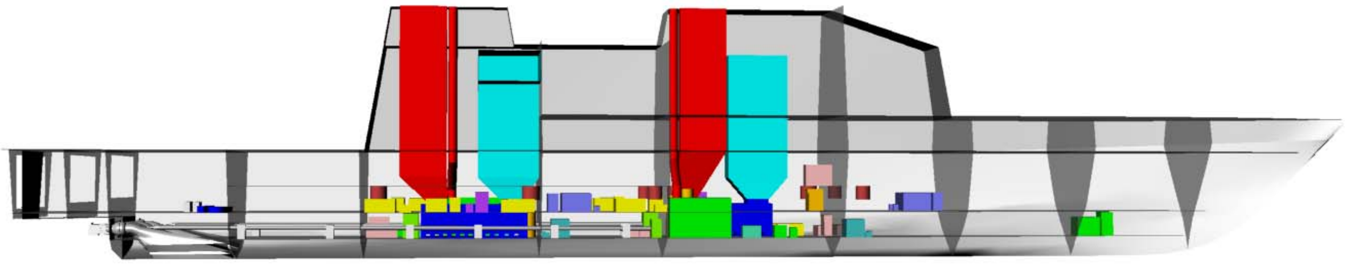
Virginia Tech
Aerospace & Ocean Engineering

Design Report

Agile Surface Combatant, Aluminum (ASCal)

VT Total Ship Systems Engineering



ASCal Variant 26
Ocean Engineering Design Project
AOE 4065/4066
Fall 2008 – Spring 2009
Virginia Tech Team 2

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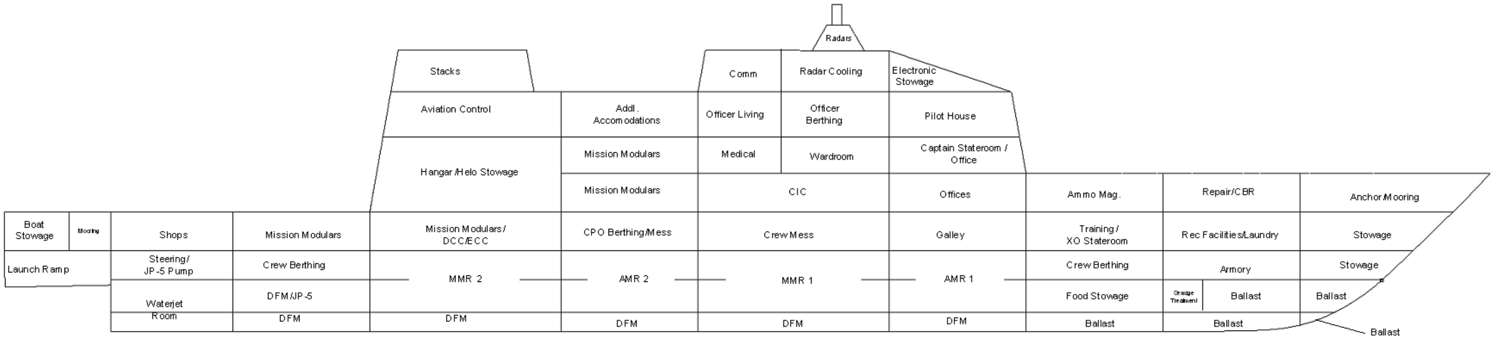
Executive Summary



This report describes the Concept Exploration and Development of an Agile Surface Combatant, Aluminum Variant (ASCal) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The ASCal requirement is based on the LCS Initial Requirements Document (IRD) and Virginia Tech ASCal Acquisition Decision Memorandum.

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

ASCal is small, high-speed, agile, low draft naval vessel offering a platform for the implementation of a number of modular mission packages. The use of aluminum represents a major departure from traditional naval shipbuilding. While aluminum has had a troubled past in naval applications, modern metallurgy, production, processing and design details make it a viable and valuable material for the construction of high-speed military ships.

Powered by 2 LM2500+ gas turbines and 2 CAT3616 diesel engines, power predictions show that the 100 meter long ASCal is capable of reaching sustained speeds of 47 knots at its 2868 MT design displacement. The ship's hangar houses two embarked SH-60 helicopters capable of supporting a number of different missions including mine-warfare, small craft prosecution and anti-submarine warfare.

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 CDD within cost and risk constraints.

Final Baseline Design Characteristics

Ship Characteristic	Value
LWL	99.9 m
Beam	13.1 m
Draft	3.72 m
D10	11.6 m
Lightship weight	2063 MT
Full load weight	2757 MT
Sustained Speed	42.5 knots
Endurance Speed	18 knots
Sprint Range	1143 nm
Endurance Range	3578 nm
Propulsion and Power	2 x LM2500+ gas turbines (2 fixed waterjets), 2 x CAT 3616 w/ epicyclic gears (2 steerable waterjets)
BHP	70119 kW
Personnel	88
OMOE (Effectiveness)	0.54
OMOR (Risk)	0.76
Ship Acquisition Cost	$320M
Life-Cycle Cost	$681M
Combat Systems (Modular and Core)	AAW: EADS TR-3D C-band radar, 1 x 11 cell Sea RAM, AIMS IFF, COMBAT DF, 2 x SRBOC, 2 x SKWS decoy launcher, COMBAT SS ASUW: AN/SPS-73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR ASW: SSTD, AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, MK89 TFCS, Mine Avoidance Sonar CCC: Comm. Suite Level A, CTSCE LAMPS: 2 x Embarked LAMPS w/ Hangar

Table of Contents

1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of an Agile Surface Combatant, Aluminum Variant, (ASCal) for the United States Navy. The ASCal requirement is based on the LCS Initial Requirements Document (IRD - Appendix A) and Virginia Tech ASCal Acquisition Decision Memorandum (ADM). The implementation of an all-aluminum monohull and deckhouse is of particular interest to this study. This design option will be compared with steel and composite construction in later studies. This concept design was completed in a two-semester ship design course at Virginia Tech. ASCal must perform the following missions using interchangeable mission modules:

- Mine Counter Measures (MCM)
- Littoral Anti-Submarine Warfare (ASW)
- Anti-Surface Warfare (ASUW)
- Inherent Missions

Required Inherent capabilities of ASCal are:

- Joint Littoral Mobility
- Intelligence, Surveillance, and Reconnaissance (ISR)
- Special Operations Forces (SOF) Support
- Maritime Interdiction Interception Operations (MIO)
- Home Land Defense (HLD)
- Anti-Terrorism/Force Protection (ATFP)

Concept of Operations:

- The ASC CONOPS is developed from the LCS Interim Requirements Document with elaboration and clarification obtained by discussion and correspondence with the customer, and reference to pertinent documents and web sites.
- ASC must contribute to Sea Power 21 and the emerging Global Naval Concept of Operations including:
    - Sea Strike - perform persistent ISR, enable forced entry, and engage in power projection with the USMC and Special Ops forces.
    - Sea Shield - provide assured access, supporting homeland defense, and missions in MIW, littoral ASW, ASUW, ISR, and SOF support.
    - Sea Basing - project persistent offensive and defensive power, providing security for joint assets, enabling sea-based forces, maneuvering and logistics for joint mobility and sustainment.
- ASC will use interchangeable, networked, tailored mission modules or packages built around off-board, unmanned systems removed or added into modular bays as required - Mine Counter Measures package; Small Boat Prosecution (ASUW) package; Littoral ASW package; and inherent missions not requiring special modules.
- ASC must provide excellent seakeeping and maneuverability, and high sustained speed (Agile).

1.2 Design Philosophy, Process, and Plan

The design philosophy for the development of ASCal is to:

- Provide a consistent format and methodology for making affordable multi-objective acquisition decisions and trade-offs in non-dominated design space.
- Provide practical and quantitative methods for measuring mission effectiveness.
- Provide practical and quantitative methods for measuring risk.

- Provide an efficient and robust method to search design space for optimal concepts – Multi-Objective Genetic Optimization (MOGO).
- Provide an effective framework for transitioning and refining concept development in a multidisciplinary design optimization (MDO).
- Use the results of first-principle analysis codes at earlier stages of design.
- Consider designs and requirements together.
- Initially, consider a very broad range of designs, requirements, cost and risk.

Figure 1 shows the process used for Concept Exploration in the ASCal design. A detailed mission description was developed from the IRD/ICD and Acquisition Decision Memorandum (ADM). Required Operation Capabilities (ROCs) and Measures of Performance (MOPs) were identified based on this mission description. Alternative technologies (with their associated levels of risk) that potentially enable the required capabilities were identified. An Overall Measure of Effectiveness (OMOE) model was created from the MOPs. Expert opinion was used with the Analytical Hierarchy Process (AHP) to develop MOP weights and Value of Performance (VOP) functions in the OMOE model. Design Variables (DVs) describing the design space were identified from the ROCs and technologies. Overall Measure of Risk (OMOR) and cost models were developed consistent with these technologies and design space. A ship synthesis model was developed from previous models and a Multi-Objective Genetic Optimization (MOGO) was run using this synthesis model to search the design space for non-dominated designs based on Total Ownership Cost (TOC), effectiveness (OMOE), and risk (OMOR). The products from concept and requirements exploration include a Non-Dominated Frontier (NDF) for making the acquisition decision, a Concept Development Document (CDD) specifying specific performance and cost requirements, technology selection, and an initial baseline design including principle characteristics, “single-digit” weights, major Hull Mechanical and Electrical (HM&E) systems, combat systems, and a class “F” cost estimate.

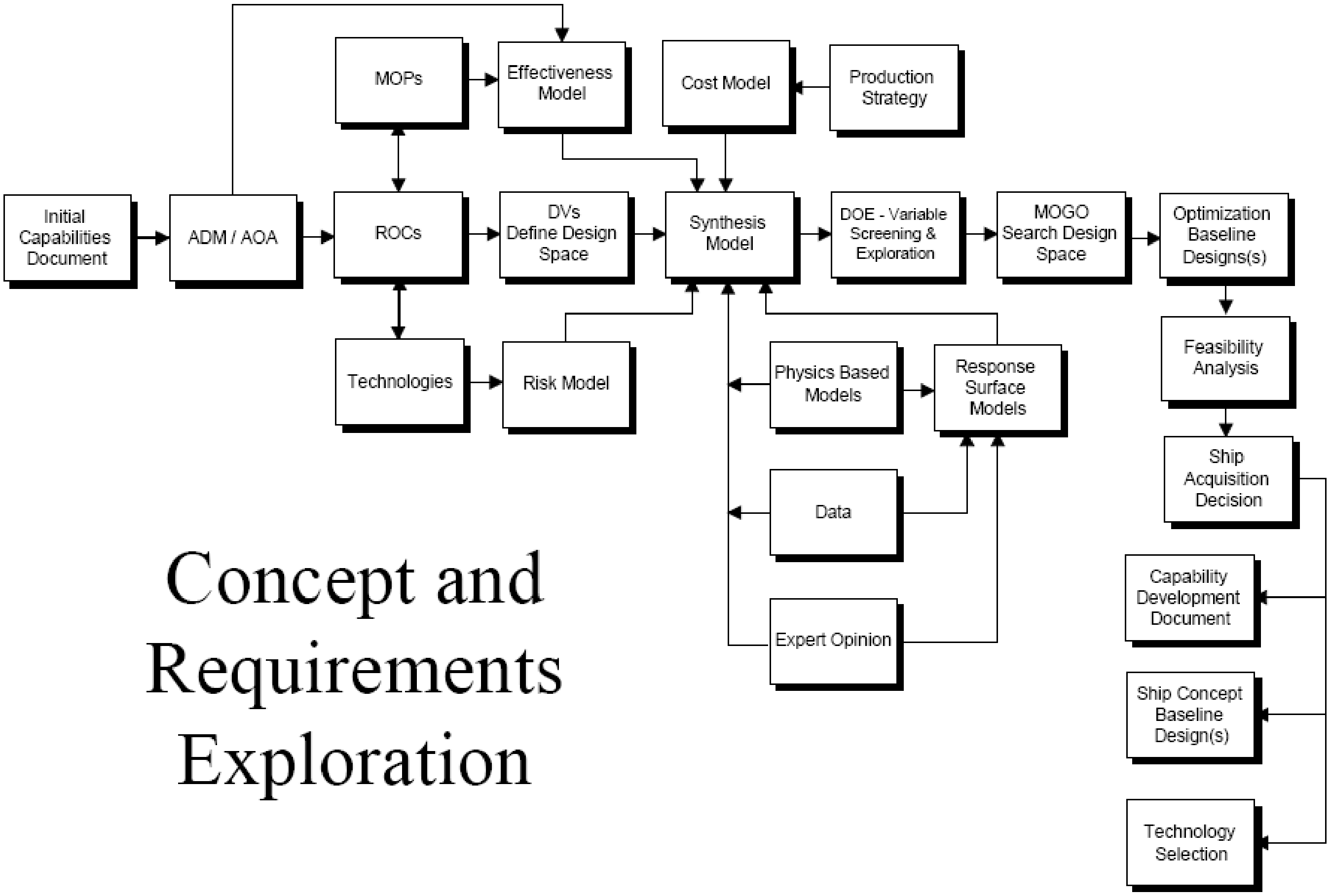


Figure 1 - Concept and requirements exploration process

Concept Development was performed using a more traditional design-spiral approach. Figure 2 shows the design spiral used for ASCal. Due to the limited time available for this design project, only a single iteration was completed around the spiral with recommendations for subsequent iterations.

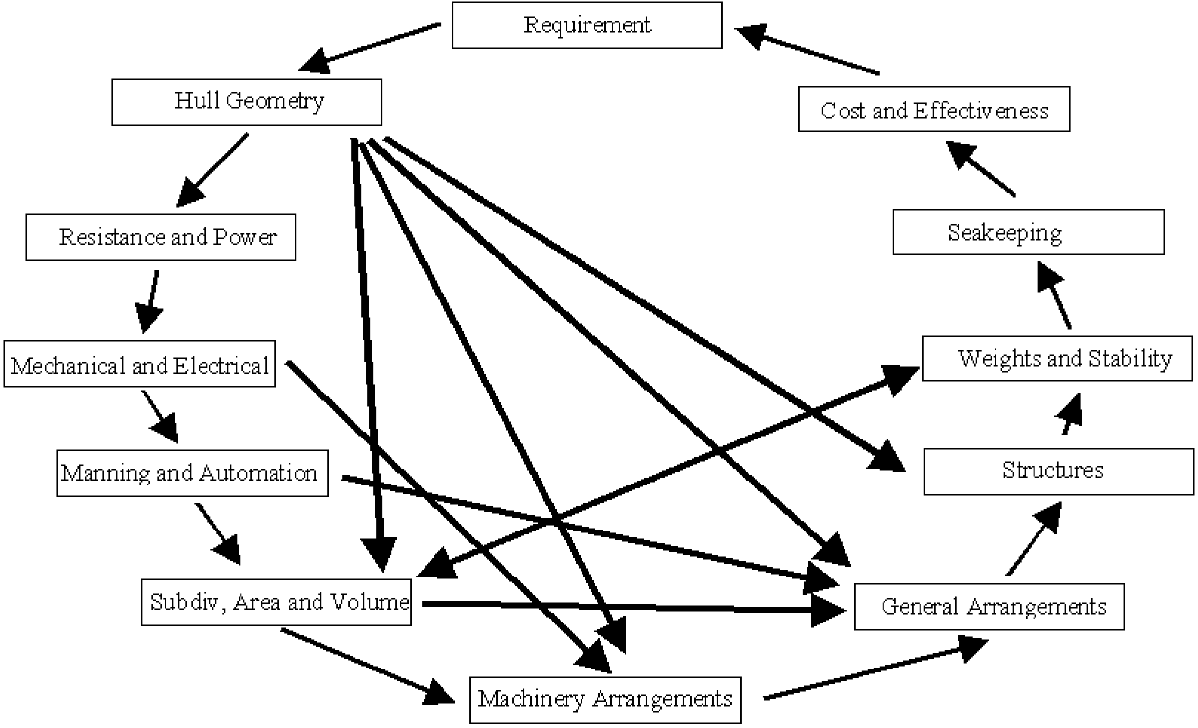


Figure 2 - VT Concept Development Design Spiral (Brown 2008)

1.3 Work Breakdown

ASCal Team 2 consists of six students from Virginia Tech. Each student is assigned areas of work according to his or her interests and special skills as listed in Table 1.

Table 1 - Work Breakdown

Name	Specialization
Ryan Coe	Team Leader/Hydrostatics
Michael Alban	Modeling/Balance
Thomas Helfrich	Maneuvering and Control
Matthew Bierwagen	Structures
David Winyall	Powering and Machinery Arrangements
James Hotsko	Arrangements/Modeling

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, Rhino/ORCA
Resistance/Power	NavCAD/MathCAD
Dynamics and Control	Scaled Model Testing/CFD
Ship Synthesis Model	MathCad/Model Center/ASSET
Structure Model	MAESTRO

The analysis also employs the use of rough estimates and calculations to assess the validity of mathematical models and computer calculations.

2 Mission Definition

The Agile Surface Combatant Aluminum Variant (ASCal) design described in this report is based on the LCS Interim Requirements Document (IRD) (Appendix A – LCS IRD) and the ASCal Acquisition Decision Memorandum (ADM) (Appendix B – Acquisition Decision Memorandum). The use of aluminum as a building material is of particular interest to this study. A ship equipped with an aluminum hull and deckhouse will be compared to more traditional steel options. This concept design was completed in a two-semester ship design course at Virginia Polytechnic Institute and State University.

2.1 Concept of Operations

The mission definition for ASCal was developed from the LCS Interim Requirements Document with explanation and clarification obtained from the customer and additional documents. ASCal is designed to contribute to the Sea Power 21 vision and the emerging Global Naval Concept of Operations such as Sea Strike, Sea Shield, and Sea Basing.

Sea Strike's missions are to perform unrelenting ISR (Intelligence, Surveillance and Reconnaissance), enable forced entry, and project US military power with the USMC and Special Ops forces. Sea Shield's missions are to provide assured military access and support homeland defense. A Sea Shield component should also be able to complete missions in MIW, littoral ASW, ASUW, ISR, and SOF support. Sea Basing is designed to project persistent offensive and defensive military power by enabling sea-based forces, maneuvering and logistics.

The ASCal design also possesses the ability to use interchangeable, mission tailored modules. These modules include, but are not limited to; Mine Counter Measures (MCM), Small Boat Prosecution (ASUW), and littoral ASW packages. In addition, unmanned systems may be added or removed for modular bays as required. Permanent installations will be necessary for mission capabilities inherent to the ship's general operation.

The final design of ASCal must excel in seakeeping and maneuverability while maintaining high speeds. Through these concepts and operational needs ASCal will become one of the Navy's premier littoral water combatants.

2.2 Projected Operational Environment (POE) and Threat

Although littoral waters represent the primary projected operational environment for ASCal, the ship must be able to survive open ocean crossings inherent to the multi-theatre needs of the Navy. ASCal must be able to survive in sea states (SS) 1-8, be fully operational in SS 1-4, and maintain effective operations in SS 1-5. It must be able to withstand all weather conditions.

Since the principle operational needs of ASCal are in littoral waters, threats include small surface craft, diesel-electric submarines, and mines. In addition, littoral naval operations force ASCal into close proximity with land-based air assets such as missiles or aircraft, and chemical/biological weapons. These realities were strongly considered in the design of ASCal to insure that the final design possesses the proper threat detection and identification capabilities, as well as the ability to protect itself and complete its mission.

2.3 Specific Operations and Missions

The ASCal anti-aircraft warfare (AAW) mission package employs signature management, hard kill and soft kill systems to counter and disrupt the threat's detect-to-engage sequence in the littoral environment. These capabilities are networkable with US and other friendly military assets to improve situational awareness; complementing hard kill, soft kill, and signature management systems. To facilitate these capabilities, ASCal will use both Link 16 and Cooperative Engagement Capability (CEC) systems. The capability to provide point defense against Anti-Ship Cruise Missile (ASCMs) and threat aircraft through the use of hard-kill and soft-kill systems, counter-targeting systems, speed, and maneuverability is also an important ability for the ship to possess. The Close-In Weapon System (CIWS) Mk 12 Blk 1B, Rolling Airframe Missile (RAM) system (RAM), and NULKA (a shipboard decoy system) provide good options to support these mission needs in Flight 0 of ASCal. To provide these capabilities at any time of need, ASCal will have the capability to operate in clear and severe natural and electronic countermeasure environments typical of littoral operating areas, and will have the capability to evaluate and engage air targets.

The Mine Counter-Measure (MCM) package will allow ASCal to detect, classify, and identify surface, moored, and bottom mines to permit maneuvering or use of selected sea areas. The need to coordinate/support mission planning and execution in the absence of dedicated Mine Warfare (MIW) command and control platforms is also a major responsibility for ASCal. MIW mission planning requires the use of both organic and remotely operated sensors. ASCal will exchange MIW tactical information including Mine Danger Areas (MDAs), mine locations, mine types, environmental data, bottom maps, off-board system locations, planned search areas, and confidence factors with US assets and friendly militaries. The principal purposes of the MCM package are to perform mine reconnaissance, bottom mapping, minefield break through/punch through operations and mine sweeping.

The Anti-Submarine Warfare (ASW) package conducts both offensive and defensive ASW missions. ASCal must achieve a mission abort or sink a threat submarine if the submarine target of interest is transiting through a designated key choke point or operating in a designated search/surveillance area. The package will also be able to handle a threat submarine attack against units operating in company with the CSGs, ESGs, or ASCal. ASCal is meant to be capable of achieving a mission abort or sink a threat submarine through the use of both on-board and off-board hard-kill weapon systems. In addition the package must be able to conduct coordinated ASW with other military assets. The ship will contribute to the Common Undersea Picture, as well as maintain and share situational awareness and tactical control in a coordinated ASW environment. To complete these mission needs, ASCal will be able to detect, classify, localize, track, and attack diesel submarines operating on batteries in shallow water environments. This includes submarines resting on the sea floor. It must also perform acoustic range prediction and ASW search planning, as well as conduct integrated undersea surveillance by employing on-board and off-board systems. It will also be capable of employing signature management and soft kill systems to counter and disrupt the threat’s detect-to-engage sequence in littoral environments. The need for a platform to deploy, control, recover, and conduct day and night operations with towed and off-board systems, and to process data from off-board systems continues to be an important aspect of ASW.

Anti-Surface Warfare (ASUW) requirements are also important for ASCal. The ASUW package must be able to discriminate and identify friendly and neutral surface vessels from surface threats in high-density shipping environments common in the ASCal littoral areas of operation. This will be accomplished through the surface surveillance via both onboard and off-board sensors. It must also conduct coordinated ASUW mission planning, contribute to and receive the Common Tactical Picture. When necessary, ASCal will be fully capable of initiating engagement of surface threats through its combat systems independently and as part of a combat group. This includes threats in the line-of-sight and over-the-horizon. In addition to hard kill capabilities, ASCal will use agility and speed, signature management and soft kill measures to disrupt a threat’s detect-to-engage sequence and conduct offensive operations.

ASCal, like other modern naval vessels, must be a flexible platform for completing a number of missions. ASCal will perform Anti-Terrorism/Force Protection as well as Homeland Defense. These two missions go closely hand-in-hand. To complete both these missions, ASCal must be able to perform maritime interception, interdiction, and law enforcement operations, which may include providing a staging area for Maritime Interception Operation (MIO) teams and secure holding areas for detainees. Possible law enforcement operations include counter-narcotic missions as well as boarder protection. ASCal will also be capable of employing, reconfiguring, and supporting MH-60 and smaller rotary wing aircraft of HLD and AT/FP operations.

In addition ASCal must provide protection for other vessels, both US and friendly forces, when in port, at anchorage, at periods of restricted mobility, and other times when the vessel has limited defenses. The defense capability of ASCal will incorporate both passive design and active weapon measures, including non-lethal mechanisms, that can deter, delay, and defend against attack by terrorists and unconventional threats.

For homeland defense ASCal will provide emergency, humanitarian, and disaster assistance. ASCal must also have the capacity to support Joint Special Operations Force (JSOF) hostage rescue missions, conduct marine environmental protect, and perform naval diplomatic presence operations.

Special Operations Force (SOF) support represents another large part of ASCal’s predicted operational needs. ASCal must support Naval Special Warfare (NSW) Task Unit and surface/subsurface combatant craft and mobility platforms, or their JSOF equivalent. This may include weapons and equipment stowage, berthing, C4ISR connectivity and the ability to provide a space in the hull for mission planning and rehearsal. ASCal should be able to launch, recover, and conduct organic maintenance on multiple embarked and organic craft. It must also support Marine Expeditionary Unit and JSOF hostage recovery operations, and conduct aircraft operations for helicopters such as the MH-60s. SOF support requires that ASCal refuel MK V Special Operations Craft and Medium Range Insertion Craft, support SOF in Noncombatant Evacuation Operations (NEO), provide compressed air (diving quality) for SEAL Delivery Vehicles (SDVs), embark a Fly Away Recompression Chamber, support and conduct Combat Search and Rescue (CSR) operations, and finally, support a Tactical Sensitive Compartmented Information Facility (TSCIF).

ASCal must also provide Intelligence/Surveillance/Reconnaissance (ISR) and act as a Command/Control/ Communication/Computer (C4) node. ASCal can use organic and non-organic resources to conduct surveillance and reconnaissance operations. This requires the use of both onboard and off-board equipment. Surveillance and reconnaissance requirements necessitate that ASCal collect, process, and disseminate strategic, operational, and tactical information. ASCal must be able to provide total ship and squadron command; providing automation of command and control function, ship situational awareness, and decision-making to other adjacently operating military assets. In addition, ASCal will be called on to simultaneously coordinate and control multiple manned and unmanned systems in support of a mission. The ship's C4 capabilities must also include implementing Total Ship Computing Environment (TSCE). TSCE incorporates processors, networks, storage devices, and human system interface in support of core and modular mission capabilities, and provides multiple levels of security as required by mission systems. The need for an external communications capability with joint, allied, coalition, and interagency forces as well as both embarked and off-board systems, is also inherent to the mission needs of ASCal. ASCal will have secure, reliable, automated, wide bandwidth, high data rate communications with ship based and shore based warfare component commanders.

The littoral operational environment of ASCal gives it the unique opportunity to provide land, sea, and air support. The ship will provide facilities for secure stowing of transported materials and equipment, provide habitability support for transported personal, replenishment and refueling at sea the MH-60, MH-60 sized non-organic helicopters and SOF craft/boats. The ship must also provide support for the deployment and operation of Carrier Strike Groups (CSGs), ESG, and LCS groups, as well as support and conduct search and rescue operations. Additionally the ship should be capable of performing seamanship and navigation evolutions such as formation steaming, precision navigation, precision anchoring, and recovery of man overboard. The ability to handle small craft and off-board mission systems, maneuvering for torpedo evasion, and ASCM countermeasures is also inherent to littoral combat. Deck evolutions, such underway vertical and connected replenishment, and the recovery of a man overboard are essential requirements for the ship to meet. ASCal will possess the capability to launch/recover off-board sensors and vehicles, handle small boats as well as tow disabled vessels or be towed itself. For aviation support, ASCal will be able handle organic day/night, all weather manned rotary wing and unmanned aviation assets to support the principle missions. The ASCal design must consider class II facilities (NAEC-ENG-7576) to include electricity, fresh water, and fuel (landing, fueling, hangar, reconfigure, and rearm) for the MH-60 family of helicopters. Joint and interagency rotary wing capabilities and the handling vertical take-off unmanned aerial vehicles (VTUAVs) should also be considered. With this ability to handle aircraft comes the need for a control system for both manned and unmanned aircraft.

2.4 Mission Scenarios

Mission scenarios for the primary ASCal missions are provided in Table 3 through Table 6.

Table 3 – Mine Counter Measures (MCM) Mission Scenario

Day	Mission scenario
1-21	Small ASC squadron transit from CONUS
21-24	Port call, replenish and load MCM modules
25-30	Conduct mine hunting
29	Conduct ASUW defense against small boat threat
31-38	Repairs/Port call
39	Engage submarine threat for self defense
41	Engage air threats for self defense
39-43	Conduct mine hunting operations
43	UNREP
44-59	Join CSG/ESG, continue mine hunting and mapping
60+	Port call or restricted availability

As seen in Table 3, even though the MCM module is installed on ASCal for this particular mission scenario, ASCal must remain capable of some aspects of the other missions. In this case, it is required to defend itself against a number of threats. While the mission depends on the modules installed, ASCal is always capable of performing in a self defense role.

Table 4 - Littoral Anti-Submarine Warfare (ASW) Mission Scenario

Day	Mission scenario
1-21	ASC squadron transit from CONUS
21-24	Port call, replenish and load ASW modules
25-30	Conduct ASW operations in the littoral area
26	Engage air threat for self defense
27-35	Conduct ISR
36	UNREP
37-42	Sprint to area of hostility
43-45	Mine avoidance
47	Engage small boat threat for ASUW self defense
51	UNREP
52-59	Support LAMPS operations against submarines
60+	Port call/restricted availability

Table 4 shows a mission scenario for ASCal when equipped with the ASW module. Even though ASCal is installed with the ASW package, it must still be able to perform other mission types, such as Mine Avoidance on days 43-45 in the this scenario. This shows the need for basic mine avoidance measures to be an inherent capability of ASCal.

Table 5 - Anti-Surface Warfare (ASUW) Mission Scenario

Day	Mission scenario
1-21	ASC transit from CONUS
21-24	Port call, replenish and load AUSW modules
25-30	Conduct ASUW operations in the littoral area
26	Target and engage enemy submarine, ASW self-defense
31-35	Support helicopter operations against surface forces
36	UNREP
37-38	Transit to port
39-42	Change out/offload modules to support SOF personnel insertion
43-45	Sprint to SOF insertion point
45	Insert SOF personal
45-58	Conduct ISR, support SOF
47	Engage air threat for self defense
52	Mine avoidance
57-59	Extract SOF personnel and transit to port
60+	Port call/restricted availability

Table 5 is an example of how while out for a specific mission, when the need arises, ASCal can return to port, swap out modules, and be ready to go and complete a different mission in a matter of days. In this scenario, ASCal was originally performing an ASUW mission when a need for a SOF delivery vessel arises. ASCal returns to port and changes out modules and prepares to take on a SOF team. It then takes the SOF team to their insertion location and provides support until their mission is complete before returning to base after its 60 day stint at sea.

ASCal is designed to operate and provide additional missions without a specified modular package onboard. In the case shown in Table 6, ASCal does not make a port of call on arrival from CONUS transit. Instead underway replenishment is used, allowing ASCal to complete its missions, in this case providing humanitarian relief.

Table 6 - Independent Operations Scenario

Day	Mission scenario
1-21	ASC transit from CONUS
22	UNREP
23-33	Deliver humanitarian aid, provide support
34-35	Defend against surface threat (ASUW) on return from aid mission
36	UNREP
37-40	Provide support for search and rescue mission
41-42	Transit to port
43	Input, load MCM modules
44-45	Travel to CSG
45-58	Provide mine hunting and mapping for CSG
50	Avoid submarine threat
60+	Port call/restricted availability

2.5 Required Operational Capabilities

To support the missions and mission scenarios described in Section 0, the capabilities listed in Table 7 - List of Required Operational Capabilities (ROCs) are required. Each of these can be related to functional capabilities required in the ship design, and, if in 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 1.2	Support area anti-air defense
AAW 1.3	Provide unit anti-air self defense
AAW 2	Provide anti-air defense in cooperation with other forces
AAW 5	Provide passive and soft kill anti-air defense
AAW 6	Detect, identify and track air targets
AAW 9	Engage airborne threats using surface-to-air armament
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations
AMW 6.3, 6.4, 6.5, 6.6	Conduct all-weather helo ops (including helo hanger, haven, and 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, 1.2, 1.3	Engage surface ships at long, medium, and close range
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, identify, localize, and track surface ship targets.
ASU 4.1	Detect, localize, and track surface contacts with radar
ASU 4.4	Detect, identify, classify and track surface contacts visually.
ASU 4.7	Identify surface contacts.
ASU 6	Disengage, evade and avoid surface attack
ASU 6.2	Employ evasion techniques.
ASU 6.3	Employ EMCON procedures
ASW (WITH MODULARITY) 1	Engage submarines
ASW (WITH MODULARITY) 1.2	Engage submarines at medium range
ASW (WITH MODULARITY) 1.3	Engage submarines at close range
ASW (WITH MODULARITY) 4	Conduct airborne ASW/recon

ROCs	Description
ASW (WITH MODULARITY) 5	Support airborne ASW/recon
ASW (WITH MODULARITY) 7	Attack submarines with antisubmarine armament
ASW (WITH MODULARITY) 7.6	Engage submarines with torpedoes
ASW (WITH MODULARITY) 8	Disengage, evade, avoid and deceive submarines
CCC 1.6	Provide a Helicopter Direction Center (HDC)
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions
CCC 3	Provide own unit Command and Control
CCC 4	Maintain data link capability
CCC 6	Provide communications for own unit
CCC 9	Relay communications
CCC 21	Perform cooperative engagement
FSO 5	Conduct towing/search/salvage rescue operations
FSO 6	Conduct SAR operations
FSO 8	Conduct port control functions
FSO 9	Provide medical care to assigned and embarked personnel.
FSO 10	Provide first aid assistance
FSO 11	Provide triage of casualties/patients
FSO 12	Provide medical/surgical treatment for casualties/patients
FSO 14	Provide medical regulation, transport/evacuation and receipt of casualties and patients
INT 1	Support/conduct intelligence collection
INT 2	Provide intelligence
INT 3	Conduct surveillance and reconnaissance
INT 8	Process surveillance and reconnaissance information
INT 9	Disseminate surveillance and reconnaissance information
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)
LOG 1	Conduct underway replenishment
LOG 2	Transfer/receive cargo and personnel
LOG 6	Provide airlift of cargo and personnel
MIW (WITH MODULARITY) 3	Conduct mine neutralization/destruction
MIW (WITH MODULARITY) 4	Conduct mine avoidance
MIW (WITH MODULARITY) 6	Conduct magnetic silencing (degaussing, deperming)
MIW (WITH MODULARITY) 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
STW 3	Support/conduct multiple cruise missile strikes

3 Concept Exploration

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

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

Available technologies and concepts necessary to provide required functional capabilities are identified and defined in terms of performance, cost, risk and ship impact (weight, area, volume, power). Changes are made to the ship synthesis model to incorporate these technologies. 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

Alternative hull forms are identified through a several step process beginning with the Transport Factor methodology. Transport Factor incorporates the parameters of payload/cargo weight, sustained speed, endurance speed, and range to calculate a single coefficient (see Figure 3). This coefficient can be compared to the data of ships with known Transport Factors and hull types to determine good hull form candidates.

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

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

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

Figure 3 – Transport Factor equations

The projected characteristics for ASCal based on mission scenarios and similar ships include:

- small, fast littoral combat ship with a semi-planing hull (specified in ADM)
- endurance greater than 3,500 nm @ 18 knots (combatant, worldwide operations)
- sustained speed of 40 - 50 knots
- expect displacement around 3,000 MT

From these approximations, the ASCal transport factor is estimated to be approximately 15 @ 45 knots. Figure 4 and Table 8 provide comparison data for similar ships and suggest alternative hull form types.

Further selection is accomplished by identifying specific mission requirements and the constraints they impose on the platform. A number of important hull form characteristics were identified for consideration in ASCal. Although the hull may be of a semi-planing or planing type, it must remain efficient when operating at lower speeds in displacement mode, satisfy a number of seakeeping operational requirements and accommodate a series of modularity packages. Operation in littoral waters requires that the ship must have a reduced draft. As with any modern naval vessel of moderate size, the hull must provide a stable platform for helicopter operations and present a reduced radar signature from its above water geometry. The ship must also be structurally efficient to assist in the use of aluminum as the primary building material and be producible to support to construction of a large fleet.

These mission requirements can be reduced further to sets of general and specific requirements. In general, the hull must be producible, structurally efficient, possess good sea keeping performance and be able to launch and recover various technologies. Possible assets for launch and recovery may include Autonomous Underwater, Surface and Air Vehicles (AUVs, ASVs and AAVs), and other small craft.

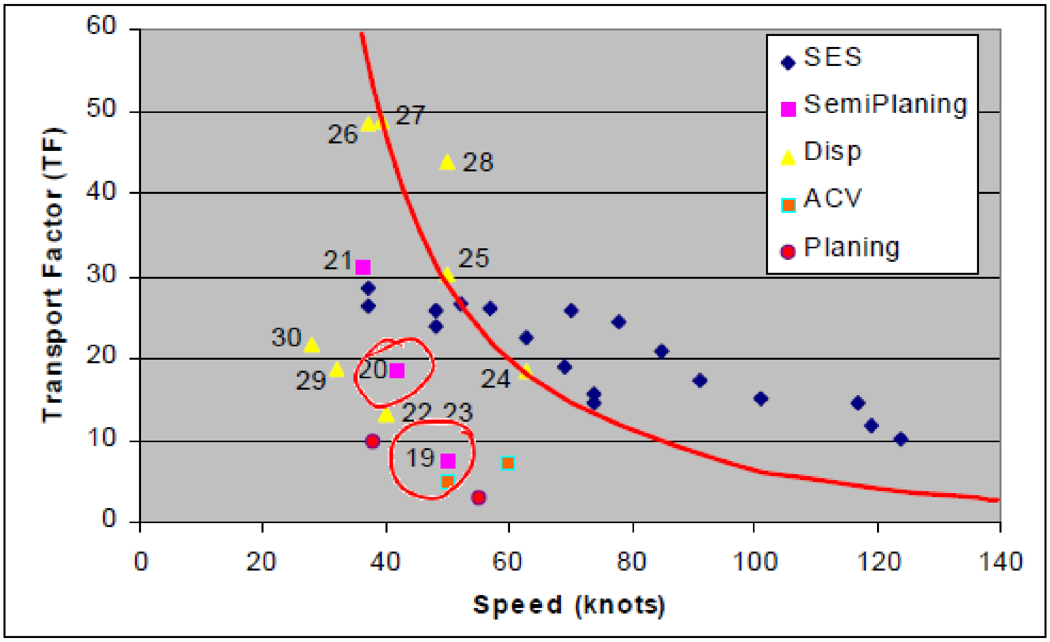


Figure 4 - Transport Factors for similar ships. See Table 8 for specific ship information.

Table 8 – Transport Factor database

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

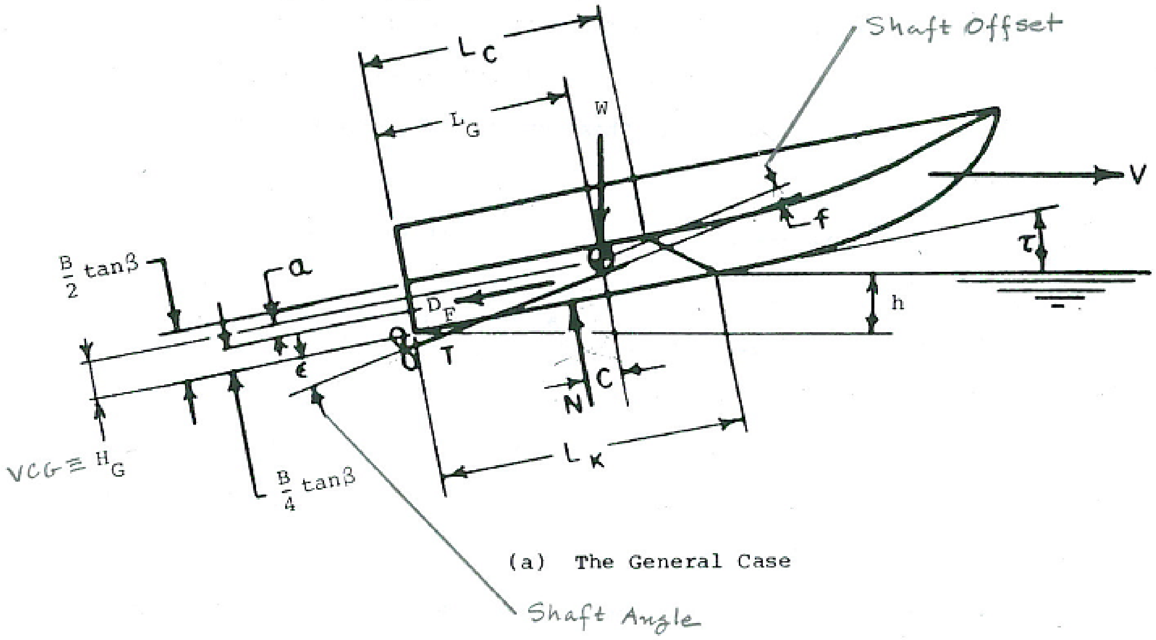
Different types of hullforms offer different advantages and disadvantages. Planing hulls provide good handling and efficiency for moderate to high-speed travel, while also providing reasonable deck space for the placement of landing pads, combat systems and deckhouses. Monohull designs are superior to multi-hulls and catamarans in the amount of large object space they provide below deck for equipment like large modules, main engines, generators and transmissions, in structural efficiency, and producibility. A monohull was specifically directed by our ADM.

The general and specific requirements can be analyzed along with information from monohull parent hulls to develop a set of design lanes. Using the LCS-1 as a parent hull and the requirements specified above, the following design lanes were developed.

- LBP = 90-110m
- L/B = 4 –7
- L/D = 8-12
- Beta = 10 – 15 degrees
- LCG = .35 - .45 (from transom)
- Hullform Type = semi-planing, double chine, moderate warp for sea-keeping and directional stability, water-jet notch in stern vice rocker, no beam taper at stern

The Savitsky and Holtrop-Menon methods are used to determine resistance of the resulting hull at sustained speed and endurance speed respectively. Figure 5 shows dimensions and force designations used in the Savitsky analysis. This method basically balances the forces and moments acting on a planing craft to determine the angle of trim and drag force for a given speed.

From Savitsky (1964, pp 89 and 90)



(a) The General Case

Figure 5 - Planing craft Savitsky balance of forces and moments (from Savitsky 1964)

3.1.2 Propulsion and Electrical Machinery Alternatives

To construct the general machinery requirements a rough estimation of the ship's needs is used along with guidance and ROCs developed with the customer. A general knowledge of available technologies and guidelines are used to assemble a set of viable machinery alternatives with a selection hierarchy. A more complete and quantitative study of actual products is used in the ship synthesis model (see Section 3.3).

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 – High speed requirements for ASCal dictate high power density alternatives. Both gas turbine and diesel engine with epicyclic (planetary) reduction gears options are considered. Two to four main engines, 25,000 – 40,000 KW each, should be sufficient to satisfy the powering needs of the ship. Kamewa 225SII (27000 BKW) waterjets are used as baseline propulsors to attain efficient high speed (40-50 knots) operation because of their industry prevalence and well documented capabilities. More recent waterjet designs with higher efficiency and power density will be considered in Concept Development. A major constraint is transom mounting dimensions. Mechanical drive and hybrid Integrated Power Systems (IPSs) with diesels supplying SS power and outboard cruise waterjets are the two primary transmission options examined. Endurance speed may also consider the use of a single prop or an azimuthing thruster.

Sustained Speed and Propulsion Power – Only non-nuclear options are considered for this design of ASCal. Grade A shock certified and Navy qualified gas turbines and diesels are required. To meet the performance needs of the Navy, the prime movers considered span a power range of 50 to 100 MW with total maximum ship service generator power of 8 MW MFLM. Propulsion power must provide a minimum sustained speed of 40 knots in full load, calm water conditions with a clean hull, using no more than 80% of the installed power. A speed of 50 knots is the goal for the ship. The minimum range of ASCal must be 3500 nautical miles at 18 knots to insure an efficient open ocean crossing capability.

Ship Control and Machinery Plant Automation – An integrated bridge system including integrated navigation, radio communications, interior communications, and ship maneuvering equipment and systems will be developed. It will comply with the ABS Guide for One Man Bridge Operated (OMBO) Ships and comply with ABS ACCU requirements for periodically unattended machinery spaces. Crew and personnel will be present to continuously monitor auxiliary systems, electric plant and damage control systems from the Strategic Command Center (SCC), Material Control Center (MCC) and Chief Engineer's office, and control the systems from the MCC and local controllers

Propulsion Engine and Ship Service Generator Certification – Because of the importance of propulsion and ship service power to many aspects of the ship's mission and survivability, this equipment shall be Grade A shock certified and non-nuclear. Low IR signature and cruise/boost options for high endurance will be considered.

3.1.2.2 Machinery Plant Alternatives

Figure 6 shows the alternatives developed for the machinery plant of ASCal. The first level of the tree (shown in dark blue) shows the generator options to supply electrical power for the ship. From there, the propulsion system is divided into mechanical drive systems and systems using IPS coupled with mechanical drive. Below the drive systems, the propulsor alternatives are shown in yellow, with their supporting prime movers shown in light blue.

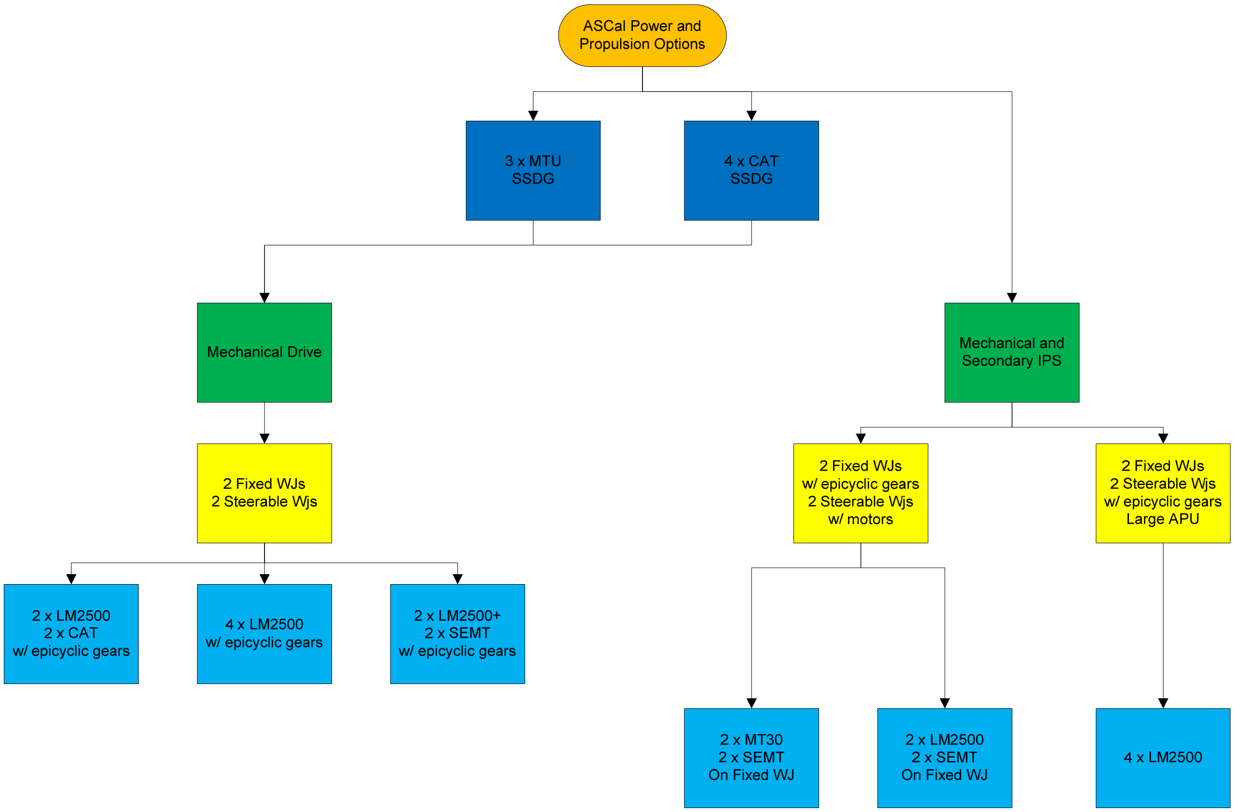


Figure 6 – Machinery plant alternative tree

Efficient endurance speed operation is achieved using diesel engines while the high power density required to achieve higher speeds necessitates the additional use of gas turbines and epicyclic gears. Various combinations of MT30 and LM2500+ gas turbine engines are considered.

In considering mechanical drive propulsions systems and combination mechanical drive with IPS systems, the various advantages and disadvantages offered by each alternative were considered. IPS advantages over mechanical drive are primarily in flexibility and efficiency. IPS systems allow for the location of engines and generators throughout the ship while still providing both ship service power and propulsion. Location flexibility allows for shorter shaft lengths while mechanical drive systems still require inline connections between the propellers and engines. This limits the flexibility in locating the various system components. Efficiency over mechanical drive systems is attained by being able to optimize the engine RPM and match it to a required power output. With mechanical drive, the engine rpm is dependent on the propeller and gear ratio for a particular power output. IPS generated power can be used throughout the ship while mechanical drive power can only be harnessed for ship-wide use with the installation of separate power take off systems. IPS systems are flexible in that they can work with newer podded propulsion units while still being backwards compatible with conventional fixed propellers and shafts.

Mechanical drive is limited to conventional propulsion systems and their drive shafts. Disadvantages to the IPS system include high cost for newer technologies, larger space and weight requirements, and not having withstood the test of time while mechanical drive systems have been used and proven seaworthy on previous naval vessels.

Waterjets were considered as the primary propulsor option given their higher efficiency at operating speeds of 40-50 knots over submerged and surface piercing propellers. Figure 7 compares these three options over a range of speeds. Given that ASCal's operating envelope requires frequent high speed operations, lower waterjet efficiency compared to conventional propellers at lower speeds is considered acceptable.

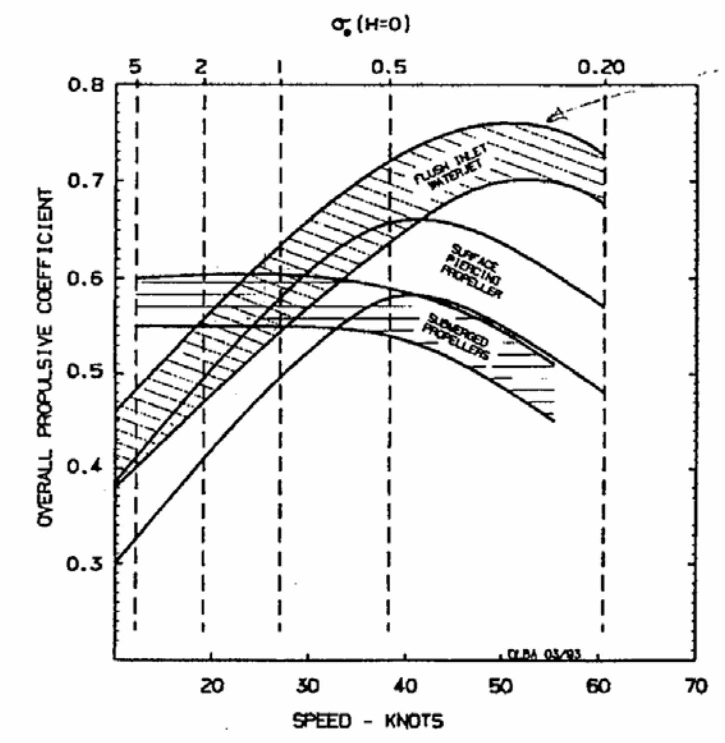


Figure 7 – Propulsor type comparison

The Kamewa S3 waterjet is shown in Figure 8. This is a very recent Kamewa design and S3 performance data was not available so 225SII data was extrapolated to consider higher power and efficiency possibilities.

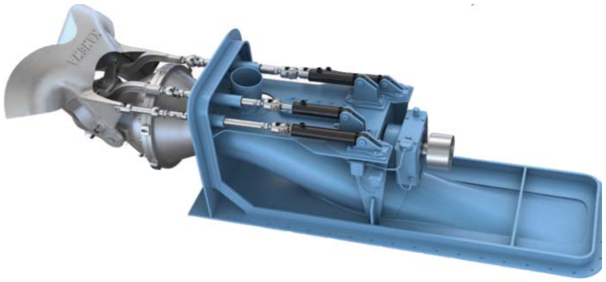


Figure 8 – S3 Kamewa waterjet

Performance curves for the 225SII waterjet are presented in Figure 9. The 225SII performance map was modified and extended based on the manufacturer's S3 description to model the S3-180.

A combination of 4 waterjets, 2 fixed inside and 2 outboard steerable, is considered for ASCal. Figure 10 shows a diagram of the proposed propulsion arrangement.

Combinations of the General Electric LM2500+, Rolls-Royce MT30, CAT and SEMT diesel engines were selected as primary movers. The LM2500+ in Figure 11 is an updated version of the US Navy's workhorse gas turbine engine the LM2500.

Figure 12 shows a comparison of the LM2500 variations that GE currently offers for marine applications. The Rolls Royce MT30 offers an increased power output up to 36MW at the cost of being slightly larger than the LM2500+.

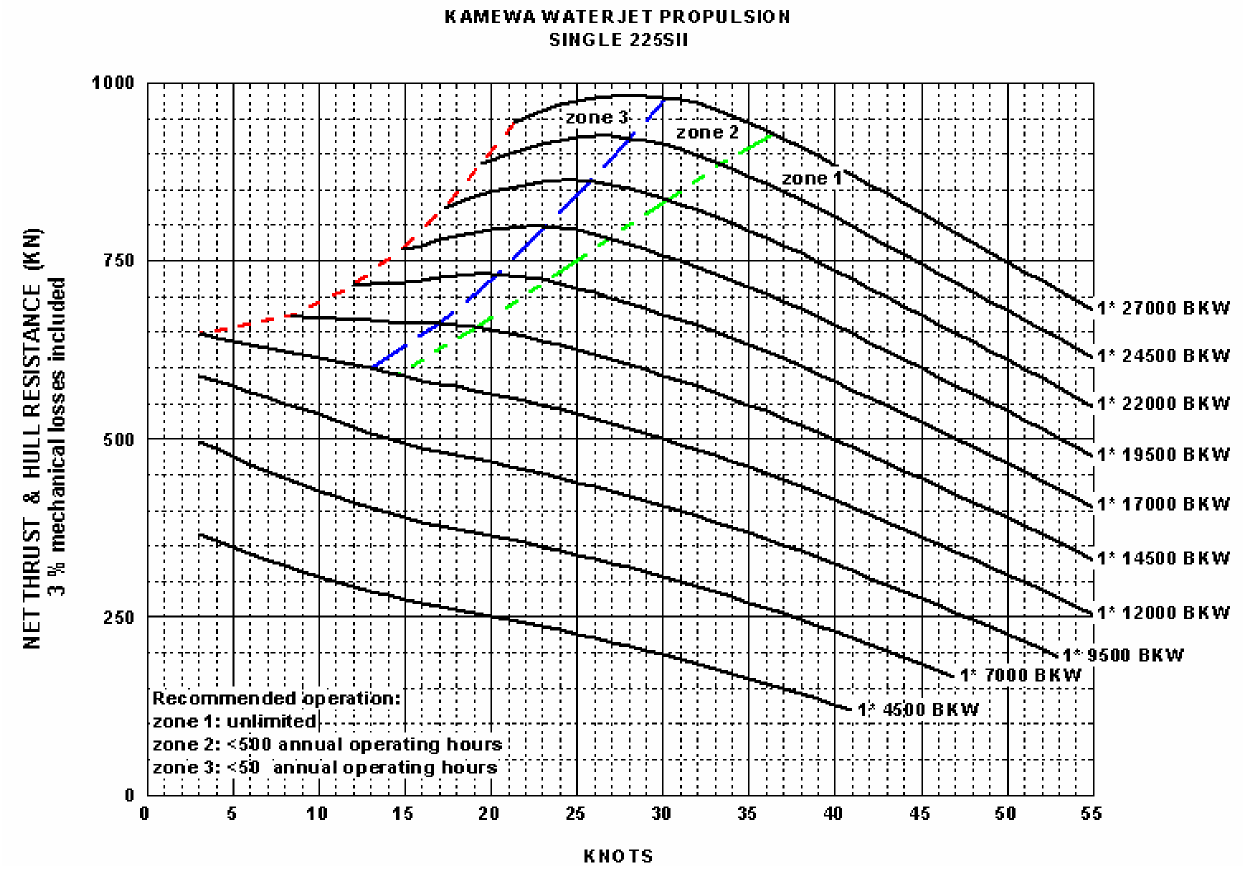


Figure 9 – Kamewa waterjet thrust curve

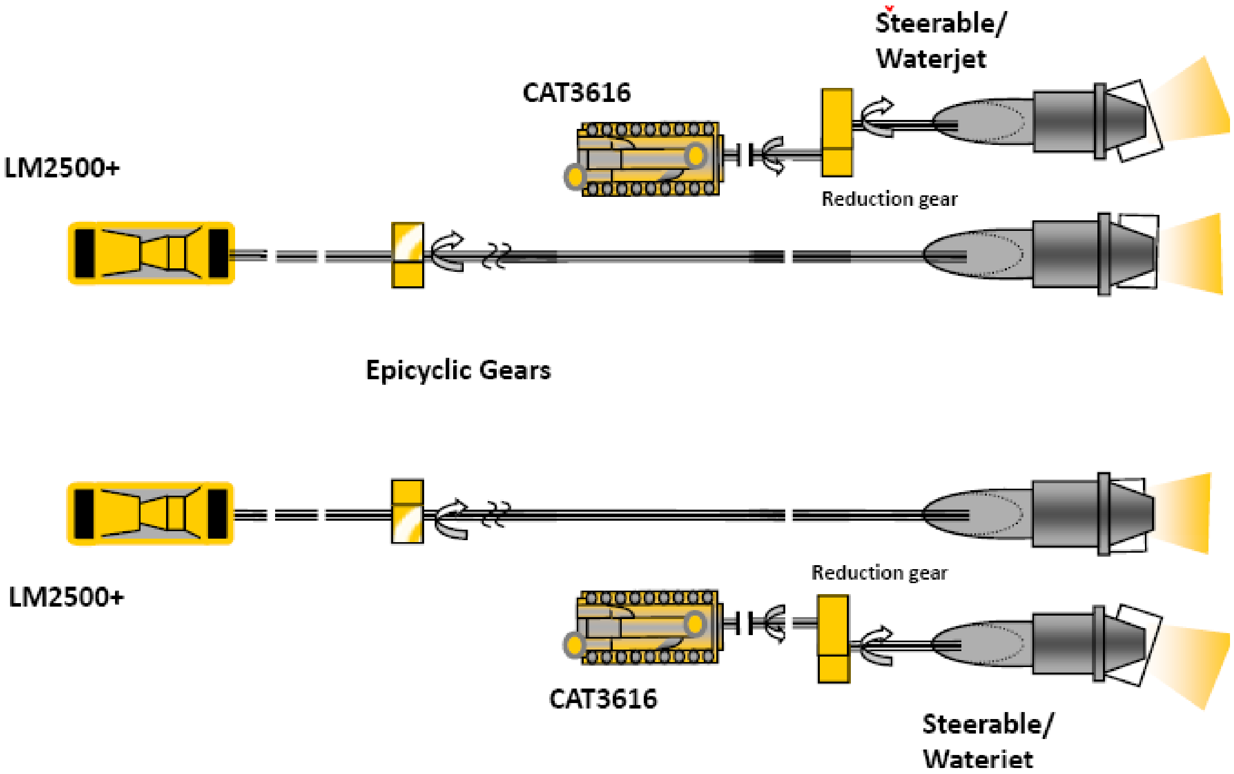


Figure 10 – ASCal proposed propulsion arrangement

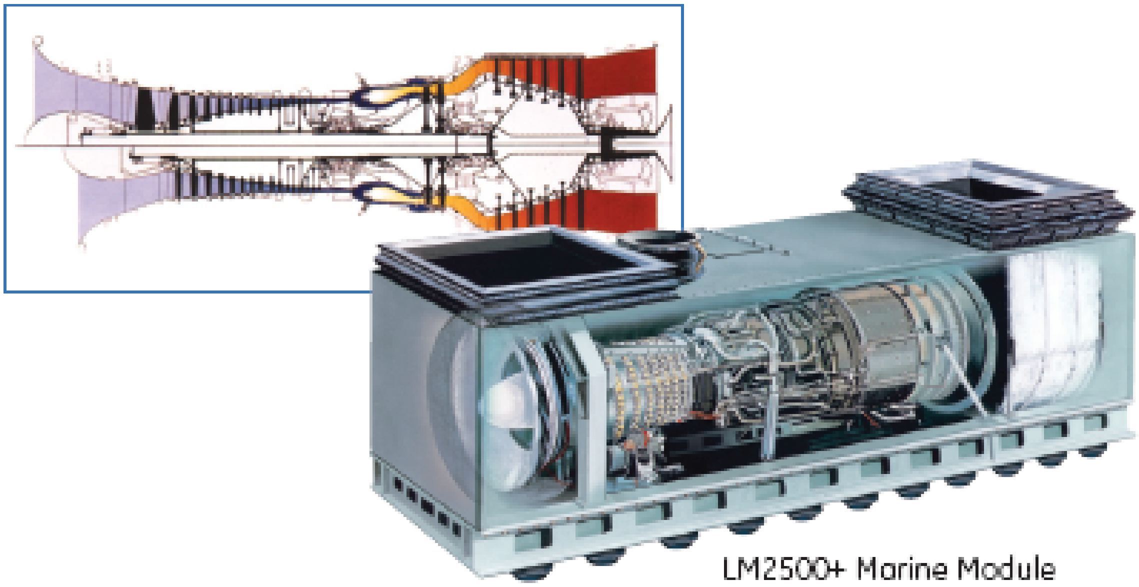


Figure 11 – GE LM2500+ gas turbine

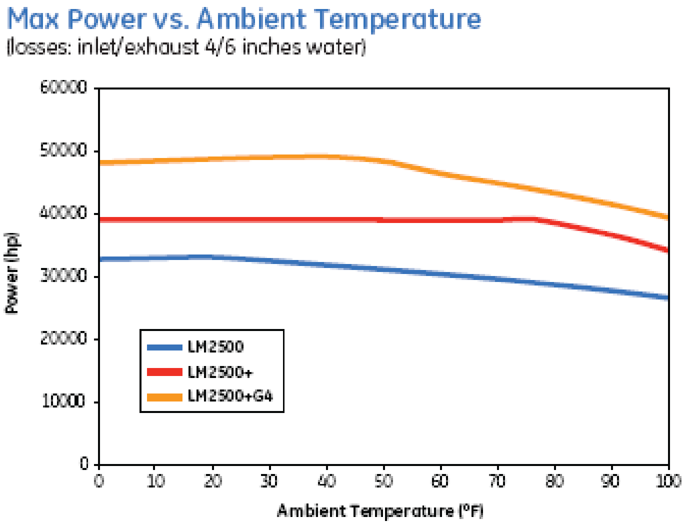
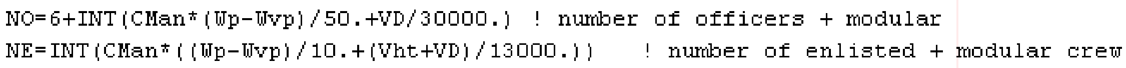


Figure 12 – GE gas turbine comparison

3.1.3 Automation and Manning Parameters

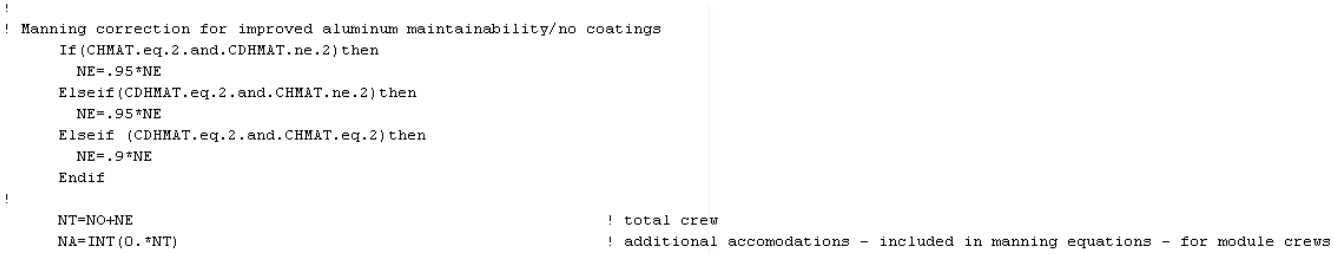
Manning is a very important issue to be explored during the process of ship design, particularly because of the high cost associated with it. A large portion of the money spent to keep a ship at sea arises from the costs associated with manning and manning has a major ship impact. Reducing the need for personnel onboard through automation is therefore highly beneficial to the customer. Certain tasks onboard a ship can be dangerous, sometimes resulting in injury to a crewmember. Automating some of these dangerous or even repetitive tasks can free up the crew to perform other tasks or to oversee and observe from a safe distance. One such option involves firefighting. Fighting fires is a dangerous job in which the risk is only increased on a seagoing vessel. Having automated extinguishing systems can prevent the crew from being exposed to such hazardous conditions. Additionally, automation can reduce the number of people needed to run the bridge at any given time. Emerging technologies that allow the ship to follow preset paths and even perform obstacle avoidance can eliminate the need for a substantial number of personnel. On-shore training facilities and simulators can also be used to train personnel on new procedures and techniques, reducing the need to experience it firsthand out at sea.

