Design Report

Air Superiority Cruiser

(CGX)

VT Total Ship Systems Engineering

CGX Variant 1
Ocean Engineering Design Project
AOE 4065/4066
Fall 2005 – Spring 2006

Virginia Tech Team 1

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Executive Summary

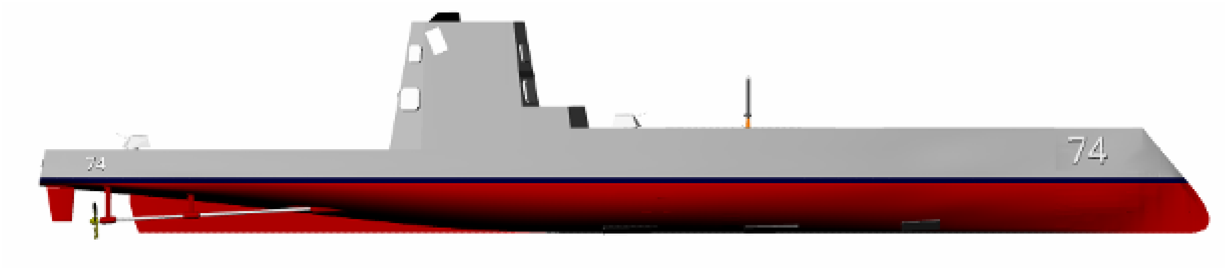

Figure 1

This report describes the Concept Exploration and Development of an Air Superiority Cruiser CG(X) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The CG(X) requirement is based on the CG(X) Mission Need Statement (MNS), and Virginia Tech CG(X) Acquisition Decision Memorandum (ADM), Appendix A and Appendix B.

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

CG(X) design 4-76 is a medium risk, medium cost, and highly effective monohull design on the non-dominated frontier

CG(X) is likely to be forward deployed in peacetime, conducting extended cruises to sensitive regions prepositioned for BMD. Producibility cost reductions should be assumed when CG(X) propulsion and hull are similar to current DD(X)'s integrated power system (IPS) and reduced radar cross section (RCS) hull. Capabilities of CG(X) include sustained air superiority, and detection, tracking, and engagement of ballistic missiles outside the atmosphere. CG(X) will provide BMD, anti-air warfare (AAW), anti-surface warfare (ASUW), anti-submarine warfare (ASW), and power projection ashore while maintaining outer umbrella of air superiority. CG(X) must reduce crew size, operational, and support costs to meet current naval requirements.

Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, propulsion and power system development and arrangement, general arrangements, machinery arrangements, combat system definition and arrangement, seakeeping analysis, cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements in the ORD in cost and risk constraints.

Table 1

L	Value
LWL	172.5 m
Beam	21.75 m
Draft	7.5 m
D10	15.75 m
Lightship weight	10,948 MT
Full load weight	13,168 MT
Sustained Speed	30.2 knots
Endurance Speed	20 knots
Endurance Range	5130 nm
Propulsion and Power	2 Shaft FPP IPS 3xLM2500+ 2x Allison 501k34
BHP	90.0 MW
Personnel	33 Officers, 199 Enlisted (232 Total)
OMOE (Effectiveness)	0.816
OMOR (Risk)	0.396
Lead Ship Acquisition Cost	$2.351B
Follow Ship Acquisition Cost	$1.642B
Life-Cycle Cost	$2.156B
AAW system	SPY-3 (4 panel), VSR, AEGIS MK 99 FCS
ASUW system	SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker
ASW system	SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
NSFS	2 MK 110 57 mm gun
CCC/STK/SEW	Enhanced CCC
GMLS	128 cells, MK 41 and/or MK57 PVLS
LAMPS	Embarked single LAMPS w/Hangar

Table of Contents

1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of an Air Superiority Cruiser CG(X) for the United States Navy. The CG(X) requirement is based on the CG(X) Mission Need Statement (MNS), and Virginia Tech CG(X) Acquisition Decision Memorandum (ADM), Appendix A and Appendix B. This concept design was completed in a two-semester ship design course at Virginia Tech. CG(X) must perform the following missions:

I. Surface action group (SAG)
II. Carrier battle group (CBG)
III. Ballistic missile defense (BMD)

CG(X) must reduce crew size, operational, and support costs to meet current naval requirements. Producibility cost reduction should be included when CG(X) propulsion and hull are similar to current DD(X)'s integrated power system (IPS) and reduced radar cross section (RCS) hull. Capabilities of CG(X) include sustained air superiority, and detection, tracking, and engagement of ballistic missiles outside the atmosphere. CG(X) is likely to be forward deployed in peacetime, conducting extended cruises to sensitive regions prepositioned for BMD. CG(X) will provide BMD, anti-air warfare (AAW), anti-surface warfare (ASUW), anti-submarine warfare (ASW), and power projection ashore while maintaining outer umbrella of air superiority.

1.2 Design Philosophy, Process, and Plan

Figure 2 shows a breakdown of the design process into five distinct stages: exploratory design, concept development, preliminary design, contract design, and detailed design. This process can take 15-20 years depending on technology integration, facilities, and funding. Engineering firms and ship yards continuously assess existing and new technologies and how these technologies integrate with one another. Exploratory design is an ongoing process with engineering firms, ship yards, and government involvement. The mission, current and future threat, new ships, new missions and technologies are also constantly being considered. Technologies are continuously being developed, and some will be integrated into the ship design.

This project considers only concept exploration and development for CG(X). Products of concept exploration are a baseline design, technology selection and requirements definition. After concept exploration and development are complete, a final concept is defined. This is followed by preliminary design, contract design, and detailed design. Preliminary design uses the decisions made in concept development and matures the design further to reduce risk and refine the design to understand capability and performance. Contract design uses preliminary design to make drawings and a full set of specifications to the level of detail required to contract the ship. Detailed design is the final stage performed by the ship builder. Detailed design is the actual construction, and is often where problems are discovered. The first ship is constructed to satisfy the design requirements and outlined missions. After the first ship is built, feasibility studies are performed to understand the design better by reducing the risk of implementation and estimate the cost and performance more accurately.

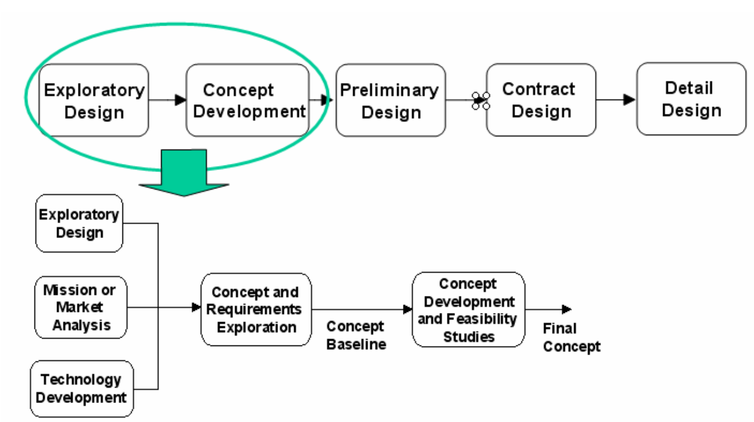

Figure 2 - Design Strategy

Figure 3 illustrates the approach to the overall design process viewed from a broad perspective (design philosophy), working from left to right. A broad range of costs, risks, and technical alternatives are considered for the design space and then reduced to a set of non-dominated designs using multi-objective genetic optimization (MOGO). From the non-dominated designs a decision is made to go forward with some subset of the designs. It is common to consider only 50 or 100 separate alternatives while performing the concept exploration process. A far greater number of design alternatives will be considered in our process using the multi-objective optimization. The next step is to select from the non-dominated frontier and to add detail by doing analysis in concept development to minimize risk. In concept development individual non-dominated designs are refined and optimized.

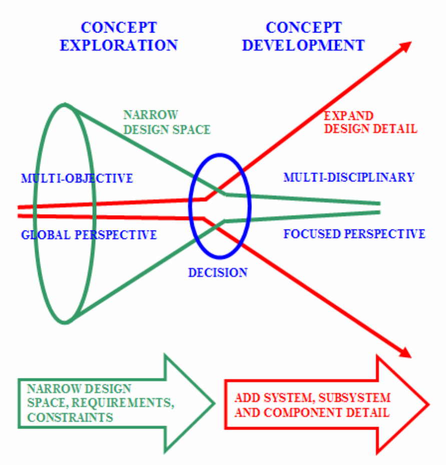

Figure 3 - Overall Design Philosophy

Figure 4 shows the overall concept and requirements exploration process, which integrates models for risk, cost, and effectiveness with the design space, design variables, and synthesis model into a multi-objective optimization. The process is initiated by a Mission Need Statement (MNS) that identifies a need for a new ship. An Acquisition Decision Memorandum (ADM) specifies the general requirements and projected fleet requirement, based on the MNS. Research is done to identify current technologies based on cost, benefits, risk, integration, feasibility, and effectiveness based on mission types. Performance and technology relate to required operational capabilities (ROC's). The ROC's are developed to identify a set of design variables (DV's) that define a design space. The synthesis model includes an effectiveness model, risk model, and cost model. Response surface models, physics based models, data, and expert opinions are used to develop the synthesis model.

The synthesis model is used to perform a design of experiments (DOE) where screening and exploration are conducted to ensure efficiency and accuracy of the multi-objective genetic optimization (MOGO). The MOGO optimizes based on overall measure effectiveness (OMOE's), overall measures of risk (OMOR), and ship cost estimates. The result of the MOGO is a variety of ships in a non-dominated frontier (NDF). A ship is chosen from this NDF with desired risk, effectiveness, and cost. Ship concept development can now be conducted using an Operational Requirements Document (ORD), and selected technology.

Concept development follows concept exploration and concept requirements exploration. Figure 5 illustrates that the concept development process is similar to a design spiral, beginning with a baseline design, a requirement (ORD), and a selection of technologies. The process follows a spiral-like path until it arrives at the refined design that meets or exceeds requirements, threats, and missions. The real design process is more complicated than a simple spiral or loop, including a variety of cross communication to develop a network for integration and refinement of the final ship.

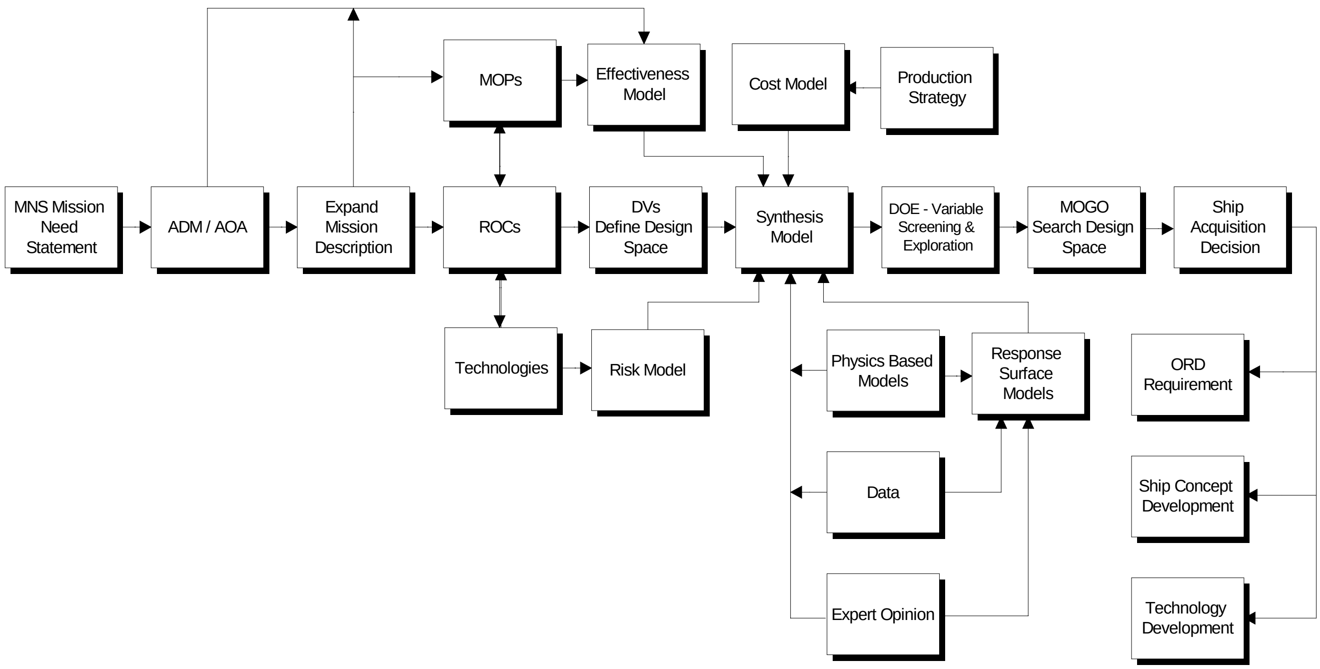

Figure 4 - Concept and Requirements Exploration

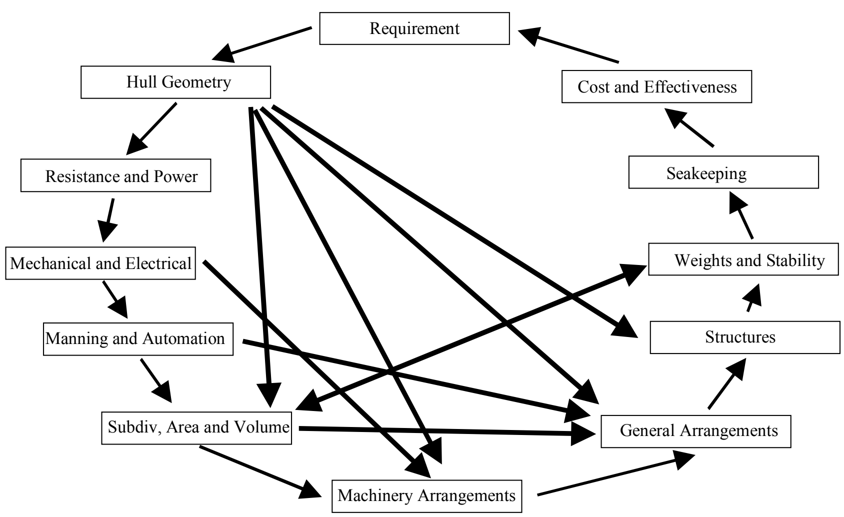

Figure 5 - Concept Development Design Spiral

1.3 Work Breakdown

CG(X) Team 1 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 (Table 2). The areas are specific to an individual's interests, but the communication with other team members is essential to integrate all pieces of a ship to an overall design. The team leader, as well as keeping the project on schedule, is considered an easily accessible bridge to communicate information between students and the faculty advisor.

Table 2 - Work Breakdown

Name	Specialization
Nate Reimold	Subdivision, Combat Systems, General Arrange-ments, Writer
Erika Kast	Propulsion and Resistance, Cost, Risk, Writer, Editor
John Wilde	Combat Systems, Subdivision, Weights and Stability, Seakeeping, Writer
Justin Baity	Hull form, Structures, Writer, Editor
Rich Hardy	Machinery Arrangements, Electrical, Writer
James Schultz	Hull form, Feasibility, Effectiveness, Manning and Automation, Writer

1.4 Resources

Computational and modeling tools used in this project and their functions are listed below (Table 3). Synthesis modeling, mathematical aids, and graphical design software enables a smoother and more effective design cycle by reducing required design time and allowing the testing of more possibilities without model testing.

Table 3 - Tools

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

2 Mission Definition

The CG(X) requirement is based on the CG(X) Mission Need Statement (MNS), and Virginia Tech CG(X) Acquisition Decision Memorandum (ADM), Appendix A and Appendix B, with elaboration and clarification obtained by discussion and correspondence with the customer, and reference to pertinent documents and web sites referenced in the following sections.

2.1 Concept of Operations

This concept of operations is based on the SC-21 Mission Need Statement and AOA guidance for a surface combatant that maintains Battle Space Dominance and operates in the outer littorals and "blue water" areas. CG(X) will provide BMD, AAW, ASUW, ASW, and power projection ashore while maintaining an outer umbrella of air superiority for the battle force and supporting ballistic missile defense. It will operate with SAG's and CBG's, and in independent operations. It will perform unobtrusive peacetime presence missions in areas of hostility, and immediately respond to escalating crises and regional conflicts. CG(X) is likely to be forward deployed in peacetime, conducting extended cruises to sensitive regions prepositioned for BMD. CG(X) will minimize personnel vulnerability in combat through automation, innovative concepts for minimum crew size, and signature reduction. CG(X) may be required to perform preemptive strike, counter strike, battle force defense, and assume all command and control responsibilities of the group.

2.2 Projected Operational Environment (POE) and Threat

The CG(X) is designed to be capable of performing battle group and independent missions under all weather conditions. The ship will be expected to survive in open ocean environments of sea states 0 - 9, to function in sea states 0 – 7, and to be fully capable of performing missions in sea states 0 – 5. The final deign will possess the capability to detect and respond to threats including:

- Conventional, chemical and nuclear weapons
- Surface, submarine, air, and land launched missiles
- Ballistic missiles
- Mines
- Fast gunboats
- Diesel/electric submarines

2.3 Specific Operations and Missions

CG(X) is expected to perform missions in a carrier battle group (CBG), in a surface action group (SAG), and independently.

- Carrier Battle Group (CBG)
  The ship will serve as an escort and a secondary center of communications for the CBG. CG(X) will detect, communicate, and, when applicable, engage potential threats from air, surface, and submerged threats in defense of the battle group. The ship will serve as a platform for search and rescue operations and intelligence and reconnaissance missions.
- Surface action group (SAG)
  The ship will serve as an escort and a center of communications for the SAG. CG(X) will detect, communicate, and, when applicable, engage potential threats from air, surface, and submerged threats in defense of the battle group. The ship will serve as a platform for search and rescue operations and intelligence and reconnaissance missions.
- Independent ballistic missile defense (BMD)
  CG(X) will be fully capable of independent operations with self-defense, communications control, reconnaissance, and search and rescue capabilities. The ship will perform ballistic missile defense (BMD) with missile detection and destruction ability.

2.4 Mission Scenarios Mission

Table 4 and Table 5 display mission scenarios for the primary CG(X) missions. The mission scenario for the BMD/SAG is weighted more than the CBG mission since the MNS calls for a ship to provide BMD.

Table 4 – CBG 90 day Mission

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

Table 5 – BMD/SAG 90 Day Mission

DAY	MISSION DESCRIPTION
1-21	SAG transit from CONUS
21 - 24	Port call, replenish
25 - 28	ISR
27	Conduct ASUW defense against medium boat threat
28-32	Sit and Wait to Fire/Intercept
33-40	Repairs/Port Call
41	Engage TBM for allied defense
42 - 45	Conduct SAR
46	UNREP
47 - 55	Rejoin SAG
51	Multiple AAW threats for SAG defense.
56 - 63	Repairs / Port call
64 - 70	Conduct ASW operations with SAG and SSN
69	Engage submarine threat for SAG defense.
70	Emergency evacuation to U.S. Naval base.
71 - 75	Rejoin SAG
76 - 78	Joint land attack
79 - 89	Provide support and surveillance for SAG defense
90+	Port call / Restricted availability

2.5 Required Operational Capabilities

The capabilities listed in Table 6 are required to support the missions and mission scenarios described in Section 2.4. Each of these can be related to functional capabilities required in the ship design, and if in the scope of the Concept Exploration design space, the ship's ability to perform these functional capabilities is measured by explicit Measures of Performance (MOPs).

Table 6 - List of Required Operational Capabilities (ROCs)

CG(X) ROCs

(From: OPNAVINST C3501.2J - Naval Warfare Mission Areas and Required Operational Capabilities)

ROCs	Description
AAW 1	Provide anti-air defense
AAW 1.1	Provide area anti-air defense
AAW 1.2	Support area anti-air defense
AAW 1.3	Provide unit anti-air self defense
AAW 2	Provide anti-air defense in cooperation with other forces
AAW 3	Support Theater Ballistic Missile Defense (TBMD)
AAW 5	Provide passive and soft kill anti-air defense
AAW 6	Detect, identify and track air targets
AAW 9	Engage airborne threats using surface-to-air armament
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations
AMW 6.3	Conduct all-weather helo ops
AMW 6.4	Serve as a helo hangar
AMW 6.5	Serve as a helo haven
AMW 6.6	Conduct helo air refueling
AMW 12	Provide air control and coordination of air operations
ASU 1	Engage surface threats with anti-surface armaments
ASU 1.1	Engage surface ships at long range
ASU 1.2	Engage surface ships at medium range
ASU 1.3	Engage surface ships at close range (gun)
ASU 1.5	Engage surface ships with medium caliber gunfire
ASU 1.6	Engage surface ships with minor caliber gunfire
ASU 1.9	Engage surface ships with small arms gunfire
ASU 2	Engage surface ships in cooperation with other forces
ASU 4	Detect and track a surface target
ASU 4.1	Detect and track a surface target with radar
ASU 6	Disengage, evade and avoid surface attack
ASW 1	Engage submarines
ASW 1.1	Engage submarines at long range
ASW 1.2	Engage submarines at medium range
ASW 1.3	Engage submarines at close range
ASW 4	Conduct airborne ASW/recon
ASW 5	Support airborne ASW/recon
ASW 7	Attack submarines with antisubmarine armament
ASW 7.6	Engage submarines with torpedoes
ASW 8	Disengage, evade, avoid and deceive submarines
CCC 1	Provide command and control facilities
CCC 1.6	Provide a Helicopter Direction Center (HDC)
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions

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

3 Concept Exploration

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

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

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

3.1.1 Hull Form Alternatives

3.1.1.1 Transport Factors

The transport factor method is used to compare the ability of various hull forms to fulfill the basic requirements for payload weight, sustained and endurance speeds, and range. The assumptions made to calculate a required transport factor are based on known mission requirements and characteristics of similar ships:

- CG(X) will carry large, heavy equipment (e.g., radar, missiles). More than CG-47 or DDG-51.
- As a major combatant operating worldwide, CG(X) requires an endurance of more than 4000 nautical miles at 20 knots.
- Displacement mass (Δ) is expected to be > 14,000 MT.
- Shaft horsepower (SHP) is expected to be > 100,000 hp (75 MW).
- Requires a sustained speed of 29 – 35 knots.

The transport factor is then estimated using (1).

$$TF = \frac{\Delta V_S}{SHP}\left(5.052\frac{kW}{MT * knt}\right) = 30.2 @ 32knt \qquad (1)$$

Figure 6 shows transport factors of existing ships of various types. Based on this information, a monohull is the preferred option for the CG(X).

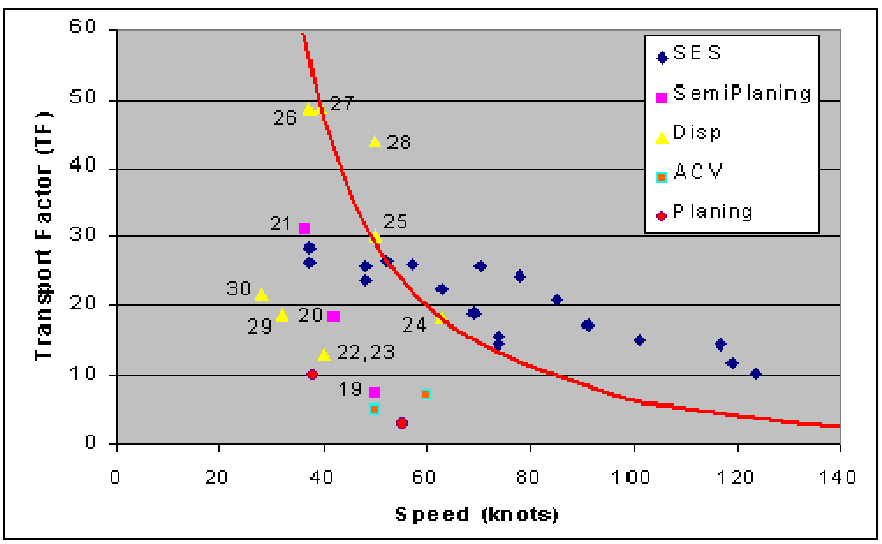

Figure 6 - Transport Factors of Existing Ships

3.1.1.2 Further Requirements and Selection of Hull Form Types

The transport factor can now be combined with other performance metrics:

- Deck area must be available for helicopter or V-22 landing and takeoff.
- Low radar cross section—consider tumblehome hull.
- Low maintenance and production cost.
- Large interior volume for heavy machinery (e.g., hangar decks, weapons magazines, VLS modules, etc)—implies monohull.
- Good seakeeping characteristics during both loitering and high speed operations.
- Structurally efficient—implies monohull.

Considering the requirements of Section 3.1.1.1 and 3.1.1.2, the best hull form types for CG(X) are monohulls, with flare or with tumblehome. A simple parametric model using length, beam, draft, depth, and the prismatic and maximum section coefficients is used to define the hull form in concept exploration. A full 3-D model will be developed in concept development.

3.1.1.3 Hull Parameter Ranges from Design Lanes

Reasonable characteristics for a cruiser hull form are determined from published design lanes for destroyers and cruisers (Table 7).

Table 7 – Hull Characteristics

Displacement	12000 – 16000 lton
Length	$\frac{\Delta}{\left(L/100\right)^3} = \frac{lton}{ft^3} = 43.4 - 65.6 \Rightarrow L = 567 to 717\ ft$
L/B	$7.9 - 9.9 \Rightarrow B = 57 to 89\ ft$ (PANAMAX = 80ft.)
L/D	$10.75 - 17.8 \Rightarrow D = 32 to 65\ ft$
B/T	$2.9 - 3.2 \Rightarrow T = 18 to 31\ ft$ (PANAMAX = 28ft.)
C_P	0.56 – 0.64
C_X	0.75 – 0.84
C_{RD}	0.70 – 1.00

3.1.1.4 Hull Form Concept Exploration Design Space Summary

Table 8 summarizes hull form design space described in sections 3.1.1.1, 3.1.1.2, and 3.1.1.3.

Table 8 – Baseline Hullform Characteristics

Hull Form Type	Monohull
Flare	±10º
Displacement	12000 – 16000 lton
L	$L = 567 - 717\ ft$
B	$B = 57 - 80\ ft$
D	$D = 32 - 65\ ft$
T	$T = 18 - 28\ ft$
C_P	0.56 – 0.64
C_X	0.75 – 0.84
C_{RD}	0.70 – 1.00

3.1.2 Propulsion and Electrical Machinery Alternatives

3.1.2.1 Machinery Requirements

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

General Requirements.

- Consider mechanical drive or an integrated power system using a DC bus, permanent magnet motors, and zonal distribution.
- Consider cruise/boost engine configurations.
- Design 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).
- Moderate to high speed dictates high power density; therefore, consider only gas turbine engines.
- For ease of maintenance, only 2 – 4 main engines may be installed.
- Consider fixed pitch propeller (FPP), controllable pitch propeller (CPP), and podded propulsion.

Sustained Speed and Propulsion Power.

- Alternatives must provide 75 – 150 MW total installed propulsion power.
- Requires a minimum sustained speed of 30 knots fully loaded, in calm water, and with a clean hull using no more than 80% of the installed engine or motor maximum continuous rating (MCR).
- Goal speed of 35 knots.

Ship Control and Machinery Plant Automation. To reduce operational costs and to ensure effective command and control in a battle scenario, the ship power plants should:

- Comply with ABS ACCU requirements for periodically unattended machinery spaces.
- 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.
- Integrated bridge system—integrated navigation, radio communications, interior communications, and ship maneuvering equipment and systems; comply with ABS Guide for One Man Bridge Operated (OMBO) ships.

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 should:

- Be non-nuclear.
- Be Navy qualified and Grade A shock certified.

3.1.2.2 Machinery Plant Alternatives

This section describes the options for power plant, power transmission, and propulsor alternatives considered in the design for CG(X).

There are two power transmission alternatives: a mechanical drive system, in which the engines are connected to the propulsor by a traditional reduction gear and propeller shaft; or an integrated power system (IPS), in which the power plants drive generators, which provide electricity to power motors (either advanced AC induction motors, or AC permanent magnet synchronous motors) connected to the propulsors. The mechanical drive system is currently the standard on all US Navy conventional combatants, but the less-proven IPS promises more flexibility and easier maintenance, and holds the favor of Navy planners for future projects.

There are three propulsor alternatives: fixed pitch propeller (FPP), controllable pitch propeller (CPP), and podded propulsors. The FPP and CPP are both proven technologies in US Navy combatants, and can utilize both mechanical drive and IPS. The podded propulsors—which typically use a FPP—provide unparalleled maneuverability and efficiency, but at the expense of resilience (they are not yet shock certified) and the ability to utilize mechanical drive options.

For the engines, only gas turbine engines are considered because of the high required power density implied by the size, speed, and payload capacity required, as described in section 3.1.1. Table 9 displays the three prime movers and the one ship service backup generator type that are considered.

Table 9 - Power Plant Options

Prime Movers	
LM 2500+ (GE)	26.1 MW
	Navy Qualified and Grade A Shock Certified
	Thermal Efficiency of 39% at ISO Conditions
	<72-Hour Swap-Out
MT 30 (Rolls Royce)	36.0 MW
	Marketplace Leading Power to Weight Ratio
	>40% Thermal Efficiency
	Integral Electrical Generator and Acoustic Isolation
ICR WR 21/29 (Rolls Royce)	21.7 MW
	Intercooled Recuperative (ICR) Engine
	27% Lower Fuel Consumption
	Lower maintenance costs.
Ship Service Gas Turbine Generator (SSGTG)	
AG9140/AG9140RF (Allison)	3.43 MW
	Fleet-Proven
	Integral Maintenance Rigging and Easy-Access Configuration
	Can be Remotely Controlled

When combined, the options for the power and propulsion system result in 16 alternatives. Figure 7 illustrates these alternatives, and Table 10 and Table 11 list the characteristics of the various engines and generators considered.

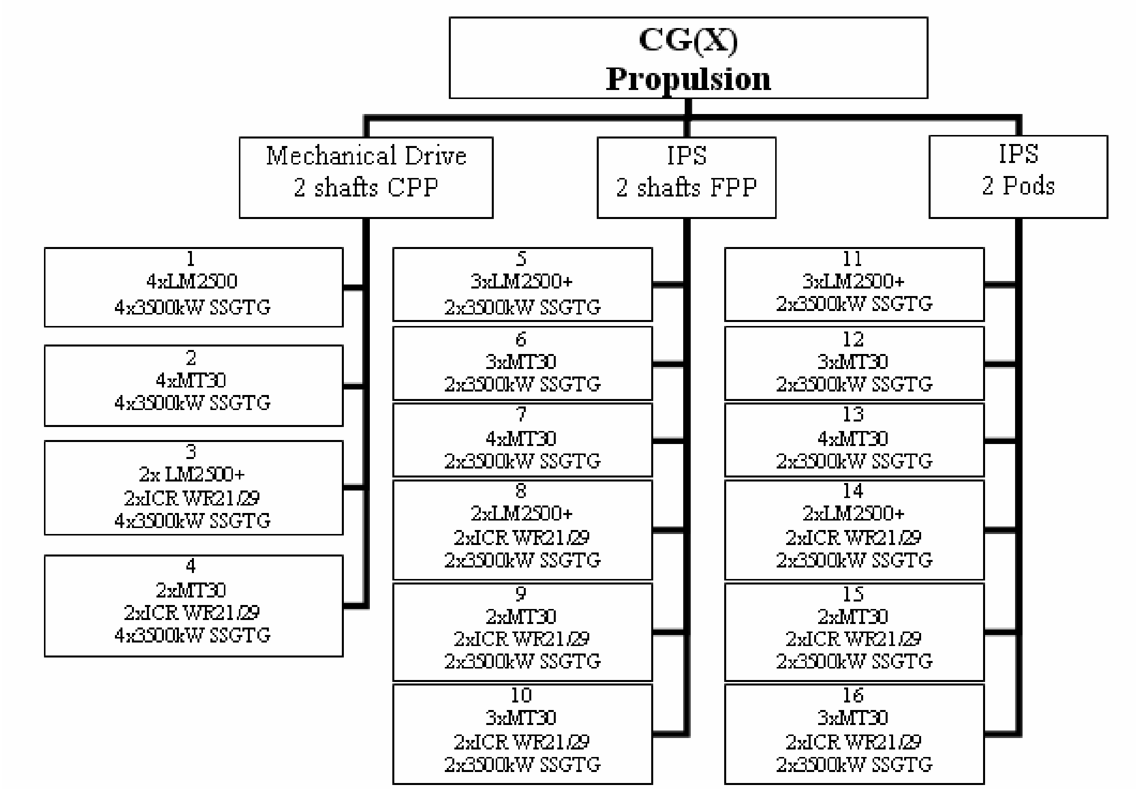

Figure 7 - Power and Propulsion System Alternatives

Table 10 - Propulsion System Data

Propulsion Option	Propulsion Option	Propulsion System Type $PSYS_{TYI}$	Propulsors	Endurance Propulsion Engine Type, PENGtype (1=GT, 2=ICR,3=Diesel)	Total Propulsion Engine Brake Power (kW) $P_{BENGTOT}$	Endurance Brake Propulsion Power, Pbpengend (kW)	Endurance Propulsion SFC SFC_{eE}(kg/kwhr)	Machinery Box Minimum Length $L_{MB\ req}$(m)	Machinery Box Minimum Height $H_{MB\ req}$(m)	Machinery Box Required Volume $V_{MB\ req}$(m^3)	Basic Propulsion Machinery Weight W_{BM}(MT)	Propulsion Inlet and Uptake Area A_{IE}(m^2)
MD 4xLM2500 2 Shaft CPP	1	1	2	1	104396	52198	0.226	15.95	5.00	2734	504.4	123.6
MD 4xMT30 2 Shaft CPP	2	1	2	1	144000	72000	0.213	17.21	5.78	3526	690.4	174.0
MD 2xLM2500+ 2xICR WR21/29 2Shafts CPP	3	1	2	2	95508	43310	0.199	15.88	6.42	3137	728.4	110.8
MD 2xMT30 2xICR WR21/29 2shafts CPP	4	1	2	2	115310	43310	0.199	16.99	6.42	3601	654.4	136
IPS 3xLM2500 2shafts FPP	5	2	2	1	78297	26099	0.226	18.44	5.00	2797	634.0	92.7
IPS 3xMT30 2shafts FPP	6	2	2	1	108000	36000	0.213	20.76	5.78	3482	852.8	130.5
IPS 4xMT30 2shafts FPP	7	2	2	1	144000	72000	0.213	20.76	5.78	4373	1127.7	173.2
IPS 2xLM2500+ 2xICR WR21/29 2shafts FPP	8	2	2	2	95508	43310	0.199	18.44	6.42	3425	835.6	110.8
IPS 2xMT30 2xICR WR21/29 2shafts FPP	9	2	2	2	115310	43310	0.199	20.76	6.42	3854	983.1	136.0
IPS 3xMT30 2xICR WR21/29 2shafts FPP	10	2	2	2	151310	43310	0.199	20.76	6.42	4741	1259.4	179.5
IPS 3xLM2500 2pods	11	4	2	1	78297	26099	0.226	18.44	5.00	2279	656.6	92.7
IPS 3xMT30 2pods	12	4	2	1	108000	36000	0.213	20.76	5.78	2933	883.6	130.5
IPS 4xMT30 2pods	13	4	2	1	144000	72000	0.213	20.76	5.78	3775	1170	173.2
IPS 2xLM2500+ 2xICR WR21/29 2pods	14	4	2	2	95508	43310	0.199	18.44	6.42	2885	863.2	110.8
IPS 2xMT30 2xICR WR21/29 2pods	15	4	2	2	115310	43310	0.199	20.76	6.42	3290	1016.2	136.0
IPS 3xMT30 2xICR WR21/29 2pods	16	4	2	2	151310	43310	0.199	20.76	6.42	4129	1304.1	179.5

Table 11 - Generator System Data

SSG Option	GSYS Option	GENGtype (1=Diesel, 2=Gas Turbine)	Number of SGs NSSG	SSG Power (ea) KWG(kW)	KWgend	Endurance SSG SFC SFCeG(kg/kwhr)	Basic Electric Machinery Weight WBMG(MT)	SSG Uptake Area AGIE(m2)
DDA 501-K34	**1**	**2**	**5**	**3430**	**6860**	**0.288**	**205.2**	**36**
DDA 501-K34	**2**	**2**	**4**	**3430**	**6860**	**0.288**	**157.9**	**27**
DDA 501-K34	**3**	**2**	**2**	**3430**	**0** **(IPS)**	**0.288**	**110.7**	**18**

3.1.3 Automation and Manning Parameters

At the current time, a high level of manning is necessary for a CG(X) ship to perform necessary operations and missions. However, with an increased amount of automation, it is possible to reduce manning. In doing so the overall life cycle of the ship can be reduced and minimize the personnel vulnerability. Types of automation that may be added to a ship include electronic log keeping, Integrated Condition Assessment System (ICAS), and other such enabling technologies. A high level of automation is necessary on newer ships to lower costs of manning and to update the ship to current technology status.

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. Figure 8 illustrates the standard manning calculation. 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.

$$N_O := 3 + \text{ceil}\left[1 + C_{MAN} \cdot \frac{(W_P - W_{VP})}{300} + \frac{V_D}{100000}\right]$$

$$N_E := \text{ceil}\left[C_{MAN} \cdot \left[(N_{PROP}) \cdot 2 + N_{SSG} + \frac{(W_P - W_{VP})}{50} + \frac{(V_{HT} + V_D)}{30000}\right]\right]$$

where N_O is number of ship officers and N_E is number of ship enlisted men

$$N_T := N_O + N_E \qquad N_A := \text{ceil}(0.1 \cdot N_T)$$

where N_T is the total number of ship crew and N_A is the additional accomodations

Figure 8 - "Standard" Manning Calculation

3.1.4 Combat System Alternatives

A range of combat system alternatives were identified, and ship impact was assessed for each configuration. The impact of the CG(X) mission systems was also identified. Analytical Hierarchy Process (AHP) and Multi-Attribute Value Theory (MAVT) were used to estimate the Value of Performance (VOP) for each system alternative. The VOPs are included in the total ship synthesis model and used to evaluate effectiveness. The combat system alternatives and CG(X) mission systems are selected based on effectiveness, cost, and risk in a multi-objective genetic optimization (MOGO). Component data for combat system options are listed in Table 20

3.1.4.1 AAW

CG(X) AAW system alternatives include systems listed in Table 12. The alternatives include: AN/SPY-3 and AN/SPY-1B Multi-Function Radars (MFR), Volume Search and AN/SPS-49A Air Surveillance Radars, AN/SPG-62 Fire Control Radar, Infrared Search and Track (IRST), AN/UPX-36(V) CIFF-SD, and AN/SRS-1A(V) Combat DF. All sensors and weapons in each suite are integrated using the Aegis MK 99 fire control system. This system is installed on all Aegis ships. The MK 99 improves effectiveness by coordinating hard kill and soft kill and employing them to their optimum tactical advantage.

Table 12 – AAW System Alternatives

War fighting System	Options	Components (Table 20)
AAW	Option 1) SPY-3 (4 panel), VSR, AEGIS MK 99 FCS	19, 20, 20, 136, 137, 1, 7, 15, 17
	Option 2) SPY-3 (2 panel), VSR, AEGIS MK 99 FCS	19, 20, 136, 137, 1, 7, 15, 17
	Option 3) SPY-1B (4 panel), SPS-49, 4xSPG-62, AEGIS MK 99 FCS	6, 119, 119, 14, 14, 14, 14, 21, 21,128, 1, 7, 15, 17

Sub-system descriptions are as follows:

- AN/SPY-3 Multi-Function Radar (MFR) – AN/SPY-3 is an X-band active phased-array radar that meets all horizon search and fire control requirements for the 21st century fleet. The arrays are engineered to preserve ship signature requirements by being embedded into the topside superstructure. SPY- 3 is expected to provide horizon search, limited above-the-horizon search, and fire control track and illumination of both surface and air threats. The radar will also provide automatic detection, tracking, and illumination of advanced sea and surface skimming missiles in adverse weather conditions.

- Volume Search Radar (VSR) – VSR is a three-dimensional S-band solid state active array surveillance radar. It is designed to provide long range above the horizon detection and tracking of air and ballistic missile threats as well as provide queuing data to the AN/SPY-3 radar.

- SPY-1B Multi-Function Radar – SPY-1B (Figure 9) is the primary air and surface radar for the current Aegis Combat System installed on the Ticonderoga (CG-47) class cruisers. It is a multi-function phased-array radar capable of search, automatic detection, transition to track, tracking of air and surface targets, and missile engagement support. SPY-1B radars use two transmitters linked to four phased-array antennas, each of which emits an electronically controlled beam across a 110° field. The four fixed arrays send out beams of electromagnetic energy in all directions simultaneously, continuously providing a search and tracking capability for hundreds of targets at the same time.

Figure 9 – SPY-1D Phased-array

- AN/SPS-49A Long-Range Air Surveillance Radar – AN/SPS-49A (Figure 10) is an L-band, narrow beam, long-range, two-dimensional, air-search radar system. It provides automatic detection and reporting of targets in its surveillance volume and operates in the presence of clutter, chaff, and electronic countermeasures. A line of sight / horizon stabilized antenna for low altitude in conjunction with an upshot feature for high-diving threats allow AN/SPS-49A to detect small fighter aircraft in excess of 225 miles away.

Figure 10 – AN/SPS-49 Long-Range Air Surveillance Radar

- AN/SPG-62 Fire Control Radar – AN/SPG-62 (Figure 11) is an I/J-band fire control radar and is a component of the MK-99 Fire Control System. It provides a continuous wave illuminating radar, providing a very high probability of kill. It also controls the target illumination for the terminal guidance of Ship Launched SM-2 Anti-Air Missiles.

Figure 11– AN/SPG-62 Fire Control Radar

- Infrared Search and Track (IRST) – IRST is a shipboard integrated sensor designed to detect and report low flying ASCMs by their hot exhaust plumes. It scans the horizon plus or minus a few degrees but can be manually changed to search higher, and provides accurate bearing, elevation angle, and relative thermal intensity readings of a target.

- Mk 99 Fire Control System (FCS) – Mk 99 is a major component of the AEGIS Combat system. It controls loading and arming of the selected weapon, l fdaunches the weapon, and provides terminal guidance for AAW missiles. FCS controls the continuous wave illuminating radar AN/SPG-62, providing a very high probability of kill.

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

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

3.1.4.2 ASUW

Anti-Surface Warfare system alternatives listed in Table 13 – ASUW System Alternatives include: AN/SPS-73(V)12 and AN/SPQ-9 surface search radar, and MK 160/34 and MK 86 Gun Fire Control System (GFCS). Specific sub-system descriptions are as follows:

Table 13 – ASUW System Alternatives

War fighting System	Options	Components (Table 20)
ASUW	Option 1) SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker	140, 129, 31, 33, 143, 29
	Option 2) SPS-73(V)12, SPQ-9, MK 86 GFCS, Small Arms Locker	140, 68, 31, 33, 143, 29

- AN/SPS-73(V)12 – AN/SPS-73(V)12 (Figure 12) is a short-range 2D, surface search and navigation radar. It provides short range detection and surveillance of surface units and low-flying air units, contact range and bearing information, and enables quick and accurate determination of own ship's position relative to nearby vessels and navigational hazards.

Figure 12 – AN/SPS-73(V)12 Surface Search Radar

- SPQ-9 – The SPQ-9 is a high resolution, X-band surface surveillance and tracking radar. It is used in conjunction with the MK 86 GFCS providing queuing to other ship self defense systems and excellent detection of low sea-skimming cruise missiles in heavy clutter.

- MK 160/34 GFCS (Gun Fire Control System) – The MK 34 GFCS integrates data from radars or other tracking systems and passes the information to the Mk 160 which computes the firing solution for the gun system. The MK 160/34 GFCS maintains up to four continuously tracked surface and air targets and ten NGFS targets, and is capable of providing indirect fire for NGFS.

- MK 86 GFCS – The MK 86 GFCS (Figure 13) is a lightweight gun and missile fire control system capable of targeting both surface and sir targets and providing indirect fire for NGFS.

Figure 13 – Console of MK 86 GFCS

3.1.4.3 ASW/MCM

CG(X) Anti-Submarine Warfare (ASW) system alternatives include AN/SQS-53C/D and AN/SQS-56 Bow Mounted Sonar, AN/SQQ-89 and MK 116 ASW Control System, MK 32 Surface Vessel Torpedo Tube (SVTT), AN/SLQ-25 NIXIE, AN/SQR-19B TACTAS, and LAMPS MK3 SH-60 Seahawk Helicopter (Section 3.1.4.6) as listed in Table 14. 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.

Table 14 – ASW/MCM System Alternatives

War fighting System	Options	Components (Table 20)
ASW/MCM	Option 1) SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, MK 116	34, 43, 130, 49, 63, 40, 44, 51, 41, 38, 98
	Option 2) SQS-56, MK 116 UWFCS, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, SQQ-89	35, 44, 130, 58, 63, 39, 43, 51, 41, 38, 98

Specific sub-system descriptions are as follows:

- AN/SQS-53C/D Bow-Mounted Sonar – AN/SQS-53 is a computer controlled surface ship sonar operating in either active or passive modes to provide precise information for ASW weapons control and guidance. It provides direct path ASW search, detection, localization, and tracking from a hull mounted transducer array. The 53C retains the transducer assembly from the 53A/B, provides greater range and detection capability with only half of the electronics footprint and less weight. Implemented in standard electronic modules, the AN/SQS-53C is an all digital system with stable performance, on-line reconfiguration in the event of a component failure, and performance monitoring/fault location software to quickly isolate failures. Functions of the system are the detection, tracking, and classification of underwater targets. It can also be used for underwater communications, countermeasure against acoustic underwater weapons, and certain oceanographic recording uses. The AN/SQS-53A/B hull-mounted sonars are being upgraded to digital by the use of Commercial-Off-The-Shelf (COTS) processors, and are re-designated SQS-53D.

- AN/SQS-56 Bow-Mounted Sonar – AN/SQS-56 is a hull-mounted sonar with digital implementation. The system is controlled by a built-in mini computer and an advanced display system, and is extremely flexible and easy to operate. It operates in both active and passive modes using a preformed beam providing panoramic echo ranging and panoramic (DIMUS) passive surveillance. A single operator can search, track, classify and designate multiple targets from the active system while simultaneously maintaining anti-torpedo surveillance on the passive display.

- MK 32 Surface Vessel Torpedo Tube (SVTT) – MK 32 (Figure 14) is a ASW launching system which is capable of stowing and pneumatically launching up to three torpedoes over the side of the vessel. It handles the MK-46 and MK-50 torpedoes and can launch the under local control or remote control from an ASW fire control system.

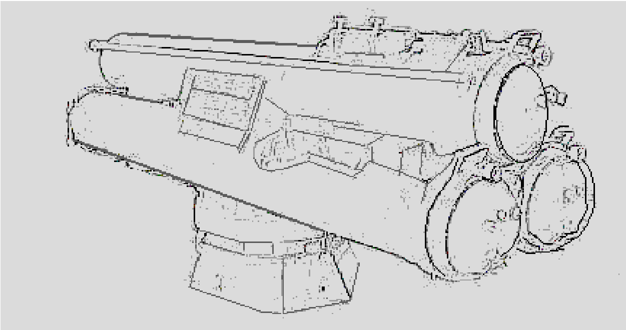

Figure 14 – MK 32 Surface Vessel Torpedo Tube (SVTT)

- AN/SLQ-25A NIXIE – AN/SLQ-25A (Figure 15) is a tow-behind decoy that employs an underwater acoustic projector which is towed behind the ship. It provides deceptive countermeasures against acoustic homing torpedoes and can be used in pairs.

Figure 15 – AN/SLQ-25A NIXIE in Action

- AN/SQQ-89 ASW Control System (ASWCS) – AN/SQQ-89 is an integrated undersea warfare detection, classification, display, and targeting system. It supports SQQ-89 tactical sonar suite, SQS-53C/D and Tactical Towed Array Sonar (TACTAS), and is fully integrated with Light Airborne Multi-Purpose System (LAMPS MK III) helicopter, MK 116 ASWCS and MK 309 Torpedo Fire Control System. AN/SQQ-89 is currently deployed on all US surface combatants.

- AN/SQR-19B Tactical Towed Array Sonar (TACTAS) – AN/SQR-19B (Figure 16) is a component sensor of the AN/SQQ-89(V)6 ASW Combat System. It is a passive towed array system that provides the ability to detect, classify, and track while being towed far behind the ship to eliminate interference from ship noise.

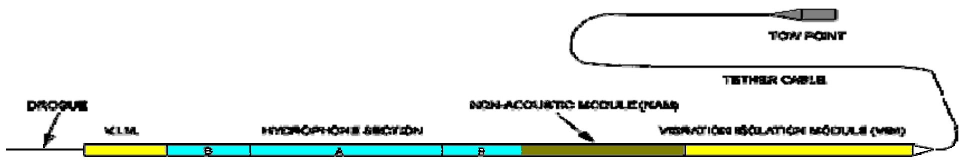

Figure 16 – AN/SQR-19B TACTAS Schematic

- MK 116 Anti-Submarine Weapon Control System (ASWCS) Underwater Fire Control System – MK 116 is used in conjunction with the SQS-53 and SQR-19 sonars on the DDG51 class Flight IIA. It takes all the tracking data from the AN/SQS-53C/D and ITASS and is capable of firing a torpedo using the Surface Vessel Torpedo Tubes (SVTT) or fire an ASROC (Anti-Submarine Rocket Assisted Torpedo) from the VLS system.

- Mine avoidance sonar – Mine Avoidance Sonar (MAS) (Figure 17) is an active MCM that will allow for the detection and avoidance of mines and other dangerous objects. The Multi-Purpose Sonar System VANGUARD is a versatile two-frequency active and broadband passive sonar system. Though primarily designed to detect mines it can be used to detect other moving or stationary objects. VANGUARD also assists in navigation. The passive sonar mode can be used to detect other sonar signals and underwater noise over a wide range of frequencies.

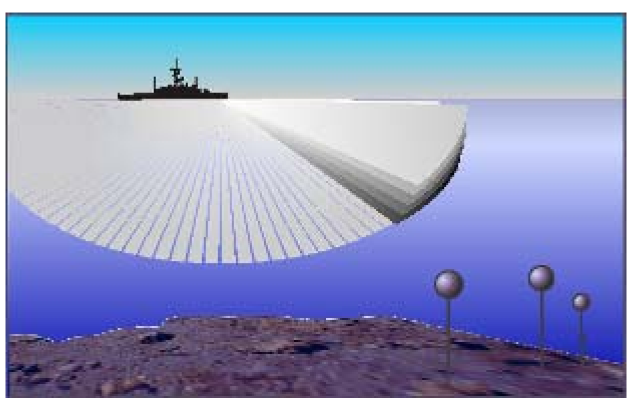

Figure 17 - MAS

- Degaussing – Degaussing (Figure 18) is a passive MCM that reduces the magnetic signature of a ship. It works by passing a current through a mesh of wires to generate a magnetic field that cancels out the ship's magnetic field.

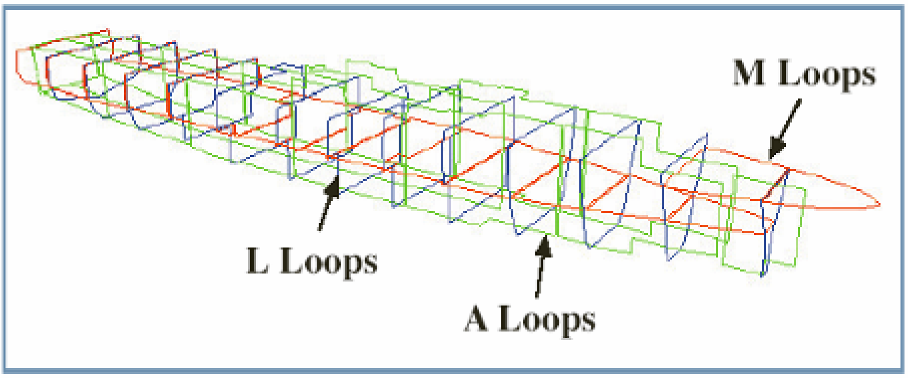

Figure 18 – Schematic of a Ship Degaussing System

3.1.4.4 NSFS

Naval Surface Fire Support (NSFS) system alternatives are listed in Table 15.

