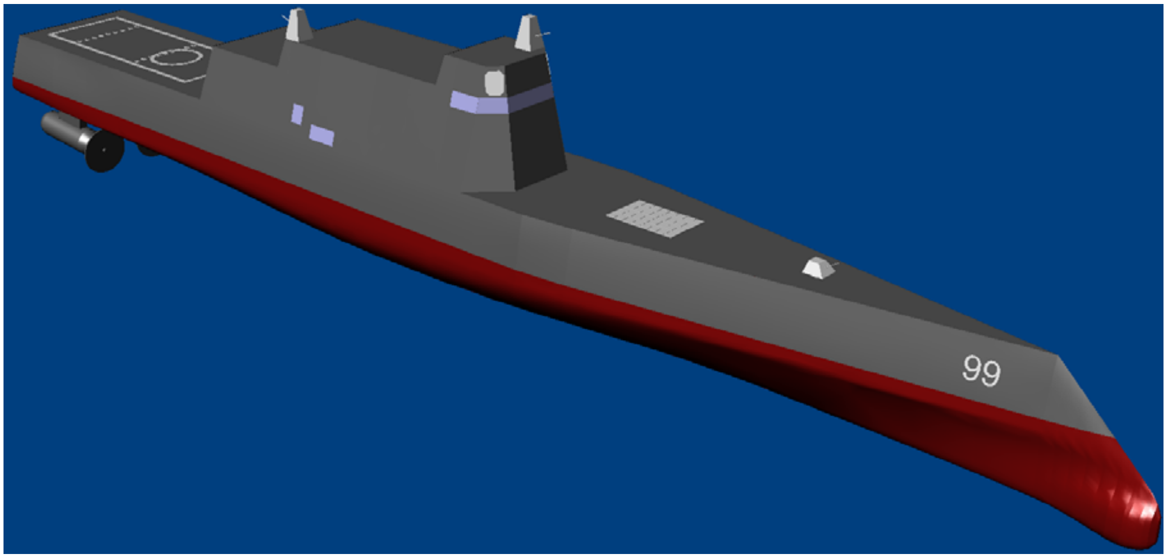
Aerospace & Ocean Engineering

Design Report

AREA DEFENSE FRIGATE

VT Total Ship Systems Engineering



ADF Design 95
Ocean Engineering Design Project
AOE 4065/4066
Fall 2006 – Spring 2007
Virginia Tech Team 5

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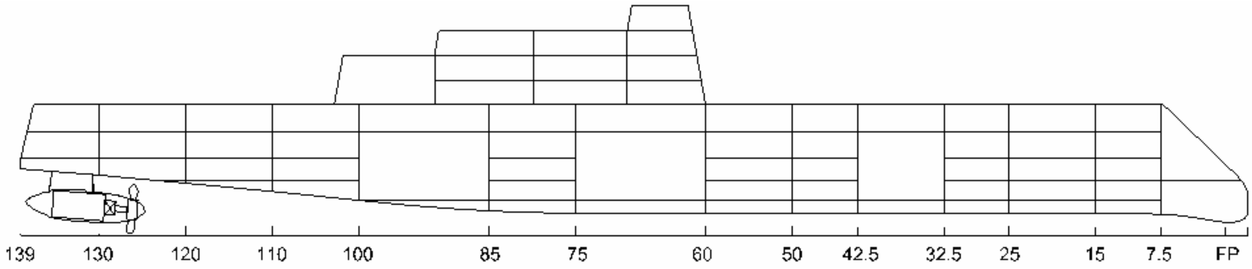
Executive Summary



This report describes the Concept Exploration and Development of an Area Defense Frigate (ADF) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The ADF requirement is based on the Initial Capabilities Document (ICD) and the Virginia Tech ADF 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 key performance parameters and a cost threshold based on the customer's preference. ADF 95 is a monohull design selected from the high end of the non-dominated frontier with high levels of cost, risk, and effectiveness.

The wave-piercing tumblehome hull form of ADF 95 reduces radar cross-section and resistance in waves. The monohull design provides sufficient displacement and large-object space for a 32 cell Vertical Launch System. ADF 95 also provides significant surface combatant capability for a relatively low cost compared to DD1000 and CGX in addition to being a force multiplier.

ADF 95 is capable of reaching a sustained speed of nearly 32 knots. This speed is achieved using an Integrated Power System (IPS) drive system that incorporates two pods, two gas turbines, and two diesel generators.

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 key performance parameters in the Capability Development Document (CDD) within cost and risk constraints.

Ship Characteristic	Value
LWL	139.0 m
Beam	17.18 m
Draft	5.81 m
D10	12.51 m
Lightship weight	5483 MT
Full load weight	6530 MT
Sustained Speed	31.8 knots
Endurance Speed	20.0 knots
Endurance Range	5362 nm
Propulsion and Power	2 Pods IPS 2 x LM2500+ GTG, 1 x ICR 2 x CAT3608 IL8 DG
BHP	66687 kW
Personnel	246
OMOE (Effectiveness)	0.841
OMOR (Risk)	0.509
Lead Ship Acquisition Cost	$919.4M
Follow Ship Acquisition Cost	$642.0M
Life-Cycle Cost	$1.12B
ASW/MCM system	SQS-56, SQQ 89, 2 x MK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
NSFS/ASUW system	MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
AAW system	SPY-3 (3 panel), AEGIS MK 99 FCS
CCC	Enhanced CCC
GMLS	32 cells, MK41
LAMPS	Embarked 2 x LAMPS w/ Hangar

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1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the concept exploration and development of an Area Defense Frigate (ADF) for the United States Navy. The ADF requirement is based on the ADF Initial Capabilities Document (ICD), and Virginia Tech ADF Acquisition Decision Memorandum (ADM), Appendix A and Appendix B. This concept design was completed in a two-semester ship design course at Virginia Tech. The ADF must perform the following missions:

Table 1– Missions

ADF Required Missions	
I.	Escort: Carrier Strike Group (CSG), Expeditionary Strike Group (ESG), MCG, Convoy
II.	Surface Action Group (SAG)
III.	Independent Ops
IV.	Homeland Defense / Interdiction

The ADF must provide and support the joint functional areas: Force Application, Force Protection and Battlespace Awareness. This means the ADF must provide force application from the sea, force protection and awareness at sea, and protection of homeland and critical bases from the sea.

