	70858	779438	0.02638	6828	7619
20.00	0.313	0.884	9.57e08	0.001539	0.026898	0.028837	758418	0	11053	0	0	76947	846418	0.02864	7803	8709
21.00	0.328	0.928	1.00e09	0.001530	0.026532	0.028462	825277	0	12186	0	0	83746	921209	0.03117	8916	9952
22.00	0.344	0.973	1.05e09	0.001521	0.025965	0.027886	887421	0	13374	0	0	90080	990875	0.03352	10044	11215

Figure 63 - Endurance Speed EHP

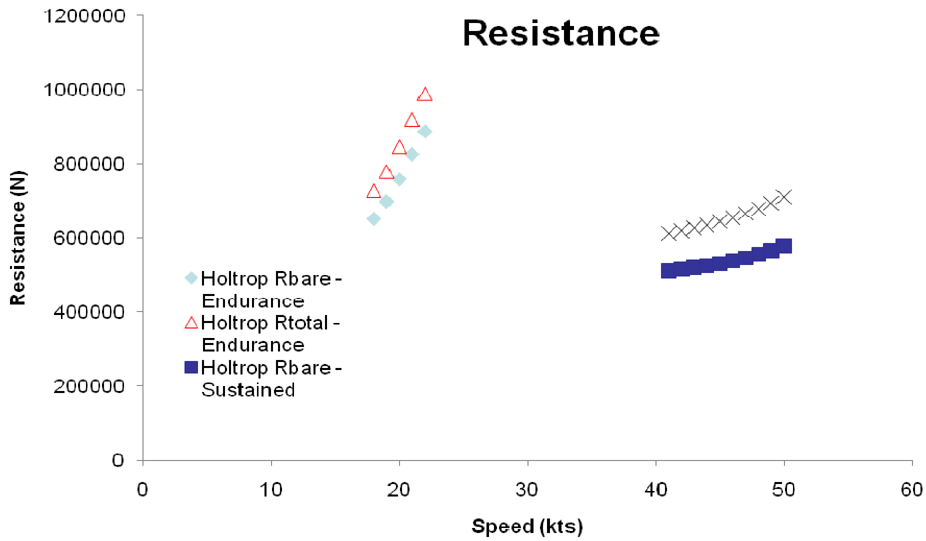


Figure 64 - Resistance at Endurance and Sustained Speeds

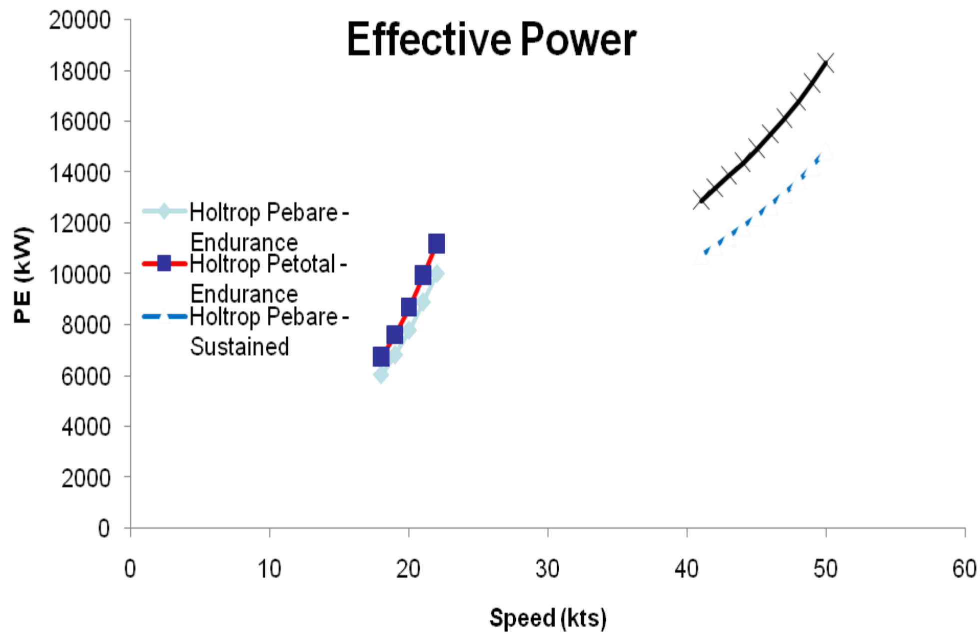
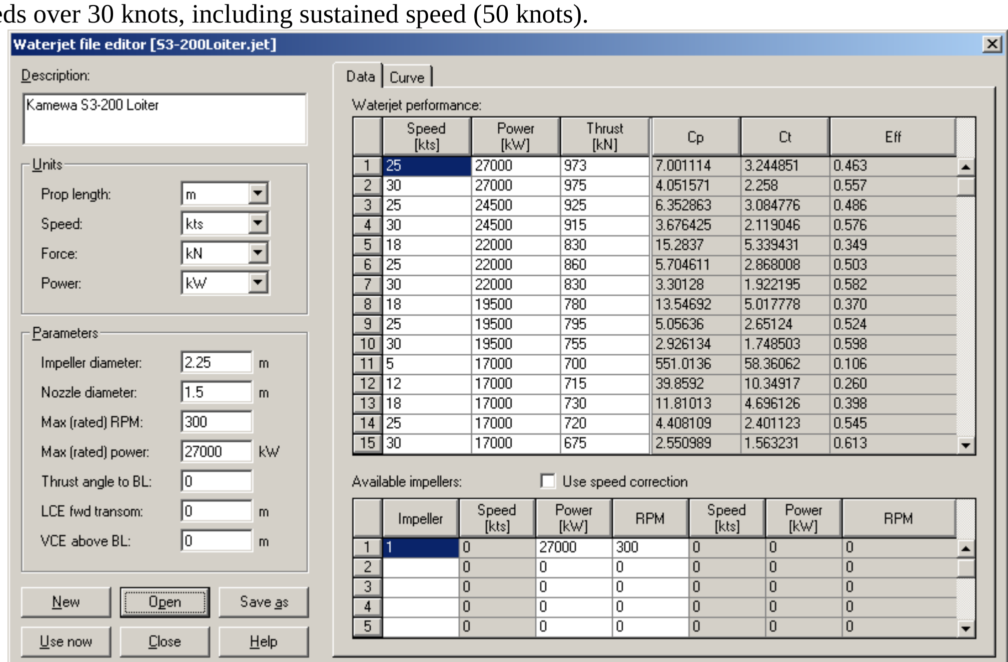


Figure 65 - EHP at Endurance and Sustained Speeds

4.6.2 Propulsion Analysis – Endurance Range and Sustained Speed

The propulsion system on the SSC is a CODLAG consisting of two gas turbines (MT30) rated at 36 MW each at 3600 rpm, two diesel generators (SEMT16PA6B) rated at 4.6 MW each at 1050 rpm, one 1 MW secondary propulsion motor, two CAT3508B ship service diesel generators, and two Kamewa S3-200 water jets. The diesels are only operated at endurance speed (22 knots) and the gas turbines are only operated at speeds over 30 knots, including sustained speed (50 knots).


Waterjet file editor [S3-200Loiter.jet]

Description: Kamewa S3-200 Loiter

Units
Prop length: m
Speed: kts
Force: kN
Power: kW

Parameters
Impeller diameter: 2.25 m
Nozzle diameter: 1.5 m
Max (rated) RPM: 300
Max (rated) power: 27000 kW
Thrust angle to BL: 0
LCE fwd transom: 0 m
VCE above BL: 0 m

New | Open | Save as | Use now | Close | Help

Data | Curve

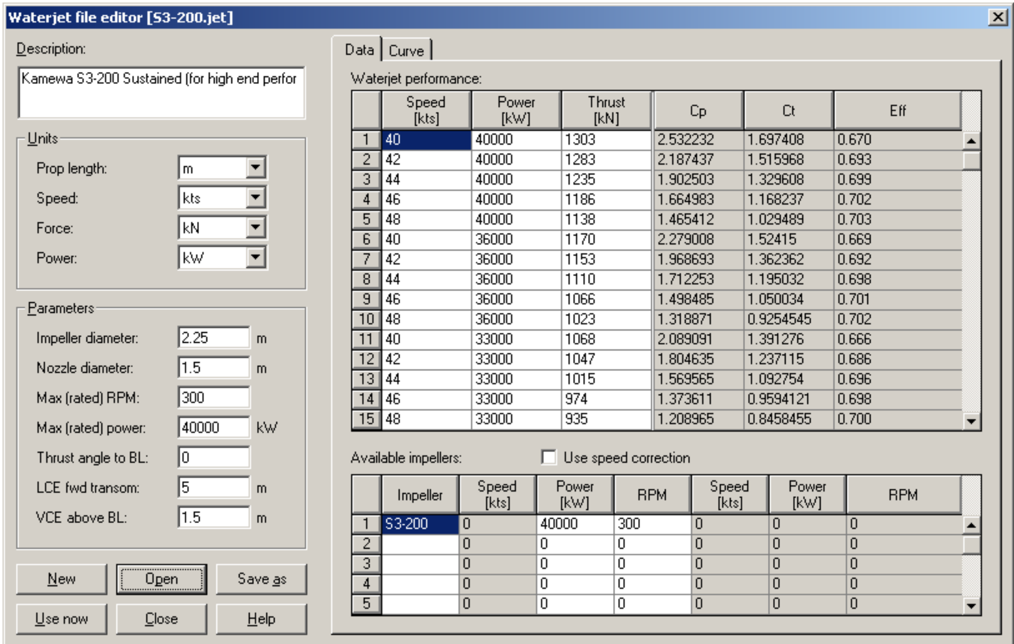
Waterjet performance:

	Speed [kts]	Power [kW]	Thrust [kN]	Cp	Ct	Eff
1	25	27000	973	7.001114	3.244851	0.463
2	30	27000	975	4.051571	2.258	0.557
3	25	24500	925	6.352863	3.084776	0.486
4	30	24500	915	3.676425	2.119046	0.576
5	18	22000	830	15.2837	5.339431	0.349
6	25	22000	860	5.704611	2.868008	0.503
7	30	22000	830	3.30128	1.922195	0.582
8	18	19500	780	13.54692	5.017778	0.370
9	25	19500	795	5.05636	2.65124	0.524
10	30	19500	755	2.926134	1.748503	0.598
11	5	17000	700	551.0136	58.36062	0.106
12	12	17000	715	39.8592	10.34917	0.260
13	18	17000	730	11.81013	4.696126	0.398
14	25	17000	720	4.408109	2.401123	0.545
15	30	17000	675	2.550989	1.563231	0.613

Available impellers: Use speed correction

	Impeller	Speed [kts]	Power [kW]	RPM	Speed [kts]	Power [kW]	RPM
1	1	0	27000	300	0	0	0
2		0	0	0	0	0	0
3		0	0	0	0	0	0
4		0	0	0	0	0	0
5		0	0	0	0	0	0

Figure 66 - Waterjet at Low Speeds



	Speed [kts]	Power [kW]	Thrust [kN]	Cp	Ct	Eff
1	40	40000	1303	2.532232	1.697408	0.670
2	42	40000	1283	2.187437	1.515968	0.693
3	44	40000	1235	1.902503	1.329608	0.699
4	46	40000	1186	1.664983	1.168237	0.702
5	48	40000	1138	1.465412	1.029489	0.703
6	40	36000	1170	2.279008	1.52415	0.669
7	42	36000	1153	1.968693	1.362362	0.692
8	44	36000	1110	1.712253	1.195032	0.698
9	46	36000	1066	1.498485	1.050034	0.701
10	48	36000	1023	1.318871	0.9254545	0.702
11	40	33000	1068	2.089091	1.391276	0.666
12	42	33000	1047	1.804635	1.237115	0.686
13	44	33000	1015	1.569565	1.092754	0.696
14	46	33000	974	1.373611	0.9594121	0.698
15	48	33000	935	1.208965	0.8458455	0.700

	Impeller	Speed [kts]	Power [kW]	RPM	Speed [kts]	Power [kW]	RPM
1	S3-200	0	40000	300	0	0	0
2		0	0	0	0	0	0
3		0	0	0	0	0	0
4		0	0	0	0	0	0
5		0	0	0	0	0	0

Figure 67 - Waterjet (High Performance)

Water jets were selected based on prior studies. The location of each jet was assumed based on hullform, which takes up all extra transom space. The chosen jet, the Kamewa S3-200, has an impeller diameter of 2 m, a nozzle diameter of 1.5 m, a maximum rpm of 300 rpm, and a maximum rated power of 40000 kW.

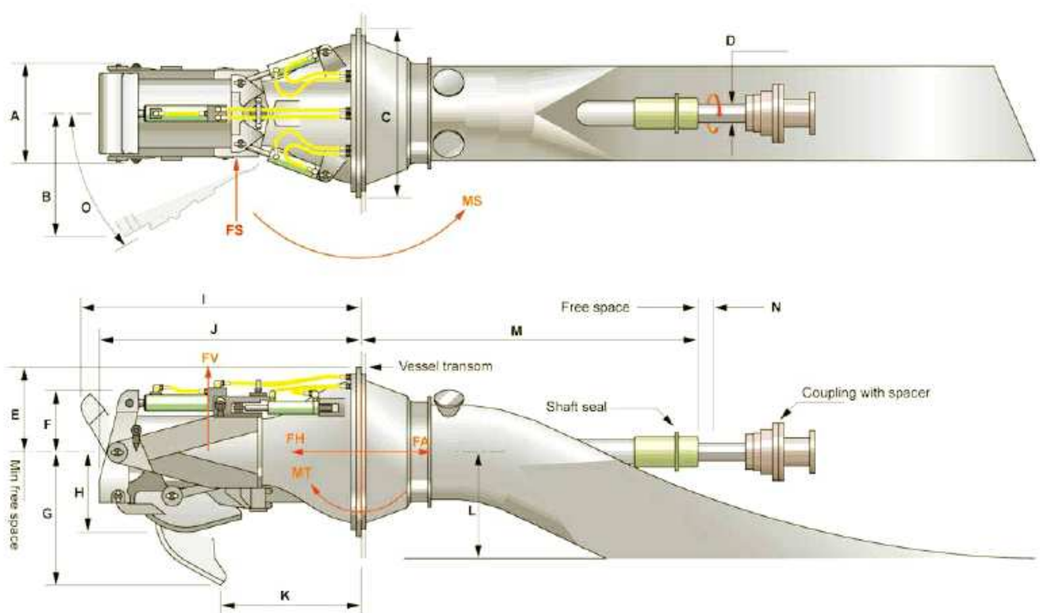


Figure 68 - Kamewa S3-200 Waterjet

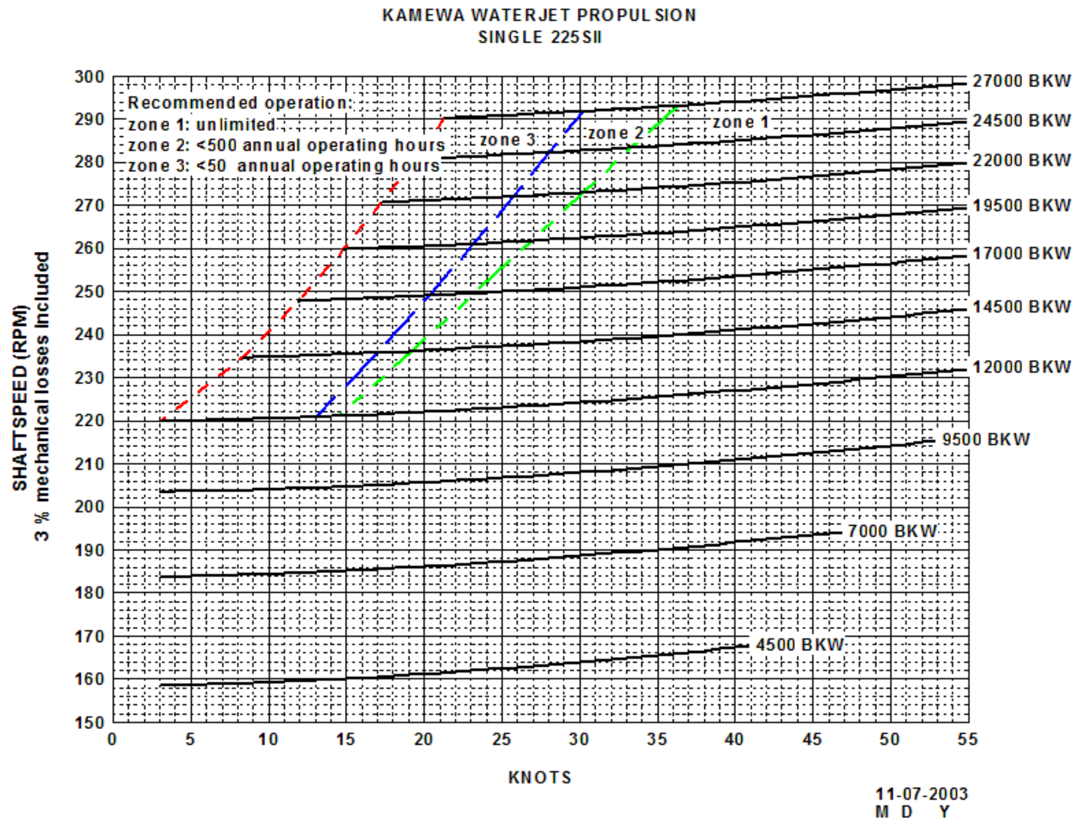


Figure 69 - Waterjet Performance Curves

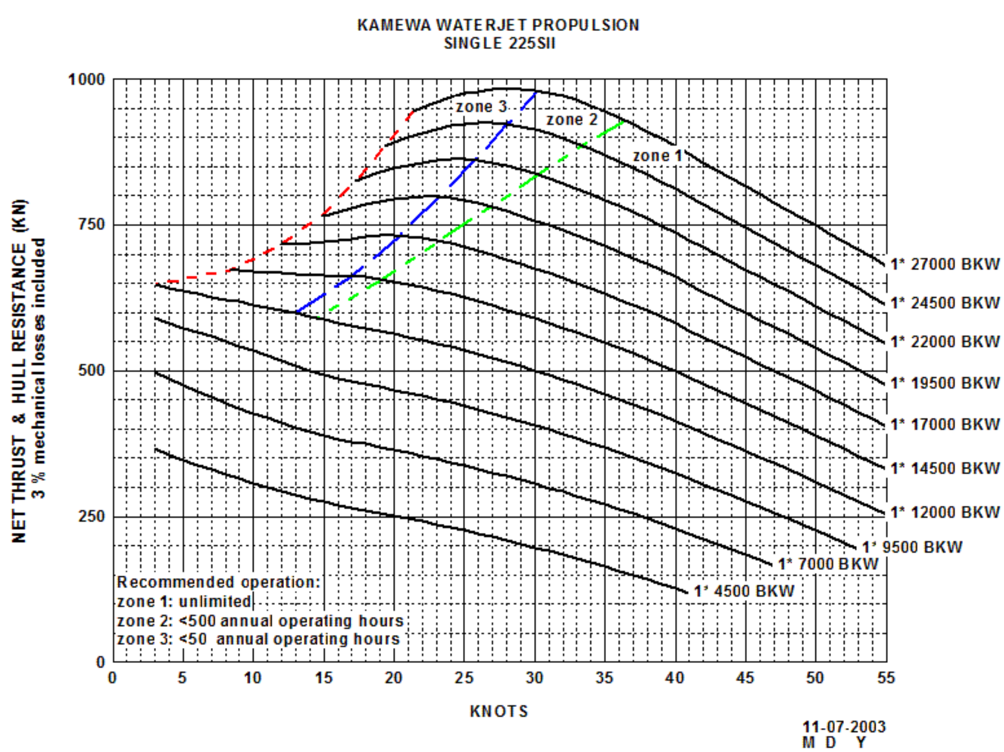
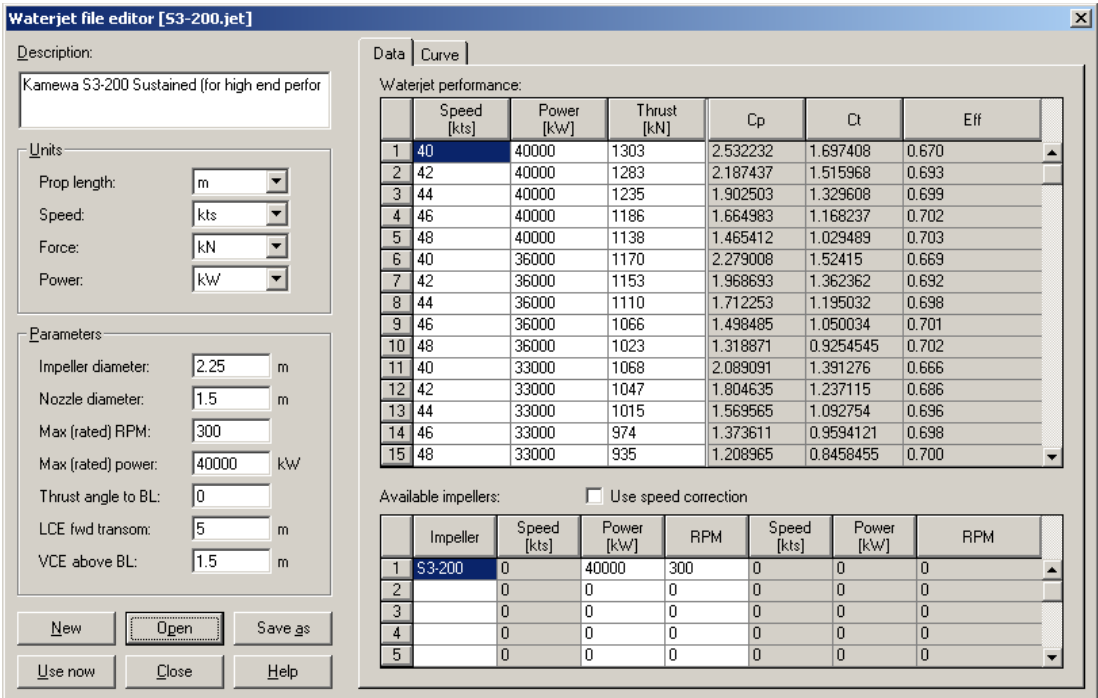


Figure 70 - Waterjet Perfromance Curves



	Speed [kts]	Power [kW]	Thrust [kN]	Cp	Ct	Eff
1	40	40000	1303	2.532232	1.697408	0.670
2	42	40000	1283	2.187437	1.515968	0.693
3	44	40000	1235	1.902503	1.329608	0.699
4	46	40000	1186	1.664983	1.168237	0.702
5	48	40000	1138	1.465412	1.029489	0.703
6	40	36000	1170	2.279008	1.52415	0.669
7	42	36000	1153	1.968693	1.362362	0.692
8	44	36000	1110	1.712253	1.195032	0.698
9	46	36000	1066	1.498485	1.050034	0.701
10	48	36000	1023	1.318871	0.9254545	0.702
11	40	33000	1068	2.089091	1.391276	0.666
12	42	33000	1047	1.804635	1.237115	0.686
13	44	33000	1015	1.569565	1.092754	0.696
14	46	33000	974	1.373611	0.9594121	0.698
15	48	33000	935	1.208965	0.8458455	0.700

	Impeller	Speed [kts]	Power [kW]	RPM	Speed [kts]	Power [kW]	RPM
1	S3-200	0	40000	300	0	0	0
2		0	0	0	0	0	0
3		0	0	0	0	0	0
4		0	0	0	0	0	0
5		0	0	0	0	0	0

Figure 71 - NavCad Inputs (Waterjet)

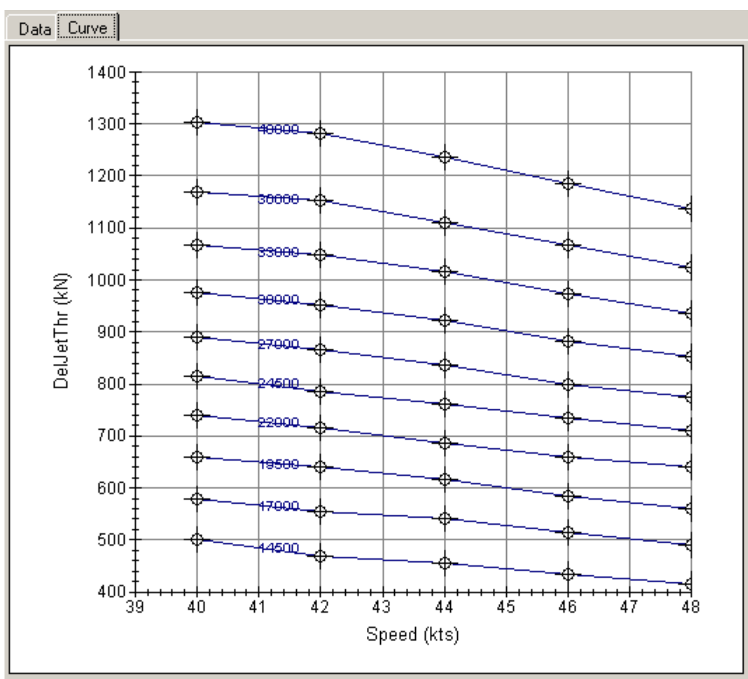


Figure 72 - NavCad Inputs (Waterjet Performance Curves)

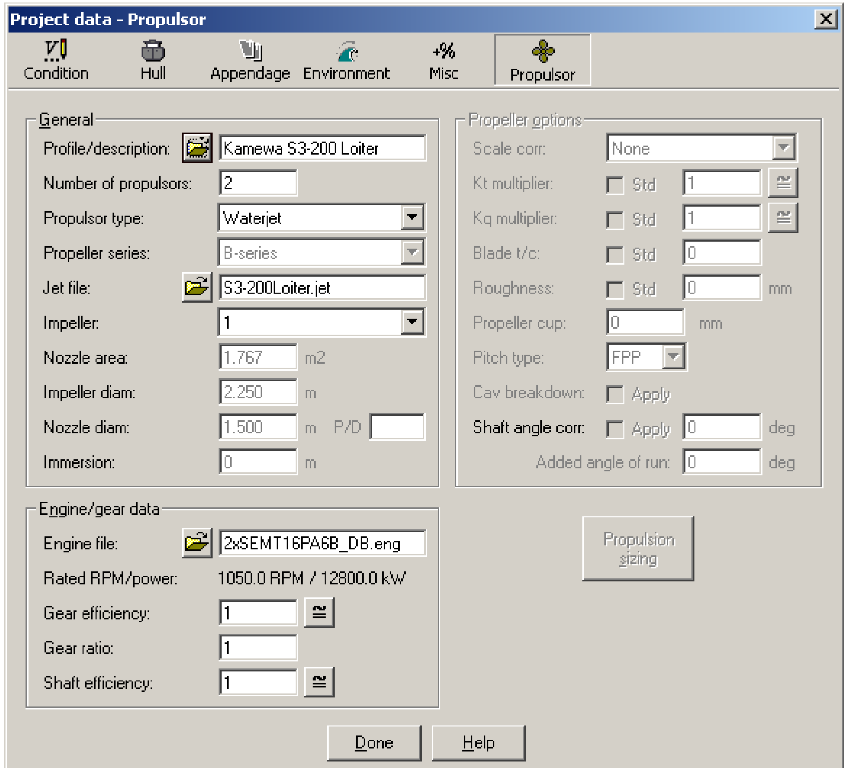


Figure 73 - NavCad Inputs (Endurance Propulsion)

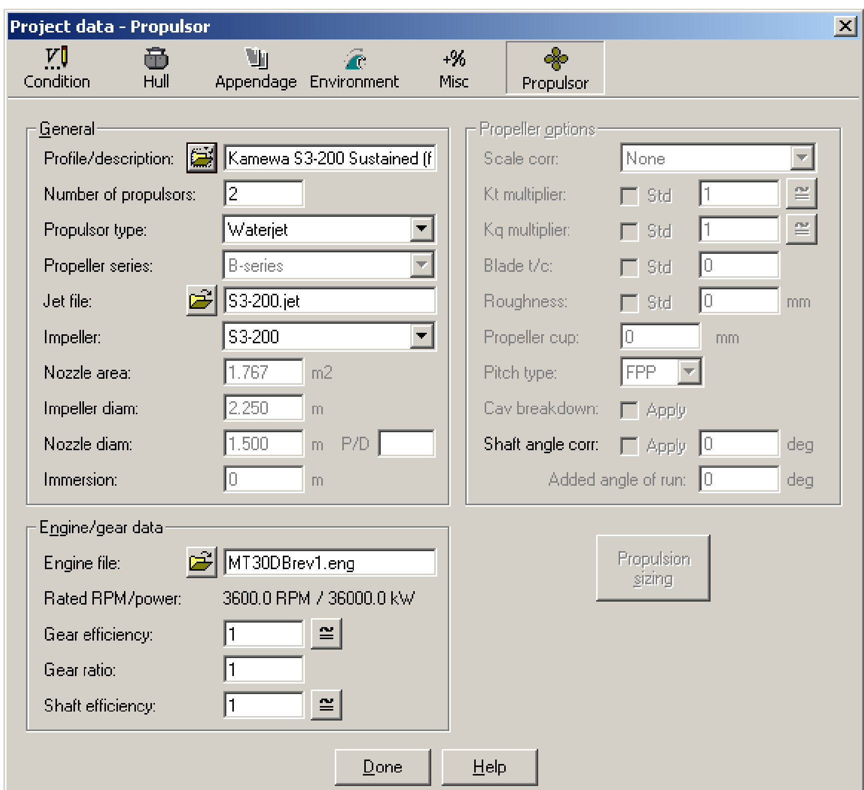


Figure 74 - NavCad Inputs (Sustained Propulsion)

Once the water jet characteristics are found, the shaft horsepower (SHP) is calculated for each shaft at endurance and sustained speeds. The brake horsepower (BHP) required for endurance and sustained speed is calculated for the entire ship.