Table 15 – NSFS System Alternatives

War fighting System	Options	Components (Table 20)
NSFS	Option 1) MK 45 5" – 64 mod 4 gun	75, 67, 150
	Option 2) 2 MK 110 57 mm gun	147, 146, 144, 145

Sub-system descriptions are as follows:

- MK 45 5"/62-caliber MOD 4 ERGM Gun Mount – Modifications to the basic MK 45 Gun Mount (Figure 19): 62-caliber barrel, strengthened trunnion supports, lengthened recoil stroke, an ERGM initialization interface, round identification capability, and an enhanced control system. The MOD 4 also has a new gun mount shield to reduce overall radar signature, maintenance, and production cost. Extended Range Guided Munitions also extend the max range of the MK 45 from 13 nautical miles to over 60 nautical miles.

Figure 19 – MK 45 5"/62-caliber Naval Gun

- MK 110 57-mm Mod 0 – MK 110 (Figure 20) is a highly survivable multi mission capable medium-caliber shipboard weapon. It fires automatic salvos of 57-mm MK 295 Mod 0 6-mode programmable ammunition at a rate of 220 rounds per minute. The MK 110 is lightweight, has minimal deck penetration, and requires minimal manpower, and has a maximum range of 17,000 meters.

Figure 20 – MK 110 57-mm Bofors Naval Gun

3.1.4.5 CCC/SEW/STK

Command, Control, Communications (CCC), Signal and Electronic Warfare (SEW), and Strike (STK) system alternatives include those listed in Table 16. Electronic Warfare system alternatives include AN/SLQ-32(V)3 Electronic Warfare system, MK 36 DLS SRBOC, and MK 53 DLS NULKA Decoy system. Descriptions of the specific sub-systems are as follows:

Table 16 – CCC/SEW/STK System Alternatives

War fighting System	Options	Components (Table 20)
CCC/SEW/STK	Option 1) Enhanced CCC, SLQ-32-AV3, MK 36 SRBOC, NULKA	100, 77, 151, 58, 102, 152, 103, 79
	Option 2) Basic CCC (CG 47)	102, 138, 139, 2, 79, 77, 151, 152

- CCC – The design variable for Command Control and Communications is based on systems currently in place aboard CG-47 including the following with allowances for future upgrades:
    - Global Broadcast System (GBS)
    - EHF SATCOM
    - UHF SATCOM
    - IMARSAT
    - Link 11
    - Link 16
    - Low Observable Multifunction Stack (Figure 21)
    - Distributed Computer Networks
    - Cooperative Engagement Capability

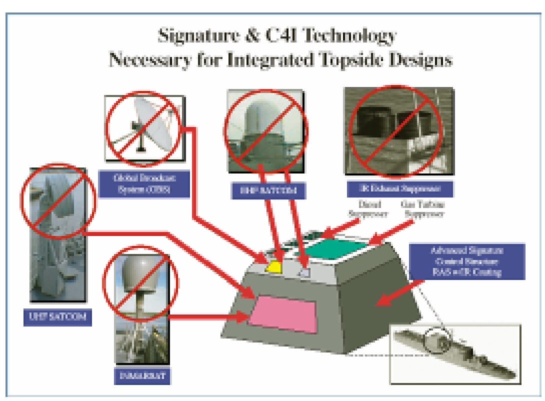

Figure 21 – CCC Components Installed in a Low Observable Multifunction Stack

- AN/SLQ-32A(V)3 Electronic Warfare (EW) System – AN/SQS-32(V)3 (Figure 22) provides warning, identification, and direction-finding of incoming anti-ship cruise missiles (ASCM). It also provides early warning, identification, and direction-finding against targeting radars. (V)3 also provides jamming capability against targeting radars.

Figure 22 – AN/SQS-32(V)3 Electronic Warfare System

- MK 36 DLS SRBOC (Super Rapid Bloom Offboard Countermeasures Chaff and Decoy Launching System) – MK 36 (Figure 23) is a deck mounted, mortar-type countermeasure system used to confuse hostile missile guidance and fire control systems by creating false signals. The MK 137 launcher has six 130mm fixed tubes arranged in two parallel rows at angles of 45 and 60 degrees, allowing the MK 36 to launch decoys at a variety of altitudes.

Figure 23 – MK 36 DLS SRBOC

- MK 53 DLS NULKA – MK 53 (Figure 24) 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.

Figure 24 – MK 53 DLS NULKA

3.1.4.6 LAMPS

The Sikorsky SH-60 LAMPS (Figure 25) is used in a variety of roles. It is capable of performing ASW, ASUW, search and rescue (SAR), SPECOPS, medical evacuation (MEDEVAC), vertical replenishment (VERTREP), naval gunfire support (NGFS), and communications relay (COMREL). In an ASW role it deploys sonobuoys and utilizes ALFS (Airborne Low Frequency Sonar) to classify and localize a potential threat and deploy both MK 46 and MK 50 torpedoes for neutralization of the threat. In an ASUW role LAMPS will employ a Multi-Mode Radar (MMR) (including Inverse Synthetic Aperture Radar (ISAR) and imaging and periscope detection modes), an ESM upgrade, a fully automated protection system, and a Forward Looking Infrared (FLIR) sensor with laser designator to observe, identify, and if necessary attack threat platforms beyond ship's radar and/or electronic support measure (ESM) horizon. In a surface attack scenario the SH-60 will deploy a variety of weapons including AGM-119 Penguin anti-ship missile, AGM-114 Hellfire anti-armor missile, and a door mounted 7.62 mm machine gun. LAMPS System alternatives are listed in Table 17.

Figure 25 – SH-60 LAMPS Firing an AGM-119 Penguin Anti-Ship Missile

Table 17 – LAMPS System Alternatives

War fighting System	Options	Components (Table 20)
LAMPS	Option 1) Embarked 2 LAMPS w/Hangars	54, 53, 55, 56, 57, 36
	Option 2) Embarked single LAMPS w/Hangar	148, 46, 47, 50, 52
	Option 3) LAMPS haven (flight deck)	149, 57, 36, 46, 48

3.1.4.7 SDS

The MK 15 CIWS Phalanx Close-in Weapons System Phalanx (Figure 26) combines a proven 20-mm M61A1 Gatling gun firing Armor Piercing, Discarding Sabot (APDS) rounds at a selectable 3000/4500 spm, with an advanced search and track Ku-band radar featuring closed-loop spotting technology, to provide autonomous target detection and engagement. The system can also be interfaced to virtually any ship combat system and can provide target designation for other shipboard weapons. The Block 1B Surface Mode configuration builds on the existing capabilities of Block 1A with the addition of new Optimized Gun Barrels (OGB) for an improved dispersion pattern and an integrated Forward Looking Infrared System (FLIR). The FLIR provides the MK 15 with the capability to search, track, and engage littoral warfare threats. Ship Defense System (SDS) alternatives are listed in Table 18.

Figure 26 – MK 15 CIWS Phalanx Close-in Weapons System

Table 18 – SDS System Alternatives

War fighting System	Options	Components (Table 20)
SDS	Option 1) 2xCIWS	22, 24, 24, 12
	Option 2) 1xCIWS	12, 24, 123
	Option 3) none	

3.1.4.8 GMLS

The Guided Missile Launching System (GMLS) may use a combination of MK 41 VLS and MK 57 PVLS to achieve a desired missile loadout. GMLS system alternatives are listed in Table 19.

Table 19 – GMLS System Alternatives

War fighting System	Options	Components (Table 20)
GMLS	Option 1) 224 cells, MK 41 and/or MK57 PVLS	110, 109, 111, 112, 115, 113, 114, 116, 117
	Option 2) 192 cells, MK 41 and/or MK57 PVLS	110, 89, 111, 80, 115, 113, 83, 116, 85
	Option 3) 160 cells, MK 41 and/or MK57 PVLS	109, 89, 112, 80, 115, 114, 83, 117, 85
	Option 4) 128 cells, MK 41 and/or MK57 PVLS	89, 89, 80, 80, 115, 83, 83, 85, 85

Sub-system description is as follows:

- MK 41/57 Vertical Launching System (VLS) – The MK 41/57 VLS (Figure 27) provides a superior level of performance to conventional mechanical pointing-type launching systems. The capability of VLS to simultaneously prepare one missile in each half of a launcher module allows for fast reaction to multiple threats with concentrated, continuous firepower. Multi-mode operation of VLS extends firepower capabilities to allow simultaneous interface and missile preparation for discrete AAW, ASW, and ASUW missions. The VLS design also provides a high degree of battle survivability. With missiles and associated launch equipment all located below the armored deck (MK 41) and in a peripheral position (MK 57), the launcher module performs all launch functions and eliminates the possibility of single-point failure modes.

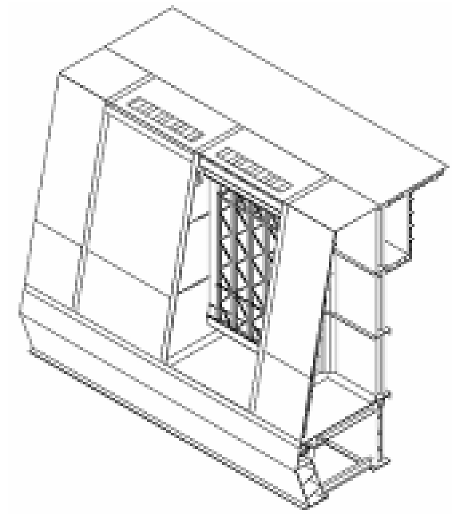

Figure 27 – MK 57 Peripheral VLS

3.1.4.9 Combat Systems Payload Summary

To trade-off combat system alternatives with other alternatives in the total ship design, combat system characteristics listed in Table 20 are included in the ship synthesis model database.

Table 20 - Combat System Component Characteristics

ID	NAME	DV	WTGRP	ID	SingleD	WT (lton)	HD10	HAREA	DHAREA	CRSKW	BATKW
1	BALLISTIC PLATING, MISC	AAW	164	1	100	25.9	20.56	0	0	0	0
2	CIC, DDG51	AAW/CCC	411	2	400	17.34	-3.3	1989	0	74.5	74.5
103	CIC, CG47	AAW/CCC	411	103	400	25	3.30	2500		150	150
6	RADAR, AIR SEARCH 2-D, SPS-49	AAW	452	6	400	6.91	17.19	0	52	79	79
7	IFF, MK XII AIMS	AAW	455	7	400	2.3	29.2	0	0	3.2	4
119	RADAR, MFAR, SPY-1B (2CH, 2FACE)	AAW	456	119	400	70.4	14.5	0	1894	299	504
136	RADAR, S BAND VSR	AAW	456	136	400	138.3	25.5	0	0	622.7	1092.7
137	RADAR, MFAR X-BAND FOR HOR AND ABOVE SCH, SD ILLUM, SPY-3 (2CH, 2FACE)	AAW	456	137	400	27.2	59.5	0	0	382.7	382.7
14	RADAR, ILLUMINATOR, SPG-62, 1EA	AAW	482	14	400	4.8	20.9	0	320	11.6	21.7
15	GMFCS, MK99 (AEGIS)	AAW	482	15	400	0.7	6.4	0	9	34.7	65.2
17	COMBAT DF	AAW	495	17	400	8.26	21	0	448	15.47	19.34
19	COOLING EQUIPMENT FOR S BAND RADAR, VSR	AAW	532	19	500	276	-11.81	1731	0	2992	3442
20	COOLING EQUIPMENT FOR LARGE X-BAND RADAR, SPY-3 (2 CH)	AAW	532	20	500	13.16	-21.81	112	0	32.24	32.24
21	COOLING EQUIPMENT FOR SPY-1D, SPY 1A and SPY-1B (2 CH)	AAW	532	21	500	9	-34	0	960.8	0	0
33	SMALL ARMS AMMO, DDG51 - 7.62MM + 50 CAL + PYRO	ASUW	21	33	20	4.1	-6	0	0	0	0
128	RADAR, SURFACE SEARCH & TRACK, SPQ-9	ASUW	451	128	400	0.8	30	0	100	15	25
140	RADAR, SURFACE SEARCH and NAVIGATION, AN/SPS-73	ASUW	451	140	400	0.24	8.00	0.00	0.00	0.20	0.20
143	IR Search and Track System (IRST)	ASUW	452	143	400	1.60	8.00	0.00	19.90	40.00	40.00
68	GFCS, MK86	ASUW	481	68	400	7.18	-5.6	0	168	6	15.4
129	GFCS, MK160/34	ASUW	481	129	400	10	-6	0	200	10	20
29	HARPOON, AN/SWG-1, WCS, LNCH CONTROL SYSTEM IN CIC	ASUW	482	29	400	1.1	-3.3	0	100	0	15

ID	NAME	DV	WTGRP	ID	SingleD	WT (lton)	HD10	HAREA	DHAREA	CRSKW	BATKW
31	SMALL ARMS AND PYRO STOWAGE LOCKER, DDG51	ASUW	760	31	700	5.8	-6.3	203	0	0	0
98	MK-50 ADCAP TORPEDOS X 8	ASW	21	98	20	2.68	0	0	0	0	0
34	SONAR, BOW, SQS-53B-D, 5M, DOME STRUCTURE	ASW	165	34	100	85.7	-43.14	0	0	0	0
35	SONAR, KEEL, SQS-56, 1.5M, DOME STRUCTURE	ASW	165	35	100	7.43	-30.2	0	0	0	0
38	TACTAS, SQR-19	ASW	462	38	400	23.3	-25.72	473	0	26.6	26.6
39	SONAR, KEEL, SQS-56, 1.5M, ELEX	ASW	463	39	400	5.88	-28.3	1340	0	19.7	19.7
40	SONAR, BOW, SQS-53C/D, 5M, ELEX	ASW	463	40	400	67.4	-28.3	2870	0	55	55
41	NIXIE, AN/SLQ-25	ASW	473	41	400	3.6	-5.72	172	0	3	4.2
43	ASW, UNDERWATER FIRE CONTROL SYSTEM, BASIC, MK116	ASW	483	43	400	0.4	-9.6	124	0	11.5	11.5
44	ASW, CONTROL SYSTEM [ASWCS], SQQ-89	ASW	483	44	400	4.8	-11	185	0	19.5	19.5
130	ASW TORPEDO CONTROL SYSTEM, MK 309	ASW	483	130	400	2	-10	150	0	15	15
49	SONAR, BOW, SQS-53B-D, 5M, SONAR DOME HULL DAMPING	ASW	636	49	600	20.1	-37.07	0	0	0	0
58	SONAR, BOW, SQS-56, SONAR DOME HULL DAMPING	ASW	636	58	600	2.01	-37.07	0	0	0	0
51	SVTT, MK32, 2X, ON DECK	ASW	750	51	700	2.7	1.14	0	0	0.6	1.1
138	ADCON 21 - Warfare CDR (-) C/C Suite (DDG 79, 1992) - 1 of 2	CCC	411	138	400	2.20	-1.50	60.00	0.00	62.44	62.44
139	ADCON 21 - Warfare CDR (-) C/C Suite (DDG 79, 1992)-2 of 2	CCC	412	139	400	6.20	-1.50	81.35	0.00	0.00	0.00
102	NAVIGATION SYSTEM, DDG51	CCC	420	102	400	7.5	16.1	0	50	16.4	20.5
100	ADVANCED C4I SYSTEM	CCC	440	100	400	32.3	-7.9	1270	95	93.3	96.4
89	VLS, 64 CELL, MISSILES - 64	GMLS	21	89	20	98.4	-11.06	0	0	0	0
109	VLS, 96 CELL, MISSILES - 96	GMLS	21	109	20	147.6	-11.06	0	0	0	0
110	VLS, 128 CELL, MISSILES - 128	GMLS	21	110	20	196.8	-11.06	0	0	0	0
80	VLS, 64 CELL, ARMOR - LEVEL III HY-80	GMLS	164	80	100	21.1	-6.17	0	0	0	0
111	VLS, 128 CELL, ARMOR - LEVEL III HY-80	GMLS	164	111	100	42.2	-6.17	0	0	0	0
112	VLS, 96 CELL, ARMOR - LEVEL III HY-80	GMLS	164	112	100	31.65	-6.17	0	0	0	0
115	VLS, WEAPON CONTROL SYSTEM (2 MODULES)	GMLS	482	115	400	1.4	-9.66	112	0	30	32
83	VLS, 64 CELL MAGAZINE DEWATERING SYSTEM	GMLS	529	83	500	3	-6.97	0	0	0	0
113	VLS, 128 CELL MAGAZINE DEWATERING SYSTEM	GMLS	529	113	500	6	-6.97	0	0	0	0
114	VLS, 96 CELL MAGAZINE DEWATERING SYSTEM	GMLS	529	114	500	4.5	-6.97	0	0	0	0
85	VLS, 64 CELL	GMLS	721	85	700	147.8	-13.66	2245	0	63.4	63.4
116	VLS, 128 CELL	GMLS	721	116	700	295.6	-13.66	4490	0	126.8	126.8
117	VLS, 96 CELL	GMLS	721	117	700	221.7	-13.66	3368	0	95.1	95.1
53	LAMPS, 18 X MK46 TORP & SONOBUOYS & PYRO	LAMPS	22	53	20	9.87	4.8	0	588	0	0
54	LAMPS MKIII 2 X SH-60B HELOS AND HANGER (BASED)	LAMPS	23	54	20	12.73	4.5	0	3406	5.6	5.6
148	LAMPS MKIII 1 X SH-60B HELO AND HANGER (BASED)	LAMPS	23	148	20	6.36	4.5	0	1800	5.6	5.6
149	LAMPS MKIII 1 X SH-60B HELO (ON DECK)	LAMPS	23		20	6.36	4.5	0	0	0	0
55	LAMPS, AVIATION SUPPORT AND SPARES	LAMPS	26	55	20	9.42	5	357	0	0	0
56	LAMPS, BATHYTHERMOGRAPH PROBES	LAMPS	29	56	20	0.2	-16.11	0	0	0	0
57	LAMPS, AVIATION FUEL [JP-5]	LAMPS	42	57	40	64.4	-28.81	0	0	0	0

ID	NAME	DV	WTGRP	ID	SingleD	WT (lton)	HD10	HAREA	DHAREA	CRSKW	BATKW
36	LAMPS, SQQ-28 ELECTRONICS	LAMPS	460	36	400	3.4	3	15	0	5.3	5.5
46	LAMPS, AVIATION FUEL SYS	LAMPS	542	46	500	4.86	-11	30	0	2	2.9
47	LAMPS, RAST/RAST CON-TROL/HELO CONTROL	LAMPS	588	47	500	31.1	-1.6	219	33	4.4	4.4
48	LAMPS, SECURING SYSTEM	LAMPS	588	48	500	3.6	9.62	0	0	0	0
50	LAMPS, AVIATION SHOP AND OFFICE	LAMPS	665	50	600	1.04	-4.5	194	75	0	0
52	LAMPS, REARM MAGAZINE	LAMPS	780	52	700	2.7	4.64	212	0	0	4.4
63	MINE AVOIDANCE SONAR	MCM	462	63	400	11.88	-18.03	350	0	5	5
75	GUN, 5IN/62 MK 45, MOD 4, AMMO W/ERGM - 600RDS	NSFS	21	75	20	41.1	-10.75	905	0	0	0
146	GUN, 57mm Ammo in Gun Mount 120 RDS 3 of 4	NSFS	21	146	20	0.75	2.00	0.00	0.00	0.00	0.00
147	GUN, 57mm Ammo in Magazine 880 RDS 4 of 4	NSFS	21	147	20	5.46	-2.00	0.00	0.00	0.00	0.00
67	GUN, 5IN MK45, HY-80 ARMOR	NSFS	164	67	100	20.2	-0.35	0	0	0	0
150	GUN, 5IN/62 MOD 4	NSFS	710	150	700	39	1.44	300	0	36.6	50.2
144	57mm MK 3 Naval Gun Mount 1 of 4	NSFS	711	144	700	6.80	2.00	31.00	0.00	4.00	10.00
145	57mm Stowage 2 of 4	NSFS	713	145	700	2.70	2.00	0.00	0.00	0.00	0.00
24	CIWS, 20MM AMMO - 16000 RDS	SDS	21	24	20	8.3	20	0	257	0	0
12	CIWS WEAPON CONTROL SYSTEM	SDS	481	12	400	1	14.5	0	464	3.2	10.4
22	CIWS, 2X & WORKSHOP	SDS	711	22	700	13.2	21	0	321	14	42
123	CIWS, 1X & WORKSHOP	SDS	711	123	700	9.2	21	0	221	8	32
152	2X-MK 137 LCHRs Loads (4NULKA, 12 SRBOC) (2 OF 2)	SEW	21	152	20	0.57	1.00	0.00	21.66	0.00	0.00
77	ECM, SLQ-32[V]3	SEW	472	77	400	11.61	20.6	40	300	6.4	87
151	2X-MK 137 LCHRs (Combined MK 53 SRBOC & NULKA LCHR) (1 OF 2)	SEW	721	151	700	0.74	1.00	0.00	0.00	0.00	0.00
79	TOMAHAWK, WEAPON CONTROL SYSTEM (IN CIC)	STK	482	79	400	5.6	-3.3	5	0	11.5	11.5

3.2 Design Space

Twenty-five design variables in Table 21 are used to describe the CG(X) design. The optimizer chooses the design variable values from the range provided and inputs the values into the ship synthesis model. Once the design variable values are input into the ship synthesis model, the ship is balanced, checked for feasibility, and assessed based on risk, cost, and effectiveness. Hull design parameters (DV1-11) are described in Section 3.1.1. Sustainability alternatives (DV14) and performance measures are described in Section 3.2.2. Propulsion and Machinery alternatives (DV12 and 13) are described in Section 3.1.2. Automation alternatives (DV17) are described in Section 3.1.3. The final design variables are Combat system alternatives (DV 18-25) described in Section 3.1.4.

Table 21 - Design Variables (DVs)

DV #	DV Name	Description	Design Space
1	LWL	Waterline Length	550 – 700 ft. (150-200m)
2	LtoB	Length to Beam ratio	7.9-9.9
3	LtoD	Length to Depth ratio	10.75-17.8
4	BtoT	Beam to Draft ratio	2.9-3.2
5	Cp	Prismatic coefficient	0.56 – 0.64
6	Cx	Maximum section coefficient	0.75 – 0.84
7	Crd	Raised deck coefficient	0.7 – 1.0
8	VD	Deckhouse volume	100,000-150,000 ft^3 (2800-4250m^3)
9	Cdhmat	Deckhouse material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite
10	HULLtype	Hull: Flare or Tumblehome	1: flare= 10 deg; 2: flare = -10 deg

DV #	DV Name	Description	Design Space
11	BALtype	Ballast/fuel system type	0 = clean ballast, 1 = compensated fuel tanks
12	PSYS	Propulsion system alternative	Option 1) 2 shaft, mechanical, CPP, 4xLM2500+ Option 2) 2 shaft, mechanical, CPP, 4xMT30 Option 3) 2 shaft, mechanical, CPP, 2xLM2500+, 2x ICR WR29 Option 4) 2 shaft, mechanical, CPP, 2xMT30, 2x ICR WR29 Option 5) 2 shaft. IPS, FPP, 3xLM2500+ Option 6) 2 shaft. IPS, FPP, 3xMT30 Option 7) 2 shaft. IPS, FPP, 4xMT30 Option 8) 2 shaft. IPS, FPP, 2xLM2500+, 2x ICR WR29 Option 9) 2 shaft. IPS, FPP - 2xMT30, 2x ICR WR29 Option 10) 2 shaft. IPS, FPP, 3xMT30, 3x ICR WR29 Option 11) 2 pods, IPS, 3xLM2500+ Option 12) 2 pods, IPS, 3xMT30 Option 13) 2 pods. IPS, 4xMT30 Option 14) 2 pods, IPS, 2xLM2500+, 2x ICR WR29 Option 15) 2 pods, IPS, 2xMT30, 2x ICR WR29 Option 16) 2 pods, IPS, 3xMT30, 2x ICR WR29
13	GSYS	Ship Service Generator system alternatives	Option 1) 5 x Allison 501K34 (@3,500 kW) Option 2) 4 x Allison 501K34 (@3,500 KW) Option 3) 2 x Allison 501K34 (@3,500 KW) For PSYS=5-16: no additional SSGTGs
14	Ts	Provisions duration	45-60 days
15	Ncps	Collective Protection System	0 = none, 1 = partial, 2 = full
16	Ndegaus	Degaussing system	0 = none, 1 = degaussing system
17	Cman	Manning reduction and automation factor	0.5 – 0.1
18	AAW	Anti-Air Warfare alternatives	Option 1) SPY-3 (4 panel), VSR, AEGIS MK 99 FCS Option 2) SPY-3 (2 panel), VSR, AEGIS MK 99 FCS Option 3) SPY-1B (4 panel), SPS-49, 4xSPG-62, AEGIS MK 99 FCS
19	ASUW	Anti-Surface Warfare alternatives	Option 1) SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker Option 2) SPS-73(V)12, SPQ-9, MK 86 GFCS, Small Arms Locker
20	ASW	Anti-Submarine Warfare alternatives	Option 1) SQS-53D, SQQ 89, MK 116 UWFCS, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS Option 2) SQS-56, SQQ 89, MK 116 UWFCS, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
21	NSFS	Naval Surface Fire Support alternatives	Option 1) MK 45 5" – 64 mod 4 gun Option 2) 2 MK 110 57 mm gun
22	CCC	Command Control Communication alternatives	Option 1) Enhanced CCC Option 2) Basic CCC (CG 47)
23	LAMPS	LAMPS alternatives	Option 1) Embarked 2 LAMPS w/Hangars Option 2) Embarked single LAMPS w/Hangar Option 3) LAMPS haven (flight deck)
24	SDS	Self Defense System alternatives	Option 1) 2xCIWS Option 2) 1xCIWS Option 3) none
25	GMLS	Guided Missile Launching System alternatives	Option 1) 224 cells, MK 41 and/or MK57 PVLS Option 2) 192 cells, MK 41 and/or MK57 PVLS Option 3) 160 cells, MK 41 and/or MK57 PVLS Option 4) 128 cells, MK 41 and/or MK57 PVLS

3.3 Ship Synthesis Model

The CG(X) ship synthesis model is a group of modules that are run in order to analyze and balance the selected designs. The modules use FORTRAN code, and physics and regression-based equations. The modules are linked with wrappers in Model Center (MC), where each subsequent module receives the input of calculated or defined values from previous modules. Each set of values is assessed to be feasible or infeasible. The optimization is based on Feasibility, Cost, OMOE, and OMOR of the design, which make up the final four modules in the model. Model Center (MC) design environment software is used to execute and integrate the synthesis model. Figure 28 shows the synthesis model in MC. The following are brief summaries of each of the modules:

- **Input module** – Receives input values from user or optimizer. Input values are written to an output file where they can be read by any subsequent modules. Values from the input module are used by each of the following modules. The first 16 variables in the module correspond to the design variables shown in Figure 28. Other input parameters include average deck height, endurance speed, minimum sprint speed, minimum and maximum endurance range, minimum and maximum GM/B ratio needed for stability and the maximum total manning which are the same for all designs.

- **Combat system module** – receives as input values for AAW, ASUW, ASW, CCC, NSFS, GMLS, LAMPS and SDS combat systems, and data with the weight, power, and volume characteristics of these systems. The module also receives length of the waterline and the length to depth ratio. From these inputs the module calculates the depth at station 10 and constructs a payload vector for each combat system listed above. These vectors are combined to form an overall payload vector. The values from this overall vector are used to input each component's weight and vertical center of gravity (VCG). The module also outputs electric power and deckhouse and hull area required based on component payload.
- **Propulsion module** – receives as input the propulsion system alternative and generator system alternative including the corresponding propulsion and generator system characteristics including the number systems, brake horsepower, weight of the system, specific fuel consumptions, power required, the machinery weights, and the machinery box dimensions. The module also receives LWL, Beam, average deck height, Depth at station 10, and the volume of the deckhouse. It outputs the selected propulsion system characteristics, the number of hull decks, the endurance and sustained speed specific fuel consumptions, the required machinery box dimensions and weight, the hull and deckhouse area lost to the propulsion system, transmission efficiency for the propulsion system, the total weight of the system, and the area impact of the inlets and exhaust.
- **Hull form module** – receives the length of the ship (LWL), beam to length ratio (B/L), depth at station 10 to length ratio (D/L), draft to beam ratio (T/B), prismatic coefficient (C_p), Maximum section coefficient (C_x), and sonar type as input. The module uses a Taylor series method to calculate hull surface area and inputs sonar dome surface area and volume. The module calculates block coefficient (C_b), full load displaced volume with appendages, beam to draft ratio, volume coefficient (C_v), total hull surface area, the design waterplane coefficient (C_w), beam, draft, and hull flare which are all written to the output file.
- **Space available module** – receives as input ship characteristics such as load waterline, beam, draft, deckhouse volume, the required machinery box dimensions, and total hull volume. The module then determines the minimum depth at station 10 based on four factors including hull strength, heeled flooding prevention, machinery box accommodation, and the fact that this depth must be greater than or equal to the depth at station 20. This minimum depth is output with total hull volume, hull cubic number, total ship volume, height and volume of machinery box, and average depth. It calculates the available arrangeable space by subtracting the tankage and the machinery volumes from the hull volume.
- **Electric module** – receives as input various geometric ship characteristics, propulsion type, manning factor, electric margin factors, and payload weights and powers. The module calculates the total electric power required for the ship as the sum of individual electrical requirements with margins. The module also calculates and outputs manning requirements and auxiliary machinery room volume.
- **Resistance module** – receives as input overall ship characteristics, displacement volume, propulsion system characteristics, and total hull surface area and volume. The module uses the Holtrop-Mennon resistance calculation procedure to find the effective horsepower of the ship. This process includes calculations for viscous, wave-making, and bare hull resistance. These factors are then combined to find the total ship resistance and then to calculate horsepower. The module outputs the ship's effective shaft horsepower, sustained speed, and propeller diameter.
- **Weight module** – receives as input ship characteristics such as length, beam, and draft, propulsion system characteristics, payload weights, output from the combat systems module, and manning requirements. It uses a series of parametric equations to calculate the SWBS weights. The total weight of the ship must equal displacement. Fuel weight is used as a slack variable to balance the displacement and weight. Parametric equations are also used to calculate VCGs for each weight. The module outputs the deckhouse weight, weights corresponding to each SWBS group, the interior communications system weight, weights of the ship fuel, lube oil, and freshwater, the total ship weight, and the ship's KG.
- **Tankage module** – receives as input: ballast type, propulsion transmission efficiency, manning requirements, propulsion system characteristics, sustained and endurance speeds, required electric power, and specific fuel consumptions. The module then calculates annual fuel consumption assuming 2500 hours of endurance steaming per year, and fuel consumption for endurance range based on Navy DDS 200-1. The module calculates and outputs total tankage volume, fuel tankage volume, endurance range, brake propulsion power required at endurance speed, and gallons of fuel used per year.
- **Space required module** – receives as input: deckhouse volume, tankage volume, machinery room volume, required deckhouse area for payload, required hull area for payload, required area for engine inlets and exhausts, and manning requirements. The module calculates the total required and total available vol-

ume and arrangeable area. Required and available deckhouse area and total ship area are output by the module.

- **Feasibility module** – receives as input: available and required arrangeable areas, endurance range and required endurance range, sustained speed and required sustained speed, available and required generator power, GM/B ratio, minimum and maximum GM/B ratio, depth at Station 10 and minimum depth at Station 10, total manning, and maximum total manning. The module performs feasibility calculations using ratios of the difference of available and required properties to the required values. The resulting feasibility ratio value must be greater than or equal to zero within a 5% tolerance to be feasible. The module outputs feasibility ratios for total arrangeable area, deckhouse area, sustained speed, endurance speed, endurance range, electric power, hull depth, and maximum and minimum metacenter to beam ratio.
- **Cost module** – receives as input: propulsion system characteristics, endurance speed and range, fuel requirements, SWBS group weights, manning, base year profit margin, the number of ships to be built, inflation rates before and after the base year, and the shipbuilding rate per year after the lead ship. The module uses these values and modified weight-based parametrics with complexity factors to calculate lead and follow ship cost by SWBS group. Lead ship acquisition cost, follow ship acquisition cost, and follow ship ownership cost are returned as output. The cost module is discussed in section 3.4.3.
- **Effectiveness and Risk modules** are discussed in Sections 3.4.1 and 3.4.2.

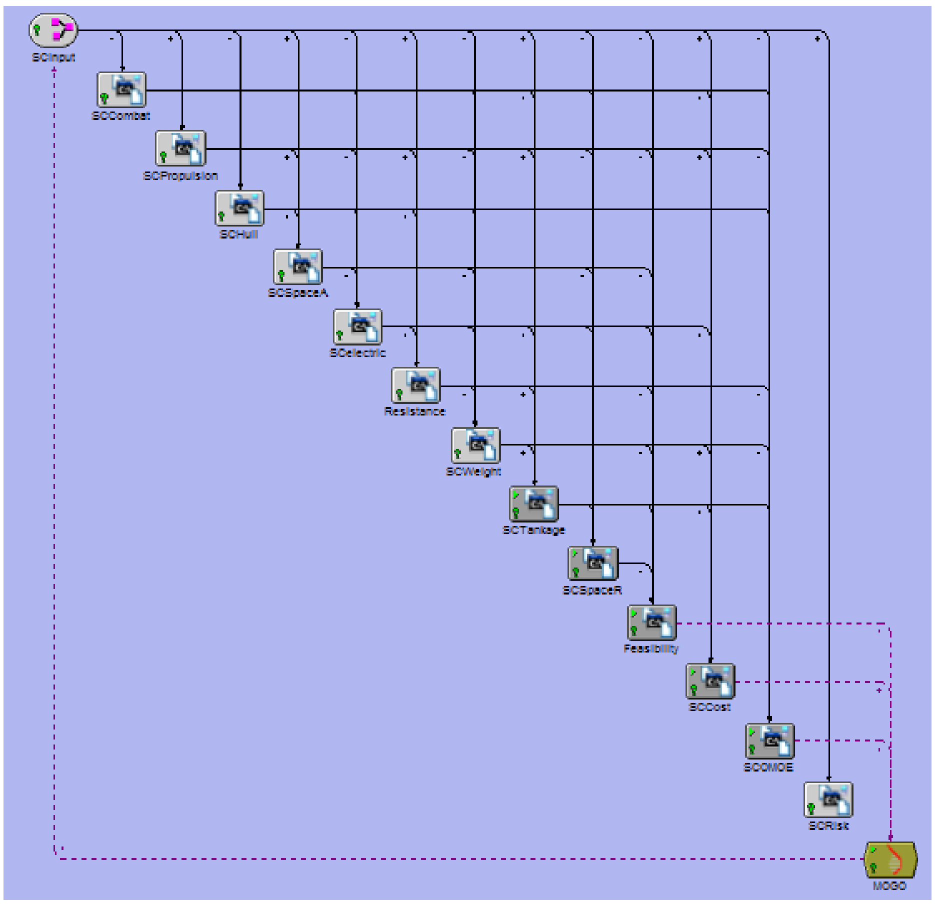

Figure 28 - Ship Synthesis Model in Model Center (MC)

3.4 Objective Attributes

3.4.1 Overall Measure of Effectiveness (OMOE)

The Overall Measure of Effectiveness (OMOE) is a single overall figure of merit ranging from 0-1.0 and is based on Measures of Performance (MOP), Values of Performance (VOP), and weighting factor (w_i). The equation for this OMOE is shown in (2).

$$OMOE = g[VOP_i(MOP_i)] = \sum_i w_i VOP_i(MOP_i) \quad (2)$$

To build the OMOE function, the first step is to identify the MOPs that are critical to the ship mission with goal values of 1.0 and threshold values of 0 (Table 22 and Table 23). These MOPs are then organized into an OMOE hierarchy (Figure 29) which assigns the MOPs into groups such as mission, mobility, susceptibility, vulnerability, etc. Each of these groups receives its own weight and is incorporated into the OMOE under specific Mission Types such as SAG or CBG. At this point Expert Choice is used to conduct pairwise comparison to calculate the weights for the MOPs based off of their relative importance to a specific mission type, where the sum of these weights equals 1 (Figure 30-Figure 43). A VOP with goal value of 1.0 and threshold value of 0 is assigned to a specific MOP to a specific mission area for a specific mission type. Refer to Figure 30 through Figure 43.

Table 22 - ROC/MOP/DV Summary

ROCs	Description	MOP	Related DV	Goal	Threshold
AAW 1	Provide anti-air defense	AAW	AAW, GMLS	AAW=1 GMLS=1	AAW=3 GMLS=4
AAW 1.1	Provide area anti-air defense	AAW	AAW GMLS	AAW=1 GMLS=1	AAW=3 GMLS=4
AAW 1.2	Support area anti-air defense	AAW	AAW GMLS	AAW=1 GMLS=1	AAW=3 GMLS=4
AAW 1.3	Provide unit anti-air self defense	AAW, RCS, IR	SDS, VD, PSYS	SDS=1 1500m3	SDS=2 2000m3
AAW 2	Provide anti-air defense in cooperation with other forces	AAW	CCC	CCC=1	CCC=2
AAW 3	Support Theater Ballistic Missile Defense (TBMD)	AAW	CCC	CCC=1	CCC=2
AAW 5	Provide passive and soft kill anti-air defense	AAW, IR, RCS	VD, PSYS	1500m3	2000m3
AAW 6	Detect, identify and track air targets	AAW, IR, RCS	VD PSYS	1500m3	2000m3
AAW 9	Engage airborne threats using surface-to-air armament	AAW, IR, RCS	VD PSYS	1500m3	2000m3
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 6.3	Conduct all-weather helo ops	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 6.4	Serve as a helo hangar	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 6.5	Serve as a helo haven	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 6.6	Conduct helo air refueling	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 12	Provide air control and coordination of air operations	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious operation	NSFS	NSFS	NSFS=1	NSFS=2
ASU 1	Engage surface threats with anti-surface armaments	ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 1.1	Engage surface ships at long range	ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 1.2	Engage surface ships at medium range	ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 1.3	Engage surface ships at close range (gun)	ASUW	NSFS	NSFS=1	NSFS=2

ROCs	Description	MOP	Related DV	Goal	Threshold
ASU 1.5	Engage surface ships with medium caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.6	Engage surface ships with minor caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.9	Engage surface ships with small arms gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 2	Engage surface ships in cooperation with other forces	ASUW, FSO	CCC	CCC=1	CCC=2
ASU 4	Detect and track a surface target	ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 4.1	Detect and track a surface target with radar	ASUW	ASUW LAMPS	ASUW=1 LAMPS=1	ASUW=2 LAMPS=3
ASU 6	Disengage, evade and avoid surface attack	ASUW	ASUW	ASUW=1	ASUW=2
ASW 1	Engage submarines	ASW	ASW	ASW=1	ASW=2
ASW 1.1	Engage submarines at long range	ASW	ASW	ASW=1	ASW=2
ASW 1.2	Engage submarines at medium range	ASW	ASW	ASW=1	ASW=2
ASW 1.3	Engage submarines at close range	ASW	ASW, PSYS	ASW=1 PSYS=5-16	ASW=2
ASW 4	Conduct airborne ASW/recon	ASW	LAMPS	LAMPS=1	LAMPS=3
ASW 5	Support airborne ASW/recon	ASW	LAMPS CCC	LAMPS=1, CCC=1	LAMPS=3 CCC=2
ASW 7	Attack submarines with antisubmarine armament	ASW	ASW LAMPS CCC	ASW=1 LAMPS=1 CCC=1	ASW=2 LAMPS=3 CCC=2
ASW 7.6	Engage submarines with torpedoes	ASW	ASW LAMPS CCC	ASW=1 LAMPS=1 CCC=1	ASW=2 LAMPS=3 CCC=2
ASW 8	Disengage, evade, avoid and deceive submarines	ASW	ASW	ASW=1	ASW=2
CCC 1	Provide command and control facilities	CCC	CCC	CCC=1	CCC=2
CCC 1.6	Provide a Helicopter Direction Center (HDC)	CCC, ASW, ASUW	CCC	CCC=1	CCC=2
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions	CCC, FSO	CCC	CCC=1	CCC=2
CCC 3	Provide own unit Command and Control	CCC	CCC	CCC=1	CCC=2
CCC 4	Maintain data link capability	ASW, ASUW, AAW	CCC	CCC=1	CCC=2
CCC 6	Provide communications for own unit	CCC	CCC	CCC=1	CCC=2
CCC 9	Relay communications	CCC	CCC	CCC=1	CCC=2
CCC 21	Perform cooperative engagement	CCC, FSO	CCC	CCC=1	CCC=2
FSO 5	Conduct towing/search/salvage rescue operations	FSO	LAMPS	LAMPS=1	LAMPS=3
FSO 6	Conduct SAR operations	FSO	LAMPS	LAMPS=1	LAMPS=3
FSO 8	Conduct port control functions	FSO	CCC, ASUW, LAMPS	CCC=1 ASUW=1 LAMPS=1	CCC=2 ASUW=2 LAMPS=3
FSO 9	Provide routine health care	All designs			
FSO 10	Provide first aid assistance	All designs			
FSO 11	Provide triage of casualties/patients	All designs			
INT 1	Support/conduct intelligence collection	INT	CCC	CCC=1	CCC=2
INT 2	Provide intelligence	INT	CCC	CCC=1	CCC=2
INT 3	Conduct surveillance and reconnaissance	INT	LAMPS	LAMPS=1	LAMPS=3
INT 8	Process surveillance and reconnaissance information	INT, CCC	CCC	CCC=1	CCC=2
INT 9	Disseminate surveillance and reconnaissance information	INT, CCC	CCC	CCC=1	CCC=2
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)	INT, CCC	CCC	CCC=1	CCC=2
MIW 4	Conduct mine avoidance	MIW	Degaus	Yes	Yes
MIW 6	Conduct magnetic silencing (degaussing, deperming)	Magnetic Signature	Degaus	Yes	Yes

ROCs	Description	MOP	Related DV	Goal	Threshold
MIW 6.7	Maintain magnetic signature limits	Magnetic Signature	Degaus	Yes	Yes
MOB 1	Steam to design capacity in most fuel efficient manner	Sustained Speed, Endurance Range	Hullform PSYS	Vs = 35 knts E=4000	Vs = 29 knt E = 5000 nm
MOB 2	Support/provide aircraft for all-weather operations	ASW, ASUW, FSO (NCO)	LAMPS	LAMPS=1	LAMPS=3
MOB 3	Prevent and control damage	VUL	Cdhmat	Cdmat =1 Composite	Cdmat = 3 steel
MOB 3.2	Counter and control NBC contaminants and agents	NBC	CPS	CPS=2 (full)	CPS=0 (none)
MOB 5	Maneuver in formation	All designs			
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	All designs			
MOB 10	Replenish at sea	All designs			
MOB 12	Maintain health and well being of crew	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	provisions	Ts	60 days	45 days
MOB 16	Operate in day and night environments	All designs			
MOB 17	Operate in heavy weather	Seakeeping index	hullform	MCR=15	MCR=4
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations	Compensated Fuel System/ Clean Ballast	BalType	BalType=0	BalType=1
NCO 3	Provide upkeep and maintenance of own unit	All designs			
NCO 19	Conduct maritime law enforcement operations	NCO	ASUW NSFS	ASUW =1 NSFS=1	ASUW = 2 NSFS = 2
SEW 2	Conduct sensor and ECM operations	AAW	CCC	CCC=1	CCC=2
SEW 3	Conduct sensor and ECCM operations	AAW	CCC	CCC=1	CCC=2
SEW 5	Conduct coordinated SEW operations with other units	AAW	CCC	CCC=1	CCC=2
STW 3	Support/conduct multiple cruise missile strikes	STK	GMLS CCC	GMLS=1 CCC=1	GMLS=4 CCC=2

Table 23 - MOP Table

MOP #	MOP	Metric	Goal	Threshold
1	AAW	AAW Option GMLS Option SDS Option CCC Option	AAW =1 GMLS=1 SSD=1 CCC =1	AAW =3 GMLS=4 SSD=3 CCC =2
2	ASW	ASW Option LAMPS Option CCC Option	ASW =1 LAMPS=1 CCC =1	ASW =2 LAMPS=3 CCC =2
3	ASUW/NSFS	ASUW Option LAMPS Option NSFS Option CCC Option SDS Option	ASUW=1 LAMPS=1 NSFS=1 CCC =1 SDS=1	ASUW=2 LAMPS=3 NSFS=2 CCC=2 SDS=3
4	C4I	CCC Option	CCC=1	CCC=2
5	STK	GMLS Option C4I Option	GMLS=1 CCC=1	GMLS=4 CCC=2
6	BMD	AAW Option GMLS Option CCC Option	AAW=2 GMLS=1 CCC=1	AAW=3 GMLS=4 CCC=2
7	Sustained Speed	Knts	Vs=35knt	Vs=29knt
8	Endurance Range	Nm	E=6000nm	E=4000nm
9	Provisions Duration	Days	Ts=60days	Ts=45days
10	Seakeeping	McCreight Index HULLtype	McC=16 flare	McC=6 tumblehome
11	Environmental	Ballast Option	clean	Compensated fuel
12	Vulnerability	Cdhmat PSYS	Steel No pods	Composite pods
13	NBC	CPS Option	full	part
14	RCS	ft3 HULLtype SDS	VD=100000ft3 Tumblehome none	VD=150000ft3 Flare 2xCIWS
15	Acoustic Signature	PSYStype	PSYStype=5	PSYStype=2,13
16	IR Signature	PENGtype	PENGtype=1	PENGtype=1
17	Magnetic Signature	Ndegaus PSYS	Degaussing No pods	None pods

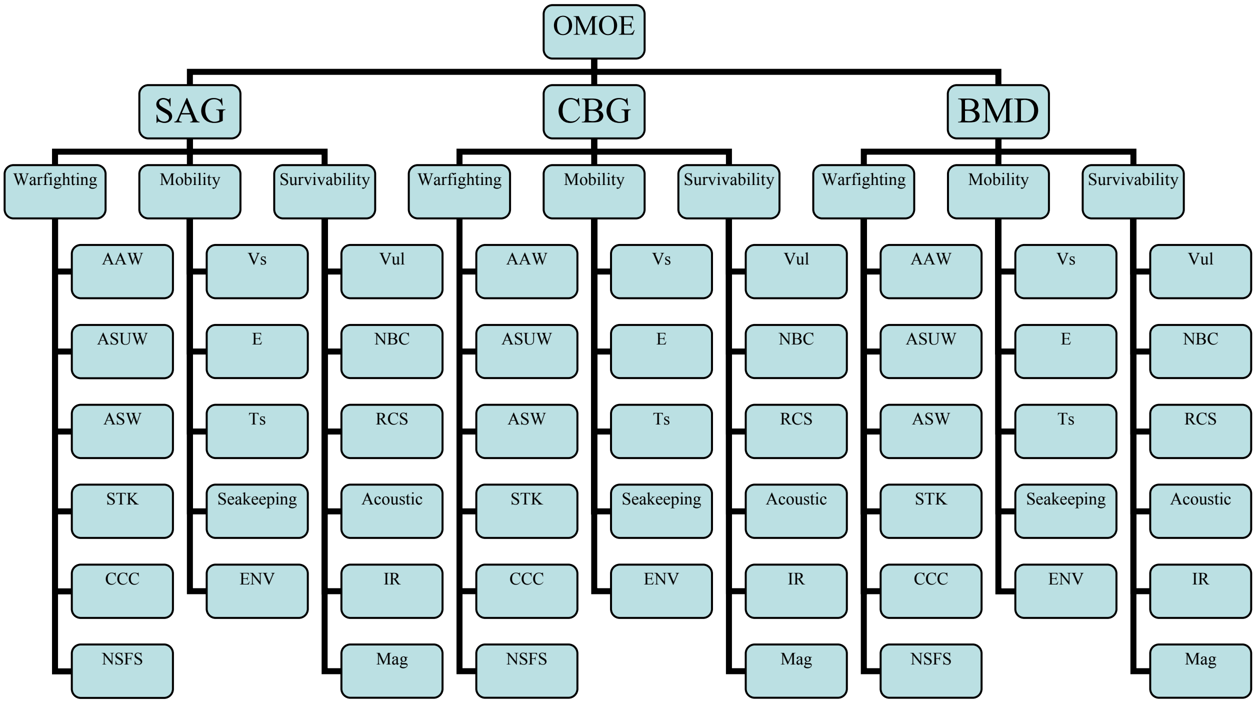

Figure 29 - OMOE Hierarchy

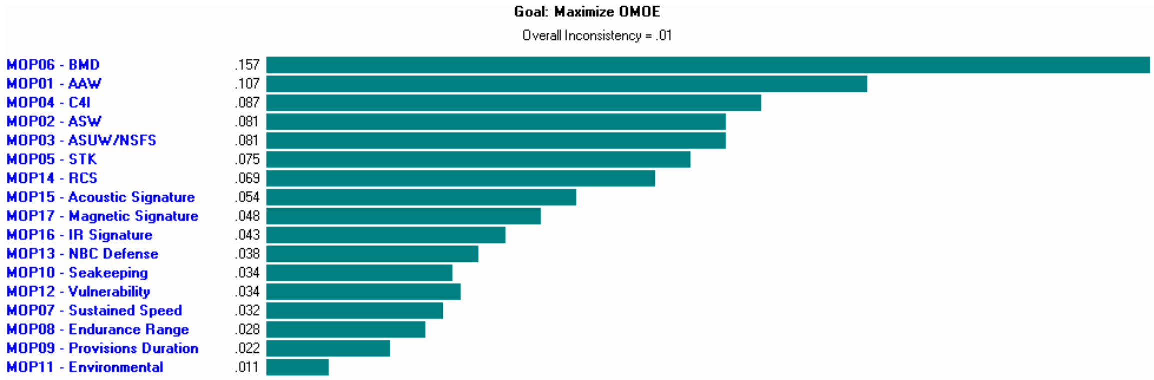

Figure 30 – Bar Chart Showing MOP Weights

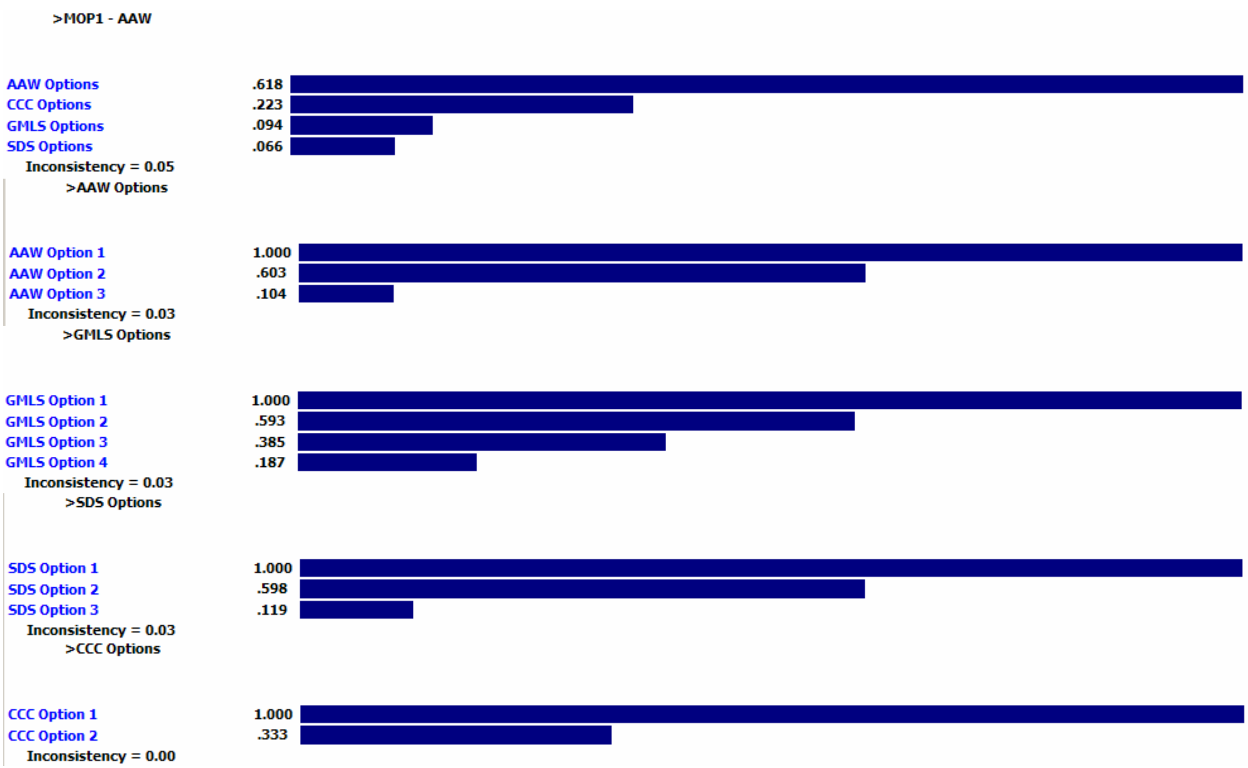

Figure 31 - MOP1 AAW

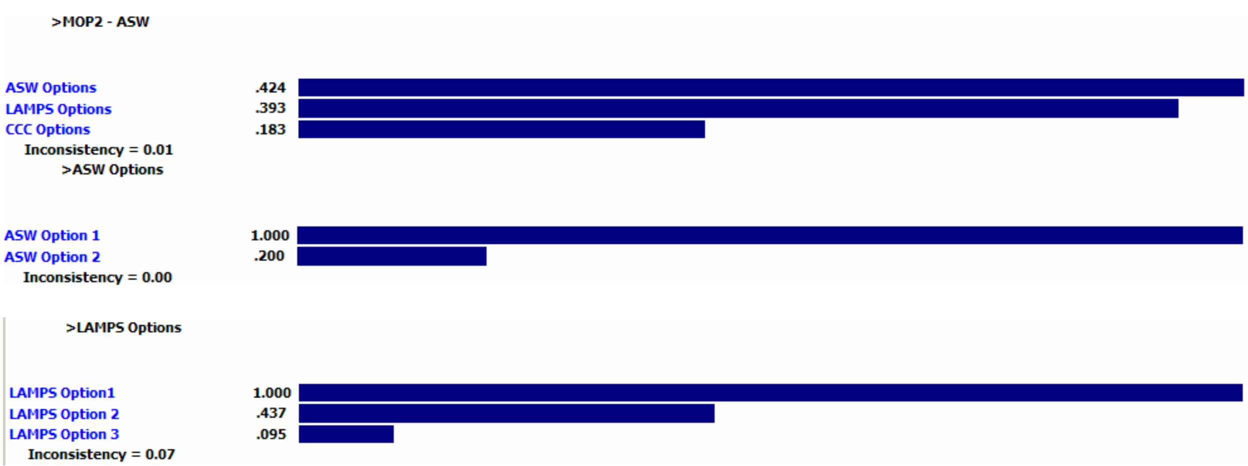

Figure 32 - MOP2 ASW

Figure 33 – MOP5 STK

Figure 34 – MOP6 BMD

Figure 35 - MOP7 Sustained Speed

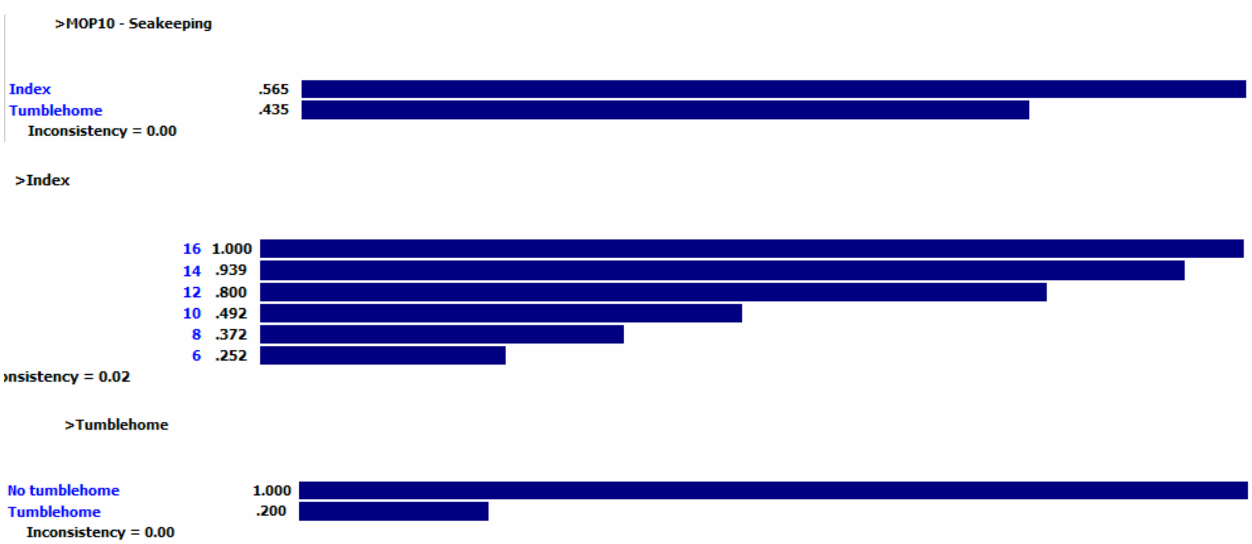

Figure 36 – MOP 10 Seakeeping (McCreight Index)