The Concept of Operations (CONOPS) identifies seven critical US military operational goals.

- Protecting critical bases of operations
- Assuring information systems
- Protecting and sustaining US forces while defeating denial threats
- Denying enemy sanctuary by persistent surveillance
- Tracking and rapid engagement
- Enhancing space systems
- Leveraging information technology

The US Navy plans to support these goals by building a sufficient number of ships to provide warfighting capabilities in the following areas.

- Sea Strike: strategic agility, maneuverability, ISR, and time-sensitive strikes
- Sea Shield: project defense around allies, exploit control of seas, littoral sea control, and counter threats
- Sea Base: accelerated deployment and employment time, and enhanced seaborne positioning of joint assets

The new ADF will have the same modular systems as LCS in addition to core capabilities with AAW/BMD (with queuing) and blue/green water ASW. The lead ship acquisition cost of the new frigate must be no more than \$1B and the follow-ship acquisition cost shall not exceed \$700M. The platforms must be highly producible with minimum time from concept to delivery to the fleet. There should be maximum system commonality with LCS and the platforms should be able to operate within current logistics support capabilities. There should be minimum manning, a reduction in signature, and the Inter-service and Allied C^4/I (inter-operability) must be considered. It is expected that 20 ships of this type will be built with IOC in 2015.

1.2 Design Philosophy, Process, and Plan

The design process for the ADF is broken down into the 5 distinct stages in Figure 1. This report will focus on Concept Exploration and Concept Development. Exploratory design is an ongoing process and is the assessment of new and existing technologies and the integration of these technologies in the ship design. With regards to a Navy ship design, there is also an on-going mission or market analysis of threat, existing ships, technology and consequently the determination of need for new ship designs or characteristics. The exploratory design stage will lead to a baseline design, feasibility studies, and finally a final concept.

The next stage is Concept Development where the concept is developed and matured to reduce risk and clarify cost. From this stage, the Preliminary Design is created. The next stage is contract design where a full set of drawings and specifications are made to the required level of detail to contract and acquire ships. Finally, the Detail

Design is performed by the ship builder where the process and details necessary to build the design are developed. The entire engineering process can take 15 to 20 years.

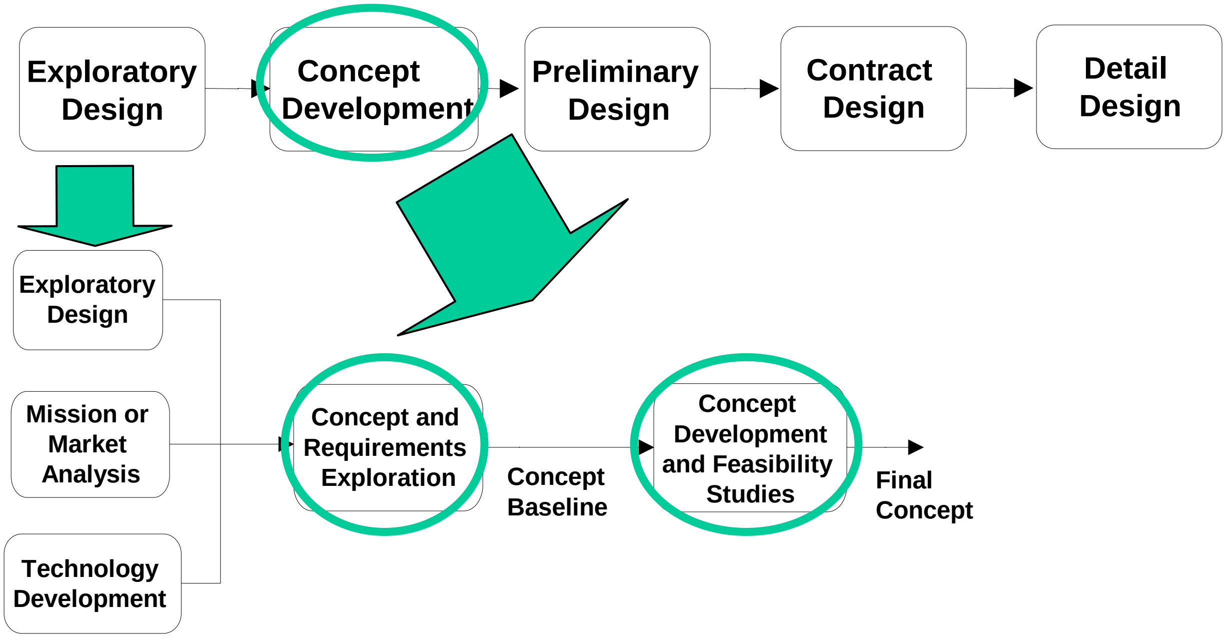


Figure 1 – Design stages.

The design strategy is presented in Figure 2, where the diagram is read from left to right. First a broad perspective is taken where the whole design space is looked at with a broad range of cost, risk and technical alternatives. The selection of technical alternatives is narrowed down to a set of non-dominated designs, and then some of the non-dominated designs are selected for further consideration. To do this, a multi-objective optimization with millions of possible different designs is conducted. The designs are sorted through the funnel and narrowed down to a non-dominated frontier. From the non-dominated frontier the design detail is expanded and the risk is minimized with additional analysis in concept development.

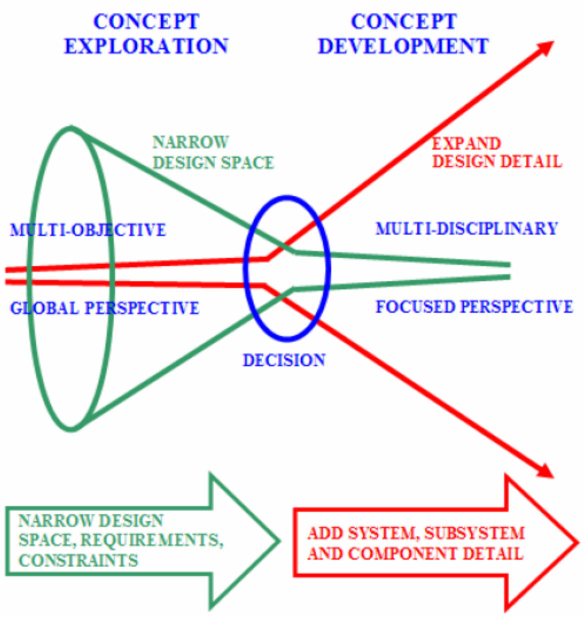


Figure 2 – Design Strategy

Figure 3 shows the concept and requirements exploration process. The process begins with the Initial Capabilities Document (ICD), the Acquisition Decision Memorandum (ADM) and the Analysis of Alternatives (AOA) guidance. The mission description is expanded into a detailed description that can be used in developing effectiveness metrics for engineering purposes. From the mission description, the Required Operational Capabilities (ROCs), the Measures of Performance (MOPs), and the alternative technologies that are able to achieve the necessary capabilities are identified. The alternative technologies have certain levels of risk associated with them because there are many unknowns.