In concept exploration it is difficult to deal with automation manning reductions explicitly, so a ship manning and automation factor is used. This factor represents reductions from “standard” manning levels resulting from automation. The manning factor, C_{Man}, varies from 0.5 to 1.0. It is used in the regression-based manning equations shown in Figure 13. A manning factor of 1.0 corresponds to a “standard” (current) manned ship. A ship manning factor of 0.5 results in a 50% reduction in manning and implies a large increase in automation. The manning factor is also applied using simple expressions based on expert opinion for automation cost, automation risk, damage control performance and repair capability performance. Manning calculations changes resulting from the use of an aluminum hull and deckhouse are shown in Figure 14. A more detailed manning analysis is performed in concept development.



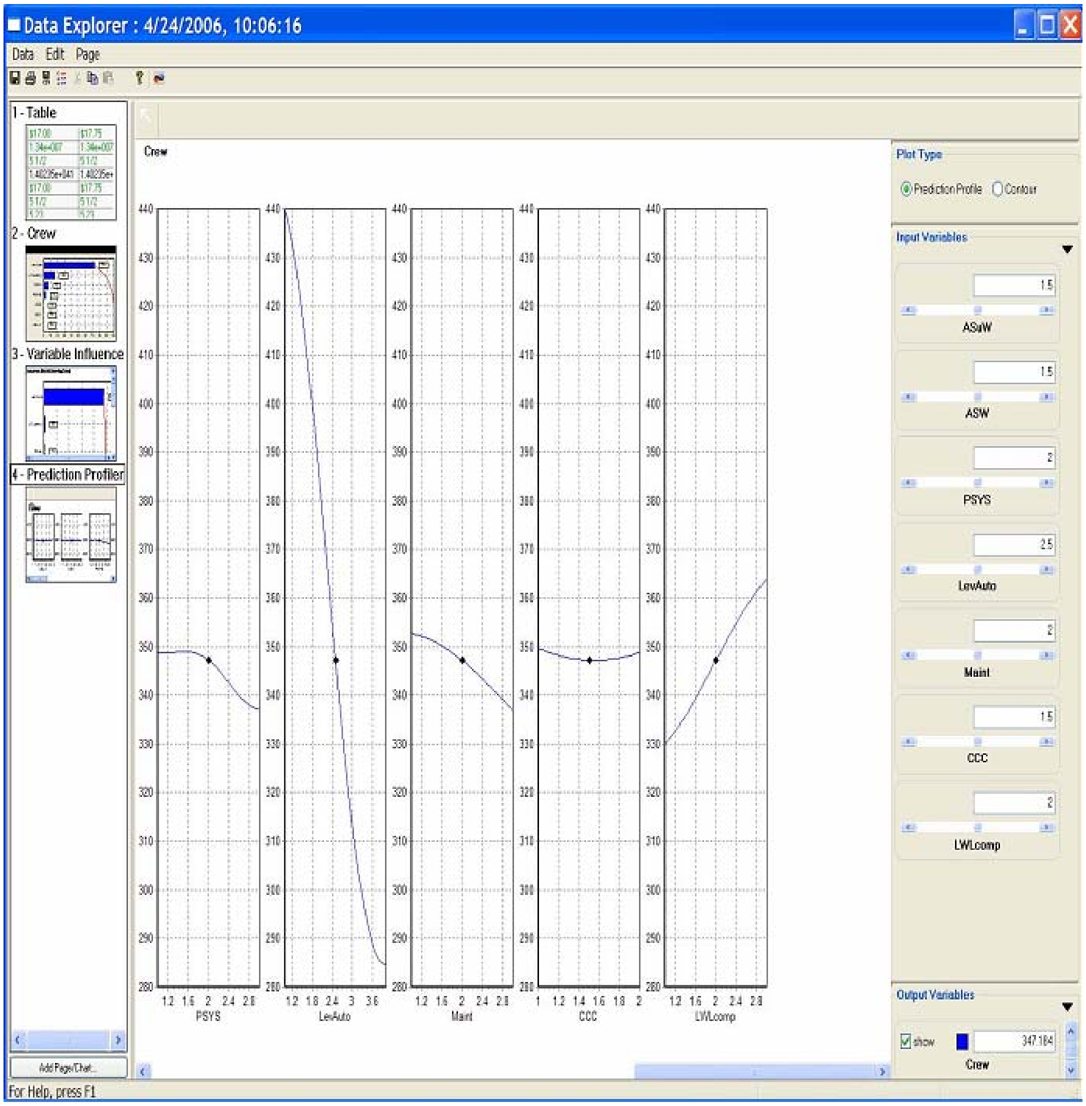
```
NO=6+INT(CMan*(Wp-Wvp)/50.+VD/30000.) ! number of officers + modular
NE=INT(CMan*((Wp-Wvp)/10.+(Vht+VD)/13000.))    ! number of enlisted + modular crew
```

Figure 13 - Manning calculation



```
!
! Manning correction for improved aluminum maintainability/no coatings
      If(CHMAT.eq.2.and.CDHMAT.ne.2)then
        NE=.95*NE
      Elseif(CDHMAT.eq.2.and.CHMAT.ne.2)then
        NE=.95*NE
      Elseif (CDHMAT.eq.2.and.CHMAT.eq.2)then
        NE=.9*NE
      Endif
!
      NT=NO+NE                                             ! total crew
      NA=INT(0.*NT)                                        ! additional accomodations - included in manning equations - for module crews
```

Figure 14 – Correction to standard manning calculation for aluminum hull and deckhouse



● Prediction Profile ○ Contour

ASuW 1.5
ASW 1.5
PSYS 2
LevAuto 2.5
Maint 2
CCC 1.5
LWLcomp 2

☑ show Crew 347.184

Figure 15 – Manning Response Surface Profile Predictor

The Response Surface Model (RSM) was created with the Integrated Simulation Manning Analysis Tool (ISMAT) and Model Center. With a library of equipment, compartment and manning definitions, ISMAT calculates optimum manning on a basis of crew cost. The crew can be defined of a pool of operators capable of performing a number of different tasks with varying levels of automation. By changing independent variables within Model Center, such as ship size, the effect on crew size can be studied to develop a mathematical function (the RSM). Figure 15 shows the Profile Predictor in Model Center used to visualize these trends. The RSM is then used in the ship synthesis model.

3.1.4 Combat System Alternatives

ASCal combat system alternatives are grouped as Anti-Air Warfare / Signal and Electronic Warfare (AAW/SEW), Anti-Surface Warfare (ASUW), Anti-Submarine Warfare / Mine Counter-Measures (ASW/MCM), Command, Control and Communications (CCC) and Light Airborne Multi-Purpose System (LAMPS).

3.1.4.1 AAW

ASCal inherent Anti-Air Warfare / Space Electronic Warfare (AAW/SEW) systems provide detection and protection against air threats. AAW/SEW options for goal and threshold performances are provided in Table 9 with data in Table 14.

Table 9 – AAW / SEW Combat Systems Options

Warfighting System	Options	Components
AAW / SEW	Option 1(goal): Sea RAM, ICMS, AIMS IFF, 16 cell ESSM, AIEWS, COMBAT DF, 3 x SRBOC, 2 x NULKA, IRST	2, 4, 14, 6, 26, 15, 17, 18, 21, 22, 16
	Option 2: EADS TR-3D C-band radar, 1 x 11 cell Sea RAM, AIMS IFF, COMBAT DF, 2 x SRBOC, 2 x SKWS decoy launcher, COMBAT SS-21, WBR 2000, IRST	3, 11, 12, 13, 14, 15, 17, 18, 22, 24, 25, 5, 7, 8, 9, 10, 253, 16, 27
	Option 3: SEA Giraffe G/H band radar, 1 x 11 cell Sea RAM, AIMS IFF, EDOES 3601 ESM, ICMS, SEA STAR SAFIRE III, COMBAT DF, IRST	1, 11, 12, 13, 14, 28, 4, 39, 15, 7, 8, 9, 10, 16

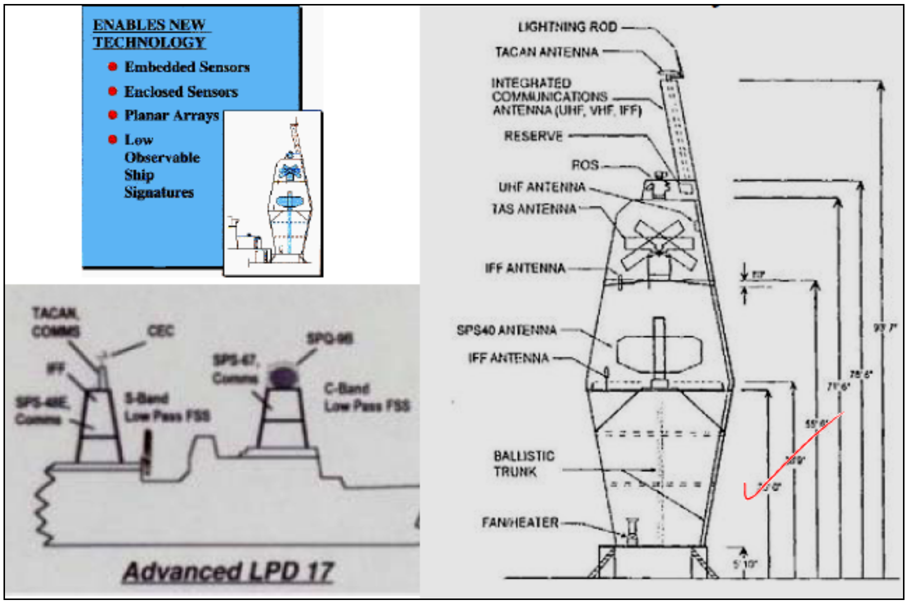


Figure 16 - AEM/S Advanced Enclosed Mast / Sensor.

Figure 17 - AEM/S Advanced Enclosed Mast / Sensor aboard the USS Arthur Radford.

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

The Advanced Enclosed Mast/Sensor (AEM/S) system is a new mast developed and tested by the Navy designed to integrate the ship's radar and sensors into a newer, stealthier structure (see Figure 16). It relies heavily on advanced materials including fiber reinforced composites and consists of a faceted radome with internally mounted platforms. Current installations such as that on the Spruance class destroyer, the USS Arthur W. Radford shown in Figure 17, have been shown to provide a significant reduction in radar cross-section.

The AN/SRS-1A(V) Combat DF is an automated long range hostile target signal acquisition and direction finding system. It can detect, locate, categorize and archive combat data into the ship's tactical data system and provides greater flexibility against a wide range of threat signals. It provides warship commanders near-real-time indications, situational awareness, and cueing information for targeting systems.

The AN/SLQ-32A(V)2 in Figure 18 provides early warning of threats and automatic dispensing of chaff decoys. The passive system uses surveillance and targeting radars used by missiles and aircraft to provide information to defensive countermeasures. The (V)2 is currently installed on a number of Navy frigates and destroyers.

Figure 18 - AN/SLQ-32A (V)2

Figure 19 - MK 36 DLS SRBOC

Shown in Figure 19, the Super Rapid Bloom Offboard Countermeasures Chaff and Decoy Launching System (MK 36 DLS SRBOC) provides decoys launched at a variety of altitudes. The decoys emit a number of false radar signals to confuse incoming enemy missiles.

The Self-defense Evolved Sea Sparrow Missile Active Rolling Airframe Missile (SEARAM) is shown in Figure 20. These missiles take cueing from the ship's ESSM suite or radar to engage both incoming enemy aircraft and cruise missiles. It uses a forward looking infrared (FLIR) system to control missile fire.

Figure 20 - Self-Defense Evolved Sea Sparrow Missile Active Rolling Airframe Missile (SEARAM)

The Sea GIRAFFE is a naval 3D, multi-function search radar based on Ericsson 3D agile multi-beam technology. It provides both air and surface tracking capabilities along with general surveillance. It is also capable of performing target indication and area mapping functions.

3.1.4.2 ASUW

Anti-Surface Warfare combat systems provide the ability to detect and defend against surface threats. ASCal's inherent combat system options for ASUW are listed in Table 10 with data in Table 14.

Table 10 - ASUW Combat System Options

Warfighting System	Options	Components
ASUW	Option 1(goal): AN/SPS–73 Surface Search radar, IRST, 7m RHIB, 30mm CIGS, MK 45 5"/62 gun, MK 86 GFCS	29, 30, 44, 31, 32, 33, 34, 49, 47, 48, 46, 36, 35, 37
	Option 2: AN/SPS–73 Surface Search radar, IRST, 7m RHIB, 57mm MK 3 Naval gun, DORNA EOD EO/IR	29, 30, 44, 40, 41, 42, 43, 38, 46, 36, 35, 37
	Option 3: AN/SPS–73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR	29, 30, 44, 40, 41, 42, 43, 39, 46, 36, 35, 37

The AN/SPS-73(V)12 Radar is a short-range, two-dimensional, surface-search/navigation radar system that provides short-range detection and surveillance of surface units and low-flying air units. It can provide contact range and bearing information while enabling quick and accurate determination of ship position relative to nearby vessels and navigational hazards. Figure 21 shows the AN/SPS-73(V)12 radar in operation.

Figure 21 - AN/SPS-73 (V) 12 Radar

The MK46 Mod 1 30mm Close-I Gun System (shown in Figure 22) is a two-axis stabilized chain gun that can fire up to 250 rounds/min. The system uses a forward-looking infrared sensor, a low light television camera and laser rangefinder with a closed-loop tracking system to optimize accuracy against small, high-speed surface targets. It can be operated locally at the gun's weapon station (turret) or fired remotely by a gunner in the ship's CCC.

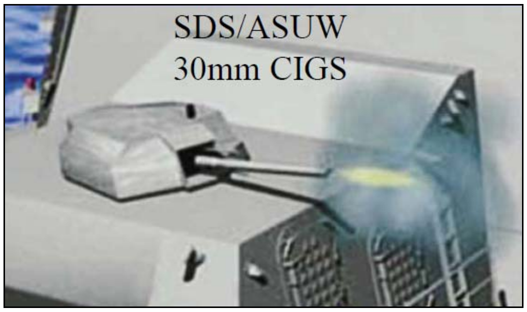


Figure 22 - MK46 Mod 1 30mm CIGS.

A FLIR (Forward Looking Infrared Sensor) system is shown in Figure 23. The FLIR uses infrared detection of thermal energy to create an image of its surroundings. The thermal imaging technology employed by the FLIR can be used in all weather conditions and can distinguish heat sources at several miles.

Figure 23 - FLIR (Forward Looking Infrared Sensor)

The MK 45 5-inch / 62-caliber (MOD 4 ERGM) shown in Figure 24 provides surface combatants with accurate naval gunfire against fast, highly maneuverable surface, air and shore targets during amphibious operations. Controlled by either the Mk 86 Gun Fire Control System or the Mk 160 Gun Computing System, it is fully-automatic and capable of firing 16-20 rounds per minute at 475-500 rounds per magazine to a range of 13 nautical miles. This range can be extended to 63 nautical miles with the use of Extended Range Guided Munitions (ERGMs).

Figure 24 - MK45 5-inch / 62-caliber (MOD 4 ERGM) gun

The 57mm MK 3 Naval gun represents another option of ASUW. Figure 25 shows the 57mm MK 3 gun.

Figure 25 - 57mm MK 3 Naval gun

3.1.4.3 ASW/MCM

ASC inherent Anti-Submarine Warfare and Mine Counter-Measures (ASW/MCM) combat system options are listed in Table 11. These options offer some protection to ASCal from underwater threats and allow for ASCal to engage enemy targets if the situation dictates. Component data is listed in Table 14.

Table 11 - ASW/MCM Combat System Options

Warfighting System	Options	Components
ASW/MCM	Option 1(goal): SSTD, AN/SLQ-25 NIXIE, 2 x MK32 SVTT, MK89 TFCS, Mine Avoidance Sonar	52, 51, 53, 50, 54
	Option 2: AN/SLQ-25 NIXIE, MK 32 SVTT, MK89 TFCS, Mine Avoidance Sonar	51, 53, 50, 54
	Option 3: AN/SLQ – 25 NIXIE, Mine Avoidance Sonar	51, 54

The AN/SLQ-25A NIXIE shown in Figure 26 is a tow-behind decoy that employs an underwater acoustic projector activated by a shipboard signal generator. It provides deceptive countermeasures against acoustic homing torpedoes and can be used in pairs or alone.

Figure 26 - AN/SLQ-25A NIXIE aboard the USS Iowa

The Multi-Purpose Sonar System Vanguard uses dual frequency, active and broadband passive sonar to for navigational purposes on surface vessels around dangerous objects, such as mines. Although mine warfare protection is the systems main purpose, it is also capable of identifying other underwater objects. Figure 27 is an illustration of the system in action.

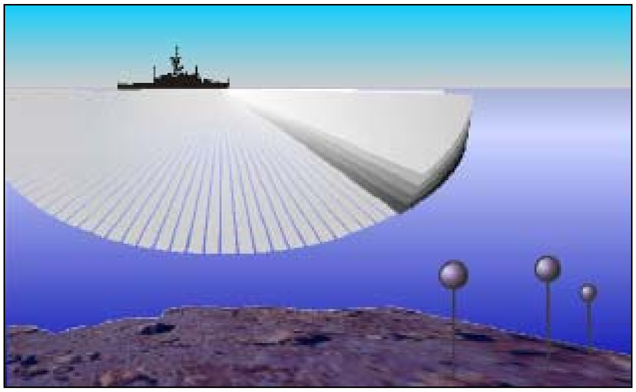


Figure 27 - Mine Avoidance Sonar

The MK32 Surface Vessel Torpedo Tube (SVTT) shown in Figure 28 is designed to pneumatically launch torpedoes over the side of surface vessels. It is capable of handling MK-46 and MK-50 torpedoes and can stow and launch up to three torpedoes without reloading. Torpedo launching can be controlled locally or remotely from an ASW fire control system such as the MK 309 Torpedo Fire Control System (SQQ-89 is used on all current USN SCs).

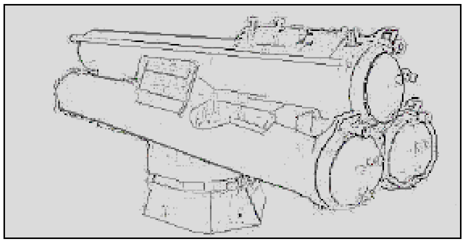


Figure 28 - MK 32 Surface Vessel Torpedo Tube

3.1.4.4 **CCC**

Command, Control and Communications (CCC) refers to the ability to control ship systems, and communicate with all shipboard and offboard personnel from one central location. ASCal inherent Combat System Options for CCC are listed in Table 12 with component data in Table 14.

Table 12 - CCC Combat System Options

Warfighting System	Options	Components
C4	Option 1(goal): Comm. Suite Level A, CTSCE	57, 59, 55, 56
	Option 2: Comm. Suite Level B, CTSCE	58, 59, 55, 56

CCC allows a ship to communicate all aspects of its operating environment, status to its personnel and to other vessels in the war fighting force, allowing for a more precise global picture of the theatre. This concept of data-centralization is shown in Figure 29.

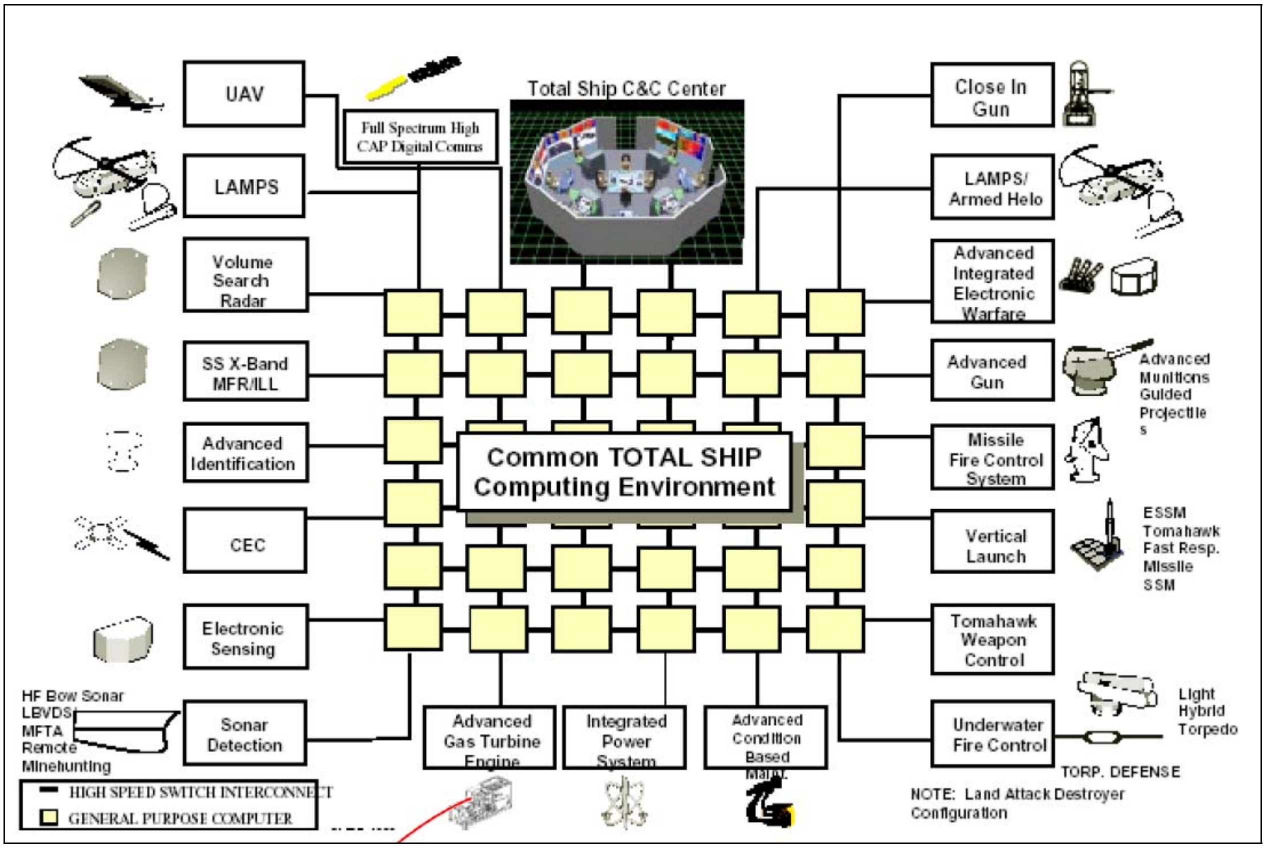


Figure 29 - Total Ship Concept of Data collection.

Figure 30 shows a multi-function low observable stack integrating various communication systems devices into one central location. This technology not only allows for a centralization of systems, but helps to reduce the ships radar signature.

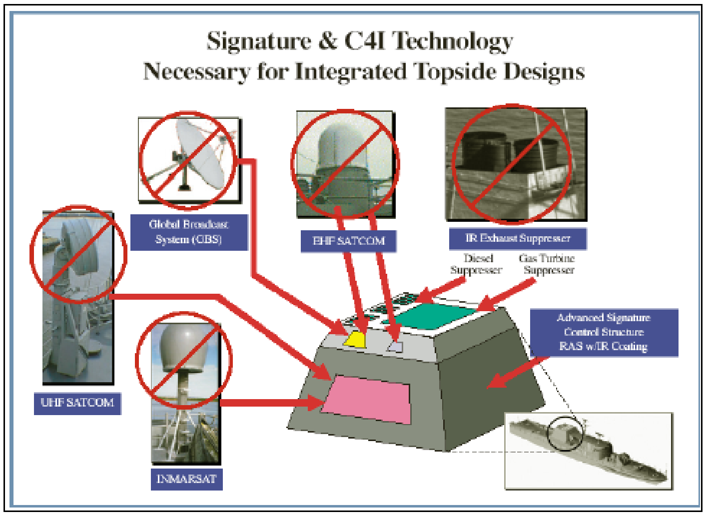


Figure 30 - Multi-Function Low Observable Stack for CCC Integration

3.1.4.5 LAMPS

Light Airborne Multi-Purpose System (LAMPS) refers to the onboard operations involved in the launching, recovering, refueling, and storage of aircraft, such as SH-60 Seahawks. Table 13 lists the combat system options for this system with component data in Table 14.

Table 13 - LAMPS Combat Systems Options

Warfighting System	Options	Components
LAMPS	Option 1(goal): 2 x Embarked LAMPS w/ Hangar, 3 x VTUAV	66, 67, 68, 69, 70, 71, 72, 73, 99-102
	Option 2: 1 x Embarked LAMPS w/ Hangar, 3 x VTUAV	60, 61, 62, 63, 64, 65, 72, 73, 99-102
	Option 3: LAMPS haven (flight deck), 3 x VTUAV	61, 62, 63, 64, 65, 72, 73, 99-102

The SH-60 Seahawk (LAMPS MK III) seen in Figure 31 is the backbone of LAMPS, and is able to perform a wide range of missions, including LAMPS/ASW/ASUW, Search and Rescue, SPECOPS, and Cargo Lift. It houses 2 x 7.62mm machine guns and can carry a complement of AGM-119 Penguin missiles, MK46 and MK50 torpedoes. The Seahawk has a retractable fueling probe allowing for extended operation through in-flight refueling, and can be used to deploy sonobuoys that extend the ship's sonar capabilities. The helicopters own radar can be integrated with a ship's radar for extend radar surveillance.

Figure 31 - SH-60 Seahawk (LAMPS MK III)

Figure 32 - Vertical Takeoff Unmanned Aerial Vehicle (VTAUV)

Figure 32 shows a Vertical Takeoff Unmanned Aerial Vehicle (VTAUV) that can be stored on board with relative ease due to its small size. This unmanned aircraft, like the Seahawk, can be used to extend the ship's radar and sensor capabilities and is ideal for performing missions without the need for personnel.

3.1.4.6 Combat Systems Payload Summary

To trade-off combat system alternatives with other alternatives in the total ship design, combat system characteristics listed in Table 14 are included in the ship synthesis model data base. These characteristics outline the Required Operational Capabilities (ROCs) for ASCal.

Table 14 - Combat System Component Characteristics

NAME	WAR AREA	WT GRP	ID	Single SWBS	WT (MT)	HD10 (m)	H AREA (m2)	DH AREA (m2)	CRSKW	BATKW
SEA GIRAFFE AMB RADAR	AAW	456	1	400	7.28	8.00	0.00	7.50	96.96	97.84
SEAPAR MFR	AAW	456	2	400	12.98	8.00	0.00	15.00	137.50	150.00
EADS TRS-3D C-BAND RADAR	AAW	456	3	400	8.64	8.00	0.00	8.00	100.00	110.00
ICMS (Integrated Combat Management System)	AAW	482	4	400	2.946	5	0	12	43.3	65.8
COMBATSS-21 (Combat Management System)	AAW	482	5	400	2.95	5.00	0.00	11.00	45.00	70.00
16 CELL ESSM w/ MK48 VERTICAL LAUNCH SYSTEM	AAW	721	6	700	25.00	-2.80	6.80	0.00	0.00	0.00
1X MK 16 CIWS/SEAPAR Radar 1 of 4	AAW	711	7	700	6.44	1.50	0.00	22.45	5.89	15.89
1X MK 16 CIWS/SEAPAR Local Control 2 of 4	AAW	481	8	400	0.71	1.50	1.00	0.00	0.00	0.00
1X MK 16 CIWS/SEAPAR Remote Control 3 of 4	AAW	481	9	400	0.10	1.50	0.00	0.00	0.44	0.44
1X MK 16 CIWS/SEAPAR Workshop 4 of 4	AAW	482	10	400	0.00	1.50	0.00	10.00	0.00	0.00
RAM/SEAPAR LAUNCHER - 11 CELL LAUNCHER 1 OF 3	AAW	721	11	700	3.45	2.00	0.00	0.00	4.80	4.80
RAM/SEAPAR LAUNCHER - 11 READY SERVICE MISSILES 2 OF 3	AAW	21	12	20	1.12	2.00	0.00	0.00	0.00	0.00
RAM/SEAPAR LAUNCHER - 11 CELL - 11 RAM MISSILE MAGAZINE 3 OF 3	AAW	21	13	20	1.12	2.00	0.00	0.00	0.00	0.00
MK XII AIMS IFF	AAW	455	14	400	2.14	8.00	0.00	0.00	2.70	2.40
COMBAT DF	AAW	495	15	400	8.392	6.00	0.00	8.00	15.47	19.34
IR Search and Track System (IRST)	AAW	452	16	400	1.63	8.00	0.00	19.90	40.00	40.00
2X-MK 137 LCHRs (Combined MK 53 SRBOC & NULKA LCHR) (1 OF 2)	AAW/SEW	721	17	700	0.75	1.00	0.00	2.10	0.00	0.00
2X-MK 137 LCHRs Loads (4NULKA, 12 SRBOC) (2 OF 2)	AAW/SEW	21	18	20	0.58	1.00	0.00	0.00	0.00	0.00
6X-MK 137 LCHRs (Combined MK 53 SRBOC & NULKA LCHR) (1 OF 2)	AAW/SEW	721	19	700	2.27	1.00	0.00	7.10	0.00	0.00
6X-MK 137 LCHRs Loads (12 NULKA, 36 SRBOC) (2 OF 2)	AAW/SEW	21	20	20	1.73	1.00	0.00	0.00	0.00	0.00
NULKA Magazine (12 Nulka)	AAW/SEW	21	21	20	0.73	1.00	0.00	3.00	0.00	0.00
SRBOC Magazine (200 SRBOC)	AAW/SEW	21	22	20	5.53	1.00	0.00	7.00	0.00	0.00
SKWS DECOY Magazine (Ship Soft Kill Weapon System)	AAW/SEW	21	23	20	2.44	1.00	0.00	4.00	0.00	0.00
2XSKWS DECOY LAUNCHER (1 OF 2)	AAW/SEW	721	24	700	0.75	1.00	0.00	2.10	0.00	0.00
2XSKWS DECOY Loads (2 OF 2)	AAW/SEW	21	25	20	0.58	1.00	0.00	0.00	0.00	0.00
AIEWS ADVANCED SEW SYSTEM	AAW/SEW	472	26	400	3.05	-1.50	0.00	21.00	6.40	6.40
WBR 2000 ESM (Electronics Support Measures)	AAW/SEW	471	27	400	2.54	-1.50	0.00	10.00	5.00	5.00
EDO 3601 ESM (Electronics Support Measures)	AAW/SEW	471	28	400	2.03	-1.50	0.00	10.00	5.00	5.00
Fwd Surface Search Radar - AN/SPS-73	ASUW	451	29	400	0.24	8.00	0.00	0.00	0.20	0.20
Sea Star SAFIRE II FLIR	ASUW	452	30	400	0.16	8.00	0.00	1.00	0.00	1.50
1X 30MM CIGS GUN MOUNT 1 of 4 (Close In Gun System)	ASUW	711	31	700	3.53	1.50	11.82	0.00	12.03	36.09
1X 30MM CIGS GUN AMMO STOWAGE 2 of 4	ASUW	713	32	700	0.56	2.00	0.00	0.00	0.00	0.00
1X 30MM CIGS GUN BALLISTIC PROTECTION 3 of 4	ASUW	164	33	100	4.72	1.50	0.00	0.00	0.00	0.00
1X 30MM CIGS GUN AMMO - 2500 ROUNDS 4 of 4	ASUW	21	34	20	4.06	1.00	0.00	0.00	0.00	0.00
SMALL ARMS AMMO, 7.62MM + 50 CAL + PYRO	ASUW	21	35	20	4.166	-2	0	0	0	0
2x50cal MACHINE GUNS	ASUW	21	36	20	0.41	1.00	0.00	0.00	0.00	0.00
SMALL ARMS AND PYRO STOWAGE LOCKER	ASUW	760	37	700	5.893	-2.3	2.1	0	0	0
DORNA EOD EO/IR Fire Control	ASUW	481	38	400	1.321	2	0	12	4	10.2
SEASTAR SAFIRE III Thermal Imaging System	AAW	452	39	400	0.16	1.80	0.00	1.00	0.00	1.50
57mm MK 3 Naval Gun Mount 1 of 4	ASUW	711	40	700	6.91	1.00	31.00	0.00	4.00	10.00
57mm Stowage 2 of 4	ASUW	713	41	700	2.74	1.00	0.00	0.00	0.00	0.00
57mm Ammo in Gun Mount 120 RDS 3 of 4	ASUW	21	42	20	0.76	1.00	0.00	0.00	0.00	0.00
57mm Ammo in Magazine 880 RDS 4 of 4	ASUW	21	43	20	5.55	-2.00	0.00	0.00	0.00	0.00
1X 7M RHIB	ASUW	583	44	500	3.56	-3.00	19.01	0.00	0.00	0.00
1X 11M RHIB COMMON LAUNCH-RECOVER SLED	ASUW	583	45	500	1.54	-3.00	19.01	0.00	0.00	0.00
1X COMMON LAUNCH-RECOVER ADDED STRUCT (Stern)	ASUW	185	46	100	0.92	-3.00	0.00	0.00	0.00	0.00
GFCS, MK86	ASUW/NSFS	481	47	400	4.247	2	0	16	6	15.4
GUN, 5IN/62 MK 45, AMMO - 600RDS	ASUW/NSFS	21	48	20	33.63	-3.2	82	0	0	0

NAME	WAR AREA	WT GRP	ID	Single SWBS	WT (MT)	HD10 (m)	H AREA (m2)	DH AREA (m2)	CRSKW	BATKW
GUN, 5IN/62 MOD 4	ASUW/NSFS	710	49	700	39.62	0.54	44	0	36.6	50.2
UNDERWATER FIRE CONTROL SYSTEM, BASIC SQQ-89	ASW	483	50	400	0.406	-3.2	13.2	0	11.5	11.5
AN/SLQ-25A (NIXIE) and AN/SLR-24I Towed Array (TRIPWIRE)	ASW	473	51	400	6.01	-3.00	14.30	0.00	6.15	6.15
SSTD	ASW	483	52	400	0.305	-3.5	3	0	1.5	1.5
SVTT, MK32, 2X, ON DECK	ASW	750	53	700	2.743	0.4	0	0	0.6	1.1
NDS 3070 Vanguard - Mine Avoidance Sonar	ASW/MIW	463	54	400	0.91	-8.00	0.83	0.00	0.00	1.60
ADCON 21 - C/C Suite (1 of 2)	C4I	411	55	400	2.24	-1.50	60.00	0.00	62.44	62.44
ADCON 21 - C/C Suite (2 of 2)	C4I	412	56	400	6.30	-1.50	81.35	0.00	0.00	0.00
COMMS SUITE LEVEL A	C4I	440	58	400	33.47	-1.50	55.72	0.00	36.60	37.20
COMMS SUITE LEVEL B	C4I	440	57	400	14.76	-1.50	35.77	0.00	26.25	32.32
Cooperative Engagement Capability (CEC)	C4I	415	59	400	1.56	-1.50	1.80	2.00	1.60	1.60
SINGLE SH-60 MODULAR DET - 1 HELO AND HANGAR	LAMPS	23	60	20	9.64	3.00	0.00	88.00	0.00	0.00
SINGLE SH-60 MODULAR DET - MISSION FUEL	LAMPS	42	61	40	27.94	-6.00	0.00	0.00	0.00	0.00
SINGLE SH-60 MODULAR DET - SUPPORT MOD 1	LAMPS	26	62	20	7.05	3.00	0.00	37.52	0.00	0.00
SINGLE SH-60 MODULAR DET - SUPPORT MOD 2	LAMPS	26	63	20	6.83	3.00	0.00	37.52	0.00	0.00
SINGLE SH-60 MODULAR DET - SUPPORT MOD 3	LAMPS	26	64	20	3.40	3.00	0.00	37.52	0.00	0.00
SINGLE SH-60 MODULAR DET - SUPPORT MOD 4	LAMPS	26	65	20	3.40	3.00	0.00	37.52	0.00	0.00
DUAL SH-60 MODULAR DET - 2 HELOS AND HANGAR	LAMPS	23	66	20	19.28	3.00	0.00	176.00	0.00	0.00
DUAL SH-60 MODULAR DET - MISSION FUEL	LAMPS	42	67	40	55.88	-6.00	0.00	0.00	0.00	0.00
DUAL SH-60 MODULAR DET - SUPPORT MOD 1	LAMPS	26	68	20	7.05	3.00	0.00	37.52	0.00	0.00
DUAL SH-60 MODULAR DET - SUPPORT MOD 2	LAMPS	26	69	20	6.83	3.00	0.00	37.52	0.00	0.00
DUAL SH-60 MODULAR DET - SUPPORT MOD 3	LAMPS	26	70	20	3.66	3.00	0.00	37.52	0.00	0.00
DUAL SH-60 MODULAR DET - SUPPORT MOD 4	LAMPS	26	71	20	3.40	3.00	0.00	37.52	0.00	0.00
RAST + RAST CONT + HELO CONT	LAMPS	588	72	500	32.90	-1.00	16.26	0.00	0.00	0.00
AVIATION MAGAZINE - (12) MK46 - (24) HELLFIRE - (6) PENQUIN 1 of 2	LAMPS	22	73	20	11.40	-6.00	0.00	51.75	0.00	0.00
1X MODULAR RMS - 1 RMS VEHICLE	MIW	23	74	20	2.76	-3.00	19.42	44.00	0.00	0.00
1X MODULAR RMS - 1 CONTROL MODULE	MIW	476	75	400	5.10	-3.00	37.52	0.00	0.00	0.00
1X MODULAR RMS - 1 MAINT-TRANSP MODULE	MIW	26	76	20	3.50	-3.00	37.52	0.00	0.00	0.00
1X MODULAR RMS - 1 TRANSP 1 MODULE	MIW	23	77	20	3.99	-3.00	37.52	0.00	0.00	0.00
1X MODULAR RMS - 1 TRANSP 2 MODULE	MIW	23	78	20	4.40	-3.00	37.52	0.00	0.00	0.00
1X RMS COMMON LAUNCH-RECOVER SLED	MIW	583	79	500	1.38	-3.00	19.01	0.00	0.00	0.00
1X RMS VEHICLE DAVIT	MIW	23	80	20	2.07	-3.00	2.00	0.00	0.00	0.00
1X SMALL UUV DET - 3 BPUAV - 5 REMUS	MIW	23	81	20	4.06	-3.00	0.00	0.00	0.00	0.00
1X SMALL UUV DET - 1 BATT-RECHARGE MODULE	MIW	313	82	300	3.46	-3.00	37.52	0.00	0.00	0.00
1X SMALL UUV DET - 1 CONTROL MODULE	MIW	476	83	400	2.64	-3.00	37.52	0.00	0.00	0.00
1X SMALL UUV DET - 1 VEHICLE STOWAGE MODULE	MIW	23	84	20	3.25	-3.00	37.52	0.00	0.00	0.00
HELICOPTER MIW MODULE	MIW	26	85	20	4.63	3.00	0.00	60.50	0.00	0.00
TEU - 1X 11M EOD SCULPIN SUPPORT MODULE	MIW	29	86	20	2.34	-3.00	37.52	0.00	0.00	0.00
TEU - 1X 11M EOD SUPPORT MODULE	MIW	29	87	20	4.10	-3.00	37.52	0.00	0.00	0.00
TEU - 1X 11M EOD SUPPORT MODULE	MIW	29	88	20	4.10	-3.00	37.52	0.00	0.00	0.00
TEU - SINGLE SH-60 ALMDS & AQS-20	MIW	26	89	20	4.37	3.00	0.00	60.50	0.00	0.00
TEU - SINGLE SH-60 AMDS & RAMICS	MIW	26	90	20	5.28	3.00	0.00	60.50	0.00	0.00
TEU - SINGLE SH-60 OASIS	MIW	26	91	20	3.15	3.00	0.00	60.50	0.00	0.00
TEU - SINGLE SH-60 PUK MODULE	MIW	26	92	20	5.99	3.00	0.00	60.50	0.00	0.00
1x 11M MODULAR SPARTAN DET USV VEHICLE and STOWAGE	SPARTAN	23	93	20	10.71	-3.00	37.52	0.00	0.00	0.00
1X 11M MODULAR SPARTAN (USV) DET - 1 MAINT MODULE	SPARTAN	26	94	20	2.64	-3.00	37.52	0.00	0.00	0.00
1X 11M MODULAR SPARTAN DET - 1 CONTROL MODULE	SPARTAN	495	95	400	3.01	-3.00	37.52	0.00	2.40	2.40
1X 11M MODULAR SPARTAN DET - 1 MIW SUPPORT MODULE	SPARTAN	29	96	20	3.90	-3.00	37.52	0.00	0.00	0.00
1X 11M MODULAR SPARTAN DET - 1 WEAPON (ASUW) MODULE	SPARTAN	791	97	700	2.63	-3.00	37.52	0.00	0.00	0.00
MODULAR SPARTAN DET - MISSION FUEL	SPARTAN	42	98	40	4.57	-6.00	0.00	0.00	0.00	0.00
VTUAV DET - MODULAR - HANGAR AND 3 VEHICLES	VTUAV	23	99	20	3.46	-3.00	0.00	73.00	0.00	0.00
VTUAV DET - MODULAR - MAINTENANCE MODULE	VTUAV	26	100	20	3.11	3.00	0.00	37.52	0.00	0.00
VTUAV DET - MODULAR - MISSION COMMAND MODULE	VTUAV	492	101	400	3.06	3.00	0.00	37.52	0.00	0.00
VTUAV DET - MODULAR - MISSION FUEL	VTUAV	42	102	40	11.18	-6.00	0.00	0.00	0.00	0.00

3.2 Design Space

Table 15 lists the design variables used for the ASCal design. Both discrete and continuous variables are listed in this table.

Table 15 - Design Variables (DVs)

DV #	DV Name	Description	Design Space
1	LWL	Length on waterline	90-110 m
2	LtoB	Beam	6.5 - 7.5
3	LtoD	Depth	8.5 - 10
4	β	Transom Deadrise	10°-15°
5	C_p	Prismatic coefficient	0.59-0.72
6	C_x	Section Coefficient	0.68-0.84
7	CHMAT	Hull material	Option 1: Aluminum
			Option 2: Steel
8	CDHMAT	Deckhouse material	Option 1: Aluminum
			Option 2: Steel
			Option 3: Composit
9	GSYS	Ship Service Generator System	Option 1: 4 x CAT
			Option 2: 4 x MTU
10	Ts	Provisions duration	14-30 days
11	Cman	Manning Reduction Factor	0.5-1.0
12	PSYS	Propulsion System	Option 1: 2xLM2500 + 2xCAT3616, 2x30MW + 2x6.5MW steerable
			Option 2: 2xMT30 + 2xSEMT16PA6B, 2x35MW + 2x6 MW steerable
			Option 3: 2xLM2500 + 2xCAT3616, 2x30MW + 1x13MWsteerable
			Option 4: 2xMT30 + 2xSEMT16PA6B, 2x35MW + 1x12MWsteerable
			Option 5: 2xLM2500 + 2xCAT3616, 2x30MW + 1x6MWsteer + 1MW SPU
			2xMT30 + 2xSEMT16PA6B, 2x35MW 1x6MWsteer 1MW SPU
13	AAW/SEW	Anti-Air Warfare/Space and Electronic Warfare	Option 1 (goal): Sea Par MFR, ICMS, AIMS IFF, 16 cell ESSM, AIEWS, TACTICOS, COMBAT DF, 3 x SRBOC, 2 x NULKA
			Option 2: EADS TR-3D C-band radar, 1 x 11 cell Sea Par, AIMS IFF, COMBAT DF, 2 x SRBOC, 2 x SKWS decoy launcher, COMBAT SS-21
			Option 3:SEA Giraffe G/H band radar, 1 x 11 cell SeaRAM, AIMS IFF, ED OES 3601 ESM, ICMS, TACTICOS, SEASTAR SAFIRE III, COMBAT DF
14	ASUW	Anti-Surface Warfare	Option 1 (goal): AN/SPS -73 Surface Search radar, IRST, 7m RHIB, 30mm CIGS, MK 45 5"/62 gun, MK 86 GFCS
			Option 2: AN/SPS-73 Surface Search radar, IRST, 7m RHIB, 57mm MK 3 Naval gun, DORNA EOD EO/IR
			Option 3: AN/SPS-73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR
15	ASW/MCM	Anit-Submarine Warfare/Mine counter-measures	Option 1 (goal): SSTD, AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, MK89 TFCS, Mine Avoidance Sonar
			Option 2: AN/SLQ-25 NIXIE, MK 32 SVTT, MK 89 TFCS, Mine Avoidance Sonar, degaussing
			Option 3: AN/SLQ-25 NIXIE, Mine Avoidance Sonar
16	C4I	Command, Control, Communications, Computers, and Intelligence	Option 1 (goal): Comm Suite Level A, CTSCE
			Option 2: Comm Suite Level B, CTSCE
17	LAMPS	Light Airborne Multi-Purpose System	Option 1 (goal): 2 x Embarked LAMPS w/ Hangar
			Option 2: 1 x Embarked LAMPS w/ Hangar
			Option 3: LAMPS haven (fight deck)

3.3 Ship Synthesis Model

The ship synthesis model evaluates the balance and feasibility of a set of design variables. For balanced and feasible designs, the synthesis model also analyzes performance, effectiveness, cost and risk. This is achieved using a series of models, such as cost, hull resistance and feasibility. For this study, the Darwin optimizer in Model Center along with gradient based methods are used (see Figure 33). A more complete explanation of the optimization process is given in Section 3.5.

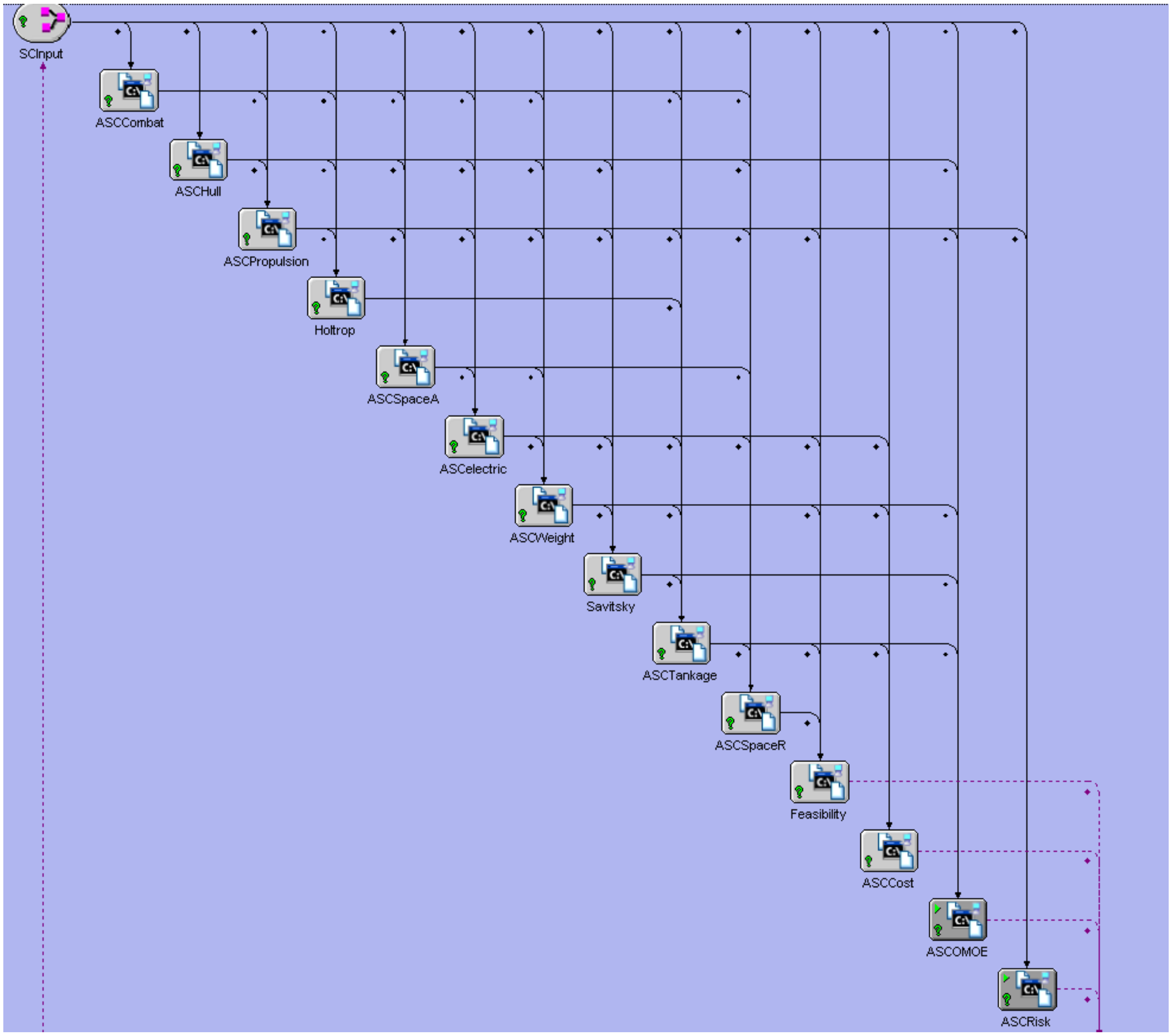


Figure 33 – Ship synthesis modules in Model Center

3.3.1 Synthesis Model

A set of modules using both physics and regression-based algorithms are employed in the ship synthesis model. A brief description is given for each of these modules below.

- Input Module - The input module, unlike the other modules does not perform any calculations. The input module serves to receive, store and link the design variable values used by the other modules when performing their respective calculations. The parameters and variables are user entered and stored in a list. Design Variable values are also received from the Optimizer.
- Combat Systems Module - The combat module calculates payload characteristics for Combat Systems. This module is dependent on the selection of discrete variables. For example, if AAW = 1 then the module incorporates all the inherent payloads for AAW option number 1. The payload weights, centers and power for all input variables are calculated. Inherent systems and weights are used for the corresponding input variable option. The data used by this module is shown in Table 14.
- Hull Module - The hull system module calculates hull characteristics and defines hull parameters through the use of ratios and LCS-1 parent hull data. The module scales data from the LCS-1 3000 LT design waterline. Ratios such as LtoB and LtoD are used to determine the resulting hull parameters for a daughter design. Length on the Waterline (LWL) is used to size the designs. With the length known, the beam and depth can be found from the ratios LtoB and LtoD. Other values, such as draft and volumetric coefficient are then found in turn. Table 15 shows the design variable ranges that define the design space for this process.

- Propulsion Module - The propulsion system module calculates generator and propulsion system characteristics for ASCal. The module inputs the propulsion alternative from the Input module, extracts its related data from the Propulsion Data Table, and calculates basic propulsion and power characteristics for the design.
- Holtrop-Menon Resistance Module - The Holtrop-Menon module calculates hull resistance for the ASCal semi-planing hullform at endurance speed, where the hull acts in displacement mode. The Holtrop method uses correlation allowance, viscous resistance, wavemaking resistance, bulb resistance, and transom resistance to find the resistance of the hull. Values for wind resistance, air drag and appendage drag are also added. Effective HP and Shaft HP at endurance speed are calculated.
- Space Available Module - The space available module uses scaled LCS data to find the available space of ASCal. Areas and volumes calculated for the parent are adjusted for the daughter characteristics. Values for total ship volume, height of machinery box, and volume of machinery box are also determined.
- Electric Module - The electric systems module calculates the electrical loading and auxiliary machinery room volume for a given design. This module considers manning needs and accommodations in its calculations. The electric module calculates the following required power using regression-based equations and adds these values to payload requirements.
    - Propulsion auxiliary electric power required
    - Steering electric power required, SWBS 561
    - SWBS 300 electric power required
    - Collective Protection System electric power required
    - Miscellaneous electric power required
    - Electric power required, SWBS 521
    - Fuel handling electric power required, SWBS 540
    - Misc. auxiliary electric power required
    - Services electric power required, SWBS 600

  Maximum functional load with margins and 24-hour average electrical load are calculated and output.
- Weight Module - The weight module calculates single digit weights, lightship weight with margins, full load weight and stability characteristics. Most weights are estimated using regression-based equations in addition to except payload and propulsion machinery weights.
- Savitsky Resistance Module - The Savitsky module calculates hull resistance using the Savitsky Method. The module returns sustained speed and the total power required for ASCal to make speed on-plane. This is achieved by balancing forces and moments experienced by the hull due to propeller, lift, buoyancy and gravity.
- Tankage Module - The tankage module calculates tankage requirements for ASCal. The module uses the DDS 200-1 process for calculating endurance range. The tankage module computes the following:
- Engine fuel consumption rates
- Fuel weight = Full load displacement (from Hull Module) minus the sum of all weights except fuel (from Weight module).
- Endurance Range
- Sustained speed range and Surge Refuels
- Annual Fuel Used - assumes endurance speed for 2500 hours per year and NSWCCD Philadelphia speed/time profile.
- Tank volumes for propulsion fuel, helo fuel, lube oil, potable water, sewage, waste oil and ballast based on fuel weight and a number of margins.
- Space Required Module - The space required module calculates the total required area and volume for ASCal. This includes the hull and deckhouse space as well as habitability requirements for officers and enlisted men. This is achieved by calculating area for personnel (officers and enlisted) using a regression-based method. It also calculates area for stores, maintenance, and various other ship functions. It then sums these areas and volumes with payload, tankage, power and propulsion area and volume requirements to calculate the total required volume and arrangeable area.
- Feasibility Module - This module determines the feasibility of a potential design by comparing calculated characteristics to threshold values and requirements such as total arrangeable area, deckhouse area, sustained speed, electric power, stability and range.
- Cost Module - The cost module calculates lead-ship acquisition cost, follow-ship acquisition cost, and life cycle cost for the ship. The calculation is primarily weight-based with complexity and producibility factor adjustments. See Section 3.4.3 for a more complete explanation of cost.
- OMOE Module - This module calculates the overall measure of effectiveness (OMOE) for the given design. It uses combat system options, propulsion options, and various ship parameters and calculated ship characteristics

as input values. OMOE weights and value functions are derived using AHP and MAVT to organize expert opinion into a usable OMOE metric as described in Section 3.4.1.

- Risk Module - The risk module calculates the technology risk associated with a particular ship design using an Overall Measure Of Risk (OMOR) metric as described in Section 3.4.2.

3.4 Objective Attributes

3.4.1 Overall Measure of Effectiveness (OMOE)

The Overall Measure of Effectiveness (OMOE) is the single overall figure of merit index (0-1.0) describing the ship's effectiveness in its specified missions. In this design project, the OMOE function is derived using the Analytical Hierarchy Process (AHP). AHP operates by organizing the criteria in a natural way (hierarchy) and using pairwise comparison and expert opinion to quantify their relationship.

The first step in implementing the AHP to build an OMOE function is to identify the MOPs (Measures of Performance) for the design. Measures of Performance (Table 17) are defined as a specific ship or system performance metric of required capabilities independent of mission. They are taken from the ROC/MOP/DV table that is developed together with ROCs and DVs (Table 16). The MOPs are then organized into an OMOE Hierarchy (Figure 34). Pairwise comparison and AHP are used to calculate the relative weights of the different MOPs and their value functions. Figure 35 shows the Expert Choice software window used for pairwise comparison and Figure 36 shows the Measures Of Performance weights. Value functions are also used so that each OMOE metric is normalized to a value between VOP = 0.0 (threshold) and VOP = 1.0 (goal). Figure 37 shows a typical VOP function. The VOP is a merit index (0-1.0) specifying the value of a specific MOP to a specific mission area for a specific mission type. The chosen MOPs and VOPs are then multiplied and summed to gain a final value for OMOE. Equation (1) is the final OMOE function with weights and VOPs corresponding to MOPs.