Figure 37 - MOP 11 Environmental

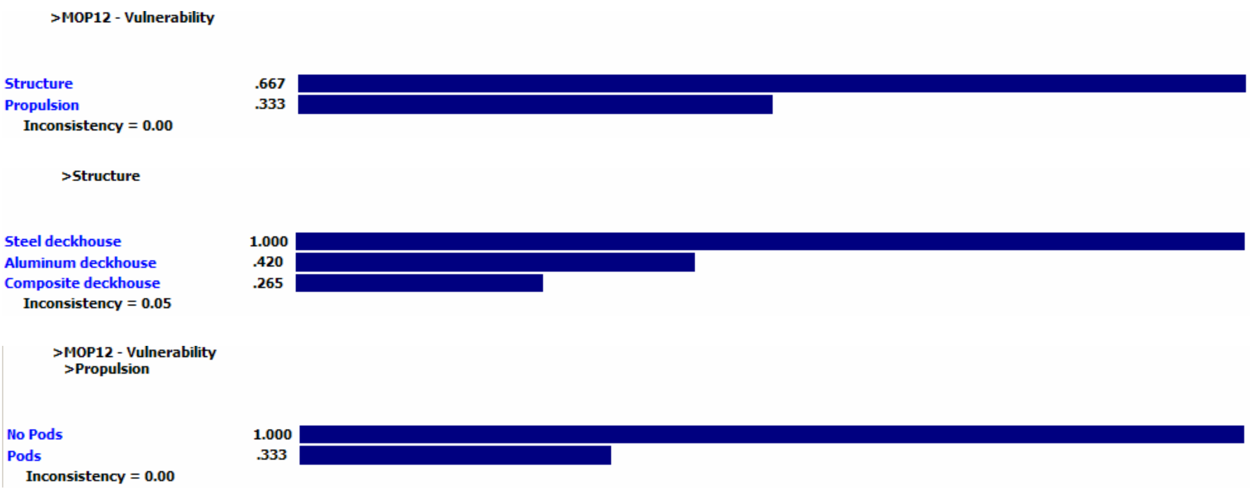

Figure 38 - MOP12 Vulnerability

Figure 39 - MOP13 NBC Defense

Figure 40 - MOP14 RCS

Figure 41 - MOP15 Acoustic Signature

Figure 42 - MOP 16 IR Signature

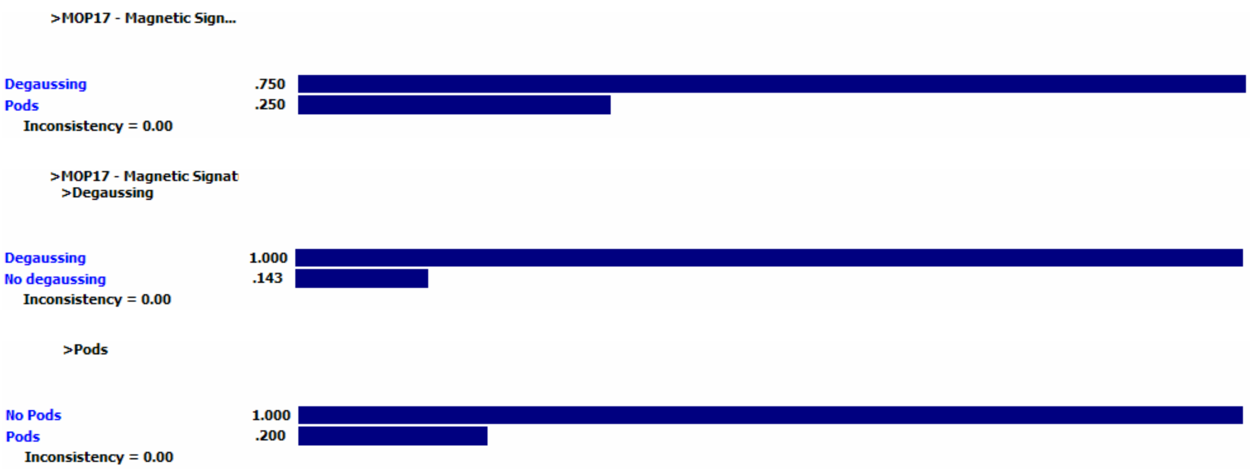

Figure 43 - MOP17 Magnetic Signature

3.4.2 Overall Measure of Risk (OMOR)

In the process to design a new naval vessel there are often new and untested technologies that are sometimes necessary to be embraced so that specific performance or cost criteria can be attained. These new technologies often come with inherent risk of failure.

OMOR is a numerical representation of the total risk associated with a ship. It is based on three risk events including performance, cost, and schedule. The risk for each event for a selected technology is a product of probability of occurrence (P_i) and consequence of the occurrence (C_i) ((3).

$$R_i = P_iC_i \qquad (3)$$

Table 24 and Table 25 illustrate estimates of the probability of the risk event, P_i, and the estimates for corresponding consequence respectively. Table 26 shows the Risk Register, in which the risk event for performance, cost, and schedule for each DV are combined. Equation 4 is then used to calculate the OMOR hierarchy, where W_{perf}, W_{cost}, and W_{sched} are the weights for each type of risk and w_i, w_j, and w_k are the risk for each event.

$$OMOR = W_{perf}\sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{\cos t}\sum_j w_j P_j C_j + W_{sched}\sum_k w_k P_k C_k \qquad (4)$$

Table 24 - 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 25 - Event Consequence Estimate

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

Table 26 - Risk Register

SWBS	Risk Type	Related DV #	DV Options	DV Description	Risk Event Ei	Risk Description	Event #	Pi	Ci	Ri
1	Performance	DV9	3	Deckhouse Material	Composite material producibilitty problems	USN lack of experience with material	1	0.5	0.6	0.3
1	Performance	DV9	3	Deckhouse Material	Composite material RCS, and fire performance does not meet performance predictions	In development and test	2	0.4	0.5	0.2
1	Cost	DV9	3	Deckhouse Material	Composite material cost overuns impact program	In development and test	3	0.5	0.3	0.15
1	Schedule	DV9	3	Deckhouse Material	Composite material schedule delays impact program	In development and test	4	0.5	0.2	0.1
1	Performance	DV10	2	Hull Type	Tumblehome Seakeeping Performance	Seakeeping not satisfactory	5	0.7	0.8	0.56
2	Performance	DV12	5-16	Propulsion Systems	IPS Development and Implementation	Reduced reliability and performance (un-proven)	6	0.3	0.6	0.18
2	Cost	DV12	5-16	Propulsion Systems	IPS Development, acquisition and integration cost overruns	Reasearch and Development cost overruns	7	0.4	0.4	0.16
2	Schedule	DV12	5-16	Propulsion Systems	IPS Schedule delays impact program	In development and test	8	0.3	0.4	0.12
2	Performance	DV12	3,4,8,9,10, 14,15,16	Propulsion Systems	ICR Development and Implementation	Unproven, recuperator problems	9	0.6	0.5	0.3
2	Cost	DV12	3,4,8,9,10, 14,15,16	Propulsion Systems	ICR Development, acquisition and integration cost overruns	Unproven, recuperator problems	10	0.6	0.4	0.24
2	Schedule	DV12	3,4,8,9,10, 14,15,16	Propulsion Systems	ICR Schedule delays impact program	Unproven, recuperator problems	11	0.6	0.5	0.3
2	Performance	DV12	11-16	Propulsion Systems	Development and Implementation of podded propulsion	Reduced Reliability (un-proven)	12	0.7	0.4	0.28
2	Performance	DV12	11-16	Propulsion Systems	Development and Implementation of podded propulsion	Shock and vibration of full scale system unproven	13	0.7	0.6	0.42
2	Cost	DV12	11-16	Propulsion Systems	Podded Propulsion Implimentation Problems	Unproven for USN, large size	14	0.6	0.45	0.27
2	Schedule	DV12	11-16	Propulsion Systems	Podded Propulsion Schedule delays impact program	Unproven for USN, large size	15	0.6	0.6	0.36
4	Performance	DV17	0.5	Automation	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	16	0.6	0.7	0.42
4	Cost	DV17	0.5	Automation	Automation systems development, acquisition and integration cost overruns	Reasearch and Development cost overruns	17	0.5	0.5	0.25
4	Schedule	DV17	0.5	Automation	Automation systems schedule delays impact program	Reasearch and Development schedule delays	18	0.5	0.7	0.35
4	Performance	DV18	1,2	AAW Systems	SPY-3 and VSR Development and implementation	Reduced Reliability and Performance (un-proven)	19	0.3	0.8	0.24
4	Cost	DV18	1,2	AAW Systems	SPY-3 and VSR Development, acquisition and integration cost overruns	Reasearch and Development cost overruns	20	0.4	0.5	0.2
4	Schedule	DV18	1,2	AAW Systems	SPY-3 and VSR Schedule delays impact program	Reasearch and Development schedule delays	21	0.4	0.7	0.28

3.4.3 Cost

Two types of cost are calculated for CG(X): lead ship and follow ship acquisition cost. Figure 44, below, illustrates the total breakdown of how the cost components are broken down. The lead ship acquisition cost is estimated using weighted averages of all the SWBS areas, and the total of these averages are accounted for in the Basic Cost of Construction (BCC) shown in Figure 44. The follow ship acquisition cost accounts for shipbuilder profit and any change orders that develop along the process of shipbuilding. Included in the model but held separate in Figure 44 are the government costs, which include a sum of the Government Furnished Material (GFM) and Program Managers Growth. In the end the total end cost of the ship is the sum of the Government Cost and the Shipbuilder Cost. The final CG(X) life cycle cost includes the Total End Cost and additional operating and support costs due to manning and fuel.

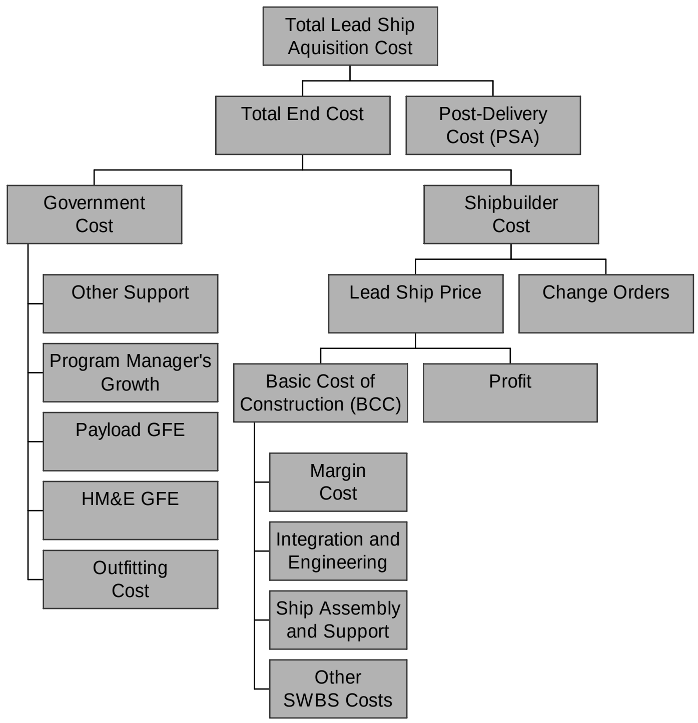

Figure 44 - Naval Ship Acquisition Cost Components

3.5 Multi-Objective Optimization

The Multi-Objective Genetic Optimization (MOGO) is performed in Model Center using the Darwin optimization plug-in. The objective attributes include effectiveness, risk, and cost. These are discussed in Section 3.4. Figure 45 is a flow chart of the MOGO process.

In the first design generation, the optimizer defines a random set of 200 balanced ships using the ship synthesis model (3.3) to calculate cost and measures of effectiveness and risk. This population is ranked according to dominance of each design in the objective attributes. This ranking is called the ship's fitness level. Penalties are applied to designs that occur at bunching (or "niching") points in the design space, and for infeasibility.

The second generation consists of designs randomly selected from the first generation. These are then weighted to apply higher selection probabilities to ships with higher fitness levels. Twenty-five percent of these are selected for crossover—or swapping—of some of their design variable values. In addition, 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 form a frontier. After 300 generations of evolution, the non-dominated frontier (or surface) of designs is defined as shown in Figure 47. 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.

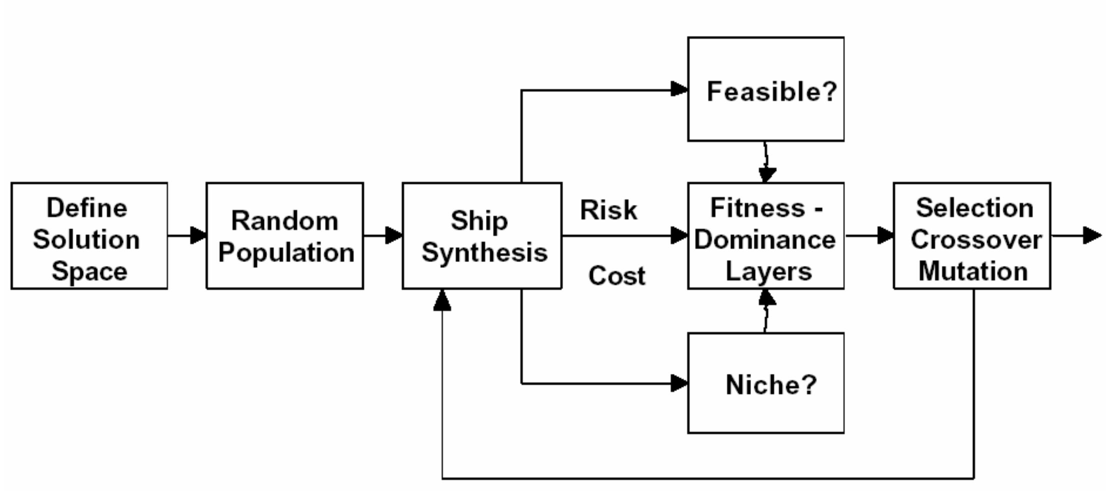

Figure 45 - Multi-Objective Genetic Optimization (MOGO)

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 46 and described in Sections 3.4.1 and 3.4.2.

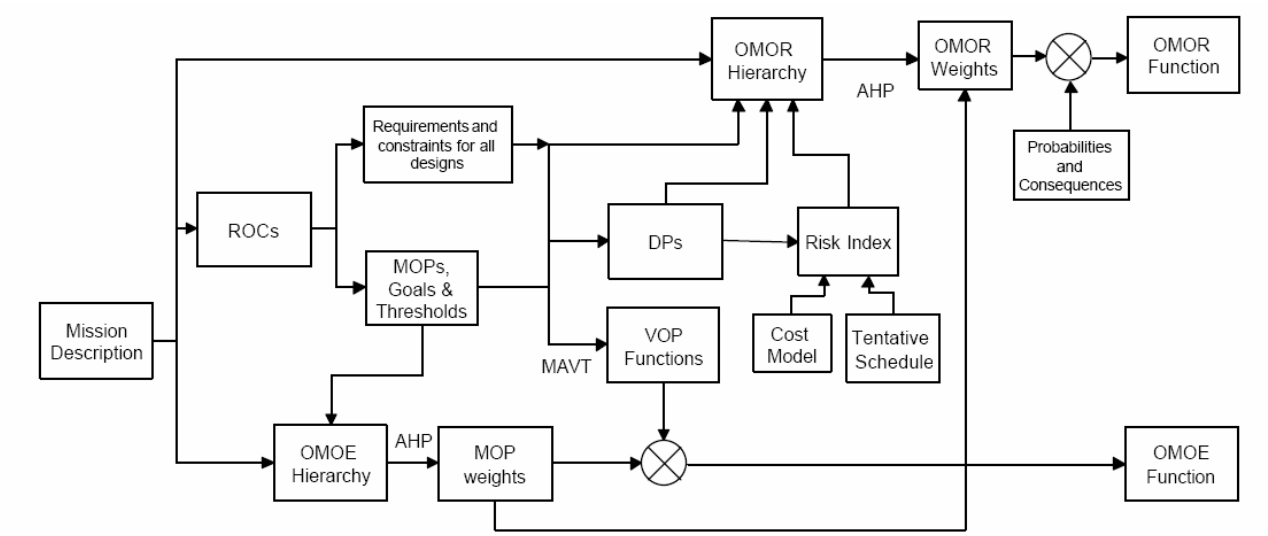

Figure 46 - OMOE and OMOR Development Process

3.6 Optimization Results

Figure 47 shows the final effectiveness-cost-risk non-dominated frontier generated by the multi-objective genetic optimization (MOGO). Each point on the frontier represents objective attribute values for feasible non-dominated ship designs. All of the feasible designs are represented in Figure 47 with cost (along the x-axis), OMOE (along the y-axis), and risk, indicated by color, as low (OMOR < 0.2), medium (0.2 < OMOR < 0.4), or high (OMOR > 0.4). Interesting design possibilities for the customer are often located at the "knees" in the curve. These are points on the frontier where there is a sharp increase in the effectiveness with only slight increase in cost, and a lower risk ship can achieve similar effectiveness as a higher risk ship. The measures of performance that influenced the effectiveness the most are ballistic missile defense (MOP 6, Figure 30) and anti-air warfare (MOP1, Figure 30) as they have the highest values of performance.

Three desirable designs are numbers 1-39, 4-76, and 2-102 since they are located at "knees" in the curve for high risk, medium risk, and low risk respectively. Higher risk designs typically are not attractive to the customer, but provide educational gains as newer systems and technologies are considered. Design 4-76 shown in Figure 47 was assigned to Team 1. This is our baseline concept design.

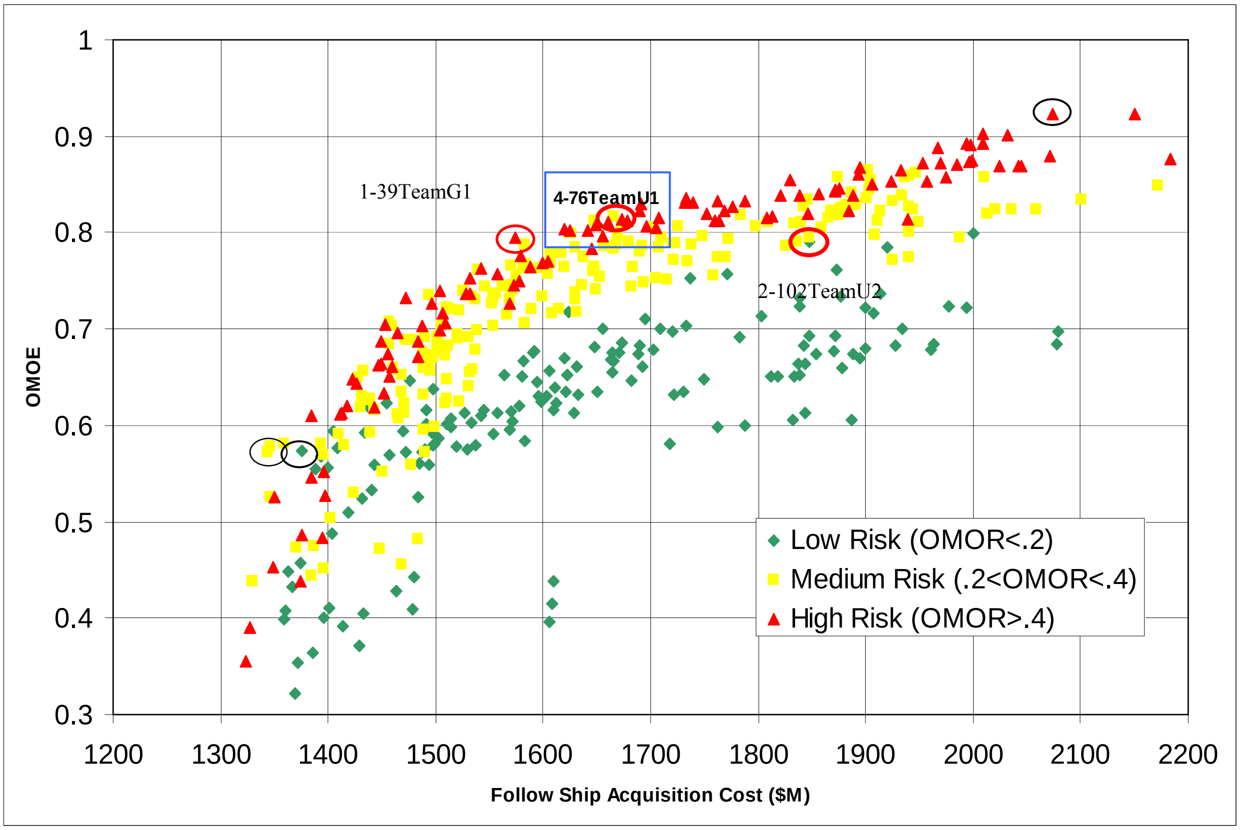

Figure 47 - Non-Dominated Frontier based on Follow Ship Acquisition Cost

3.7 Baseline Concept Design

Design 4-76 has a high measure of effectiveness compared to ships around the same price range, with only medium risk. The effectiveness of this particular ship is relatively high due to a 60 day provision period (max), enhanced CCC (goal), option 1 of AAW (goal), option 1 of ASW (goal), option 1 of ASUW (goal), and a single LAMPS with hangar. The mid range cost is due to a advanced IPS system and proven LM2500+ propulsion system with 128 cell VLS setup (threshold). With the IPS and tumblehome hull, this design is similar to the DD(X), further reducing construction costs. Risk is reduced by incorporating a full degaussing MCM, full collective protection system, a high level of automation to reduce crew size (to 232 personnel), a steel deckhouse, and enhanced CCC. Table 27 lists the design variables and options/range, along with the design space values of CG(X). Table 28 lists the weights and vertical center of gravity (VCG) values for the SWBS groups along with full and lightship values. Table 29 lists the concept exploration area summary including hull, deckhouse, and total arrangeable area. Table 30 lists the concept exploration electrical load values. Table 31 lists the MOPs along with each VOP used to determine the OMOE. Table 32 gives an overview of the baseline values attained for CG(X) design 4-76.

Table 27 - Design Variables Summary

DV #	Description	Design Options/Range	CG(X) Design Space Values
1	Waterline Length	150-200m.	172.5 m
2	Length to Beam Ratio	7.9-9.9	7.93
3	Length to Depth Ratio	10.75-17.8	10.9
4	Beam to Draft Ratio	2.9-3.2	2.92
5	Prismatic Coefficient	0.56 – 0.64	0.560
6	Maximum Section Coefficient	0.75 – 0.84	0.792
7	Raised Deck Coefficient	0.7 – 1.0	0.6
8	Deckhouse Volume	2,500-5,500 cubic meters	4,000 cubic meters
9	Deckhouse Material	1 = Steel, 2 = Aluminum, 3 = Advanced Composite	Steel
10	Hull: Flare or Tumblehome	1: flare= 10 deg; 2: flare = -10 deg (tumblehome)	Flare = -10
11	Ballast/Fuel System Type	0 = clean ballast, 1 = compensated fuel tanks	Clean Ballast
12	Propulsion System Slternative	Option 1) 2 shaft, mechanical, CPP, 4xLM2500+ Option 2) 2 shaft, mechanical, CPP, 4xMT30 Option 3) 2 shaft, mechanical, CPP, 2xLM2500+, 2x ICR WR29 Option 4) 2 shaft, mechanical, CPP, 2xMT30, 2x ICR WR29 Option 5) 2 shaft. IPS, FPP, 3xLM2500+ Option 6) 2 shaft. IPS, FPP, 3xMT30 Option 7) 2 shaft. IPS, FPP, 4xMT30 Option 8) 2 shaft. IPS, FPP, 2xLM2500+, 2x ICR WR29 Option 9) 2 shaft. IPS, FPP - 2xMT30, 2x ICR WR29 Option 10) 2 shaft. IPS, FPP, 3xMT30, 3x ICR WR29 Option 11) 2 pods, IPS, 3xLM2500+ Option 12) 2 pods, IPS, 3xMT30 Option 13) 2 pods. IPS, 4xMT30 Option 14) 2 pods, IPS, 2xLM2500+, 2x ICR WR29 Option 15) 2 pods, IPS, 2xMT30, 2x ICR WR29 Option 16) 2 pods, IPS, 3xMT30, 2x ICR WR29	Option 5) 2 shaft IPS FPP 3xLM2500+
13	Ship Service Generator System Alternatives	Option 1) 5 x Allison 501K34 (@3,500 kW) Option 2) 4 x Allison 501K34 (@3,500 KW) Option 3) 2 x Allison 501K34 (@3,500 KW) For PSYS=5-16: GSYS = option 3	Option 3) 2 x Allison 501K34 (@3,500 kW)
14	Provisions Duration	45-60 days	60 days
15	Collective Protection System	0 = none, 1 = partial, 2 = full	Full
16	Degaussing system	0 = none, 1 = degaussing system	Degaussing System
17	Manning Reduction and Automation Factor	0.5 - 0.1	0.5
18	Anti-Air Warfare Alterna-tives	Option 1) SPY-3 (4 panel), VSR, AEGIS MK 99 FCS Option 2) SPY-3 (2 panel), VSR, AEGIS MK 99 FCS Option 3) SPY-1B (4 panel), SPS-49, 2xSPG-62, AEGIS MK 99 FCS	1 (Goal)
19	Anti-Surface Warfare Alternatives	Option 1) SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker Option 2) SPS-73(V)12, SPQ-9, MK 86 GFCS, Small Arms Locker	1 (Goal)
20	Anti-Submarine Warfare Alternatives	Option 1) SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS Option 2) SQS-56, MK 116 UWFCS, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS	1 (Goal)
21	Naval Surface Fire Support Alternatives	Option 1) MK 45 5" – 64 mod 4 gun Option 2) 2 MK 110 57 mm gun	2
22	Command Control Comm Alternatives	Option 1) Enhanced CCC Option 2) Basic CCC (CG 47)	1 (Goal)

DV #	Description	Design Options/Range	CG(X) Design Space Values
23	LAMPS Helo Alternatives	Option 1) Embarked 2 LAMPS w/Hangars Option 2) Embarked single LAMPS w/Hangar Option 3) LAMPS haven (flight deck)	2
24	Self Defense System Alternatives	Option 1) 2xCIWS Option 2) 1xCIWS Option 3) none	2
25	Guided Missile Launching System Alternatives	Option 1) 224 cells, MK 41 and/or MK57 PVLS Option 2) 192 cells, MK 41 and/or MK57 PVLS Option 3) 160 cells, MK 41 and/or MK57 PVLS Option 4) 128 cells, MK 41 and/or MK57 PVLS	4 (Threshold)

Table 28 - Concept Exploration Weights (MT) and Vertical Center of Gravity (m) Summary

Group	Weight	VCG
SWBS 100	5409	8.61
SWBS 200	976	5.73
SWBS 300	332	8.67
SWBS 400	691	15.40
SWBS 500	1466	11.75
SWBS 600	750	9.43
SWBS 700	332	12.16
Loads	2219	4.60
Lightship	9952	9.45
Lightship w/Margin	10948	8.59
Full Load w/Margin	13168	7.92

Table 29 - Concept Exploration Area (m^2) Summary

Area	Required	Available
Total-Arrangeable	7750	7778
Hull	6541	6528
Deck House	1209	1250

Table 30 - Concept Exploration Electric Power (kW) Summary

Group	Description	Power
SWBS 200	Propulsion	339
SWBS 300	Electric Plant, Lighting	273
SWBS 430, 475	Miscellaneous	101
SWBS 521	Firemain	125
SWBS 540	Fuel Handling	202
SWBS 530, 550	Miscellaneous Auxiliary	151
SWBS 561	Steering	115
SWBS 600	Services	92
CPS	CPS	173
KW_{NP}	Non-Payload Functional Load	1453
KW_{MFLM}	Max. Functional Load w/Margins	10452
KW_{24}	24 Hour Electrical Load	4967

Table 31 - Measures of Performance

Measure	Description	Value of Performance	MOP Weights	Measures of Effectiveness
MOP 1	AAW	0.895	0.107	0.096
MOP 2	ASW	0.779	0.081	0.063
MOP 3	ASUW/NSFS	0.61	0.081	0.049
MOP 4	CCC	1	0.087	0.087
MOP 5	STK	0.512	0.075	0.038
MOP 6	BMD	0.867	0.157	0.136
MOP 7	Sustained Speed	0.319	0.032	0.01
MOP 8	Endurance Range	0.935	0.028	0.026
MOP 9	Provisions	1	0.022	0.022
MOP 10	Seakeeping	0.652	0.034	0.022
MOP 11	Environmental	1	0.011	0.011
MOP 12	Vulnerability	1	0.034	0.034
MOP 13	NBC	1	0.038	0.038
MOP 14	RCS	0.819	0.069	0.057
MOP 15	Acoustic Signature	1	0.054	0.054
MOP 16	IR Signature	0.526	0.043	0.023
MOP 17	Magnetic Signature	1	0.048	0.048
OMOE	Overall Measure of Effectiveness			0.816

Table 32 - Concept Exploration Baseline Design Principal Characteristics

Characteristic	Baseline Value
Hull form	flare = -10 deg Wave Piercing (Tumble home)
Δ (MT)	13167.54
LWL (m)	172.5
Beam (m)	21.75
Draft (m)	7.5
D10 (m)	15.75
Beam to Draft Ratio, C_{BT}	2.9
W1 (MT)	5409
W2 (MT)	976
W3 (MT)	332
W4 (MT)	691
W5 (MT)	1466
W6 (MT)	750
W7 (MT)	332
Lightship Δ (MT)	10948
KG (m)	8.69
GM/B=	9.287×10^{-2}
Propulsion system	2 shaft. IPS, FPP 3xLM2500+ 2 x Allison 501K34
Engine inlet and exhaust	Vertical
AAW system	SPY-3 (4 panel), VSR, AEGIS MK 99 FCS
ASUW system	SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker
ASW system	SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
NSFS	2 MK 110 57 mm gun
CCC/STK/SEW	Enhanced CCC
GMLS	128 cells, MK 41 and/or MK57 PVLS
LAMPS	Embarked single LAMPS w/Hangar
SDS	1xCIWS
Total Officers	33
Total Enlisted	199
Total Manning	232
Follow Ship Acquisition Cost	1.642 Billion

4 Concept Development (Feasibility Study)

Once the objectives and requirements are identified in Concept Exploration the Concept Development immediately follows. The design spiral for Concept Development, Figure 5, iterates through the hull, subdivisions, arrangements, power and propulsion, structures, weights, seakeeping, and cost. CG(X) must meet the objectives and requirements obtained in Concept Development, listed in the ORD and baseline design principle characteristics. Concept Development delves further into the values obtained in Concept Exploration by refining the numbers obtained, matching volume requirements, satisfying the missions, and conforming to standards set by the current Navy.

4.1 Hullform

4.1.1 Hullform

The objectives for the hullform were to:

- Model concept baseline characteristics
- Minimize drag of CG(X)
- Match deck, mission, and propulsion volume requirements
- Meet or exceed current Naval Requirements (LRC)
- Minimize Drag
- Determine Floodable Length Curve

The hullform is based on a conventional DD parent hullform from the Advanced Surface Ship Evaluation Tool (ASSET). ASSET creates a hullform to baseline characteristics: length (L), beam (B), draft (T), depth (D), prismatic coefficient (Cp), and cross-sectional coefficient (Cx) listed in Table 33. The ASSET model needed to be modified in Rhino modeling center to include a wave piercing bow with tumblehome, transom, and main deck.

The wave piercing tumblehome hullform (WPTH) design currently is being incorporated into the latest iteration of the Navy's newest destroyer DD(X). Commonality with DD(X) will aid in reduced labor and production costs and building risks along with reduced radar cross section (RCS). All structures above the waterline are set at a 10 degree angle and all systems that were conventionally placed on the main deck are now placed within these angled structures to effectively reduce the radar signature. The wave piercing bow aids in stability, specifically when using tubmblehome, and reduces wave resistance. Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52 are the waterline, profile, bow, stern, and isometric views of CG(X) Air Superiority Cruiser. Figure 53 and Figure 54 are the sectional area curves, and lines drawing for CG(X).

Table 33 Baseline Characteristics

Characteristic	Baseline Value
Hull form	flare = -10 deg (Tumble home) Wave Piercing
Δ (MT)	13167.54
LWL (m)	172.5
Beam (m)	21.75
Draft (m)	7.5
D10 (m)	15.75
Beam to Draft Ratio, CBT	2.9
Cp	0.56
Cx	0.79
Crd	0.6
Deckhouse Volume, m^3	4000
Lightship D (MT)	10948
KG (m)	8.69
GM/B=	9.287 x 10-2

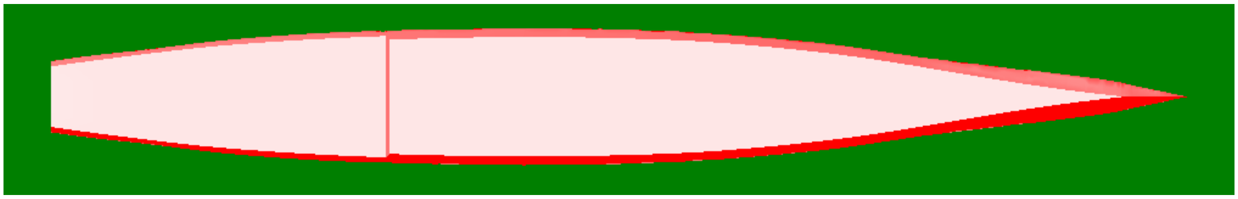

Figure 48 - Waterline View

Figure 49 - Profile View

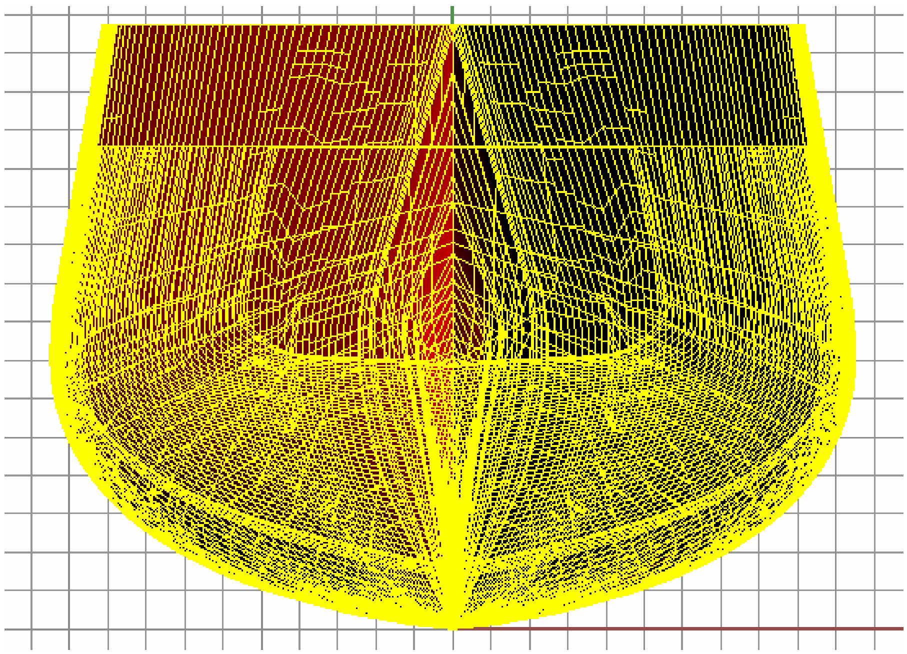

Figure 50 - Bow View

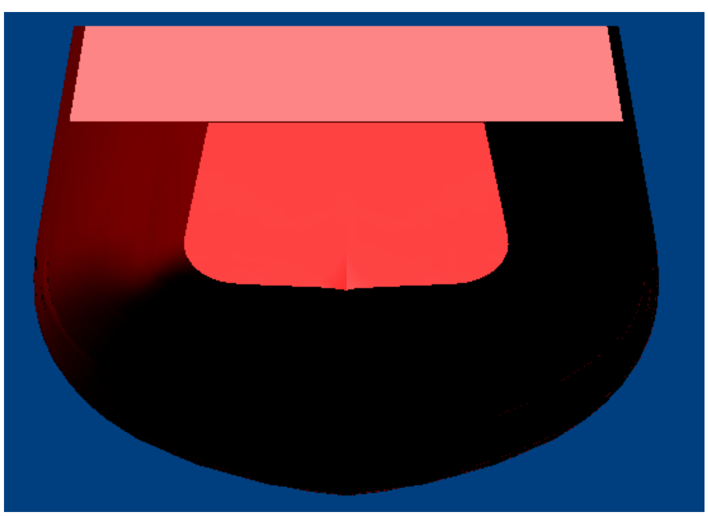

Figure 51 - Stern View

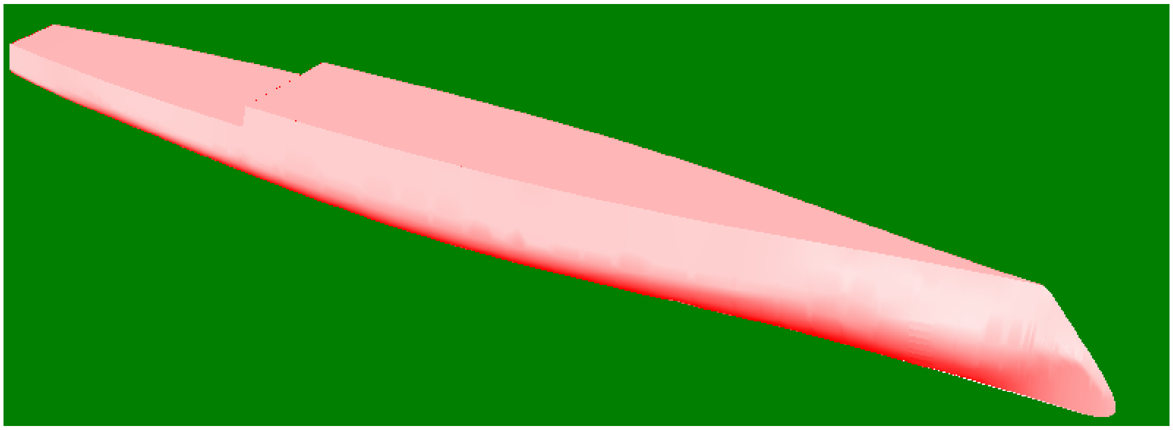

Figure 52 - Isometric View

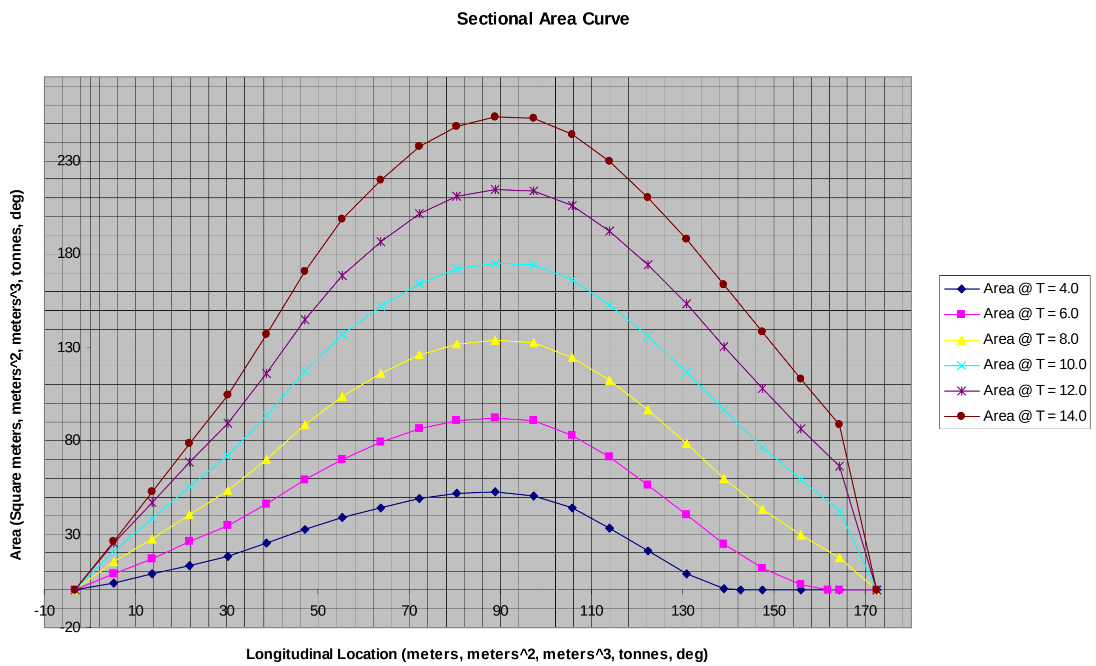

Figure 53 - Sectional Area Curves

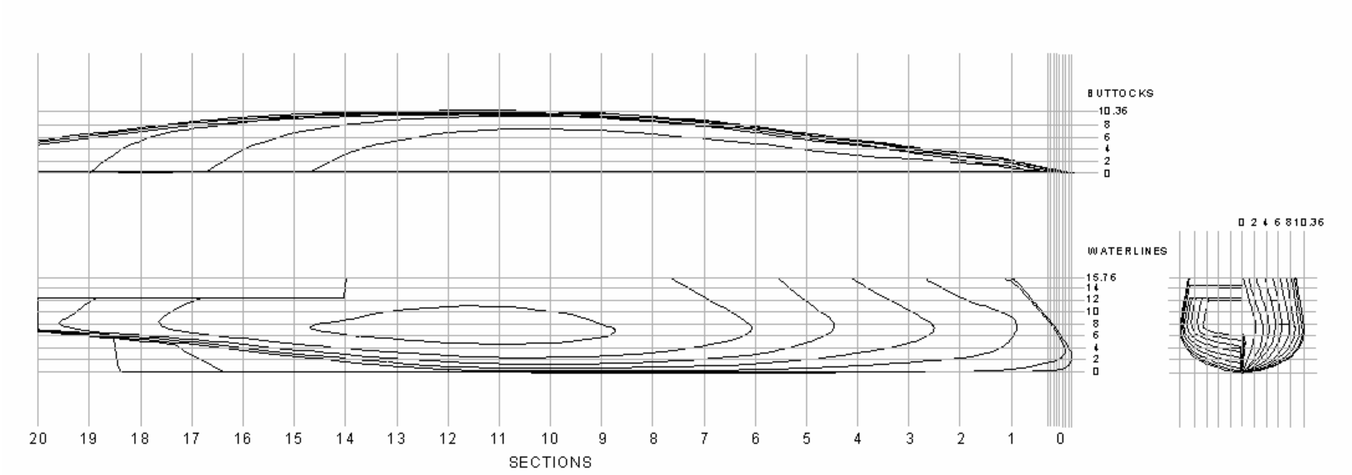

Figure 54 - Lines Drawing

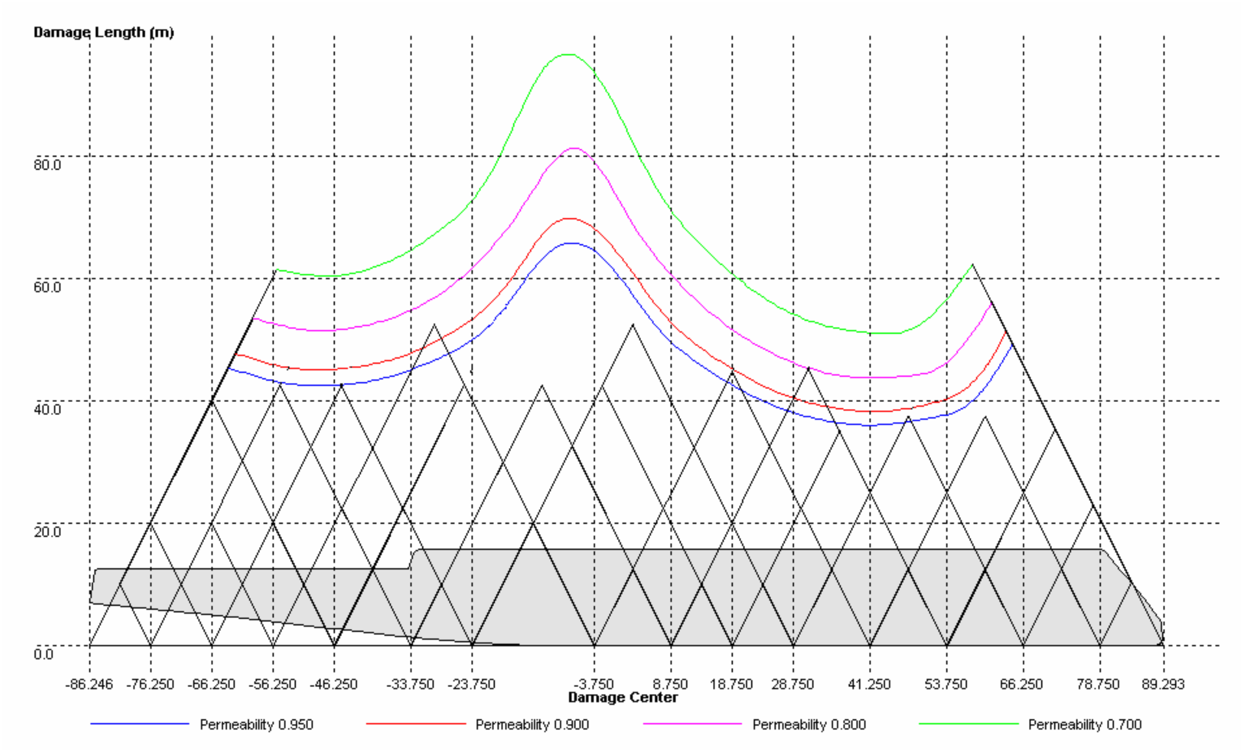

Figure 55 - Floodable Length Curves

4.2 Conceptual Arrangements (Cartoon)

The Air Superiority Cruiser general arrangements was approached from a holistic perspective, addressing the deckhouse, propulsion system, machinery rooms, tankage, and warfighting arrangements. This approach allows for a divided work environment with a medium for discussion in most aspects of ship design. General arrangements of the cartoons in profile view are seen in Figure 56 and Figure 57.