Next, the MOPs are put into an Overall Measure of Effectiveness model (OMOE). Then the Design Variables (DVs) and the Design Space are defined from the design possibilities. The Risk, Cost, Effectiveness, Design Space, and Design Variables are included in the synthesis model and the model is then evaluated with a design of experiments (DOE) with variable screening and exploration. Ultimately the Multi-Objective Genetic Optimization (MOGO) is used to search the design space for a non-dominated frontier of designs using the Ship Synthesis model to assess the feasibility, cost, effectiveness and risk of alternative designs. From the non-dominated fronteir, concept baseline designs are selected for each team based on “knees” in the graph. For their design, each team creates a Capabilities Development Document (CDD) including Key Performance Parameters (KPPs), a ship concept, and determines some subset of technology development.

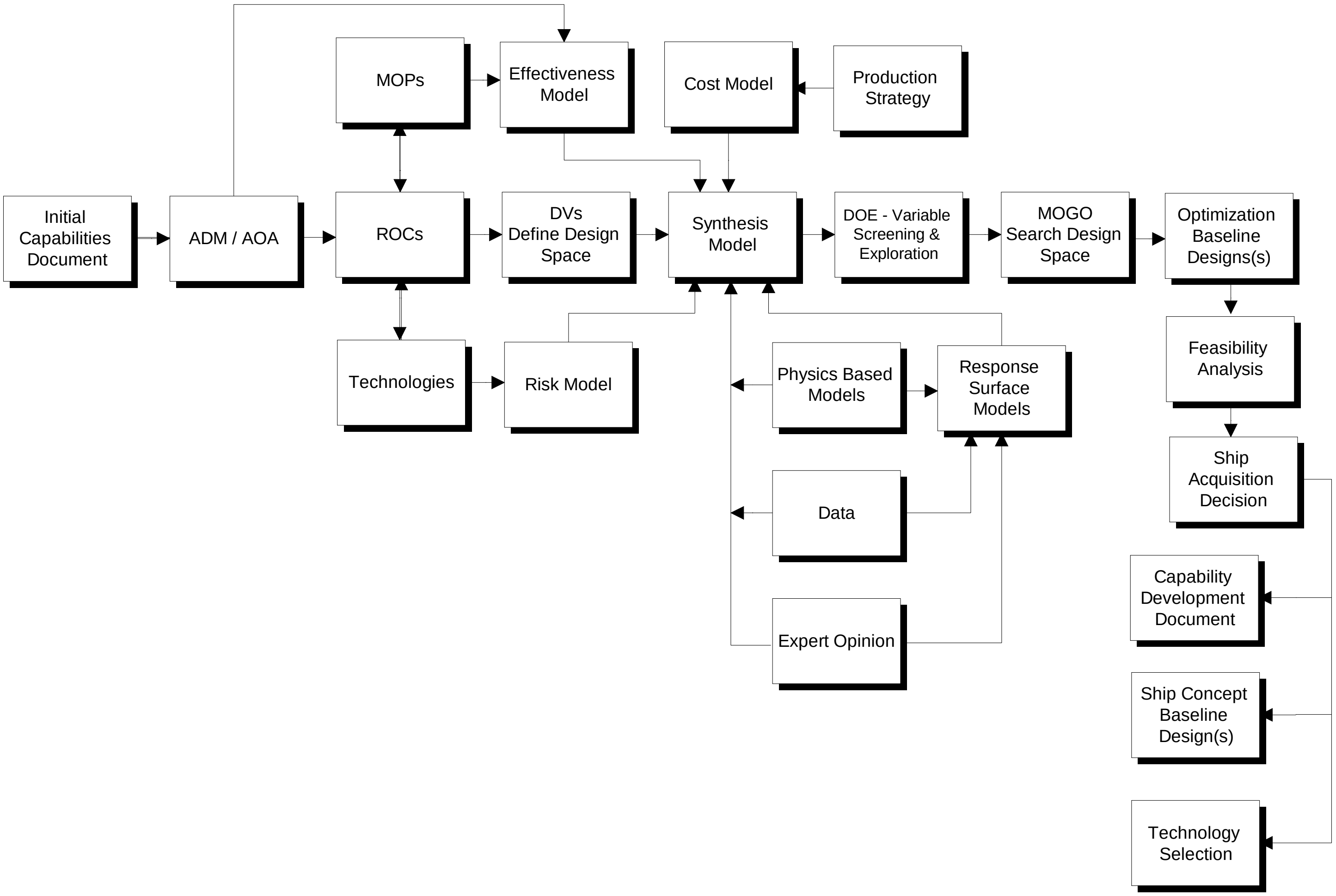


Figure 3 – Concept and Requirements Exploration

After finishing concept and requirements exploration, concept development is started as shown in Figure 4. The process is very similar to the traditional design spiral. The baseline design is based on concept exploration, the Capabilities Development Document (CDD) and a selection of technologies. A number of steps are taken in a spiral-like process where the concept is revised and the spiral is re-traveled until converging to a refined design. Typical steps in the process are the development and assessment of hull geometry, resistance and power, manning and automation, structural design, space and arrangements, hull mechanical and electrical (HM&E), weights and stability, seakeeping and maneuvering, and a final assessment of cost and risk. If there are things that need to be changed then the spiral must be traveled again.