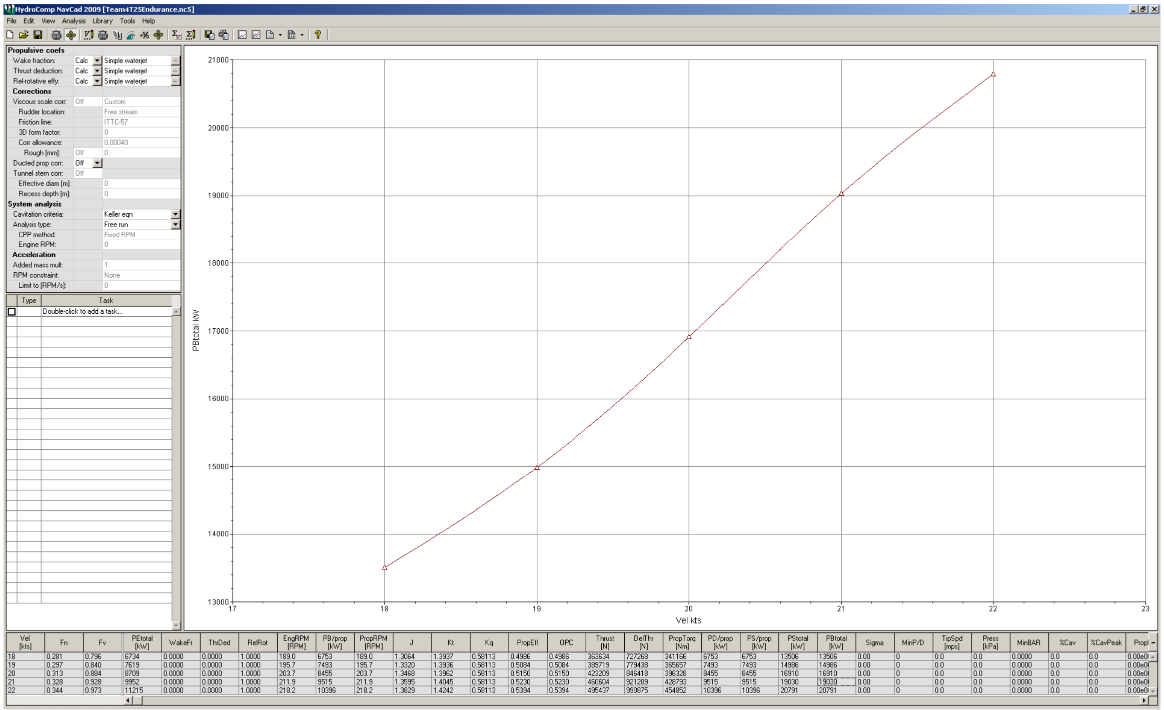


Figure 75 - Endurance Speed Power

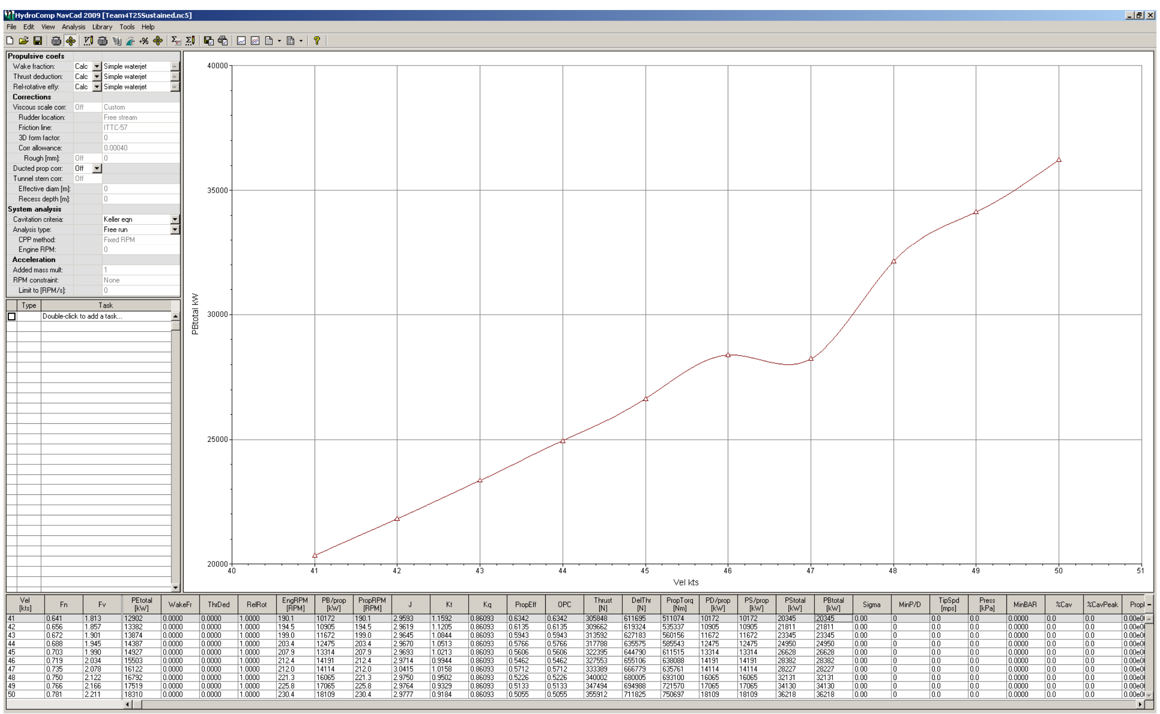


Figure 76 - Sustained Speed Power

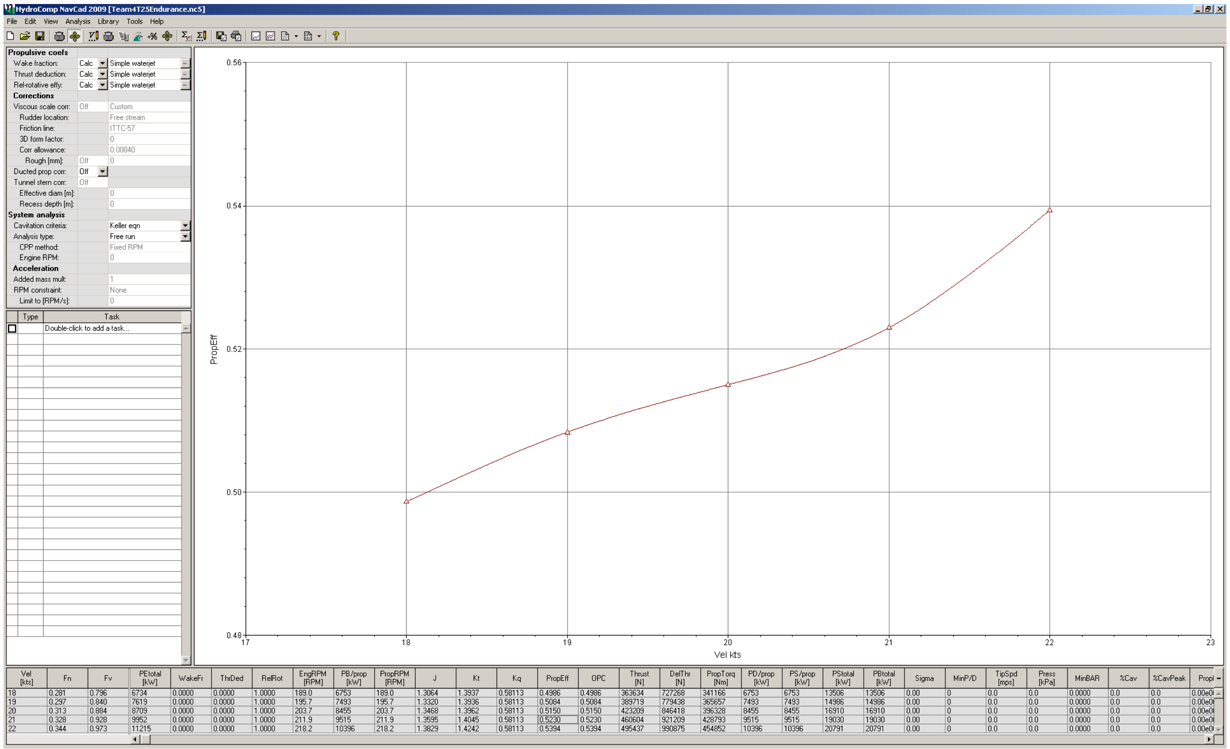


Figure 77 - OPE at Endurance Speed

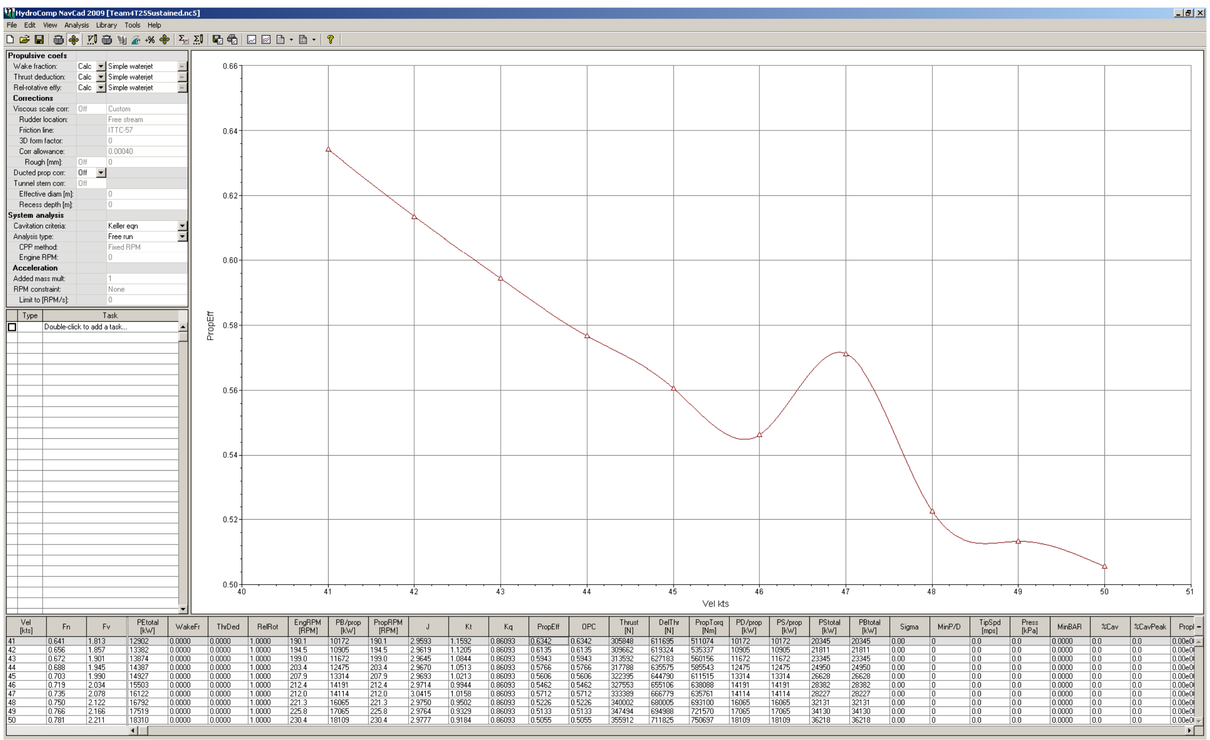


Figure 78 - OPE at Sustained Speed

Engine performance maps are used for endurance speed conditions in order to determine the engine RPM for optimum specific fuel consumption (SFC). The RG ratio is calculated and then the sustained speed engine RPM is determined. If the RPM is greater than 3600 rpm, the RG ratio must be re-calculated for an engine speed of 3600 rpm. The SFC can then be determined from engine performance maps at this speed. With the new RG ratio, the endurance speed engine RPM and SFC must be re-calculated.

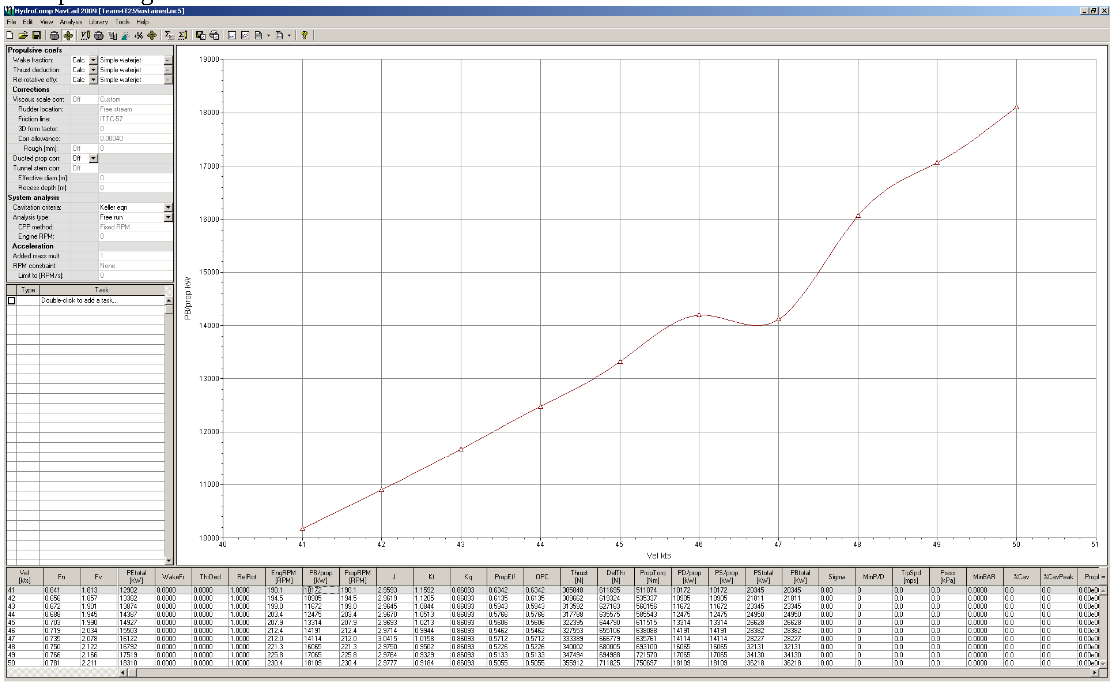


Figure 79 - BHPreq at Sustained Speed

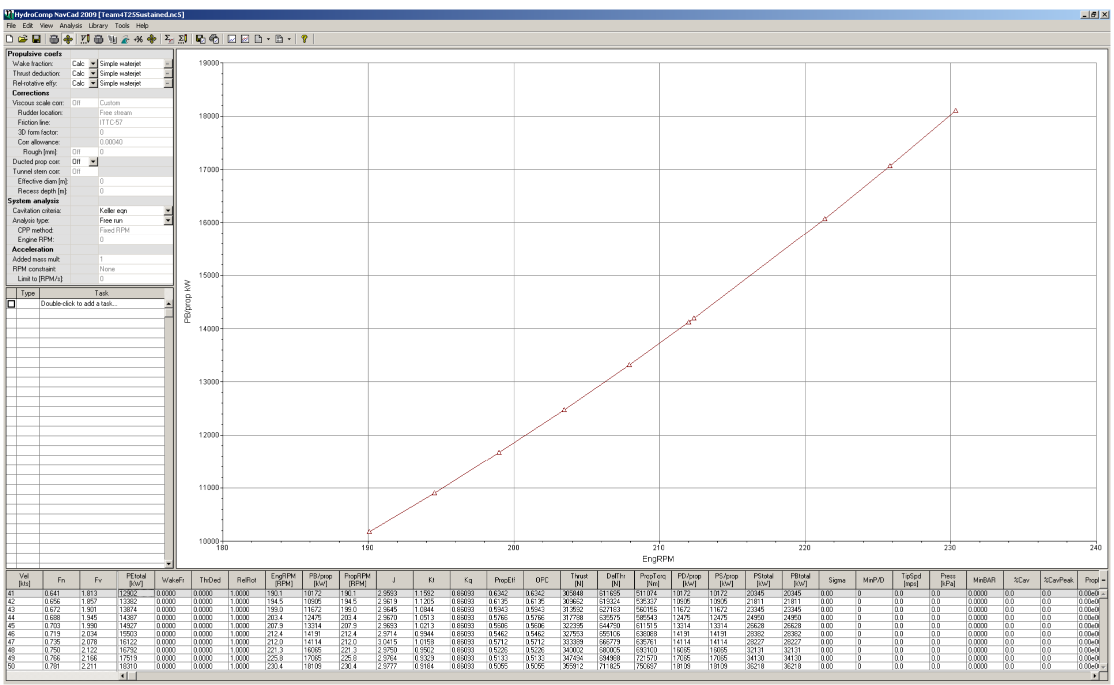


Figure 80 - Coupling at Sustained Speed

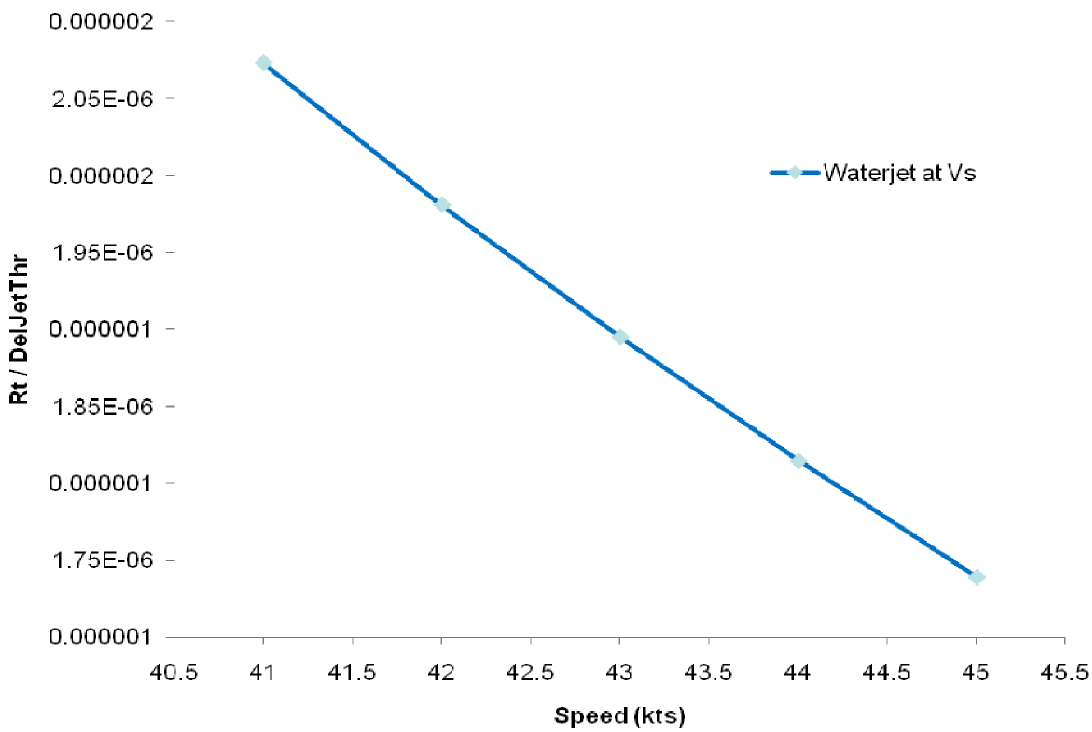


Figure 81 - Waterjet at Sustained Speed

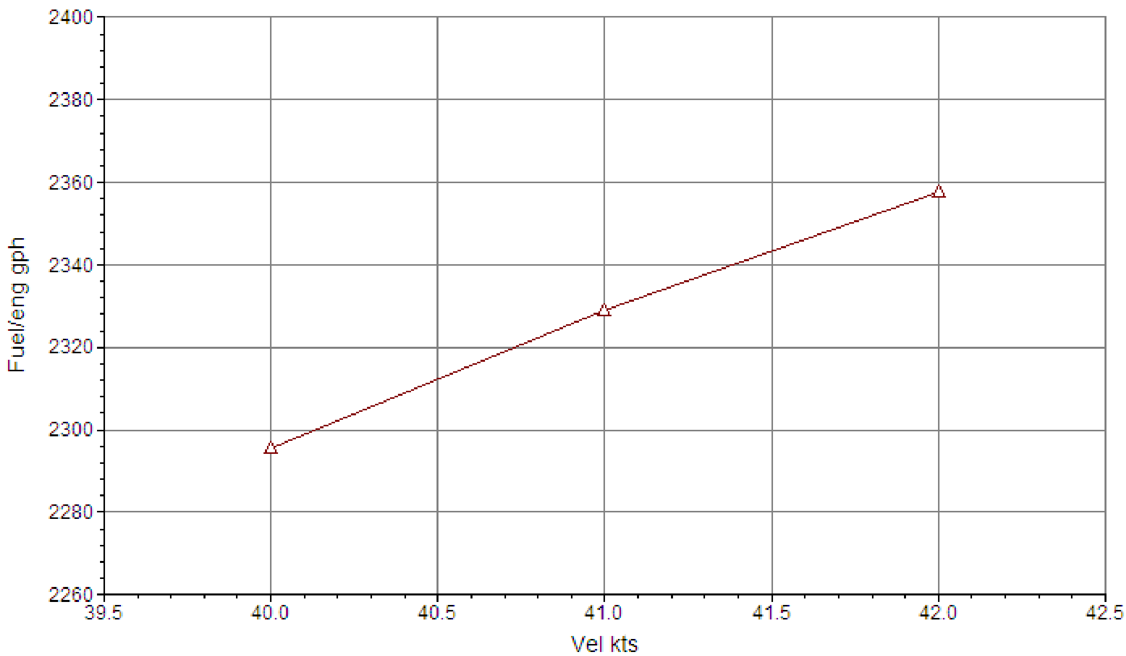


Figure 82 - Sustained Speed Fuel Consumption

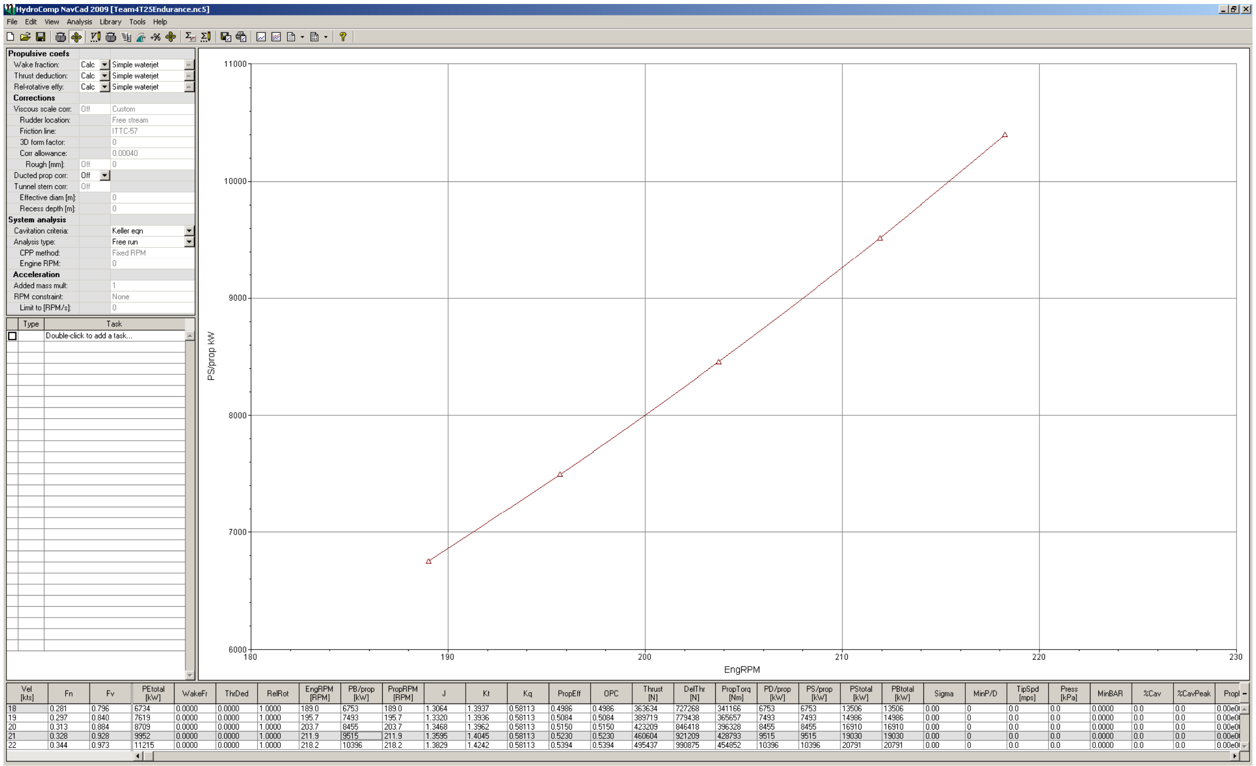


Figure 83 - Coupling at Endurance Speed

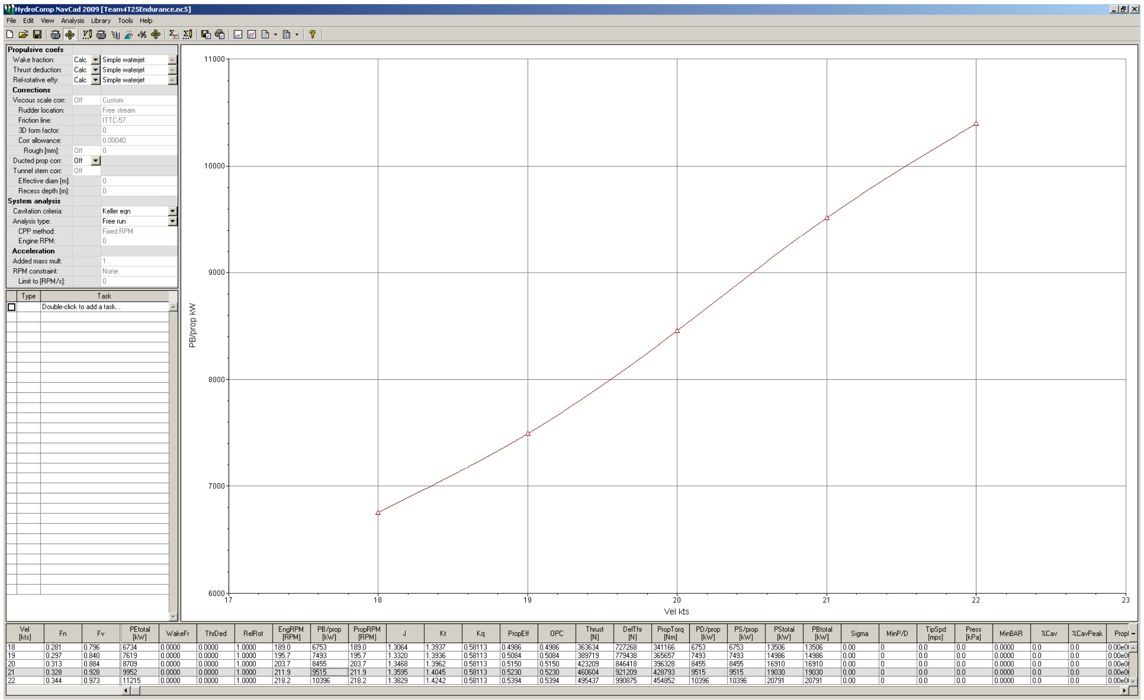


Figure 84 - BHPreq at Endurance Speed

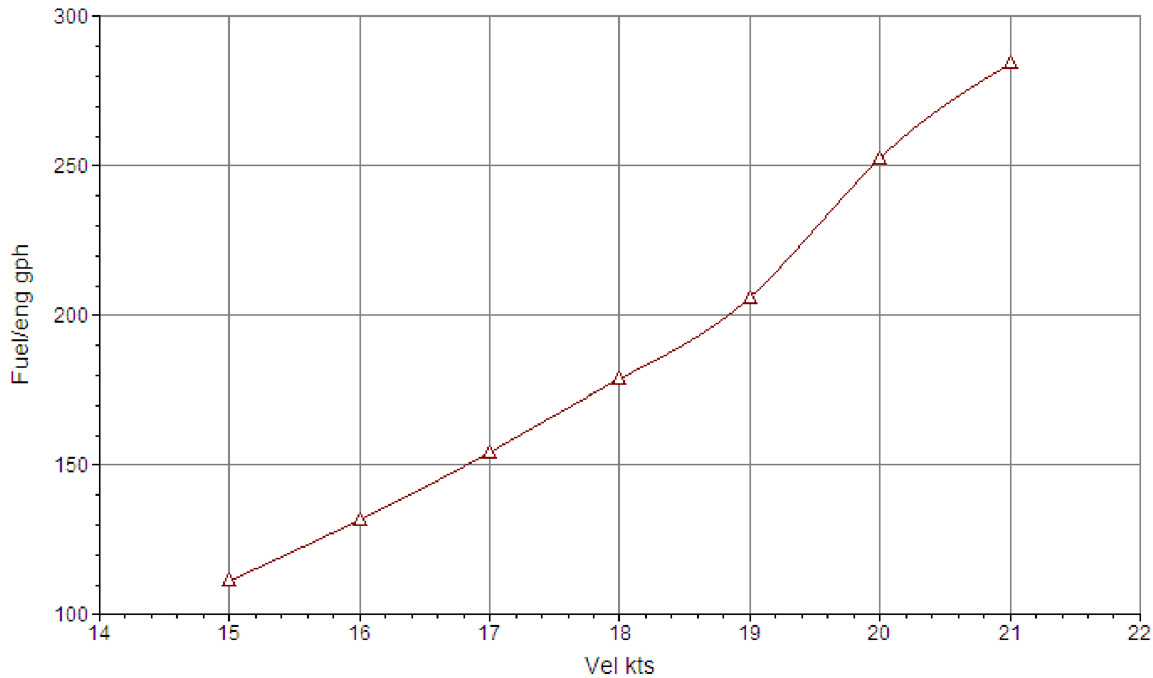


Figure 85 - Endurance Speed Fuel Consumption

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

From NAVCAD at endurance speed:

$V_e := 22 \cdot knt$ $N_E := 2$ $BHP_{SPGM} := 18310\,hp$ $BHP_{eSPGM} := 11215\,hp$ $GPH_{eENG} := 252.5\frac{gal}{hr}$

From SSSM at cruise condition:

$N_G := 2$ $KW_g := 2000\,kW$ $KW_{gtot} := N_G \cdot KW_g$

$KW_{24AVG} := 2100\,kW$ $SFC_g := .35 \cdot \frac{lbf}{hp \cdot hr}$ $V_{F41} := 600 \cdot m^3$

Conversion of units:

$GPH_e := N_E \cdot GPH_{eENG}$ $GPH_e = 67.509\frac{ft^3}{hr}$ $SFC_{eSPGM} := \frac{GPH_e}{\delta_F \cdot BHP_{eSPGM}}$ $SFC_{eSPGM} = 0.309\frac{lbf}{hp \cdot hr}$

Figure 86 - MathCad Inputs for Endurance Range

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

Correction for instrumentation inaccuracy and machinery design changes:

$$f_1 := \begin{cases} 1.04 & \text{if } BHP_{eSPGM} \le \frac{1}{3} \cdot BHP_{SPGM} \\ 1.02 & \text{if } BHP_{eSPGM} \ge \frac{2}{3} \cdot BHP_{SPGM} \\ 1.03 & \text{otherwise} \end{cases} \qquad f_1 = \blacksquare$$

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{eSPGM}$ $\quad FR_{SP} = \blacksquare \cdot \frac{lbf}{hp \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years:

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

Figure 87 - MathCad Calculations

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

Correction for instrumentation inaccuracy and machinery design changes:

$$f_{g1} := \begin{cases} 1.04 & \text{if } KW_{24AVG} \le \frac{1}{3} \cdot KW_{gtot} \\ 1.02 & \text{if } KW_{24AVG} \ge \frac{2}{3} \cdot KW_{gtot} \\ 1.03 & \text{otherwise} \end{cases} \qquad f_{g1} = \blacksquare$$

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

Average fuel rate allowing for plant deterioration over 2 years:

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

Tailpipe allowance: $TPA := 0.95$

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

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

$$E := \frac{W_{F41} \cdot V_e \cdot TPA}{BHP_{eSPGM} \cdot FR_{AVGp} + KW_{24AVG} \cdot FR_{AVGg}} \qquad E = \blacksquare \cdot nm$$

Figure 88 - MathCad Results

4.6.3 Electric Load Analysis (ELA)

Table 31 - Electric Load Analysis Summary

SWBS	Description		Condition I (kW)	Loiter (kW)	Cruise (kW)	In Port (kW)	Anchor (kW)	Emergency (kW)
100	Deck		0	0	0	17.1	11.5	0
200	Propulsion		225.2	225.2	225.2	0	0	204.6
300	Electric		71.6	71.6	71.6	34.8	34.8	50.3
430&475	Miscellaneous		101.4	101.4	101.4	11.3	17.3	13.2
510	HVAC		421.6	421.6	421.6	421.6	421.6	97.6
520	Seawater Systems		32.6	32.6	32.6	32.6	32.6	32.6
530&550	Misc. Auxiliary		77.0	77.0	77.0	77.0	77.0	23.5
540	Fuel Handling		55.1	55.1	55.1	0	0	0
560	Ship Control		47.3	47.3	47.3	0	0	47.3
600	Services		34.4	34.4	34.4	34.4	34.4	16.8
700	Payload		164.5	164.5	164.5	164.5	164.5	164.5
	Max Functional Load		1230.7	1230.7	1230.7	793.2	793.6	650.4
	MFL w/ Margins		1489.1	1489.1	1489.1	959.8	960.3	787.0
235	Electric Propulsion Drive		0	2319.4	0	0	0	0
	Total Load w/ Margins		1489.1	3808.5	1489.1	959.8	960.3	787.0
	24 Hour Ship Service Average		826.8	826.7	826.7	436.3	436.5	496.3
Number	**Generator**	**Rating (kW)**	**Condition I**	**Loiter**	**Cruise**	**In Port**	**Anchor**	**Emergency**
3	SSGTG	3000	2	2	1	1	1	1

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.

Many of the systems that were required had a specific location where they had to be placed, so those were put in first. Following this, the rest of the machinery was spread throughout the Machinery Rooms in order to maximize the space for personnel to work.

The restrictions that were faced consisted of the size of the machinery relative to the size of the space available, room in the Helicopter hangar to fit two SH-60's, and a small shaft angle from the engines to the water jets.

4.7.1 Integrated Power System (IPS) (or Ship Service Power) and Electrical Distribution

The design for this ship was a hybrid integrated power system and mechanical drive. To accomplish this, the ship has two MT30 gas turbines with reduction gears, two secondary diesel engines with generators (SEMT16PA6V), and two secondary electric IPS motors. The gas turbines and reduction gears are connected to shafts leading to the waterjets through the IPS motors. The IPS motors generate power to control the waterjets. The frequency changer used in the IPS system converts power from the IPS generators on the secondary engines to IPS system requirements. The hybrid system allows for more reliability than a full integrated power system while having some of the advantages of a full IPS. Figure 89 shows the One-Line Diagram for the hybrid design on this team's ship.

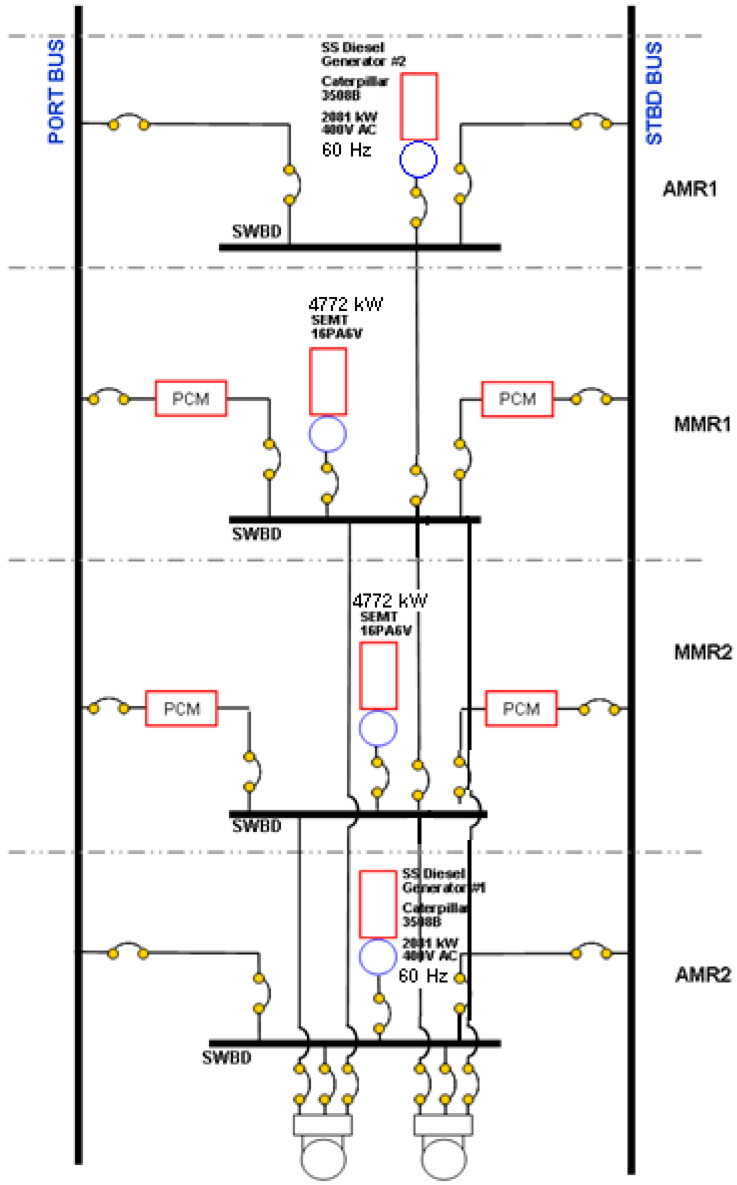


Figure 89 - One-Line Electrical Diagram

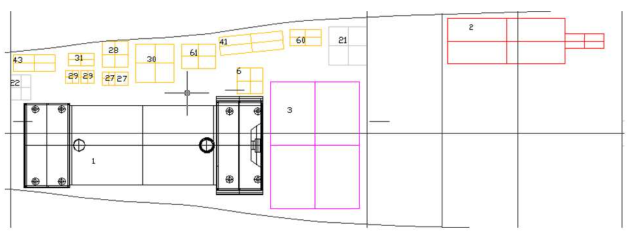
4.7.2 Service and Auxiliary Systems

There are two ship service diesel generators in the design. They are CAT3508B generators, providing 2081kW of power. In addition, all of the air conditioning equipment is located in the Auxiliary Machinery Rooms, along with the fresh water unit, brominators, and potable water pump.

4.7.3 Main and Auxiliary Machinery Spaces and Machinery Arrangement

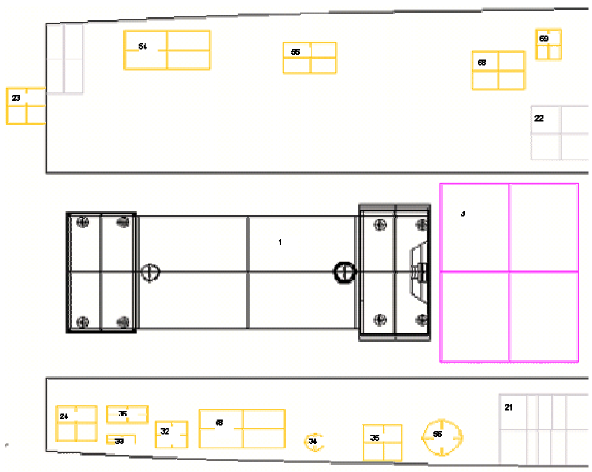
There are two main machinery rooms (MMR) and two auxiliary rooms (AMR). All are located around midships, creating a small shaft angle from the main gas turbines to the waterjets. Each main machinery room consists of a gas turbine and a reduction gear. One secondary diesel engine and its attached generator (SEMT16PA6V) are in the forward auxiliary machinery room because the forward main machinery room inner was too tight on space. The other secondary diesel engine is in the aft main machinery room. The reduction gears are aft of the gas turbines in the main machinery rooms with the shafts to the waterjets connected to them. Also in the main machinery rooms are the main seawater circulating pumps, compressed air systems, the main gas turbines hydraulic starting units and lube oil storage, conditioning, and coolers for the gas turbines and reduction gears. There is also an emergency switchboard located in the aft main machinery room. Figures of the main machinery room arrangements are shown below.

The auxiliary machinery rooms consist mainly of the ship service diesel generators, the secondary integrated power system motors, and the frequency changer for the IPS. Due to space, one secondary diesel engine is in the forward auxiliary machinery room rather than the forward main machinery room. The auxiliary machinery rooms also contain the air conditioning plants, refrigeration plants, all of the systems needed for JP-5 fueling operations, and fresh water systems.



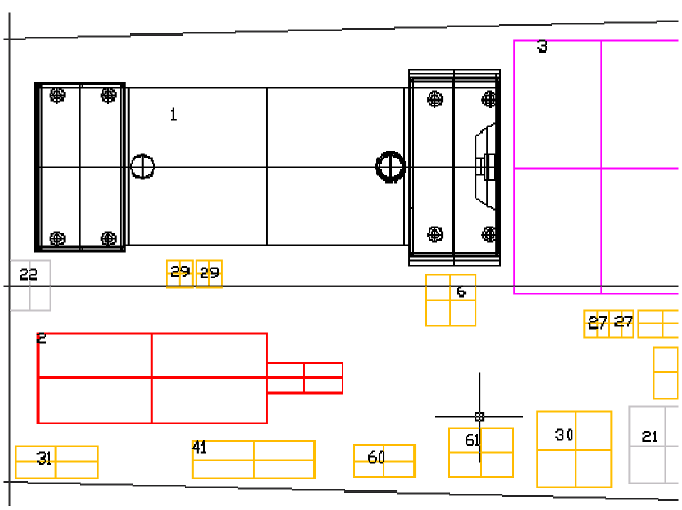
1	Gas Turbine MT30	29	RG LO Strainer
2	Diesel Gen. (Secon.)	30	RG LO Cooler
3	Reduction Gear	31	RG LO Serv Pump
6	Hydaul. Start. Unit	41	Fire Pump
21	Ladder	43	Bilge Pump
22	Escape Trunk	60	OW Transfer Pump
27	Main SW Circ Pump	61	Oil/Water Separator
28	LO Stor. And Condit.		

Figure 90 - MMR 1 Lower Level



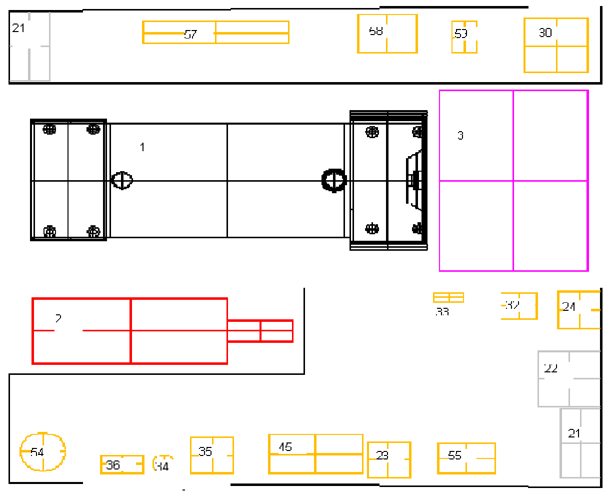
1	Gas Turbine (MT30)	35	Fuel Oil Purifier
3	Reduction Gear	36	Fuel Transfer Pump
21	Ladders	48	Recirc. Brominator
22	Trunks	54	Starting Air Receiver
23	Mach. Space Fan (Supply)	55	MP Air Compressor
24	Mach. Space Fan (Exhaust)	56	SS Air Receiver
32	Lube Oil Purifier	58	LP SS Air Compressor
33	Lube Oil Transfer Pump	59	Air Dyer

Figure 91 - MMR 1 Upper Level



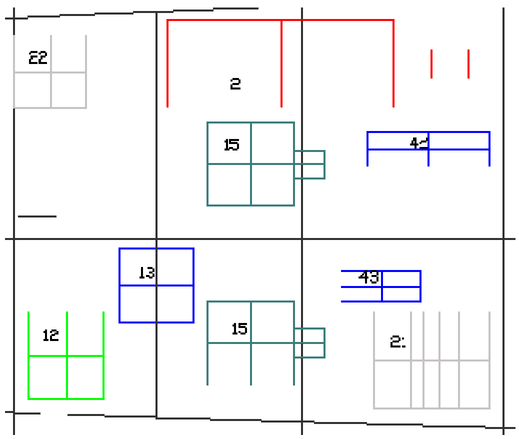
1	Gas Turbine MT30	28	LO Stor. And Condit.
2	Diesel Gen. (Secon.)	29	RG LO Strainer
3	Reduction Gear	30	RG LO Cooler
6	Hydaul. Start. Unit	31	RG LO Serv Pump
21	Ladder	41	Fire Pump
22	Escape Trunk	60	OW Transfer Pump
27	Main SW Circ Pump	61	Oil/Water Separator

Figure 92 - MMR 2 Lower Level



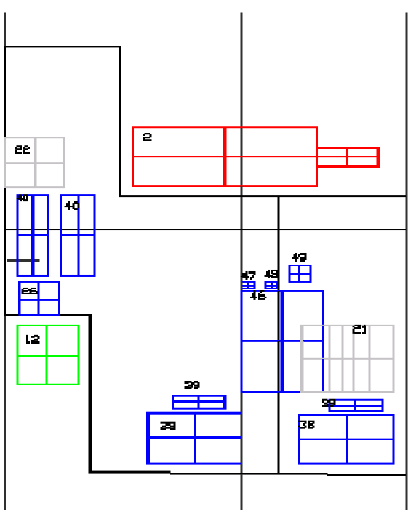
1	Gas Turbine (MT30)	33	LO Transfer Pump
2	Diesel Generator (Secondary)	34	Gas Turbine Fuel Filter/Separator
3	Reduction Gear	35	Fuel Oil Purifier
21	Ladder	36	Fuel Transfer Pump
22	Escape Trunk	45	AFFF Station
23	Mach. Space Fan-Supply	54	Starting Air Receiver
24	Mach. Space Fan-Exhaust	55	MP Air Compressor
30	RG LO Cooler	58	LP SS Air Compressor
32	LO Purifier	59	Air Dryer

Figure 93 - MMR 2 Upper Level



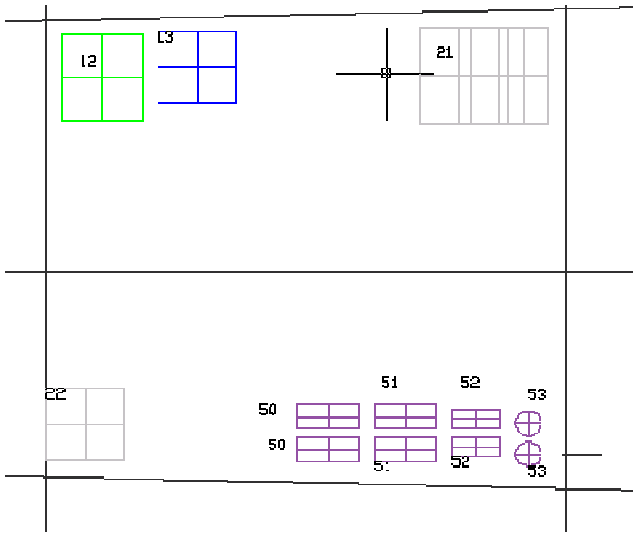
2	Diesel Generator (Secondary)
12	Electric Secondary IPS Motor
13	Frequency Changer
15	SS Diesel Generator
21	Ladder
22	Escape Trunk
42	Fire/Ballast Pump
43	Bilge Pump

Figure 94 - AMR1 Lower Level



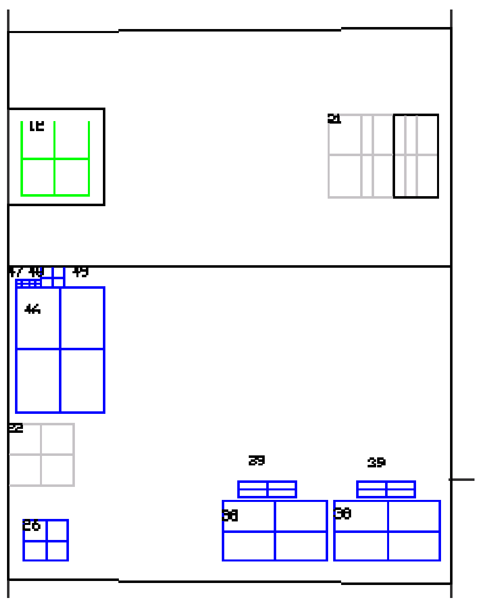
2	Diesel Generator (Secondary)	38	Air Conditioning Plants
12	Electric Secondary IPS Motor	39	Chilled Water Pump
21	Ladder	40	SS Refrigeration Plants
22	Escape Trunk	46	Fresh Water Unit
26	Aux Mach. Fan-Exhaust	47	Proportioning Brominator
28	MGT LO Storage and Condit.	48	Recirculation Brominator
29	RG LO Strainer	49	Potable Water Pump

Figure 95 - AMR1 Upper Level



12	Electric Secondary IPS Motor
13	Frequency Changer
21	Ladder
22	Escape Trunk
50	JP-5 Transfer Pump
51	JP-5 Service Pump
52	JP-5 Stripping Pump
53	JP-5 Filter/Separator

Figure 96 - AMR2 and Pump Room Lower Level



12	Electric Secondary IPS Motor	38	Air Conditioning Plants
21	Ladder	39	Chilled Water Pump
22	Escape Trunk	46	Fresh Water Unit
26	Aux Mach. Space Fan-Exhaust	47	Proportioning Brominator
29	RG LO Strainer	48	Recirculation Brominator
36	Fuel Transfer Pump	49	Potable Water Pump

Figure 97 - AMR 2 Upper Level

4.8 Manning

The process for manning includes several steps. The first is to develop a hierarchy chart and table to assign personnel to divisions or departments. Secondly, use estimates from ASSET to determine how many personnel are available. Finally, check if the number of personnel is feasible. Using the hierarchy chart, we obtain five departments and 17 divisions. The department/division breakdown is show in Figure 98. Due to the high risk optimization of the ship, the manning automation factor is .65, which allows for increased automation yet enough personnel available if the automation were to fail. The level of automation is significantly increased compared to current naval vessels. Having increased automation has allowed for a small crew size of 69. This breaks down into 19 officers and 50 enlisted personnel. The break down for each department and division is found in Table 33.

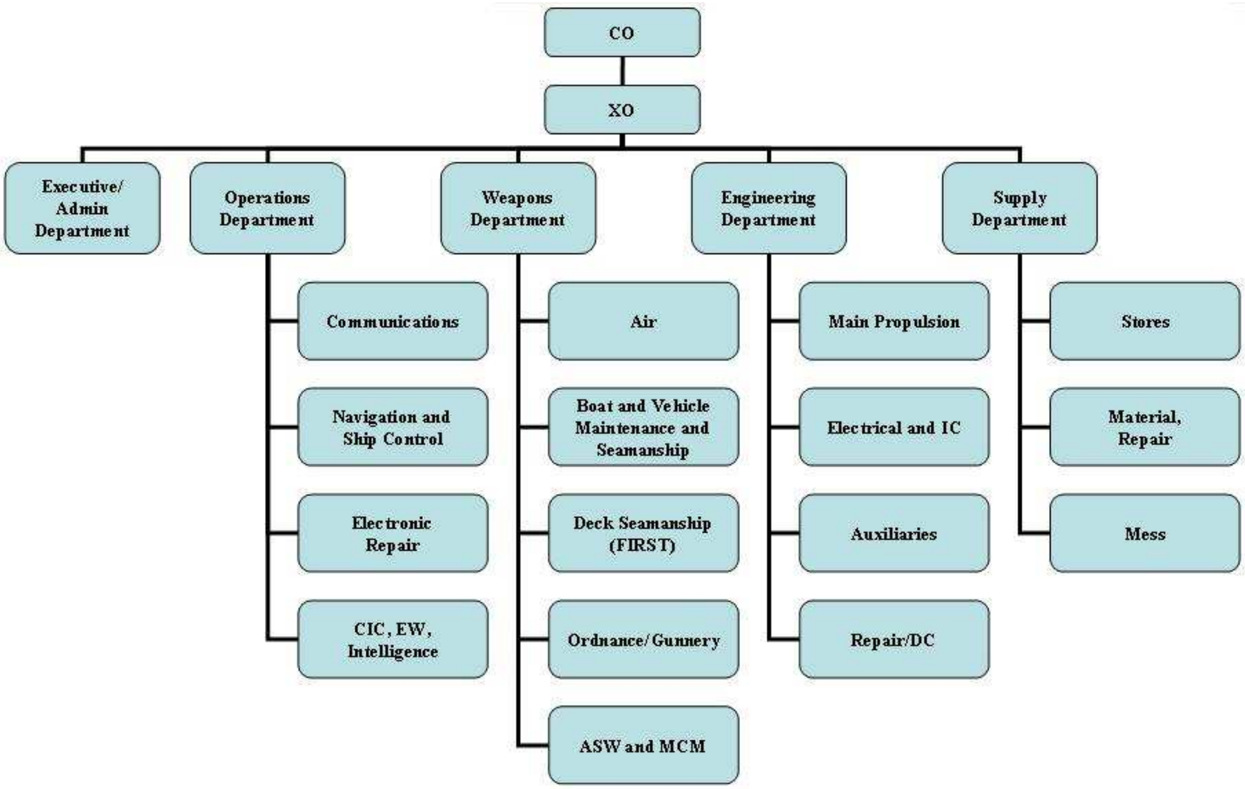


Figure 98 - Manning Organization

Table 33 - Manning Summary

Department	Division	Officers	CPO	Enlisted	Total Department
	CO/XO	2			
	Department Heads	4			6
Executive/Admin	Executive/Admin		1	1	2
Operations	Communications	1	1	3	16
	Navigation and Control	1	1	1	
	Electronic Repair		1	2	
	CIC, EW and Intelligence	1	1	2	
	Medical			1	
Weapons	Air	2 (pilots)	1	2	19
	Boat & Vehicle		1	2	
	Deck	1	1	2	
	Ordnance/Gunnery	1	1	2	
	ASW/MCM		1	2	
Engineering	Main Propulsion	1	1	4	19
	Electrical/IC		1	3	
	Auxiliaries		1	3	
	Repair/DC		1	4	
Supply	Stores		1	1	7

	Material/Repair			1	
	Mess		1	3	
	Total	14	16	39	69
	Addl Accommodations	3	5	13	21
	Total Accommodations	17	21	52	90

4.9 Space and General Arrangements

HECSALV, Rhino and AutoCad were used to generate and assess subdivision and arrangements. HECSALV is primarily used for subdivision, tank arrangements and loading. Rhino is used for the 3-D geometry and AutoCad is used to construct 2-D drawings of the inboard and outboard profiles, deck and platform plans, and detailed drawings of berthing, sanitary, and messing spaces. A profile view showing the internal arrangements is shown in Figure 99 and Figure 100.

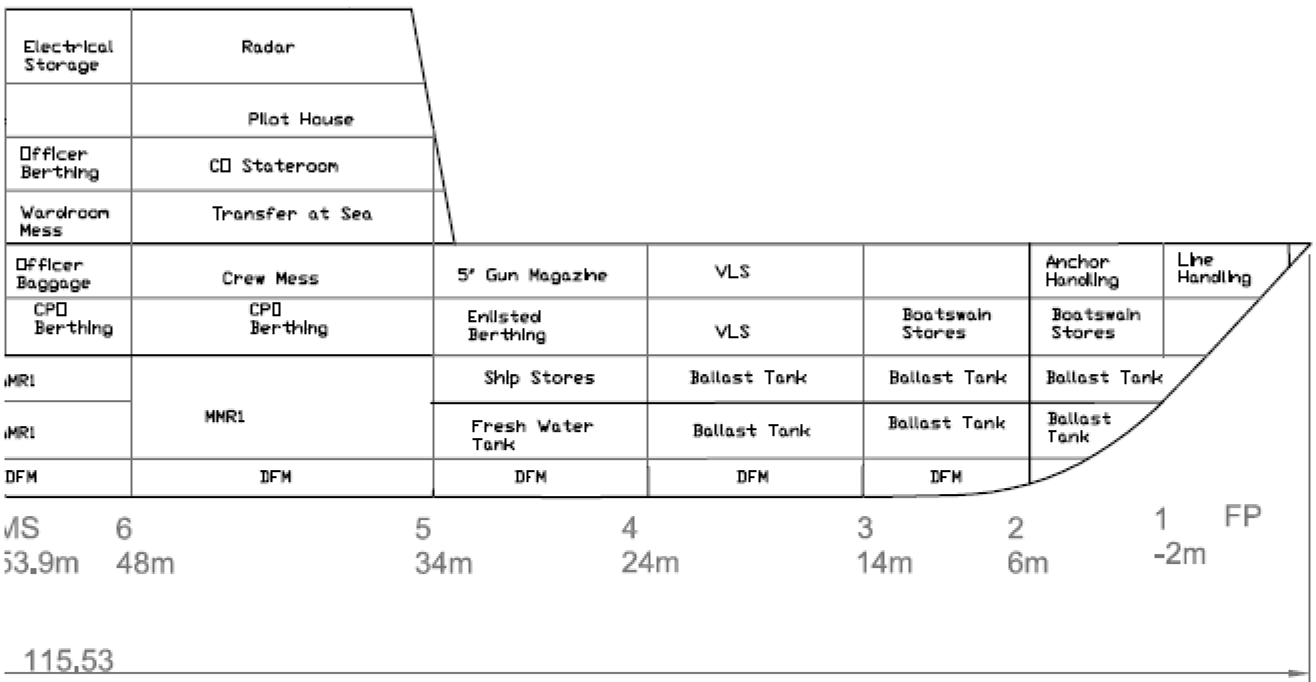


Figure 99 - Profile View showing arrangements (Forward)

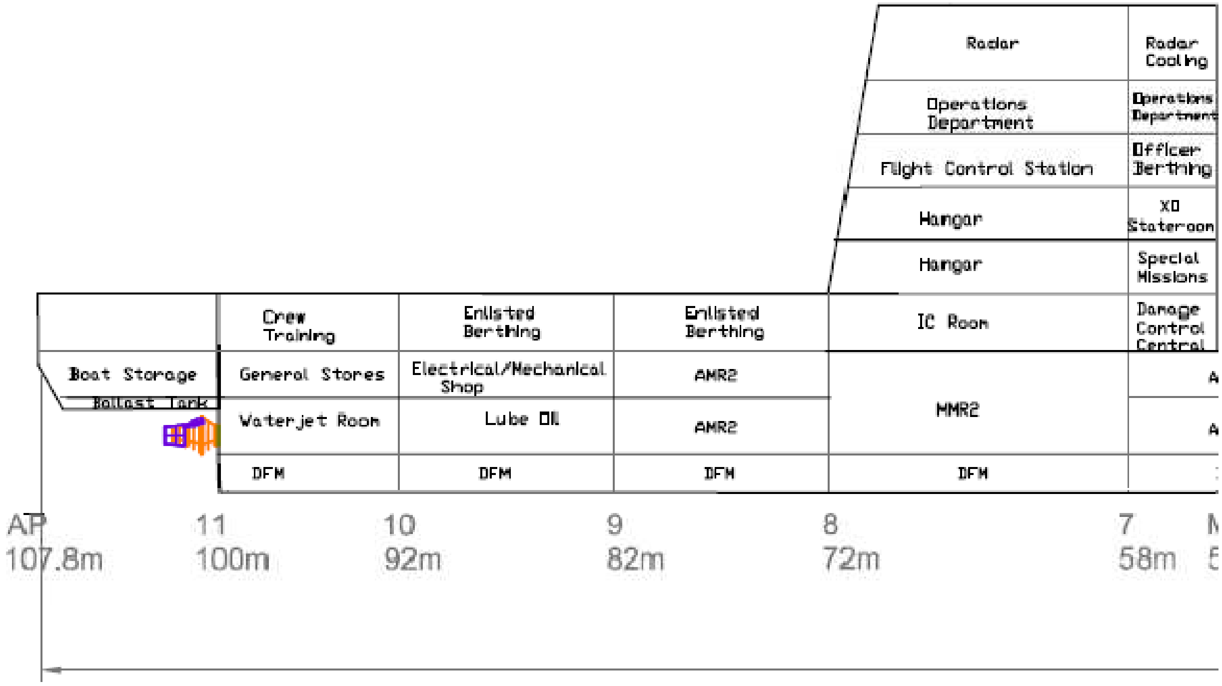


Figure 100 - Profile View showing arrangements (Aft)

4.9.1 Internal Arrangements

The SSC is arranged using the four major space classification categories obtained from ASSET: Mission Support, Human Support, Ship Support, and Ship Machinery Spaces. The approximate minimum areas and volume summaries for these spaces are listed in Appendix E.