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

3.4.2 Overall Measure of Risk (OMOR)

The purpose of the OMOR is to calculate a quantitative measure of a risk for a specific design based on the selection of technologies. Risk events associated with specific design variable required capabilities, schedule, and cost are identified. Table 18 shows the risk register for ASCal. Each row in the table represents a specific risk. The P and C columns represent the probability and consequence for each risk, estimated using Table 19 and Table 20. The R column is the product of the P and C columns. The total performance, cost and schedule risk are normalized and summed into an OMOR function, Equation (2).

$$OMOR = W_{perf} \sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{\cos t} \sum_j w_j P_j C_j + W_{sched} \sum_k w_k P_k C_k \tag{2}$$

Table 16 - ROC/MOP/DV Summary

ROCs	Description	MOP	Related DV	Goal	Threshold
AAW 1.2	Support area anti-air defense	AAW	AAW GMLS SEW	AAW/SEW=1 CCC=1	AAW/SEW=3 CCC=2
AAW 1.3	Provide unit anti-air self defense	AAW RCS IR	AAW	AAW=1	AAW=3
AAW 2	Provide anti-air defense in cooperation with other forces	AAW	CCC	CCC=1	CCC=2
AAW 5	Provide passive and soft kill anti-air defense	AAW RCS IR	SEW PSYS	Option 1-3	Option 4-5
AAW 6	Detect, identify and track air targets	AAW RCS IR	C4I AAW	Option 1	Option 2
AAW 9	Engage airborne threats using surface-to-air armament	AAW RCS IR	AAW	AAW=1	AAW=3
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations	AMW	LAMPS	LAMPS=1	LAMPS=3
AMW 6.3, 6.4, 6.5, 6.6	Conduct all-weather helo ops (including helo hanger, haven, and refueling	ASW ASUW FSO NCO	LAMPS	LAMPS=1	LAMPS=3
AMW 12	Provide air control and coordination of air operations	NSFS	NSFS	NSFS=1	NSFS=4
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious operation	NSFS	NSFS	NSFS=1	NSFS=4
AMW 15	Provide air operations to support amphibious	NSFS	NSFS	NSFS=1	NSFS=4

ROCs	Description	MOP	Related DV	Goal	Threshold
	operations				
ASU 1	Engage surface threats with anti-surface armaments	ASUW	ASUW	ASUW=1	ASUW=1
ASU 1.1, 1.2, 1.3	Engage surface ships at long, medium, and close range	ASUW	ASUW LAMPS NSFS	ASUW=1 LAMPS=1 CCC=1	ASUW=3 LAMPS=3 CCC=2
ASU 1.6	Engage surface ships with minor caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=4
ASU 1.9	Engage surface ships with small arms gunfire	All	NSFS	NSFS=1	NSFS=4
ASU 2	Engage surface ships in cooperation with other forces	ASUW	CCC	CCC=1	CCC=2
ASU 4	Detect, identify, localize, and track surface ship targets.	ASUW	C4I PSYS	Option 1 Option 1-3	Option 2 Option 4-6
ASU 4.1	Detect, localize, and track surface contacts with radar	ASUW	C4I PSYS	Option 1 Option 1-3	Option 2 Option 4-6
ASU 4.4	Detect, identify, classify and track surface contacts visually.	ASUW	C4I PSYS	Option 1 Option 1-3	Option 2 Option 4-6
ASU 4.7	Identify surface contacts.	ASUW	C4I	Option 1	Option 2
ASU 6	Disengage, evade and avoid surface attack	ASUW	C4I PSYS	Option 1 Option 1-3	Option 2 Option 4-6
ASU 6.2	Employ evasion techniques.	ASUW			
ASU 6.3	Employ EMCON procedures	ASUW			
ASW (WITH MODULARITY) 1	Engage submarines	ASW	ASW	ASW=1	ASW=3
ASW (WITH MODULARITY) 1.2	Engage submarines at medium range	ASW	ASW PSYS	ASW=1 Option 1-3	ASW=3 Option 4-6
ASW (WITH MODULARITY) 1.3	Engage submarines at close range	ASW	ASW PSYS	ASW=1 Option 1-3	ASW=3 Option 4-6
ASW (WITH MODULARITY) 4	Conduct airborne ASW/recon	ASW	LAMPS	LAMPS=1	LAMPS=3
ASW (WITH MODULARITY) 5	Support airborne ASW/recon	ASW	LAMPS CCC	LAMPS=1 CCC=1	LAMPS=3 CCC=2
ASW (WITH MODULARITY) 7	Attack submarines with antisubmarine armament	ASW	ASW	ASW=1	ASW=3
ASW (WITH MODULARITY) 7.6	Engage submarines with torpedoes	ASW	ASW PSYS	ASW=1 Option 1-3	ASW=3 Option 4-6
ASW (WITH MODULARITY) 8	Disengage, evade, avoid and deceive submarines	ASW	ASW PSYS	ASW=1 Option 1-3	ASW=3 Option 4-6
CCC 1.6	Provide a Helicopter Direction Center (HDC)	CCC	CCC	CCC=1	CCC=2
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions	CCC	CCC	CCC=1	CCC=2
CCC 3	Provide own unit Command and Control	CCC	CCC	CCC=1	CCC=2
CCC 4	Maintain data link capability	AAW ASUW ASW	CCC	CCC=1	CCC=2
CCC 6	Provide communications for own unit	CCC	CCC	CCC=1	CCC=2
CCC 9	Relay communications	CCC	CCC	CCC=1	CCC=2
CCC 21	Perform cooperative engagement	AAW ASUW ASW	CCC	CCC=1	CCC=2
FSO 5	Conduct towing/search/salvage rescue operations	FSO	LAMPS	LAMPS=1	LAMPS=3
FSO 6	Conduct SAR operations	FSO	LAMPS	LAMPS=1	LAMPS=3
FSO 8	Conduct port control functions	FSO	LAMPS	LAMPS=1	LAMPS=3
FSO 9	Provide medical care to assigned and embarked personnel.	ALL			
FSO 10	Provide first aid assistance	ALL			
FSO 11	Provide triage of casualties/patients	ALL			
FSO 12	Provide medical/surgical treatment for casualties/patients	ALL			
FSO 14	Provide medical regulation, transport/evacuation and receipt of casualties and patients	ALL			
INT 1	Support/conduct intelligence collection	INT	LAMPS	LAMPS=1	LAMPS=3
INT 2	Provide intelligence	INT	LAMPS	LAMPS=1	LAMPS=3
INT 3	Conduct surveillance and reconnaissance	INT	LAMPS	LAMPS=1	LAMPS=3
INT 8	Process surveillance and reconnaissance information	INT	LAMPS	LAMPS=1	LAMPS=3
INT 9	Disseminate surveillance and reconnaissance information	INT	LAMPS	LAMPS=1	LAMPS=3
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)	INT	LAMPS	LAMPS=1	LAMPS=3
LOG 1	Conduct underway replenishment				
LOG 2	Transfer/receive cargo and personnel				
LOG 6	Provide airlift of cargo and personnel				
MIW (WITH MODULARITY)	Conduct mine neutralization/destruction	MIW	MIW PSYS	MIW=1 Option 1-3	MIW=3 Option 4-6

ROCs	Description	MOP	Related DV	Goal	Threshold
3					
MIW (WITH MODULARITY) 4	Conduct mine avoidance	MIW	MIW PSYS	MIW=1 Option 1-3	MIW=3 Option 4-6
MIW (WITH MODULARITY) 6	Conduct magnetic silencing (degaussing, deperming)	Magnetic Signature	Degaussing	YES	NO
MIW (WITH MODULARITY) 6.7	Maintain magnetic signature limits	Magnetic Signature	Degaussing	YES	NO
MOB 1	Steam to design capacity in most fuel efficient manner	Sus. Speed, End. Range	Hullform, PSYS	Option 1-3	Option 1-3
MOB 2	Support/provide aircraft for all-weather operations	ALL			
MOB 3	Prevent and control damage	VUL	Cdhmat		
MOB 3.2	Counter and control NBC contaminants and agents	NBC	CPS		
MOB 5	Maneuver in formation	ALL			
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	ALL			
MOB 10	Replenish at sea	ALL			
MOB 12	Maintain health and well being of crew	ALL			
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	provisions	Ts	Ts=21 days	Ts=14 days
MOB 16	Operate in day and night environments	ALL			
MOB 17	Operate in heavy weather	Sea-keeping	Hullform		
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations	Fuel Sys., Clean ballast	BalType	BalType =1	BalType =3
NCO 3	Provide upkeep and maintenance of own unit	ALL			
NCO 19	Conduct maritime law enforcement operations	NCO	ASUW NSFS	ASUW=1 NSFS=1	ASUW=3 NSFS=3
SEW 2	Conduct sensor and ECM operations	AAW	SEW	SEW=1	SEW=3
SEW 3	Conduct sensor and ECCM operations	AAW	SEW	SEW=1	SEW=3
STW 3	Support/conduct multiple cruise missile strikes	STK	GMLS CCC	GMLS=1 CCC=1	GMLS=2 CCC=2

Table 17 - MOP Table

MOP #	MOP	Metric	Goal	Threshold
1	AAW	AAW/SEW option GMLS option SSD option CCC option	AAW=1 GMLS=1 SEW=1 SSD=1 CCC=1	AAW=3 GMLS=2 SEW=1 SSD=2 CCC=2
2	ASUW	ASUW option LAMPS option NSFS option CCC option	ASUW=1 LAMPS=1 SEW=1 NSFS=1 CCC=1	ASUW=2 LAMPS=3 SEW=1 NSFS=4 CCC=2
3	ASW	ASW option LAMPS option CCC option	ASW=1 LAMPS=1 CCC=1	ASW=3 LAMPS=3 CCC=2
4	CCC	CCC option	CCC=1	CCC=2
5	MCM	MCM option	MCM=1	MCM=1
6	ISR	LAMPS option CCC option	LAMPS=1 CCC=1	LAMPS=3 CCC=2
7	Vs	knots	Vs=35knt	Vs=28knt
8	E	nm	E=6000nm	E=4000nm
9	Ts	days	Ts=60	Ts=45
10	Seakeeping	McCreight index	McC=15	McC=4
11	VUL	Deckhouse material, Hull Material	Cdhmat=1	Cdhmat=3
12	NBC	CPS option	Ncps=1	Ncps=1
13	RCS	Deckhouse volume	VD=2000m3	VD=3500m3
14	Acoustic Signature	PSYS option	PSYS=5-16	PSYS=1-4
15	IR Signature	PSYS option	PSYS=5-16	PSYS=1-4
16	Magnetic Signature	Degaussing option	Ndegaus = 1	Ndegaus = 1

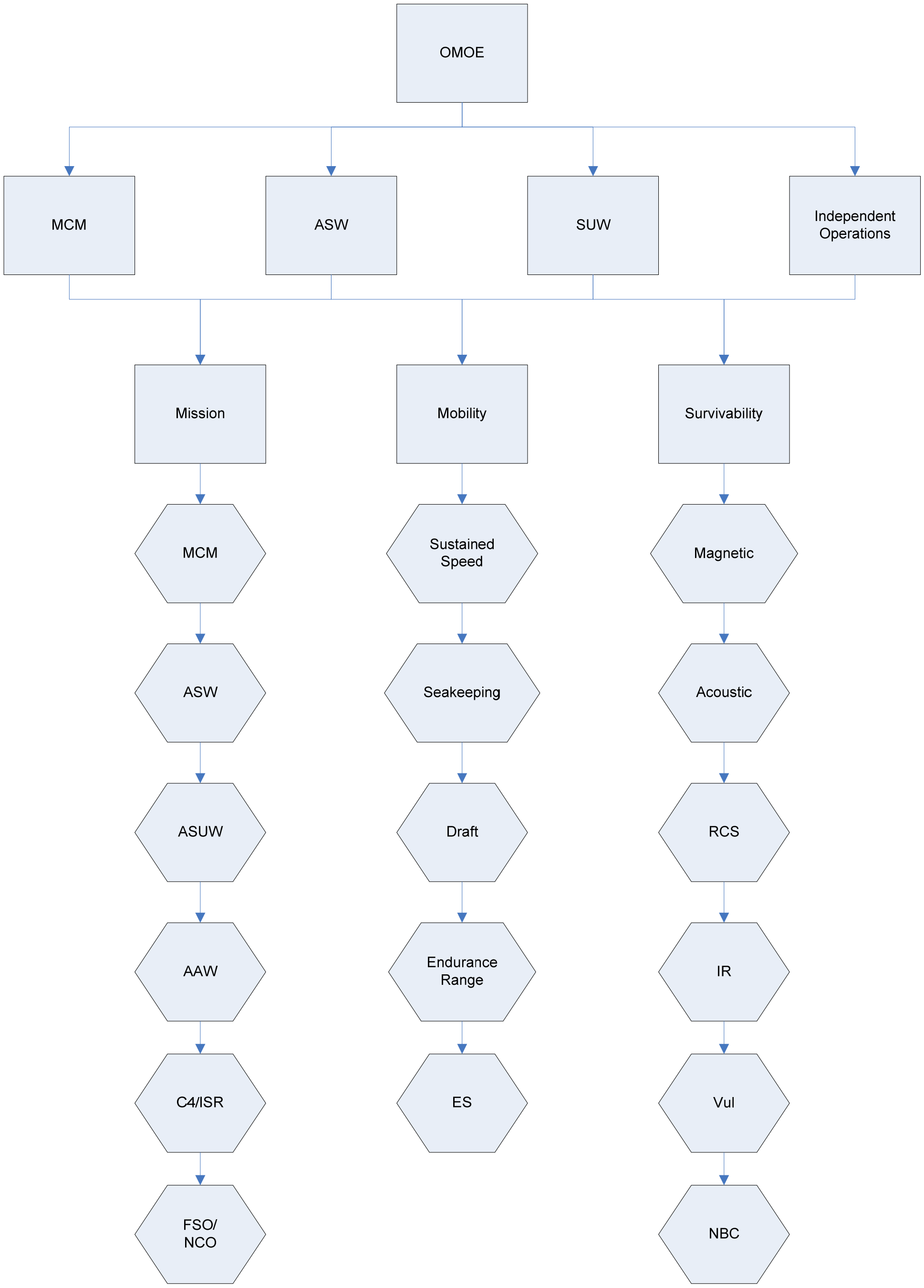
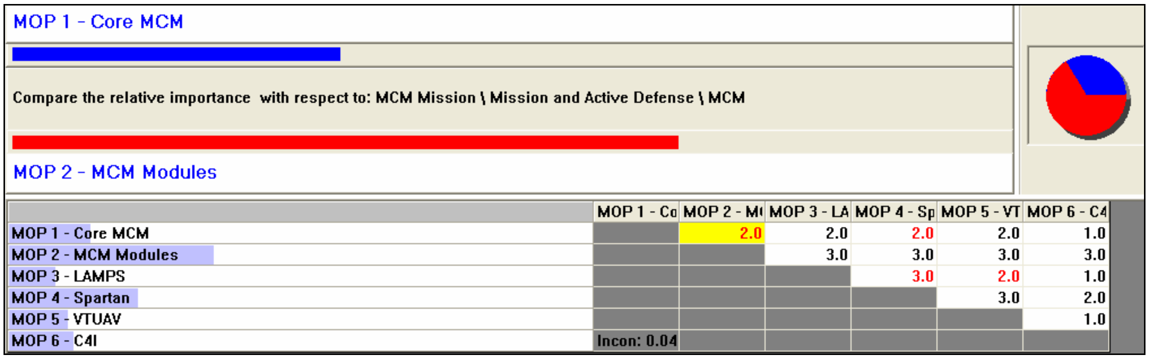


Figure 34 - OMOE Hierarchy



MOP 1 - Core MCM

Compare the relative importance with respect to: MCM Mission \ Mission and Active Defense \ MCM

MOP 2 - MCM Modules

	MOP 1 - Co	MOP 2 - M	MOP 3 - LA	MOP 4 - Sp	MOP 5 - VT	MOP 6 - C4
MOP 1 - Core MCM		2.0	2.0	2.0	2.0	1.0
MOP 2 - MCM Modules			3.0	3.0	3.0	3.0
MOP 3 - LAMPS				3.0	2.0	1.0
MOP 4 - Spartan					3.0	2.0
MOP 5 - VTUAV						1.0
MOP 6 - C4I	Incon: 0.04					

Figure 35 - AHP Pairwise Comparison

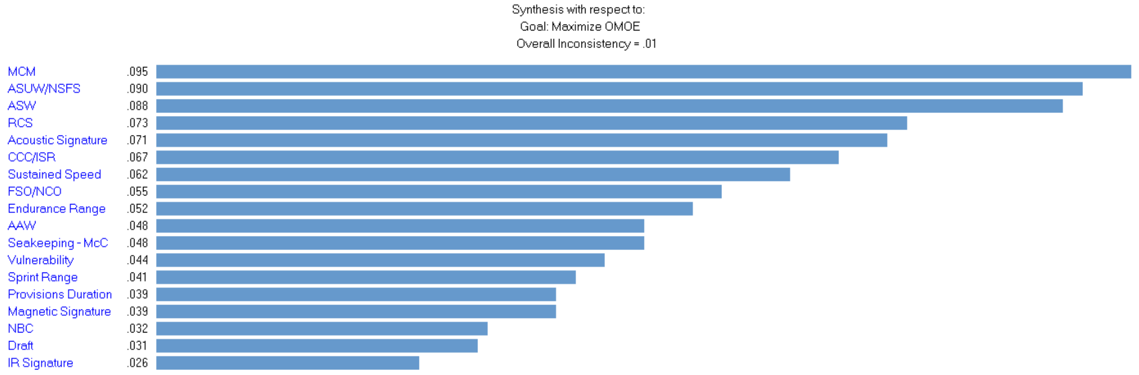


Figure 36 – Bar Chart Showing MOP Weights

Figure 37 - Value of Performance Function for Sprint (Sustained) Speed

Table 18 - Risk Register

SWBS	Risk Type	Related DV #	DV Options	DV Description	Risk Event Ei	Risk Description	Event #	Pi	Ci	Ri
1	Performance	DV17	3	Deckhouse Material	Aluminum producibility problems	USN lack of experience with material	1	0.6	0.6	0.36
1	Performance	DV17	3	Deckhouse Material	Aluminum fire performance does not meet performance predictions	In development and test	2	0.6	0.5	0.3
1	Cost	DV17	3	Deckhouse Material	Aluminum cost overruns impact program	In development and test	3	0.5	0.3	0.15
1	Schedule	DV17	3	Deckhouse Material	Aluminum schedule delays impact program	In development and test	4	0.5	0.2	0.1
1	Performance	DV18	2	Hull Material	Aluminum producibility problems	USN lack of experience with material	5	0.6	0.6	0.36
1	Performance	DV18	2	Hull Material	Aluminum fire performance does not meet performance predictions	In development and test	6	0.6	0.5	0.3
1	Cost	DV18	2	Hull Material	Aluminum cost overruns impact program	In development and test	7	0.5	0.3	0.15
1	Schedule	DV18	2	Hull Material	Aluminum schedule delays impact program	In development and test	8	0.5	0.2	0.1
2	Performance	DV11	(5-16)	Propulsion Systems	WJ Development and Implementation	Reduced reliability and performance (un-proven)	9	0.3	0.6	0.18
2	Cost	DV11	(5-16)	Propulsion Systems	WJ Development, acquisition and integration cost overruns	Research and Development cost overruns	10	0.4	0.4	0.16

2	Schedule	DV11	(5-16)	Propulsion Systems	WJ Schedule delays impact program	In development and test	11	0.3	0.4	0.12
2	Performance	DV11	3,4,8,9,10,14,15,16	Propulsion Systems	WJ Development and Implementation	Unproven, recuperator problems	12	0.5	0.5	0.25
2	Cost	DV11	3,4,8,9,10,14,15,16	Propulsion Systems	WJ Development, acquisition and integration cost overruns	Unproven, recuperator problems	13	0.6	0.4	0.24
2	Schedule	DV11	3,4,8,9,10,14,15,16	Propulsion Systems	WJ Schedule delays impact program	Unproven, recuperator problems	14	0.6	0.5	0.3
2	Performance	DV11	(11-16)	Propulsion Systems	Development and Implementation of APU	Reduced Reliability (un-proven)	15	0.7	0.4	0.28
2	Performance	DV11	(11-16)	Propulsion Systems	Development and Implementation of APU	Shock and vibration of full scale system unproven	16	0.7	0.6	0.42
2	Cost	DV11	(11-16)	Propulsion Systems	APU Implementation Problems	Unproven for USN, large size	17	0.6	0.5	0.3
2	Schedule	DV11	(11-16)	Propulsion Systems	APU Schedule delays impact program	Unproven for USN, large size	18	0.5	0.6	0.3

Table 19 - 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 20 - Event Consequence Estimate

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

3.4.3 Cost

The cost to acquire a lead naval ship is shown in Figure 38. This acquisition cost can be divided into two portions; the cost for the shipbuilder to construct the vessel and costs covered directly by the government. Government costs include unique components needed to build the ship and some of the outfitting that occurs after the vessel has been delivered by the shipbuilder.

Government Furnished Equipment (GFE) refers to equipment specialized to the construction of a ship and used by the shipbuilder, but owned by the government. Life Cycle Cost (LCC) represents the direct total cost to the government of acquisition and ownership of a system over its useful life. This includes cost of the acquisition as well as development, operations, support, and disposal of the military asset. Total Ownership Cost (TOC or CTOC) is another term, which is similar to LCC but with more indirect cost such as logistics support and training. These costs can include any extra cost related items that are not necessarily a product of any singular ship but occur because of specific ship designs. For the design purposes of ASCal, Total Ownership Cost was used to be the objective cost factor. Not only does CTOC better represent the actual price of a ship than the acquisition cost, but it also helps account for the additional costs inherent to the use of new technologies common in ASCal.

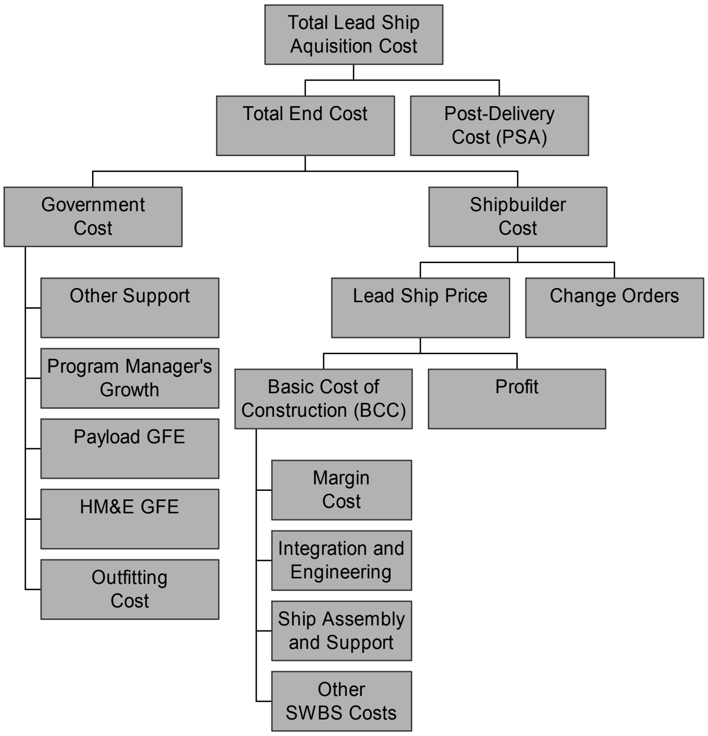


Figure 38 - Naval Ship Acquisition Cost Components

The cost module is used to calculate cost in Concept Exploration. The acquisition cost estimate is based primarily on weight-based regression equations. Hull, deckhouse, propulsion and command-control complexity and producibility factors are used to adjust weight-based estimates. Life cycle cost includes manning and fuel cost. Manning cost is based on the manning estimate and an annual cost/sailor. Fuel cost is based on annual fuel consumption and estimated fuel cost. Manning and fuel consumption are calculated in other modules. Acquisition costs are inflated from the year of their estimates to the base year (FY2010 for ASCal) and future costs are discounted to the base year.

3.5 Multi-Objective Optimization

Multi-Objective Genetic Optimization (MOGO) is the process used to search the design space for the best, non-dominated designs. The optimization process uses a set of objectives, constraints and design variables to develop a non-dominated frontier of the most favorable designs. In the case of this design, the objectives used for optimization were OMOE, OMOR and TOC (see Section 3.4).

The genetic Darwin algorithm was used in conjunction with gradient-based methods during the optimization process. The main difference between the two methods is the management of discrete variables. While genetic algorithms are capable of manipulating both continuous and discrete variables, gradient-based methods are suited only to continuous variables. This allows genetic algorithms, like the Darwin algorithm used for this study, to use parameters like length and draft, as well as discrete options like AAW or propulsion plant options. To produce the initial design configuration of ASCal, the Darwin algorithm was used. A gradient-based method was used after selecting an initial baseline design, with the discrete variables fixed, to further optimize the design.

The basic method of a MOGO is shown in Figure 39. Initially, a random vector of design variables is randomly selected from the design space for a population of ship designs. The ship synthesis model (see Section 3.3) is then used to resolve the level of feasibility, effectiveness (OMOE), risk (OMOR) and cost of each ship in the population. It is important that the design population represent as well as possible the full spectrum of possibilities. To insure a wide spread of options, closely spaced designs (which are said to be in a niche) are penalized.

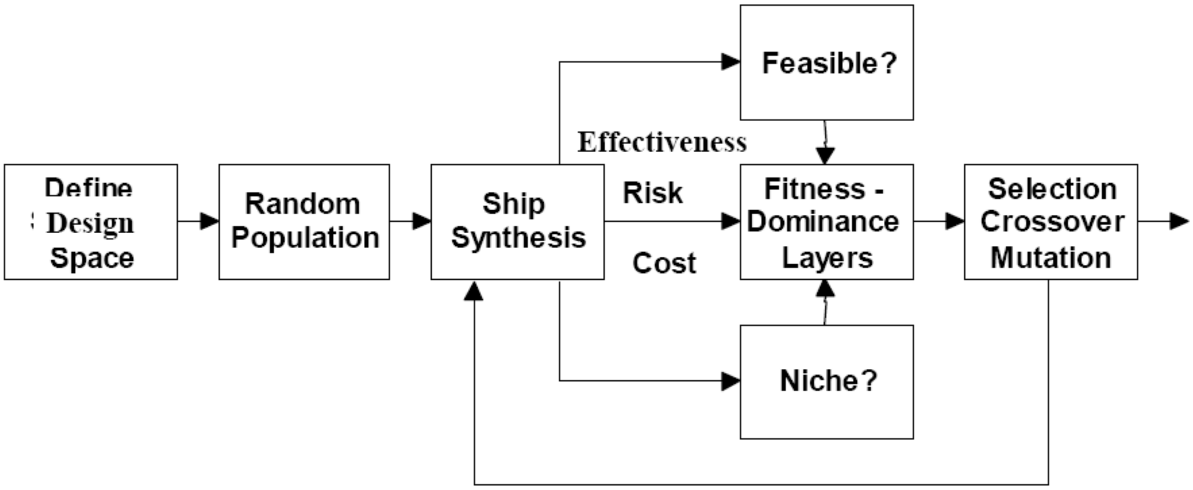


Figure 39 - Multi-Objective Genetic Optimization (MOGO)

The comparative dominance of the population's designs can then be compared. In the case of this study, a dominant design is one that has the highest level of effectives for a given cost and risk. The most dominant designs are selected to create a new population. To develop increased diversity in this new population, variables from pairs of designs are swapped or crossed over to create a new series of designs. The mutation step shown in Figure 39 chooses a random variable from a design and arbitrarily changes that variable. This operation helps to insure that optimization is being performed throughout the entire design space. The selection, crossover and mutation processes work to create a new population, more dominant than the previous. This process can be iterated indefinitely to obtain increasing degrees of refinement.

To control the level of refinement for the ASCal optimization, the number of generations without improvement (a gain in effectiveness for a given cost and risk) is recorded. Once 10 generations (iterations of populations) were created without improvement, the genetic optimization terminated. An upper limit of a total of 100 generations was also set on the convergence of this process.

3.6 Optimization Results and Initial Baseline Design (Variant 26)

The multi-objective optimization produced a non-dominated frontier with 107 variants from which a preferred design was selected. The results resemble a typical non-dominated frontier with a large scattering of designs in the overall measure of risk (OMOR), total ownership cost (CTOC) and overall measure of effectiveness (OMOE) objective space. A large body of variants occur in a common range of OMOR values and varies extensively in CTOC and OMOE. Extremes exist in all three axes and smaller groups of variants occur with varying levels of OMOR and OMOE well distanced from the majority of the non-dominated frontier. The selected design, Variant 26, is highlighted in the non-dominated frontier. Refer to Figure 40 and Figure 41 to see where Variant 26 occurs in relation to the other variants.

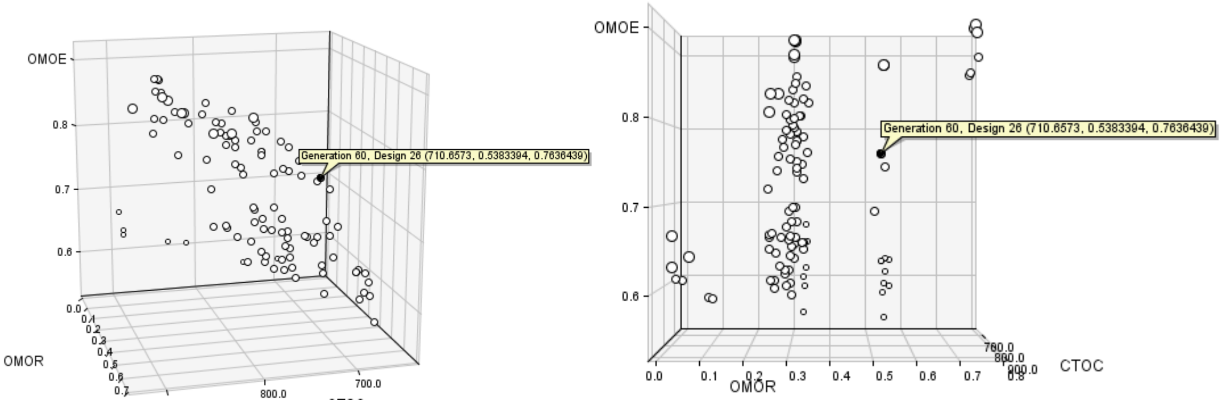


Figure 40 - Non-Dominated Frontier

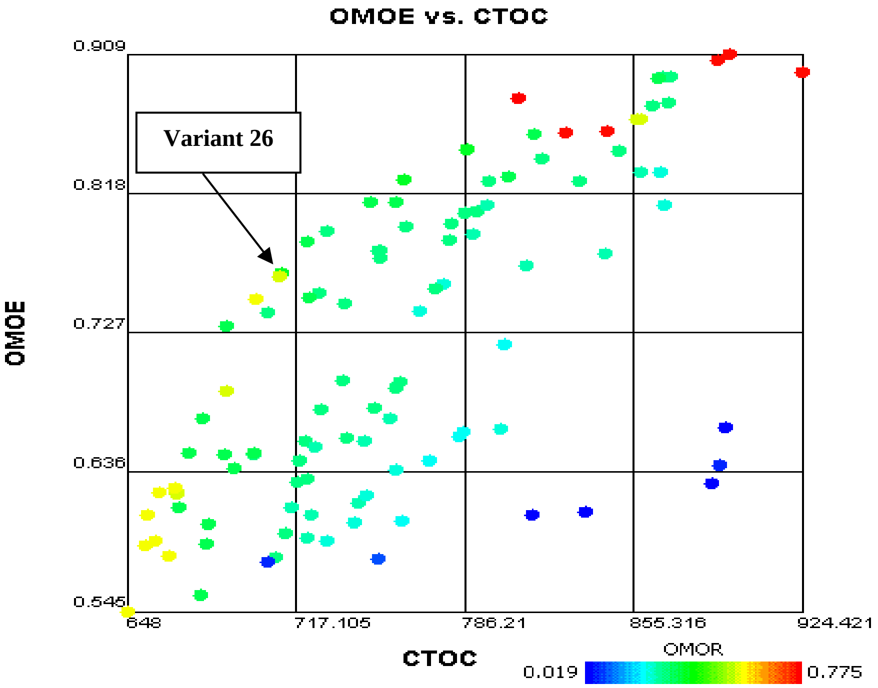


Figure 41 – ASCal 2-D non-dominated frontier

Variant 26 is in the moderate to high risk group shown in Figure 40 primarily due to the selection of aluminum as the design's hull and deckhouse material and high level of automation. It occurs at a "knee" of the curve in this risk group where total ownership cost begins to increase faster than any beneficial gains in overall measure of effectiveness. Variant 26 has an OMOE = 0.764, OMOR = 0.538 and CTOC = $711M (discounted FY 2010). Figure 41 displays a two dimensional representation of the non-dominated frontier with Variant 26 labeled clearly showing its location on a knee of the curve. OMOE is plotted versus CTOC with OMOR shown in color. Variant 26 DV values are listed in Table 21 and compared to the Improved Baseline discussed in the next section. Variant 26 is an all-aluminum design; this includes both the hull and deckhouse. The propulsion system uses two LM2500+ gas turbine engines and two CAT3616 diesel engines. These engines drive the four water jets, with the turbine engines powering two fixed water jets near the centerline and the diesel engines powering two steerable water jets outboard. An arrangement like this is typically referred to as a cruise/boost arrangement. The Collective Protection System uses a partial CPS. This refers to the use of a "sanctuary," or protected area, in the ship. Spaces outside of the sanctuary do not have CPS systems. Anyone needing to venture in or out of these protected spaces must wear a protection suite and be decontaminated when they renter. The design uses a degaussing system to reduce magnetic signature. The combat systems are mostly mid-range options with 2 embarked LAMPS and large hangar able to accommodate AAVs and various mission modules. The Improved Baseline uses the same discrete options as the Initial Baseline with further optimization of hullform, deckhouse area and manning reduction continuous variables.

3.7 Improved Baseline Design

After the Initial Baseline selection, a gradient-based single objective optimization was performed in Model Center using the same discrete variable values as the Initial Baseline, but optimizing hullform, deckhouse area and manning reduction continuous variables constraining Total Ownership Cost (TOC) and risk (OMOR) to be less than or equal to the Initial Baseline values and maximizing effectiveness (OMOE). This optimization resulted in a slightly smaller hull and deckhouse with higher OMOE and lower TOC. Improved Baseline results are compared to the Initial Baseline in Table 21. After conducting a quick feasibility study using ASSET, described in the next section, this Improved Baseline will be the starting point for Concept Development, described in Chapter 4.

Characteristics of the Improved Baseline are provided in Table 21 through Table 26. Table 22 is the Improved Baseline Weight Summary by SWBS group. Table 23 lists the Improved Baseline area requirements and availabilities. The Improved Baseline electrical power requirements are given in Table 24. Improved Baseline MOP values and their associated VOPs are listed in Table 25, and Table 26 provides an overall Improved Baseline principal characteristics summary. Table 26 also compares this Improved Baseline to the ASSET feasibility study results described in the next section. These characteristics compare reasonably well.

Table 21 – Baseline Design Variable and Objectives Summary

Design Variable	Description	Trade-off Range	Initial Baseline Design (Variant 26)	Improved Baseline Design
LWL	Length Water Line	90 to 110 m	102.5	99.9m
LtoB	Length to Beam Ratio	6.5 to 7.5	7.585	7.63
LtoD	Length to Depth Ratio	8.5 to 10	10.663	11.4
beta	Deadrise angle	11 to 13deg	12.314	12 deg
Ccg	Center of Gravity	0.35 to 0.45	.3648	0.388
VD	Volume of the Deckhouse	3000 to 5000 m^3	4278	4149 m^3
CHMAT	Hull Material	1 to 2	1 = Aluminum	
CDHMAT	Deckhouse Material	1to 3	1 = Aluminum	
CMan	Manning Factor	0.5 to 1	.625	0.627
PSYS	Propulsion System Option	1, 2, 6	1 = 2xLM2500 + 2xCAT3616	
Ts	Endurance Time	15 to 45 Days	45 days	
Ncps	Collective Protection System Option	0 to 2	1 = partial	
AAW	Anti-Air Warfare Option	1 to 3	2 = EADS TR-3D C-band radar, 1 x 11 cell Sea Ram, AIMS IFF, COMBAT DF, 2 x SRBOC, 2 x SKWS decoy launcher, COMBAT SS-21	
ASUW	Anti-Surface Warfare Option	1 to 3	3 = AN/SPS-73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR	
ASW	Anti-Submarine Warfare Option	1 to 3	1 = SSTD, AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, MK89 TFCS, Mine Avoidance Sonar	
CCC	Command Control Communications	1 to 2	2 = Comm Suite Level B, CTSCE	1 = Comm Suite Level A, CTSCE
LAMPS	LAMPS Helo Option	1 to 3	1 = 2 x Embarked LAMPS w/ Hangar	
Ndegaus	Degaussing Option	0 to 1	1 = yes	
OMOE	Overall Measure of Effectiveness	0-1.0	.764	.781
OMOR	Overall Measure of Risk	0-1.0	.538	.538
TOC	Total Ownership Cost ($M)		721	681

Table 22 – Improved Baseline Weight Summary

Group	Weight
SWBS 100	508
SWBS 200	549
SWBS 300	126
SWBS 400	147
SWBS 500	245
SWBS 600	113
SWBS 700	31.7
Lightship	1720
Lightship w/Margin	1892
Loads	629
Full Load w/Margin	2521

Table 23 – Improved Baseline Area Summary

Area	Required	Available
Total-Arrangeable	3077	3124
Hull	1707	1740
Deckhouse	1369	1383

Table 24 – Improved Baseline Electric Power Summary

Group	Description	Power (kW)
SWBS 200	Propulsion	303.7
SWBS 300	Electric Plant, Lighting	99.9
SWBS 430, 475	Miscellaneous	101.4
SWBS 521	Firemain	45.5
SWBS 540	Fuel Handling	57.1
SWBS 530, 550	Miscellaneous Auxiliary	26.0
SWBS 561	Steering	33.2
SWBS 600	Services	15.8
CPS	CPS	63.4
KW_{NP}	Non-Payload Functional Load	405.2
KW_{MFLM}	Max. Functional Load w/Margins	2302
KW_{24}	24 Hour Electrical Load	1161

Table 25 - Improved Baseline MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Performance	Value of Performance
MOP 1	AAW	AAW=2, CCC=1	0.878
MOP 2	ASW	ASW=1, LAMPS=1	1.0
MOP 3	FSO/NCO	LAMPS=1, CCC=1	1.0
MOP 4	ASUW	ASUW=3, LAMP=1, CCC=1	0.688
MOP 5	CCC/ISR	CCC=1	1.0
MOP 6	MCM	LAMPS=1, ASW=1, CCC=1	1.0
MOP 7	Sustained Speed	47.3 kts	0.927
MOP 8	Endurance Range	4099 nm	0.915
MOP 9	McCreight Seakeeping	5.0	0.0
MOP 10	Provisions Duration	45 Days	1.0
MOP 11	Draft	3.74 m	0.919
MOP 12	Sprint Range	1143 nm	0.605
MOP 13	Vulnerability	CDHMAT=1, CHMAT=1, PSYStype=1	0.371
MOP 14	NBC	Ncps=1	0.845
MOP 15	RCS	VD=4149 m2, CDHMAT=1	0.516
MOP 16	Acoustic Signature	PSYStype=1	0.345
MOP 17	Magnetic Signature	Ndegause=1, CHMAT=1	1.0
MOP 18	IR Signature	VD=4149 m2	1.0
OMOE	Overall Measure of Effectiveness	NA	0.781
OMOR	Overall Measure of Risk	NA	0.554

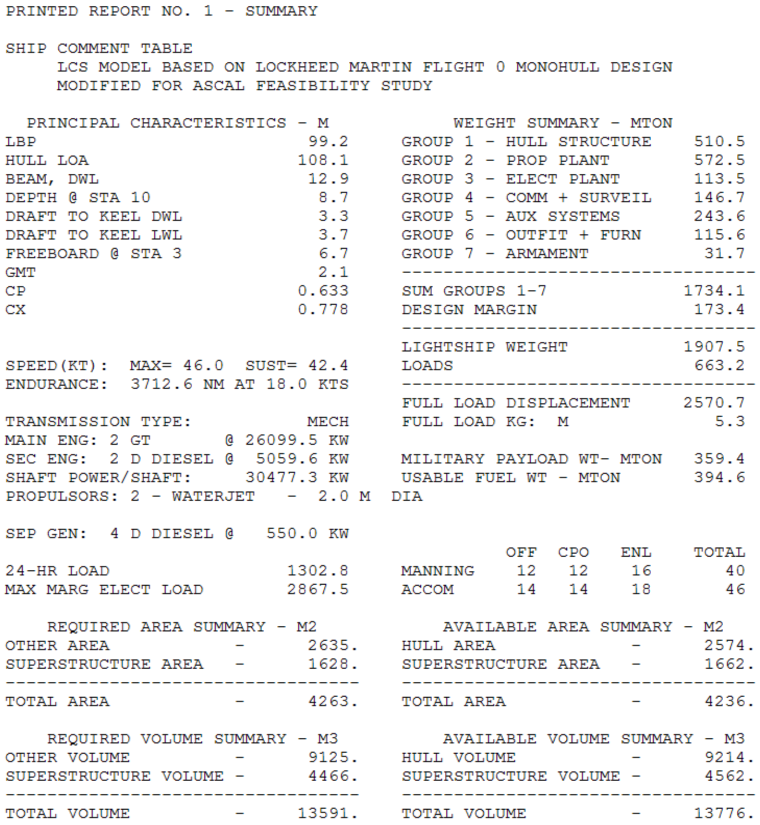
Table 26: Improved Baseline / ASSET Principal Characteristics

Characteristic	Improved Baseline Value (MC)	Baseline Value (ASSET)
Hull form	Semi-Planing Monohull	Semi-Planing Monohull
Δ (MT)	2521	2571
LWL (m)	99.9	99.2
Beam (m)	13.1	12.9
Draft (m)	3.74	3.7
D10 (m)	8.73	8.7
W1 (MT)	508	511
W2 (MT)	549	573
W3 (MT)	126	114
W4 (MT)	147	147
W5 (MT)	245	244
W6 (MT)	113	116
W7 (MT)	31.7	31.7
Wp (MT)	360	359
Lightship w/margin (MT)	1892	1908
KG w/margin (m)	5.22	5.3
Propulsion system	1: 2xMT30 (fixed WJ epicyclic gears), 2xMT30 steerable WJ (IPS)	
Engine inlet and exhaust	Dry Exhaust	
MCM/ASW system	1: SSTD, AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, MK89 TFCS, Mine Avoidance Sonar	
ASUW system	3: AN/SPS-73 Surface Search radar, FLIR, 7m RHIB, 57mm MK 3 Naval gun, SEASTAR SAFIRE III E/O IR	
AAW system	2: EADS TR-3D C-band radar, 1 x 11 cell Sea Par, AIMS IFF, COMBAT DF, 2 x SRBOC, 2 x SKWS decoy launcher, COMBAT SS-21	
Average deck height (m)	3	2.85
Hangar deck height (m)	6	
Total Officers	12	
Total Enlisted	28	
Total Manning	40	
Number of SPARTANs	1	
Number of VTUAVs	3	
Number of LAMPS	2 with Hangar	
Follow-Ship Acquisition Cost ($ Million)	320	NA
Total Ownership Cost ($ Million $FY2010)	681	NA

3.8 ASSET Feasibility Study

ASSET was used to perform a quick feasibility study on the Improved Baseline to increase confidence in our synthesis model analysis. The Lockheed Martin LCS hullform was used as parent hull for the ASCal ASSET model. Figure 42 is the Design Summary for the ASCal ASSET model. Table 26 compares the principal characteristics of the ASSET results to the Improved Baseline. The waterline length and beam are slightly less than the Improved Baseline at the ASSET model's slightly smaller draft. Weights compare well except for a small difference in SWBS

200. This is a result of limitations in ASSET for modeling the ASCal four waterjet propulsion configuration. The space match is also good except for a small deficit in ASSET arrangeable area. The profile generated by ASSET is shown in Figure 43. Shear will be eliminated in concept development to improve producibility and an internal raised deck step will be added. This should also correct the arrangeable area deficit. Resistance, range, sustained speed and electric power will be revisited more thoroughly in Concept Development. In general the two models compare well.



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PRINTED REPORT NO. 1 - SUMMARY

SHIP COMMENT TABLE
     LCS MODEL BASED ON LOCKHEED MARTIN FLIGHT 0 MONOHULL DESIGN
     MODIFIED FOR ASCAL FEASIBILITY STUDY

  PRINCIPAL CHARACTERISTICS - M            WEIGHT SUMMARY - MTON
LBP                            99.2    GROUP 1 - HULL STRUCTURE    510.5
HULL LOA                      108.1    GROUP 2 - PROP PLANT        572.5
BEAM, DWL                      12.9    GROUP 3 - ELECT PLANT       113.5
DEPTH @ STA 10                  8.7    GROUP 4 - COMM + SURVEIL    146.7
DRAFT TO KEEL DWL               3.3    GROUP 5 - AUX SYSTEMS       243.6
DRAFT TO KEEL LWL               3.7    GROUP 6 - OUTFIT + FURN     115.6
FREEBOARD @ STA 3               6.7    GROUP 7 - ARMAMENT           31.7
GMT                             2.1    ----------------------------------
CP                            0.633    SUM GROUPS 1-7             1734.1
CX                            0.778    DESIGN MARGIN               173.4
                                       ----------------------------------
                                       LIGHTSHIP WEIGHT           1907.5
SPEED(KT):  MAX= 46.0  SUST= 42.4      LOADS                       663.2
ENDURANCE:  3712.6 NM AT 18.0 KTS      ----------------------------------
                                       FULL LOAD DISPLACEMENT     2570.7
TRANSMISSION TYPE:             MECH    FULL LOAD KG:  M              5.3
MAIN ENG: 2 GT       @ 26099.5 KW
SEC ENG:  2 D DIESEL @  5059.6 KW      MILITARY PAYLOAD WT- MTON   359.4
SHAFT POWER/SHAFT:     30477.3 KW      USABLE FUEL WT - MTON       394.6
PROPULSORS: 2 - WATERJET   -  2.0 M  DIA

SEP GEN:  4 D DIESEL @   550.0 KW
                                                 OFF  CPO   ENL    TOTAL
24-HR LOAD                   1302.8    MANNING    12   12    16       40
MAX MARG ELECT LOAD          2867.5    ACCOM      14   14    18       46

    REQUIRED AREA SUMMARY - M2             AVAILABLE AREA SUMMARY - M2
OTHER AREA            -       2635.    HULL AREA             -      2574.
SUPERSTRUCTURE AREA   -       1628.    SUPERSTRUCTURE AREA   -      1662.
----------------------------------     ----------------------------------
TOTAL AREA            -       4263.    TOTAL AREA            -      4236.