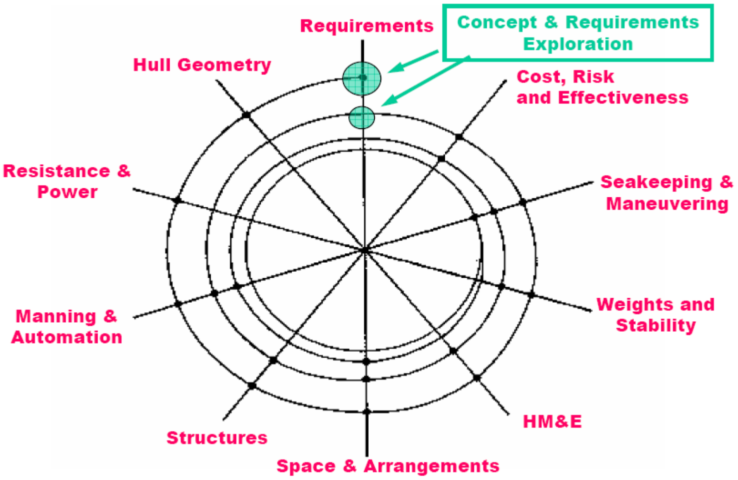


Figure 4 – Idealized Concept Development Design Spiral

The real design spiral is never as smooth as presented in Figure 4. Often times the different departments communicate with each other a lot and build a complex network of communications between disciplines. For example, Figure 5 shows that once hull geometry is developed, it is communicated to the structures, general arrangements, machinery arrangements, and subdivision area and volume specialists. For this ship process, there may only be enough time to run through the design spiral once, and any inconsistencies will be noted for further evaluation.

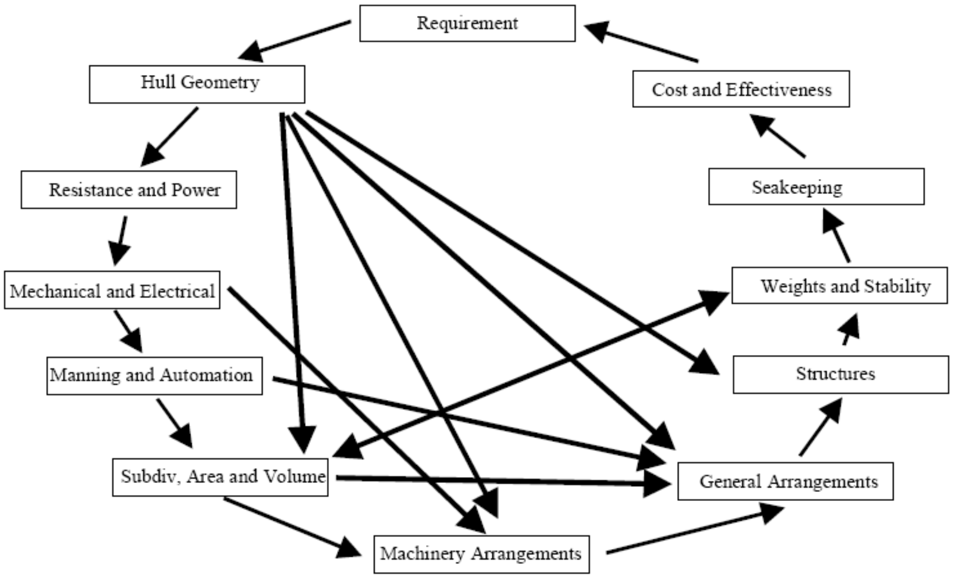


Figure 5 – Concept Development Design Spiral

1.3 Work Breakdown

ADF Team 5 consists of five students from Virginia Tech. Each student requested or was assigned areas of work according to his or her interests and special skills as listed in Table 2. The team leader is in charge of communications between team members and Virginia Tech faculty. In addition, the team leader is also in charge of keeping everything organized and keeping the team on schedule.

Table 2 – Work Breakdown

Name	Specialization
William Downing	Propulsion and Resistance, Manning and Automation, Weights and Stability
Jason Eberle	Combat Systems, General & Machinery Arrangements, Electrical, Subdivision
Michael Kipp	Feasibility, Cost & Risk, Effectiveness, General & Machinery Arrangements
Anne-Marie Sattler	Writer / Editor, Structures, Preliminary Arrangement, Producibility
Lawrence Snyder	Hull Form, Structures, Seakeeping, Propulsion and Resistance, Weights and Stability

1.4 Resources

Computational and modeling tools used in this project are listed in Table 3. The analyses that were completed are listed on the left and the software packages used are listed on the right. These tools simplified the ship design process and decreased the overall time. Their applications are presented in Sections 3 and 4.

Table 3 – Tools

Analysis	Software Package
Arrangement Drawings	AutoCAD, Rhino
Baseline Concept Design	ASSET
Hull form Development	Rhino
Hydrostatics	HECSALV, Rhino Marine
Resistance/Power	Mathcad
Ship Motions	SMP
Ship Synthesis Model	Model Center, Fortran
Structure Model	MAESTRO, HECSALV, Mathcad

2 Mission Definition

The ADF requirement is based on the ADF Initial Capabilities Document (ICD), and Virginia Tech ADF Acquisition Decision Memorandum (ADM), Appendix A and Appendix B with elaboration and clarification obtained by discussion and correspondence with the customer.

2.1 Concept of Operations

In Appendix A, the 2001 Quadrennial Defense Review identifies seven critical US military operational goals:

- Protecting critical bases of operations
- Assuring information systems
- Protecting and sustaining US forces while defeating denial threats
- Denying enemy sanctuary by persistent surveillance
- Tracking and rapid engagement
- Enhancing space systems
- Leveraging information technology

The US Navy plans to support these goals by building a sufficient number of ships to provide warfighting capabilities in the following areas:

- Sea Strike: strategic agility, maneuverability, ISR, and time-sensitive strikes
- Sea Shield: project defense around allies, exploit control of seas, littoral sea control, and counter threats
- Sea Base: accelerated deployment and employment time, and enhanced seaborne positioning of joint assets

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

Ships must be able to support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C4/I reconnaissance vehicles. The Naval forces will be the first military forces on-scene and will have "staying and convincing" power to promote peace and prevent crisis escalation. They must also have the ability to provide a "like-kind, increasing lethality" response to influence decisions of regional political powers, and have the ability to remain invulnerable to enemy attack. The Naval forces must also be able to support non-combatant and maritime interdiction operations in conjunction with national directives. They must also be flexible enough to support peacetime missions yet be able to provide instant wartime response should a crisis escalate. Finally, Naval forces must posses sufficient mobility and endurance to perform all missions on extremely short notice and at locations far removed from home port. To accomplish this, the naval forces must be pre-deployed and virtually on station in sufficient numbers around the world.