Mission Support includes communications and combat systems. This includes area and volume estimates for: pilot house, navigation, aviation support, aviation stores, aviation hangar, JP-5 fuel, and special mission packages. Human support consists of living spaces broken into sections for CO, XO, other officers and enlisted personnel. It also comprises the initial areas for food stores, messing, recreation, and general ship spaces for everyone living on the ship. Ship Support systems include the daily operations of the ship, such as damage control, maintenance, stowage, tankage, and ship control. Ship administration is comprised of general ship administration, executive, engineering, supply, deck, and operations departments. Damage control is located on the second deck at midships. Ship support includes accessibility, including ship passageways and escape trunks. All major passageways are two meters wide, which accommodates medical passageways. Each passageway through compartments has watertight bulkheads. There are two escape trunks in both the main and auxiliary machinery rooms. Detailed general arrangement drawings are shown in Appendix F.

4.9.2 Living Arrangements

Initially living space requirements were estimated based on crew size from the ship synthesis model then, refined using the manning estimate. With a smaller crew it is necessary to have a better trained crew that would be more deserving of larger living accommodations. An additional 21 spaces are allocated for special mission crews.

Galley and crew's mess are located on the main deck. The officer's wardroom is located in the deckhouse on the 01 level. The CO and XO have the largest berthing and sanitary facilities on the ship which are located in the deckhouse. Department Head berthing is also located in the deckhouse. CPO berthing is located on second deck along with the living space for enlisted crew. General ship spaces including laundry and recreational facilities are located on the second deck. Table 34 shows accommodation space requirements.

Table 34 - Accommodation Space

Item	Accomodation Quantity	Per Space	Number of Spaces	Area Each (m2)	Total Area (m2)
CO	1	1	1	37.3	37.3
XO	1	1	1	13.9	13.9
Department Head	4	1	4	11.6	46.5
Other Officer	12	2	6	12.5	75
CPO	24	4	6	13.64	81.84
Enlisted	60	20	3	49.9	149.7
Officer Sanitary	18	6	3	7	21
CPO Sanitary	24	5	5	4	20
Enlisted Sanitary	60	20	3	9.3	27.9
Total			32		473.14

4.9.3 External Arrangements

In today's Navy, minimizing Radar Cross Section (RCS) is a major consideration in the design of any naval ship. All sides above the weather deck are flared in at a ten degree angle to help provide an adequate RCS signature. An advanced enclosed mast structure is located at the top of the deckhouse. It conceals IRST, AN/SPS-73, and MK XII AIMS IFF.

A ramp in the aft conceals the RHIBs to help reduce RCS. Two 50 caliber machine guns are located on the top of the deckhouse to provide protection. AN/SPY 1E has three locations on the sides of the deckhouse to provide 360 degrees of protection. The 57mm MK3 is located in the forward half of the ship on the weather deck. It has the longest range and is able to protect the ship from threats that are at a distance. The MK48 VLS helps protect the ship from air threats and is located forward of the MK3 on the weather deck. Figure 101 shows a plan view of the combat mission systems.

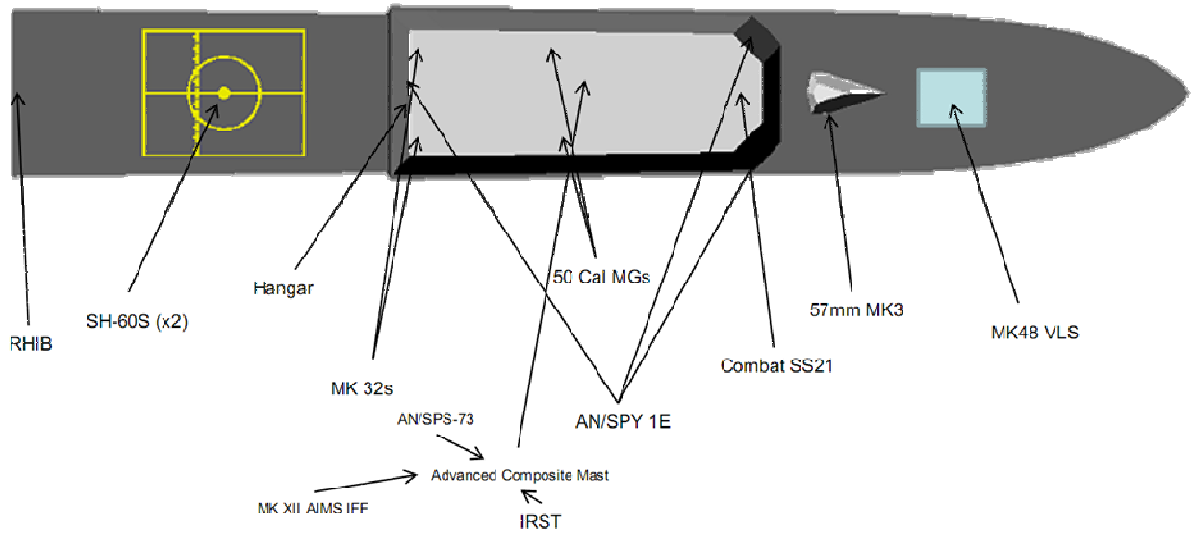


Figure 101 - Plan View of Combat Mission Systems

4.9.4 Area and Volume

During preliminary calculations in our ship synthesis model, initial space requirements and availability were determined. After obtaining area and volume estimates, the requirements are refined. Table 35 shows the required tankage volume versus the final tankage volume.

Table 35 - Required vs. Final Tankage Volume

Variable	SSSM/ASSET requirement (m^3)	Final Concept Design Tankage Capacity (m^3)
JP-5	73.6	74
Endurance Fuel	614.1	624
Saltwater Ballast	264.1	267
Freshwater	17.5	18
Dirty Oil	4.4	6
Sewage	1.1	2

4.10 Weights, Loading and Stability

The purpose of the weights, loading, and stability module is to determine the location of all weights on the ship, to determine the moments generated from said weights, to determine minimum operating (MINOP) and full load conditions, and to use HECSALV to determine how damage to certain compartments affect overall ship stability in accordance with DDS 079-1. Three intact loading conditions are used: the lightship, full load, and MINOP conditions. These conditions are observed at still water and hogging and sagging wave conditions. Each condition produces a stability summary, a righting arm summary, and a strength summary for each loading condition. For damaged stability, 20 cases of damage are entered into HECSALV, three of them at worst case in accordance with DDS 079-1. These three worst cases have damaged stability analysis performed on them, generating a damaged righting arm curve, a criteria comparison, and a profile graphic of damage and ship condition.

4.10.1 Lightship Weights

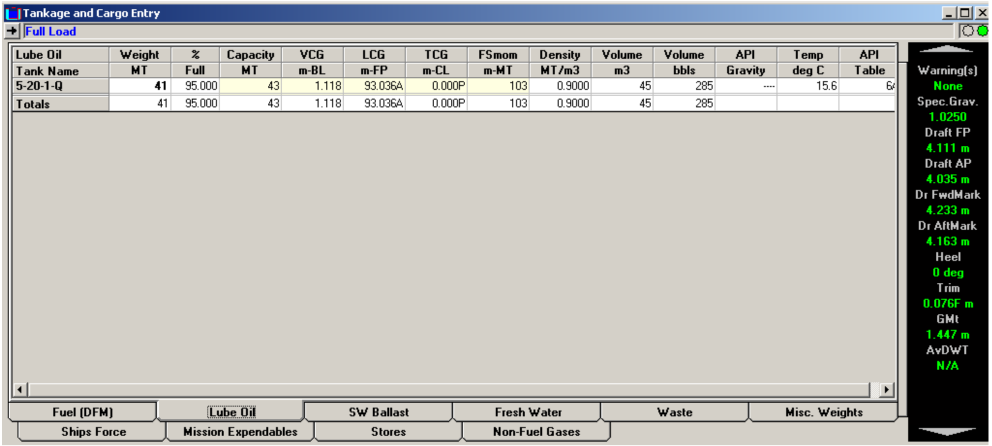
Weights generated from ASSET and locations from general arrangements are used to calculate SWBS weights, centers of gravity, and moments. Tank volumes, densities, and locations from HECSALV are used to calculate full load and MINOP condition characteristics.

Table 36 - Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m-Abv BL)	LCG (m-Aft FP)
100	2729.3	6.21	53.87
200	1498.3	1.98	73.79
300	626.93	4.07	75.11
400	187.77	13.04	40.39
500	406.4	6.17	36.44
600	27.4	9.68	57.69
700	34.4	9.13	33.91
Margin	551.07	5.08	59.85
Total (LS)	6061.81	5.08	59.85

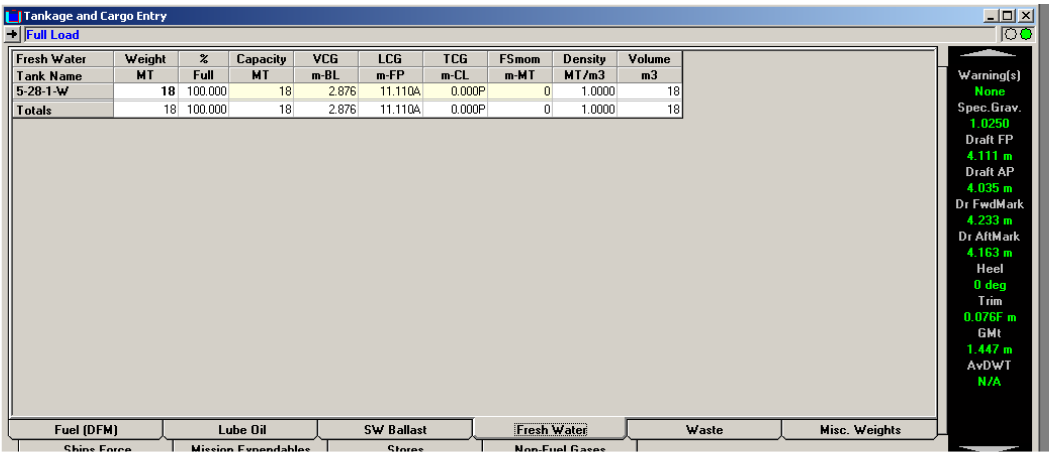
4.10.2 Loads and Loading Conditions

The following loading conditions are created for this module: full load, MINOP, and lightship. Full load is the condition where all fuel, ordnance, and personnel are accounted for. MINOP is the minimum required amount of fuel, ammunition, and crew necessary to meet all requirements for operation. Lightship is the condition where there is no fuel, ordnance, or personnel on board.



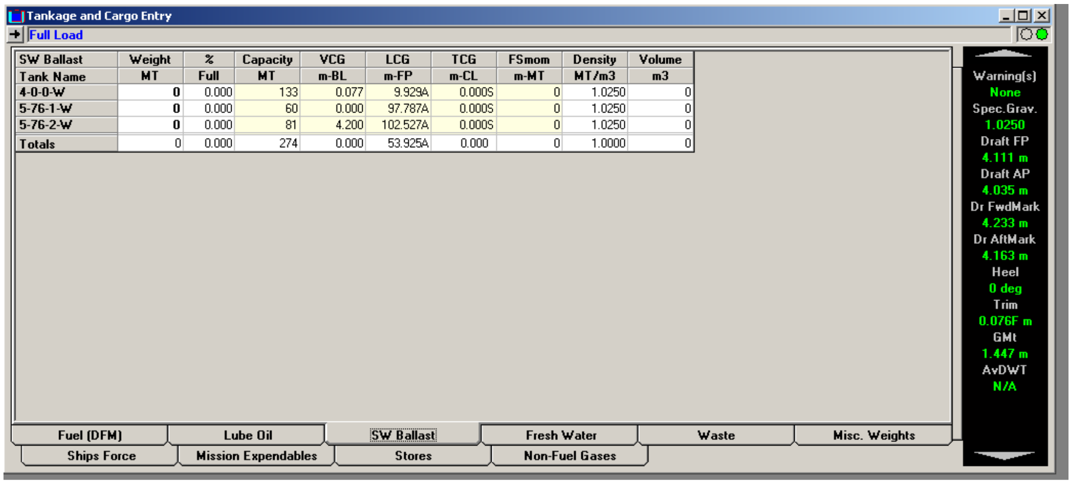
Lube Oil Tank Name	Weight MT	% Full	Capacity MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Density MT/m3	Volume m3	Volume bbls	API Gravity	Temp deg C	API Table
5-20-1-Q	41	95.000	43	1.118	93.036A	0.000P	103	0.9000	45	285	----	15.6	6
Totals	41	95.000	43	1.118	93.036A	0.000P	103	0.9000	45	285			

Figure 102 - Full Load Condition (Lube Oil)



Fresh Water Tank Name	Weight MT	% Full	Capacity MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Density MT/m3	Volume m3
5-28-1-W	18	100.000	18	2.876	11.110A	0.000P	0	1.0000	18
Totals	18	100.000	18	2.876	11.110A	0.000P	0	1.0000	18

Figure 103 - Full Load Condition (Fresh Water)



SW Ballast Tank Name	Weight MT	% Full	Capacity MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Density MT/m3	Volume m3
4-0-0-W	0	0.000	133	0.077	9.929A	0.000S	0	1.0250	0
5-76-1-W	0	0.000	60	0.000	97.787A	0.000S	0	1.0250	0
5-76-2-W	0	0.000	81	4.200	102.527A	0.000S	0	1.0250	0
Totals	0	0.000	274	0.000	53.925A	0.000	0	1.0000	0

Figure 104 - Full Load Condition (Salt Water Ballast)

Tankage and Cargo Entry — Full Load

Fuel (DFM) Tank Name	Weight MT	% Full	Capacity MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Density MT/m3	Volume m3	Volume bbls	API Gravity	Temp deg C	API Table
4-20-3-F	145	95.000	152	1.133	73.609A	1.806S	146	0.8300	174	1,096	----	15.6	6
4-20-4-F	145	95.000	152	1.133	73.609A	1.806P	146	0.8300	174	1,096	----	15.6	6
4-12-1-F	88	95.000	93	1.141	37.384A	1.099S	52	0.8300	106	668	----	15.6	6
4-12-2-F	88	95.000	93	1.141	37.384A	1.099P	52	0.8300	106	668	----	15.6	6
4-68-1-F	28	95.000	30	3.177	79.341A	5.657S	3	0.8100	35	220	----	15.6	6
4-68-2-F	28	95.000	30	3.177	79.341A	5.657P	3	0.8100	35	220	----	15.6	6
4-12-3-F	13	95.000	14	3.106	90.059A	5.707S	1	0.8300	16	100	----	15.6	6
4-12-4-F	13	95.000	14	3.106	90.059A	5.707P	1	0.8300	16	100	----	15.6	6
Totals	549	95.000	577	1.442	63.354A	0.000P	404	0.8279	663	4,167			

Warning(s) None; Spec.Grav. 1.0250; Draft FP 4.111 m; Draft AP 4.035 m; Dr FwdMark 4.233 m; Dr AftMark 4.163 m; Heel 0 deg; Trim 0.076F m; GMt 1.447 m; AvDWT N/A

Fuel (DFM) | Lube Oil | SW Ballast | Fresh Water | Waste | Misc. Weights | Ships Force | Mission Expendables | Stores | Non-Fuel Gases

Figure 105 - Full Load Condition (Diesel Fuel Marine)

Tankage and Cargo Entry — Full Load

Waste Tank Name	Weight MT	% Full	Capacity MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Density MT/m3	Volume m3	Volume bbls	API Gravity	Temp deg C	API Table
SEWAGE1	0	0.000	2	0.000	95.175A	0.101S	0	0.9500	0	0	----	15.6	6
DIRTY OIL	0	0.000	4	0.000	95.325A	0.102P	0	1.0250	0	0	----	15.6	6
DIRTY OIL1	0	0.000	2	0.000	95.475A	0.102S	0	1.0250	0	0	----	15.6	6
Totals	0	0.000	7	0.000	53.925A	0.000	0	1.0000	0	0			

Warning(s) None; Spec.Grav. 1.0250; Draft FP 4.111 m; Draft AP 4.035 m; Dr FwdMark 4.233 m; Dr AftMark 4.163 m; Heel 0 deg; Trim 0.076F m; GMt 1.447 m; AvDWT N/A

Fuel (DFM) | Lube Oil | SW Ballast | Fresh Water | Waste | Misc. Weights | Ships Force | Mission Expendables | Stores | Non-Fuel Gases

Figure 106 - Full Load Condition (Waste)

Tankage and Cargo Entry — Full Load

Misc. Weights	Weight MT	VCG m-BL	LCG m-FP	TCG m-CL	FSmom m-MT	Fwd Bound m-FP	Aft Bound m-FP
Totals	0	----	----	----	----	----	----

Warning(s) None; Spec.Grav. 1.0250; Draft FP 4.111 m; Draft AP 4.035 m; Dr FwdMark 4.233 m; Dr AftMark 4.163 m; Heel 0 deg; Trim 0.076F m; GMt 1.447 m; AvDWT N/A

Fuel (DFM) | Lube Oil | SW Ballast | Fresh Water | Waste | Misc. Weights | Ships Force | Mission Expendables | Stores | Non-Fuel Gases

Figure 107 - Full Load Condition (Miscellaneous Weights)

Following the input of the full load and MINOP conditions, the trim for each condition is checked. Full load trim is between 0 and 0.1 m without ballast. Acceptable MINOP trim is between 0 and 0.5 m with ballast. If these conditions are not met, tank locations and lightship LCG are adjusted.

4.10.3 Final Hydrostatics and Intact Stability

Intact stability criteria are based off of US Navy standards, DDS 079-1. The wind heeling arm at the intersection of the righting arm and heeling arm curves must not be six-tenths of the maximum righting arm. Also, the area under the righting arm curve above the wind heeling arm curve (A1) must not be less than 1.4 times the area under the heeling arm curve and above the righting arm curve (A2).

Intact Trim and Stability Summary

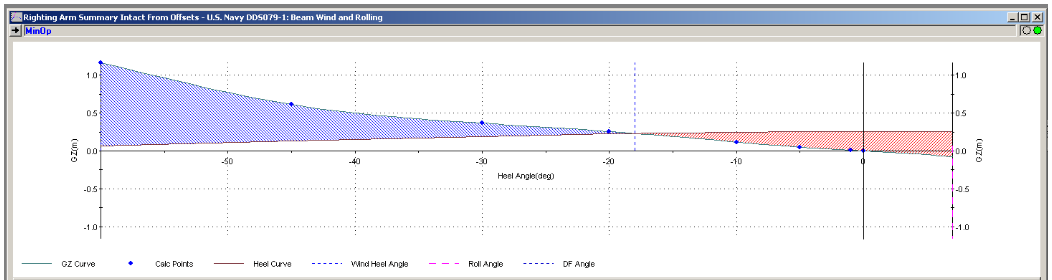
MinOp

Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	2,467	6.750	61.500A	0.000	----
Constant	0	0.000	61.500A	0.000	0
Fuel (DFM)	191	0.913	63.467A	0.000P	308
Lube Oil	14	0.630	93.041A	0.000P	161
SW Ballast	0	----	----	----	----
Fresh Water	12	2.373	11.113A	0.000S	11
Waste	7	1.146	95.330A	0.011P	0
Misc. Weights	0	----	----	----	----
Ships Force	6	0.000	46.610A	0.000	0
Mission Expendables	0	0.000	57.770A	0.000	0
Stores	6	0.000	50.380A	0.000	0
Non-Fuel Gases	19	0.000	15.700A	0.000	0
Displacement	2,721	6.201	61.304A	0.000P	479

Stability Calculation			Trim Calculation		
KMt	7.132	m	LCF Draft	3.749	m
VCG	6.201	m	LCB	61.293A	m-FP
GMt (Solid)	0.931	m	LCF	58.462A	m-FP
FSc	0.176	m	MT1cm	64	m-MT/cm
GMt (Corrected)	0.755	m	Trim	0.291	m-F
			List	0P	deg
Specific Gravity	1.0250		TPcm	10.7	MT/cm
Hull calcs from offsets			Tank calcs from tables		

Drafts			Strength Calculation		
Draft at F.P.	3.907	m	Shear	119	MT at 98.050A m-FP
Draft at M.S.	3.762	m	Bending	3,308H	m-MT at 65.257A m-FP
Draft at A.P.	3.616	m			
Draft at FwdMarks	4.373	m			
Draft at Mid Marks	4.239	m			
Draft at AftMarks	4.105	m			

Figure 108 - MinOp Intact Trim and Stability Results



U.S. Navy DDS079-1: Beam Wind and Rolling	Units	Value	Required
Wind Heel	deg	18	---
Wind Heeling Arm Lw	m	0.231	---
Maximum Righting Arm Ratio		0.2	0.60
Capsizing Area A2	m-rad	0.08	---
Righting Area A1	m-rad	0.30	0.11
Angle Limiting Area	deg	60	---
Maximum Righting Arm	m	1.163	---
Angle at Max. GZ	deg	60	---
Projected Sail Area	m2	803.00	---
Heeling Arm at 0 deg.	m	0.256	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.00	
Reference Draft	m	0.000	
Projected Sail Area	m2	0.00	
Vertical Center of Sail Area -BL	m	0.000	
Factor f where p = f*V^2 (lb/ft^2)		0.004	
Roll Angle	deg	25	

Figure 109 - MinOp Righting Arm and Heeling Arm Curve

Intact Trim and Stability Summary

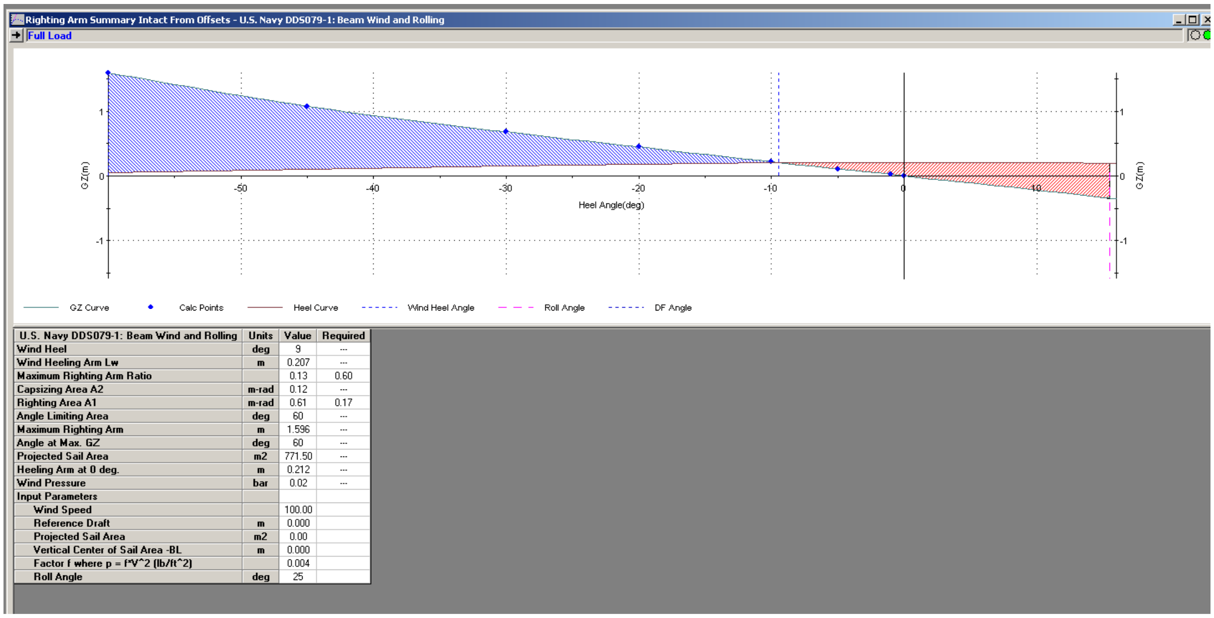
Full Load

Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	2,467	6.750	61.500A	0.000	----
Constant	0	0.000	61.500A	0.000	0
Fuel (DFM)	549	1.442	63.354A	0.000P	404
Lube Oil	41	1.118	93.036A	0.000P	103
SW Ballast	0	----	----	----	----
Fresh Water	18	2.876	11.110A	0.000P	0
Waste	0	----	----	----	----
Misc. Weights	0	----	----	----	----
Ships Force	6	0.000	46.610A	0.000	0
Mission Expendables	0	0.000	57.770A	0.000	0
Stores	6	0.000	50.380A	0.000	0
Non-Fuel Gases	19	0.000	15.700A	0.000	0
Displacement	3,104	5.650	61.623A	0.000P	508

Stability Calculation			Trim Calculation		
KMt	7.261	m	LCF Draft	4.068	m
VCG	5.650	m	LCB (even keel)	61.810A	m-FP
GMt (Solid)	1.610	m	LCF	60.226A	m-FP
FSc	0.164	m	MT1cm	76	m-MT/cm
GMt (Corrected)	1.447	m	Trim	0.076	m-F
			List	0	deg
Specific Gravity	1.0250		TPcm	12.0	MT/cm
Hull calcs from tables			Tank calcs from tables		

Drafts			Strength Calculation		
Draft at F.P.	4.111	m	Shear	96	MT at 98.050A m-FP
Draft at M.S.	4.073	m	Bending	2,921H	m-MT at 64.050A m-FP
Draft at A.P.	4.035	m			
Draft at FwdMarks	4.233	m			
Draft at Mid Marks	4.198	m			
Draft at AftMarks	4.163	m			

Figure 110 - Full Load Intact Trim and Stability Results

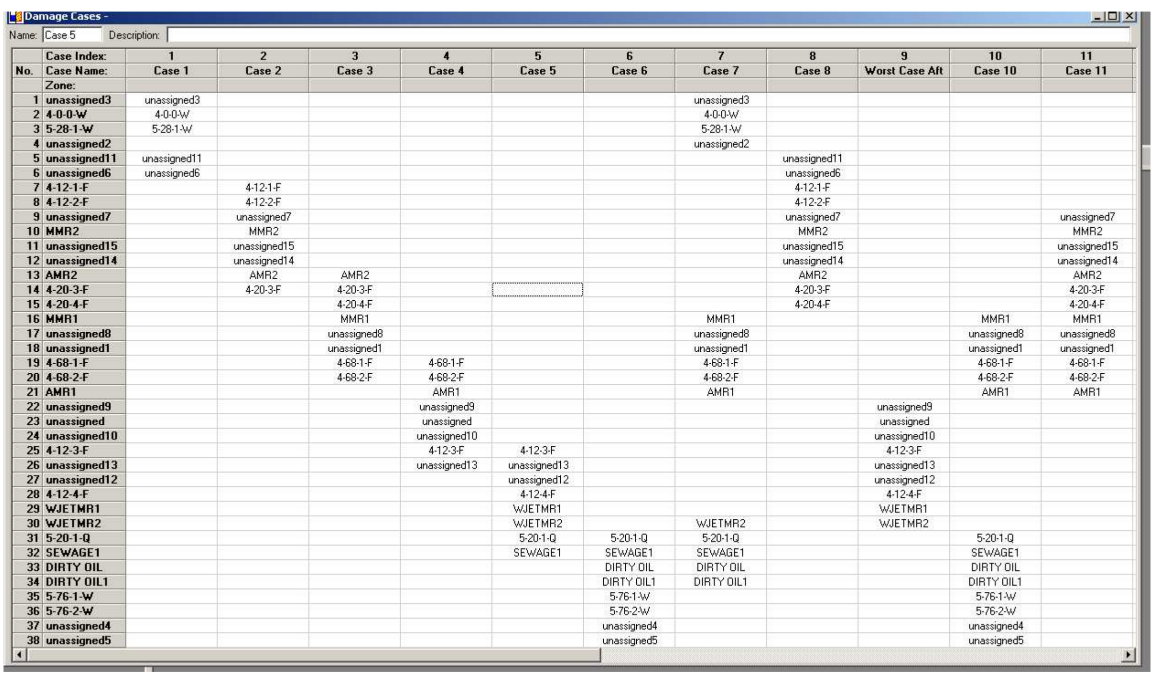


U.S. Navy DDS079-1: Beam Wind and Rolling	Units	Value	Required
Wind Heel	deg	9	---
Wind Heeling Arm Lw	m	0.207	---
Maximum Righting Arm Ratio		0.13	0.60
Capsizing Area A2	m-rad	0.12	---
Righting Area A1	m-rad	0.61	0.17
Angle Limiting Area	deg	60	---
Maximum Righting Arm	m	1.596	---
Angle at Max. GZ	deg	60	---
Projected Sail Area	m2	771.50	---
Heeling Arm at 0 deg.	m	0.212	---
Wind Pressure	bar	0.02	---
Input Parameters			
Wind Speed		100.00	
Reference Draft	m	0.000	
Projected Sail Area	m2	0.00	
Vertical Center of Sail Area -BL	m	0.000	
Factor f where p = f*V^2 (lb/ft^2)		0.004	
Roll Angle	deg	25	

Figure 111 - Full Load Righting Arm and Heeling Arm Curve

4.10.4 Damage Stability

In the damage stability module, transverse bulkheads must be tested to ensure that floodable length requirements are met. Full Load and MINOP conditions are analyzed for damage stability using 15% LWL damage length (16.5 m for SSC). Damage is considered to the centerline and past the centerline. Damage cases extend from the keel to the weather deck. 20 cases are considered, three of which are worst case scenarios. The heel of all these cases must remain less than 15 degrees, the margin line must not be submerged, and the remaining dynamic stability must also be adequate (A1 > 1.4A2).