    REQUIRED VOLUME SUMMARY - M3           AVAILABLE VOLUME SUMMARY - M3
OTHER VOLUME          -       9125.    HULL VOLUME           -      9214.
SUPERSTRUCTURE VOLUME -       4466.    SUPERSTRUCTURE VOLUME -      4562.
----------------------------------     ----------------------------------
TOTAL VOLUME          -      13591.    TOTAL VOLUME          -     13776.
```

Figure 42 – ASSET ASCal hull characteristicsc

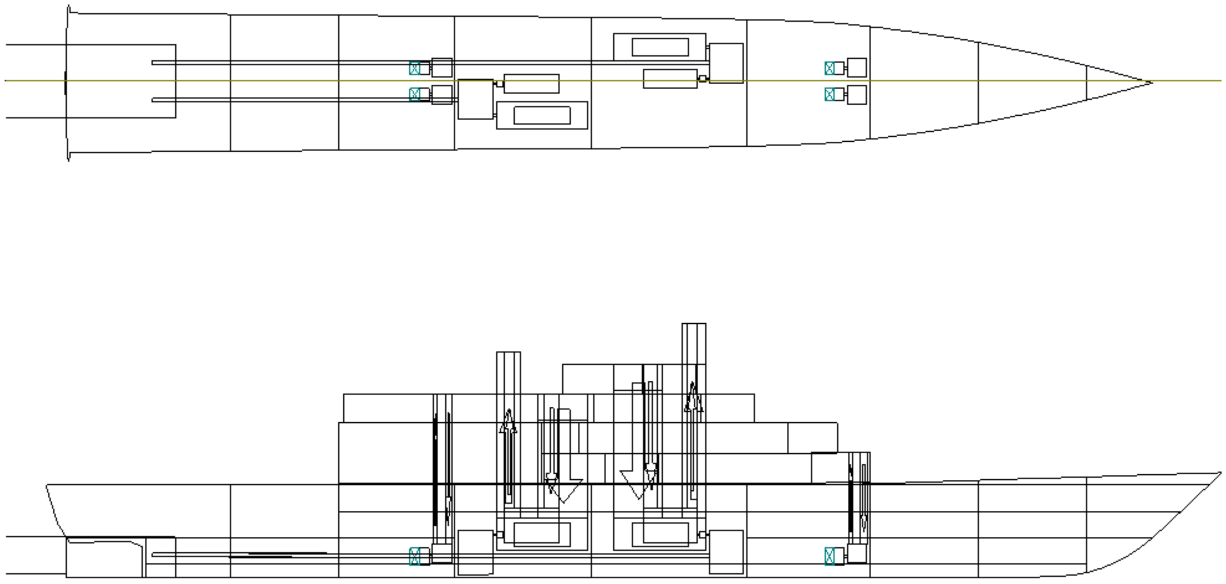


Figure 43 – ASSET ASCal Profile and Plan View

The products of ASCal Concept Exploration are the Improved Baseline Design, technology selection and preliminary requirements (Appendix C – Concept Development Document). These will be the starting point in Concept Development described in Chapter 4.

4 Concept Development

Concept Development of ASCal begins with the Concept Exploration Improved Baseline design, and basically follows the design spiral in sequence, once around. In Concept Development the general concepts for the ship's hull, systems and arrangements are developed. These general concepts are refined into specific systems and subsystems that meet the CDD requirements. Design risk is reduced by this analysis and the parametrics used in Concept Exploration are validated.

4.1 Preliminary Arrangement Cartoon

As a preliminary step in finalizing hull form geometry, deck house geometry, and general arrangements, an arrangement cartoon was developed for areas supporting mission operations, propulsion, and other critical constrained functions. Machinery rooms are located beneath the deckhouse. This configuration allows for vertical venting of exhaust and intake for the gas turbines. Ballast tanks were located in the far forward and aft sections, giving a maximum available trimming moment for the least amount of space. Modular mission spaces have been located in the aft portion of the ship below the flight deck, hangar and forward of the hangar.

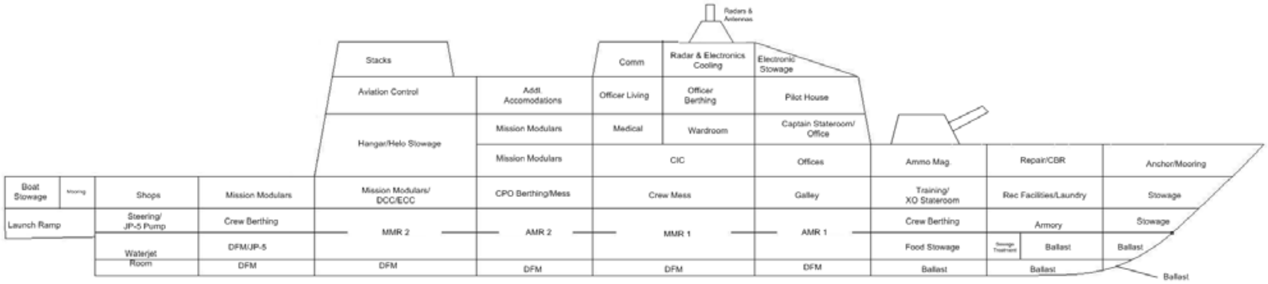


Figure 44 – General Arrangement Cartoon

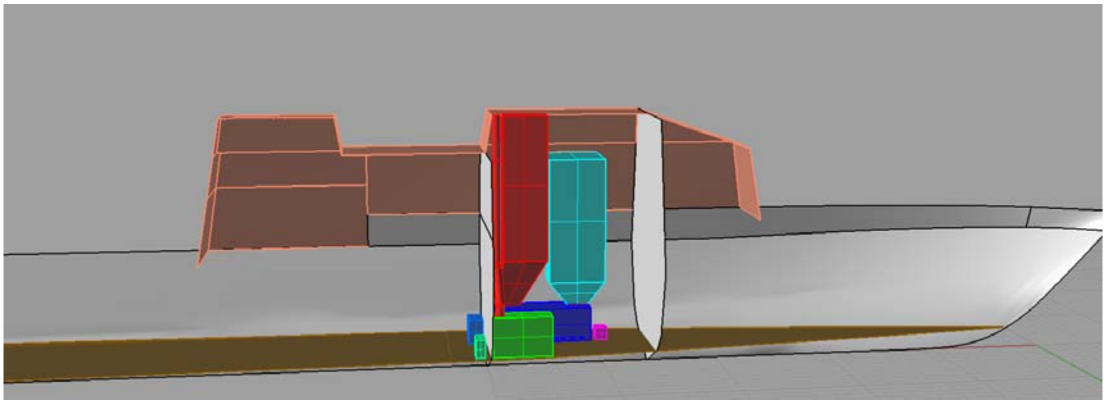


Figure 45 – Main Machinery Room 1 with Intake and Exhaust

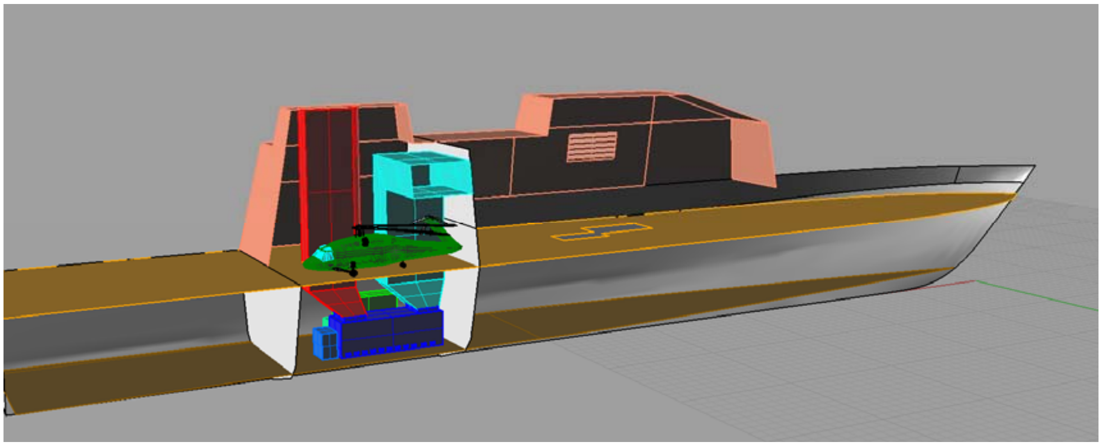


Figure 46 – Main Machinery Room 2 with Intake and Exhaust

Shear was eliminated in the foredeck with an internal raised deck step just forward of the hangar. This improved producibility, increased freeboard forward, improved structural continuity and slightly increased arrangeable area.

Figure 45 show Main Machinery Room 1 (MMR1) and its intake and exhaust vents between transverse bulkheads 4 and 5. Exhaust travels out through the top of the deckhouse, and intake comes in from side at the 02 level. Figure 46 shows Main Machinery Room 2 (MMR2) and its intake and exhaust vents between transverse bulkheads 4 and 5. Both intake and exhaust vents travel up through the center of hangar space, leaving room for the storage of one SH-60 helicopters on each side. This 3D model was developed from the original cartoon to sort out potential alignment and hangar space problems.

The major details of ASCal's topside arrangement are shown in Figure 47**.** The use of a stepped deck allows for all mooring and anchor handling equipment to be located below deck and reduce RCS. The 57mm MK3 deck gun is the only major feature on the ship's deck, but even it has been given a radar cross-section reducing shield.

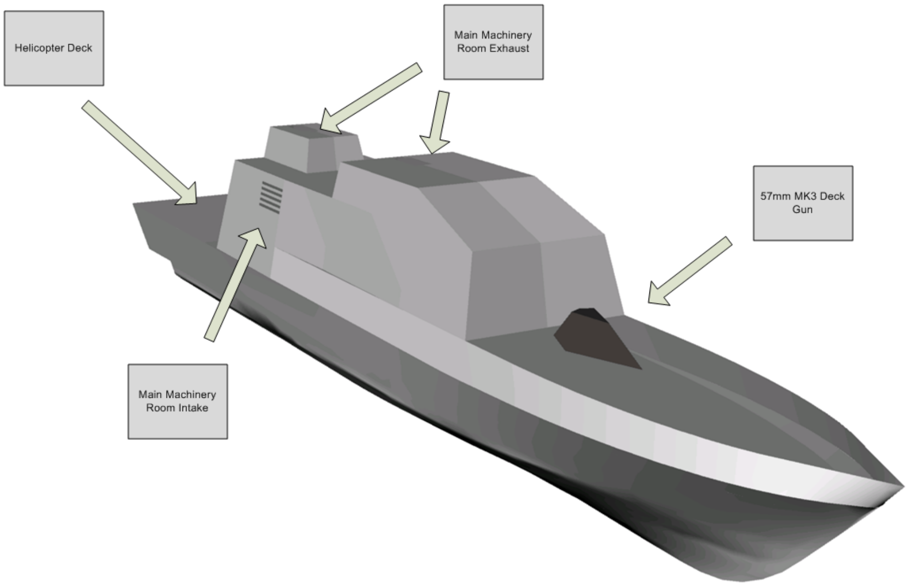


Figure 47 – ASCal Topside Arrangement

4.2 Hull Form, Subdivision and Deck House

4.2.1 Hullform

The principle characteristics of the ASCal Improved Baseline hullform are listed in Table 27, extracted from **Error! Reference source not found.**. The ASSET feasibility study hullform was imported into Rhino and modified, primarily above the waterline, improve producibility, seakeeping, RCS, arrangements and structural continuity.

Table 27 – ASCal Improved Baseline Hullform Characteristics

	Value
LWL	99.9m
LOA	105.9m
B	13.1m
T	3.74m
D_{10}	8.73m
Δ	2521MT

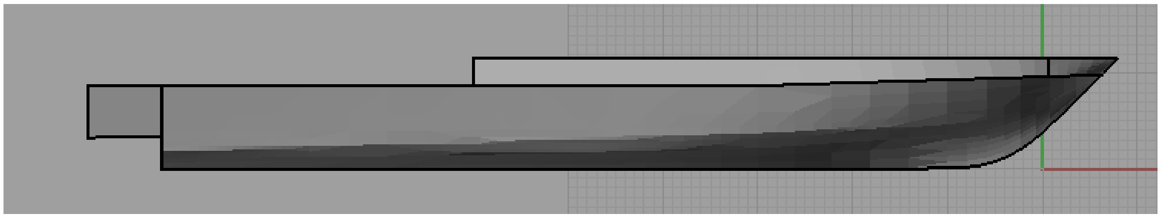


Figure 48 – Profile View of ASCal Hullform Showing Step in Deck

Radar cross-section, producibility and seakeeping were all improved by changing the originally sheared weather deck to a stepped deck, shown in Figure 48. This change allows for all anchor and rope handling equipment to be located below deck, reducing radar cross-section. The elimination of a curved shear deck also increases producibility. The increased depth at the ship's bow is advantageous for seakeeping.

Figure 49 shows the body plan for the ASCal hull. Notice the hard chines present in the design to improve the semi-planing characteristics of the ship. A stepped transom also allow for waterjet installation along with a rear craft launching area. Curves of form are shown in Figure 50.

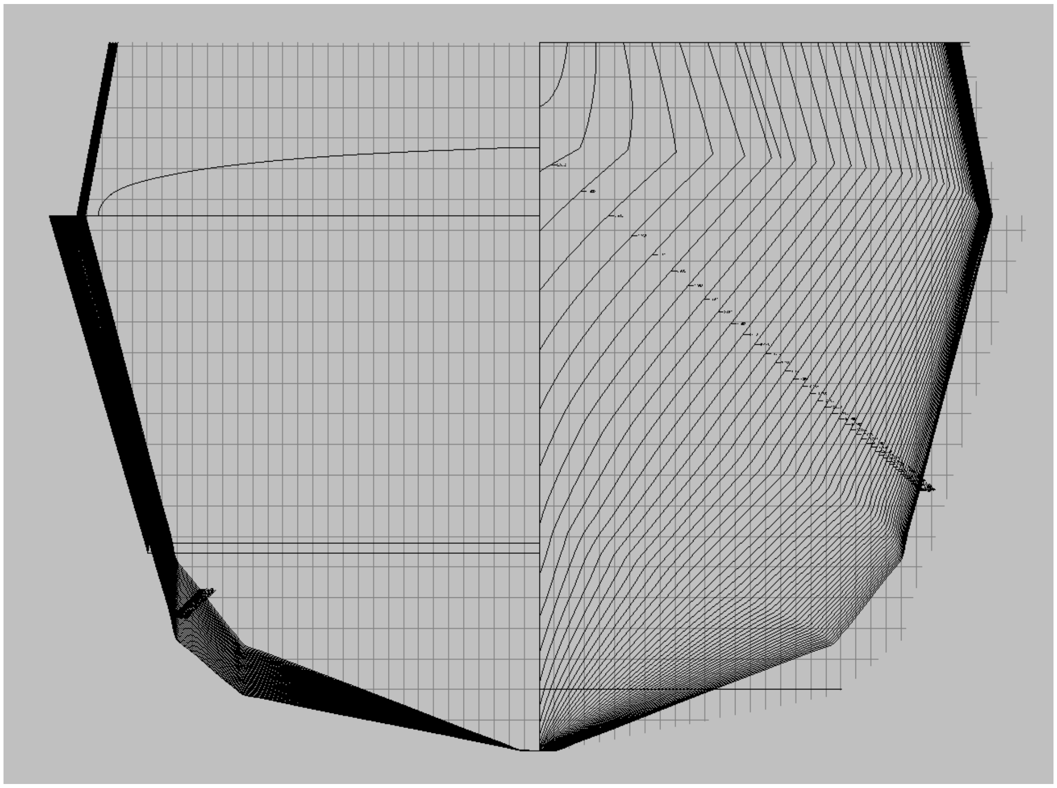


Figure 49 – ASCal Body Plan

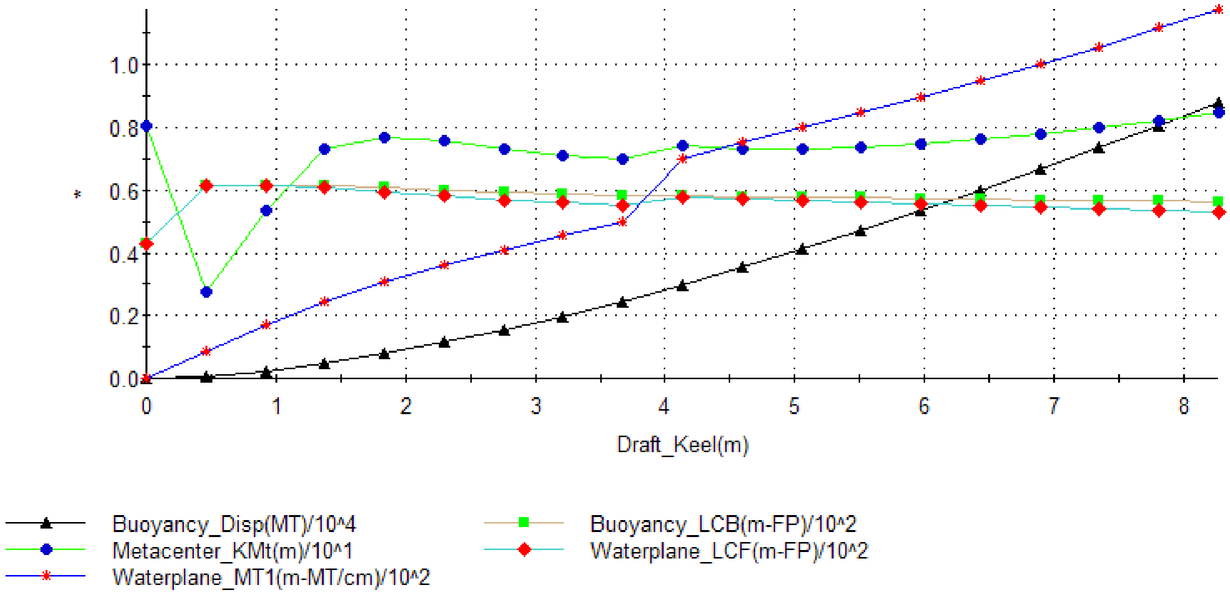
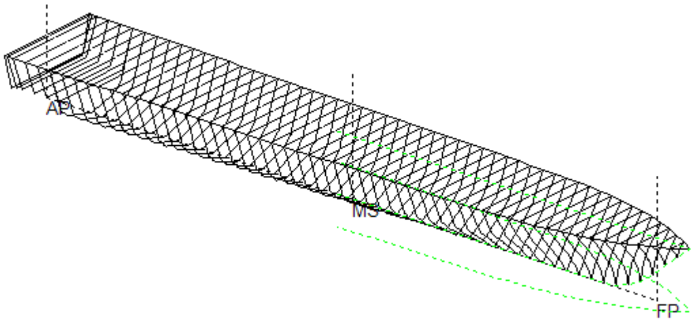
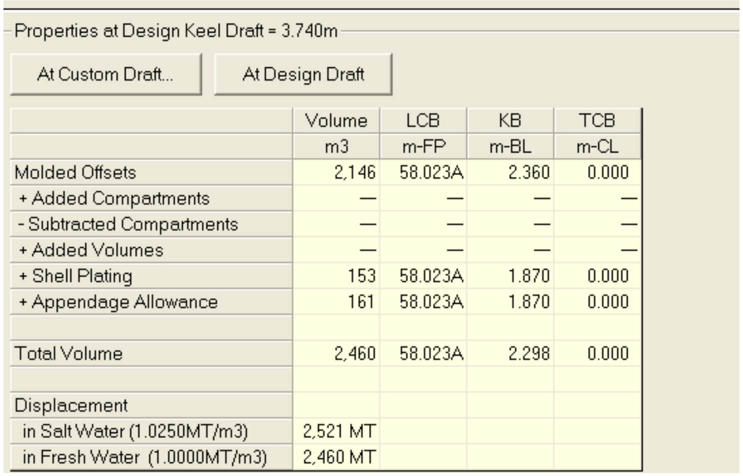


Figure 50 – ASCal Curves of Form

4.2.2 Improved Baseline Subdivision and Preliminary Loading

Subdivision, tankage design and loading were done using HECSALV. Transverse bulkhead location and tankage are necessary inputs to general arrangements, machinery arrangements and the structural design. Figure 51 shows the ASCal hullform imported into HECSALV. Figure 52 shows the floodable length curve for ASCal developed using HECSALV. The ship was assessed and transverse bulkhead locations adjusted to satisfy a 15% damage length as specified in DDS 079-1.





Properties at Design Keel Draft = 3.740m

	Volume m3	LCB m-FP	KB m-BL	TCB m-CL
Molded Offsets	2,146	58.023A	2.360	0.000
+ Added Compartments	—	—	—	—
- Subtracted Compartments	—	—	—	—
+ Added Volumes	—	—	—	—
+ Shell Plating	153	58.023A	1.870	0.000
+ Appendage Allowance	161	58.023A	1.870	0.000
Total Volume	2,460	58.023A	2.298	0.000
Displacement				
in Salt Water (1.0250MT/m3)	2,521 MT			
in Fresh Water (1.0000MT/m3)	2,460 MT			

Figure 51: Improved Baseline Hullform with Displacement Match

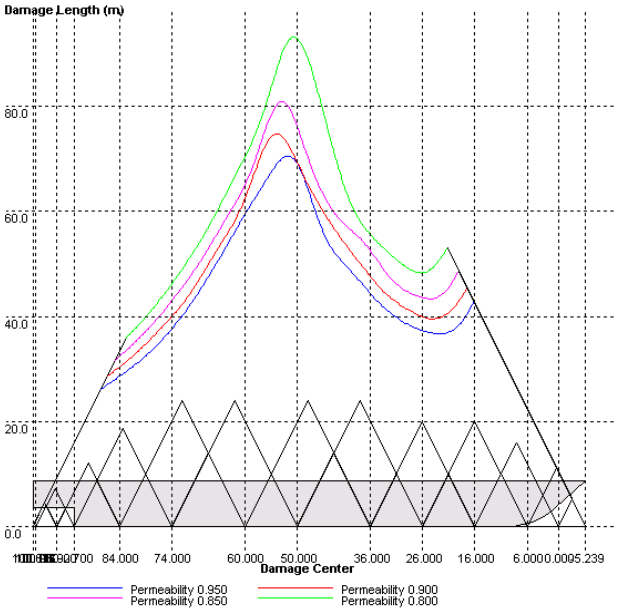
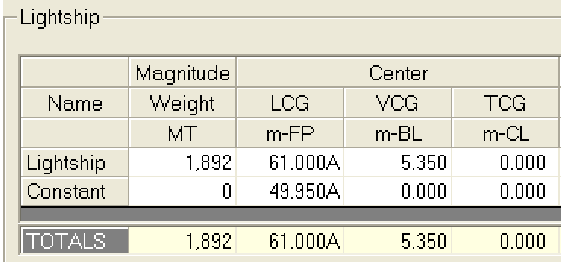


Figure 52 – Improved Baseline Floodable Length Curve

The Savitsky resistance calculation for the Improved Baseline included an optimum LCG location to minimize planing resistance. A Full Load LCG of 0.388*LBP forward of the AP or 61.14 meters aft of the FP (99.9-.388*99.9) was specified. The lightship weight LCG and tankage locations were adjusted to achieve this Full Load LCG, and an approximate lightship weight distribution was generated for use with structural loads to match this LCG. Figure 53 shows the resulting Improved Baseline lightship weight distribution. The resulting tankage arrangement is shown in Figure 54.



	Magnitude	Center		
Name	Weight	LCG	VCG	TCG
	MT	m-FP	m-BL	m-CL
Lightship	1,892	61.000A	5.350	0.000
Constant	0	49.950A	0.000	0.000
TOTALS	1,892	61.000A	5.350	0.000

Lightship Weight Blocks

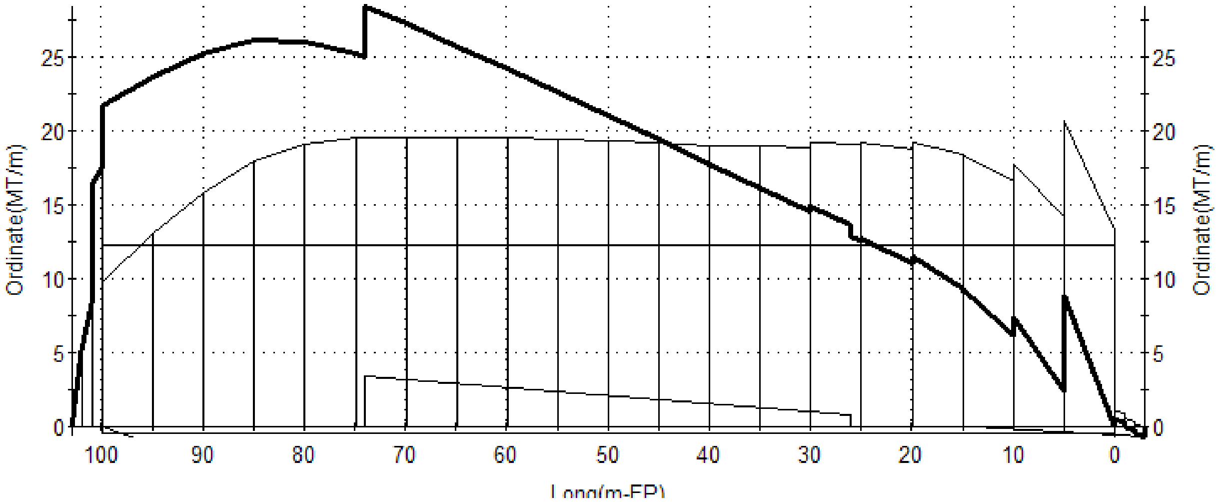
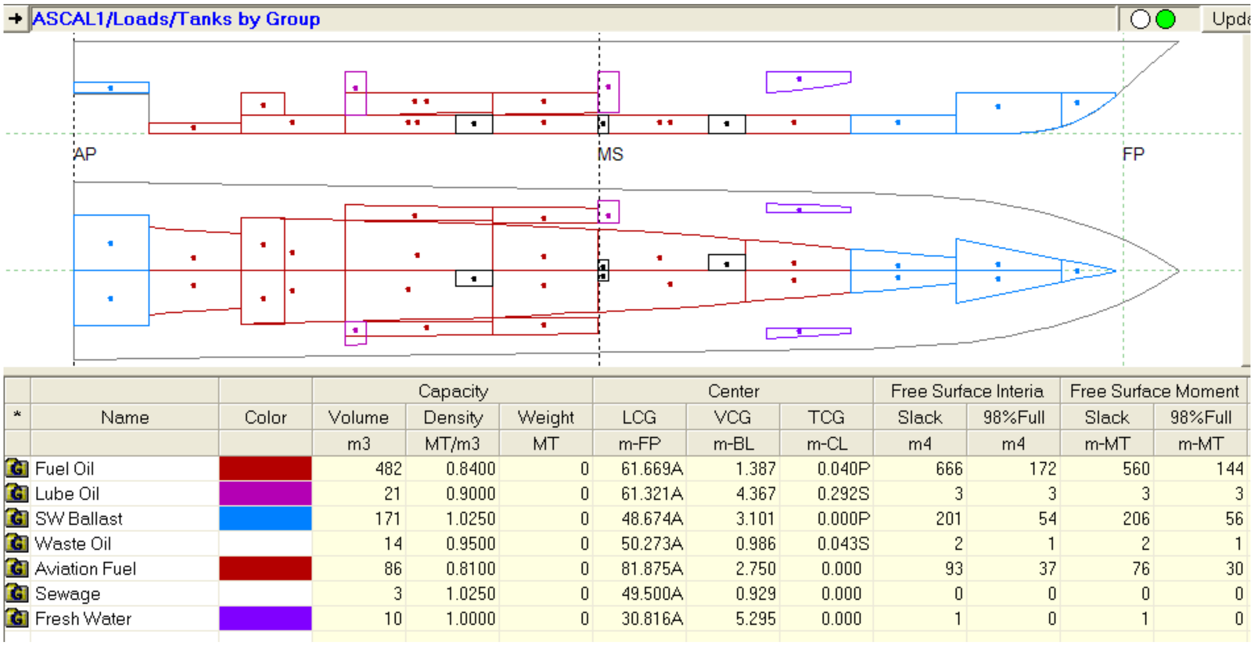


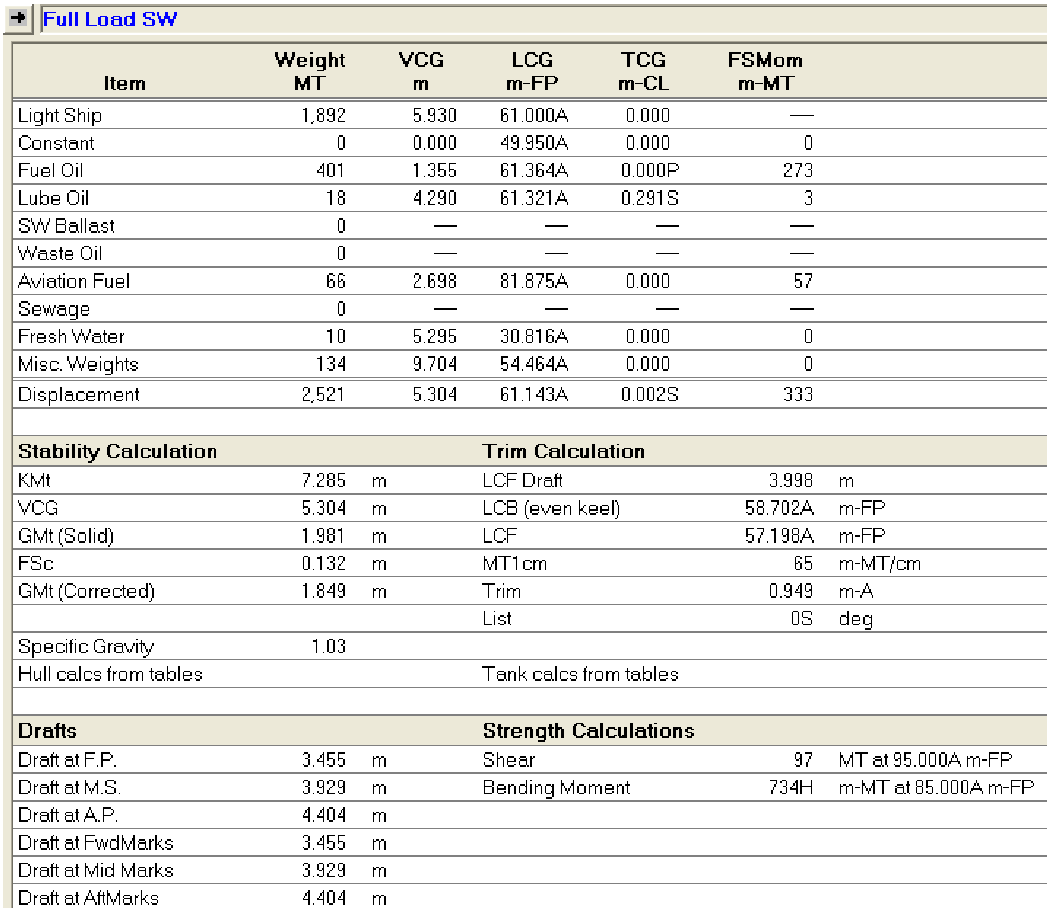
Figure 53: Lightship Weight Distribution



*	Name	Color	Capacity			Center			Free Surface Interia		Free Surface Moment	
	Name	Color	Volume	Density	Weight	LCG	VCG	TCG	Slack	98%Full	Slack	98%Full
			m3	MT/m3	MT	m-FP	m-BL	m-CL	m4	m4	m-MT	m-MT
	Fuel Oil	🟥	482	0.8400	0	61.669A	1.387	0.040P	666	172	560	144
	Lube Oil	🟪	21	0.9000	0	61.321A	4.367	0.292S	3	3	3	3
	SW Ballast	🟦	171	1.0250	0	48.674A	3.101	0.000P	201	54	206	56
	Waste Oil		14	0.9500	0	50.273A	0.986	0.043S	2	1	2	1
	Aviation Fuel	🟥	86	0.8100	0	81.875A	2.750	0.000	93	37	76	30
	Sewage		3	1.0250	0	49.500A	0.929	0.000	0	0	0	0
	Fresh Water	🟪	10	1.0000	0	30.816A	5.295	0.000	1	0	1	0

Figure 54: Tankage Arrangement

Figure 55 through Figure 58 show the preliminary stability analysis for the ship's Full Load and Minimum Operational (MinOp) loading conditions. Trim angle (slight down by stern), LCG location and intact stability were satisfactory in this preliminary analysis. The LCG match was good.

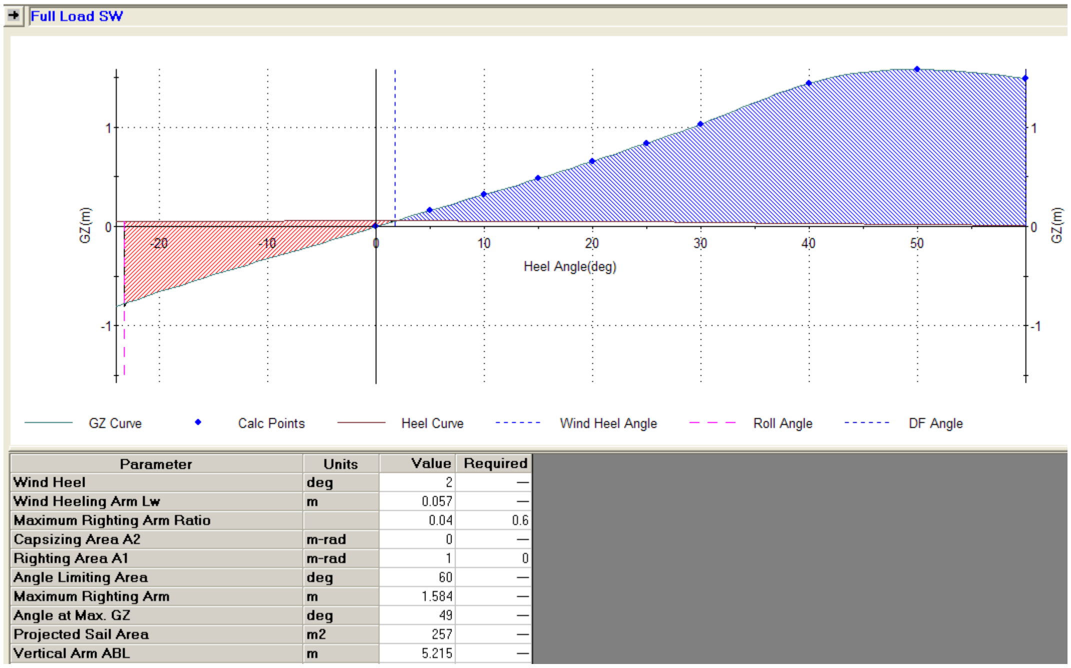


Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	1,892	5.930	61.000A	0.000	—
Constant	0	0.000	49.950A	0.000	0
Fuel Oil	401	1.355	61.364A	0.000P	273
Lube Oil	18	4.290	61.321A	0.291S	3
SW Ballast	0	—	—	—	—
Waste Oil	0	—	—	—	—
Aviation Fuel	66	2.698	81.875A	0.000	57
Sewage	0	—	—	—	—
Fresh Water	10	5.295	30.816A	0.000	0
Misc. Weights	134	9.704	54.464A	0.000	0
Displacement	2,521	5.304	61.143A	0.002S	333

Stability Calculation			Trim Calculation		
KMt	7.285	m	LCF Draft	3.998	m
VCG	5.304	m	LCB (even keel)	58.702A	m-FP
GMt (Solid)	1.981	m	LCF	57.198A	m-FP
FSc	0.132	m	MT1cm	65	m-MT/cm
GMt (Corrected)	1.849	m	Trim	0.949	m-A
			List	0S	deg
Specific Gravity	1.03				
Hull calcs from tables			Tank calcs from tables		

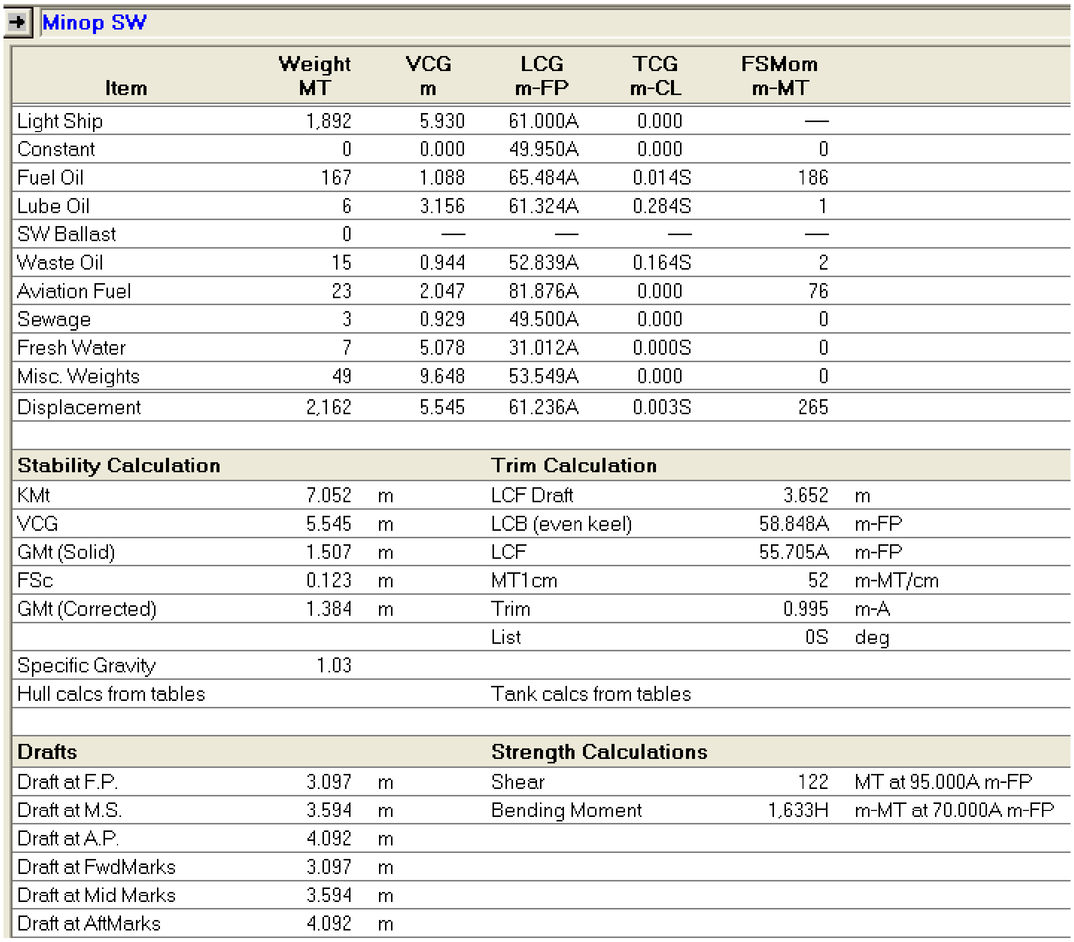
Drafts			Strength Calculations		
Draft at F.P.	3.455	m	Shear	97	MT at 95.000A m-FP
Draft at M.S.	3.929	m	Bending Moment	734H	m-MT at 85.000A m-FP
Draft at A.P.	4.404	m			
Draft at FwdMarks	3.455	m			
Draft at Mid Marks	3.929	m			
Draft at AftMarks	4.404	m			

Figure 55: Improved Baseline Preliminary Intact Full Load Condition to Check LCG and Stability



Parameter	Units	Value	Required
Wind Heel	deg	2	—
Wind Heeling Arm Lw	m	0.057	—
Maximum Righting Arm Ratio		0.04	0.6
Capsizing Area A2	m-rad	0	—
Righting Area A1	m-rad	1	0
Angle Limiting Area	deg	60	—
Maximum Righting Arm	m	1.584	—
Angle at Max. GZ	deg	49	—
Projected Sail Area	m2	257	—
Vertical Arm ABL	m	5.215	—

Figure 56: Preliminary Full Load Improved Baseline Righting Arm Curve



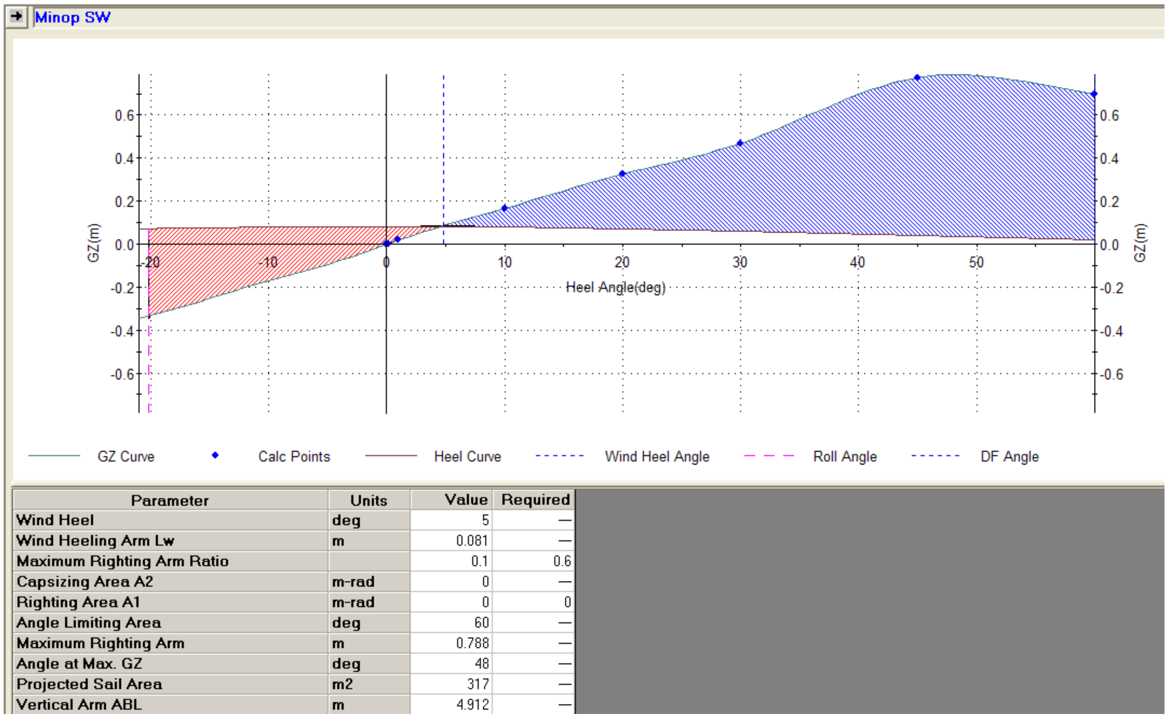
Minop SW

Item	Weight MT	VCG m	LCG m-FP	TCG m-CL	FSMom m-MT
Light Ship	1,892	5.930	61.000A	0.000	—
Constant	0	0.000	49.950A	0.000	0
Fuel Oil	167	1.088	65.484A	0.014S	186
Lube Oil	6	3.156	61.324A	0.284S	1
SW Ballast	0	—	—	—	—
Waste Oil	15	0.944	52.839A	0.164S	2
Aviation Fuel	23	2.047	81.876A	0.000	76
Sewage	3	0.929	49.500A	0.000	0
Fresh Water	7	5.078	31.012A	0.000S	0
Misc. Weights	49	9.648	53.549A	0.000	0
Displacement	2,162	5.545	61.236A	0.003S	265

Stability Calculation			Trim Calculation		
KMt	7.052	m	LCF Draft	3.652	m
VCG	5.545	m	LCB (even keel)	58.848A	m-FP
GMt (Solid)	1.507	m	LCF	55.705A	m-FP
FSc	0.123	m	MT1cm	52	m-MT/cm
GMt (Corrected)	1.384	m	Trim	0.995	m-A
			List	0S	deg
Specific Gravity	1.03				
Hull calcs from tables			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at F.P.	3.097	m	Shear	122	MT at 95.000A m-FP
Draft at M.S.	3.594	m	Bending Moment	1,633H	m-MT at 70.000A m-FP
Draft at A.P.	4.092	m			
Draft at FwdMarks	3.097	m			
Draft at Mid Marks	3.594	m			
Draft at AftMarks	4.092	m			

Figure 57: Improved Baseline Preliminary Intact MinOp Condition to Check LCG and Stability



Parameter	Units	Value	Required
Wind Heel	deg	5	—
Wind Heeling Arm Lw	m	0.081	—
Maximum Righting Arm Ratio		0.1	0.6
Capsizing Area A2	m-rad	0	—
Righting Area A1	m-rad	0	0
Angle Limiting Area	deg	60	—
Maximum Righting Arm	m	0.788	—
Angle at Max. GZ	deg	48	—
Projected Sail Area	m2	317	—
Vertical Arm ABL	m	4.912	—

Figure 58: Preliminary MinOp Improved Baseline Righting Arm Curve

4.2.3 Deck House

Figure 59 shows the ASCal deckhouse and major deckhouse arrangement information. Including the helicopter hangar, the deckhouse is approximately 50m long and is centered slightly forward of amidships. At its two highest points, the deckhouse itself (not including the enclosed radar mast) rises approximately 16m above the design waterline. The pilot house is located 1 deck above the forward weather deck. Specific design considerations were made for the shape of the pilot house. ASCal possesses a low angle deckhouse (unlike LCS-1) to offer maximum usability, visibility and access. Wind resistance penalty was determined to be small. All non-horizontal faces are sloped 10° from the vertical plane to reduce radar cross-section.

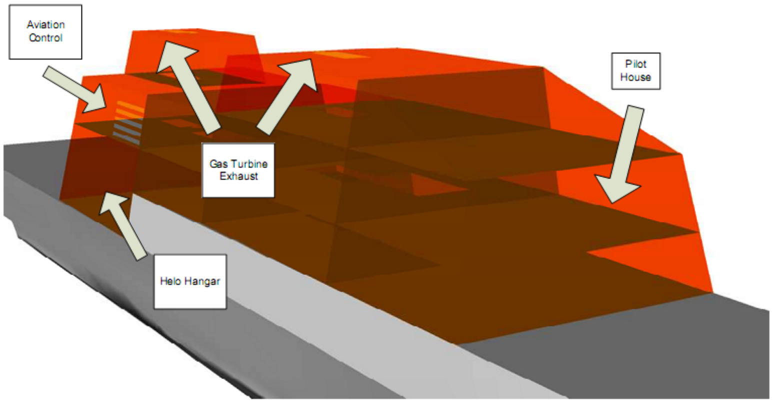


Figure 59 – ASCal Deckhouse

Along with aviation control and the ship's pilot house, the deckhouse holds officer berthing, a ship medical space and modular mission spaces. The CIC is located below the deckhouse, to provide a central and survivable location for combat systems coordination. Figure 60 shows a close up of the General Arrangement layout centered on the deckhouse (see Section 4.8 for a full explanation of General Arrangements).

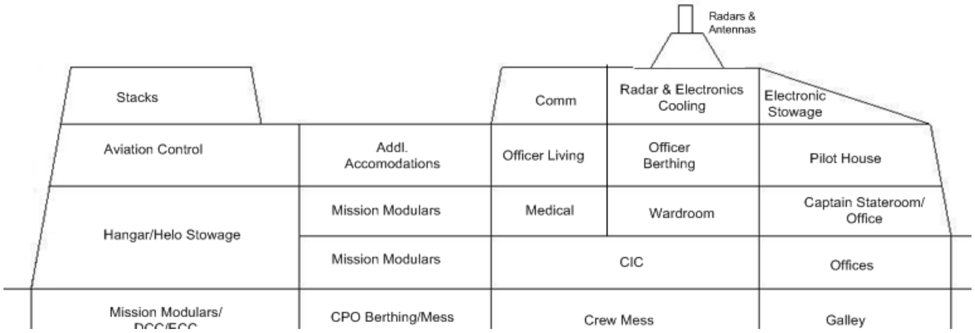


Figure 60 – ASCal Arrangement

4.3 Ship Production

ASCal has an aluminum hull and deckhouse. The hull is a producible monohull with no difficult appendages and minimal curvature above the waterline. Issues and characteristics unique to ASCal production are as follows:

- General Group Classification and Zones:
  - Bow/stern - 1000/4000 - more curvature and transition to transverse stiffening
  - Hull Cargo - 2000
  - Machinery - 3000- difficult distributed systems and outfitting
  - On-board - 5000 - actually defines construction stage - electrical wiring, etc.
  - Special - 6000 – high skill - electronics, CS, accommodations
- Block break criteria
  - Above deck (10cm) and aft of TBHD (25cm)
  - Stiffeners on fwd side of TBHD
  - Blocks extend between TBHD - attempt to keep TBHD spacing less than plate length (50')
  - Max block width - 15m
  - Blocks one deck high except wing tanks/spaces and in bow
  - Max block weight - 60 MT

- General arrangements
  - Air locks on fwd side of TBHD
  - Standard openings / closures
  - Escape trunks on fwd side of TBHD
  - Standard space arrangements, avoid mirror image (AFFF, Troop Living, Crew Living, Fanrooms etc.)
  - Transverse passageways on aft side of TBHD
- Special Processes and Specifications
  - Maximum use of outfit package units (test before install)
  - Permit wirebrushing in lieu of blasting of erection butts and seams
  - Permit one-sided welding with ceramic backing tape when joining units
  - Use sleeve couplings to join piping
  - Use pre-fab plate with piping welded to it for bulkhead penetrations.
  - Maximize retention of CFE and GFE paint
  - Permit use of weld-through primer

Figure 61 shows the ASCal production block diagram and Table 28 is the ASCal claw chart.

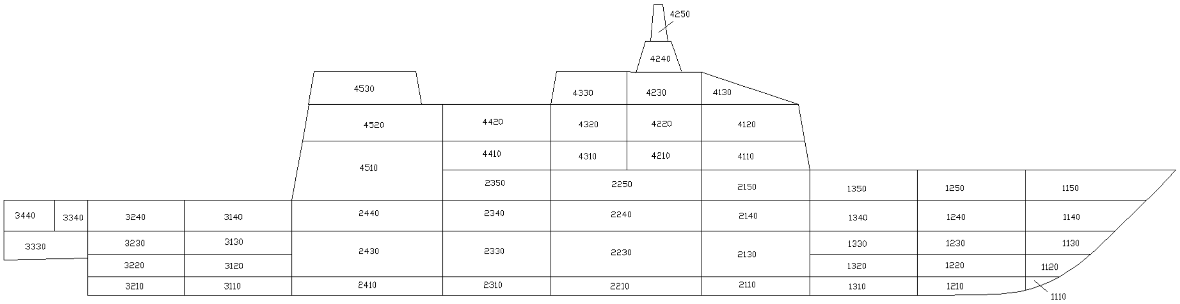


Figure 61 – ASCal Production Block Diagram

Table 28 – ASCal Production Claw Chart

Week #	1100	1200	1300	2100	4100 2200	4200 2300	4300 2400	4400 3100	3200	3300	3400
1					2210	2310					
2				2110			2410				
3					2230			3110			
4					MMR 1		2430				
5				2130			MMR 2				
6				AMR 1		2330					
7			1310			AMR 2					
8			1320		2240						
9		1220				2340					
10	1120						2440				
11			1330					3110			
12		1230							3210		
13	1130			2140				3120			
14			1340						3220		
15		1240						3130			
16	1140								3230		
17								3140		3320	
18									3240		3430
19	SSHAFT									3330	
20	PSHAFT									3340	
21							4310				3440
22						4210		4420			
23						4220	4320				
24					4110		4330				
25					4130			4430			
26						4240	4340				

4.4 Structural Design and Analysis

Structural design and analysis started with ASSET geometry and scantlings which we refined in MAESTRO. Figure 62 shows our overall structural design process. The initial hull form and scantlings came from the Structures

Module of ASSET. This provided plate, stiffener, girder, and frame dimensions, stiffener spacing, and material properties. Next a finite element model was built using MAESTRO. The model is comprised of a series of modules, each module spanning from one transverse bulkhead to the next. End points in MAESTRO were creating using the nodes from ASSET. Each of these endpoints was connected to the adjacent endpoints by strakes. Each strake consisted of a stiffened panel and at appropriate spacing the girders and frames. The girder and frame placement was chosen with producibility, arrangements, and structural integrity in mind. Once the finite element model was completed, load cases were developed based on the ABS rules and applied to determine the stresses and strains in each component. These stresses and strains were then compared to safety criteria (limit states) for the structure.

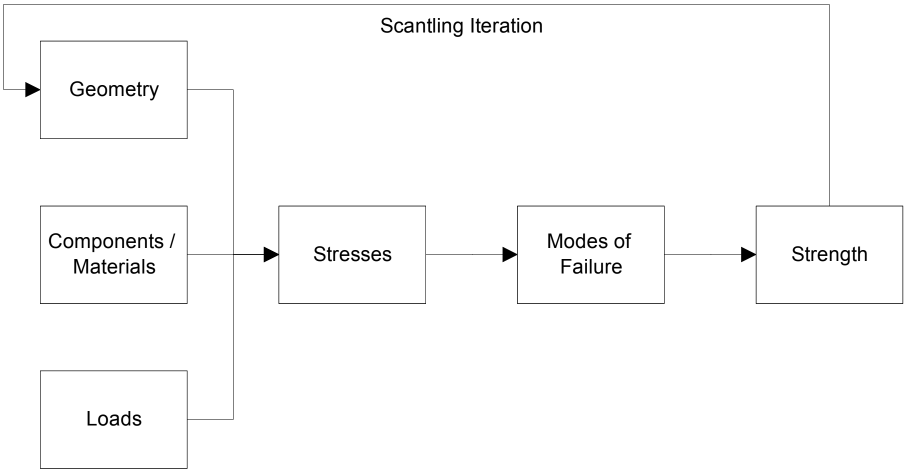


Figure 62 - Structural Design Process

4.4.1 Geometry, Components and Materials

The general structural concept as modeled uses plate with longitudinal stiffeners running continuously. The frames are evenly spaced every 2 meters along the length of the ship; girders are placed in accordance with the analysis run in ASSET, adjusted to be consistent with load paths and continuity. Transverse bulkheads are placed in accordance with functional and floodable length considerations. Each transverse bulkhead also uses stiffeners running vertically along the forward side of the bulkhead. All of the plates, stiffeners, girders, and frames are made out of Aluminum alloy 5083. The properties of Al 5083 are listed in Table 29.

Table 29 - Strength Properties of Al 5083

Property	Value
Ultimate Tensile Strength [N/mm^2]	269
As-welded Yield Strength [N/mm^2]	145
Un-welded Yield Strength [N/mm^2]	200
Shear Strength [N/mm^2]	83

The use of traditional aluminum construction methods was assumed in this model. Stiffeners, girders, frames, and panels are welded using MIG welding procedures. The use of extruded shapes and advanced welding techniques like Friction Stir Welding were not considered. This is an area requiring more focus and in depth research.

The finite element model for ASCal is shown in Figure 63 through Figure 65. Figure 63 gives an overview of the whole finite element model. Notice the absence of the 2nd deck between bulkheads 3 through 7. This is where the machinery rooms are located and due to the large volume taken up by the machinery there is not room for structural decks in these compartments. Columns are added to this space. There will be platforms to provide working space and access to controls, but the platforms are not structural and therefore they are not modeled here. Figure 64 provides an overview of the exterior of the hull. Here the deck step, and “cut” in the transom can be seen. Also visible in the forward section are the hard chine lines that are necessary for planing performance. The profile view in Figure 65 provides a better view of the transom cut and the step in the deck.

Figure 66 provides an overview of the interior structure of the hull. The decks have been hidden to allow the frames and girders to be visible. The girders and stiffeners, not visible, are continuous and run the length of the ship, going through the transverse bulkheads and the frames.

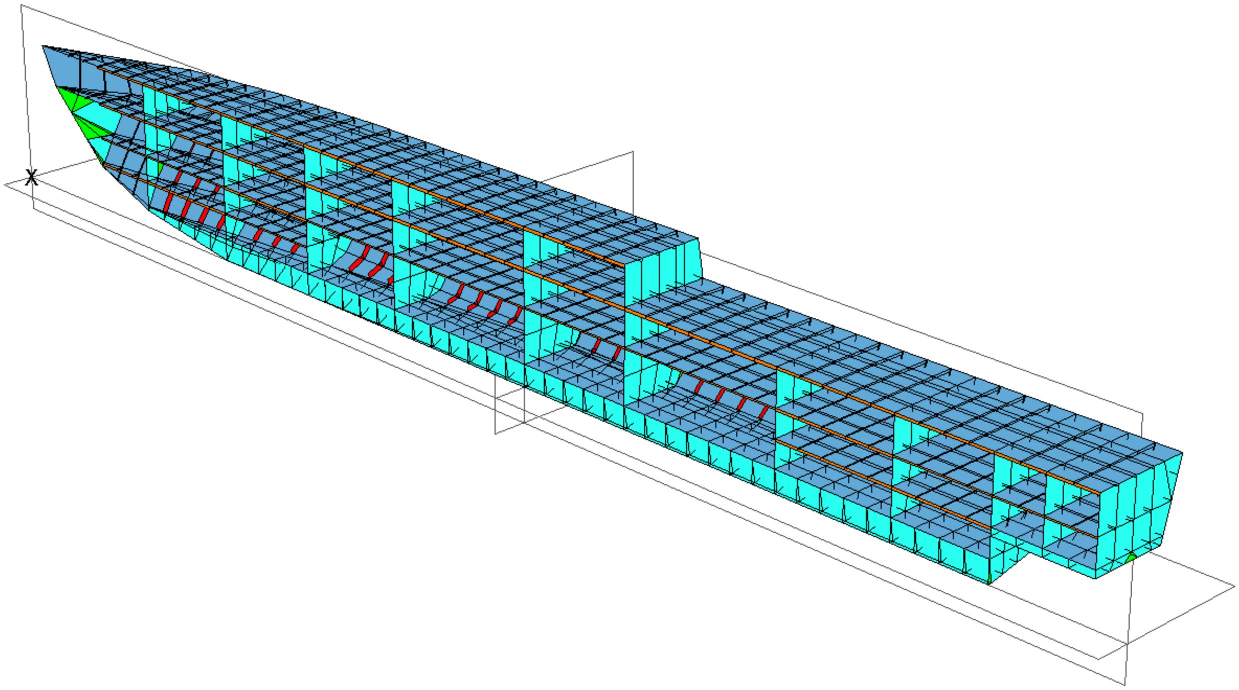


Figure 63 - ASCal Finite Element Model, Showing the Interior of the Hull

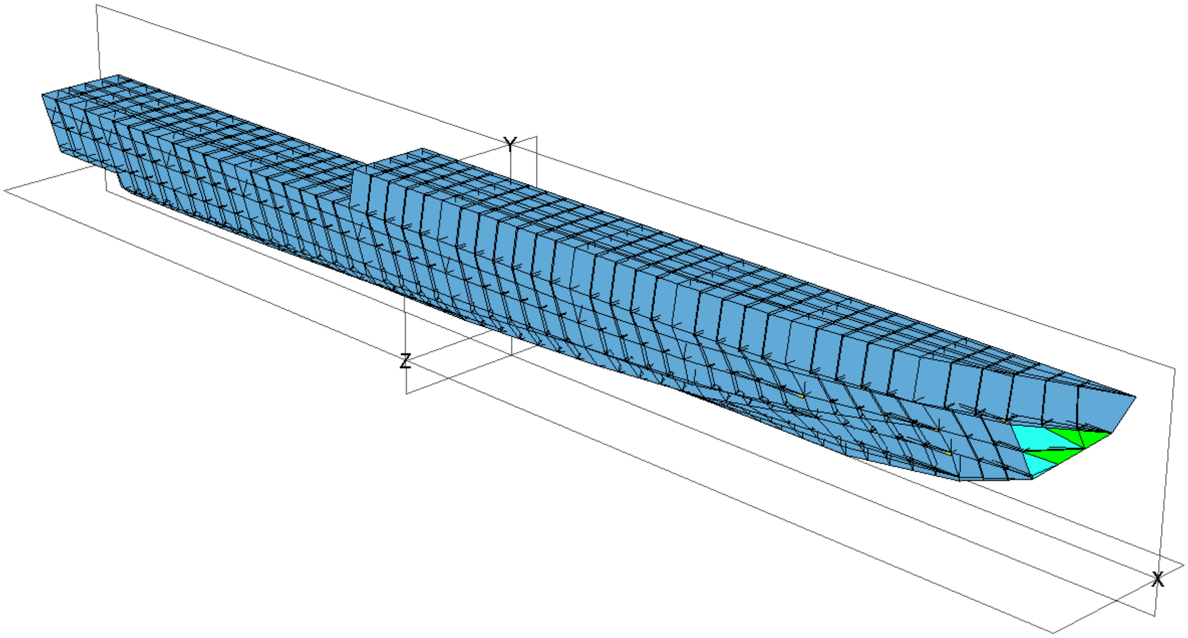


Figure 64 - Starboard Side View, Showing the Exterior of the Hull

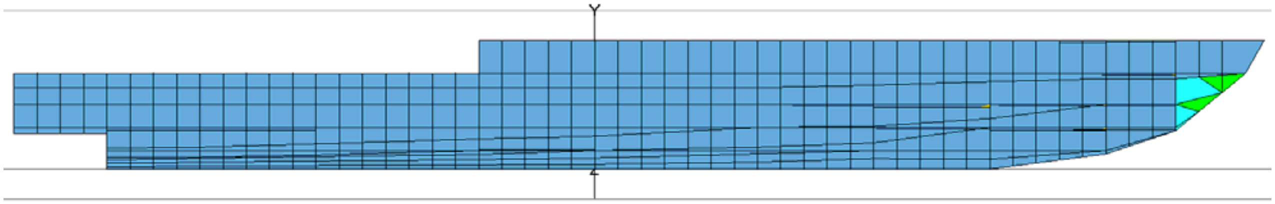


Figure 65 - Profile View of the Exterior of the Hull

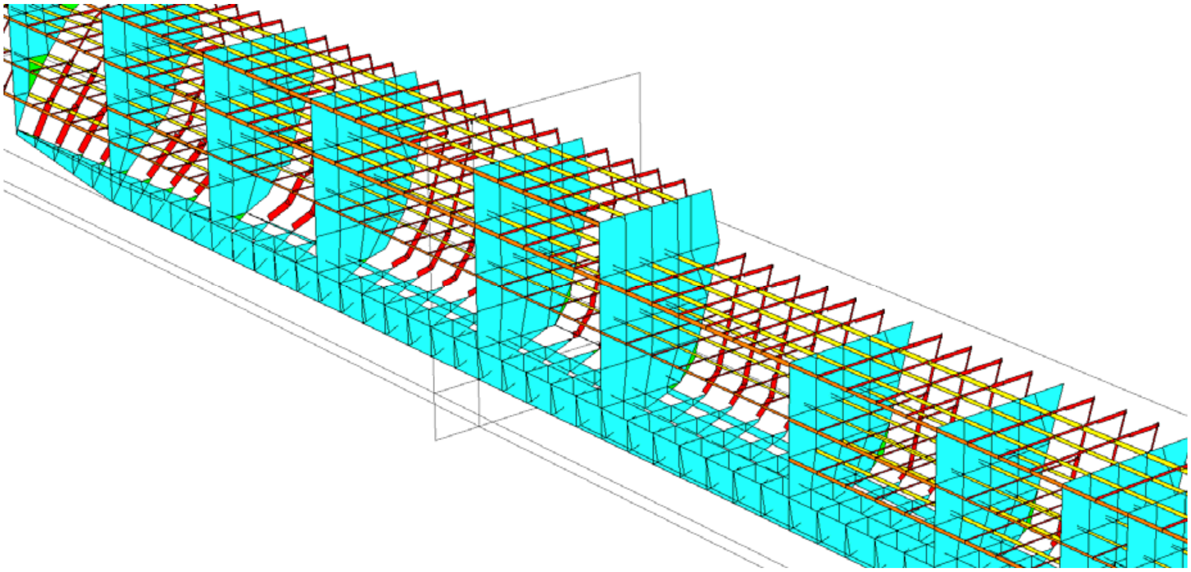


Figure 66 - Overview of Frames, Girders and Transverse Bulkheads

Figure 67 through Figure 69 show the full level of structural detail for a single module. This module was taken from the aft end of the ship and is a typical module. Starting with Figure 67 one can see the whole module, with all parts in it. In Figure 68 the strakes, or stiffened panels, have been hidden so that the frames and girders can be visible. Finally in Figure 69 the frames and girders have been hidden so that the details of the inner bottom can be seen.

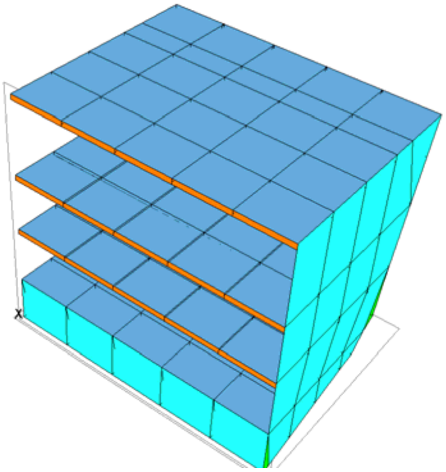


Figure 67 - Complete Aft Section Showing All Decks and Innner Bottom

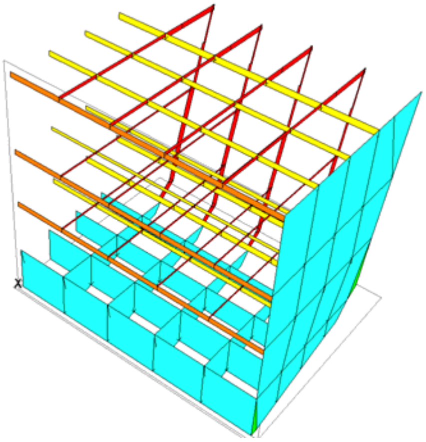


Figure 68 - Aft Section with Decks Hidden, Showing Frames and Girders

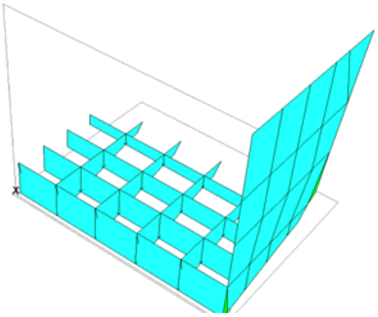


Figure 69 - Aft Section with Decks, Frames, and Girders Hidden, Showing the Detail of the Inner Bottom

The last two structural figures, Figure 70 and Figure 71, show an aft module and a forward module respectively. In each of these different details of the design can be seen including deadrise, hard chines, and the deck step.

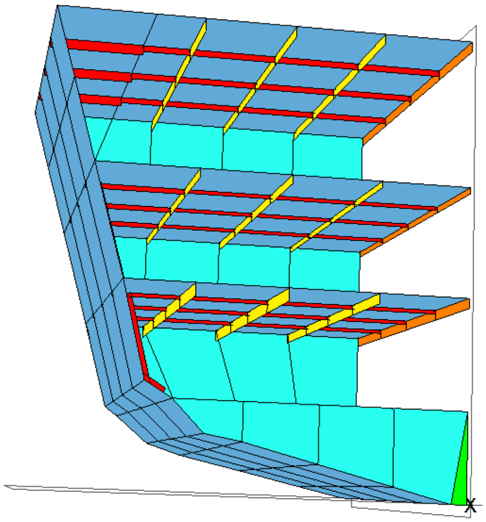


Figure 70 - Aft Section Showing Internal Arrangement, and Deadrise

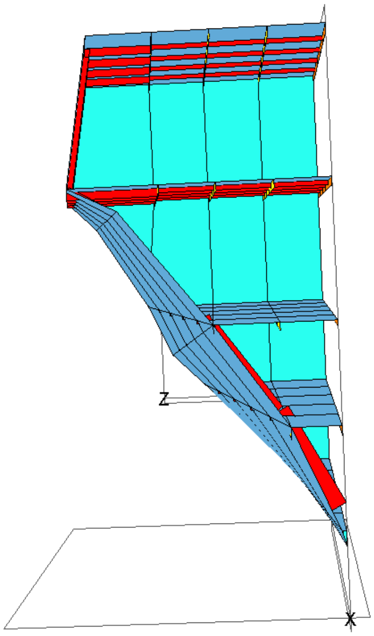


Figure 71 - Forward Section Showing Hard Chine Lines and Deck Step

4.4.2 Loads

Loading cases were developed using the American Bureau of Shipping (ABS) Guide for Building and Classing High Speed Naval Craft, 2007. The bending moment values given for waves amidships, sagging (Mws) and hogging (Mwh), and still water, sagging (Msws) and hogging (Mswh), are listed in Table 30.

Table 30 – ABS Required Bending Moments

Mws (kN-m)	-1.38×10^{5}
Mwh (kN-m)	1.10×10^{5}
Msws (kN-m)	0.00
Mswh (kN-m)	8.24×10^{4}

A variety of load cases were developed and tested. There were three wave conditions used and two loading conditions used. The wave conditions were still water, hogging, and sagging, and the loading conditions were full load, all fuel tanks 95% full, and MinOp, where fuel tanks were 33% full. The still water loading case is shown in Figure 72. For the hogging and sagging cases waves were applied to the ASCal model in MAESTRO. The wave length used was the same as the ship's length, and the wave amplitude used was as required to generate the ABS required bending moments. These are called equivalent waves and provide a 3D loading condition. Figure 73 and Figure 74 show ASCal on the wave, in both the hogging and sagging conditions.

4.4.3 Adequacy

Limit states and stresses based on the above described load cases are compared within MAESTRO in a series of failure modes. Strength ratio (r) is given by a member's stress divided by the failure stress for the considered failure modes. The failure stress includes margins for the factor of safety and all the applicable margins. Adequacy is defined as:

$$\frac{1-r}{1+r}$$

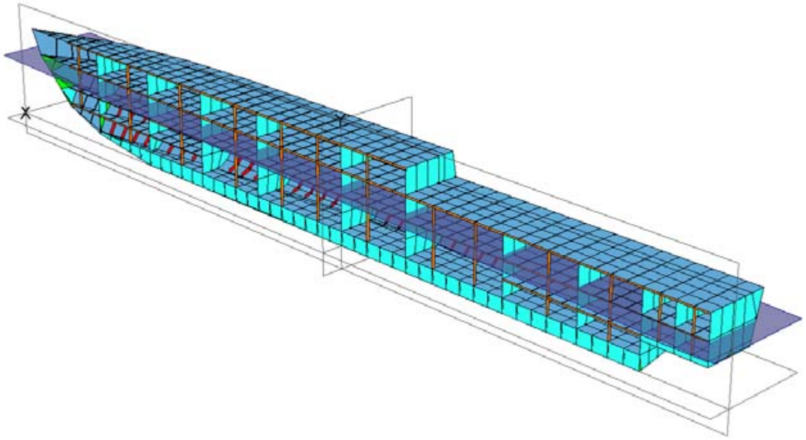


Figure 72 - ASCal Loaded on Calm Waterline

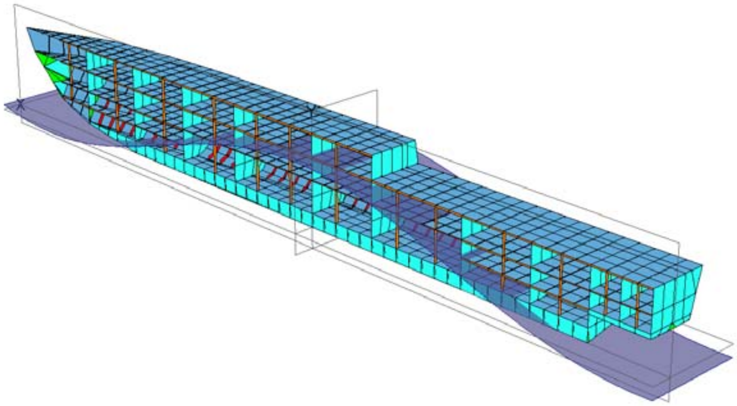


Figure 73 - ASCal Loaded on Hogging Wave

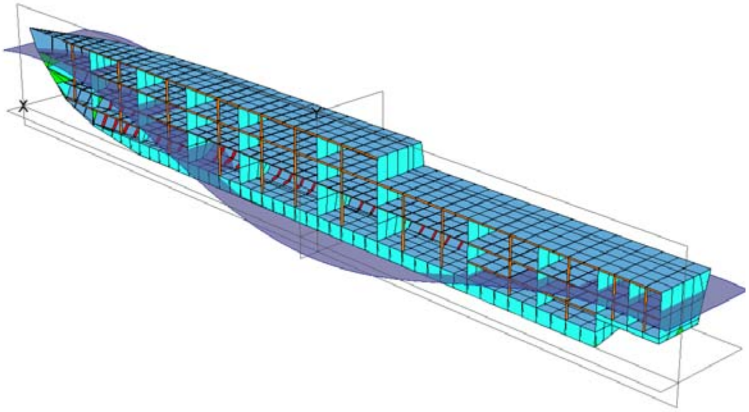


Figure 74 - ASCal Loaded on Sagging Wave

Using this formula, a structural component will always have an adequacy parameter between -1 and 1. Negative adequacy signifies that an element is insufficient to support the experience stresses, while positive values show some level of over-design. A value of zero therefore represents a member that exactly meets its required loads. The structural model was manually optimized to achieve positive limit state values. The goal was to keep all adequacy levels as close to zero as possible while making sure that they remain positive. Figure 75 through Figure 80 show the adequacy calculation results for the six loading cases applied. In these figures the color scale represents the adequacy value, a value of 1 is blue and a value of -1 is red. After the optimization of the structure there are still a few panels that show as failures, in red and orange. In particular longitudinal floors in the inner bottom including the centerline vertical keel are failing in combined buckling (Hogging and Stillwater conditions), and require longitudinal stiffeners and thicker plate. These were corrected in the next iteration after these figures were captured.

Figure 75 and Figure 76 show the still water cases for both full load and MinOp, respectively.

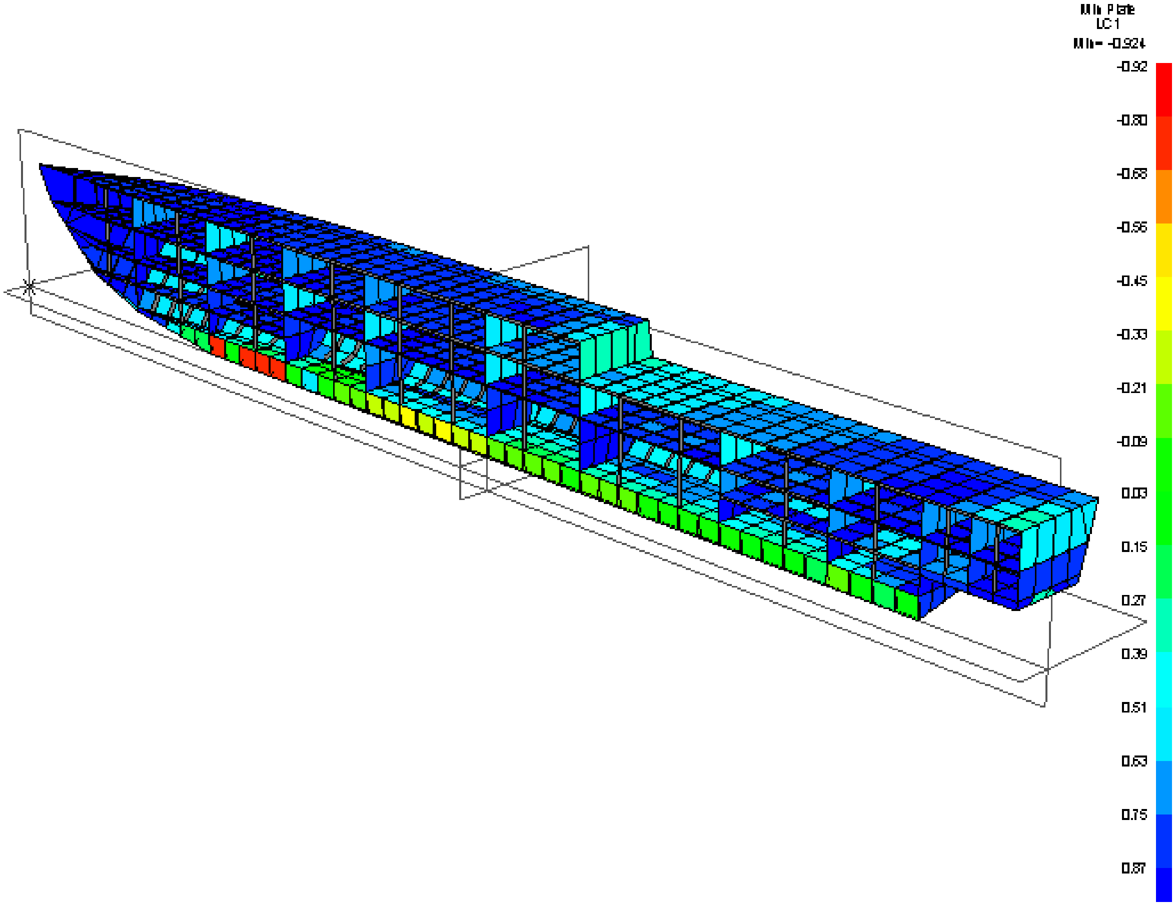


Figure 75 – Worse Case Limit State Adequacy for Still Water, Full Load

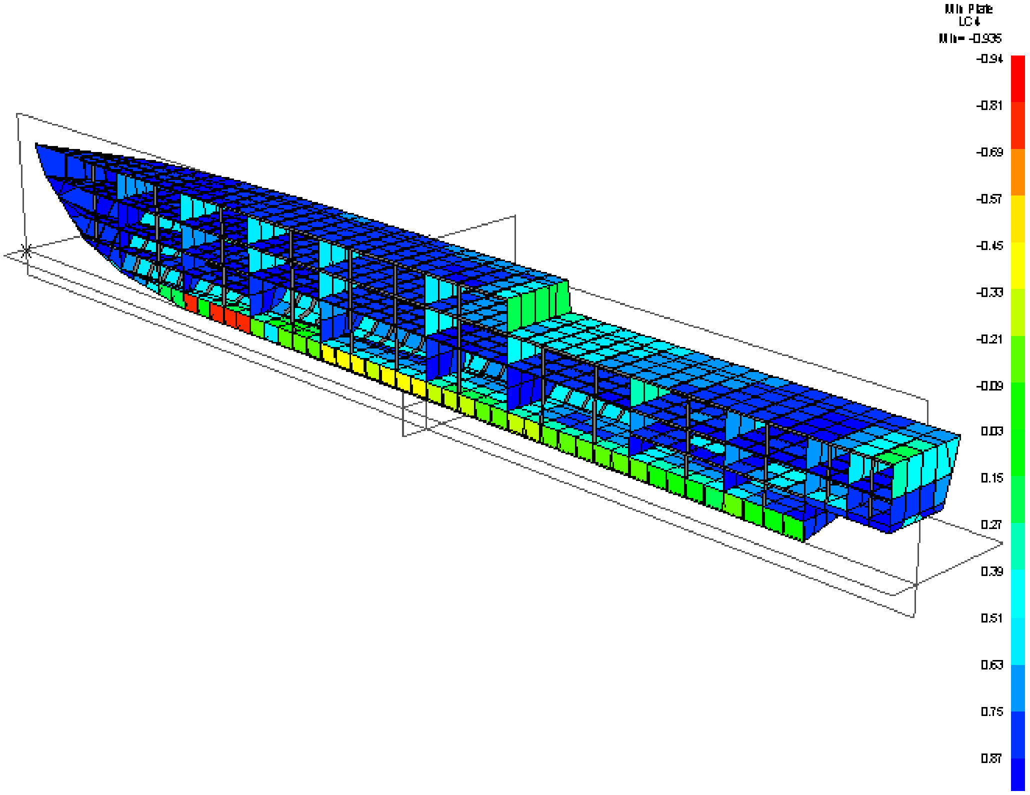


Figure 76 - Worse Case Limit State Adequacy for Still Water, MinOp

Figure 77 and Figure 78 show the hogging wave in the full load and MinOp loading condition respectively. In each of these cases the stress is concentrated near amidships, where the ship is balancing on the crest of the wave.

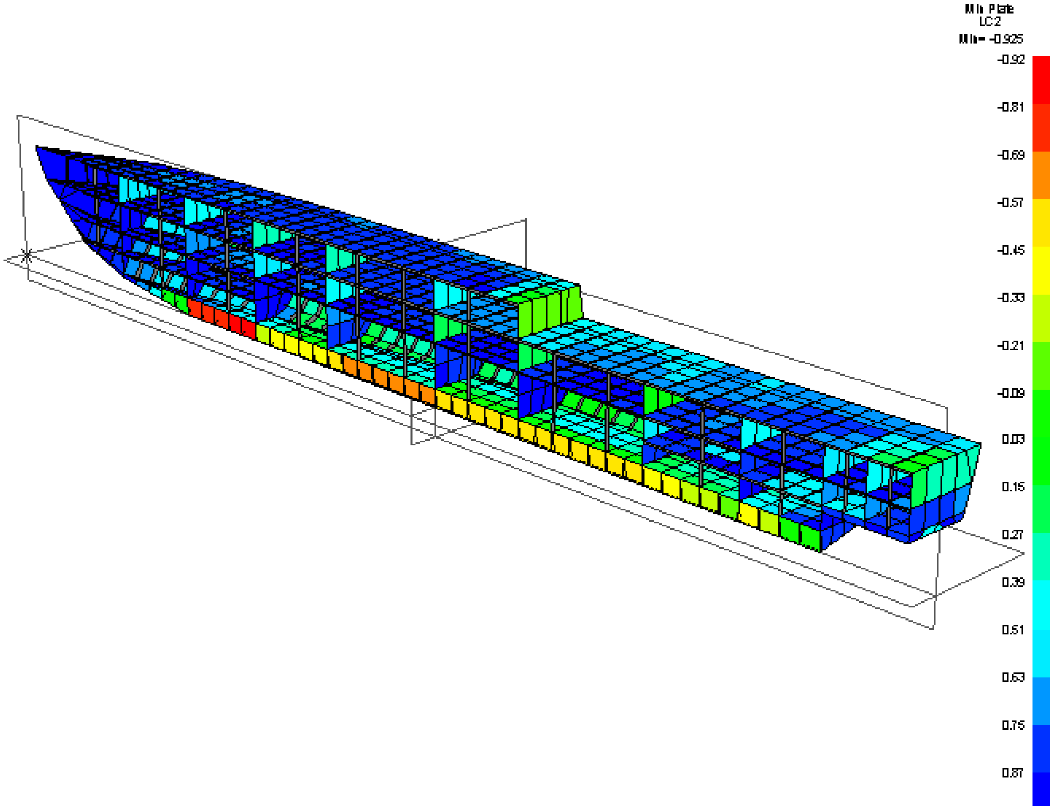


Figure 77 - Worse Case Limit State Adequacy for Hogging, Full Load

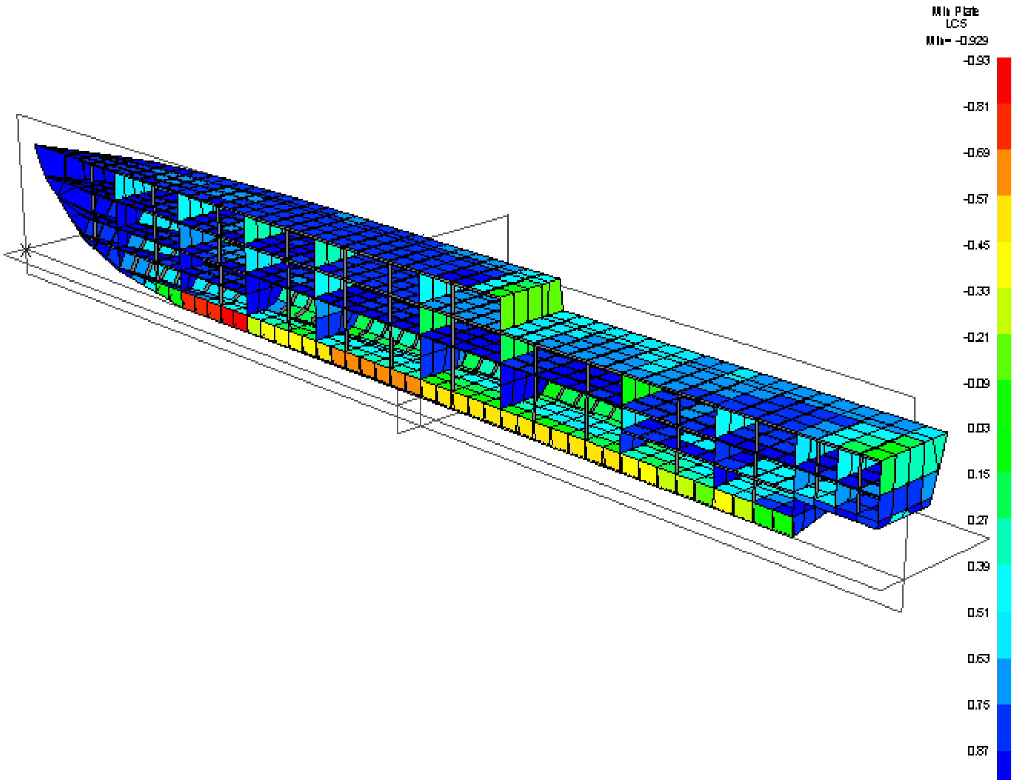


Figure 78 - Worse Case Limit State Adequacy for Hogging, MinOp

Figure 79 and Figure 80 show a sagging wave for the full load and the min opt load conditions. Here it can be seen that the stresses are greater at the bow and stern of the ship, where the wave crests are, and less in the middle where the trough is.

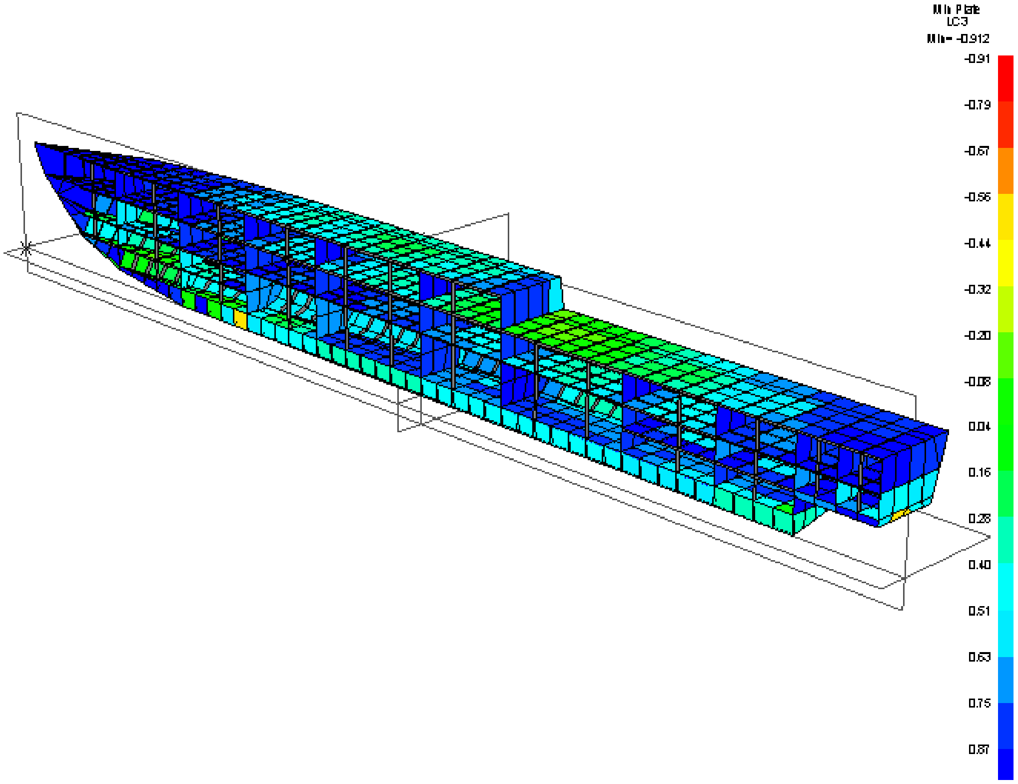


Figure 79 - Worse Case Limit State Adequacy for Sagging, Full Load

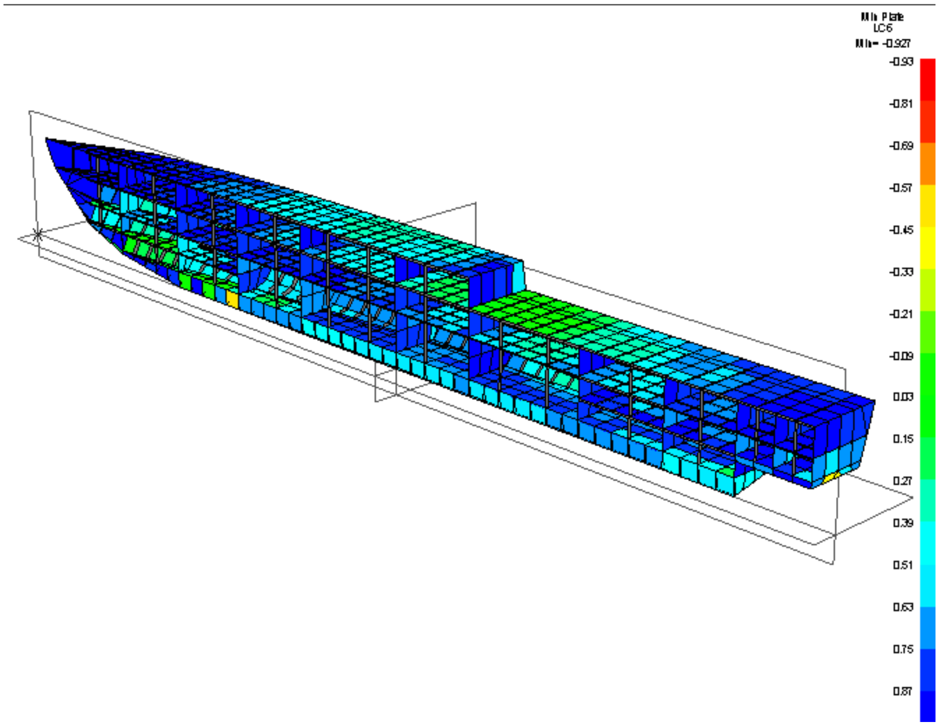


Figure 80 - Worse Case Limit State Adequacy for Sagging, MinOp

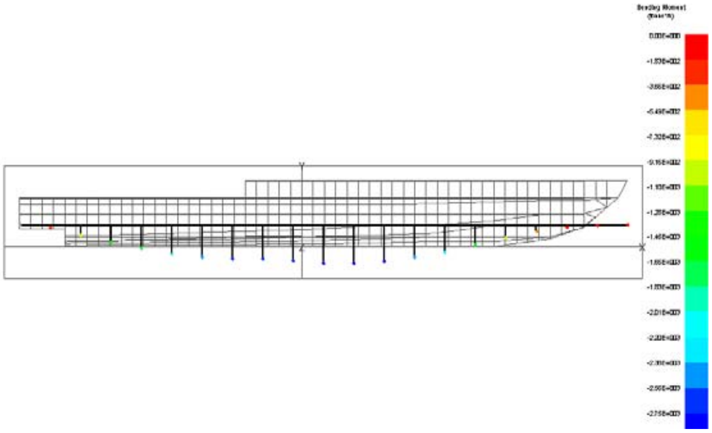


Figure 81 - ASCal Bending Moment, Still Water, Full Load

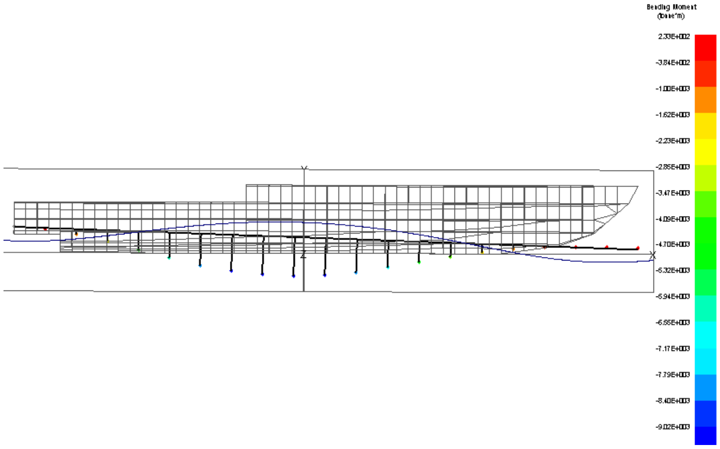


Figure 82 - ASCal Bending Moment, Hogging, Full Load

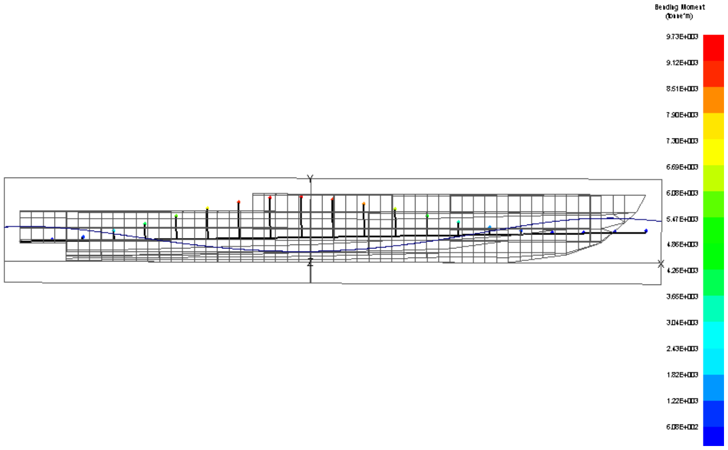


Figure 83 - ASCal Bending Moment, Sagging, Full Load

Figure 84 shows the hull plating thickness. Final structural geometry and scantlings are provided in the Midship Section Drawing.

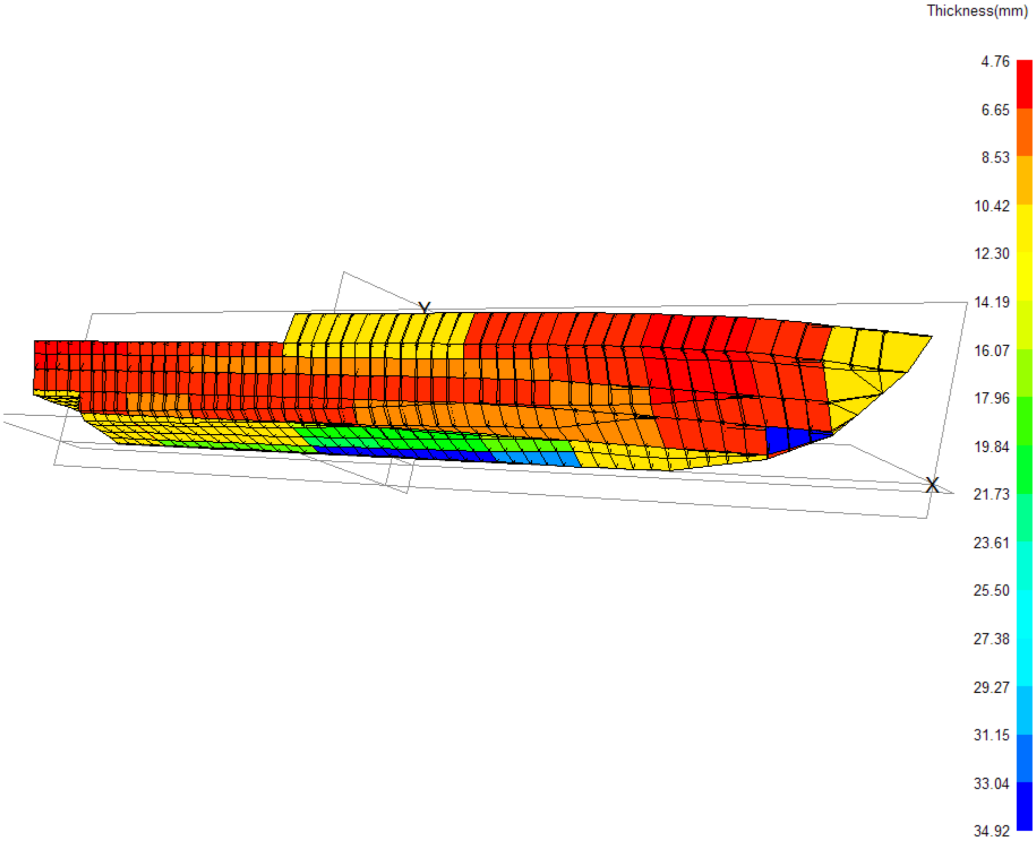


Figure 84: ASCal Hull Plating Thickness

4.5 Power and Propulsion

Propulsion prime movers include two Caterpillar 3616 diesel engines providing 6 MW of propulsion power each and two LM-2500+ gas turbines providing 30 MW of propulsion power each. Ship service power is provided by 4 Caterpillar ship service diesel generators producing 728 kW each. When at loiter or endurance speed, the diesel engines are online and powering the two outboard steerable Kamewa S3-80 waterjets. When accelerating and operating at sustained speed both diesel engines and both gas turbines are used. The gas turbines power two inboard fixed Kamewa S3-180 waterjets, allowing ASCal to exceed hump speed and operate in the semi-planing regime.

4.5.1 Resistance

Resistance calculations were computed using different models for endurance and sustained speed. The Holtrop-Menon method is used when ASCal is operating at endurance speed as a displacement hull, and the Savitsky Method is used at sustained speed. The endurance calculation includes a 10% resistance margin, correlation allowance of 0.0004 and is evaluated at speeds of 14 to 21 knots. In both analyses, wind drag is included. Due to the nature of waterjets and the fact that there are no shafts, struts, or rudders located outside the hull appendage drag is small. The resistance, powering and Ct plots for this calculation are shown in Figure 85 through Figure 87.

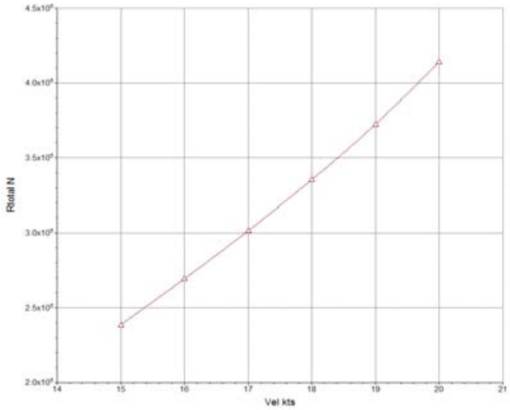


Figure 85 – Improved Baseline Total Resistance in Endurance Speed Range

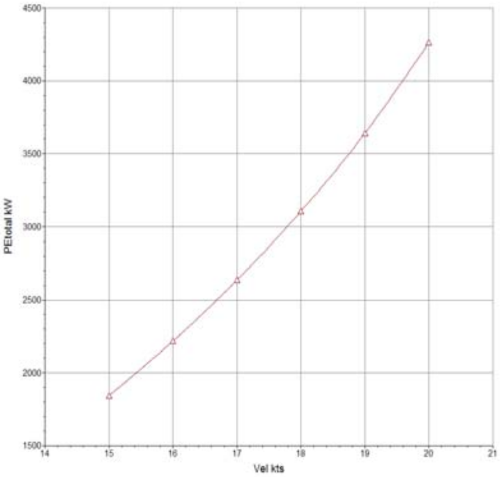


Figure 86 – Improved Baseline EHP in Endurance Speed Range

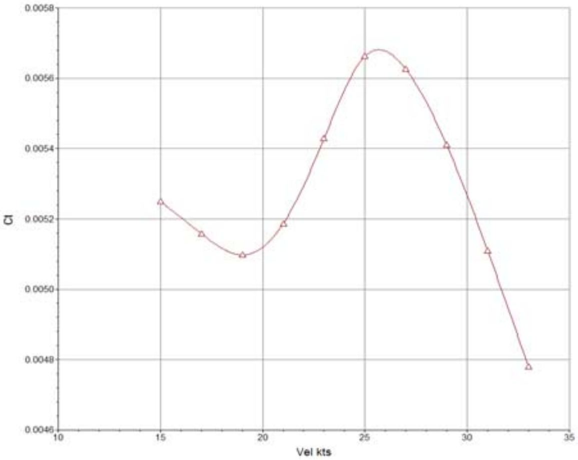


Figure 87 - Ct curve endurance (note the hump occurring at approx 26 knots)

Looking closely at the plot of Ct, the endurance speed of 18 knots design point falls close to a local minimum of resistance. This was likely a result of the Model Center optimization process. Increasing speed past this point Ct rises to a hump and then begins to decrease again. This is the point where ASCal begins to enter the semi-planing and planing regime. The Savitsky method assumes that the body is fully planing. Figure 88 is the resistance curve for sustained speed.

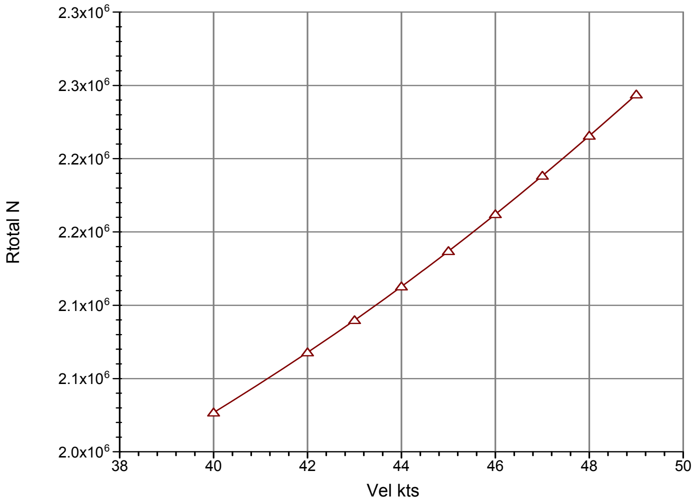


Figure 88 – Improved Baseline Total Resistance in Sustained Speed Range

Effective power plots (EHP) for endurance and sustained speeds are shown in Figure 86 and Figure 89 respectively.

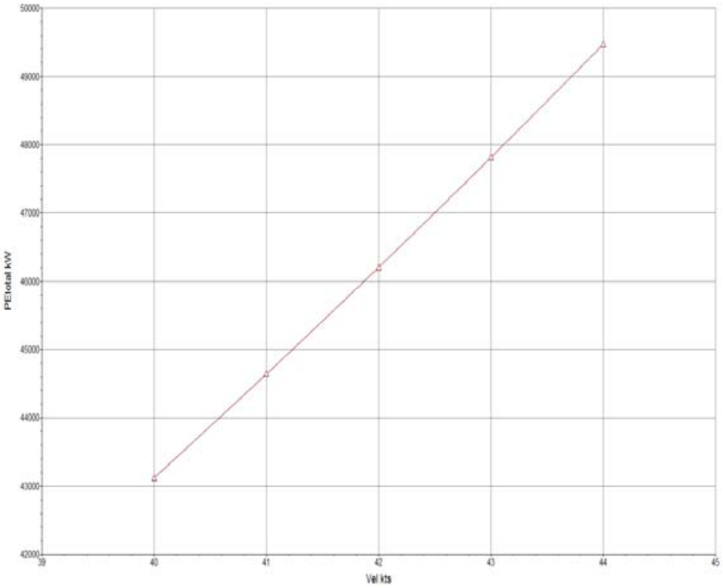
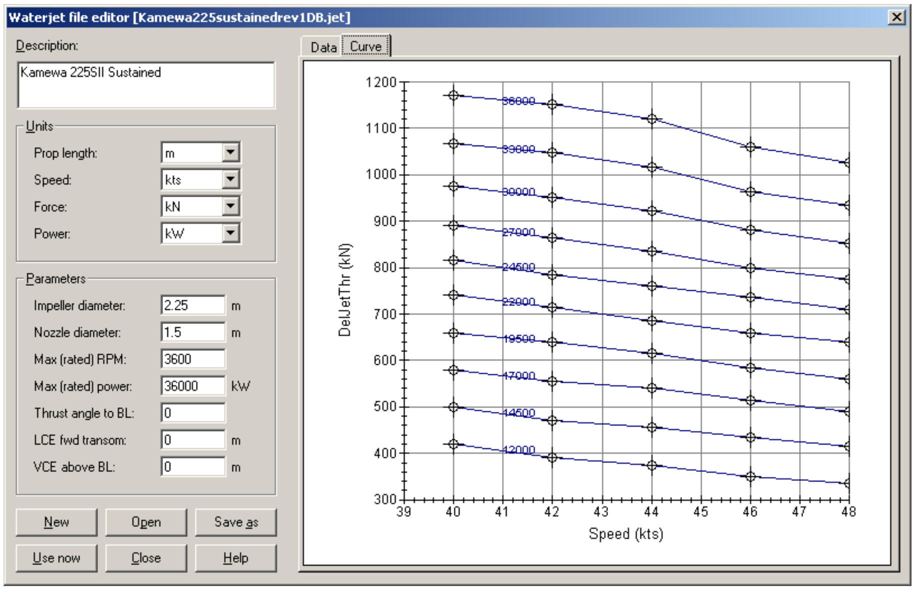


Figure 89 - Improved Baseline Total EHP for Sustained Speed Range

4.5.2 Propulsion

Propulsors selected for the Improved Baseline are two outboard Kamewa S3-180 waterjets providing 30000 kW each at a maximum RPM of 300 and two inboard Kamewa S3-80 waterjets providing 6000 kW each at a maximum RPM of 300. Waterjet and engine files were created in NAVCAD, as is shown in Figure 90 and Figure 91. Due to the set up of the propulsion system using NAVCAD required some ingenuity. In endurance mode the engine file used was created from data on the Caterpillar 3616 diesel engine. In sustained mode, the engine file used was created from the base data from the LM-2500+ gas turbines with the additional power from the Caterpillar diesel engines added in to account for their contribution at sustained speeds. Waterjet characteristics modeled the S3-180 at high power (30MW+6MW=36MW) and the S3-80 at low power. The 225SII performance map, Figure 9, was modified and extended based on the manufacturer's S3 description to model the S3-180 and S3-80.