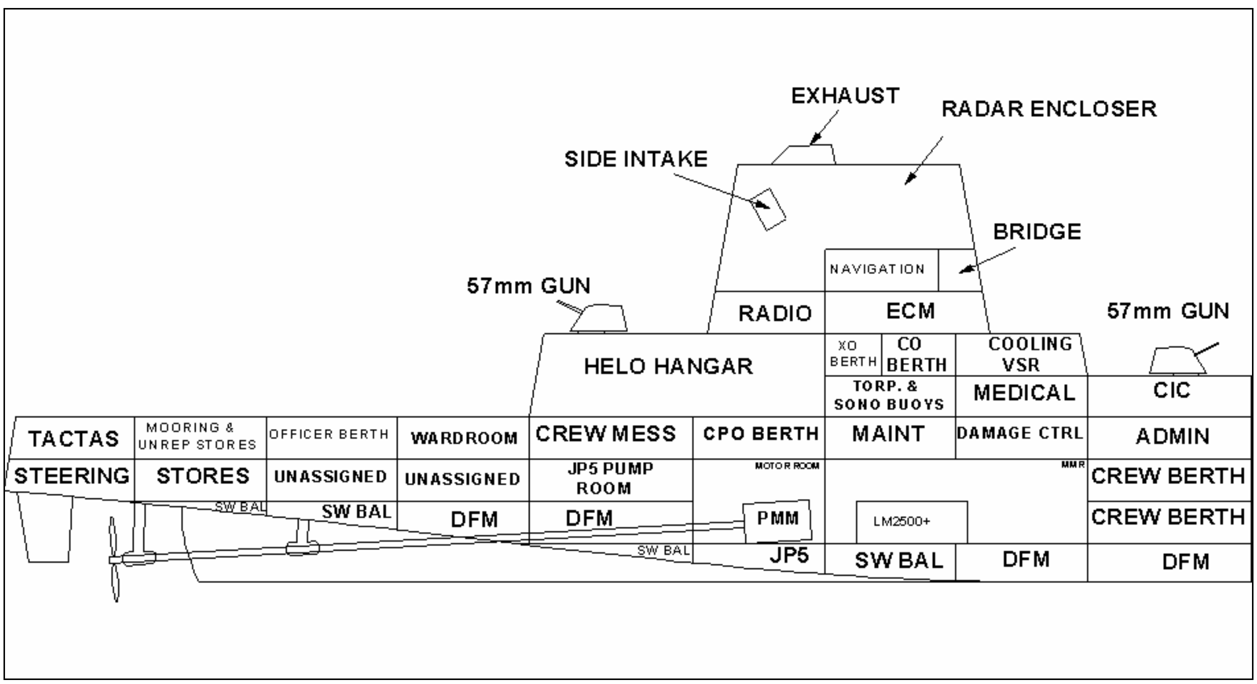

Figure 56 – Aft Profile Cartoon Section

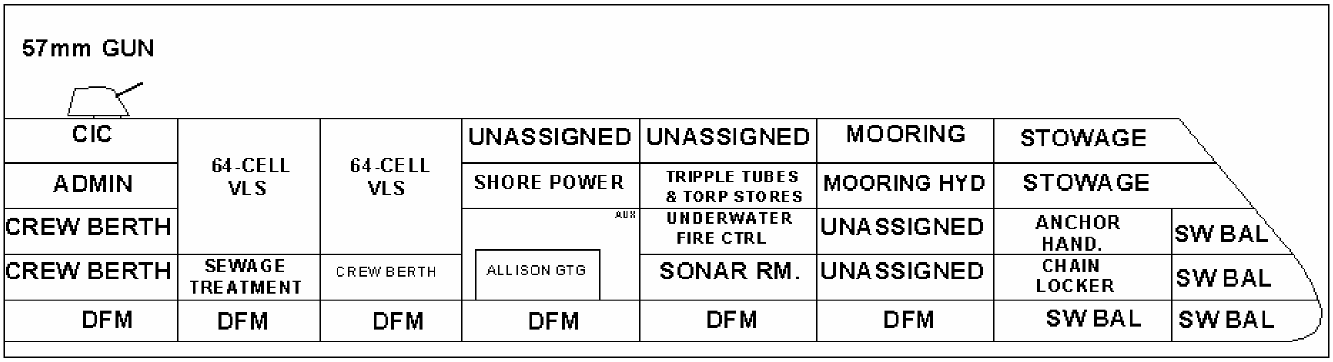

Figure 57 – Bow Profile Cartoon Section

4.2.1 Deckhouse Arrangements

In order to reduce RCS the deckhouse was created to be one unit, as per Figure 58, located slightly aft of amidships to accommodate the helicopter hangar. The uppermost level of the deckhouse contains the bridge, navigation, and an at-sea cabin for the CO. Located below is the radio room and aviation office looking aft towards the helo pad. The 01 level of the deckhouse includes cooling equipment for the various radar arrays and berths for the CO/XO and several department heads. The main deck level contains the helo hangar with LAMPS torpedo storage, aviation spares, and a shop. The top of the deckhouse is outfitted with an advanced enclosed mast/sensor that encloses the SPS-73 navigation radar, IRST, SLQ-32[V]3, and a host of other antennas.

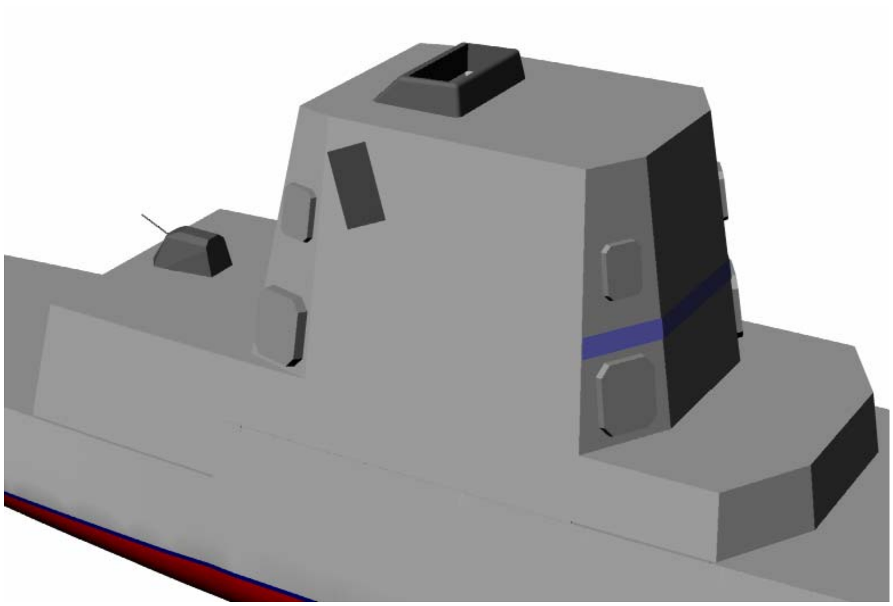

Figure 58 - Rendered View of Deckhouse

4.2.2 Propulsion Room Arrangements

The motor room is located directly aft of the machinery room (Figure 59). It contains both permanent magnetic motors separated by a longitudinal bulkhead. Also included in the space are several electric switchboards. Placement of this compartment allows for a maximum of 3.25º incline of the propeller shaft while still maintaining the proper clearance between the propeller and the hull and minimizing the required length of the shaft—reducing mechanical losses and vibrations.

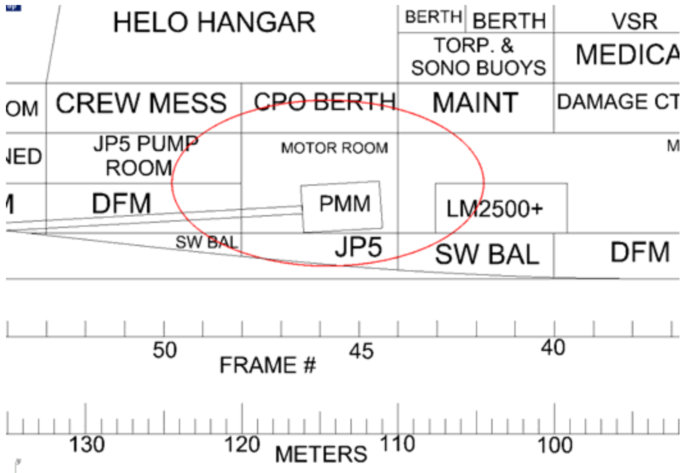

Figure 59 - Profile View Showing Location of Motor Room

4.2.3 Machinery Room Arrangements

Our ship has one main machinery room (Figure 60) which houses our three LM2500+ engines along with their generator sets. This was done to reduce cost and to accommodate one set of inlet and exhaust vents through a relatively compact deckhouse. Included in the large space are various switchboards which have the option of being isolated using a transverse bulkhead running through the compartment. This ship also accommodates one forward auxiliary machinery room (Figure 61) housing two Allison ship service generators. This compartment was located as far forward as possible so that it would be isolated from any damage involving the main machinery room.

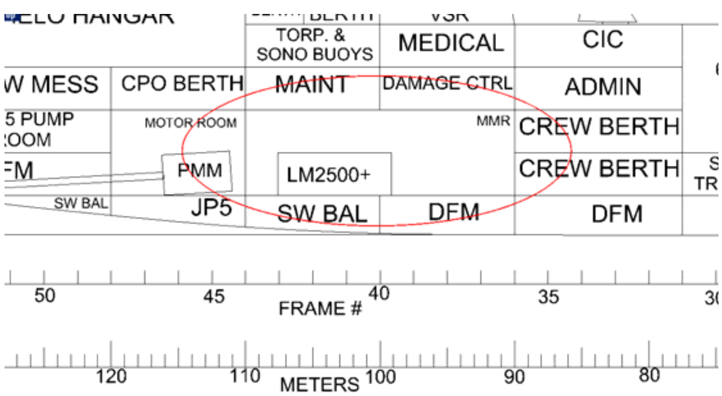

Figure 60 - Profile View Showing Location of Main Machinery Room

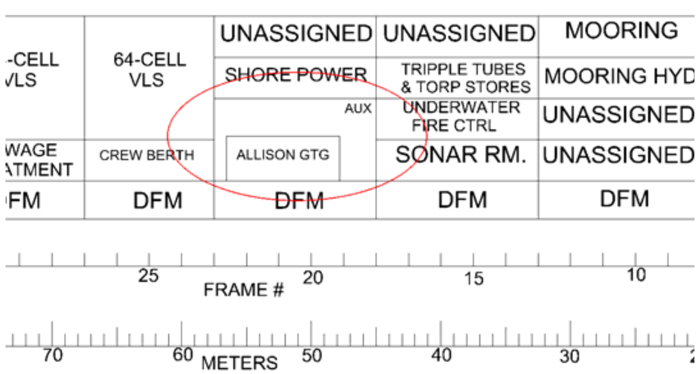

Figure 61 - Profile View Showing Location of Auxiliary Machinery Room

4.2.4 Tankage Arrangements

This ship accommodates the following types of tanks: DFM, salt water clean ballast, JP5, sewage, potable water, lube oil, and waste oil whose volumes can be found in Table 34 & Table 35. Ballast tanks are located forward and aft to provide for corrections in trim, and more tanks are located near amidships to provide for corrections in heel and draft. Two JP5 tanks are located under the helo hangar to provide as direct a flow as possible to the JP5 pump room and the hangar itself. One of two waste oil tanks is located near the main machinery room while the other is located near the auxiliary machinery room, and the lube oil tank is located near the main machinery room as well. The sewage tank is located just forward of amidships where a majority of crew berthing and heads are located. The potable water tanks are located port and starboard on the 3rd platform between amidships and the VLS providing balanced distribution between crew living and messing areas. The remainder of the tank space in the inner bottom and on the 3rd platform is occupied by DFM. For visual references refer to Figure 62.

Table 34- Required v. Available Tankage Volumes

Tank	Required Volume (m^3)	Available Volume (m^3)
DFM	2247	2356
SW Clean Ballast	617	670
JP5	84	104
Lube Oil	21	24
Waste Oil	45	48
Sewage	15	37
Potable Water	36	48

Table 35 - Tank Capacity Plan (Frame = 2.5m)

Tank	Capacity (m^3)		Tank	Capacity (m^3)
5-8-1-F (DFM)	66		4-31-1-W (FW)	24
5-8-2-F (DFM)	66		4-31-2-W (FW)	24
5-13-1-F (DFM)	96		5-A-0-W (SW)	96
5-13-2-F (DFM)	96		4-A-0-W (SW)	48
5-18-1-F (DFM)	137		3-0-0-W (SW)	58
5-18-2-F (DFM)	113		5-40-1-W (SW)	130
5-23-1-F (DFM)	134		5-40-2-W (SW)	130
5-23-2-F (DFM)	134		5-48-1-W (SW)	23
5-27-2-F (DFM)	152		5-48-2-W (SW)	23
5-28-1-F (DFM)	116		5-57-1-W (SW)	68
5-31-1-F (DFM)	202		5-57-2-W (SW)	68
5-31-2-F (DFM)	202		5-61-1-W (SW)	13
5-36-1-F (DFM)	157		5-61-2-W (SW)	13
5-36-2-F (DFM)	157		5-45-1-J (JP5)	52
4-48-0-F (DFM)	234		5-45-2-J (JP5)	52
4-53-1-F (DFM)	145		5-22-2-F (WO)	24
4-53-2-F (DFM)	145		5-44-1-F (WO)	24
5-44-2-F (LO)	24		5-27-1-Q (SEWAGE)	37

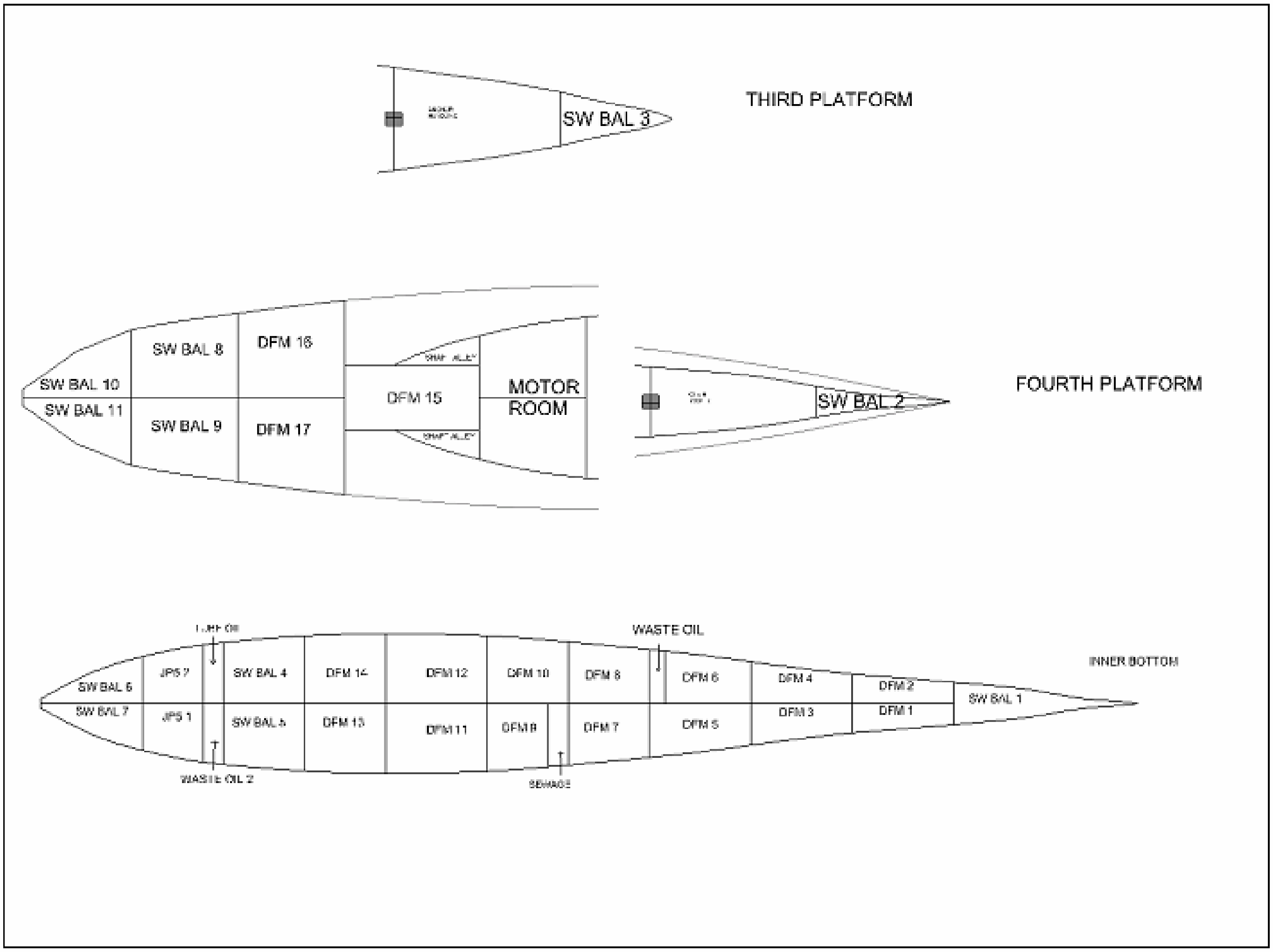

Figure 62 - Plan Views Showing Locations of Tanks

4.2.5 Warfighting Arrangements

From Table 20 we established the combat systems to be incorporated into this ship. Two 64-cell VLS modules are located in adjacent compartments starting just aft of the auxiliary machinery room. Placement was decided upon since there is not enough internal volume forward of the machinery space, and at least one compartment separation from the main machinery room was desired to reduce risk to the space in case of an internal explosion.

This ship is also outfitted with two 57mm MK 3 naval guns. One is located on the 01 level just aft of the second VLS module, the second naval gun is mounted atop the helo hangar. Together they provide 360° fire support for ASUW and SDS. On the 02 level of the deckhouse is a possible mounting platform for one CIWS if desired by the fleet.

Two MK 32 triple tubes are located internally near the bow on the main deck level. Placement at this location eliminated RCS, and places the tubes at the maximum beam for that particular longitudinal reference while still remaining above the designed waterline.

The last major sets of components from the list are the X-band Spy-3 radar, S-band Volume Search Radar (VSR), and the sonar arrays (Figure 63 & Figure 64). The Spy-3 radar and VSR are both 4 panel wide aperture arrays, with the Spy-3 mounted as high as possible on a angled portion of the deckhouse to provide 360° coverage, the VSR panels are mounted directly below the Spy-3. Four wide aperture array sonar panels modeled after those on the Virginia Class submarine are located along the baseline of the ship, there were positioned as far away from the propellers as possible. Located forward of these are two mine avoidance sonar panels mounted to provide a forward viewing angle.

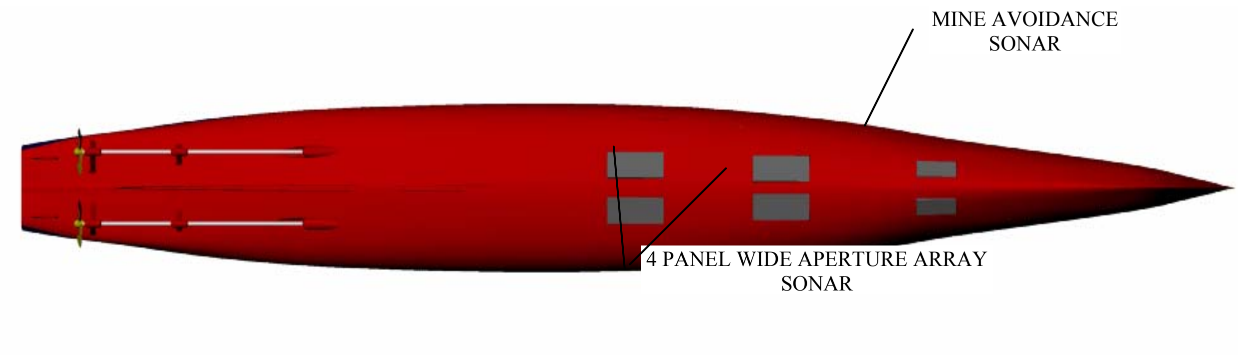

Figure 63 - Rendered View Showing Locations of Sonar Arrays

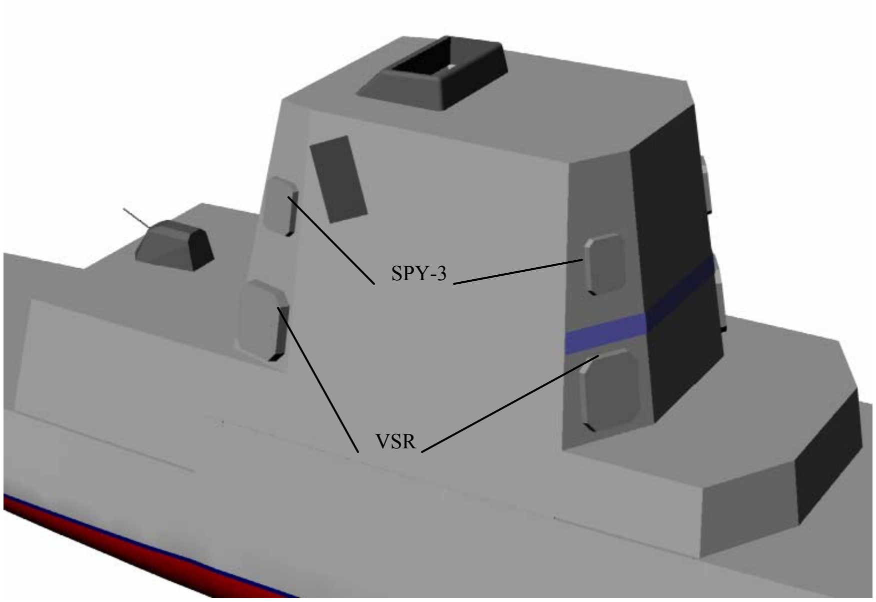

Figure 64 - Rendered View Showing Locations of Radar Arrays

4.3 Structural Design and Analysis

4.3.1 Overview

The structural design of the CG(X) follows an iterative process, as illustrated in Figure 65:

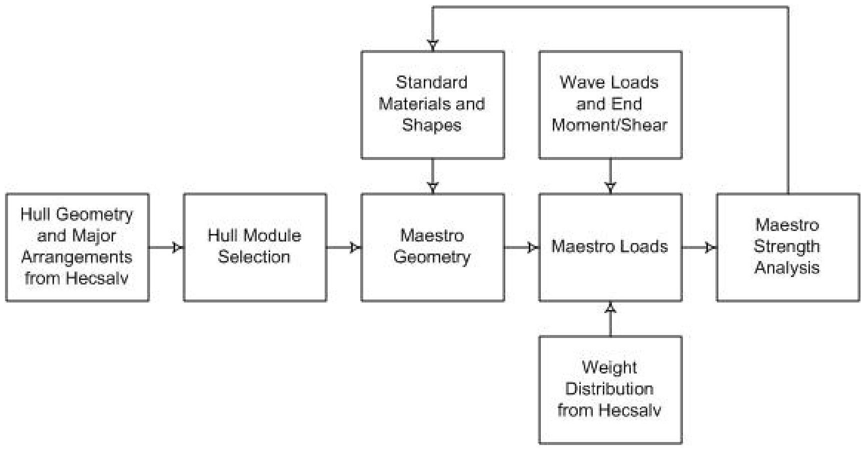

Figure 65 - Structural Design Process

The structural design and analysis was performed in Maestro, a pair of symbiotic finite element programs optimized for ship design. To accelerate the analysis, only about a third of the ship was modeled—a section which spanned from 33.75m aft of amidships to 28.75m forward, as shown in Figure 66. This section was chosen because it included the midship section, it spans from bulkhead to bulkhead, and it covers several structurally important features—such as the main machinery room, the motor room, and the two 64-cell VLS modules. From stern to bow, the four modules modeled are 10m, 20m, 12.5m, and 20m long.

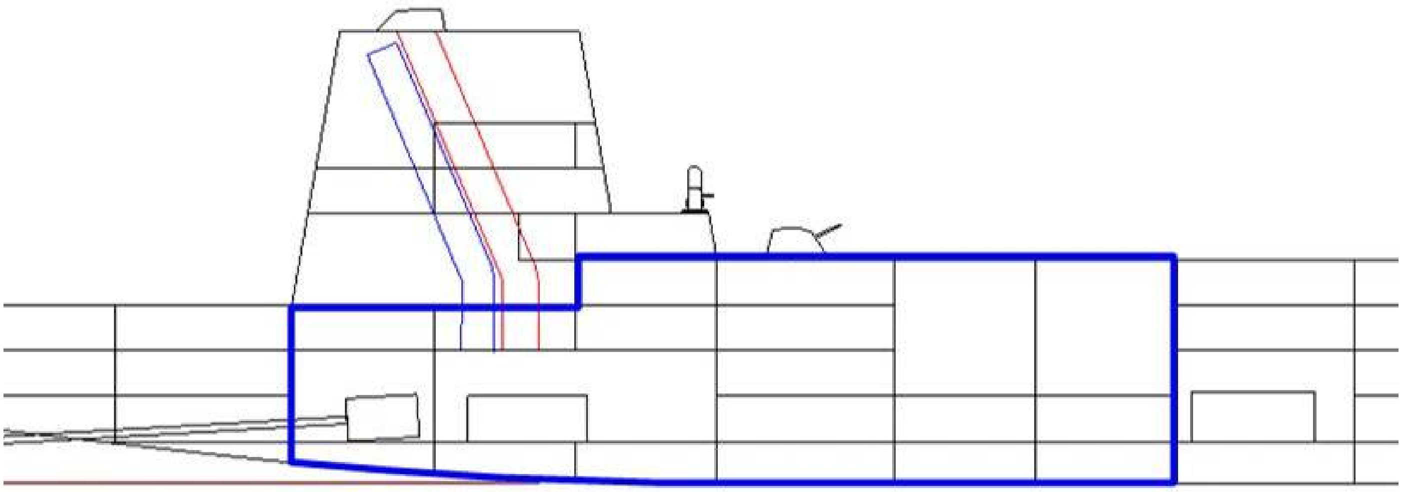

Figure 66 - The Structural Model Compared to the Whole Ship

4.3.2 Initial Geometry

The first version of the structural model was designed from the tankage, stability, and subdivision model in HECSALV, which was, in turn, based on the 3D hull form model made in Rhino. HECSALV reduces the faired hull in Rhino to cross sections filled with flat panels. To import the hull geometry, stations had to be interpolated where bulkheads exist (typically, bulkheads are the extents of hull modules) and points had to be interpolated at required locations within each set of offsets. The points which define the bulkheads are the only points in the Maestro structural model which were drawn from HECSALV.

In Maestro, hulls are formed primarily from longitudinal flat plates, on which stiffeners, girders, and frames are arranged. There is no way to force a strake to follow the curve of the hull except by defining the two edge points to follow the hull, but because of the organization of structural elements in Maestro a strake cannot be as thin as necessary to accurately portray a sharply curving hull. In the end, the Maestro model is inaccurate because the hull is linearized both between bulkheads and between endpoints on the bulkheads; however, the resulting discrepancy between the buoyancy calculated in Maestro is scant, less than 1% below that predicted by the finer-mesh HECSALV model.

CG(X) has a frame spacing of 2.5m, which is consistent with Navy practice for surface combatants. Decks are located 2.96m, 6.16m, 9.36m, 12.56m, and 15.75m above the baseline. This deck height of roughly 3.2m is also roughly consistent with Navy practice, but was defined in the parametric model in the optimization process, as described in section 3.5.

In the initial design, there are longitudinal girders every 2m out from the centerline—that is, up to four longitudinal girders on each side (excluding any centerline girder). This is a heavier construction than is typical, but with the combined influence of the VLS and the engine and motor rooms, the significant components of this arrangement are considerably reduced to the arrangement shown in Figure 67, and detailed in Figure 68 and Figure 69.

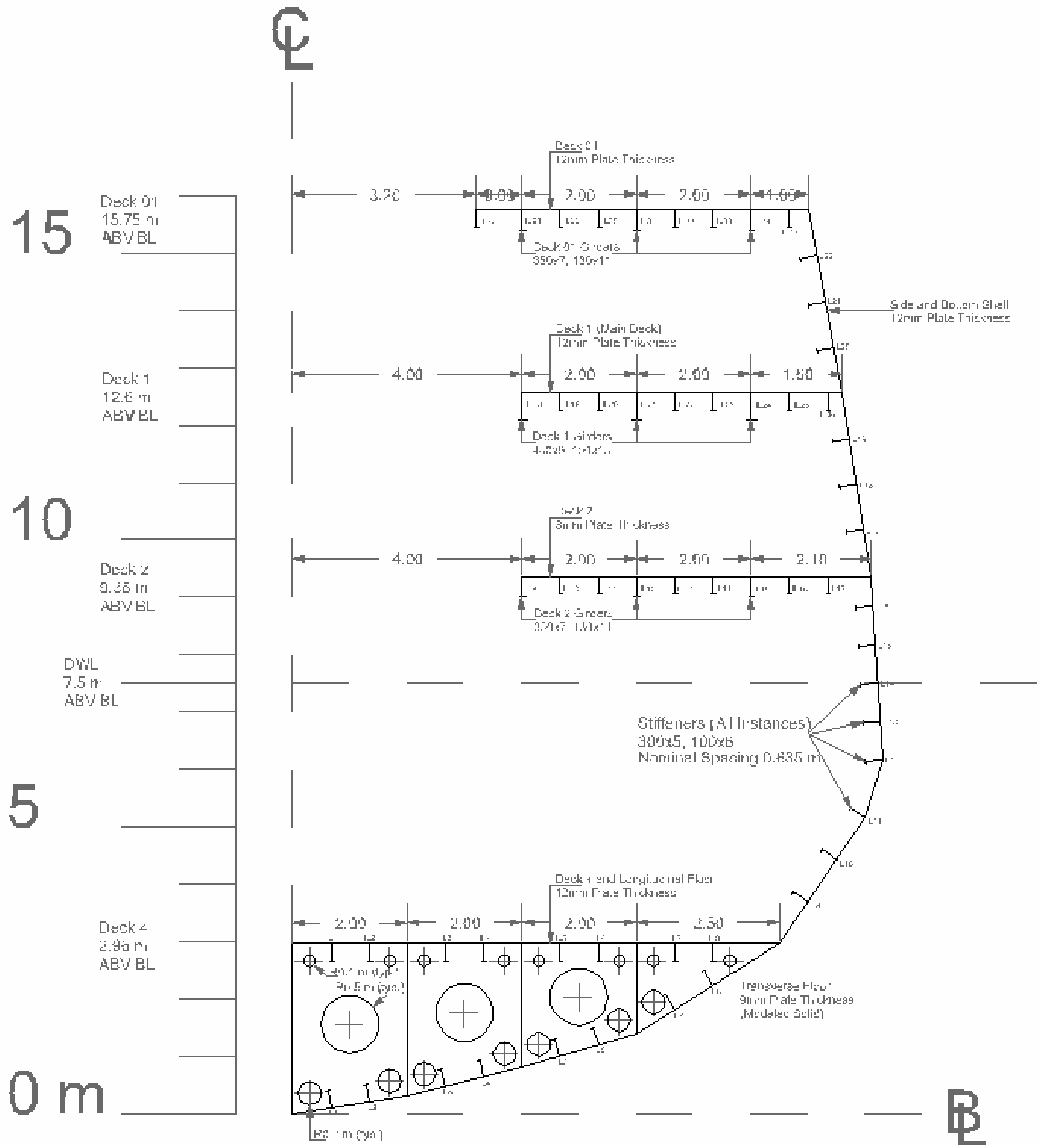

Figure 67 – Longitudinally-Significant Structural Members at Amidships

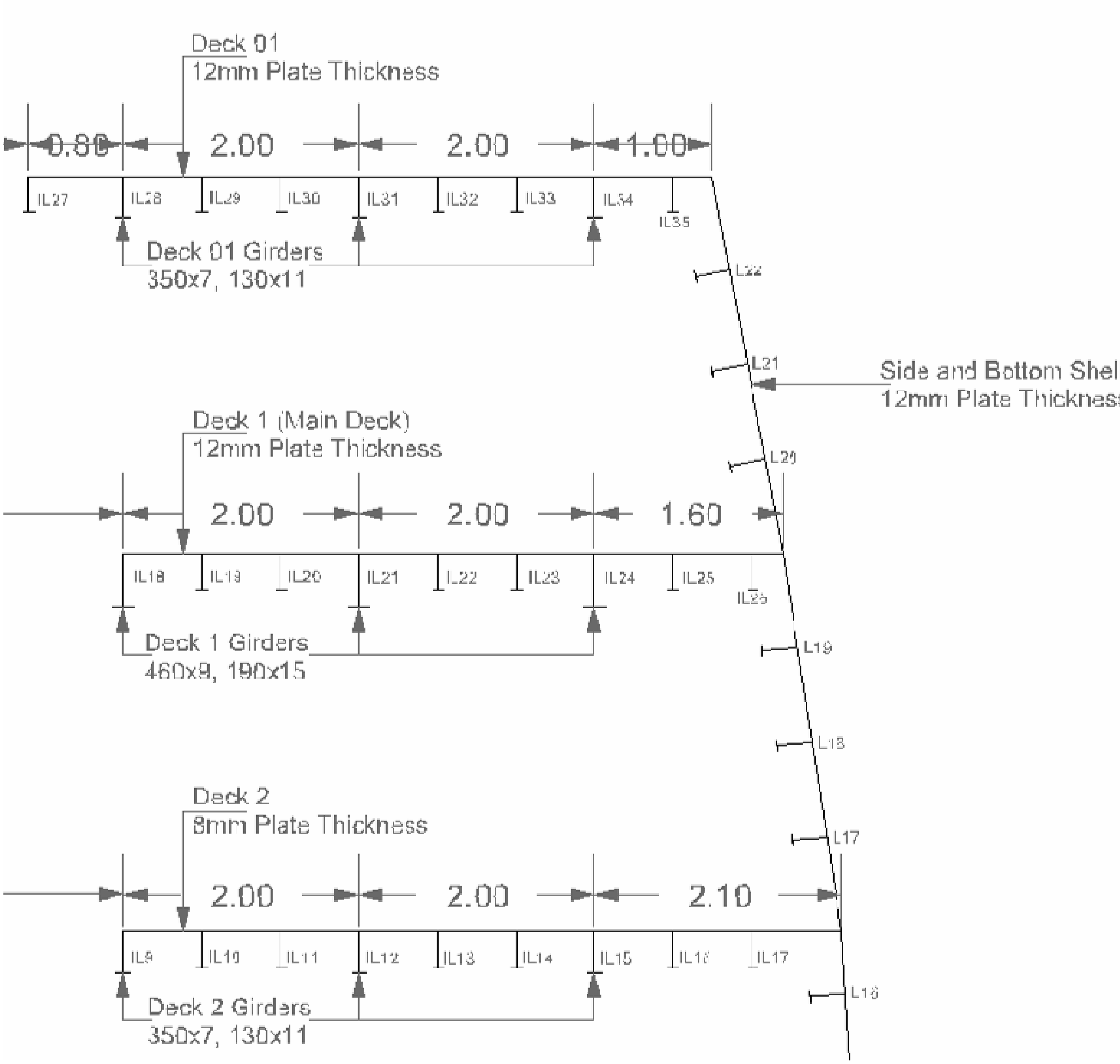

Figure 68 - Detail of Figure 67.

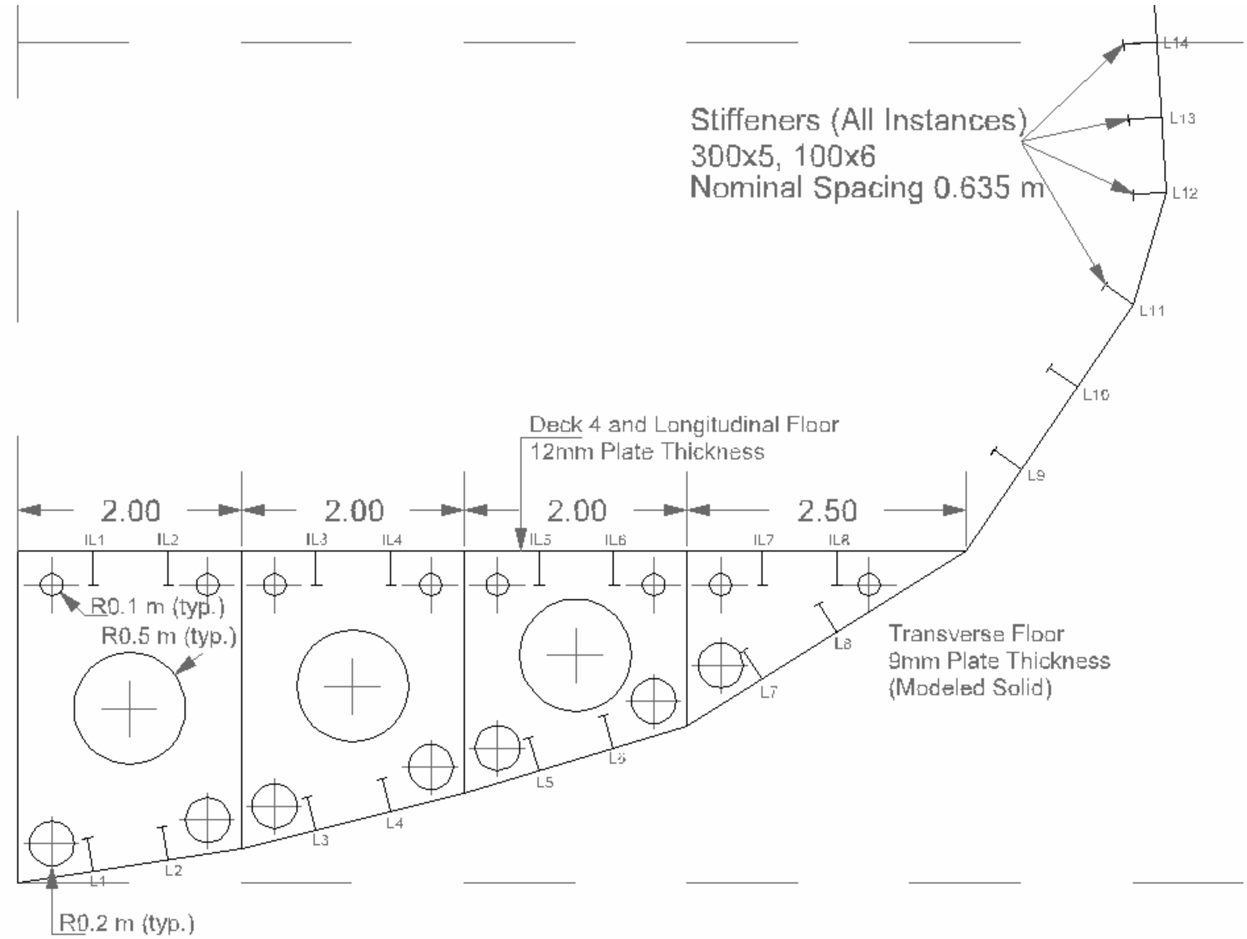

Figure 69 - Detail of Figure 67

The inner bottom design of Figure 67 and Figure 69 was driven by several factors. It was convenient to place longitudinal floors at the 2m locations (a number that was itself chosen because it was convenient for expressing the curve of the hull), because of some inaccuracies involved with ending strakes in Maestro without having at least a girder at the edge, and because it assures that any column or bulkhead placed above would have a clear load path to the bottom of the ship. Likewise, the transverse floors have openings for flow of fluid (e.g., fuel) between frames, and for maintenance access. Maestro does not have a good way to model this—it is more detail than Maestro was ever meant to handle—so to model it accurately there were two options: use frames and columns rather than plates, or use very thin plate to replicate the loss of effectiveness from the openings. The latter was chosen, and the plate thickness reduced by 25% from the standard (see Table 37).

4.3.3 Components and Materials

The components used in the structural design are all standard shapes and materials. To simplify the model and save time in the first design iteration, a minimum of different components were used—e.g., one stiffener type was used throughout the ship. The standard beam components used in the initial design are listed in Table 36, and the various plates are listed in Table 37. See Table 38 for materials used.

Table 36 - Beam Geometries Used in the Initial Design

Shape Number	Use	Web (m)		Flange (m)	
		Height	Thickness	Breadth	Thickness
81	Girder	0.457	0.009	0.1905	0.0145
49	Frames and Light Girders	0.35	0.0065	0.13	0.0107
24	Stiffener	0.3	0.005	0.1	0.0057
6	Light Frame	0.2	0.0043	0.1	0.0052

Table 37 - Plate Properties Used in the Initial Design

Use	Thickness (mm)	Material
Standard Plate	12	HTS
Armor Plate (VLS and Engine Modules)	20	HY-100
Stringer and Sheer Strakes	12	HY-80
Middle-Grade Plate	10	HTS
Low-Grade Plate	8	HTS
Inner Bottom Transverse Floors	9	HTS

Table 38 - Materials Used in the Initial Design

Name	Use	Yield Stress (MPa)	Ult. Tensile Stress (MPa)
HTS	Default	324	496
HY-80	Stringer and Sheer Strakes	552	689
HY-100	Armor Plate	689	793

Although an attempt was made to limit the number of different geometries used, lighter versions of the geometries were used where stresses should be relatively low, in an attempt to save weight—hence the light girder, light frame, and middle- and low-grade plate geometries.

Only one stanchion geometry was used: a circular column 30cm in diameter with a 2cm wall thickness.

The stiffeners were arranged on a strake-by-strake basis, as there was no standard strake width (the possibility of this was eliminated by the preeminence of other factors in endpoint selection). In general, the Navy standard stiffener spacing of 22”-28” (about 0.56m – 0.71m) was used to bound reasonable values, but it was aimed to have, as close as possible, a standard spacing of about 0.635m.

4.3.4 Loads

The loads on the model were obtained from Hecsalv. In Hecsalv, weights of components were added to structural weight (computed in Hecsalv based on parametric equations), and a wave was applied (with a length equal to the ship length and an amplitude equal to one-fortieth of the length). Hecsalv computed weight, shear, and bending moment along the length of the ship.

The values of weight from HECSALV includes structural weight and would not easily yield installed weight, so Maestro’s structural weight was turned off in favor of assuming the HECSALV structure weight was close enough. This is a source of error, but it is also the only way to make the shear and bending moment values from HECSALV valid, given the project time constraints. It would be best to build a full structural model in Maestro and load weights directly from arrangements—thereby eliminating HECSALV from the loads process—but this is very time consuming.

After the weight was applied (evenly across the length of each of the four modules) the values of the shear and bending moment at the location of the extents of the structural model were taken from HECSALV and applied in Maestro.

This procedure was performed for two worst-case load cases—full load hogging and full load sagging. Figure 70 and Figure 71 show the HECSALV graphical output and the points where the values were taken for the Maestro model.

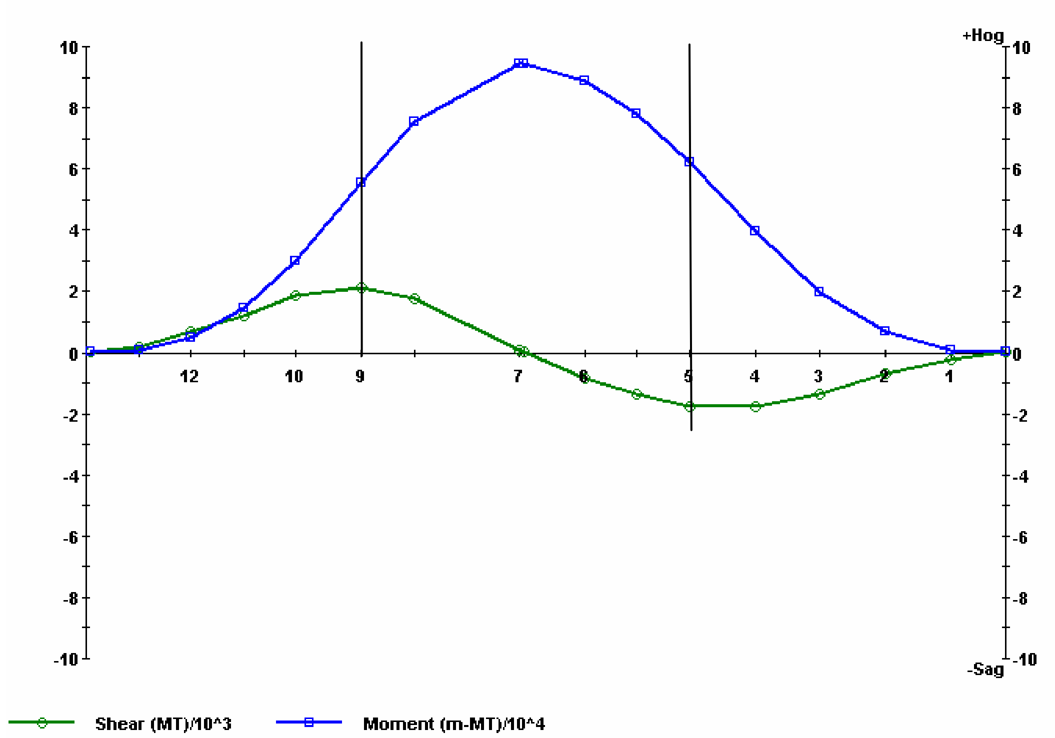

Figure 70 - Full Load Hogging Shear and Bending Moment Diagrams (Full Ship)

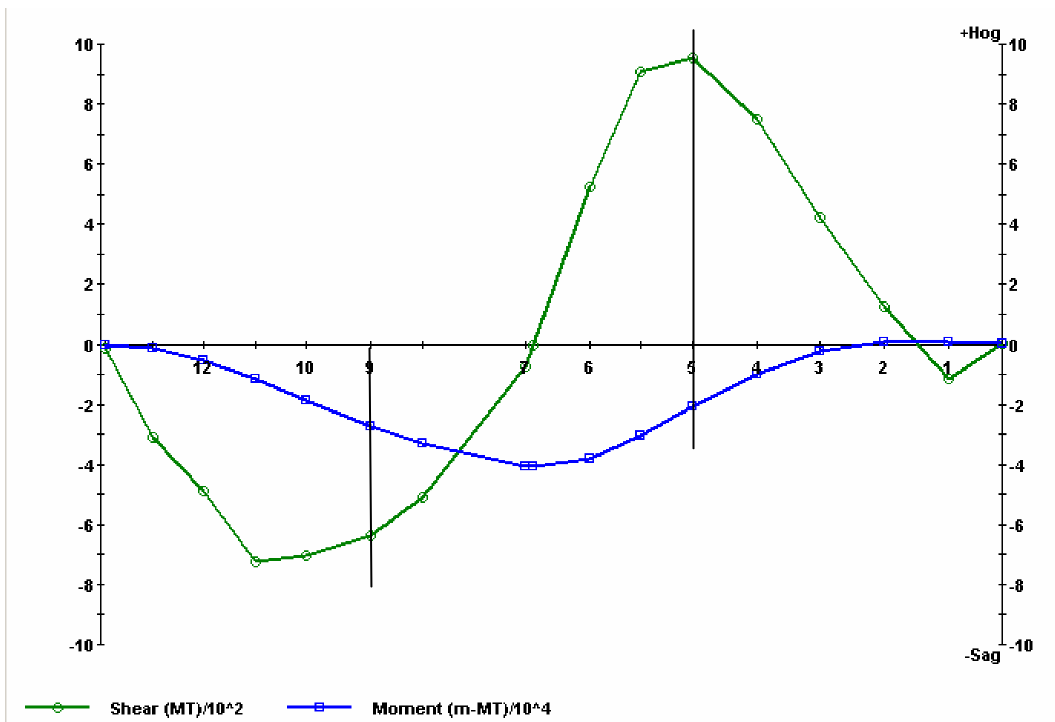

Figure 71 - Full Load Sagging Shear and Bending Moment Diagrams (Full Ship)

4.3.5 Adequacy and Design Iteration

After the model is constructed and the loads applied, Maestro Scalable Solver (as opposed to Maestro Modeler, the graphical interface that has been used exclusively until this stage) is run to quantify the adequacy of the components in the structural design. Maestro simplifies this process by computing a modified strength for stiffened panels rather than treating stiffeners and girders as individual finite elements—therefore, with the exception of manually inserted beams and columns, structural adequacy is determined and adjusted plate-by-plate.

4.4 Power and Propulsion

The Air superiority Cruiser uses an electrical drive system for propulsion. This electrical drive system includes two shafts, fixed pitch propellers, integrated power system (IPS) driven by three LM2500+ engines. In addition, there are two Allison 501K34 generators supporting this system.

4.4.1 Resistance

Resistance calculations were performed using a MathCad file that implemented the Holtrop-Mennen process. The MathCad file required inputs of length of the waterline, beam, draft, prismatic coefficient, block coefficient, endurance speed, and propeller diameter. These inputs were then used to calculate viscous, wave making drag, and bare hull resistance. Figure 72 displays all of the various types of resistance versus speed. From this bare hull resistance, the total effective horsepower was calculated at speeds from 20 to 35 knots. The values of effective horsepower for these speeds are shown in Figure 73 and a plot is shown in Figure 74. A complete MathCad file for these calculations is found in Appendix D.

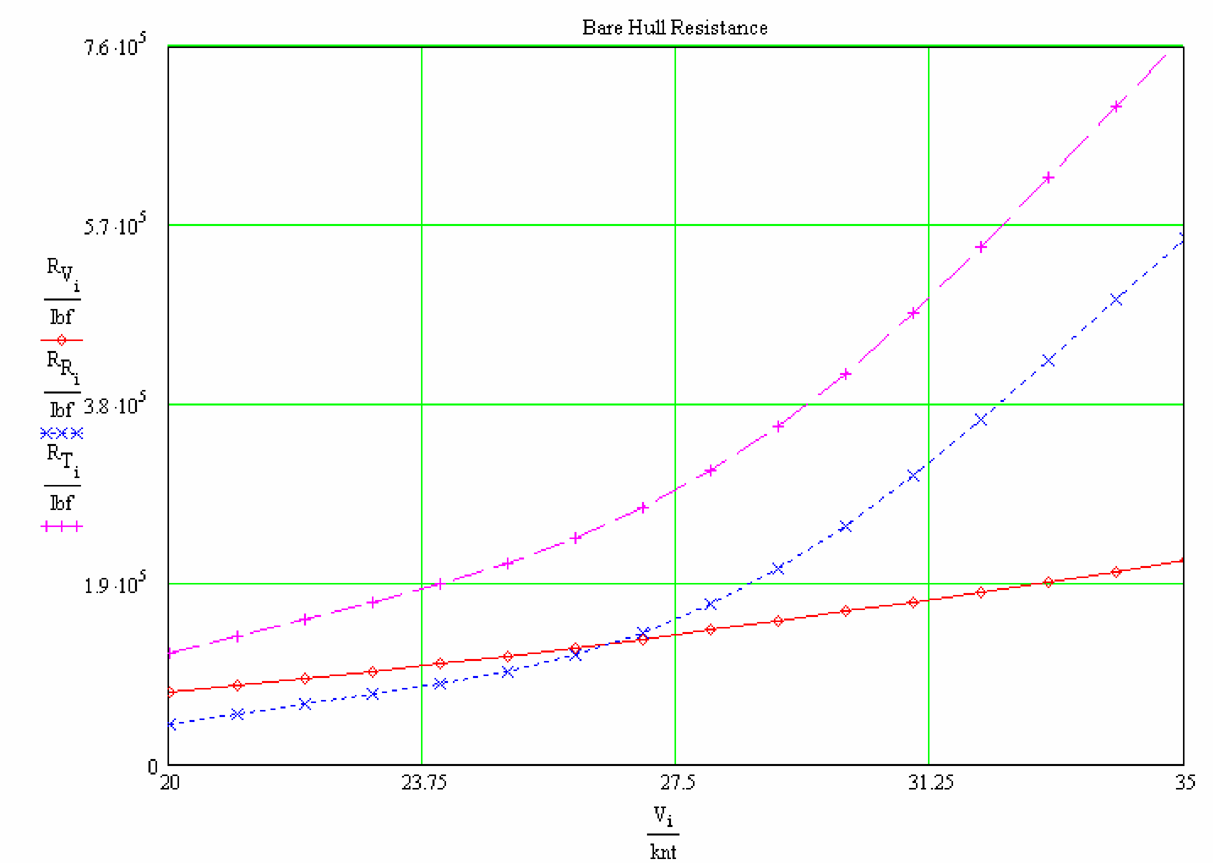

Figure 72 - Resistance vs. Speed Curve.

	V (knt)	EHP (hp)
1	20	11465
2	21	13641
3	22	16039
4	23	18639
5	24	21505
6	25	24780
7	26	28641
8	27	33283
9	28	38899
10	29	45655
11	30	53660
12	31	62934
13	32	73398
14	33	84884
15	34	97165
16	35	109991

Figure 73 - Values for Effective Horsepower for speeds from 20 to 35 knots.

