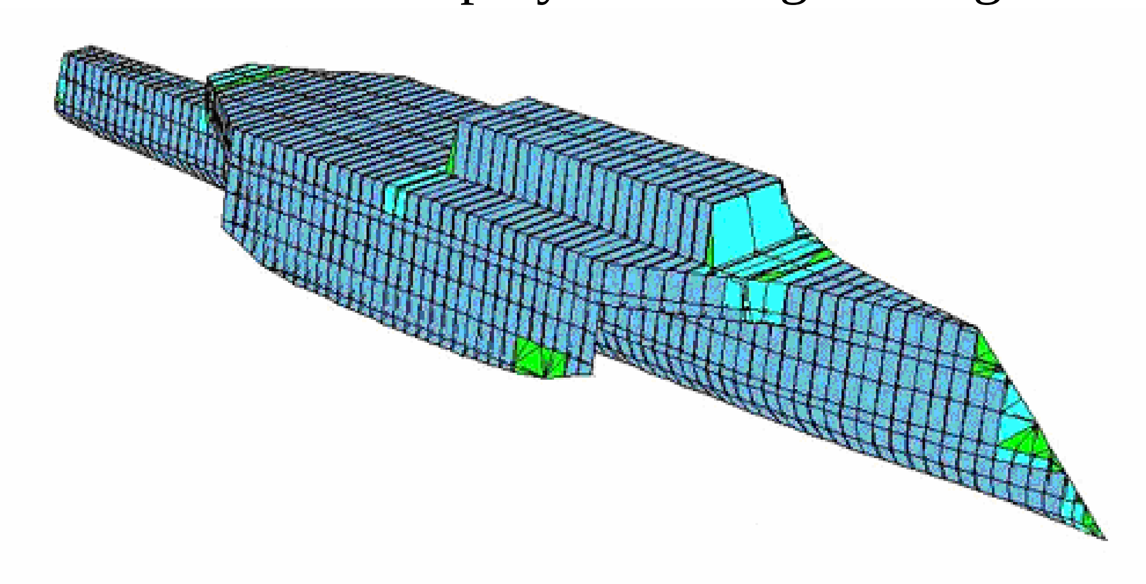
Design Report

Agile Surface Combatant (ASC)

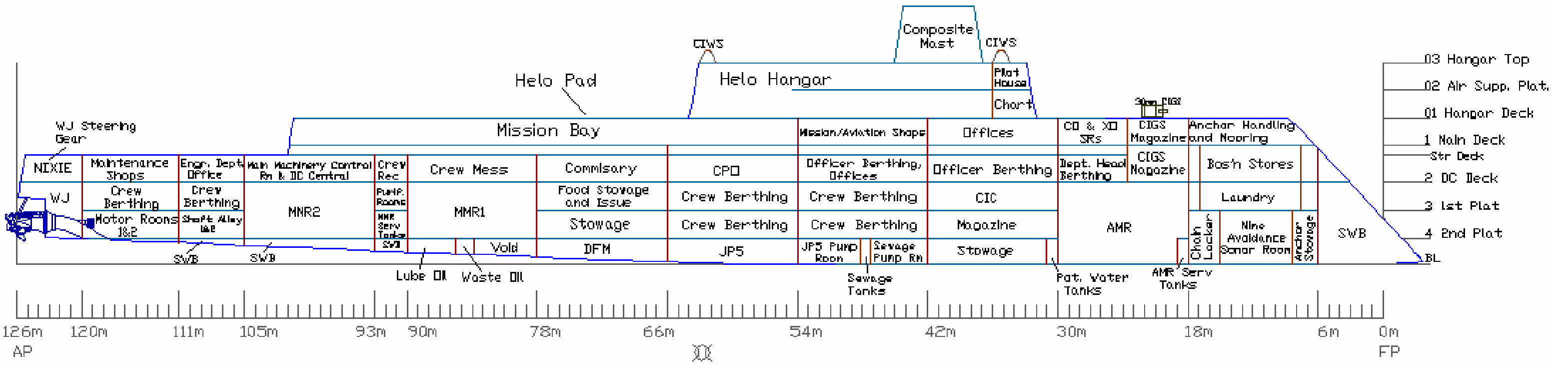
VT Total Ship Systems Engineering



Trimaran ASC-HI2 Option
Ocean Engineering Design Project
AOE 4065/4066
Fall 2003 – Spring 2004
Virginia Tech Team 2

David Cash	____________________	17147
Gerritt Lang	____________________	19588
Dorothy McDowell – Team Leader	____________________	17788
Cory McGraw	____________________	21514
Scott Patten	____________________	19592
Joshua Staubs	____________________	21529

Executive Summary



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

The ASC requirement is based on the LCS Flight 0 Preliminary Design Interim Requirements Document and ASC Acquisition Decision Memorandum (ADM). ASC will operate in littoral areas, close-in, depend on stealth, with high endurance and low manning. ASC must perform ISR, MCM, ASW and ASUW missions using interchangeable, networked, tailored modular mission packages built around off-board, unmanned systems. It must support Spartan UCSV's, VTUAV's and LAMPS, providing for launch and takeoff, recovery and landing, fueling, maintenance, weapons load-out, planning and control. The VTUAV's will provide surface, subsurface, shore, and deep inland intelligence, surveillance, reconnaissance (ISR) and electronic warfare. LAMPS will provide Anti-Submarine Warfare (ASW) and Anti-Surface Ship Warfare (ASUW) defense. The UCSV's can engage surface threats with anti-surface armaments, conduct SAR operations, support and conduct intelligence collection, and conduct surveillance and reconnaissance.

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 (ship acquisition cost and life cycle cost), risk (technology, cost, schedule and performance) and military effectiveness. The product of this optimization is a series of cost-risk-effectiveness frontiers which are used to select the ASC HI2 Baseline Concept Design and define Operational Requirements (ORD1) based on the customer's preference for cost, risk and effectiveness.

ASC HI2 is the highest-end alternative on the life-cycle cost frontier. This design was chosen to provide a challenging design project using higher risk technology. ASC HI2 characteristics are listed below. ASC HI2 has a wave-piercing tumblehome (WPTH) hullform to reduce radar cross section and improve high speed performance in waves, and a unique moon pool for launching and recovering UCSVs and mine hunting UAVs (RMS). It uses significant automation technology including an automated mess, an Integrated Survivability Management System (ISMS), and watch standing technologies that include GPS, automated route planning, electronic charting and navigation (ECDIS), collision avoidance, and electronic log keeping. Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, IPS 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 within cost and risk constraints with additional work required to improve structural and system vulnerability and reduce structural weight.

Ship Characteristic	Value
LWL	126.3 m
Beam	24.9 m
Draft	4.2 m
D10	10.1 m
Lightship weight	2193 MT
Full load weight	2825 MT
Sprint Speed	42.7 knots
Endurance Speed	20 knots
Sprint Range	1241 nm
Endurance Range	3881 nm
Propulsion and Power	2 LM2500+ engines, 2 225SII Kamewa waterjets, Secondary Integrated Power System (IPS)
BHP	69733 HP
Personnel	88
OMOE (Effectiveness)	0.635
OMOR (Risk)	0.691
Ship Acquisition Cost	$489M
Life-Cycle Cost	$877M
Combat Systems (Modular and Core)	SSDS, TISS, AN/SPS-73, AN/SLQ-32A(V)3, 2xCIWS, 1xCIGS, 7m RHIB, AN/SLQ-25 NIXIE, UUV, RMS, MK XII AIMS IFF, Sea Giraffe AMP Radar
UCSVs (Spartan)	2
VTUAVs	3
LAMPS	1

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1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of an Agile Surface Combatant (ASC) for the United States Navy. The ASC requirement is based on the LCS Flight 0 Preliminary Design Interim Requirements Document (PD-IRD), and Virginia Tech ASC Acquisition Decision Memorandum (ADM), Appendix A. This concept design was completed in a two-semester ship design course at Virginia Tech. ASC must perform the following missions using interchangeable, networked, tailored modular mission packages built around off-board, unmanned systems:

1. Intelligence, Surveillance, and Reconnaissance (ISR)
2. Mine Counter Measures (MCM)
3. Anti-Submarine Warfare (ASW)
4. Anti-Surface Ship Warfare (ASuW)
5. Anti-Air Warfare (AAW) self defense

Unmanned systems may include the Spartan Unmanned Combat Surface Vehicle (UCSV) and the Vertical Takeoff Unmanned Air Vehicle (VTUAV), both transformational technologies in development. "Transformation is about seizing opportunities to create new capabilities by radically changing organizational relationships, implementing different concepts of warfighting and inserting new technology to carry out operations in ways that profoundly improve current capabilities and develop desired future capabilities."

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.

The concepts introduced in the ASC design include moderate to high-risk alternatives.

1.2 Design Philosophy, Process, and Plan

The traditional approach to ship design is largely an 'ad hoc' process. Experience, design lanes, rules of thumb, preference, and imagination guide selection of design concepts for assessment. Often, objective attributes are not adequately synthesized or presented to support efficient and effective decisions. This project uses a total system approach for the design process, including a structured search of the design space based on the multi-objective consideration of effectiveness, cost and risk.

The scope of this project includes the first two phases in the ship design process, Concept Exploration and Concept Development, as illustrated in Figure 1. The Concept Exploration process is shown in Figure 2. The results of this process are: a preliminary Operational Requirements Document (ORD1) that specifies performance and cost requirements; technology selection; and a baseline concept design with principal characteristics, "one-digit" weights, identification of major HM&E and combat systems, performance predictions and a Class "F" cost estimate. Concept Development follows the more traditional design spiral as illustrated in Figure 3. This process results in a more detailed ship geometry with "two-digit" weights, additional definition of HM&E and combat systems, rough order general arrangements, additional performance prediction and analysis, manning estimate, draft Operational Requirements Document (ORD1), a Preliminary Design Plan, a System Development Plan, and a study report.

In Concept Exploration, the ship design is completed to a level of detail called "Rough Order of Magnitude (ROM)". It considers those design parameters that have a significant impact on ship balance. The acquisition and design process is normally initiated by a Mission Need Statement (MNS) that includes policy, threat, mission, non-material and material alternatives, and constraints. Specific material alternatives, technologies, and general concepts to be explored are then specified in an Acquisition Decision Memorandum (ADM). The initial ASC project requirement is based on the Littoral Combat Ship (LCS) Interim Requirements Document and ADM, Appendix A. The mission definition is developed from a number of LCS mission presentations (Chapter 2). The naval architect must then translate this general requirement into specific engineering terms, identify specific design alternatives and variables, and specify the design space to be considered for ship synthesis, screening, and optimization. A multiple-objective design optimization is used to search the design space and perform trade-offs. The Agile Surface Combatant (ASC) Concept Exploration considers two types of hull form, the catamaran and the trimaran. Monohull alternatives are considered in a separate study. It also considers various propulsion systems, combat systems, and automation alternatives using mission effectiveness, risk, and acquisition cost as objective attributes that must be defined mathematically. A ship synthesis model is used to balance these parameters in total ship designs, to assess feasibility and to calculate cost, risk and effectiveness. In more traditional monohull designs, parametric equations may be used in place of physics-based models to speed up the ship synthesis optimization. Because of the unique nature of the ASC Catamaran and Trimaran designs, physics-based analysis must first be used to generate response surface (parametric) models (RSMs) for the ship synthesis model. The final design combinations are ranked by cost, risk, and effectiveness, and presented as a series of non-dominated frontiers. A non-dominated frontier (NDF) represents ship designs in the design space that have the highest effectiveness for a given cost and risk. Concepts for further study and development are chosen from this frontier.

The Concept Development process shown in Figure 3 represents the more traditional design process used in the second stage of this project. A complete circuit around the design spiral is frequently called a Feasibility Study. It investigates each step in the traditional design spiral at a level of detail necessary to demonstrate that assumptions and results obtained in concept exploration are not only balanced, but also feasible. In the process, a second layer of detail is added to the design and risk is reduced.

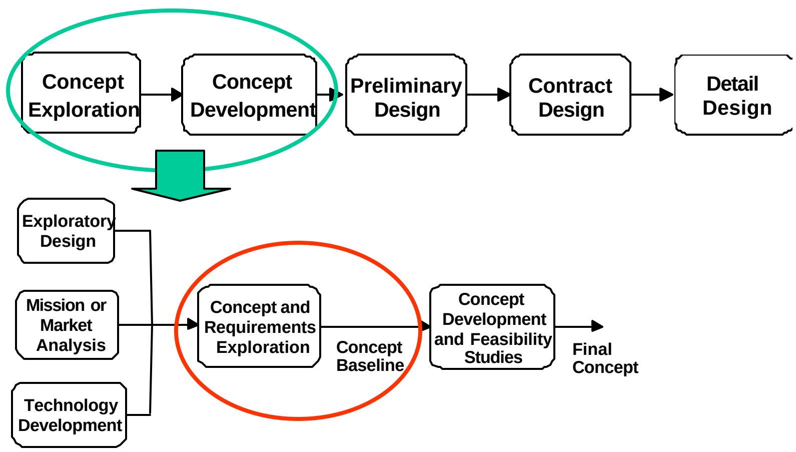

Figure 1 - Design Process [4]

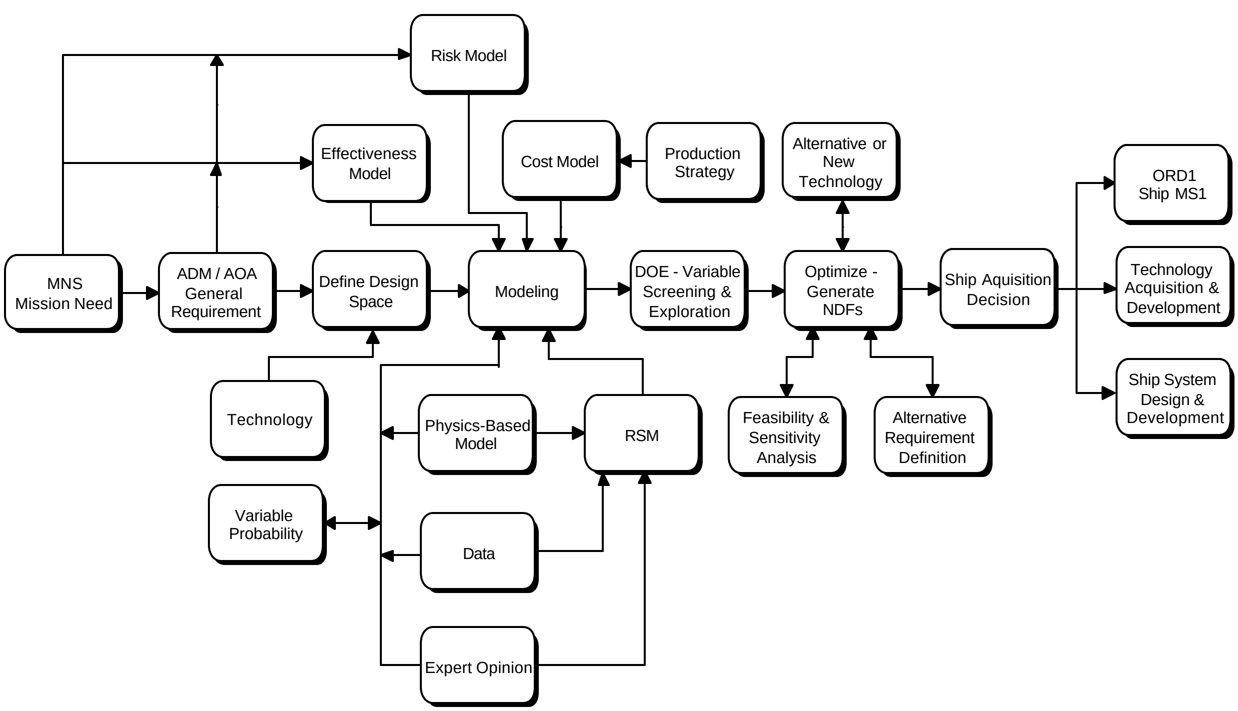

Figure 2 - Concept Exploration Process [4]

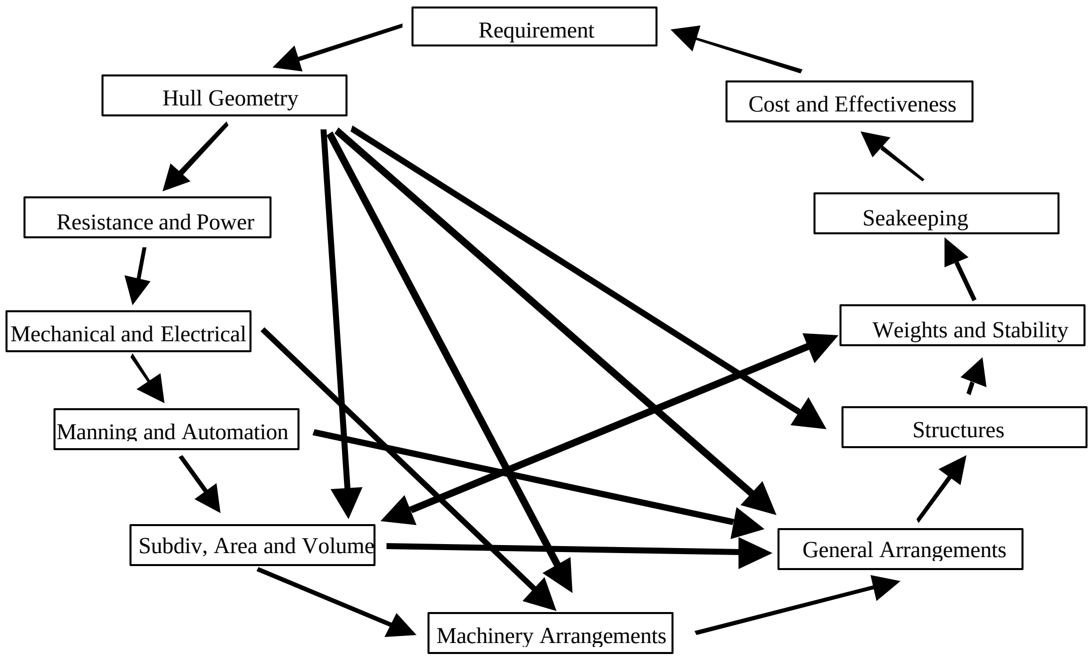

Figure 3 - Concept Development Design Spiral (Chapter 4) [4]

1.3 Work Breakdown

The ASC Trimaran team 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. This specialization allows members to concentrate efforts on thoroughly understanding a subject. A team leader was also selected to effectively coordinate the efforts of the team. Although each team member had his/her own area of expertise there was generally a great deal of overlap. This is a team effort!

Table 1 - Work Breakdown

Name	Specialization
Dorothy McDowell (Team Leader)	Feasibility, Cost, Risk, Seakeeping
David Cash	Writer, Effectiveness
Gerritt Lang	General Arrangements, Machinery Arrangements
Cory McGraw	Hull Form, Structures, Combat Systems
Scott Patten	Weights and Stability, Subdivision
Joshua Staubs	Propulsion and Resistance, Electrical, Manning and Automation

1.4 Resources

Table 2 - Tools

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

When software is used, much time and effort is applied to learning and completely understanding the theory behind the input and outputs of each program. In order to ensure our answers make sense, rough order of magnitude calculations are made.

2 Mission Definition

The ASC mission definition is based on the Littoral Combat Ship Flight 0 Preliminary Design Interim Requirements Document (PD-IRD) and ASC Acquisition Decision Memorandum (ADM), Appendix A, with elaboration and clarification obtained by discussion and correspondence with the customer, and reference to pertinent documents and web sites referenced in the following sections.

2.1 Concept of Operations

ASC will operate in littoral areas, close-in, depend on stealth, with high speed, minimum external support, and low manning. ASC will contribute to Sea Power 21 and the emerging Global Naval Concept of Operations. It will have tactical employment in future contingency and wartime operations. ASC will rely on modular mission packages built around off-board, unmanned systems. It will provide a Sea Strike basis by performing persistent ISR, enabling forced entry, and engaging in power projection with USMC and Special Operations Forces. It will perform a Sea Shield basis by providing assured access and sea/littoral superiority by conducting MIW, littoral ASW, SUW, ISR, and SOF support mission and supporting homeland defense. ASC will provide Sea Basing by projecting persistent offensive and defensive power, providing security for joint assets and enable sea-based forces with a maneuver and logistics element for joint mobility and sustainment. The Agile Surface Combatant will support the breadth of its mission through the use of interchangeable, networked, tailored mission modules. Table 3 lists ASC modular mission packages and their capabilities.

Table 3 - ASC Modular Packages and their Capabilities

Modular Package	Modular Mission Capabilities
Mine Counter Measure package	Provide organic punch through capability Search, map, avoid with limited neutralization Support remote & autonomous UV's and operate helos Massed ASC Division = Dedicated MCM capability
Littoral ASuW package	Integrated surface surveillance using on-board/off-board sensors Employ, reconfigure, and support MH-60 series helicopters Conduct SUW Battle Damage Assessment Contribute to and receive the Common Tactical Picture Deploy, control, and recover off-board systems
Littoral ASW package	Integrated with multiple off-board sensor systems Automatic on-board processing Helicopter(s) Permits dedicated ASC ASW division
Inherent missions	SOF Maneuver, logistics, replenishment NEO MIO Medical, etc.

Mission packages use "plug-in" technology, which interfaces with ASC core support systems. They may require additional "trained" personnel to operate. Packages are built for rapid reconfiguration, are scalable and transportable by air and ship. They will rely on unmanned, distributed off-board systems. Like an "airframe", visualize ASC as a "sea frame".

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.

2.2 Projected Operational Environment (POE) and Threat

ASC will provide worldwide operation against two distinct classes of threats. These threats include: (1) Threats from nations with a major military capability, or the demonstrated interest in acquiring such a capability. Specific weapons systems that could be encountered include land and surface launched cruise missiles, and significant land based air assets and submarines; and (2) Threats from smaller nations who support, promote, and perpetrate activities that cause regional instabilities detrimental to international security and/or have the potential development of nuclear weapons. Specific weapons systems include diesel/electric submarines, land-based air assets, chemical/biological/radiological/nuclear weapons, and surface to air missiles (mobile and fixed). Since many potentially unstable nations are located on or near geographically constrained bodies of water, the future tactical picture will be on smaller scales relative to open ocean warfare. Many encounters may occur in shallow water. This increases the difficulty of detecting and successfully prosecuting targets.

Mission modular packages must be able to operate in the following environments:

- Dense contact and threat environment
- Conventional and nuclear weapons environments
- Open-ocean (sea states 0 through 8) and littoral regions

2.3 ASC Operations and Missions

ASC operation types include the following:

- Integrated with CSG/ESG
  - Notionally, 2 to 3 ASC ships assigned to each strike group - operational environment drives ASC configuration
  - Mission configuration will complement other strike group combatants - provides defense against mine threat, littoral ASC threat, and small boat threat
  - Commander determines "tailored" mission configurations – ASC sprint speed results in rapid mission execution thereby eliminating the threat early on and enabling flow of follow-on forces
- ASC Division Operations
  - Forward deployed, separate from but in support of CSG/ESG
  - Collective flexibility & versatility while providing mutual support
  - Maintain a continuous presence in critical theaters of operation
  - First response capability to anti-access crisis, defeats threats early on
  - Integrated with Joint Task Force assets to execute access assurance
  - Rapid reconfiguration to meet mission needs
- Limited Independent Operations
  - Inherent (mobility) mission tasking in a known threat environment
  - Insertion/extraction of Army, USMC, & SOF personnel
  - Movement of Cargo and Personnel
  - Logistics support of operations ashore
  - Replenishment of ASC force
  - Rapid response to contingency mission tasking

2.4 Mission Scenarios

Mission scenarios for the primary ASC missions are provided in Table 4 through Table 7.

Table 4 - Mine Counter Measures (MCM) Mission

Day	Mission scenario for MCM
1-21	Small ASC squadron transit from CONUS
21-24	Port call, replenish and load MCM modules
25-30	Conduct mine hunting operations
29	Conduct ASuW defense against small boat threat
31-38	Repairs/Port Call
39	Engage submarine threat for self-defense
41	Engage air threat 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

Table 5 - Anti-Submarine Warfare (ASW) Mission

Day	Mission scenario for ASW
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
43-50	Support LAMPS operations against submarine threat
43-45	Mine avoidance
47	Engage small boat threat in ASUW self-defense
51	Unrep
52-59	Support LAMPS operations against submarine threat
60+	Port call/restricted availability

Table 6 - Anti-Surface Warfare (ASUW) Mission

Day	Mission scenario for ASuW
1-21	ASC Transit from CONUS
21-24	Port call, replenish and load ASUW modules
25-30	Conduct ASUW operations in the littoral area
26	Target and engage enemy submarine, ASW self defense
31-35	Support helo operations against surface forces
36	Unrep
37-38	Transit to port
39-42	Changeout/offload modules to support SOF personnel insertion
43-45	Sprint to SOF insertion point
45	Insert SOF Personnel
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 7 - Independent Operations Scenario

Day	Mission scenario for Independent Ops
1-21	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	Import, load MCM modules
37-58	Conduct mine hunting and mapping
50	Avoid submarine threat (ASW)
56	Engage air threat for self defense
59	Transit to port
60+	Port call / return home

2.5 Required Operational Capabilities

In order to support the missions and mission scenarios described in Section 2.4, the capabilities listed in Table 8 are required. Each of these can be related to functional capabilities required in the ship design, and, if within the scope of the Concept Exploration design space, the ship's ability to perform these functional capabilities is measured by explicit Measures of Performance (MOPs). ASC will have focused mission capabilities of Mine Warfare (MIW), Littoral Surface Warfare (SUW) against small, highly armed boats, and Littoral Anti-Submarine Warfare (ASW).

Table 8 - List of Critical ASC Required Operational Capabilities (ROCs)

ROCs	Description
MOB 1	Steam to design capacity in most fuel efficient manner
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
AAW 1	Provide anti-air defense in cooperation with other forces
AAW 1.2	Provide unit self defense
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
ASU 1	Engage surface threats with anti-surface armaments
ASU 2	Engage surface ships in cooperation with other forces
ASU 6	Disengage, evade and avoid surface attack
ASW 1	Engage submarines
ASW 1.2	Engage submarines at medium range (LAMPS)
ASW 1.3	Engage submarines at close range (torpedo)
ASW 4	Conduct airborne ASW/recon (LAMPS)
ASW 5	Support airborne ASW/recon
ASW 10	Disengage, evade, and avoid submarine attack by employing countermeasures and evasion techniques
MIW 1	Conduct mine-hunting
MIW 4	Conduct mine avoidance
MIW 6.7	Maintain magnetic signature limits
CCC 3	Provide own unit CCC
CCC 4	Maintain data link capability
SEW 2	Conduct sensor and ECM operations
SEW 3	Conduct sensor and ECCM operations
FSO 6	Conduct SAR operations
FSO 7	Provide explosive ordnance disposal services
FSO 8	Conduct port control functions
INT 1	Support/conduct intelligence collection
INT 3	Conduct surveillance and reconnaissance
NCO 3	Provide upkeep and maintenance of own unit
NCO 19	Conduct maritime law enforcement operations

3 Concept Exploration

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

3.1 Standards and Specifications

The ABS Guide for Building and Classing High Speed Naval Craft will be used as the primary concept design standard. In addition to this requirement, the following standards shall be used as design "guidance":

- Stability and Buoyancy: DDS 079-1 (2002)
- Endurance Fuel: DDS 200-1
- Electric Load Analysis: DDS 310-1

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

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

3.2.1 Hull Form Alternatives

The ASC hull form must satisfy the following general requirements:

- Speed of 40 – 50 knots
- Transport Factor of 10 – 20
- Displacement of approximately 2000 to 3500 MT
- Low cost
- Good seakeeping characteristics
- Draft of 3-5 meters
- Hull Service Life of 20 – 30 years
- Support Various Modular Mission Packages

The Transport Factor (TF) provides a non-dimensional relationship between weight, speed, endurance and propulsion power [12]:

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

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

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

Figure 4 displays Transport Factor as a function of speed for a range of hull forms. The red line represents a theoretical limit on TF as a function of speed for displacement ships. Four possible hull form alternatives were selected for ASC using this curve, and based on satisfying the speed requirement (40-50 knots) with at least a modest lift capacity or Transport Factor (10-20). These are:

- Slender monohull
- Catamaran
- Trimaran
- Surface Effect Ship (SES)

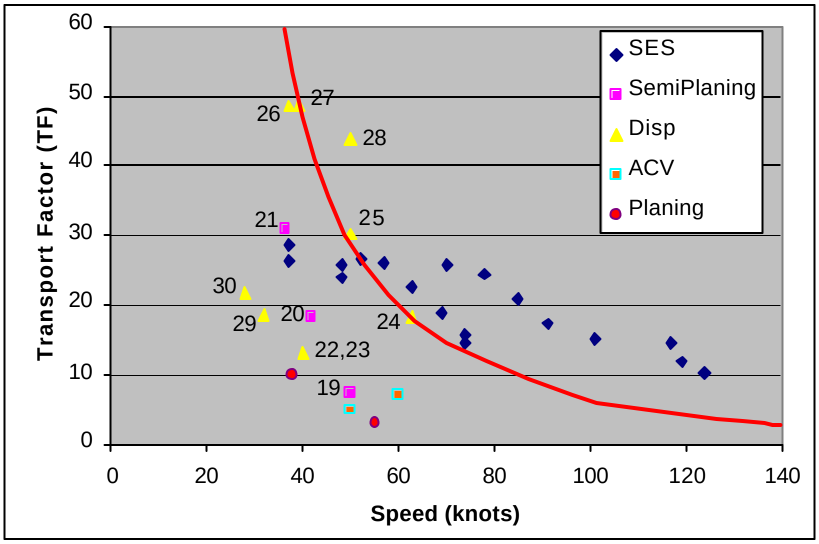

Figure 4 - Examples of Transport Factors [12]

Each of the hull form types was assessed based on the ASC requirements with the following conclusions:

- Conventional Monohull - An optimized conventional monohull form with bow flare is the most traditional design considered. Shipyards have more experience building monohulls and this could improve producibility and reduce construction cost. Monohulls have larger large-object space than most other hull form alternatives for a given displacement. The structural characteristics are well known. Conventional monohulls have a large residuary resistance at high speeds. The radar cross-section for a ship with bow flare and vertical or flared sides may be significant. Compared to multi-hulls there is less usable deck area.

- Catamaran - The Catamaran or twin-hull concept has been employed in high-speed craft design for several years. The component hulls (demihulls) usually have V-type sections and a cut-off transom stern. The division of displacement and waterplane area between two relatively slender hulls results in a large deck area, good stability, and smaller roll angles than monohulls of similar displacement under similar sea conditions. However, seakeeping qualities in terms of angle and rate of pitch are poor compared to a monohull. This problem can be reduced using active control of pitching motions. The wetted surface area ratio, slenderness ratio, and hull spacing strongly affect the resistance of a catamaran. The wetted surface area ratio is high compared with planing monohulls of the same displacement. Thus, catamarans have relatively high resistance at low speeds ($Fn < 0.35$) where skin friction is dominant. At higher speeds, the low wave-making resistance provides low total resistance. Beneficial wave interference can be achieved by the cancellation of part of the divergent wave systems of each demihull. Catamarans have a relatively high radar cross section, especially end-on. The displacement to length ratio is high and the large object volume is relatively low compared to a monohull. The cost for building a catamaran is higher than that for a monohull of the same displacement. U.S. shipyards have little experience in the construction of catamarans.

- Trimaran - The trimaran hull form consists of a slender monohull with shorter very slender hulls attached to each side. The trimaran hull form has some advantages over a conventional hull form such as decreased resistance for Froude numbers greater than 0.3, increased stability and more deck area for flight operations. The decreased resistance of the trimaran hull form is important for ASC and the reduced resistance is an advantage for fuel savings. Trimarans could reduce heat signatures by ducting exhausts between the hulls. The radar cross-section of a trimaran is comparable or greater than a conventional monohull or similar displacement. Given that a trimaran has slender hulls, the large-object arrangeable volume is relatively small and limited. The cost of a trimaran would be greater than for a conventional monohull of similar displacement and U.S. shipyards have little to no experience in building trimarans. It is a compromise between monohull and catamaran.

- Surface Effect Ship (SES) - The SES, or Surface Effect Ship, is a rigid side hulled hovercraft. An SES vessel can achieve very high speeds while maintaining high transport efficiency. The SES relies on a cushion of air beneath the hull to lift a portion of the hull out of the water, thereby reducing the drag, which results in increased speed. There are, however, several major flaws in this concept. The air under the hull acts as an undampened spring, resulting in a poor ride when sea waves approach the natural frequency of the vessel. A ride control system is required. In addition, auxiliary motors and fans are required to create the aircushion to lift the vessel out of the water, which adds to the complexity, weight and cost of the ship. Very high speeds are possible on relatively modest propulsion power. Unlike a classic air cushion vehicle, excellent maneuverability is achieved. Reliability and performance in high sea states are major concerns.

Table 9 - Hull Form Advantages (+) / Disadvantages (-)

	Low RCS	Low Cost	Resistance at Sustained Speed	Good Large-Object Spaces	Good Seakeeping	Reliability
Conventional Monohull		++		++	-	
Catamaran	-	-	++	+	+	
Trimaran	-	-	++	+	++	
Surface Effect Ship (SES)	-	-	++		-	--

Table 9 summarizes the preliminary assessment of hull forms for ASC. The slender monohull was recently studied by the Center for Innovation in Ship Design (CISD), and the reliability of an SES is somewhat in question because of its dynamic lift system. The catamaran and trimaran were selected for trade-off in our project. The ASC ADM assigns the catamaran to Team 1 and the trimaran to Team 2.

Parametric equations for estimating hull form performance and structural weight are not available for the multihull designs. Analysis is required. To make this task manageable, it was decided to consider only geosims of parent catamaran and trimaran hull forms. A series of hull form variants were created to support Response Surface Modeling (RSM) for estimating structural weight and hull form performance of the geosims as a function of displacement.

A MAESTRO model of the Research Vessel (R/V) Triton, Figure 5, was used as a template for the parent trimaran hull form. A table of offsets was generated from the MAESTRO model and used to create the parent hull form model in FASTSHIP, Figure 6. Patches are created and modified to take the shape of separate sections of the hull form: the centerline hull, the inboard half of the outrigger, the outboard half of the outrigger, and the joiner connecting the outriggers to the centerline hull. The port side is reflected to match the starboard side. Net lines are added after the patches have been shaped to sharpen curvature and to form hard chines. Finally, a transom is added to the stern by creating a vertical patch, merging and trimming to fit.

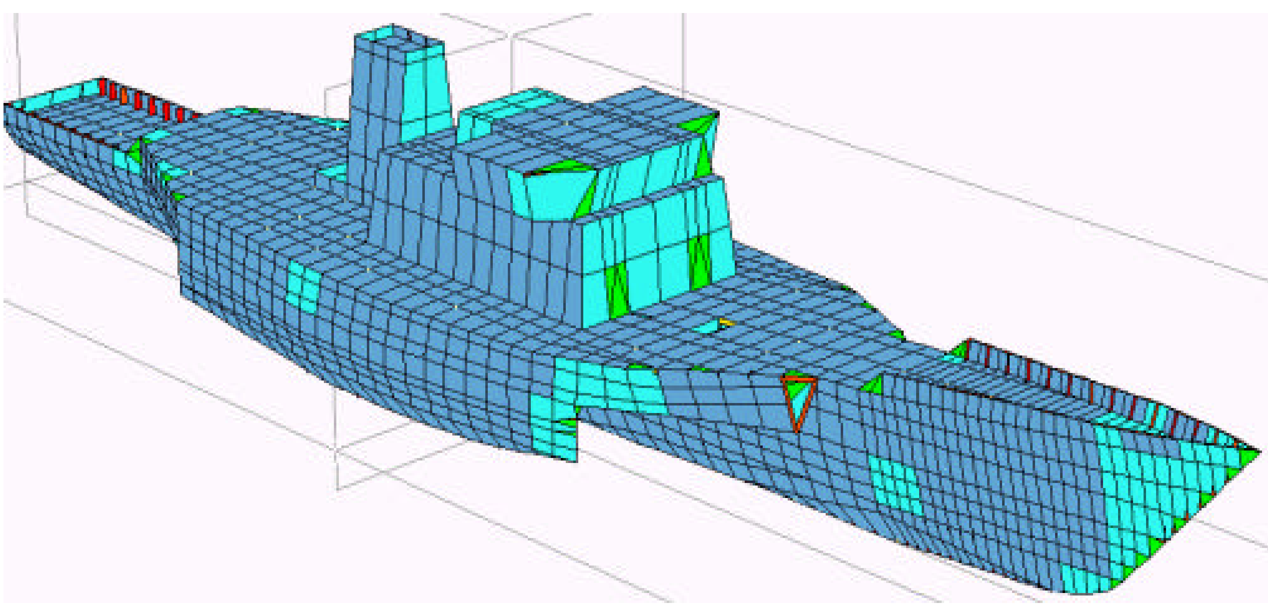

Figure 5 - MAESTRO Model of the R/V Triton

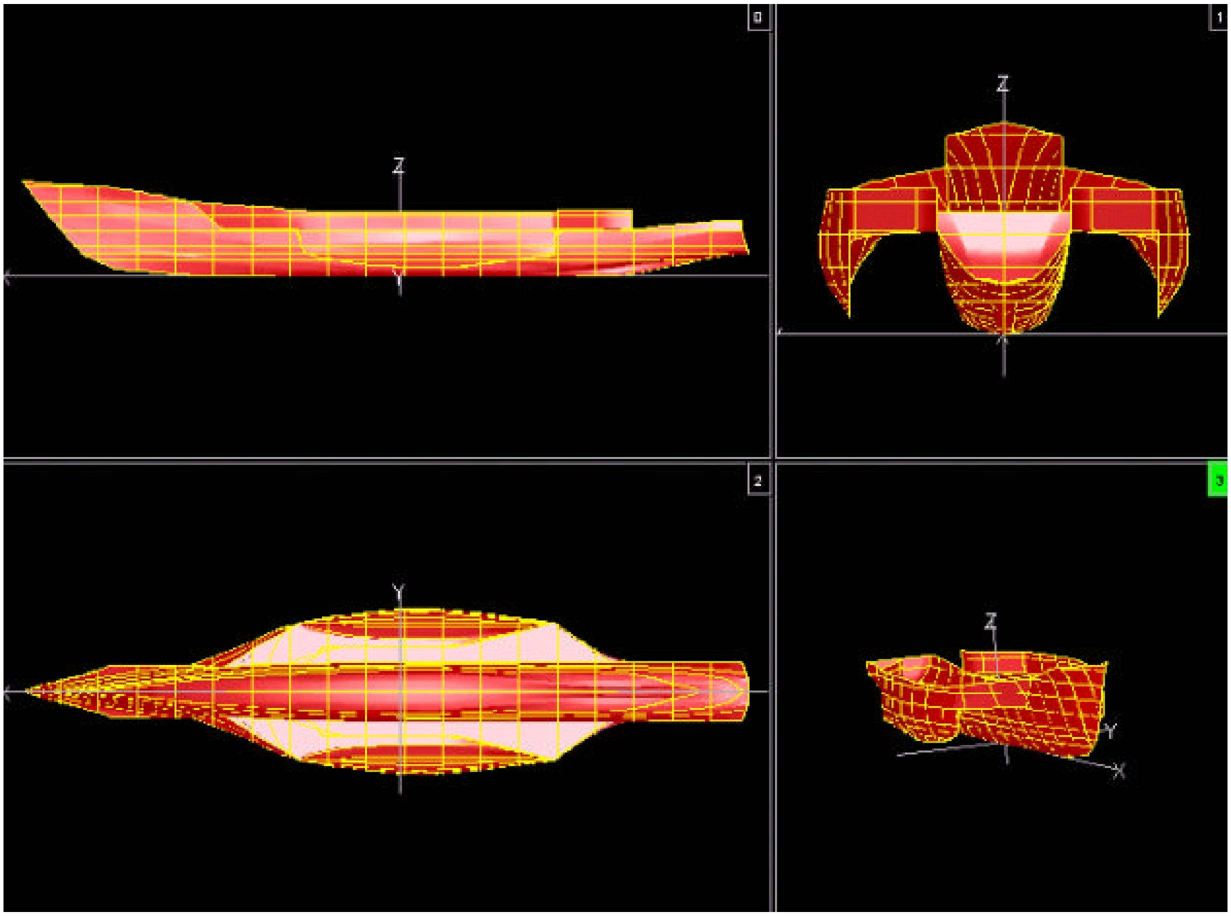

Figure 6 - Various views of FASTSHIP Parent Trimaran Hull form

Three geosims of the parent hull form were created in FASTSHIP for use in response surface modeling (RSM). Their characteristics are listed in Table 10. Variants were chosen to provide a LBP that could be evenly subdivided with transverse bulkheads and frames. A similar process was followed by Team 1 for the catamaran hull form parent and geosims, Figure 7.

Table 10 - Trimaran Parent Hull form and Geosim Data

Variant	Displacement (MT)	LBP	Frame Spacing (m)	Stiffener Spacing (mm)	Materials
Triton Baseline	907	90.13	1.0	300	Steel
TRI-1 Triton Geosim	2141	120	1.0,1.2, 1.5	250,500	Al 5486-H116, H112 Steel – DH36
TRI-2 Triton Geosim	2849	132	1.0,1.2, 1.5	250,500	Al 5486-H116, H112 Steel – DH36
TRI-3 Triton Geosim	3699	144	1.0,1.2, 1.5	250,500	Al 5486-H116, H112 Steel – DH36

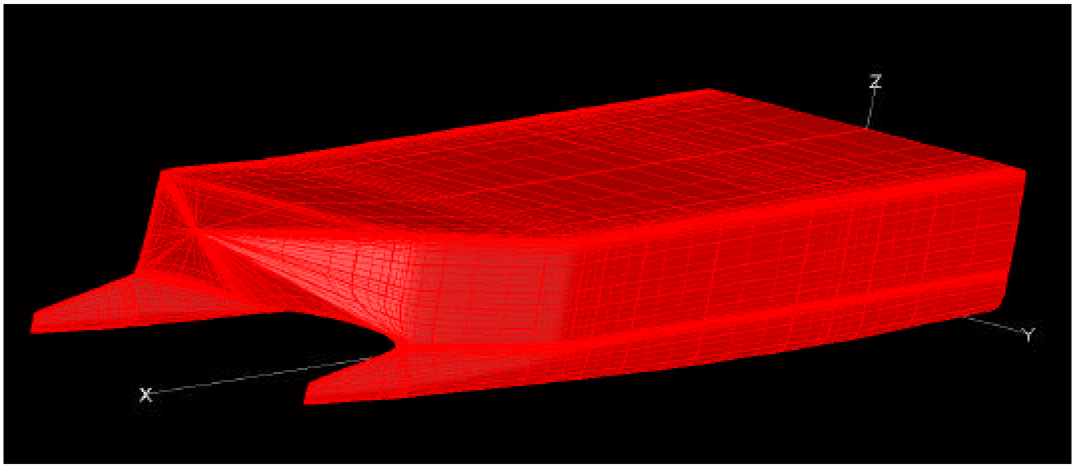

Figure 7 - FASTSHIP Parent Catamaran Hull form

3.2.2 Sustainability Alternatives

Sustainability characteristics for ASC include sprint range, endurance range, and provisions storage duration. ASC sprint range goal and threshold values are 1500 nm and 1000 nm. A threshold value of 4000 nm is a typical minimum for surface-combatant endurance range. ASC endurance range goal and threshold values are 4500 nm and 3500 nm, respectively. Provisions and stores duration goal and threshold values for ASC are 24 days and 14 days.

3.2.3 Propulsion and Electrical Machinery Alternatives

3.2.3.1 Machinery Requirements

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

General Requirements – The propulsion engines must be non-nuclear, grade A shock certified, and Navy qualified. The machinery system alternatives must span a total power range of 50000–100000 SHP with total ship service power greater than 4000 kW MFLM. The propulsion engines should have a low IR signature, and cruise/boost options should be considered for high endurance.

Sustained Speed and Propulsion Power – The ship shall be capable of a minimum sustained speed of 40 knots in the full load condition, calm water, and clean hull using no more than 80% of the installed engine rating (maximum continuous rating, MCR) of the main propulsion engine(s) or motor(s), as applicable for mechanical drive plants or electric propulsion plants.

Range and Endurance – The ship shall have sufficient burnable fuel in the full load condition for a minimum range of 3500 nautical miles at 20 knots. The total fuel rate for the propulsion engines and generator sets to be used in determining the endurance fuel requirements shall be calculated using methods described in DDS 200-1. Fuel efficient propulsion options such as ICR gas turbines shall be considered.

Ship Control and Machinery Plant Automation – An integrated bridge system shall be provided in the Navigating Bridge to incorporate integrated navigation, radio communications, interior communications, and ship maneuvering equipment and systems and shall comply with ABS Guide for One Man Bridge Operated (OMBO) Ships. Propulsion control shall be possible from the ship control console (SCC) on the Navigating Bridge and the main control console (MCC) at the Enclosed Operating Station (EOS). In addition to compliance with ABS ACCU requirements for periodically unattended machinery spaces, the machinery centralized control system shall be designed to continuously monitor auxiliary systems, electric plant and damage control systems from the SCC, MCC and Chief Engineer’s office, and control the systems from the MCC and local controllers.

Propulsion Engine and Ship Service Generator Certification – Because of the criticality of propulsion and ship service power to many aspects of the ship’s mission and survivability, this equipment shall be Navy-qualified and Grade-A shock certified.

Temperature and Humidity – Design environmental conditions shall be based on the requirement for extended vessel operations in the Persian Gulf. Propulsion engine ratings shall be based on the ship operating temperatures listed in Table 11.

Table 11 - Ship Operating Temperatures

Condition	Summer	Winter
Outside Dry Bulb	40 degrees C	-18 degrees C
Outside Wet Bulb	30 degrees C	
Seawater	35 degrees C	-2 degrees C

Fuel - The machinery plant shall be designed for continuous operation using distillate fuel in accordance with ASTM D975, Grade 2-D; ISO 8217, F-DMA, DFM (NATO Code F-76 and JP-5 (NATO Code F-44).

3.2.3.2 Machinery Plant Alternatives

Seven machinery plant alternatives are considered in the ASC propulsion trade-off study. These alternatives are shown in Figure 8. The high speed design requires high power density so only gas turbine engines and epicyclic (planetary) reduction gears are considered. Alternatives 1 and 2 are mechanical drive systems with epicyclic gears and Alternatives 3-7 are electric drive systems (IPS). The power requirement is satisfied with 2-4 main engines.

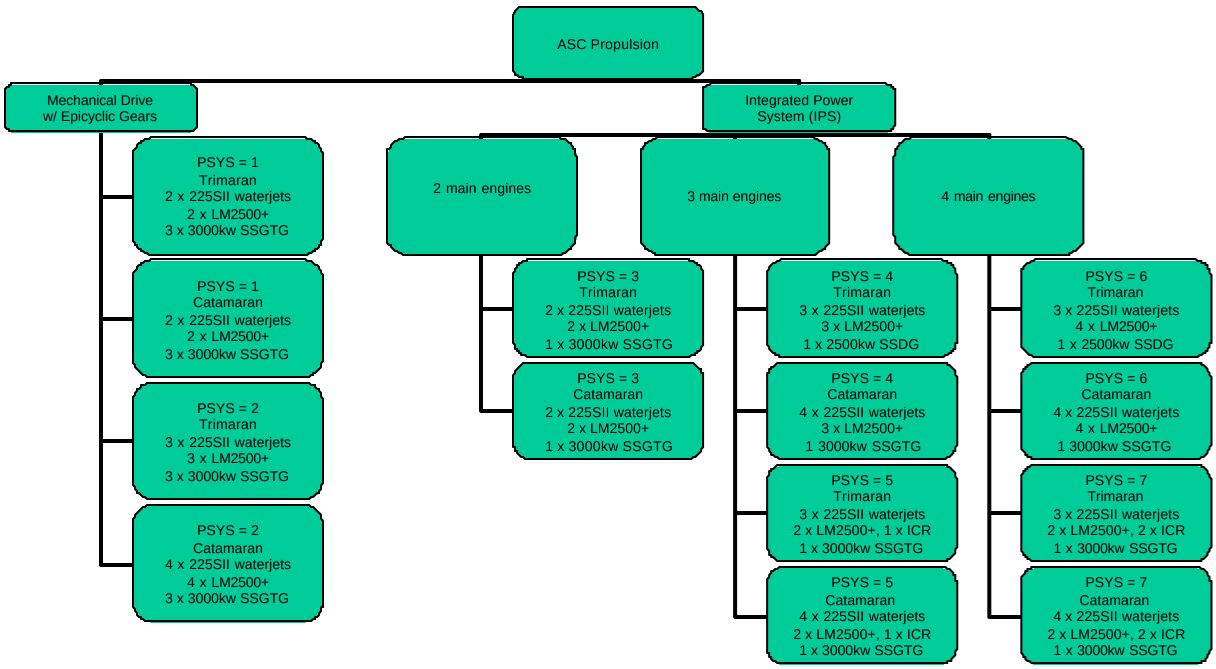

Figure 8 - ASC Machinery Alternatives

Mechanical Drive and IPS systems – Both mechanical drive and IPS systems are considered in the machinery trade-off. Important advantages of a mechanical system are that sub-systems and components are proven in previous Navy ships and cost less than in an IPS system. Mechanical drive systems also weigh less and occupy less volume. The main disadvantage of a mechanical drive system is that it requires a direct in-line connection to the propellers limiting arrangement and location options. Mechanical drive systems are often less efficient than IPS because engine rpm at a given power is governed by the propeller rpm and reduction gear ratio, while engines in an IPS system may be operated at optimum rpm for a given power output. Mechanical drive power can only be used for electrical power if some type of power-take-off system is installed. The main advantages of an IPS system are the ability to locate propulsion engines and generators almost anywhere in the ship, and to provide both propulsion and ship service electrical power. The survivability of the ship also increases with shorter shaft lengths. Another advantage of an IPS system is that it can be used with a traditional fixed pitch propeller or podded propulsion system. The acoustic signature of IPS ships is less because the engines are not connected mechanically to the shaft and fixed pitch propellers have inherently lower signatures and cavitation than CPP. The use of fixed pitch propellers and the ability to run the engines at their maximum efficiency makes IPS systems more efficient. They provide arrangement and operational flexibility, future power growth, improved fuel efficiency and survivability with moderate weight and volume penalties. IPS systems allow easier introduction of new technologies into existing ships. Today's IPS systems occupy a larger volume and weigh more than most mechanical drive systems.