Description: Kamewa 225SII Sustained

Units

Prop length: m

Speed: kts

Force: kN

Power: kW

Parameters

Impeller diameter: 2.25 m

Nozzle diameter: 1.5 m

Max (rated) RPM: 3600

Max (rated) power: 36000 kW

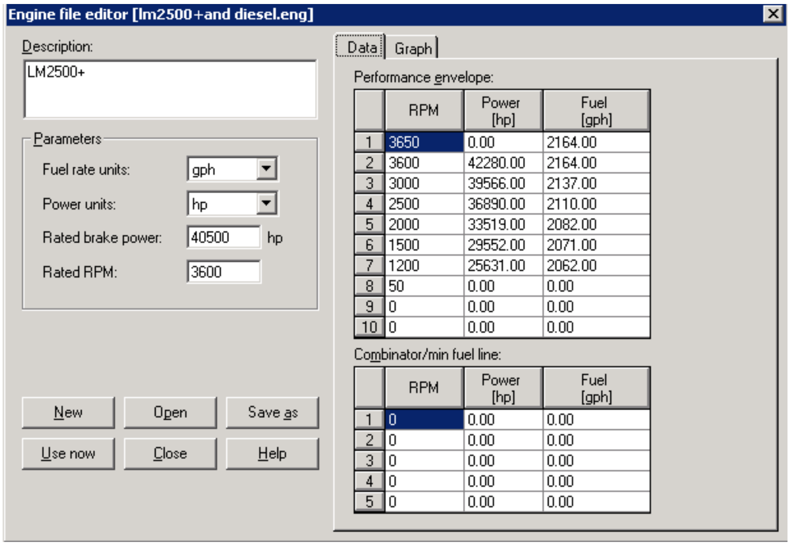
Thrust angle to BL: 0

LCE fwd transom: 0 m

VCE above BL: 0 m

Figure 90 - Waterjet model for Kamewa S180

Inboard waterjets are driven by LM-2500+ gas turbines through epicyclic gears with a reduction ratio of 12.2 which is optimized for maximum sustained speed. The LM-2500+ GT have maximum RPM of 3600 and are capable of providing 30 MW of power. Gear efficiency is assumed to be 0.99, shaft efficiency 0.99, for an overall transmission efficiency of 0.98. The NAVCAD engine editor for the LM2500+ is shown in Figure 91.



Description: LM2500+

Parameters

Fuel rate units: gph

Power units: hp

Rated brake power: 40500 hp

Rated RPM: 3600

Performance envelope:

	RPM	Power [hp]	Fuel [gph]
1	3650	0.00	2164.00
2	3600	42280.00	2164.00
3	3000	39566.00	2137.00
4	2500	36890.00	2110.00
5	2000	33519.00	2082.00
6	1500	29552.00	2071.00
7	1200	25631.00	2062.00
8	50	0.00	0.00
9	0	0.00	0.00
10	0	0.00	0.00

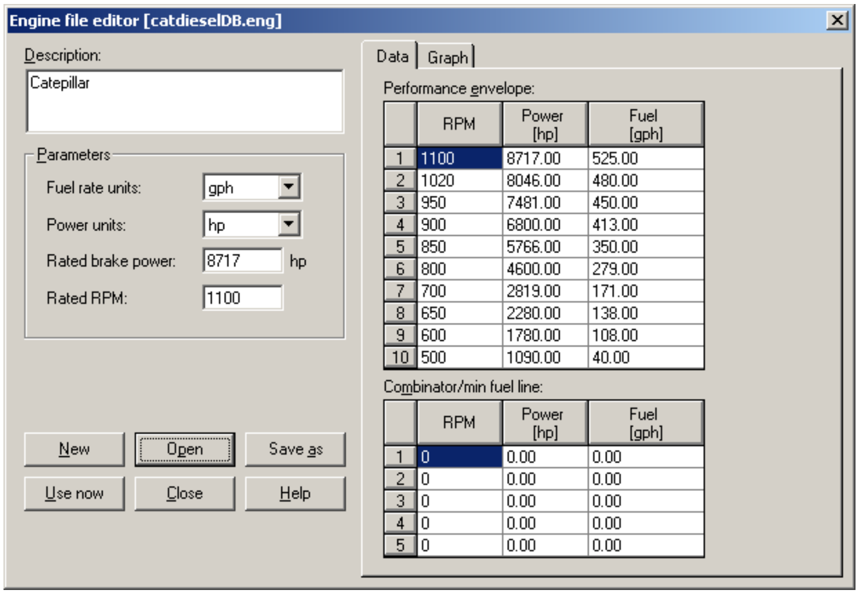
Combinator/min fuel line:

	RPM	Power [hp]	Fuel [gph]
1	0	0.00	0.00
2	0	0.00	0.00
3	0	0.00	0.00
4	0	0.00	0.00
5	0	0.00	0.00

Figure 91 - LM-2500+ Engine Model

Outboard waterjets are driven by Caterpillar 3616 diesel engines through epicyclic gears with a reduction gear ratio of 5.6 which is optimized to minimize fuel consumption. These have a maximum RPM of 1100 and 6 MW of power. The same gear, shaft, and overall efficiency are assumed. Reverse thrust is created by lowering reverse buckets over the outboard waterjets. This gives ASCal its reverse mechanism through thrust vectoring rather than a controllable pitch propeller or mechanical transmission mechanism. This also contributes highly to the maneuverability characteristics of ASCal when in port and docking.

Shaft power per engine versus engine RPM is shown in Figure 93 and Figure 94 superimposed on the engine performance map for endurance and sustained speeds. Ship speeds are listed on the shaft horsepower per engine line (in blue). Reduction gear ratios were adjusted to minimize fuel consumption and maximize sustained speed. Maximum sustained speed is approximately 42.5 knots. This is well below the 47 knot estimate and requirement set in Concept Exploration and is attributed to using a more complete and correct propulsion system and resistance model. The waterjet efficiency versus ship speed curve is shown in Figure 95. At 18 knots the waterjet efficiency is 0.648.



Description:

Catepillar

Parameters

Fuel rate units: gph

Power units: hp

Rated brake power: 8717 hp

Rated RPM: 1100

Performance envelope:

	RPM	Power [hp]	Fuel [gph]
1	1100	8717.00	525.00
2	1020	8046.00	480.00
3	950	7481.00	450.00
4	900	6800.00	413.00
5	850	5766.00	350.00
6	800	4600.00	279.00
7	700	2819.00	171.00
8	650	2280.00	138.00
9	600	1780.00	108.00
10	500	1090.00	40.00

Combinator/min fuel line:

	RPM	Power [hp]	Fuel [gph]
1	0	0.00	0.00
2	0	0.00	0.00
3	0	0.00	0.00
4	0	0.00	0.00
5	0	0.00	0.00

Figure 92 - Engine model of Caterpillar 3616

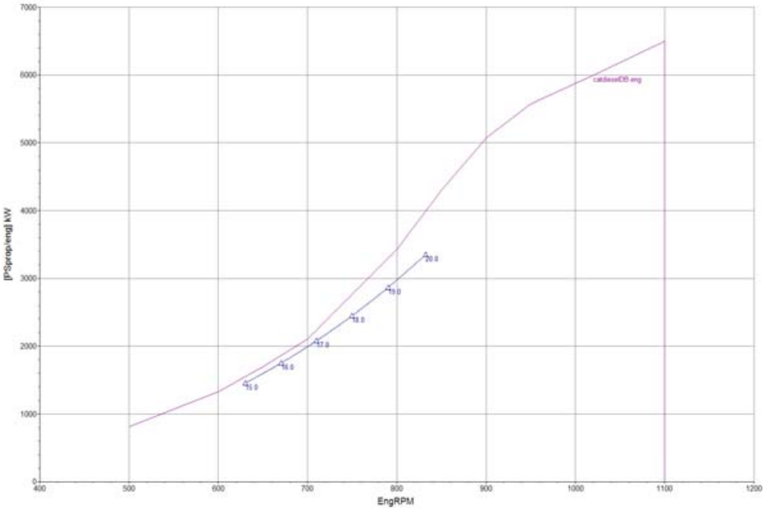


Figure 93 - Shaft power per engine superimposed on engine performance map

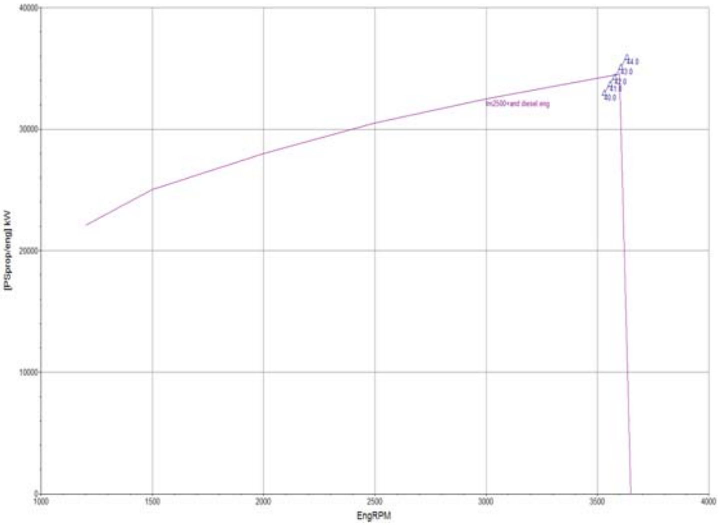


Figure 94 - Shaft power per engine superimposed on engine performance map

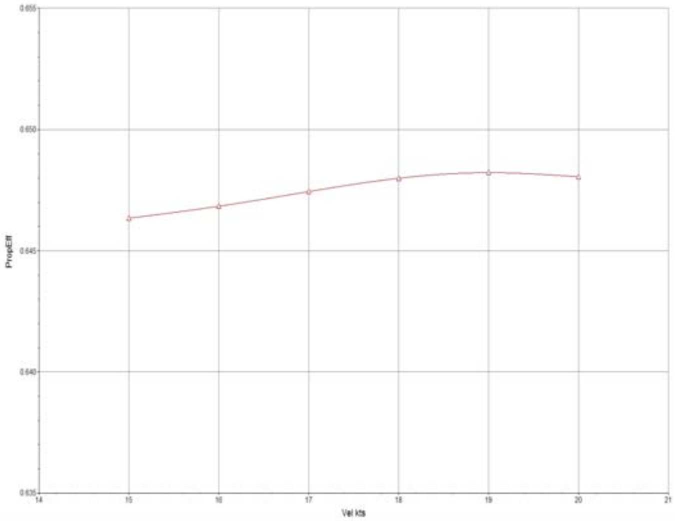


Figure 95 - Waterjet efficiency coefficient in endurance speed range

Fuel consumption versus ship speed for both speeds are shown in Figure 96 and Figure 97. Fuel consumption value at endurance speed is 199 gph and 2170 gph at sustained speed.

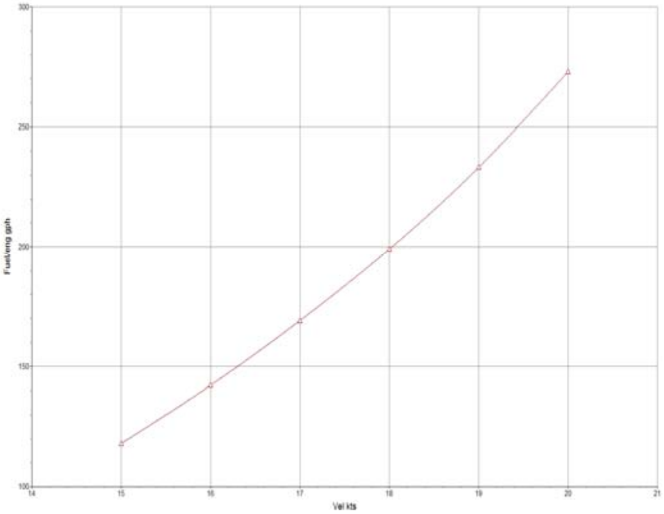


Figure 96 - Fuel consumption at endurance speed (per engine)

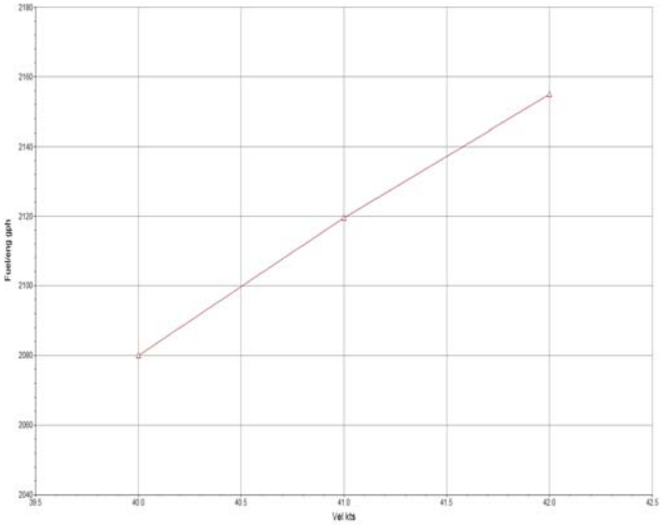


Figure 97 - Fuel consumption at sustained speed

4.5.3 Fuel Calculation

A fuel calculation was performed for endurance range and sprint range in accordance with DDS 200-1. The endurance requirements and results are listed in Table 31 for both endurance and sustained speeds. Summaries of the calculations are shown in Table 32 and Table 33.

Table 31 – ASCal Fuel Calculations

Required Endurance Range at 18 knots	4099	nm
Available Endurance Range	4346	nm
Required Sustained Speed (sprint) Range	1143	nm
Available Sustained Speed (sprint) Range	1087	nm

Table 32 - ASCal Endurance Range Calculation

Average Endurance brake horsepower required (includes 10% margin, PMFe)				
Np (waterjets online)	2			
BHPereq / engine	2548	kW =	3417	hp
Pe Brake avg: (total) PeBAVG = BHPereq*Np	6834	hp		
Ve =	18	knots		
Correction for instrument inacc.				
and machinery design changes				
f1	1.04			
SFCePE (57% load)	0.361	lbf/(hp*hr)		
Specified fuel rate: FRsp = f1*SFCePE	0.375	lbf/(hp*hr)		
Avg fuel rate allowing for plant deterioration				
over 2 years: FRavg = 1.05*FRsp	0.394	lbf/(hp*hr)		
KW24avg	1161	kW =	1557	hp
# Gen: Ngen =	2			
P Generator avg: Pgenavg = 1.1*KW24avg/Ngen	638.7	kW =	857	hp
Margin for instrumentation inaccuracy and				
machinery design changes: f1e =	1.04			
Specified Fuel Rate generator: SFCge =	0.369	lbf/(hp*hr)		
Specified Fuel Rate: FRgsp = f1e * SFCge	0.384	lbf/(hp*hr)		
Average Fuel Rate: FRgavg = 1.05*FRgsp	0.403	lbf/(hp*hr)		
(allow for plant det.)				
Tailpipe allowance: TPA =	0.95			
Specific weight of fuel: delf =	43.6	ft^3/lton		
Fuel tank volume: Vf41 =	498	m^3 =	17597	ft^3
Fuel Weight (5% expansion, 2% internal structure)				
Wf41 = Vf41/(1.02*1.05*delf)	376.8	lton =	844126	lbf
Endurance Range				
E = (Wf41*Ve*TPA)/(PeBAVG*FRavg + KW24avg*FRgavg)	4346	nm		

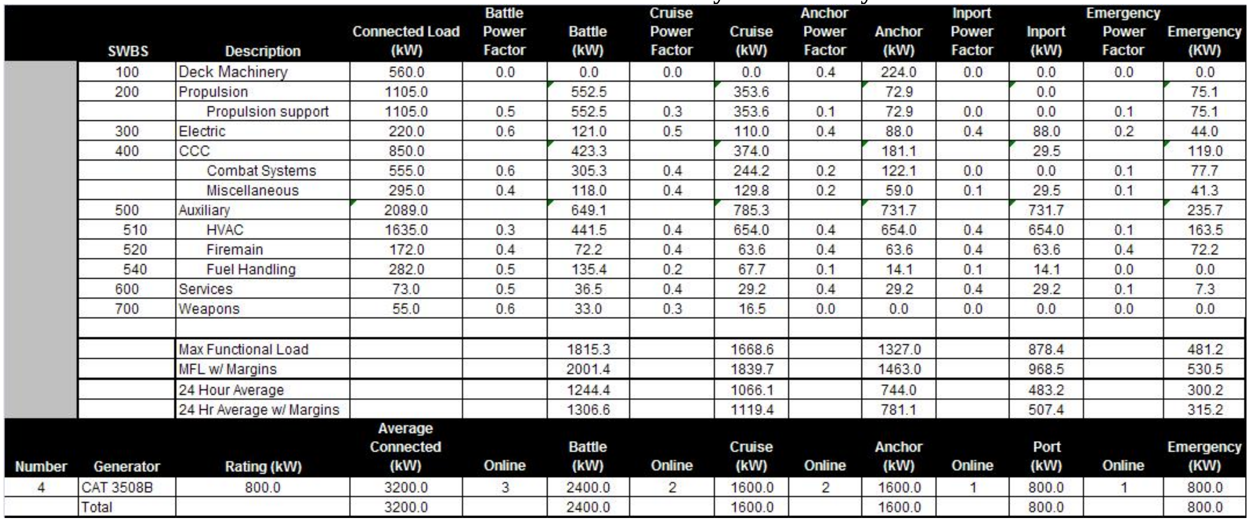
Table 33 - ASCal Sustained Range Fuel Calculation

Average Sustained brake horsepower required (includes 25% margin, PMFs)				
Np = number of shafts	2			
BHPsreq (only 10% endurance margin vice 25% speed) per shaft	31680	kW =	42483	hp
Pe Brake avg: PsBAVG = BHPsreq*Np total	84966	hp		
Vs =	42.5	knots		
Correction for instrument inacc.				
and machinery design changes				
f1	1.04			
SFCsPE	0.331	lbf/(hp*hr)		
Specified fuel rate: FRsp = f1*SFCsPE	0.344	lbf/(hp*hr)		
Avg fuel rate allowing for plant deterioration				
over 2 years: FRavg = 1.05*FRsp	0.361	lbf/(hp*hr)		
KW24avg	1161.22	kW =	1557.196	hp
# Gen: Ngen =	2			
P Generator avg: Pgenavg = 1.1*KW24avg/Ngen	638.671	kW =	856.4578	hp
Margin for instrumentation inaccuracy and				
machinery design changes: f1e =	1.04			
Specified Fuel Rate generator: SFCge =	0.369	lbf/(hp*hr)		
Specified Fuel Rate: FRgsp = f1e * SFCge	0.384	lbf/(hp*hr)		
Average Fuel Rate: FRgavg = 1.05*FRgsp	0.403	lbf/(hp*hr)		
(allow for plant det.)				
Tailpipe allowance: TPA =	0.95			
Specific weight of fuel: delf =	43.6	ft^3/lton		
Fuel tank volume: Vf41 =	498	m^3 =	17596.86	ft^3
Fuel Weight (5% expansion, 2% internal structure)				
Wf41 = Vf41/(1.02*1.05*delf)	376.8	lton =	844125.9	lbf
Sustained Range				
S = (Wf41*Vs*TPA)/(PsBAVG*FRavg + KW24avg*FRgavg)	1087.5	nm		

4.5.4 Electric Load Analysis (ELA)

Table 34 shows the electric load analysis summary for ASCal broken down by SWBS group. Load factors determined the power consumption for each of these groups in each of ASCal's operating conditions.

Table 34 - Electric Load Analysis Summary



SWBS	Description	Connected Load (kW)	Battle Power Factor	Battle (kW)	Cruise Power Factor	Cruise (kW)	Anchor Power Factor	Anchor (kW)	Inport Power Factor	Inport (kW)	Emergency Power Factor	Emergency (KW)
100	Deck Machinery	560.0	0.0	0.0	0.0	0.0	0.4	224.0	0.0	0.0	0.0	0.0
200	Propulsion	1105.0		552.5		353.6		72.9		0.0		75.1
	Propulsion support	1105.0	0.5	552.5	0.3	353.6	0.1	72.9	0.0	0.0	0.1	75.1
300	Electric	220.0	0.6	121.0	0.5	110.0	0.4	88.0	0.4	88.0	0.2	44.0
400	CCC	850.0		423.3		374.0		181.1		29.5		119.0
	Combat Systems	555.0	0.6	305.3	0.4	244.2	0.2	122.1	0.0	0.0	0.1	77.7
	Miscellaneous	295.0	0.4	118.0	0.4	129.8	0.2	59.0	0.1	29.5	0.1	41.3
500	Auxiliary	2089.0		649.1		785.3		731.7		731.7		235.7
510	HVAC	1635.0	0.3	441.5	0.4	654.0	0.4	654.0	0.4	654.0	0.1	163.5
520	Firemain	172.0	0.4	72.2	0.4	63.6	0.4	63.6	0.4	63.6	0.4	72.2
540	Fuel Handling	282.0	0.5	135.4	0.2	67.7	0.1	14.1	0.1	14.1	0.0	0.0
600	Services	73.0	0.5	36.5	0.4	29.2	0.4	29.2	0.4	29.2	0.1	7.3
700	Weapons	55.0	0.6	33.0	0.3	16.5	0.0	0.0	0.0	0.0	0.0	0.0
	Max Functional Load			1815.3		1668.6		1327.0		878.4		481.2
	MFL w/ Margins			2001.4		1839.7		1463.0		968.5		530.5
	24 Hour Average			1244.4		1066.1		744.0		483.2		300.2
	24 Hr Average w/ Margins			1306.6		1119.4		781.1		507.4		315.2

Number	Generator	Rating (kW)	Average Connected (kW)	Online	Battle (kW)	Online	Cruise (kW)	Online	Anchor (kW)	Online	Port (kW)	Online	Emergency (KW)
4	CAT 3508B	800.0	3200.0	3	2400.0	2	1600.0	2	1600.0	1	800.0	1	800.0
	Total		3200.0		2400.0		1600.0		1600.0		800.0		800.0

4.6 Mechanical and Electrical Systems

Mechanical and electrical systems were 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. The major components of the mechanical and electrical systems and the methods used to size them are described in the following two subsections. The arrangement of these systems is detailed in Section 4.8.2.

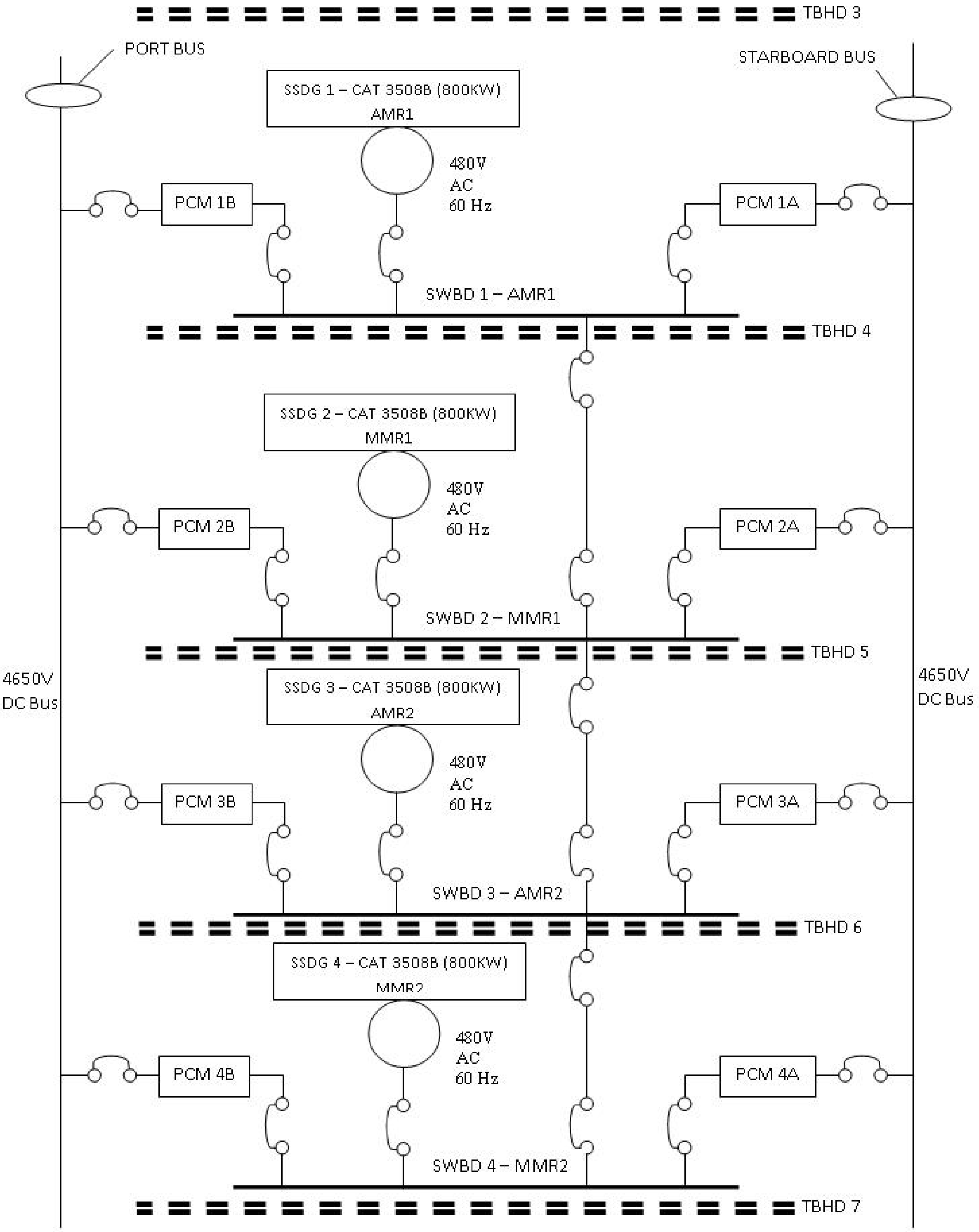


Figure 98 - One-Line Electrical Diagram

4.6.1 Ship Service Power

The ASCal one-line diagram is shown in Figure 98 outlining the ship service power buses and generators. Four CAT 3508B diesel engines, each providing 800KW, 480V at 60HZ of AC electric power, function as the Ship Service Generators (SSGs). Each generator is connected to separate primary ship service switchboards, one located in each of the MMRs and AMRs. The switchboards are interconnected for redundancy, reliability, and are directly connected to the starboard and port service buses so that power can be routed to service loads throughout the ship using Power Conversion Modules. Each generator set has automatic paralleling and load sharing capabilities and can be started manually or automatically either through a remote connection at the EOS or a local control panel.

4.6.2 Service and Auxiliary Systems

Lube, waste and fuel oil tanks on ASCal are sized based on the Ship Synthesis model. The model performs a scaling operation based on ships of a similar size. Most equipment is located within or near the Main and Auxiliary Machinery Rooms.

Purifiers for fuel and lube oil are sized based on engine consumption. Once of each (fuel oil and lube oil) purifier is located in each of the Main Machinery rooms. The systems are meant to perform operations for their respective MMR, but they may be cross-connected if necessary.

One fresh water reverse osmosis distiller is located in each of the Auxiliary Machinery rooms. Ten cubic meters of fresh water can be stored in the ship's tanks. With an allotment of 0.16 m^3 of water per person per day, this is sufficient to support the 40 member crew.

Each AMR also houses two 150 ton centrifugal air conditioning units a piece. The size of the AC units is based on the crew size and arrangeable space. Based on the 40 person crew, two 4.3 ton refrigeration plants were selected. A rate of 10 tons of refrigeration for every 200 personnel was used to determine this need.

4.6.3 Ship Service Electrical Distribution

ASCal has a traditional (non-IPS) power system. Ship service power can be distributed from any of 4 main switchboards shown in Figure 98. Conversion of ship service power, automatic reconfiguration and enhanced circuit protection are handled by Power Conversion Modules (PCMs) located at each of these SSG zones. Conversion from AC to CD and back is possible.

4.7 Manning

The reduction of manning represents a central goal for the modern Navy. The utilization of automation and unmanned systems allows for significant potential in the crew required to operate a ship. The use of a Level A Comm. Suite will provide major manning reductions in that video conferencing will allow for the access to on-shore experts. ASCal has a crew size of 40 sailors. Modular mission packages will require additional crew for proper operation. For this reason, ASCal will offer accommodations for a crew of up to 104. Table 35 shows a complete summary of the manning estimate for ASCal.

Original manning estimates were taken from the ASCal ship synthesis model (see Section 3.3). This estimate is based on an empirical regression-based manning formal, scaled to ASCal based on ship size and propulsion systems. Additional manning reductions were estimated based on the use of aluminum for a hull and deckhouse material. Further refinement of this estimate was achieved through comparison to manning information available on other naval ships.

4.7.1 Executive/Administrative Department

The main task of the Executive/Administrative department is to govern the coordinated performance of the rest of the ship's departments. This department is also responsible for the management and maintenance of the personnel records.

4.7.2 Operations Department

The operations department must conduct sensor, combat, radio and communication system functions. Watch standing, medical operations, electronic and communication maintenance also fall under the responsibilities of the Operations department. One department head is needed to oversee 2 department officers, who are responsible for Communications and CIC-EW-Intelligence respectively. Each of the 5 divisions within the department is assigned a CPO. The division as a total has 6 enlisted assigned to it.

Communications, Navigations-Control, Electronic Repair, CIC-EW-Intelligence and Medical are the 5 divisions that make up the Operations department. The main functions of the divisions within the operations department are as follows (crew size by division is shown in Table 35):

- Communications
  - Interpret electronic systems output
  - Relay information to appropriate receiver

- Navigations and Control
    - Navigation
    - Meteorology
- Electronic Repair
    - Maintenance of electronic equipment
- CIC, EW and Intelligence
    - Electronic warfare
    - Manning of the bridge
    - Gathering of intelligence
- Medical
    - Basic medical oversight

Table 35 - Manning Summary

Department	Division	Officers	CPO	Enlisted	Total Department
	CO/XO	2			2
	Department Heads	4			
Executive/Admin	Executive/Admin			1	1
Operations	Communications		1	2	11
	Navigation and Control		1	1	
	Electronic Repair		1	1	
	CIC, EW and Intelligence		1	1	
	Medical			1	
Weapons	Air	2	1	1	10
	Boat & Vehicle		1	1	
	Deck		1	1	
	Ordnance/Gunnery			1	
	ASW/MCM				
Engineering	Main Propulsion		1	2	10
	Electrical/IC		1	1	
	Auxilaries		1	1	
	Repair/DC		1	1	
Supply	Stores			1	6
	Material/Repair			1	
	Mess			3	
	Total	8	11	21	40
	Addl Accommodations	3	6	11	20
	Total Accommodations	11	17	32	60

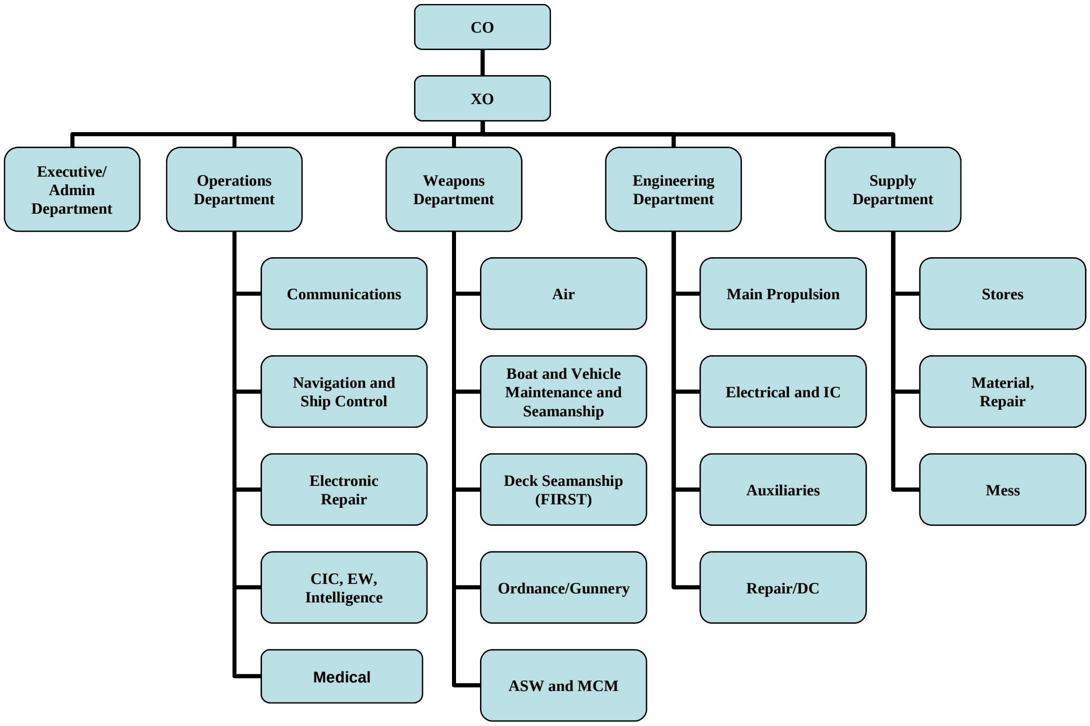


Figure 99 – ASCal Manning Organization

4.7.3 Weapons Department

Weapons assembly, loading, onboard transportation and maintenance are encompassed within the responsibilities of the Weapons department. The department is also in charge of the management of all onboard weapons magazines and issuing of ammunition to the ship's arsenal. The department head oversees 2 department officers, who are in charge of the Air division, and 4 enlisted. The main functions of the divisions within the operations department are as follows (crew size by division is shown in Table 35):

- Air
    - LAMPS
    - VTUAVs
    - Aircraft maintenance
- Boat and Vehicle
    - RHIB launch and recovery
    - Spartan launch and recovery
    - Small craft maintenance
- Deck
    - Line handling
    - Anchors
    - Life boat maintenance
    - Topside maintenance
    - Helmsmen
- Ordinance/Gunnery
    - Weapons
        - Procurement
        - Maintenance
        - Issuance
- ASW/MCM
    - RMS
        - Launch
        - Recovery
        - Operation
    - Mine avoidance sonar

4.7.4 Engineering Department

The two LM2500+ gas turbines, two CAT 3616 diesels and ship service generators are operated and maintained by the Engineering department. The Engineering department also maintains and operates all engine support systems, ship electrical systems and most major mechanical or electrical systems. The main functions of the divisions within the operations department are as follows (crew size by division is shown in Table 35):

- Main Propulsion
    - Maintenance
    - Repair
- Electrical/IC
- Auxiliary
    - LAMPS equipment
    - Weapons elevators
    - Motorized doors and Hatches
    - Pumps
    - Damage control equipment
- Repair/Damage Control
    - Major repairs
    - Controlling of damage as it occurs

4.7.5 Supply Department

The Supply department is in charge of ordering, receiving, organizing and storing different materials including but not limited to food and spare parts. This division also holds the responsibility of food preparation and all related tasks. Laundry, ships store, barber shop, pay distribution and postal service also fall under the Supply division. One department head and 5 enlisted are assigned to the supply division. The main functions of the divisions within the operations department are as follows (crew size by division is shown in Table 35):

- Stores
    - General Supplies
- Material/Repair
    - Obtain repair materials
- Messing
    - Food preparation

4.8 Space and Arrangements

Figure 100 through Figure 110 show the external and internal arrangements for ASCal. Arrangements are based on functional requirements, damage and vulnerability requirements, stability, maintainability, efficiency, access and convenience. They arrangements are discussed further in the following sections. Initial space requirements and space availability in the ship were determined in the ship synthesis model. These requirements were adjusted by designing the actual arrangements.

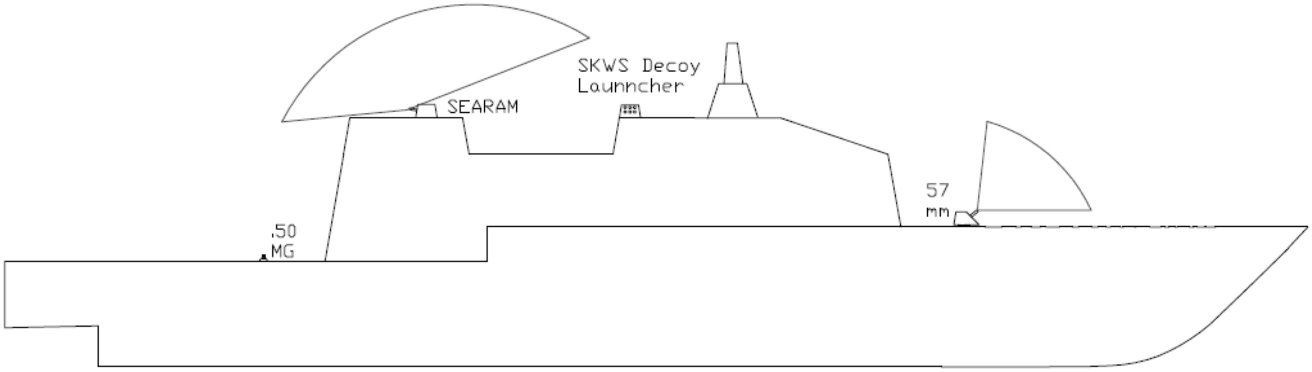


Figure 100 – ASCal External Combat Systems Profile View

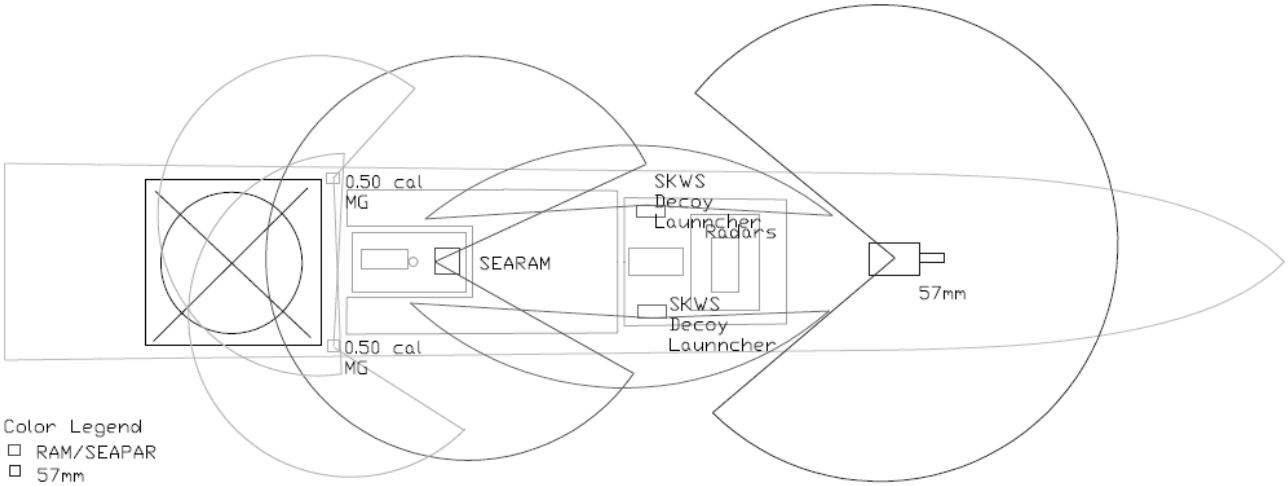


Figure 101 – ASCal External Combat Systems Topside View

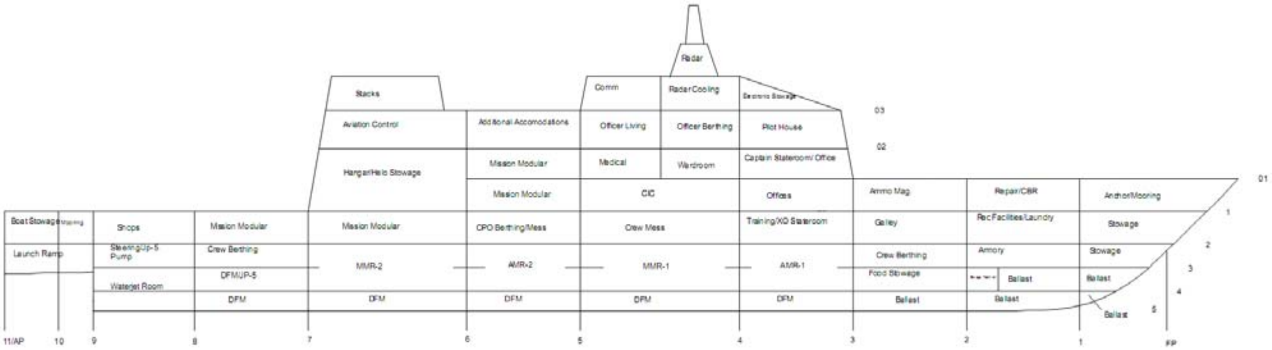


Figure 102 – ASCal Internal Profile

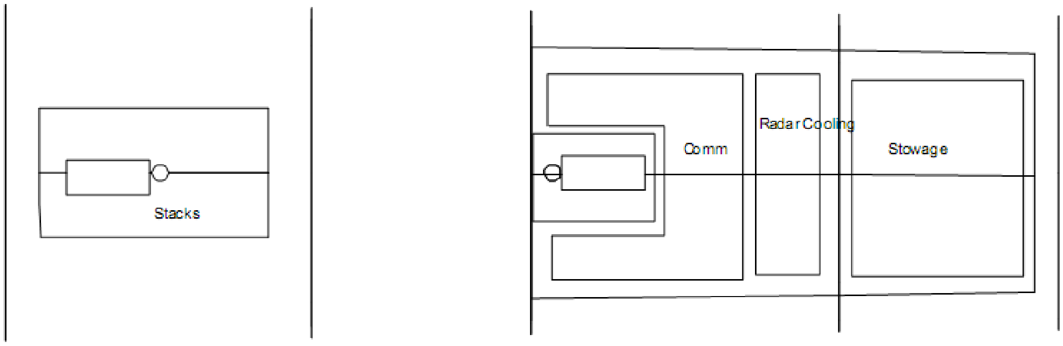


Figure 103 – Internal Plan View, 03 Level

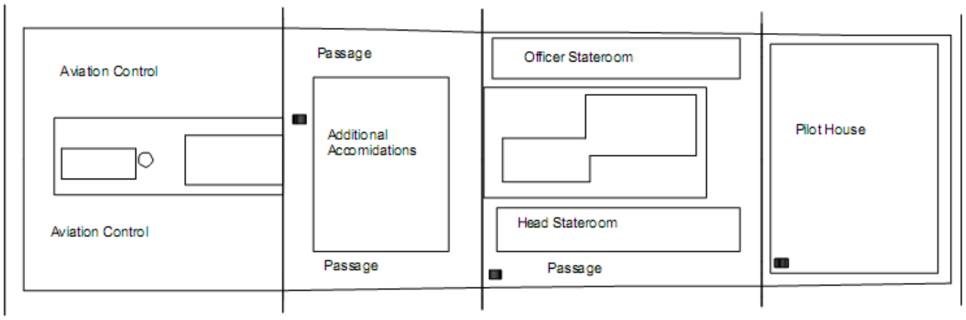


Figure 104 – Internal Plan View, 02 Level

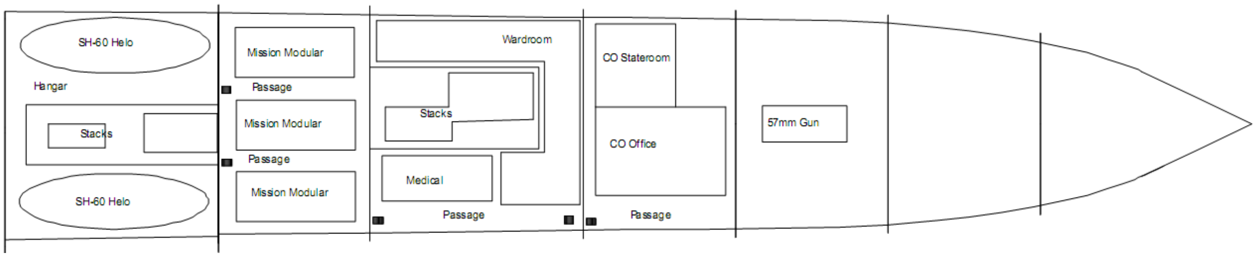


Figure 105 – Internal Plan View, 01 Level

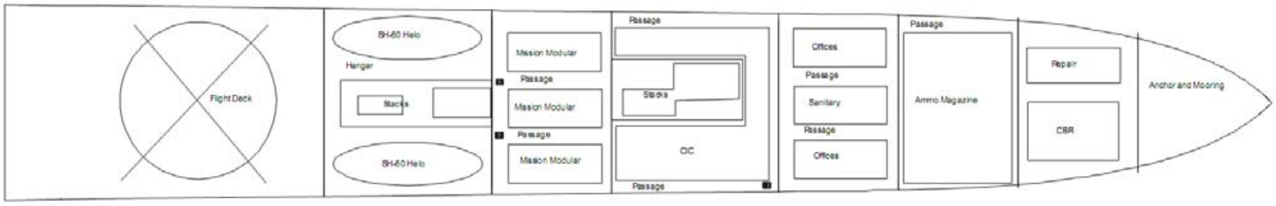


Figure 106 – Plan View, 1st Deck(Main Deck)

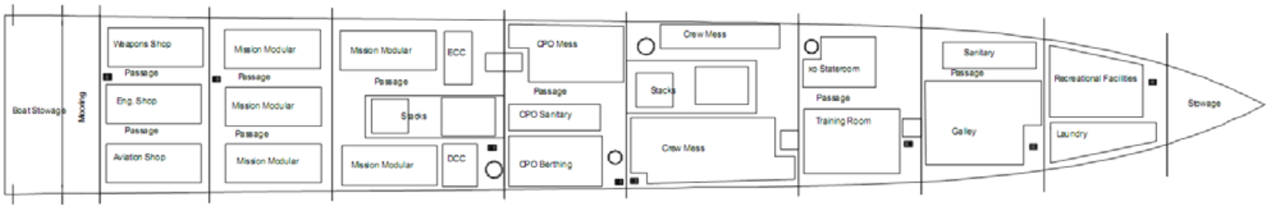


Figure 107 – Plan View, 2nd Deck (Damage Control)

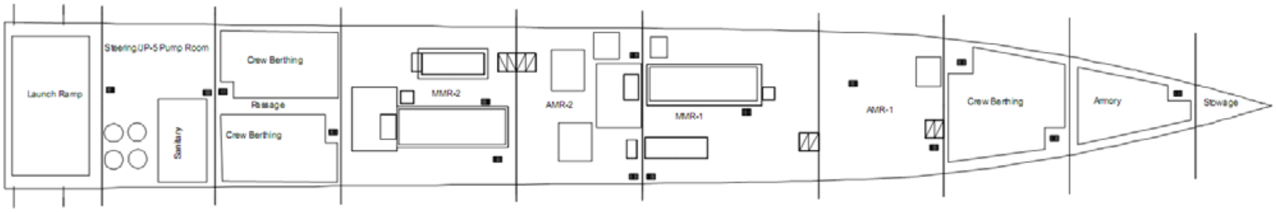


Figure 108 – Plan View, 3rd Deck

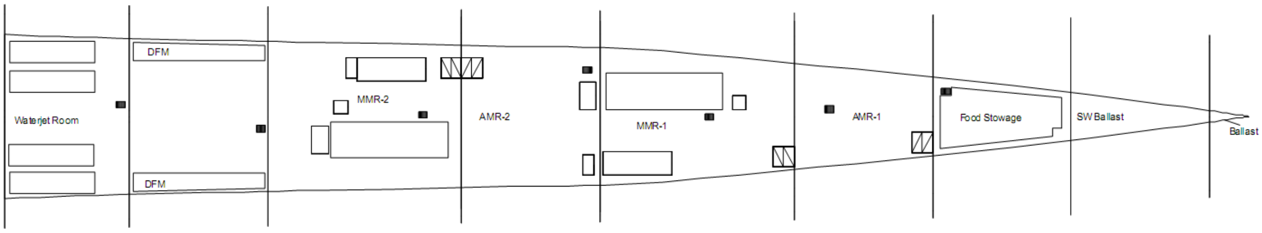


Figure 109 – Plan View, 4th Deck

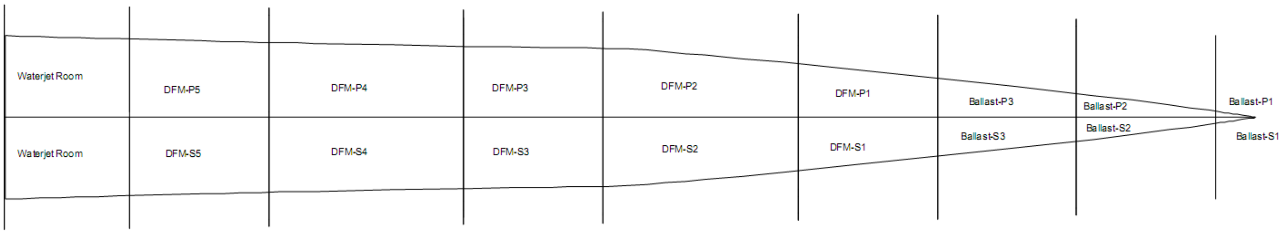


Figure 110 – Plan View, Inner Bottom

4.8.1 Tankage

Table 36 compares required tankage volume and actual tankage volume. Figure 54 shows the ASCal tankage arrangement and Table 37 lists individual tanks and volumes. The main objective when creating the tank arrangement was to maximize stability, and achieve the LCG calculated to minimize planing resistance. This was achieved by concentrating the majority of propulsion fuel aft of midships and storing it in the inner bottom/wing tanks to keep a low VCG. The JP-5 is also stored aft for optimum location to the helicopters and hanger. The ballast tanks are located in the bow and stern of the ship to for trim purposes and to weigh down the stern when carrying out launch ramp operations. The lube oil/wasted oil are located in the main machinery rooms and the potable water is kept isolated from all other tanks to avoid contamination. Reduction in ballast tank volume required was demonstrated as feasible in the intact stability analysis, section 4.10.1.

Table 36 – Required vs. Available Tankage Volume

Variable	Required(m^3)	Final Design (m^3)
Waste Oil	12.5	14
Lube Oil	21	21
Potable Water	7.5	10
Sewage	2.7	3
Helicopter Fuel (JP5)	86	86
Clean Ballast	268.5	171
Propulsion Fuel (DFM)	624	582

Table 37 - Individual Tanks and Volumes

Tank	Capacity (m^3)	Tank	Capacity (m^3)
DFM 1P	21	LO 1P	10
DFM 1S	21	LO 1S	11
DFM 2P	33	POT 1S	5
DFM 2S	40	POT 1P	5
DFM 3P	35	BAL 1	6
DFM 3PW	17	BAL 2P	33
DFM 3S	35	BAL 2S	33
DFM 3SW	17	BAL 3S1	14
DFM 4P	55	BAL 3P1	14
DFM 4PW	21	BAL 5P	36
DFM 4S	48	BAL 5S	36
DFM 4SW	18	AFM 2S	43
DFM 5P	45	AFM 2P	43
DFM 5PW	15	WO 1S	7
DFM 5S	45	WO 1P	7
DFM 5SW	15	SEW 1S	1
DFM 6P	16	SEW 1P	1
DFM 6PW	35		
DFM 6S	16		
DFM 6P	36		

4.8.2 Main and Auxiliary Machinery Spaces and Machinery Arrangement

Six compartments contain the primary propulsion, auxiliary, and electrical machinery. There are two main machinery rooms, MMR1 and MMR2, two auxiliary machinery rooms, AMR1 and AMR2, one JP-5 Pump Room, and one waterjet room. The MMR and AMR rooms are placed in an alternating configuration amidships, separating main machinery rooms and components to increase survivability under attack. The waterjet and JP-5 Pump rooms are both located at the aft end of the ship with the waterjet room on the inner bottom and the JP-5 Pump Room one deck above the inner bottom.

Each MMR contains an LM2500+ main gas turbine and a CAT 3616 secondary diesel engine. Epicyclic reduction gears for the engines are located in MMR2 and in the lower level of AMR2 for MMR1 engines. Four CAT 3508B Ship Service Generators are placed with one in each of the AMR and MMR rooms. MGT Lube Oil assemblies are located on the upper and lower levels of MMR2 and MMR1, respectively, next to the main gas turbines. Lube Oil Coolers, pumps, and strainers are located the upper levels of MMR2 and AMR2 above the reduction gears. Bilge and Fire pumps are spread through all four machinery spaces. Two Air Conditioning plants and a Refrigeration plant are located on the upper level of each of the AMR and each of the lower levels house a fresh water distiller.

Table 38 - MMR and AMR Main Equipment

ITEM	QTY	NOMENCLATURE	LOCATION
1	2	Gas Turbine, Main	MMR
2	2	Diesel Engine, Secondary	MMR
3	2	Gear, Propulsion Reduction	MMR & AMR
4	2	Gear, Propulsion Reduction	MMR & AMR
7	18	Bearings, Line Shaft	AMR1 & AFT
8	2	Unit, MGT Hydraulic Starting	MMR
10	2	Diesel Generator, Ships Service	MMR
11	2	Diesel Generator, Ships Service	AMR
19	2	Assembly, MGT Lube Oil Storage and Conditioning	MMR
20	4	Strainer, Reduction Gear Lube Oil	MMR & AMR
21	4	Cooler, Reduction Gear Lube Oil	MMR & AMR
22	4	Pump, Reduction Gear Lube Oil Service	MMR & AMR
23	2	Purifier, Lube Oil	MMR & AMR
24	2	Pump, Lube Oil Transfer	MMR & AMR
28	4	Air Conditioning Plants	AMR
29	4	Pump, Chilled Water	AMR
30	2	Refrig. Plants, Ships Service	AMR
31	4	Pump, Fire	MMR & AMR
32	1	Pump, Fire/Ballast	AMR
33	2	Pump, Bilge	MMR
34	1	Pump, Bilge/Ballast	AMR
36	2	Distiller, Fresh Water	AMR
37	2	Brominator	AMR
38	2	Brominator	AMR
39	2	Pump, Potable Water	AMR
40	2	Pump, JP-5 Transfer	JP-5 PUMP ROOM
41	2	Pump, JP-5 Service	JP-5 PUMP ROOM
42	1	Pump, JP-5 Stripping	JP-5 PUMP ROOM
43	2	Filter/Separ., JP-5 Transfer	JP-5 PUMP ROOM
44	2	Filter/Separ., JP-5 Service	JP-5 PUMP ROOM

Figure 111 and Figure 112 show the machinery arrangements in the upper and lower levels of MMR1 and AMR1. Figure 113 and Figure 114 show the upper and lower levels of MMR2 and AMR2. Figure 115 shows the layout of pumps and filters in the JP-5 PUMP Room. Numbers are keyed to the MEL. Table 38 contains a partial MEL of large equipment in these spaces with the full MEL located in Appendix D. Figure 116, Figure 117 and Figure 118 show these spaces in the ASCal 3D model. Figure 119 shows a profile view of ASCal, highlight the ship's machinery rooms and stacks.

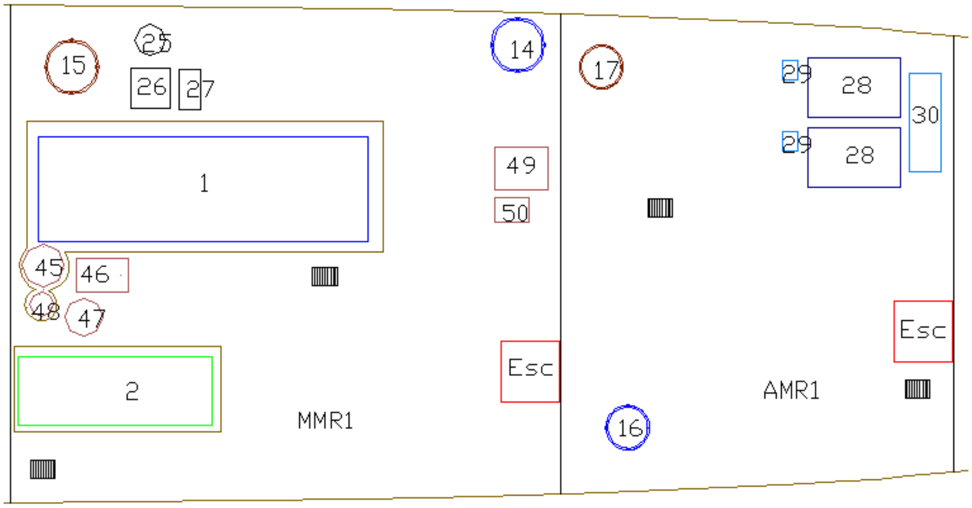


Figure 111 - MMR1 & AMR1 - 1st Platform

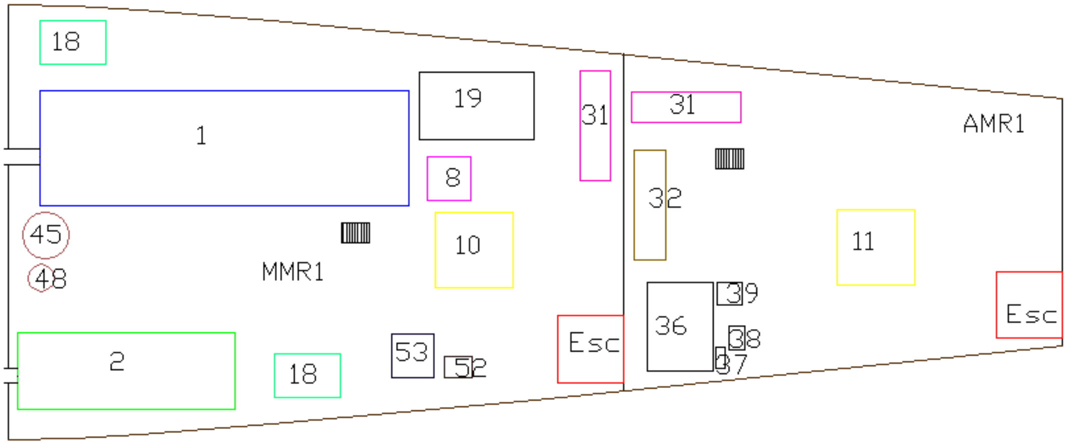


Figure 112 - MMR1 & AMR1 - 2nd Platform

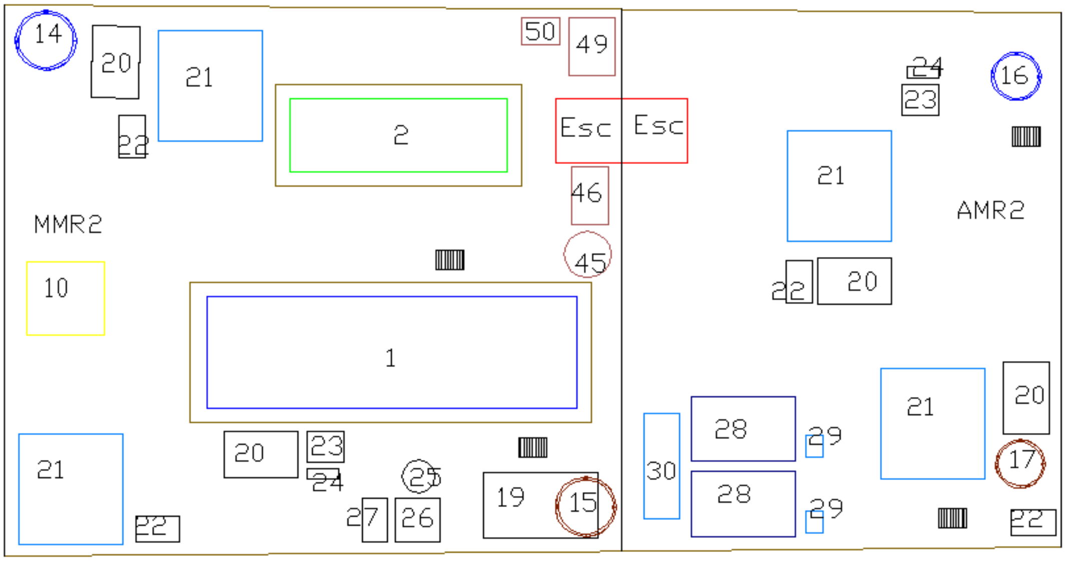


Figure 113 - MMR2 & AMR2 - 1st Platform

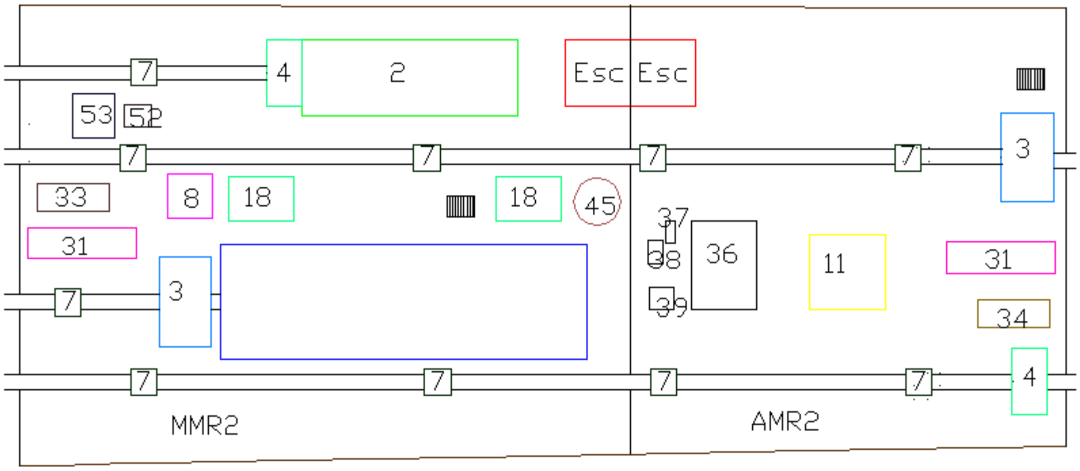


Figure 114 - MMR2 & AMR2 - 2nd Platform

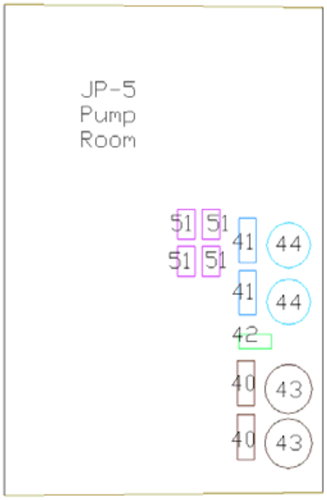


Figure 115 - JP-5 Pump Room

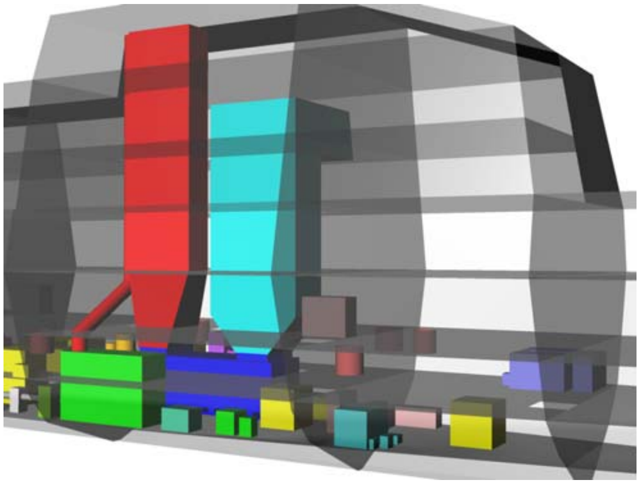


Figure 116 – MMR1 and AMR1 in 3D Model

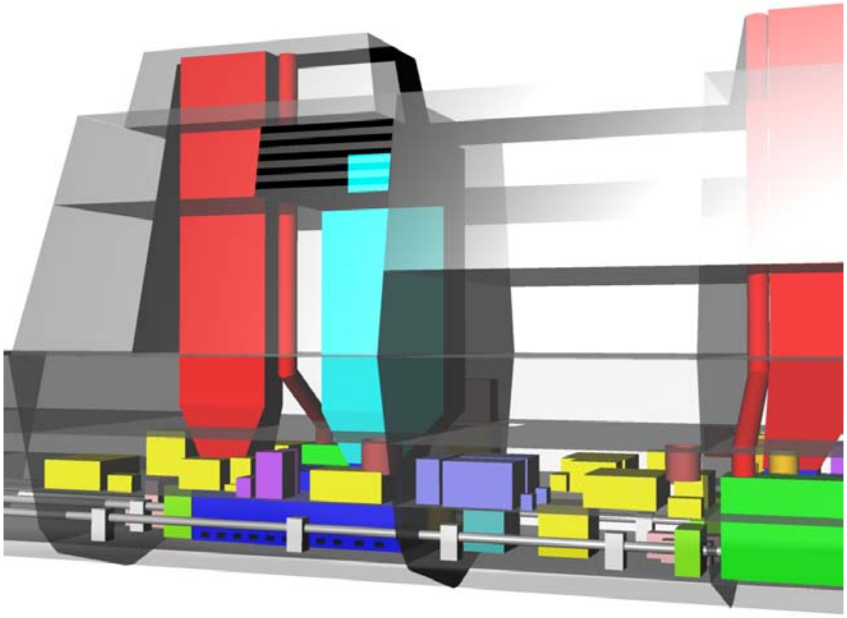


Figure 117 – MMR2 and AMR2 in 3D Model

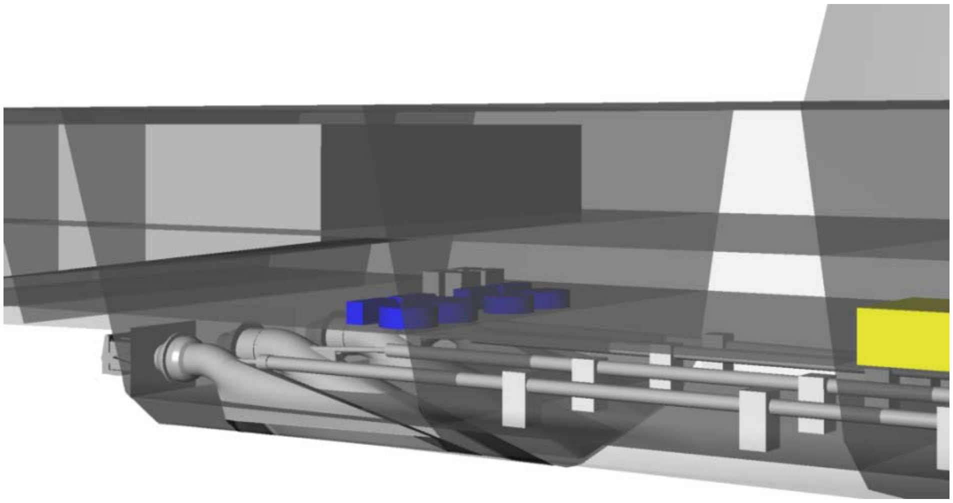


Figure 118 – JP-5 Pump Room in 3D Model

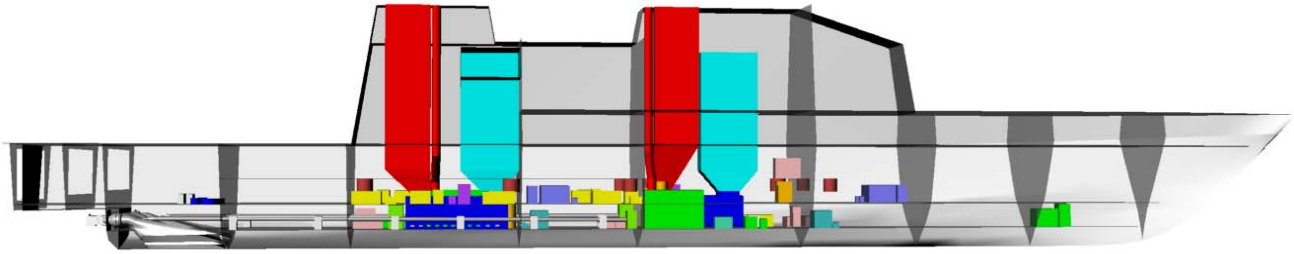


Figure 119 – ASCal Profile Showing Machinery Rooms and Stacks

4.8.3 Internal Arrangements

Figure 102 through Figure 110 show the internal arrangements of ASCal from the 03 level to the inner bottom. The stepped weather deck shows up in both Main Deck and 4th Platform drawings

4.8.4 Living Arrangements

Living area estimates are based on research of previous naval ships and habitability standards. Scaling is applied based on the number of crew members within each category. Table 39 shows a summary of the living space estimates for ASCal. The table is broken shown into space allotted for each type of sailor habitability area on ship.

Table 39 - Accommodation Space

Item	Accommodation Quantity	Per Space	Number of Space	Area Each (m2)	Total Area (m2)
CO	1	1	1	15	15
XO	1	1	1	10	10
Department Head	4	1	4	8	32
Other Officer	7	2	4	8	32
CPO	17	6	3	15	45
Enlisted	32	12	3	15	40
Officer Sanitary	11	6	2	30	60
CPO Sanitary	17	6	3	25	75
Enlisted Sanitary	32	12	6	20	120
Total			**27**		**429**

Figure 122 through Figure 125 show plan views of ASCal crew mess, officer wardroom, crew, CO, XO and department head berthing respectively.

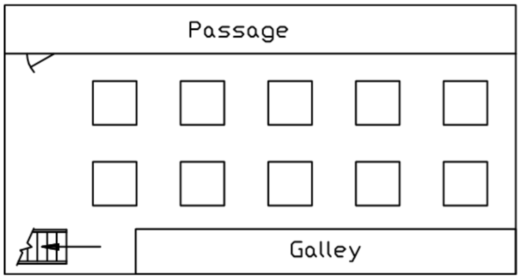


Figure 120 – Crew Mess Plan View

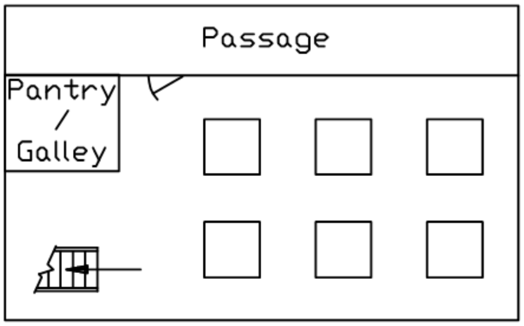


Figure 121 – Officer Wardroom

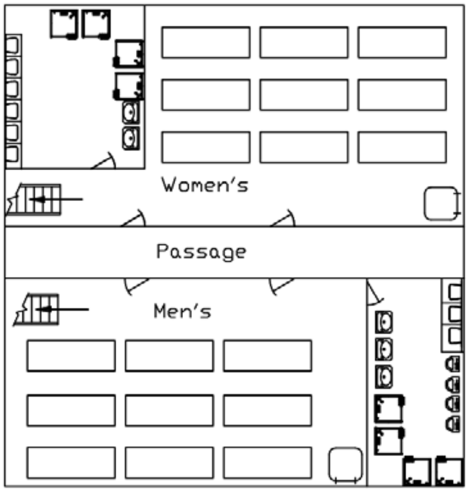


Figure 122 – Crew Berthing Plan View

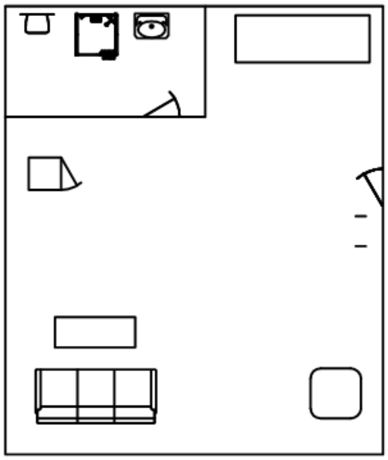


Figure 123 – CO Berthing Plan View

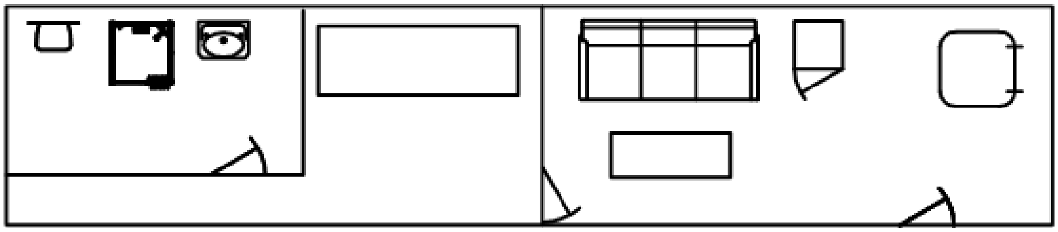


Figure 124 – XO Berthing Plan View

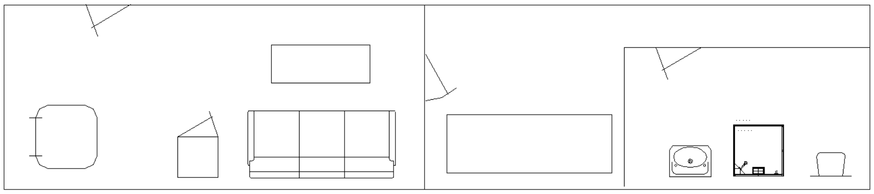


Figure 125 – Department Head Berthing Plan View

Multiple crew berthing areas exist on the ship, but each will generally follow the layout shown in Figure 122. All mess and berthing areas are located as close to amidships as possible to decrease dynamic motion while at sea.

4.8.5 External Arrangements

Figure 100 and Figure 101 show ASCal's external arrangements. Radar Cross-Section (RCS) is important to the external arrangement of ASCal. All non-horizontal surfaces are angled at 10° to reduce RCS. All anchor handling and mooring equipment is located below deck.

The need to provide a stable and safe platform for the operation of mission modules, helicopters and rotary wing AUVs is also important. The large helicopter pad in the aft of the ship provides ample space for vertical takeoff and landing operations. The hangar is large enough to house two SH-60 helicopters with their rotors folded. Above the hangar, a dedicated flight control space provides personnel with a direct view of the helo pad. Figure 126 shows a 3D view of the combat systems arrangements.

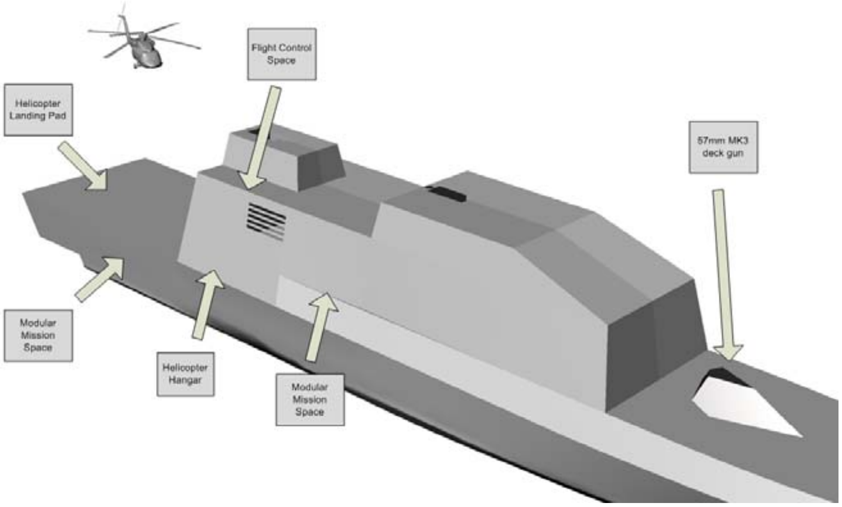


Figure 126 – Combat Systems Arrangements

4.9 Weights and Loading

4.9.1 Lightship Weights

Ship weights are grouped by SWBS. Research of manufacturer-supplied information for ship components and materials provided a basis for weights. Weight values calculated by the synthesis model were also used in this analysis. Vertical and longitudinal centers of gravity (VGC and LCG) are calculated based on ship arrangements. A summary of lightship weights and centers of gravity by SWBS group is listed in Table 40. The weights spreadsheet is provided in Appendix E.

Table 40 – ASCal Final Baseline Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m-Abv BL)	LCG (m-Aft FP)
100	582	5.76	52.0
200	572	4.48	62.8
300	114	5.24	52.0
400	157	9.77	34.5
500	373	7.13	55.2
600	30.3	7.62	44.9
700	47.4	10.1	29.1
Margin	187	6.09	53.8
L.S. w/margin	2063	6.09	53.8

4.9.2 Loading Conditions

Minimum Operating and Full Load conditions are assessed. Table 41 and Table 42 summarize the weights for these two loading conditions defined in DDS-079-1. The Full Load Condition represents the ship at the time it is leaving port with the full allowance of loads and cargo. The Minimum Operating Condition represents the ship as if it had been at sea for a longer period of time. This is usually the condition of lowest stability due to the decreased liquid in the tanks.