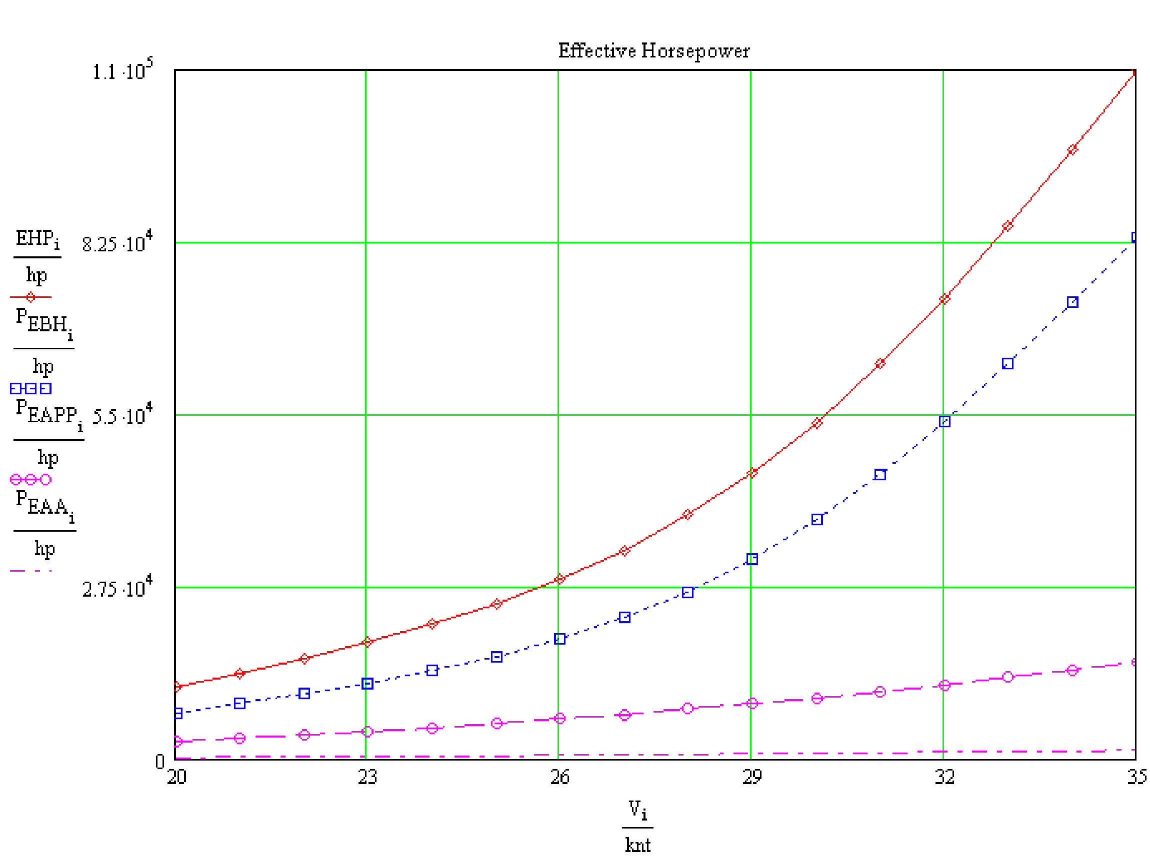

Figure 74 – Effective Horsepower versus Speed Curve

4.4.2 Propulsion

Two fixed pitch propellers are used for propulsion for the Air Superiority Cruiser. Each of these propellers has a diameter of 6.0 meters. The efficiency of the propeller was determined at endurance speed using the EHP from the resistance programs as well the POP from the University of Michigan using optimization. From this program the efficiency, RPM, and BHP were determined.

Propeller characteristics at endurance speed are shown in Figure 75. This plot was output from POP. The POP was used again this time using evaluation, output from the previous optimization, and input for sustained speed. The value for sustained speed is 30.2 knots. The output was efficiency, RPM, and BHP. It is important to note that at sustained speed the ship cavitates. The propeller characteristics at sustained speed are in Figure 76.

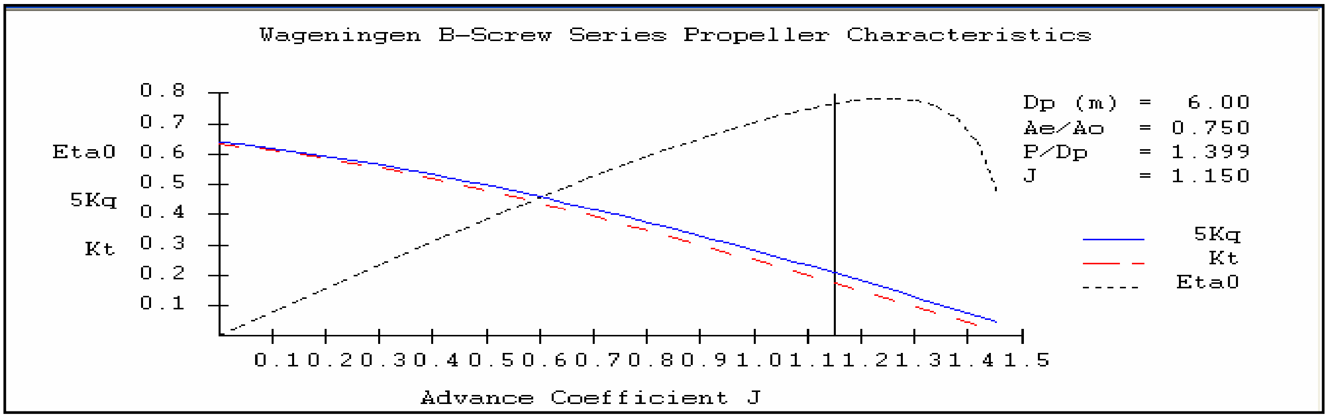

Figure 75 - Propeller Characteristics at Endurance Speed (20 knots).

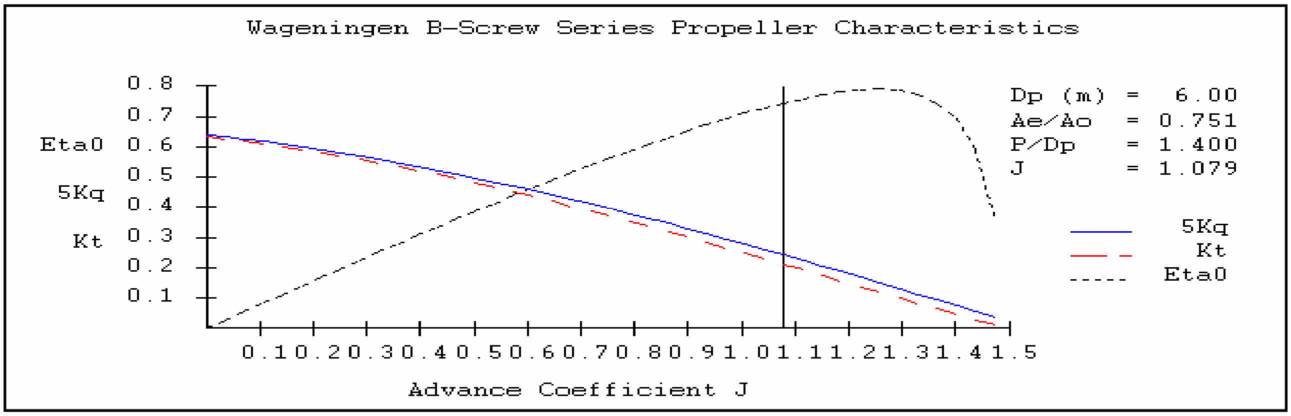

Figure 76 - Propeller Characteristics at Endurance Speed (30.2 knots).

A propeller selection and endurance range MathCad file was used in calculating propulsive efficiency, operating conditions resulting in endurance range. This MathCad file required the previous input as used by the first file as well as KW_{MFLM} and KW_{24AVG}. At the beginning of the file the thrust deduction fraction, wake deduction fraction and hull efficiency were calculated. Principal Characteristics are shown in Table 39.

Table 39 - Principle Characteristics of Air Superiority Cruiser

Thrust deduction fraction (t)	**0.101**
Wake fraction (w)	**0.059**
Hull efficiency	**0.955**

KWMFLM (kW)	**10500**
KW24AVG (kW)	**5220**

Next, the Engine operating characteristics were determined for the electrical engine to determine the specific fuel consumption for that engine speed. The RPM at both sustained and endurance speed was 3600, constant due to the electrical drive system. From this RPM the engine performance curve in Figure 77 was used to determine the SFC for each speed. In addition, the BHP for each speed was required; after the SFC was calculated the power per engine was calculated. These values for endurance and sustained speed are shown in Table 40. The entirety of this MathCad file is available in Appendix D.

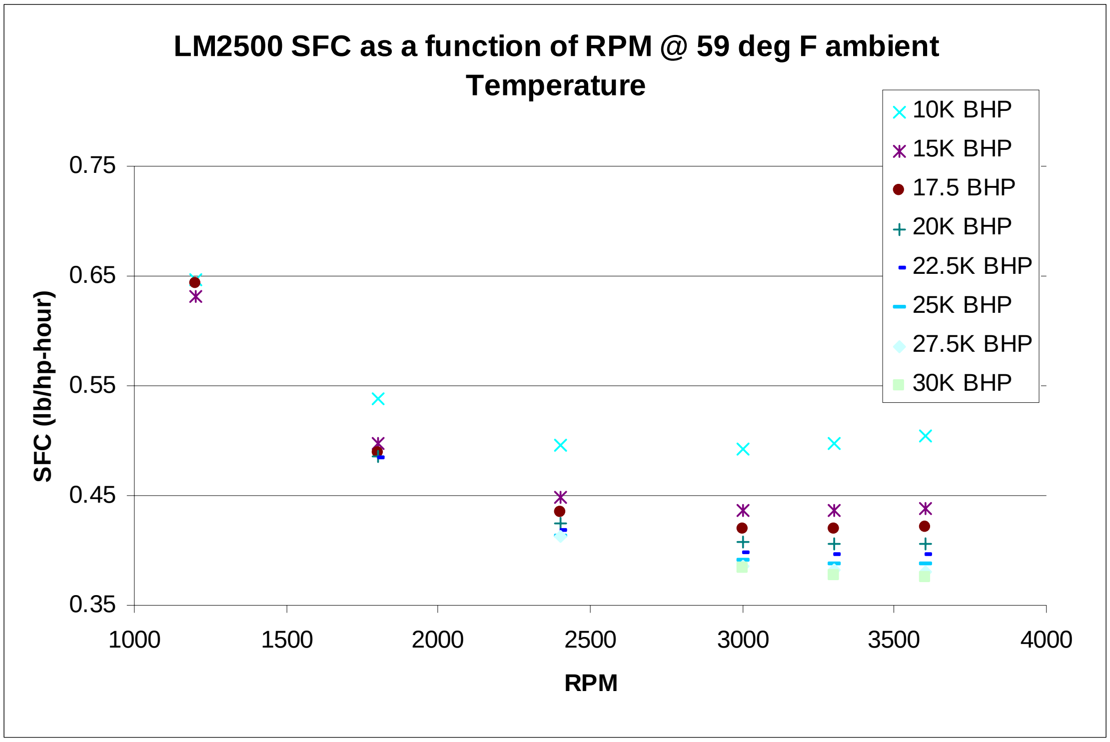

Figure 77 - Engine Performance Curve for the LM2500+

Table 40 - Engine Operating Characteristics

	Endurance	**Sustained**
nPEopt (RPM)	**3600**	**3600**
PBPENG (kW)	**20200**	**25900**
SFCPE (lb/hp*hr)	**0.386**	**0.363**

4.4.3 Endurance Range Calculation

Finally, the last calculation to take place was the endurance fuel calculation determining endurance range. In this process the first thing that had to be calculated was the specified fuel rate. This was a value of 0.394 lbf/hp*hr. Next, the average fuel rate was calculated and was 0.554 lbf/hp*hr. Finally, the endurance range was calculated and is 5130 nm. This calculation is found at the end of the second MathCad file titled ‘Prop Design and Engine Match and Fuel Calculation’.

4.5 Mechanical and Electrical Systems

Mechanical and electrical systems were chosen according to mission requirements, standard naval combatant vessel requirements, and expert opinion. The machinery equipment list (MEL) of all major non-mission mechanical and electrical equipment to support propulsion, ship service and habitability systems includes weights, dimensions, and locations by compartment for each item. The complete MEL is provided in Appendix . The following sections describe the major components of the mechanical and electrical systems and the methods used to size them. The arrangement of these components is detailed in Section 4.7.2.

4.5.1 Ship Service Power

Figure 78 is an electrical diagram that represents basic one-line connection of generators, propulsors, and ship service power buses. Two Ship Service Gas Turbine Generators (SSGTGs) provide 460V AC 60 HZ power to a ship service switchboard which has direct connection to port and starboard ship service zonal buses. Three Main Gas Turbine Generators (MGTGs) provide 4160V AC 60HZ power to a propulsion switchboard. This power can be routed to ship service loads through Power Conversion Modules (PCMs) to the ship service switchboard or directly to the port and starboard zonal buses. Each generator set has a control panel for local control, and they may be automatically or manually started locally or remotely from the EOS. Automatic Paralleling and load sharing capability are provided for each set.

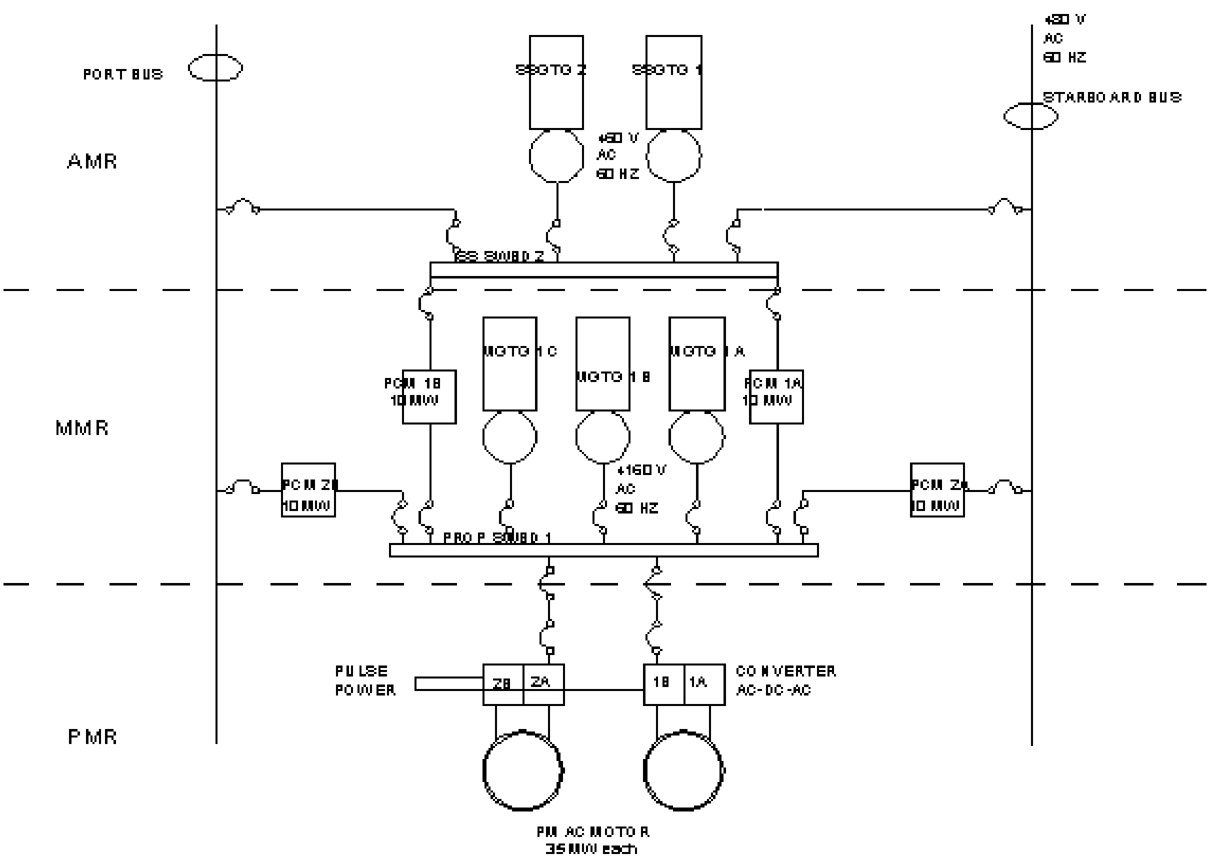

Figure 78: One-Line Electrical Diagram

4.5.2 Service and Auxiliary Systems

Tanks designated for lube oil, fuel oil, and waste oil are sized according to capacity values from the Ship Synthesis Model. Equipment is sized based on capacity ratings, similar ship designs, and expert opinion. Fuel and lube oil purifiers and pumps are sized relative to the fuel and oil consumption of each engine, and are located in a purifier room and the main machinery room (MMR). Four 150-ton air conditioning units and two 4.3-ton R-134a refrigeration plants are located in an AC and Refrigeration room. Two distillers are used to produce potable water from seawater at a capacity of 76 m^3 per day each. Two proportioning and two recalculating brominators are used with this system, which are sized based on crew numbers and are located in the Auxiliary Machinery Room (AMR). A sewage collection unit and a sewage plant, also sized according to crew numbers, are located in a separate sewage treatment room. Other ship service equipment includes hydraulic starting units, lube oil filters and coolers, and pumps for chilled water, potable water, bilge, and ballast.

4.5.3 Ship Service Electrical Distribution

Ship service power is distributed from either of the two main switchboards to port and starboard zonal buses. The ship is divided into five CPS and Electrical Distribution Zones. 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 activated in the event of power loss to one of the zonal buses. Zonal systems are also used for the ship's fire main system and Collective Protection System. The fire main is located on the Damage Control (DC) Deck with fire pumps in each zone. CPS zones are separated by chambers with airlocks on all external accesses.

4.6 Manning

The Air Superiority Cruiser addresses the Navy's current requirement of manning reduction by incorporating automation and unmanned systems. CGX will be able to support 21 officers and 211 enlisted, making a crew size of 232. The manning listed in Table 41 is based on the latest DDG and CG manning numbers. The original estimate from concept exploration was 33 officers and 199 enlisted obtained from the FORTRAN model in Model Center. The FORTRAN numbers were based on ship size, displacement, and propulsion systems. The departments of CGX consist of Executive, Navigation, Medical, Operations, Combat Systems, Supply, and Engineering.

Table 41 – Manning Summary

Departments	Officers	Enlisted	Total Department
Executive	3	7	10
Navigation	1	5	6
Medical	0	2	2
Operations	4	56	60
Combat Systems	7	66	73
Engineering	4	41	45
Supply	2	34	36
Totals	21	211	**232**

4.7 Space and Arrangements

4.7.1 Ship Service Electrical Distribution

4.7.2 Main and Auxiliary spaces and Machinery Arrangements

There are seven machinery compartments in CG(X). These spaces include one main machinery room (MMR), one auxiliary machinery room (AMR), two propulsion motor rooms (PMRs) separated by a centerline bulkhead, one JP-5 pump room, one sewage treatment room, and one AC and refrigeration room. All machinery equipment is arranged to produce port/starboard symmetry wherever possible to avoid heel. Machinery is spaced to allow access to crew members for maintenance and inspection. Equipment near bulkheads is required to have a minimum clearance of 0.4 meters. Plan and Profile drawings of the MMR are shown in Figure 79. Three LM2500+ Gas

Turbine Generators rated at 26 MW each are located in the MMR. The AMR contains two Allison 501k34 Gas Turbine Generators rated at 3.5 MW each. Plan and profile drawings of AMR are shown in Figure 80. The propulsion motor rooms are depicted in Figure 81. Each contains one permanent magnet AC motor rated at 35 MW. The sewage treatment room and JP-5 pump room are arranged as shown in Figure 82 and Figure 83.

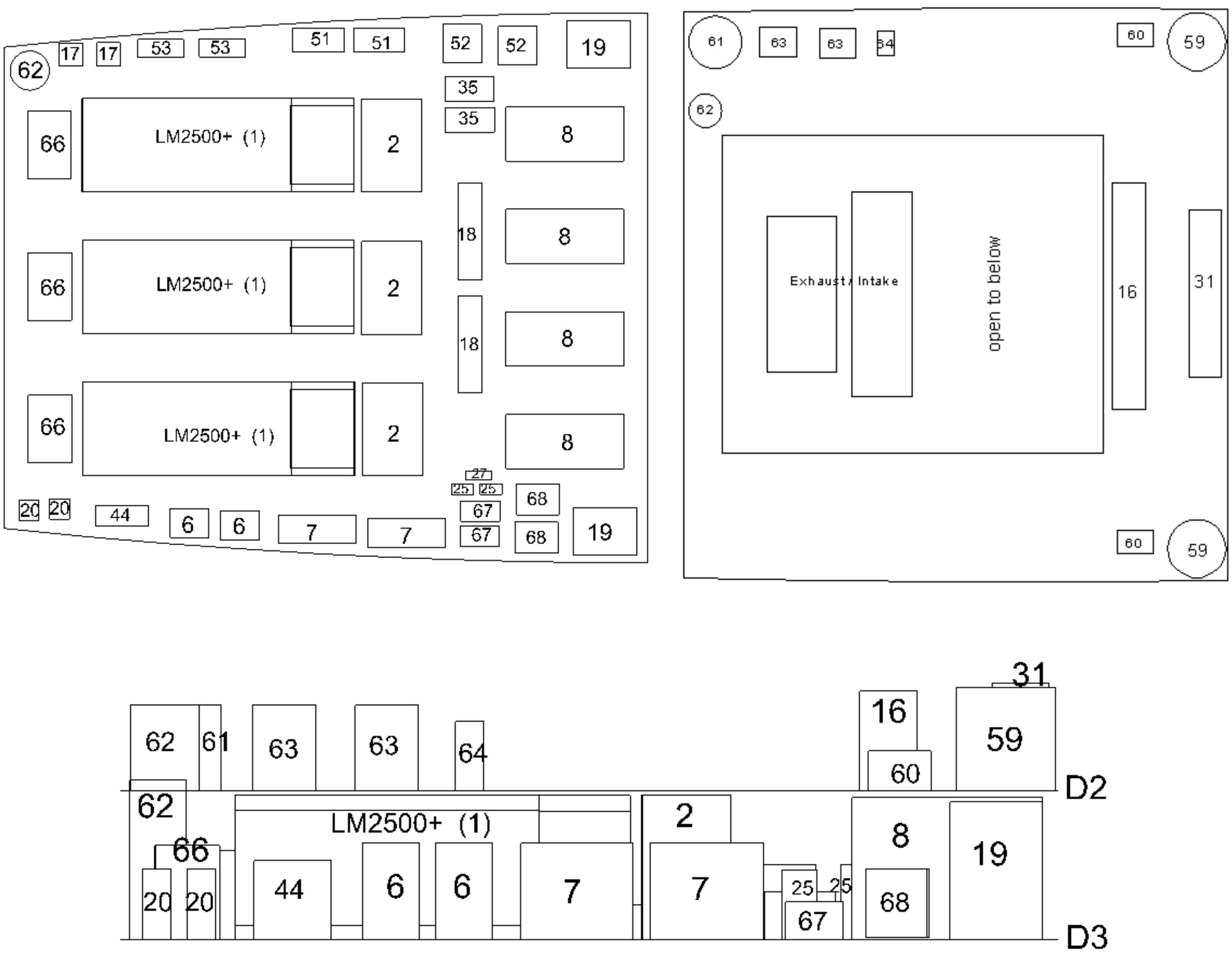

Figure 79 - Main Machinery Room (MMR)

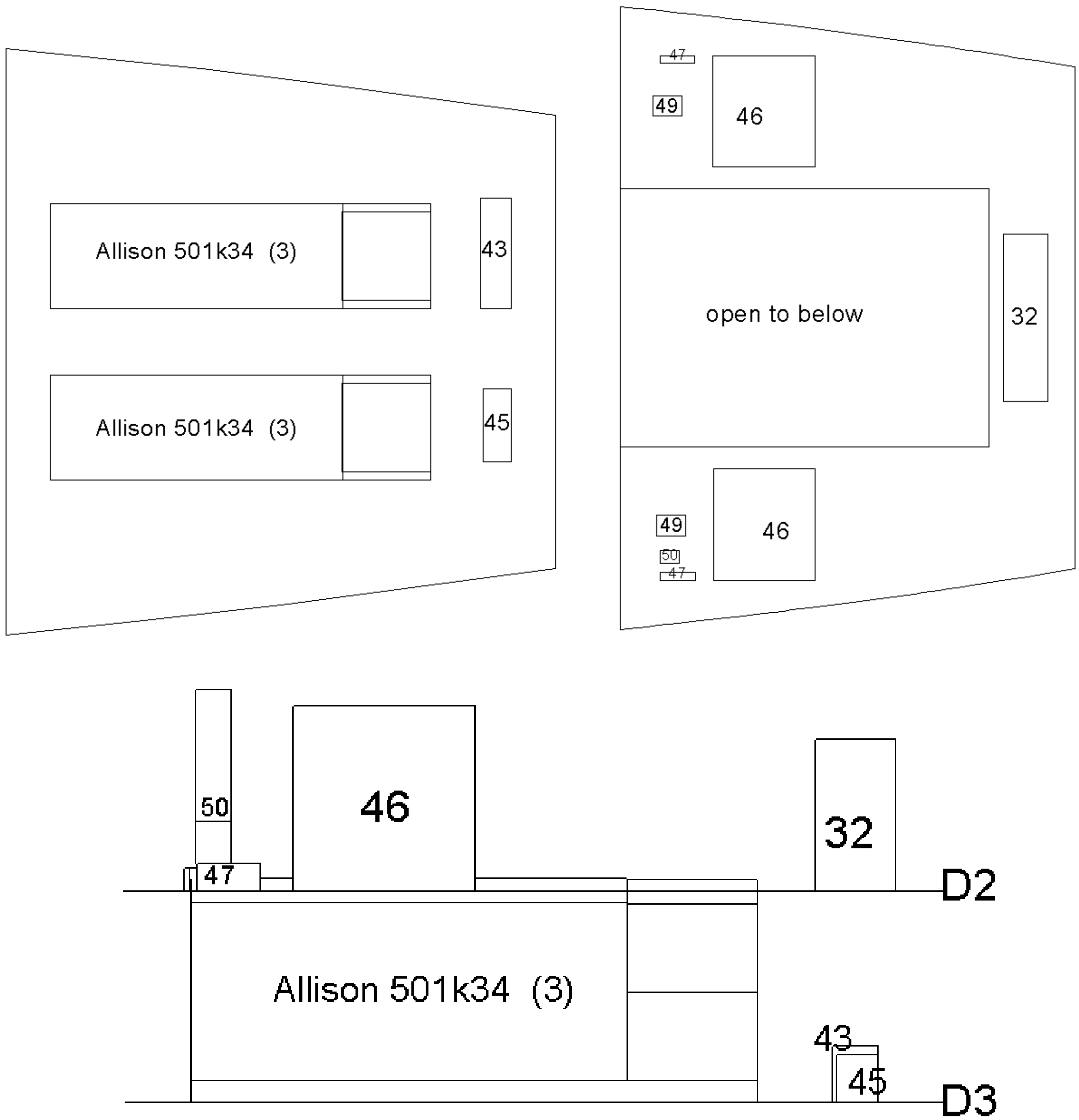

Figure 80 - Auxiliary Machinery Room (AMR)

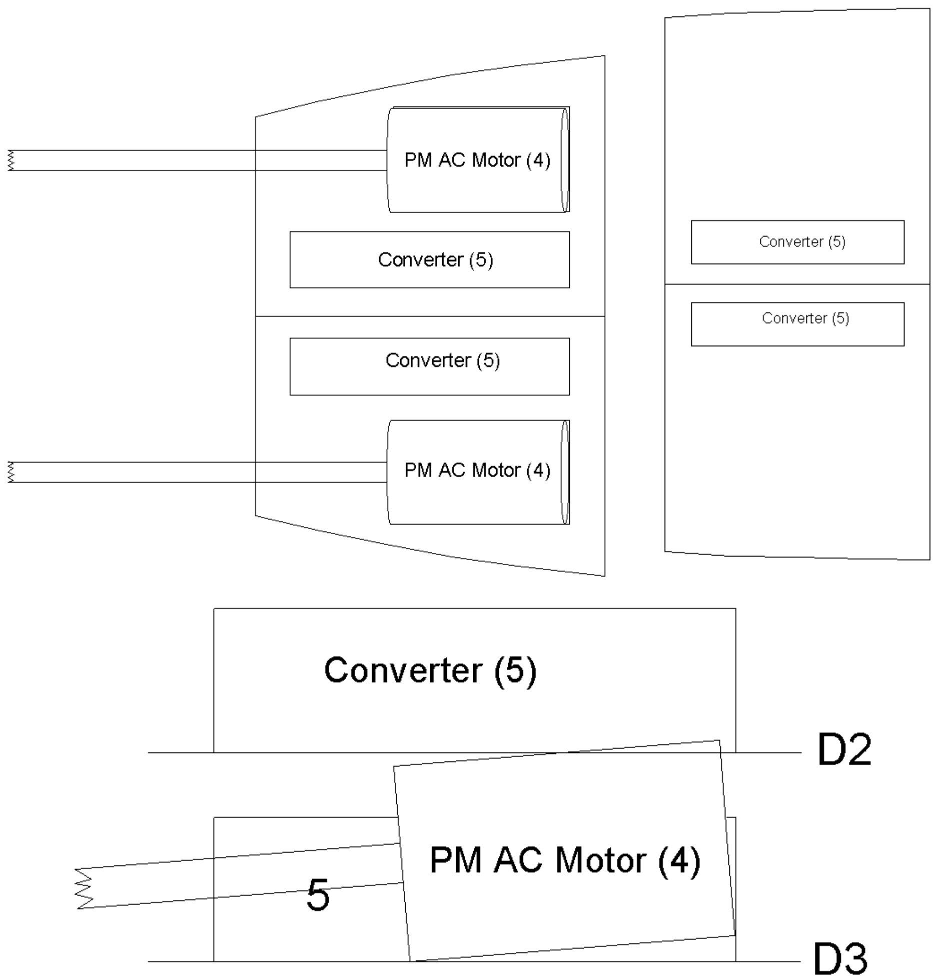

Figure 81 - Propulsion Motor Room (PMR)

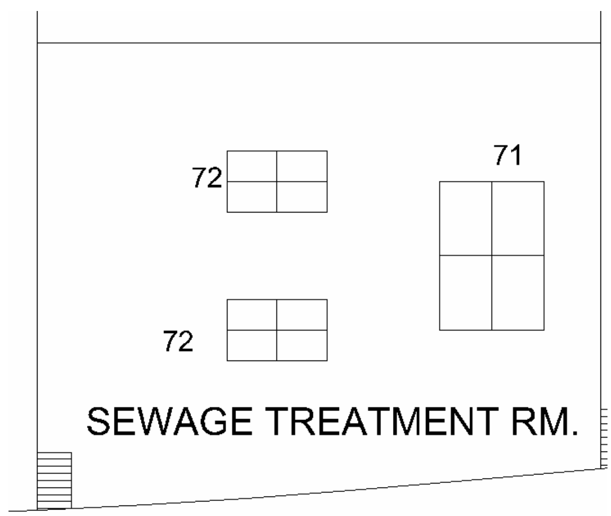

Figure 82 - Sewage Treatment Room

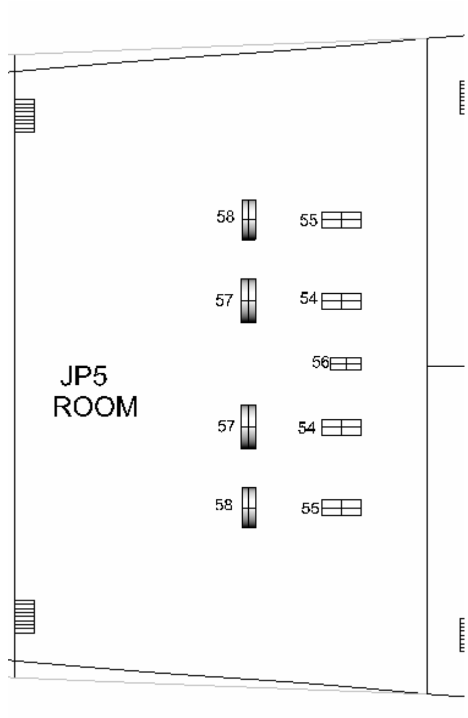

Figure 83 - JP5 Pump Room

4.7.3 Internal Arrangements

CG(x) is internally arranged using four major space classifications categories: Mission Support, Machinery Spaces, Human Support, and Ship Support. Minimum Areas and volume summaries for these spaces are located in Table 20, Appendix D – Machinery Equipment List (MEL), and in Appendix F – Approximate Human & Ship Support Minimum Areas.

Missions Support includes CG(X) mission operations as well as combat systems and communications. The 03 through 01 Levels are shown in Figure 84 – Figure 86, Main deck in Figure 87 – Figure 88, second deck (damage control deck, or DC) in Figure 89 – Figure 91, and the third and fourth platforms in Figure 92 – Figure 94.

The 03 level contains the Bridge with the CO at-sea cabin and head located adjacent to it, navigation, and additional control systems and consoles for various radar and antenna arrays. The aviation office with helo control is found at the rear corner of the 02 level looking out over the flight deck. Also found on the 02 level are the radio room and the ECM room. The majority of the 01 level is occupied by the cooling systems for the large S-band VSR. Cooling is placed here to keep it in close proximity to the radar arrays themselves. The rest of the 01 level is occupied by the CO stateroom, XO stateroom, and space for up to four department head staterooms. The helo hangar is found on the main deck along with aviation support and spares, aviation shop, torpedo and sonobuoy storage, and the Lamps rearm magazine. Other mission systems found on this level are two modules of 64-cell VLS and the CIC room. Triple tubes and their torpedo storage rooms are found on the second deck with the VLS weapon control system, NIXIE & TACTAS in the far aft, and the small arms locker. The underwater fire control system is found on the third platform with the sonar room residing on the fourth platform.

Human Support consists of living and commissary spaces, medical and dental, and general ship services. The living and commissary spaces are detailed in section 4.7.4. The medical and dental room is located two compartments forward of the helo hangar on the main deck. Located within the same compartment are laundry, ship store, mail room, and phones.

Ship Support includes the daily operations of the ship such as ship administration, ship control, damage control, deck auxiliaries, maintenance, stowage, tankage. Ship administration is comprised of general ship administration, executive, engineering, supply, and operations department offices. The engineering department office is located next to damage control with engineering maintenance in the same compartment too which is located on the DC deck above the main machinery room. The rest of the ship administration offices are located in the compartment forward of damage control on the DC deck. Ship control is located in the aft of the ship on the third platform over top of the rudders and houses both steering gears and the hydraulic steering ram. Deck auxiliaries are located on the main deck one compartment aft of the forward perpendicular and on the second deck one compartment forward of the aft perpendicular. Deck auxiliaries also include anchor handling on the third platform with the chain locker located in the compartment beneath it on the fourth platform. Since CG(X) is a tumblehome hull, a conventional anchor would not suffice, so we have adopted an anchor similar to that of current submarines. Stowage is located in the most forward compartment on the main deck and second deck, ship stores are located on the third platform below one of the deck auxiliary rooms. Ship maintenance is predominately located on the damage control deck in the compartment surrounding the intake and exhaust directly behind damage control central. Tankage, as mentioned in section 4.2.4, is predominately located within the inner bottom, and also includes spaces on the fourth platform.

Ship Support also includes accessibility, including ship passageways and machinery room escape trunks. All major passageways are 1.22 meters wide with medical passageways of 1.6 meters wide; all are located on the damage control deck and the main deck with transverse passageways about every two compartments. Each passageway through compartments has watertight bulkheads. For the third and fourth platforms the only means of entry and exit are through vertical ladders from the above compartment. Each ladder has its own watertight hatch. There are two escape trunks in the main and auxiliary machinery rooms and the motor room.

Ship Machinery spaces are all described in the previous section.

A complete set of detailed arrangements are included with this report.

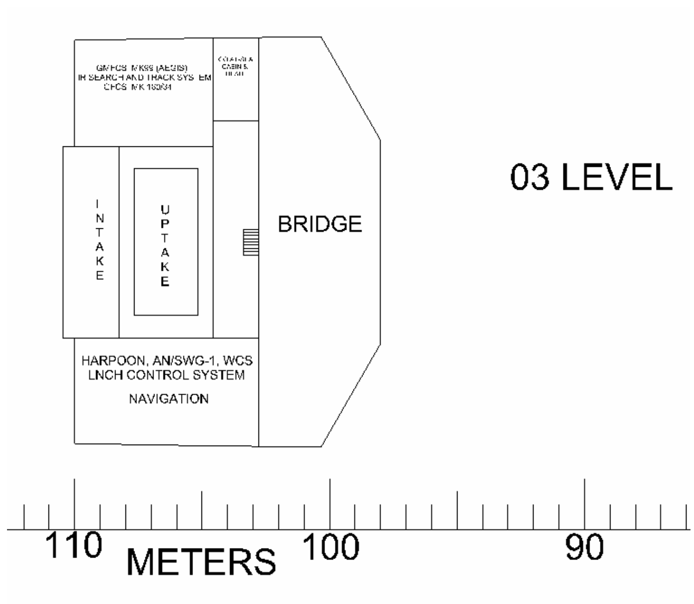

Figure 84 - Plan View of 03 Level Arrangements

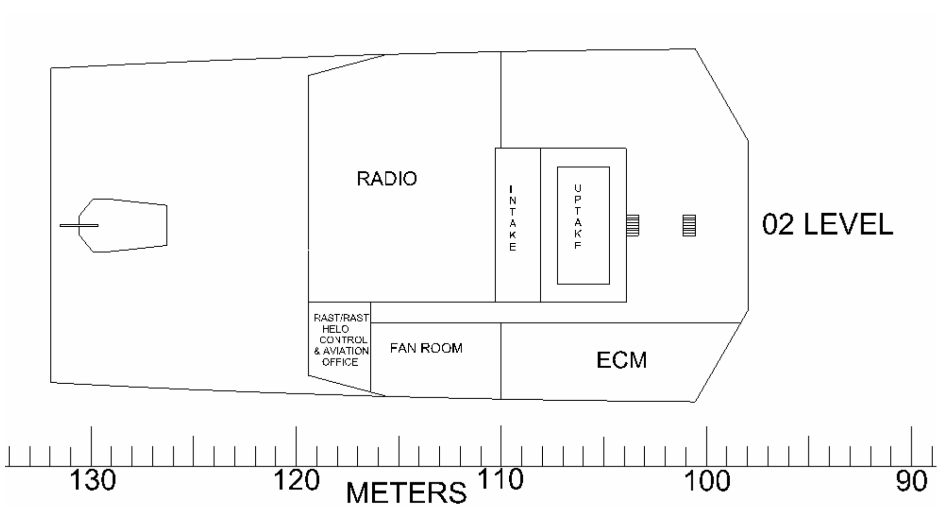

Figure 85 - Plan View of 02 Level Arrangements

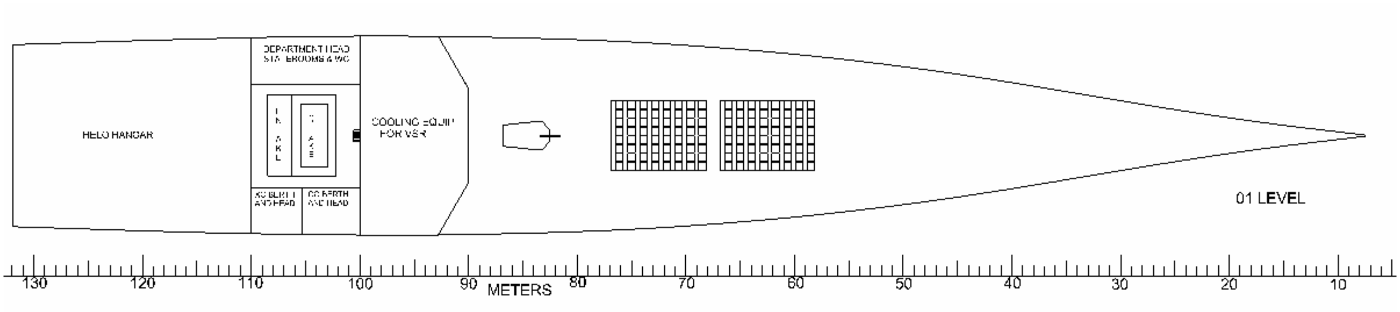

Figure 86 - Plan View of 01 Level Arrangements

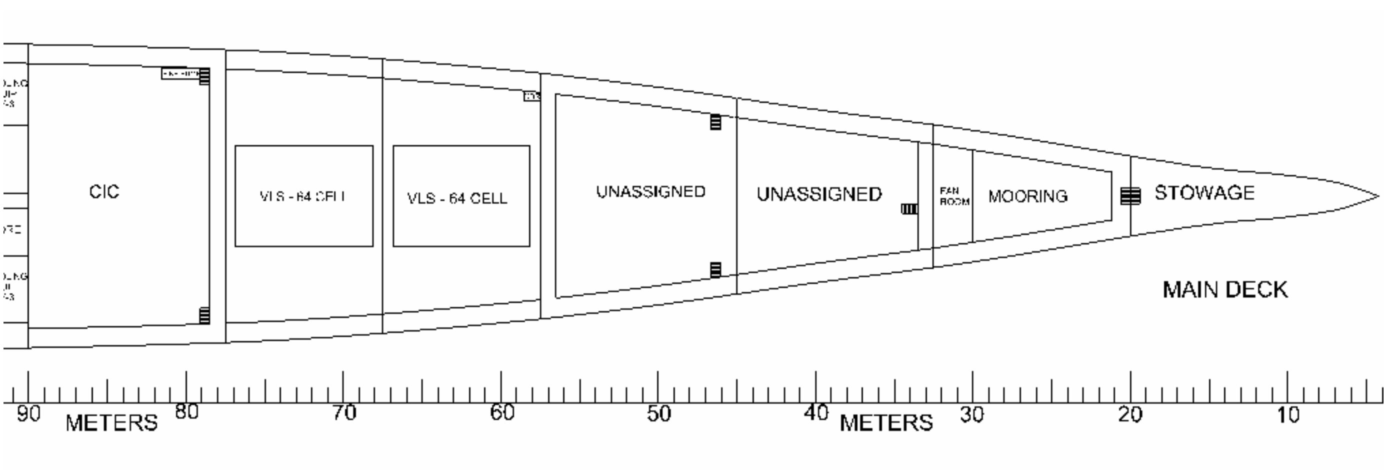

Figure 87 - Plan View Main Deck Arrangements Forward

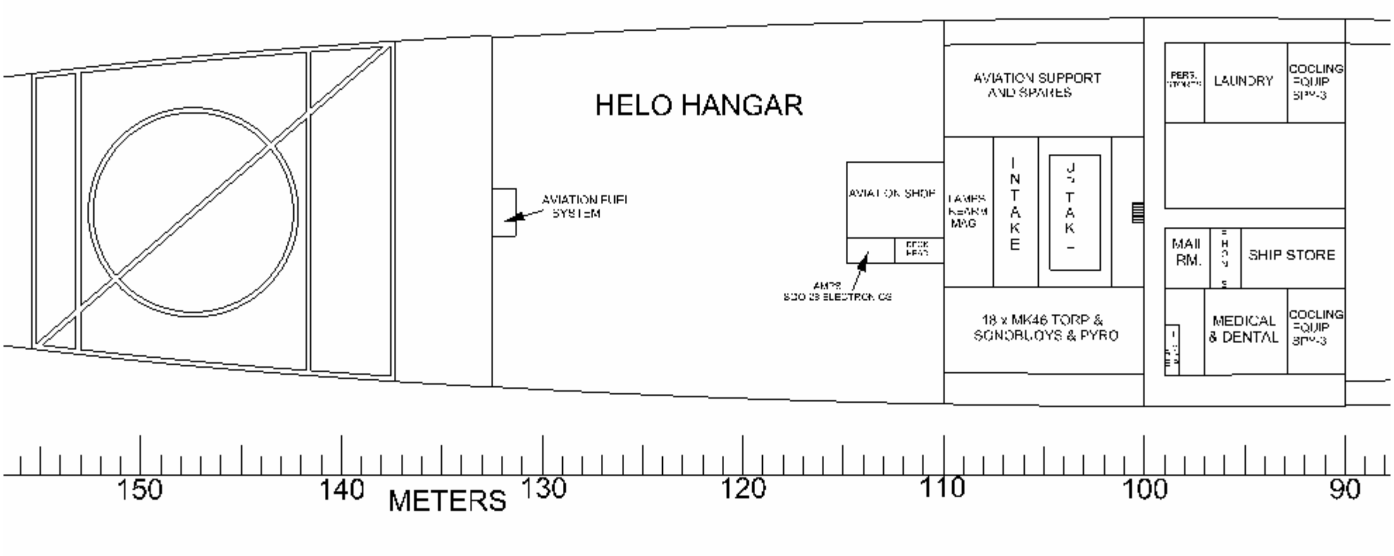

Figure 88 - Plan View Main Deck Arrangements Aft

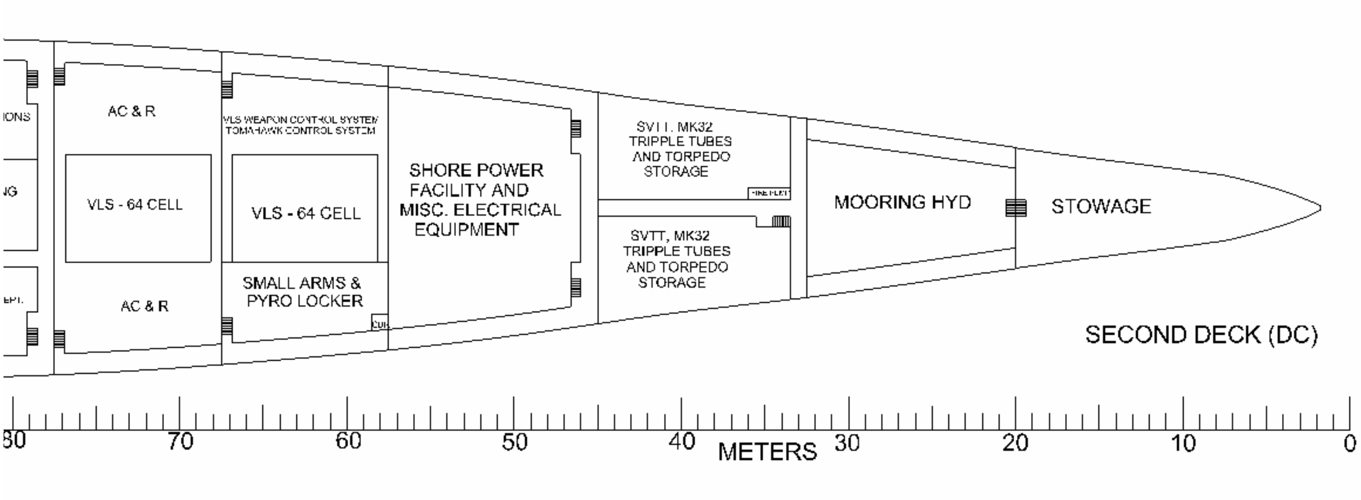

Figure 89 - Plan View DC Deck Arrangements Forward

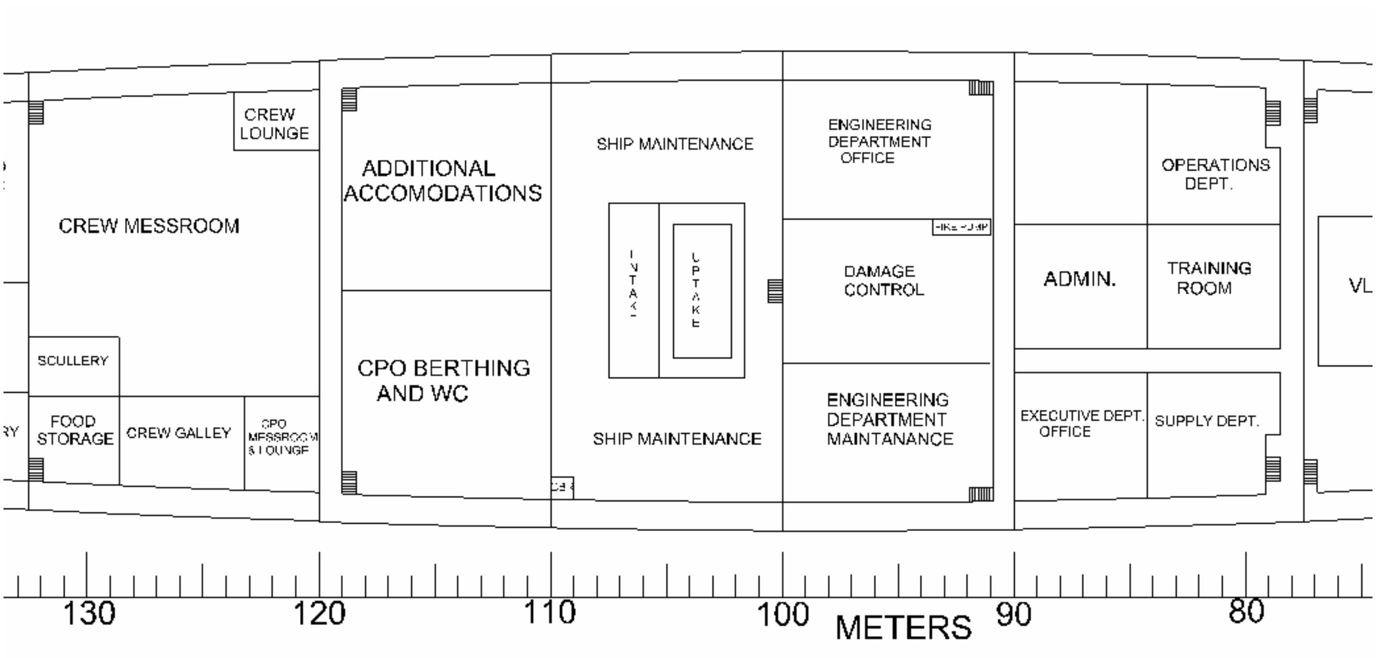

Figure 90 - Plan View DC Deck Arrangements Amidships

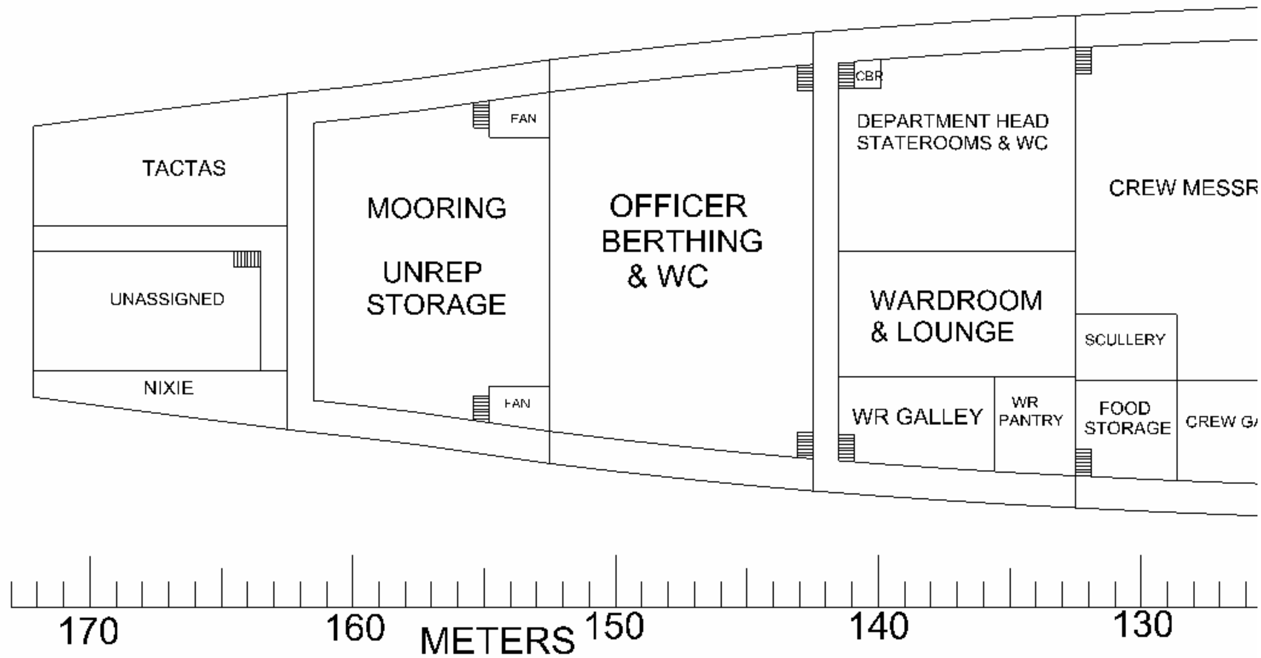

Figure 91 - Plan View DC Deck Arrangements Aft

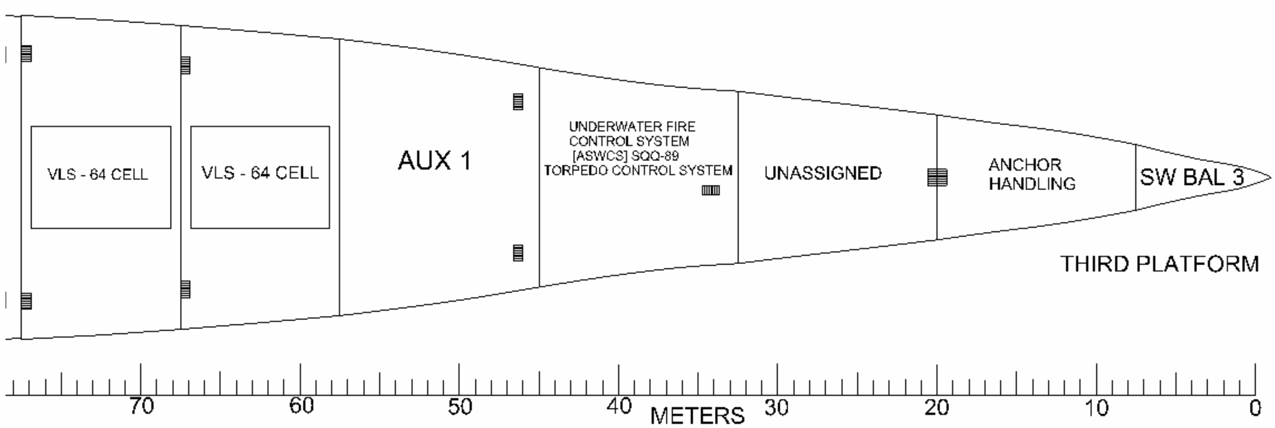

Figure 92 - Plan View Third Platform Arrangements Forward

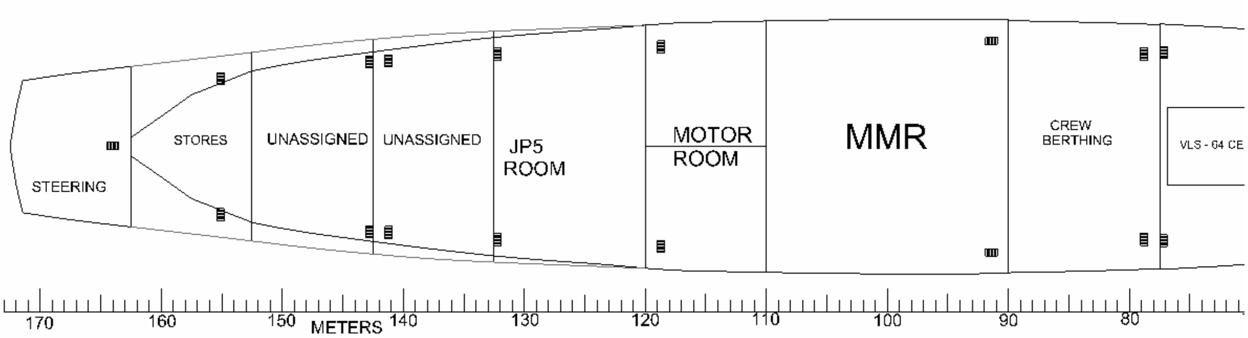

Figure 93 - Plan View Third Platform Arrangements Aft

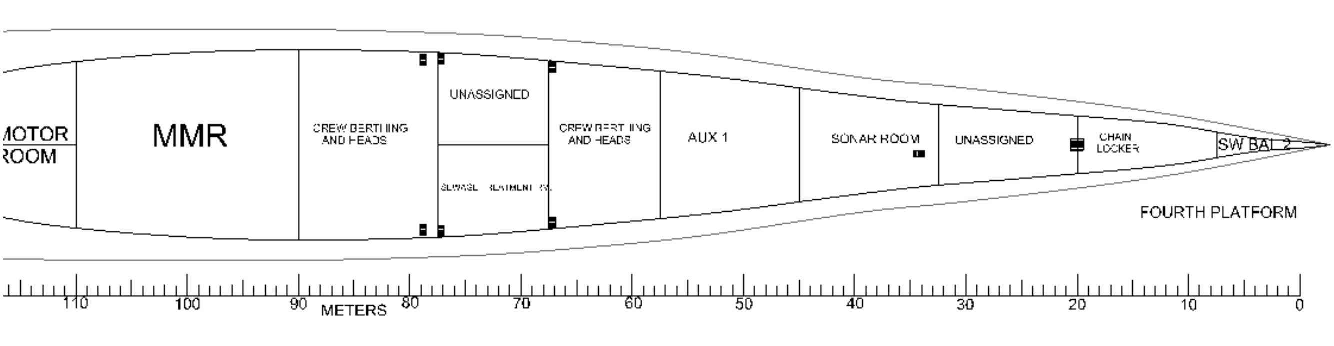

Figure 94 - Plan View Fourth Platform Forward

4.7.4 Living Arrangements

Living space requirements were initially estimated based on the initial crew size from the ship synthesis model, then refined using the manning estimate. CG(X) final areas are capable of accommodating a larger crew than currently needed which may suggest more mission capabilities in future iterations of the design spiral. However the additional space may be necessary to support a highly capable and versatile crew, and provides flexibility in living arrangements. Table 42 lists the accommodation space for the crew.