	Case Index:	1	2	3	4	5	6	7	8	9	10	11
No.	Case Name:	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Worst Case Aft	Case 10	Case 11
	Zone:											
1	unassigned3	unassigned3						unassigned3				
2	4-0-0-W	4-0-0-W						4-0-0-W				
3	5-28-1-W	5-28-1-W						5-28-1-W				
4	unassigned2							unassigned2				
5	unassigned11	unassigned11							unassigned11			
6	unassigned6	unassigned6							unassigned6			
7	4-12-1-F		4-12-1-F						4-12-1-F			
8	4-12-2-F		4-12-2-F						4-12-2-F			
9	unassigned7		unassigned7						unassigned7			unassigned7
10	MMR2		MMR2						MMR2			MMR2
11	unassigned15		unassigned15						unassigned15			unassigned15
12	unassigned14		unassigned14						unassigned14			unassigned14
13	AMR2		AMR2	AMR2					AMR2			AMR2
14	4-20-3-F		4-20-3-F	4-20-3-F					4-20-3-F			4-20-3-F
15	4-20-4-F			4-20-4-F					4-20-4-F			4-20-4-F
16	MMR1			MMR1				MMR1			MMR1	MMR1
17	unassigned8			unassigned8				unassigned8			unassigned8	unassigned8
18	unassigned1			unassigned1				unassigned1			unassigned1	unassigned1
19	4-68-1-F			4-68-1-F	4-68-1-F			4-68-1-F			4-68-1-F	4-68-1-F
20	4-68-2-F			4-68-2-F	4-68-2-F			4-68-2-F			4-68-2-F	4-68-2-F
21	AMR1				AMR1			AMR1			AMR1	AMR1
22	unassigned9				unassigned9					unassigned9		
23	unassigned				unassigned					unassigned		
24	unassigned10				unassigned10					unassigned10		
25	4-12-3-F				4-12-3-F	4-12-3-F				4-12-3-F		
26	unassigned13				unassigned13	unassigned13				unassigned13		
27	unassigned12					unassigned12				unassigned12		
28	4-12-4-F					4-12-4-F				4-12-4-F		
29	WJETMR1					WJETMR1				WJETMR1		
30	WJETMR2					WJETMR2		WJETMR2		WJETMR2		
31	5-20-1-Q					5-20-1-Q	5-20-1-Q	5-20-1-Q			5-20-1-Q	
32	SEWAGE1					SEWAGE1	SEWAGE1	SEWAGE1			SEWAGE1	
33	DIRTY OIL						DIRTY OIL	DIRTY OIL			DIRTY OIL	
34	DIRTY OIL1						DIRTY OIL1	DIRTY OIL1			DIRTY OIL1	
35	5-76-1-W						5-76-1-W				5-76-1-W	
36	5-76-2-W						5-76-2-W				5-76-2-W	
37	unassigned4						unassigned4				unassigned4	
38	unassigned5						unassigned5				unassigned5	

Figure 112 - Damage Stability Cases

One Line Summary (Defined KG/GMt)

#	Draft	Status	Case	Intact T AP	Intact T FP	Intact GMt	Damaged T AP	Damaged T FP	Damaged Heel
				m	m	m	m	m	deg
1	1	1	1	4.391	4.391	2.122	3.785	6.385	0.0
2	1	1	2	4.391	4.391	2.122	4.637	5.710	0.4
3	1	1	3	4.391	4.391	2.122	5.378	4.732	-1.8
4	1	1	4	4.391	4.391	2.122	6.300	3.687	9.9
5	1	1	5	4.391	4.391	2.122	5.304	3.891	0.0
6	1	1	6	4.391	4.391	2.122	4.846	4.112	0.0
7	1	1	7	4.391	4.391	2.122	3.660	15.247	-0.7
8	1	1	8	4.391	4.391	2.122	4.590	7.050	-1.1
9	1	1	9	4.391	4.391	2.122	7.057	3.238	-1.0
10	1	1	10	4.391	4.391	2.122	5.704	4.118	2.2
11	1	1	11	4.391	4.391	2.122	5.583	5.391	0.0
12	1	1	12	4.391	4.391	2.122	5.945	3.452	0.0
13	1	1	13	4.391	4.391	2.122	4.146	6.530	2.3
14	1	1	14	4.391	4.391	2.122	5.116	5.033	-1.7
15	1	1	15	4.391	4.391	2.122	5.154	4.525	-2.4
16	1	1	16	4.391	4.391	2.122	15.030	-1.961	-1.1
17	1	1	17	4.391	4.391	2.122	3.629	7.513	0.1
18	1	1	18	4.391	4.391	2.122	6.266	3.296	-2.5
19	1	1	19	4.391	4.391	2.122	3.968	6.360	0.0
20	1	1	20	4.391	4.391	2.122	5.457	4.793	14.1

Figure 113 - Damage Stability Results

	Flooding Summary			For equilibrium at 0 deg. S							
Compartment	Seawater	Oil	Perm.	Density	VCG	LCG	TCG	Delta KM	Sounding	Specified	Pressure
	MT	MT		MT/m3	m	m-FP	m-CL	m	m	% Full	barG
5-28-1-W	19	-----	0.950	1.0250	2.876	11.085A	0.000S	0.000	[Free]	-----	-----
unassigned7	167	-----	1.000	1.0250	3.045	41.111A	2.444S	0.000	[Free]	-----	-----
unassigned3	-----	-----	1.000	-----	-----	-----	-----	-----	[Free]	-----	-----
4-12-1-F	115	-----	0.950	1.0250	1.173	37.354A	1.127S	0.000	[Free]	-----	-----
unassigned6	617	-----	1.000	1.0250	3.121	30.418A	0.000P	0.000	[Free]	-----	-----
unassigned11	1	-----	1.000	1.0250	1.219	12.265A	0.000P	0.000	[Free]	-----	-----
MMR2	159	-----	0.950	1.0250	3.045	41.111A	2.444P	0.000	[Free]	-----	-----
4-12-2-F	115	-----	0.950	1.0250	1.173	37.354A	1.127P	0.000	[Free]	-----	-----
4-0-0-W	127	-----	0.950	1.0250	4.925	6.320A	0.003S	0.050	[Free]	-----	-----
Totals	1,319	0			2.933	31.650A	0.016S	0.050			

Figure 114 - Full Load Worst Cast for Forward Trim

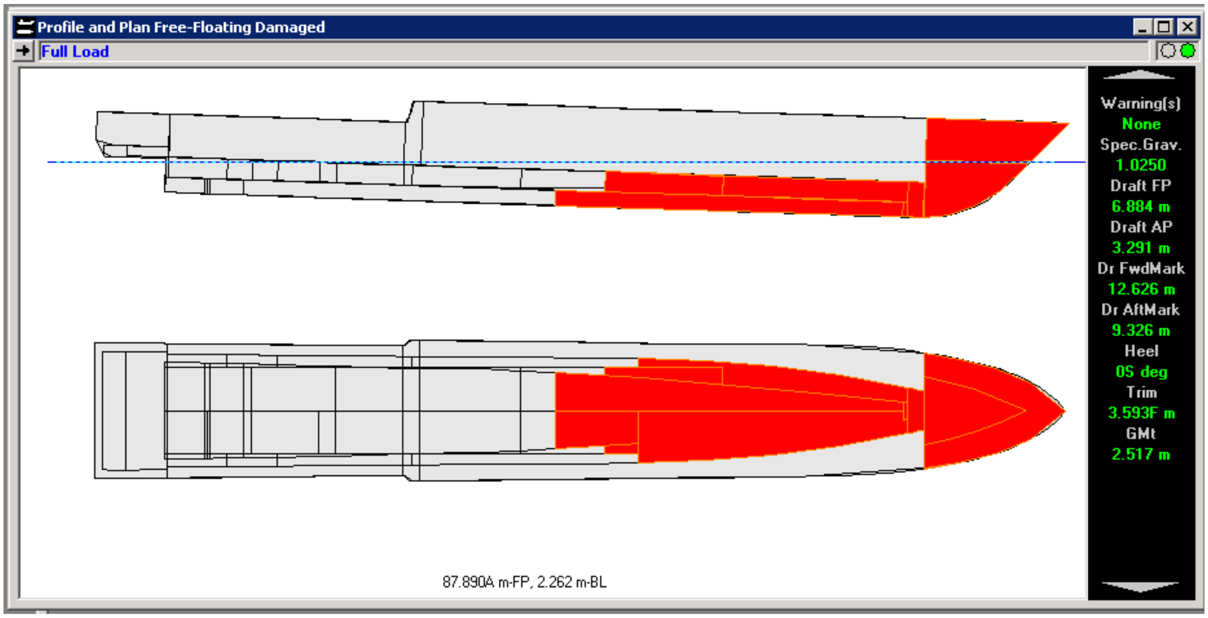
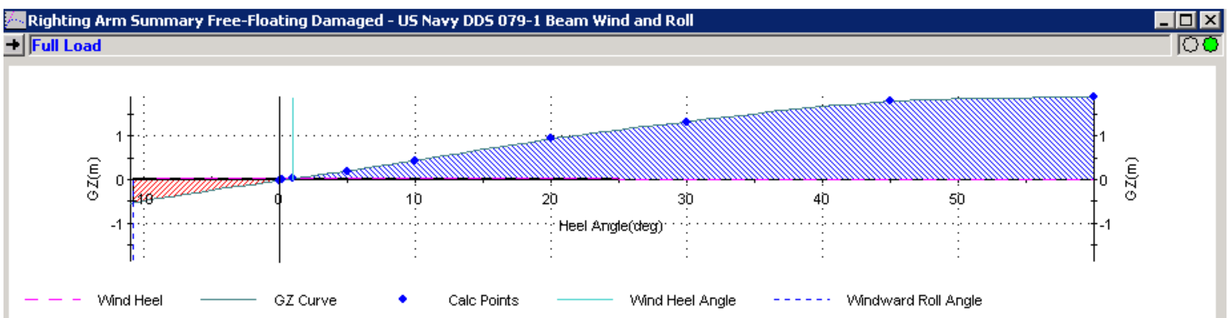


Figure 115 - Full Load Forward Damage



US Navy DDS 079-1 Beam Wind and Roll	Units	Available	Required
Wind Speed	knots	32.31	32.31
Windward Roll Angle	deg	12	12
Area A1	m-rad	0.76	0.02
GZMax Minimum	m	1.904	0.081
Angle of List or Loll	deg	1	15
Wind Heel	deg	1	----
Area Ratio A1/A2		13.84	1.40
Freeboard to Margin Line	m	4.598	0.000
Freeboard to Downflooding	m	----	----
Longitudinal GM	m	185.208	----
Angle to Downflooding (Unprotected)	deg	----	----
Calculation Parameters			

Figure 116 - Forward Damage Righting Arm and Heeling Arm Curve

Compartment Flooding / Oil Remaining

Full Load

	Flooding Summary			For equilibrium at 3 deg. P							
Compartment	Seawater	Oil	Perm.	Density	VCG	LCG	TCG	Delta KM	Sounding	Specified	Pressure
	MT	MT		MT/m3	m	m-FP	m-CL	m	m	% Full	barG
unassigned	559	-----	1.000	1.0250	4.966	87.463F	0.676P	2.090	[Free]	-----	-----
4-12-3-F	17	-----	1.000	1.0250	3.158	90.034F	5.715S	0.000	[Free]	-----	-----
4-12-4-F	17	-----	1.000	1.0250	3.158	90.034F	5.715P	0.000	[Free]	-----	-----
unassigned10	125	-----	1.000	1.0250	3.000	85.000F	2.550P	0.000	[Free]	-----	-----
unassigned9	100	-----	1.000	1.0250	3.000	76.000F	2.550S	0.000	[Free]	-----	-----
WJETMR1	123	-----	0.950	1.0250	3.000	95.150F	2.550S	0.000	[Free]	-----	-----
WJETMR2	123	-----	0.950	1.0250	3.000	95.150F	2.550P	0.000	[Free]	-----	-----
unassigned13	38	-----	1.000	1.0250	3.144	93.636F	5.730S	0.000	[Free]	-----	-----
unassigned12	38	-----	1.000	1.0250	3.144	93.636F	5.730P	0.000	[Free]	-----	-----
Totals	1,142	0			3.977	88.331F	0.387P	2.090			

Figure 117 - Full Load Worst Case for Aft Trim

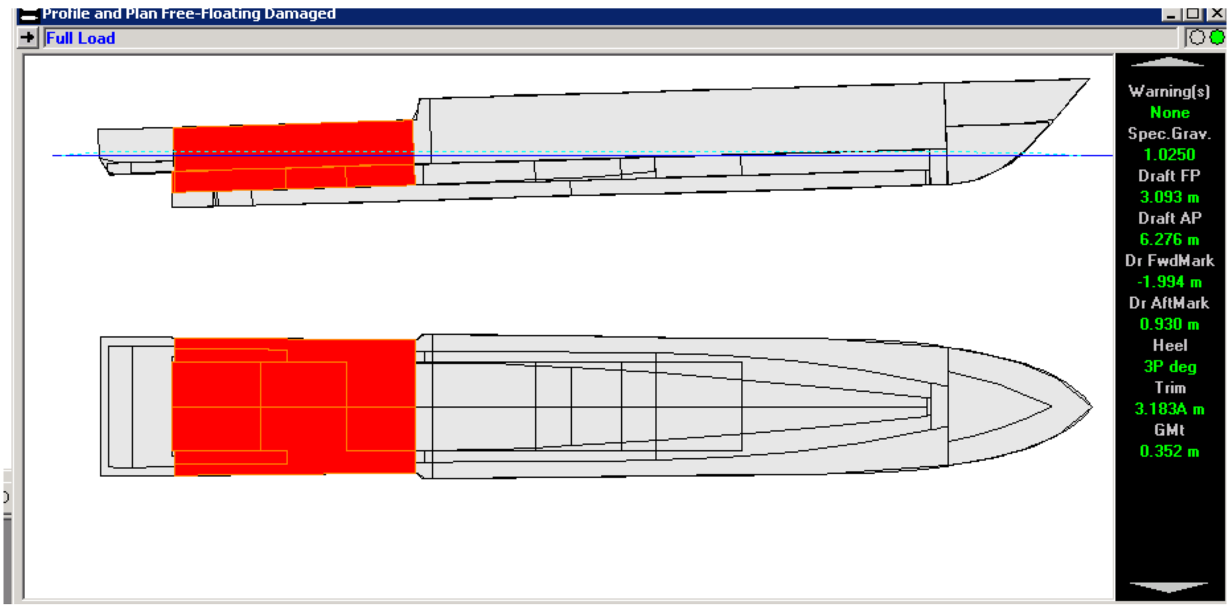
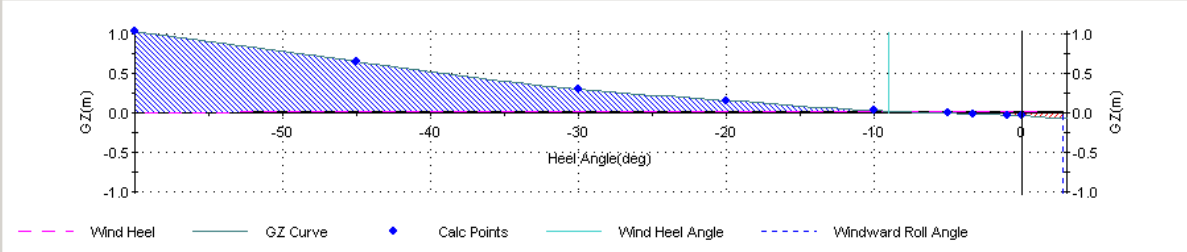


Figure 118 - Full Load Aft Damage

Righting Arm Summary Free-Floating Damaged - US Navy DDS 079-1 Beam Wind and Roll

Full Load



US Navy DDS 079-1 Beam Wind and Roll	Units	Available	Required
Wind Speed	knots	32.31	32.31
Windward Roll Angle	deg	12	12
Area A1	m-rad	0.17	0.02
GZMax Minimum	m	1.029	0.082
Angle of List or Loll	deg	6	15
Wind Heel	deg	9	----
Area Ratio A1/A2		24.32	1.40
Freeboard to Margin Line	m	3.747	0.000
Freeboard to Downflooding	m	----	----
Longitudinal GM	m	143.308	----
Angle to Downflooding (Unprotected)	deg	----	----
Calculation Parameters			

Figure 119 - Aft Damage Righting Arm and Heeling Arm Curve

Compartment Flooding / Oil Remaining

Full Load

	Flooding Summary			For equilibrium at 13 deg. S							
Compartment	Seawater	Oil	Perm.	Density	VCG	LCG	TCG	Delta KM	Sounding	Specified	Pressure
	MT	MT		MT/m3	m	m-FP	m-CL	m	m	% Full	barG
unassigned7	-----	-----	1.000	-----	-----	-----	-----	-----	[Free]	-----	-----
unassigned9	-----	-----	1.000	-----	-----	-----	-----	-----	[Free]	-----	-----
4-20-3-F	1	-----	0.950	1.0250	0.095	76.539F	0.478S	0.000	[Free]	-----	-----
4-12-1-F	-----	-----	0.950	-----	-----	-----	-----	-----	[Free]	-----	-----
MMR1	-----	-----	0.950	-----	-----	-----	-----	-----	[Free]	-----	-----
unassigned15	-----	-----	1.000	-----	-----	-----	-----	-----	[Free]	-----	-----
4-68-1-F	-----	-----	0.950	-----	-----	-----	-----	-----	[Free]	-----	-----
Totals	1	0			0.091	74.019F	0.457S	0.000			

Figure 120 - Full Load Worst Case for Heel

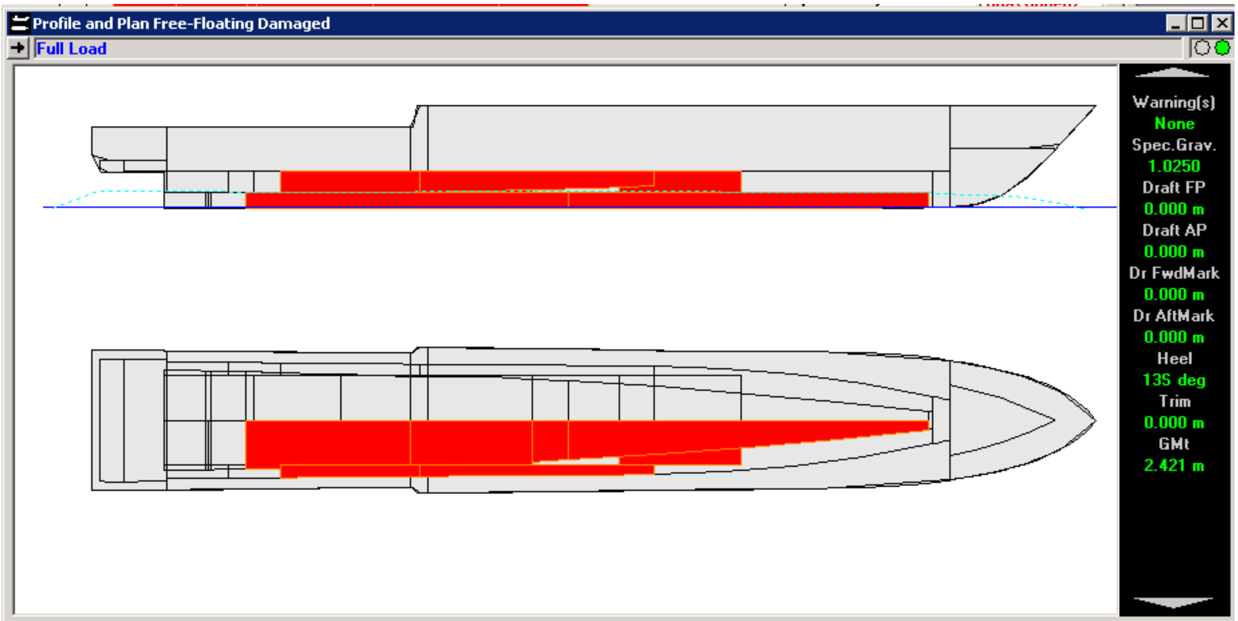


Figure 121 - Full Load Heel

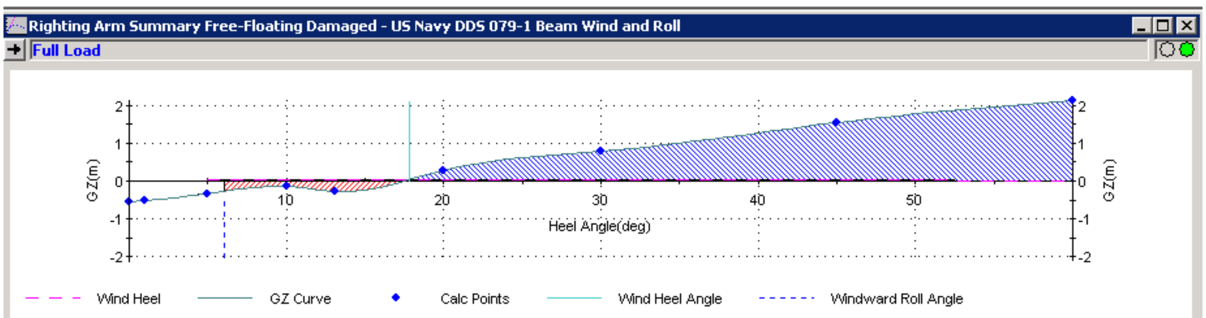


Figure 122 - Heel Damage Righting Arm and Heeling Arm Curve

4.11 Seakeeping, Maneuvering and Control

A major facet of a naval ship is its sea-keeping ability. The ship needs to be operational in a variety of sea-states in order to maximize its effectiveness. In order to analyze the sea-keeping characteristics of the SSC, a ship motions program, SMP, was used in conjunction with HECSALV. SMP analyzes ship motions based on its geometry, and the sea-state characteristics calibrated by the user. Examples of sea state characteristics are outlined in the figures below.

Sea State Number	Significant Wave Height (m)		Sustained Wind Speed (Knots)*		Percentage Probability of Sea State	Modal Wave Period (Sec)	
	Range	Mean	Range	Mean		Range**	Most Probable
0 - 1	0 - 0.1	0.05	0 - 6	3	0	–	–
2	0.1 - 0.5	0.3	7 - 10	8.5	5.7	3 - 15	7
3	0.5 - 1.25	0.88	11 - 16	13.5	19.7	5 - 15.5	8
4	1.25 - 2.5	1.88	17 - 21	19	28.3	6 - 16	9
5	2.5 - 4	3.25	22 - 27	24.5	19.5	7 - 16.5	10
6	4 - 6	5	28 - 47	37.5	17.5	9 - 17	12
7	6 - 9	7.5	48 - 55	51.5	7.6	10 - 18	14
8	9 - 14	11.5	56 - 63	59.5	1.7	13 - 19	17
>8	>14	>14	>63	>63	0.1	18 - 24	20

*Ambient wind sustained at 19.5 m above surface to generate fully-developed seas. To convert to another altitude, H_2, apply $V_2 = V_1(H_2/19.5)^{1/7}$

**Minimum is 5 percentile and maximum is 95 percentile for periods given wave height range.

WMO Sea State Code	Wave Height (meters)	Characteristics
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight
4	1.25 to 2.5	Moderate
5	2.5 to 4	Rough
6	4 to 6	Very rough
7	6 to 9	High
8	9 to 14	Very high
9	Over 14	Phenomenal

- Typically collect data for 4 cases – SS 4-7; Hw = 1.88, 3.25, 5, 7.5; Modal Period = 9, 10, 12, 14 sec; smaller ships use less like SS 3-6
- See Limit Criteria Handout for response limits

Figure 123 - Sea State Definitions

Due to the smaller size of the SSC, it was analyzed for sea-states 3 through 6.

Based on the sea-state encountered by the ship, SMP can automatically analyze the results in comparison to limiting responses. These are conditions designed to ensure the operability of various ship functions. These could range from hull stresses to wave motions affecting the crew to functionality of weapons systems. These limiting conditions are outlined in the following figure.

SS 7

Hull Type	Performance Limitations Motion	Limit	Location
Monohull	Wetness (Bow)	30/hr	Bow STA 0
Monohull	Slamming (Keel)	20/hr	Keel STA 3
Aircraft Carrier	Slamming	20/hr	Sponson
SWATH	Slamming	20/hr	Lower Leading Edge of Cross Structure
SWATH	Relative Motion	Depth re Waterline	1/4 Propeller Emersion
SWATH	Wetness	5/hr	Lower Leading Edge of Cross Structure

Vertical Launch Systems

SS 6

Operation	Performance Limitations Motion	Limit	Location
Launch	Roll	17.5°	CG
"	Pitch	3°	CG
"	Yaw	1.5°	CG
"	Longitudinal Acceleration	0.3g	Launcher outboard corner
"	Transverse Acceleration	0.7g	Launcher outboard corner
"	Vertical Acceleration	0.6g	Launcher outboard corner

Radars (air search and surface search radar with elevation stabilized antennae)-

SS 7

Maximum design roll angle for 100% effectiveness- 25 degrees
Roll angel for 0% effectiveness- 0 degrees

Sonars (hull mounted)- Degradation in sonar performance will occur due to emergence of dome, signal modification due to bearing fluctuation, and phase and frequency shift of the signal.