Expected operations include escort, surface action group (SAG), independent operations, and homeland defense. Within these operations the ship will provide area AAW, ASW and ASUW defense, along with intelligence, surveillance, and reconnaissance (ISR) and ballistic missile defense (BMD). It will also provide mine countermeasures (MCM) and will support UAVs, USVs and UUVs. The ship will also provide independent operations including support of special operations, humanitarian support and rescue, and peacetime presence.

2.2 Capability Gaps

Table 4 lists the capability gap goals and thresholds given in Appendix A.

Table 4 – Capability Gaps

Priority	Capability Description	Threshold Systems	Goal Systems
1	Core AAW/BMD (with queuing)	SPY-3 w/32 cell VLS, Nulka/SRBOC, SLQ-32V2	SPY-3 w/64 cell VLS, Nulka/SRBOC, SLQ-32V3
2	Core Blue/green water ASW	SQS-56 sonar, TACTAS, NIXIE, 2xSH-2G, SSTD	SQS-53C sonar, TACTAS, NIXIE, 2xSH-60, SSTD
3	Special-Mission Packages (MCM, SUW, ASW, ISR, Special Forces)	1xLCS Mission Packages with UAVs, USVs and stern launch	2xLCS Mission Packages with UAVs, USVs and stern launch
4	Core ISR	2xSH-2G, advanced C4I	2xSH-60, advanced C4I
5	Mobility	30knt, full SS4, 3500 nm, 45 days	35knt, full SS5, 5000 nm, 60 days
6	Survivability and self-defense	DDG-51 signatures, mine detection sonar, CIWS or CIGS	DDG1000 signatures, mine detection sonar, CIWS or CIGS
7	Maritime interdiction, ASUW	2xSH-2G, 57mm gun, 2x.50 caliber guns	2xSH-60, 57mm gun, 2x.50 caliber guns, Netfires

2.3 Projected Operational Environment (POE) and Threat

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

I. Threats from nations with either a significant military capability, or the demonstrated interest in acquiring such a capability. Specific weapons systems that could be encountered include:
    a. Ballistic missiles
    b. Land and surface launched cruise missiles
    c. Significant land based air assets
    d. Submarines

II. 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 weapons systems include:
    a. Diesel/electric submarines
    b. Land-based air assets
    c. Mines (surface, moored and bottom)

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

- Open ocean and littoral
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture
- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather Battle Group
- All-Weather Independent operations

Many potentially unstable nations are located on or near geographically constrained (littoral) bodies of water. Threats in such an environment include:

I. Technologically advanced weapons
    a. Cruise missiles like the Silkworm and Exocet
    b. Land-launched attack aircraft
    c. Fast gunboats armed with guns and smaller missiles
    d. Diesel-electric submarines

II. Unsophisticated and inexpensive passive weapons
    a. Mines (surface, moored and bottom)
    b. Chemical and biological weapons

2.4 Specific Operations and Missions

The ADF is expected to perform operations including escort, surface action group (SAG), independent operations, and homeland defense.

I. Escort

The ship will serve as an escort to protect aircraft carriers and other ships by traveling in convoy to provide direct support of Carrier Strike Group (CSG) and Expeditionary Strike Group (ESG). The ship will support CSGs by supporting flexible strike missions, providing forward presence, power projection, and crisis response. The ship will support ESGs in low to moderate threat environment by providing services such as human assistance, peace enforcement, maritime interdiction operations, and fire support.

II. Surface Action Group (SAG)

The ship may travel as part of a surface action group where it is not escorting an aircraft carrier or other ships. A surface action group generally consists of two or more surface combatants and deploys for unique operations, such as augmenting military coverage in world regions, providing humanitarian assistance, and conducting exercises with allied forces. As part of a SAG, the ship will travel with CGs, DDGs and LCSs, and will provide AAW, ASW, ASUW, BMD, MCM, and ISR.

III. Independent OPs

The ship will perform independent operations by providing area AAW, ASW and ASUW. It will also provide BMD with queuing, MCM and ISR. The ship will support special operations and has the ability to support UAV, USVs and UUVs. Specific independent operations may also include humanitarian support and rescue and peacetime presence.

IV. Homeland Defense / Interdiction

The ship will provide homeland defense from the sea against air and sea attacks. To accomplish this, the ship will perform military missions overseas including but not limited to AAW, ASW, ASUW and ISR. The ship will also perform maritime interdiction operations (MIO) in wartime and peacetime including eliminating enemy's surface military potential, terrorist threats and illegal interactions at sea.

2.5 Mission Scenarios

Mission scenarios for the primary ADF missions are provided in Table 5 and Table 6. The scenarios are for 60 days but actual scenarios may take as long as 90+ days.

Table 5 – CSG Mission

Day	Mission scenario
1-21	Small ADF squadron transit from CONUS
22	Underway replenishment (Unrep)
23-33	Deliver humanitarian aid, provide support
29	Defend against surface threat (ASUW) during aid mission
31-38	Repairs/Port Call
39	Unrep
42	Engage submarine threat for self-defense
43	Avoid submarine threat (ASW)
44-59	Join CSG/ESG
60+	Port call or restricted availability

Table 6 – SAG Mission

Day	Mission scenario
1-21	ADF transit from CONUS
21-24	Port call, replenish and load AAW/ASW/ASUW/BMD modules
24	Engage air threat for self defense
25-30	Conduct AAW/ASW/ASUW/BMD operations
31-38	Repairs/Port Call
39	Unrep
41	Engage submarine threat for self-defense
39-49	SH-60 operations against submarine threat
50	Repairs/Port Call
51-59	Mine avoidance
60+	Port call or restricted availability

2.6 Required Operational Capabilities

In order to support the missions and mission scenarios described in Section 2.5, the capabilities listed in Table 7 are required. Each of these can be related to functional capabilities required in the ship design, and, if within the scope of the Concept Exploration design space, the ship's ability to perform these functional capabilities is measured by explicit Measures of Performance (MOPs).