Waterjet Propulsion – Maximum propulsion efficiency at 40-50 knots is best achieved with waterjet propulsion as shown in Figure 9. In this design we consider scaled variants of the Kamewa 225SII (27000 BKW) waterjet between 16 and 30 kW. The catamaran design can support either 1 or 2 waterjet systems in each hull. The trimaran design cannot support a waterjet in either of its side hulls because of size constraints, but can accommodate up to three waterjets in its center hull. The Kamewa waterjet system is shown in Figure 10 with performance curves in Figure 11 and Figure 12.

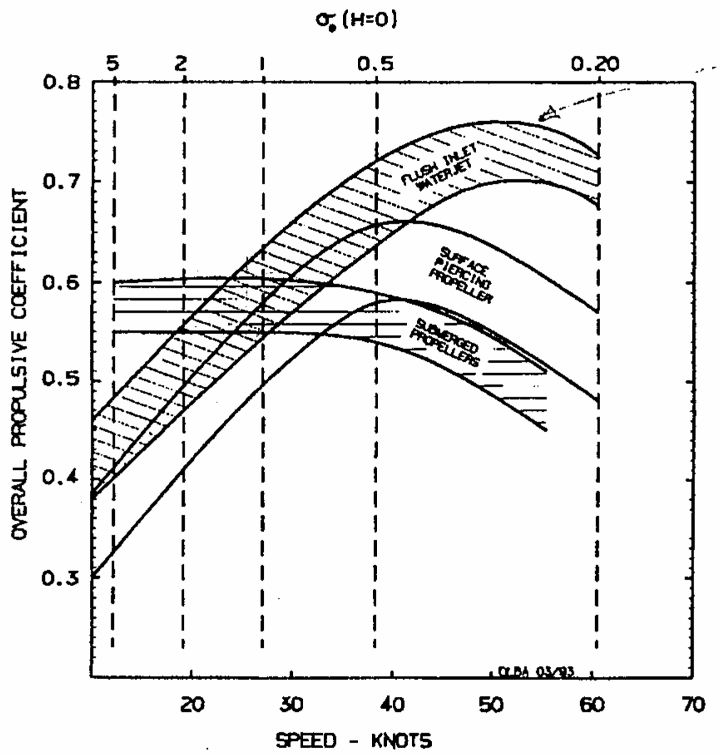

Figure 9 - Propulsion Alternatives Coefficients for Various Speeds [4]

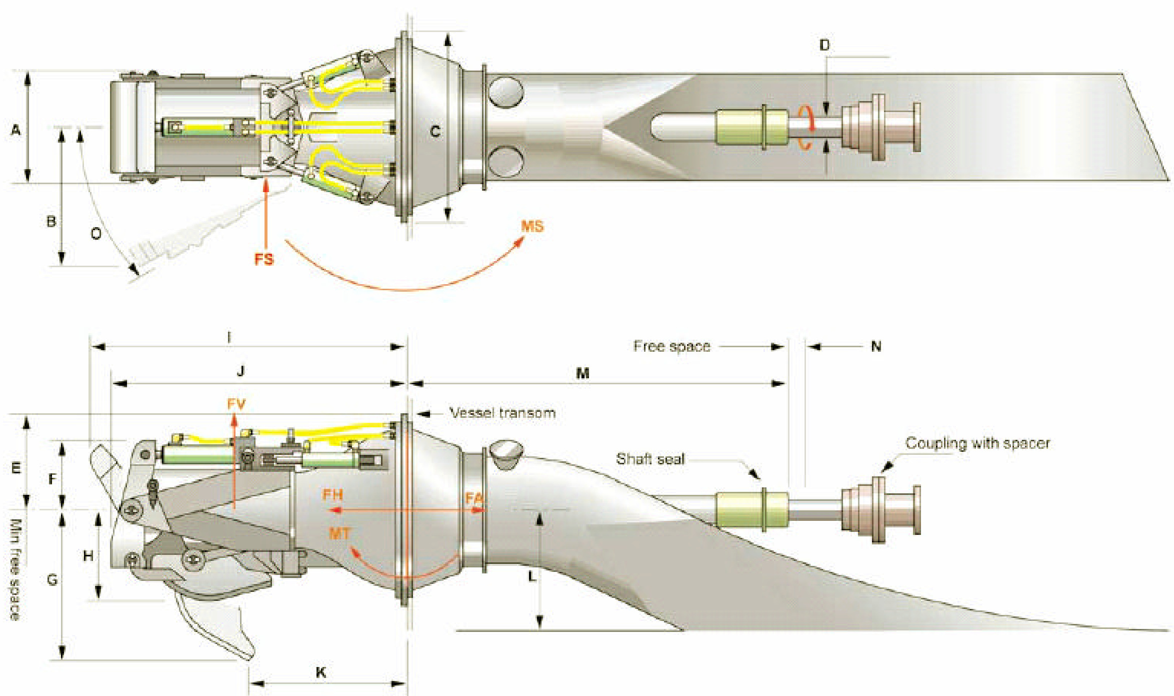

Figure 10 - Kamewa Waterjet Propulsion System [4]

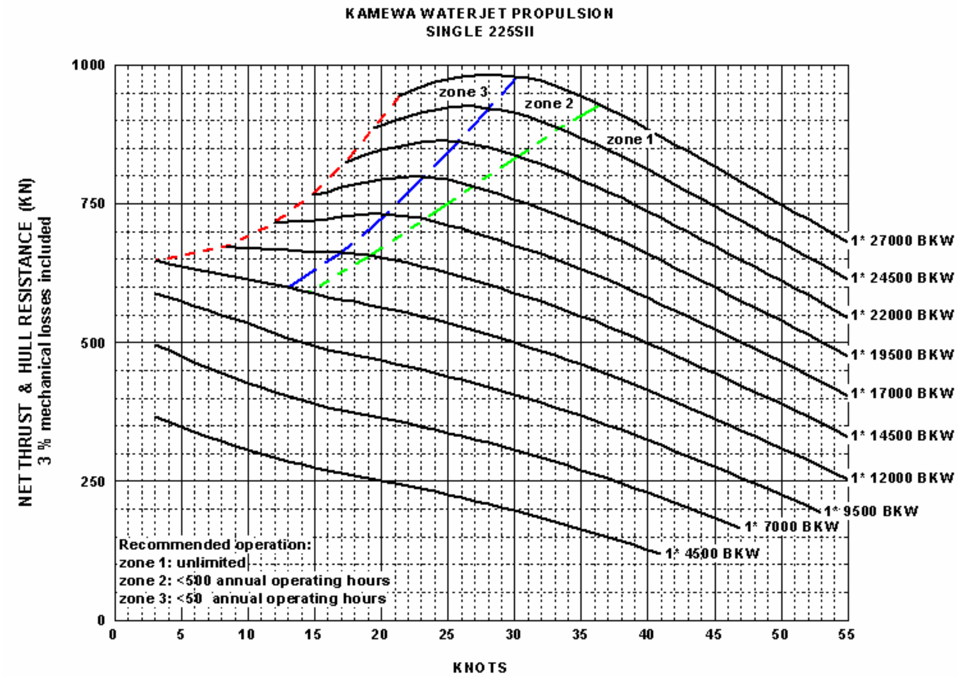

Figure 11 - Kamewa 225SII Waterjet Power and Thrust Curves [4]

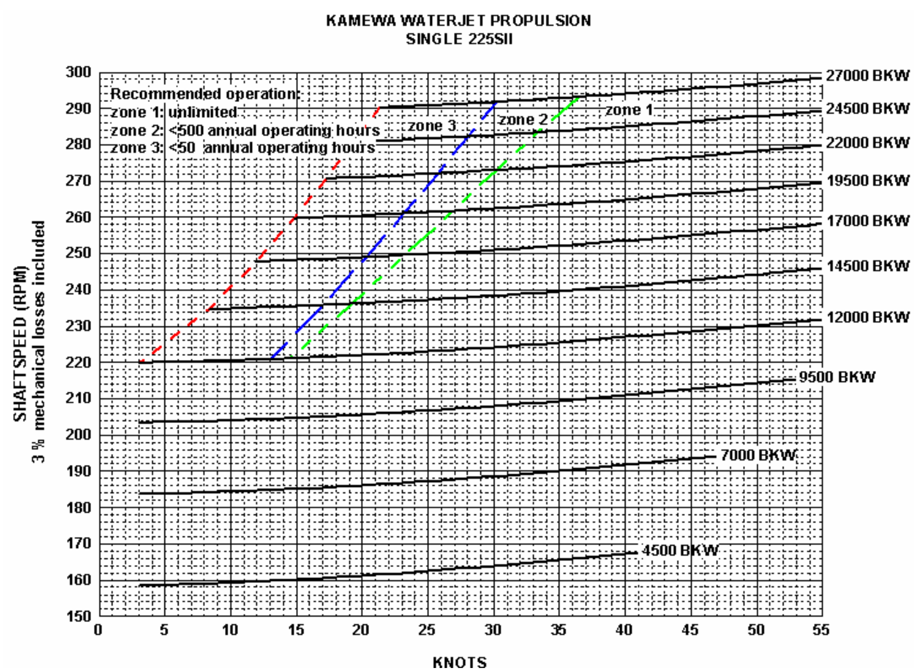

Figure 12 - Kamewa 225SII Waterjet Speed/Power Curves [4]

Propulsion Engine Alternatives – Two gas turbine engines were selected for trade-off in ASC, the LM-2500plus and WR-21 ICR. LM-2500 is the US Navy's standard gas turbine engine with good power range and high power density. The disadvantage of this engine is that it has high fuel consumption, particularly at part loads. The WR-21 ICR has much lower fuel consumption, lower IR signature and high power density. However, this engine is not yet Navy qualified. ICR will have a higher acquisition cost, weigh more than LM2500 and, at least initially, require more maintenance. Characteristics for these engines are provided in Table 12 and Table 13.

Alternatives are included for selection in the ship synthesis model with characteristics listed in Table 14. This data was collected by creating alternative propulsion plants in a single baseline ship using ASSET.

Table 12 - LM-2500 Specifications and Dimensions

Engine Reference Characteristics

Rating				Size		
Model	GE LM2500-30			Length	4.77	m
Power	19575	bkW		Width	1.58	m
Speed	3600	rpm		Height	1.58	m
Mass Flow	61.46	kg/s		Weight	3.20	mton
Exhaust Temp	559.44	deg C				
SFC	0.2390	kg/kW-hr		Scale Fac	0.9	

Table 13 - ICR Specifications and Dimensions

Engine Reference Characteristics

Rating				Size		
Model	WESTHS WR21 29			Length	4.70	m
Power	21655	bkW		Width	1.57	m
Speed	3600	rpm		Height	1.79	m
Mass Flow	65.23	kg/s		Weight	4.42	mton
Exhaust Temp	353.89	deg C				
SFC	0.1991	kg/kW-hr		Scale Fac	0.9	

Table 14 - Propulsion System Alternative Data

Propulsion Option (PSYS)	Description	Propulsion System Type $PSYS_{TYP}$	Number of Waterjets, N_{prop}	Waterjet kW	Number of Propulsion Engines N_{PENG}	Total Brake Propulsion Power $P_{BPENGTOT}$ (kW)	Number of SGs N_{SSG}	SSG Power (ea) KW_G(kW)	Endurance Propulsion SFC SFC_{ePE}(kg/kwhr)	Sustained Speed Propulsion SFC $SFCs_{PE}$(kg/kwhr)	Endurance SSG SFC SFC_{eG}(kg/kwhr)	Minimum Center Transom Width at WL wCTrans(m)	Minimum Side Transom Width at WL wSTrans(m)	Basic Electric Machinery Weight W_{BMG}(MT)
PSYS=1 Trimaran 1	2xLM2500+ 3x3000kw SSGTG	1	2 (2 dir)	25	2	52000	3	3000	0.288	0.236	0.29	5.5	0	150.1
1 Catamaran 2	2xLM2500+ 3x3000kw SSGTG	1	2	25	2	52000	3	3000	0.288	0.236	0.29	0	3	150.1
2 Trimaran 3	3xLM2500+ 3x3000kw SSGTG	1	3 (2 dir)	25	3	78000	3	3000	0.288	0.236	0.29	8	0	150.1
2 Catamaran 4	4xLM2500+ 3x3000kw SSGTG	1	4	25	4	104000	3	3000	0.288	0.236	0.29	0	5.5	150.1
3 Trimaran 5	2xLM2500+ 1x3000kw SSGTG	2	2 (2 dir)	23	2	52000	2	3000	0.257	0.235	0.257	8	0	107.2
3 Catamaran 6	2xLM2500+ 1x3000kw SSGTG	2	2	23	2	52000	2	3000	0.256	0.235	0.256	0	5.5	107.2
4 Trimaran 7	3xLM2500+ 1x3000kw SSGTG	2	3 (2 dir)	23	3	78000	2	3000	0.251	0.235	0.251	8	0	107.2
4 Catamaran 8	3xLM2500+ 1x3000kw SSGTG	2	4	18	3	78000	2	3000	0.255	0.235	0.255	0	5.5	107.2
5 Trimaran 9	2xLM2500+ 1xICR 1x3000kw SSGTG	2	3 (2 dir)	22	3	74000	2	3000	0.198	0.218	0.198	8	0	107.2
5 Catamaran 10	2xLM2500+ 1xICR 1x3000kw SSGTG	2	4	16	3	74000	2	3000	0.198	0.218	0.198	0	5.5	107.2
6 Trimaran 11	4xLM2500+ 1x3000kw SSGTG	2	3 (2 dir)	30	4	104000	2	3000	0.257	0.235	0.257	5.5	3	107.2
6 Catamaran 12	4xLM2500+ 1x3000kw SSGTG	2	4	23	4	104000	2	3000	0.257	0.235	0.257	0	5.5	107.2
7 Trimaran 13	2xLM2500+ 2xICR 1x3000kw SSGTG	2	3 (2 dir)	28	4	96000	2	3000	0.198	0.215	0.198	5.5	3	107.2
7 Catamaran 14	2xLM2500+ 2xICR 1x3000kw SSGTG	2	4	22	4	96000	2	3000	0.198	0.215	0.198	0	5.5	107.2

Ship Service Generator Option – Only a gas turbine generator set is considered because of weight. The gas turbine generator option is the DDA 501-K34. This is the newer version of the DDA 501-K17 with higher power output. This generator is Grade A shock qualified and US Navy certified. It has a high power density. Characteristics for the generator engine are listed in Table 15.

Table 15. DDA 501-K34 Gas Turbine Specifications and Dimensions

Rating				Size		
Model	DDA 501-K34			Length	2.29	m
Power	3430	bkW		Width	0.85	m
Speed	14300	rpm		Height	0.79	m
Mass Flow	16.37	kg/s		Weight	0.58	mton
Exhaust Temp	551.67	deg C				
SFC	0.2875	kg/kW-hr		Scale Fac	0.9	

3.2.4 Automation and Manning Parameters

To minimize ASC acquisition cost, life cycle cost and personnel vulnerability during combat, it is very important to reduce manning. A number of automation technologies for aircraft and surface vehicle launch and recovery, handling, maintenance, and weapons handling are considered for ASC. Some of the enabling technologies considered are computer/CD-ROM software, GUI's, large flat panel displays, expert systems, reliable sensors, fiber optics, corrosion and wear-resistant coatings, video teleconferencing, and personal access display devices (PADDs). Some watch standing technologies considered for ASC include GPS, automated route planning, electronic charting and navigation (ECDIS), collision avoidance, and electronic log keeping. Some condition-based maintenance possibilities for ASC include and Integrated Condition Assessment System (ICAS), trend-analysis, expert assistance, and links to Interactive Electronic Tech Manuals (IETMs)/Gold Discs for automated troubleshooting. ASC may include an automated mess, personnel locators/active badges, standard consoles/integrated networks, an Integrated Survivability Management System (ISMS), and training through multimedia. By maintaining most administration and personnel work ashore, ASC will be a paperless ship. Manning will also be reduced through improved preservation methods and materials. Unicoat provides a 300% improvement in life-expectancy, self-priming, 50% reduction in paint time, and 50% reduction in VOC's. Future technologies not yet available which could be used on ASC include a bridge in the CIC providing large screen displays, 360 degree coverage, and multiple magnification and spectra. Also possible are unmanned machinery spaces that require only a virtual presence and employ IR imaging sensors (through smoke) and robot arms for fire suppression, rigging, and damage control.

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

The simple regression-based manning equations are based on the following independent variables:

- W_P : total payload weight
- N_{SSG} : number of ship service generators
- N_{PENG} : number of propulsion engines
- V_{FL} : full load hull displacement volume
- V_D : deckhouse volume
- V_{HT} : total hull volume

The simple regression-based equations calculate the following:

- N_O : number of ship officers
- N_E : number of ship enlisted men
- N_T : total number of ship crew
- N_A : additional accommodations

Manning, where N_O and N_E stand for number of officers and enlisted, respectively:

$$N_O := 3 + \mathrm{ceil}\left[\frac{N_{PENG}}{2} + \frac{W_P}{450\cdot \mathrm{lton}} + \frac{V_{FL} + V_D}{85000\cdot \mathrm{ft}^3} + (4 - \mathrm{MCM}) + (3 - \mathrm{LAMPS}) + \mathrm{VTUAV} + (4 - \mathrm{SPARTAN})\right]$$

$$N_E := \mathrm{ceil}\left[C_{AUTO}\cdot\left(N_{PENG}\cdot 5 + N_{SSG}\cdot 3 + \frac{W_P}{6.4\cdot \mathrm{lton}} + \frac{V_{HT} + V_D}{20000\cdot \mathrm{ft}^3}\right)\right] + 4\cdot(5 - \mathrm{MCM}) + 3\cdot(4 - \mathrm{LAMPS}) \ldots + 3\cdot \mathrm{VTUAV} + 3\cdot(4 - \mathrm{SPARTAN})$$

$N_O = 13$ $N_E = 74$ $C_{AUTO} = 0.5$

N_T defines the total crew size, N_A the additional accommodations: $N_T := N_E + N_O$ $N_A := \mathrm{ceil}(.1\cdot N_T)$

$N_T = 87$ $N_A = 9$

Figure 13 - ASC-HI2 "Standard" Manning Calculation

3.2.5 Combat System Alternatives

3.2.5.1 MCM

Mine Countermeasures (MCM) includes any activity to prevent or reduce the danger from enemy mines. Passive countermeasures operate by reducing a ship's acoustic and magnetic signatures, while active countermeasures include mine avoidance, mine-hunting, minesweeping, detection and classification, and mine neutralization. ASC MCM system alternatives are listed in Table 16 and are as follows:

- Mine Avoidance Sonar (Figure 14) – determines the type and presence of mines. MAS is an active MCM that detects mines and allows ASC to avoid dangerous areas. The Multi-Purpose Sonar System VANGUARD is a versatile two frequency active and passive broadband passive sonar system conceived for use on surface vessels to assist navigation and permit detection of dangerous objects. The system is designed primarily to detect mines but will also be used to detect other moving or stationary underwater objects. It can be used as navigation sonar, i.e. as a navigational aid in narrow or dangerous waters. In addition it can complement the sensors onboard anchoring surface vessels with regard to surveillance and protection against divers.

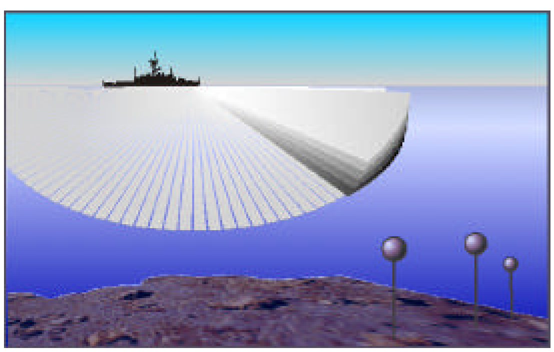

Figure 14 – Mine Avoidance Sonar

- Remote Mine-hunting System (RMS) - The AN/WLD-1 RMS (Figure 15) is an off-board system that will be launched, operated, and recovered from a host surface ship and will employ mine reconnaissance sensors. The RMS is intended to provide battle groups and individual surface combatants with an organic means of detecting and avoiding mines. The remotely operated system, using computer aided detection and precise navigation systems, will detect and classify mines and record their locations for avoidance or subsequent removal. The system, with organic handling, control and logistic support, is designed to be air transportable to forces anywhere in the world. The RMS will provide a rapidly deployable mine countermeasures system to surface combatant forces in the absence of deployable mine countermeasures forces.

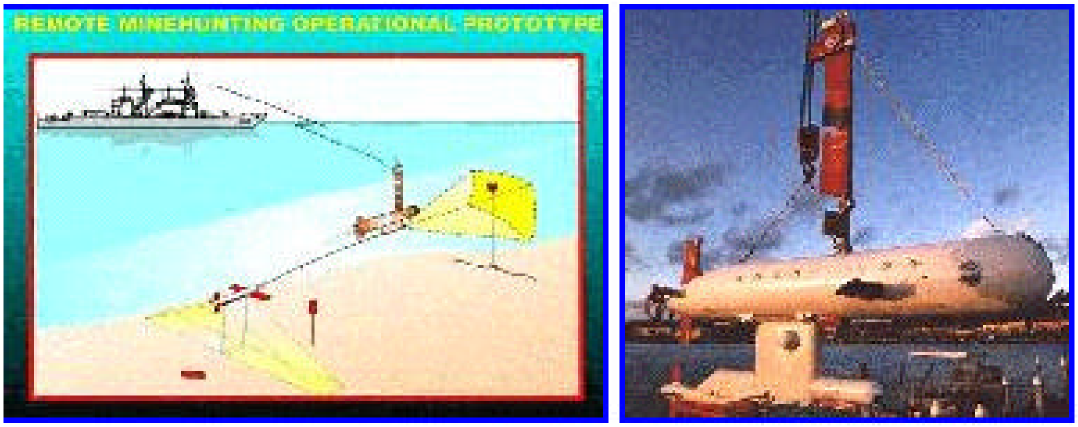

Figure 15 – Remote Mine-hunting System (RMS)

- Underwater Unmanned Vehicles (UUVs) - During Operation Iraqi Freedom, the Remus UUV (Figure 16) was able to operate 24 hours a day and verify that the port was mine free.

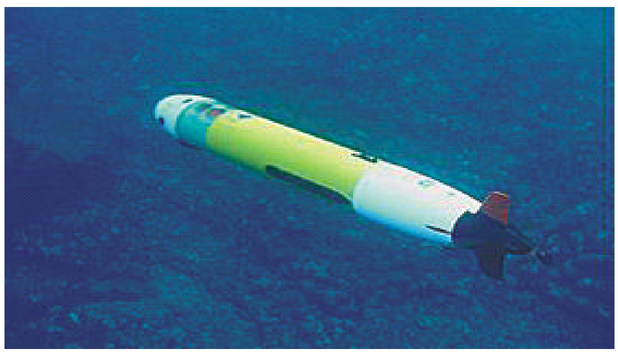

Figure 16 – REMUS UUV

- ALMDS, AQS-14 and AQS-20 (Figure 17 and Figure 18)- The Airborne Laser Mine Detection System (ALMDS) is an airborne laser system used to detect, localize, and classify near-surface moored and floating mines. The AN/AQS-14A Side-Looking Sonar, or "Q-14 Alpha" as it is commonly called, is an underwater towed body containing a high resolution, side-looking, multi-beam sonar system used for mine-hunting along the ocean bottom. Developed by Northrop Grumman Oceanic Products, this rapidly-deployable system provides real-time sonar images to operators in the aircraft to locate, classify, mark and record mine-like objects and underwater terrain features. The AQS-14A has an active, stabilized underwater vehicle, equipped with advanced multiple-beam side-looking sonar. The MH-53E Sea Dragon helicopter tows the underwater body by a small-diameter electromechanical cable. On board the helicopter, an operator can view the underwater image and identify objects on a video monitor while recording the data on Exabyte AME digital tapes for post mission analysis. Operators actually fly the device underwater, actively controlling the depth or altitude of the device in the water column. Once located, the exact coordinates of mine-like objects can be used by Explosive Ordinance Disposal (EOD) personnel to reacquire and neutralize the mine. The AN/AQS-14A system includes a digital recorder-reproducer, high-resolution 19-inch color video monitor, and a navigation and acoustic control processor. The AN/AQS-20 mine hunting sonar systems will be employed for deeper mine threats. The "Q-20", as it is commonly called, is an underwater towed body containing a high resolution, side-looking, multi-beam sonar system used for mine-hunting along the ocean bottom. This rapidly-deployable system provides real-time sonar images to operators in the aircraft to locate, classify, mark and record mine-like objects and underwater terrain features. The AQS-20 has an active, stabilized underwater vehicle, equipped with advanced multiple-beam side-looking sonar. The MH-53E Sea Dragon helicopter tows the underwater body by a small-diameter electromechanical cable. On board the helicopter, an operator can view the underwater image and identify objects on a video monitor while recording the data on S-VHS digital tapes for post mission analysis. Operators actually fly the device underwater, actively controlling the depth or altitude of the device in the water column. Once located, the exact coordinates of mine-like objects can be used by Explosive Ordinance Disposal (EOD) personnel to reacquire and neutralize the mine.

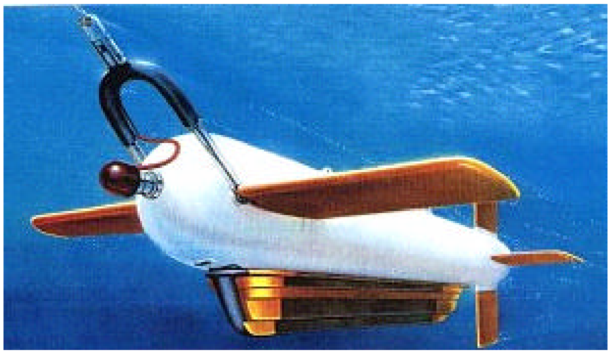

Figure 17 – AN/AQS-14A Minehunting System

Figure 18 – AN/AQS-20 Minehunting System

- AMDS and RAMICS - The Rapid Airborne Mine Clearance System (RAMICS) is a targeting, fire control, and gun system which fires a supercavitating projectile as a countermeasure against near surface moored mines. The LIDAR and gun system are mounted on the helicopter. The LIDAR directs the gun fire to the target mine. Mine deflagration utilizes reactive material and kinetic energy of the super cavitating projectile.
- OASIS (Figure 19) - The Organic Airborne and Surface Influence Sweep (OASIS) is a self-contained, high speed, shallow water magnetic and acoustic influence sweeping device under development by EDO Corporation. The OASIS towed body is 10 feet long by 20 inches in diameter. It is deployed from the helicopter and provides rapid mine clearance. The OASIS allows for the emulation of the magnetic and acoustic signatures of the platforms in transit through an assault area as well as the conduct of generic minesweeping operations. Designed to operate in shallow waters at speeds up to 40 knots, it can be towed as a single unit or in tandem.

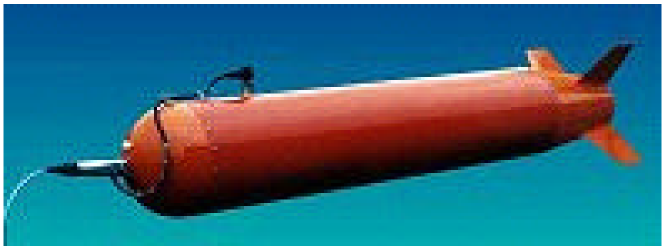

Figure 19 - Organic Airborne and Surface Influence Sweep (OASIS)

- Degaussing - Degaussing is a passive MCM that reduces ASC magnetic signature. Degaussing works by passing a current through a mesh of wires to generate a magnetic field that cancels the ship's magnetic field as shown in Figure 20.

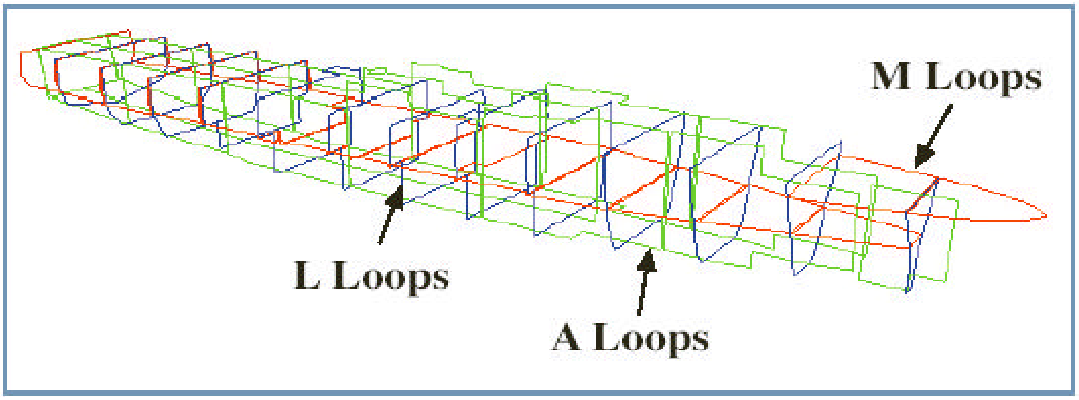

Figure 20 – Degaussing System

Table 16 - MCM System Alternatives

ID	MCM System Alternatives	1 (Goal)	2	3	4 (Threshold)
66	NDS 3070 Vanguard - Mine Avoidance Sonar	1	1	1	1
67-73	Remote Minehunting System (RMS)	3	2	2	1
74-77	Small UUV Detachment	1	1	1	1
78	SH-60 MIW Module	1			
79-81	EOD Support Modules	(or) 1	(or) 1	(or) 1	(or) 1
82	SH-60 ALMDS & AQS-20 Module	1	1	1	1
83	SH-60 AMDS & RAMICS Module	1	1	1	1
84	SINGLE SH-60 OASIS Module	(or)1	(or)1	(or)1	(or)1
85	SINGLE SH-60 PUK Module	1	1	1	1
NA	Degaussing System	NA	NA	NA	NA

3.2.5.2 ASUW

ASC ASUW system alternatives are listed in Table 17 and are as follows:

- AN/SPS-73(V) Radar (Figure 21) - AN/SPS-73(V) is a short-range, two-dimensional, surface-search/navigation radar system. It provides contact range and bearing information. It also enables quick and accurate determination of own ship position relative to nearby vessels and navigational hazards, making it valuable for navigation and defense.

Table 17 - ASUW System Alternatives

ID	ASuW System Alternatives	1(Goal)	2	3	4 (Threshold)
23	AN/SPS-73 Surface Search Radar	1	1	1	1
24	Thermal Imaging Sensor System (TISS)				1
25	Sea Star SAFIRE II FLIR			1	
26	IR Search and Track System (IRST)	1	1		
27-30	30mm CIGS Gun		2		1
31-34	57mm MK3 Naval Gun	2		1	
35,36,37	7m RHIB	1	1	1	1

Figure 21 – AN/SPS-73(V) Radar

- Thermal Imaging Sensor System (TISS) - The Thermal Imaging Sensor System (TISS) AN/SAY-1 (Figure 22) is a stabilized imaging system which provides a visual infrared (IR) and television image to assist operators in identifying a target by its contrast or infrared characteristics. The AN/SAY-1 detects, recognizes, laser ranges, and automatically tracks targets under day, night, or reduced visibility conditions, complementing and augmenting existing shipboard sensors. The AN/SAY-1 is a manually operated system which can receive designations from the command system and designate to the command system providing azimuth, elevation, and range for low cross section air targets, floating mines, fast attack boats, navigation operations, and search and rescue missions. The sensor suite consists of a high-resolution Thermal Imaging Sensor (TIS), two Charged Coupled Devices (CCDs), daylight imaging Television Sensors (TVS), and an Eye-Safe Laser Range Finder (ESLRF). The AN/SAY-1 also incorporates an Automatic Video Tracker (AVT) that is capable of tracking up to two targets within the TISS field of view.

Figure 22 – Thermal Imaging Sensor System (TISS)

- Sea Star SAFIRE II FLIR (Figure 23)

Figure 23 – Forward Looking Infrared (FLIR)

- IR Search and Track System (IRST)
- 30mm CIGS Gun (Figure 24) - The Mk-46 30mm gun system is a two-axis stabilized chain gun that can fire up to 250 rds/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 combat center.

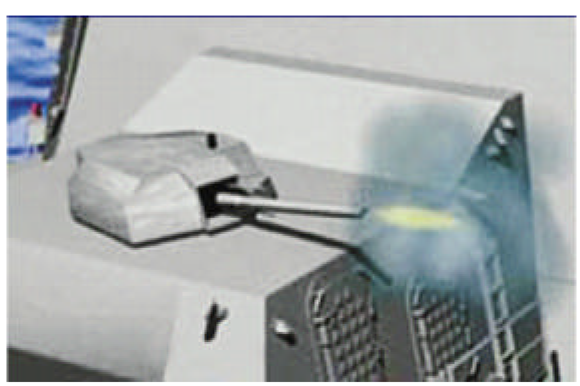

Figure 24 – MK-46 30mm Close In Gun System (CIGS)

- 57mm MK3 Naval Gun (Figure 25) - The Mk-3 Naval 57 mm gun is capable of firing 2.4 kilogram shells at a rate of 220 rounds per minute at a range of more than 17 kilometers.

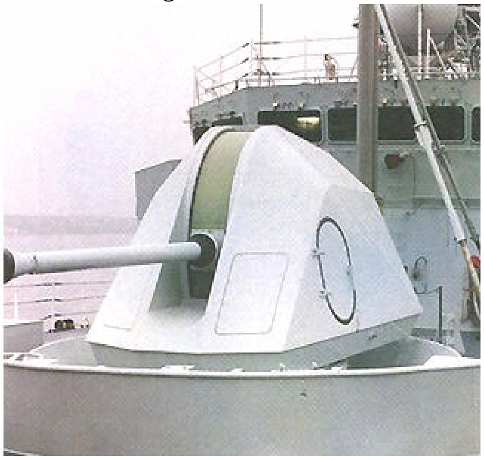

Figure 25 – MK3 Naval 57mm Gun

- 7m Rigid Hull Inflatable Boat (RHIB) – (Figure 26)

Figure 26 – 7m Rigid Hull Inflatable Boat (RHIB)

- The Penguin Missile (Figure 27) is a LAMPS launched anti-ship missile. It can operate in "Fire and Forget" mode to allow multiple target acquisition.

Figure 27 – Penguin Missile

3.2.5.3 ASW

ASC ASW systems include LAMPS MK3 SH-60 Seahawk Helo (Section 3.2.5.7), SSTD (Surface Ship Torpedo Defense), and AN/SLQ-25 NIXIE as listed in Table 18. Specific sub-system descriptions are as follows:

- Surface Ship Torpedo Defense (SSTD) includes countermeasures and acoustic sensors to detect, track, and divert incoming torpedoes. It provides torpedo defense against all threatening torpedoes. SSTD consists of detection, control, and counter-weapon subsystems. A layered-attrition approach utilizes outer (hard kill) and inner (soft kill) subsystems for defense.

- NIXIE is a passive, electro-acoustic decoy system used to provide deceptive countermeasures against acoustic homing torpedoes. The AN/SLQ-25A employs an underwater acoustic projector housed in a streamlined body which is towed astern on a combination tow/signal-transfer coaxial cable. An onboard generated signal is used by the towed body to produce an acoustic signal to decoy the hostile torpedo away from the ship. The AN/SLQ-25A includes improved deceptive countermeasures capabilities. The AN/SLQ-25B includes improved deceptive countermeasures capabilities, a fiber optic display LAN, a torpedo alert capability and a towed array sensor.

Table 18 - ASW System Alternatives

ID	ASW System Alternatives	1(Goal)	2(Threshold)
	LAMPS MK3 SH-60 Seahawk Helo	3	1
42	SSTD (Surface Ship Torpedo Defense)	1	0
42	AN/SLQ-25 NIXIE	1	1

3.2.5.4 AAW

ASC AAW trade-off alternatives include goal and threshold systems listed in Table 19. The alternatives include: Sea GIRAFFE AMB Radar, SEAPAR Radar, MK XII AIMS IFF, MK 16 CIWS, RAM 8 Cell, RAM 21 Cell, Combined MK 53 SRBOC & NULKA LCHR, Advanced SEW System (AIEWS), and AN/SLQ-32(V)3. All sensors and weapons in each suite are integrated using the Ship Self Defense System (SSDS). This system is intended for installation on all non-Aegis ships. The SSDS improves effectiveness by coordinating hard kill and soft kill and employing them to their optimum tactical advantage. However, SSDS does not improve the performance of any sensor or weapon beyond its stand-alone capability. The SSDS is a versatile system that can be used as a tactical decision aid or an automatic weapon system. SSDS uses mostly Commercial Off-the-Shelf (COTS) products, including a fiber optic Local Area Network (LAN). SSDS employs single or multiple Local Access Unit (LAU) cabinets with an Uninterruptible Power Supply (UPS) and VME card cage. Processor cards are identical and interchangeable, so spares can be stocked.

Table 19 - AAW and SEW System Alternatives

ID	AAW System Alternatives	1(Goal)	2	3(Threshold)
1	SEA GIRAFFE AMB RADAR			1
2	SEAPAR RADAR - MFR MOUNTED IN DOGHOUSE	1	1	
3	MK XII AIMS IFF	1	1	1
4-8	MK 16 CIWS	1	1	1
9-12	RAM 8 Cell		1	
13-16	RAM 21 Cell	1		
17-22	Combined MK 53 SRBOC & NULKA LCHR	6	6	2
92	Advanced SEW System (AIEWS)	1	1	1
93	AN/SLQ-32(V)3	1	1	1

Specific sub-system descriptions are as follows:

- The Sea GIRAFFE AMB is a state-of-the-art naval multi-function radar using Ericsson's outstanding true 3D Agile Multi-Beam technology. The system functions simultaneously for air surveillance and tracking, surface surveillance and tracking, target indication to weapon systems, and high-resolution splash spotting.
- AN/SLQ-32 Electronic Warfare (EW) System provides warning, identification, and direction-finding of incoming anti-ship cruise missiles (ASCM). It provides early warning, identification, and direction-finding against targeting radars. It also provides jamming capability against targeting radars.
- CIFF (Centralized Id. Friend or Foe) is a centralized, controller processor-based system that associates different sources of target information. It accepts, processes, correlates and combines IFF sensor inputs into one IFF track picture. It controls the interrogations of each IFF system and ultimately identifies all targets as a friend or foe.
- Phalanx Close-In Weapons System (CIWS, Figure 28) provides defense against low altitude ASCMs. It is a hydraulically driven 20 mm gatling gun capable of firing 4500 rounds per minute. CIWS magazine capacity is 1550 rounds of tungsten ammunition. CIWS is computer controlled to automatically correct aim errors. Phalanx Surface Mode (PSUM) incorporates its side mounted Forward Looking Infrared Radar (FLIR) to engage low, slow or hovering aircraft and surface craft.

Figure 28 – MK 16 Close in Weapons System (CIWS)

- Rolling Airframe Missile (RAM, Figure 29) is the threshold missile system. It is cued from SSDS. RAM is a self contained package. It can use Active Optical Target Detector (AOTD) for improved effectiveness in presence of aerosols. RAM also features Infrared Modular Update (IRMU) to provide capability against non-RF radiating threats. It is comprised of the GMLS (launching system) and GMRP (round pack). RAM is effective and lethal against most current ASCMs. Its capability against LAMPS, aircraft, and surface targets is being developed.

Figure 29 – Rolling Airframe Missile (RAM)

- The Decoy Launching System (DLS) Mk 53 (NULKA) is a rapid response Active Expendable Decoy (AED) System capable of providing highly effective defense for ships of cruiser size and below against modern radar homing anti-ship missiles. It is combined with the Super Rapid Bloom Offboard Countermeasures (SRBOC) Chaff and Decoy Launching System that provides decoys launched at a variety of altitudes to confuse a variety of missiles by creating false signals.

Figure 30 – MK53 SRBOC and NULKA

3.2.5.5 SEW

Electronic Warfare system alternatives include AN/SLQ-32 and the AEIWS Advanced SEW System. Descriptions of the specific sub-systems are as follows:

- AN/SLQ-32 is a sensor system that provides early detection and identification of threats. It serves as the electronic eyes of the SSDS. It also provides radar jamming.
- The AN/SLY-2 (V) Advanced Integrated Electronic Warfare System (AIEWS) is the Navy's next-generation shipboard Electronic Warfare (EW) system designed to meet the projected threat in the 2005 to 2010 time frame. The primary functions of AIEWS are detection, correlation, and identification of threat emitters as well as automatic employment of coordinated on-board countermeasures.

3.2.5.6 C4ISR

The Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) system includes the alternatives listed in Table 20. Specific sub-system descriptions are as follows:

- The Cooperative Engagement Capability (CEC, Figure 31) is a system of hardware and software that allows the sharing of radar data on air targets among ships. Radar data from individual ships of a Battle Group is transmitted to other ships in the group via a line-of-sight, data distribution system (DDS). Each ship uses identical data processing algorithms resident in its cooperative engagement processor (CEP), resulting in each ship having essentially the same display of track information on aircraft and missiles. An individual ship can launch an anti-air missile at a threat aircraft or anti-ship cruise missile within its engagement envelope, based on track data relayed to it by another ship. Program plans include the addition of E-2C aircraft equipped with CEP and DDS, to bring airborne radar coverage plus extended relay capability to CEC. CEP-equipped units, connected via the DDS network, are known as Cooperating Units (CUs).

Table 20 – C4ISR System Alternatives

ID	AAW System Alternatives	1(Goal)	3(Threshold)
61,62	ADCON 21	1	1
65	CEC	1	1
63	COMM Suite Level A		1
64	COMM Suite Level B	1	

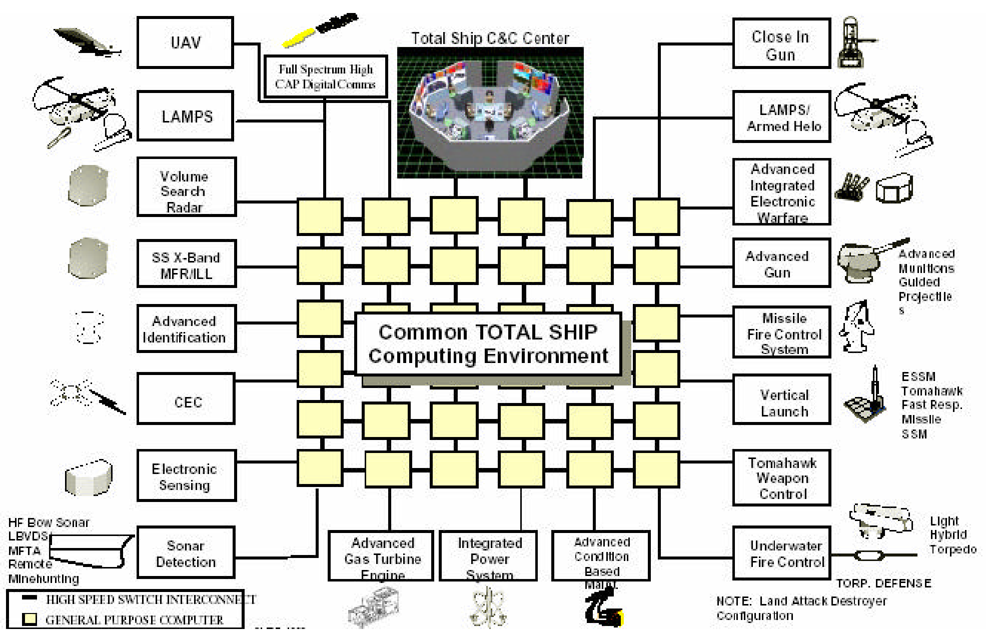

Figure 31 – Cooperative Engagement Capability (CEC)

- Advanced Connectivity (ADCON-21, Figure 32) is the Navy's newest concept for future distribution for all C4ISR connectivity. It will be designed to have an open architecture, a common computing engineering base, ship-wide integrated information transfer, and system-wide resource management.

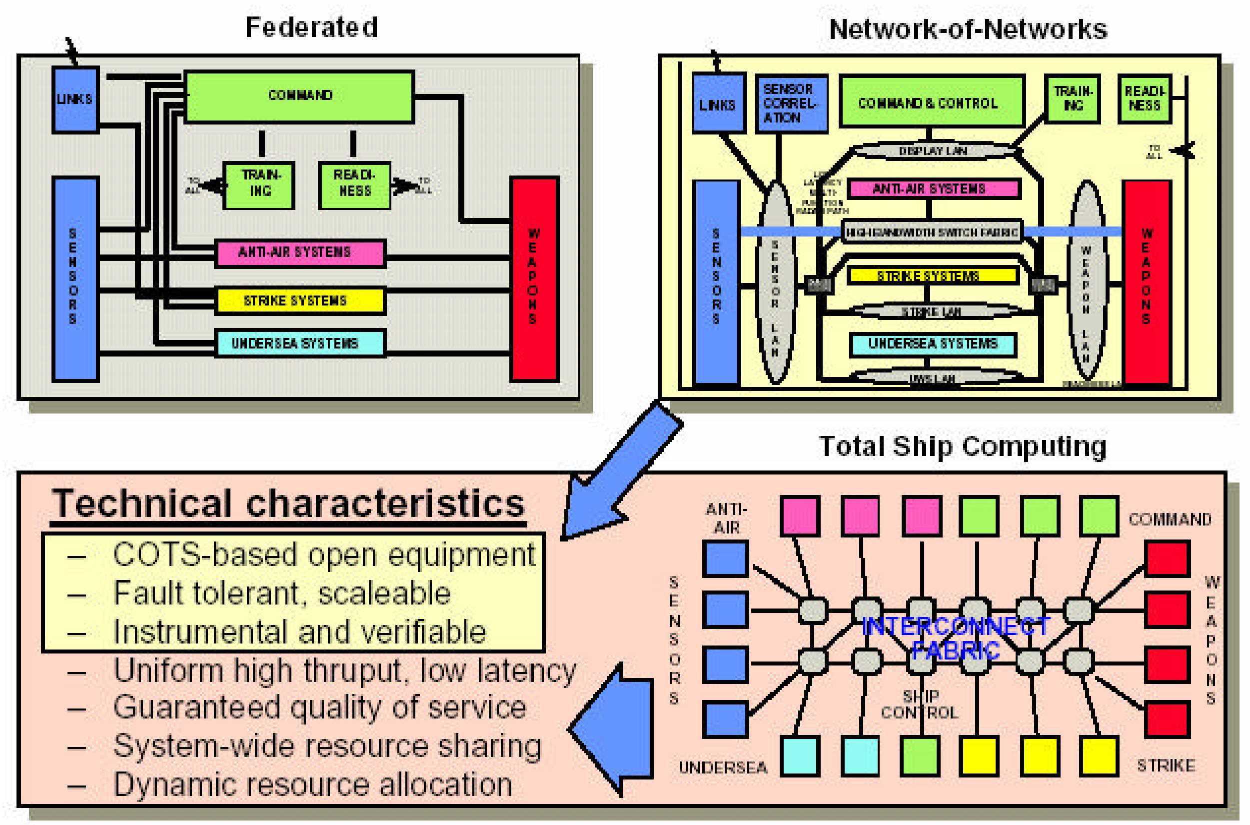

Figure 32 – Advanced Connectivity

3.2.5.7 LAMPS

LAMPS (SH-60) alternatives are listed in Table 21. SH-60 Seahawk (Figure 33) can perform ASW, ASUW, search and rescue, SPECOPS, and cargo lift. It also deploys sonobuoys and torpedoes and extends ship's radar capabilities. It has a retractable in-flight fueling probe for prolonged loitering time. Self defense is provided by two 7.62mm machine guns. It is capable of carrying and launching AGM-114 Hellfire missiles, AGM-119 Penguin missiles, and Mk46 or Mk50 torpedoes.