SS 6

Hull Mounted Sonar	Performance Limitations Motion	Limit	Location
Active Sonar	Emergence	24/hr	Intersection of dome with hull
Active Sonar	Roll	15°	CG
Active Sonar	Pitch	5°	CG
Passive Sonar	Emergence	90/hr	Intersection of dome with hull

Guns- Degradation in single hit probabilities of a 5"/54 gun with MK 68 Fire Control System

SS 5

Representative Gun System	Performance Limitations Motion	Limit	Location
5"/54	Roll	7.5°	CG
5"/54	Pitch	7.5°	CG
5"/54	Vertical Velocity	3 ft/sec	Gun Mount

Figure 124 - Limiting Responses for Slamming, Sonar, and Gun Systems

Torpedo Systems SS 5

Subsystem	Performance Limitations		
	Motion	Limit	Location
Launcher	Roll or Pitch	7.5°	CG
Loading with Torpedoes on Dollies	Roll or Pitch	2.5°	CG
Loading by Hand	Roll or Pitch	3°	CG
Automatic Direct Loading	Roll or Pitch	7.5	CG

Notes- Torpedo is not limited by ship motion during launch

combined < Roll 4° CG, Pitch 1.5° CG   SS 5

UNDERWAY REPLENISHMENT SYSTEMS

Limiting Factor	Performance Limitations		
	Motion	Limit	Location
VERTREP Pallet Control	Roll	4°	CG
CONREP Pallet Control	Roll	4°	CG
CONREP Transfer Equipment	Roll	7.5°	CG
CONREP Transfer Equipment	Pitch	1.5°	CG
CONREP Missile Handling	Roll	5°	CG
FAS Transfer Equipment	Roll	5°	CG
FAS Transfer Equipment	Pitch	1.5°	CG

SS 5

AIRCRAFT SYSTEMS

Helicopter and STOL Launch and Recovery

Aircraft L+R and Handling < Roll 5°, Pitch 3°, V 6.5 ft/s

Operation	Performance Limitations		
	Motion	Limit	Location
Generic Helicopter Launch	Roll	5°	CG
Generic Helicopter Launch	Pitch	3°	CG
Generic Helicopter Launch	Relative Wind	Generic VTO Envelope	
Generic Short Takeoff	Roll	5°	CG
Generic Short Takeoff	Pitch	3°	CG
Generic Short Takeoff	Relative Wind	Generic STO Envelope	
Generic Helicopter Recovery	Roll	5°	CG
Generic Helicopter Recovery	Pitch	3°	CG
Generic Helicopter Recovery	Vertical Velocity	6.5 ft/sec	Aft Landing Spot
Generic Helicopter Recovery	Vertical Velocity	6.5 ft/sec	Fwd Landing Spot
Generic Helicopter Recovery	Relative Wind	Generic VL Envelope	

Figure 125 - Limiting Responses for Torpedo and Aircraft Systems

PERSONNEL SS 7

Application	Motion	Performance Limitations	
		Limit	Location
General	Roll	8	CG
General	Pitch	3	CG
General	Vertical Acceleration	0.4g	Bridge
General	Lateral Acceleration	0.2g	Bridge
Specific Task	Motion Sickness Incidence	20 % of crew	Task Location
Specific Task	Motion Induced Interruption	1/min	Task Location
Specific Task	Relative Wind	35 kts	Flight Deck

Figure 126 - Limiting Responses for Personnel

After importing the hull geometry into SMP, defining loads, the desired sea-states, and choosing what ship motions are of most interest to the design, SMP is capable of analyzing specific points in the geometry in response to the ship's motions. These points are used to apply the limiting conditions to their applicable system. The points are defined at the systems' locations, and the appropriate limit condition as applied to each point. After running SMP's analyses, the user can view the results in color-scaled graphs indicating how the point faired under the different sea-states. These graphs provide a clear understanding of the ship's operability in response to sea conditions. The results obtained for the SSC are described below.

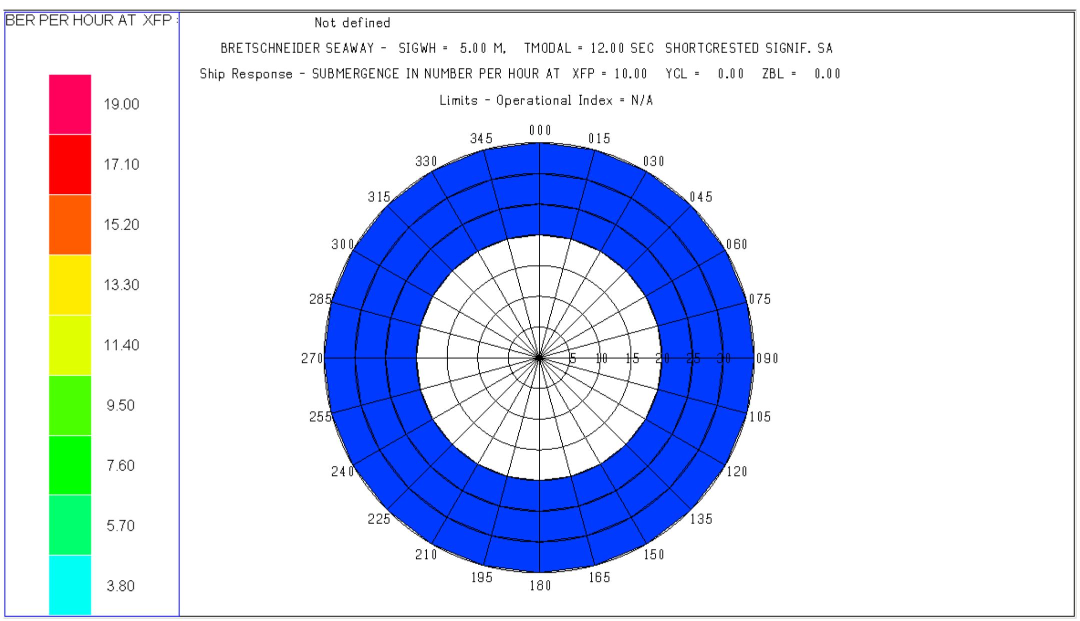


Figure 127 - Bow Wetness Limit (30/hr, SS7)

Based on the above figure, the SSC is fully operational up to 35 knots with waves encountered from any direction for considering bow wetness.

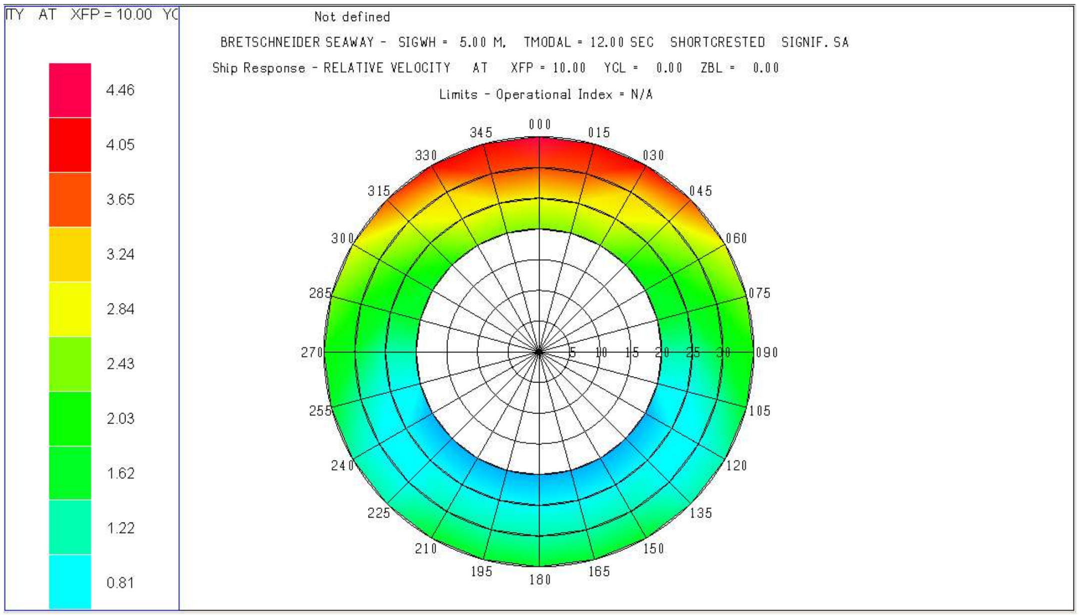


Figure 128 - Keel Slam Limit (20/hr, SS7)

The above figure indicates that the SSC is fully operational up to 35 knots, with waves encountered from any condition for considering keel slamming.

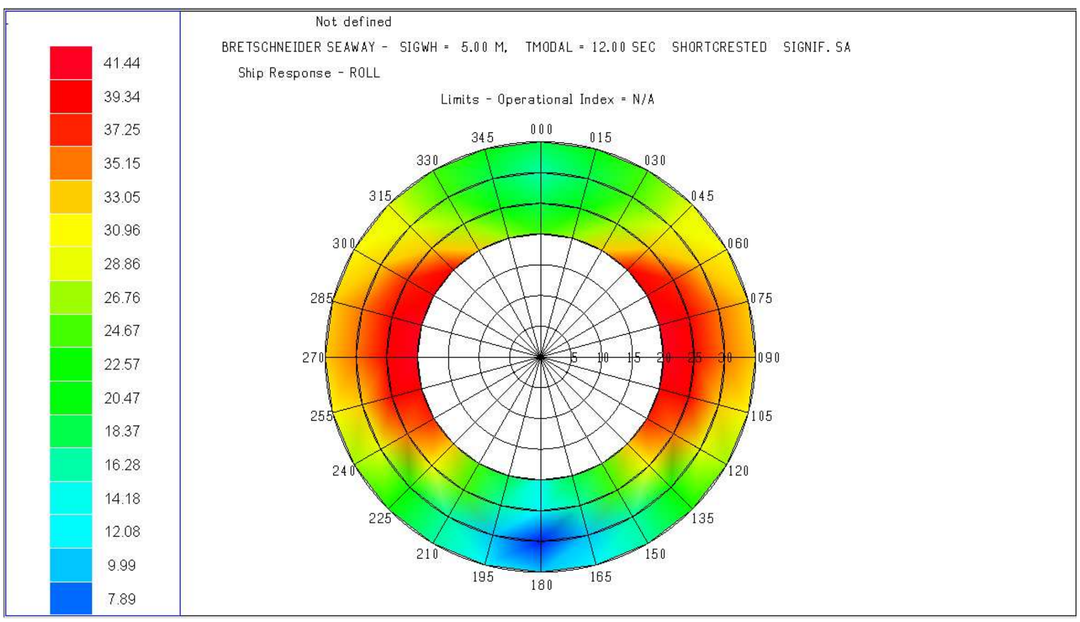


Figure 129 - Radar Roll (25°, SS7)

Based on these results, the ship's radar system would not be functional in beam seas encountered beyond 15 to 20 knots.

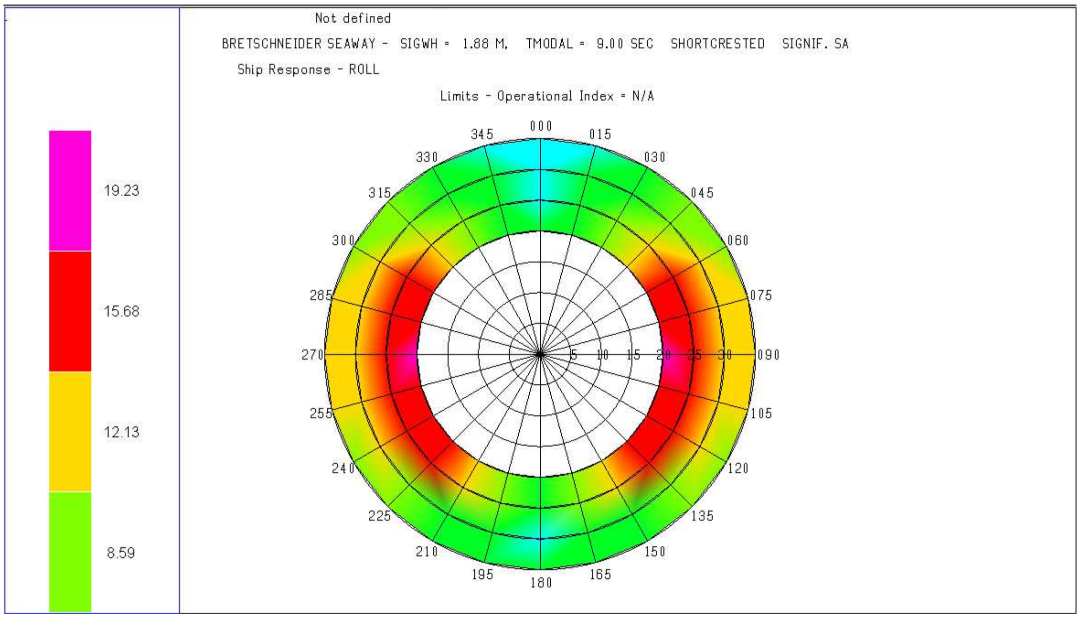


Figure 130 - Gun Roll (7.5°, SS5)

According to these results, the ship's gun system would not be operable at any speed, with waves encountered from any direction. The gun system would be completely non-operational.

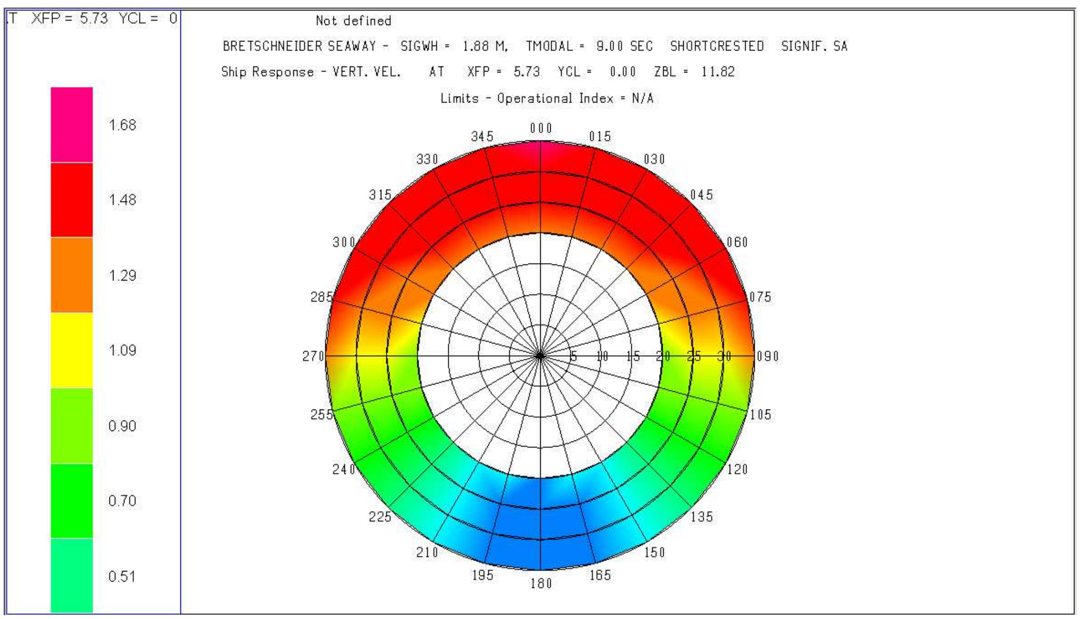


Figure 131 - Gun Vertical Velocity (1m/s, SS5)

This figure demonstrates another analysis for the gun system, specifically its vertical motion. They indicate that the gun system would only be functional in following seas.

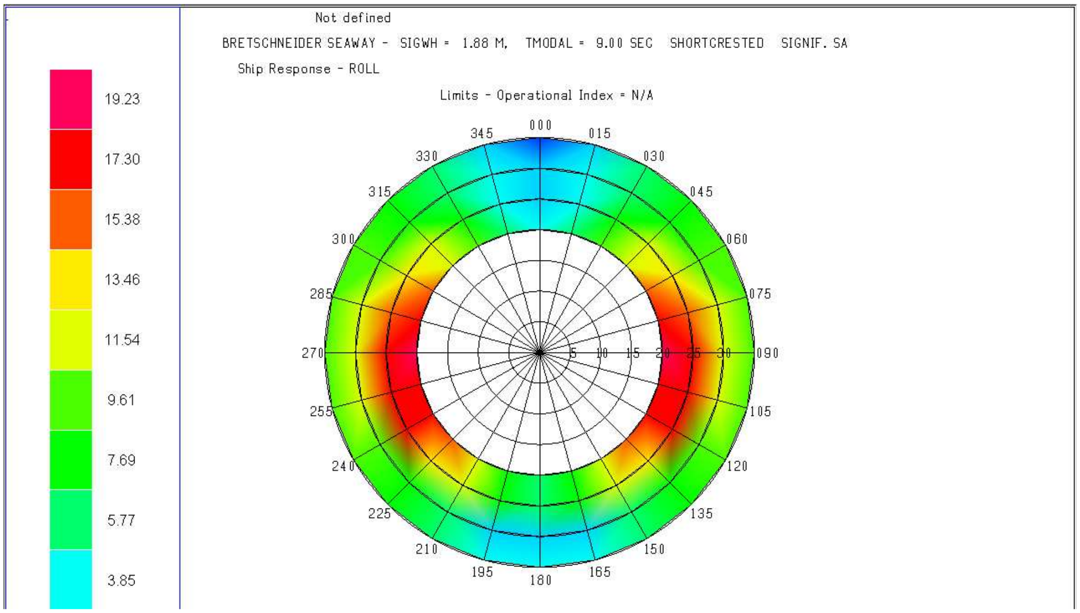


Figure 132 - Torpedo Launch Roll (7.5^o, SS5)

This analysis checks the condition of the torpedo system when the ship is experiencing roll. They indicate that the torpedo systems would be functional in head and following seas.

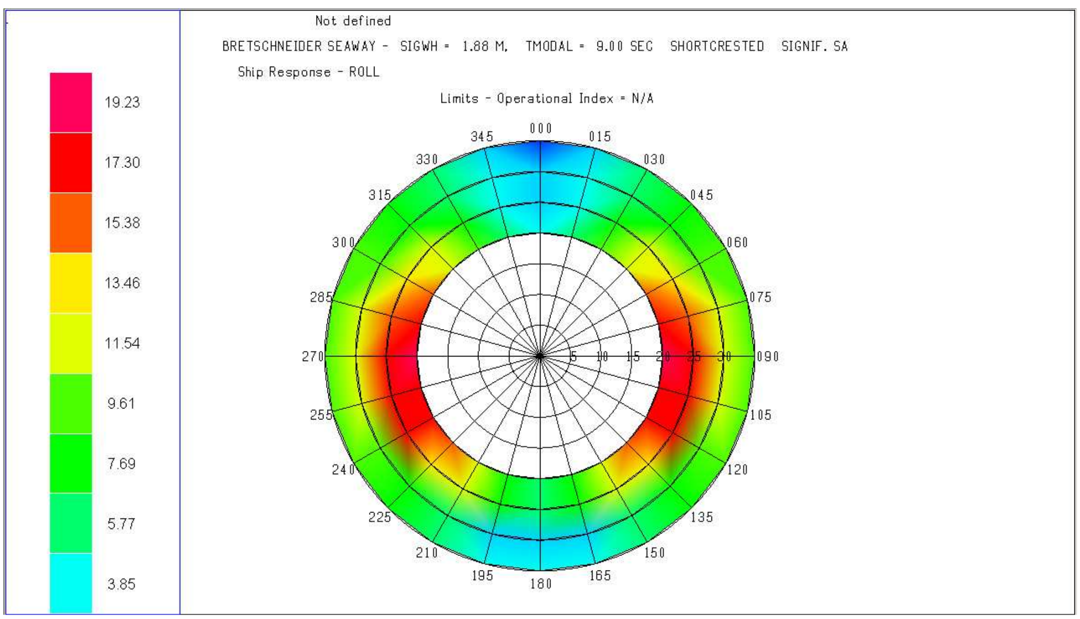


Figure 133 - Helo Launch and Recovery Roll (5^o, SS5)

This graph shows the helicopter systems operability for launch and recovery missions while the ship is experiencing roll. They indicate that the helicopter system would be functional in head and following seas.

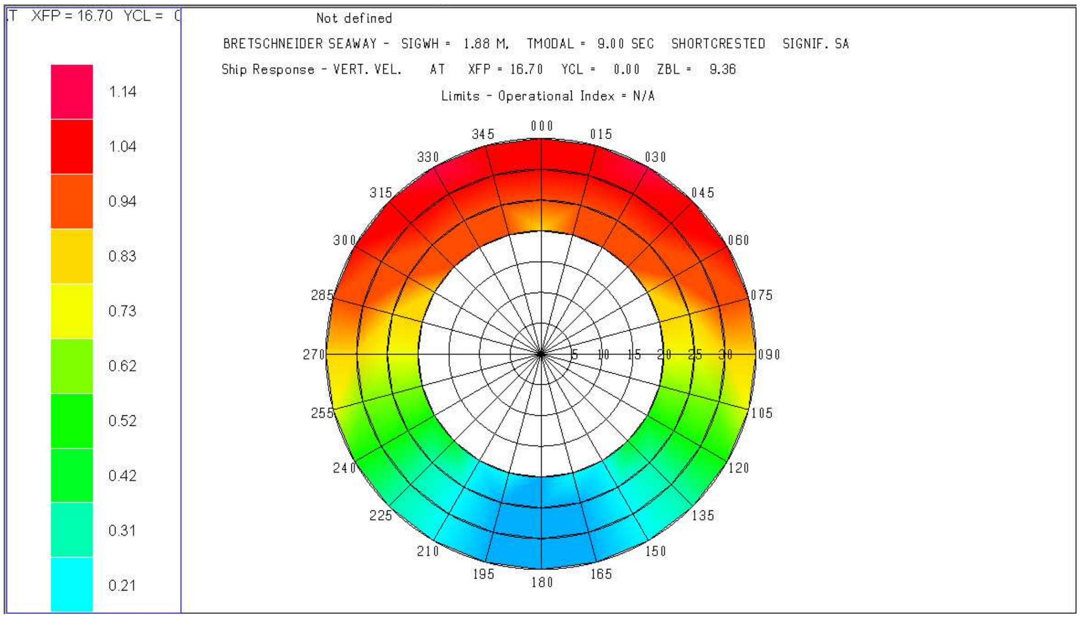


Figure 134 - Helo Launch and Recovery Velocity (2m/s, SS5)

These results indicate that when considering the vertical velocity motions of the helipad, launch and recovery missions will be fully operational.

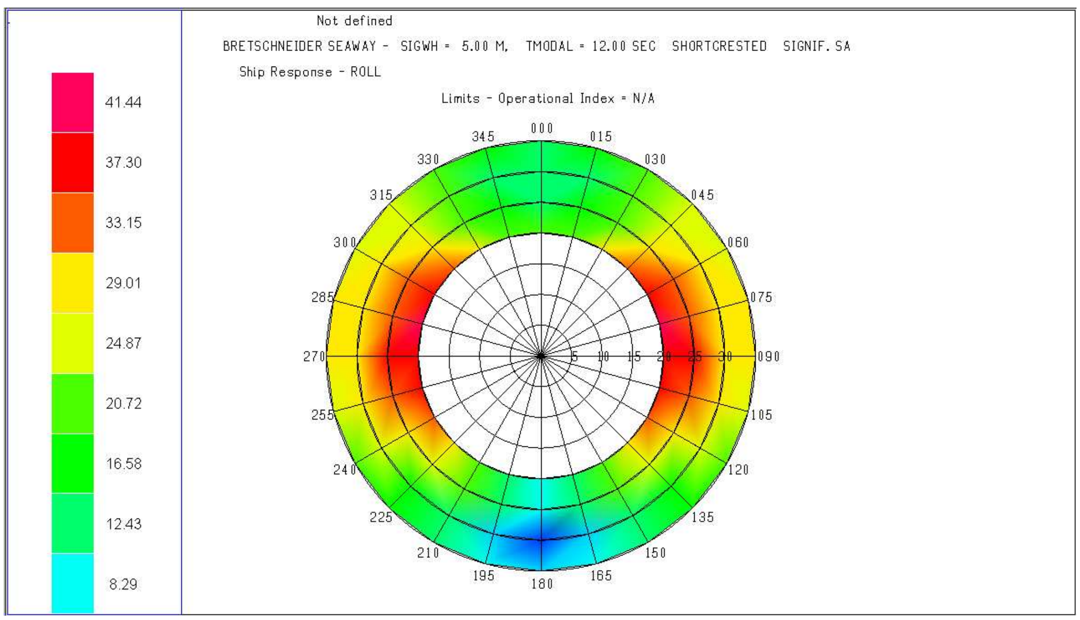


Figure 135 - Personnel Roll (8°, SS7)

In this analysis the ship's rolling motions are compared with the safety of crew and personnel in mind. According to the analyses, crew are only experiencing comfortable ship motions in following seas.

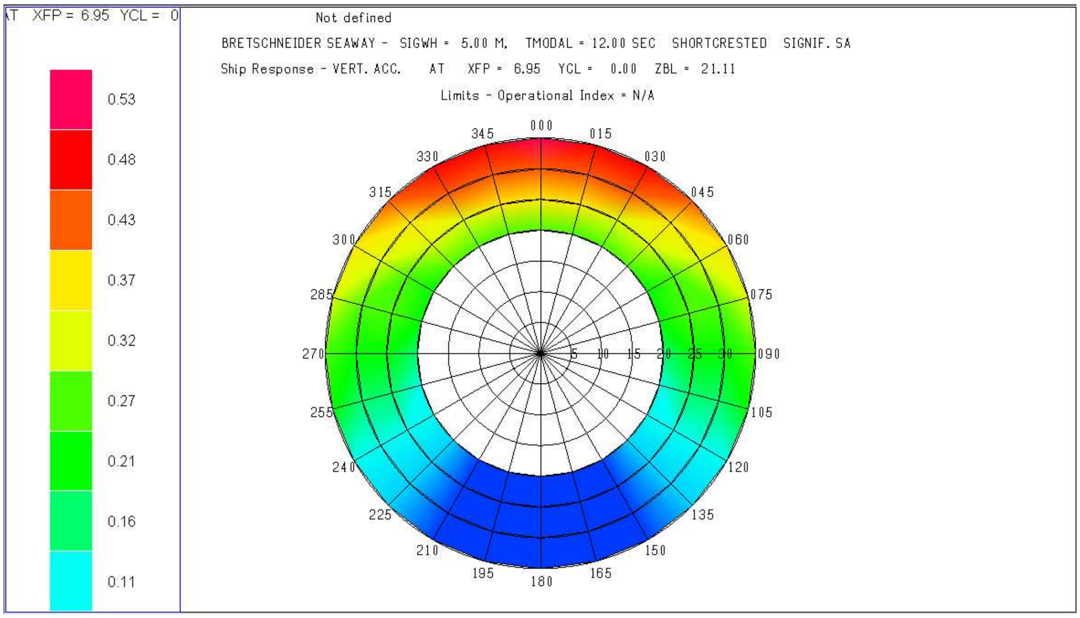


Figure 136 - Personnel Vertical Acceleration (0.4g, SS7)

This test analyzes the vertical accelerations of the ship under waves, and applies it to the safety requirements needed to ensure the crew's feet stay on deck. According to the results, the crew are safe except for in head seas with the ship exceeding 25 knots.

The below figure summarizes the results of the sea-keeping analysis.

Criteria	Seastate Threshold	Assessment
Bow Wetness	6	Fully Operational
Keel Slam	6	Fully Operational
Radar (roll)	6	Exceeded in Beam Seas
Gun (roll)	4	Not Operational
Gun (vert. veloc.)	4	Operational in Following Seas
Torpedo Launch (roll)	4	Operational in Head and Following Seas
Helo (roll)	4	Operational in Head and Following Seas
Helo (vert. veloc.)	4	Fully Operational
Personnel (roll)	6	Operational in Following Seas
Personnel (vert. accel.)	6	Limit Exceeded in Head Seas over 25 Knots
OVERALL		Limited combat capabilities

Figure 137 - Seakeeping Analysis Summary

By viewing this summary, it can be seen that the SSC has very limited combat capabilities in the desired sea-states. In a second design spiral, characteristics of the ship would need to be changed in order to better accommodate the limiting conditions of the combat systems. The changes would most likely come from analyzing the roll of the ship and making changes to the design metacentric height in order to obtain more desirable roll angles. Also, the sea-states governing the systems could be reduced, but this would cost the SSC mission capabilities due to its limited ability to operate in higher sea-states.

4.12 Cost and Risk Analysis

To determine the cost of the Lead and subsequent Follow Ships, a weight-based parametric model based on a class of 30 ships with a 40 year operational life over a 10 year period was used. A learning rate of four percent was used to simulate the problems solved as more ships are built and the operational life of the ships increases. Figure 138 and Figure 139 show that the Propulsion Plant and Hull (SWBS groups 200 and 100, respectively) account for a majority of the total weight of the ship but account for only 38 percent of the cost. The electrical systems onboard the ship account for a majority of the overall cost ($76.20 million). Tables 37 through 48 provide a more detailed breakdown of the costs.

The model predicts a Lead Ship Acquisition Cost of $712.38 million and a Follow Ship Acquisition Cost of $488.31 with an Average Acquisition Cost of $491.20 million per ship. This estimate is higher than the maximum Follow Ship Cost as defined in the Acquisition Decision Memorandum (ADM) shown in Appendix B.