Table 7 – List of Required Operational Capabilities (ROCs)

ROCs	Description
AAW 1	Provide anti-air defense
AAW 1.1	Provide area anti-air defense
AAW 1.2	Support area anti-air defense
AAW 1.3	Provide unit anti-air self defense
AAW 2	Provide anti-air defense in cooperation with other forces
AAW 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
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious operation
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
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, design space exploration and optimization are accomplished using a Multi-Objective Genetic Optimization (MOGO).

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

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

3.1.1 Hull Form Alternatives

3.1.1.1 Finding an Appropriate Hull Form

To find an appropriate hull form, estimated hull parameters were compared to the hull parameters of proven ships. This method, called the Transport Factor method, uses these parameters to return a Transport Factor value. By comparing this calculated value to the Transport Factor of proven ships at a similar sustained speed, the most suitable hull-type can be determined. The Transport Factor is estimated using the following the following equation:

$$TF = \left(5.052\frac{kW}{MT * knt}\right)\frac{\Delta V_s}{SHP} = 20.6@30knt$$

It is based on the following hull parameters:

- Full load weight of the ship
- Light ship weight
- Payload weight
- Sustained speed
- Endurance speed
- Total shaft power
- Endurance range
- Specific fuel consumption at endurance speed

A plot of the Transport Factor versus ship speed appears in Figure 6. Based on Transport Factor methodology, a monohull is most suitable.

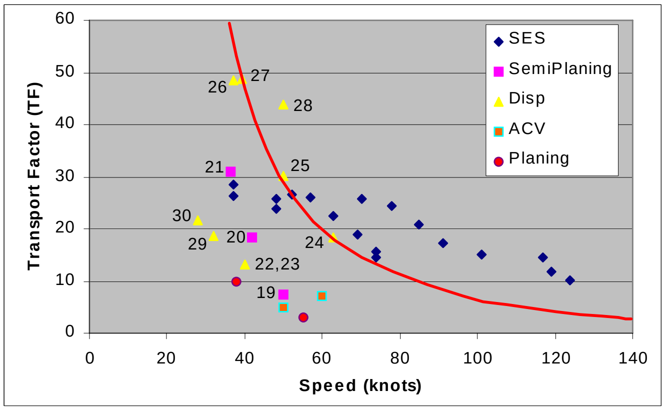


Figure 6 – Transport Factors for Various Hull-Types

3.1.1.2 Additional Considerations Pertaining to Hull-Type

The following were ship considerations that were not taken into account by the Transfer Factor:

- Must be able to accommodate large and heavy combat systems (radar, cooling, and missiles)
- Must have sufficient deck area for LAMPS and possible V-22 ops
- Must have low radar cross section (RCS)
- Must be production efficient (low maintenance, low cost)
- Must have a large object volume for machinery spaces, hangar decks, weapon magazines, 32 cell VLS, and radar
- Must be structurally efficient
- Must have good seakeeping performance

Bearing in mind the Transport Factor and the additional considerations pertaining to choosing a hull-type, the best candidate hull from for ADF was a monohull.

3.1.1.3 Area Defense Frigate Design Lanes

Based on other proven naval ships a set of design ranges was chosen and appears in Table 8. These values were used to define the hull form design space, DV1 – DV7 in Table 20.

Table 8 – Hull Characteristics

Characteristic	Range or Value
Displacement (Mt)	approx. 6100
$\Delta/(L/100)^3$ (Mt/m^3)	55.2 – 72.5
L/B	7 – 10
L/D	10.5 – 17.8
B/T	2.8 – 3.2
C_p	0.56 - 0.64
C_x	0.75 - 0.85
C_{rd}	0.7 - 1.0

3.1.2 Propulsion and Electrical Machinery Alternatives

3.1.2.1 Machinery Requirements

General Requirements

The propulsion for ADF 95 will use gas turbines, diesel engines, or IPS configurations in various mechanical drives. The preliminary power requirement includes two to four main engines capable of producing 10000 to 30000 kW per engine. The propulsion system has a goal of a Grade A shock certification and Navy qualification.

The propulsion drive type will be mechanical or IPS, and the propulsors will be fixed pitch or controllable pitch propellers or pods. Potential use of IPS with DC Bus, zonal distribution and permanent magnet motors will take into consideration operational flexibility, improved efficiency and survivability, and will be weighed against moderate weight and volume penalties.

Finally, the design must continuously operate 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).

Sustained Speed and Propulsion Power

The ship must have a minimum sustained speed of at least 30 knots in calm water, clean hull, and full load condition and must use no more than 80% of the installed engine rating (MCR) of main propulsion engines or motors. The ship also must have a minimum range of 3500 nautical miles when operating at 20 knots.

Additionally, all propulsion type alternatives must span 50-115 MW power range with ship service power in excess of 5000 kW MFLM.

Ship Control and Machinery Plant Automation

Ship control and machinery plant automation will use an integrated bridge system that integrates navigation, radio communication, interior communications, and ship maneuvering equipment. This system will be compliant with the ABS Guide for One Man Bridge Operated (OMBO) Ships as well as with ABS ACCU requirements for periodically unattended machinery spaces.

Sufficient manning and automation will be required to continuously monitor auxiliary systems, electric plant and damage control systems from the SCC, MCC and Chief Engineer’s office, and to control the systems from the MCC and local controllers.

Propulsion Engine and Ship Service Generator Certification

Because propulsion and ship service power is critical to many aspects of mission and survivability for ADF 95, this equipment shall be:

- Navy qualified & grade A shock certified gas turbines are alternatives (design variable)
- Non-nuclear
- Consider low IR signature and cruise/boost options for high endurance

3.1.2.2 Machinery Plant Alternatives

Consider two types of main drive systems:

1. Mechanical drive system, where the motor is coupled to a reduction gear that turns the driveshaft, which is directly connected to the propeller. This is the standard system for many navy ships.
2. Integrated power system (IPS), where the generator supplies power to an electric motor that is either directly connected to the propeller or turns a short driveshaft that is connected to the propeller. This system uses new technology and allows for more options when arranging the machinery room. This system may also eliminate the need for separate ship service generators.

Consider three types of propulsors:

1. Conventional fixed pitch propeller (FPP), which is standard for all systems.
2. Controllable pitch propeller (CPP), which allows the drive system to go from forward to reverse propulsion with out stopping the motors.
3. Podded propulsor, which may use either the FPP or the CPP. This system provides greater maneuverability and efficiency, but is not as resistant to shockwaves.