Table 21 – LAMPS System Alternatives

ID	LAMPS System Alternatives	1 (Goal)	2	3 (Threshold)
47	SINGLE SH-60 MODULAR DET - 1 HELOS AND HANGAR		1	
48	SINGLE SH-60 MODULAR DET - MISSION FUEL		0	
49	SINGLE SH-60 MODULAR DET - SUPPORT MOD 1		1	
50	SINGLE SH-60 MODULAR DET - SUPPORT MOD 2		1	
51	SINGLE SH-60 MODULAR DET - SUPPORT MOD 3		(or) 1	
52	SINGLE SH-60 MODULAR DET - SUPPORT MOD 4		(or) 1	
53	DUAL SH-60 MODULAR DET - 2 HELOS AND HANGAR	1		
54	DUAL SH-60 MODULAR DET - MISSION FUEL	1		
55	DUAL SH-60 MODULAR DET - SUPPORT MOD 1	1		
56	DUAL SH-60 MODULAR DET - SUPPORT MOD 2	1		
57	DUAL SH-60 MODULAR DET - SUPPORT MOD 3	(or) 1		
58	DUAL SH-60 MODULAR DET - SUPPORT MOD 4	(or) 1		
59	RAST + RAST CONT +HELO CONT	1	1	1
60	AVIATION MAGAZINE - (12) MK46 - (24) HELLFIRE - (6) PENQUIN	1	1	1

Figure 33 – SH-60 Seahawk Helicopter (LAMPS)

3.2.5.8 SPARTAN

SPARTAN system alternatives are listed in Table 22. SPARTAN is shown in Figure 34. SPARTAN can engage surface threats with anti-surface armaments, conduct SAR operations, support and conduct intelligence collection, and conduct surveillance and reconnaissance. It can be equipped with multi-purpose radar, GPS tracking system, video cameras for navigation and control, multiple antennas, side-scan sonar, chemical/biological detectors, and weapon systems including a hellfire missile launcher or 7.62mm gatling gun.

Table 22 – SPARTAN System Alternatives

ID	SPARTAN System Alternatives	1 (Goal)	2	3 (Threshold)
86	1x 11M MODULAR SPARTAN DET USV VEHICLE and STOWAGE	3	2	1
87	1X 11M MODULAR SPARTAN (USV) DET- 1 MAINT MODULE	1	1	1
88	1X 11M MODULAR SPARTAN DET - 1 CONTROL MODULE	1	1	1
89	1X 11M MODULAR SPARTAN DET - 1 MIW SUPPORT MODULE	3	2	1
90	1X 11M MODULAR SPARTAN DET - 1 WEAPON (ASUW) MODULE	(or) 3	(or) 2	1
91	MODULAR SPARTAN DET - MISSION FUEL	3	2	1

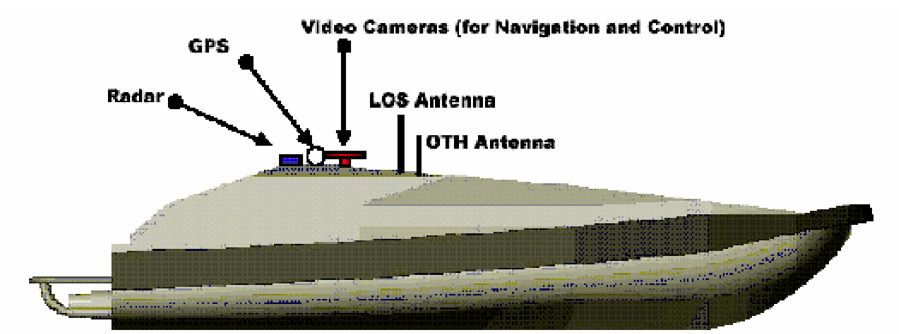

Figure 34 – Spartan Unmanned Surface Vehicle Core System

3.2.5.9 VTUAV

VTUAV alternatives are listed in Table 23. The VTUAV is shown in Figure 35. The Vertical Take-off Unmanned Aircraft Vehicle (VTUAV) is used in littoral operations both on shore and off. It provides an extension of the ship's sensors and is suited for high risk missions. VTUAVs are small in size and so can be stored easily onboard. They require very little space for take-off.

Table 23 – VTUAV System Alternatives

ID	VTUAV System Alternatives	1 (Goal)	0 (Threshold)
38	VTUAV DET - MODULAR - HANGAR AND 3 VEHICLES	1	1
39	VTUAV DET - MODULAR - MAINTENANCE MODULE	1	0
40	VTUAV DET - MODULAR - MISSION COMMAND MODULE	1	1
41	VTUAV DET - MODULAR - MISSION FUEL	1	0

Figure 35 – Vertical Takeoff Unmanned Aircraft Vehicle (VTUAV)

3.2.5.10 Topside Design

In order to minimize radar cross section, ASC alternative technologies may include the following:

- Advanced Enclosed Mast Sensor System is a low RADAR Cross Section (RCS) enclosure that hides ASC's sensors in one structure as shown in Figure 36. It uses a polarization technique to allow ASC sensor radiation in and out while screening and reflecting enemy sensor radiation. It also protects ASC's sensors from the environment and provides for 360 degree radiation and sensing without mast blanking.

- The Low Observable Multi Function Stack shown in Figure 37 is another low RCS structure for antennas and stacks. It incorporates active ventilation to reduce ASC's heat signature and houses Global Broadcast System (GBS), EHF SATCOM, UHF SATCOM, IMARSAT, Link 11, and Link 16 antennas.

3.2.5.11 Combat Systems Payload Summary

In order to trade-off combat system alternatives with other alternatives in the total ship design, combat system characteristics listed in Table 24 are included in the ship synthesis model data base.

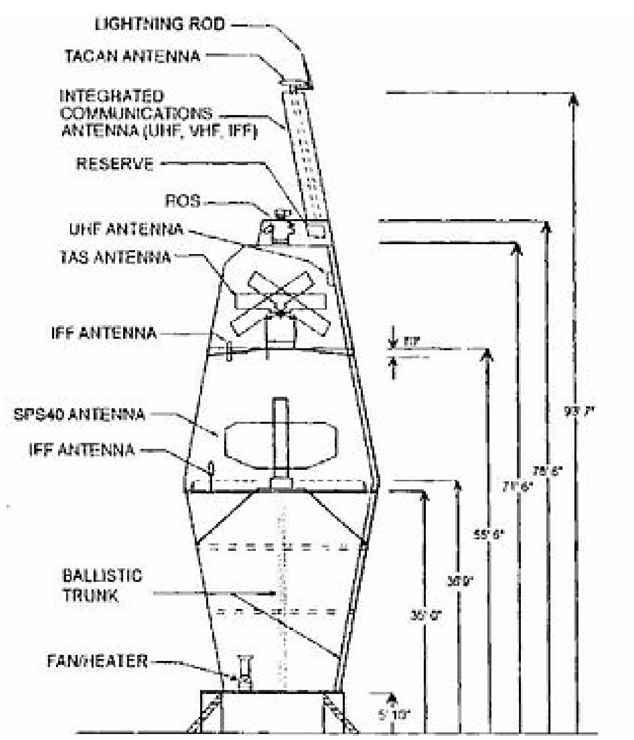

Figure 36 - Advance Enclosed Mast Sensor System [4]

Table 24 - Combat System Ship Synthesis Characteristics

ID	NAME	WTGRP	WT (lton)	HD10	HAREA	DHAREA	CRSKW	BATKW	WARAREA
1	SEA GIRAFFE AMB RADAR	456	2.24	0.00	0.00	9.50	6.96	7.84	AAW
2	SEAPAR RADAR - MFR MOUNTED IN DOGHOUSE	456	10.81	1.00	0.00	9.00	117.50	140.00	AAW
3	MK XII AIMS IFF	455	2.11	1.00	0.00	0.00	2.70	2.40	AAW
4	1X MK 16 CIWS Gun Mount 1 of 5	711	6.34	1.00	0.00	22.45	5.89	15.89	AAW
5	1X MK 16 CIWS Local Control 2 of 5	481	0.70	1.00	1.00	0.00	0.00	0.00	AAW
6	1X MK 16 CIWS Remote Control 3 of 5	481	0.10	1.00	0.00	0.00	0.44	0.44	AAW
7	1X MK 16 CIWS Workshop 4 of 5	482	0.00	1.00	0.00	18.58	0.00	0.00	AAW
8	1X MK 16 CIWS 25mm Guns – Ammo 5 of 5	21	4.26	1.00	0.00	12.48	0.00	0.00	AAW
9	RAM LAUNCHER - 8 CELL LAUNCHER 1 OF 4	721	2.27	0.00	0.00	0.00	4.80	4.80	AAW
10	RAM LAUNCHER - 8 CELL - CONTROL ROOM 2 OF 4	481	1.13	0.00	0.00	11.34	0.00	0.00	AAW
11	RAM LAUNCHER - 8 CELL- 8 READY SERVICE MISSILES 3 OF 4	21	0.86	0.00	0.00	0.00	0.00	0.00	AAW
12	RAM LAUNCHER - 8 CELL - 8 RAM MISSILE MAGAZINE 4 OF 4	21	1.02	0.00	0.00	0.00	0.00	0.00	AAW
13	RAM LAUNCHER - 21 CELL LAUNCHER 1 OF 4	721	3.22	1.00	0.00	0.00	8.88	8.88	AAW
14	RAM LAUNCHER - 21 CELL - CONTROL ROOM 2 OF 4	481	1.36	1.00	0.00	11.34	0.00	0.00	AAW
15	RAM LAUNCHER - 21 CELL - 21 READY SERVICE MISSILES 3 OF 4	21	2.24	1.00	0.00	0.00	0.00	0.00	AAW
16	RAM LAUNCHER - 21 CELL - 21 RAM MISSILE MAGAZINE 4 OF 4	21	2.68	1.00	0.00	0.00	0.00	0.00	AAW
17	2X-MK 137 LCHRs (Combined MK 53 SRBOC & NULKA LCHR) (1 OF 2)	721	0.74	0.00	0.00	21.66	0.00	0.00	AAW
18	2X-MK 137 LCHRs Loads (4NULKA, 12 SRBOC) (2 OF 2)	21	0.57	0.00	0.00	0.00	0.00	0.00	AAW
19	6X-MK 137 LCHRs (Combined MK 53 SRBOC & NULKA LCHR) (1 OF 2)	721	2.23	1.00	0.00	65.00	0.00	0.00	AAW
20	6X-MK 137 LCHRs Loads (12 NULKA, 36 SRBOC) (2 OF 2)	21	1.70	1.00	0.00	0.00	0.00	0.00	AAW
21	NULKA Magazine (12 Nulka)	21	0.72	1.00	0.00	3.00	0.00	0.00	AAW
22	SRBOC Magazine (200 SRBOC)	21	5.44	1.00	0.00	7.00	0.00	0.00	AAW
23	Fwd Surface Search Radar - AN/SPS-73	451	0.24	1.00	0.00	0.00	0.20	0.20	ASUW
24	Thermal Imaging Sensor System (TISS)	452	0.13	0.00	0.00	0.00	0.00	0.00	ASUW
25	Sea Star SAFIRE II FLIR	452	0.16	0.00	0.00	1.00	0.00	1.50	ASUW
26	IR Search and Track System (IRST)	452	1.60	1.00	0.00	19.90	40.00	40.00	ASUW
27	1X 30MM CIGS GUN MOUNT 1 of 4 (Close In Gun System)	711	3.47	0.00	11.82	0.00	12.03	36.09	ASUW
28	1X 30MM CIGS GUN AMMO STOWAGE 2 of 4	713	0.55	0.00	0.00	0.00	0.00	0.00	ASUW
29	1X 30MM CIGS GUN BALLISTIC PROTECTION 3 of 4	164	4.65	0.00	0.00	0.00	0.00	0.00	ASUW
30	1X 30MM CIGS GUN AMMO - 2500 ROUNDS 4 of 4	21	2.00	0.00	0.00	0.00	0.00	0.00	ASUW
31	57mm MK 3 Naval Gun Mount 1 of 4	711	6.80	2.00	31.00	0.00	4.00	10.00	ASUW
32	57mm Stowage 2 of 4	713	2.70	2.00	0.00	0.00	0.00	0.00	ASUW
33	57mm Ammo in Gun Mount 120 RDS 3 of 4	21	0.75	2.00	0.00	0.00	0.00	0.00	ASUW
34	57mm Ammo in Magazine 880 RDS 4 of 4	21	5.46	2.00	0.00	0.00	0.00	0.00	ASUW
35	1X 7M RHIB	583	3.50	1.00	19.01	0.00	0.00	0.00	ASUW
36	1X 11M RHIB COMMON LAUNCH-RECOVER SLED	583	1.52	1.00	0.00	0.00	0.00	0.00	ASUW
37	1X COMMON LAUNCH-RECOVER ADDED STRUCT (Stern)	185	0.91	1.00	0.00	0.00	0.00	0.00	ASUW
38	VTUAV DET - MODULAR - HANGAR AND 3 VEHICLES	23	3.41	0.00	0.00	73.00	0.00	0.00	VTUAV
39	VTUAV DET - MODULAR - MAINTENANCE MODULE	26	3.06	0.00	0.00	37.52	0.00	0.00	VTUAV
40	VTUAV DET - MODULAR - MISSION COMMAND MODULE	492	3.01	0.00	0.00	37.52	0.00	0.00	VTUAV
41	VTUAV DET - MODULAR - MISSION FUEL	42		0.00	0.00	0.00	0.00	0.00	VTUAV
42	AN/SLQ-25A (NIXIE) and AN/SLR-24I Towed Array (TRIPWIRE)	473	5.92	1.00	14.30	0.00	6.15	6.15	ASW
43	F100 SONAR GROUP 165	165	3.63	1.00	0.00	0.00	0.00	0.00	ASW
44	F100 SONAR GROUP 460	460	2.72	1.00	19.40	0.00	45.00	45.00	ASW
45	F100 SONAR GROUP 498	498	3.18	1.00	0.00	0.00	0.00	0.00	ASW
46	F100 SONAR GROUP 636	636	0.00	1.00	0.00	0.00	0.00	0.00	ASW
47	SINGLE SH-60 MODULAR DET - 1 HELOS AND HANGAR	23	9.49	0.00	0.00	88.00	0.00	0.00	LAMPS
48	SINGLE SH-60 MODULAR DET - MISSION FUEL	42		0.00	0.00	0.00	0.00	0.00	LAMPS
49	SINGLE SH-60 MODULAR DET - SUPPORT MOD 1	26	6.94	0.00	0.00	37.52	0.00	0.00	LAMPS
50	SINGLE SH-60 MODULAR DET - SUPPORT MOD 2	26	6.72	0.00	0.00	37.52	0.00	0.00	LAMPS
51	SINGLE SH-60 MODULAR DET - SUPPORT MOD 3	26	3.35	0.00	0.00	37.52	0.00	0.00	LAMPS
52	SINGLE SH-60 MODULAR DET - SUPPORT MOD 4	26	3.35	0.00	0.00	37.52	0.00	0.00	LAMPS
53	DUAL SH-60 MODULAR DET - 2 HELOS AND HANGAR	23	18.98	1.00	427.96	0.00	0.00	0.00	LAMPS
54	DUAL SH-60 MODULAR DET - MISSION FUEL	42		3.00	0.00	0.00	0.00	0.00	LAMPS
55	DUAL SH-60 MODULAR DET - SUPPORT MOD 1	26	6.94	1.00	0.00	37.52	0.00	0.00	LAMPS
56	DUAL SH-60 MODULAR DET - SUPPORT MOD 2	26	6.72	1.00	0.00	37.52	0.00	0.00	LAMPS
57	DUAL SH-60 MODULAR DET - SUPPORT MOD 3	26	3.60	1.00	0.00	37.52	0.00	0.00	LAMPS
58	DUAL SH-60 MODULAR DET - SUPPORT MOD 4	26	3.35	1.00	0.00	37.52	0.00	0.00	LAMPS
59	RAST + RAST CONT +HELO CONT	588	32.38	1.00	16.26	0.00	0.00	0.00	LAMPS
60	AVIATION MAGAZINE - (12) MK46 - (24) HELLFIRE - (6) PENQUIN 1 of 2	22	11.22	1.00	0.00	51.75	0.00	0.00	LAMPS
61	ADCON 21 - Warfare CDR (-) C/C Suite (DDG 79, 1992) - 1 of 2	411	2.20	1.00	60.00	0.00	62.44	62.44	C4I
62	ADCON 21 - Warfare CDR (-) C/C Suite (DDG 79, 1992)-2 of 2	412	6.20	1.00	81.35	0.00	0.00	0.00	C4I
63	COMMS SUITE LEVEL A	440	14.53	0.00	65.77	0.00	26.25	32.32	C4I
64	COMMS SUITE LEVEL B	440	23.10	1.00	45.72	0.00	36.60	37.20	C4I
65	Cooperative Engagement Capability (CEC)	415	1.54	1.00	1.80	2.00	1.60	1.60	C4I
66	NDS 3070 Vanguard - Mine Avoidance Sonar	463	0.90	1.00	0.83	0.00	0.00	1.60	MIW
67	1X MODULAR RMS - 1 RMS VEHICLE	23	2.72	4.00	19.42	44.00	0.00	0.00	MIW
68	1X MODULAR RMS - 1 CONTROL MODULE	476	5.02	1.00	37.52	0.00	0.00	0.00	MIW
69	1X MODULAR RMS - 1 MAINT-TRANSP MODULE	26	3.45	1.00	37.52	0.00	0.00	0.00	MIW
70	1X MODULAR RMS - 1 TRANSP 1 MODULE	23	3.92	1.00	37.52	0.00	0.00	0.00	MIW
71	1X MODULAR RMS - 1 TRANSP 2 MODULE	23	4.33	1.00	37.52	0.00	0.00	0.00	MIW
72	1X RMS COMMON LAUNCH-RECOVER SLED	583	1.36	4.00	0.00	0.00	0.00	0.00	MIW
73	1X RMS VEHICLE DAVIT	23	2.04	1.00	0.00	0.00	0.00	0.00	MIW
74	1X SMALL UUV DET - 3 BPUAV - 5 REMUS	23	0.00	1.00	0.00	0.00	0.00	0.00	MIW
75	1X SMALL UUV DET - 1 BATT-RECHARGE MODULE	313	3.41	1.00	37.52	0.00	0.00	0.00	MIW
76	1X SMALL UUV DET - 1 CONTROL MODULE	476	2.60	1.00	37.52	0.00	0.00	0.00	MIW
77	1X SMALL UUV DET - 1 VEHICLE STOWAGE MODULE	23	7.45	1.00	26.00	0.00	0.00	0.00	MIW
78	HELICOPTER MIW MODULE	26	4.56	0.00	0.00	60.50	0.00	0.00	MIW
79	TEU - 1X 11M EOD SCULPIN SUPPORT MODULE	29	2.30	1.00	30.25	0.00	0.00	0.00	MIW
80	TEU - 1X 11M EOD SUPPORT MODULE	29	4.04	1.00	30.25	0.00	0.00	0.00	MIW
81	TEU - 1X 11M EOD SUPPORT MODULE	29	4.04	1.00	30.25	0.00	0.00	0.00	MIW
82	TEU - SINGLE SH-60 ALMDS & AQS-20	26	4.30	1.00	0.00	60.50	0.00	0.00	MIW
83	TEU - SINGLE SH-60 AMDS & RAMICS	26	5.20	1.00	0.00	60.50	0.00	0.00	MIW
84	TEU - SINGLE SH-60 OASIS	26	3.10	1.00	0.00	60.50	0.00	0.00	MIW
85	TEU - SINGLE SH-60 PUK MODULE	26	5.90	1.00	0.00	60.50	0.00	0.00	MIW
86	1x 11M MODULAR SPARTAN DET USV VEHICLE and STOWAGE	23	10.54	3.00					SPARTAN
87	1X 11M MODULAR SPARTAN (USV) DET - 1 MAINT MODULE	26	2.60	1.00	37.52	0.00	0.00	0.00	SPARTAN
88	1X 11M MODULAR SPARTAN DET - 1 CONTROL MODULE	495	2.96	1.00	37.52	0.00	2.40	2.40	SPARTAN
89	1X 11M MODULAR SPARTAN DET - 1 MIW SUPPORT MODULE	29	3.84	3.00	37.52	0.00	0.00	0.00	SPARTAN
90	1X 11M MODULAR SPARTAN DET - 1 WEAPON (ASUW) MODULE	791	2.59	3.00	37.52	0.00	0.00	0.00	SPARTAN
91	MODULAR SPARTAN DET - MISSION FUEL	42	4.50	3.00	0.00	0.00	0.00	0.00	SPARTAN
92	AIEWS ADVANCED SEW SYSTEM	472	3.00	2.00	40.00	132.00	6.40	6.40	SEW
93	AN/SLQ-32(V)3	471	6.13	2.00	4.74	15.70	11.10	29.30	SEW

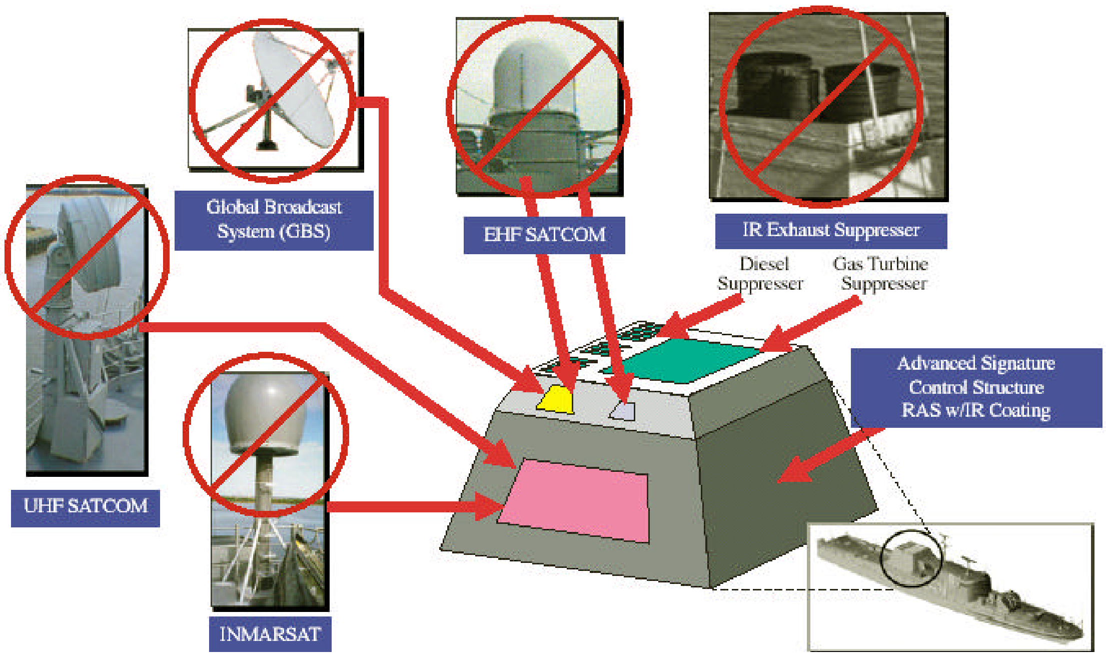

Figure 37 - Multi-Function Stack [4]

3.3 Design Space

Each ship design is described using 17 design variables (**Table 25**). Design-variable values are selected by the optimizer from the range indicated and input into the ship synthesis model. The ship is then balanced, checked for feasibility, and ranked based on risk, cost and effectiveness. Hull form alternatives and other hull design parameters (DV1-5) are described in Section 3.2.1. Sustainability alternatives (DV17) and performance measures are described in Section 3.2.2. Propulsion and Machinery alternatives (DV7 and 8) are described in Section 3.2.3. Automation alternatives (DV9) are described in Section 3.2.4. Combat system alternatives (DP 8, 10-16) are described in Section 3.2.5.

3.4 Ship Synthesis Model

A ship synthesis model is required to balance and assess designs selected by the optimizer in the Concept Exploration phase of the design process. Modules in the synthesis model were developed using MathCad software, and the model is integrated and executed in Model Center (MC). The Multi-Objective Genetic Optimization is run in MC using a Darwin optimization plug-in. Figure 38 shows the synthesis model in MC. Measures of Performance (MOPs) are calculated based on the design parameters and their predicted performance in a balanced design. Values of Performance (VOPs), an Overall Measure of Effectiveness (OMOE), Overall Measure of Risk (OMOR), and life cycle cost are also calculated by the synthesis model.

Table 25 - ASC Design Variables (DVs)

	Description	Metric	Range
1	Hull form	type	1 – catamaran, 2 - trimaran
2	Displacement	MT	2000-4000
3	Deckhouse Volume	m3	500-2000
4	Hull Material Type	alternative	1 – steel, 2 - aluminum
5	Deckhouse Material Type	alternative	1 – steel, 2 - aluminum
6	Collective Protection System Type	alternative	None, partial, full
7	Propulsion System Type	alternative	1-7
8	Degaussing System	y/n	0,1
9	Manning and Automation Factor	ND	0.5 – 1.0
10	MCM Alternative	alternative	1 (goal), 2,3,4(threshold)
11	ASUW Alternative	alternative	1 (goal), 2,3,4(threshold)
12	AAW Alternative	alternative	1 (goal), 2,3(threshold)
13	ASW Alternative	alternative	1 (goal), 2(threshold)
14	LAMPS Alternative	alternative	1 (goal), 2,3(threshold)
15	VTUAV Alternative	y,n	0,1
16	SPARTAN Alternative	alternative	1 (goal), 2,3(threshold)
17	Provisions Duration	days	14-24

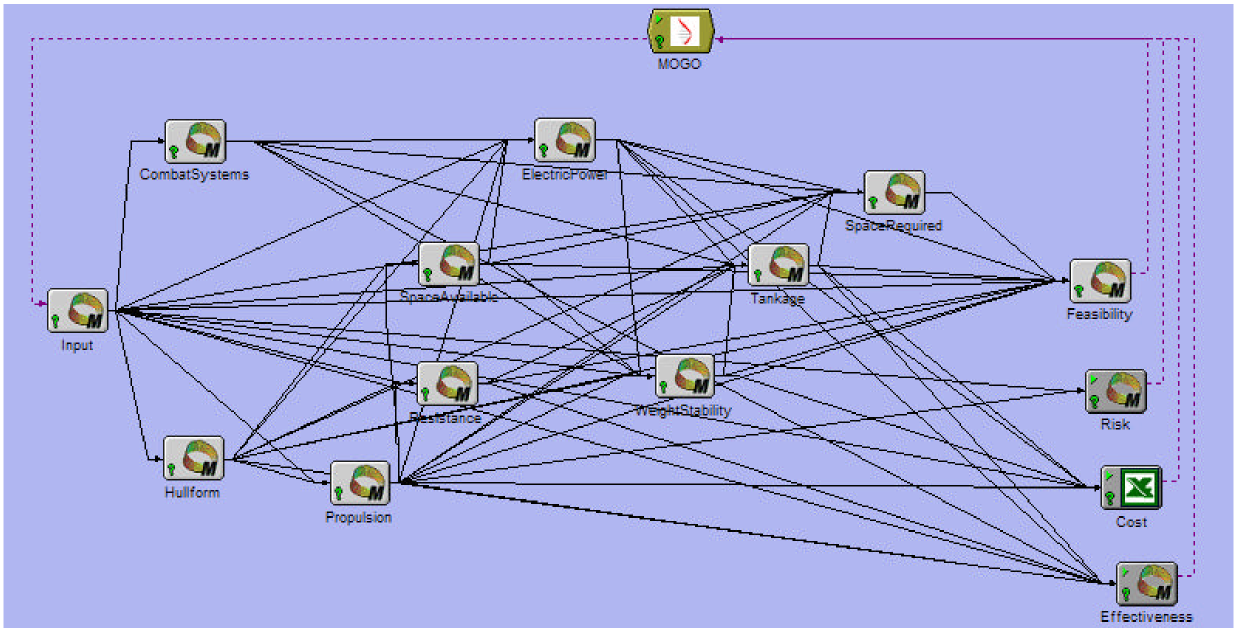

Figure 38 - Ship Synthesis Model in Model Center (MC)

The ship synthesis model is organized into modules as shown in Figure 38:

- Input Module - Inputs, decodes and processes the design variable vector and other design parameters that are constant for all designs. Provides this input to the other modules.
- Combat Systems Module - Retrieves combat systems data from the Combat Systems Data Base as specified by the combat system design variables. Calculates payload SWBS weights, VCGs, areas and electric power requirements and assesses performance for the total combat system.
- Hull form Module - Calculates hull form principal characteristics and supplies them to other modules. It scales the "parent" (baseline) characteristics of the trimaran and catamaran to match the specified displacement and hull form type. It calculates the scaling factor, scales the parent hull characteristics to the daughter hull, adds appendage volumes, and calculates daughter hull characteristics including lengths, areas, and volumes.
- Propulsion Module - Retrieves propulsion system data from the Propulsion System Data Base as specified by the propulsion system design variable. Database generated by modeling similar power plants in ASSET using single baseline design. Data listed in.
- Space Available Module - Calculates available volume and area, minimum depth required at amidships, cubic number, CN, and the height and volume of the machinery box.
- Resistance Module - Calculates hull resistance, sustained speed, and required shaft horsepower at endurance speed and sprint speed. The resistance is calculated using the Holtrop-Mennen regression-based method. It takes the input data of the individual side and center hulls and calculates the resistance for each. It adds the individual hull resistances with a 10% addition for hull interference. The module then calculates the effective bare hull power, appendage drag, and air drag. The propulsive coefficient is approximated. A value of 0.65 is assumed for waterjets. The sustained speed is calculated based on total BHP available with a 25% margin.
- Electric Power Module - Calculates maximum functional electric load with margins (KW_{MFLM}), required generator power (KW_{GREQ}), required average 24-hour electric power (KW_{24AVG}), and required auxiliary machinery room volume (V_{AUX}). It estimates system power requirements using known values and parametric equations, sums and applies margins, assumes one ship service generator is unavailable, uses a power factor of 0.9, and uses the electric load analysis method from DDS 310-1.
- Weight and Stability Module - Calculates single digit SWBS weights, total weight, fuel weight, and GM/B ratio using parametric equations and known weights. The module uses a combination of known weights and parametric equations to calculate the SWBS weights. KG is calculated from single digit weights and VCGs, estimated using parametric equations. The KM is calculated using geosim scaling of the parent hull KM.
- Tankage Module - Calculates tankage volume requirements based on required sprint and endurance range, and parametric equations. It uses a number of input variables including fluid specific volumes, ballast

type, transmission efficiency, fuel weight, fuel consumption at sprint and endurance speeds, average generator engine fuel consumption, average electric load, sprint and endurance speed, total propulsion engine BHP, potable water weight, and lube oil weight. It uses parametric equations for various tank volumes and design data sheet DDS-200-1 for endurance fuel calculations. It outputs total required tankage volume, fuel tank volume, sprint range and endurance range.

- Space Required Module - Calculates deckhouse arrangeable area required and available, and total ship area required and available using parametric equations. Inputs include number and type of personnel, cubic number, known area requirements, hull and deckhouse volumes, large object volumes, average deck height, beam, and stores duration.
- Feasibility Module - Assesses the overall design feasibility of the ASC. It compares available to required characteristics including total arrangeable ship area, deckhouse area, sustained speed, electrical plant power, minimum and maximum GM/B ratios, endurance range, sprint range, and transom beam.
- Cost Module - Calculates cost using the Naval Surface Warfare Center Carderock Small Fast Ship Cost Calculator. This calculator uses parametric equations for construction costs based on single digit (SWBS) weights, hull type, hull and deckhouse material, propulsion power type, propulsor type, and propulsion power. Fuel and personnel costs are added to calculate life cycle cost. It normalizes costs to the base year (2003) to find discounted life cycle cost. Other life cycle costs are assumed to be the same for all designs. It assumes a service life of 30 years with 3000 steaming hours underway per year. All recurring costs are excluded. The calculator assumes historical costs of modern surface combatants.
- Effectiveness Module - Calculates Values of Performance (VOPs) for sprint range, endurance range, provisions duration, sustained speed, draft, personnel, and RCS using their VOP functions. Inputs combat system VOPs from the combat system module. Calculates the OMOE using these VOPs and their associated weights.
- Risk Module - Calculates a quantitative Overall Measure of Risk (OMOR) for a specific design taking into account performance risk, cost risk, and schedule risk.

3.5 Multi-Objective Optimization

The optimization is performed in Model Center using the Darwin optimization plug-in. Objective attributes for this optimization are life cycle cost, risk (technology cost, schedule and performance risk) and military effectiveness. A flow chart for the Multi-Objective Genetic Optimization (MOGO) is shown in Figure 39. In the first design generation, the optimizer randomly defines 200 balanced ships using the ship synthesis model to balance each ship and to calculate cost, effectiveness and risk. Each of these designs is ranked based on their fitness or dominance in effectiveness, cost and risk relative to the other designs in the population. Penalties are applied for infeasibility and niching or bunching-up in the design space. The second generation of the optimization is randomly selected from the first generation, with higher probabilities of selection assigned to designs with higher fitness. Twenty-five percent of these are selected for crossover or swapping of some of their design variable values. A small percentage of randomly selected design variable values are mutated or replaced with a new random value. As each generation of ships is selected, the ships spread across the effectiveness/cost/risk design space and frontier. After 300 generations of evolution, the non-dominated frontier (or surface) of designs is defined as shown in Figure 46. Each ship on the non-dominated frontier provides the highest effectiveness for a given cost and risk compared to other designs in the design space. The "best" design is determined by the customer's preferences for effectiveness, cost and risk.

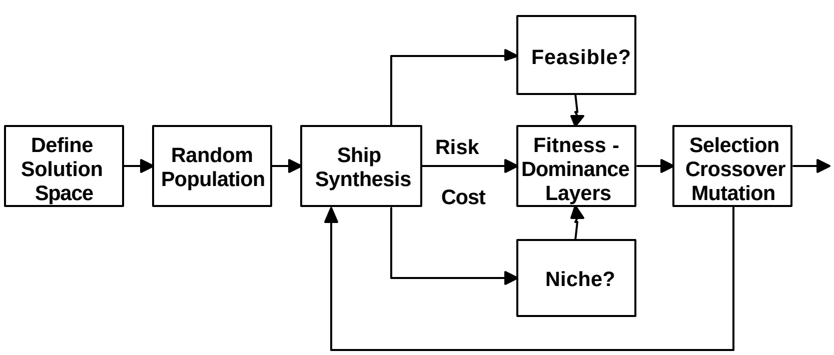

Figure 39 - Multi-Objective Genetic Optimization

In order to perform the optimization, quantitative objective functions are developed for each objective attribute. Effectiveness and risk are quantified using overall measures of effectiveness and risk developed as illustrated in Figure 40 and described in Sections 3.5.1 and 3.5.2. Life Cycle Cost (LCC) is calculated using the Naval Surface Warfare Center Carderock Small Fast Ship Cost Calculator.

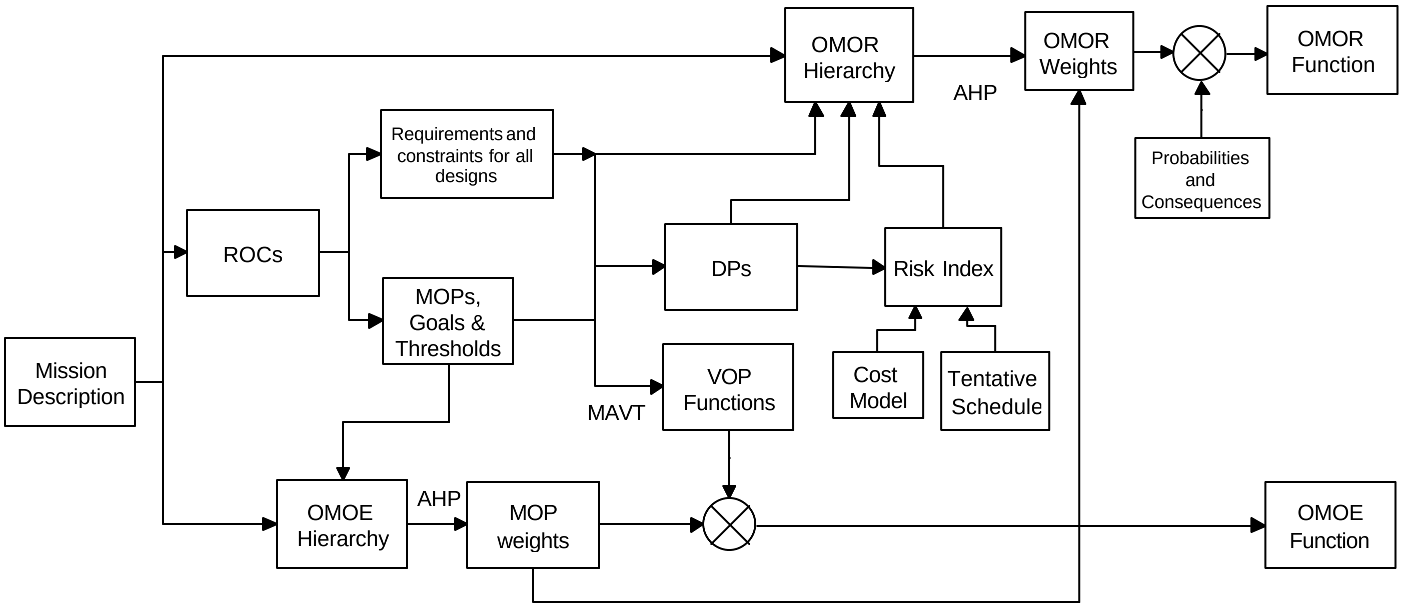

Figure 40 - OMOE and OMOR Development Process

3.5.1 Overall Measure of Effectiveness (OMOE)

Figure 40 illustrates the process used to develop the ASC OMOE and OMOR. Important terminology used in describing this process includes:

- Overall Measure of Effectiveness (OMOE) - Single overall figure of merit index (0-1.0) describing ship effectiveness over all assigned missions or mission types
- Mission or Mission Type Measures of Effectiveness (MOEs) - Figure of merit index (0-1.0) for specific mission scenarios or mission types
- Measures of Performance (MOPs) - Specific ship or system performance metric independent of mission (speed, range, number of missiles)
- Value of Performance (VOP) - Figure of merit index (0-1.0) specifying the value of a specific MOP to a specific mission area for a specific mission type.

There are a number of inputs which must be integrated when determining overall mission effectiveness in a naval ship: 1) defense policy and goals; 2) threat; 3) existing force structure; 4) mission need; 5) mission scenarios; 6) modeling and simulation or war gaming results; and 7) expert opinion. Ideally, all knowledge about the problem could be included in a master war-gaming model to predict resulting measures of effectiveness for a matrix of ship performance inputs in a series of probabilistic scenarios. Regression analysis could be applied to the results to define a mathematical relationship between input ship MOPs and output effectiveness. The accuracy of such a simulation depends on modeling the detailed interactions of a complex human and physical system and its response to a broad range of quantitative and qualitative variables and conditions including ship MOPs. Many of the inputs and responses are probabilistic so a statistically significant number of full simulations must be made for each set of discrete input variables. This extensive modeling capability does not yet exist for practical applications.

An alternative to modeling and simulation is to use expert opinion directly to integrate these diverse inputs, and assess the value or utility of ship MOPs in an OMOE function [1]. This can be structured as a multi-attribute decision problem. Two methods for structuring these problems dominate the literature: Multi-Attribute Utility Theory and the Analytical Hierarchy Process. In the past, supporters of these theories have been critical of each other, but recently there have been efforts to identify similarities and blend the best of both for application in Multi-Attribute Value (MAV) functions. This approach is adapted here for deriving an OMOE.

Table 26 - ROC/MOP/DV Summary

ROC	Primary MOP or Constraint	Threshold or Constraint	Goal	Related DV
MOB 1 - Steam to design capacity in most fuel efficient manner	MOP10 – Sprint range MOP11 – Endurance range MOP13 – Sprint speed	1000 nm 3500 nm 40 knots	1500 nm 4500 nm 50 knots	DV1 – Hull form, DV2 - Displacement DV1 – Hull form, DV2 - Displacement DV 7 – Propulsion System alternative
MOB 3 - Prevent and control damage	MOP16 – Structural vulnerability MOP17 – Personnel vulnerability MOP18 – Damage stability MOP20 – RCS MOP21 – Acoustic signature MOP22 – IR Signature MOP23 – Magnetic signature	Aluminum hull 100 Catamaran 7000 m3 Mechanical LM2500+ Aluminum No Degaussing	Steel hull 50 Trimaran 2000 m3 IPS ICR Steel Degaussing	DV4 – Hull material type DV9 – Manning and automation factor DV1 – Hull form DV3 – Deckhouse volume DV7 – Propulsion System alternative DV7 – Propulsion System alternative DV4 – Hull material type DV8 – Degaussing system
MOB 3.2 - Counter and control NBC contaminants and agents	MOP19 - CBR	No CPS	Full CPS	DV6 – Collective Protection System Type
MOB 5 - Maneuver in formation	Required all designs			
MOB 7 - Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	Required all designs			
MOB 10 - Replenish at sea	Required all designs			
MOB 12 - Maintain health and well being of crew	Required all designs			
MOB 13 - Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support	MOP11 – Endurance range MOP12 – Provisions	3500 nm 14 days	4500 nm 24 days	DV1 – Hull form DV2 – Displacement DV7 – Propulsion System alternative DV18 – Provisions Duration
MOB 16 - Operate in day and night environments	Required all designs			
MOB 17 - Operate in heavy weather	MOP15 – Loiter seakeeping	Catamaran	Trimaran	DV1 – Hull form DV2 – Displacement
MOB 18 - Operate in full compliance of existing US and international pollution control laws and regulations	Required all designs			
AAW 1 – Provide anti-air defense in cooperation with other forces	MOP9 – Core AAW MOP6 – C4ISR	AAW = 3 C4ISR = 2	AAW = 1 C4ISR = 1	DV12 – AAW DV14 – C4ISR
AAW 1.2 - Provide unit self defense	MOP9 – Core AAW	AAW = 3	AAW = 1	DV12 – AAW
AAW 5 - Provide passive and soft-kill anti-air defense	MOP9 – Core AAW	AAW = 3	AAW = 1	DV12 – AAW
AAW 6 - Detect, identify and track air targets	MOP9 – Core AAW	AAW = 3	AAW = 1	DV12 – AAW
AAW 9 – Engage airborne threats using surface-to-air armaments	MOP9 – Core AAW	AAW = 3	AAW = 1	DV12 – AAW
ASU 1 - Engage surface threats with anti-surface armaments	MOP7 – Core SUW MOP3 – LAMPS MOP4 – Spartan MOP5 – VTUAV	ASUW = 4 LAMPS =3 SPARTAN = 3 VTUAV = 0	ASUW = 1 LAMPS = 1 SPARTAN = 1 VTUAV = 1	DV11 – ASUW DV15 – LAMPS DV17 – SPARTAN DV16 – VTUAV
ASU 2 - Engage surface ships in cooperation with other forces	MOP6 – C4ISR MOP7 – Core SUW	C4ISR = 2 ASUW = 4	C4ISR = 1 ASUW = 1	DV14 – C4ISR DV11 – ASUW
ASU 6 - Disengage, evade and avoid surface attack	MOP13 – Sprint speed	40 knots	50 knots	DV1 – Hull form DV2 – Displacement DV7 – Propulsion System alternative
ASW 1 - Engage submarines	MOP8 – Core ASW MOP3 – LAMPS	ASW = 2 LAMPS = 3	ASW = 1 LAMPS = 1	DV13 – ASW DV15 – LAMPS
ASW 1.2 – Engage submarines at medium range (LAMPS)	MOP8 – Core ASW MOP3 – LAMPS	ASW = 2 LAMPS = 3	ASW = 1 LAMPS = 1	DV13 – ASW DV15 – LAMPS
ASW 1.3 – Engage submarines at close range (torpedo)	MOP8 – Core ASW MOP3 – LAMPS	ASW = 2 LAMPS = 3	ASW = 1 LAMPS = 1	DV13 – ASW DV15 – LAMPS

ROC	Primary MOP or Constraint	Threshold or Constraint	Goal	Related DV
ASW 4 - Conduct airborne ASW/recon (LAMPS)	MOP8 – Core ASW MOP3 – LAMPS MOP6 – C4ISR	ASW = 2 LAMPS = 3 C4ISR = 2	ASW = 1 LAMPS = 1 C4ISR = 1	DV13 – ASW DV15 – LAMPS DV14 – C4ISR
ASW 5 – Support airborne ASW/recon	MOP3 – LAMPS MOP6 – C4ISR	LAMPS = 3 C4ISR = 2	LAMPS = 1 C4ISR = 1	DV15 – LAMPS DV14 – C4ISR
ASW 10 – Disengage, evade and avoid submarine attack by employing countermeasures and evasion techniques	MOP8 – Core ASW MOP13 – Sprint Speed MOP10 – Sprint Range	ASW = 2 40 knots 1000 nm	ASW = 1 50 knots 1500 nm	DV13 – ASW DV1 – Hull form DV2 – Displacement DV7 – Propulsion System alternative
MIW 1 – Conduct mine-hunting	MOP1 – Core MCM MOP2 – MCM Modules MOP3 – LAMPS MOP4 – Spartan MOP5 – VTUAV MOP6 – C4ISR	MCM = 4	MCM = 1	DV10 – MCM DV15 – LAMPS DV17 – Spartan DV16 – VTUAV DV14 – C4ISR
MIW 4 – Conduct mine avoidance	MOP1 – Core MCM	MCM = 4	MCM = 1	DV10 – MCM
MIW 6.7 – Maintain magnetic signature limits	MOP 23 – Magnetic Signature	Steel No	Aluminum Yes	DV4 – Hull Material type DV 8 – Degaussing System
CCC 3 - Provide own unit CCC	MOP6 – C4ISR	C4ISR = 2	C4ISR = 1	DV14 – C4ISR
CCC 4 - Maintain data link capability	MOP6 – C4ISR	C4ISR = 2	C4ISR = 1	DV14 – C4ISR
SEW 2 - Conduct sensor and ECM operations	Required all designs	AAW = 2	AAW = 2	DV12 – AAW
SEW 3 – Conduct sensor and ECCM operations	Required all designs	AAW = 2	AAW = 2	DV12 – AAW
FSO 6 - Conduct SAR operations	MOP3 – LAMPS MOP4 – Spartan MOP5 – VTUAV	LAMPS =3 SPARTAN = 3 VTUAV = 0	LAMPS = 1 SPARTAN = 1 VTUAV = 1	DV15 – LAMPS DV17 – SPARTAN DV16 – VTUAV
FSO 7 – Provide explosive ordnance disposal services	MOP2 – MCM Modules	MCM = 4	MCM = 1	DV10 – MCM
FSO 8 – Conduct port control functions	MOP13 – Sprint speed MOP14 – Draft	40 knots 5.5 meters	50 knots 3 meters	DV1 – Hull form DV2 – Displacement DV7 – Propulsion System alternative
INT 1 - Support/conduct intelligence collection	MOP3 – LAMPS MOP4 – Spartan MOP5 – VTUAV	LAMPS =3 SPARTAN = 3 VTUAV = 0	LAMPS = 1 SPARTAN = 1 VTUAV = 1	DV15 – LAMPS DV17 – SPARTAN DV16 – VTUAV
INT 3 - Conduct surveillance and reconnaissance (ISR)	MOP3 – LAMPS MOP4 – Spartan MOP5 – VTUAV MOP6 – C4ISR	LAMPS =3 SPARTAN = 3 VTUAV = 0 C4ISR = 2	LAMPS = 1 SPARTAN = 1 VTUAV = 1 C4ISR = 1	DV15 – LAMPS DV17 – SPARTAN DV16 – VTUAV DV14 – C4ISR
NCO 3 - Provide upkeep and maintenance of own unit	Required all designs			
NCO 19 - Conduct maritime law enforcement operations	MOP13 – Sprint speed MOP14 – Draft	40 knots 5.5 meters	50 knots 3 meters	DV1 – Hull form DV2 – Displacement DV7 – Propulsion System alternative

The process described in Figure 40 begins with the Mission Need Statement and mission description. Required capabilities (ROCs) are identified to perform the ship's mission(s) and measures of performance (MOPs) are specified for those capabilities that will vary in the designs as a function of the ship design variables (DVs). Each MOP is assigned a threshold and goal value. Required capabilities and applicable restraints to all designs are also specified.