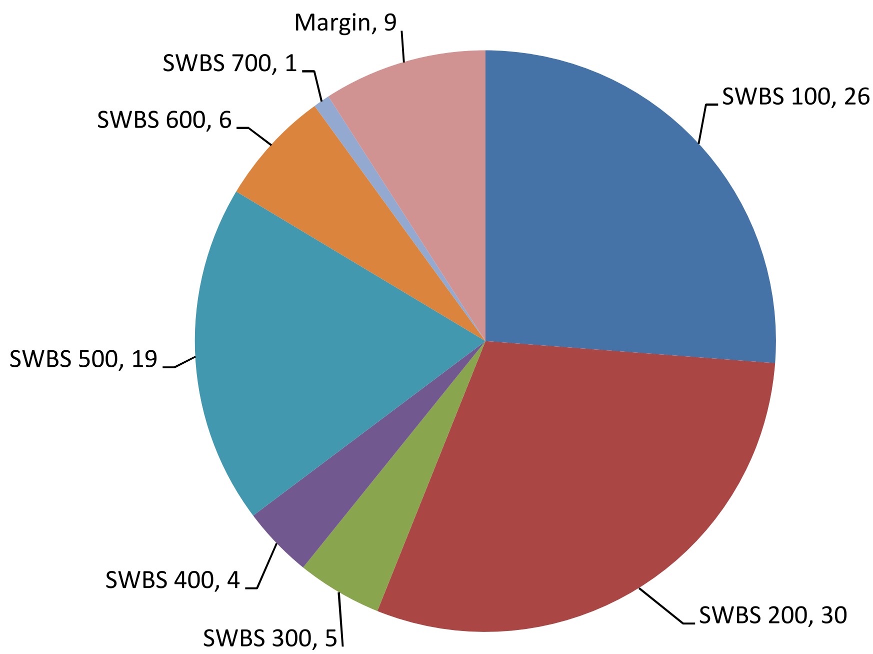


Figure 138 - Total Weight Percentage by SWBS Group

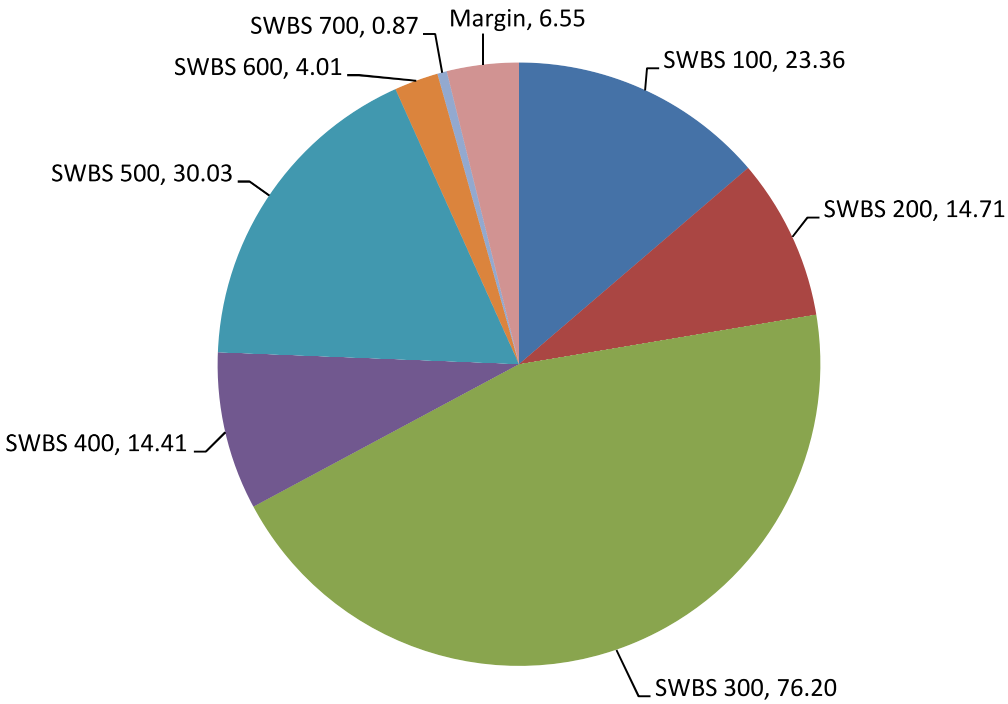


Figure 139 - Total SWBS Costs in Million $

Table 37 - SWBS Weight and Cost

SWBS	Total Weight %	Cost (Million $)
SWBS 100	26	23.36
SWBS 200	30	14.71
SWBS 300	5	76.20
SWBS 400	4	14.41
SWBS 500	19	30.03
SWBS 600	6	4.01
SWBS 700	1	0.87
Margin	9	6.55
Total	100	170.15

Table 38 - Lead Ship Shipbuilder's Cost

Items	Cost (Million $)
SWBS Total	170.15
800	96.20
900	20.09
Total LS	286.44
Profit	28.64

Shipbuilder Price	315.09
Change Orders	37.81
Total Shipbuilder Portion	352.90

Table 39 - Lead Ship Government Associated Costs

Lead Ship Government Portion	Cost (Million $)
Other Support	7.88
Program Manager's Growth	31.51
Payload GFE	285.44
HM&E GFE	6.30
Outfitting	12.60
Total Government Portion	343.73

Table 40 - Final Lead Ship Costs

Final Lead Ship Costs	Cost (Million $)
Total Shipbuilder Portion	352.90
Total Government Portion	343.73
Total Lead Ship End Cost	696.62
Post Delivery Cost	15.754
Total Lead Ship Acquisition Cost	712.38

Table 41 - Lead Ship v. Follow Ship Costs (in Million $)

	Follow Ship	Lead Ship
SWBS	154.91	170.15
800	34.71	96.20
900	10.61	20.09
Total FS Construction	200.24	286.44
Profit	20.02	28.64
Shipbuilder Price	220.26	315.09
Change Orders	25.21	37.81
Total Shipbuilder Portion	245.47	352.90

Table 42 - Lead Ship v. Follow Ship Other Associated Costs (in Million $)

	Follow Ship	Lead Ship
Other Support	5.51	7.88
Program Manager's Growth	11.01	31.51
Payload GFE	206.04	285.44
HM&E GFE	4.41	6.30

Outfitting	8.81	12.60
Total Government Portion	235.771	343.73

Table 43 - Total Costs

	Follow Ship	Lead Ship
Total Shipbuilder Portion	245.47	352.90
Total Government Portion	235.77	343.73
Total Ship End Cost	481.24	696.62
Post Delivery Cost	7.07	15.75
Total Ship Acquisition Cost	488.31	712.38
Average Ship Acquisition Cost	491.20	

Table 44 - Undiscounted Life Cycle Costs

	Cost (Million $)
R&D Costs	575.00
Investment	30700.00
Operations and Support	44070.00
Residual Value	1550.00
Total	73795.00

Table 45 - Discounted v. Undiscounted Life Cycle Costs

Life Cycle Costs	Undiscounted	Discounted
R&D Costs	575.00	612.26
Investment	30700.00	8020.00
Operations and Support	44070.00	1547.00
Residual Value	1550.00	8.74
Total	73795.00	10170.53

5 Conclusions and Future Work

5.1 Assessment

Table 46 compares the CDD KPPs to the performance of the baseline design.

Table 46 - Compliance with Operational Requirements

Technical Performance Measure	CCD KPP (Threshold)	Original Goal	Improved Baseline	Final Baseline
Endurance Range (nm)	3030	3030	3030	3030
Sustained Speed (knots)	40	40	44.1	44.1
Endurance Speed (knots)	20	20	20	22
Collective Protection System	full	full	full	full
Crew Size	69	69	69	69
Maximum Draft (m)	4.39	4.39	4.39	4.39

Vulnerability (hull material)	aluminum	aluminum	aluminum	aluminum
Ballast/Fuel System	Clean, separate ballast tanks	Clean, separate ballast tanks	Clean, separate ballast tanks	Clean, separate ballast tanks

5.2 Future Work

There are a number of concerns and issues that could be addressed in future design spirals. The areas that could be addressed include the hull, deckhouse, and machinery, among others.

The hull and deckhouse are currently made of aluminum. In the future, a composite deckhouse should be investigated. A composite deckhouse would allow for an integrated mast and radar placed directly on the sides of the deckhouse. This will help to decrease radar cross section. In addition, the hull plates and beams are currently various sizes. The beams should be changed to standard sizes for ease during production. Also, the variety of different plate thicknesses and beam sizes should be decreased. Many plates and beams are similar in size. During production, it would be easier to acquire more plates and beams of a single size or a few sizes rather than ones that are slightly different.

Machinery and machinery spaces could be reevaluated in the next design spiral. The ship currently has two auxiliary machinery rooms. One may suffice if the arrangements in the forward auxiliary machinery room were redone. In addition, the current propulsion system has a hybrid mechanical drive and integrated power system. There may be an option to switch to a completely integrated power system and run only on electric power. This will increase the ship's survivability if one of the main engines was damaged.

Final considerations that could be taken into account in the next design spiral would be to increase modularity. There are modular spaces in the general arrangements now; however the overall modularity could be increased in the next spiral. In addition, the ship does not have advanced sonar for submarine detection. Combat systems overall should be reevaluated in the future.

5.3 Conclusions

The small SSC design presented in this report represents a feasible, highly effective solution for a fast ship with combat systems capabilities. The design is highly effective at its primary mission of support for larger surface combatants due in large to its planning capabilities and combat systems. The design is modular and incorporates a hybrid IPS, along with a vertical launch system. The ship is flexible for future growth due to its modularity, power generation, and IPS. Multi-mission capabilities are achieved through the incorporation on both LAMPS and an aft boat ramp for RHIBs along with guns forward for fire support.

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Appendix A – Initial Capabilities Document (ICD)

UNCLASSIFIED

INITIAL CAPABILITIES DOCUMENT

FOR A

Small 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; special operations forces; and support of manned and unmanned air, surface and
- subsurface vehicles.
- Power Projection - The range of military application for this function includes special operations forces.
- Operational timeframe considered: 2016-2060. This extended timeframe demands flexibility in upgrade and
- capability over time.

2 REQUIRED FORCE CAPABILITY(S)

- Provide surface and subsurface defense around friends, joint forces and critical bases of operations at sea
- (ASUW, ASW)
- Provide a sea-based layer of surface and subsurface homeland defense (HLD)
- Provide persistent intelligence, surveillance and reconnaissance (ISR)
- Provide maritime interdiction/interception operations (MIO)
- Provide anti-terrorism protection (AT)
- Provide special operations forces (SOF) support
- Provide logistics support
- Support distributed off-board systems
- Support mine warfare operations
- Support area AAW defense (larger SSCs)

Provide these capabilities through the use of interchangeable, networked, tailored mission modules in combination with inherent systems. Consider a broad range of SSC size, 2000-5000 MT.

3 CONCEPT OF OPERATIONS SUMMARY

Support CSG/ESGs - 2 to 3 SSC ships could be assigned to each strike group. Their mission configuration would complement the other strike group combatants. Larger SSCs may be able to contribute to CSG and ESG area AAW defense. Tailored mission configurations could include defense against mine threats, littoral ASW threats, and small boat threats using distributed off-board systems. High speed and agility could provide tactical advantage.
SSC Surface Action Groups (SAGs) – Operate as a force of networked, dispersed SSCs, providing collective flexibility, versatility and mutual support. SSC SAGs could provide defense against mine threats, littoral ASW threats, and small boat threats ahead of larger CSGs/ESGs including first-response capability to anti-access crises. High speed and agility should provide significant tactical advantage.

SSC Independent Operations - SSC would perform inherent (mobility) mission tasking in known threat environments including defense against mine threats, littoral ASW threats, and small boat threats. Rapid response to contingency mission tasking could provide OTH Targeting, reach-back for mission planning, insertion/extraction of USMC, Army, SOF personnel, and movement of cargo/personnel. SSC could provide ISR ahead of CSG/ESG operations and maritime interdiction/interception operations, overseas or in support of homeland defense, possibly as USCG assets.

Ship deployments could be extended with rotating crews alternately returning to CONUS. Interchangeable, networked mission modules could be changed in 2-3 days, in theater, to support force needs and changing threats. Some MSCs could be configured with more capable AAW sensors and weapons that could also be modular, but require extended availability for upgrade or change-out. Hull plugs, modular deckhouse and modular mast options should be considered for these MSC variants. They would be able to contribute significant area AAW support for ESGs or as part of CSGs.

4 CAPABILITY GAP(S)

The overarching capability gap addressed by this ICD is to provide affordable small surface combatant capabilities in sufficient numbers for worldwide coverage of strike group and independent platform requirements. Specific capability gaps and requirements include:

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	Support of distributed off-board systems including MH-60 and MH-53 aircraft	Hangar and flight deck for 1xMH-60 and 2xVTUAV; side launch and recovery of surface and underwater vehicles	Hangar and flight deck for 2xMH-60 and 2xVTUAV; side and stern launch and recovery of surface and underwater vehicles
2	Agility (speed, maneuverability, shallow draft)	Sustained speed of 30 knots, 5 meter draft	Sustained speed of 45 knots, 3 meter draft.
3	Mission flexibility and capacity	1xLCS capacity for interchangeable modules	2xLCS capacity for interchangeable modules
4	Area AAW support as part of CSG/ESG	AAW self-defense only	
5	Platform Passive Susceptibility	DDG-51 signatures	DDG1000 signatures

5 THREAT AND OPERATIONAL ENVIRONMENT

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 8) 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).

- Increased reliance on foreign small surface combatant support (Japan, NATO, etc.) to meet the interests of the U.S.

b. Ideas for Materiel Approaches

- Design and build small, high speed surface combatants (LCS) with limited capability for dedicated CSG operations, no significant area AAW contribution beyond self defense, and very limited multi-mission capability.
- Do not consider building surface combatants smaller than 5000 MT. Satisfy all surface combatant requirements with MSCs.
- Design and build a scalable modular family of new SSC ships, 2000-5000 MT, with capabilities sufficient to satisfy the full range of specified SSC capability gaps using interchangeable, networked mission modules, and with the option of more capable AAW sensors and weapons that could also be modular, but added in construction or in a major availability using a hull plug, modular deckhouse, or modular mast(s). These variants would be able to contribute significant area AAW support for ESGs or as part of CSGs.

7 FINAL RECOMMENDATIONS

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

b. LCS-1 and 2 as designed may not be affordable in required force numbers. Reconfiguration for area AAW capability would be difficult. They may be too small and not sufficiently robust for required open ocean transits and CSG operations. Their service life may also be inadequate.

c. Satisfying the small surface combatant requirement with all MSCs in necessary force numbers is not affordable.

d. The option of a scalable modular family of new SSC ships, 2000-5000 MT, with capabilities sufficient to satisfy the full range of specified SSC capability gaps using interchangeable, networked mission modules, and with the option of more capable AAW sensors and weapons should be explored. The feasibility of limiting follow-ship acquisition cost to $300M ($FY2013) must be investigated with an absolute constraint of $400M. Compromises in speed and inherent multi-mission capabilities may have to be considered.
Trade-offs should be made based on total ownership cost (including cost of upgrade), effectiveness (including flexibility) and risk. It is anticipated that 50 of these ships may be built with a required service life of 30 years.

Appendix B– Acquisition Decision Memorandum

August 24, 2009

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

Subject: ACQUISITION DECISION MEMORANDUM FOR a Small Surface Combatant

Ref: (a) Virginia Tech SSC 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 scalable modular family of new SSC ships, 2000-5000 MT, with capabilities sufficient to satisfy the full range of specified SSC capability gaps using interchangeable, networked mission modules, and with the option of more capable AAW sensors and weapons. AAW sensors and weapons could also be modular, but would be added in construction as a SSC variant or in a major availability using a hull plug, modular deckhouse, or modular mast(s). These variants would be able to contribute significant area AAW support for ESGs or as part of CSGs. A full range of affordable 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 inherent multi-mission capabilities.

3. The feasibility of limiting follow-ship acquisition cost to $300M ($FY2013) must be investigated with an absolute constraint of $400M. Compromises in speed and inherent multi-mission capabilities may have to be considered to achieve these cost goals and constraints. Trade-offs should be made based on total ownership cost (including cost of upgrade), effectiveness (including flexibility) and risk. It is anticipated that 50 of these ships may be built with IOC in 2016, and with a required service life of 30 years.

A.J. Brown
VT Acquisition Executive

Appendix C– Concept Development Document (CDD)

UNCLASSIFIED

CAPABILITY DEVELOPMENT DOCUMENT

FOR

SMALL SURFACE COMBATANT – ALUMINUM
Variant #51
VT Team 4

6 Capability Discussion.

SSC requirements are based on the SSC Initial Capabilities Document (ICD), and SSC Acquisition Decision Memorandum (ADM) issued by the Virginia Tech Acquisition Authority on 24 August 2009. This SSC ADM authorized SSC Concept Exploration and Development using an aluminum monohull, and a steel, aluminum or composite (integrated) deckhouse. Aluminum hull concepts will be compared to previously-authorized SSC steel hull designs. SSC will contribute to the Sea Power 21 vision and Global Naval Concept of Operations including Sea Strike, Sea Shield, and Sea Basing. The overarching capability gaps addressed by SSC are: Provide and support functional areas with sufficient numbers of reconfigurable-mission ships; and provide focused mission ships capable of defeating conventional and asymmetric access-denial threats in the littoral. SSC will use open systems architecture and modular characteristics that will enable timely change-out of Mission Packages enabling SSC to be optimized to confront these threats. SSC will be a dominant and persistent platform that enables sea-based joint forces to operate uncontested and provide affordable lethality in the littorals.

Specific capability gaps resulting from insufficient force numbers with adequate inherent core capabilities include: Joint Littoral Mobility; Special Operations Forces (SOF) support; Maritime Interdiction / Interception Operations (MIO); Home-Land Defense (HLD); Anti-Terrorism / Force Protection (AT/FP). Additional SSC capabilities using interchangeable, mission tailored modules include, but are not limited to; Mine Counter Measures (MCM), Small Boat Prosecution (ASUW), additional Special Operations Forces (SOF) support, and littoral ASW packages. In addition, unmanned systems may be added or removed to modular bays as required. Permanent installations will be necessary for mission capabilities inherent to the ship's general operation. The final design of the SSC must excel at seakeeping and maneuverability at high speeds. Table 1 lists capability gap requirements to be addressed by SSC.

Table 1 – Mission Capability Gaps (inherent characteristics not including mission modules)

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	ASW/MCM	SQS-56, Nixie, 2xMK 32 Triple Tubes, SQQ 89 FCS	SQS-56, Nixie, 2xMK 32 Triple Tubes, MK 309 Torpedo FCS, SQQ 89 FCS
2	ASUW, Maritime Interdiction	SPS-73, 1x30mm CIG, 57mm MK3	SPS-73, 1x30mm CIG, 57mm MK3
3	AAW Self Defense	EADS TRS-3D C-Band Radar, 1xMK16, Ram/Searam, Combat DF	Sea Giraffe AMB radar, 1xMK16, Ram/Searam, Mk XII AIMS IFF
4	C4I	Comm Suite Level B, CTSCE	Comm Suite Level A, CTSCE
5	LAMPS	LAMPS haven (fight deck)	2 x Embarked LAMPS w/ Hangar
6	Special-Mission Packages (MCM, SUW, ASW, ISR, Special Forces)	1xLCS Mission Packages with UAVs, USVs and stern launch	2xLCS Mission Packages with UAVs, USVs and stern launch

7	Mobility	40 knts, full SS4, 3500 nm, 15 days	50 knts, full SS5, 4500 nm, 45 days
8	Survivability and self-defense	Low magnetic signatures, mine detection sonar, CIWS or CIGS	Low magnetic signatures, mine detection sonar, CIWS or CIGS

7 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 an additional material alternative for a Small Surface Combatant (SSC). Required SSC capabilities will include the ability to adapt to a wide range of missions using interchangeable, networked, tailored modular missions packages built around off-board, unmanned systems. The platform will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict. Small crew size and limited logistics requirements, falling within current logistic support capabilities, will facilitate efficient forward deployment in peacetime and wartime to sensitive littoral regions. It will provide its own defense with significant dependence on passive survivability and stealth. Inter-service and Allied C^4/I (inter-operability) must be considered. Designs must be highly producible, and will minimize life cycle cost through application of producibility enhancements and manning reduction using automation.

Concept Exploration was conducted from 24 August 2009 through 9 December 2009. A Concept Design and Requirements Review was conducted on 22 January 2009. This CDD presents the baseline requirements approved at 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). A Multi-Objective Genetic Optimization (MOGO) process was used to perform trade-off evaluations using technology and concept design parameters in conjunction with set optimization objectives to develop a non-dominated frontier of the most favorable designs. In this case, the optimization objectives were overall mission effectiveness (OMOE), technology risk (OMOR), and total ownership cost (CTOC). A 107 variant non-dominated frontier, Figure 1, was produced including designs with a wide range of effectiveness and cost, each having the highest effectiveness for a given cost and risk.

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. Virginia Tech Team 4 selected Variant 51 shown in Figure 1 at a "knee in the curve". Risk and cost are moderate and effectiveness is very good. Selection of a point on the non-dominated frontier determines cost-risk-effective requirements, technologies and the baseline design.

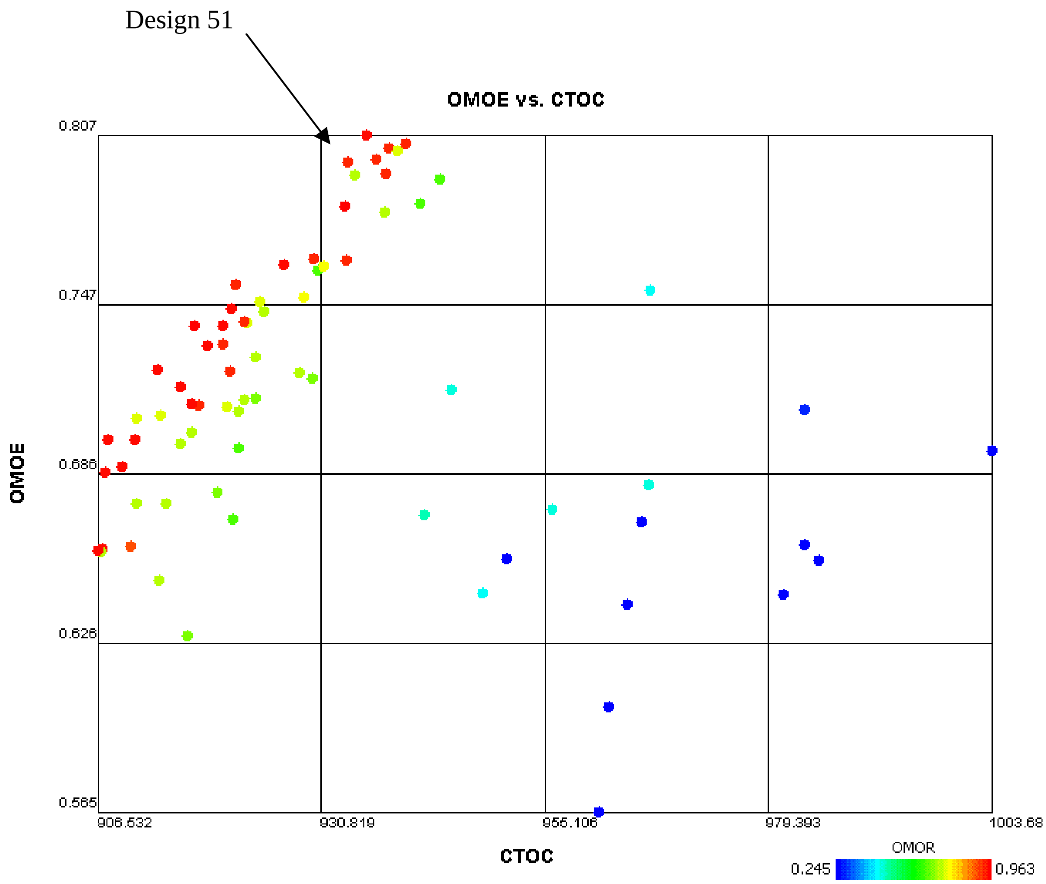


Figure 1 – SSC 2-D non-dominated Frontier

8 Concept of Operations Summary

The SSC class will be able to operate as a scalable modular family of SSC ships with capabilities sufficient to satisfy the full range of specified SSC capability requirements using interchangeable, networked mission modules, and with the option of more capable Anti-Air Warfare (AAW) sensors and weapons could also be modular, but would be added in construction as a SSC variant or in a major availability using a hull plug, modular deckhouse, or modular mast(s). These variants will be able to contribute significant area AAW support for Expeditionary Strike Groups (ESG) or as part of Carrier Strike Groups (CSG).

SSC will also be used in support of CSG/ESGs. Two to three SSC ships could be assigned to each strike group with Medium Surface Combatants (MSC) and a carrier or amphibious ship. Their mission configuration would complement the other strike group combatants. Larger SSCs may be able to contribute to CSG and ESG area AAW defense. Tailored mission configurations could include defense against mine threats, littoral Anti-Submarine Warfare (ASW) threats, and small boat threats using distributed off-board systems. High speed and agility could provide tactical advantage.

SSC Surface Action Groups (SAGs) will also be utilized. They will operate as a force of networked, dispersed SSCs, providing collective flexibility, versatility and mutual support. SSC and MSC SAGs could provide defense against mine threats, littoral ASW threats, and small boat threats ahead of larger CSGs/ESGs including first-response capability to anti-access crises. High speed and agility should provide a significant tactical advantage.

During SSC Independent Operations, SSC would perorm inherent (mobility) mission tasking in known threat environments including defense against mine threats, littoral ASW threats, and small boat threats. Rapid response to contingency mission tasking could provide OTH Targeting, reach-back for mission planning, insertion/extraction of USMC, Army, SOF personnel, and movement of cargo/personnel. SSC could provide ISR ahead of CSG/ESG operations and maritime interdiction/interception operations, overseas or in support of homeland defense, possibly as USCG assets.

Ship deployments could be extended with rotating crews alternately returning to CONUS. Interchangeable, networked mission modules could be changed in 2-3 days, in theater, to support force needs and changing threats. Some SSCs could be configured with more capable AAW sensors and weapons that could also be modular, but require extended availability for upgrade or change-out. Hull plugs, modular deckhouse and modular mast options should be considered for these SSC variants. They would be able to contribute significant area AAW support for ESGs or as part of CSGs.

9 Threat Summary.

SSC will be used for world-wide operation in cluttered, littoral environments or constrained bodies of water with smaller scales relative to open ocean warfare. These environments create an increased difficulty of detecting and successfully prosecuting targets. It will also be used in open ocean environments as part of CSGs and ESGs, so it must be able to withstand Sea States 1 through 8.

The threats that SSC will face are asymmetric, overlapping, and commercially available. They include threats from nations with a major military capability, or the demonstrated interest in acquiring such a capability. Major military capabilities include land, surface, and air launched cruise missiles, diesel submarines, land-attack cruise missiles, and theatre ballistic missiles.

However, since the principal operational needs of the SSC are in littoral waters, the tactical picture will be on smaller scales relative to open ocean warfare. Threats in this environment include: (1) sea-based highly maneuverable small surface craft, diesel-electric submarines, and mines (surface, moored, and bottom); (2) close proximity to land-based air assets; (3) advanced cruise missiles like the Silkworm and Exocet; and (4) chemical / 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.

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

Key Performance Parameter (KPP)	Development Threshold or Requirement
AAW	SEA Giraffe G/H band radar, 1 x 11 cell Sea RAM, AIMS IFF, EDOES 3601 ESM, ICMS, TACTICOS, SEA STAR SAFIRE III, COMBAT DF
ASUW/NSFS	3 AN/SPS-73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR
ASW/MCM	1 AN/SLQ-25 NIXIE, Mine Avoidance Sonar
CCC	1 Comm Suite Level A, CTSCE
LAMPS	2 x Embarked LAMPS w/ Hangar
LCS Modules	1 x LCS loadout with UAVs, USVs and stern launch
Hull	High-speed planing monohull
Power and Propulsion	2 waterjets, 2xMT30, secondary IPS with 2xSEMT16PA6B and 2xCAT3508B
Endurance Speed (knots)	18 knots
Endurance Range (nm)	4000-6000 nm
Sustained Speed (knots)	47.3 knots
Sprint Range (nm)	1143 nm
Stores Duration (days)	45 days
Collective Protection System	Partial
Crew Size (maximum)	40
RCS (m^3)	4150 m3
Maximum Draft (m)	3.75 m
Vulnerability (Hull Material)	Aluminum hull and deckhouse
Ballast/fuel system	Clean, separate ballast tanks
Degaussing System	Yes
McCreight Seakeeping Index	4

KG margin (m)	0.5m
Propulsion power margin (design)	10%
Propulsion power margin (fouling and seastate)	25%
Electrical margins	5%
Net Weight margin (design and service)	10%

11 Program Affordability.

Follow-ship acquisition cost shall not exceed $400M (FY 2010) with lead ship acquisition cost less than $950M. It is expected that 30 ships of this type will be built with IOC in 2015.