Consider two types of engines:

1. Gas turbines, which allow for more power with less weight.
2. Diesel engines, which have a low speed but high efficiency.

The various propulsion arrangement options are shown in Figure 7. Table 9 shows the characteristics of each propulsion system arrangement, and Table 10 shows the generator arrangement options and characteristics.

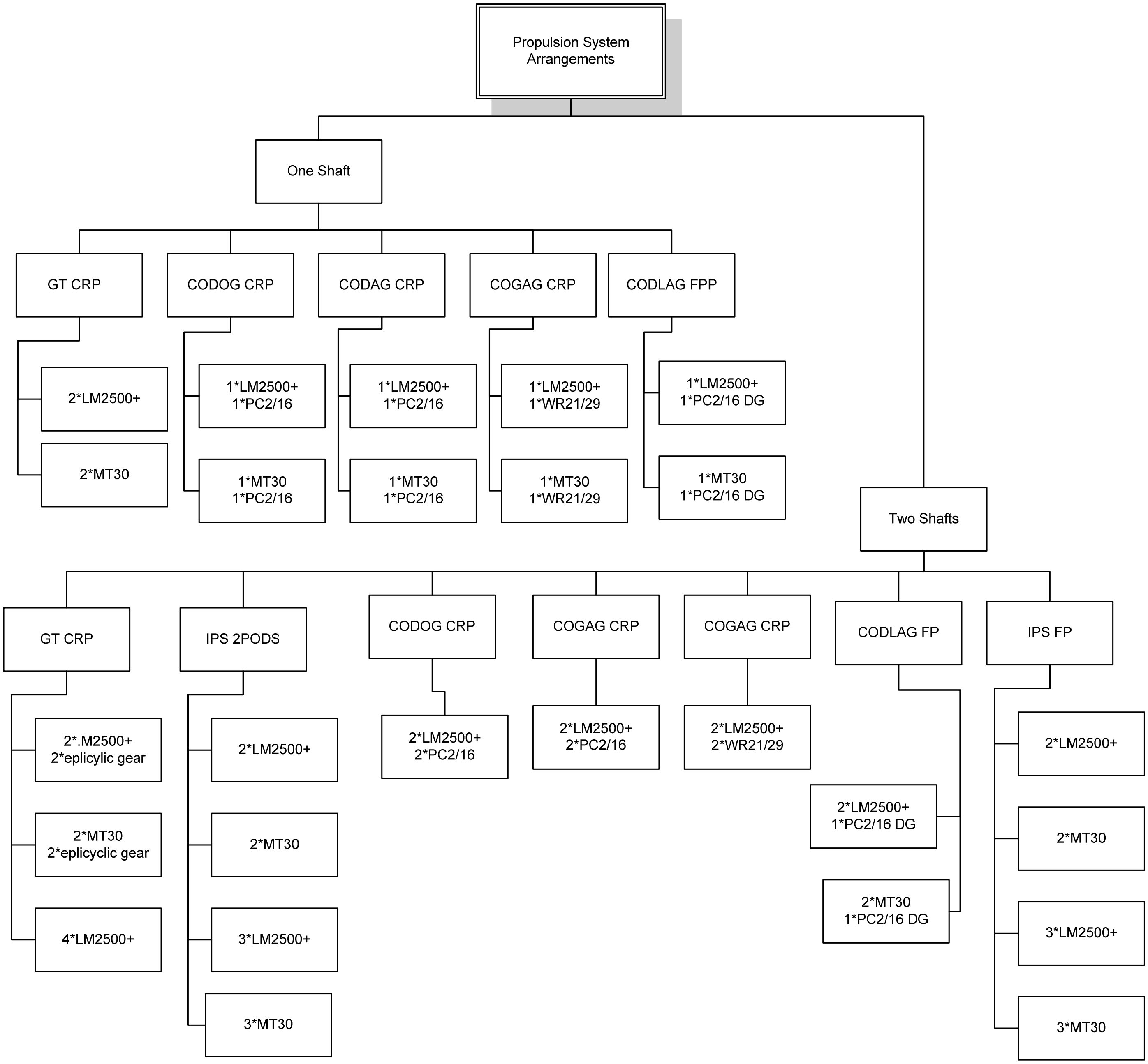


Figure 7 – Propulsion and Power System Alternatives

Table 9 – Propulsion System Data

Propulsion Option	Propulsion System Type PSYSTYP	Propeller Shafts Nprop	Endurance Propulsion Engine Type, PENGtype (1=GT, 2=ICR, 3=Diesel)	Total Propulsion Engine BHP PBPENGTOT (kW)	Endurance Brake Propulsion Power, Pbpengend (kW) Engine	Endurance Propulsion SFCePE (kg/kwhr) Engine	Machinery Box Minimum Length LMBreq (m)	Machinery Box Minimum Height HMBreq (m)	Machinery Box Required Volume VMBreq (m3)	Basic Propulsion Machinery Weight WBM (MT)	Propulsion Inlet and Uptake Area APIE (m2)
2xLM2500+	1	1	1	52198	26099	0.226	17.61	4.54	2012	273.7	28.2
CODOG 1xMT30 1xPC2/16	1	1	3	43755	7755	0.207	18.33	9.18	2442	398.4	24.2
CODAG 1xMT30 1xPC2/16	1	1	3	43755	7755	0.207	18.49	9.10	2466	403.5	24.2
COGAG 1xLM2500+ 1xWR21/29	1	1	1	47754	21655	0.199	17.53	8.57	2270	310.5	25.8
COGAG 1xMT30 1xWR21/29	1	1	1	57655	21655	0.199	18.73	9.00	2734	373.3	33.0
CODLAG 1xMT30 1xPC2/16	1	1	3	43755	7755	0.207	13.19	9.22	2195	353.0	24.3
2xLM2500+ 2xepicyclis	1	2	1	52198	26099	0.226	14.91	7.00	2223	241.1	28.2
CODOG 2xLM2500+ 2xPC2/16	1	2	3	52198	7755	0.207	16.39	7.89	3298	619.1	34.0
CODLAG 2xLM2500+ 1xPC2/16	1	2	3	59953	7755	0.207	13.19	9.22	2740	406.4	31.2
2xLM2500+ 1x2/16	2	2	2	59953	7755	0.207	13.95	9.22	2495	490.7	31.1
2xLM2500+ 1x2/16	3	2	2	59953	7755	0.207	13.95	9.22	2495	490.7	31.1