Table 26 summarizes the ROCs, DV and MOPs definition for ASC. An Overall Measure of Effectiveness (OMOE) hierarchy is developed for the MOPs using the Analytical Hierarchy Process (AHP) to calculate MOP weights and Multi-Attribute Value Theory (MAVT) to develop individual MOP value functions. The result is a weighted overall effectiveness function (OMOE) that is used as one of three objectives in the multi-objective optimization. In the AHP, pair-wise comparison questionnaires are produced to solicit expert and customer opinion, required to calculate AHP weights. Value of Performance (VOP) functions (generally S-curves) are developed for each MOP and VOP values are calculated using these functions in the ship synthesis model. A particular VOP has a value of zero corresponding to the MOP threshold, and a value of 1.0 corresponding to the MOP goal.

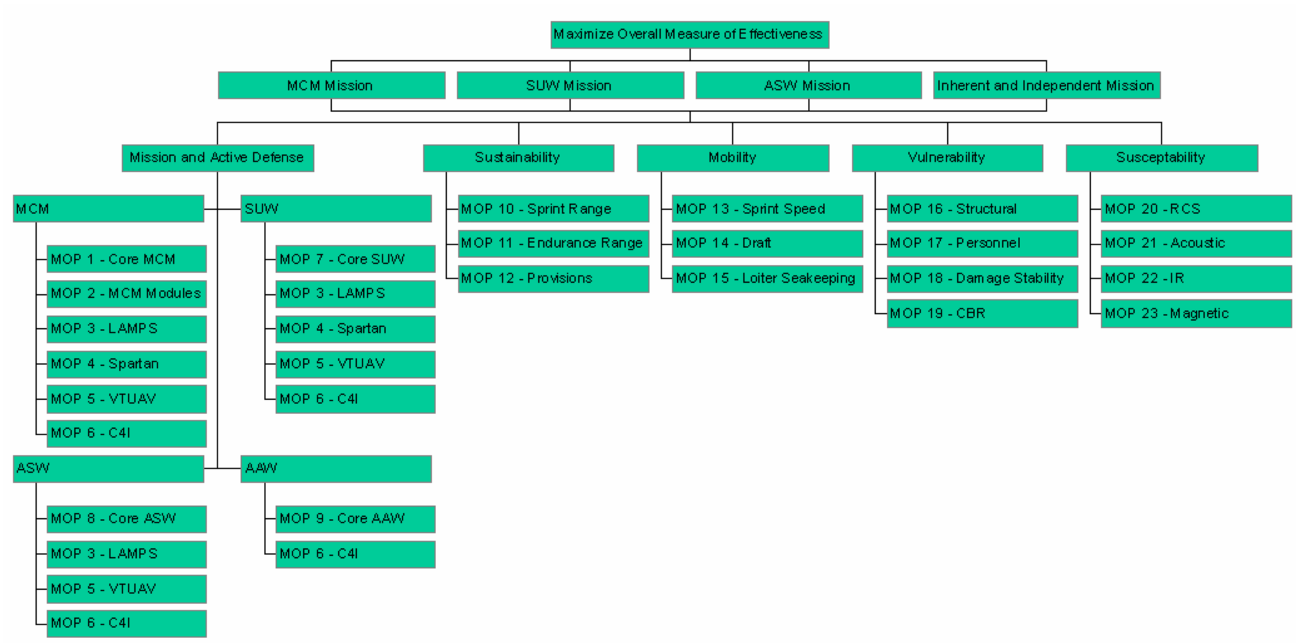

Figure 41 - OMOE Hierarchy

Table 27 - MOP Table

Primary MOP or Constraint	Threshold or Constraint	Goal	Related DV
MOP1 – Core MCM	MCM = 4	MCM = 1	DV10 - MCM
MOP2 – MCM Modules	MCM = 4	MCM = 1	DV10 - MCM
MOP3 – LAMPS	LAMPS =3	LAMPS = 1	DV15 – LAMPS
MOP4 – Spartan	SPARTAN = 3	SPARTAN = 1	DV17 – SPARTAN
MOP5 – VTUAV	VTUAV = 0	VTUAV = 1	DV16 - VTUAV
MOP6 – C4ISR	C4I = 2	C4I = 1	DV14 – C4I
MOP7 – Core SUW	ASUW = 4	ASUW = 1	DV11 – ASUW
MOP8 – Core ASW	ASW = 2	ASW = 1	DV13 - ASW
MOP9 – core AAW	AAW = 3	AAW = 1	DV12 – AAW
MOP10 – Sprint range	1000 nm	1500 nm	DV1 – Hullform, DV2 - Displacement
MOP11 – Endurance range	3500 nm	4500 nm	DV1 – Hullform, DV2 - Displacement
MOP12 – Provisions	14 days	24 days	DV18 – provisions duration
MOP13 – Sprint speed	40 knots	50 knots	DV7 – Propulsion System alternative
MOP14 – Draft	5.5 meters	3 meters	DV2 - Displacement
MOP15 – Loiter seakeeping	Catamaran	Trimaran	DV1 – Hullform
MOP16 – Structural vulnerability	Aluminum hull	Steel	DV4 – Hull material type
MOP17 – Personnel vulnerability	100	50	DV9 – Manning and automation factor
MOP18 – Damage stability	Catamaran	Trimaran	DV1 – Hullform
MOP19 - CBR	No CPS	Full CPS	DV6 - Collective Protection System Type
MOP20 – RCS	7000 m3	2000 m3	DV3 – Deckhouse volume
MOP21 – Acoustic signature	Mechanical	IPS	DV7 – Propulsion System alternative
MOP22 – IR Signature	LM2500	ICR	DV7 – Propulsion System alternative
MOP23 – Magnetic signature	Aluminum	Steel	DV4 – Hull material type
	No Degaussing	Degaussing	DV8 – Degaussing system

Figure 41 illustrates the OMOE hierarchy for ASC derived from

Table 26. Separate hierarchies are developed for each type of mission for ASC. MOPs are grouped into five categories (mission and active defense, sustainability, mobility, vulnerability, and susceptibility) under each mission. MOPs are listed in Table 27. MOP weights are calculated using expert opinion and pair wise comparison as shown in Figure 42. Results are shown in Figure 43. A typical ASC VOP curve (for sprint (sustained) speed, MOP 13) is illustrated in Figure 44. Other VOP curves and functions are similar. MOP weights and value functions are finally assembled in a single OMOE function:

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

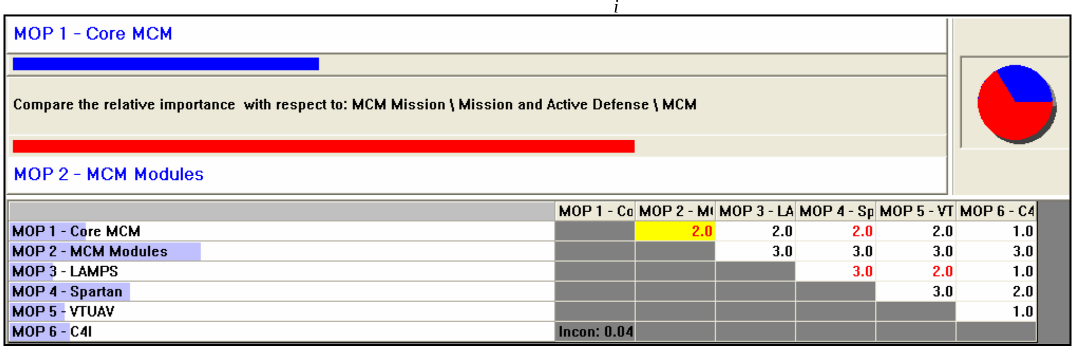

Figure 42 - AHP Pairwise Comparison

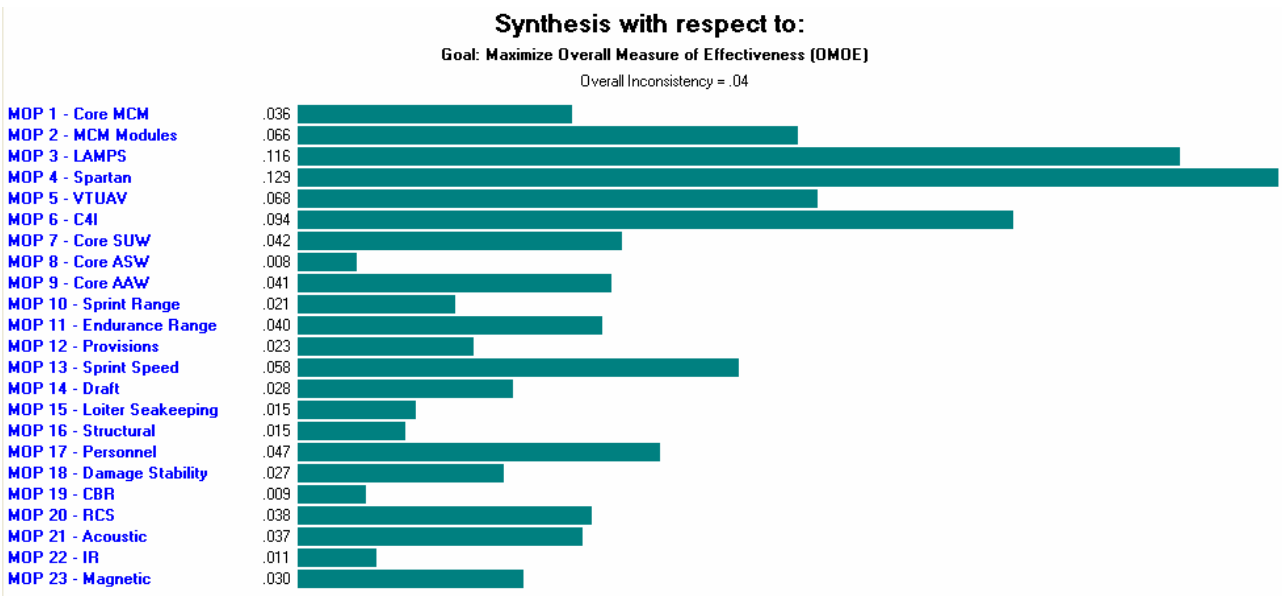

Figure 43 - MOP Weights

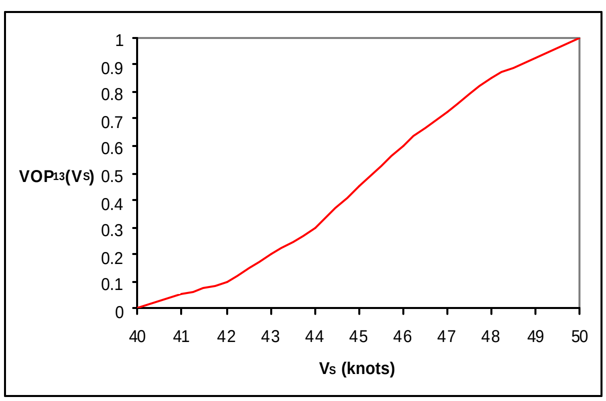

Figure 44 - Value of Performance Function for Sprint (Sustained) Speed

3.5.2 Overall Measure of Risk (OMOR)

The naval ship concept design process often embraces novel concepts and technologies that carry with them an inherent risk of failure simply because their application is the first of its kind. This risk may be necessary to achieve specified performance or cost reduction goals.

Three types of risk events are considered in the ASC risk calculation: performance, cost and schedule. The initial assessment of risk performed in Concept Exploration, as illustrated in Figure 40, is a very simplified first step in the overall Risk Plan and the Systems Engineering Management Plan (SEMP) for ASC. Referring to Figure

40, after the ship's missions and required capabilities are defined and technology options identified, these options and other design variables are assessed for their potential contribution to overall risk. MOP weights, tentative ship and technology development schedules and cost predictions are also considered. Calculating the OMOR first involves identifying risk events associated with specific design variables, required capabilities, cost, and schedule. The Risk is calculated for each event and a risk table or register is created. Possible risk events identified for ASC are listed in Table 28. Some possible performance risk events are MCM, Spartan, or VTUAV systems fail to perform as predicted, structural failure from transverse loading, aluminum material problems, poor seakeeping performance, poor resistance estimate, and poor IPS reliability or performance. Cost and schedule risk events include IPS or automation exceeding cost or development schedule estimates. The AHP and expert pair-wise comparison are then used to calculate OMOR hierarchy weights, Wperf, Wcost, Wsched, wj and wk. The OMOE performance weights calculated previously that are associated with risk events are normalized to a total of 1.0, and reused for calculating the OMOR. Once possible risk events are identified, a probability of occurrence, P_i, and a consequence of occurrence, C_i, are estimated for each event using Table 29 and Table 30. The OMOR is calculated using these weights and probabilities in Equation 3-2:

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

Once the OMOR variables have been determined, the OMOR function is used as the third objective attribute in the MOGO.

3.5.3 Cost

ASC construction costs are estimated for each SWBS group using weight-based equations. Figure 45 illustrates acquisition cost components calculated in the model. The Basic Cost of Construction (BCC) is the sum of all SWBS group costs. Ship price includes profit. In naval ships, the Total Shipbuilder Portion is the sum of the projected cost of change orders and the BCC. The Total Government Portion is the sum of the cost of Government-Furnished Material (GFM) and Program Managers Growth. The Total End Cost is the Sum of the Total Shipbuilder Portion and the Total Government Portion. ASC life cycle cost includes construction costs plus operating and support costs.

Table 28 - ASC Risk Register

System	Risk Type	Risk ID	Related DV	DV Description	DV Value	Risk Event E_i	Risk Description	P_i	C_i	R_i
Hull	Performance	1	DV_1	Hullform	1	High Transverse Loading for Multi-hull	Possibility of structural failure	0.5	0.9	0.45
Hull	Performance	1	DV_1	Hullform	2	High Transverse Loading for Multi-hull	Possibility of structural failure	0.3	0.9	0.27
Hull	Performance	2	DV.	Hull Material Type	2	Implementation problems	USN lack of experience with aluminum	0.5	0.7	0.35
Hull	Performance	3	DV_1	Hullform	1, 2	Unable to accurately predict seakeeping performance	Lack of available data for multi-hulls	0.5	0.5	0.25
Hull	Performance	4	DV_1	Hullform	1, 2	Unable to accurately predict resistance performance	Lack of available data for multi-hulls	0.4	0.5	0.20
Propulsion	Performance	5	DV_7	Integrated power system	2	Development and use of new IPS system	New equipment and systems will have reduced reliability	0.4	0.4	0.16
Propulsion	Cost	6	DV_7	Integrated power system	2	Development and integration of new IPS systems will have cost overruns	Unexpected problems with new equipment and systems	0.3	0.6	0.18
Propulsion	Schedule	7	DV_7	Integrated power system	2	Development and integration of new IPS system will be behind schedule	Unexpected problems with new equipment and systems	0.3	0.3	0.09
Automation	Performance	8	DV_9	Manning and Automation Factor	0.5- 1.0	Development and Integration of automation systems	Equipment and systems will have reduced reliability	0.3	0.7	0.21
Automation	Cost	9	DV_9	Manning and Automation Factor	0.5 -1.0	Development and Integration of automation systems will have cost overruns	Unexpected problems with equipment and systems	0.4	0.4	0.16
Automation	Schedule	10	DV_9	Manning and Automation Factor	0.5- 1.0	Development and Integration of automation systems will be behind schedule	Unexpected problems with equipment and systems	0.4	0.4	0.16
MCM	Performance	11	DV_{10}	MCM Alternative	≤ 4	Development of new technologies and integration of modules	New equipment and systems will have reduced reliability	0.5	0.8	0.4
VTUAV	Performance	12	DV_{15}	VTUAV Alternative	1	Development of new technologies	New equipment and systems will have reduced reliability	0.3	0.5	0.15
SPARTAN	Performance	13	DV_{15}	SPARTAN Alternative	≤ 3	Development of new technologies	New equipment and systems will have reduced reliability	0.2	0.8	0.16

Table 29 - 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 30 - 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%

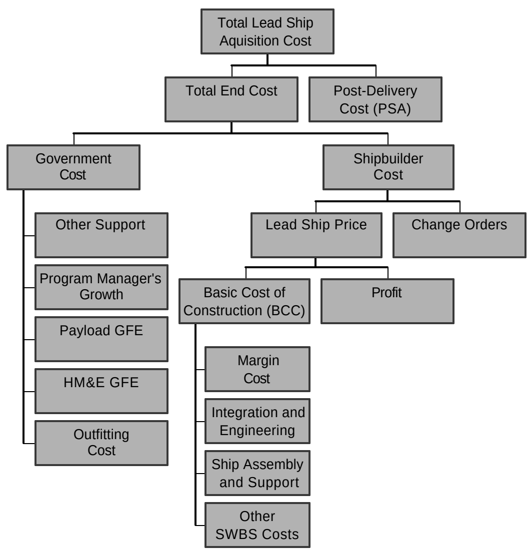

Figure 45 - Naval Ship Acquisition Cost Components

3.6 Optimization Results

Figure 46 shows the final effectiveness-cost-risk frontier generated by the genetic optimization. Each point in Figure 46 represents objective attribute values for a feasible non-dominated ship design. Non-dominated frontiers for different levels of risk (OMORs) are represented by different colors. Extreme designs and distinctive "knees" in the curve are labeled as candidate designs for discussion. Alternative designs at the extremes of the frontiers and at knees in the curve are often the most interesting possibilities for the customer. The "Knees" are distinct irregularities in the curves at the top of steep slopes where substantial effectiveness improvement occurs for a small increase in cost. The HI2 design variant shown in Figure 46 was assigned to Team 2.

The higher risk frontiers represent a greater use of higher risk alternatives including LAMPS, SPARTANs, and VTUAVs. However, as these alternatives increase the OMOR they also greatly increase the OMOE as seen in the figure. These increases in high risk alternatives are responsible for the rising slopes seen throughout the frontier. Of course, these additions to the combat systems create an increase in required support and manning resulting in higher costs. HI2 occurs at one of the "knees" as described above and is the best alternative with the highest effectiveness. It has an OMOE of 0.586 and an OMOR of 0.691.

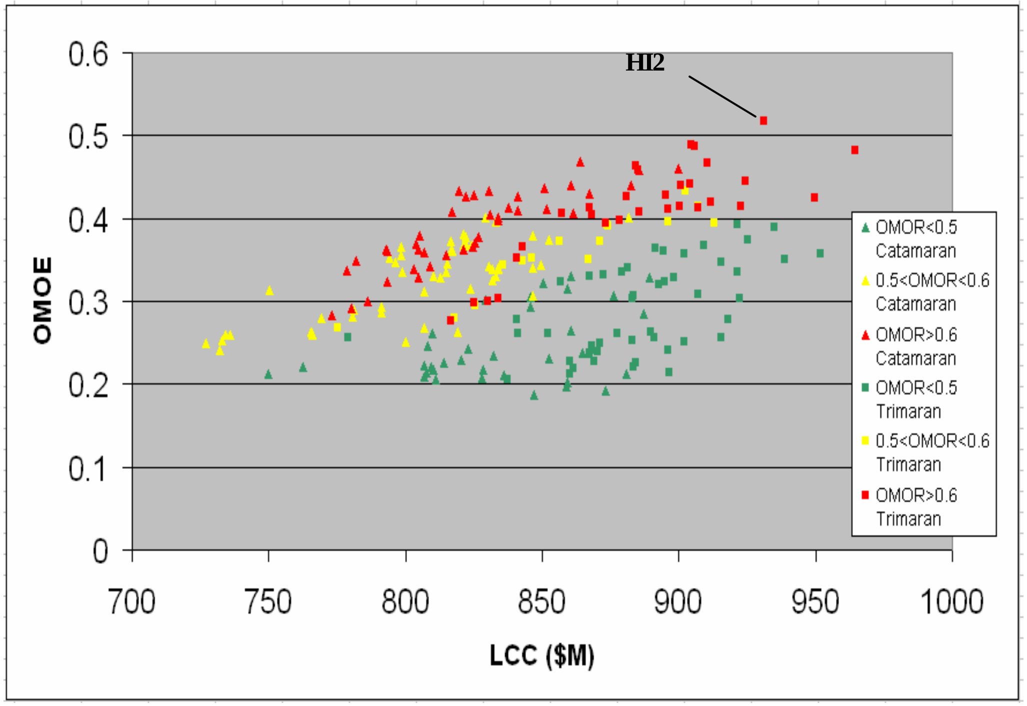

Figure 46 - Non-Dominated Frontier based on Life Cycle Cost

3.7 HI2 Baseline Concept Design

The HI2 design is a relatively high risk, high life cycle cost and effectiveness non-dominated design identified by the MOGO. The high OMOR of 0.691 is due to the inclusion of high risk combat system alternatives, waterjet propulsion, wave piercing bow, and the multi-hull form. These are all higher risk alternatives. Table 31 - Table 36 summarize the baseline ship characteristics. Table 31 shows the design variables and ranges considered for ASC and the design variable values selected for HI2. Aluminum was chosen as the hull material because of its light weight and ease of fabrication combined with good corrosion and fatigue resistance. Table 32 lists the ship weights and vertical centers of gravity by SWBS group with margins. Table 33 summarizes arrangeable area. Table 34 is an electric power summary by SWBS group. Table 35 summarizes the values given to each Measure of Performance in determining HI2's Overall Measure of Effectiveness and Risk. Table 36 lists principal characteristics with descriptions of the propulsion system and combat systems. This table also contains information about the number of VTUAVs, SPARTANS, LAMPS, manning broken down by officers and enlisted, deck heights, and lead/follow ship costs.

Table 31 - Design Variables Summary

Design Variable	Description	Trade-off Range	HI2 Values
DV 1	Hull Form type	1. Catamaran 2. Trimaran	2. Trimaran
DV 2	Displacement	2000 – 4000 MT	2800 MT
DV 3	Deckhouse Volume	500 – 2000 m^3	875 m^3
DV 4	Hull Material Type	1. Steel 2. Aluminum	2. Aluminum
DV 5	Deckhouse Material Type	1. Steel 2. Aluminum	2. Aluminum
DV 6	Collective Protection System	1. Full Ship 2. Partial Ship 3. None	2. Partial
DV 7	Propulsion System Type	1. 2 LM2500, 3 3000kw SSGTG, 2 225SII waterjets, mech. 2. 3 LM2500, 3 3000kw SSGTG, 3 225SII waterjets, mech. 3. 2 LM2500, 1 3000kw SSGTG, 2 225SII waterjets, IPS 4. 3 LM2500, 1 3000kw SSGTG, 3 225SII waterjets, IPS 5. 2 LM2500, 1 3000kw SSGTG, 3 225SII waterjets, IPS 6. 4 LM2500, 1 3000kw SSGTG, 3 225SII waterjets, IPS 7. 2 LM2500, 1 3000kw SSGTG, 3 225SII waterjets, IPS	1. 2 LM2500 3 3000 kw SSGTG 2 225SII waterjets mechanical
DV 8	Degaussing System	1. Yes 2. No	1. Yes
DV 9	Manning and Automation Factor	0.5 – 1.0	0.5
DV 10	MCM Alternative	1(Goal), 2, 3, 4(Threshold)	2
DV 11	ASUW Alternative	1(Goal), 2, 3, 4(Threshold)	3
DV 12	AAW Alternative	1(Goal), 2, 3(Threshold)	3 (Threshold)
DV 13	ASW Alternative	1(Goal), 2(Threshold)	2 (Threshold)
DV 14	LAMPS Alternative	1(Goal), 2, 3, 4(Threshold)	2
DV 15	VTUAV Alternative	1(Goal), 2(Threshold)	1 (Goal)
DV 16	SPARTAN Alternative	1(Goal), 2, 3(Threshold)	2
DV 17	Provisions Duration	1. 24 days 2. 14 days	1. 24 days

Table 32 - Concept Exploration Weights and Vertical Center of Gravity Summary

Group	Weight	VCG
SWBS 100	1119 MT	5.53 m
SWBS 200	346 MT	3.05 m
SWBS 300	178 MT	5.73 m
SWBS 400	118 MT	8.80 m
SWBS 500	195 MT	6.70 m
SWBS 600	129 MT	6.12 m
SWBS 700	17 MT	10.95 m
Loads	549 MT	2.94 m
Lightship	2103 MT	5.51 m
Lightship w/Margin	2208 MT	
Full Load w/Margin	2800 MT	5.74 m

Table 33 - Concept Exploration Area Summary

Area	Required	Available
Total-Arrangeable	1752.6 m^2	2218.6 m^2
Hull	1521.4 m^2	1885.3 m^2
Deck House	231.2 m^2	233.3 m^2

Table 34 – Concept Exploration Electric Power Summary

Group	Description	Power
SWBS 200	Propulsion	225 kW
SWBS 300	Electric Plant, Lighting	70 kW
SWBS 430, 475	Miscellaneous	101 kW
SWBS 521	Firemain	32 kW
SWBS 540	Fuel Handling	53 kW
SWBS 530, 550	Miscellaneous Auxiliary	57 kW
SWBS 561	Steering	51 kW
SWBS 600	Services	34 kW
CPS	CPS	44 kW
KW_{NP}	Non-Payload Functional Load	643 kW
KW_{MFLM}	Max. Functional Load w/Margins	1440 kW
KW_{24}	24 Hour Electrical Load	733 kW

Table 35 - MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Value of Performance
MOP 1	Core MCM	0.8
MOP 2	MCM Modules	0.8
MOP 3	LAMPS	0.7
MOP 4	SPARTAN	0.7
MOP 5	VTUAV	1
MOP 6	C4ISR	1
MOP 7	Core SUW	0.2
MOP 8	Core ASW	0
MOP 9	Core AAW	0
MOP 10	Sprint Range	0.017
MOP 11	Endurance Range	0.051
MOP 12	Provisions	1
MOP 13	Sprint Speed	0
MOP 14	Draft	0.379
MOP 15	Loiter Seakeeping	1
MOP 16	Structural	0
MOP 17	Personnel	0.16
MOP 18	Damage Stability	1
MOP 19	CBR	1
MOP 20	RCS	1
MOP 21	Acoustic	0
MOP 22	IR	0
MOP 23	Magnetic	1
OMOE	Overall Measure of Effectiveness	0.586
OMOR	Overall Measure of Risk	0.691

Table 36 - Concept Exploration Baseline Design Principal Characteristics

Characteristic	Baseline Value
Hull form	Trimaran
Δ (MT)	2800
LWL (m)	131.24
Beam (m)	32.47
Draft (m)	4.368
D10 (m)	10.411
Displacement to Length Ratio, $C_{\Delta L}$ (lton/ft^3)	6.4
Beam to Draft Ratio, C_{BT}	7.43
W1 (MT)	1119
W2 (MT)	346
W3 (MT)	178
W4 (MT)	118
W5 (MT)	195
W6 (MT)	129
W7 (MT)	17
Wp (MT)	369
Lightship Δ (MT)	2208
KG (m)	5.735
GM/B=	0.6618
Propulsion system	Mechanical drive w/ epicyclic gears 2 x 225SII waterjets 2 x LM2500+ 3 x 3000kw SSGTG
Engine inlet and exhaust	Stern
MCM system	NDS 3070 Vanguard Mind Avoidance Sonar, 2 Remote Minehunting Systems, 1 Small UUV Detachment, SH-60 ALMDS & AQS-20 Module, SH-60 AMDS & RAMICS Module, Single SH-60 PUK Module
ASW system	LAMPS MK3 SH-60 Seahawk Helo, AN/SLQ-25 NIXIE
ASUW system	AN/SPS-73 Surface Search Radar, Sea Star SAFIRE II FLIR, 57mm MK3 Naval Gun, 7m RHIB
AAW system	SEA GIRAFFE AMB RADAR, MK XII AIMS IFF, MK 16 CIWS, Combined MK 53 SRBOC & NULKA LCHR, Advanced SEW System, (AIEWS), AN/SLQ-32(V)3
Average deck height (m)	2.55
Hangar deck height (m)	6
Total Officers	13
Total Enlisted	74
Total Manning	87
Number of SPARTANs	2
Number of VTUAVs	3
Number of LAMPS	1
Ship Acquisition Cost	$481M (2003$)
Life Cycle Cost	$957M (2003$)

4 Concept Development (Feasibility Study)

Concept Development of ASC follows the design spiral, Figure 3, in sequence after Concept Exploration. In Concept Development the general concepts for the hull, systems and arrangements are developed. These general concepts are refined into specific systems and subsystems that meet the requirements of ASC. Design risk is reduced by this analysis and parametrics used in Concept Exploration are validated.

4.1 General Arrangement and Combat Operations Concept (Cartoon)

As a preliminary step in finalizing hull form geometry, deck house geometry, and all general arrangements, an arrangement cartoon was developed for areas supporting mission operations, propulsion, and other critical constrained functions. VTUAV, SPARTAN, and LAMPS operation and support were primary considerations throughout arrangement development. The dimensions of the VTUAVs, SPARTANs, and LAMPS, and their required equipment for operation and support are based on the most accurate data available. These dimensions were used to arrange combat alternatives in the hangar and mission bay areas. Scaled layouts of the hangar, flight deck, and the mission bay areas are shown in Figure 47 through 51. Since this ship is designed with a wave piercing tumble home hull form, the usable deck area at the bow is limited. Also, the 10 degree angled sides necessary to minimize radar cross-section decrease the beam of each successive deck moving higher in the ship.

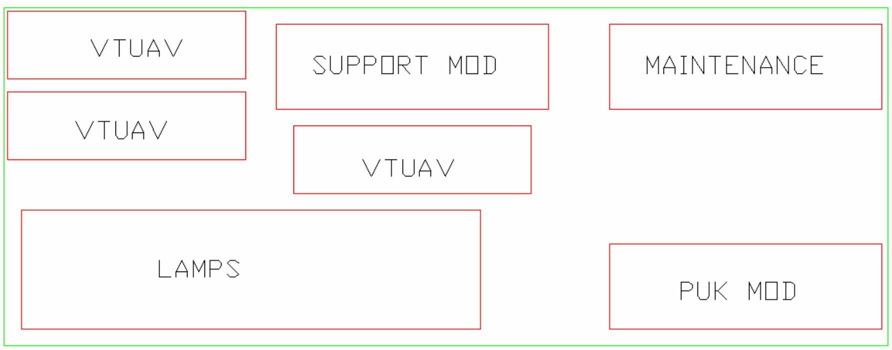

Figure 47 - Hangar Bay Lower Level Arrangement

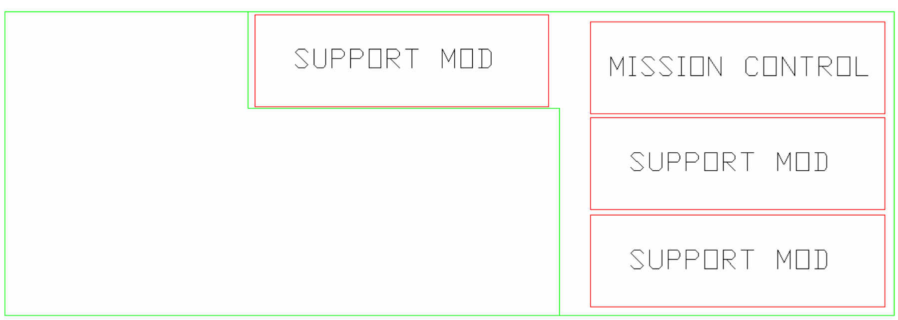

Figure 48 - Hangar Bay Upper Level Arrangement

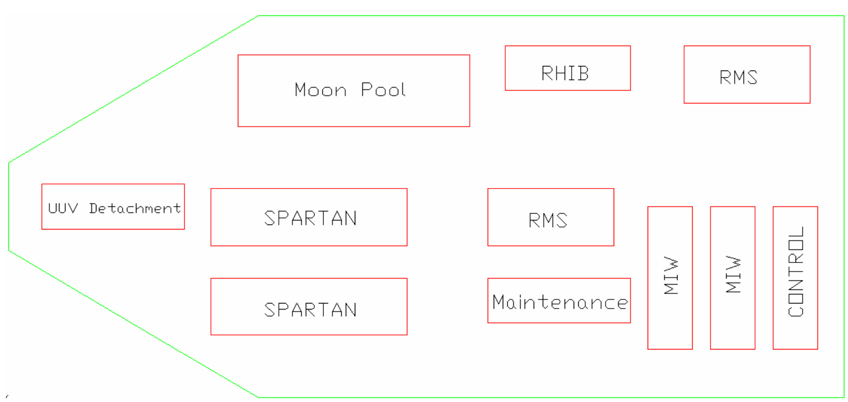

Figure 49 - Mission Bay Arrangement

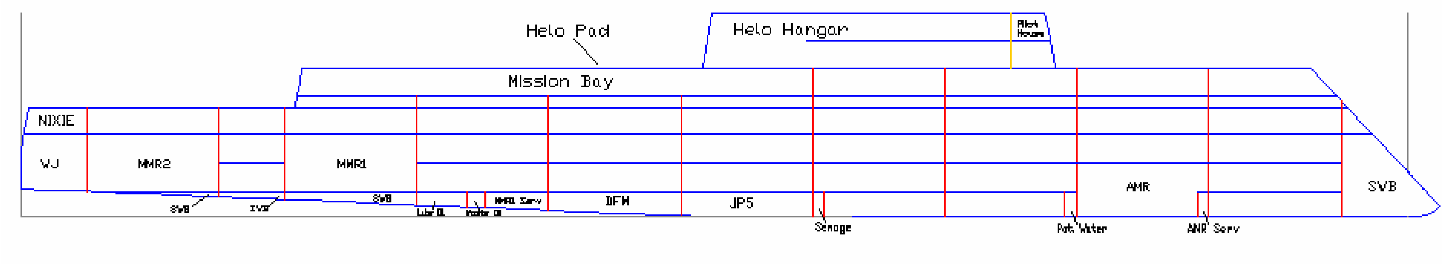

Figure 50 - Profile (Cartoon)

4.1.1 Mission Operations

The combat system payloads are accommodated in the hangar at flight deck level enclosed in the deck house and in a mission bay located under the flight deck. The hangar houses the HELO, three VTUAVs, and all necessary maintenance, support, and operational equipment. A second level was created forward in the hangar that only partially covers the lower level. This allows the hangar to accommodate all the necessary equipment with sufficient overhead space for the SH-60 helo. The mission bay located under the flight deck houses the two SPARTANs, the 7m RHIB, two RMS detachments, a UUV detachment, and all of their required operation and support equipment. The mission bay has a moon pool for launching and recovering vehicles and boats that is located between the center hull and the port side hull. This is a sheltered and minimum motion location ideal for launching these craft.

4.1.2 Machinery Room Arrangements

There are two Main Machinery Rooms, MMR#1 and MMR#2, and an Auxiliary Machinery Room (AMR). Both MMR#1 and MMR#2 contain one LM2500+ and one 3000kw SSGTG. The AMR contains the third 3000kw SSGTG. Both of the MMRs are located aft of amidships with MMR#1 just forward of MMR#2. Main engines use side air intakes and exhausts. This prevents impacts on the available area in the mission bay and protrusions on the flight deck that would be affected by top exhaust. The side intakes and exhausts use louvered panels with a plenum to prevent water entry and maintain the 10 degree tumblehome.

4.2 Hull Form and Deck House

4.2.1 Hullform

The baseline hullform used in Concept Exploration is a geosim based on the R/V Triton hullform. This baseline hullform is modified in concept development by widening the transom to accommodate waterjets (Triton has propellers). Other changes include narrowing the center hull beam, shortening the distance between the outer hulls and center hull, creating a fan tail by removing the top deck of the aft of the ship to reduce weight, adding a wave piercing tumble home bow, and modifying all structure above the waterline to an angle of 10 degrees to reduce radar cross section. The hull form dimensions are re-optimized and balanced to consider these changes. Table 37 compares the concept development HI2 hullform to the baseline hullform.

Table 37 - ASC HI2 Hullform Characteristics

	Baseline	ASC HI2
LWL	131.24 m	126.29 m
B	32.47 m	24.88 m
T	4.368 m	4.21 m
D_{10}	10.41 m	10.05 m
Δ	2800 MT	2825 MT

A body plan view of the HI2 alternative is shown in Figure 51. The hullform above the waterline is modified to have a tumblehome of ten degrees to reduce radar cross section (RCS). Figure 52 is an isometric view of the widened transom that accommodates the two waterjets. The wave piercing tumble home (WPTH) hull form, seen in Figure 53, also helps to reduce radar cross section and decrease wave resistance. A hard chine was created just above the waterline where single curvature or flat angled plates on the side of the ship meet the round bilge radius. This improves the producibility of the design. The transom also has a ten degree incline to reduce RCS.

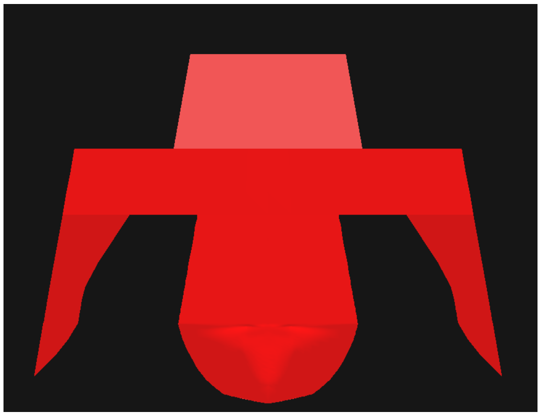

Figure 51 - ASC HI2 Body View

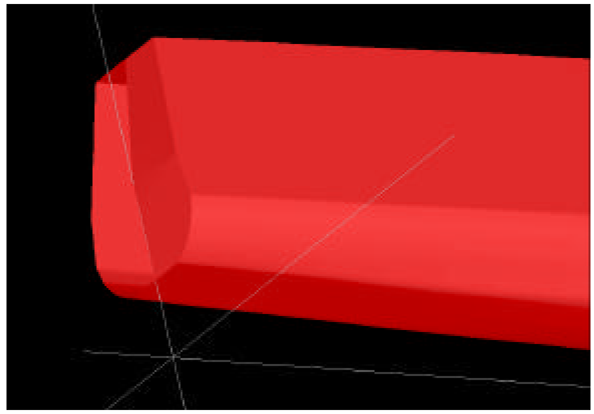

Figure 52 - ASC HI2 Isometric View of Transom

The bow is raked back to 47 degrees as shown in Figure 53 to give good wave-piercing qualities. This angle and shape were estimated based on expert opinion and comparison to pictures and drawings of wave-piercing tumblehome hull forms in the literature.

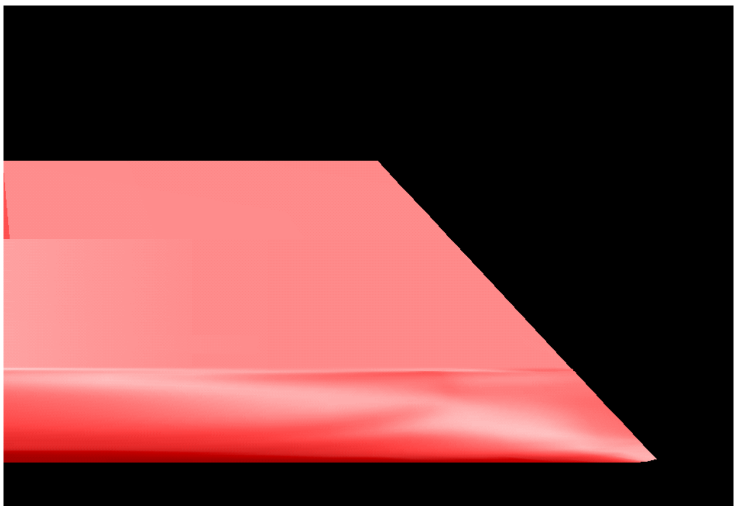

Figure 53 - Profile close-up of bow section

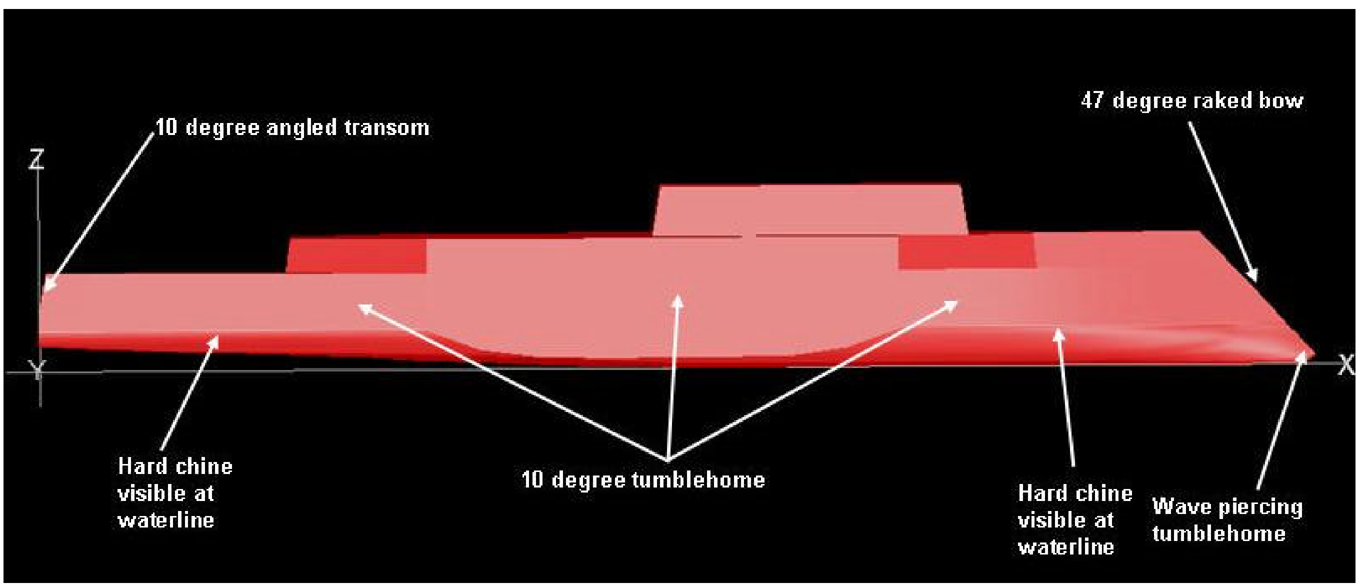

Figure 54 - ASC HI2 wave piercing tumblehome in profile view

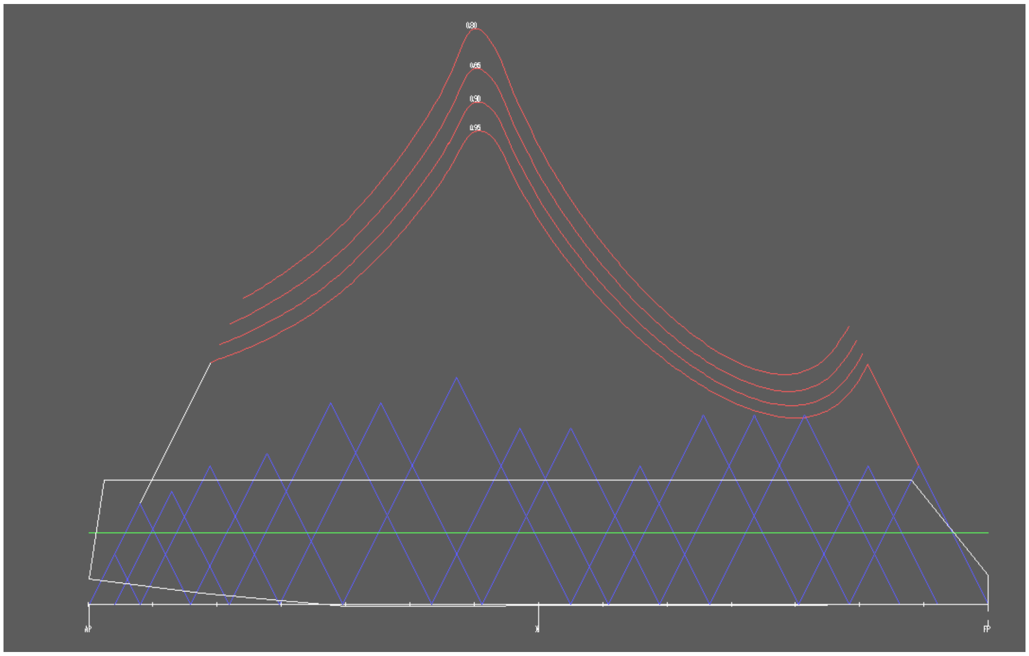

Figure 55 - Floodable Length Curve

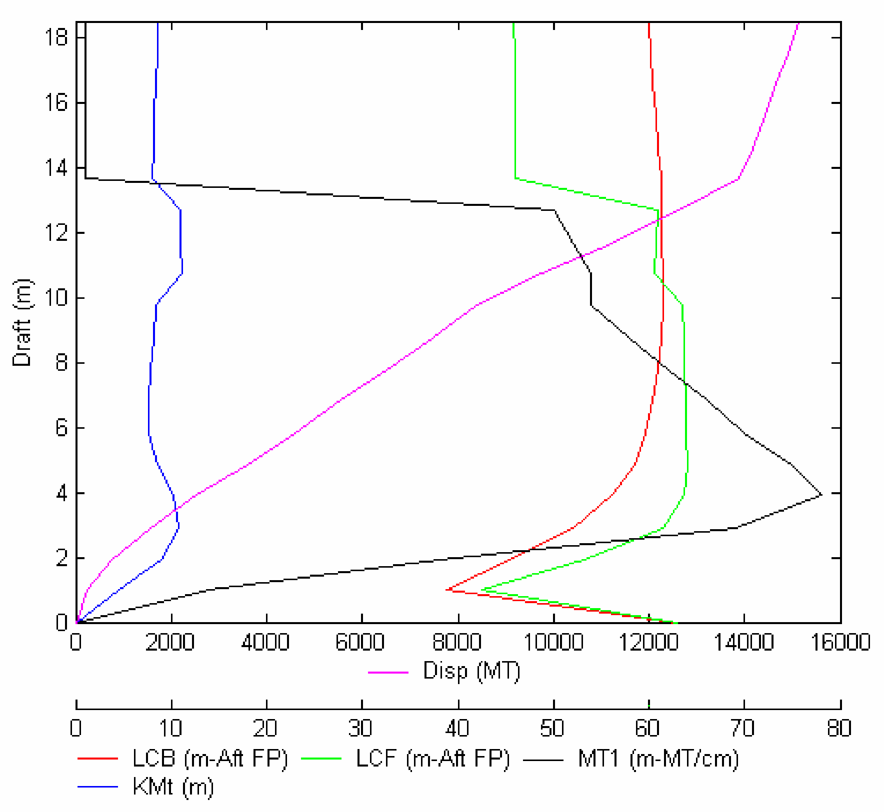

Figure 56 - Curves of Form

4.2.2 Deck House

The aviation hangar, pilot house, chart room and flight control are located in the deckhouse. The aviation hangar houses the LAMPS, VTUAVs, and their support modules and containers. The pilot house (bridge) is located in the forward upper corner of the deckhouse as shown in Figure 57. This location provides necessary forward visibility. Flight and Recovery Control is located in the aft end of the deckhouse. The flight control space supports LAMPS and VTUAV operations.

Radar and other antennas are housed in the ASC-HI2's Advanced Enclosed Mast/Sensor (AEMS). This tower is located forward on top of the deckhouse. It has a footprint of 65 m^2 in an octagonal shape that flares inward on all sides at an angle of 10 degrees to a minimum area of 44 m^2 to reduce RCS. Figure 58 is a profile view of the AEMS showing deck heights. The upper deck contains the SPS-73, the surface search/navigational radar. The height and width of this deck is governed by the size of the SPS-73. The lower deck contains the SLQ-32. The upper deck external shell is constructed with an advanced hybrid frequency-selective surface that allows ASC-HI2's own radar in and out, but not foreign radar.

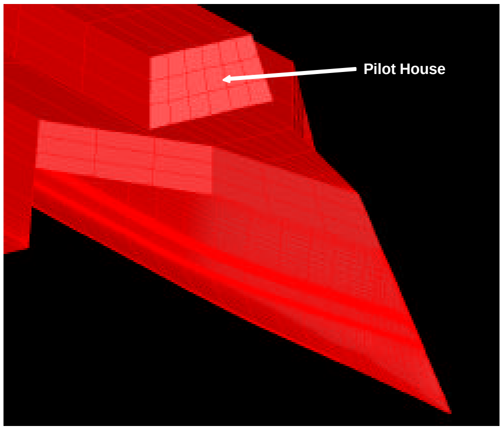

Figure 57 - Pilot House Location

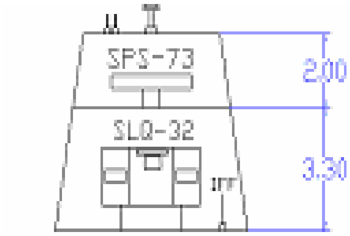

Figure 58 - Advanced Enclosed Mast/Sensor (AEMS)

4.3 Structural Design and Analysis

The structural design process for ASC HI2 is illustrated in Figure 59.