Appendix D – Machinery Equipment List (MEL)

System: Main Engines and Transmission								
1	2	Gas Turbine, Main	MT30	36MW	MMR	234	Includes Acoustic Enclosure	9.18 x 3.74 x 3.78
2	2	Diesel Generator, Secondary	SEMT 16PA6V	4772.5 kW	MMR	230	From asset	4.60 x 1.78 x 2.48
3	2	Gear propulsion,reduction	Double Stage, 1.14:8.40:1 Gear Ratio	50 MW	MMR	241	from asset, LTDR and solar 2-speed epicyclic	3.51x 4.98 x 3.99
4	2	Shaft, Line	370mm (OD)	-	various	243	port shaft weight = 26.8 MTON, stbd shaft weight = 16.8 MTON	0.37m D as req'd, port length 51.98m, stbd length 32.61m
5	6	Bearing, Line Shaft	Journal	575 mm Line Shaft	various	244	Calculate number required and locate	1 x .125 x .125
6	2	Unit, MGT Hydraulic Starting	HPU with Pumps and Reservior	14.8 m^3/hr @ 414 bar	MMR	556	near end ME away from RG	1 x 1 x 1
7	2	Main Engine Exhaust Duct	GE LM2500 Marine Turbine	75 kg/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out stack	8.7 sq. m
8	2	Main Engine Inlet Duct	GE LM2500 Marine Turbine	65 kg/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	18.6 sq.m
9	2	Secondary Engine Exhaust Duct	SEMT 16PA6V	10.7 kg/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	0.7 sq. m
10	2	Secondary Engine Inlet Ducts	SEMT 16PA6V	6.1 m/sec	MMR and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	1.4 sq. m
11	1	Console, Main Control	Main Propulsion	NA	ECC	252	On 2nd deck with DCC	3x1x2
12	2	Electric, secondary	Secondary IPS Motor	6 MW	AMR	311	Generates power for control of waterjet, double-duty with Secondary IPS system	1.55 x 1.78 x 2.48
13	2	Frequency Changer	converter	NA	AMR	314	Converts from secondary IPS generator to IPS system requirements	1.5 x 1.5 x 1.5
14	2	Controller	Waterjet, Secondary IPS	NA	ECC	252	Controls waterjet motors	0.5 x 0.5 x 0.5
System: Power Generation and Distribution								
15	2	Diesel Generator, Ships Service	Caterpillar 3508B	2081.2 kW	AMR	311	Includes enclosure, 2nd or upper level, orient F&A	1.77 x 1.70 x 1.80
16	2	SSG Exhaust Duct	Caterpillar 3508B	4.2 kg/sec	AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	0.1 sq. m
17	2	SSGTG Inlet Duct	Caterpillar 3508B	6.1 m/sec	AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	0.2 sq. m
18	1	Switchboard, Ships Service	Generator Control Power Distribution	5000 kW	ECC	324		0.5 x 2 x 2
19	2	Switchboard, Electric Motor	Generator Control Power Distribution	10 MW	ECC	324		0.5 x 1 x 2
20	1	Emergency Switchboard			MMR2			0.5 x 1 x 2
21	4	MMR and AMR ladders	Inclined ladders		MMR,AMR		May have single or double inclined ladders between levels depending on space	1.0x2.0
22	2	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
23	1	MN Machinery Space Fan	Supply	94762 m^3/hr	FAN ROOM	512	above, outside MMR	1 x 1 x 1
24	2	MN Machinery Space Fan	Exhaust	91644 m^3/hr	MMR	512	Upper level in corners	1x 1 x 1
25	2	Aux Machinery Space Fan	Supply	61164 m^3/hr	FAN ROOM	512	above, outside AMR	1 x 1 x 1
26	2	Aux Machinery Space Fan	Exhaust	61164 m^3/hr	AMR	512	Upper level in corners	1 x 1 x 1
System: Salt Water Cooling								
27	4	Pump, Main Seawater Circ	Centrifugal, Vertical, Motor Driven	230 m^3/hr @ 2 bar	2/MMR	256	P&S MMR lower level near hull and ME	.5 x .5 x .5
System: Lube Oil Service and Transfer								
28	2	Assembly, MGT Lube Oil Storage and Conditioning	Includes Oil Storage and Cooler	NA	MMR	262	next to each engine	1 x 1 x 2

29	4	Strainer, Reduction Gear Lube Oil	Duplex	200 m^3/hr	MMR	262	next to RG	0.5 x 0.5 x 1
30	2	Cooler, Reduction Gear Lube Oil	Plate Type	NA	MMR	262	next to RG and strainer	1.5 x 1.5 x 1
31	2	Pump, Reduction Gear Lube Oil Service	Pos. Displacement, Horizontal, Motor Driven	200 m^3/hr @ 5 bar	MMR	262	next to RG and strainer	1 x 0.5 x 0.5
32	2	Purifier, Lube Oil	Centrifugal, Self Cleaning, Partial	1.1 m^3/hr	MMR	264	next to LO transfer pump, 2nd or upper	.830 x .715 x 1.180
33	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								
34	2	Filter Separator, MGT Fuel	2-Stage, Static, 5 Micron	30 m^3/hr	MMR	541	next to FO purifiers	1.5 (L) x 0.5 dia
35	2	Purifier, Fuel Oil	Self Cleaning, Centrifugal, Partial Discharge Type	7.0 m^3/hr	MMR	541	2nd or upper level MMR	1 x 1 x 1.5
36	2	Pump, Fuel Transfer	Gear, Motor Driven	45.4 m^3/hr @ 5.2 bar	MMR	541	next to FO purifiers	1 x 0.5 x 0.5
37	2	Fuel Oil Service Tanks			MMR		lower level MMR P&S	size for 4 hours at endurance speed
System: Air Conditioning and Refrigeration								
38	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
39	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
40	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								
41	4	Pump, Fire	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	VARIOUS	521	lower levels	2.490 x .711 x .864
42	1	Pump, Fire/Ballast	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	AMR	521	lower levels	2.490 x .711 x .864
43	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
44	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
45	2	Station, AFFF	Skid Mounted	227 m^3/hr @3.8 bar	above MMR	555	for entering space	2.190 x 1.070 x 1.750
System: Potable Water								
46	2	Fresh Water Unit	Reverse Osmosis	76 m^3/day (3.2 m^3/hr)	AMR	531	lower or 2nd level	2 x 3 x 2
47	2	Brominator	Proportioning	1.5 m^3/hr	AMR	531	next to distillers	0.3 x 0.2 x 0.4
48	2	Brominator	Recirculation	5.7 m^3/hr	AMR	533	next to distillers	0.3 x 0.2 x 0.4
49	2	Pump, Potable Water	Centrifugal, Horizontal, Motor Driven	22.7 m^3/hr @ 4.8 bar	AMR	533	next to distillers	0.5 x 0.5 x 0.3
System: JP-5 Service and Transfer								
50	2	Pump, JP-5 Transfer	Rotary, Motor Driven	11.5 m^3/hr @ 4.1 bar	JP-5 PUMP	542	in JP-5 pump room	1.194 x.483 x .508
51	2	Pump, JP-5 Service	Rotary, Motor Driven	22.7 m^3/hr @ 7.6 bar	JP-5 PUMP ROOM	542	in JP-5 pump room	1.194 x .483 x .508
52	2	Pump, JP-5 Stripping	Rotary, Motor Driven	5.7 m^3/hr @ 3.4 bar	JP-5 PUMP ROOM	542	in JP-5 pump room	.915 x .381 x .381
53	2	Filter/Separ., JP-5 Transfer	Static, Two Stage	17 m^3/hr	JP-5 PUMP	542	in JP-5 pump room	.457 (L) x 1.321 (dia)
System: Compressed Air								
54	2	Receiver, Starting Air	Steel, Cylindrical	2.3 m^3	MMR	551	near ME, compressors and bulkhead	1.067 (dia) x 2.185 (H)
55	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
56	1	Receiver, Ship Service Air	Steel, Cylindrical	1.7 m^3	MMR	551	near ME, compressors and bulkhead	1.830 (H) x .965 (dia)
57	1	Receiver, Control Air	Steel, Cylindrical	1 m^3	MMR	551	near ME, compressors and bulkhead	3.421 (H) x .610 (dia)
58	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
59	2	Dryer, Air	Refrigerant Type	250 SCFM	MMR	551	near LP air compressors	.610 x .864 x 1.473
System: Environmental								
60	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
61	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
62	1	Unit, Sewage Collection	Vacuum Collection Type w/ Pumps	28 m^3	SEWAGE TREATMENT ROOM	593	sewage treatment room	2.642 x 1.854 x 1.575
63	1	Sewage Plant	Biological Type	225 people	SEWAGE TREATMENT ROOM	593	sewage treatment room	1.778 x 1.092 x 2.007

Appendix E – SSCS Space Summary

SSCS	GROUP	VOLUME (m3)	AREA (m2)
	TOTAL AVAILABLE		5078
	TOTAL REQUIRED		6179
1	MISSION SUPPORT		
1.1	COMMAND,COMMUNICATION+SURV		
1.11	EXTERIOR COMMUNICATIONS		
1.111	RADIO		
1.113	VISUAL COM		5.9
1.12	SURVEILLANCE SYS		
1.121	SURFACE SURV (RADAR)		
1.122	UNDERWATER SURV (SONAR)		
1.13	COMMAND+CONTROL		41.3
1.131	COMBAT INFO CENTER		
1.132	CONNING STATIONS		41.3
1.1321	PILOT HOUSE		34.3
1.1322	CHART ROOM		6.9
1.14	COUNTERMEASURES		
1.141	ELECTRONIC		
1.142	TORPEDO		
1.143	MISSILE		
1.15	INTERIOR COMMUNICATIONS		25.1
1.16	ENVIORNMENTAL CNTL SUP SYS		
1.2	WEAPONS		
1.21	GUNS		
1.214	AMMUNITION STOWAGE		
1.22	MISSILES		
1.24	TORPEDOS		
1.26	MINES		
1.3	AVIATION	72.4	196.4
1.32	AVIATION CONTROL		20.4
1.321	FLIGHT CONTROL		9.3
1.322	NAVIGATION		11.1
1.323	OPERATIONS		

1.33	AVIATION HANDLING		
1.34	AIRCRAFT STOWAGE		176
1.342	HELICOPTER HANGAR		
1.35	AVIATION ADMINISTRATION		8.4
1.353	AVIATION OFFICE		8.4
1.36	AVIATION MAINTENANCE		17.6
1.37	AIRCRAFT ORDINANCE		
1.374	STOWAGE		
1.38	AVIATION FUEL SYS	72.4	
1.381	JP-5 SYSTEM	72.4	
1.3813	AVIATION FUEL	72.4	
1.39	AVIATION STORES		21.4
1.8	SPECIAL MISSIONS		7.4
1.9	SM ARMS,PYRO+SALU BAT		6
2	HUMAN SUPPORT		469.3
2.1	LIVING		300.3
2.11	OFFICER LIVING		165.1
2.111	BERTHING		141.3
2.1111	SHIP OFFICER		141.3
2.1111	COMMANDING OFFICER STATEROOM		16.3
2.1111	EXECUTIVE OFFICER STATEROOM		
2.1111	DEPARTMENT HEAD STATEROOM		
2.1111	OFFICER STATEROOM (DBL)		96.2
2.1114	AVIATION OFFICER		
2.112	SANITARY		23.7
2.1121	SHIP OFFICER		23.7
2.1121	COMMANDING OFFICER BATH		4.6
2.1121	EXECUTIVE OFFICER BATH		2.8
2.1121	OFFICER		
2.1124	AVIATION OFFICER		
2.12	CPO LIVING		
2.121	BERTHING		
2.122	SANITARY		
2.13	CREW LIVING		120.8
2.131	BERTHING		99.6
2.132	SANITARY		21.2
2.133	RECREATION		
2.14	GENERAL SANITARY FACILITIES		6.9
2.142	BRIDGE WASHRM & WC		2.3
2.15	SHIP RECREATION FAC		4.1
2.16	TRAINING		3.3
2.2	COMMISSARY		120.6
2.21	FOOD SERVICE		70.2
2.211	WARDROOM MESSRM & LOUNGE		46.5

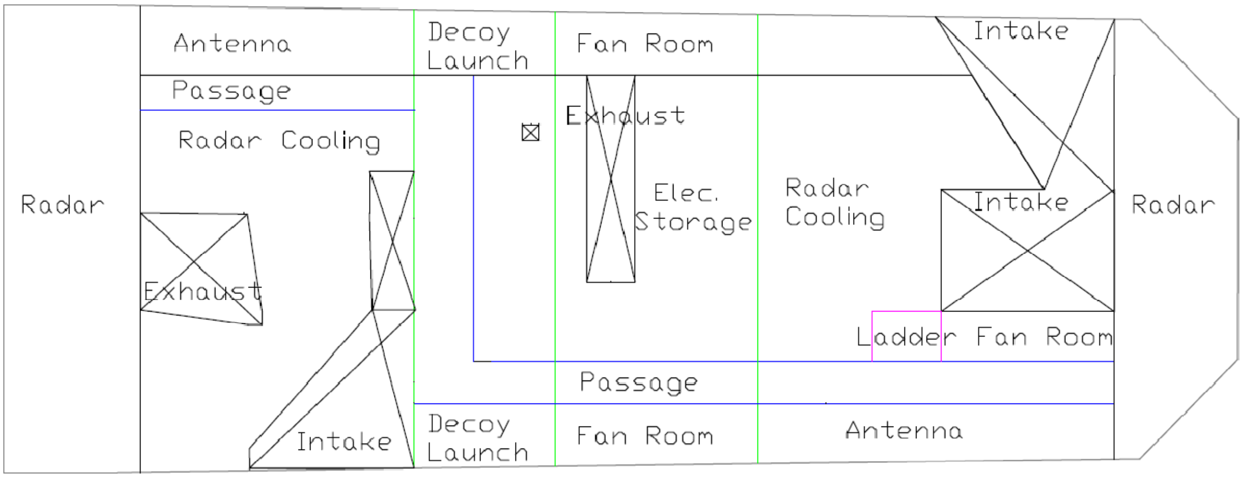
2.212	CPO MESSROOM AND LOUNGE		
2.213	CREW MESSROOM		23.8
2.22	COMMISSARY SERVICE SPACES		40.5
2.222	GALLEY		23.8
2.2222	WARD ROOM GALLEY		8.7
2.2224	CREW GALLEY		15.1
2.223	WARDROOM PANTRY		7.4
2.224	SCULLERY		9.3
2.23	FOOD STORAGE+ISSUE		9.8
2.231	CHILL PROVISIONS		3.2
2.232	FROZEN PROVISIONS		2.1
2.233	DRY PROVISIONS		4.5
2.3	MEDICAL+DENTAL		1.4
2.4	GENERAL SERVICES		16.7
2.41	SHIP STORE FACILITIES		4.6
2.42	LAUNDRY FACILITIES		12.1
2.44	BARBER SERVICE		
2.46	POSTAL SERVICE		
2.47	BRIG		
2.5	PERSONNEL STORES		9.1
2.51	BAGGAGE STOREROOMS		3.9
2.55	FOUL WEATHER GEAR		0.6
2.6	CBR PROTECTION		19.5
2.61	CBR DECON STATIONS		
2.62	CBR DEFENSE EQUIPMENT		10.2
2.63	CPS AIRLOCKS		9.3
2.7	LIFESAVING EQUIPMENT		1.9
3	SHIP SUPPORT	1575.2	1497.4
3.1	SHIP CNTL SYS (STEERING)		49.4
3.11	STEERING GEAR		49.4
3.12	ROLL STABILIZATION		
3.15	STEERING CONTROL		
3.2	DAMAGE CONTROL		53
3.21	DAMAGE CNTRL CENTRAL		
3.22	REPAIR STATIONS		32.1
3.25	FIRE FIGHTING		21
3.3	SHIP ADMINISTRATION		30.5
3.301	GENERAL SHIP		3.6
3.302	EXECUTIVE DEPT		8.3
3.303	ENGINEERING DEPT		5.1
3.304	SUPPLY DEPT		4.3
3.305	DECK DEPT		2.2
3.306	OPERATIONS DEPT		7
3.307	WEAPONS DEPT		
3.5	DECK AUXILIARIES		44.9
3.51	ANCHOR HANDLING		22.4

3.52	LINE HANDLING		
3.53	TRANSFER-AT-SEA		16.6
3.54	SHIP BOATS STOWAGE		
3.6	SHIP MAINTENANCE		82.3
3.61	ENGINEERING DEPT		63.4
3.611	AUX (FILTER CLEANING)		8
3.612	ELECTRICAL		18.8
3.613	MECH (GENERAL WK SHOP)		26.4
3.62	OPERATIONS DEPT (ELECT SHOP)		14.4
3.63	WEAPONS DEPT (ORDINANCE SHOP)		4.4
3.64	DECK DEPT (CARPENTER SHOP)		
3.7	STOWAGE		358.3
3.71	SUPPLY DEPT		253.1
3.711	HAZARDOUS MATL (FLAM LIQ)		28.8
3.713	GEN USE CONSUM+REPAIR PART		184.4
3.714	SHIP STORE STORES		7.3
3.72	ENGINEERING DEPT		6.1
3.73	OPERATIONS DEPT		8.5
3.74	BOATSWAIN STORES		74.9
3.75	WEAPONS DEPT		5.4
3.78	CLEANING GEAR STOWAGE		4
3.8	ACCESS		866.3
3.82	INTERIOR		866.3
3.821	NORMAL ACCESS		855.8
3.822	ESCAPE ACCESS		10.4
3.9	TANKS	1575.2	12.6
3.91	SHIP PROP SYS TNKG	1398.6	
3.9111	ENDUR FUEL TANK (INCL SERVICE)	978	
3.914	FEEDWATER TNKG		
3.92	BALLAST TNKG		
3.93	FRESH WATER TNKG	17.5	
3.94	POLLUTION CNTRL TNKG		12.6
3.941	SEWAGE TANKS		2.1
3.942	OILY WASTE TANKS		10.5
3.95	VOIDS	159.1	
4	SHIP MACHINERY SYSTEM		1333.4
4.1	PROPULSION SYSTEM		643.4
4.142	COMBUSTION AIR (INTAKE)		22.2
4.143	EXHAUST		48.9
4.2	PROPULSOR & TRANSMISSION SYST		
4.23	WATERJET ROOMS		

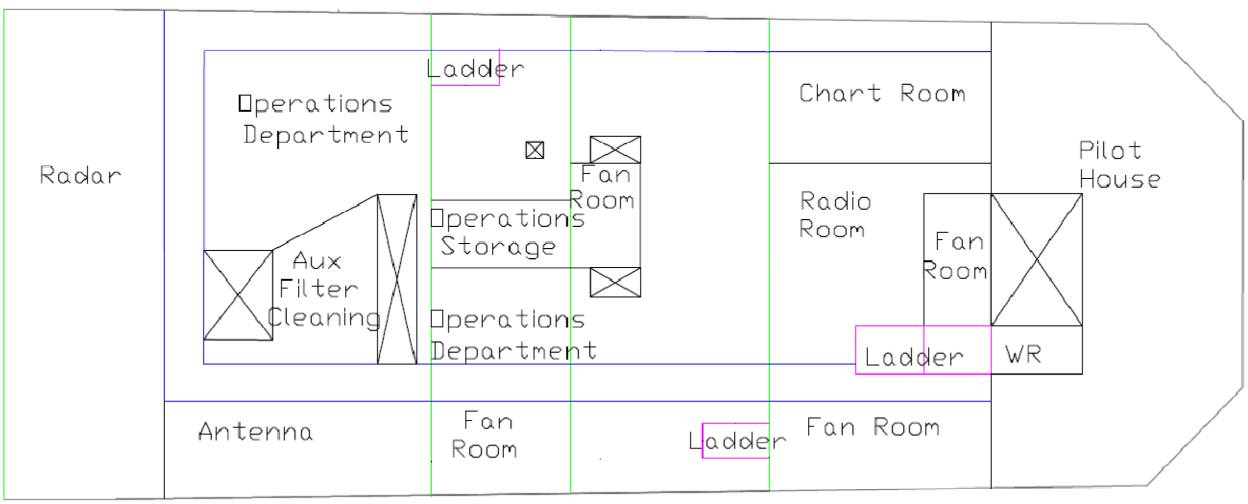
4.23	PROP SHAFT ALLEY		
4.3	AUX MACHINERY		690
4.33	ELECTRICAL		2.4
4.331	POWER GENERATION		
4.334	DEGAUSSING		2.4
4.34	POLLUTION CONTROL SYSTEMS		5.3
4.36	VENTILATION SYSTEMS		127.7

Appendix F – Detailed General Arrangements Drawings

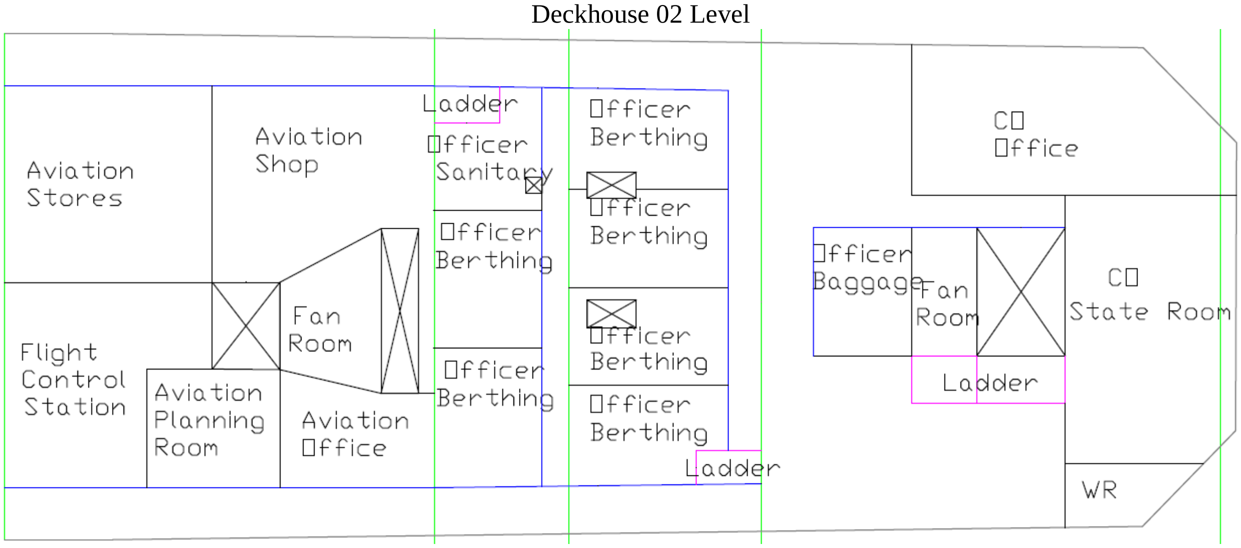
Deckhouse 04 level



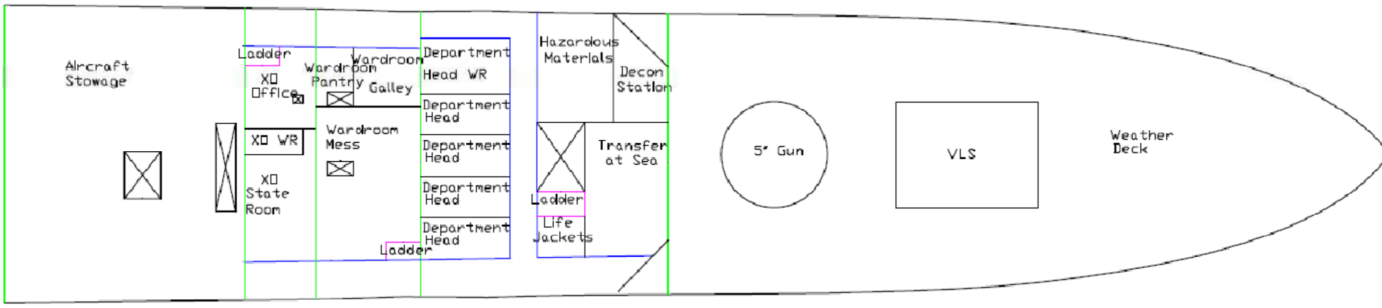
Deckhouse 03 Level



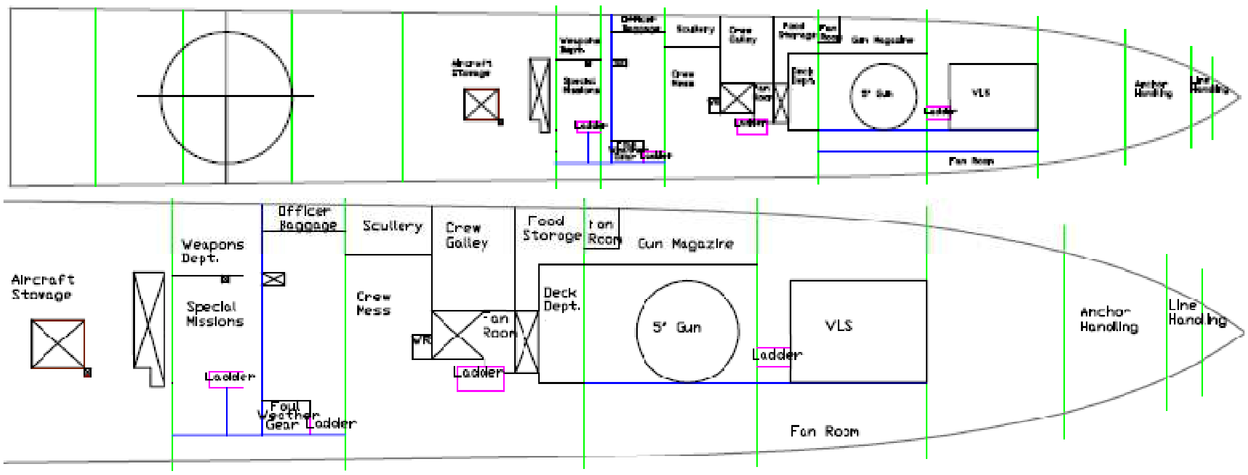
Deckhouse 02 Level



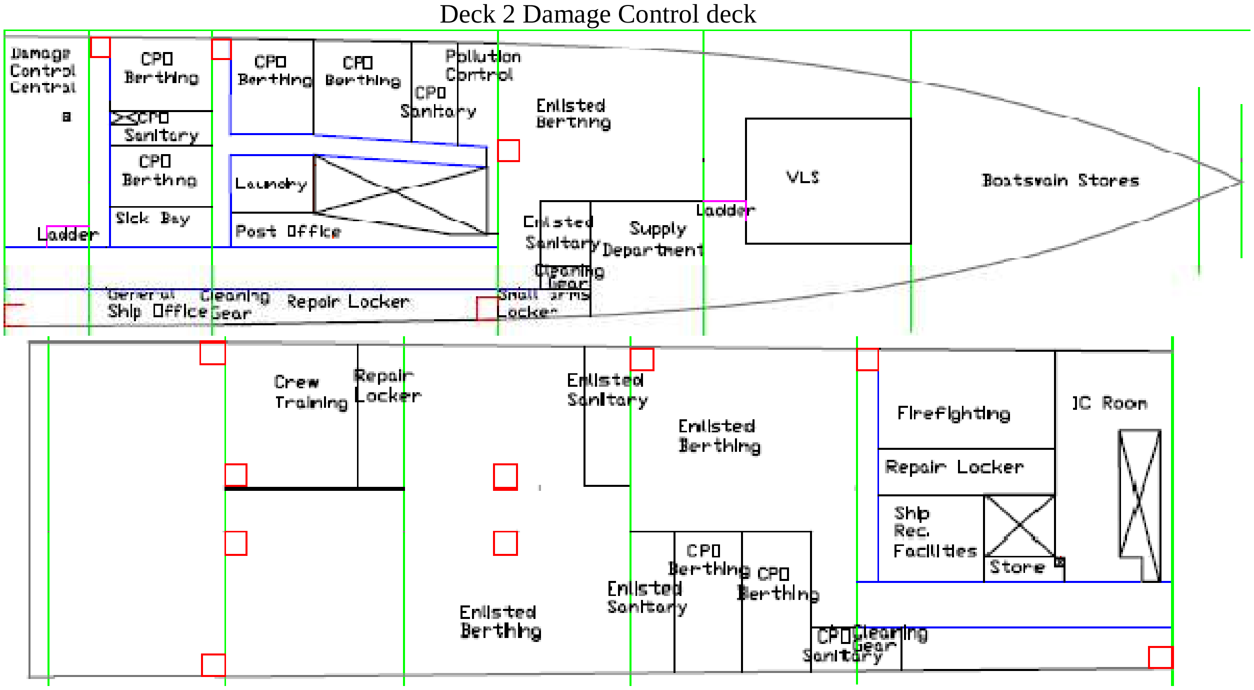
Deckhouse 01 Level



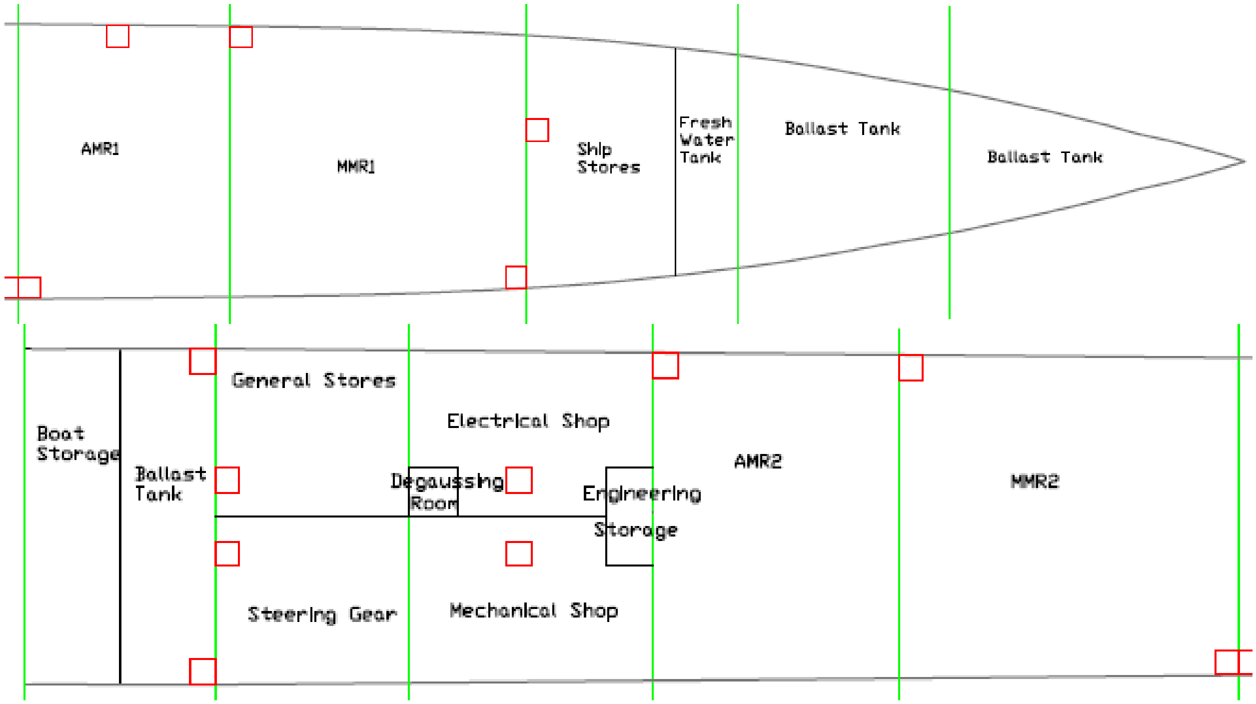
Deck 1 Main deck



Deck 2 Damage Control deck



Deck 3



Inner Bottom