Table 42 - Accommodation Space

Item	Maximum Capacity	Ocupied	Area (m^2)
CO Stateroom & WC/WR	1	1	23.4
XO Stateroom & WC/WR	1	1	20
Department Heads berthing & WC/WR	4	2	67.8
Department Heads berthing & WC/WR	3	2	43.5
Other Officer berthing & WC/WR	32	15	141.1
CPO berthing & WC/WR	20	15	79.8
Crew berthing & WC/WR	102	90	257
Crew berthing & WC/WR	84	60	212.4
Crew berthing & WC/WR	56	46	142
Additional Accomodations	10	0	79
Totals	313	232	1066

Living Space is located on the DC deck aft of amidships adjacent to the mess facilities and on the third and fourth platforms between the main and auxiliary machinery rooms. The CO has the largest berthing and sanitary facility on the ship followed by the XO. Department head berthing is located on the 01 level near the CO and XO staterooms and also on the DC deck close to officer berthing. CPO berthing is located in the same compartment as the additional accommodations, which are located forward of the mess and galley facilities. Enlisted berthing is located on the third and fourth platforms allowing for some separation from the officers. There are three compartments for enlisted berthing. All living spaces are intended to contain both men and women berthing and sanitary facilities. Berthing Spaces for the officers, CPOs, and crew have sufficient space for recreation activities. The mess rooms for each also have space available for recreation.

Lounge and mess rooms are located between the officer berthing and CPO berthing on the DC deck. This space also contains one serving bar and a television. The crew galley and scullery are located in the compartment just forward of the wardroom. In this compartment is also found the crew mess room. The CPO mess room and lounge are also located in this compartment.

4.7.5 External Arrangements

Minimizing Radar Cross Section (RCS) is a major consideration in the design of this ship. All sides starting below the waterline are flared at a negative ten degree taper to offer the best RCS signature. An advanced enclosed mast structure is located at the top of the deckhouse to conceal various antennas and other arrays. Triple tubes which are normally mounted on deck are now mounted internally and fire through door openings in the hull. Conventional ship anchors as mentioned earlier were replaced by anchors similar to those found on board submarines which tuck up into the hull from the keel.

The original design called for one CIWS but since CG(X) is armed with two 57mm naval guns capable of providing 360° protection and has a six-way programmable round, should be capable of replacing CIWS and offers a better RCS. Therefore with careful consideration CIWS was removed, however space and a platform remain if fleet still desires to have one CIWS mounted on board. Figure 95 shows profile and plan coverage zone covered by the two naval guns.

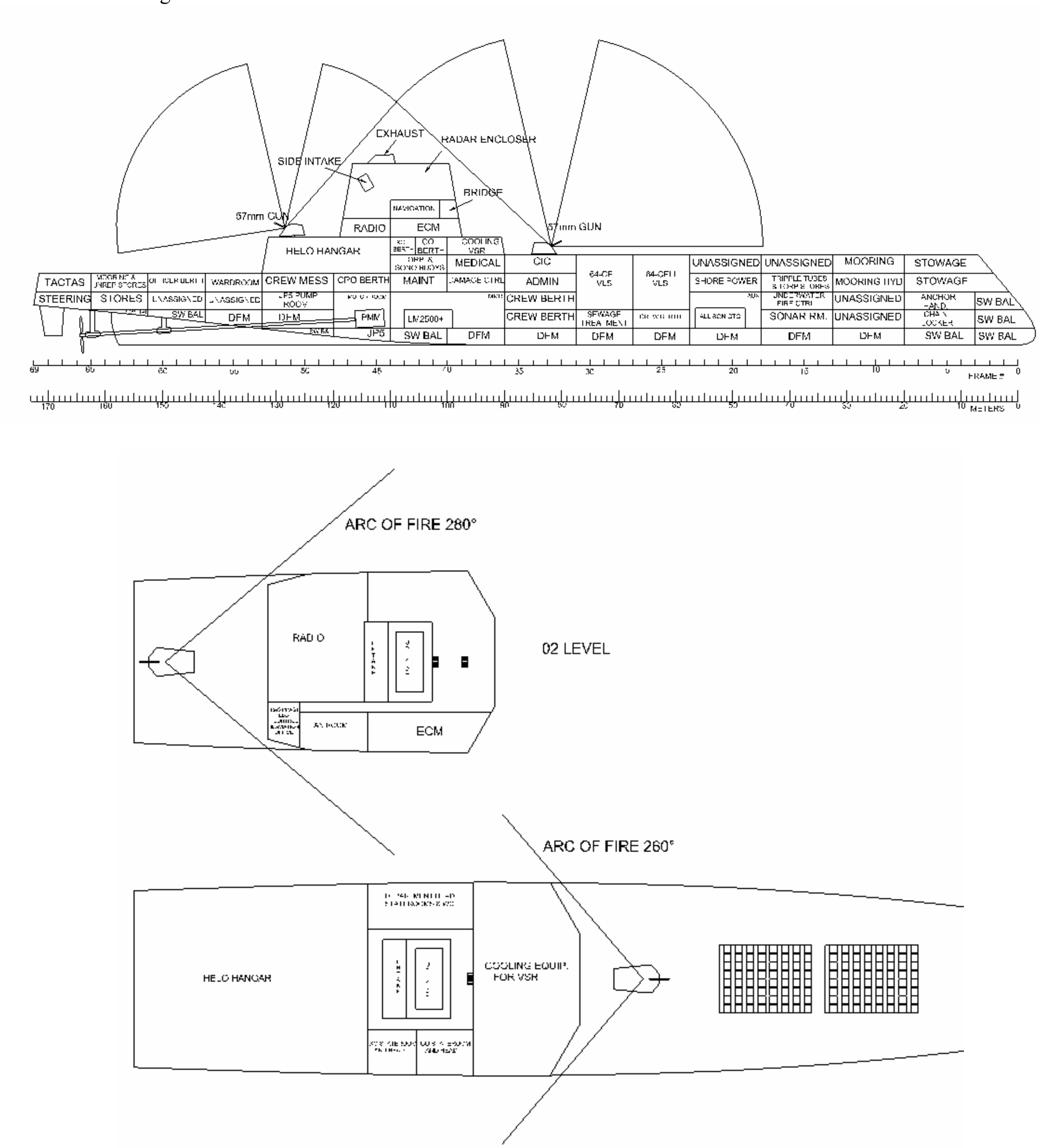

Figure 95 - Naval Gun Coverage Zones (Profile and Plan Views)

4.8 Weights and Loading

4.8.1 Weights

Ship weights are grouped by SWBS. The majority of the weights are obtained from manufacturer information. ASSET parametrics and the ship synthesis model were used when this information was unavailable. The VCGs and LCGs of the weights are determined from the general ship and machinery arrangements. These values are used to calculate mass moments and the lightship centers of gravity. A summary of lightship weights and centers of gravity by SWBS group is listed in Table 43.

Table 43–Weight Summary: Lightship

SWBS	Weight (MT)	VCG (m-BL)	LCG (m-AP)
100	5408	8.59	93.27
200	976	4.25	60.72
300	331	2.57	36.19
400	690	6.89	96.29
500	1466	11.40	86.05
600	747	9.34	88.97
700	332	12.52	102.72
Margin (1 %)	995	8.45	87.31
Total (LS + Margin)	10946	8.45	87.31

4.8.2 Loading Conditions

There are two loading conditions, as defined in U.S. Navy's DDS 079-1, to be considered for CG(x): Full Load and Minimum Operating (Min Op). The lightship weight and centers of gravity are used in both loading conditions along with the loads weights and centers in order to determine the centers of gravity for each condition. In the Full Load condition, ammunition, provisions and personal stores, general stores, and potable water are all at full capacity, while all diesel fuel marine (DFM), lubricating oil, and JP-5 tanks are filled to 95% capacity. In the Minimum Operating condition, ammunition, provisions and personal stores, general stores, and potable water are all at 33% capacity, while all diesel fuel marine (DFM), lubricating oil, and JP-5 tanks are filled to 32% capacity. Ballast tanks 1-4 are filled to 100% in the Min Op condition. A summary of the weights for the Full Load and Minimum Operating condition is provided in Table 44 and Table 45 respectively.

Table 44 – Full Load Condition: Weight Summary

Item	Weight (MT)	VCG (m-BL)	LCG (m-AP)
Total (LS + Margin)	10946	8.45	87.31
Ships Force	27	11.53	88.41
Ship Ammunition	220	12.26	102.02
Ord Del Sys Ammo	5	14.20	77.50
Ord Del Sys (Aircraft)	13	15.30	63.28
Provisions and Personal Stores	35	8.51	88.41
General Stores	11	9.64	88.41
Diesel Fuel Marine (DFM)	1875	2.45	90.39
JP-5	99	2.25	56.66
Lubricating Oil	21	2.09	61.28
Sea Water Ballast	0	0.00	0.00
Fresh Water	48	4.38	88.41
Total	13300	7.61	87.70

Table 45 –Minimum Operating Condition: Weight Summary

Item	Weight (MT)	VCG (m-BL)	LCG (m-AP)
Total (LS + Margin)	10946	8.45	87.31
Ships Force	27	11.53	88.41
Ship Ammunition	73	12.26	102.02
Ord Del Sys Ammo	5	14.20	77.50
Ord Del Sys (Aircraft)	13	15.30	63.28
Provisions and Personal Stores	12	8.51	88.41
General Stores	4	9.64	88.41
Diesel Fuel Marine (DFM)	632	1.59	90.47
JP-5	33	1.71	57.04
Lubricating Oil	7	1.45	61.31
Waster Oil	0	0.00	0.00
Sea Water Ballast	43	1.93	88.61
Fresh Water	32	4.10	88.36
Sewage	35	1.75	103.74
Total	11862	8.04	87.50

4.9 Hydrostatics and Stability

HECSALV was employed to assess the hydrostatics, intact stability, and damage stability of CG(x). The ship offsets are imported from RHINO and hydrostatics are calculated for a range of drafts. The curves of form, coefficients of form, and cross curves are calculated using this information. Once the load conditions are defined and balanced, intact stability and damage stability are analyzed.

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. Two criteria must be met to achieve satisfactory intact stability: (1) the heeling arm at the intersection of the righting arm and heeling arm curves must not be six-tenths of the maximum righting arm; (2) the area under the righting arm curve 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). The Full Load trim and stability summary are shown in Table 46 and the Min Op trim and stability summary are shown in Table 47. Figure 96 and Table 48 show the Full Load condition righting arm and heeling arm curve and the accompanying data respectively. Min Op results can be seen in Figure 97 and Table 49.

Table 46 – Full Load: Trim and Stability Summary

Item	Weight	VCG (m-BL)	LCG (m-AP)	TCG (m-CL)	FSMom (m-MT)
Lightship	10946	8.45	87.31	0.01 S	0
Lube Oil	21	2.087	61.28	0	30
Fresh Water	48	4.376	88.41	0	0
Sea Water Ballast	0				
Diesel Fuel Marine (DFM)	1875	2.449	90.39	0.02 P	2215
JP-5	99	2.245	56.655	0	125
Waste Oil	0				
Sewage	0				
Misc. Weights	320	11.99	96.23	0.090 S	0
Displacement	13309	7.619	87.694	0.003 S	2371

Stability Calculation		Trim Calculation	
KMt	10.375 m	LCF Draft	7.782 m
VCG	7.619 m	LCB	87.629 m-AP
GMt (Solid)	2.756 m	LCF Draft	77.027 m-AP
FSc	0.178 m	MT1cm	279 m-MT/cm
GMt (Corrected)	2.578 m	Trim	0.056 m-Aft
		List	0.1 S deg

Table 47 – Minimum Operating: Intact Trim and Stability Summary

Item	Weight	VCG (m-BL)	LCG (m-AP)	TCG (m-CL)	FSMom (m-MT)
Lightship	10946	8.45	87.31	0.01 S	0
Lube Oil	7	1.447	61.31	1.1713 P	26
Fresh Water	32	4.097	88.356	0	5
Sea Water Ballast	0				0
Diesel Fuel Marine (DFM)	632	1.59	90.474	0.014 P	1887
JP-5	33	1.708	57.04	0	127
Waste Oil	43	1.928	88.613	0.109 S	54
Sewage	35	1.751	103.743	2.868 S	48
Misc. Weights	137	28	92.77	0.120 S	0
Displacement	11865	8.232	87.498	0.018 S	2146

Stability Calculation		Trim Calculation	
KMt	10.734 m	LCF Draft	7.256 m
VCG	8.232 m	LCB	87.414 m-AP
GMt (Solid)	2.502 m	LCF Draft	77.199 m-AP
FSc	0.181 m	MT1cm	278 m-MT/cm
GMt (Corrected)	2.321 m	Trim	0.694 m-Aft
		List	0.4 S deg

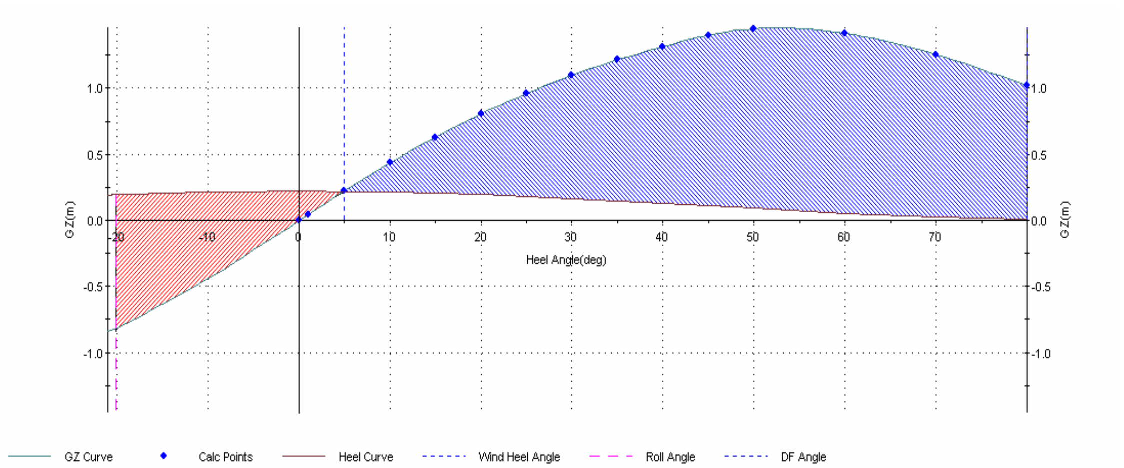

Figure 96 – Full Load Condition: Righting Arm (GZ) and Heeling Arm Curve

Table 48 – Full Load Condition: Righting Arm (GZ) and Heeling Arm Curve Data

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	13309 MT	Angle at Maximum GZ	52.7 deg
GMt (corrected)	2.578 m	Wind Heeling Arm Lw	0.218 m
Mean Draft	7.5 m	Angle at Intercept	52.7 deg
Projected Sail Area	1300 m^2	Wind Heel Angle	5 deg
Vertical Arm	13.14 m-BL	Maximum GZ	1.458 m
Wind Pressure Factor	0.0035	Righting Area A1	1.29 m-rad
Wind Pressure	0.02 bar	Capsizing Area A2	0.23 m-rad
Wind Velocity	100 knts	Heeling Arm at 0 deg	0.22 deg
Roll Back Angle	25 deg		

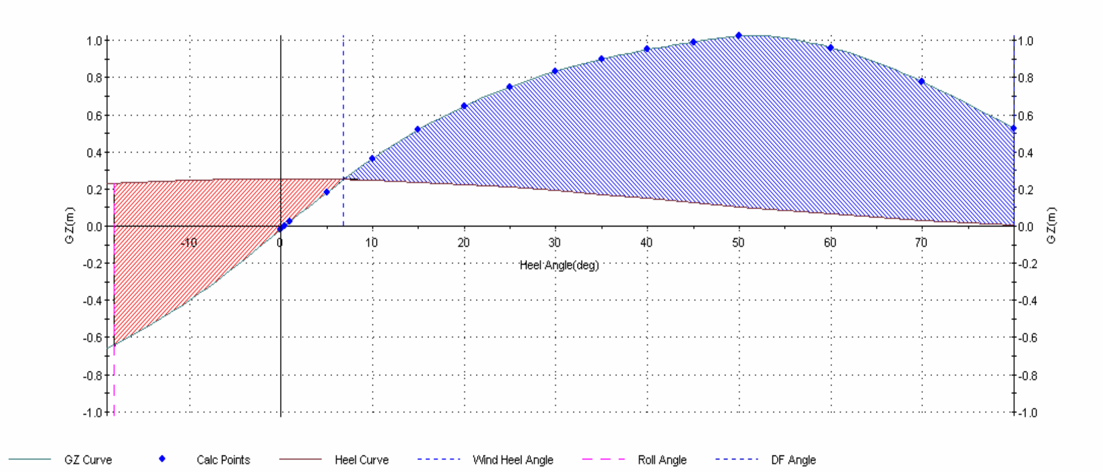

Figure 97 – Min Op Condition: Righting Arm (GZ) and Heeling Arm Curve

Table 49 - Min Op Condition: Righting Arm (GZ) and Heeling Arm Data

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Displacement	10946 MT	Angle at Maximum GZ	50.9 deg
GMt (corrected	2.578 m	Wind Heeling Arm Lw	0.255 m
Mean Draft	7.5 m	Angle at Intercept	50.9 deg
Projected Sail Area	1300 m^2	Wind Heel Angle	7 deg
Vertical Arm	12.86 m-BL	Maximum GZ	0.99 m
Wind Pressure Factor	0.0035	Righting Area A1	0.81 m-rad
Wind Pressure	0.02 bar	Capsizing Area A2	0.2 m-rad
Wind Velocity	100 knts	Heeling Arm at 0 deg	0.259 deg
Roll Back Angle	25 deg		

The calculated trim and heel are acceptable for the ship's stability criteria for both lading conditions. Both conditions for beam winds with rolling defined by DDS 079-1 are also satisfied. Therefore, CG(x) is satisfactory in both loading conditions for intact stability.

4.9.2 Damage Stability

Transverse bulkheads are located to insure floodable length requirements are met. The Full Load and Minimum Operating conditions are then analyzed for damage stability using a 15% LWL damage length in accordance with DDS 079-1 for surface combatants. The 15% damage length, 25.9 meters for CG(x), is applied along the length of the center hull from bow to stern. Worst case penetration to centerline and penetration past centerline is used. The vertical height of the damage extends from the keel to the weather deck. There are 136 damage cases, 68 for each loading condition. In each case, the heel of the ship must remain less than 15 degrees, and the margin line (3 inches below the deck edge) must not be submerged. The remaining dynamic stability must also be adequate (A1 > 1.4A2).

Table 50 – Full Load: Worse Damage Cases

	Intact	Damage BH 44-57 (Trim)	Damage BH 44-57 (Heel)
Draft AP (m)	7.807	12.57	11.47
Draft FP (m)	7.751	7.503	7.676
Trim on LBP (m)	0.056 A	5.067 A	3.794 A
Total Weight (MT)	13309	20077	18544
Static Heel (deg)	0.1 S	0.3 S	15.4 S
GMt (upright) (m)	2.578	1.395	1.103
Maximum GZ (m)		0.867	0.69
Maximum GZ angle (deg)		57	61.3
GZ Pos. Range (deg)		2.4 - 80 S	15.4 - 80 S

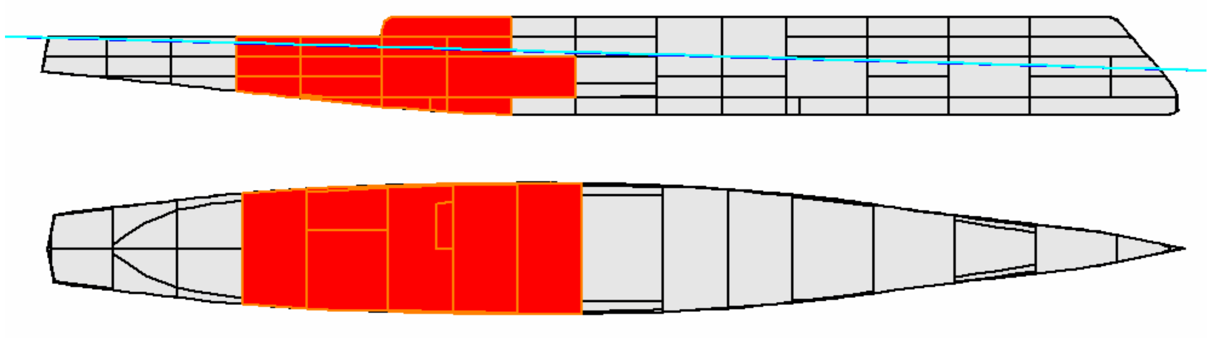

Figure 98 – Full Load: Limiting Trim Case

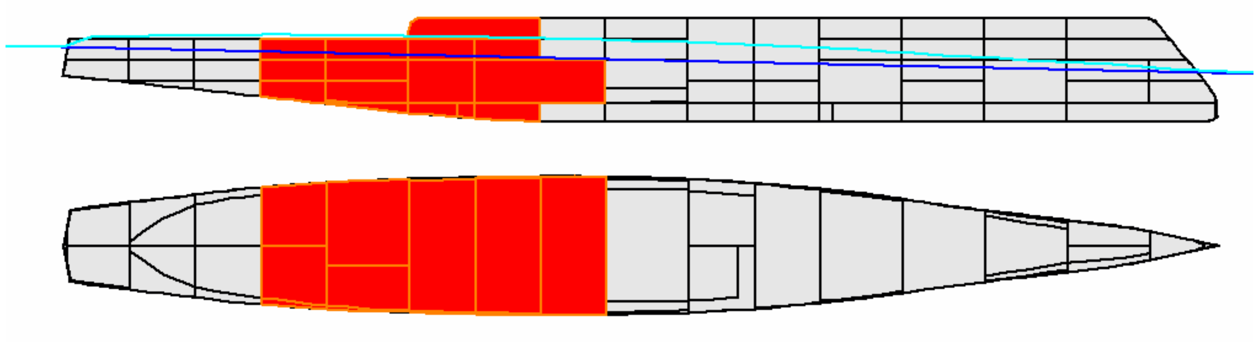

Figure 99 – Full Load: Limiting Heel Case

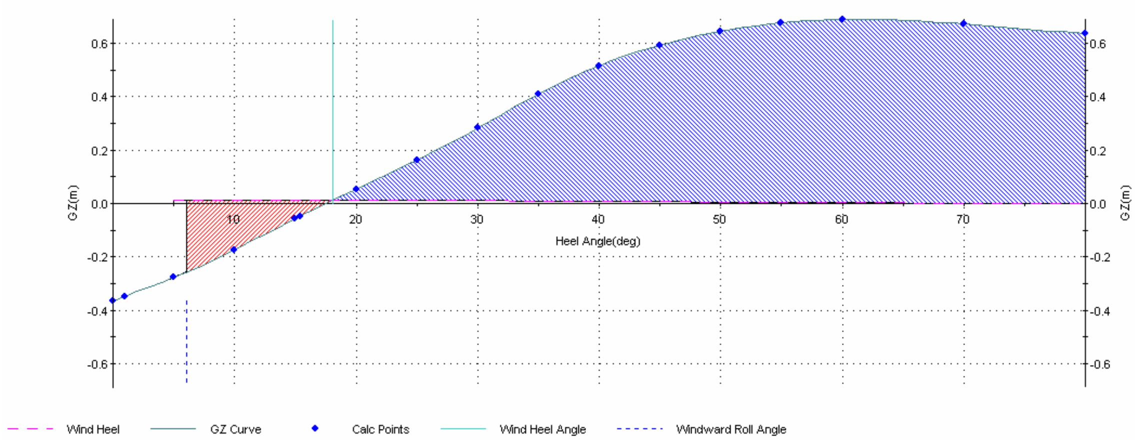

Figure 100 – Full Load: Righting Arm (GZ) and Heeling Arm for Limiting Heel Case

Table 51 – Minimum Operating: Worse Damage Cases

	Intact	Damage BH 44-57 (Trim)	Damage BH 44-57 (Heel)
Draft AP (m)	7.566	12.502	11.207
Draft FP (m)	6.872	6.735	7.088
Trim on LBP (m)	0.694 A	5.767 A	4.119 A
Total Weight (MT)	11865	19062	17283
Static Heel (deg)	0.4 S	0.8 S	23.1 S
GMt (upright) (m)	2.321	1.035	0.261
Maximum GZ (m)		0.554	0.365
Maximum GZ angle (deg)		51.7	55.6
GZ Pos. Range (deg)		3.7 - 80 S	23.1 - 80 S

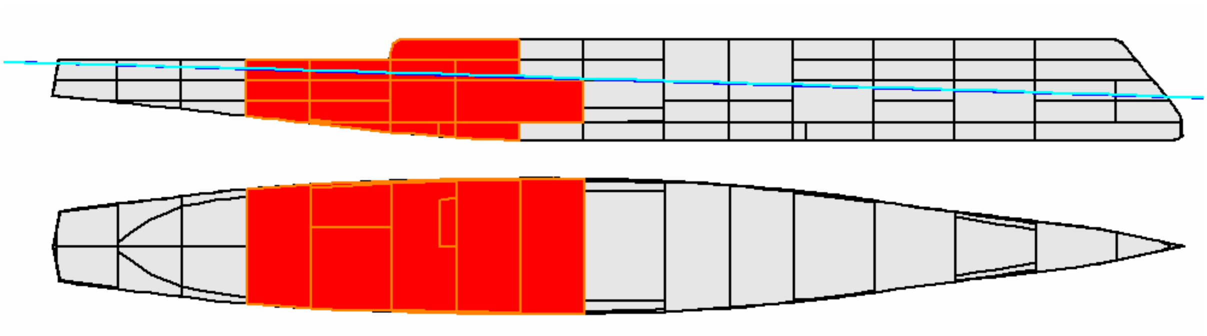

Figure 101 – Minimum Operating: Limiting Trim Case

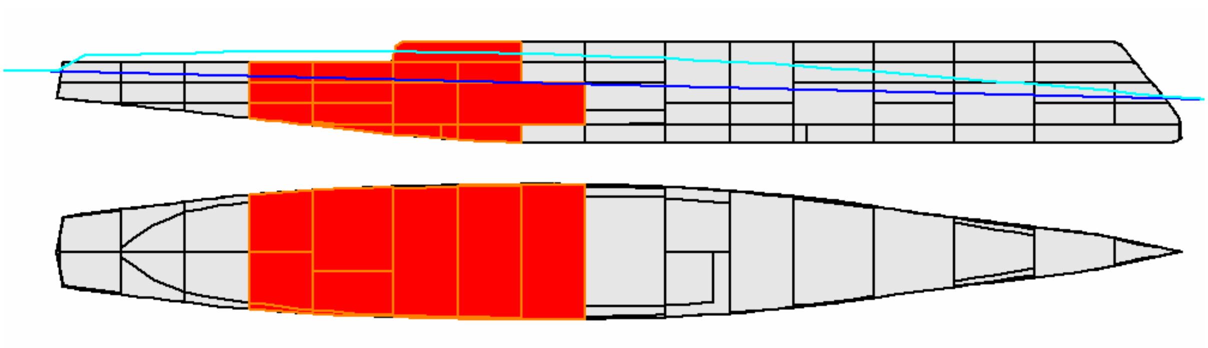

Figure 102 – Minimum Operating: Limiting Heel Case

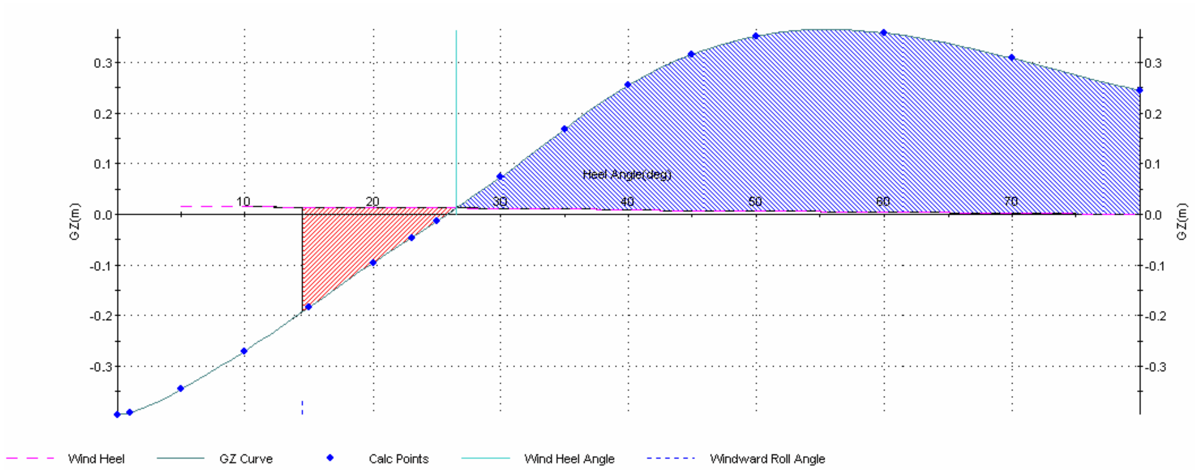

Figure 103 – Minimum Operating: Righting Arm (GZ) and Heeling Curve for Limiting Heel Case

The limiting trim and heel case for the Full Load condition is for damage between bulkheads 44 (62 meters aft of FP) and 57 (30 meters forward of AP), with the port motor room not flooded in the heel case. The results of which can be seen in Table 43Table 50. The trim case is shown in Figure 98, displaying the damaged compartments in red. Figure 99 shows the damage of the limiting heel case along with the righting arm curve in Figure 100. CG(x) damaged stability is not adequate for either the trim or heel case, this is due to submersion of the margin line in both cases and a heel angle greater than 15 degrees in the heeling case.

The limiting trim and heel case for the Minimum Operating condition is for damage between bulkheads 44 and 57 as well, with the port motor room not flooded in the heel case. The results of which can be seen in Table 51. The trim case is shown in Figure 101, displaying the damaged compartments in red. Figure 102 shows the damage of the limiting heel case along with the righting arm curve in Figure 103. CG(x) damaged stability is adequate for the limiting trim case; however, damaged stability is not adequate for the limiting heel case due to submersion of the margin line and a heel angle greater than 15 degrees.

4.10 Cost and Risk Analysis

4.10.1 Cost and Producibility

As part of the multi-objective optimization performed at the end of concept exploration (see sections 3.4.3, 3.5, and 3.6), cost was estimated for both lead ship and follow ship using parametric mathematical models. These models use, primarily, the rough estimates for weight (by SWBS group) determined by other parametric math models to estimate the basic cost of construction. Other factors considered included endurance range, brake horsepower, propulsion system type (IPS vs. mechanical), and engine type. Estimates for shipbuilder profit, government costs and change orders, and a variety of other capital-consuming aspects were added to this cost to come up with the final cost estimates.

In concept development, many of the assumptions and estimations on which the cost estimate was based were changed, or re-calculated as firm numbers presented themselves or as the design changed. Therefore, a re-estimation of cost is in order at the end of concept development.

Table 52 compares the estimates for the estimates at the two stages of design. It was attempted to reduce the cost as much as possible. The hull remains similar to that of DD(X), reducing research and construction costs. Both ships have large sections of hull that are flat or of a single curvature, so on top of the shared geometry (and thus, jigs, etc., in the shipyard) is an inherently cheaper-to-produce design. The CIWS, which was indicated in the optimization, was removed in favor of relying on the two 57-mm cannon for close-in defense—this reduces not only the cost of the installed systems and ammunition, but eliminates some maintenance issues, reducing operational cost.

4.10.2 Risk

CG(X) is a design with moderate risk. The optimization resulted in an OMOR of about 0.4, which is moderate. Some changes were made in concept development which reduce the risk, such as enclosing all radars, minimizing the deckhouse, channeling all of the main exhaust through a single stack, utilizing the two (much stealthier) 57-mm cannon for close-in defense, and providing a very large helipad. The enclosed radars, the smaller deckhouse, the single stack, the loss of the very un-stealthy Phalanx, and what amounts to a doubling of CIWS capability all reduce the likelihood of an enemy weapon hitting the ship. Changes made in order to achieve those ends included the combining of all main engines in a single machinery room—the decrease in signature described above should compensate for the increase in vulnerability, and moreover given the addition of heavy armor around the machinery spaces and VLS. However, the research necessary to prove and quantify this is beyond the means of students with regards to both time and capability—the math models which were used to calculate risk do not factor in many of these variables, so the approach taken in section 4.10.1 will not work here.

Table 52 - Lead and Follow Ship Cost Estimate Comparison

Characteristic	Concept Baseline	Final Concept Design
Design Variables		
Hull Structure Material	Steel	Steel
Deck House Material	Steel	Steel
Hull Form	Monohull - wave piercing tumblehome	Monohull - wave piercing tumblehome
Sustained Speed	30.2 knots	30.2 knots
Endurance Speed	20 knots	20 knots
Endurance Range	5523 nm	5130 nm
Propulsion and Power	2 Shaft FPP	2 Shaft FPP
	IPS	IPS
	3xLM2500+	3xLM2500+
	2x Allison 501k34	2x Allison 501k34
BHP	79 MW	90.0 MW
Fuel Volume	2248	2248
Weights (MT)		
Lightship Weight	10948	10946
Full Load Displacement	13168	13300
100 (hull structures)	5409	5409
200 (propulsion plant)	976	976
300 (electrical)	332	332
400 (command and surveillance)	691	691
500 (auxiliary)	1466	1466
600 (outfit)	750	748
700 (armament)	332	332
Internal communications	59	59
Ordinance Loads Weight	249	249
Operating and support		
Number of Officer Crew	33	21
Number of Enlisted Crew	199	211
Total Crew	232	232
Fuel Usage (Gal./Yr.)	5.374E+06	5.374E+06
Service Life (years)	30	30
Cost Elements		
Number of Ships to be Built	20	20
Shipbuilder	$731.71M	$741.09M
Government Furnished Equipment (a)	$878.3M	$889.1M
Other Costs	$31.99M	$34.31M
Follow Ship Acquisition Cost	$1.642B	$1.665B
Personnel (Direct &Indirect)	$403.8M	$404.2M
Unit Level Consumption (Fuel, Supplies, Stores, etc.)	$110.2M	$110.03M
Life-Cycle Cost	$2.156B	$2.179B

5 Conclusions and Future Work

5.1 Final Concept Design

Table 53 – Final Concept Design with Comparison to Baseline

Characteristic	Concept Baseline	Final Concept Design
Hullform	Wave-piercing tumblehome	Wave-piercing tumble-home
LWL	172.5 m	172.5 m
Beam	21.75 m	21.75 m
Draft	7.5 m	7.5 m
D10	15.75 m	15.75 m
Lightship weight	10,948 MT	10,946 MT
Full load weight	13,168 MT	13,300 MT
W1 (MT)	5409	5409
W2 (MT)	976	976
W3 (MT)	332	332
W4 (MT)	691	691
W5 (MT)	1466	1467
W6 (MT)	750	748
W7 (MT)	332	332
Sustained Speed	30.2 knots	30.2 knots
Endurance Speed	20 knots	20 knots
Endurance Range	5523 nm	5130 nm
Propulsion and Power	2 Shaft FPP	2 Shaft FPP
	IPS	IPS
	3xLM2500+	3xLM2500+
	2x Allison 501k34	2x Allison 501k34
BHP	90.0 MW	90.0 MW
AAW system	SPY-3 (4 panel), VSR, AEGIS MK 99 FCS	SPY-3 (4 panel), VSR, AEGIS MK 99 FCS
ASUW system	SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker	SPS-73(V)12, MK 160/34 GFCS, Small Arms Locker
ASW system	SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS	SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
NSFS	2 MK 110 57 mm gun	2 MK 110 57 mm gun
CCC/STK/SEW	Enhanced CCC	Enhanced CCC
GMLS	128 cells, MK 41 and/or	128 cells, MK 41 and/or
	MK57 PVLS	MK57 PVLS
SDS	1 X CIWS	NONE
LAMPS	Embarked single LAMPS w/Hangar	Embarked single LAMPS w/Hangar
Total Officers	33	21
Total Enlisted	199	211
Total Manning	232	232
OMOE (Effectiveness)	0.816	0.816
OMOR (Risk)	0.396	0.396
Lead Ship Acquisition Cost	$2.351B	$2.380 B
Follow Ship Acquisition Cost	$1.642B	$1.665 B
Life-Cycle Cost	$2.156B	$2.179 B

Displacement increased for full load weight due to an increased amount of detail that was put into the load calculation. Endurance Range increased due to an increase of resistance than earlier anticipated by previous calculation. The CIWS was eliminated due to the fact the 57 mm performed all the necessary applications for the ship. The overall total manning number did not change, however the officers decreased and the enlisted numbers increased. This was due to the current numbers are based on the latest DDG and CG manning numbers. The original estimate, however, was based on the FORTRAN model in Model Center.

5.2 Assessment

A comparison of final concept design results to ORD requirements is presented in Table 54.

Table 54 – Compliance with Requirements

Technical Performance Measure	Original Threshold	Original Goal	Concept BL	ORD TPM (Req.)	Final Concept BL
Hull	Flare	Wave-piercing Tumblehome	Wave-piercing Tumblehome	Wave-piercing Tumblehome	Wave-piercing Tumblehome
Endurance Range (nm)	4000	6000	5523	5523	5130
Sustained Speed (knots)	29	35	30.2	30.2	30.2
Endurance Speed (knots)	20	20	20	20	20
Stores Duration (days)	45	60	60	60	60
Crew Size	232	332	232	232	232
RCS (m3)	4248	2832	4000	4000	5118
Maximum Draft (m)	7.5	7.5	7.5	7.5	7.5
Vulnerability (Hull Material)	Composite	Steel	Steel	Steel	Steel
Ballast/fuel system	Comp. Fuel	Clean	Clean	Clean	Clean
Degaussing System	No	Yes	Yes	Yes	Yes
Average follow-ship Acquisition Cost	$2.2 B	$1.3 B	$1.642 B	$1.7 B	$1.665 B
Life-Cycle Cost			$2.156B	$2.156 B	$2.179 B
OMOR (Risk)	0	1	0.816	0.816	0.816
OMOE (Effectiveness)	0	1	0.396	0.396	0.396

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Appendix A – Mission Need Statement (MNS)

MISSION NEED STATEMENT

FOR

21st CENTURY SURFACE COMBAT PLATFORM(s)

1. DEFENSE PLANNING GUIDANCE ELEMENT.

The Department of the Navy's 1992 white paper, "From the Sea", outlines a significant change in priorities from a "Blue Water Navy fighting a traditional Super Power". The rapidly changing global political climate, and seven major theater operations conducted over the following 22 months, prompted the Department of the Navy to publish a revised white paper, "Forward from the Sea", in December 1994.

"Forward from the Sea" emphasizes the importance of action against aggression of regional powers at the farthest points on the globe. Such action requires a rapid, flexible response to emergent crises which projects decisive military power to protect vital U.S. interests (including economic interests), and defend friends and allies. It states, "...the most important mission of naval forces in situations short of war is to be *engaged* in forward areas, with the objectives of *preventing* conflicts and *controlling* crises". Naval forces have five fundamental and enduring roles in support of the National Security Strategy: projection of power from sea to land, sea control and maritime supremacy, strategic deterrence, strategic sealift, and forward naval presence.

Recently, the Quadrennial Defense Review Report, the Department of the Navy's whitepaper, "Naval Transformational Roadmap", and CNO's "Sea Power 21" vision statement provide additional unclassified guidance and clarification on current DoD and USN defense policies and priorities.

The Quadrennial Defense Review Report identifies six critical US military operational goals. These are: 1) protecting critical bases of operations; 2) assuring information systems; 3) protecting and sustaining US forces while defeating denial threats; 4) denying enemy sanctuary by persistent surveillance, 5) tracking and rapid engagement; 6) enhancing space systems; and 7) leveraging information technology.

The "Naval Transformational Roadmap" and "Sea Power 21" provide the US Navy's plan to Support these goals including nine necessary war fighting capabilities in the areas of Sea Strike – strategic agility, maneuverability, ISR, time-sensitive strikes; Sea Shield – project defense around allies, exploit control of seas, littoral sea control, counter threats; and Sea Base – accelerated deployment & employment time, enhanced seaborne positioning of joint assets.

This Mission Need Statement specifically addresses critical components of Sea Strike and Sea Shield consistent with operational goals 1), 3) and 5) of the Quadrennial Defense Review. While addressing these capabilities, there is also a need to reduce cost and minimize personnel in harms way.

2. MISSION AND THREAT ANALYSIS.

a. Threat.

(1) The shift in emphasis from global Super Power conflict to numerous regional conflicts requires increased flexibility to counter a variety of threat scenarios which may rapidly develop. Two distinct classes of threats to U.S. national security interests exist:
(a) Threats from nations with either a superior military capability, or the demonstrated interest in acquiring such a capability. Specific weapons systems that could be encountered include ballistic missiles, land and surface launched cruise missiles, significant land based air assets and submarines.
(b) Threats from smaller nations who support, promote, and perpetrate activities which cause regional instabilities detrimental to international security and/or have the potential for development of nuclear weapons. Specific weapon systems include diesel/electric submarines, land-based air assets, and mines.

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

b. Mission

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

(2) The new platforms must ultimately perform the missions of all ship classes to be replaced, including traditional "Blue Water" AAW, ASUW and ASW operations. This may be accomplished by a single multi-mission platform or a family of multiple mission platforms.

(3) Power Projection requires the execution and support of flexible strike missions and support of naval amphibious operations. This includes gunfire support, protection to friendly forces from enemy attack, unit self defense against littoral threats, area defense, and theater ballistic missile defense.

(4) The platforms must be able to maintain Battle Space Dominance, including: command/control/communications/connectivity and intelligence (C_4/I) operations beyond weapons range.

(5) The platforms must be able to support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C_4/I reconnaissance

vehicles.

(6) The platform must possess sufficient mobility and endurance to perform all missions on extremely short notice, at locations far removed from home port.

(8) The platform must be able to support non-combatant or NEO operations in conjunction with national directives. It must be flexible enough to support a peacetime presence mission yet be able to provide instant wartime response should a crisis escalate.

c. Need:

With the decommissioning of the *Perry* class frigates, the number of surface combatants available
to carry out these requirements has been significantly reduced. The current inventory of exceptionally capable ships, the *Ticonderoga* and *Arleigh Burke* classes, will be retired before the
end of the third decade of the next century. **There is a need for multi and multiple mission ships to complement, and eventually replace the *Ticonderoga* and *Arleigh Burke* class surface combatants. Immediate deficiencies include strike, fire support, and Ballistic Missile Defense (BMD). These new ships must start delivery no later than 2003.**

3. NON-MATERIAL ALTERNATIVES.

a. Change the U.S. role in the world by reducing U.S. international involvement.

b. Increase reliance on foreign political and military activity to meet the interests of the U.S.

c. Increase reliance on non-military assets and options to enhance the U.S. performance of the missions identified above while requiring a smaller inventory of naval forces.

4. POTENTIAL MATERIAL ALTERNATIVES.

a. Retain and upgrade current fleet assets as necessary. Possibilities include a service life extension to the most capable current assets. Continue production of the *Arleigh Burke* class at a rate that maintains surface combatant force levels.

b. Design and build a new modified-repeat DDG. Select those changes that satisfy identified mission deficiencies, improve overall capabilities, or improve affordability.

c. Design and build a new class or classes of surface combatant ships satisfying current mission deficiencies in strike, fire support, and Ballistic Missile Defense (BMD). Upgrade or follow these ships with additional new ships to replace multi-mission capability of retiring ships.

d. Design and build a family of variants with a single hull design and common HM&E which is configured for adaptability to alternate mission or combat system capabilities.

5. CONSTRAINTS.

a. The cost of the platforms must be kept to the absolute minimum, acknowledging the rapidly decreasing U.S. defense department budget.

b. The platforms must be highly producible, minimizing the time from concept to delivery to the Fleet.
The design must be flexible enough to support variants if necessary.

c. The platforms must operate in current logistics support capabilities.

d. Inter-service and Allied C_4/I (inter-operability) must be considered in the development of any new platform or the upgrade of existing assets.

e. The platform or system must be capable of operating in the following environments:
(1) A dense contact and threat environment;
(2) Conventional and nuclear weapons environments;
(3) Open ocean (sea states 0 through 9) and littoral regions;
(4) All-Weather, Battle Group Environments;
(5) Independent operations.

f. The platform must have absolute minimum manning.

Appendix B– Acquisition Decision Memorandum

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

215 Randolph Hall
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Phone # 540-231-6611 Fax: 540-231-9632

August 24, 2005

From: Virginia Tech Naval Acquisition Executive
To: CG(X) Design Teams

Subject: ACQUISITION DECISION MEMORANDUM FOR an Air Superiority Cruiser

Ref: (a) Virginia Tech SC-21 Battle Force Combatant Mission Need Statement

1. This memorandum authorizes concept exploration of a single material alternative proposed in Reference (a) to the Virginia Tech Naval Acquisition Board on 24 August 2005. Additional material and non-material alternatives supporting this mission may be authorized in the future.

2. Concept exploration is authorized for a CG(X) Air Superiority Cruiser consistent with the mission requirements and constraints specified in Reference (a), with particular emphasis on providing outer umbrella air superiority for the entire battle force, and supporting national ballistic missile defense using long-range missiles (Kinetic Energy Interceptor, KEI) and air defense X-band radars currently under development. The radar system must be able to: counter low-radar cross section (RCS) threats at extended ranges; and detect, track and engage ballistic missiles outside of the atmosphere. Additional essential requirements include survival in a high-threat environment and operation in all warfare areas (multi-mission). The design must minimize personnel vulnerability in combat through automation, innovative concepts for minimum crew size, and signature reduction. CG(X) must consider significant commonality with DD-21/DD(X) including: propulsion and power system and hull form. Likely differences include additional missile capacity, and removal of the Advanced Gun System (AGS). Concepts shall include moderate to high-risk alternatives. Average follow-ship acquisition cost shall not exceed \$1.7B (FY2010) with a lead ship acquisition cost less than \$2.5B. It is expected that 18 ships of this type will be built with IOC in 2015.

A.J. Brown
VT Acquisition Executive

Appendix C– Operational Requirements Document

Operational Requirements Document (ORD)
Air Superiority CG(X) Cruiser Design 4-76
Virginia Tech Team 1

1. Mission Need Summary

The CG(X) requirement is based on the Virginia Tech CG(X) Mission Need Statement (MNS) and Acquisition Decision Memorandum (ADM). CG(X) must perform the following missions:

1. Surface action group (SAG)
2. Carrier battle group (CBG)
3. Independent ballistic missile defense (BMD)

CG(X) is likely to be forward deployed in peacetime, conducting extended cruises to sensitive regions prepositioned for BMD. Producibility cost reductions should be assumed when CG(X) propulsion and hull are similar to current DD(X)'s integrated power system (IPS) and reduced radar cross section (RCS) hull. Capabilities of CG(X) include sustained air superiority, and detection, tracking, and engagement of ballistic missiles outside the atmosphere. CG(X) will provide BMD, anti-air warfare (AAW), anti-surface warfare (ASUW), anti-submarine warfare (ASW), and power projection ashore while maintaining outer umbrella of air superiority. CG(X) must reduce crew size, operational, and support costs to meet current naval requirements.