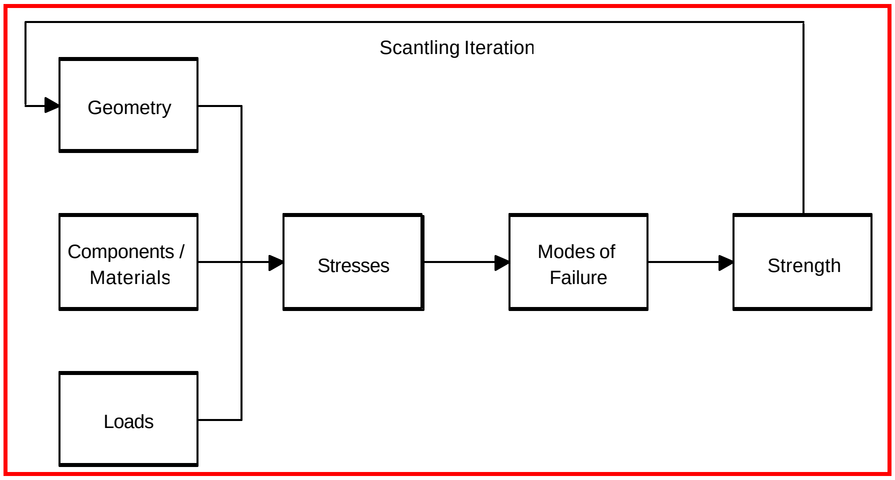

Figure 59 - ASC Structural Design Process

4.3.1 Geometry, Components and Materials

The geometry is modeled in MAESTRO, a coarse-mesh finite element solver with the additional ability to assess individual failure modes. After assessing adequacy, a few iterations of scantling changes to correct inadequacies and reduce weight were performed.

A three-dimensional mesh of ASC-HI2's hullform is created in FASTSHIP. This mesh is imported into MAESTRO. The coordinate axes are adjusted such that the origin is coincident with the aft perpendicular of the imported mesh and the X-axis is positive in the forward direction, the Y-axis is positive vertically upward, and the Z-axis was positive in the starboard direction. Using the vertices of the imported mesh as reference points, the hull panel endpoints are created in MAESTRO. Figure 61 shows the completed MAESTRO model.

ASC-HI2 is a longitudinally-stiffened ship with transverse frames every 1.5 meters. Initial scantlings are chosen based on similar designs. Figure 60 shows the midship section, and Figure 62 shows the ASC-HI2 midship module. The structure is similar to a traditional single hull design with decks and side shells supported by longitudinal stiffeners, girders, and transverse frames with tee-shaped cross-sections. Deep deck beams and pillars are used to support the flight deck. A transverse web cross-structure is used to connect the centerhull to the sidehulls, and resist transverse loads. This structure also provides space for piping and wire ways.

Figure 63 shows the interior of the MAESTRO model. ASC-HI2 has one full deck above the damage control deck and two platform decks below the damage control deck. The platform decks are not continuous through the machinery rooms. There is one centerline bulkhead in the ship, separating the waterjets, shafts and motor rooms for survivability. The model includes two substructures, each with ten individual modules. The ASC-HI2 is modeled such that each module spans the entire beam of the ship.

Al5456-H116 aluminum was selected for the hull plating, decks, transverse bulkheads, etc. Al5456-H112 was selected for the girders, frames, and stiffeners. A standard catalog of shapes and plate thicknesses was developed using I-Ts, Ts, and a limited number of fabricated shapes. The catalog was kept as small as possible to maximize producibility. ASC-HI2 uses an aluminum sandwich panel as shown in Figure 64 for the flight deck. The sandwich panel provides significant out-off plane stiffness and is very resistant to point loads (helicopter wheels). It effectively replaces a thick steel flight deck.

Stiffener	Material	Web Height	Web Thick-ness	Flange Width	Flange Thick-ness
T80	Al5456-H112	0.0738m	0.0045m	0.045m	0.0062m
T100	Al5456-H112	0.0936m	0.005m	0.05m	0.0064m
T120	Al5456-H112	0.1123m	0.0055m	0.055m	0.0077m
T140	Al5456-H112	0.1313m	0.006m	0.06m	0.0087m
T200	Al5456-H112	0.2m	0.01m	0.1m	0.012m
T500	Al5456-H112	0.5m	0.02m	0.2m	0.025m
Pillar	Al5456-H112	Outer Dia: 0.175m		Thickness: 0.02m	

Plate	Material	Thickness
Bottom	Al5456-H116	0.015m
Side	Al5456-H116	0.01m
Internal Deck	Al5456-H116	0.008m
Floor	Al5456-H116	0.015m
Bulkhead	Al5456-H116	0.01m
CVK	Al5456-H116	0.015m
Sandwich Panel	Al5456-H116	0.031m

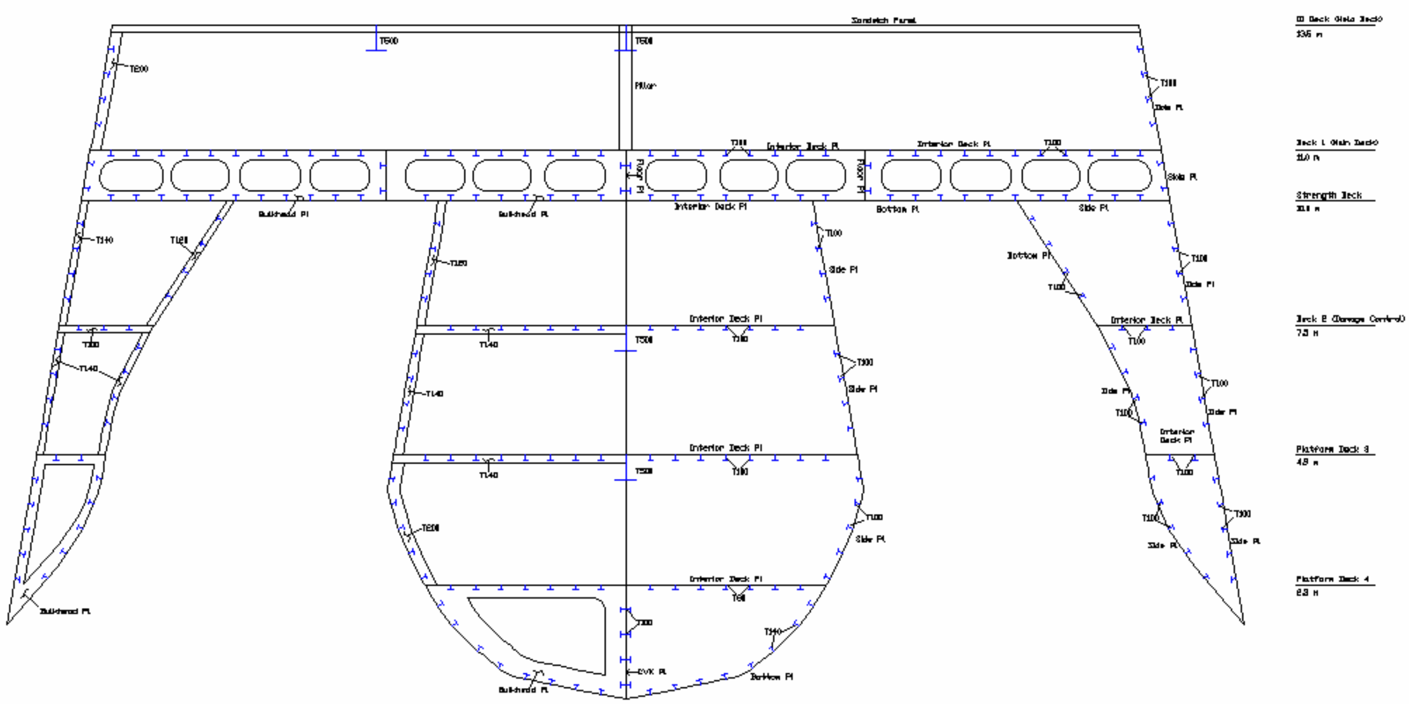

Figure 60 - ASC-HI2 Midship AutoCAD Structure Section

4.3.2 Loads

Load cases were applied in MAESTRO using equivalent waves to meet or exceed longitudinal bending moment requirements calculated using the ABS Guide for Building and Classing High Speed Naval Craft, 2003 (multi-hull ships). ABS-required bending moments, other loads and requirements are listed in Table 38. The weight distribution curve and still water bending moment curve developed for ASC-HI2 are shown in Figure 65 and Figure 66. Equivalent wave hogging and sagging load cases, transverse bending moments, helicopter deck loading, internal deck pressures, and water on deck/green seas deck pressures are evaluated. The equivalent bending moment curves for the longitudinal bending cases are shown in Figure 67 and Figure 68. The required transverse bending moment is achieved by applying equivalent side hull pressures as shown in Figure 69.

4.3.3 Adequacy

MAESTRO calculates stresses for each load case and compares them to limit state values for various failure modes. Stress divided by failure stress for various modes of failure results in a strength ratio, r. This value can range between zero and infinity. An adequacy parameter is defined as: $(1 - r)/(1 + r)$. This parameter is always between negative one and positive one. A negative adequacy parameter indicates that an element is inadequate, a positive value indicates that it is over-designed, and a value of zero indicates that it exactly meets the requirement with a specified factor of safety. At this level of analysis, the main objective is to make as many of the adequacy parameters as close to zero as possible while staying on the positive side. In a more detailed analysis, the objective would be to adjust the scantlings throughout the ship such that all adequacy parameters were zero, again staying on the positive side. A safety factor of 1.25 is used for serviceability limit states and 1.5 for collapse limit states.

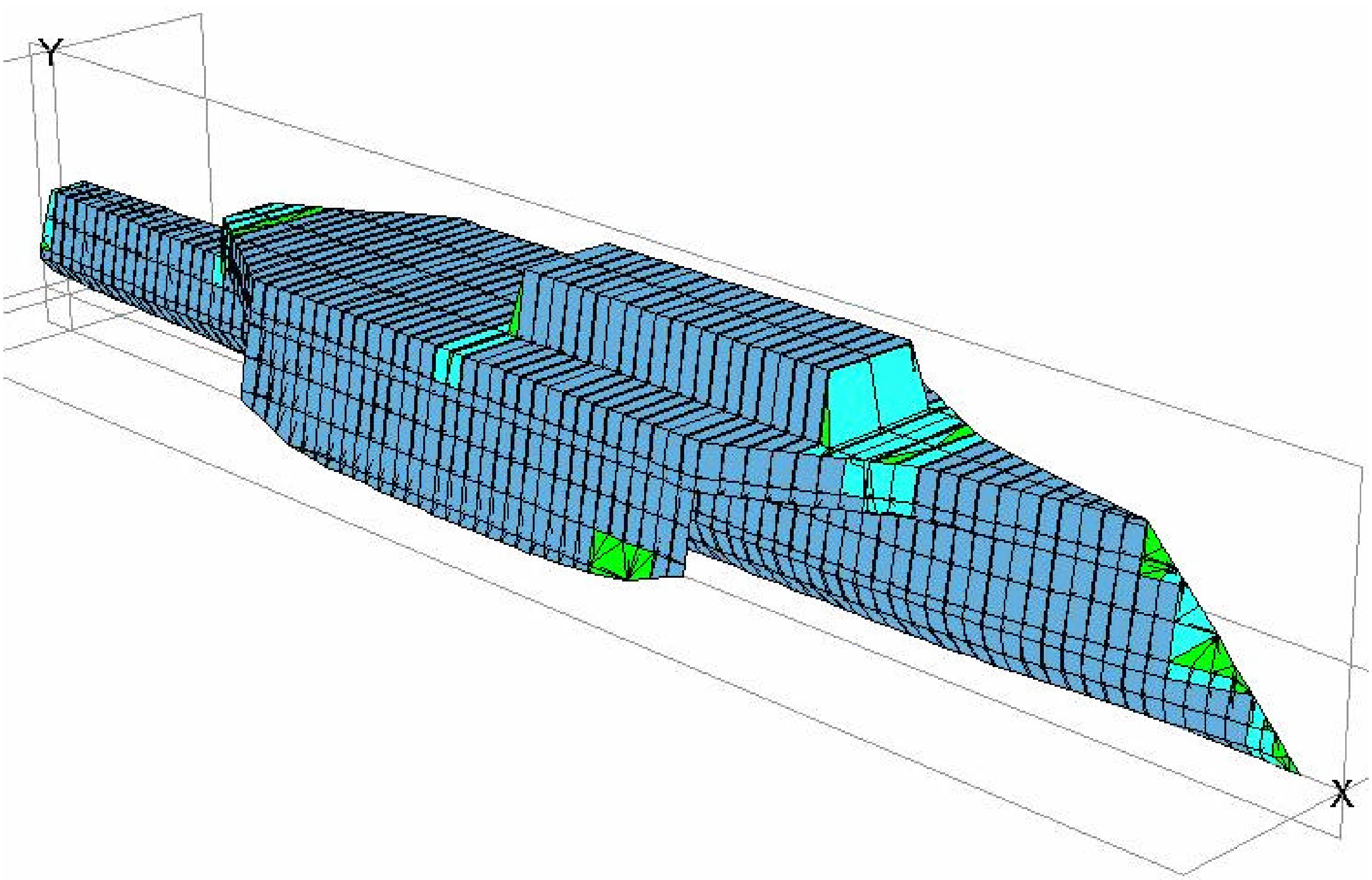

Figure 61 - ASC-HI2 MAESTRO Model

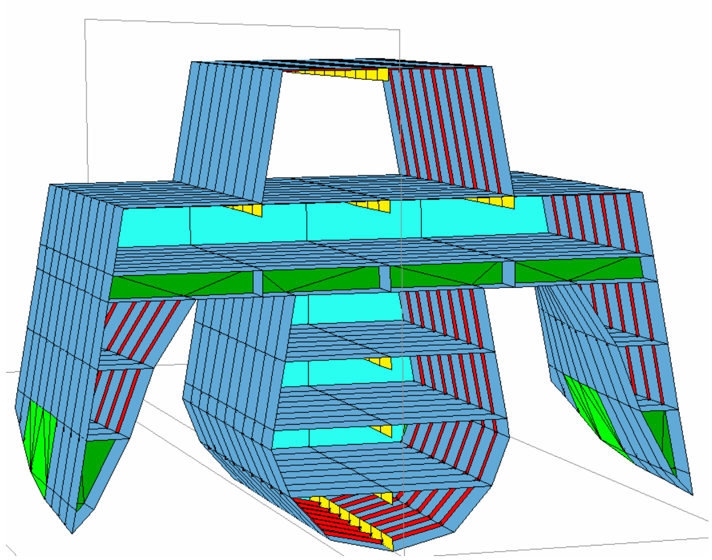

Figure 62 - ASC HI2 Midship MAESTRO Model

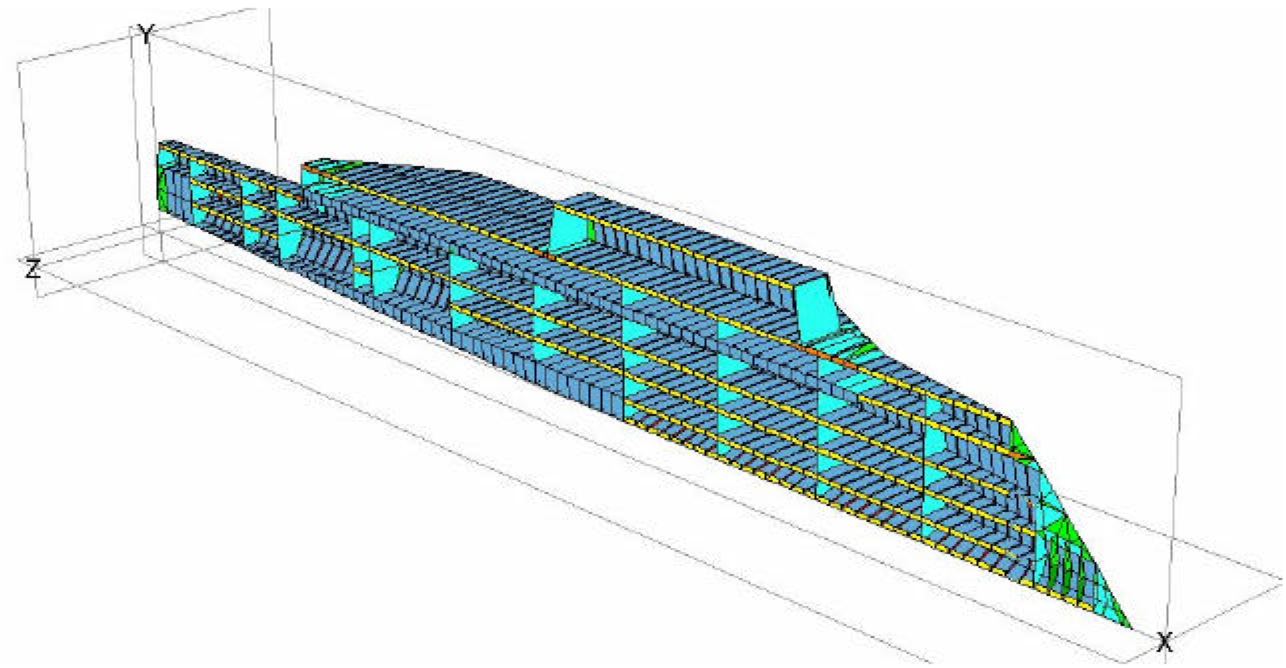

Figure 63 - Interior of MAES TRO model

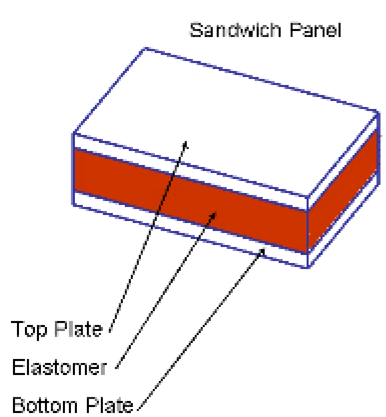

Figure 64 - Sandwich Panel used for Flight Deck

Table 38 - ABS Load Requirements for ASC-HI2

Wave Sagging Longitudinal Bending Moment	-252965.39 kN-m
Wave Hogging Longitudinal Bending Moment	201664.72 kN-m
Still Water Sagging Longitudinal Bending Moment	0.00 kN-m
Still Water Hogging Longitudinal Bending Moment	150916.85 kN-m
Slamming and Dynamic Longitudinal Bending	1478364.87 kN-m
Largest Combine Longitudinal Bending Moment	1478364.87 kN-m
Transverse Bending Moment	158551.99 kN-m
Torsional Bending Moment	1478364.87 kN-m
Weather Deck Loads (0-25m aft of FP)	32.8 N/m^2
Weather Deck Loads (25 m aft of FP to AP)	18.7 N/m^2
Internal Deck Loads	5.00 kN/m^2
Required Section Modulus at Midship	31811.27 cm^2-m
Required Moment of Inertia at Midship	968424.99 cm^2–m

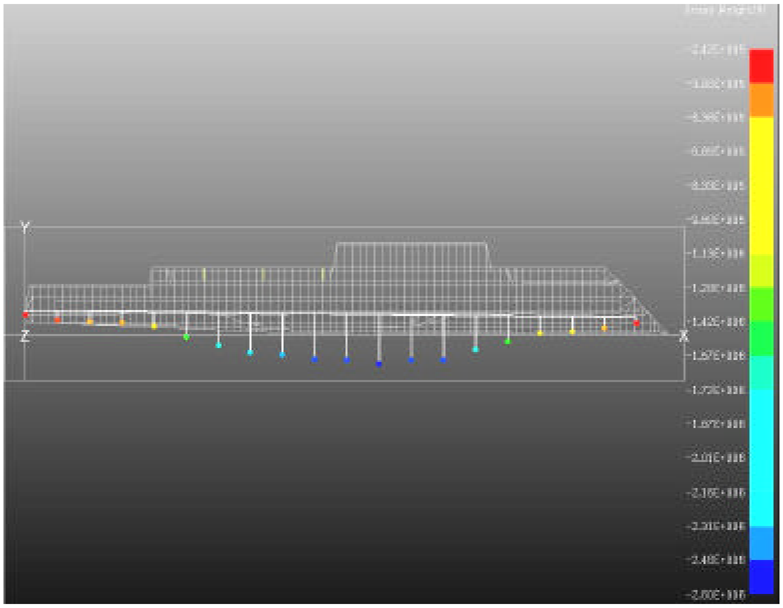

Figure 65 - Full Load Stillwater Weight Distribution in MAESTRO

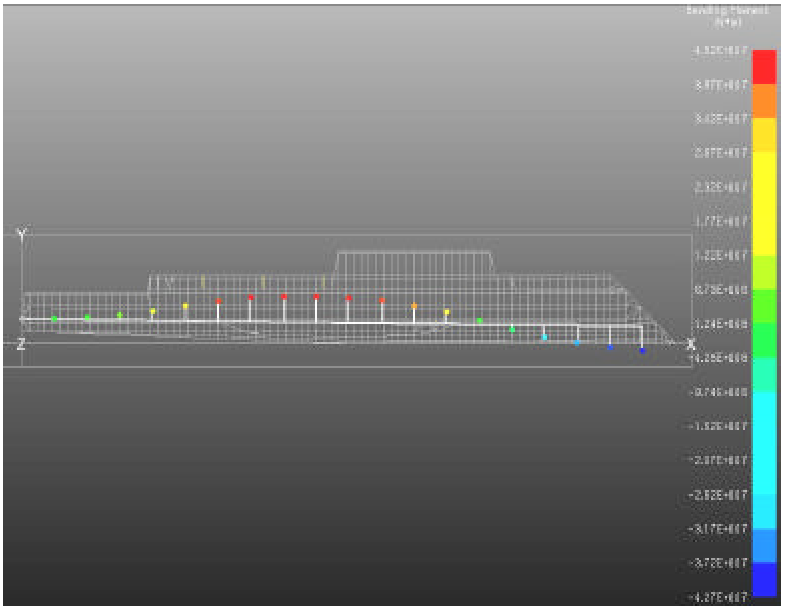

Figure 66 - Stillwater Bending Moment

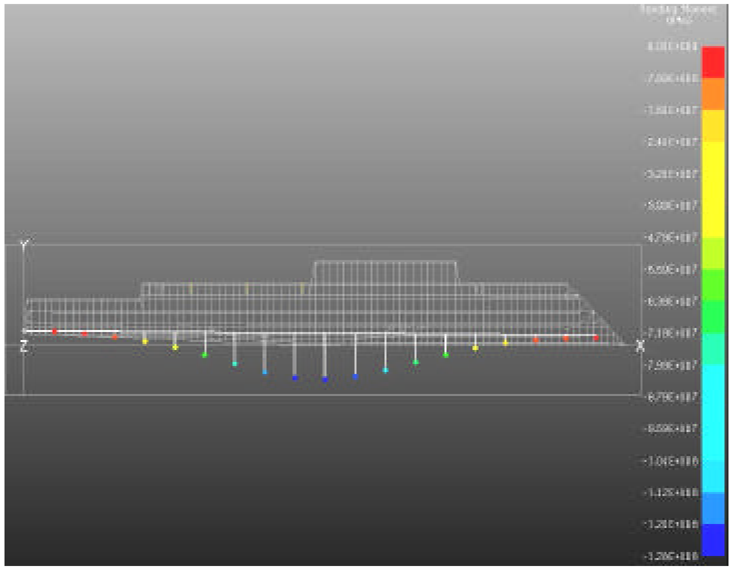

Figure 67 - Bending moment diagram for the ABS hogging load case

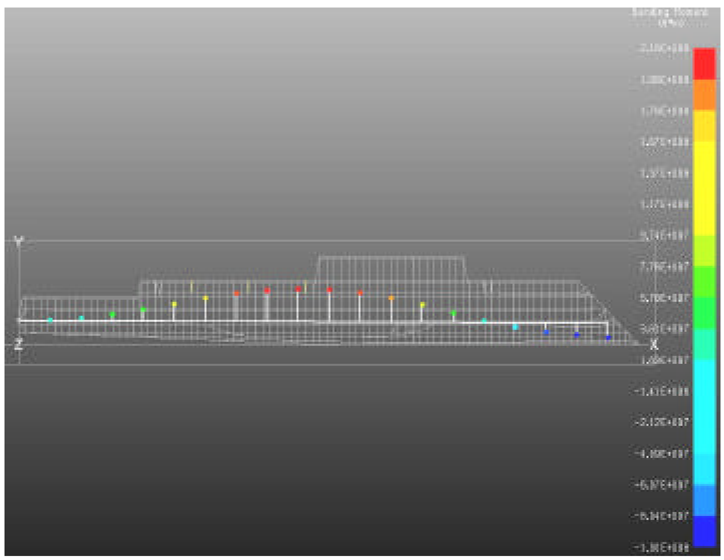

Figure 68 - Bending moment diagram for the ABS sagging load case

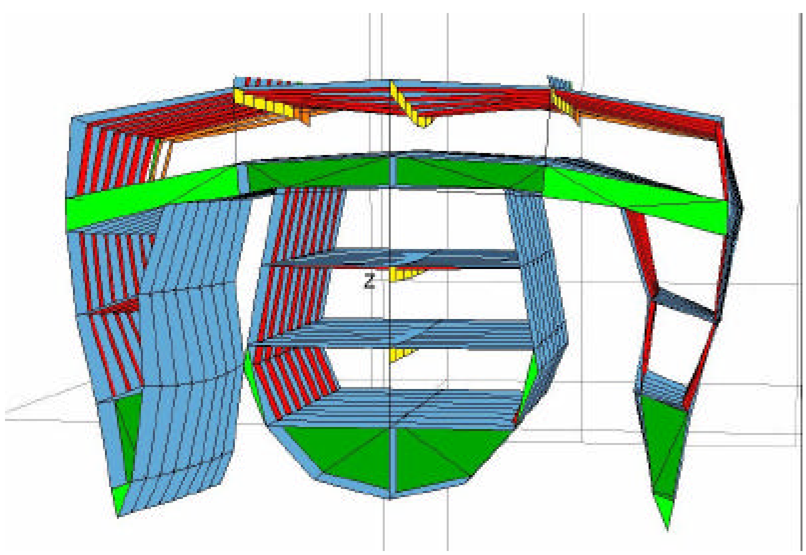

Figure 69 – Deformation (Exaggerated) for Equivalent Side Pressures Modeling Transverse Bending Moment

ASC-HI2 adequacy parameters, Figure 70 and Figure 71, show the minimum values for plate and beam failure modes for all load cases.

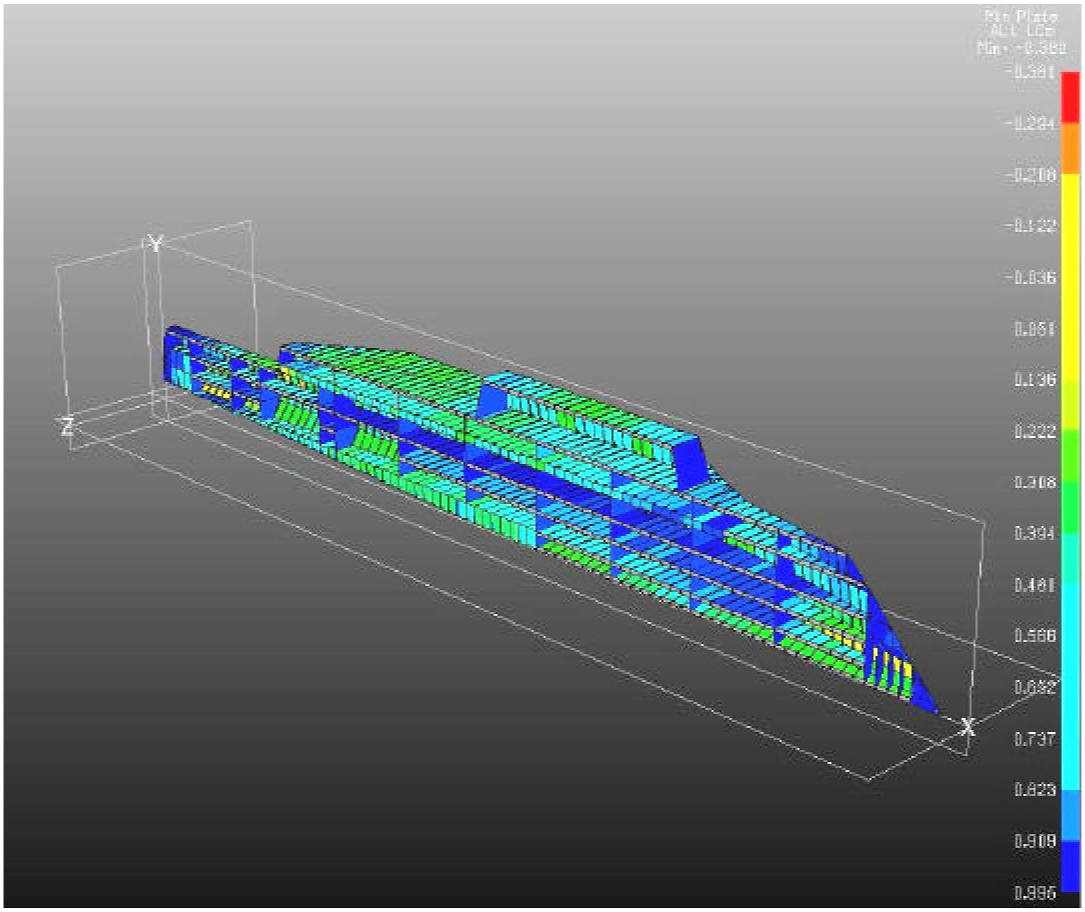

Figure 70 - Plate adequacy - Minimum values for all load cases

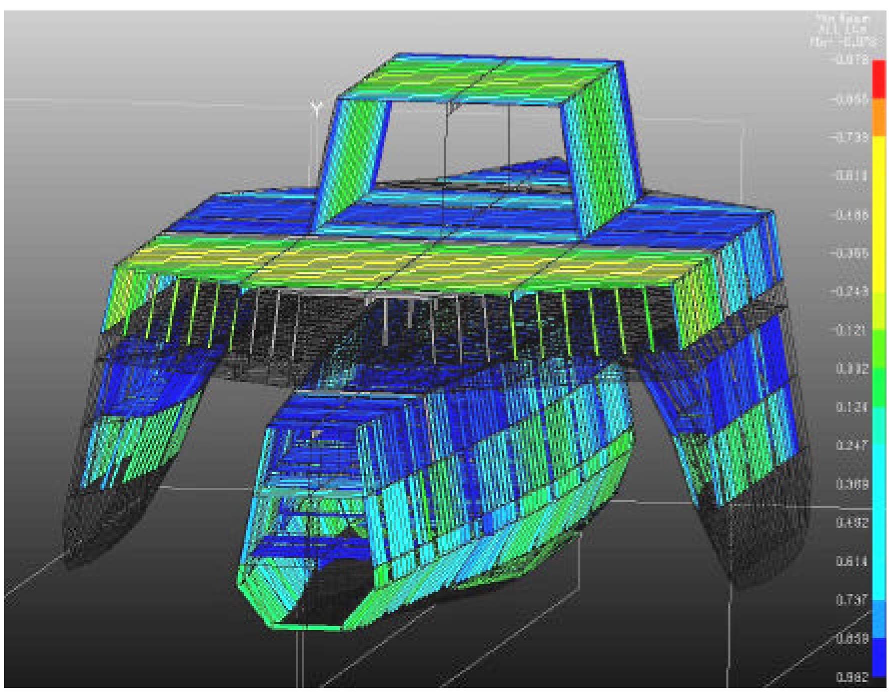

Figure 71 - Beam Adequacy – Minimum values for all load cases

4.4 Power and Propulsion

ASC-HI2 uses a mechanical drive system for primary propulsion, an Integrated Power System (IPS) for secondary propulsion, and IPS for ship service power. The mechanical drive system is used for speeds above 14 knots. The IPS is used when the ship is operating below 14 knots.

4.4.1 Resistance

Resistance, speed and power calculations are performed using NAVCAD. NAVCAD requires input of hull characteristics, speed, wind and wave conditions, propulsor (waterjet) characteristics, and engine characteristics. The Holtrop-Mennen method is used for a preliminary estimate of ASC HI2's resistance. Speeds between 5 and 43 knots are considered. NAVCAD does not have the direct capability of performing these calculations for a trimaran, so both the center hull and side hulls are modeled as monohulls with a 10% resistance margin added for multi-hull interaction. An additional 10% margin is added for the endurance speed/fuel calculation and a 25% margin is added for the sustained speed calculation. Figure 72 is the resistance vs. speed curve. Figure 73 is the speed/power curve.

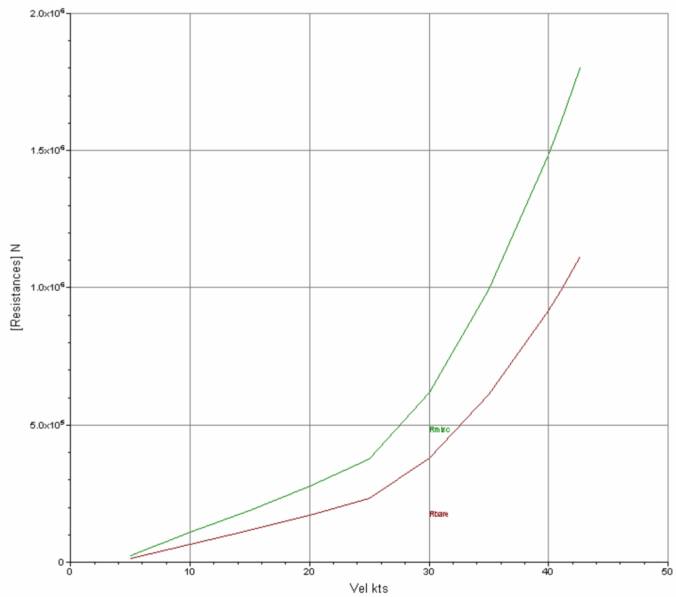

Figure 72 - Resistance vs. Speed Curve

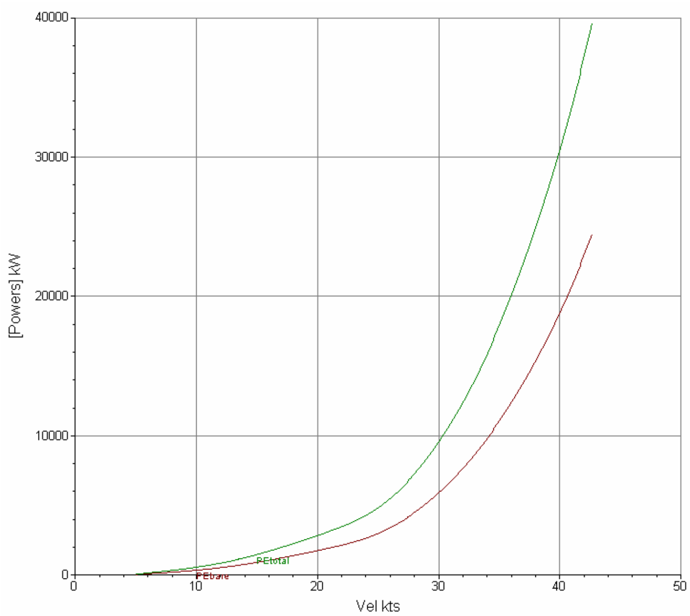

Figure 73 - Power vs. Speed Curve

4.4.2 Propulsion

Two 225SII Kamewa Waterjets, Figure 10, are used for propulsion in ASC-HI2. Each has an impeller diameter of 2.25 meters and a nozzle diameter of 1.5 meters. Maximum impeller speed is 300 RPM, and maximum power is 27000 kW. Figure 11 and Figure 12 provide performance data for this family of waterjets. A waterjet model was created in NAVCAD, Figure 74, using this data.

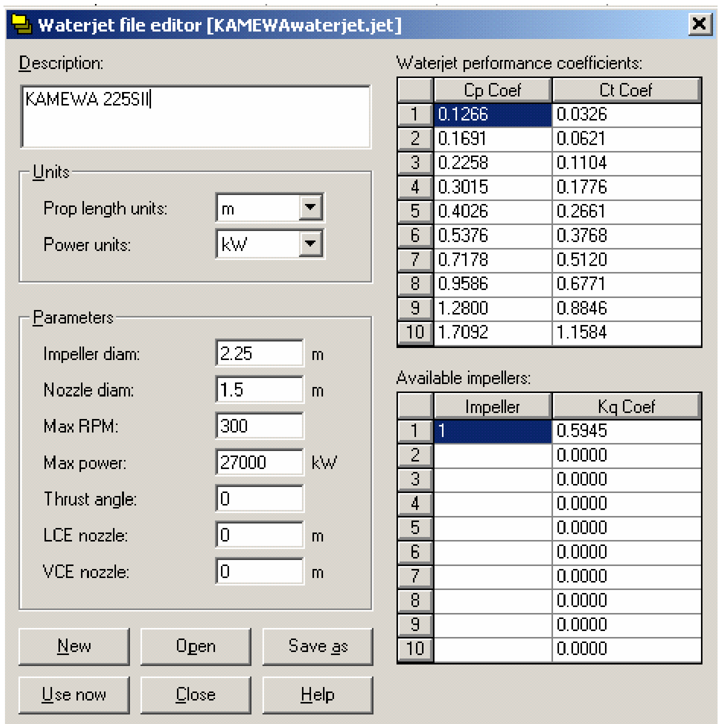

Figure 74 - 225SII Kamewa waterjet file in NAVCAD

Each waterjet is driven by an LM2500+ engine with epicyclic reduction gear operating with a reduction gear ratio of 11.7. A gear efficiency of 0.99 and a shaft efficiency of 0.99 are assumed, for an overall transmission efficiency of 0.98. Each LM2500+ has a maximum speed of 3600 RPM. An engine performance model, Figure 75, was generated in NAVCAD using data from the LM2500+ performance map.

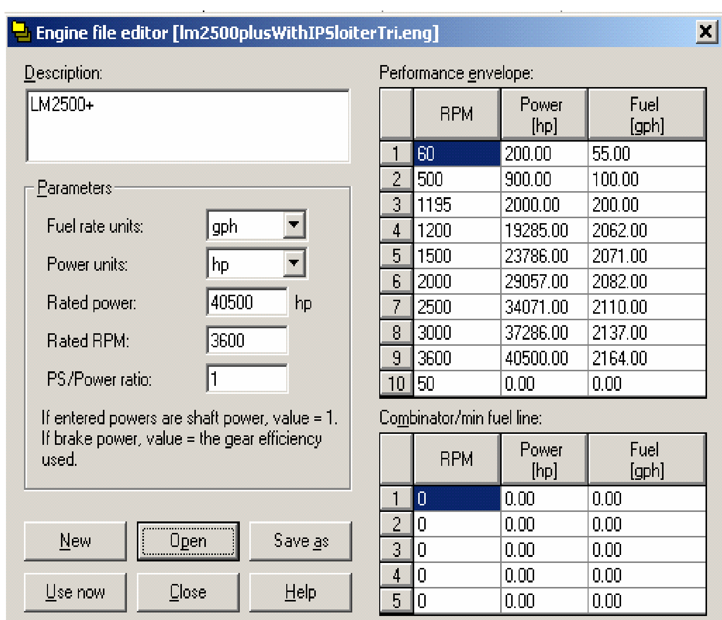

Figure 75 - LM2500+ engine file in NAVCAD

Figure 76 shows shaft propulsion power vs. engine speed (RGratio = 11.7) superimposed on the engine performance (power vs. speed) curve with points indicating resulting ship speed. This is the ship speed/power curve including the 25% sustained speed margin. The reduction gear ratio is adjusted for a maximum sustained speed of 42.7 knots. Figure 77 is the shaft propulsion power vs. engine speed curve with the 10% endurance speed margin. This curve is extended below 14 knots and engine idle speed. Two 2500 kW IPS AC propulsion motors are used in this region to provide better efficiency and slower speeds. They are connected to the shafts by geared drives with clutches. The motor drive clutches are engaged and loaded automatically at low speeds. The LM2500+ engines are clutched out and shut down at these speeds. Single waterjet LM2500+ operation at speeds down to 10 knots is also possible. Reverse thrust is achieved using the waterjet reverse buckets with engines or motors. The SSGTGs provide power for the IPS system and two motors. A more complete propulsion system description and arrangements are provided in Section 4.5 and 4.7.2.

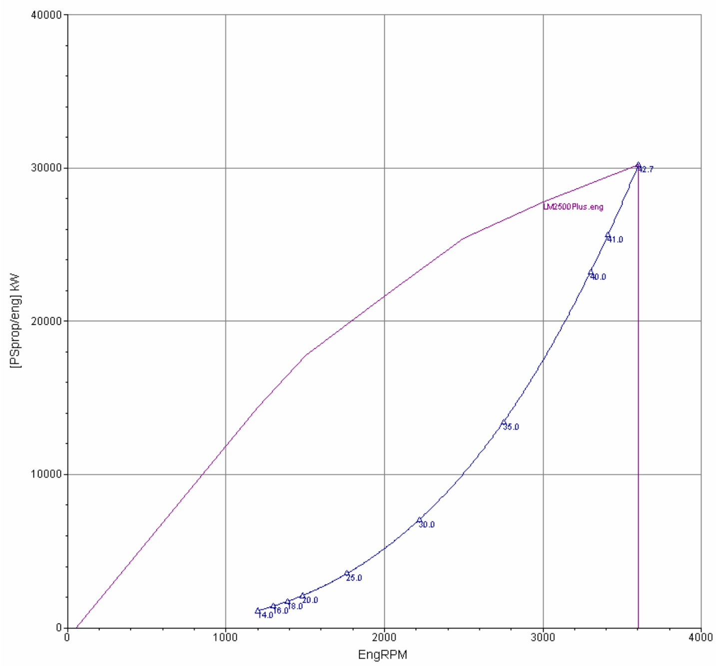

Figure 76 - Propulsion shaft power vs. engine speed with sustained speed power margin

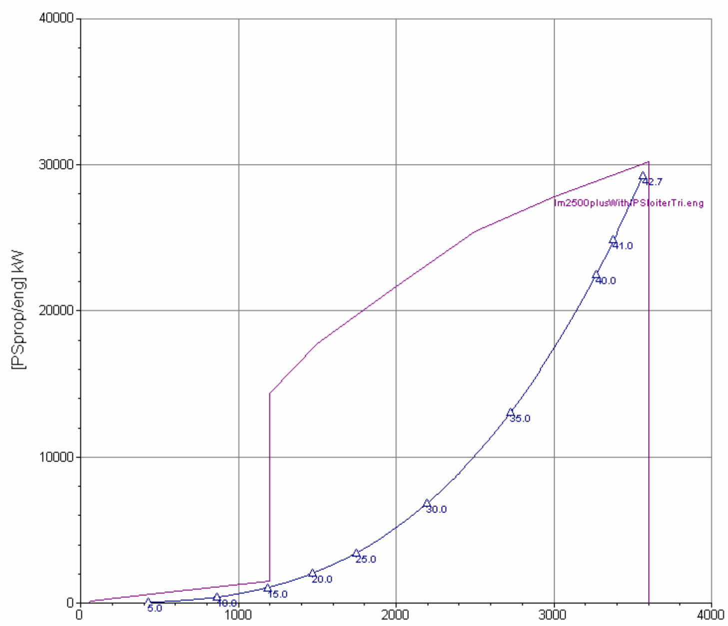

Figure 77 - Propulsion shaft power vs. engine speed with endurance speed power margin

Figure 78 and Figure 79 show propulsion efficiency and total power available versus engine speed. Figure 80 shows fuel consumption per engine with 10% endurance power margin versus ship speed.

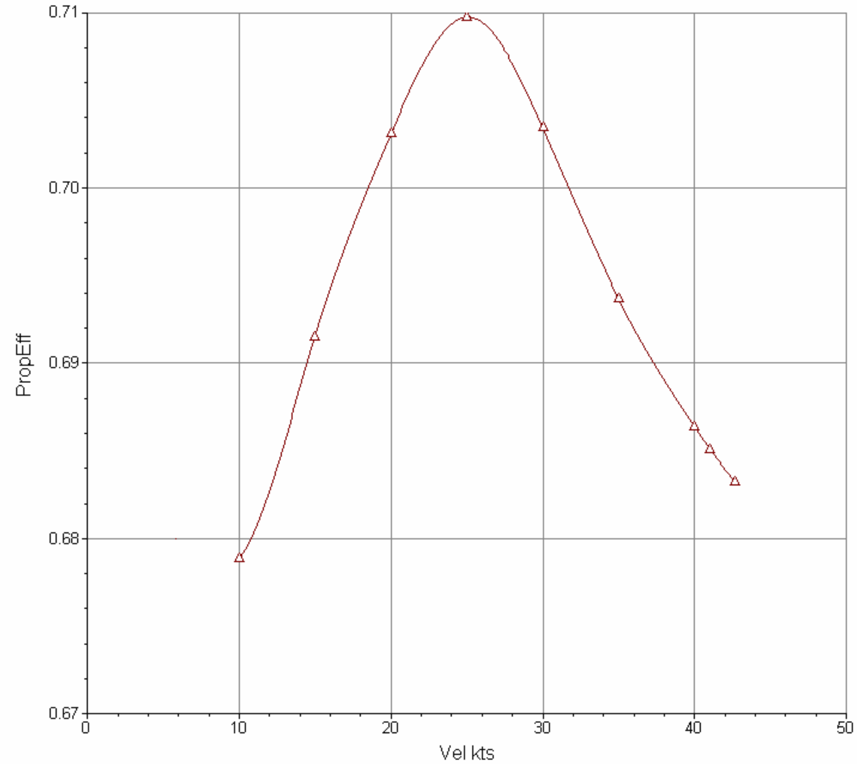

Figure 78 - Propulsion Efficiency (PC) vs. Speed

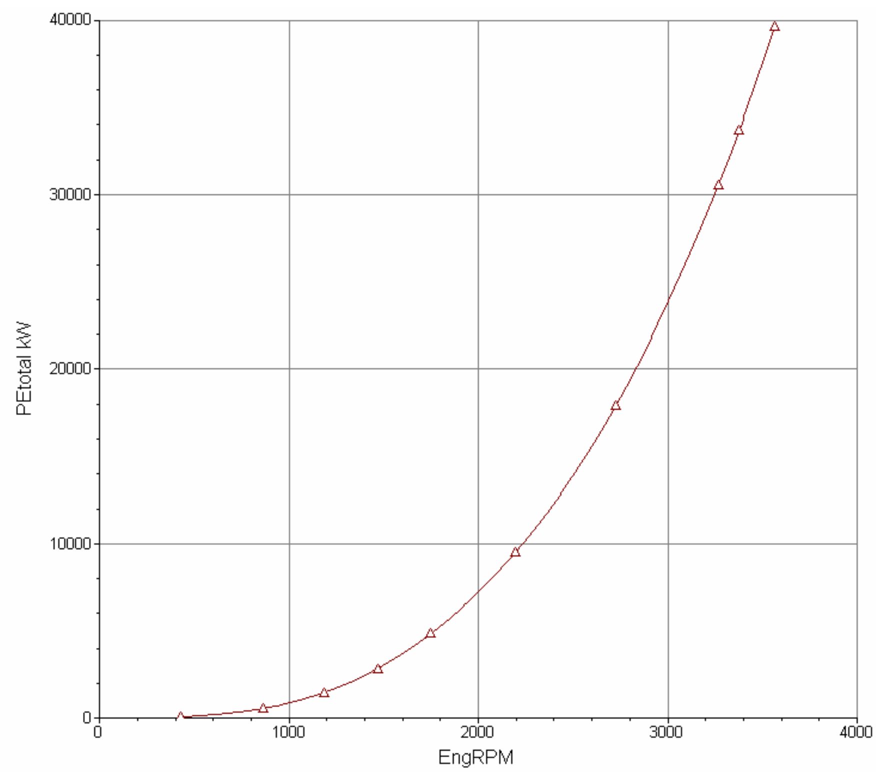

Figure 79 - Total Engine Power vs. Engine Speed (2 engines)

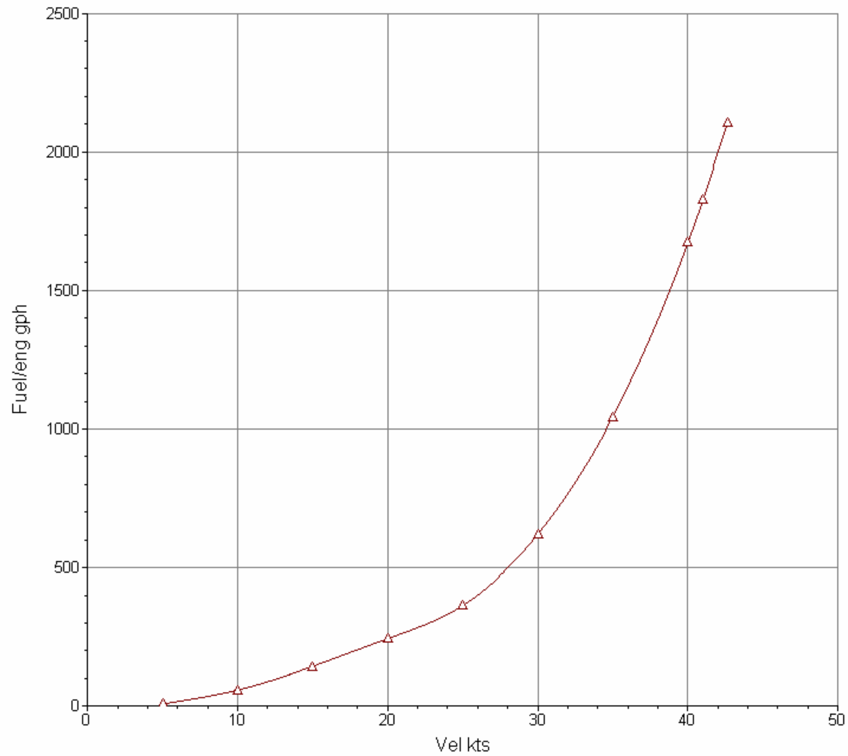

Figure 80 - Fuel consumption vs. Ship Speed

4.4.3 Electric Load Analysis (ELA)

Electric power requirements for SWBS groups 100 through 700 equipment and machinery are summarized in the Electric Load Analysis Summary, Table 39. Load factors are used to estimate the electric power requirement for each component in each of five operating conditions, including Condition 1, loiter, cruise, in-port, anchor, and emergency. The SSGTGs are very lightly loaded in all conditions. 1500 kW SSDGs will be considered in subsequent design iterations.