Table 41 - Weight Summary: Full Load Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship w/ Margin	2063	5.35	61
Ships Force	6	6.5	42.7
Total Weapons Loads	100	8.4	50
Aircraft	6.9	8.73	68
Provisions	50	8.4	50
General Stores	6	6.3	45.45
Diesel Fuel Marine	483	1.584	64.984
JP-5	66	2.692	81.875
Lubricating Oil	20	4.197	65.416
SW Ballast	0	0	0
Fresh Water	10	5.295	30.816
Total	2810.9	5.117	61.018

Table 42 - Weight Summary: Minop Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship	2063	5.35	61
Ships Force	6	6.49	42.7
Total Weapons Loads	30	8.4	50
Aircraft	6.9	8.73	68
Provisions	20	8.4	50
General Stores	2	6.3	45.45
Diesel Fuel Marine	254	1.3	65.
JP-5	23	2.	81.9
Lubricating Oil	7	3.3	65.4
Compensated Fuel-Ballast	0	0	0
SW Ballast	0	0	0
Fresh Water	7	5.1	31.0
Total	2419	5.3	60.7

4.10 Hydrostatics and Stability

Hydrostatic, intact stability and damage stability calculations are performed using HECSALV.

4.10.1 Intact Stability

In each condition, trim, stability and righting arm data are calculated. The criteria used to determine this information are from DDS-079-1. If the ship meets all of the particular criteria then it is believed to have a substantial chance for survival. The factors affecting a ship's intact stability include the effects of beam winds and the rolling motion incurred from them. These two forces are considered at the same time because rough seas are normally caused by strong winds. The criteria for adequate stability under adverse wind conditions are based on a comparison of the ship's righting arm curve and the wind heeling arm curve as illustrated in Figure 99 and 100.

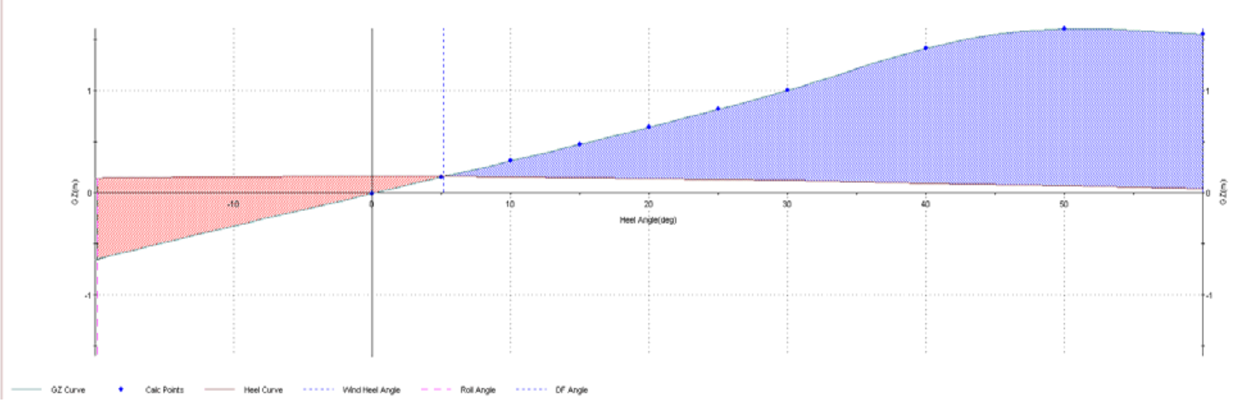


Figure 127- Intact Stability: Min Op

Table 41 - Righting Arm (GZ) and Heeling Arm Data for Minop Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	2379	Angle at Maximum GZ	51.2S
GMt (corrected)	1.733	Wind Heeling Arm Lw	.157
Mean Draft	3.811	Angle at Intercept	0
Projected Sail Area	502.95	Wind Heel Angle	5.1
Vertical Arm	6.292	Maximum GZ	1.604
Wind Pressure Factor	.02	Righting Area A1	.9
Wind Pressure	.02	Capsizing Area A2	.17
Wind Velocity	100	Heeling Arm at 0 deg	5
Roll Back Angle	25		

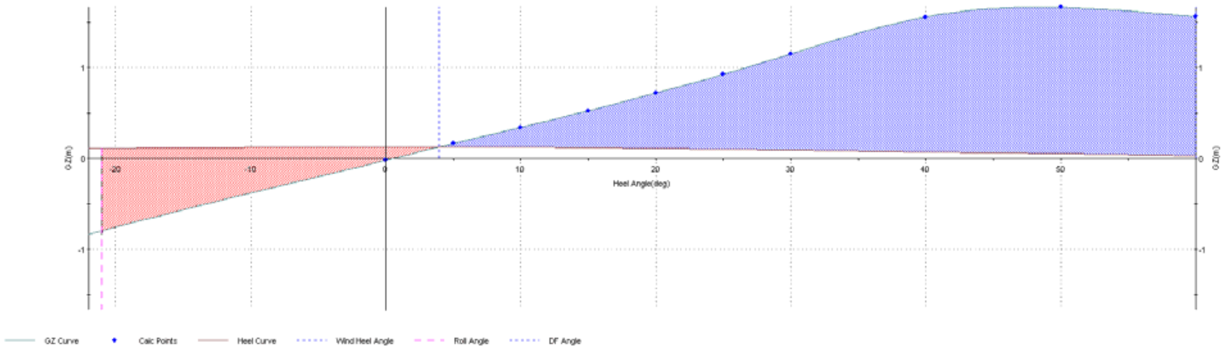


Figure 128-Intact Stability: Full Load

Table 42 - Righting Arm (GZ) and Heeling Arm Data for Full Load Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	2757	Angle at Maximum GZ	48.5S

GMt (corrected)	2.273	Wind Heeling Arm Lw	.127
Mean Draft	4.147	Angle at Intercept	0
Projected Sail Area	469.44	Wind Heel Angle	4
Vertical Arm	6.457	Maximum GZ	1.666
Wind Pressure Factor	.02	Righting Area A1	1
Wind Pressure	.02	Capsizing Area A2	.2
Wind Velocity	100	Heeling Arm at 0 deg	.128
Roll Back Angle	25		

Full Load and MinOp conditions are assessed using DDS 079-1 stability standards for beam winds with rolling. The numerical data for the two conditions is shown below. Tables 43 and 44 display the trim and stability summaries that were produced for the two conditions. The tables show the weights that were input as well as the adjustments made to the vessel's position in the water as a consequence of the weight change. Tables 39 and 40 give the explanation for the plots shown above and tabulate the values used to determine the illustrations. The GZ can be seen to increase as the heel angle grows larger.

Table 43 – ASCal Final Baseline Minop Trim and Stability Summary

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT	
Light Ship	2063	5.35	61	0	0	
Constant	0	0	49.40	0	0	
Lube Oil	7	3.31	65.42	2.14S	1	
Fresh Water	7	5.07	31.02	0	0	
SW Ballast	0	0	0	0	0	
Fuel (JP5)	23	2.05	81.9	0	76	
Misc. Weights	183	10.9	50.6	0	0	
Fuel (DFM)	254	1.3	65.0	.014S	336	
Waste Oil	13	.9	50.7	.033S	1	
Sewage	0	0	0	0	0	
Displacement	2379	5.3	60.7	.008S	414	
Stability Calculation			Trim Calculation			
KMt	7.184	M	LCF Draft		3.862	m
VCG	5.28	M	LCB (even keel)		58.8	m-MS
GMt (Solid)	1.91	M	LCF		56.55	m-MS
FSc	.174	M	MT1cm		59	m-MT/cm
GMt (Corrected)	1.733	M	Trim		.78	m-A
			List		2.4	Deg
Specific Gravity	1.03					
Hull calcs from tables			Tank calcs from tables			
Drafts			Strength Calculations			
Draft at A.P.	3.42	M	Shear		212 MT	at 45m
Draft at M.S.	3.81	M	Bending Moment		15,586H	m-MT at 0
Draft at F.P.	4.20	M				
Draft at Aft Marks	3.42	M				
Draft at Mid Marks	3.81	M				
Draft at Fwd Marks	4.201	m				

Table 44 – ASCal Final Baseline Full Load Trim and Stability Summary

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT	
Light Ship	2063	5.35	61	0	0	
Constant	0	0	49.95	0	0	
Lube Oil	20	4.20	65.42	.014S	1	
Fresh Water	10	5.30	30.82	0	0	
SW Ballast	0	0	0	0	0	
Fuel (JP5)	66	2.70	81.88	0	61	
Misc. Weights	286	9.99	50.32	0	0	
Fuel (DFM)	483	1.58	64.98	.014s	332	
Waste Oil	0	0	0	0	0	
Sewage	0	0	0	0	0	
Displacement	2757	5.1	61.012	.018S	394	
Stability Calculation			Trim Calculation			
KMt	7.37	m	LCF Draft		4.219	m
VCG	5.1	m	LCB (even keel)		58.62	m-MS
GMt (Solid)	2.27	m	LCF		57.73	m-MS
FSc	.143	m	MT1cm		71	m-MT/cm
GMt (Corrected)	2.13	m	Trim		.926	m-A
			List		.5S	deg
Specific Gravity	1.025					
Hull calcs from tables			Tank calcs from tables			
Drafts						
Draft at A.P.	3.68	m	Shear		278 MT	at 45A
Draft at M.S.	4.15	m	Bending Moment		15584m-MT	at 0
Draft at F.P.	4.61	m				
Draft at Aft Marks	3.68	m				
Draft at Mid Marks	4.15	m				
Draft at Fwd Marks	4.61	m				

4.10.2 Damage Stability

The purpose of the damage stability calculation is to test the worst case scenarios that ASCal could expect to encounter with damage on a mission. This was done by testing a number of different conditions in HECSALV and determining which situations caused the worst condition in the ship. Because this ship is a combatant craft it should be able to take on rapid flooding to a shell opening equal to .15 LBP. Table 43 and Table 44 show ASCal at its intact state and the after effects of interior flooding. Figure 129 through Figure 136 show MinOp and Full Load damage stability conditions and righting arm curves for a variety of scenarios.

Table 43 - Minop Damage Worse Damage Cases

	Intact	Damage BH 0-16	Damage BH 84-100 (worst case)
Draft AP (m)	4.201	3.61	5.32
Draft FP (m)	3.421	4.13	2.17
Trim on LBP (m)	0.78A	.518F	3.15A
Total Weight (MT)	2,379	2,623	2,884
Static Heel (deg)	0.3S	0.4S	0.9S
GM_t (upright) (m)	1.733	1.12	0.65
Maximum GZ	0.971	.92	.63

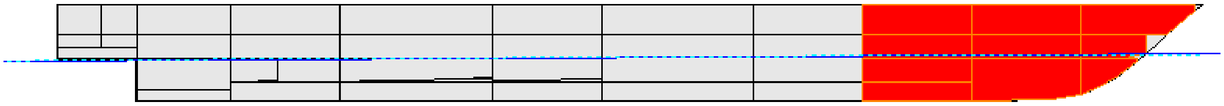


Figure 129 - MinOp Flooded Bow Frame (0-16)

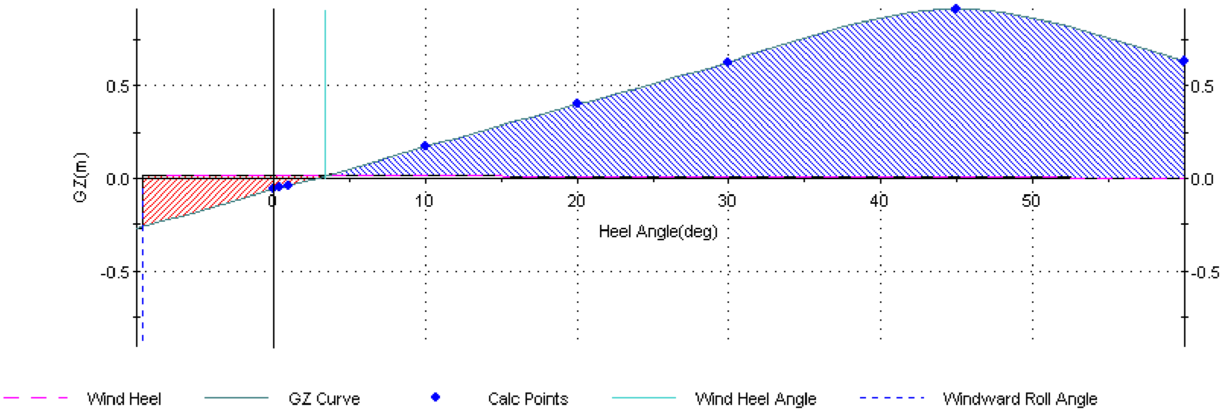


Figure 130 - MinOp Flooded Bow Righting Arm Curve Frame (0-16)

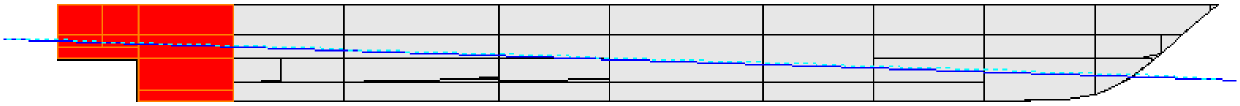


Figure 131 - MinOp Flooded Stern (Frame 84-100)

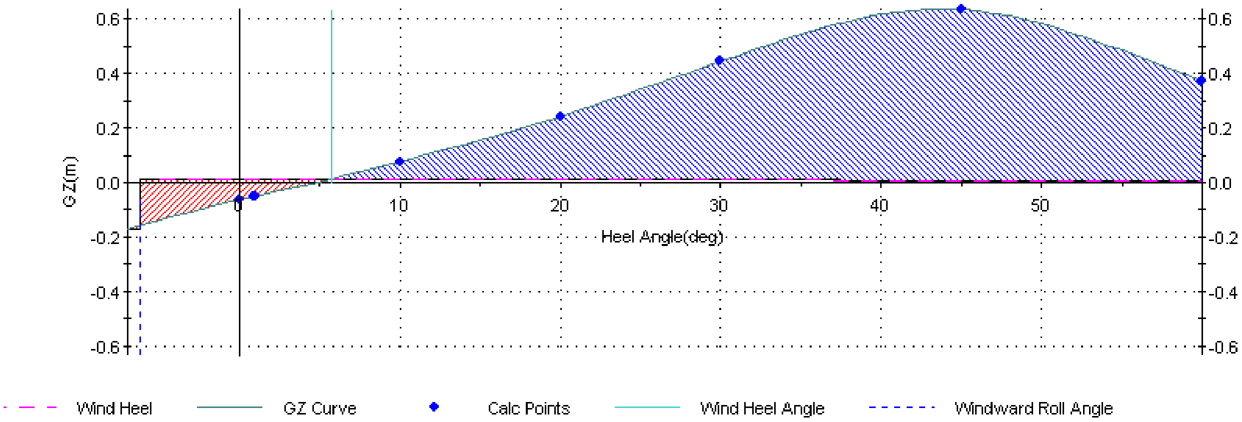


Figure 132 - MinOp Flooded Stern Righting Arm Curve Frame (84-100)

Table 44 - Full Load Damage Results

	Intact	Damage BH 0-16	Damage BH 84-100 (worst case)
Draft AP (m)	4.61	3.99	5.9
Draft FP (m)	3.68	4.41	2.262
Trim on LBP (m)	0.926A	0.417F	3.639A
Total Weight (MT)	2,757	3,026	3,323
Static Heel (deg)	0.5S	0.3S	0.8S
GM_t (upright) (m)	2.13	1.705	0.85
Maximum GZ	1.67	1.10	0.75

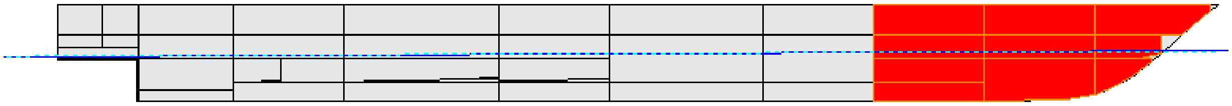


Figure 133 - Full Load Bow Flooded Frame (0-16)

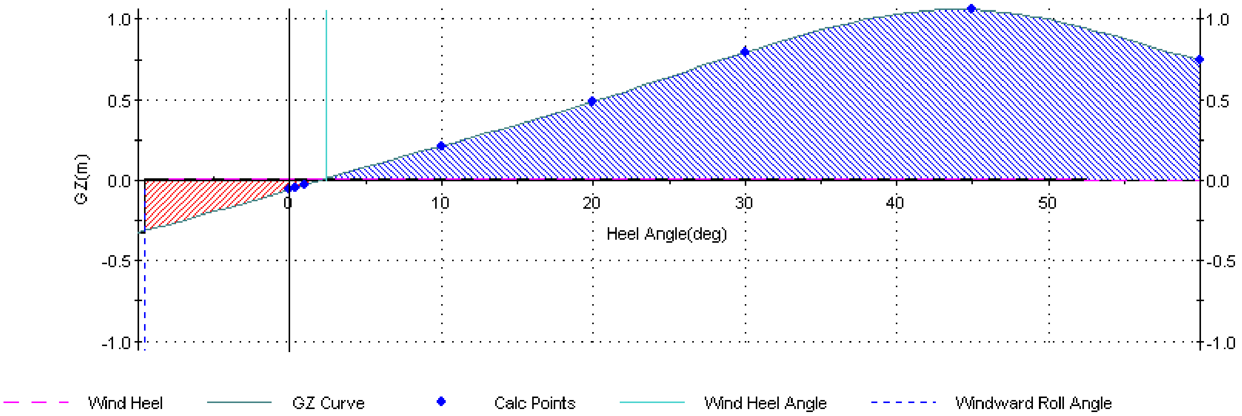


Figure 134 - Full Load Bow Flooded Righting Arm Curve Frame (0-16)

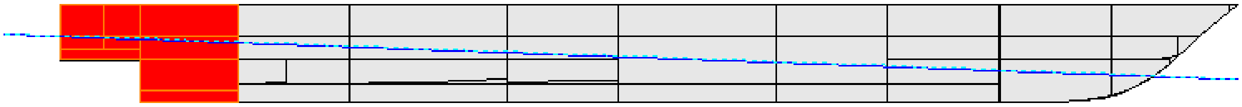


Figure 135 - Full Load Stern Flooded Frame (84-100)

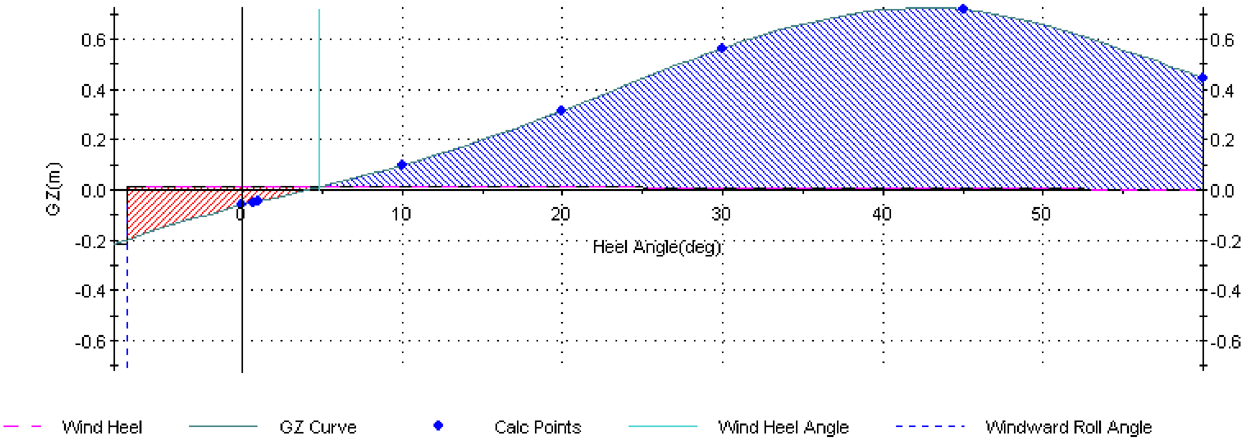
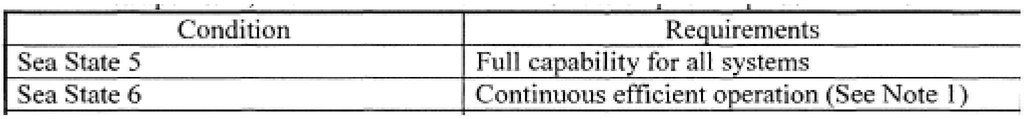


Figure 136 - Full Load Stern Flooded Righting Arm Curve Frame (84-100)

4.11 Seakeeping and Maneuvering

A seakeeping and maneuvering analyses in the full load condition will be performed in tandem by a 1/50 scale free-running model and Computational Fluid Dynamics (CFD) analysis with 6-Degree of Freedom solvers. The weather and environmental operating requirements for ASCal as set out by the LCS Interim Requirements Document (see Appendix A – LCS IRD) are shown in Table 45.

Table 45 – LCS IRD Weather and Environmental Operating Requirements



Condition	Requirements
Sea State 5	Full capability for all systems
Sea State 6	Continuous efficient operation (See Note 1)

4.11.1 Model Testing

The model test model is shown in Figure 137 – ASCal Scale Model at an early stage of production. The model, CNCed from high-density closed-cell foam, houses an On Board Computer (OBC) to run Data Acquisition (DAQ) and control operations for a variety of seakeeping and maneuverability tests.

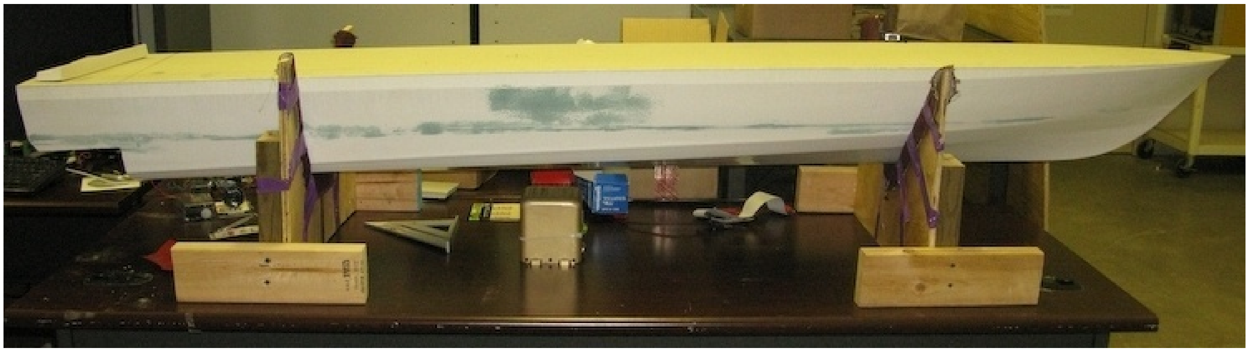


Figure 137 – ASCal Scale Model

Figure 138 shows a schematic of the test model. The lines in this diagram show major electrical and mechanical connections.

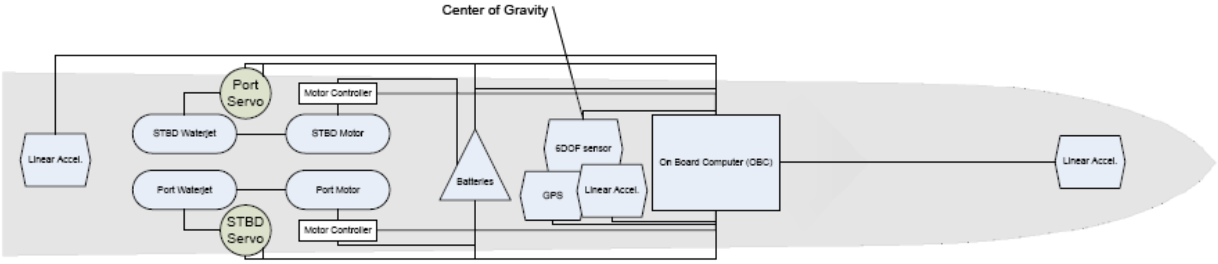


Figure 138 – ASCal Scale Model Hardware Diagram

The model's OBC in located in a cavity close to the ship's design LCG. Shown in Figure 139, the OBC consists of three PC-104 style boards; a processing board running with 256 Mb of RAM, a power supply board offering ±5 and 12V DC and a 32 slot Analog I/O board. The OBC runs Windows XP and uses LabVIEW VIs as the primary means for test control and data acquisition. Wireless capability is achieved through a USB dongle.

Figure 139 – Test Model On Board Computer (OBC)

Data can be acquired from a number of sources on the model including a 6-DOF IMU unit, 2 single axis liner accelerometers, 1 three axis linear accelerometer and USB interfaced GPS unit.

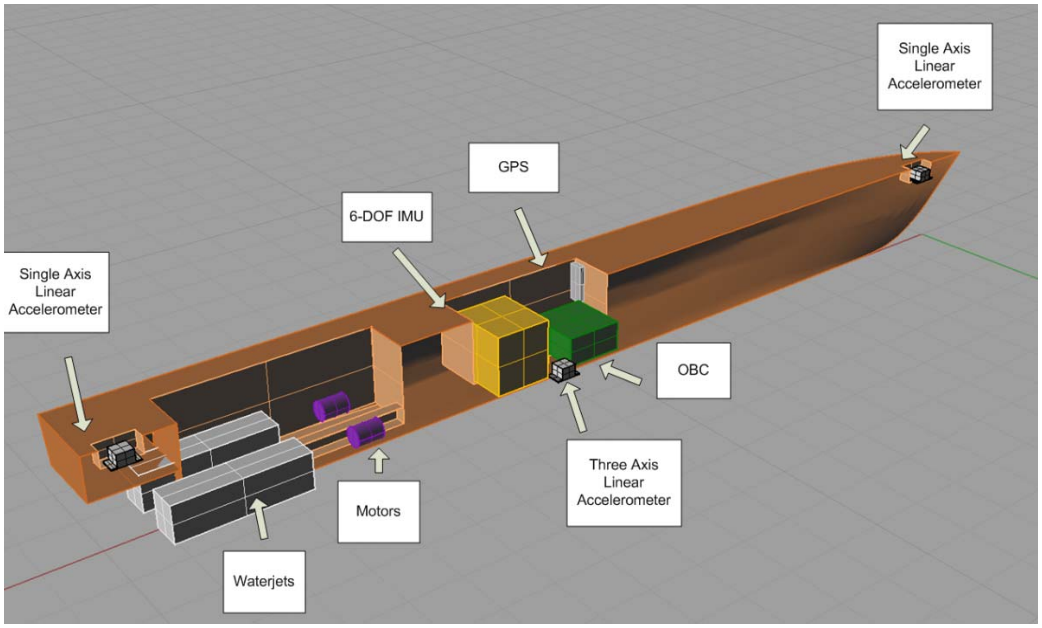


Figure 140 – Test Model Component Locations

Two miniaturized steerable waterjets are powered by two brushless DC motors. It should be noted that ASCal is equipped with 4 waterjets (2 steerable, 2 fixed). The complexities of a waterjet propulsor do not scale well, meaning the model scale waterjets wind up being much larger than the scaled space allocated for them in the ship. With the proper powering, the model's two waterjets should be capable of propelling it to the necessary testing speeds. To achieve the scaled equivalent to ASCal's 42.5 knot sustained speed, the model will reach a top speed of approximately 6 knots or 3 m/s.

4.11.2 Computational Fluid Dynamics

In addition to scaled model testing, numerical analysis, in the form of computational fluid dynamics (CFD), was used to analyze the seakeeping characteristics of ASCal. Using the Star-CCM+ software package, both 6-Degree OF Freedom seaway motion and topside wind turbulence simulations were run. The seaway motion simulations will compared with model testing results for validation.

Topside CFD

With helicopter operations of such a great level of importance, the ability to predict wind patterns on the ASCAL landing pad is of great value. A k-epsilon turbulence model was used in modeling the airflow which was assumed to incompressible for the cases studied. The domain used (shown in Figure 141) captures the geometry of the ship above the waterline.

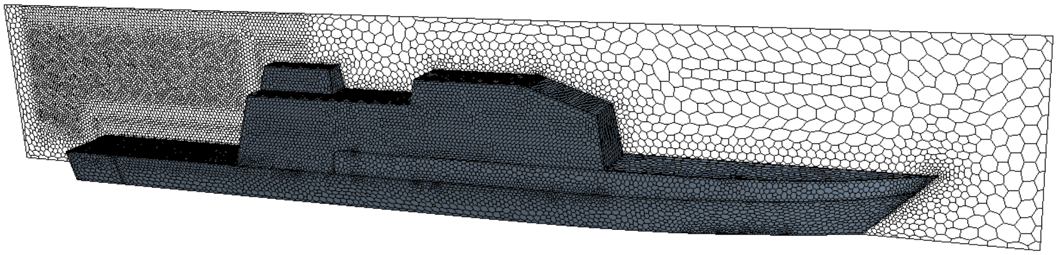


Figure 141 - Wind Flow Computational Domain

A mesh containing 0.13 million polyhedral cells was used to run a series of time independent simulations with wind speeds ranging from 10 to 70 knots, and headings from 0° to 90°. Increased mesh resolution in the flight deck area can be seen in Figure 142.

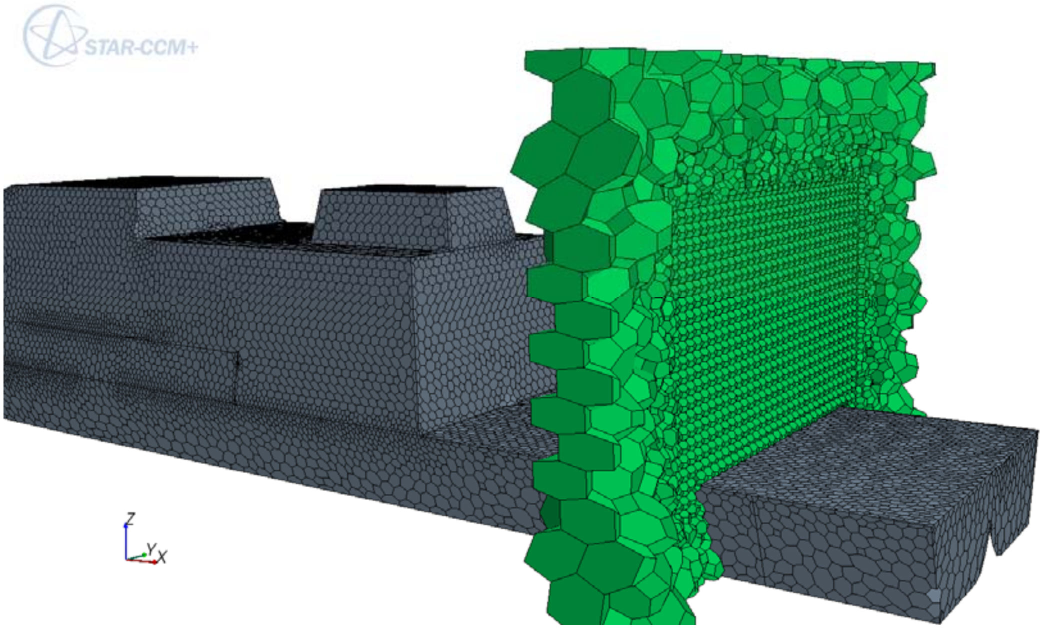


Figure 142 - Increased volume mesh resolution in flight deck area

While quantitative limiting conditions of for helicopter landing operations were not available for this study, flow patterns consistently show that an approach from the aft of the ship in most flow patterns is best. Figure 143 shows the results from a simulation of head on flow at 10 knots. Turbulence is plotted in the scalar, with “hotter” colors having higher levels of turbulent kinetic energy.

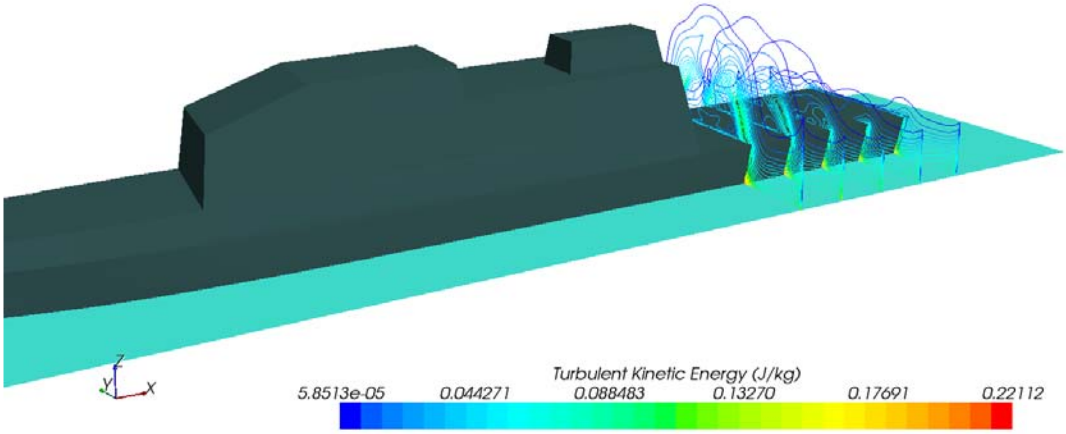


Figure 143 - Turbulent kinetic energy for 10 knot head on flow

Figure 144, Figure - 145 and Figure - 146 show the flow predicted for a 35 m/s crosswind on the port side of the ship. Figure - 145 shows the probe grid used to find the average and maximum turbulent kinetic energy (TKE) levels in the flight deck area. Figure - 146 shows velocity magnitude in plane located slightly above the flight deck. Local air velocity is shown by the scalar color.

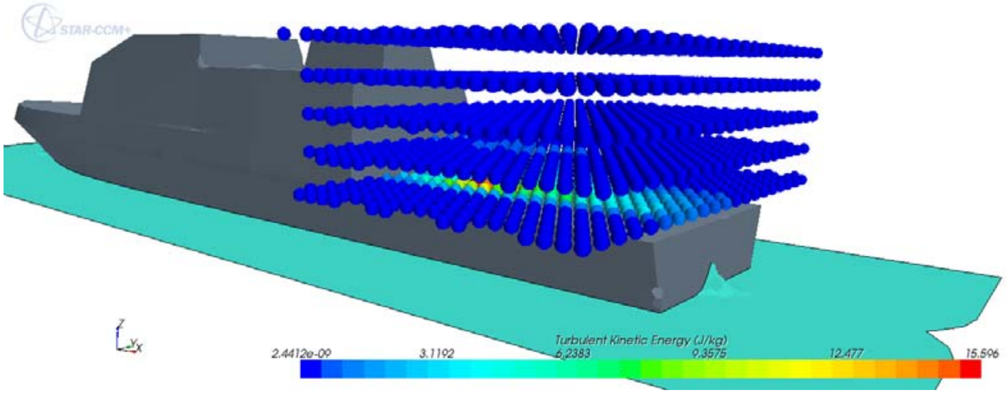


Figure 144 - Landing area probe grid showing TKE in 35 m/s crosswind

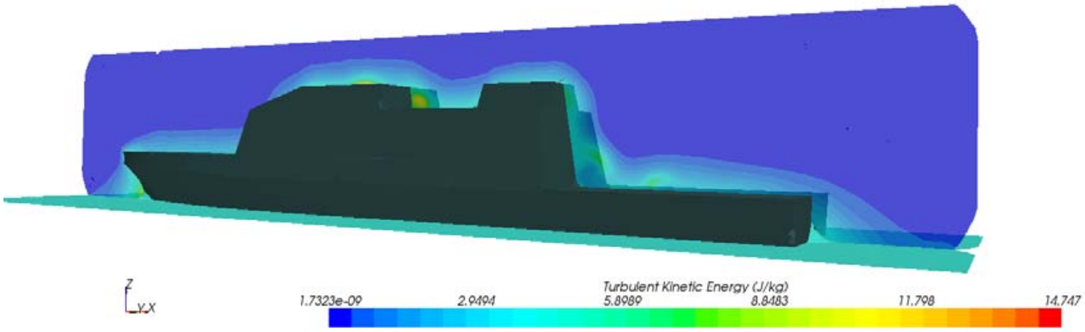


Figure - 145 TKE from crosswind at 35 m/s

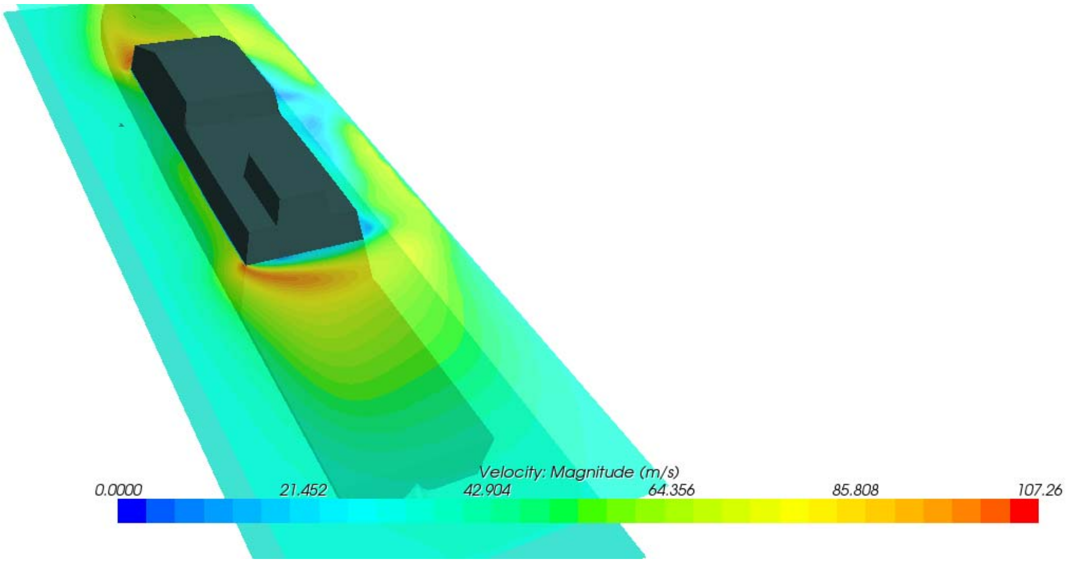


Figure - 146 Horizontal velocity section of 35 m/s crosswind

Figure 147 and Figure 148 show the maximum and average turbulent kinetic energy levels respectively in the landing pad area for a variety of headings and wind speeds. Second-order polynomial regressions have been applied to the data in order to allow for future interpolation and extrapolation as necessary.

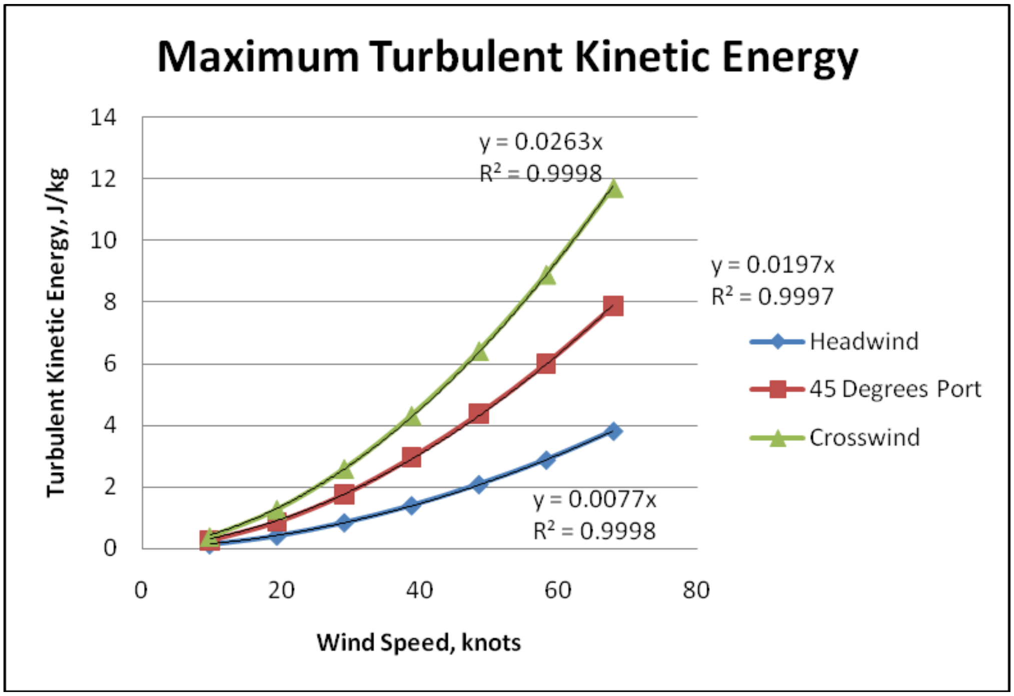


Figure 147 - Maximum turbulent kinetic energy of wind flow over the ASCal landing pad area

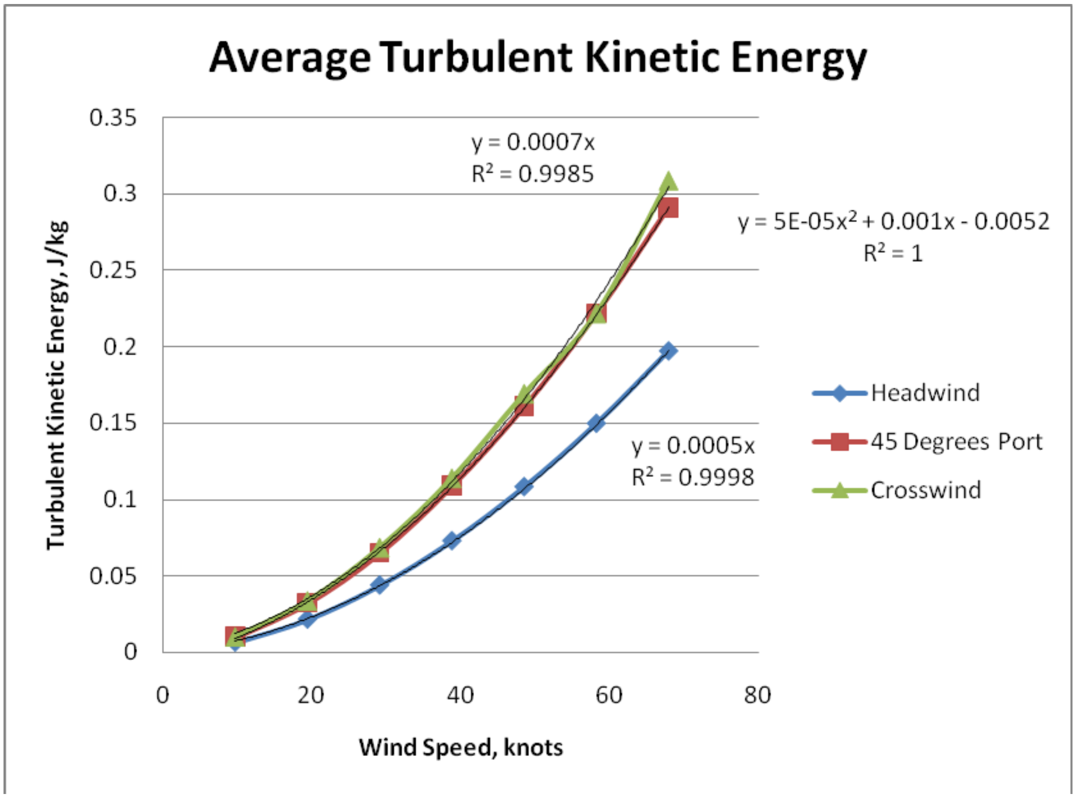


Figure 148 - Average turbulent kinetic energy of wind flow over the ASCal landing pad area

Although the maximum and average TKE levels increase as the wind source moves from head on to a 90° crosswind, the large turbulence levels for the cross wind situation tend to be located very close to deck. While this is important to note, it may not have the same adverse affects on helicopter operations as turbulence located higher in the air column.

Seakeeping CFD

With Volume Of Fluid (VOF) free surface and 6-DOF solvers applied in a time implicit simulation, seakeeping tests were run numerically. The computational mesh domain shown in Figure 149 has an increased mesh density near the predicted free surface to provide higher resolution and decrease error. The trapezoidal domain shape was used to reduce error in turbulence modeling calculations. The elimination of a flow parallel to a domain edge along the free surface was shown to greatly reduce turbulence model problems. Except for the aft most face of the trapezoid, which is set as a pressure outlet, all of its faces are set to be “velocity inlets,” where a flow speed, direction, and free surface height are specified.

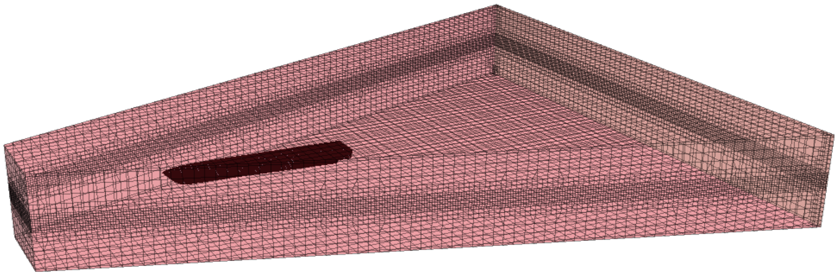


Figure 149 - ASCal Seakeeping Simulation Computational Domain

The center of gravity and moment of inertia of the model are set to match ASCal. This numerical model allows for tests to be run in a large variety of seastates, speeds, and headings. Due to the need to use a time implicit scheme in these simulations, they can become computationally intensive quite quickly.

To better develop the settings used in this analysis, a simulation in calm water was used. This provides a valuable chance to insure that the ship’s mass properties are correct, and that the simulation is robust enough to handle the large amplitude motions of a seakeeping test. Figure 150 and Figure 151 show ASCal at a speed of 5 m/s. While wake patterns at this Froude number are not highly pronounced, they are still somewhat visible in these renderings.

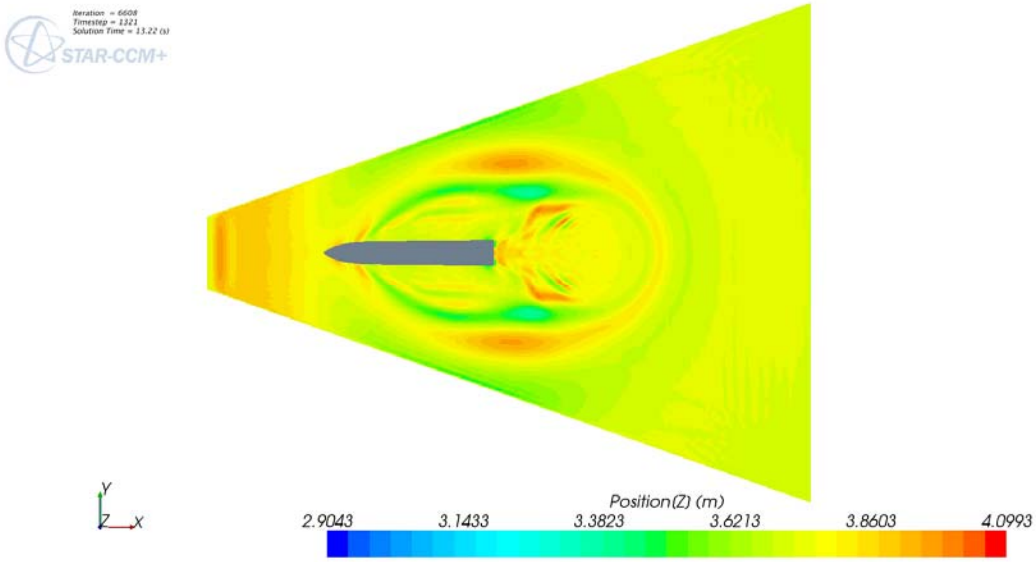


Figure 150 - Calm water 6-DOF simulation plan view with free surface height scalar

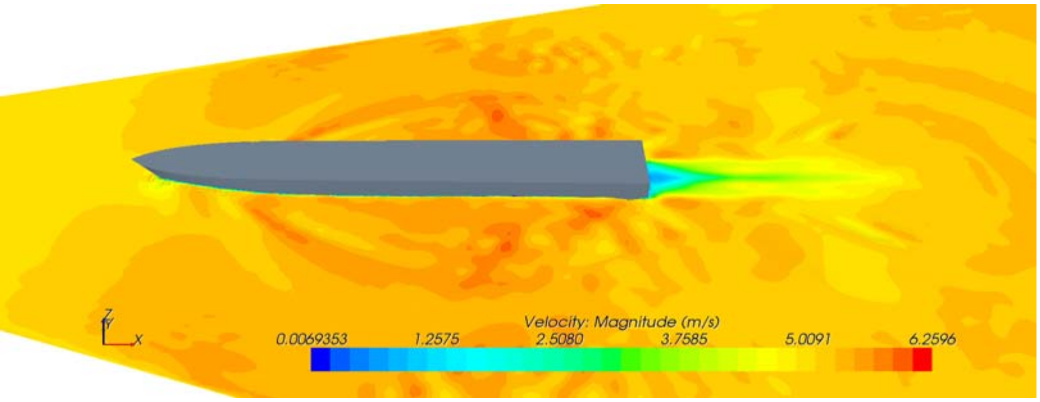


Figure 151 - Calm water 6-DOF simulation with free surface velocity scalar

Figure 152 shows the settling motions of the ship in the calm water simulation. These are the result of a number of simulations. Since time implicit simulations are computationally intensive, it was advantageous to attempt to estimate the running trim and draft for the ship at speed instead of letting it settle completely on its own. A number of simulations were run in succession, with each newest simulation using a slightly different trim and draft. In this way a more accurate solution can be obtained in a shortened time period.

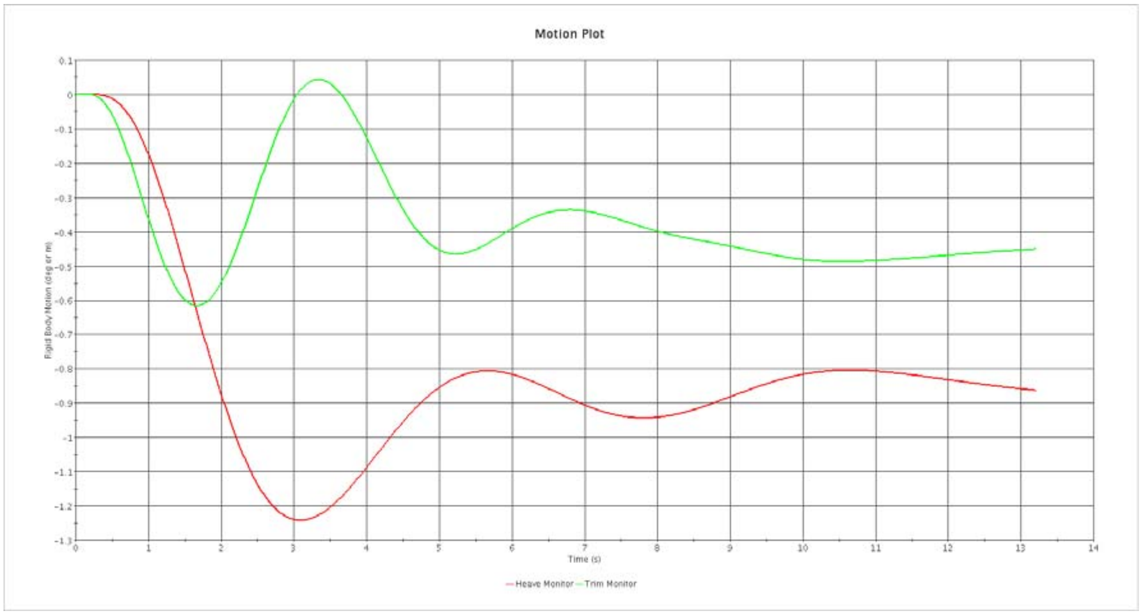


Figure 152 - Ship motion (Red = Heave, Green = Trim) for calm water simulation

Figure 153 shows the numerically predicted heave and pitch motions of ASCal in Seastate 5 in head on seas at a speed of 10 knots. These conditions were modeled using a 1st order Stokes Theory approximation with a wave amplitude of 1.5m and a wavelength of 40m.

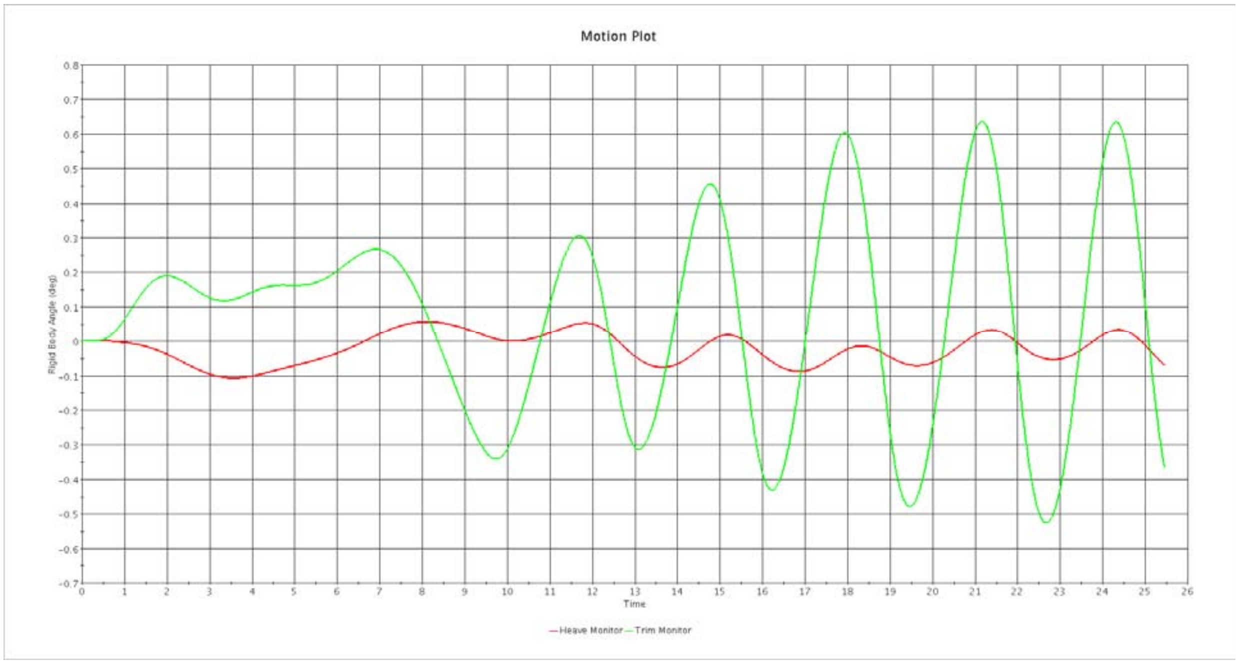


Figure 153 - Seakeeping motion plot (Red=Heave, Green=Trim) for Seastate 5

Figure 154 shows a rendering from the above described simulation. At this point in time the ship has not yet completely reached a regular oscillatory motion, as can be seen in the motions plotted in Figure 153. The stern of the ship has just passed the first wave of the simulation. Regular motion should therefore begin shortly.

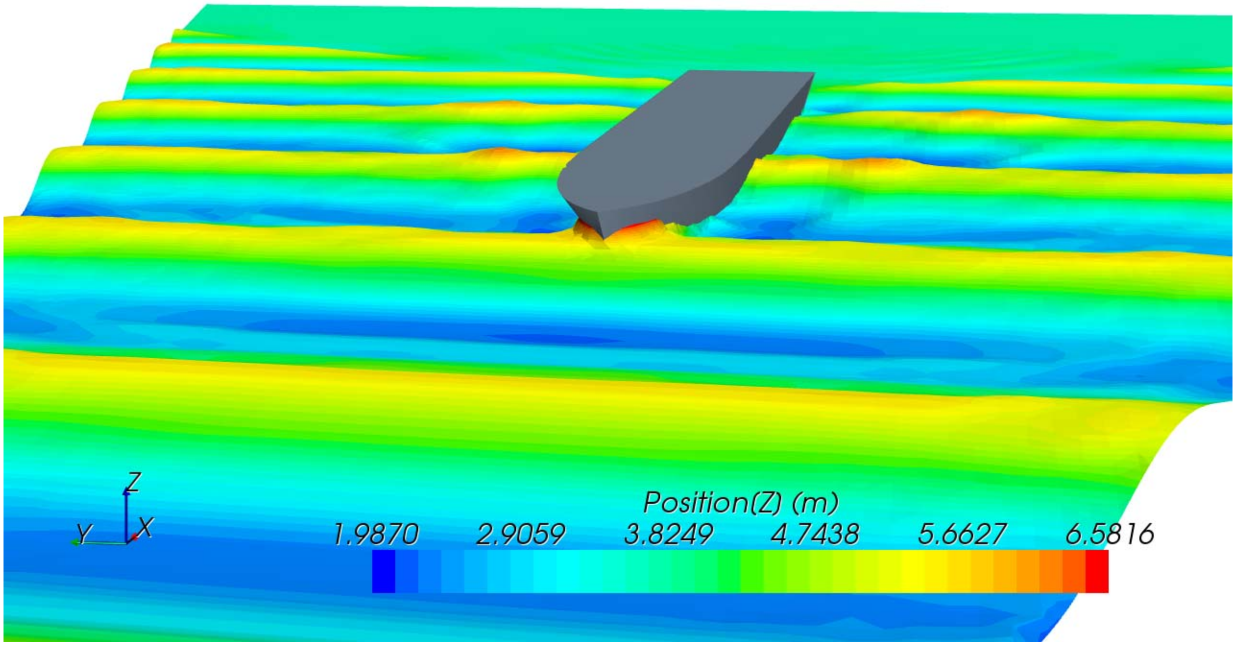


Figure 154 - Seakeeping test in Seastate 5

These results can be used to develop an RAO for ASCal as well as test motion limitations (MSI and MII).

4.11.3 Seakeeping Results

Table 46 shows the results and requirements for seakeeping motion of ASCal. Specified operational thresholds are shown a number of ships components and operations.

Table 46 – Limiting Motion Criteria and ASCal Results

Application	Roll (deg)	Pitch (deg)	Yaw (deg)	Surge (g)	Sway (g)	Heave (g)	ORD Threshold Seastate	Seastate Achieved
VTUAV	17.5	3	1.5	0.3	0.7	0.6	5	
Vertical Underway Replenishment	4						5	
LAMPS	5	3					5	
Bridge Personnel	8	3		0.2		0.4	6	

4.12 Cost and Risk Analysis

4.12.1 Cost and Producibility

Cost is calculated based on weight, power, and manning variables. SWBS groups 100 to 700 are inputted as well as brake horsepower and manning needs. The calculation accounts for the ship builder’s portion of the cost and also the government’s portion. Inflation and interest are accounted for over the life of the project. Number of ships and time to complete the build is also accounted. Acquisition cost does not satisfy requirements set by the CDD. A cost comparison is shown in Table 47.

Table 47 – ASCal Cost Comparison

Engineering Input	Concept Baseline	Final Concept Baseline
Hull Structure Material (select one)		
Steel	0	0
Aluminum	1	1
Composite	0	0
Deckhouse Material (select one)		
Steel	0	0
Aluminum	1	1
Composite	0	0
Hullform (select one)		
Monohull	1	1
Catamaran	0	0
Trimaran	0	0
Plant Type (select one)		
Gas Turbine	0	0
Diesel	0	0
Diesel Electric	0	0
CODOG	0	0
CODAG	1	1
Plant Power (select one)		
Power rating (in SHP)	70,119	70,119
Main Propulsion Type (select one)		
Fixed Pitch Propeller	0	0
Controllable Reversable Propeller	0	0
Waterjet	1	1
Weights (provide in metric tons)		
100 (less deckhouse)	383	457
150 (deckhouse)	125	125
200 (less propeller)	471	494
245 (propeller)	77.90	78
300	126	114
400	147	157
500	245	373
600	112	30
700	32	47
Margin	172	188
Lightship and Margin	1892	2063.93
Full Load Displacement	2521	2742.83
Operating and Support		
Complement	40	60
Steaming Hrs Underway/Yr	2500	2500
Fuel Usage (BBL/Yr)	38,226	38,226
Service Life (Yrs)	30	30
Cost Element	**Concept Baseline**	**Final Concept Baseline**
Shipbuilder	**$225**	**$234**
Government Furnished Equipment (a)	**$279**	**$290**
Other Costs	**$33**	**$11**
Operating and Support	**$392**	**$388**
Personnel (Direct and Indirect)	*$109*	*$109*
Unit Level Consumption (Fuel, Supplies, Stores,	*$60*	*$59*
Maintenance and Support	*$223*	*$220*
Life Cycle Cost (less non-recurring)	**$929**	**$923**
LCC Threshold	**$950M**	
Average Acquisition Cost	**$320M**	**$427M**
Average Acquisition Cost Threshold	**$500M**	

The ASCal Final Concept Baseline costs more than what the Concept Baseline suggests, however it is less than the average acquisition and life cycle cost thresholds. Final Concept Baseline calculations are based on the SWBS weight groups, power, and manning. Concept Baseline costs are derived from the Model Center MOGO cost module and they differ because of different SWBS weights and manning variables between them. The differences derive from manipulation of the MOGO variant 26 design as needed. For instance, the concept baseline manning compliment is 40 and the final concept baseline is 60. Taking into account all variables used to calculate final concept baseline cost generates an average acquisition cost higher than that of the concept baseline.

ASCal is a highly producible design. The stepped deck means that the only curved surfaces are located on ship's hull. While aluminum construction has been problematic in the past, with the proper design and production planning, it can be an effective material to work with. Detailed designs must consider the specific characteristics and producibility aspects of aluminum, instead of treating it as light weight steel.

4.12.2 Risk Analysis

Based on the OMOR, ASCal is a relatively high risk ship. The high level of risk is derived from an all aluminum hull and deckhouse as well as cutting edge technology, automated systems, unmanned air and underwater vehicles, its operating environment, and propulsion system. These are all high risk alternatives and further testing and analysis on the incorporated technologies and materials is needed to reduce this risk.

5 Conclusions and Future Work

5.1 Assessment

As is shown in Table 48, ASCal meets and exceed the CDD specified requirements.

Table 48 - Compliance with Operational Requirements

Technical Performance Measure	CDD TPM (Threshold)	Original Goal	Concept BL	Final Concept BL
Number of VTUAVs	3	3	3	3
Number of SPARTANs	2	3	2	1
Number of LAMPS	haven	2	2	2
Number of RMSs	1	2	1	1
Total mission payload weight (core, Modules, fuel) (MT)	100	360	150	150
Endurance Range (nm)	3500	4500	4099	3599
Sprint Range (nm)	1000	1500	1143	1496
Stores duration (days)	15	45	45	45
CBR	Partial	Full	Partial	Partial
Sustained (Spring) Speed Vs (knots)	40	50	47.3	42.5
Crew Size	90	40	40	60
Maximum Draft (m)	10	3.5	3.75	3.74
Vulnerability (Hull Material)	Aluminum	Aluminum	Aluminum	Aluminum
Seakeeping capabilities (sea state)				
Launch and recovery aircraft	SS4	SS4	SS4	SS4
Launch and recover watercraft	SS3	SS3	SS3	SS3
Full capability of all systems	SS5	SS5	SS5	SS5
Survive	SS8	SS8	SS8	SS8
Follow-ship Acquisition cost ($M)	500	320	320	440
Life cycle cost ($M)	900	500	681	695
Overall Measure of Effectiveness (OMOE)	0.584	0.9	0.7809	0.7809
Maximum level of Risk (OMOR)	0.691	0.1	0.538	0.538

ASCal uses a variety of technologies to achieve its goals. Modular mission packages allow the ship to support a number of missions effectively. The low RCS, low draft hullform and deckhouse provide an excellent platform for littoral operations. The lightweight, semi-planing, hard chined hullform and 70000kW of available power allow ASCal to reach a sustained speed of 42.5 knots. Efficient, low heat signature, endurance operation using diesel power is also possible.

5.2 Future Work

Future work items in the Concept Development process are as follows:

- Model seakeeping and maneuvering test completion and anaylsis
- Further CFD testing
- Employ same diesel engine model for propulsion and SSG
- Further aluminum structural and production analysis
- Further development of high-speed semi-planing craft loads
- Design of larger waterjets

5.3 Conclusions

The requirements for ASCal are based on the LCS Flight0 Preliminary Design Interim Requirements Document and the ASC Acquisition Decision Memorandum (ADM), which can be found in Appendix A – LCS IRD and Appendix B – Acquisition Decision Memorandum respectively. ASCal will operate in littoral waters and depend heavily on maneuverability, a low radar cross-section and small draft. Modular Mission packages will allow ASCal to support a number of missions including LAMPS, MCM, ASW and ASUW.

The Concept Exploration phase of this design used a Multi-Objective Genetic Optimization (MOGO) system to search a defined design space for a baseline design. Overall Measure Of Risk (OMOR) was calculated for each of these possible designs based on the technology incorporated in the design. New and unproven technologies give a higher risk, which is further amplified by a technology's importance to the ship as whole. Overall Measure of Effectiveness was also calculated based on a design's ability to meet the goals and thresholds set out by the LCS IRD and ADM documents. With the cost of each design also estimated, a non-dominated frontier showing a range of designs within the design space with developed. From set of design, the ASCal baseline concept design was chosen based on its ability to deliver a high level of effectiveness for a degree of risk and cost that set it above opposing designs. This design has been further optimized during the design process.

The aluminum hull and deckhouse used in the ASCal design were the main drivers of risk. This material has had a less than perfect history in naval applications. Production, design and operational experience of aluminum within the Navy and its contractors is small compared to that of steel. Even with this added risk, aluminum was shown be a superior material for the construction of ASCal. Weight savings, after consideration for the proper insulation to accommodate for aluminum's lower melting temperature, have been shown to be in the range of 20 to 30%. New formulations of aluminum and modern production techniques can provide a ship like ASCal with significant weight savings for ship with the same level of safety and durability as steel.

ASCal provides an excellent platform for the deployment of Modular Mission packages in littoral waters. Its small draft and low RCS make it capable of operating in shallow, crowded waters under a number of missions. With a predicted sustained speed of 47 knots, ASCal can delivery Navy presence when needed. ASCal supports stern launched small craft and houses a topside hangar capable of supporting 2 embarked SH-60 helicopters for a variety of missions. ASCal offers a highly capable platform tailored to the needs of the modern Navy.

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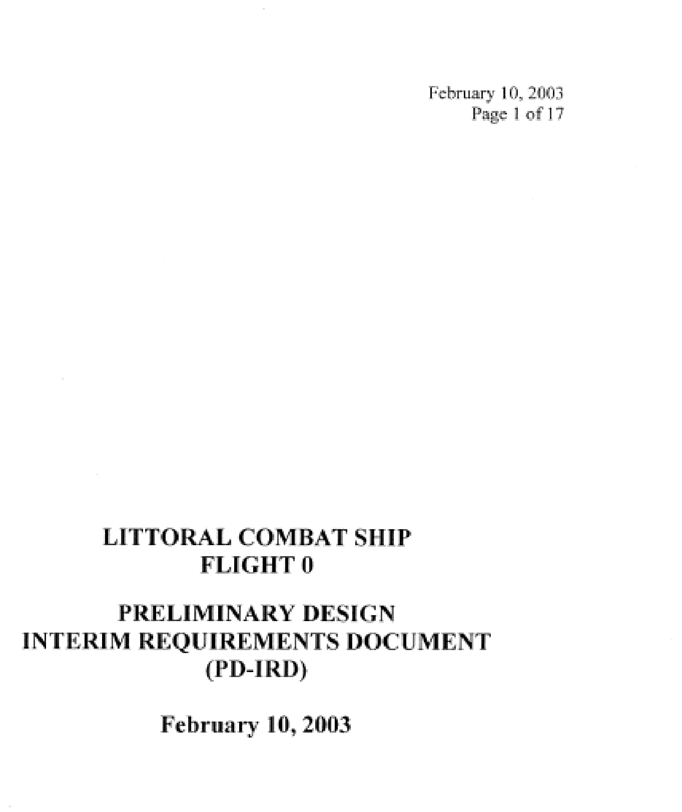
Appendix A – LCS IRD

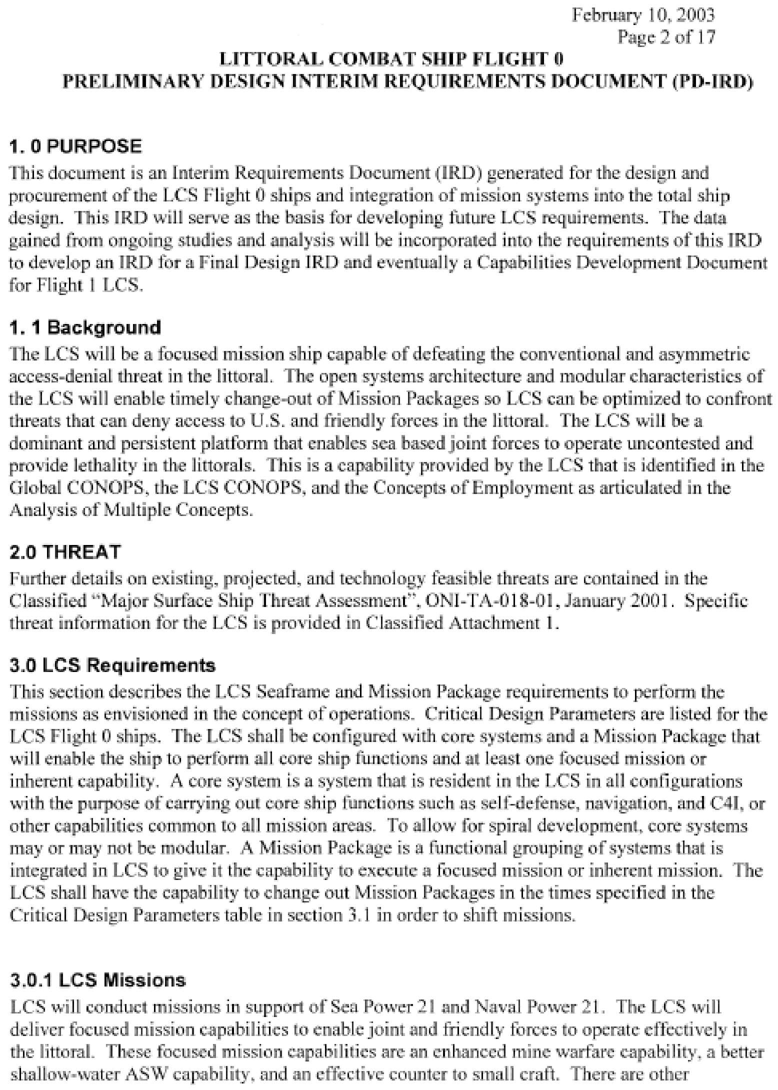


February 10, 2003
Page 1 of 17

LITTORAL COMBAT SHIP
FLIGHT 0

PRELIMINARY DESIGN
INTERIM REQUIREMENTS DOCUMENT
(PD-IRD)

February 10, 2003



February 10, 2003
Page 2 of 17

LITTORAL COMBAT SHIP FLIGHT 0
PRELIMINARY DESIGN INTERIM REQUIREMENTS DOCUMENT (PD-IRD)

1. 0 PURPOSE

This document is an Interim Requirements Document (IRD) generated for the design and procurement of the LCS Flight 0 ships and integration of mission systems into the total ship design. This IRD will serve as the basis for developing future LCS requirements. The data gained from ongoing studies and analysis will be incorporated into the requirements of this IRD to develop an IRD for a Final Design IRD and eventually a Capabilities Development Document for Flight 1 LCS.

1. 1 Background

The LCS will be a focused mission ship capable of defeating the conventional and asymmetric access-denial threat in the littoral. The open systems architecture and modular characteristics of the LCS will enable timely change-out of Mission Packages so LCS can be optimized to confront threats that can deny access to U.S. and friendly forces in the littoral. The LCS will be a dominant and persistent platform that enables sea based joint forces to operate uncontested and provide lethality in the littorals. This is a capability provided by the LCS that is identified in the Global CONOPS, the LCS CONOPS, and the Concepts of Employment as articulated in the Analysis of Multiple Concepts.

2.0 THREAT

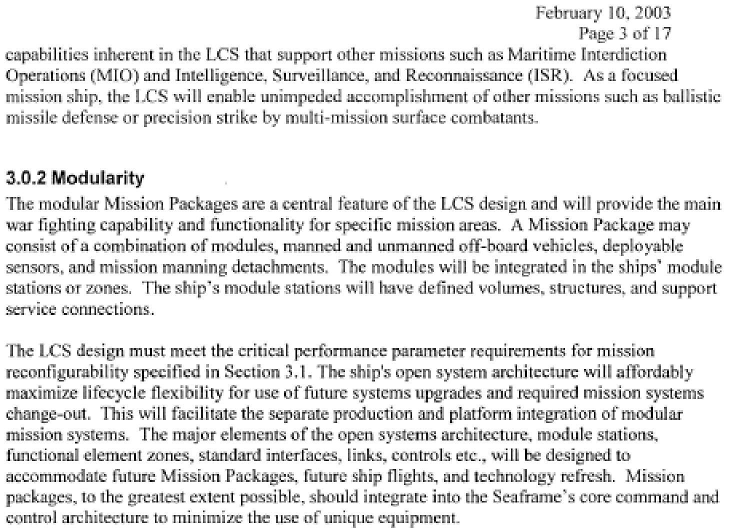
Further details on existing, projected, and technology feasible threats are contained in the Classified "Major Surface Ship Threat Assessment", ONI-TA-018-01, January 2001. Specific threat information for the LCS is provided in Classified Attachment 1.

3.0 LCS Requirements

This section describes the LCS Seaframe and Mission Package requirements to perform the missions as envisioned in the concept of operations. Critical Design Parameters are listed for the LCS Flight 0 ships. The LCS shall be configured with core systems and a Mission Package that will enable the ship to perform all core ship functions and at least one focused mission or inherent capability. A core system is a system that is resident in the LCS in all configurations with the purpose of carrying out core ship functions such as self-defense, navigation, and C4I, or other capabilities common to all mission areas. To allow for spiral development, core systems may or may not be modular. A Mission Package is a functional grouping of systems that is integrated in LCS to give it the capability to execute a focused mission or inherent mission. The LCS shall have the capability to change out Mission Packages in the times specified in the Critical Design Parameters table in section 3.1 in order to shift missions.