2. Acquisition Decision Memorandum (ADM)

Concept exploration is authorized for a CG(X) Air Superiority Cruiser consistent with the mission requirements and constraints specified in the CG(X) MNS, with particular emphasis on providing outer umbrella air superiority for the entire battle force, and supporting national ballistic missile defense using long-range missiles and air defense X-band radars currently under development. The radar system must be able to: counter low-radar cross section (RCS) threats at extended ranges; and detect, track and engage ballistic missiles outside of the atmosphere. Additional essential requirements include survival in a high-threat environment and operation in all warfare areas (multi-mission). The design must minimize personnel vulnerability in combat through automation, innovative concepts for minimum crew size, and signature reduction. CG(X) should consider design alternatives that have significant commonality with DD-21/DD(X) including: propulsion and power system and hull form. Likely differences include additional missile capacity, and removal of the Advanced Gun System (AGS). Concepts shall include moderate to high-risk alternatives. Average follow-ship acquisition cost shall not exceed \$2.0B (\$FY2010) with a lead ship acquisition cost less than \$2.7B. It is expected that 18 ships of this type will be built with IOC in 2015.

3. Results of Concept Exploration

Concept exploration was performed using a multi-objective genetic optimization (MOGO). A broad range of non-dominated CG(X) alternatives within the scope of the ADM were identified based on average follow-ship cost, effectiveness and risk. **This ORD specifies a requirement for concept development of CG(X) design alternative 4-76.** Other alternatives are specified in separate ORDs. Design 4-76 is a medium risk, medium cost, and highly effective monohull design on the non-dominated frontier shown in Figure 1.

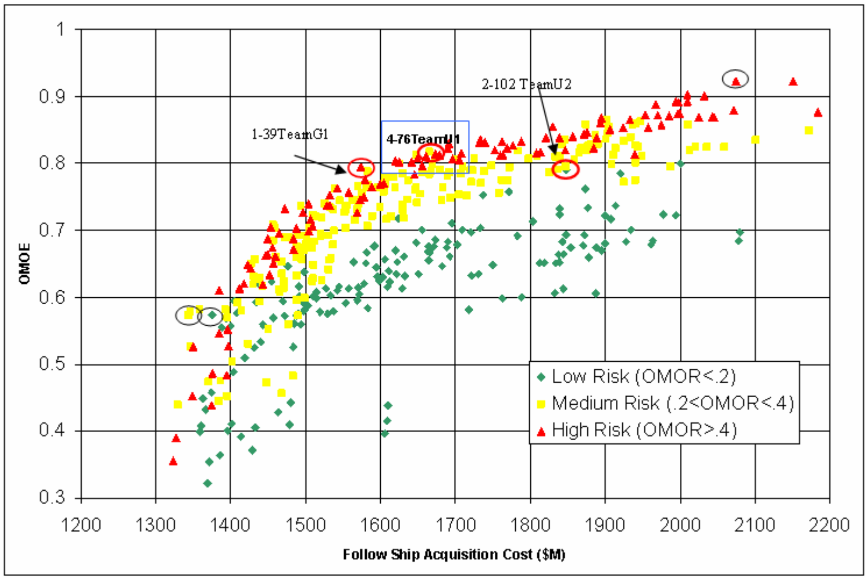

Figure 1 - CG(X) Non-Dominated Frontier (NDF)

4. Technical Performance Measures (TPMs) and System Requirements

TPM	Threshold	
Mission payload	AAW	SPY-3 (4 panel), VSR, Aegis MK 99 FCS
	ASUW	SPS-73(V)12, Mk 160/34 GFCS, Small Arms Locker
	ASW	SQS-53D, SQQ 89, ASROC, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
	NSFS	2xMK 110 57 mm gun
	CCC	Enhanced CCC
	LAMPS	Embarked Single LAMPS w/ Hangar
	SDS	1xCIWS
	GMLS	128 cells, MK 41 and/or MK 57 PVLS
Hull	Wave-piercing Tumblehome	
Power and Propulsion	IPS, 2 shaft FPP, 3xLM2500+, 2xAllison 501K34	
Endurance Range (nm)	5523	
Sustained Speed (knots)	30.2	
Endurance Speed (knots)	20	
Stores Duration (days)	60	
CBR	full	
Crew Size	232	
RCS (m^3)	4000	
Maximum Draft (m)	7.5	
Vulnerability (Hull Material)	Steel	
Ballast/fuel system	Clean, separate ballast tanks	
Degaussing System	Yes	
McCreight Seakeeping Index	25.0	
Seakeeping Capabilities (sea state)		
- launch and recover aircraft	5	
- full capability of all systems	6	
- survive	8	

5. Program Requirements

Program Requirement	Threshold
Average follow-ship acquisition cost (FY2010 $M)	1642
Lead ship acquisition cost (FY2010 $M)	2351
Life cycle cost (FY2010 $M)	2156
Maximum level of risk (OMOR)	0.396

6. Other Design Requirements, Constraints and Margins

KG margin (m)	0.5
Propulsion power margin (design)	10%
Propulsion power margin (fouling and seastate)	25% (0.8 MCR)
Electrical margins	5%
Weight margin (design and service)	5%

7. Special Design Considerations and Standards

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

- General Specifications for Ships of the USN (1995)
- 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 = 2010
- IOC = 2015
- Total ship acquisition = N_S = 20 ships
- Production rate = R_P = 2 per year

Appendix D - Machinery Equipment List (MEL)

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION	SWBS #	REMARKS	PWR REQ'D	UNIT WEIGHT (kg)	DIMENSIONS LxWxH (mm)
1	3	Gas Turbine, Main	GE LM 2500+ Marine Gas Turbine	26MW	MMR	234	Includes Acoustic Enclosure	8 kW	15000	8434 x 2906 x 3064
2	3	Generator, Main GT	4160 V AC 60 HZ	26 MW	MMR	234		-		1870 x 2906 x 3064
3	2	Gas Turbine, Auxillary	Allison 501k34 - 460 V AC 60 HZ	3.5 MW	AMR	234	Includes Enclosure and Generator	-	29256	8656 x 2377 x 3383
4	2	Motor, Propulsion	PM AC Motor	35MW	PMR.A,B	235		-	108000	5050 (L) x 3000 (dia)
5	4	Converter, Prpln Power	AC/AC	6500 kW	MMR	235		-	12000	8000 x 1625 x 2206
6	2	Control Unit, Prpln Motor		-	MMR	235		-	850	2400 x 900 x 2080
7	2	Exciter Unit, Prpln Motor		40kW	MMR	235	Standby Units		580	1200 x 900 x 2080
8	4	Power Conversion Module		10 MW	MMR	235		-	10000	3660 x 1680 x 3050
9	2	Shaft, Line	575 mm (OD), 380 mm (ID)	-	various	243	ABS Grade 2 Steel	-	14090	11800
10	2	Shaft, Stern Tube	600 mm (OD), 400mm (ID)	-	various	243	ABS Grade 2 Steel	-	25000	19,000
11	2	Shaft, Tail	625 mm (OD, 400 mm (ID)	-	various	243	ABS Grade 2 Steel	-	15000	10,000
12	4	Bearing, Line Shaft	Journal	575 mm Line Shaft	various	244		-	1762	978 x 1257 x 1220
13	2	Bearing, Main Strut	Oil Lubricated	625 mm Tail Shaft	varios	244		-	900	1250 (L) x 680 (OD)
14	4	Bearing, Stern Tube	Oil Lubricated	600 mm Stern Tube Shaft	various	244		-	438	600 (L) x 680 (OD)
15	2	Propeller, Fixed Pitch	5 Blades, Ni-AL Bronze	-	-	245		-	25000	6000 (D)
16	1	Console, Main Control	Main Propulsion	NA	MMR	252	MMR upper level looking down on engines	5 kW	3632	8334 x 1219 x 2134
17	2	Pump, FW Cooling	Centrifugal, Vertical, Motor Driven	600 m3/hr @4bar	MMR	256	1 Duty / 1 Standby Per central cooling loop	125 HP	1287	724 x 724 x 1905
18	2	Cooler, FW	Plate Type	-	MMR	256		-	2724	2997 x 762 x 1499
19	2	Strainer, Seawater	Simplex Basket	-	MMR	256		-	6577	2438 x 1829 x 3626
20	2	Pump, Main Seawater Circ	Centrifugal, Vertical, Motor Driven	230 m^3/hr @ 2 bar	MMR	256	Also STBY for Aux. SW System	30 HP	517	622 x 622 x 1511
21	4	Pump, Main Strut and Stern Tube Lube Oil	Pos. Displ., Horizontal, Motor Driven	1.1 m^3/hr @2bar	Steering Gear Room	262	2 Duty / 2 Standby	0.5 HP	82	914 x 610 x 1219
22	4	Cooler, Lube Oil	Plate Type		Various	262	For Stern Tubes and Struts	-	91	610 x 204 x 533
23	4	Filter/ Coalescer, Lube Oil		1.1 m^3/hr	Various	262	For Stern Tubes and Struts	-	68	914 (L) x 410 (OD)
24	2	Purifier, MGTG Lube Oil	Centrifugal, Vertical, Motor Driven	2.9 m^3/hr	Purifier Rooms	264		12 kW	1620	1120 x 1470 x 1420
25	2	Pump, MGTG Lube Oil Purifier Feed	Pos. Displ., Horizontal, Motor Driven	2.9 m^3/hr @ 5bar	MMR	264		1.5HP	120	683 x 330 x 232
26	2	Purifier Heater, MGTG Lube Oil	Electric		Purifier Rooms	264		56 kW	106	580 x 355 x 895
27	1	Pump, Lube Oil Transfer	Pos. Displ., Horizontal, Motor Driven	6.5 m^3/hr@5bar	MMR	264		5 HP	165	800 x 267 x 318
28	1	UPS	Centralized Control	100 A	EOS	313		-	150	1829 x 610 x 610
29	1	Shore Power Facility		2400 A		324		-	363	2134 x 610 x 2286
30	1	Switchboard, Propulsion				324		-	12000	6400 x 2439 x 2286
31	1	Switchboard, Ships Service	Generator Control Power Distribution	-	MMR	324	MMR upper level in main control	-	11804	6096 x 1220 x 2286
32	1	Switchboard, Ships Service	Generator Control Power Distribution	-	AMR	324	AMR upper level	-	3950	4572 x 1220 x 2286
33	4	Switchboard, Load Center	Power Distribution	-	various	324				
34	4	Propulsion Motor Control Center	460 V / 3 Phase	-	Various	324		-	727	2439 x 508 x 2286
35	3	Assembly, MGT Lube Oil Storage and Conditioning	Includes Oil Storage and Cooler	NA	MMR	264	next to engines	-	680	1525 x 760 x 1040
36	4	Air Conditioning Plants	150 Ton, Centrifugal Units	150 ton	AC & R	514	lower level	200 HP	4994	3353 x 1500 x 2159

ITEM	QTY	NOMENCLATURE	DESCRIPTION	CAPACITY RATING	LOCATION	SWBS #	REMARKS	PWR REQ'D	UNIT WEIGHT (kg)	DIMENSIONS LxWxH (mm)
36	4	Air Conditioning Plants	150 Ton, Centrifugal Units	150 ton	AC & R	514	lower level	200 HP	4994	3353 x 1500 x 2159
37	2	Refrig Plants, Ships Service	R-134a	4.3 ton	AC & R	516	lower level	19 kW	1040	2464 x 813 x 2083
38	2	MN Machinery Space Fan	Supply	94762 m^3/hr	MMR INTAKE	512		50 HP	522	1118 (L) x 1384 (dia)
39	2	MN Machinery Space Fan	Exhaust	91644 m^3/hr	MMR UPTAKE	512		30 HP	522	1118 (L) x 1384 (dia)
40	4	Aux Machinery Space Fan	Supply	61164 m^3/hr	FAN ROOM	512		30 HP	477	1092 (L) x 1118 (dia)
41	4	Aux Machinery Space Fan	Exhaust	61164 m^3/hr	FAN ROOM	512		20 HP	477	1092 (L) x 1118 (dia)
42	6	Pump, Fire	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	VARIOUS	521	lower levels	250 HP	1458	2490 x 711 x 864
43	1	Pump, Fire/Ballast	Centrifugal, Horizontal, Motor Driven	454 m^3/hr @ 9 bar	AMR	521	lower levels	250 HP	1458	2490 x 711 x 864
44	2	Pump, Bilge	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	AMR	529	lower levels	40 HP	926	1651 x 635 x 1702
45	1	Pump, Bilge/Ballast	Centrifugal, Horizontal, Motor Driven	227 m^3/hr @3.8 bar	AMR	529	lower levels	40 HP	926	1651 x 635 x 737
46	2	Distiller, Fresh Water	Distilling Unit	76 m^3/day (3.2 m^3/hr)	AMR	531	lower level	2 HP	8172 (wet)	2794 x 3048 x 2794
47	2	Brominator	Proportioning	1.5 m^3/hr	AMR	531	lower level	-	11.5	965 x 203 x 406
48	4	Pump, Chilled Water	Centrifugal, Horizontal, Motor Driven	128 m^3/hr @4.1 bar	AC & R	532	next to AC plants	30 HP	377	1321 x 381 x 508
49	2	Pump, Potable Water	Centrifugal, Horizontal, Motor Driven	22.7 m^3/hr @ 4.8 bar	AMR	533	next to distillers	10 HP	189	787 x 559 x 356
50	2	Brominator	Recirculation	5.7 m^3/hr	AMR	533	next to distillers	5 HP	118	533 x 356 x 1042
51	2	Filter Separator, MGT Fuel	2-Stage, Static, 5 Micron	30 m^3/hr	MMR	541	next to FO purifiers	-	295	1600 (L) x 762 (dia)
52	2	Purifier, Fuel Oil	Self Cleaning, Centrifugal, Partial Discharge Type	7.0 m^3/hr	MMR	541		12 HP	1050	1200 x 1200 x 1600
53	2	Pump, Fuel Transfer	Gear, Motor Driven	45.4 m^3/hr @ 5.2 bar	MMR	541	next to FO purifiers	30 HP	400	1423 x 559 x 686
54	2	Pump, JP-5 Transfer	Rotary, Motor Driven	11.5 m^3/hr @ 4.1 bar	JP-5 PUMP ROOM	542		3 HP	261	1194 x 483 x 508
55	2	Pump, JP-5 Service	Rotary, Motor Driven	22.7 m^3/hr @ 7.6 bar	JP-5 PUMP ROOM	542		10 HP	261	1194 x 483 x 508
56	1	Pump, JP-5 Stripping	Rotary, Motor Driven	5.7 m^3/hr @ 3.4 bar	JP-5 PUMP ROOM	542		1.5 HP	386	915 x 381 x 381
57	2	Filter/Separ., JP-5 Transfer	Static, Two Stage	17 m^3/hr	JP-5 PUMP ROOM	542		-	363	457 (L) x 1321 (dia)
58	2	Filter/Separ., JP-5 Service	Static, Two Stage	22.7 m^3/hr	JP-5 PUMP ROOM	542		-	316	407 (L) x 1219 (dia)
59	2	Receiver, Starting Air	Steel, Cylindrical	2.3 m^3	MMR	551	near ME	-	976	1067 (dia) x 2185 (H)
60	2	Compressor, Start Air	Reciprocating Motor Driven, Water Cooled	80 m^3/hr FADY @ 30 bar	MMR	551	upper level	17 kW	570	1334 x 841 x 836
61	1	Receiver, Ship Service Air	Steel, Cylindrical	1.7 m^3	MMR	551		-	726	1830 (H) x 965 (dia)
62	1	Receiver, Control Air	Steel, Cylindrical	1 m^3	MMR	551		-	427	3421 (H) x 610 (dia)
63	2	Compressor, Air, LP Ship Service	Reciprocating, Rotary Screw	8.6 bar @ 194 SCFM	MMR	551	upper level	50 HP	1000	1346 x 1067 x 1829
64	1	Dryer, Air	Refrigerant Type	250 SCFM	MMR	551	near LP air compressor	-	259	610 x 864 x 1473
65	2	Station, AFFF	Skid Mounted	227 m^3/hr @3.8 bar	above MMR	555	for entering space	7.5 HP	1200	2190 x 1070 x 1750
66	3	Unit, MGT Hydraulic Starting	HPU with Pumps and Reservior	14.8 m^3/hr @ 414 bar	MMR	556	near ME	150 kW	2373	1354 x 2092 x 2021
67	2	Pump, Oily Waste Transfer	Motor Driven	12.3 m^3/hr @ 7.6 bar	MMR	593	lower level	10 HP	286	1219 x 635 x 813
68	2	Separator, Oil/Water	Coalescer Plate Type	2.7 m^3/hr	MMR	593	lower level near oily waste transfer pump	1 kW	500 (dry)	1321 x 965 x 1473
69	2	Hydraulic Pump and Motor	Steering Gear		aft Steering Gear Room		over rudders			2000x800x800
70	1	Hydraulic Steering Ram	Steering Gear		aft Steering Gear Room		over rudders			1200x5500x1500
71	1	Unit, Sewage Collection	Vacuum Collection Type w/ Pumps	28 m^3	SEWAGE TREATMENT	593		5.4 HP	1567	2642 x 1854 x 1575
72	1	Sewage Plant	Biological Type	225 people	SEWAGE TREATMENT	593		6.4 kW	980	1778 x 1092 x 2007

Appendix E - Personnel Support Arrangement Requirements

PERSONNEL SUPPORT ARRANGEMENT REQUIREMENTS
(PER GEN SPECS AND NAVSEA DESIGN PRACTICES
AND CRITERIA MANUAL CHAPTER 070)

GENERAL PERSONNEL MOVEMENT:

1. All compartments must be closable by some appropriate means depending upon the compartment's particular purpose and location.

2. High traffic passageways must have at least 36" clear width (normally 48" actual width)(27" on submarines) and provide the most direct and convenient route where practical. Bridge level and control stations in particular should have the most direct route. Minimum clear passage width for stretchers in medical spaces is 60".

3. Headroom should be 6'5" (6'3" for subs) at minimum, except steering gear room can be less.

4. Door and arches in transverse bulkheads, with passage routes on the same level, generally should be located in line longitudinally.

5. Two fore-and-aft passages, well separated port and starboard, shall be provided on the DC Deck with transverse passages at suitable intervals, approximately every other subdivision.

6. A set of two vertical access trunks shall be provided within each subdivision from the DC Deck passageways to all other decks, levels and platforms. Preferable they shall be vertically aligned for ease of escape in smoke or dark.

7. There shall be no access opening in the subdivision bulkheads below the DC Deck. All personnel access trunks that pass through the DC deck shall have an access on the DC deck.

8. Egress from a vital space manned with 10 or more men or all other spaces manned with 21 men or more shall have two means separated widely apart. One may be the normal access. The secondary means of egress is primarily for emergency escape (e.g. overhead scuttle). If this compartment is within a watertight envelope, then access should be into another watertight compartment.

9. Vital spaces that do not have direct access above the V-lines shall be provided a watertight trunk to a location above the V-lines. Minimum size for watertight trunks shall be 48 inches square.

10. Spaces which are manned below the watertight level and manned at general quarters shall be provided with an access in the overhead.

11. At least one vertical means of access is required for all ballistically protected spaces.

There shall be sufficient passages to provide direct access from the main passageways to each compartment which is manned or requires frequent inspections.

13. Machinery spaces should have as a minimum one normal access (inclined ladder) and one escape route. If over 50 feet long, two means of normal access and two escape trunks should be provided. Escape trunks shall extend from the lowest operating level to the deck above the V-lines or the DC deck, but in no case above the weather deck. An enclosed operating station having normal access through the machinery spaces shall be provided with an escape route that does not lead through the machinery space.

14. Damage Control spaces for cruisers, destroyers and frigates shall include Repair 2, 3, 5, and Crash and Salvage. Each repair station shall be accessible from the weather deck via two independent access routes.

FIRE ZONE BOUNDARIES:

A fire zone boundary is a physical boundary designed to retard the passage of flame and smoke. Designated by symbol "FZ" on general arrangement drawing.

1. Surface ships with LOA greater than 220 feet shall be divided into vertical fire zones by utilizing main subdivision bulkheads and portions of the deck where the subdivision is stepped. FZ bulkheads shall be continued from main subdivision bulkheads through the superstructure.

2. The distance between FZ boundaries shall not exceed 131 feet.

VITAL SPACES:

Vital spaces are those spaces in which continued operation is essential for maintaining ship control, propulsion, communications, seaworthiness, and fighting capability.

1. Vital spaces entirely or partially below the flooding water levels shall have watertight boundaries.

2. All vital spaces except fan rooms and electronic cooling equipment rooms are considered manned.

PRINCIPAL WATERTIGHT BULKHEADS:

The main transverse watertight bulkheads, the shell, and the damage control deck constitutes the watertight envelope and subdivision which enables the ship to maintain watertight integrity and survive extensive underwater damage.

GENERAL REQUIREMENTS FOR LIVING, MESSING AND RECREATION SPACES:

1. Clearance: A primary access in berthing spaces should not be less than 36" (27" submarines) with secondary accesses not less than 24" (On submarines, 24" for officers, 20" for CPO's, 18" for enlisted).

2. One berth per accommodation. Accomodations shall be 110% of ship's complement.

3. "Net walking area" is defined as the compartment area not taken up as fixed furniture such as berths, lockers, etc.

NET WALKING AREA (minimum, for ships 301-600 feet, Ref: OPNAV 9330.5A)

Commanding Officer	70 sq ft	
Executive Officer	55	
Department Head (single)	45	
Double Stateroom	22	
Officer Bunk Room	20	(Maximum of 6 berths per stateroom)
CPO	10	
Crew	7	

4. A Wardroom Galley is NOT required on frigates.

Maximum accommodations per sanitary facility:

	Waterclosets	Showers
Officers	8	10
Chief Petty Officers	10	12
Crew Members	23	25

6. Lounge Facilities: There should be one seat allocated for each:

5 Officers
3 Chief Petty Officers
10 Crew Members

7. There should be sufficient messing space to provide feeding for 30% of the crew at one setting.

8. A frigate size ship shall have one main and one auxiliary battle dressing station and a medical treatment room (sick bay).

9. In the service spaces, a barber shop with 2 chairs, and a walk-in ship store are required. Ship store area =0.60*(No. accommodations) <1100 ft sq.

10. A physical fitness room shall be provided on ships with 200 or more accommodations.

Appendix F – Approximate Living Areas

SSCS	GROUP	APROX. MIN. AREA M2
2	HUMAN SUPPORT	702.3
2.1	LIVING	460.7
2.11	OFFICER LIVING	120
2.111	BERTHING	100.5114
2.1111	SHIP OFFICER	98.4
2.11111	COMMANDING OFFICER STATEROOM	13.9
2.111121	EXECUTIVE OFFICER STATEROOM	12.1
2.111123	DEPARTMENT HEAD STATEROOM	11.1
2.11113	OFFICER STATEROOM (DBL)	61.3
2.1114	AVIATION OFFICER	
2.112	SANITARY	17.9
2.1121	SHIP OFFICER	17.9
2.11211	COMMANDING OFFICER BATH	4.6
2.11212	EXECUTIVE OFFICER BATH	2.8
2.11212	OFFICER BATH	
2.11213	OFFICER WR, WC & SH	10.5
2.1124	AVIATION OFFICER	
2.12	CPO LIVING	52.4
2.121	BERTHING	37.6
2.122	SANITARY	14.8
2.13	CREW LIVING	273
2.131	BERTHING	232.2
2.132	SANITARY	40.8
2.133	RECREATION	
2.14	GENERAL SANITARY FACILITIES	6.9
2.142	BRIDGE WASHRM & WC	2.3
2.143	DECK WASHRM & WC	2.3
2.144	ENGINEERING WR & WC	2.3
2.15	SHIP RECREATION FAC	5.1
2.151	MUSIC	2
2.152	MOTION PIC FILM+EQUIP	1.9
2.153	PHYSICAL FITNESS	1.2
2.154	TV ROOM	
2.16	TRAINING	3.3
2.2	COMMISSARY	195.9
2.21	FOOD SERVICE	134.2
2.211	WARDROOM MESSRM & LOUNGE	34.8
2.212	CPO MESSROOM AND LOUNGE	12.8
2.213	CREW MESSROOM	86.6
2.22	COMMISSARY SERVICE SPACES	47.1
2.221	FOOD PREPARATION SPACES	
2.222	GALLEY	30.4
2.2222	WARD ROOM GALLEY	8.7
2.2224	CREW GALLEY	21.7
2.223	WARDROOM PANTRY	7.4
2.224	SCULLERY	9.3
2.23	FOOD STORAGE+ISSUE	14.6
2.231	CHILL PROVISIONS	3.3
2.232	FROZEN PROVISIONS	3.6
2.233	DRY PROVISIONS	7.7
2.3	MEDICAL+DENTAL	8.1
2.4	GENERAL SERVICES	23.2
2.41	SHIP STORE FACILITIES	11.1
2.42	LAUNDRY FACILITIES	12.1
2.44	BARBER SERVICE	
2.46	POSTAL SERVICE	
2.47	BRIG	
2.48	RELIGIOUS	
2.5	PERSONNEL STORES	9.2
2.51	BAGGAGE STOREROOMS	2.8
2.52	MESSROOM STORES	3.3
2.55	FOUL WEATHER GEAR	0.8
2.56	LINEN STOWAGE	1.7
2.57	FOLDING CHAIR STOREROOM	0.6
2.6	CBR PROTECTION	3.3
2.61	CBR DECON STATIONS	
2.62	CBR DEFENSE EQUIPMENT	3.3
2.63	CPS AIRLOCKS	
2.7	LIFESAVING EQUIPMENT	1.9

SSCS	GROUP	APROX. MIN. AREA M2
3	SHIP SUPPORT	278.7
3.1	SHIP CNTL SYS (STEERING)	34.9
3.11	STEERING GEAR	34.9
3.12	ROLL STABILIZATION	
3.15	STEERING CONTROL	
3.2	DAMAGE CONTROL	39.7
3.21	DAMAGE CNTRL CENTRAL	
3.22	REPAIR STATIONS	28.1
3.25	FIRE FIGHTING	11.6
3.3	SHIP ADMINISTRATION	85.3
3.301	GENERAL SHIP	10.1
3.302	EXECUTIVE DEPT	23.1
3.303	ENGINEERING DEPT	14.2
3.304	SUPPLY DEPT	29.4
3.305	DECK DEPT	6.1
3.306	OPERATIONS DEPT	2.4
3.307	WEAPONS DEPT	
3.31	SHIP PHOTO/PRINT SVCS	
3.5	DECK AUXILIARIES	21.5
3.51	ANCHOR HANDLING	14.4
3.52	LINE HANDLING	
3.53	TRANSFER-AT-SEA	7.1
3.54	SHIP BOATS STOWAGE	
3.6	SHIP MAINTENANCE	59.9
3.61	ENGINEERING DEPT	46.1
3.611	AUX (FILTER CLEANING)	5.4
3.612	ELECTRICAL	12.7
3.613	MECH (GENERAL WK SHOP)	17.8
3.614	PROPULSION MAINTENANCE	10.2
3.62	OPERATIONS DEPT (ELECT SHOP)	4.9
3.63	WEAPONS DEPT (ORDINANCE SHOP)	3
3.64	DECK DEPT (CARPENTER SHOP)	5.9
3.7	STOWAGE	37.4
3.71	SUPPLY DEPT	29.7
3.711	HAZARDOUS MATL (FLAM LIQ)	2.1
3.712	SPECIAL CLOTHING	9.9
3.713	GEN USE CONSUM+REPAIR PART	13.5
3.714	SHIP STORE STORES	0.5
3.715	STORES HANDLING	3.7
3.72	ENGINEERING DEPT	0.4
3.73	OPERATIONS DEPT	0.6
3.74	DECK DEPT (BOATSWAIN STORES)	5.5
3.75	WEAPONS DEPT	0.4
3.76	EXEC DEPT (MASTER-AT-ARMS STOR)	0.5
3.78	CLEANING GEAR STOWAGE	0.3

Appendix G - Fortran Code

Feasibility

```
      Program Feasible
         real KWg,KWgreq,KW24avg
         integer PSYStype
! Input
!   Atr=total required arrangeable area (m2)
!   Ata=total available arrangeable area (m2)
!   Adr=required deckhouse area (m2)
!   Ada=available deckhouse area (m2)
!   E=endurance range (nm)
!   Emin=endurance range threshold (nm)
!   Vs=sustained speed (knts)
!   Vsmin=sustained speed threshold (knts)
!     KWg=ship service electrical power, ea (kW)
!     KWgreq=required ship service generator electrical power, ea (kW)
!     Cgmbmin=minimum GM/B
!     Cgmbmax=maximum GM/B
!     Cgmb=GM/B
!     D10=hull depth at station 10 (m)
!     D10=minimum hull depth at station 10
!
      open(4,file='Feasible.in',status='old')
         read(4,*) Atr,Ata,Adr,Ada,E,Emin,Vsmin,Vs,KWg,KWgreq,Cgmbmin,Cgmbmax,&
                Cgmb,D10,D10MIN,Pebavg,Pbpengend,KW24avg,PSYStype
         close(4)
!
         If(PSYStype.eq.2.or.PSYStype.eq.4) then
            Pebavg=Pebavg+KW24avg
            KWg=KWgreq
         Endif
!
         Eta=(Ata-Atr)/Atr                   ! total arrangeable area feasibility ratio
         Eda=(Ada-Adr)/Adr                   ! deckhouse area feasibility ratio
         Evs=(Vs-Vsmin)/Vsmin                ! sustained speed feasibility ratio
         Eve=(Pbpengend-Pebavg)/Pbpengend    ! endurance speed feasibility ratio
         Ekw=(KWg-KWgreq)/KWgreq             ! electric power feasibility ratio
         Egmmin=(Cgmb-Cgmbmin)/Cgmbmin       ! minimum GM/B feasibility ratio
         Egmmax=(Cgmbmax-Cgmb)/Cgmbmax       ! maximum GM/B feasibility ratio
         ED10=(D10-D10MIN)/D10MIN            ! hull depth feasibility ratio
         Ee=(E-Emin)/Emin                    ! endurance range feasibility ratio
! Output
         open(5,file='Feasible.out',status='old')
         write(5,*) Eta,Eda,Evs,Eve,Ekw,Egmmin,Egmmax,ED10,Ee
         close(5)
!
      stop
         End
```

Resistance

```
      Program HoltropR
! Calculates hull resistance
         real LWL,KWmflm,V(15),Shp(15),Pireq(15),Lr,lambda,ie,m1,m4
         integer PSYStype
```

```
! Input
!     LWL=waterline length on design waterline=LBP (m)
!     B=beam on design waterline (m)
!     D10=hull depth at station 10 (m)
!     T=draft to design waterline (m)
!     S=total hull surface area to design waterline (m2)
!     Ssd=sonar dome or bulb surface area to design waterline (m2)
!     Vfl=full load displaced volume to design waterline (m3)
!     Ve=endurance speed (knt)
!     HDK=average deck height
!     KWmflm=electric maximum functional load with margins (kW)
!     Pbpengtot=total brake propulsion engine power (kW)
!     Cp=prismatic coefficient
!     Cx=maximum section coefficient
!     Ca=resistance correlation allowance
!     Cb=block coefficient
!     Cbt=beam to draft ratio
!     Cw=waterplane coefficient
!     eta=propulsion transmission efficiency
!     PSYStype=propulsion system type (1=mechanical,2=electric drive)
!     Nprop=number of propulsors
!     Nfins=number of pairs of fins
!     PMF=propulsion margin factor
!     PC=overall propulsion coefficient
!
      open(4,file='Resistance.in',status='old')
        read(4,*) LWL,B,D10,T,S,Ssd,Vfl,Ve,HDK,KWmflm,Pbpengtot,Cp,Cx,Ca,Cb,Cbt,Cw,eta,&
              PSYStype,Nprop,Nfins,PMF,PC
        close(4)
        LWL=LWL*3.28084
        B=B*3.28084
        D10=D10*3.28084
        T=T*3.28084
        S=S*10.76391
        Ssd=Ssd*10.76391
        Vfl=Vfl*35.315
        HDK=HDK*3.28084
        Pbpengtot=Pbpengtot/.7457
      KWmflm=KWmflm/.7457
!
        ro=1.9905                   ! Sea water density in [lbf*s^2/ft^4]
      Tf=T                          ! draft forward
        Cm=Cx                           ! midship section coefficient
        Cv=Vfl/LWL**3                   ! volume coefficient
        ABT=Ssd/6.                  ! sonar dome or bulb maximum cross sectional area
        hb=(ABT/3.14159)**.5        ! height of bulb center above baseline
        AT=B*T*Cx/20.                   ! transom area
      Lr=(1-Cp)*LWL                 ! hull run length
        formfac=1.03*(.93+((T/LWL)**.22284)*((B/Lr)**.92497)*((.95-Cp)**-.521448)&
              *((1-Cp+.05)**.6906))+2.7*(Ssd/S) ! form factor
        CDAPP=(-4e-9*LWL**3+9e-6*LWL**2-0.0081*LWL+5.0717)*1e-5/(1.69**3)    ! appendage drag coeffi-
cient [hp*sec^3/ft^5].
        If(Nprop.gt.1)then
          Cprop=1.0                     ! propeller diameter coefficient
        Else
            Cprop=1.2
        Endif
```

```
      Dp=(0.64*T+0.013*LWL)*Cprop ! propeller diameter
    If(PSYStype.eq.2) then
         Piprp=Pbpengtot-KWmflm/.98      ! available propulsion brake horsepower
      Else
     Piprp=Pbpengtot
      Endif
      Do 10 i=1,11
     U=Ve+2.*(i-1)
       V(i)=U*1.69        ! Convert knots to [ft/sec].
! Correlation Allowance
     Ra=.5*ro*Ca*V(i)**2*S
! Viscous resistance.
       RN=LWL*V(i)/1.2817e-5                 ! Reynold's number
       CF=0.075/(log10(RN)-2)**2             ! ITTC coefficient of frictional resistance
       Rv=0.5*ro*S*CF*formfac*V(i)**2
! Wavemaking resistance
     Fn=V(i)/(LWL*32.2)**.5               ! Froude number
     c3=.56*ABT**1.5/(B*T*(.31*ABT**.5+Tf-hb))
     c2=exp(-1.89*c3**.5)
     c5=1-.8*AT/(B*T*Cm)
     lambda=1.446*Cp-.036
     if(LWL/B.lt.12.) lambda=1.446*Cp-.03*LWL/B
     c15=-1.69385+((1/Cv)**.333-8.)/2.36
     if(1./Cv.lt.512.) c15=-1.69385
         if(1./Cv.gt.1726.91) c15=0.0
         c7=B/LWL
         if(B/LWL.lt.0.11) c7=.229577*(B/LWL)**.33333
         if(B/LWL.gt.0.25) c7=.5-.0625*LWL/B
         c16=1.73014-.7067*Cp
         if(Cp.lt.0.8) c16=8.07981*Cp-13.8673*Cp**2+6.984388*Cp**3
         ie=1+89.*exp(-(LWL/B)**.80856*(1-Cw)**.30484*(1-Cp)**.6367*(Lr/B)**.34574*(100.*Cv)**.16302)
         c1=2223105.*c7**3.78613*(T/B)**1.07961*(90.-ie)**-1.37565
         m1=.0140407*LWL/T-1.75254*(Cv)**.3333-4.79323*B/LWL-c16
         m4=.4*c15*exp(-.034*Fn**-3.29)
         Rw=Vfl*ro*32.2*c1*c2*c5*exp(m1/Fn**.9+m4*cos(lambda/Fn**2))
! Bulb Resistance
         Pb=.56*ABT**.5/(Tf-1.5*hb)
         Fni=V(i)/(32.17*(Tf-hb-.25*ABT**.5)+.15*V(i)**2)**.5
         Rb=.11*exp(-3./Pb**2)*Fni**3*ABT**1.5*ro*32.17/(1.+Fni**2)
! Transom Resistance
         FnT=V(i)/(64.34*AT/(B+B*Cw))**.5
         c6=0.
         if(FnT.lt.5.) c6=.2*(1.-.2*FnT)
         Rtr=.5*ro*V(i)**2*AT*c6
! Bare hull total resistance.
         RT=Rv+Rw+Rb+Rtr+Ra
! Effective horse power.
         PEBH=RT*V(i)/550       ! Bare hull, converted to [hp].
         PEfins=0.025*PEBH
         if(Nfins.eq.0) PEfins=0.0
         PEAPP=1.23*LWL*Dp*CDAPP*V(i)**3+PEfins    ! Appendages, in [hp].
         Aw=1.05*B*(D10-T+3*HDK)                  ! bow projected area
         Caa=.7                            ! wind resistance coefficient
         PEAA=0.5*Caa*Aw*0.0023817*V(i)**3/550    ! Air drag, in [hp].
         PET=PEBH+PEAPP+PEAA          ! Total effective power, in [hp].
         EHP=PET*PMF
         Shp(i)=EHP/PC                     ! Shaft horsepower.
```

```
            Pireq(i)=1.25*Shp(i)/eta/PMF         ! Sustained speed required total engine BHP
            If (Pireq(i).gt.Piprp) then
             If(i.eq.1) then
                Vs=Ve-5.                  ! sustained speed (knt)
             else
                Vs=(Piprp-Pireq(i-1))*(V(i)-V(i-1))/(Pireq(i)-Pireq(i-1))+V(i-1)
             endif
             Go to 20
            Endif
 10    Continue
!
       Vs=V(i-1)
 20    SHPe=Shp(1)                            ! endurance speed shaft horsepower
! Output
       SHPe=SHPe*.7457
       Dp=Dp/3.28084
       Vs=Vs/1.69
       open(5,file='Resistance.out',status='old')
       write(5,*) SHPe,Vs,Dp
       close(5)
!
      stop
       End
```

Combat

```
      program SCCombat
!
! Version 0.0; 7/10/05; AJB
! Calculates Payload characteristics; Data input in US units;
!                         otherwise input and output in SI units
!
       real WT(200),HD10(200),HAREA(200),DHAREA(200),CRSKW(200),BATKW(200),KWpay
       integer ID(200),WG(200),Pay1(14),Pay2(6),Pay3(11),Pay4(8),&
             Pay5(3),Pay6(4),Pay7(3),Pay8(2),Pay9(9),Pay10(4),Pay11(10)
       integer AAW,ASUW,ASW,CCC,MCM,NSFS,SEW,STK,GMLS,LAMPS,SDS
       real MOMp100,MOMp400,MOMp500,MOMp600,MOMp700,MOMF20,LWL,LtoD
       integer SONtype,Pay(74)
!
 998  open(4,file='SCCombat.in',status='old')
! Input
!     AAW = AAW option
!     ASUW = ASUW option
!     ASW = ASW option
!     CCC = CCC Option
!     NSFS = NSFS option
!     GMLS = GMLS option
!     LAMPS = LAMPS option
!     SDS = SDS option
!     D10 = depth at station 10
!
       read(4,*) AAW,ASUW,ASW,CCC,NSFS,GMLS,LAMPS,SDS,LWL,LtoD
!
       close(4)
!
! Convert Input to US units
       D10=LWL/LtoD
```

```
        D10=D10*3.281
!
! 1 - AAW Payload
        If(AAW.eq.1) then
                Pay1=(/1,7,15,17,19,20,20,136,137,137,0,0,0,0/)
            Else if(AAW.eq.2) then
                Pay1=(/1,7,15,17,19,20,136,137,0,0,0,0,0,0/)
            Else
                Pay1=(/1,7,15,17,6,14,14,14,14,21,21,119,119,128/)
        Endif
! 2 - ASUW Payload
        If(ASUW.eq.1) then
                Pay2=(/31,29,33,129,140,143/)
            Else
                Pay2=(/31,29,33,68,140,143/)
        Endif
! 3 - ASW Payload
        If(ASW.eq.1) then
                Pay3=(/34,43,130,49,63,40,44,51,41,38,98/)
                SONtype=2
            Else
                Pay3=(/35,44,130,58,63,39,43,51,41,38,98/)
                SONtype=0
        Endif
! 4 - C4I Payload
        If(CCC.eq.1) then
                Pay4=(/100,77,151,58,102,152,103,79/)
            Else
                Pay4=(/102,138,139,2,79,77,151,152/)
        Endif
! 5 - MCM Payload
!       If(MCM.eq.1) then
!               Pay5=(/0,0,0/)
!           Else if(MCM.eq.2) then
!               Pay5=(/0,0,0/)
!           Else if(MCM.eq.3) then
!               Pay5=(/0,0,0/)
!           Else
                Pay5=(/0,0,0/)
!       Endif
! 6 - NSFS Payload
        If(NSFS.eq.1) then
                Pay6=(/75,67,150,0/)
            Else
                Pay6=(/147,146,144,145/)
        Endif
! 7- SEW Payload
!       If(SEW.eq.1) then
!               Pay7=(/25,78,77/)
!           Else
!               Pay7=(/25,78,76/)
!       Endif
        Pay7=(/0,0,0/)
! 8 - STK Payload
            Pay8=(/0,0/)
! 9 - GMLS Payload
        If(GMLS.eq.1) then
```

```
            Pay9=(/110,109,111,112,115,113,114,116,117/)
        Else if(GMLS.eq.2) then
            Pay9=(/110,89,111,80,115,113,83,116,85/)
        Else if(GMLS.eq.3) then
            Pay9=(/109,89,112,80,115,114,83,117,85/)
        Else
            Pay9=(/89,89,80,80,115,83,83,85,85/)
      Endif
! 10- SDS Payload
      If(SDS.eq.1) then
            Pay10=(/22,24,24,12/)
       Else if(SDS.eq.2) then
            Pay10=(/12,24,123,0/)
        Else
            Pay10=(/0,0,0,0/)
      Endif
! 11- LAMPS Payload
      If(LAMPS.eq.1) then
            Pay11=(/54,53,55,56,57,36,46,47,50,52/)
       Else if(LAMPS.eq.2) then
            Pay11=(/148,53,55,56,57,36,46,47,50,52/)
        Else
            Pay11=(/149,57,36,46,48,0,0,0,0,0/)
      Endif
!
      Pay=(/Pay1,Pay2,Pay3,Pay4,Pay5,Pay6,Pay7,Pay8,Pay9,Pay10,Pay11/)    ! Payload vector
!
      open(20,file='SCPAYLOAD.prn',status='old')
      Read (20,*) NPAY
      Do 3, i=1,NPAY
 3    Read (20,*) ID(i),WG(i),WT(i),HD10(i),HAREA(i),DHAREA(i),CRSKW(i),BATKW(i)
      close(20)
      Wp100=0.01      ! payload structure weight
      Wp400=0.01      ! payload CCC weight
      CKWpay=0.0      ! payload required cruise power (kw)
      BKWpay=0.0      ! payload required battle power (kw)
      AHPC=0.0        ! payload required hull CCC area
      ADPC=0.0        ! payload required deckhouse CCC area
      Wp500=0.0       ! payload auxiliaries weight
      AHPA=0.0        ! payload required hull armament area
      ADPA=0.0        ! payload required deckhouse armament area
      Wp600=0.01      ! payload outfit weight
      Wp700=0.01      ! payload weapons weight
      WF20=0.01       ! expendable ordnance weight
      WF42=0.01       ! helo miscelaneous weights
      MOMp100=0.0 ! payload SWBS 100 weight moment
      MOMp400=0.0 ! payload SWBS 400 weight moment
      MOMp500=0.0 ! payload SWBS 500 weight moment
      MOMp600=0.0 ! payload SWBS 600 weight moment
      MOMp700=0.0 ! payload SWBS 700 weight moment
      MOMF20=0.0  ! payload SWBS F20 weight moment
      Do 100, n=1,74
        If(Pay(n).eq.0) Go to 100
        Do 10, m=1,NPAY
            If(ID(m).eq.Pay(n)) then
                If(WG(m).eq.100) then
                    Wp100=Wp100+WT(m)
```

```
                MOMp100=MOMp100+WT(m)*HD10(m)
            Endif
            If(WG(m).eq.400) then
                Wp400=Wp400+WT(m)
                MOMp400=MOMp400+WT(m)*HD10(m)
                CKWpay=CKWpay+CRSKW(m)
                BKWpay=BKWpay+BATKW(m)
                AHPC=AHPC+HAREA(m)
                ADPC=ADPC+DHAREA(m)
            Endif
            If(WG(m).eq.500) then
                Wp500=Wp500+WT(m)
                MOMp500=MOMp500+WT(m)*HD10(m)
                CKWpay=CKWpay+CRSKW(m)
                BKWpay=BKWpay+BATKW(m)
                AHPA=AHPA+HAREA(m)
                ADPA=ADPA+DHAREA(m)
            Endif
            If(WG(m).eq.600) then
                Wp600=Wp600+WT(m)
                MOMp600=MOMp600+WT(m)*HD10(m)
                AHPA=AHPA+HAREA(m)
                ADPA=ADPA+DHAREA(m)
            Endif
            If(WG(m).eq.700) then
                Wp700=Wp700+WT(m)
                MOMp700=MOMp700+WT(m)*HD10(m)
                CKWpay=CKWpay+CRSKW(m)
                BKWpay=BKWpay+BATKW(m)
                AHPA=AHPA+HAREA(m)
                ADPA=ADPA+DHAREA(m)
            Endif
            If(WG(m).eq.20) then
                WF20=WF20+WT(m)
                MOMF20=MOMF20+WT(m)*HD10(m)
                CKWpay=CKWpay+CRSKW(m)
                BKWpay=BKWpay+BATKW(m)
                AHPA=AHPA+HAREA(m)
                ADPA=ADPA+DHAREA(m)
            Endif
            If(WG(m).eq.40) then
                WF42=WT(m)
                VCGF42=HD10(m)+D10
            Endif
            Go to 100
        Endif
10      Continue
100  Continue
        VCGp100=D10+MOMp100/Wp100      ! payload SWBS 100 VCG
        VCGp400=D10+MOMp400/Wp400      ! payload SWBS 400 VCG
        VCGp500=D10+MOMp500/Wp500      ! payload SWBS 500 VCG
        VCGp600=D10+MOMp600/Wp600      ! payload SWBS 600 VCG
        VCGp700=D10+MOMp700/Wp700      ! payload SWBS 700 VCG
        VCGF20=D10+MOMF20/WF20         ! payload SWBS F20 VCG
        Wvp=WF20+WF42                  ! variable payload weight
        VCGvp=(WF20*VCGF20+WF42*VCGF42)/Wvp    ! variable payload VCG
        Wp=Wvp+Wp100+Wp400+Wp500+Wp600+Wp700 ! payload weight
```

```
            VCGp=(Wvp*VCGvp+Wp100*VCGp100+Wp400*VCGp400+Wp500*VCGp500+&
                    Wp600*VCGp600+Wp700*VCGp700)/Wp                    ! payload VCG
            KWpay=BKWpay                               ! payload electric power required
            ADPR=ADPA+ADPC                               ! payload deckhouse area required
            AHPR=AHPA+AHPC                               ! payload hull area required
! Convert Output to SI units
            Wp=Wp*1.016047
            VCGp=VCGp*.3048
            Wvp=Wvp*1.016047
            VCGvp=VCGvp*.3048
            Wp100=Wp100*1.016047
            VCGp100=VCGp100*.3048
            Wp400=Wp400*1.016047
            VCGp400=VCGp400*.3048
            Wp500=Wp500*1.016047
            VCGp500=VCGp500*.3048
            Wp600=Wp600*1.016047
            VCGp600=VCGp600*.3048
            Wp700=Wp700*1.016047
            VCGp700=VCGp700*.3048
            WF42=WF42*1.016047
            WF20=WF20*1.016047
            ADPC=ADPC*.0929
            ADPA=ADPA*.0929
            AHPC=AHPC*.0929
            AHPA=AHPA*.0929
            ADPR=ADPR*.0929
            AHPR=AHPR*.0929
            D10=D10/3.281
!
        open(5,file='SCCombat.out',status='old')
! Output
        write(5,*) Wp,VCGp,Wvp,VCGvp,Wp100,VCGp100,Wp400,VCGp400,Wp500,VCGp500,&
                Wp600,VCGp600,Wp700,VCGp700,WF42,WF20,SONtype,&
            ADPC,ADPA,AHPC,AHPA,KWpay,ADPR,AHPR,D10
!
        close(5)
!
      stop
        End
```

Electric

```
      Program SCElectric
! This subroutine calculates electrical load and auxiliary machinery rooms
! total volume.All loads in [kW].
      real LWL,KWp,KWs,KWe,KWm,KWcps,KWb,KWf,KWhn,KWa,KWserv,KWnp,KWpay
        real KWmfl,KWh,KWv,KWac,KWmflm,KWgreq,KW24,KW24avg,KG,KWfins
! Input
!     LWL=length at design waterline=LBP (m)
!     T=draft to design waterline (m)
!     Vt=total ship volume (m3)
!     Vfl=full load displaced hull volume (m3)
!     VD=deckhouse volume
!     Pbpengtot=total brake propulsion power (kW)
!     Vht=total hull volume (m3)
!     KWpay=payload required electric power (kW)
!     Vmb=propulsion machinery box volume required (m3)
```

```
!     Ncps=Collective Protection System alternative (0=none,1=partial,2=full)
!     Nfins=number of stabilizer fin pairs
!     Nssg=number of ship service generators
!     EFMF=electric power fuel margin factor
!     EDMF=electric power design margin factor
!     E24MF=electric power 24 hour average margin factor
!     PSYStype=propulsion system type (1=mechanical, 2=elctric drive
!     CMan=manning reduction and automation factor
!     Wp=total payload weight
!     Nprop=number of propulsors
!
      open(4,file='SCelectric.in',status='old')
        read(4,*) LWL,T,Vt,Vfl,VD,Pbpengtot,Vht,KWpay,Vmb,Ncps,Nfins,Nssg,EFMF,&
              EDMF,E24MF,PSYStype,CMan,Wp,Nprop
        close(4)
        LWL=LWL*3.28084
        T=T*3.28084
        Vt=Vt*35.315
        Pbpengtot=Pbpengtot/.7457
        Vht=Vht*35.315
        Vmb=Vmb*35.315
        Vfl=Vfl*35.315
        VD=VD*35.315
      Wp=Wp/1.016047
!
!       Manning
        NO=4+INT(Nprop+Wp/150+(Vfl+VD)/35000)            !=number fo officers
        NE=INT(CMan*(Nprop*9+Nssg*3+Wp/25+(Vfl+VD)/1900))    !=number of enlisted
        NT=NO+NE                                             !=total crew
        NA=INT(.1*NT)                                        !=additional accomodations
!
        KWp=0.00323*Pbpengtot                 !=propulsion auxiliary electric power reqd
        KWs=0.00826*LWL*T                     !=steering electric power reqd, SWBS 561
        KWe=0.000213*Vt                       !=SWBS 300 electric power reqd
        Wcps=Ncps*.00005*Vt                   !=Collective Protection System weight
        if(Wcps.gt.0.0) KWcps=0.000135*Vt  !=Collective Protection System electric power reqd
        KWm=101.4                             !=miscelaneous electric power reqd
        KWb=0.235*NT                      !=auxiliary boiler electric power reqd
        KWf=0.000097*Vt               !=firefighting electgric power reqd, SWBS 521
        KWhn=0.000177*Vht                 !=fuel handling electric power reqd, SWBS 540
        KWfins=Nfins*50.                  !=stabilizing fins electric power reqd
        KWa=0.65*NT+KWfins                    !=misc auxiliary electric power reqd
        KWserv=0.395*NT                       !=services electric power reqd, SWBS 600
        KWnp=KWp+KWs+KWe+KWm+KWb+KWf+KWhn+KWa+KWserv     !=total non-payload electric power
reqd
! Iterative loop for net electrical load and AMR volume.
        KWmfl=3000.0        ! First guess at maximum functional load
 1      Vaux=56900.0*KWmfl/3411.0     !auxiliary machinery room reqd volume
        KWh=0.00064*(Vt-Vmb-Vaux)             !=heating reqd electric power
        KWv=0.103*(KWh+KWpay)+KWcps          !=ventilation reqd electric power
        KWac=0.67*(0.1*NT+0.00067*(Vt-Vmb-Vaux)+0.1*KWpay)    !=air conditioning reqd electric power
        KWhorac=max(KWh,KWac)                 !=maximum of heating or AC reqd electric power
        f=KWnp+KWhorac+KWv+KWpay
        if(abs((KWmfl-f)/KWmfl).gt.0.01) then
            KWmfl=f
            goto 1
        endif
```

```
      KWmfl=f
      Vaux=56900.0*KWmfl/3411.0
      KWmflm=EDMF*EFMF*KWmfl            ! maximum functional load with margins
      KWgreq=KWmflm/(Nssg-1)/0.9        ! electric power reqd per generator
      if(PSYStype.eq.2) KWgreq=1000.
      KW24=0.5*(KWmfl-KWp-KWs)+KWp+KWs ! 24 hour average electrical load
      KW24avg=E24MF*KW24          ! 24 hour average electrical load with margins
! Output
      Vaux=Vaux/35.315
      open(5,file='SCelectric.out',status='old')
      write(5,*) KWmflm,KWgreq,KW24avg,Vaux,NO,NE,NT,NA
      close(5)
!
    stop
      end
```