Table 39 - Electric Load Analysis Summary

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

Number	Generator	Rating (kW)	Condition I	Loiter	Cruise	In Port	Anchor	Emergency
3	SSGTG	3000	2	2	1	1	1	1

4.4.4 Fuel Calculation

A fuel calculation is performed for endurance range and sprint range in accordance with DDS 200-1. The fuel calculations are shown in Figure 81. Results indicate an endurance range of 3881 nm and a sprint range of 1241 nm satisfying endurance range thresholds specified in the ORD.

$W_{F41} := 388.3 \cdot MT \quad PSYS_{TYP} := 1 \quad \eta := .98 \quad N_{PENG} := 2 \quad PMF := 1.1 \quad P_{BPENG} := 30150 \cdot kW$

$V_e := 20 \cdot knt \quad V_S := 41.7 \cdot knt \quad GPH_e := 486 \cdot \frac{gal}{hr} \quad GPH_S := 4210 \cdot \frac{gal}{hr} \quad SFC_{eG} := .4 \cdot \frac{lbm}{hp \cdot hr}$

$KW_{24AVG} := 1500 \cdot kW \quad KW_{MFLM} := 2000 \cdot kW$

$SHP_e := 4082 \cdot kW$ (includes 10% margin) $\quad SHP_S := 58529 \cdot kW$ (includes 10% margin)

$P_{BPENGTOT} := N_{PENG} \cdot P_{BPENG} \quad P_{BPENGTOT} = 6.03 \cdot 10^4 \cdot kW$

Required installed endurance power (BHP): $P_{IREQe} := \frac{SHP_e}{\eta} \quad P_{IREQe} = 4.165 \cdot 10^3 \cdot kW$

Required installed power (BHP): $P_{IREQS} := \frac{SHP_S}{\eta} \quad P_{IREQS} = 5.972 \cdot 10^4 \cdot kW$

Process

$SFC_{ePE} := \frac{GPH_e}{P_{IREQe} \cdot \delta_F \cdot g} \quad SFC_{ePE} = 0.616 \cdot \frac{lbm}{hp \cdot hr}$

$SFC_{SPE} := \frac{GPH_S}{P_{IREQS} \cdot \delta_F \cdot g} \quad SFC_{SPE} = 0.372 \cdot \frac{lbm}{hp \cdot hr}$

$$P_{IPRP} := \begin{cases} P_{BPENGTOT} & \text{if } PSYS_{TYP} = 1 \\ P_{BPENGTOT} - KW_{MFLM} & \text{otherwise} \end{cases}$$

Propulsion Fuel - Endurance Speed

Average endurance brake horsepower required [DDS 200-1]:

$P_{eBAVG} := P_{IREQe} \quad P_{eBAVG} = 4 \cdot 10^3 \cdot kW \quad P_{sBAVG} := P_{IREQS} \quad P_{sBAVG} = 5.972 \cdot 10^4 \cdot kW$

Correction for instrumentation inaccuracy and machinery design changes:

$$f_1 := \begin{cases} 1.04 & \text{if } 1.1 \cdot SHP_e \le \frac{1}{3} \cdot \frac{P_{BPENGTOT}}{2} \\ 1.02 & \text{if } 1.1 \cdot SHP_e \ge \frac{2}{3} \cdot \frac{P_{BPENGTOT}}{2} \\ 1.03 & \text{otherwise} \end{cases} \qquad f_1 = 1.04$$

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{ePE} \cdot g \quad FR_{SSP} := f_1 \cdot SFC_{SPE} \cdot g$

Average fuel rate allowing for plant deterioration: $FR_{AVG} := 1.05 \cdot FR_{SP} \quad FR_{AVG} = 0.673 \cdot \frac{lbf}{hp \cdot hr}$

$FR_{SAVG} := 1.05 \cdot FR_{SSP} \quad FR_{SAVG} = 0.406 \cdot \frac{lbf}{hp \cdot hr}$

Ship Service Electrical Power Fuel

Margin for instrumentation inaccuracy and machinery design changes: $f_{1e} := 1.04$ Tailpipe allowance: $TPA := 0.95$

Specified fuel rate: $FR_{GSP} := f_{1e} \cdot SFC_{eG} \cdot g$

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05 \cdot FR_{GSP} \quad FR_{GAVG} = 0.586 \cdot \frac{lbf}{kW \cdot hr}$

$$E := \frac{W_{F41} \cdot V_e \cdot TPA}{P_{eBAVG} \cdot FR_{AVG} + KW_{24AVG} \cdot FR_{GAVG}} \qquad E = 3881\ nm$$

$STMHR := 3000 \cdot hr \quad FUELperYR := (KW_{24AVG} \cdot FR_{GAVG} + P_{eBAVG} \cdot FR_{AVG}) \cdot STMHR \cdot \delta_F$

$$E_S := \frac{W_{F41} \cdot V_S \cdot TPA}{P_{sBAVG} \cdot FR_{SAVG} + KW_{24AVG} \cdot FR_{GAVG}} \qquad E_S = 1241\ nm$$

Required fuel tank volume (including allowance for expansion and tank internal structure):

$V_F := 1.02 \cdot 1.05 \cdot \delta_F \cdot W_{F41} \quad V_F = 490.262\ m^3$

Figure 81 - Fuel calculations for Sprint and Endurance speeds

4.5 Mechanical and Electrical Systems

Mechanical and electrical systems are selected based on mission requirements, standard naval requirements for combat ships, and expert opinion. The Machinery Equipment List (MEL) of major mechanical and electrical systems for ASC-HI2 includes quantities, dimensions, weights, and locations. The complete MEL is provided in Appendix C. Partial MELs are provided in Table 42 and Table 43. 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 4.7.2.

4.5.1 Integrated Power System (IPS)

Due to the US Navy's commitment to all-electric ships, integrated power system options were considered for ASC and selected for ASC HI2 in concept development. Solid-state power electronics devices utilizing programmable microprocessor-based digital control, such as silicon controlled rectifiers, thyristors, and more recently, isolated gate bipolar transistors (IGBTs), make it possible to utilize fixed frequency alternating current generator sets (SSGTGs on ASC) supplying a common bus which feeds both propulsion and ship service loads.

Figure 82 shows the one-line diagram for ASC secondary propulsion and ship service power. Three Ship Service Gas Turbine Generators (SSGTGs) provide 460 volt, 60 Hz electric power to the primary switchboards. This power may be routed to ship service loads through Power Conversion Modules and the port and starboard zonal buses, or to the propulsion buses and power converters which control the speed of the ship when in IPS secondary propulsion mode by varying the AC frequency to the two AC propulsion motors. The power converters have 3 parallel elements. Each switchboard is connected to both motors for redundancy and survivability.

To support the IPS power specified in the ELA, the SSGTGs are rated at 3000 kW each. Propulsion motors are rated at 2500 kW each. There is one propulsion motor with drive gear and clutch per shaft. The generator sets each have a generator control panel for local control, and may be automatically or manually started both locally and remotely from the EOS. Automatic paralleling and load sharing capability are provided for each set.

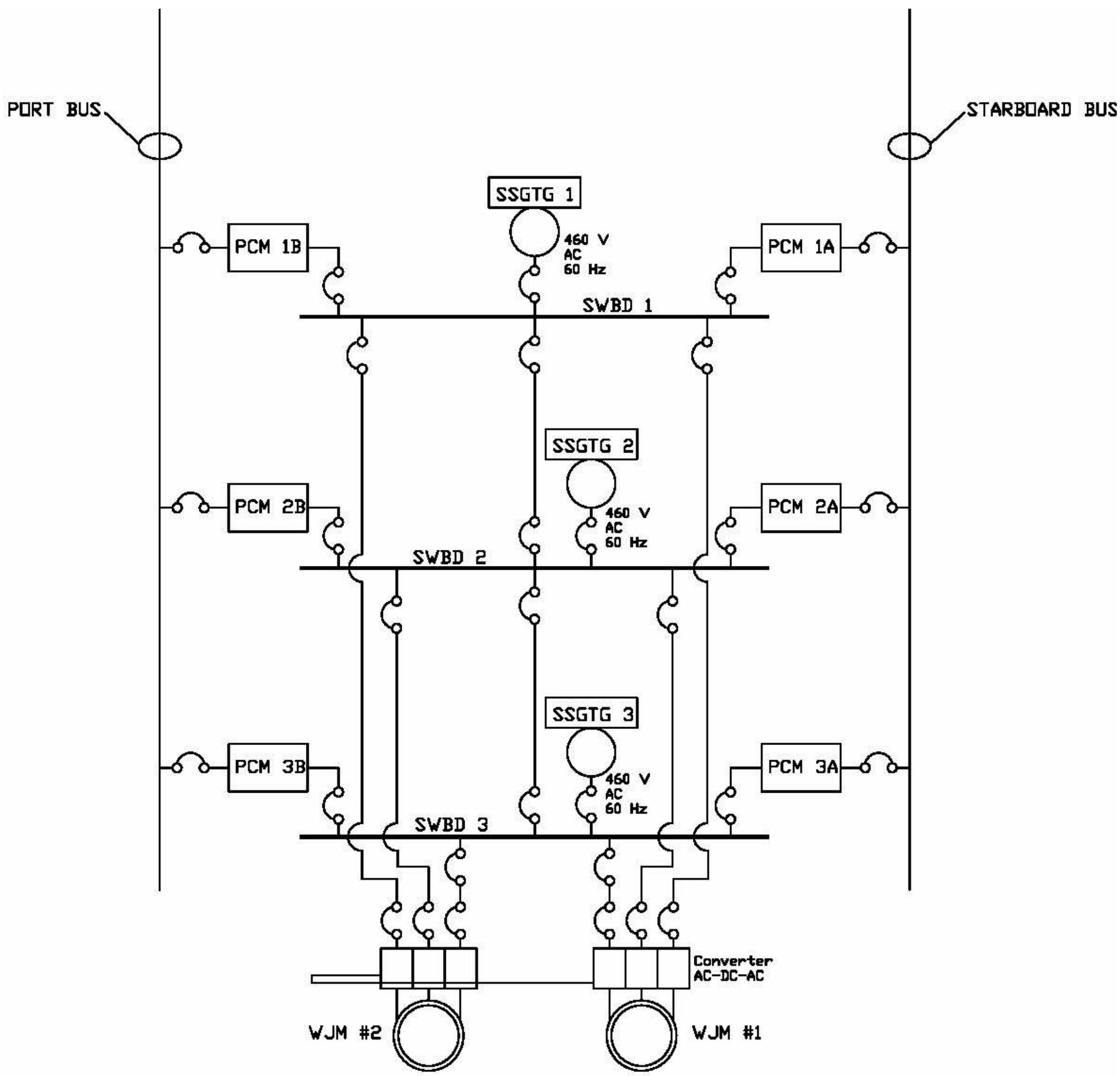

Figure 82 - One-Line Electrical Diagram

4.5.2 Service and Auxiliary Systems

Tanks for lube oil, fuel oil, and waste oil are sized based on requirements from the Ship Synthesis model. Equipment capacity and size are based on similar ships. Most equipment is located either in the Main Machinery Rooms or the Auxiliary Machinery Room.

Fuel and lube oil purifiers are sized relative to the fuel and oil consumption of each engine. There are two fuel oil purifiers and two lube oil purifiers located in the purifier rooms between MMR1 and MMR2. They are located on the port and starboard sides of a longitudinal bulkhead. One set is for purifying the fuel and oil in MMR1 and the other for MMR2, but the systems may be cross-connected.

Two reverse osmosis distillers are used to produce potable water from seawater. They are located in the AMR. For ASC HI2, the volume of the potable water tank is 14 m^3. This supports an allotment of 0.16 m^3 of water per person per day for the 88 person crew. Two 76 m^3 per day distillers are located in the AMR. This allows for refilling of the potable water tanks. Distillate pumps are used to pump water from the distillers to the potable water tanks. Potable water pumps are used to pressurize the potable water system from the tanks.

Four air conditioning plants and two refrigeration plants are required for ASC HI2. The air conditioning plants are sized based on crew size and arrangeable area. There are 4 air conditioning plants at 150 tons each. The refrigeration plants are sized at 10 tons per 200 crew, so two refrigeration plants at 4.3 tons each are used. JP-5 pumps and filters are located in the JP-5 pump rooms.

4.5.3 Ship Service Electrical Distribution

ASC HI2 has an integrated power system (IPS) supporting secondary propulsion and ship service power. Ship service power is distributed from any of the three main switchboards via a zonal bus, as shown in Figure 82. Power Conversion Modules (PCMs) are located in each zone to convert ship service power as required, provide circuit protection and automatic reconfiguration. They are able to convert AC to DC and DC to AC as required. Power from the main switchboards is supplied to the main switchboards by the three SSGTGs. Secondary propulsion power is also supplied from the 3 ship service switchboards. The ship is divided into 5 CPS and Electrical Distribution Zones. Electric power is taken from the zonal buses in each zone through the power conversion modules. If there is a vital system in a zone it draws power from both the port and starboard buses through a power conversion module and an ABT which is an automated switch to either bus in case of power loss of one of the zonal buses.

Zonal systems are also used for the ship's firemain system and Collective Protection System. The firemain is located on the Damage Control Deck with fire pumps in each zone. CPS zones are separated by air locks with airlocks on all external accesses.

4.6 Manning

An important goal for ASC is to reduce manning significantly from current Navy standards by utilizing automation and unmanned systems. ASC-HI2 has a crew of 88. Accommodations are provided for a crew of 104 to support additional crew for mission packages. The use of unmanned craft and an automated bridge are significant factors in this reduction. ASC uses various watch standing technologies including GPS, automated route planning, electronic charting and navigation, collision avoidance, and electronic log keeping. Video teleconferencing also provides a large reduction in manning because it provides quick access to onshore experts, which reduces the number of ship experts required onboard. ASC's original manning estimates were made using the ship synthesis model. These estimates were based on ship scaling factors for the size of the ship, number of propulsion systems, and ship displacement. These estimates were further refined by comparison to the manning of other naval ships. In concept development, the total manning is allocated by department and resized based on the ASC unique mission and by analogy with other ships. Engineering is the most manning intensive department on ASC. The manning estimates are based on an assumption of Watch Condition III (3 watch sections of 8 hours each), and are summarized in Table 40 and Figure 83.

Table 40 - Manning Summary ASC-HI2

Departments	Division	Officers	CPO	Enlisted	Total Department
	CO/XO	2			2
	Department Heads	4			
Executive/Admin	Administration		1	1	2
Operations	Communications	1	1	3	22
	Navigation and Control		1	3	
	Electronic Repair		1	2	
	CIC, EW, Intelligence	1	1	6	
	Medical		1		
Weapons	Air	2	1	2	24
	Boat and Vehicle		1	3	
	Deck		1	6	
	Ordnance/Gunnery		1	2	
	ASW/MCM		1	3	
Engineering	Main Propulsion		1	8	25
	Electrical/IC		1	3	
	Auxiliaries		1	3	
	Repair/DC		1	6	
Supply	Stores			2	13
	Material/Repair		1	2	
	Mess		1	6	
	Total Crew	10	17	61	88
	Accommodations	14	18	72	104

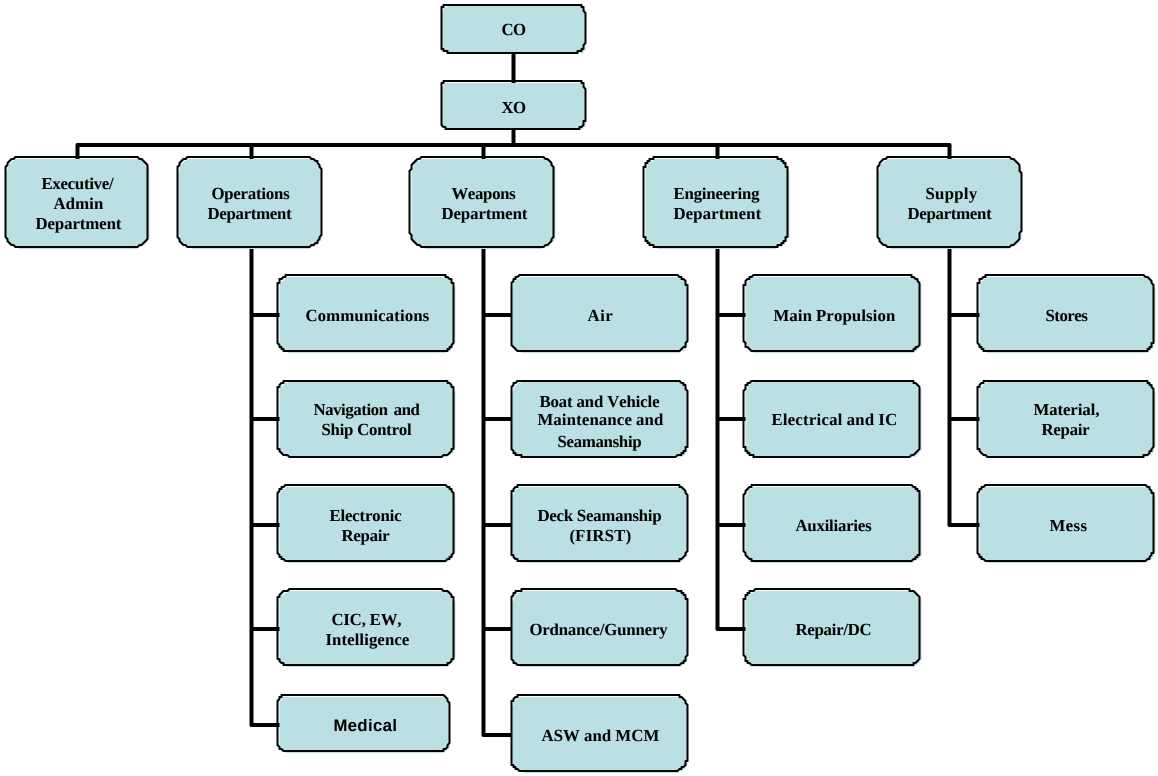

Figure 83 – ASC Manning Organization

4.6.1 Executive/Administration Department

The Executive/Administration department maintains personnel records and manages the overall administration of all the departments. This department does not have a department head (they report to the XO), but has one CPO and one enlisted (yeoman and personnelman).

4.6.2 Operations Department

The Operations department is responsible for sensor and combat systems, radio operations, communications, watch standing, maintenance of electronic and communication equipment, and medical operations. This department is assigned 1 department head and 2 officers, one to head the Communications division and one to head the CIC, EW, and Intelligence division. The department is also assigned 5 CPOs, one for each division, and 14 enlisted.

This department is comprised of the following five divisions: Communications, Navigation and Control, Electronic Repair, CIC, EW, and Intelligence, and Medical. The Communications division is required to interpret the electronic output of the systems and relay any important information gathered. This division requires three enlisted working 8 hour days and therefore will require 3 enlisted as well as one officer and one CPO. The Navigation division is responsible for navigating and meteorology. Navigation watch also requires three enlisted working 8 hour days at each position. Therefore this department is assigned 3 enlisted as well as one CPO. The Electronic Repair division maintains electronics equipment. This division requires a minimum of 2 enlisted and one CPO for maintenance and expertise. The CIC, EW, and Intelligence division is responsible for electronic warfare and manning the bridge, as well as gathering and providing intelligence to the CO. This division requires 2 enlisted working 8 hour days. Therefore, this division requires 6 enlisted, one CPO, and one officer. Due to the small crew size the medical department requires few personnel, and is therefore assigned one CPO.

4.6.3 Weapons Department

The Weapons department is responsible for the assembly, loading, and transportation of shipboard weapons, weapons maintenance, and specialized weapons use. The weapons department is also required to organize, maintain, and oversee the supply of all weapons magazines. This department issues ammunition from the ship's arsenal. There is one department head, 2 officers for the Air division (LAMPS pilots), 5 CPOs, one for each division, and 16 enlisted in this department.

This department includes the following five divisions: Air, Boat and Vehicle, Deck, Ordnance/Gunnery, and ASW/MCM. The Air division is responsible for manning the LAMPS, and for maintenance and support of the LAMPS and VTUAVs. This division is assigned 2 officers, one CPO, and 2 enlisted. Two of these personnel are assigned as pilots of the LAMPS. The Boat and Vehicle division is responsible for launching and recovering the RHIBs and Spartans and maintenance on both. This division requires one CPO and 3 enlisted. The deck division is responsible for line handling, anchoring, life boat maintenance, topside maintenance, and helmsmen. Line handling and anchoring occur only when the ship is in port. Most crew are assigned to maintenance work and transferred to line handling and anchoring as needed. There is one CPO and 6 enlisted crew assigned to the Air department. The Ordnance/Gunnery department is responsible for procuring, maintaining, and issuing weapons and ammunition as well as operation of the CIWS and CIGS. This division is assigned one CPO and 2 enlisted. The ASW/MCM division is responsible for launching, operating, and recovering the 2 RMS and the VANGUARD Mine Avoidance Sonar. This division is assigned one CPO and 3 enlisted.

4.6.4 Engineering Department

The Engineering department is responsible for operating and maintaining the two LM2500+ engines, their support systems, three DDA 501-K17 ship service gas turbine generators, all of their support systems, the electrical systems of the ship, weapons elevators, and most other major mechanical or electrical equipment on the ship. This department has one department head, 4 CPOs, one for each division, and 20 enlisted.

This department consists of the following four divisions: Main Propulsion, Electrical/IC, Auxiliary, and Repair/Damage Control. The Main Propulsion division is responsible for maintenance and repair of the main propulsion engines and their support systems. This division consists of one CPO and 8 enlisted. The Electrical/IC division is responsible for all of the ships electrical systems. This division includes one CPO and 3 enlisted. The Auxiliary division is in charge of major auxiliary equipment including LAMPS equipment, weapons elevators, motorized doors and hatches, pumps, and damage control equipment. This division is assigned one CPO and 3 enlisted. The Repair/Damage Control division is primarily responsible for repairing any major problems that may result from damage to the ship as well as controlling any damage as it occurs. This division requires one CPO and 6 enlisted. The reduction in manning for this division is enabled by the use of damage control robots.

4.6.5 Supply Department

The Supply department is responsible for ordering, receiving, organizing, and storing food, spare parts, equipment, and other material. They are also responsible for food preparation, including cooking, cleaning, beverages, and inventory. These personnel are in charge of the ships laundry, retail, tailoring, and dry cleaning. They man the ships store, barbershop, and postal service and are responsible for distributing pay. This department is assigned one department head, 2 CPOs, and 10 enlisted.

This department is divided into the following three divisions: Stores, Material/Repair, and Messing. The Stores division is responsible for maintaining the supplies onboard the ship. Due to the size of the crew, this division does not require high manning and therefore is only assigned 2 enlisted. The Material/Repair division is responsible for obtaining materials and supplies for repair of damaged equipment. This division is assigned one CPO and 2 enlisted. The Messing division is responsible for food preparation for the entire ship. Due to the use of automated mess, this division is only assigned one CPO and 6 enlisted.

4.7 Space and Arrangements

HECSALV and AutoCAD are used to generate and assess the subdivision and arrangements of ASC-HI2. HECSALV is used for primary subdivision, tank arrangements and loading. AutoCAD is used to construct 2-D drawings of the inboard and outboard profiles, deck and platform plans, detailed drawings of berthing, sanitary, and messing spaces, and a 3-D model of the ship. A profile of ASC-HI2 showing the internal arrangements is shown in Figure 84.

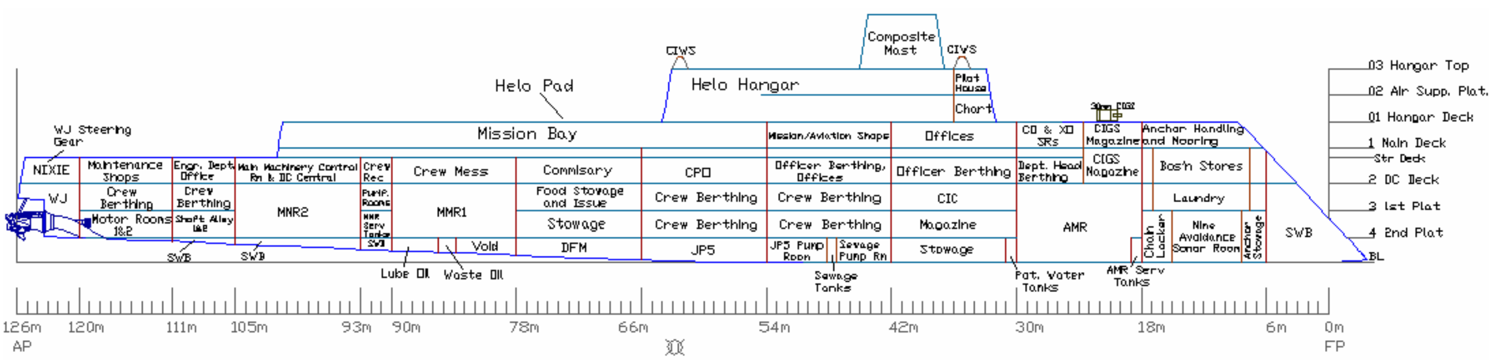

Figure 84 - Profile View Showing Arrangements

4.7.1 Volume

Initial space requirements and availability in the ship are determined in the ship synthesis model. Volume parameters output by the ship synthesis model are as follows: the machinery box height and volume, and volumes of the waste oil, lube oil, potable water, sewage, helicopter fuel, clean ballast, and propulsion fuel. These are shown in Table 41. Given the volumes and hull form, tanks are arranged in HECSALV. Lightship weight, load cases, and ballast locations are coordinated with the weight and stability analysis for proper placement. The remaining space in the ship is used primarily as arrangeable space. Arrangeable area estimates and requirements are refined in concept development arrangements and discussed in Sections 4.7.2 through 4.7.4.

Table 41 - Required, Available, Actual Space Variables from Ship Synthesis Model

Variable	Required	Final Concept Design
Machinery Box Height	5 m	7.046 m
Machinery Box Volume	1845 m^3	1845 m^3
Waste Oil	8.7 m^3	10 m^3
Lube Oil	20.8 m^3	21 m^3
Potable Water	13.6 m^3	14 m^3
Sewage	5.5 m^3	8 m^3
Helicopter Fuel (JP5)	133.7 m^3	147 m^3
Clean Ballast	119.9 m^3	123 m^3
Propulsion Fuel (DFM)	436 m^3	455 m^3

ASC-HI2 has four decks and two platforms, accommodating 88 total core personnel: 74 enlisted crew and 14 CPOs and officers. The decks and platforms are divided into the following areas: human support, machinery, weapons storage, ship support, mission support, mission bay, and hangar. 2nd Deck is the Damage Control (DC) Deck. The mission bay is located on Main Deck. Both MMRs are located on the 2nd platform. Officer berthing is on the DC Deck and crew berthing is located on the 1st and 2nd platforms.

4.7.2 Main and Auxiliary Machinery Spaces and Machinery Arrangement

The primary propulsion, auxiliary, and electrical machinery are arranged in ten compartments. There are two main machinery rooms, MMR1 and MMR2, one auxiliary machinery room, AMR, two pump rooms, two purifier rooms, two waterjet rooms and two propulsion motor rooms which are separated by a centerline bulkhead. Figure 85 and Figure 86 show the machinery arrangements in MMR#1 and #2. Table 42 lists the equipment located in these spaces. The location of components is based on ship stability, functionality, producibility, and survivability. Most equipment is arranged evenly about the centerline, with one component on the port side of the ship and a second similar component on the starboard side. Components near bulkheads have a minimum clearance of 0.5 meters. Each MMR contains a main gas turbine, propulsion reduction gear, and a ship service engine module, reduction gear, and generator. There are two supply and exhaust fans in each MMR. The MMRs are separated by two purifier rooms on the 1st platform and two service tanks on the 2nd platform.

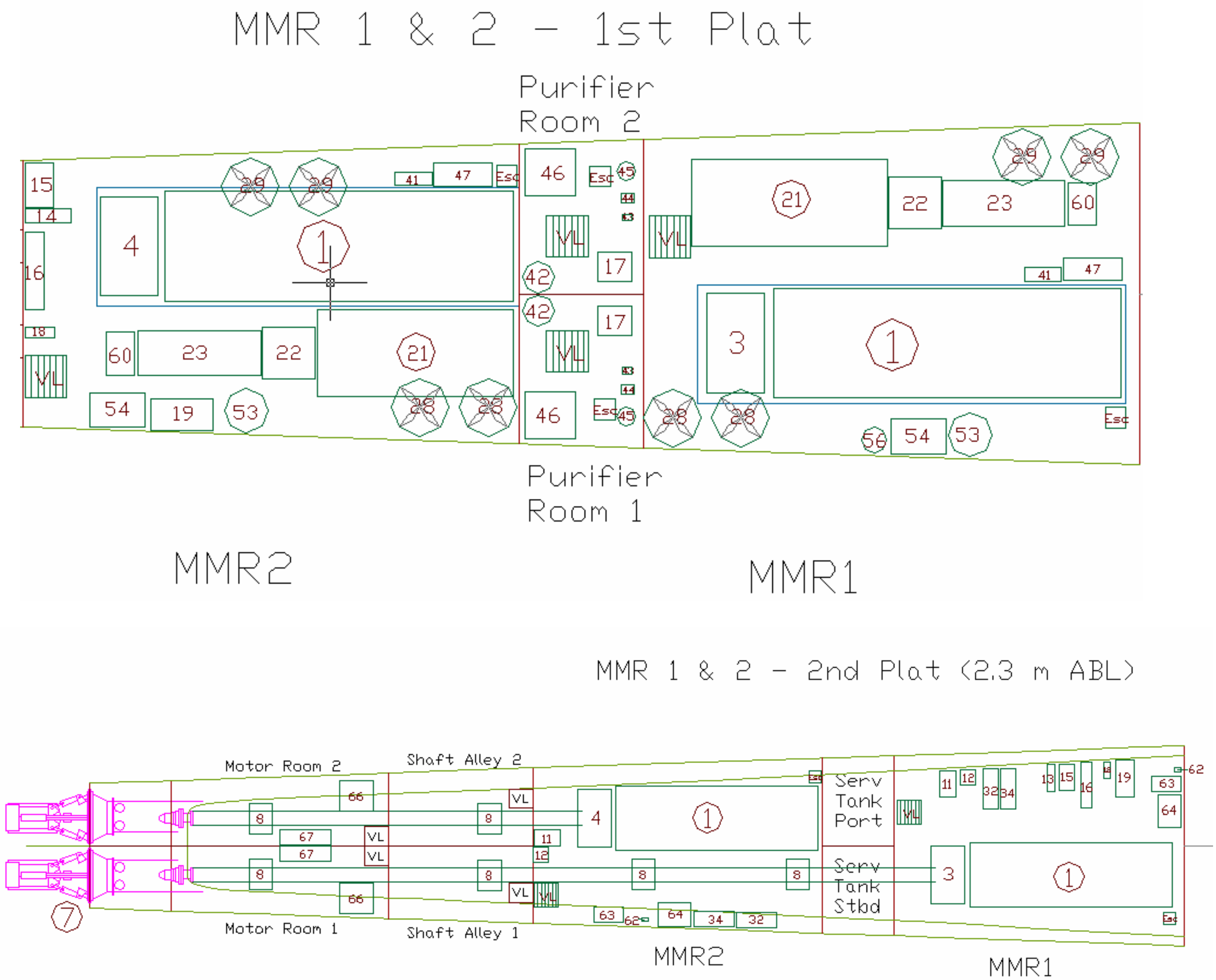

Figure 85 – MMR and Propulsion Machinery Arrangements - Plan

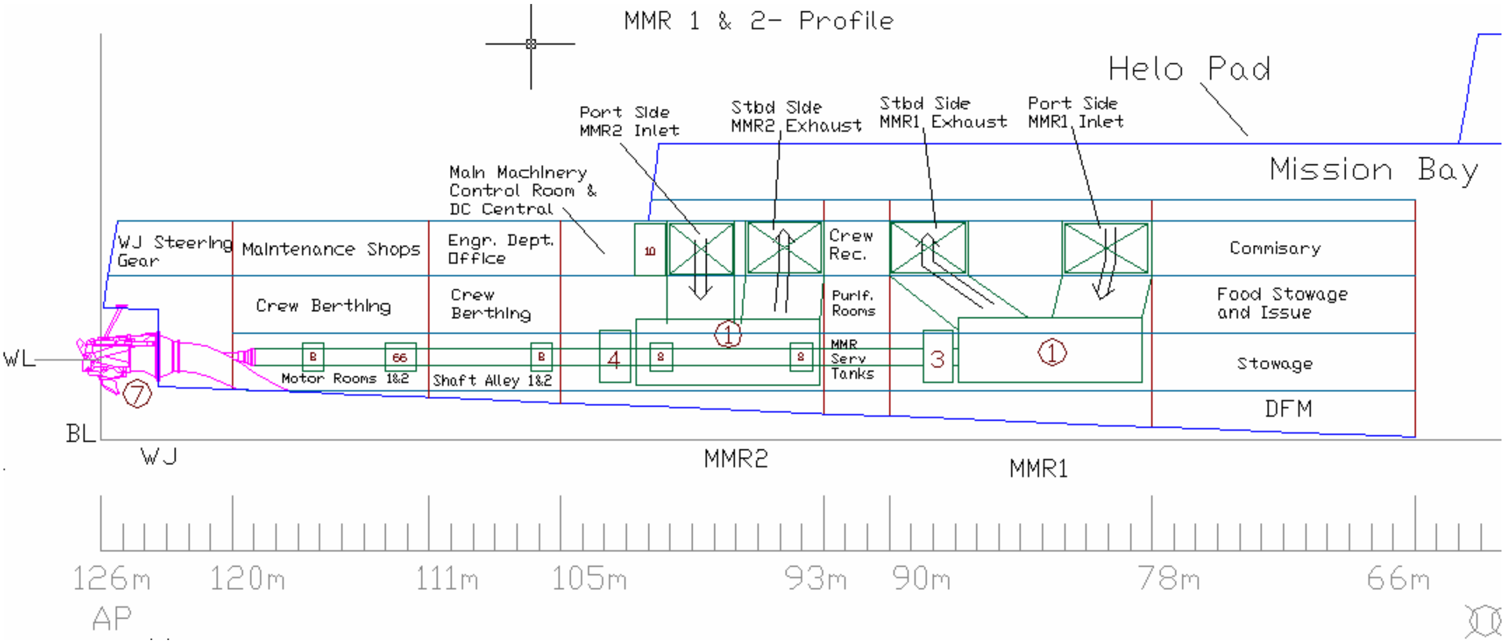

Figure 86 - MMR and Propulsion Machinery Arrangements - Profile

Table 42 - Main Machinery Room Equipment

Item	Equipment Nomenclature	Capacity Rating
1	Gas Turbine, Main	26100 kW @ 3600 RPM
3	Gear, Propulsion Reduction (stbd)	
4	Gear, Propulsion Reduction (port)	
8	Bearing, Line Shaft	0.575 m line shaft
10	Console, Main Control	
11	Strainer, Sea Water	
12	Pump, Main SW Circ	230 m^3/hr @ 2 bar
13	Pump, Stbd rd gear lube oil service	200 m^3/hr @ 5 bar
14	Pump, Pt rd gear lube oil service	154 m3/hr @ 5 bar
15	Strainer, Rd gear lube oil	200 m3/hr
16	Cooler, Rd gear lube oil	
17	Purifier, Lube Oil	1.1 m3/hr
18	Pump, Lube Oil Transfer	4 m3/hr @ 5 bar
19	Assembly, GT Lube Oil Storage and Conditioning	
21	SS Eng Enclosure Module	
22	SS Reduction Gear	
23	SS Generator	
28	MMR Supply Fan	94762 m3/hr
29	MMR Exhaust Fan	91644 m3/hr
32	Pump, Fire	454 m^3/hr @ 9 bar
34	Pump, Bilge	227 m3/hr @ 3.8 bar
41	Pump, GT Fuel Booster	15.9 m3/hr
42	Filter Separator, GT Fuel	30 m3/hr
43	Heater, GT Fuel Service	10.4 m^3/hr
44	Heater, Fuel Service	7.0 m3/hr
45	Pre-filter, GT Fuel Service	30 m3/hr
46	Purifier, Fuel Oil	7.0 m3/hr
47	Pump, Fuel Transfer	45.4 m3/hr @ 5.2 bar
53	Receiver, Starting air	2.3 m3
54	Compressor, Starting air	80 m3/hr FADY @ 30 bar
56	Receiver, Control Air	1 m3
60	GT Hydraulic Starting Unit	14.8 m3/hr @ 414 bar
62	Oil Content Monitor	15 PPM
63	Pump, Oily Waste Transfer	12.3 m3/hr @ 7.6 bar
64	Separator, Oil/Water	2.7 m3/hr
66	IPS Motors	
67	Frequency Converter	

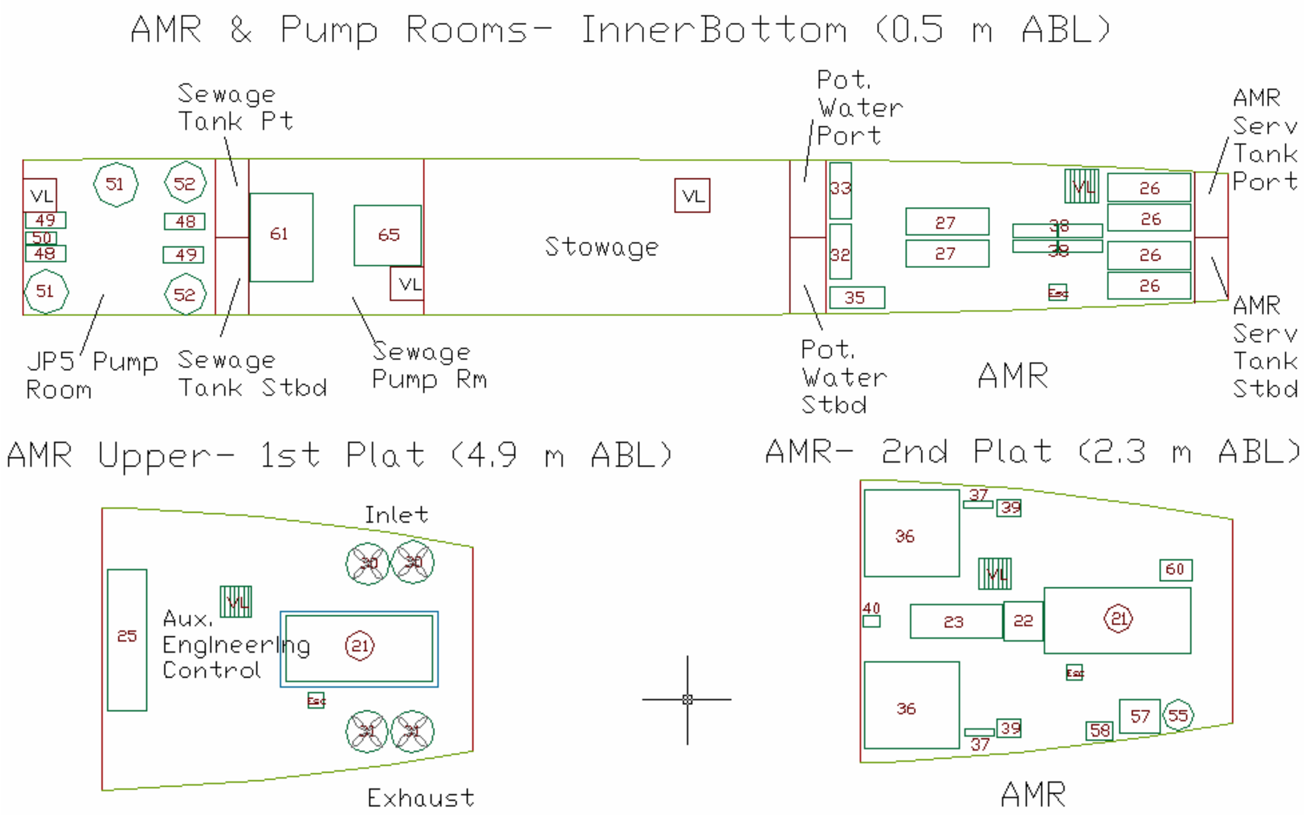

Figure 87 - AMR and Pumproom Arrangements

Figure 87 shows the general machinery arrangements in the auxiliary machinery room (AMR) and pump rooms. Table 43 lists the equipment located in these spaces. The upper level of the auxiliary machinery room houses four air conditioning plants and two refrigeration plants. The lower level houses two fresh water distillers. Just like the MMRs, the AMR contains a ship service generator engine module, reduction gear, and generator. It also contains fire and bilge/ballast pumps.

Table 43 - AMR and Pump Room Equipment

Item	Equipment Nomenclature	Capacity Rating
21	SS Eng Enclosure Module	
22	SS Reduction Gear	
23	SS Generator	
25	Switchboard, Emergency	
26	Air Conditioning Plants	150 Ton
27	Refrigeration Plants	4.3 Ton
30	AMR Supply Fan	61164 m3/hr
31	AMR Exhaust Fan	61164 m3/hr
32	Pump, Fire	454 m3/hr @ 9 bar
33	Pump, Fire/Ballast	455 m3/hr @ 9 bar
35	Pump, Bilge/Ballast	227 m3/hr @ 3.8 bar
36	Fresh Water Distiller	76 m3/day (3.2 m3/hr)
37	Brominator	1.5 m3/hr
38	Pump, Chilled Water AC	128 m3/hr @ 4.1 bar
39	Pump, Potable Water	22.7 m3/hr @ 4.8 bar
40	Brominator	5.7 m3/hr
48	Pump, JP5 Transfer	11.5 m3/hr @ 4.1 bar
49	Pump, JP5 Service	22.7 m3/hr @ 7.6 bar
50	Pump, JP5 Stripping	5.7 m3/hr @ 3.4 bar
51	Filter/Separator, JP5 Transfer	17 m3/hr
52	Filter/Separator, JP5 Service	22.7 m3/hr
55	Receiver, Ship Service Air	1.7 m^3
57	Compressor, Air, LP Ship Service	8.6 bar @ 194 SCFM
58	Dryer, Air	250 SCFM
60	GT Hydraulic Starting Unit	14.8 m^3/hr @ 414 bar
61	Sewage Collection Unit	28 m3
65	Sewage Plant	225 people

4.7.3 Internal Arrangements

Six space classifications are considered in the internal arrangements: hangar space, machinery rooms, weapons magazines, human support, ship support, and mission support. Area and volume estimates for these spaces were initially taken from the ship synthesis model and refined in the process of arranging the ship. Appendix E lists the area and volume summaries for ASC-HI2 by SWBS group.

Combat operations and vehicle support requires the largest area in the ship. The main deck and hangar deck are used primarily for LAMPS, VTUAV, and SPARTAN operations. These decks are located to most easily service, recover and launch these combat vehicles. The helo hangar is used to service, store, and prepare the LAMPS for missions. The helo hangar is connected directly to the weapons magazine by a weapons elevator. The moon pool is located on Main Deck and is used for all surface vehicle deployment and recovery as well for the Remote Minehunting System (RMS). It is located aft of amidships between the center hull and the port outer hull. The center and outer hulls provide protection of the moon pool, which allows for safe deployment and recovery of the surface vehicles and RMS even during hostile engagement.

Machinery rooms are located on the lowest deck of the ship, 2nd platform, and sized for the ships mechanical and electrical systems. Two main machinery rooms and one auxiliary machinery room contain the waterjet propulsion engines and ship service generators. Other mechanical and electrical systems including air conditioning, distillers, firemain, etc., are fit in the remaining space. Machinery rooms are separated for survivability, particularly SSGTGs and fire pumps required for firefighting. Damage Control (DC) Central and repair lockers are located on DC Deck just above MMR2. The intake and exhaust ducts for each machinery room exit the side of the ship just below the damage control deck. All exhausts are placed on the opposite side of the main hull from the moon pool. The intake and exhaust locations are chosen to minimize the area lost to ducting through the ship, and to minimize topside RCS and impact on topside mission operations

ASC-HI2 has one main weapons magazine located on the 2nd platform. The magazine stores the aircraft and surface vehicle weapons and ship weapons. There are two CIGS magazines located directly under the CIGS on main deck and damage control deck.

Ship support spaces are located throughout the ship. Each department requires its own support facilities; therefore support facilities are located close to the individual department location. Ship support looks after the day-to-day operations of the ship, such as administration, maintenance, stores handling, damage control, etc.

Mission Support areas are primarily located in or near the mission bay and helo hangar on main deck and hangar deck. These areas include the pilothouse and flight operations control. CIC is located on the 1st platform between the AMR and crew berthing. It is well embedded in the ship for survivability.

Tankage for ASC-HI2 is located primarily below the 2nd platform. This puts the weight associated with the ships fuel, oil, etc., as low as possible. Table 41 lists the required and actual tankage for ASC-HI2. Propulsion fuel tanks are located just forward of the MMRs allowing for easier transfer of fuel to the engines. Saltwater ballast tanks are placed in the extreme fore and aft of the ship. This requires less volume to correct trim conditions. Table 44 lists the individual tanks throughout the ship and their volumes.

The Main passageway is located along the centerline of the hull and runs longitudinally along the entire length of the DC (2nd) deck. This provides easy access into and out of compartments with sufficient width for DC equipment. Secondary passageways run transversely through the ship and are required only on main deck. Main passageways are 1.5 meters wide and secondary passageways are 1 meter wide. All main passageways have watertight doors located at the watertight bulkheads. Below the damage control deck there is no longitudinal access to compartments. Ladders provide vertical access through watertight hatches to the damage control deck and the main passageways. Figure 88 and 88 show the passageways on main deck and DC Deck.

A complete set of detailed arrangement drawings are included with this report.