3.0.1 LCS Missions

LCS will conduct missions in support of Sea Power 21 and Naval Power 21. The LCS will deliver focused mission capabilities to enable joint and friendly forces to operate effectively in the littoral. These focused mission capabilities are an enhanced mine warfare capability, a better shallow-water ASW capability, and an effective counter to small craft. There are other

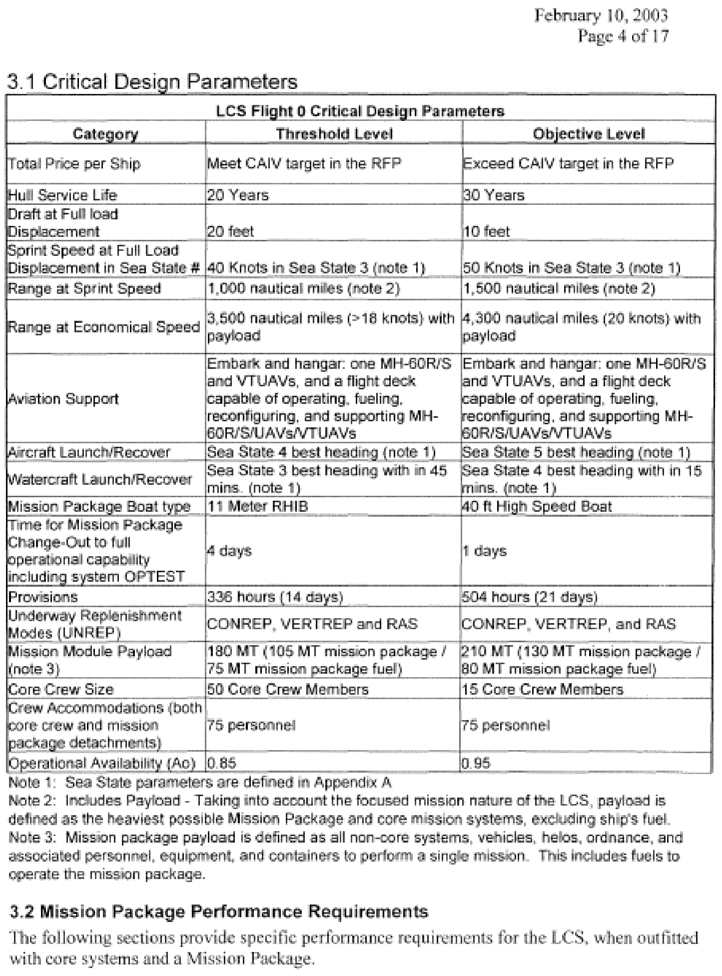


capabilities inherent in the LCS that support other missions such as Maritime Interdiction Operations (MIO) and Intelligence, Surveillance, and Reconnaissance (ISR). As a focused mission ship, the LCS will enable unimpeded accomplishment of other missions such as ballistic missile defense or precision strike by multi-mission surface combatants.

3.0.2 Modularity

The modular Mission Packages are a central feature of the LCS design and will provide the main war fighting capability and functionality for specific mission areas. A Mission Package may consist of a combination of modules, manned and unmanned off-board vehicles, deployable sensors, and mission manning detachments. The modules will be integrated in the ships' module stations or zones. The ship's module stations will have defined volumes, structures, and support service connections.

The LCS design must meet the critical performance parameter requirements for mission reconfigurability specified in Section 3.1. The ship's open system architecture will affordably maximize lifecycle flexibility for use of future systems upgrades and required mission systems change-out. This will facilitate the separate production and platform integration of modular mission systems. The major elements of the open systems architecture, module stations, functional element zones, standard interfaces, links, controls etc., will be designed to accommodate future Mission Packages, future ship flights, and technology refresh. Mission packages, to the greatest extent possible, should integrate into the Seaframe's core command and control architecture to minimize the use of unique equipment.



February 10, 2003
Page 4 of 17

3.1 Critical Design Parameters

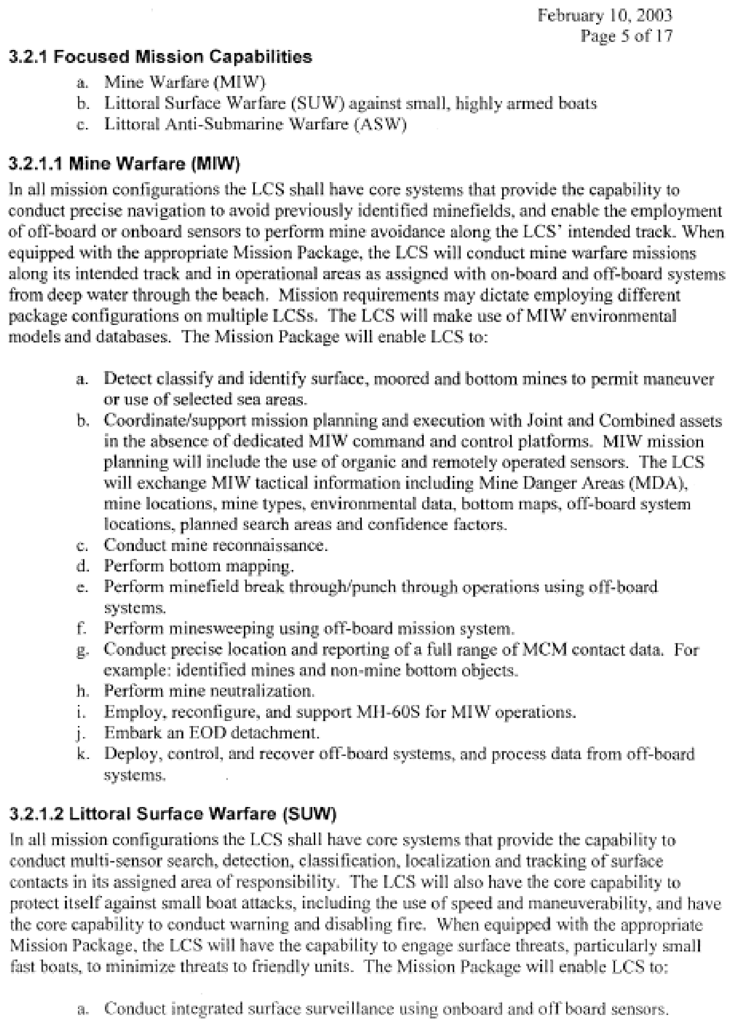
LCS Flight 0 Critical Design Parameters

Category	Threshold Level	Objective Level
Total Price per Ship	Meet CAIV target in the RFP	Exceed CAIV target in the RFP
Hull Service Life	20 Years	30 Years
Draft at Full load Displacement	20 feet	10 feet
Sprint Speed at Full Load Displacement in Sea State #	40 Knots in Sea State 3 (note 1)	50 Knots in Sea State 3 (note 1)
Range at Sprint Speed	1,000 nautical miles (note 2)	1,500 nautical miles (note 2)
Range at Economical Speed	3,500 nautical miles (>18 knots) with payload	4,300 nautical miles (20 knots) with payload
Aviation Support	Embark and hangar: one MH-60R/S and VTUAVs, and a flight deck capable of operating, fueling, reconfiguring, and supporting MH-60R/S/UAVs/VTUAVs	Embark and hangar: one MH-60R/S and VTUAVs, and a flight deck capable of operating, fueling, reconfiguring, and supporting MH-60R/S/UAVs/VTUAVs
Aircraft Launch/Recover	Sea State 4 best heading (note 1)	Sea State 5 best heading (note 1)
Watercraft Launch/Recover	Sea State 3 best heading with in 45 mins. (note 1)	Sea State 4 best heading with in 15 mins. (note 1)
Mission Package Boat type	11 Meter RHIB	40 ft High Speed Boat
Time for Mission Package Change-Out to full operational capability including system OPTEST	4 days	1 days
Provisions	336 hours (14 days)	504 hours (21 days)
Underway Replenishment Modes (UNREP)	CONREP, VERTREP and RAS	CONREP, VERTREP, and RAS
Mission Module Payload (note 3)	180 MT (105 MT mission package / 75 MT mission package fuel)	210 MT (130 MT mission package / 80 MT mission package fuel)
Core Crew Size	50 Core Crew Members	15 Core Crew Members
Crew Accommodations (both core crew and mission package detachments)	75 personnel	75 personnel
Operational Availability (Ao)	0.85	0.95

Note 1: Sea State parameters are defined in Appendix A
Note 2: Includes Payload - Taking into account the focused mission nature of the LCS, payload is defined as the heaviest possible Mission Package and core mission systems, excluding ship's fuel.
Note 3: Mission package payload is defined as all non-core systems, vehicles, helos, ordnance, and associated personnel, equipment, and containers to perform a single mission. This includes fuels to operate the mission package.

3.2 Mission Package Performance Requirements

The following sections provide specific performance requirements for the LCS, when outfitted with core systems and a Mission Package.



3.2.1 Focused Mission Capabilities

a. Mine Warfare (MIW)
b. Littoral Surface Warfare (SUW) against small, highly armed boats
c. Littoral Anti-Submarine Warfare (ASW)

3.2.1.1 Mine Warfare (MIW)

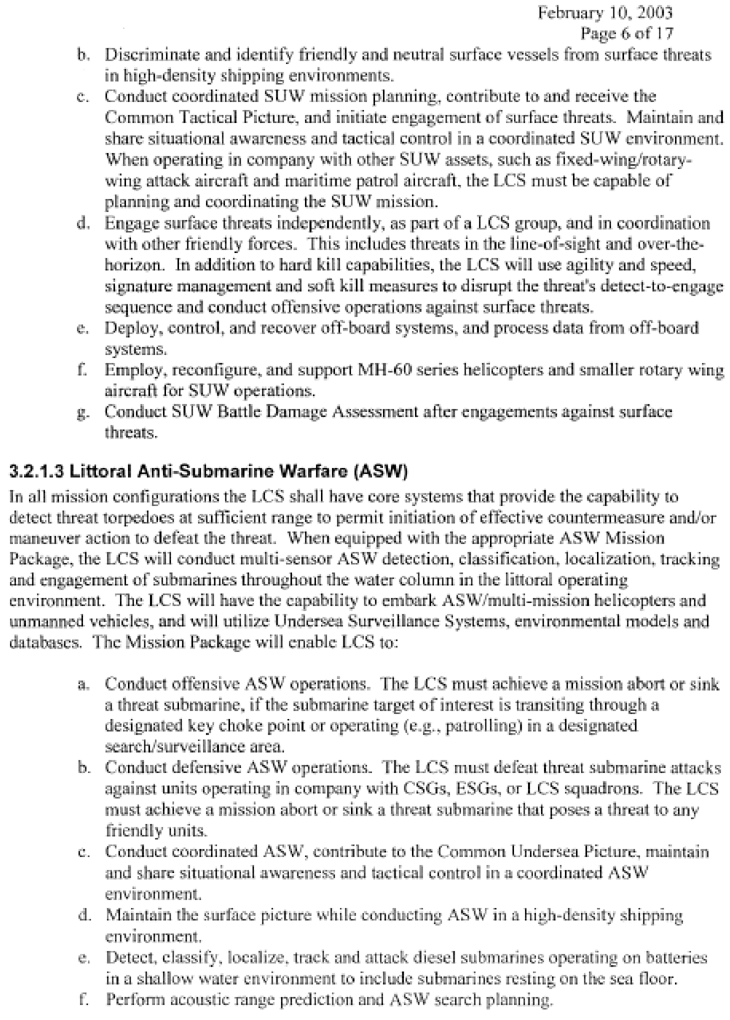
In all mission configurations the LCS shall have core systems that provide the capability to conduct precise navigation to avoid previously identified minefields, and enable the employment of off-board or onboard sensors to perform mine avoidance along the LCS' intended track. When equipped with the appropriate Mission Package, the LCS will conduct mine warfare missions along its intended track and in operational areas as assigned with on-board and off-board systems from deep water through the beach. Mission requirements may dictate employing different package configurations on multiple LCSs. The LCS will make use of MIW environmental models and databases. The Mission Package will enable LCS to:

a. Detect classify and identify surface, moored and bottom mines to permit maneuver or use of selected sea areas.
b. 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.
c. Conduct mine reconnaissance.
d. Perform bottom mapping.
e. Perform minefield break through/punch through operations using off-board systems.
f. Perform minesweeping using off-board mission system.
g. Conduct precise location and reporting of a full range of MCM contact data. For example: identified mines and non-mine bottom objects.
h. Perform mine neutralization.
i. Employ, reconfigure, and support MH-60S for MIW operations.
j. Embark an EOD detachment.
k. Deploy, control, and recover off-board systems, and process data from off-board systems.

3.2.1.2 Littoral Surface Warfare (SUW)

In all mission configurations the LCS shall have core systems that provide the capability to conduct multi-sensor search, detection, classification, localization and tracking of surface contacts in its assigned area of responsibility. The LCS will also have the core capability to protect itself against small boat attacks, including the use of speed and maneuverability, and have the core capability to conduct warning and disabling fire. When equipped with the appropriate Mission Package, the LCS will have the capability to engage surface threats, particularly small fast boats, to minimize threats to friendly units. The Mission Package will enable LCS to:

a. Conduct integrated surface surveillance using onboard and off board sensors.

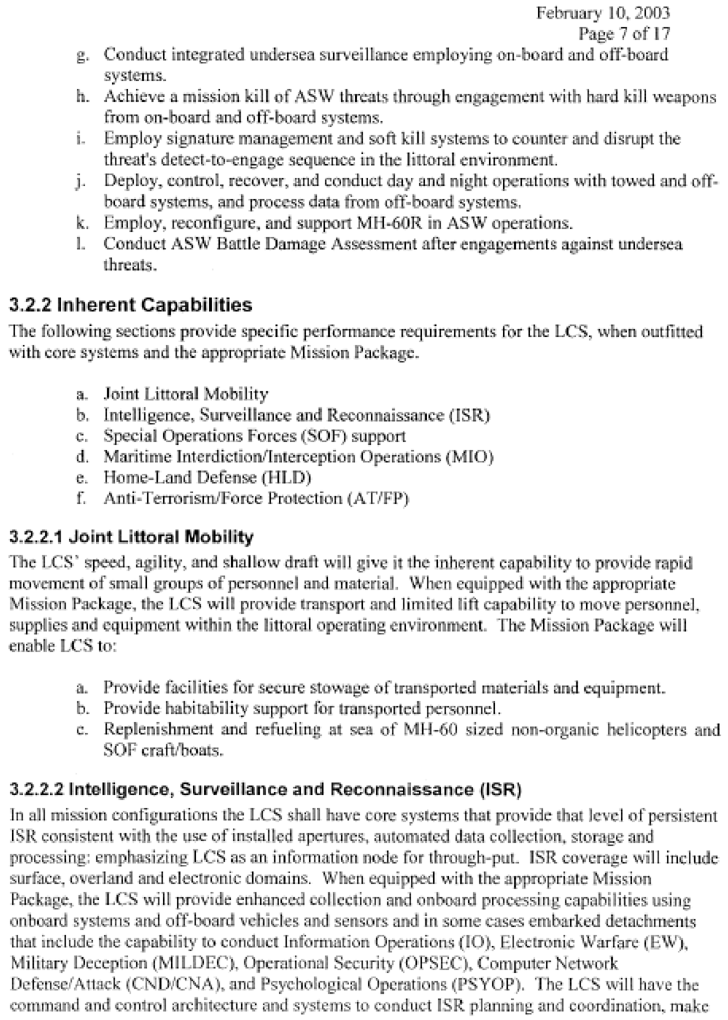


b. Discriminate and identify friendly and neutral surface vessels from surface threats in high-density shipping environments.
c. Conduct coordinated SUW mission planning, contribute to and receive the Common Tactical Picture, and initiate engagement of surface threats. Maintain and share situational awareness and tactical control in a coordinated SUW environment. When operating in company with other SUW assets, such as fixed-wing/rotary-wing attack aircraft and maritime patrol aircraft, the LCS must be capable of planning and coordinating the SUW mission.
d. Engage surface threats independently, as part of a LCS group, and in coordination with other friendly forces. This includes threats in the line-of-sight and over-the-horizon. In addition to hard kill capabilities, the LCS will use agility and speed, signature management and soft kill measures to disrupt the threat's detect-to-engage sequence and conduct offensive operations against surface threats.
e. Deploy, control, and recover off-board systems, and process data from off-board systems.
f. Employ, reconfigure, and support MH-60 series helicopters and smaller rotary wing aircraft for SUW operations.
g. Conduct SUW Battle Damage Assessment after engagements against surface threats.

3.2.1.3 Littoral Anti-Submarine Warfare (ASW)

In all mission configurations the LCS shall have core systems that provide the capability to detect threat torpedoes at sufficient range to permit initiation of effective countermeasure and/or maneuver action to defeat the threat. When equipped with the appropriate ASW Mission Package, the LCS will conduct multi-sensor ASW detection, classification, localization, tracking and engagement of submarines throughout the water column in the littoral operating environment. The LCS will have the capability to embark ASW/multi-mission helicopters and unmanned vehicles, and will utilize Undersea Surveillance Systems, environmental models and databases. The Mission Package will enable LCS to:

a. Conduct offensive ASW operations. The LCS must achieve a mission abort or sink a threat submarine, if the submarine target of interest is transiting through a designated key choke point or operating (e.g., patrolling) in a designated search/surveillance area.
b. Conduct defensive ASW operations. The LCS must defeat threat submarine attacks against units operating in company with CSGs, ESGs, or LCS squadrons. The LCS must achieve a mission abort or sink a threat submarine that poses a threat to any friendly units.
c. Conduct coordinated ASW, contribute to the Common Undersea Picture, maintain and share situational awareness and tactical control in a coordinated ASW environment.
d. Maintain the surface picture while conducting ASW in a high-density shipping environment.
e. Detect, classify, localize, track and attack diesel submarines operating on batteries in a shallow water environment to include submarines resting on the sea floor.
f. Perform acoustic range prediction and ASW search planning.



g. Conduct integrated undersea surveillance employing on-board and off-board systems.
h. Achieve a mission kill of ASW threats through engagement with hard kill weapons from on-board and off-board systems.
i. Employ signature management and soft kill systems to counter and disrupt the threat's detect-to-engage sequence in the littoral environment.
j. Deploy, control, recover, and conduct day and night operations with towed and off-board systems, and process data from off-board systems.
k. Employ, reconfigure, and support MH-60R in ASW operations.
l. Conduct ASW Battle Damage Assessment after engagements against undersea threats.

3.2.2 Inherent Capabilities

The following sections provide specific performance requirements for the LCS, when outfitted with core systems and the appropriate Mission Package.

a. Joint Littoral Mobility
b. Intelligence, Surveillance and Reconnaissance (ISR)
c. Special Operations Forces (SOF) support
d. Maritime Interdiction/Interception Operations (MIO)
e. Home-Land Defense (HLD)
f. Anti-Terrorism/Force Protection (AT/FP)

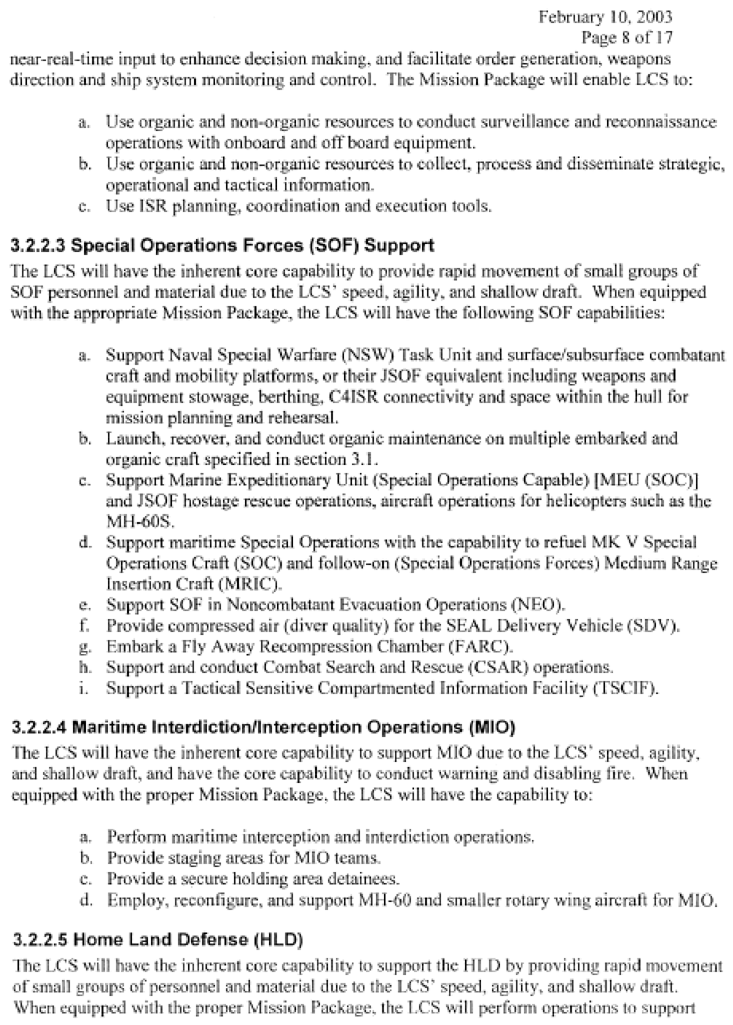
3.2.2.1 Joint Littoral Mobility

The LCS' speed, agility, and shallow draft will give it the inherent capability to provide rapid movement of small groups of personnel and material. When equipped with the appropriate Mission Package, the LCS will provide transport and limited lift capability to move personnel, supplies and equipment within the littoral operating environment. The Mission Package will enable LCS to:

a. Provide facilities for secure stowage of transported materials and equipment.
b. Provide habitability support for transported personnel.
c. Replenishment and refueling at sea of MH-60 sized non-organic helicopters and SOF craft/boats.

3.2.2.2 Intelligence, Surveillance and Reconnaissance (ISR)

In all mission configurations the LCS shall have core systems that provide that level of persistent ISR consistent with the use of installed apertures, automated data collection, storage and processing: emphasizing LCS as an information node for through-put. ISR coverage will include surface, overland and electronic domains. When equipped with the appropriate Mission Package, the LCS will provide enhanced collection and onboard processing capabilities using onboard systems and off-board vehicles and sensors and in some cases embarked detachments that include the capability to conduct Information Operations (IO), Electronic Warfare (EW), Military Deception (MILDEC), Operational Security (OPSEC), Computer Network Defense/Attack (CND/CNA), and Psychological Operations (PSYOP). The LCS will have the command and control architecture and systems to conduct ISR planning and coordination, make



near-real-time input to enhance decision making, and facilitate order generation, weapons direction and ship system monitoring and control. The Mission Package will enable LCS to:

a. Use organic and non-organic resources to conduct surveillance and reconnaissance operations with onboard and off board equipment.
b. Use organic and non-organic resources to collect, process and disseminate strategic, operational and tactical information.
c. Use ISR planning, coordination and execution tools.

3.2.2.3 Special Operations Forces (SOF) Support

The LCS will have the inherent core capability to provide rapid movement of small groups of SOF personnel and material due to the LCS' speed, agility, and shallow draft. When equipped with the appropriate Mission Package, the LCS will have the following SOF capabilities:

a. Support Naval Special Warfare (NSW) Task Unit and surface/subsurface combatant craft and mobility platforms, or their JSOF equivalent including weapons and equipment stowage, berthing, C4ISR connectivity and space within the hull for mission planning and rehearsal.
b. Launch, recover, and conduct organic maintenance on multiple embarked and organic craft specified in section 3.1.
c. Support Marine Expeditionary Unit (Special Operations Capable) [MEU (SOC)] and JSOF hostage rescue operations, aircraft operations for helicopters such as the MH-60S.
d. Support maritime Special Operations with the capability to refuel MK V Special Operations Craft (SOC) and follow-on (Special Operations Forces) Medium Range Insertion Craft (MRIC).
e. Support SOF in Noncombatant Evacuation Operations (NEO).
f. Provide compressed air (diver quality) for the SEAL Delivery Vehicle (SDV).
g. Embark a Fly Away Recompression Chamber (FARC).
h. Support and conduct Combat Search and Rescue (CSAR) operations.
i. Support a Tactical Sensitive Compartmented Information Facility (TSCIF).

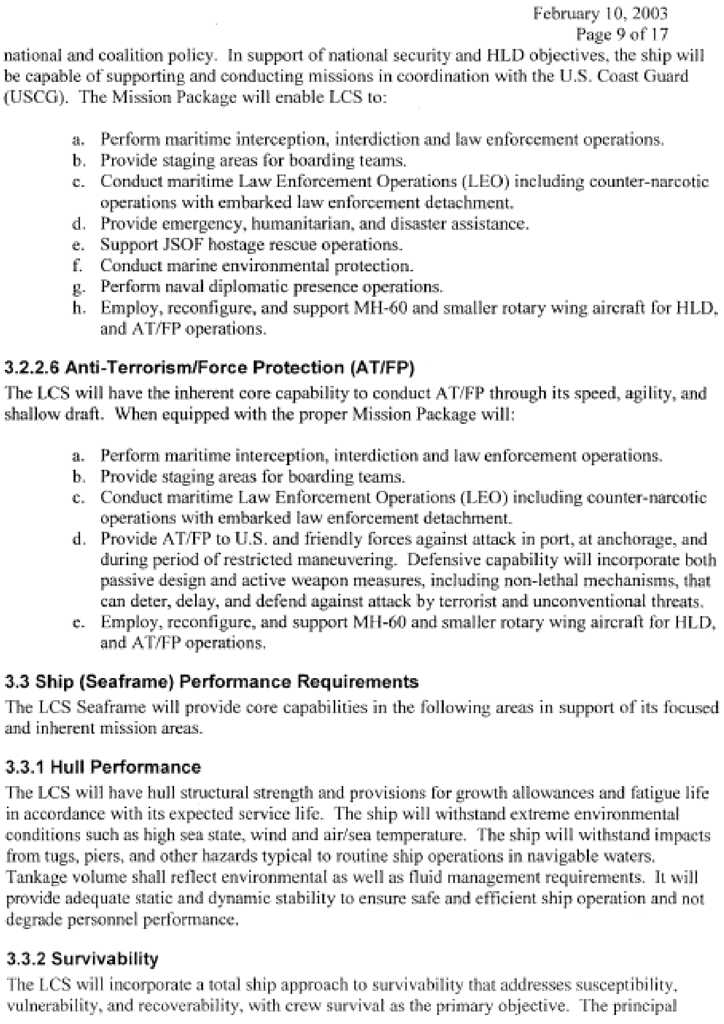
3.2.2.4 Maritime Interdiction/Interception Operations (MIO)

The LCS will have the inherent core capability to support MIO due to the LCS' speed, agility, and shallow draft, and have the core capability to conduct warning and disabling fire. When equipped with the proper Mission Package, the LCS will have the capability to:

a. Perform maritime interception and interdiction operations.
b. Provide staging areas for MIO teams.
c. Provide a secure holding area detainees.
d. Employ, reconfigure, and support MH-60 and smaller rotary wing aircraft for MIO.

3.2.2.5 Home Land Defense (HLD)

The LCS will have the inherent core capability to support the HLD by providing rapid movement of small groups of personnel and material due to the LCS' speed, agility, and shallow draft. When equipped with the proper Mission Package, the LCS will perform operations to support



national and coalition policy. In support of national security and HLD objectives, the ship will be capable of supporting and conducting missions in coordination with the U.S. Coast Guard (USCG). The Mission Package will enable LCS to:

a. Perform maritime interception, interdiction and law enforcement operations.
b. Provide staging areas for boarding teams.
c. Conduct maritime Law Enforcement Operations (LEO) including counter-narcotic operations with embarked law enforcement detachment.
d. Provide emergency, humanitarian, and disaster assistance.
e. Support JSOF hostage rescue operations.
f. Conduct marine environmental protection.
g. Perform naval diplomatic presence operations.
h. Employ, reconfigure, and support MH-60 and smaller rotary wing aircraft for HLD, and AT/FP operations.

3.2.2.6 Anti-Terrorism/Force Protection (AT/FP)

The LCS will have the inherent core capability to conduct AT/FP through its speed, agility, and shallow draft. When equipped with the proper Mission Package will:

a. Perform maritime interception, interdiction and law enforcement operations.
b. Provide staging areas for boarding teams.
c. Conduct maritime Law Enforcement Operations (LEO) including counter-narcotic operations with embarked law enforcement detachment.
d. Provide AT/FP to U.S. and friendly forces against attack in port, at anchorage, and during period of restricted maneuvering. Defensive capability will incorporate both passive design and active weapon measures, including non-lethal mechanisms, that can deter, delay, and defend against attack by terrorist and unconventional threats.
e. Employ, reconfigure, and support MH-60 and smaller rotary wing aircraft for HLD, and AT/FP operations.

3.3 Ship (Seaframe) Performance Requirements

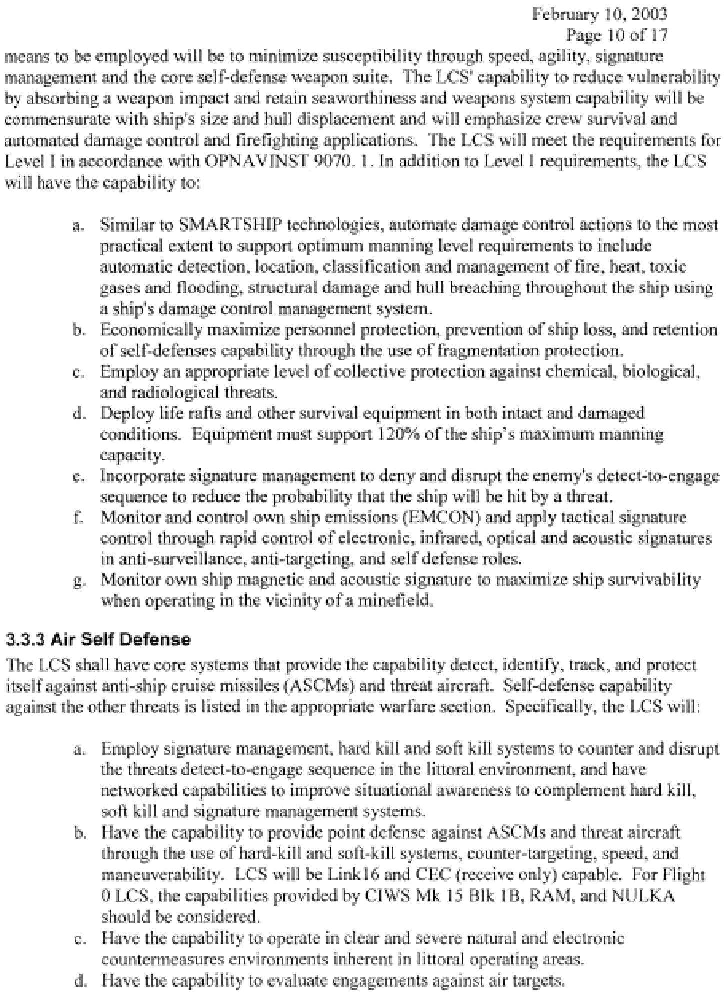
The LCS Seaframe will provide core capabilities in the following areas in support of its focused and inherent mission areas.

3.3.1 Hull Performance

The LCS will have hull structural strength and provisions for growth allowances and fatigue life in accordance with its expected service life. The ship will withstand extreme environmental conditions such as high sea state, wind and air/sea temperature. The ship will withstand impacts from tugs, piers, and other hazards typical to routine ship operations in navigable waters. Tankage volume shall reflect environmental as well as fluid management requirements. It will provide adequate static and dynamic stability to ensure safe and efficient ship operation and not degrade personnel performance.

3.3.2 Survivability

The LCS will incorporate a total ship approach to survivability that addresses susceptibility, vulnerability, and recoverability, with crew survival as the primary objective. The principal



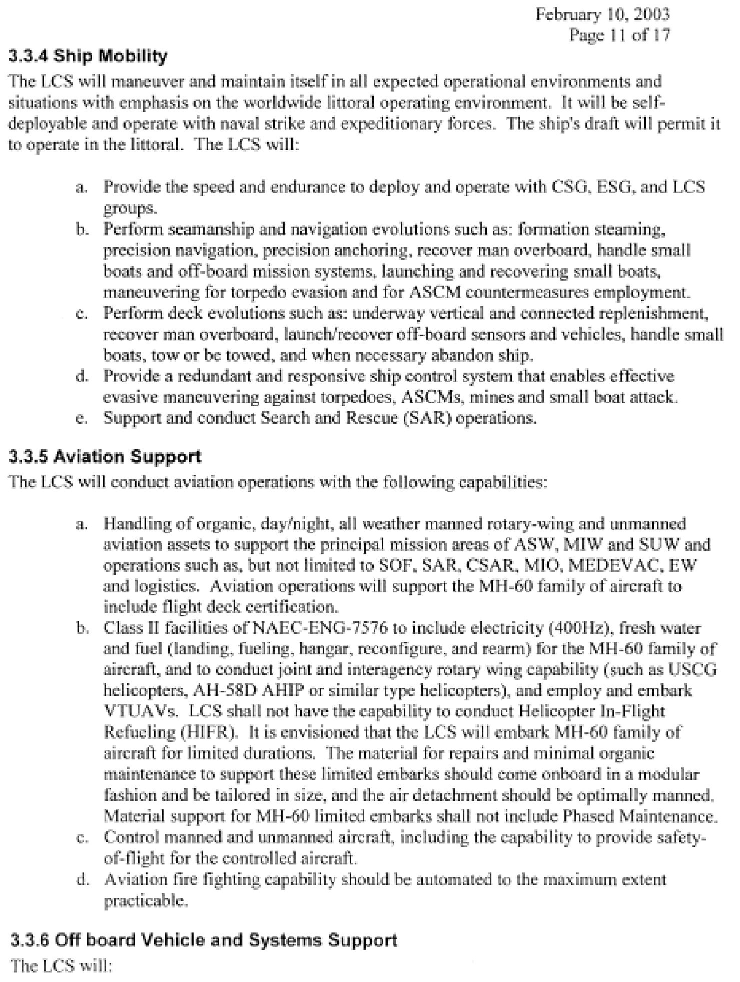
means to be employed will be to minimize susceptibility through speed, agility, signature management and the core self-defense weapon suite. The LCS' capability to reduce vulnerability by absorbing a weapon impact and retain seaworthiness and weapons system capability will be commensurate with ship's size and hull displacement and will emphasize crew survival and automated damage control and firefighting applications. The LCS will meet the requirements for Level I in accordance with OPNAVINST 9070. 1. In addition to Level I requirements, the LCS will have the capability to:

a. Similar to SMARTSHIP technologies, automate damage control actions to the most practical extent to support optimum manning level requirements to include automatic detection, location, classification and management of fire, heat, toxic gases and flooding, structural damage and hull breaching throughout the ship using a ship's damage control management system.
b. Economically maximize personnel protection, prevention of ship loss, and retention of self-defenses capability through the use of fragmentation protection.
c. Employ an appropriate level of collective protection against chemical, biological, and radiological threats.
d. Deploy life rafts and other survival equipment in both intact and damaged conditions. Equipment must support 120% of the ship's maximum manning capacity.
e. Incorporate signature management to deny and disrupt the enemy's detect-to-engage sequence to reduce the probability that the ship will be hit by a threat.
f. Monitor and control own ship emissions (EMCON) and apply tactical signature control through rapid control of electronic, infrared, optical and acoustic signatures in anti-surveillance, anti-targeting, and self defense roles.
g. Monitor own ship magnetic and acoustic signature to maximize ship survivability when operating in the vicinity of a minefield.

3.3.3 Air Self Defense

The LCS shall have core systems that provide the capability detect, identify, track, and protect itself against anti-ship cruise missiles (ASCMs) and threat aircraft. Self-defense capability against the other threats is listed in the appropriate warfare section. Specifically, the LCS will:

a. Employ signature management, hard kill and soft kill systems to counter and disrupt the threats detect-to-engage sequence in the littoral environment, and have networked capabilities to improve situational awareness to complement hard kill, soft kill and signature management systems.
b. Have the capability to provide point defense against ASCMs and threat aircraft through the use of hard-kill and soft-kill systems, counter-targeting, speed, and maneuverability. LCS will be Link16 and CEC (receive only) capable. For Flight 0 LCS, the capabilities provided by CIWS Mk 15 Blk 1B, RAM, and NULKA should be considered.
c. Have the capability to operate in clear and severe natural and electronic countermeasures environments inherent in littoral operating areas.
d. Have the capability to evaluate engagements against air targets.



February 10, 2003
Page 11 of 17

3.3.4 Ship Mobility

The LCS will maneuver and maintain itself in all expected operational environments and situations with emphasis on the worldwide littoral operating environment. It will be self-deployable and operate with naval strike and expeditionary forces. The ship's draft will permit it to operate in the littoral. The LCS will:

a. Provide the speed and endurance to deploy and operate with CSG, ESG, and LCS groups.
b. Perform seamanship and navigation evolutions such as: formation steaming, precision navigation, precision anchoring, recover man overboard, handle small boats and off-board mission systems, launching and recovering small boats, maneuvering for torpedo evasion and for ASCM countermeasures employment.
c. Perform deck evolutions such as: underway vertical and connected replenishment, recover man overboard, launch/recover off-board sensors and vehicles, handle small boats, tow or be towed, and when necessary abandon ship.
d. Provide a redundant and responsive ship control system that enables effective evasive maneuvering against torpedoes, ASCMs, mines and small boat attack.
e. Support and conduct Search and Rescue (SAR) operations.

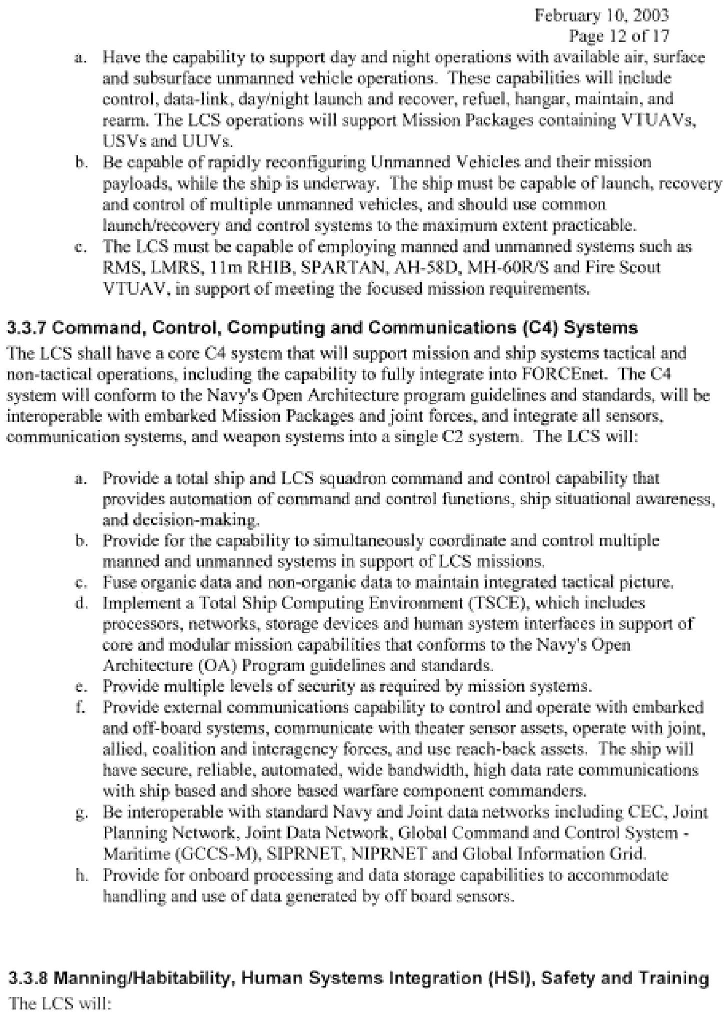
3.3.5 Aviation Support

The LCS will conduct aviation operations with the following capabilities:

a. Handling of organic, day/night, all weather manned rotary-wing and unmanned aviation assets to support the principal mission areas of ASW, MIW and SUW and operations such as, but not limited to SOF, SAR, CSAR, MIO, MEDEVAC, EW and logistics. Aviation operations will support the MH-60 family of aircraft to include flight deck certification.
b. Class II facilities of NAEC-ENG-7576 to include electricity (400Hz), fresh water and fuel (landing, fueling, hangar, reconfigure, and rearm) for the MH-60 family of aircraft, and to conduct joint and interagency rotary wing capability (such as USCG helicopters, AH-58D AHIP or similar type helicopters), and employ and embark VTUAVs. LCS shall not have the capability to conduct Helicopter In-Flight Refueling (HIFR). It is envisioned that the LCS will embark MH-60 family of aircraft for limited durations. The material for repairs and minimal organic maintenance to support these limited embarks should come onboard in a modular fashion and be tailored in size, and the air detachment should be optimally manned. Material support for MH-60 limited embarks shall not include Phased Maintenance.
c. Control manned and unmanned aircraft, including the capability to provide safety-of-flight for the controlled aircraft.
d. Aviation fire fighting capability should be automated to the maximum extent practicable.

3.3.6 Off board Vehicle and Systems Support

The LCS will:



February 10, 2003
Page 12 of 17

a. Have the capability to support day and night operations with available air, surface and subsurface unmanned vehicle operations. These capabilities will include control, data-link, day/night launch and recover, refuel, hangar, maintain, and rearm. The LCS operations will support Mission Packages containing VTUAVs, USVs and UUVs.
b. Be capable of rapidly reconfiguring Unmanned Vehicles and their mission payloads, while the ship is underway. The ship must be capable of launch, recovery and control of multiple unmanned vehicles, and should use common launch/recovery and control systems to the maximum extent practicable.
c. The LCS must be capable of employing manned and unmanned systems such as RMS, LMRS, 11m RHIB, SPARTAN, AH-58D, MH-60R/S and Fire Scout VTUAV, in support of meeting the focused mission requirements.

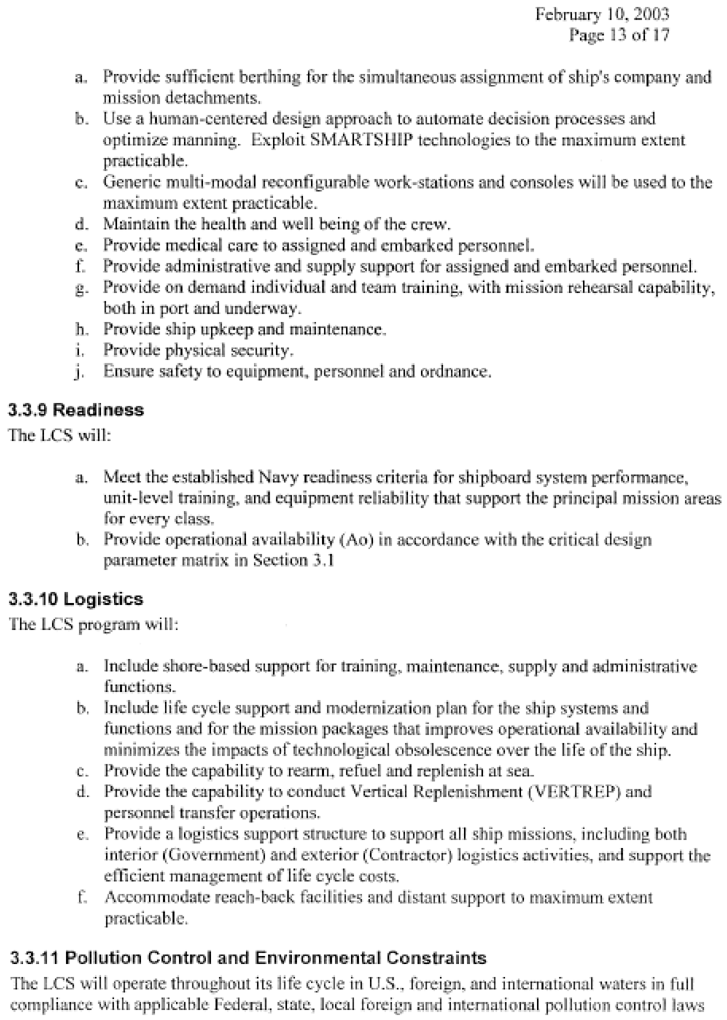
3.3.7 Command, Control, Computing and Communications (C4) Systems

The LCS shall have a core C4 system that will support mission and ship systems tactical and non-tactical operations, including the capability to fully integrate into FORCEnet. The C4 system will conform to the Navy's Open Architecture program guidelines and standards, will be interoperable with embarked Mission Packages and joint forces, and integrate all sensors, communication systems, and weapon systems into a single C2 system. The LCS will:

a. Provide a total ship and LCS squadron command and control capability that provides automation of command and control functions, ship situational awareness, and decision-making.
b. Provide for the capability to simultaneously coordinate and control multiple manned and unmanned systems in support of LCS missions.
c. Fuse organic data and non-organic data to maintain integrated tactical picture.
d. Implement a Total Ship Computing Environment (TSCE), which includes processors, networks, storage devices and human system interfaces in support of core and modular mission capabilities that conforms to the Navy's Open Architecture (OA) Program guidelines and standards.
e. Provide multiple levels of security as required by mission systems.
f. Provide external communications capability to control and operate with embarked and off-board systems, communicate with theater sensor assets, operate with joint, allied, coalition and interagency forces, and use reach-back assets. The ship will have secure, reliable, automated, wide bandwidth, high data rate communications with ship based and shore based warfare component commanders.
g. Be interoperable with standard Navy and Joint data networks including CEC, Joint Planning Network, Joint Data Network, Global Command and Control System - Maritime (GCCS-M), SIPRNET, NIPRNET and Global Information Grid.
h. Provide for onboard processing and data storage capabilities to accommodate handling and use of data generated by off board sensors.

3.3.8 Manning/Habitability, Human Systems Integration (HSI), Safety and Training

The LCS will:



February 10, 2003
Page 13 of 17

a. Provide sufficient berthing for the simultaneous assignment of ship's company and mission detachments.
b. Use a human-centered design approach to automate decision processes and optimize manning. Exploit SMARTSHIP technologies to the maximum extent practicable.
c. Generic multi-modal reconfigurable work-stations and consoles will be used to the maximum extent practicable.
d. Maintain the health and well being of the crew.
e. Provide medical care to assigned and embarked personnel.
f. Provide administrative and supply support for assigned and embarked personnel.
g. Provide on demand individual and team training, with mission rehearsal capability, both in port and underway.
h. Provide ship upkeep and maintenance.
i. Provide physical security.
j. Ensure safety to equipment, personnel and ordnance.

3.3.9 Readiness

The LCS will:

a. Meet the established Navy readiness criteria for shipboard system performance, unit-level training, and equipment reliability that support the principal mission areas for every class.
b. Provide operational availability (Ao) in accordance with the critical design parameter matrix in Section 3.1

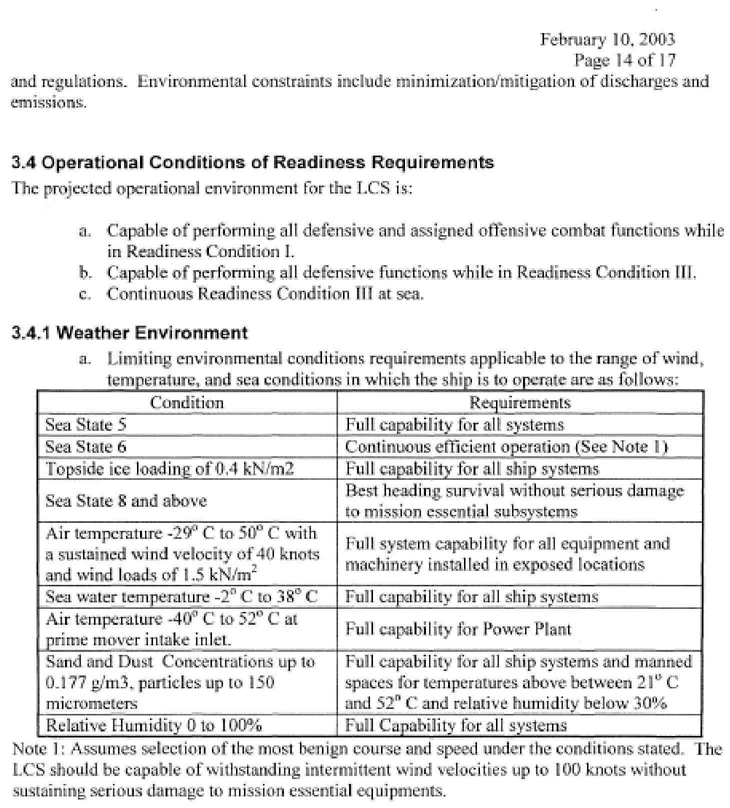
3.3.10 Logistics

The LCS program will:

a. Include shore-based support for training, maintenance, supply and administrative functions.
b. Include life cycle support and modernization plan for the ship systems and functions and for the mission packages that improves operational availability and minimizes the impacts of technological obsolescence over the life of the ship.
c. Provide the capability to rearm, refuel and replenish at sea.
d. Provide the capability to conduct Vertical Replenishment (VERTREP) and personnel transfer operations.
e. Provide a logistics support structure to support all ship missions, including both interior (Government) and exterior (Contractor) logistics activities, and support the efficient management of life cycle costs.
f. Accommodate reach-back facilities and distant support to maximum extent practicable.

3.3.11 Pollution Control and Environmental Constraints

The LCS will operate throughout its life cycle in U.S., foreign, and international waters in full compliance with applicable Federal, state, local foreign and international pollution control laws



and regulations. Environmental constraints include minimization/mitigation of discharges and emissions.

3.4 Operational Conditions of Readiness Requirements

The projected operational environment for the LCS is:

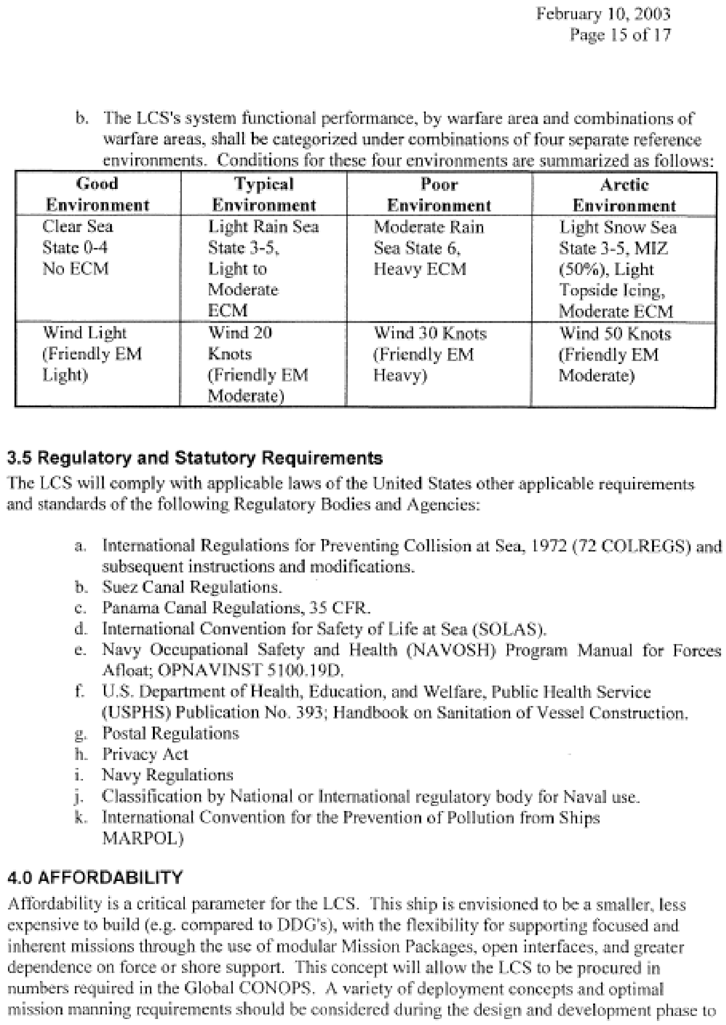
a. Capable of performing all defensive and assigned offensive combat functions while in Readiness Condition I.
b. Capable of performing all defensive functions while in Readiness Condition III.
c. Continuous Readiness Condition III at sea.

3.4.1 Weather Environment

a. Limiting environmental conditions requirements applicable to the range of wind, temperature, and sea conditions in which the ship is to operate are as follows:

Condition	Requirements
Sea State 5	Full capability for all systems
Sea State 6	Continuous efficient operation (See Note 1)
Topside ice loading of 0.4 kN/m2	Full capability for all ship systems
Sea State 8 and above	Best heading survival without serious damage to mission essential subsystems
Air temperature -29° C to 50° C with a sustained wind velocity of 40 knots and wind loads of 1.5 kN/m^2	Full system capability for all equipment and machinery installed in exposed locations
Sea water temperature -2° C to 38° C	Full capability for all ship systems
Air temperature -40° C to 52° C at prime mover intake inlet.	Full capability for Power Plant
Sand and Dust Concentrations up to 0.177 g/m3, particles up to 150 micrometers	Full capability for all ship systems and manned spaces for temperatures above between 21° C and 52° C and relative humidity below 30%
Relative Humidity 0 to 100%	Full Capability for all systems

Note 1: Assumes selection of the most benign course and speed under the conditions stated. The LCS should be capable of withstanding intermittent wind velocities up to 100 knots without sustaining serious damage to mission essential equipments.



b. The LCS's system functional performance, by warfare area and combinations of warfare areas, shall be categorized under combinations of four separate reference environments. Conditions for these four environments are summarized as follows:

Good Environment	Typical Environment	Poor Environment	Arctic Environment
Clear Sea State 0-4 No ECM	Light Rain Sea State 3-5, Light to Moderate ECM	Moderate Rain Sea State 6, Heavy ECM	Light Snow Sea State 3-5, MIZ (50%), Light Topside Icing, Moderate ECM
Wind Light (Friendly EM Light)	Wind 20 Knots (Friendly EM Moderate)	Wind 30 Knots (Friendly EM Heavy)	Wind 50 Knots (Friendly EM Moderate)

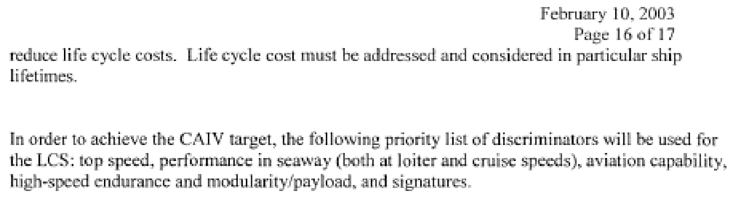
3.5 Regulatory and Statutory Requirements

The LCS will comply with applicable laws of the United States other applicable requirements and standards of the following Regulatory Bodies and Agencies:

a. International Regulations for Preventing Collision at Sea, 1972 (72 COLREGS) and subsequent instructions and modifications.
b. Suez Canal Regulations.
c. Panama Canal Regulations, 35 CFR.
d. International Convention for Safety of Life at Sea (SOLAS).
e. Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat; OPNAVINST 5100.19D.
f. U.S. Department of Health, Education, and Welfare, Public Health Service (USPHS) Publication No. 393; Handbook on Sanitation of Vessel Construction.
g. Postal Regulations
h. Privacy Act
i. Navy Regulations
j. Classification by National or International regulatory body for Naval use.
k. International Convention for the Prevention of Pollution from Ships MARPOL)

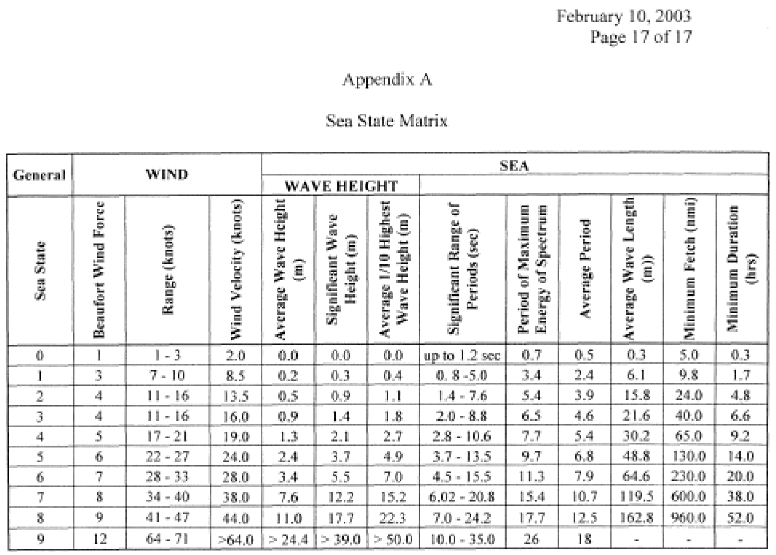
4.0 AFFORDABILITY

Affordability is a critical parameter for the LCS. This ship is envisioned to be a smaller, less expensive to build (e.g. compared to DDG's), with the flexibility for supporting focused and inherent missions through the use of modular Mission Packages, open interfaces, and greater dependence on force or shore support. This concept will allow the LCS to be procured in numbers required in the Global CONOPS. A variety of deployment concepts and optimal mission manning requirements should be considered during the design and development phase to



reduce life cycle costs. Life cycle cost must be addressed and considered in particular ship lifetimes.

In order to achieve the CAIV target, the following priority list of discriminators will be used for the LCS: top speed, performance in seaway (both at loiter and cruise speeds), aviation capability, high-speed endurance and modularity/payload, and signatures.



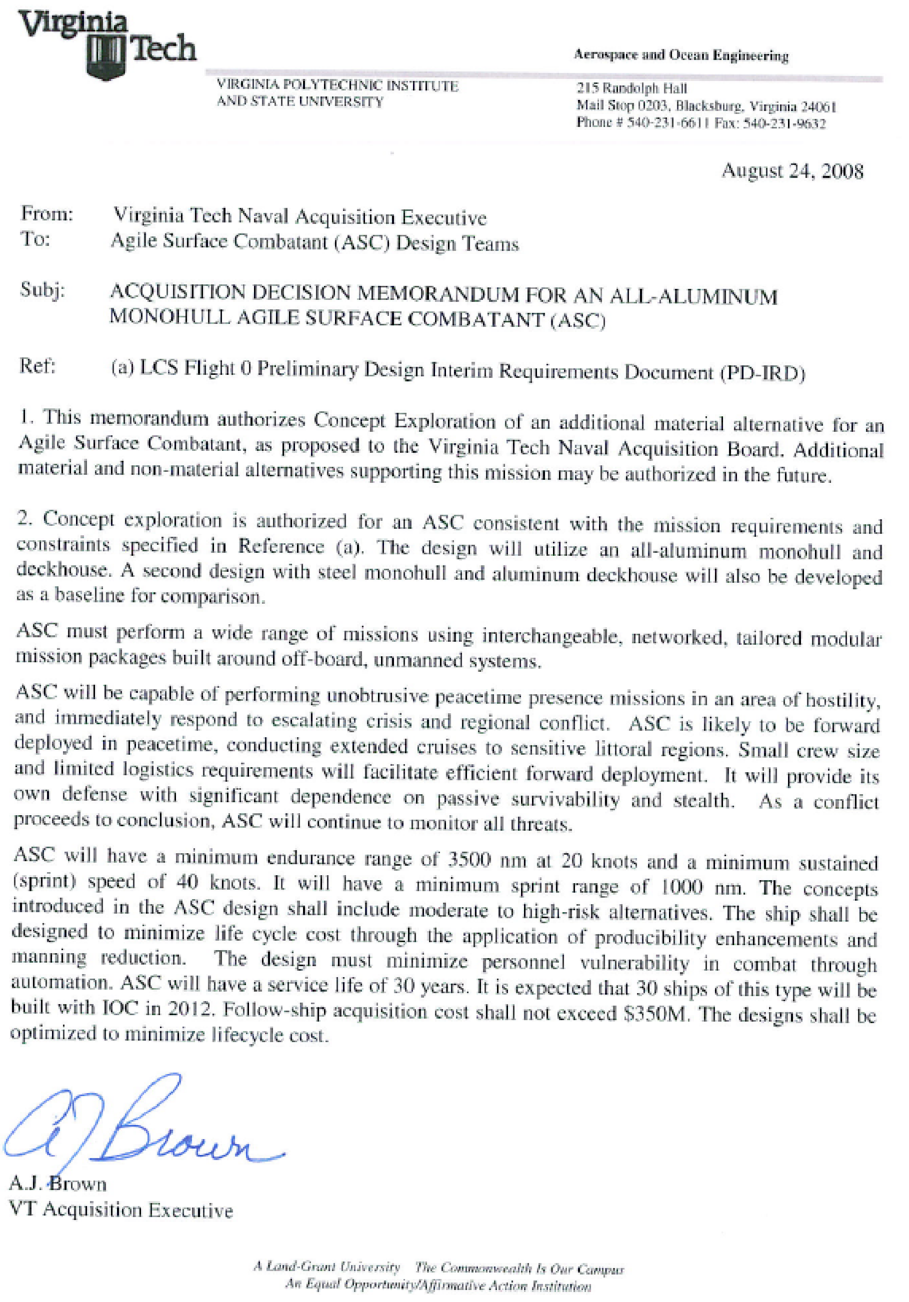
February 10, 2003
Page 17 of 17

Appendix A

Sea State Matrix

General	**WIND**			**SEA**									
				WAVE HEIGHT									
Sea State	**Beaufort Wind Force**	**Range (knots)**	**Wind Velocity (knots)**	**Average Wave Height (m)**	**Significant Wave Height (m)**	**Average 1/10 Highest Wave Height (m)**	**Significant Range of Periods (sec)**	**Period of Maximum Energy of Spectrum**	**Average Period**	**Average Wave Length (m))**	**Minimum Fetch (nmi)**	**Minimum Duration (hrs)**
0	1	1 - 3	2.0	0.0	0.0	0.0	up to 1.2 sec	0.7	0.5	0.3	5.0	0.3
1	3	7 - 10	8.5	0.2	0.3	0.4	0. 8 -5.0	3.4	2.4	6.1	9.8	1.7
2	4	11 - 16	13.5	0.5	0.9	1.1	1.4 - 7.6	5.4	3.9	15.8	24.0	4.8
3	4	11 - 16	16.0	0.9	1.4	1.8	2.0 - 8.8	6.5	4.6	21.6	40.0	6.6
4	5	17 - 21	19.0	1.3	2.1	2.7	2.8 - 10.6	7.7	5.4	30.2	65.0	9.2
5	6	22 - 27	24.0	2.4	3.7	4.9	3.7 - 13.5	9.7	6.8	48.8	130.0	14.0
6	7	28 - 33	28.0	3.4	5.5	7.0	4.5 - 15.5	11.3	7.9	64.6	230.0	20.0
7	8	34 - 40	38.0	7.6	12.2	15.2	6.02 - 20.8	15.4	10.7	119.5	600.0	38.0
8	9	41 - 47	44.0	11.0	17.7	22.3	7.0 - 24.2	17.7	12.5	162.8	960.0	52.0
9	12	64 - 71	>64.0	> 24.4	> 39.0	> 50.0	10.0 - 35.0	26	18	-	-	-

Appendix B – Acquisition Decision Memorandum



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August 24, 2008

From: Virginia Tech Naval Acquisition Executive
To: Agile Surface Combatant (ASC) Design Teams

Subj: ACQUISITION DECISION MEMORANDUM FOR AN ALL-ALUMINUM MONOHULL AGILE SURFACE COMBATANT (ASC)

Ref: (a) LCS Flight 0 Preliminary Design Interim Requirements Document (PD-IRD)

1. This memorandum authorizes Concept Exploration of an additional material alternative for an Agile Surface Combatant, as proposed to the Virginia Tech Naval Acquisition Board. Additional material and non-material alternatives supporting this mission may be authorized in the future.

2. Concept exploration is authorized for an ASC consistent with the mission requirements and constraints specified in Reference (a). The design will utilize an all-aluminum monohull and deckhouse. A second design with steel monohull and aluminum deckhouse will also be developed as a baseline for comparison.

ASC must perform a wide range of missions using interchangeable, networked, tailored modular mission packages built around off-board, unmanned systems.

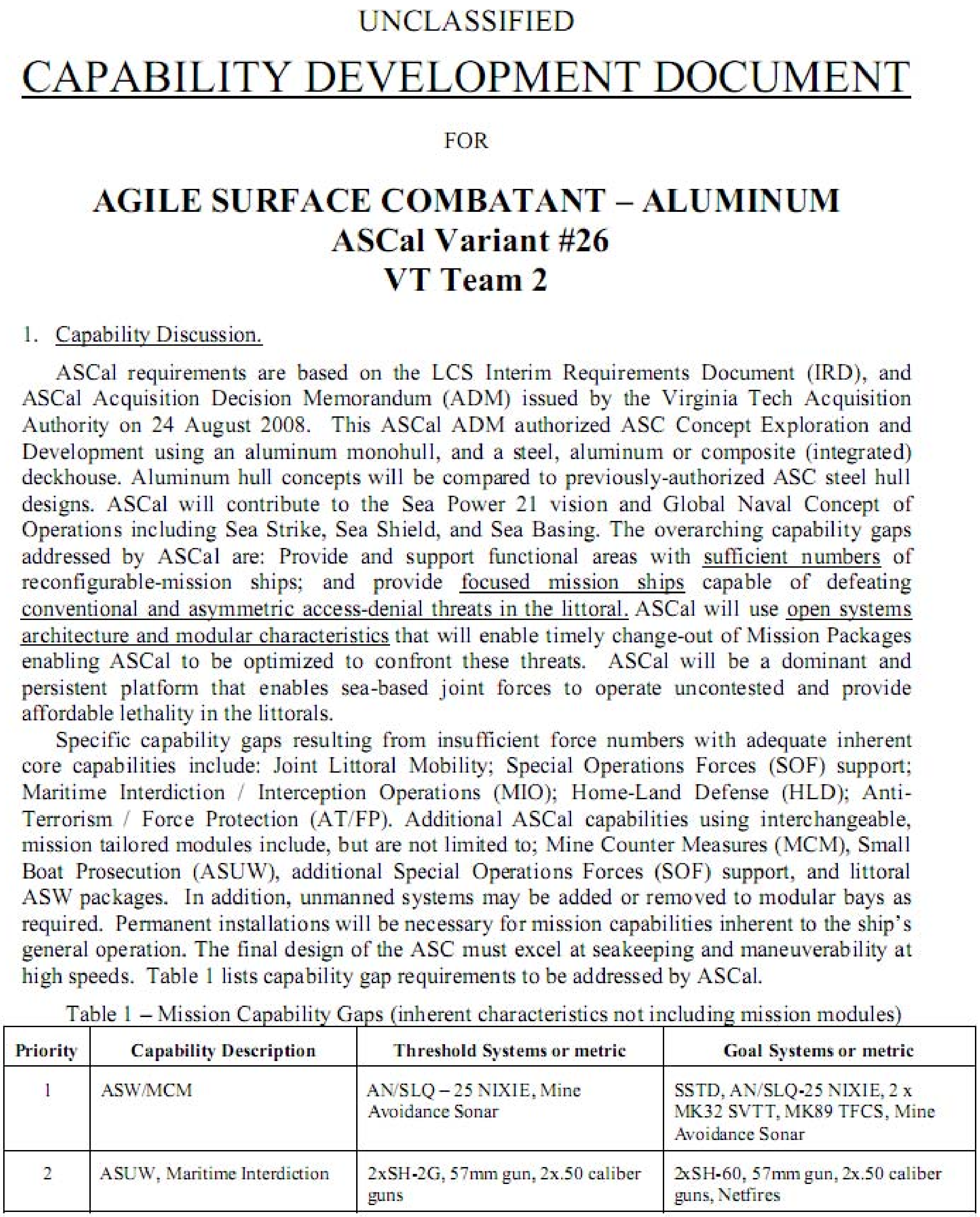
ASC will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict. ASC is likely to be forward deployed in peacetime, conducting extended cruises to sensitive littoral regions. Small crew size and limited logistics requirements will facilitate efficient forward deployment. It will provide its own defense with significant dependence on passive survivability and stealth. As a conflict proceeds to conclusion, ASC will continue to monitor all threats.

ASC will have a minimum endurance range of 3500 nm at 20 knots and a minimum sustained (sprint) speed of 40 knots. It will have a minimum sprint range of 1000 nm. The concepts introduced in the ASC design shall include moderate to high-risk alternatives. The ship shall be designed to minimize life cycle cost through the application of producibility enhancements and manning reduction. The design must minimize personnel vulnerability in combat through automation. ASC will have a service life of 30 years. It is expected that 30 ships of this type will be built with IOC in 2012. Follow-ship acquisition cost shall not exceed $350M. The designs shall be optimized to minimize lifecycle cost.

AJ Brown

A.J. Brown
VT Acquisition Executive

Appendix C – Concept Development Document



UNCLASSIFIED

CAPABILITY DEVELOPMENT DOCUMENT

FOR

AGILE SURFACE COMBATANT – ALUMINUM
ASCal Variant #26
VT Team 2

1. Capability Discussion.

ASCal requirements are based on the LCS Interim Requirements Document (IRD), and ASCal Acquisition Decision Memorandum (ADM) issued by the Virginia Tech Acquisition Authority on 24 August 2008. This ASCal ADM authorized ASC 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 ASC steel hull designs. ASCal 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 ASCal 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. ASCal will use open systems architecture and modular characteristics that will enable timely change-out of Mission Packages enabling ASCal to be optimized to confront these threats. ASCal 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 ASCal 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 ASC must excel at seakeeping and maneuverability at high speeds. Table 1 lists capability gap requirements to be addressed by ASCal.

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	AN/SLQ – 25 NIXIE, Mine Avoidance Sonar	SSTD, AN/SLQ-25 NIXIE, 2 x MK32 SVTT, MK89 TFCS, Mine Avoidance Sonar
2	ASUW, Maritime Interdiction	2xSH-2G, 57mm gun, 2x.50 caliber guns	2xSH-60, 57mm gun, 2x.50 caliber guns, Netfires

3	AAW	SEA Giraffe G/H band radar, 1 x 11 cell Sea RAM, AIMS IFF, EDOES 3601 ESM, ICMS, SEA STAR SAFIRE III, COMBAT DF, IRST	Sea Par MFR, ICMS, AIMS IFF, 16 cell ESSM, AIEWS, COMBAT DF, 3 x SRBOC, 2 x NULKA, IRST
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

2. Analysis Summary.

An Acquisition Decision Memorandum issued on 24 August 2008 by the Virginia Tech Acquisition Authority directed Concept Exploration and Analysis of Alternatives (AoA) for an additional material alternative for an Agile Surface Combatant (ASC). Required ASC 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 26 August 2008 through 9 December 2008. 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 2 selected Variant 26 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.

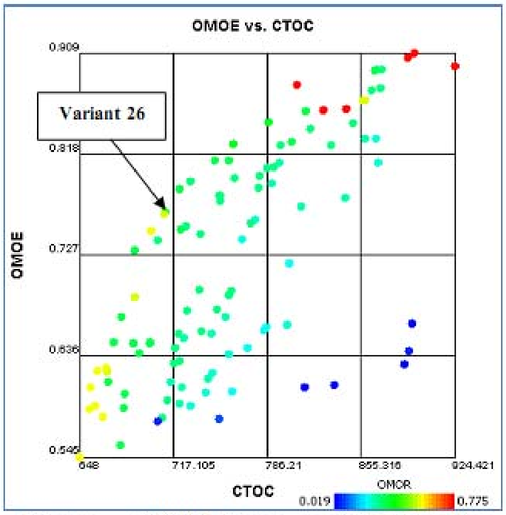


Figure 1 – ASCal 2-D non-dominated Frontier

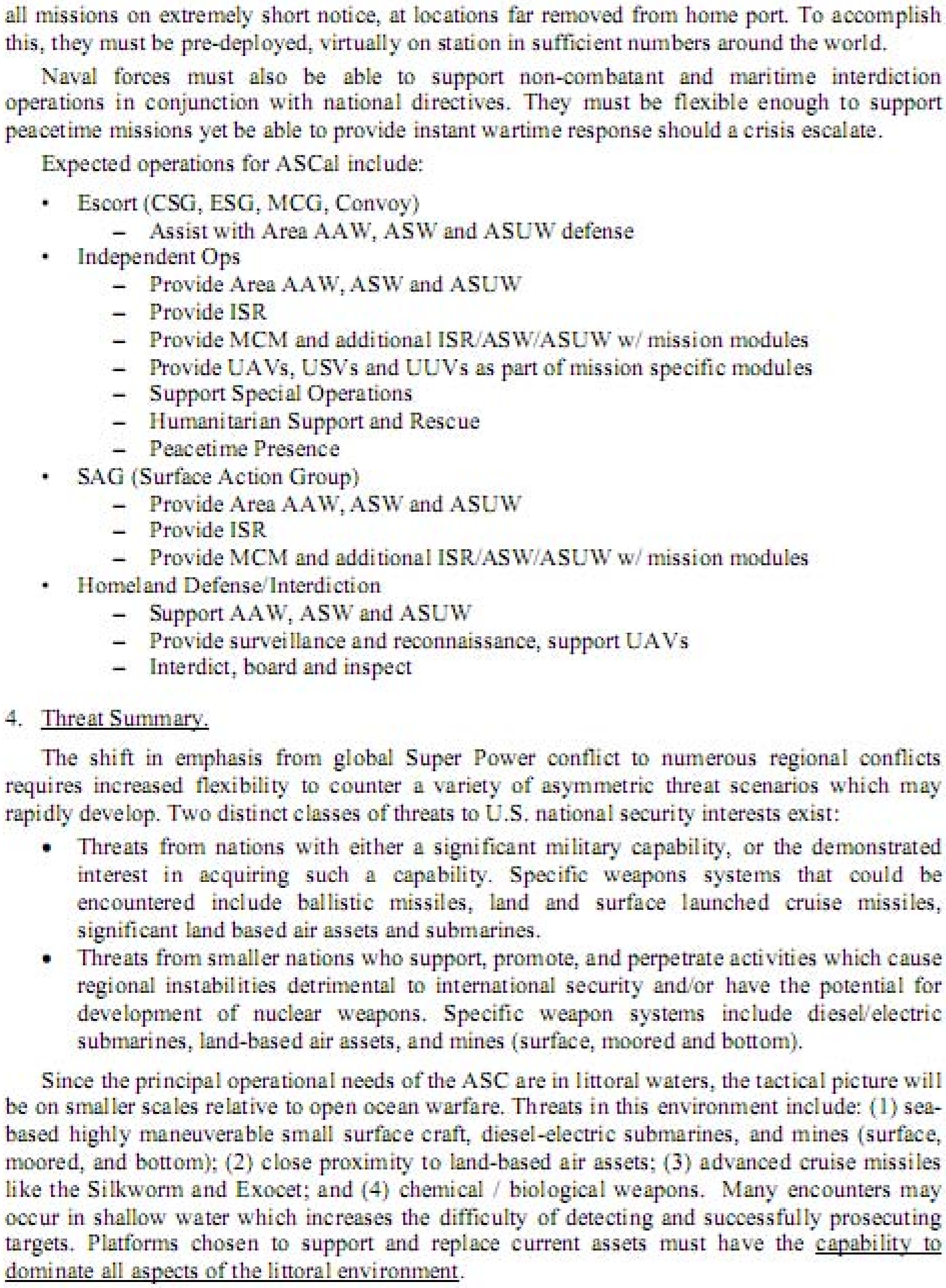
3. Concept of Operations Summary

The range of military operations for the functions in this CCD includes: force application from the sea; force application, protection and awareness at sea; and protection of homeland and critical bases from the sea. Timeframe considered: 2010-2050. This extended timeframe demands flexibility in upgrade and capability over time. The 2001 Quadrennial Defense Review identifies seven critical US military operational goals. These are: 1) protecting critical bases of operations; 2) assuring information systems; 3) protecting and sustaining US forces while defeating denial threats; 4) denying enemy sanctuary by persistent surveillance, 5) tracking and rapid engagement; 6) enhancing space systems; and 7) leveraging information technology.

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

Forward-deployed naval forces will be the first military forces on-scene having "staying and convincing" power to promote peace and prevent crisis escalation. The force must have the ability to provide a "like-kind, increasing lethality" response to influence decisions of regional political powers. It must also have the ability to remain invulnerable to enemy attack. New ships must complement and support this force.

Power Projection requires the execution and support of flexible strike missions and support of naval amphibious operations. This includes protection to friendly forces from enemy attack, unit self defense against littoral threats, area defense, mine countermeasures and support of theater ballistic missile defense. Ships must be able to support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C^4/I reconnaissance vehicles. Naval forces must possess sufficient mobility and endurance to perform



all missions on extremely short notice, at locations far removed from home port. To accomplish this, they must be pre-deployed, virtually on station in sufficient numbers around the world.

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

Expected operations for ASCal include:

- Escort (CSG, ESG, MCG, Convoy)
  - Assist with Area AAW, ASW and ASUW defense
- Independent Ops
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
  - Provide MCM and additional ISR/ASW/ASUW w/ mission modules
  - Provide UAVs, USVs and UUVs as part of mission specific modules
  - Support Special Operations
  - Humanitarian Support and Rescue
  - Peacetime Presence
- SAG (Surface Action Group)
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
  - Provide MCM and additional ISR/ASW/ASUW w/ mission modules
- Homeland Defense/Interdiction
  - Support AAW, ASW and ASUW
  - Provide surveillance and reconnaissance, support UAVs
  - Interdict, board and inspect

4. Threat Summary.

The shift in emphasis from global Super Power conflict to numerous regional conflicts requires increased flexibility to counter a variety of asymmetric threat scenarios which may rapidly develop. Two distinct classes of threats to U.S. national security interests exist:

- Threats from nations with either a significant military capability, or the demonstrated interest in acquiring such a capability. Specific weapons systems that could be encountered include ballistic missiles, land and surface launched cruise missiles, significant land based air assets and submarines.
- Threats from smaller nations who support, promote, and perpetrate activities which cause regional instabilities detrimental to international security and/or have the potential for development of nuclear weapons. Specific weapon systems include diesel/electric submarines, land-based air assets, and mines (surface, moored and bottom).

Since the principal operational needs of the ASC 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.

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

- Open ocean and littoral SS 1-8, fully operational through SS4, and maintain effective operations in SS 1-5
- Shallow and deep water
- Noisy and reverberation-limited ASW environment
- Degraded radar picture
- Crowded shipping; Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather Battle Group and independent operations

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

Key Performance Parameter (KPP)	Development Threshold or Requirement
2 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	4 waterjets, 2xLM2500+, 2xCAT3618
Endurance Speed (knots)	18 knots
Endurance Range (nm)	4099 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^2)	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% (0.8 MCR)
Electrical margins	5%
Net Weight margin (design and service)	10%

6. Program Affordability.

Follow-ship acquisition cost shall not exceed $320M with lead ship acquisition cost less than $422M. It is expected that 30 ships of this type will be built with IOC in 2015.

Appendix D – Machinery Equipment List

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION
System: Main Engines and Transmission					
1	2	Gas Turbine, Main	GE LM2500+ Marine Turbine	30.2MW	MMR
2	2	Diesel Engine, Secondary	CAT 3616	5.06MW	MMR
3	2	Gear, Propulsion Reduction	Double Stage, 28:24:1 Gear Ratio (epicyclic)	50MW	MMR
4	2	Gear, Propulsion Reduction	Single Stage, 8:1 Gear Ratio (epicyclic)	5 MW	MMR
5	2	Shaft, Line	350 mm (OD), 250 mm (ID)	-	various
6	2	Shaft, Secondary Line	250 mm (OD), 150 mm (ID)		various
7	8	Bearing, Line Shaft	Journal	575 mm Line Shaft	various
8	2	Unit, MGT Hydraulic Starting	HPU with Pumps and Reservoir	14.8 m^3/hr @ 414 bar	MMR
	2	Main Engine Exhaust Duct	GE LM2500+ Marine Turbine	90.5 kg/sec	MMR and up
	2	Main Engine Inlet Duct	GE LM2500+ Marine Turbine	79.4 kg/sec	MMR and up
	2	2nd Engine Exhaust Duct	CAT 3616	6.9 kg/sec	MMR and up
	2	2nd Engine Inlet Duct	CAT 3616	6.9 kg/sec	MMR and up
9	1	Console, Main Control	Main Propulsion	NA	ECC
System: Power Generation and Distribution					
10	2	Diesel Generator, Ships Service	CAT 3508B	3500 kW, 480 V, 3 phase, 60 Hz, 0.8 PF	MMR
11	2	Diesel Generator, Ships Service	CAT 3508B	3500 kW, 480 V, 3 phase, 60 Hz, 0.8 PF	AMR
	2	SSDG Exhaust Duct	CAT 3508B	1.1 kg/sec	MMR, AMR and up
	2	SSDG Inlet Duct	CAT 3508B	1.1 kg/sec	MMR, AMR and up
12	1	Switchboard, Ships Service	Generator Control Power Distribution	-	ECC

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION
13	1	Switchboard, Emergency	Generator Control Emergency Power Distribution	-	AMR
		MMR and AMR ladders	Inclined ladders		MMR,AMR
	4	MMR and AMR escape trunks	Vertical ladders with fire tight doors at each level		MMR, AMR
14	2	MN Machinery Space Fan	Supply	94762 m^3/hr	FAN ROOM
15	2	MN Machinery Space Fan	Exhaust	91644 m^3/hr	MMR
16	2	Aux Machinery Space Fan	Supply	61164 m^3/hr	FAN ROOM
17	2	Aux Machinery Space Fan	Exhaust	61164 m^3/hr	AMR
System: Salt Water Cooling					
18	4	Pump, Main Seawater Circ	Centrifugal, Vertical, Motor Driven	230 m^3/hr @ 2 bar	MMR (2 ea)
System: Lube Oil Service and Transfer					
19	2	Assembly, MGT Lube Oil Storage and Conditioning	Includes Oil Storage and Cooler	NA	MMR
20	4	Strainer, Reduction Gear Lube Oil	Duplex	200 m^3/hr	MMR
21	4	Cooler, Reduction Gear Lube Oil	Plate Type	NA	MMR
22	4	Pump, Reduction Gear Lube Oil Service	Pos. Displacement, Horizontal, Motor Driven	200 m^3/hr @ 5 bar	MMR
23	2	Purifier, Lube Oil	Centrifugal, Self Cleaning, Partial Discharge Type	1.1 m^3/hr	MMR
24	2	Pump, Lube Oil Transfer	Pos. Displacement, Horizontal, Motor Driven	4 m^3/hr @ 5 bar	MMR
System: Fuel Oil Service and Transfer					
25	2	Filter Separator, MGT Fuel	2-Stage, Static, 5 Micron	30 m^3/hr	MMR
26	2	Purifier, Fuel Oil	Self Cleaning, Centrifugal, Partial Discharge Type	7.0 m^3/hr	MMR
27	2	Pump, Fuel Transfer	Gear, Motor Driven	45.4 m^3/hr @ 5.2 bar	MMR
	2	Fuel Oil Service Tanks			MMR

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION
System: Air Conditioning and Refrigeration					
28	4	Air Conditioning Plants	150 Ton, Centrifugal Units	150 ton	AMR
29	4	Pump, Chilled Water	Centrifugal, Horizontal, Motor Driven	128 m^3/hr @4.1 bar	AMR
30	2	Refrigeration Plants, Ships Service	R-134a	4.3 ton	AMR
System: Salt Water: Fire main, Bilge, Ballast					
31	4	Pump, Fire	Centrifugal, Horizontal, Motor Driven	50 m^3/hr @ 9 bar	VARIOUS
32	1	Pump, Fire/Ballast	Centrifugal, Horizontal, Motor Driven	50 m^3/hr @ 9 bar	AMR
33	2	Pump, Bilge	Centrifugal, Horizontal, Motor Driven	30 m^3/hr @3.8 bar	MMR
34	1	Pump, Bilge/Ballast	Centrifugal, Horizontal, Motor Driven	30 m^3/hr @3.8 bar	AMR
35	2	Station, AFFF	Skid Mounted	30 m^3/hr @3.8 bar	above MMR
System: Potable Water					
36	2	Distiller, Fresh Water	RO Distilling Unit	50 m^3/day (3.2 m^3/hr)	AMR
37	2	Brominator	Proportioning	1.0 m^3/hr	AMR
38	2	Brominator	Recirculation	1.5 m^3/hr	AMR
39	2	Pump, Potable Water	Centrifugal, Horizontal, Motor Driven	5 m^3/hr @ 4.8 bar	AMR
System: JP-5 Service and Transfer					
40	2	Pump, JP-5 Transfer	Rotary, Motor Driven	11.5 m^3/hr @ 4.1 bar	JP-5 PUMP ROOM
41	2	Pump, JP-5 Service	Rotary, Motor Driven	22.7 m^3/hr @ 7.6 bar	JP-5 PUMP ROOM
42	1	Pump, JP-5 Stripping	Rotary, Motor Driven	5.7 m^3/hr @ 3.4 bar	JP-5 PUMP ROOM
43	2	Filter/Separator, JP-5 Transfer	Static, Two Stage	17 m^3/hr	JP-5 PUMP ROOM
44	2	Filter/Separator, JP-5 Service	Static, Two Stage	22.7 m^3/hr	JP-5 PUMP ROOM

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION
System: Compressed Air					
45	2	Receiver, Starting Air	Steel, Cylindrical	2.3 m^3	MMR
46	2	Compressor, MP Air	Reciprocating Motor Driven, Water Cooled	80 m^3/hr FADY @ 30 bar	MMR
47	1	Receiver, Ship Service Air	Steel, Cylindrical	1.7 m^3	MMR
48	1	Receiver, Control Air	Steel, Cylindrical	1 m^3	MMR
49	2	Compressor, Air, LP Ship Service	Reciprocating, Rotary Screw	8.6 bar @ 194 SCFM	MMR
50	2	Dryer, Air	Refrigerant Type	250 SCFM	MMR
System: Steering Gear Hydraulics					
51	4	Hydraulic Pump and Motor	Water jet Buckets		aft Steering Gear Room
System: Environmental					
52	2	Pump, Oily Waste Transfer	Motor Driven	5 m^3/hr @ 7.6 bar	MMR
53	2	Separator, Oil/Water	Coalescer Plate Type	2.7 m^3/hr	MMR
54	1	Unit, Sewage Collection	Vacuum Collection Type w/ Pumps	28 m^3	SEWAGE TREATMENT ROOM
55	1	Sewage Plant	Biological Type	50 people	SEWAGE TREATMENT ROOM

Appendix E – ASCal Weights

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
	FULL LOAD WEIGHT + MARGIN	2742.83	5.58	15292.60	48.00	131660.86	-0.35	-966.24
	MINOP WEIGHT AND MARGIN	6868.73	3.83	26291.86	87.30	599660.34	-0.14	-966.24
	LIGHTSHIP WEIGHT + MARGIN	2063.93	6.09	12562.71	53.77	110969.78	-0.47	-966.24
	LIGHTSHIP WEIGHT	1876.30	6.09	11420.64	53.77	100881.62	-0.47	-878.40
	MARGIN	187.63	6.09	1142.06	53.77	10088.16	-0.47	-87.84
100	HULL STRUCTURES	582.60	5.76	3358.00	51.96	30270.38	3.23	1879.50
	BARE HULL		10.65	0.00	104.00	0.00	0.00	0.00
110	SHELL + SUPPORTS	174.60	2.53	441.74	52.05	9087.93		0.00
120	HULL STRUCTURAL BULKHDS	30.10	4.89	147.19	57.30	1724.73		0.00
130	HULL DECKS	63.40	8.83	559.82	48.75	3090.75		0.00
140	HULL PLATFORMS/FLATS	60.30	5.34	322.00	56.56	3410.57		0.00
150	DECK HOUSE STRUCTURE	125.30	12.22	1531.17	51.26	6422.88	15.00	1879.50
160	SPECIAL STRUCTURES	8.80	9.62	84.66	18.57	163.42		0.00
170	MASTS+KINGPOSTS+SERV PLATFORM		36.63	0.00	90.00	0.00	0.00	0.00
180	FOUNDATIONS	120.10	2.26	271.43	53.04	6370.10	0.00	0.00
190	SPECIAL PURPOSE SYSTEMS			0.00		0.00		0.00
200	PROPULSION PLANT	572.60	4.48	2564.66	62.76	35938.09	0.00	0.00
	BASIC MACHINERY		6.58	0.00	120.00	0.00	-3.00	0.00
230	PROPULSION UNITS	196.40	4.69	921.05	10.36	9543.04		0.00
233	DIESEL ENGINES	100.00	3.60	360.00	54.74	5474.00		0.00
234	GAS TURBINES	96.40	5.82	561.05	42.21	4069.04		0.00
240	TRANSMISSION+PROPULSOR SYSTEMS	271.00	3.23	874.66	24.07	21054.97		0.00
241	REDUCTION GEARS	131.00	4.01	525.31	61.50	8056.50		0.00
242	CLUTCHES + COUPLINGS	10.70	2.81	30.07	81.80	875.26		0.00
243	SHAFTING	41.00	2.83	116.03	84.90	3480.90	0.00	0.00
244	SHAFT BEARINGS	10.40	2.69	27.98	84.05	874.12	0.00	0.00
247	WATERJET	77.90	2.25	175.28	99.72	7768.19	0.00	0.00
250	SUPPORT SYSTEMS, UPTAKES	58.30	10.93	637.22	45.85	2673.06		0.00
260	PROPUL SUP SYS- FUEL, LUBE OIL	17.20	3.67	63.12	55.91	961.65		0.00
290	SPECIAL PURPOSE SYSTEMS	29.70	2.31	68.61	57.42	1705.37		0.00
300	ELECTRIC PLANT, GENERAL	113.60	5.24	595.19	52.07	5914.64	0.00	0.00
310	ELECTRIC POWER GENERATION	47.20	3.49	164.80	52.40	2473.32		0.00
	BASIC MACHINERY	304.80	9.32	2840.74	105.00	32004.00	0.00	0.00
311	SHIP SERVICE POWER GENERATION	38.00	2.62	99.56	51.43	1954.34		0.00
312	EMERGENCY GENERATORS	4.50	5.64	25.38	61.06	274.77		0.00
314	POWER CONVERSION EQUIPMENT	4.70	8.48	39.86	51.96	244.21		0.00
320	POWER DISTRIBUTION SYS	45.70	5.34	244.04	52.00	2376.40	0.00	0.00
330	LIGHTING SYSTEM	9.10	8.32	75.71	52.31	476.02	0.00	0.00
340	POWER GENERATION SUPPORT SYS	7.90	12.38	97.80	51.43	406.30		0.00
390	SPECIAL PURPOSE SYS	3.70	3.47	12.84	49.35	182.60		0.00
400	COMMAND+SURVEILLANCE	156.70	9.77	1530.24	34.68	5434.83	4.78	748.90
	PAYLOAD	91.06	20.96	1908.89	95.00	8650.70	5.00	455.30
	CABLING	37.70	11.98	451.70	103.00	3882.59	3.00	113.09

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
	MISC	46.01		0.00	105.00	4830.53	3.00	138.02
410	COMMAND+CONTROL SYS	24.70	8.84	218.35	33.77	834.12		0.00
420	NAVIGATION SYS	4.00	11.23	44.92	42.32	169.28		0.00
430	INTERIOR COMMUNICATIONS	8.50	7.84	66.64	45.05	382.93	5.00	42.50
440	EXTERIOR COMMUNICATIONS	47.40	8.99	426.13	46.54	2206.00		0.00
450	SURF SURVEILLANCE SYS (RADAR)	18.70	16.97	317.34	34.38	642.91		0.00
460	UNDERWATER SURVEILLANCE SYSTEMS	1.20	1.22	1.46	23.97	28.76		0.00
470	COUNTERMEASURES	29.00	6.15	178.35	25.27	732.83		0.00
480	FIRE CONTROL SYS	6.20	11.70	72.54	33.22	205.96		0.00
490	SPECIAL PURPOSE SYS	17.00	12.03	204.51	13.65	232.05		0.00
500	AUXILIARY SYSTEMS, GENERAL	373.10	7.13	2661.57	55.17	20582.77	-8.21	-3063.10
	WAUX	2207.00	10.65	23508.96	100.00	220700.00	-1.70	-3751.90
	PAYLOAD	0.00		0.00		0.00		0.00
510	CLIMATE CONTROL	76.00	10.39	789.64	53.91	4097.16		0.00
	CPS	31.80	17.00	540.60	100.00	3180.00	1.00	31.80
520	SEA WATER SYSTEMS	31.80	5.72	181.90	48.00	1526.40		0.00
530	FRESH WATER SYSTEMS	8.00	6.86	54.88	34.46	275.68		0.00
540	FUELS/LUBRICANTS,HANDLING+STORAGE	28.30	3.29	93.11	60.70	1717.81		0.00
550	AIR,GAS+MISC FLUID SYSTEM	60.60	6.74	408.44	53.38	3234.83		0.00
560	SHIP CNTL SYS	25.90	2.15	55.69	66.54	1723.39		0.00
570	UNDERWAY REPLENISHMENT SYSTEMS	24.80	8.11	201.13	77.17	1913.82		0.00
581	ANCHOR HANDLING+STOWAGE SYSTEMS	18.00	6.69	120.42	2.46	44.28		0.00
582	MOORING+TOWING SYSTEMS	17.90	9.54	170.77	46.79	837.54		0.00
583	BOATS,HANDLING+STOWAGE SYSTEMS	7.80	7.15	55.77	48.17	375.73		0.00
588	AIRCRAFT HANDLING, SUPPORT	43.80	8.54	374.05	78.03	3417.71	15.00	657.00
593	ENVIRONMENTAL POLLUTION CNTL SYS	14.90	3.00	44.70	50.57	753.49	0.00	0.00
598	AUX SYSTEMS OPERATING FLUIDS	15.30	7.26	111.08	43.46	664.94	0.00	0.00
600	OUTFIT+FURNISHING,GENERAL	30.30	7.62	231.01	44.92	1361.11	1.00	30.30
610	SHIP FITTINGS	5.00	6.38	31.90	59.55	297.75	1.00	5.00
640	LIVING SPACES	25.30	7.87	199.11	42.03	1063.36	1.00	25.30
700	ARMAMENT	47.40	10.13	479.99	29.11	1379.80	-10.00	-474.00
710	GUNS+AMMUNITION	23.80	9.82	233.72	17.83	424.35		
720	MISSLES+ROCKETS	11.50	13.49	155.14	74.95	861.93		
750	TORPEDOES	5.50	9.13	50.22		0.00		
760	SMALL ARMS+PYROTECHNICS	6.60	6.20	40.92	14.17	93.52		
	FULL LOAD CONDITION							
F00	LOADS	678.90	4.02	2729.89	30.48	20691.08	0.00	0.00
F10	SHIPS FORCE	5.50	6.49	35.70	42.70	234.85	0.00	0.00
F20	MISSION RELATED EXPENDABLES+SYS	149.60	8.44	1262.37	5.06	756.98		
F21	SHIP AMMUNITION	16.10	8.07	129.93				0.00
F22	ORD DEL SYS AMMO	11.40	2.73	31.12				0.00
F23	ORD DEL SYS (AIRCRAFT)	54.00	7.88	425.52			0.00	0.00
F26	ORD DEL SYS SUPPORT EQUIP	53.60	11.05	592.28				
F29	SPECIAL MISSION RELATED SYS	14.50	5.76	83.52				
F31	PROVISIONS+PERSONNEL STORES	4.90	6.59	32.29	44.26	216.87	0.00	0.00
F32	GENERAL STORES	0.80	4.76	3.81	53.13	42.50	0.00	0.00
F40	LIQUIDS, PETROLEUM BASED	483	2.72	1358.76	38.39	19175.81		

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F41	DIESEL FUEL MARINE	415.40	2.22	922.19			0.00	0.00
F42	JP-5	71.60	5.42	388.07			0.00	0.00
F46	LUBRICATING OIL	12.50	3.88	48.50			0.00	0.00
F52	FRESH WATER	17.10	1.94	33.17	13.04	222.98		0.00
F55	SANITARY TANK LIQUID	1.50	2.53	3.80	27.39	41.09	0.00	0.00
	MINIMUM OPERATING CONDITION							
F00	LOADS	4804.80	2.86	13729.15	101.71	488690.56	0.00	0.00
F10	SHIPS FORCE	97.65	15.98	1560.19	105.00	10252.83	0.00	0.00
F21	SHIP AMMUNITION			0.00		0.00		0.00
F22	ORD DEL SYS AMMO			0.00		0.00		0.00
F23	ORD DEL SYS (AIRCRAFT)	360.60	17.00	6130.18	105.00	37862.90	0.00	0.00
F31	PROVISIONS+PERSONNEL STORES	25.00	11.43	285.85	110.00	2750.00	0.00	0.00
F32	GENERAL STORES	8.00	11.35	90.82	110.00	880.00	0.00	0.00
F41	DIESEL FUEL MARINE	250.00	2.00	500.00	100.00	25000.00	0.00	0.00
F42	JP-5	150.00	1.00	150.00	105.00	15750.00	0.00	0.00
F46	LUBRICATING OIL	17.60	2.00	35.20	150.00	2640.00	0.00	0.00
F47	SEA WATER	3500.00	1.00	3500.00	100.00	350000.00	0.00	0.00
F52	FRESH WATER	395.95	3.73	1476.90	110.00	43554.83	0.00	0.00