Hull

```
    Program SCHullform
! Version 0.0; 7/4/05; AJB
! Calculates hull characteristics, SI units in and out
      real LWL,LtoB,LtoD
      integer SONtype, Hulltype
! Input
!     LWL=length at design waterline=LBP (m)
!     B=beam at design waterline (m)
!     D10=hull depth at station 10 (m)
!     T=draft to design waterline (m)
!     Cp=prismatic coefficient
!     Cx=maximum section coefficient
!     Sontype=sonar type (0=none,1=SPS56,2=SPS53)
    open(4,file='SCHull.in',status='old')
      read(4,*) LWL,LtoB,BtoT,Cp,Cx,SONtype,Hulltype
      close(4)
!
      B=LWL/LtoB
      T=B/BtoT
!
      If(SONtype.eq.0) then
         Ssd=.465                 ! very small bulb surface area
      Elseif(SONtype.eq.1) then
         Ssd=7.432                ! SQS-56 dome surface area
      Else
         Ssd=130.064              ! SQS-53 dome surface area
      Endif
      If(SONtype.eq.0) then
         Vsd=5                    ! very small bulb volume
      Elseif(SONtype.eq.1) then
         Vsd=19.1                 ! SQS-56 dome volume
      Else
         Vsd=163.4                ! SQS-53 dome volume
      Endif
      Cb=Cp*Cx                    !=block coefficient
      Vfl=1.015*Cb*LWL*B*T+Vsd         !=full load displaced volume w/appendages
      Cbt=BtoT                    !=beam/draft ratio
      Cv=Vfl/LWL**3                    !=volume coefficient
      A0=7.028-2.331*Cbt+.299*Cbt**2
      A1=-11.0+5.536*Cbt-.704*Cbt**2
```

```
        A2=6.913-3.419*Cbt+.451*Cbt**2
        Cstss=A0+A1*Cp+A2*Cp**2      !=Taylor standard series surface area coefficient
        Stss=Cstss*SQRT(Vfl*LWL) !=Taylor standard series surface area
        S=Stss+Ssd                   !=total hull surface area
        Cw=.278+.836*Cp              !=design waterplane coefficient
!
        If(Hulltype.eq.2) then
            flare=-10.
        Else
            flare=10.
        Endif
! Output
        open(5,file='SCHull.out',status='old')
        write(5,*) S,Ssd,Vsd,Vfl,Cw,Cv,Cbt,Cb,flare,B,T
```

Propulsion

```
      Program SCPropulsion
! Version 1.0; 10/20/05; AJB
! Calculates propulsion and generator system characteristics, SI units
        real LWL,KWg,LMBreq
        integer PSYStype,PSYS,GSYS,PENGtype,GENGtype
! Input
      open(4,file='SCPropulsion.in',status='old')
        read(4,*) PSYS,GSYS,LWL,B,HDK,D10,VD
        close(4)
!
        open(20,file='PropData.prn',status='old')
        read(20,*) NPSYS
        Do 10 n=1,NPSYS
            read(20,*)
IDP,PSYStype,Nprop,PENGtype,Pbpengtot,Pbpengend,SFCepe,LMBreq,HMBreq,VMBreq,Wbm,Apie
            If(PSYS.eq.IDP) Go to 11
 10     continue
 11     close(20)
        If(PSYStype.eq.1) then ! PSYStype=1=MD,CPP;2=IED/IPS,FPP;3=MD,RRG,FPP;4=IPS w/pods
            eta=0.98
            PC=.67
        Else if (PSYStype.eq.2) then         ! 2=IED/IPS
          eta=.92
            PC=.7
            GSYS=3
        Else                                 ! 4=IPS w/pods
          eta=.96
            PC=.7
            GSYS=3
        Endif
!
        open(21,file='SSGData.prn',status='old')
        read(21,*) NSSGSYS
        Do 20 n=1,NSSGSYS
            read(21,*) IDG,GENGtype,Nssg,KWg,KWgend,SFCeg,Wbmg,Agie
            If(GSYS.eq.IDG) Go to 21
 20     continue
 21     close(21)
        NDie=INT(VD/(HDK*B*LWL/3))
        NHpie=INT((D10-HMBreq)/HDK)
        NHDK=NHpie
        NHgie=INT(D10/HDK)-2
```

```
      HMB=D10-NHpie*HDK
      ADie=1.4*NDie*(Apie+Agie)
      AHie=1.4*(NHpie*Apie+NHgie*Agie)
! Output
      open(5,file='SCPropulsion.out',status='old')
      write(5,*) PSYStype,eta,PC,Nprop,Nssg,NHDK,Pbpengtot,Wbm,SFCepe,&
                 HMB,HMBreq,LMBreq,VMBreq,KWg,SFCeg,Wbmg,AHie,ADie,PENGtype,&
                 GENGtype,Pbpengend,KWgend
      close(5)
!
```

Space Available

```
     Program SCSpaceA
      real LWL,LMBreq
! This program calculates space available
! Input
!     LWL=length at design waterline=LBP (m)
!     B=beam at design waterline (m)
!     D10=hull depth at station 10
!     T=draft to design waterline
!     VD=deckhouse volume
!     HDK=average deck height
!     Vfl=full load displaced volume
!     HMBreq=reqd machinery box height
!     LMBreq=required machinery box length
!     Nprop=number of propulsors
!     Cw=waterplane coefficient
!     NHDK=number of hull decks crossed by propulsion inlet and exhaust
!     Cx=maximum section coefficient
!     Crd=raised deck coefficient=raised deck length/LWL
!     flare=hull flare
!
     open(4,file='SCSpaceA.in',status='old')
      read(4,*) LWL,B,D10,T,VD,HDK,Vfl,HMBreq,LMBreq,Nprop,Cw,NHDK,Cx,Crd,flare,VMBreq
      close(4)
!     Input conversion to English units
      LWL=LWL*3.28084
      B=B*3.28084
      D10=D10*3.28084
      T=T*3.28084
      VD=VD*35.315
      Vfl=Vfl*35.315
      VMBreq=35.315*VMBreq
      HDK=HDK*3.28084
      HMBreq=HMBreq*3.28084
      LMBreq=LMBreq*3.28084
!
      D10min=.21*B+T    !=minimum D10 to prevent heeled flooding or overall minimum D10
      D10min1=LWL/15   !=minimum D10 for hull strength
      D10min2=HMBreq   !=minimum D10 to accomodate machinery box
      If(D10min1.gt.D10min) then
         D10min=D10min1
      Endif
      If(D10min2.gt.D10min) then
         D10min=D10min2
      Endif
      D0=2.011827*T-6.36215e-6*LWL**2+2.780649e-2*LWL   !=depth at station 0 (DDS079-2)
      D20=0.014*LWL*(2.125+1.25e-3*LWL)+T           !=depth at station 20 (DDS079-2)
```

```
        If(D20.gt.D10min) then
          D10min=D20
        Endif
        If(D0.lt.D10) then
          D0=D10
        Endif
        F0=D0-T                              !=freeboard at station 0
        F10=D10-T                            !=freeboard at station 10
        F20=D20-T                            !=freeboard at station 20
        Apro=LWL/0.98*(F0+4*F10+F20)/6  !=projected lateral freeboard area
        Fav=Apro/LWL                         !=average freeboard
        Dav=Fav+T                               !=average depth
        CN=LWL*B*Dav/1e5                        !=hull cubic number
        Vhaw=LWL*(B+Fav*tand(flare))*Cw*Fav     !=hull volume above waterline
        Vhl=(1-Crd)*LWL*(B+Fav*tand(flare))*HDK*Cw !hull volume lost aft of raised deck
        Vht=Vfl+Vhaw-Vhl                     !=total hull volume
        Vt=Vht+VD                               !=total ship volume
        Hmb=D10-NHDK*HDK                        !=height of machinery box
        Vmb=Cx*Nprop*Hmb*LMBreq*B                  !=machinery box volume
        If(Vmb.lt.VMBreq) then
          Vmb=VMBreq
        Endif
! Output conversion to SI
        Vht=Vht/35.315
        Vt=Vt/35.315
        Hmb=Hmb/3.28084
        Vmb=Vmb/35.315
        D10min=D10min/3.28084
        Dav=Dav/3.28084
        open(5,file='SCSpaceA.out',status='old')
        write(5,*) Vht,CN,Vt,Hmb,Vmb,D10min,Dav
        close(5)
!
      stop
        end
```

Space Required

```
      Program SCSpaceR
!
! Calculates space requirements
!
! Input
!     B=ship beam at DWL
!     HDK=average deck height
!     VD=deckhouse volume
!     Vtk=total tankage volume
!     Vaux=auxiliary machinery space volume
!     Vht=total hull volume
!     Vmb=propulsion machinery box volume
!     Adpr=reqd deckhouse payload area
!     Ahpr=reqd hull or deckhouse payload area
!     Ahie=reqd hull propulsion inlet and exhaust area
!     Adie=reqd deckhouse propulsion inlet and exhaust area
!     Ts=endurance days
!     CN=hull cubic number
!     NT=total crew
!     NO=number of officers
```

```
!     NA=number of additional accomodations
!
      open(4,file='SCSpaceR.in',status='old')
        read(4,*) B,HDK,VD,Vtk,Vaux,Vht,Vmb,Adpr,Ahpr,Ahie,Adie,Ts,CN,NT,NO,NA
        close(4)
        B=B*3.28084
        HDK=HDK*3.28084
        VD=VD*35.315
        Vtk=Vtk*35.315
        Vaux=Vaux*35.315
        Vht=Vht*35.315
        Vmb=Vmb*35.315
        Adpr=Adpr*10.764
        Ahpr=Ahpr*10.764
        Ahie=Ahie*10.764
        Adie=Adie*10.764
!
        Acoxo=225.                  !CO/XO reqd habitability area
        Ado=75.0*NO                 !officer deckhouse habitability area
        Adl=Acoxo+Ado                   !total deckhouse habitability area
        Ahab=50.                    !average habitability area per man
        Ahl=Ahab*(NT+NA)-Adl            !hull habitability area
        Ahs=300.0+0.0158*NT*9*Ts!hull stores area
        Adm=0.05*(ADPR+Adl)         !deckhouse maintenance area
        Adb=16*(B-18.0)             !deckhouse bridge area
        Ahsf=1750.0*CN              !hull ship functions area
        Ahr=Ahpr+Ahl+Ahs+Ahsf+Ahie  !total hull required area
        Vhr=HDK*Ahr                 !total hull required volume
        Adr=Adpr+Adl+Adm+Adb+Adie !total deckhouse required area
        Vdr=HDK*Adr                 !total deckhouse required volume
        Atr=Ahr+Adr                 !total required area
        Vtr=Vhr+Vdr                 !total required volume
        Vha=Vht-Vmb-Vaux-Vtk            !available hull volume for arrangeable areea
        Aha=Vha/HDK                 !available hull area
        Vta=Vha+VD                  !total available volume for arrangeable area
        Ada=VD/HDK                  !available deckhouse area
        Ata=Aha+Ada                 !total available area
! Output
        Adr=Adr/10.764
        Ada=Ada/10.764
        Atr=Atr/10.764
        Ata=Ata/10.764
        open(5,file='SCSpaceR.out',status='old')
        write(5,*) Adr,Ada,Atr,Ata
        close(5)
      stop
        end
```

Tankage

```
      Program SCTankage
!
! Calculates tankage requirements; fuel tankage calculation based on DDS 200-1
!
        real KW24avg
        integer PENGtype,GENGtype,PSYStype
! Input from MC in SI units, kW, MT, knt, kg/kW*hr
!     BALtyp=ballast type(0=clean,1=compensated fuel tanks)
```

```
!    eta=propulsion transmission efficiency
!    NT=total crew
!    NA=additional accomodations
!    Pbpengtot=total propulsion brake power
!    SHPe=endurance shaft power reqd (kW)
!    Ve=endurance speed (knt)
!    KW24AVG=average 24 hour electric power reqd
!    WF42=weight of helo fuel (MT)
!    SFCeg=ship service generator endurance specific fuel consumption
!    SFCepe=propulsion engine endurance specific fuel consumption
!    WF46=lube oil weight
!    WF52=fresh water weight
!    WF41=propulsion fuel weight
!    PENGtype=endurance propulsion engine type (1=simple cycle GT,2=ICR,RACER,3=diesel)
!    GENGtype=SS generator engine type (1=simple cycle GT,2=ICR,RACER,3=diesel)
!    Pbpengend=total brake propulsion power available at endurance speed
!    Pbgengend=total brake generator engine power available at endurance speed
!    PSYStype=1=MD,CPP;2=IED/IPS,FPP;3=MD,RRG,FPP;4=IPS w/pods
!
      open(4,file='SCTankage.in',status='old')
        read(4,*) BALtyp,eta,NT,NA,Pbpengtot,SHPe,Ve,KW24AVG,WF42,&
              SFCeg,SFCepe,WF46,WF52,WF41,PENGtype,GENGtype,&
                    Pbpengend,KWgend,PSYStype
        close(4)
!
        Pebavg=1.1*SHPe/eta !brake propulsion power reqd at endurance speed
        f1=1.03
        f1g=1.03
        If(PSYStype.eq.1.or.PSYStype.eq.3) then
            PENGload=Pebavg/Pbpengend
            if(Pebavg.le.Pbpengtot/6) f1=1.04
            if(Pebavg.ge.Pbpengtot/3) f1=1.02
            if(KW24AVG.le.KWgend/6) f1g=1.04
            if(KW24AVG.ge.KWgend/3) f1g=1.02
        Else
            PENGload=(Pebavg+KW24AVG)/Pbpengend
            if((Pebavg+KW24AVG).le.Pbpengtot/6) f1=1.04
            if((Pebavg+KW24AVG).ge.Pbpengtot/3) f1=1.02
            f1g=f1
        Endif
        If (PENGtype.eq.1.and.PENGload.lt.0.146) then
               SFCepe=SFCepe*2.196
            elseif(PENGtype.eq.1.and.PENGload.ge.0.146.and.PENGload.le.1.0) then
               SFCepe=SFCepe*(.9704*PENGload**-.4059)
            elseif(PENGtype.eq.1.and.PENGload.gt.1.0) then
               SFCepe=SFCepe
            elseif(PENGtype.eq.2.and.PENGload.lt.0.025) then
               SFCepe=SFCepe*2.581
            elseif(PENGtype.eq.2.and.PENGload.ge.0.025.and.PENGload.le.1.0) then
               SFCepe=SFCepe*(.9096*PENGload**-.2796)
            elseif(PENGtype.eq.2.and.PENGload.gt.1.0) then
               SFCepe=SFCepe
            elseif(PENGtype.eq.3.and.PENGload.lt.0.025) then
               SFCepe=SFCepe*2.188
            elseif(PENGtype.eq.3.and.PENGload.ge.0.025.and.PENGload.le.0.09) then
               SFCepe=SFCepe*(-16.742*PENGload+2.5844)
            elseif(PENGtype.eq.3.and.PENGload.ge.0.09.and.PENGload.le.1.0) then
```

```
            SFCepe=SFCepe*(-.2128*PENGload+1.1933)
         else
            SFCepe=SFCepe
      Endif
!
      GENGload=KW24AVG/KWgend
      if (PSYStype.eq.2.or.PSYStype.eq.4) then  ! PSYStype=1=MD,CPP;2=IED/IPS,FPP;3=MD,RRG,FPP;4=IPS
w/pods
         SFCeg=SFCepe
      elseif (GENGtype.eq.1.and.GENGload.lt.0.146) then
         SFCeg=SFCeg*2.196
      elseif(GENGtype.eq.1.and.GENGload.ge.0.146.and.GENGload.le.1.0) then
         SFCeg=SFCeg*(.9704*GENGload**-.4059)
      elseif(GENGtype.eq.1.and.GENGload.gt.1.0) then
         SFCeg=SFCeg
      elseif(GENGtype.eq.2.and.GENGload.lt.0.025) then
         SFCeg=SFCeg*2.581
      elseif(GENGtype.eq.2.and.GENGload.ge.0.025.and.GENGload.le.1.0) then
         SFCeg=SFCeg*(.9096*GENGload**-.2796)
      elseif(GENGtype.eq.2.and.GENGload.gt.1.0) then
         SFCeg=SFCeg
      elseif(GENGtype.eq.3.and.GENGload.lt.0.025) then
         SFCeg=SFCeg*2.188
      elseif(GENGtype.eq.3.and.GENGload.ge.0.025.and.GENGload.le.0.09) then
         SFCeg=SFCeg*(-16.742*GENGload+2.5844)
      elseif(GENGtype.eq.3.and.GENGload.ge.0.09.and.GENGload.le.1.0) then
         SFCeg=SFCeg*(-.2128*GENGload+1.1933)
      else
         SFCeg=SFCeg
      endif
!
      FRsp=f1*SFCepe     !specified propulsion fuel rate
      FRavg=1.05*FRsp    !average propulsion fuel rate
      FRgsp=f1g*SFCeg    !specified generator fuel rate
      FRgavg=1.05*FRgsp       !average generator fuel rate
      TPA=.95                 !tail pipe allowance
      E=WF41*1000.*Ve*TPA/(Pebavg*FRavg+KW24AVG*FRgavg) !endurance range
      Vf=1.02*1.05*1.179*WF41         !propulsion fuel tank volume
      Vhf=1.02*1.05*1.198*WF42        !helo fuel tank volume
      Vlo=1.02*1.05*1.112*WF46        !lube oil tank volume
      Vw=1.02*1.003*WF52              !potable water tank volume
      Vsew=(NT+NA)*.057                     !sewage tank volume
      Vwaste=0.02*Vf                  !waste oil tank volume
      Vbal=0.275*Vf                   !ballast tank volume
      If(BALtyp.eq.1) then
         Vbal=.19*Vf          !1 = compensated fuel system
      Endif
      Vtk=Vf+Vhf+Vlo+Vw+Vsew+Vwaste+Vbal    !total tank volume
! Annual Fuel Used - assumes endurance speed for 2500 hours per year
      Timepertank=E/Ve   !endurance time (hours)
      Tankperyear=2500/Timepertank !full tanks used per year
      Vfperyear=Tankperyear*Vf        ! volume fuel used per year
      Fgalperyear=Vfperyear*264.172   ! gallons fuel used per year
!
! Output
      open(5,file='SCTankage.out',status='old')
      write(5,*) Vtk,Vf,E,Fgalperyear,Pebavg
```

```
      close(5)
    stop
      end
```

Weight

```
    Program SCWeight
! Version 0.0; 7/20/04; AJB
! This subroutine calculates single digit and full load weight and vcgs
    real LWL,KWg,KGmarg,KG,KB
      integer PSYStype
! Input
!     LWL=length at design waterline=LBP (m)
!     B=beam at design waterline (m)
!     D10=hull depth at station 10
!     T=draft to design waterline
!     VD=deckhouse volume
!     Vt=total tankage volume
!     HDK=average deck height
!     Dav=average hull depth
!     Hmb=machinery box height
!     KGmarg=KG margin
!     Vfl=full load displaced volume
!     Vsd=sonar dome volume
!     Pbpengtot=total propulsion brake power
!     KWg=generator power, ea
!     Dp=propeller diameter
!     Ts=endurance days
!     Wbm=basic propulsion machinery weight
!     Wbmg=basic electrical machinery weight
!     Wp100=payload SWBS 100 weight, structures
!     Wp400=payload SWBS 400 weight, command and control
!     Wp500=payload SWBS 500 weight, auxiliaries
!     Wp600-payload SWBS 600 weight, outfit
!     W7=SWBS 700, weapons system weight
!     Wvp, variable payload weight
!     VCGp100=payload SWBS 100 weight VCG, structures
!     VCGp400=payload SWBS 400 weight VCG, command and control
!     VCGp500=payload SWBS 500 weight VCG, auxiliaries
!     VCGp600-payload SWBS 600 weight VCG, outfit
!     VCG700=SWBS 700, weapons system weight VCG
!     VCGvp, variable payload weight VCG
!     Cw=waterplane coefficient
!     Cp=prismatic coefficient
!     Cx=maximum section coefficient
!     Cb=block coefficient
!     Ncps=Collective Protection System (0=none,1=partial,2=full)
!     Nprop=number of propulsors
!     Nssg=number of ship service generators
!     NT=total crew
!     NO=number of officers
!     NE=number of enlisted crew
!     CN=hull cubic number
!     CDHMAT=deckhouse material type (1=steel,2=aluminum, 3=composite)
!     WMF=weight margin factor
!
    open(4,file='SCWeight.in',status='old')
      read(4,*) LWL,B,T,D10,VD,Vt,HDK,Dav,Hmb,KGmarg,Vfl,Vsd,Pbpengtot,KWg,Dp,Ts,&
```

```
            Wbm,Wbmg,Wp100,Wp400,Wp500,Wp600,W7,Wvp,VCGp100,VCGp400,VCGp500,&
                  VCGp600,VCG700,VCGvp,Cw,Cx,Cp,Cb,Ncps,Nprop,Nssg,NT,NO,NE,CN,CDHMAT,&
                  WMF,PSYStype
      close(4)
      LWL=LWL*3.28084
      B=B*3.28084
      T=T*3.28084
      D10=D10*3.28084
      VD=VD*35.315
      Vt=Vt*35.315
      HDK=HDK*3.28084
      Dav=Dav*3.28084
      Hmb=Hmb*3.28084
      KGmarg=KGmarg*3.28084
      Vfl=Vfl*35.315
      Vsd=Vsd*35.315
      Pbpengtot=Pbpengtot/.7457
      Dp=Dp*3.28084
      Wbm=.984*Wbm
      Wbmg=.984*Wbmg
      Wp100=.984*Wp100
      Wp400=.984*Wp400
      Wp500=.984*Wp500
      Wp600=.984*Wp600
      W7=.984*W7
      Wvp=.984*Wvp
      VCGp100=VCGp100*3.28084
      VCGp400=VCGp400*3.28084
      VCGp500=VCGp500*3.28084
      VCGp600=VCGp600*3.28084
      VCG700=VCG700*3.28084
      VCGvp=VCGvp*3.28084
!
      W237=0.0                    ! Auxiliary Propulsion Unit weight
      VCG237=0.0                      ! Auxiliary Propulsion Unit VCG
      fs=.33                      ! shafting L/LWL for 1 shaft
      if(Nprop.eq.1.and.PSYStype.eq.1) then
         fs=.33                   ! shafting L/LWL for 1 shaft mechanical
      elseif(PSYStype.eq.2) then
         fs=.36                   ! shafting for electric propulsion, 2 shafts
      elseif(PSYStype.eq.4) then
        fs=0.0
      else
         fs=.5                    ! shafting L/LWL for 2 shafts mechanical
      endif
      Ws=0.82*LWL*fs                  ! total propulsion shaft weight
      Wpr=0.087*Nprop*Dp**(5.497-0.0433*Dp)/2240.0 ! total propeller weight
      Wb=0.235*(Ws+Wpr)                   ! total line shaft bearing weight
      Wst=Ws+Wb+Wpr                   ! total prop and shafting system weight
      W2=Wbm+Wst+W237                     ! total propulsion system weight
      W320=.27*LWL                        ! distribution weight
      W330=2.99*CN                    ! lighting weight
      W3=Wbmg+W320+W330                       ! total electrical system weight
      Wic=4.45e-5*Vt                  ! interior communications weight
      Wco=2.2*CN                      ! other command and control weight
      Wcc=0.3*(Wp400+Wic+Wco)             ! C&C cabling weight
      W4=Wp400+Wic+Wco+Wcc                ! total command and control weight
```

```
W593=10.0                  ! Environmental systems weight
W598=62e-6*Vt              ! Aux systems operating fluids weight
Waux=(0.000772*Vt**1.443+5.14*Vt+6.19*Vt**0.7224+377.*NT+2.74*Pbpengtot)&
 *1e-4+117.0               ! auxiliary systems weight
Wcps=Ncps*.00005*Vt        ! collective protection system weight
W5=Waux+Wp500+W593+W598+Wcps  ! total auxiliaries weight
Wofh=4.18e-4*Vt            ! hull fittings weight
Wofp=0.8*(NT-9.5)          ! personnel-related outfit weight
W6=Wofh+Wofp+Wp600             ! total outfit weight
W171=2.0                ! Mast weight
Wbh=1.68341*CN**2+167.1721*CN-103.283 ! bare hull weight
If(CDHMAT.eq.1) then
   rDHMAT=.00168           ! steel structure volume weight density
elseif(CDHMAT.eq.2) then
   rDHMAT=.000746          ! aluminum structure volume weight density
Else
   rDHMAT=.0005                ! composite
Endif
Wdh=rDHMAT*VD                      ! deckhouse weight
W180=0.0735*(Wbh+W2+W3+W4+W5+W6+W7) ! foundations weight
W1=Wbh+Wdh+W171+W180+Wp100             ! total structures weight
Wm24=WMF*(W1+W2+W3+W4+W5+W6+W7)         ! margin weight
Wls=W1+W2+W3+W4+W5+W6+W7+Wm24           ! lightship weight
WF31=NT*2.45e-3*Ts                 ! provisions weight
WF32=0.00071*Ts*NT+0.0049*NT           ! general stores weight
WF10=(236*NE+400*(NO+1))/2240.0        ! crew weight
WF46=17.6                          ! lube oil weight
WF52=NT*.15                        ! potable water weight
Wt=Wls+Wvp+WF46+WF52+WF31+WF32+WF10     ! total ship weight less WF41
Wfl=Vfl/34.977                 ! full load displacement
WF41=Wfl-Wt                        ! ship fuel weight
Wt=Wfl                         ! total ship weight
VCGbh=0.51*D10                     ! bare hull VCG
VCGdh=D10+1.5*HDK                      ! deck house VCG
VCG180=0.5*D10                     ! foundations VCG
VCG171=D10+0.13*LWL                    ! mast VCG
P100=Wbh*VCGbh+Wdh*VCGdh+W180*VCG180+W171*VCG171+Wp100*VCGp100   ! total structures
VCG
If(PSYStype.eq.1.or.PSYStype.eq.3) then
   VCGbm=0.45*D10
Else
   VCGbm=0.42*D10                  ! basic machinery VCG
Endif
VCGst=4.8+0.35*T           ! total prop and shafting system VCG
P200=Wbm*VCGbm+Wst*VCGst+W237*VCG237    ! total propulsion VCG moment
VCG300=0.55*D10                    ! total electrical VCG
P300=W3*VCG300                 ! total electrical VCG moment
VCGic=D10                      ! interior communications VCG
VCGco=5.6+0.4625*D10               ! other C&C VCG
VCGcc=0.5*D10                      ! C&C cabling VCG
P400=Wic*VCGic+Wco*VCGco+Wcc*VCGcc+Wp400*VCGp400 ! command and control VCG moment
VCGaux=0.9*(D10-9.4)               ! misc auxiliaries VCG
P500=(Waux+W593+W598+Wcps)*VCGaux+Wp500*VCGp500     ! total auxiliaries VCG moment
VCGofh=0.65*D10                    ! hull fittings VCG
VCGofp=4.2+0.4*D10                 ! personnel outfit VCG
P600=Wofh*VCGofh+Wofp*VCGofp+Wp600*VCGp600 ! total outfit VCG moment
P700=W7*VCG700             ! total weapons VCG moment
```

```
      Pwg=P100+P200+P300+P400+P500+P600+P700    ! total lightship VCG moment
      VCGls=Pwg/(Wls-Wm24)                      ! lightship VCG
      VCGF10=0.732*D10                          ! crew VCG
      VCGF31=0.523*Dav                          ! provisions VCG
      VCGF32=0.592*Dav                          ! general stores VCG
      VCGF41=10.3                          ! ship fuel VCG
      VCGF46=0.53*Hmb                      ! lube oil VCG
      VCGF52=0.138*Dav                          ! potable water VCG
      Pwgl=WF10*VCGF10+WF31*VCGF31+WF32*VCGF32+WF41*VCGF41+WF46*VCGF46+&
       WF52*VCGF52+Wvp*VCGvp                    ! total loads VCG moment
      KG=(VCGls*Wls+Pwgl)/Wt+KGmarg                  ! KG
      Cit=1.44*Cw-.537                     ! transverse waterplane coefficient
      KB=(T/3.)*(2.4-Cp*Cx/Cw)             ! KB
      BM=Cit*LWL*B**3/(12.*Vfl)                 ! BM
      GM=KB+BM-KG                               ! GM
      Cgmb=GM/B                                 ! GM/B ratio
! Output
      Wt=Wt/.98421
      Wic=Wic/.98421
      WF41=WF41/.98421
      WF46=WF46/.98421
      WF52=WF52/.98421
      W1=W1/.98421
      W2=W2/.98421
      W3=W3/.98421
      W4=W4/.98421
      W5=W5/.98421
      W6=W6/.98421
      W7=W7/.98421
      Wm24=Wm24/.98421
      Wls=Wls/.98421
      KB=KB/3.28084
      KG=KG/3.28084
      open(5,file='SCWeight.out',status='old')
      write(5,*) Wt,Wic,WF41,WF46,WF52,W1,W2,W3,W4,W5,W6,W7,Wm24,Wls,Cgmb,KB,KG
      close(5)
!
    stop
      end
```

Overall Measure of Effectiveness (OMOE)

```
    Program SCOMOE
! Version 0.0; 10/12/05; AJB
! This subroutine calculates ship OMOE
      real McC,VOP(17),WVOP(17),interp,LWL,KG,a(11),LCB,LCF,bb(11),KB,LAMPSVOP,NSFSVOP
      integer AAW,BALtype,CDHMAT,PENGtype,PSYStype,GMLS,SEW,STK,SDS,ASUW,ASW,CCC,Hulltype
! Input
    open(4,file='SCOMOE.in',status='old')
      read(4,*) LWL,B,T,Vfl,VD,KB,KG,Vs,Cgmb,Cw,AAW,ASUW,ASW,CCC,&
                NSFS,SDS,GMLS,LAMPS,E,Ts,BALtype,CDHMAT,Ncps,&
                PENGtype,PSYStype,Ndegaus,Hulltype
      close(4)
      LWL=LWL*3.28084
      B=B*3.28084
      T=T*3.28084
      Vfl=Vfl*35.315
      KB=KB*3.28084
```

```
      KG=KG*3.28084
      VD=35.315*VD
!
! Warfare MIssion VOPs
!
! VOP1 = AAW
!
      If(AAW.eq.1) then
            AAWVOP=1.0
         Else if(AAW.eq.2) then
            AAWVOP=.603
         Else
            AAWVOP=.104
      Endif
!
      If(GMLS.eq.1) then
            GMLSVOP=1.0
         Else if(GMLS.eq.2) then
            GMLSVOP=.593
         Else if(GMLS.eq.3) then
            GMLSVOP=.385
         Else
            GMLSVOP=.187
      Endif
!
      If(SDS.eq.1) then
            SDSVOP=1.0
         Else if(SDS.eq.2) then
            SDSVOP=.598
         Else
            SDSVOP=.119
      Endif
!
      If(CCC.eq.1) then
            CCCVOP=1.0
         Else
            CCCVOP=.333
      Endif
!
      VOP(1)=.618*AAWVOP+.094*GMLSVOP+.066*SDSVOP+.223*CCCVOP
!
! VOP2 = ASW
!
      If(ASW.eq.1) then
            ASWVOP=1.0
         Else
            ASWVOP=.2
      Endif
!
      If(LAMPS.eq.1) then
            LAMPSVOP=1.0
         Else if(LAMPS.eq.2) then
            LAMPSVOP=.437
         Else
            LAMPSVOP=.095
      Endif
!
```

```
      VOP(2)=.424*ASWVOP+.393*LAMPSVOP+.183*CCCVOP
!
! VOP3 = ASUW/NSFS
      If(ASUW.eq.1) then
            ASUWVOP=1.0
         Else
            ASUWVOP=.2
         Endif
!
      If(NSFS.eq.1) then
            NSFSVOP=1.0
         Else
            NSFSVOP=.143
      Endif
!
      VOP(3)=.211*ASUWVOP+.226*NSFSVOP+.227*LAMPSVOP+.184*CCCVOP+.152*SDSVOP
!
!
! VOP4 = CCC
      VOP(4)=CCCVOP
!
! VOP5 = STK
      VOP(5)=.6*GMLSVOP+.4*CCCVOP
!
! VOP6 = BMD
      VOP(6)=.54*AAWVOP+.297*CCCVOP+.163*GMLSVOP
!
! VOP7 = Sustained Speed
      If(Vs.lt.29) then
            VOP(7)=0.0
         Elseif(Vs.lt.30) then
            VOP(7)=interp(0.263,0.288,29.,30.,Vs)
         Elseif(Vs.lt.31) then
            VOP(7)=interp(0.288,0.440,30.,31.,Vs)
         Elseif(Vs.lt.32) then
            VOP(7)=interp(0.440,0.687,31.,32.,Vs)
         Elseif(Vs.lt.33) then
            VOP(7)=interp(0.687,0.839,32.,33.,Vs)
         Elseif(Vs.lt.34) then
            VOP(7)=interp(0.839,0.979,33.,34.,Vs)
         Elseif(Vs.lt.35) then
            VOP(7)=interp(0.979,1.0,34.,35.,Vs)
         Else
            VOP(7)=1.0
      Endif
!
! VOP8 = Endurance Range
      If(E.lt.4000) then
            VOP(8)=0.0
         Elseif(E.lt.4500) then
            VOP(8)=interp(0.278,0.444,4000.,4500.,E)
         Elseif(E.lt.5000) then
            VOP(8)=interp(0.444,0.6,4500.,5000.,E)
         Elseif(E.lt.5500) then
            VOP(8)=interp(0.6,0.932,5000.,5500.,E)
         Elseif(E.lt.6000) then
            VOP(8)=interp(0.932,1.0,5500.,6000.,E)
```

```
            Else
                  VOP(8)=1.0
        Endif
!
! VOP9 = Provisions Duration
        If(Ts.lt.45) then
                  VOP(9)=0.0
            Elseif(Ts.lt.50) then
                  VOP(9)=interp(0.482,0.616,45.,50.,Ts)
            Elseif(Ts.lt.55) then
                  VOP(9)=interp(0.616,0.875,50.,55.,Ts)
            Elseif(Ts.lt.60) then
                  VOP(9)=interp(0.875,1.0,55.,60.,Ts)
            Else
                  VOP(9)=1.0
        Endif
!
! VOP10 = Seakeeping
! Seakeeping Index
        x=.492
        y=.431
        z=.498
        zz=.552
        xx=2.187
!
        a=(/9.43595,.0000031045,-8.4298,-37.5995,590.435,.287418,-57.346,&
            -6.08436,.0000918775,-6.03225,-.00641495/)
        Awp=Cw*B*LWL
        Cvpf=x*Vfl/(y*Awp*T)
        Cvpa=(1-x)*Vfl/((1-y)*Awp*T)
        Awa=(1-y)*Awp
        LCB=z*LWL
        LCF=zz*LWL
        BMl=xx*LWL+KG-KB
        bb=(/1.,BMl*Vfl/115.88,Cvpf,Cvpa,BMl*Vfl/(B*LWL**3),LWL/3.281,&
           T/B,Awa/Vfl**0.6667,(LCB-LCF)*Vfl/115.88,&
             (LWL/2-LCB)/Vfl**0.3333,(LWL**2)/(B*T)/)
        McC=0.0
        Do 10, i=1,11
 10   McC=McC+a(i)*bb(i)
!
        If(McC.lt.6.0) then
                  IndexVOP=0.0
            Elseif(McC.lt.8.0) then
                  IndexVOP=interp(0.252,.372,6.,8.,McC)
            Elseif(McC.lt.10.0) then
                  IndexVOP=interp(0.372,0.492,8.,10.,McC)
            Elseif(McC.lt.12.0) then
                  IndexVOP=interp(0.492,0.8,10.,12.,McC)
            Elseif(McC.lt.14.0) then
                  IndexVOP=interp(0.8,0.939,12.,14.,McC)
            Elseif(McC.lt.16.0) then
                  IndexVOP=interp(0.939,1.0,14.,16.,McC)
            Else
                  IndexVOP=1.0
        Endif
!
```

```
! Tumblehome
        If(Hulltype.eq.1) then
                THVOP=1.0
            Else
                THVOP=.2
            Endif
!
        VOP(10)=.565*IndexVOP+.435*THVOP
!
! VOP11 = Enviromental (0=clean ballast,1=compensated fuel tanks)
        If(BALtype.eq.0) then
                VOP(11)=1.0                 ! Clean Ballast
            Else
                VOP(11)=.286          ! Compensated Fuel Tanks
        Endif
!
! VOP12 = Vulnerability
! Deckhouse Structure (1=steel,2=aluminum,3=composite)
        If(CDHMAT.eq.1) then
                DHVOP=1.0
            Else if(CDHMAT.eq.2) then
                DHVOP=.42
            Else
                DHVOP=.265
        Endif
!
! Pods (Pods=4)
        If(PSYStype.eq.4) then
                PODVOP=.333
            Else
                PODVOP=1.0
        Endif
!
        VOP(12)=.667*DHVOP+.333*PODVOP
!
! VOP13 = NBC (0=none,1=partial,2=full)
        If(Ncps.eq.2) then
                VOP(13)=1.0
            Else if(Ncps.eq.1) then
                VOP(13)=0.845
            Else
                VOP(13)=.214
        Endif
!
! VOP14 = RCS
! Tumblehome
        If(Hulltype.eq.2) then      ! tumblehome
                THVOP=1.0
            Else
                THVOP=.2              ! flare
            Endif
!
        If(VD.lt.100000.) then
                DHVOP=1.0
            Elseif(VD.lt.110000.) then
                DHVOP=interp(1.0,0.920,100000.,110000.,VD)
            Elseif(VD.lt.120000.) then
```

```
            DHVOP=interp(0.920,0.844,110000.,120000.,VD)
        Elseif(VD.lt.130000.) then
            DHVOP=interp(0.844,0.773,120000.,130000.,VD)
        Elseif(VD.lt.140000.) then
            DHVOP=interp(0.773,0.709,130000.,140000.,VD)
        Elseif(VD.lt.150000.) then
            DHVOP=interp(0.709,0.652,140000.,150000.,VD)
        Else
            DHVOP=0.0
    Endif
!
    If(SDS.eq.3) then
            SDSVOP=1.0
        Else if(SDS.eq.2) then
            SDSVOP=0.550
        Else
            SDSVOP=.303
    Endif
!
    VOP(14)=.480*THVOP+.352*DHVOP+.168*SDSVOP
!
! VOP15 = Acoustic Signature  (1=MD,CPP;2=IED/IPS,FPP;3=MD,RRG,FPP;4=IPS/pods)
    If(PSYStype.eq.2) then
            VOP(15)=1.0
        Else if(PSYStype.eq.4) then
            VOP(15)=0.833
        Else
            VOP(15)=.333
    Endif
!
! VOP16 = IR Signature              (1=GT,2=ICR,3=Diesel)
    If(PENGtype.eq.2) then
            VOP(16)=1.0
        Else if(PENGtype.eq.1) then
            VOP(16)=.526
        Else
            VOP(16)=0.
    Endif
!
! VOP17 = Magnetic Signature
    If(Ndegaus.eq.1) then  !(1=degaussing,0=none)
            DGVOP=1.0
        Else
            DGVOP=0.143
    Endif
!
    If(PSYStype.eq.4) then
            PODSVOP=.2
        Else
            PODSVOP=1.0
    Endif
!
    VOP(17)=.75*DGVOP+.25*PODSVOP
!
    WVOP=(/.107,.081,.081,.087,.075,.157,.032,.028,.022,.034,.011,.034,.038,.069,.054,.043,.048/)
    OMOE=DOT_PRODUCT(VOP,WVOP)
! Output
```

```
      open(5,file='SCOMOE.out',status='old')
      write(5,*) OMOE
      close(5)
!
    stop
      End
```

Risk

```
    program SCRisk
! Version 1.0; 10/31/05; AJB
! Calculates OMOR
      integer PSYS,AAW,CDHMAT,Hulltype,PENGtype
!
 998  open(4,file='SCRisk.in',status='old')
! Input
!    CDHMAT=deckhouse material type (1=steel,2=aluminum, 3=composite)
!
      read(4,*) CDHMAT,Hulltype,PSYS,PENGtype,CMan,AAW
!
      close(4)
!
      If(CDHMAT.eq.3)then
              PerfRiskDHMAT1=.3
              PerfRiskDHMAT2=.2
              SchedRiskDHMAT=.1
              CostRiskDHMAT=.15
         Else
              PerfRiskDHMAT1=0.
              PerfRiskDHMAT2=0.
              SchedRiskDHMAT=0.
              CostRiskDHMAT=0.
         Endif
!
      If(Hulltype.eq.2)then
              PerfRiskTH=.56
         Else
              PerfRiskTH=0.
      Endif
!
        If(PSYS.gt.4) then
              PerfRiskIED=.18
              SchedRiskIED=.12
              CostRiskIED=.16
         Else
              PerfRiskIED=0.0
              SchedRiskIED=0.0
              CostRiskIED=0.0
         Endif
!
         If(PENGtype.eq.2) then
              PerfRiskICR=.3
              SchedRiskICR=.3
              CostRiskICR=.24
         Else
              PerfRiskICR=0.0
              SchedRiskICR=0.0
              CostRiskICR=0.0
```

```
      Endif
!
      If (PSYS.ge.11) then
         PerfRiskPod1=.28
         PerfRiskPod2=.42
         SchedRiskPod=.36
         CostRiskPod=.27
      Else
         PerfRiskPod1=0.0
         PerfRiskPod2=0.0
         SchedRiskPod=0.0
         CostRiskPod=0.0
      Endif
!
    If(AAW.eq.3) then
         PerfRiskSPY=0.
         SchedRiskSPY=0.
         CostRiskSPY=0.
      Else
         PerfRiskSPY=.24
         SchedRiskSPY=.28
         CostRiskSPY=.2
      Endif
!
    PerfRiskAuto=.42*(1.0-CMan)
    CostRiskAuto=.25*(1.0-CMan)
    SchedRiskAuto=.35*(1.0-CMan)
!
    PerfRisk=(PerfRiskDHMAT1+PerfRiskDHMAT2+PerfRiskTH+PerfRiskIED+PerfRiskICR+&
         PerfRiskPod1+PerfRiskPod2+PerfRiskSPY+PerfRiskAuto)/2.9
    CostRisk=(CostRiskDHMAT+CostRiskIED+CostRiskICR+CostRiskPod+CostRiskSPY+&
         CostRiskAuto)/1.27
    SchedRisk=(SchedRiskDHMAT+SchedRiskIED+SchedRiskICR+SchedRiskPod+SchedRiskSPY+&
         SchedRiskAuto)/1.51
    OMOR=.5*PerfRisk+.3*CostRisk+.2*SchedRisk
!
    open(5,file='SCRisk.out',status='old')
! Output
    write(5,*) OMOR
!
    close(5)
!
   stop
    End
```

Cost

```
   Program Cost
! This subroutine calculates lead and follow acquisition cost and life cycle cost
! Version 1.0; 10/31/05 AJB
    real KN1,KN2,KN3,KN4,KN5,KN6,KN7,KN8,KN9,LWL,Lsum
    integer PSYStype,Ls,CDHMAT
! Input
   open(4,file='SCCost.in',status='old')
    read(4,*)
PSYStype,CDHMAT,Ve,E,Vf,Pbpengtot,W1,W2,W3,W4,Wic,W5,W6,W7,Wm24,Wls,WF20,Fgalperyear,&
       NO,NE,NT,NYbase,Fp,Ns,Ri,Rp,Rif,HDK,CMan
    close(4)
```

```
!
!    Inputs:
!    PSYStype = propulsion sytem type (1=mech, 2=secondary IPS, 3=IPS)
!    CDHMAT = type of deck house material (1=steel, 2=aluminum)
!    Ve = endurance speed
!    E = endurance range
!    Vf = fuel volume
!    Pbpengtot = total propulsion engine brake power
!    W1 = SWBS 100 stucture weight
!    W2 = SWBS 200 propulsion weight
!    W3 = SWBS 300 electrical weight
!    W4 = SWBS 400 command and control weight
!    Wic = internal communications weight
!    W5 = SWBS 500 auxiliaries weight
!    W6 = SWBS 600 outfit weight
!    W7 = SWBS 700 ordnance weight
!    Wm24 = margin weight
!    Wls = light ship weight
!    WF20 = ordnance loads weight
!    Fgalperyear = gallons fuel burned per year
!    NO = crew number of officers
!    NE = crew number of enlisted
!    NT = total crew
!    NYbase = base year for cost calculation
!    Fp = profit margin
!    Ns = number of ships to be built
!    Ri = average inflation rate before base
!    Rp = shipbuilding rate per year after lead ship
!    Rif = average inflation rate after base
!
! convert SI to English units, metric tons to long tons, kw to hp
!
      W1=W1*.98421
      W2=W2*.98421
      W3=W3*.98421
      W4=W4*.98421
      W5=W5*.98421
      W6=W6*.98421
      W7=W7*.98421
      Wt=Wt/.98421
      Wic=Wic*.98421
      Wm24=Wm24*.98421
      Wls=Wls*.98421
      WF20=WF20*.98421
      Pbpengtot=Pbpengtot/.7457
      Vf=Vf*35.315
!
! Lead ship acquisition cost
!
      Fi=1.
      DO 10 I=1,NYbase-1981
 10       Fi=Fi*(1.+Ri/100.)                ! Inflation factor
!
      NYioc=NYbase+5                       ! Initial operational capability year
!
!     Complexity Factors
!
```

```
      KN1=.75                         ! structure complexity factor
      If(CDHMAT.eq.2) KN1=.8
!
      If(PSYStype.eq.1) then       ! (1=MD,CPP;3=MD,RRG,FPP;2=IED,FPP)
         KN2=.8                       ! propulsion complexity factor
      Elseif(PSYStype.eq.2) then
         KN2=1.2
      Else
         KN2=1.1
      Endif
!
      KN4=1./CMan                     ! command and control complexity factor
!
      CL1=.03395*Fi*KN1*W1**.772      ! SWBS 100 lead ship construction cost
      CL2=.00186*Fi*KN2*Pbpengtot**.808    ! SWBS 200 lead ship construction cost
      KN3=1.0                         ! electrical complexity factor
      CL3=.07505*Fi*KN3*W3**.91            ! SWBS 300 lead ship construction cost
      CL4=.10857*Fi*KN4*W4**.617      ! SWBS 400 lead ship construction cost
      KN5=1.0                         ! auxiliaries complexity factor
      CL5=.09487*Fi*KN5*W5**.782      ! SWBS 500 lead ship construction cost
      KN6=1.0                         ! outfit complexity factor
      CL6=.09859*Fi*KN6*W6**.784      ! SWBS 600 lead ship construction cost
      KN7=1.0                         ! ordnance complexity factor
      CL7=.00838*Fi*KN7*W7**.987      ! SWBS 700 lead ship construction cost
      CLSUM=CL1+CL2+CL3+CL4+CL5+CL6+CL7    ! total SWBS 100-700 lead ship construction cost
      CLM=(Wm24/(Wls-Wm24))*CLSUM     ! margin weight lead ship construction cost
      KN8=10.0                        ! lead ship design and engineering complexity factor
      CL8=0.034*KN8*(CLSUM+CLM)**1.099     ! lead ship design and engineering cost
      KN9=2.0                         ! lead ship procuction support complexity factor
      CL9=.135*KN9*(CLSUM+CLM)**.839  ! lead ship procuction support cost
      CLCC=CLSUM+CL8+CL9+CLM               ! lead ship basic construction cost (BCC)
      CLP=Fp*CLCC                     ! lead ship shipbuilder profit
      PL=CLCC+CLP                          ! lead ship shipbuilder price
      CLCORD=.12*PL                        ! lead ship change order cost
      Csb=PL+CLCORD                        ! total lead ship shipbuilder cost
      CLOTH=.025*PL                        ! lead ship other government cost
      CLPMG=.1*PL                     ! lead ship program manager growth
      Wmp=W4+W7-Wic+WF20                   ! costed payload weight
      CLMPG=(.35*Wmp)*Fi              ! lead ship payload GFE cost
      CLHMEG=.02*PL                        ! lead ship HM&E GFE cost
      CLOUT=.04*PL                         ! lead ship government outfitting cost
      CLGOV=CLOTH+CLPMG+CLMPG+CLHMEG+CLOUT  ! lead ship government cost
      CLEND=Csb+CLGOV                      ! lead ship end cost
      CLPDEL=.05*PL                        ! lead ship delivery cost
      CLA=CLEND+CLPDEL                     ! lead ship acquisition cost
! Follow ships
     Yfol=NYbase+1+INT((Ns/2-1)/Rp) ! middle follow ship year
     Fifol=1.
     DO 20 I=1,Yfol-NYbase
 20      Fifol=Fifol*(1.+Rif/100.)    ! average follow ship inflation factor
      Rl=.98                       ! learning rate
     Fl=Rl**(Log(Float(Ns/2))/Log(2.))  ! average follow ship learning factor
      Cfolsum=CLSUM*Fifol*Fl          ! total SWBS 100-700 follow ship construction cost
      Cfolm=Fifol*Fl*CLM              ! margin weight follow ship construction cost
      Cfol8=.204*(CLSUM+CLM)**1.099        ! follow ship design and engineering cost
      Cfol9=.58*Fl*Fifol*CL9       ! follow ship procuction support cost
      Cfolcc=Cfolsum+Cfol8+Cfol9+Cfolm ! follow ship basic construction cost (BCC)
```

```
      Cfolp=Fp*Cfolcc                    ! follow ship shipbuilder profit
      Pfol=Cfolcc+Cfolp                  ! follow ship price
      Cfolcord=.08*Pfol                  ! follow ship change order cost
      Cfolsb=Pfol+Cfolcord               ! total follow ship shipbuilder cost
      Cfoloth=.025*Pfol                  ! follow ship other government cost
      Cfolpmg=.05*Pfol                   ! follow ship program manger growth
      Cfolmpg=(.19*Wmp)*Fifol*Fi         ! follow ship payload GFE cost
      Cfolhmeg=.02*Pfol                  ! follow ship HM&E GFE cost
      Cfolout=.04*Pfol                   ! follow ship government outfitting cost
      Cfolgov=Cfoloth+Cfolpmg+CfolMPG+Cfolhmeg+Cfolout ! follow ship government cost
      Cfolend=Cfolsb+Cfolgov             ! follow ship end cost
      Cfolpdel=.05*Pfol                  ! follow ship delivery cost
      Cfola=Cfolend+Cfolpdel             ! average follow ship acquisition cost
      Cfuellife=20.5*Fgalperyear*1.0/1000000. ! discounted life cycle fuel cost (30 years)
      Cmanlife=20.5*(NO+NE)*.085         ! discounted life cycle manning cost (30 years)
      CTOC=Cfola+Cfuellife+Cmanlife      ! follow ship total ownership cost
! Output
      open(5,file='SCCost.out',status='old')
      write(5,*) CLA,Cfola,CTOC
```