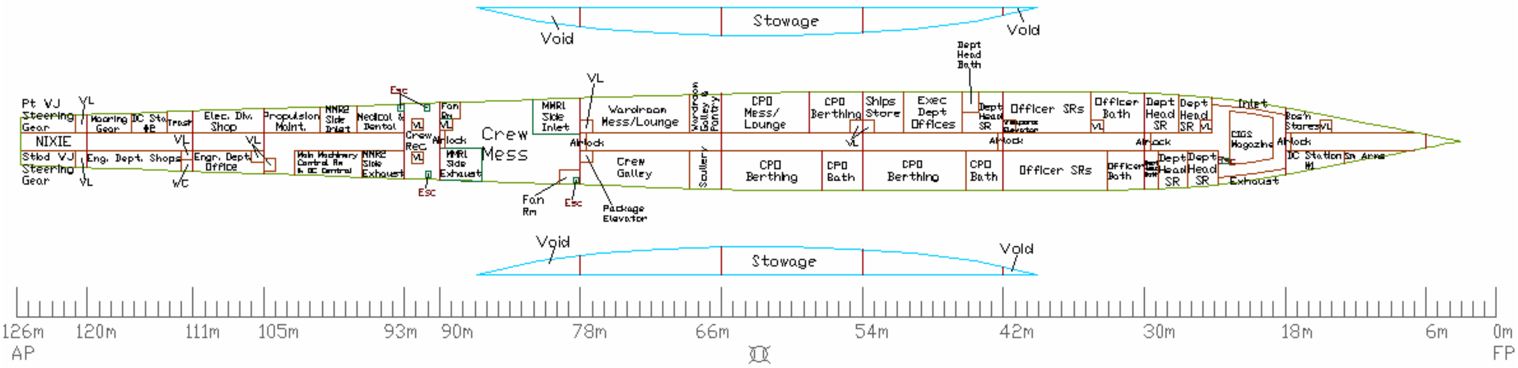

Figure 88 - Damage Control (2nd) Deck

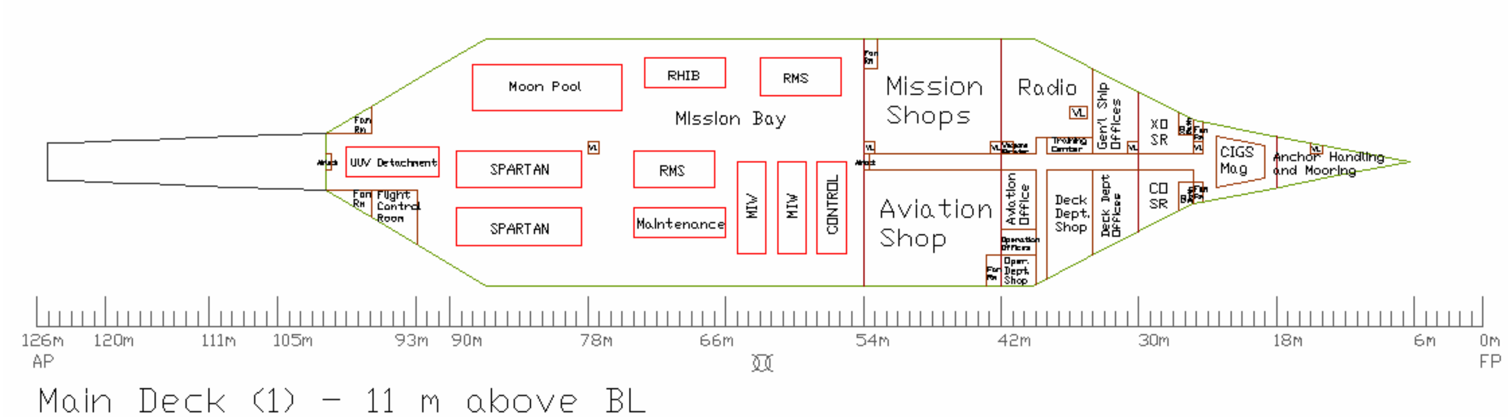

Figure 89 - Main Deck

Table 44 - Individual Tanks and Volumes

Tank	Capacity (m^3)	Tank	Capacity (m^3)
Fuel (JP5)	-----	**Lube Oil**	-----
JP5 Port	75	Lube Oil Port	11
JP5 Stbd	75	Lube Oil Stbd	11
Fuel (DFM)	-----	**Waste Oil**	-----
DFM Fwd Stbd	57	Waste Oil	10
DFM Fwd Port	57	**Fresh Water**	-----
DFM Port Sidehull 1	10	Potable Water Port	7
DFM Port Sidehull 2	42	Potable Water Stbd	7
DFM Port Sidehull 3	48	**Salt Water Ballast**	-----
DFM Port Sidehull 4	27	SWB Aft1 Port	25
DFM Stbd Sidehull 1	10	SWB Aft2 Port	5
DFM Stbd Sidehull 2	42	SWB Aft3 Port	3
DFM Stbd Sidehull 3	48	SWB Aft1 Stbd	25
DFM Stbd Sidehull 4	27	SWB Aft2 Stbd	5
AMR Service Port	5	SWB Aft3 Stbd	3
AMR Service Stbd	5	SWB Fwd Port	29
MMR1 Service Stbd	19	SWB Fwd Stbd	29
MMR1 Service Port	19	**Sewage**	-----
MMR2 Service Port	24	Sewage Port	4
MMR2 Service Stbd	24	Sewage Stbd	4

The ship is divided into 5 Collective Protection System (CPS) and electrical distribution zones as shown in Figure 90. CPS Zone 1 contains the Auxiliary Machinery Room (AMR). The CIC and Magazine, as well as some officer berthing, is located in CPS Zone 2. Most of the crew berthing and the rest of the officer berthing are included in CPS Zone 3. CPS Zone 4 contains Main Machinery Room 1 (MMR1) and crew mess. The 2nd Main Machinery Room (MMR2), the rest of the crew berthing, and the propulsion motors are located in CPS Zone 5. CPS zones are separated by airlocks with airlocks on all external accesses. Each CPS Zone has its own Fan Room that supplies ventilation. Zonal systems are also used for ship's fire system. Fire mains are located on the Damage Control Deck and there are fire pumps in each zone.

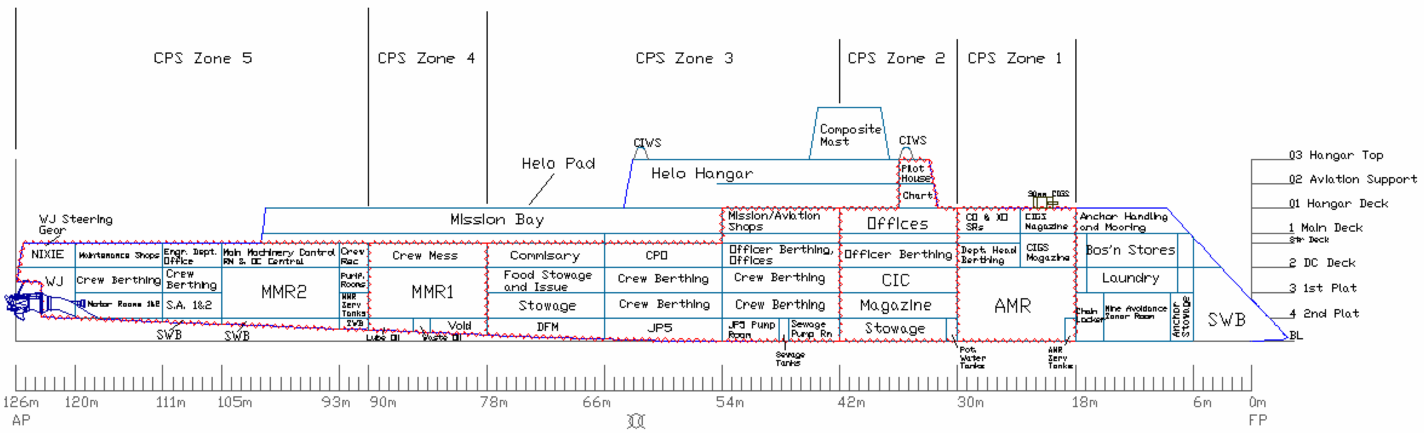

Figure 90 - CPS Zones

4.7.4 Living Arrangements

Living area requirements were initially estimated based on crew size using the ship synthesis model and refined with the manning estimate. The model estimates areas for enlisted living, officer living, mess areas, and human support facilities. Living areas are located around midships and placed in close proximity to messing spaces and other human support spaces to simplify the flow of day-to-day traffic. Crew berthing spaces are located forward of midships on the 1st and 2nd platforms and officer berthing is located above them on the damage control deck. This is out of the way of traffic with spaces sufficiently separate for survivability. The officer berthing located on DC deck is shown in Figure 88. The crew berthing located on 1st and 2nd platform is shown in Figure 91.

The total crew size is 88 with accommodations for 104. Living arrangements for officer and enlisted berthing is shown in Figure 92. Table 45 lists the accommodation space for the crew. The CO and XO have their own spaces of 15 m^2 and 10 m^2, respectively. The department heads also have their own living spaces that are 8 m^2. There are accommodations for 8 other officers, 2 officers per space, with an area of 8 m^2 for each of the 4 spaces. There are accommodations for 18 CPO in 6 spaces, 3 in each space, with 15 m^2 allocated for each space. There are accommodations for enlisted crew of 72. There are 6 spaces allocated, 12 enlisted in each space. Each space has an area of 15 m^2. There are 2 sanitary spaces for the 4 department heads and the possible 8 officers. Each of these spaces is 30 m^2. The 18 CPOs have 3 sanitary spaces, each space is 25 m^2. There are 6 sanitary spaces for the possible 72 enlisted crew with each space having an area of 20 m^2. The crew and officer mess are both on DC Deck and shown in Figure 92. Both mess areas make use of an automated messing system.

Table 45 - Accommodation Space

Item	Accomodation Quantity	Per Space	Number of Spaces	Area Each (m^2)	Total Area (m^2)
CO	1	1	1	15	15
XO	1	1	1	10	10
Department Head	4	1	4	8	32
Other Officer	8	2	4	8	32
CPO	18	6	3	15	45
Enlisted	72	12	6	15	90
Officer Sanitary	12	6	2	30	60
CPO Sanitary	18	6	3	25	75
Enlisted Sanitary	72	12	6	20	120
Total			**30**		**479**

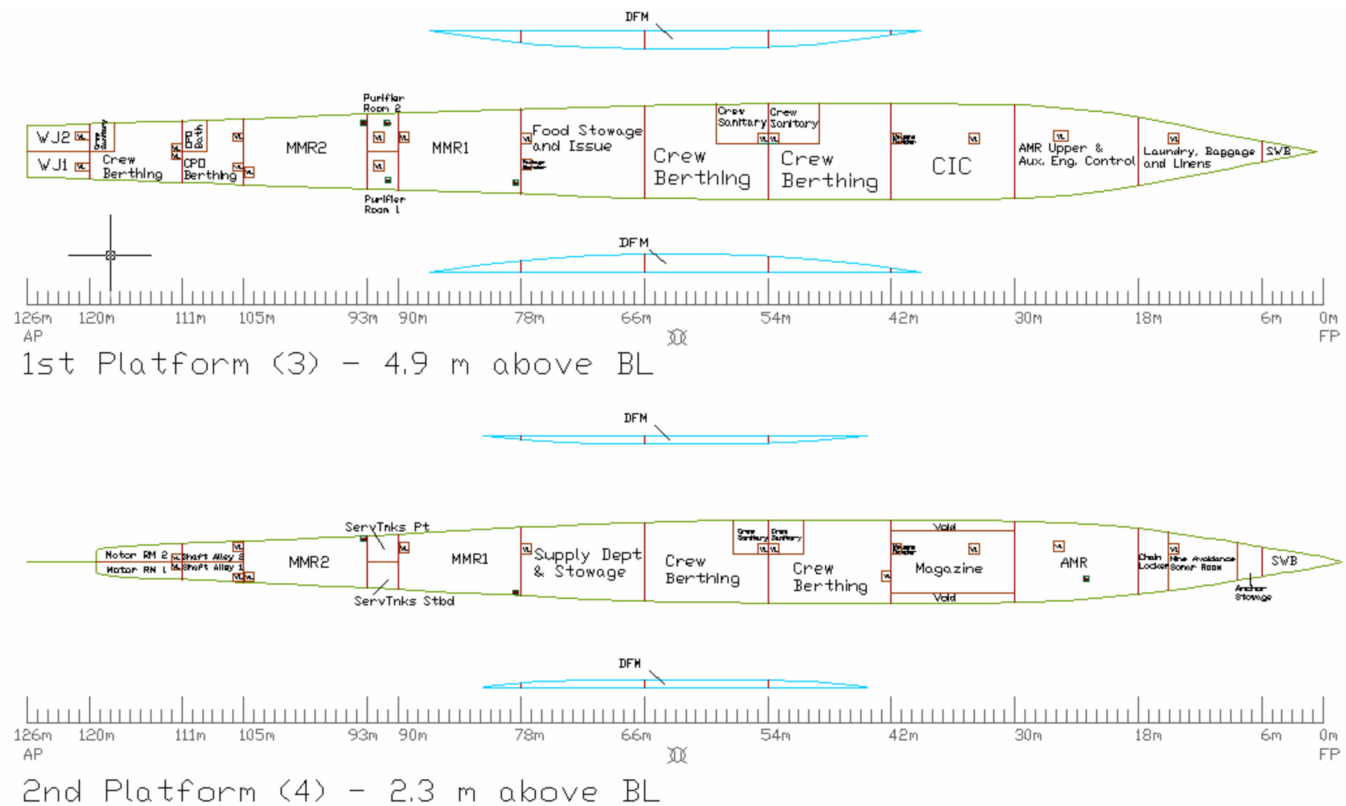

Figure 91 - 1st and 2nd Platform Arrangements

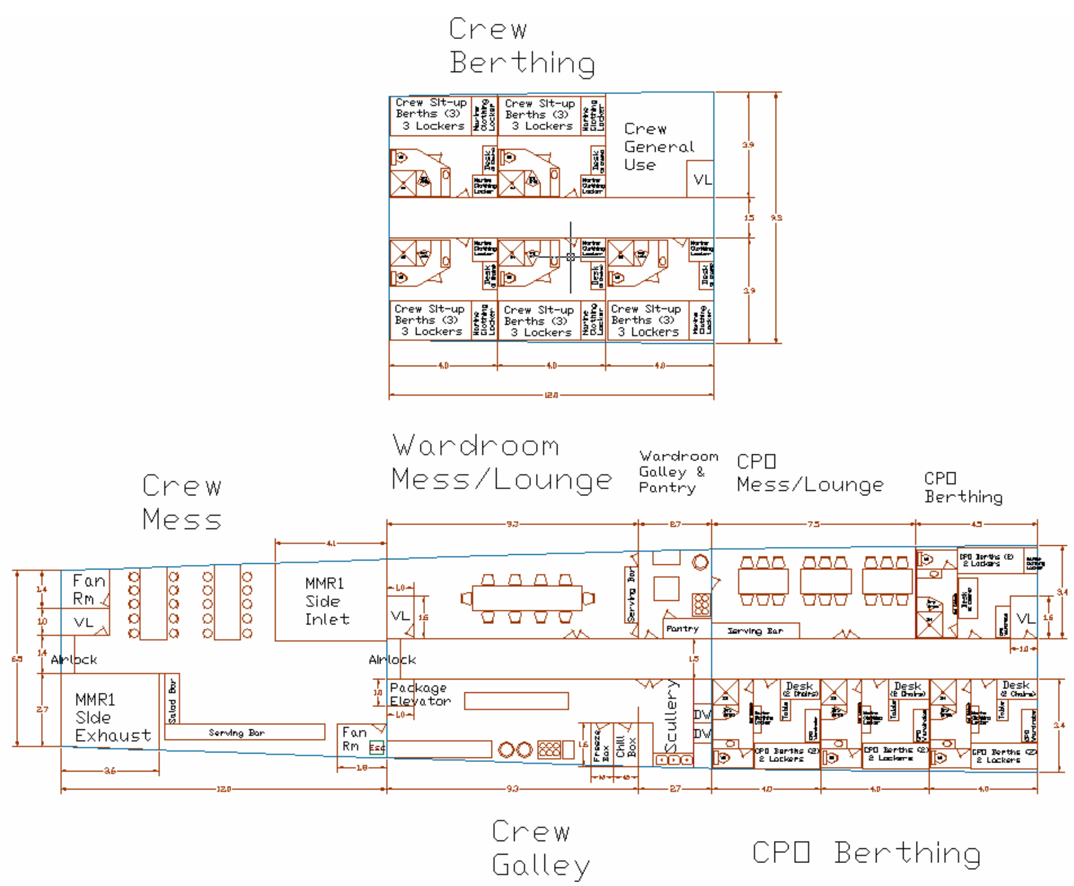

Figure 92 - Officer and Crew Berthing Arrangements

All berthing and sanitary spaces are arranged as producible modules that may be prefabricated and installed on the ship as units with standard hook-ups for piping, ventilation and electrical.

4.7.5 External Arrangements

The most important criteria for external arrangements are Radar Cross Section, aircraft operations and combat systems effectiveness. All sides of the hull, above the waterline, are angled in at ten degrees from the vertical. The ten-degree angle is also included in the design of the AEM located on top of the helo hangar.

The AEM is positioned at the forward end of the hangar. This location was selected to reduce any type of interference for the LAMPS and VTUAV when landing. The AEM is angled at 10 degrees from top to bottom.

There are two CIWS located on top of the helo hangar at the very forward and aft ends. These locations allow for the most effective angle for defense when targeting incoming aircraft or missiles. The 30mm CIGS is located near the bow for this same reason. Figure 93 is an external profile view showing the coverage zones for the 2 CIWS and CIGS.

Anchor handling and mooring are located at the forward end of the Main Deck. Anchor stowage is located just aft of the forward saltwater ballast tank between the baseline and 1st platform. Life boats are stored in the mission bay along with the 7m RHIB and are deployed through the moon pool.

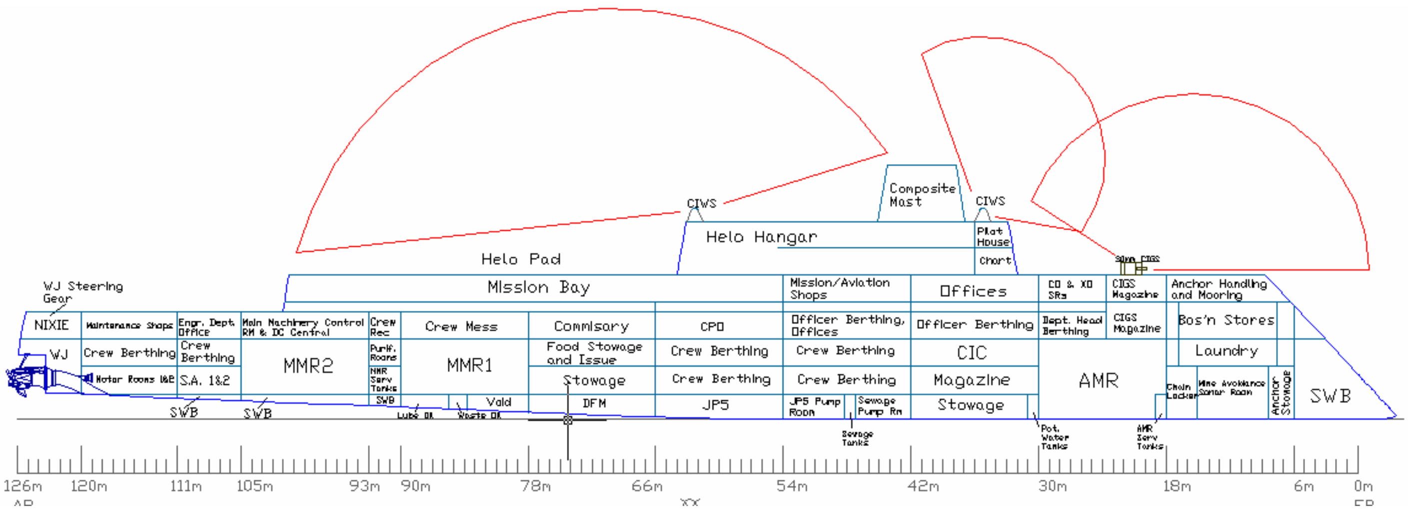

Figure 93 - Combat Systems Coverage Zones

4.8 Weights and Loading

4.8.1 Weights

Ship weights are grouped by SWBS. Weights were obtained from manufacturer information, when possible, and from the ship synthesis model and ASSET parametrics. Weight values calculated by the ship synthesis model are used when no other values are available. VCGs and LCGs for weights are estimated from machinery and ship arrangements. These centers are used to find moments and the lightship COG. A summary of lightship weights and centers of gravity by SWBS group is listed in Table 46. The entire weights spreadsheet is listed in Appendix D.

Table 46 - Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m-Abv BL)	LCG (m-Aft FP)
100	1180.14	5.31	62.76
200	345.97	4.35	105.04
300	102.03	5.53	56.51
400	118.77	8.48	63.00
500	197.96	6.40	56.25
600	131.99	5.94	58.70
700	11.28	10.5	63.00
Margin	104.41	5.78	71.87
Total (LS)	2192.53	5.78	71.87

4.8.2 Loading Conditions

Two loading conditions are considered for ASC: Full Load and Minimum Operating (Minop) as defined in DDS 079-1. The centers of gravity for the two loading conditions are calculated using the lightship weights and centers and loads weights and centers. Weights for the Full Load condition are estimated with all fuel oil and potable water tanks filled to 98% and full provisions, general stores, and weapons. The Minimum Operating condition assumes that all fuel, stores, and weapons are at 33% of their full load capacity, and that potable water tanks are 66% full. Compensated fuel/ballast tanks are used except for service tanks. A summary of the weights for the Full Load condition is provided in **Table 47**. A summary for the Minimum Operating condition is provided in Table 48.

4.9 Hydrostatics and Stability

To assess hydrostatics, intact stability, and damage stability of ASC-HI2, ship offsets are imported into HECSALV. Hydrostatics are calculated using a range of drafts. From this information, the curves of form, coefficients of form and cross curves are calculated. Using the data obtained from these calculations, intact stability is calculated in the two loading conditions. The ballast tanks are filled only as required for correct trim and heel. With intact load conditions defined and balanced, intact stability and damage stability are examined.

Table 47 - Weight Summary: Full Load Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship w/ Margin	2193	5.78	71.87
Ships Force	10.5	7.35	63.00
Total Weapons Loads	234.2	8.855	63.00
Aircraft	13.82	15.0	49.00
Provisions	5.2	5.25	63.00
General Stores	1.94	5.95	63.00
Diesel Fuel Marine	372	2.862	69.94
JP-5	116	1.353	59.871
Lubricating Oil	19	1.779	87.667
SW Ballast	0	0	0
Fresh Water	14	1.348	30.55
Total	2981	5.48	70.18

Table 48 - Weight Summary: Minop Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship	2193	5.78	71.87
Ships Force	10.5	7.35	63.00
Total Weapons Loads	234.2	8.855	63.00
Aircraft	13.82	15.0	49.00
Provisions	5.2	5.25	63.00
General Stores	1.94	5.95	63.00
Diesel Fuel Marine	123	2.06	80.825
JP-5	40	0.718	59.729
Lubricating Oil	7	1.425	87.583
Compensated Fuel-Ballast	304	3.107	64.774
SW Ballast	0	0	0
Fresh Water	9	1.035	30.55
Total	2942	5.55	70.39

Table 49 - Minop Trim and Stability Summary

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT	
Light Ship	2193	5.484	8.000F	0	---	
Constant	234	8.855	8.000F	0	0	
Lube Oil	7	1.425	24.583A	0	8	
Fresh Water	9	1.035	32.450F	0	9	
SW Ballast	0	---	---	---	---	
Fuel (JP5)	40	0.718	3.271F	0	50	
Comp. Fuel/Ballast	304	3.107	1.774A	0	---	
Fuel (DFM)	123	2.06	17.825A	0	---	
Waste Oil	9	1.732	21.613A	0	10	
Sewage	10	1.234	9.5000F	0	1	
Displacement	2928	5.265	5.776F	0	170	
Stability Calculation			**Trim Calculation**			
KMt	9.588	m	LCF Draft		4.261	m
VCG	5.265	m	LCB (even keel)		5.949F	m-MS
GMt (Solid)	4.322	m	LCF Draft		0.787A	m-MS
FSc	0.058	m	MT1cm		77	m-MT/cm
GMt (Corrected)	4.264	m	Trim		0.066	m-A
			List		0	deg
Specific Gravity	1.025					
Hull calcs from tables			Tank calcs from tables			
Drafts						
Draft at A.P.	4.293	m				
Draft at M.S.	4.26	m				
Draft at F.P.	4.227	m				
Draft at Aft Marks	4.293	m				
Draft at Mid Marks	4.26	m				
Draft at Fwd Marks	4.227	m				

4.9.1 Intact Stability

In each condition, trim, stability and righting arm data are calculated. All conditions are assessed using DDS 079-1 stability standards for beam winds with rolling. For satisfactory intact stability two criteria must be met: (1) the heeling arm at the intersection of the righting arm and heeling arm curves must not be greater than six-tenths of the maximum righting arm; (2) the area under the righting arm curve and above the heeling arm curve (A1) must not be less than 1.4 times the area under the heeling arm curve and above the righting arm curve (A2).

Table 50 - Full Load Trim and Stability Summary

Item	Weight MT	VCG m	LCG m-MS	TCG m-CL	FSMom m-MT
Light Ship	2193	5.484	8.000F	0	---
Constant	234	8.855	8.000F	0	0
Lube Oil	19	1.779	24.667A	0	9
Fresh Water	14	1.348	32.450F	0	6
SW Ballast	0	---	---	---	---
Fuel (JP5)	116	1.353	3.129F	0	70
Comp. Fuel/Ballast	0	0	0	0	0
Fuel (DFM)	372	2.862	6.940A	0	86
Waste Oil	0	---	---	---	---
Sewage	0	---	---	---	---
Displacement	2947	5.216	5.827F	0	170

Stability Calculation			Trim Calculation		
KMt	9.558	m	LCF Draft	4.279	m
VCG	5.216	m	LCB (even keel)	5.908F	m-MS
GMt (Solid)	4.342	m	LCF	0.793A	m-MS
FSc	0.058	m	MT1cm	77	m-MT/cm
GMt (Corrected)	4.284	m	Trim	0.031	m-A
			List	0	deg
Specific Gravity	1.025				
Hull calcs from tables			Tank calcs from tables		

Drafts			Strength Calculations		
Draft at A.P.	4.294	m	Bending Moment	158552	kN-m
Draft at M.S.	4.278	m			
Draft at F.P.	4.263	m			
Draft at Aft Marks	4.294	m			
Draft at Mid Marks	4.278	m			
Draft at Fwd Marks	4.263	m			

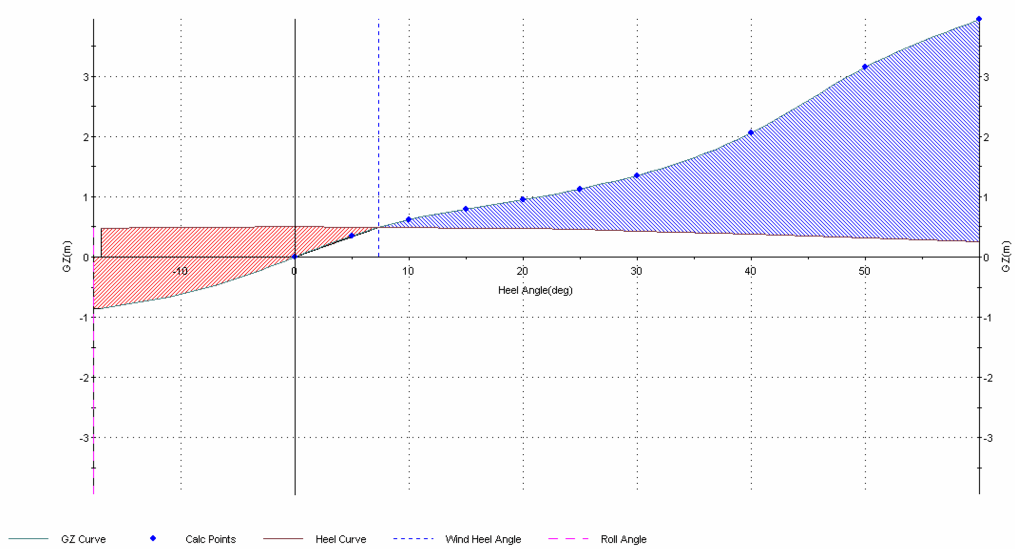

Figure 94 - Righting Arm (GZ) and Heeling Arm Curve for Minop Condition

Table 51 - Righting Arm (GZ) and Heeling Arm Data for Minop Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	2914 MT	Angle at Maximum GZ	60 deg
GMt (corrected)	4.264 m	Wind Heeling Arm Lw	0.492 m
Mean Draft	4.278 m	Angle at Intercept	60.0 deg
Projected Sail Area	1165 m2	Wind Heel Angle	7.3 deg
Vertical Arm	9.488 m ABL	Maximum GZ	3.949 m
Wind Pressure Factor	0.0035	Righting Area A1	1.43 m-rad
Wind Pressure	0.02 bar	Capsizing Area A2	0.34 m-rad
Wind Velocity	100 knts	Heeling Arm at 0 deg	0.5
Roll Back Angle	25.0 deg		

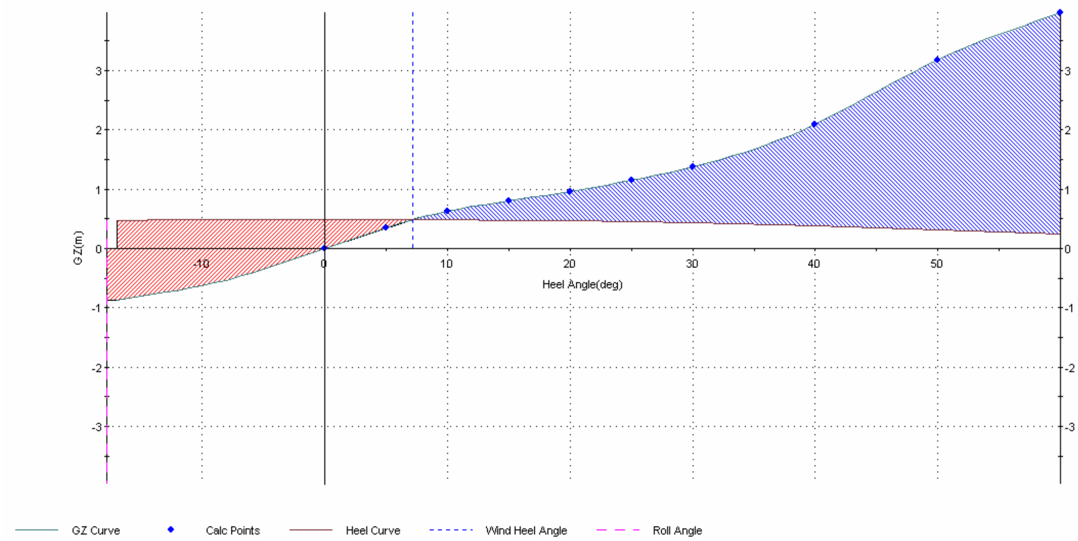

Figure 95 - Righting Arm (GZ) and Heeling Arm Curve for Full Load Condition

Table 52 - Righting Arm (GZ) and Heeling Arm Data for Full Load Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	2914 MT	Angle at Maximum GZ	60 deg
GMt (corrected)	4.264 m	Wind Heeling Arm Lw	0.488 m
Mean Draft	4.26 m	Angle at Intercept	60.0 deg
Projected Sail Area	1160 m^2	Wind Heel Angle	7.2 deg
Vertical Arm	9.48 m ABL	Maximum GZ	3.975 m
Wind Pressure Factor	0.0035	Righting Area A1	1.45 m-rad
Wind Pressure	0.02 bar	Capsizing Area A2	0.34 m-rad
Wind Velocity	100 knts	Heeling Arm at 0 deg	0.496 m
Roll Back Angle	25.0 deg		

ASC-HI2 intact stability is satisfactory for both minimum operating and full load conditions.

4.9.2 Damage Stability

In addition to locating transverse bulkheads to satisfy floodable length requirements, the two load cases, Minimum Operation (Minop) and Full Load, are checked for damage stability using a 15% and 50% LWL damage length in accordance with DDS 079-01 for large multi-hulls. The 15% length is equal to an 18.9 meter damage length which is systematically applied along the length of the ship starting from the bow and moving aft. Worst case penetration to the centerline is used. The 50% damage case was applied along the outrigger section with damage only to the outrigger hulls and not the center hull. 72 damage cases were assessed for each loading condition. In all cases, the flooded angle of heel must be less than 15 degrees, the margin line must not be submerged, and remaining dynamic stability must be adequate ($A_1 > 1.4\, A_2$).

Table 53 - Minop Damage Worse Damage Cases

	Intact	Damage BH 6-42 (trim)	Damage BH 42-78 (heel)
Draft AP (m)	4.293	-0.523	5.078
Draft FP (m)	4.227	13.384	6.113
Trim on LBP (m)	0.066 F	13.907 F	1.035 F
Total Weight (MT)	2914	5077	4319
Static Heel (deg)	0.0P	0.0S	7.2 S
GM_t (upright) (m)	4.284	5.359	1.428
Maximum GZ		4.869	4.931

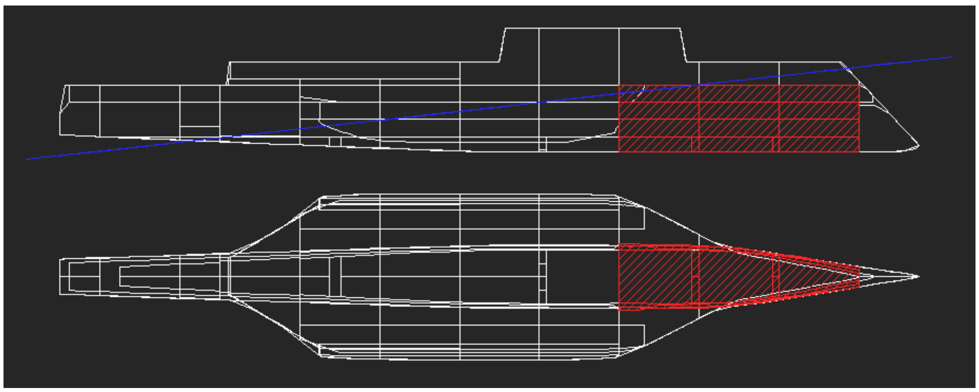

Figure 96 - Limiting Trim Case at Minop

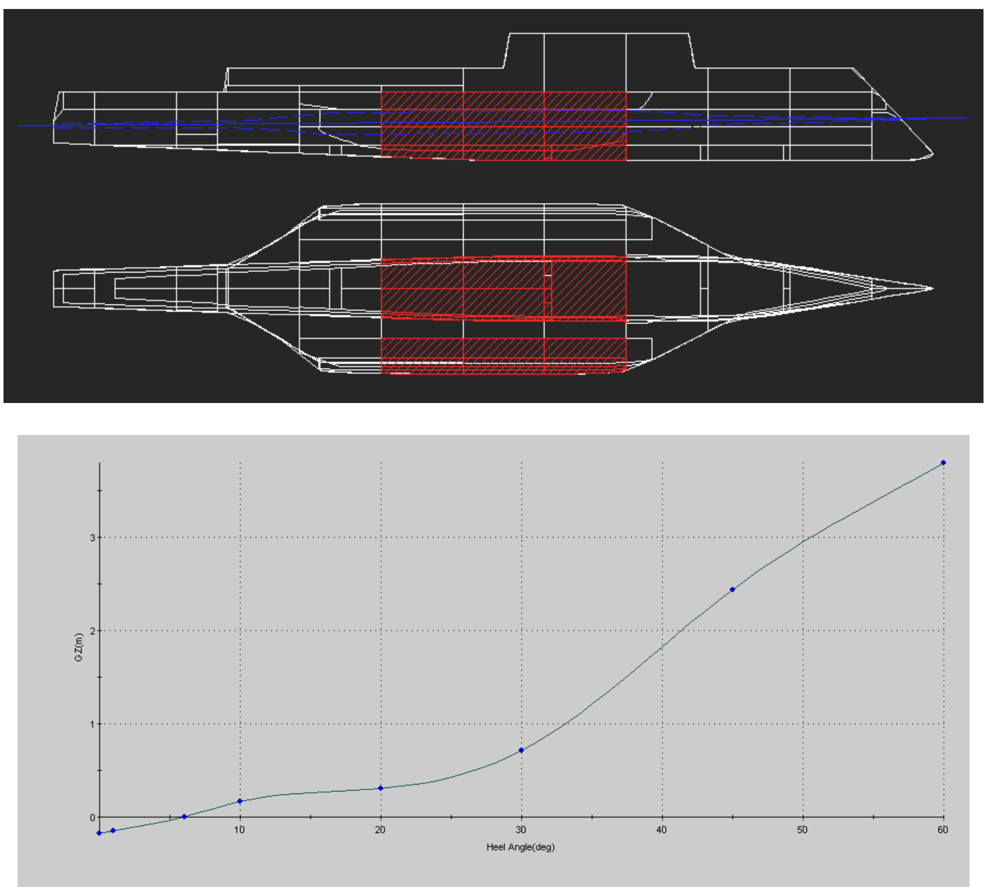

Figure 97 - Limiting Heel Case for Minop Condition

Table 54 - Full Load Damage Results

	Intact	Damage BH 6-42 (trim limit)	Damage BH 42-78 (heel limit)
Draft AP (m)	4.294	-0.477	5.103
Draft FP (m)	4.263	13.434	6.180
Trim on LBP (m)	0.031A	13.911 F	1.077 A
Total Weight (MT)	2953	5117	4366
Static Heel (deg)	0.0P	0.0S	8.0S
GM_t (upright) (m)	4.281	5.410	1.457
Maximum GZ		4.992	5.057
Maximum GZ Angle		84S	86S
GZ Pos. Range (deg)		0 - 89	8 - 89

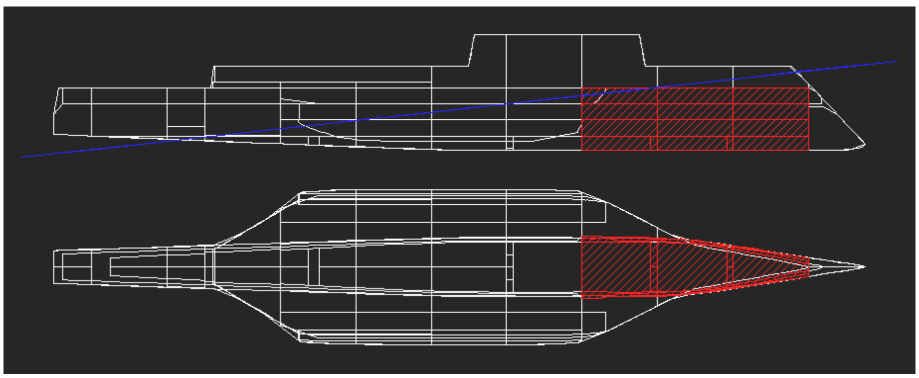

Figure 98 - Limiting Trim Case for Full Load Condition

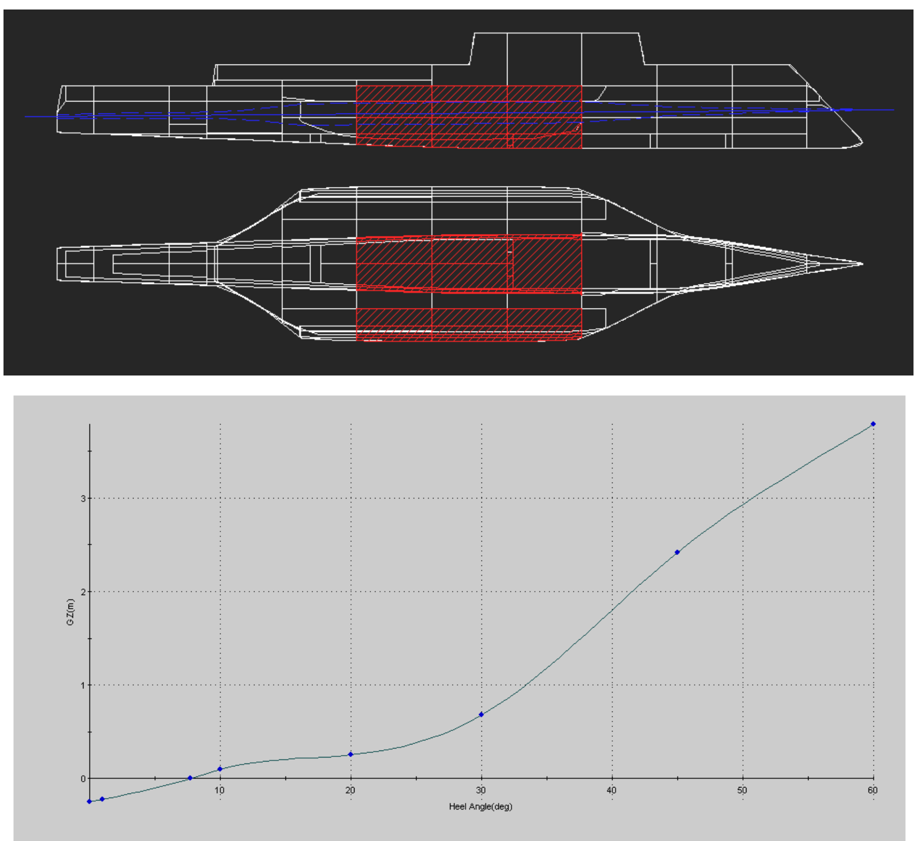

Figure 99 - Limiting Heel Case for Full Load

The limiting trim case in the Minop condition is for flooding between bulkheads at Frames 6 and 42. The limiting heel case is for flooding between bulkheads at Frames 42 and 78. Tabular results are listed in Table 53. Figure 96 shows the trim case results with the damaged compartments in red. Figure 97 shows the results in the limiting heel case with righting arm curve, flooding Frames 42 to 78. ASC damaged stability is satisfactory in the Minop condition, although the trim case is severe.

The limiting case for trim in the Full Load condition is flooding between bulkheads at Frames 6 and 42. The limiting heel case is for flooding between bulkheads at Frames 42 and 78. Tabular results are listed in Table 54. Figure 98 shows the trim results with the damaged compartments in red. Figure 99 shows the results for the limiting heel case. ASC damage stability is satisfactory in the Full Load condition, although the worse trim case is again severe.

4.10 Seakeeping

A seakeeping analysis in the full load condition was performed using SWAN2. A strip theory or extended strip theory code is not adequate for the multi-hull application. The hull was modeled using offsets from FASTSHIP. Ship responses were calculated for regular waves in Sea States 3, 4, 5, 6, 7, and 8 (significant wave heights of 0.88, 1.88, 3.25, 5, 7.5, and 11.5 meters) for forward speeds of 5, 10, 20, 30, and 40 knots and at four or more headings. Ship accelerations were analyzed at 2 locations and angular motions were analyzed at the center of gravity. These locations are described in Table 55 below. SWAN2 created output files of general ship motion RAOs, and accelerations at the helo pad and bridge. The SWAN2 TECPLOT package was used to create Speed-Polar plots showing the operating envelopes of the ship for Required Operational Capabilities (ROCs) using US Navy Motion Limit Criteria by subsystem. The plots show the ship response for various headings and forward speeds. The bold red line indicates the system limit. Significant amplitude criteria are listed in Table 56.

Table 55 - Sea Keeping Analysis Locations

Application	X location from Midships, m	Y location from CL, m	Z location from DWL, m
Vertical Launch and Recovery	-11	0	9
VERTREP	-11	0	9
Helo Launch and Recovery	-11	0	9
Bridge Personnel	32	0	11

Table 56 - Limiting Motion Criteria (Significant Amplitude) and Results

Application	Roll	Pitch	Yaw	Longitudinal Acceleration	Transverse Acceleration	Vertical Acceleration	ORD Threshold SeaState	Sea State Achieved
Bow Active Sonar	15°	5°	-	-	-	-	5	6,7 restricted 5 unrestricted
Vertical Launch and Recovery	17.5°	3°	1.5°	0.3g	0.7g	0.6g	4	6,7 restricted 5 unrestricted
VERTREP	4°	-	-	-	-	-	4	7 restricted 6 unrestricted
Helo Launch and Recovery	5°	3°	-	-	-	-	4	7 restricted 6 unrestricted
Bridge Personnel	8°	3°	-	0.2g	0.2g	0.4g	7	7 restricted 6 unrestricted

The MCM mission is performed using a Bow Passive/Active Sonar. Bow Active Sonar maximum motion limits are 15 degrees roll and 5 degrees pitch. The Bow Active Sonar operating envelope is shown in Figure 100. Restricted operation is possible in Sea States 6 and 7. The acceptable operating range in Sea State 7 requires a heading of 040-130 or 220-340. Unrestricted operation is possible in Sea State 5.

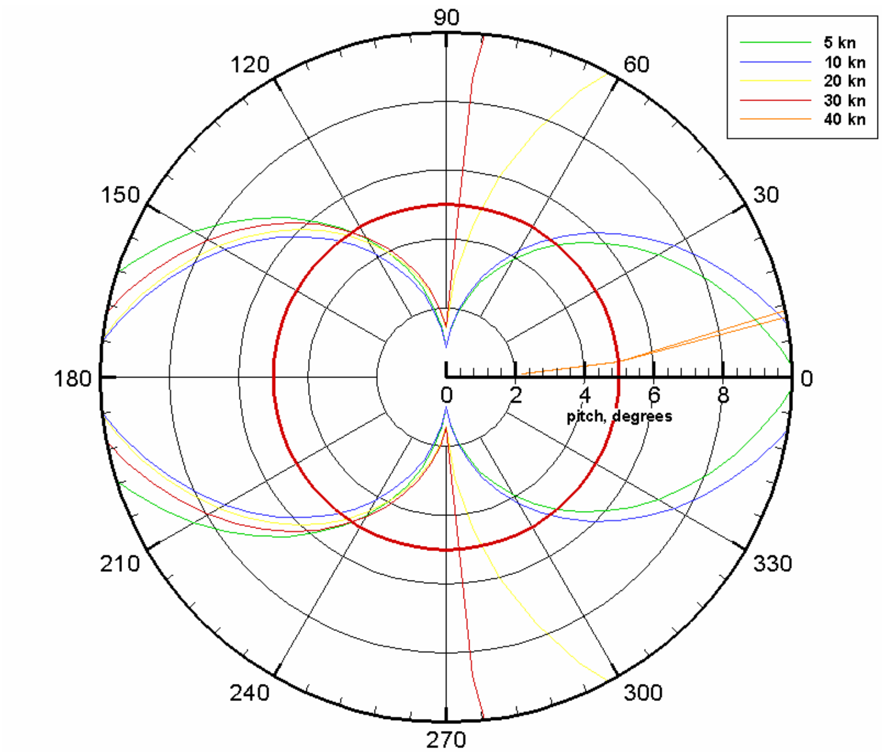

Figure 100 - MCM mission (Bow Active Sonar) Speed-Polar Plot for Pitch in Sea State 7

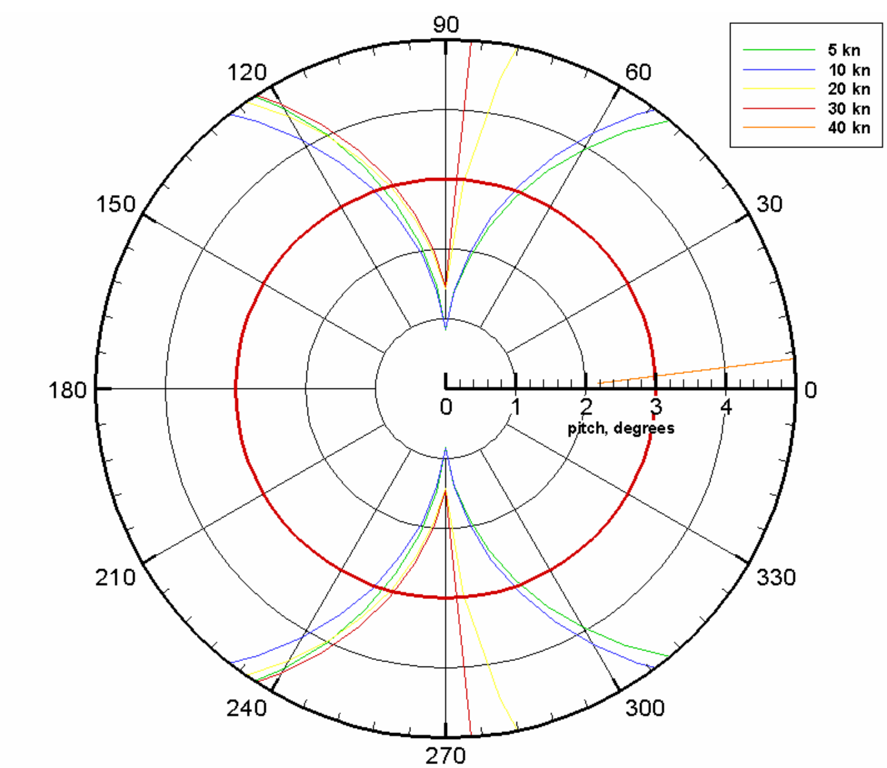

Figure 101 - VTUAV Vertical Launch and Recovery Speed-Polar Plot for Pitch in Sea State 7

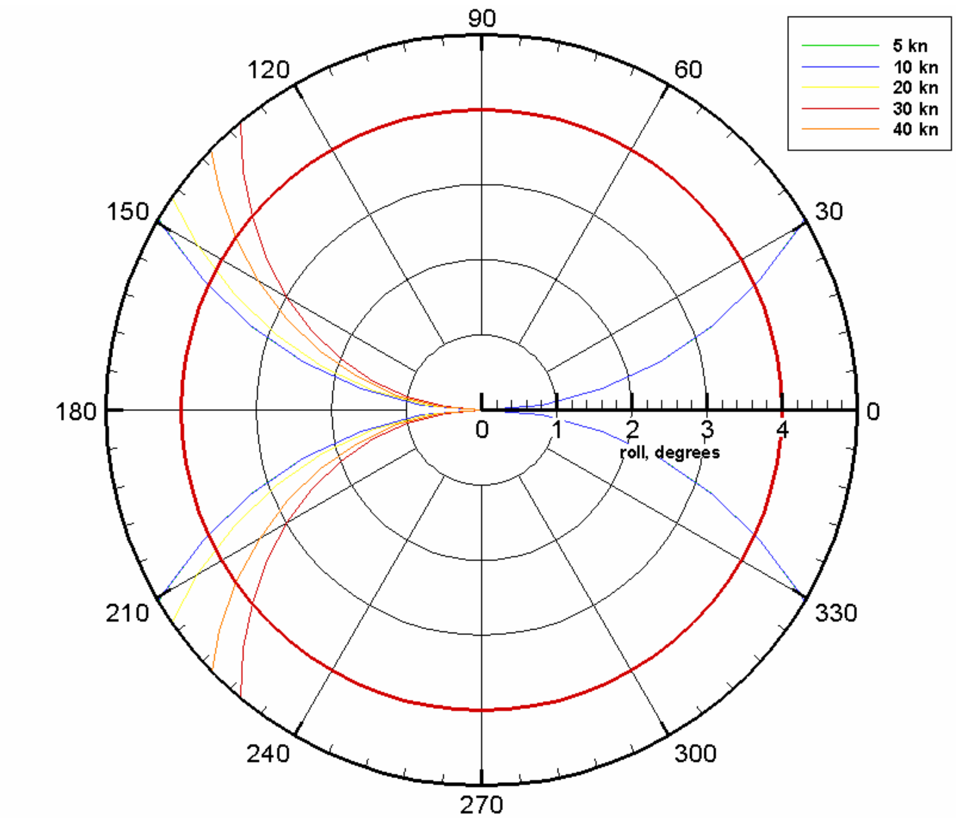

Figure 102 - VERTREP Speed-Polar Plot for Roll in Sea State 7

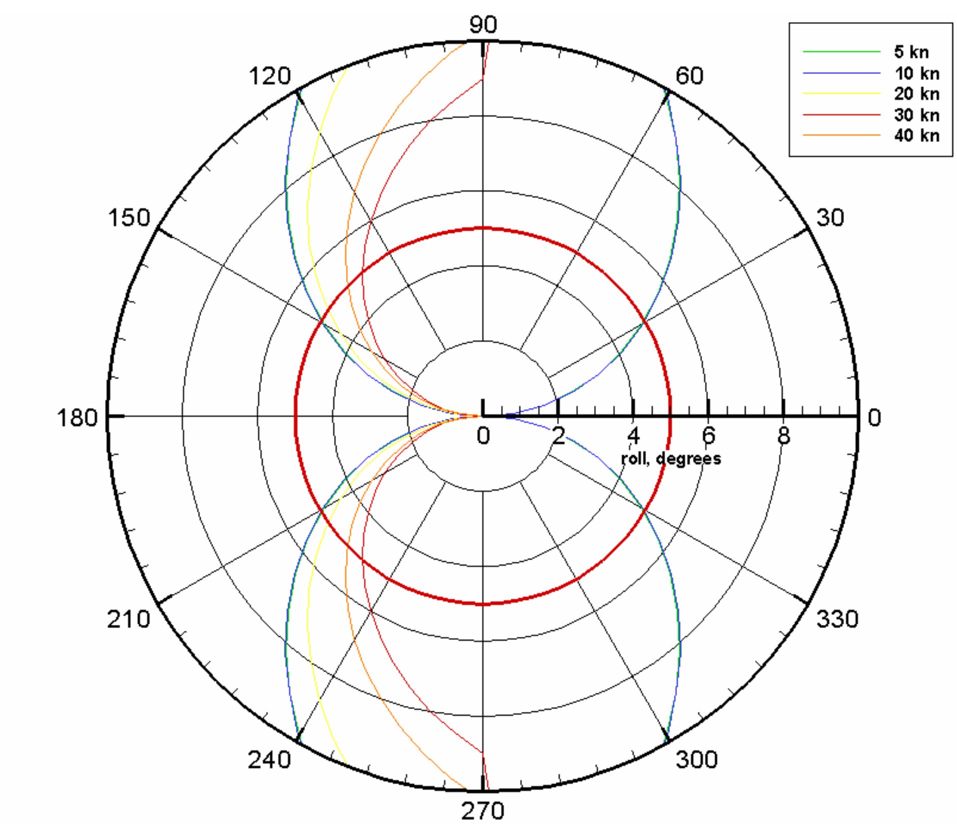

Figure 103 - Helo Launch and Recovery Speed-Polar Plot for Roll in Sea State 7

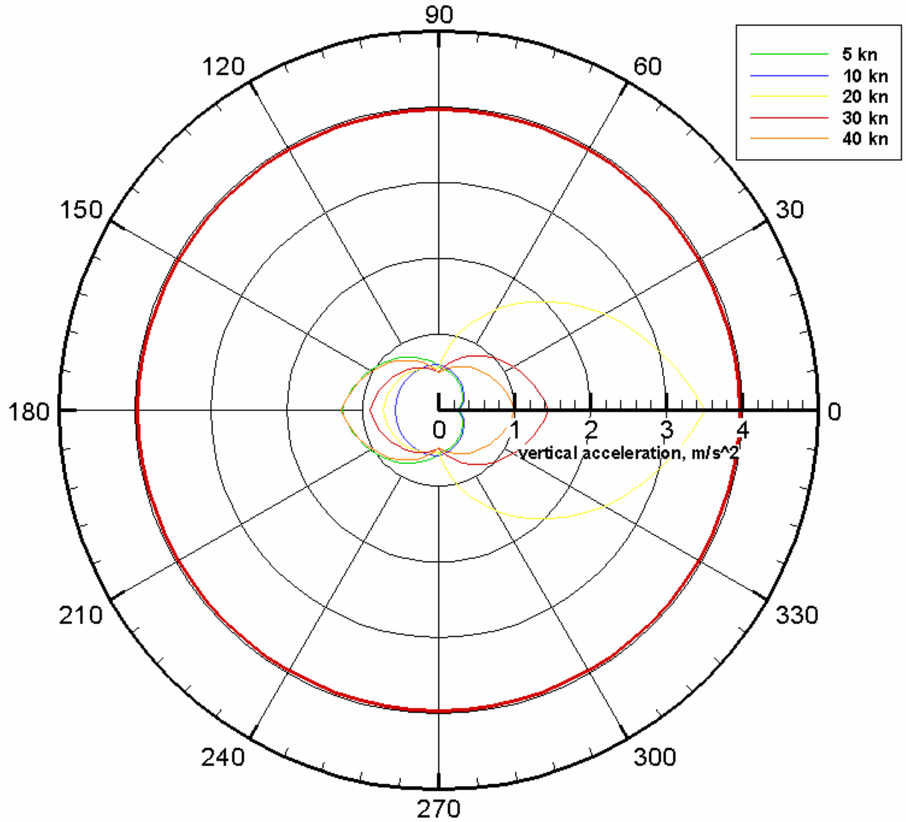

Figure 104 - Bridge Personnel Speed-Polar Plot for Vertical Acceleration in Sea State 7

VTUAV vertical launch and recovery maximum criteria are 17.5 degrees roll, 3 degrees pitch, and 1.5 degrees yaw. Longitudinal acceleration must be less than 0.3g, transverse acceleration less than 0.7g, and vertical acceleration less than 0.6g. VTUAV operations are limited by roll and pitch. Restricted operation is possible in Sea States 6 and 7. The Speed-polar plot of pitch in Sea State 7 is shown in Figure 101. The acceptable operating range in Sea State 7 requires a heading of 090-110 or 250-270. Unrestricted operation is possible in Sea State 5.

The criterion for Vertical Underway Replenishment is a maximum roll of 4 degrees. ASC is fully operational in Sea State 6 and limited in Sea State 7. The speed-polar plot for roll for Sea State 7 is shown in Figure 102. A heading of 030-330 (following seas) or 150-210 (head seas) is required to be within the criteria in Sea State 7.

ASW and ASUW missions are performed using LAMPS. The performance criteria for helo flight operations are 5 degrees roll and 3 degrees pitch. The seakeeping analysis indicates that helicopter flight operations are possible in all conditions in Sea State 6. The limiting factor for Sea State 7 is inability to meet roll and pitch criteria at the same time. Figure 103 is a Speed-polar plot showing the helo operating envelope for Sea State 7. The acceptable operating range from the aft landing spot for roll in Sea State 4 requires a heading of 150-210 (head seas) or 030-330 (following seas).

Seakeeping analysis at the location of the moon pool, for surface vehicle launch and recovery, is not calculated. The moon pool is located on Main Deck just below the helo pad where the VTUAVs and Helo are deployed and recovered. These aircraft have full capabilities for launch and recovery in Sea State 6. It is expected that the surface vehicles should have full launch and recovery capabilities in Sea State 4 or 5. This meets or exceeds the goal of Sea State 4 for surface vehicle launch and recovery. This must be demonstrated in the next design iteration. Sloshing and wave entry into the moon pool should also be investigated.

The performance degradation criteria for personnel are 8 degrees roll and 3 degrees pitch. Crew on the bridge must only be subjected to 0.2g lateral acceleration and 0.4g vertical acceleration. Figure 104 is a Speed Polar plot showing the operating envelope for personnel in Sea State 7. The limiting criterion in Sea State 7 is roll. The acceptable operating range requires a heading of 030-330 (following seas) or 150-210 (head seas).

ASC-HI2 satisfies bridge personnel requirements on restricted headings and exceeds requirements for VTUAV, Helo Launch and Recovery, VERTREP, and MCM active sonar applications.

4.11 Cost and Risk Analysis

4.11.1 Cost and Producibility

Cost calculations for ASC HI2 were based primarily on group weights using a proprietary NSWC cost spreadsheet. Concept Development changes resulted in a somewhat lower cost than originally estimated. A comparison of the costs is shown in Table 57. Acquisition cost satisfies the threshold value specified in the ORD.

Table 57 - 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	0
Composite	0	1
HullForm (select one)		
Monohull	0	0
Catamaran	0	0
Trimaran	1	1
Plant Type (select one)		
Gas Turbine	1	1
Diesel	0	0
Diesel Electric	0	0
CODOG	0	0
CODAG	0	0
Plant Power (select one)		
Power Rating (in SHP)	69,733	69,733
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)	1163	1163
150 (deckhouse)	18	18
200 (less propeller)	207	237
245 (propeller)	139	139
300	102	102
400	119	119
500	198	198
600	132	132
700	11	11
Margin	104	104
Lightship	2193	2222
Full Load Displacement	2825	2825
Operating and Support		
Complement	87	87
Steaming Hrs Underway / Yr	3000	3000
Fuel Usage (BBL / Yr)	1052.81	1052.81
Service Life (Yrs)	30	30
Cost Element	**Concept Baseline**	**Final Concept Baseline**
Shipbuilder	**$264**	**$275**
Government Furnished Equipment (a)	**$195**	**$203**
Other Costs	**$33**	**$11**
Operating and Support	**$391**	**$387**
Personnel (Direct & Indirect)	*$109*	*$109*
Unit Level Consumption (Fuel, Supplies, Stores, e	*$60*	*$59*
Maintenance & Support	*$223*	*$220*
Life Cycle Cost (less non-recurring)	**$882**	**$877**
LCC Threshold	**$930M**	
Average Acquisition Cost	**$492M**	**$489M**
Average Acquisition Cost Threshold	**$510M**	

ASC-HI2 is a producible design. A chine at the waterline transitions the curved wetted surfaces to a low-curvature freeboard. The entire hull above the waterline consists of single curvature or flat plating as does the transom. The cost of outfitting and installation is reduced by generous deck heights and the use of zonal distribution systems for electric power, firemain and ventilation. The variety of structural materials (plate and shapes) was kept to a minimum.

4.11.2 Risk Analysis

Based on the ASC OMOR, ASC-HI2 is a relatively high risk ship. This risk is due to the unproven cutting edge technology and concepts integrated into the design. The trimaran hullform, Wave Piercing Tumble Home (WPTH) hull form, Integrated Power System, unmanned aircraft and surface vehicles, automated systems, and aluminum structure are all high risk alternatives as described in Table 28. Additional technology demonstrations and tests are required to reduce this risk. An integrated test using the lead ASC-HI2 alternative would assess all high risk technologies simultaneously and could be considered as a lead (test) ship. This is a revolutionary approach.

5 Conclusions and Future Work

5.1 Assessment

ASC HI2 meets and exceeds the requirements specified in the ORD as shown in Table 58.

Table 58 - Compliance with Operational Requirements

Technical Performance Measure	ORD TPM (Threshold)	Original Goal	Concept BL	Final Concept BL
Number of VTUAVs	3	3	3	3
Number of SPARTANs	2	3	2	2
Number of LAMPS	1	2	1	1
Number of RMSs	2	4	2	2
Total mission payload weight (core, modules, fuel) (MT)	360	360	363	360
Endurance range (nm)	3600	4500	3503	3881
Sprint range (nm)	1000	1500	1196	1241
Stores duration (days)	24	24	24	24
CBR	Partial	Full	Partial	Partial
Sustained (Sprint) Speed Vs (knots)	40	50	38.9	42.7
Crew size	90	50	87	88
Maximum Draft (m)	4.4	3	4.21	4.368
Vulnerability (Hull Material)	Aluminum	Steel	Aluminum	Aluminum
Seakeeping capabilities (sea state)				
- launch and recover aircraft	SS4	SS5	---	SS5
- launch and recover watercraft	SS3	SS4	---	SS5
- full capability of all systems	SS5	SS6	---	SS6
- survive	SS8	---	---	SS8
Follow-ship Acquisition cost ($M)	500	400	492	489
Life cycle cost ($M 2003)	900	800	882	877
Overall Measure of Effectiveness (OMOE)	0.584	1.0	0.584	0.693
Maximum level of risk (OMOR)	0.691	0.0	0.691	0.691

ASC incorporates an effective combination of proven technology and new cutting edge technology. It integrates the use of non-traditional modular mission packages designed for off-board unmanned operations in littoral regions. A stealthy, low radar cross section design is effectively incorporated in the hull form to satisfy the requirement for passive defense. The advanced enclosed mast maintains ASC HI2's low radar cross section while protecting the ship's electronic sensors. The two gas turbines satisfy the threshold value for sustained speed, while the integrated power system provides the ability to efficiently operate the waterjets at speeds below 14 knots. Manning is significantly reduced compared to other naval vessels through automation while maintaining a high integrity of operations. ASC exceeds Navy damage stability requirements.

5.2 Future Work

- Consider recovering power with IPS during use of LM2500+'s above speeds of 14 knots.
- Consider details of LM2500+'s intake and exhaust.
- Consider using diesel generators (SSDGs) or smaller SSGTGs.
- Further reduce scantlings to optimize adequacy parameters and reduce weight.
- Consider use of composite materials for the hangar and pilot house.
- Consider the details of launching and retrieving operations with the moon pool.
- Analyze structural and system vulnerability.
- Assess reliability, maintainability and availability (RMA).
- Consider corrosion prevention techniques for aluminum hulls.
- Model flooded compartments in MAESTRO for each major damage case to assess damaged structural integrity.

5.3 Conclusion

The ASC requirement is based on the LCS Flight 0 Preliminary Design Interim Requirements Document and ASC Acquisition Decision Memorandum (ADM). ASC will operate in littoral areas, close-in, depend on stealth, with high endurance and low manning. It is required to support UCSVs, VTUAVs and LAMPS, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The VTUAVs will provide surface, subsurface, shore, and deep inland intelligence, surveillance, reconnaissance (ISR) and electronic warfare. LAMPS will provide Anti-Submarine Warfare (ASW) and Anti-Surface Ship Warfare (ASUW) defense. The UCSVs can engage surface threats with anti-surface armaments, conduct SAR operations, support and conduct intelligence collection, and conduct surveillance and reconnaissance.

Concept Exploration trade-off studies and design space exploration were accomplished using a Multi-Objective Genetic Optimization (MOGO) after significant technology research and definition. Objective attributes for this optimization were life-cycle cost, risk (technology, cost, schedule and performance) and military effectiveness. The product of this optimization is a series of cost-risk-effectiveness frontiers which are used to select the ASC HI2 Baseline Concept Design and define Operational Requirements (ORD1) based on the customer's preference for cost, risk and effectiveness.

ASC HI2 is the highest-end alternative on the life-cycle cost frontier. This design was chosen to provide a challenging design project using higher risk technology. ASC HI2 characteristics are listed below. ASC HI2 has a wave-piercing tumblehome (WPTH) hullform to reduce radar cross-section, and a unique moon pool for launching and recovering UCSVs and mine hunting systems (RMS). It uses significant automation technology including an automated mess, an Integrated Survivability Management System (ISMS), and watch standing technologies that include GPS, automated route planning, electronic charting and navigation (ECDIS), collision avoidance, and electronic log keeping. Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, IPS system development and arrangement, general arrangements, combat system selection, seakeeping analysis, cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements within cost and risk constraints with additional work required to improve structural and system vulnerability and reduce structural weight. ASC-HI2 meets or exceeds the requirements for this design.

The WPTH center-hull design reduces resistance and vertical motion in waves and reduces RCS. An Integrated Power System (IPS) provides electrical power to the ship using three Ship Service Gas Turbine Generators (SSGTGs). Propulsion uses a mechanical drive system, for speeds above 14 knots, and IPS, for speeds below 14 knots. The mechanical drive system includes 2 LM2500+ engines that drive the 2 Kamewa 225SII waterjets. The integrated power system includes 2 gear propulsion motors with clutch, 1 attached to each shaft, to drive the waterjets. The Mission Bay provides sufficient space to house, repair, and safely operate the 2 SPARTAN UCSVs and the RHIB, RMS, and UUV Detachment. The moon pool is located between the center and outer hulls in the mission bay, which provides a safe means of deploying and recovering these vehicles. Hangar space is sufficient to house, repair, and safely operate the LAMPS helicopter and 3 VTUAVs. A low-RCS Advanced Enclosed Mast System is located on top of the hangar at the forward end and houses the surface and air search radar. Two CIWS, one at each end of the hangar, provide anti-air defense against incoming attacks.

ASC-HI2 is a unique and capable design that should be considered as lead/test ship for a revolutionary ASC class of ships.

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Appendix A– Acquisition Decision Memorandum

Virginia Tech

Aerospace and Ocean Engineering

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

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

December 9, 2003

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

Subj: ACQUISITION DECISION MEMORANDUM FOR AN AGILE SURFACE COMBATANT (ASC)

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

1. This memorandum authorizes Concept Exploration of two material alternatives for an Agile Surface Combatant, as proposed to the Virginia Tech Naval Acquisition Board. These alternatives are: 1) a new catamaran design (VT Team 1); and 2) a new trimaran design (VT Team 2). 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). ASC must perform the following missions using interchangeable, networked, tailored modular mission packages built around off-board, unmanned systems:

1. Intelligence, Surveillance, and Reconnaissance (ISR)
2. Mine Counter Measures (MCM)
3. Anti-Submarine Warfare (ASW)
4. Anti-Surface Ship Warfare (ASuW)
5. Anti-Air Warfare (AAW) self defense

Unmanned systems may include the Spartan Unmanned Combat Surface Vehicle (UCSV) and the Vertical Takeoff Unmanned Air Vehicle (VTUAV), both transformational technologies in development. 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. 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.

3. Exit Criteria. ASC shall have a minimum endurance range of 3500 nm at 20 knots and a minimum sustained (sprint) speed of 40 knots. It shall have a minimum sprint range of 1000 nm. 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. Life cycle cost shall not exceed $1B. Average follow-ship acquisition cost shall not exceed $500M. Manning complement (core plus mission) shall not exceed 90 personnel. ASC shall be able to safely launch and recover aircraft in Sea State 4 and watercraft in Sea State 3. It shall provide full capability of all systems in Sea State 5 and survive in Sea State 8.

A.J. Brown
VT Acquisition Executive

Appendix B– Operational Requirements Document

OPERATIONAL REQUIREMENTS DOCUMENT (ORD)
AGILE SURFACE COMBATANT (ASC)
Virginia Tech Team 2 – ASC HI2 Trimaran Alternative

1. Mission Need Summary

The ASC requirement is based on the Virginia Tech ASC Acquisition Decision Memorandum (ADM) and the LCS Flight 0 Preliminary Design Interim Requirements Document (PD-IRD).

ASC is likely to be forward deployed in peacetime, conducting extended operations in sensitive littoral regions. ASC 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 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 be an active force in countering all threats. ASC will support the following missions using interchangeable, networked, tailored modular mission packages built around off-board, unmanned systems:

1. Intelligence, Surveillance, and Reconnaissance (ISR)
2. Mine Counter Measures (MCM)
3. Anti-Submarine Warfare (ASW)
4. Anti-Surface Ship Warfare (ASuW)
5. Anti-Air Warfare (AAW) self defense

Unmanned systems include the Spartan Unmanned Combat Surface Vehicle (UCSV) and the Vertical Takeoff Unmanned Air Vehicle (VTUAV). Mission packages will use "plug-in" technology, which interface with ASC core support systems. Additional "trained" personnel may be required to operate the mission packages. Packages will be built for rapid reconfiguration, and will be scalable and transportable by air and ship. Like an "airframe", visualize ASC as a "sea frame".

2. Acquisition Decision Memorandum (ADM)

The ASC ADM authorizes Concept Exploration of two material alternatives for an Agile Surface Combatant (ASC), as proposed to the Virginia Tech Naval Acquisition Board. These alternatives are: 1) a new catamaran design; and 2) a new trimaran design. Additional material and non-material alternatives supporting this mission may be authorized in the future.

3. Results of Concept Exploration

Concept exploration was performed using a multi-objective genetic optimization (MOGO). A broad range of non-dominated ASC alternatives within the scope of the ADM was identified based on life cycle cost, effectiveness and risk. **This ORD specifies a requirement for concept development of ASC trimaran alternative HI2.** Other alternatives are specified in separate ORDs. HI2 is the high end trimaran design on the ND higher-risk frontier (Figure 1).

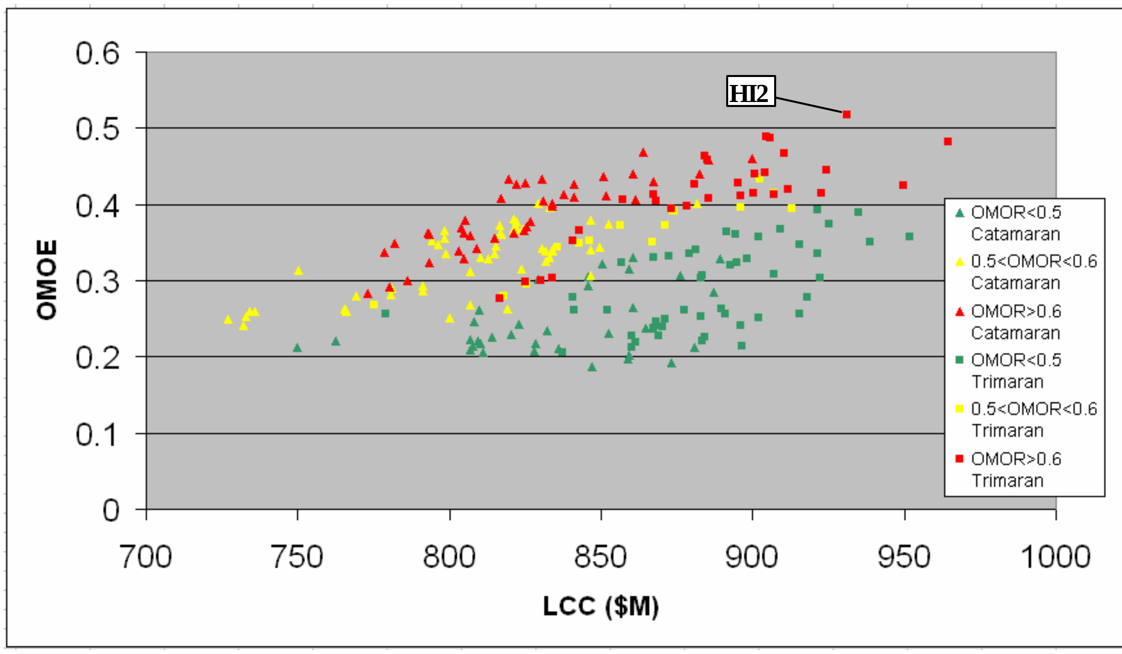

Figure 1. ASC Non-Dominated (ND) Frontier

4. Technical Performance Measures (TPMs)]

TPM	Threshold
Number of VTUAVs	3
Number of SPARTANs	2
Number of LAMPS	1
Total mission payload weight (core, modules, fuel)	360 MT
Endurance range (nm)	3600
Sprint range (nm)	1000
Stores duration (days)	24
CBR	Partial
Vs (knt)	40
Crew size	90
RCS (deckhouse m^3)	700
Maximum Draft (m)	4.4
Vulnerability (Hull Material)	Aluminum
Seakeeping capabilities (sea state)	
- launch and recover aircraft	4
- launch and recover watercraft	3
- full capability of all systems	5
- survive	8

5. Program Requirements

Program Requirement	Threshold
Average follow-ship acquisition cost ($M)	510
Life cycle cost ($M)	930
Maximum level of risk (OMOR)	0.691

6. Baseline Ship Characteristics (HI2 Alternative)

Concept development will begin with the following baseline design:

Hullform	Trimaran
Hull Material	Aluminum
Δ (MT)	2800
LWL (m)	131.24
Beam (m)	26.0
Draft (m)	4.37
D10 (m)	10.41
W1 (MT)	1120
W2 (MT)	346
W3 (MT)	178
W4 (MT)	118
W5 (MT)	195
W6 (MT)	129
Lightship Δ (MT)	2200
KG (m)	5.74
KM (m)	27.23
GM (m)	21.49
GM/B ratio	0.83
Propulsion system	Mechanical drive w/ epicyclic gears 2 x 225SII waterjets 2 x LM2500+ 3 x 3000kw SSGTG
Engine inlet and exhaust	Stern
Number of VTUAVs	3
Number of SPARTANs	2
Number of LAMPS	1

7. Other Design Requirements, Constraints and Margins

KG margin (m)	1.0
Propulsion power margin (design)	10 %
Propulsion power margin (fouling and seastate)	25% (0.8 MCR)
Electrical margins	10%
Weight margin (design and service)	10%

8. Special Design Considerations and Standards

Concept development shall consider and evaluate the following specific areas and features:

- Topside and hull design shall incorporate features to reduce total ship signatures including infrared (IR), radar cross-section (RCS), magnetic, and acoustic signatures.
- Propulsion plant options shall consider the need for reduced acoustic and infrared signatures while addressing required speed and endurance.
- Reduced manning and maintenance factors shall be considered to minimize total ownership cost

The following standards shall be used as design "guidance":

- ABS Guide for Building and Classing High Speed Naval Craft, 2003
- General Specifications for Ships of the USN (1995)
- DNV Rules for HSLC (2000)
- ASTM B 221M (2002): Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes
- Stability and Buoyancy: DDS 079-1 (2002)

- Endurance Fuel: DDS 200-1
- Electric Load Analysis: DDS 310-1

Use the following cost and life cycle assumptions:

- Ship service life = L_S = 30 years
- Base year = 2006
- IOC = 2012
- Total ship acquisition = N_S = 30 ships
- Production rate = R_P = 2 per year

Appendix C – Machinery Equipment List

Item	Equipment Nomenclature	Quantity	Capacity / Rating
1	Gas Turbine, Main	2	26100 kW @ 3600 RPM
2	Gas Turbine Enclosure Module	2	
3	Gear, Propulsion Reduction Epicyclic (stbd)	1	
4	Gear, Propulsion Reduction Epicyclic (port)	1	
5	Clutch, Prop	2	
6	Shaft, Line	2	
7	Waterjet	2	25000 kW
8	Bearing, Line Shaft	6	0.575 m line shaft
9	Bearing, Thrust	2	
10	Console, Main Control	1	
11	Strainer, Sea Water	2	
12	Pump, Main SW Circ	2	230 m^3/hr @ 2 bar
13	Pump, Stbd rd gear lube oil service	1	200 m^3/hr @ 5 bar
14	Pump, Pt rd gear lube oil service	1	154 m^3/hr @ 5 bar
15	Strainer, Rd gear lube oil	2	200 m^3/hr
16	Cooler, Rd gear lube oil	2	
17	Purifier, Lube Oil	2	1.1 m^3/hr
18	Pump, Lube Oil Transfer	2	4 m^3/hr @ 5 bar
19	Assembly, GT Lube Oil Storage and Conditioning	2	
20	Ship Service Engine	3	3156 kW @ 14845 RPM
21	SS Eng Enclosure Module	3	
22	SS Reduction Gear	3	
23	SS Generator	3	
24	Switchboard, Ship Service	1	
25	Switchboard, Emergency	1	
26	Air Conditioning Plants	4	150 Ton
27	Refrigeration Plants	2	4.3 Ton
28	MMR Supply Fan	4	94762 m^3/hr
29	MMR Exhaust Fan	4	91644 m^3/hr
30	AMR Supply Fan	2	61164 m^3/hr
31	AMR Exhaust Fan	2	61164 m^3/hr
32	Pump, Fire	3	454 m^3/hr @ 9 bar
33	Pump, Fire/Ballast	1	455 m^3/hr @ 9 bar
34	Pump, Bilge	2	227 m3/hr @ 3.8 bar
35	Pump, Bilge/Ballast	1	227 m3/hr @ 3.8 bar
36	Fresh Water Distiller	2	76 m^3/day (3.2 m^3/hr)
37	Brominator	2	1.5 m^3/hr
38	Pump, Chilled Water AC	4	128 m^3/hr @ 4.1 bar
39	Pump, Potable Water	2	22.7 m^3/hr @ 4.8 bar
40	Brominator	1	5.7 m^3/hr
41	Pump, GT Fuel Booster	2	15.9 m^3/hr
42	Filter Separator, GT Fuel	2	30 m^3/hr

Item	Equipment Nomenclature	Quantity	Capacity / Rating
43	Heater, GT Fuel Service	2	10.4 m^3/hr
44	Heater, Fuel Service	2	7.0 m^3/hr
45	Pre-filter, GT Fuel Service	2	30 m^3/hr
46	Purifier, Fuel Oil	2	7.0 m^3/hr
47	Pump, Fuel Transfer	2	45.4 m^3/hr @ 5.2 bar
48	Pump, JP5 Transfer	2	11.5 m^3/hr @ 4.1 bar
49	Pump, JP5 Service	2	22.7 m^3/hr @ 7.6 bar
50	Pump, JP5 Stripping	1	5.7 m^3/hr @ 3.4 bar
51	Filter/Separator, JP5 Transfer	2	17 m^3/hr
52	Filter/Separator, JP5 Service	2	22.7 m^3/hr
53	Receiver, Starting air	2	2.3 m^3
54	Compressor, Starting air	2	80 m^3/hr FADY @ 30 bar
55	Receiver, Ship Service Air	1	1.7 m^3
56	Receiver, Control Air	1	1 m^3
57	Compressor, Air, LP Ship Service	1	8.6 bar @ 194 SCFM
58	Dryer, Air	1	250 SCFM
59	Station, AFFF Proportioning	2	227 m^3/hr
60	GT Hydraulic Starting Unit	2	14.8 m^3/hr @ 414 bar
61	Sewage Collection Unit	1	28 m^3
62	Oil Content Monitor	2	15 PPM
63	Pump, Oily Waste Transfer	2	12.3 m^3/hr @ 7.6 bar
64	Separator, Oil/Water	2	2.7 m^3/hr
65	Sewage Plant	1	125 people
66	IPS Motors	2	
67	Frequency Converter	2	

Appendix D – Weights and Centers Summary

			Abv BL +		Aft FP +		Port CL +	
SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
	FULL LOAD WEIGHT + MARGIN	2750.37	5.22	14351.26	70.81	194761.43	0.00	-9.26
	MINOP WEIGHT AND MARGIN	2712.37	5.28	14322.89	71.11	192884.23	0.00	-9.26
	LIGHTSHIP WEIGHT + MARGIN	2201.77	5.82	12821.21	71.79	158056.66	0.00	-9.26
	LIGHTSHIP WEIGHT	2096.92	5.56	11655.64	68.52	143687.87	0.00	-8.42
	MARGIN	104.85	11.12	1165.56	137.05	14368.79	-0.01	-0.84
100	HULL STRUCTURES	1180.14	5.31	6269.83	62.76	74067.26	0.00	0.00
	BARE HULL	1013.64	5.12	5192.85	63.00	63859.01	0.00	0.00
	PAYLOAD	5.65	10.28	58.07	63.00	355.95	0.00	0.00
150	DECK HOUSE STRUCTURE	17.58	14.55	255.75	47.00	826.35	0.00	0.00
170	MASTS+KINGPOSTS+SERV PLTFRM	2.03	26.46	53.72	63.00	127.89	0.00	0.00
180	FOUNDATIONS	141.24	5.02	709.44	63.00	8898.06	0.00	0.00
200	PROPULSION PLANT	345.97	4.35	1504.13	105.04	36340.00	-0.02	-8.42
	BASIC MACHINERY	196.40	5.02	986.52	91.50	17970.60	0.00	0.00
243	SHAFTING	8.42	2.94	24.72	107.00	900.94	-1.00	-8.42
244	SHAFT BEARINGS	1.98	2.94	5.81	107.00	211.75	0.00	0.00
245	PROPULSORS	139.17	3.50	487.08	124.00	17256.71	0.00	0.00
300	ELECTRIC PLANT, GENERAL	102.03	5.53	563.69	56.51	5765.12	0.00	0.00
310	ELECTRIC POWER GENERATION			0.00		0.00		0.00
	BASIC MACHINERY	73.70	5.53	407.19	69.00	5085.30	0.00	0.00
320	POWER DISTRIBUTION SYS	18.81	5.53	103.90	24.00	451.34	0.00	0.00
330	LIGHTING SYSTEM	9.52	5.53	52.60	24.00	228.48	0.00	0.00
400	COMMAND+SURVEILLANCE	118.77	8.48	1007.46	63.00	7482.20	0.00	0.00
	PAYLOAD	69.20	9.72	672.85	63.00	4359.29	0.00	0.00
	CABLING	27.41	5.02	137.67	63.00	1726.64	0.00	0.00
	MISC	6.96	6.35	44.23	63.00	438.61	0.00	0.00
430	INTERIOR COMMUNICATIONS	15.20	10.05	152.71	63.00	957.66	0.00	0.00
500	AUXILIARY SYSTEMS, GENERAL	206.76	6.81	1407.83	55.98	11574.49	0.00	0.00
	WAUX	134.60	6.46	869.77	63.00	8479.67	0.00	0.00
	PAYLOAD	42.14	9.43	397.25	63.00	2654.82	0.00	0.00
510	CLIMATE CONTROL			0.00		0.00		0.00
	CPS	4.94	0.00	0.00	0.00	0.00	0.00	0.00
589	AIRCRAFT HANDLING, SUPPORT	8.80	16.00	140.80	50.00	440.00	0.00	0.00
593	ENVIRON. POLLUTION CNTL SYS	10.16	0.00	0.00	0.00	0.00	0.00	0.00
598	AUX SYSTEMS OPERATING FLUIDS	6.13	0.00	0.00	0.00	0.00	0.00	0.00
600	OUTFIT+FURNISHING,GENERAL	131.99	5.94	784.26	58.70	7748.16	0.00	0.00
610	SHIP FITTINGS	68.99	6.53	450.51	63.00	4346.43	0.00	0.00
640	LIVING SPACES	63.00	5.30	333.75	54.00	3401.73	0.00	0.00

SWBS	COMPONENT	WT-MT	Abv BL + VCG-m	Moment	Aft FP + LCG-m	Moment	Port CL + TCG-m	Moment
700	ARMAMENT	11.28	10.50	118.44	63.00	710.64	0.00	0.00
	FULL LOAD CONDITION							
F00	LOADS	548.60	2.79	1530.05	66.91	36704.77	0.00	0.00
F10	SHIPS FORCE	10.46	7.35	76.93	63.00	659.11	0.00	0.00
F23	ORD DEL SYS (AIRCRAFT)	10.00	14.00	140.00	54.00	540.00	0.00	0.00
F31	PROVISIONS+PERSONNEL STORES	5.20	5.25	27.31	63.00	327.47	0.00	0.00
F32	GENERAL STORES	1.94	5.95	11.53	63.00	122.16	0.00	0.00
F41	DIESEL FUEL MARINE	372.00	2.86	1064.66	69.94	26017.68	0.00	0.00
F42	JP-5	116.00	1.35	156.95	59.87	6944.92	0.00	0.00
F46	LUBRICATING OIL	19.00	1.78	33.80	87.67	1665.73	0.00	0.00
F47	SEA WATER	0.00	3.11	0.00	64.77	0.00	0.00	0.00
F52	FRESH WATER	14.00	1.35	18.87	30.55	427.70	0.00	0.00
	MIN. OPERATING CONDITION							
F00	LOADS	510.60	2.94	1501.69	68.21	34827.57	0.00	0.00
F10	SHIPS FORCE	10.46	7.35	76.91	63.00	658.98	0.00	0.00
F23	ORD DEL SYS (AIRCRAFT)	10.00	14.00	140.00	54.00	540.00	0.00	0.00
F31	PROVISIONS+PERSONNEL STORES	5.20	5.25	27.32	63.00	327.60	0.00	0.00
F32	GENERAL STORES	1.94	5.95	11.54	63.00	122.22	0.00	0.00
F41	DIESEL FUEL MARINE	123.00	2.06	253.38	80.83	9941.48	0.00	0.00
F42	JP-5	40.00	0.72	28.72	59.73	2389.20	0.00	0.00
F46	LUBRICATING OIL	7.00	1.43	9.98	87.58	613.06	0.00	0.00
F47	SEA WATER BALLAST	304.00	3.11	944.53	64.77	19690.08	0.00	0.00
F52	FRESH WATER	9.00	1.04	9.32	60.55	544.95	0.00	0.00

Appendix E – Space Available Summary

SSCS	GROUP	VOLUME M^3	AREA M^2
	TOTAL AVAILABLE		**3110.9**
1	**MISSION SUPPORT**		**1071.94**
1.1	**COMMAND,COMMUNICATION+SURV**		**329.42**
1.11	**EXTERIOR COMMUNICATIONS**		**65**
1.111	RADIO		65
1.112	UNDERWATER SYSTEMS		0
1.113	VISUAL COM		0
1.12	**SURVEILLANCE SYS**		**89.95**
1.121	SURFACE SURV (RADAR)		55.63
1.122	UNDERWATER SURV (SONAR)		34.32
1.13	**COMMAND+CONTROL**		**151.27**
1.131	COMBAT INFO CENTER		110.37
1.132	**CONNING STATIONS**		**40.9**
1.1321	PILOT HOUSE		27.4
1.1322	CHART ROOM		13.5
1.133	DATA PROCESSING		0
1.14	**COUNTERMEASURES**		**7**
1.141	ELECTRONIC		0
1.142	TORPEDO		7
1.143	MISSILE		0
1.15	INTERIOR COMMUNICATIONS		13
1.16	ENVIORNMENTAL CNTL SUP SYS		3.2
1.2	**WEAPONS**		**99.82**
1.21	**GUNS**		**27.8**
1.211	BATTERIES		9.1
1.214	AMMUNITION STOWAGE		18.7
1.22	MISSILES		72.02
1.24	TORPEDOS		
1.26	MINES		
1.28	WEAP MODULE STA & SERV INTER		
1.3	**AVIATION**		**639.2**
1.31	**AVIATION LAUNCH+RECOVERY**		**150**
1.311	LAUNCHING+RECOVERY AREAS		150
1.312	LAUNCHING+RECOVERY EQUIP		0
1.32	**AVIATION CONTROL**		**34.3**
1.321	FLIGHT CONTROL		14.3
1.322	NAVIGATION		0
1.323	OPERATIONS		20
1.33	AVIATION HANDLING		0
1.34	**AIRCRAFT STOWAGE**		**260**
1.342	HELICOPTER HANGAR		260
1.35	**AVIATION ADMINISTRATION**		**15.3**
1.353	**AIR WING**		**15.3**
1.3536	AVIATION OFFICE		15.3

SSCS	GROUP	VOLUME M^3	AREA M^2
1.36	**AVIATION MAINTENANCE**		**119.6**
1.361	AIRFRAME SHOPS		119.6
1.369	ORGANIZATIONAL LEVEL MAINTANENCE		0
1.37	**AIRCRAFT ORDINANCE**		**0**
1.372	CONTROL		0
1.373	HANDLING		0
1.374	STOWAGE		0
1.38	**AVIATION FUEL SYS**	**150**	**0**
1.381	**JP-5 SYSTEM**	**150**	**0**
1.3811	JP-5 TRANSFER		
1.3812	JP-5 HANDLING		
1.3813	AVIATION FUEL	150	
1.39	AVIATION STORES		60
1.8	**SPECIAL MISSIONS**		
1.9	**SM ARMS,PYRO+SALU BAT**		**3.5**
1.91	SM ARMS (LOCKER)		3.5
1.92	PYROTECHNICS		
1.93	SALUTING BAT (MAGAZINE)		
1.94	ARMORY		
1.95	SECURITY FORCE EQUIP		
2	**HUMAN SUPPORT**		**1135.65**
2.1	**LIVING**		**776.72**
2.11	**OFFICER LIVING**		**164.17**
2.111	**BERTHING**		**128.45**
2.1111	**SHIP OFFICER**		**128.45**
2.1111104	COMMANDING OFFICER STATEROOM		17.4
2.1111206	EXECUTIVE OFFICER STATEROOM		16.5
2.111123	DEPARTMENT HEAD STATEROOM		25.27
2.1111302	OFFICER STATEROOM (DBL)		69.28
2.1114	AVIATION OFFICER		
2.112	**SANITARY**		**35.72**
2.1121	**SHIP OFFICER**		**35.72**
2.1121101	COMMANDING OFFICER BATH		2.77
2.1121201	EXECUTIVE OFFICER BATH		2
2.1121203	OFFICER BATH		25.85
2.1121303	DEPT HEAD BATH		5.1
2.1124	AVIATION OFFICER		
2.12	**CPO LIVING**		**117.2**
2.121	BERTHING		89.4
2.122	SANITARY		27.8
2.13	**CREW LIVING**		**486.75**
2.131	BERTHING		404.73
2.132	SANITARY		62.72
2.133	RECREATION		19.3
2.14	**GENERAL SANITARY FACILITIES**		**3**
2.142	BRIDGE WASHRM & WC		2
2.143	DECK WASHRM & WC		0

SSCS	GROUP	VOLUME M^3	AREA M^2
2.144	ENGINEERING WR & WC		1
2.15	**SHIP RECREATION FAC**		**0**
2.151	MUSIC		
2.152	MOTION PIC FILM+EQUIP		
2.153	PHYSICAL FITNESS		
2.154	TV ROOM		
2.16	TRAINING		5.6
2.2	**COMMISSARY**		**270.3**
2.21	**FOOD SERVICE**		**131.03**
2.211	WARDROOM MESSRM & LOUNGE		28.62
2.212	CPO MESSROOM AND LOUNGE		40.41
2.213	CREW MESSROOM		62
2.22	**COMMISSARY SERVICE SPACES**		**46.27**
2.221	FOOD PREPARATION SPACES		
2.222	**GALLEY**		**37.46**
2.2222	WARD ROOM GALLEY		8.81
2.2224	CREW GALLEY		28.65
2.223	WARDROOM PANTRY		0
2.224	SCULLERY		8.81
2.23	**FOOD STORAGE+ISSUE**		**93**
2.231	CHILL PROVISIONS		
2.232	FROZEN PROVISIONS		
2.233	DRY PROVISIONS		
2.3	**MEDICAL+DENTAL**		**9.5**
2.4	**GENERAL SERVICES**		**34.08**
2.41	SHIP STORE FACILITIES		12.28
2.42	LAUNDRY FACILITIES		21.8
2.44	BARBER SERVICE		
2.46	POSTAL SERVICE		
2.47	BRIG		
2.48	RELIGIOUS		
2.5	**PERSONNEL STORES**		**40**
2.51	BAGGAGE STOREROOMS		20
2.52	MESSROOM STORES		10
2.55	FOUL WEATHER GEAR		
2.56	LINEN STOWAGE		10
2.57	FOLDING CHAIR STOREROOM		
2.6	**CBR PROTECTION**		**0**
2.61	CBR DECON STATIONS		
2.62	CBR DEFENSE EQUIPMENT		
2.63	CPS AIRLOCKS		
2.7	**LIFESAVING EQUIPMENT**		**5.05**
3	**SHIP SUPPORT**		**623.43**
3.1	**SHIP CNTL SYS (STEERING)**		**15.5**
3.11	STEERING GEAR		15.5
3.12	ROLL STABILIZATION		
3.15	STEERING CONTROL		

SSCS	GROUP	VOLUME M^3	AREA M^2
3.2	**DAMAGE CONTROL**		**38.1**
3.21	DAMAGE CNTRL CENTRAL		14.1
3.22	REPAIR STATIONS		14
3.25	FIRE FIGHTING		10
3.3	**SHIP ADMINISTRATION**		**101.55**
3.301	GENERAL SHIP		25.24
3.302	EXECUTIVE DEPT		16.9
3.303	ENGINEERING DEPT		11.27
3.304	SUPPLY DEPT		16.2
3.305	DECK DEPT		25.24
3.306	OPERATIONS DEPT		6.7
3.307	WEAPONS DEPT		
3.31	SHIP PHOTO/PRINT SVCS		
3.5	**DECK AUXILIARIES**		**25.8**
3.51	ANCHOR HANDLING		25.8
3.52	LINE HANDLING		
3.53	TRANSFER-AT-SEA		
3.54	SHIP BOATS STOWAGE		
3.6	**SHIP MAINTENANCE**		**196.48**
3.61	**ENGINEERING DEPT**		**35.14**
3.611	AUX (FILTER CLEANING)		
3.612	ELECTRICAL DIV SHOP		11.47
3.613	MECH (GENERAL WORKSHOP)		13.6
3.614	PROPULSION MAINTENANCE		10.07
3.62	OPERATIONS DEPT		7.9
3.63	WEAPONS DEPT (MISSIONS SHOP)		120
3.64	DECK DEPT		33.44
3.7	**STOWAGE**		**60**
3.71	**SUPPLY DEPT**		
3.711	HAZARDOUS MATL (FLAM LIQ)		
3.712	SPECIAL CLOTHING		
3.713	GEN USE CONSUM+REPAIR PART		
3.714	SHIP STORE STORES		
3.715	STORES HANDLING		
3.72	ENGINEERING DEPT		
3.73	OPERATIONS DEPT		
3.74	DECK DEPT (BOATSWAIN STORES)		
3.75	WEAPONS DEPT		
3.76	EXEC DEPT (MASTER-AT-ARMS STOR)		
3.78	CLEANING GEAR STOWAGE		
3.8	**ACCESS**		**186**
3.82	**INTERIOR**		**186**
3.821	NORMAL ACCESS		180
3.822	ESCAPE ACCESS		6
3.9	**TANKS**	**621**	
3.91	**SHIP PROP SYS TNKG**	**464**	
3.911	**SHIP ENDUR FUEL TNKG**	**464**	
3.9111	ENDUR FUEL TANK (INCL SERVICE)	464	
3.914	FEEDWATER TNKG		

SSCS	GROUP	VOLUME M^3	AREA M^2
3.92	BALLAST TNKG	125	
3.93	FRESH WATER TNKG	14	
3.94	**POLLUTION CNTRL TNKG**	**18**	
3.941	SEWAGE TANKS	8	
3.942	OILY WASTE TANKS	10	
3.95	VOIDS		
3.96	COFFERDAMS		
3.97	CROSS FLOODING DUCTS		
4	**SHIP MACHINERY SYSTEM**	**138**	**279.88**
4.1	**PROPULSION SYSTEM**		**49.93**
4.13	**INTERNAL COMBUSTION (DIESEL)**		**0**
4.132	COMBUSTION AIR (INTAKE)		
4.133	EXHAUST		
4.134	CONTROL		
4.14	**GAS TURBINE**		**49.93**
4.142	COMBUSTION AIR (INTAKE)		18.9
4.143	EXHAUST		18.47
4.144	CONTROL		12.56
4.2	**PROPULSOR & TRANSMISSION SYST**	**138**	**55.4**
4.23	**WATERJET ROOMS**	**138**	**46**
4.23001	PROP SHAFT ALLEY		46
4.24	AIR FAN ROOMS		9.4
4.3	**AUX MACHINERY**		**174.55**
4.32	**A/C & REFRIGERATION**		**46.1**
4.321	A/C (INCL VENT)		
4.322	REFRIGERATION		
4.33	**ELECTRICAL**		**95.57**
4.331	**POWER GENERATION**		**90**
4.3311	SHIP SERVICE PWR GEN		90
4.3313	BATTERIES		
4.3314	400 HERTZ		
4.332	PWR DIST & CNTRL		5.57
4.334	DEGAUSSING		
4.34	**POLLUTION CONTROL SYSTEMS**		**32.88**
4.341	SEWAGE		29
4.342	TRASH		3.88
4.35	MECHANICAL SYSTEMS		
4.36	VENTILATION SYSTEMS		

Appendix F - MathCAD Model (Add)