Table 10 – Generator System Data

SSG Option	SSG Option	GENGtype (1=Diesel, 2=Gas Turbine)	Number of SGs N_{SSG}	SSG Power (ea) KW_G(kW)	KWgend	Endurance SSG SFC SFC_{eG}(kg/kwhr)	Basic Electric Machinery Weight W_{BMG}(MT)	SSG Uptake Area $A_{GIE}(m^2)$
3xDDA 501K34 GTG	1	2	3	10101	3367	0.3	142.8	18.9
4xCAT 3516V16 DG	2	1	4	4996	3747	0.2	124.8	7.6
4xCAT 3608IL8 DG	3	1	4	10404	5202	0.2	242.2	9.6
3xCAT 3608IL8 DG	4	1	3	7803	5202	0.2	242.2	7.2
2xDDA 501K34 GTG	5	2	2	6734	3367	0.3	142.8	12.6
2xCAT 3516V16 DG	6	1	2	2498	3747	0.2	124.8	3.8
2xCAT 3608IL8 DG	7	1	2	5202	5202	0.2	242.2	4.8

3.1.3 Automation and Manning Parameters

Manning is an issue for the US Navy because of incurred cost and risk. The high “cost per man” in the US Navy because of support, training, housing, education, and so on, accounts for approximately 60% of the Navy budget. The operation and support cost for the ship is a major element in the ADF design, so to decrease this cost, a decrease in manning is desirable in addition to needing less men in combat.

For the determination of manning for the ADF, an Integrated Simulation Manning Analysis Tool (ISMAT) was used. ISMAT uses XML for libraries of equipment, manning, and compartment documents. It also employs maintenance pools where any operator within a division or department can be considered for a task. The functions within ISMAT are similar to a Gantt chart where they can be copied and pasted and the duration of the tasks and the start time can be altered.

Within ISMAT the Ship Manning Analysis and Requirements Tool (SMART) series is used to vary equipment, maintenance philosophies, and levels of automation to optimize crew size based on various goals. It employs libraries of navy equipment and maintenance procedures. The user develops a scenario to test ability of the crew and tasks and events are entered using Micro Saint with list of skills required to perform tasks. It then dynamically allocates each task to a crew member and function allocation is based on taxonomies and on the level of automation that is specified by the user. Ultimately, the size and make up of the crew is optimized for four different goals: cost (SMART database with annual cost of each rank and rate in the Navy); crew size; different jobs / crew ratings; and workload.

The input information is entered into Model Center and relayed into ISMAT. A Visual Basic program then runs the manning model interfacing with the wrapper in model center. Design explorer in Model Center samples the design space and performs a design of experiments by building up a data set spanning the full design space. Conclusions from the data collected from the DOE are used to build the response surface model and ultimately produce the RSM equation shown in Figure 8. This equation is used in the ship synthesis model, and the overall ship optimization is conducted at the end thereby eliminating the need to use ISMAT directly.

The independent variables in the RSM equation are total number of crew: NT, level of automation: LevAuto, maintenance level: MAINT, length along the waterline compared to the CG47: LWLComp, propulsion system: PSYS, and antisurface warfare: ASuW.

$$\boxed{\begin{aligned}
&\mathit{NT} = 374.49 + 82.06 * \mathit{LevAuto} - 6.09 * \mathit{MAINT} + 11.29 * \mathit{LWLComp} - 59.85 * \mathit{LevAuto}^{2} \\
&+ 2.08 * \mathit{PSYS} * \mathit{LWLComp} - .147 * \mathit{PSYS}^{3} + 8.52 * \mathit{LevAuto}^{3} - .294 * \mathit{ASuW} * \mathit{PSYS} * \\
&\mathit{LevAuto} + .341 * \mathit{ASuw} * \mathit{MAINT}^{2} - .684 * \mathit{PSYS}^{2} * \mathit{LWLComp} + .413 * \mathit{PSYS} * \mathit{LevAuto} * \\
&\mathit{CCC} - .485 * \mathit{MAINT} * \mathit{CCC} * \mathit{LWLComp} + .210 * \mathit{CCC} * \mathit{LWLComp}^{2}
\end{aligned}}$$

Figure 8 – "Standard" Manning RSM Equation

3.1.4 Combat System Alternatives

Several combat system alternatives were identified and the ship impact was documented for each configuration. To estimate the Value of Performance (VOP), the Analytical Hierarchy Process (AHP) and Multi-Attribute Value Theory (MAVT) were used. The ship synthesis model uses the VOPs to evaluate the effectiveness. The combat systems alternatives were selected based on the effectiveness, cost, risk, and MOGO or multi objective genetic optimization. All the components and the component data for the combat systems are located in Table 19. Applicable component IDs are listed for each option in Table 11 - Table 18 and keyed to Table 19.

3.1.4.1 AAW

The Anti-Air Warfare system alternatives are listed in Table 11. The different alternatives include AN/SPY-3 and AN/SPY-1D, IRST, AN/SRS-1A(V), AN/UPX-36(V) CIFF-SD. The Mk 99 Fire Control System (FCS) is used to control all the different weapons and sensors on the ship. The Mk 99 Fire Control System (FCS) improves effectiveness by coordinating the different systems and bringing them to their optimum tactical advantage.

Table 11 – AAW System Alternatives

Warfighting system	Options	Components
AAW	Option 1) SPY-3 (4 panel), AEGIS MK 99 FCS	1,3,4,5,7,15,16,17,137,137,20,20
	Option 2) SPY-3 (3 panel), AEGIS MK 99 FCS	1,3,4,5,7,15,16,17,137,20
	Option 3) SPY-1D (2 panel), AEGIS MK 99 FCS	1,3,4,5,7,15,16,17,6,8,14,14,21

Sub systems descriptions are as follows:

- AN/SPY-1D is a variant of the SPY-1B radar system, tailored for a destroyer-sized ship. The SPY-1D, ultimately installed on DDG-51, is virtually identical to the SPY-1B, but has only one transmitter, two channels and two fixed arrays. The SPY-1D radar system is shown in Figure 9.

Figure 9 – SPY-1D Phased-array

- Mk 99 Fire Control System (FCS) - major component of the AEGIS Combat System. Controls loading and arming of the selected weapon, launches the weapon, and provides terminal guidance for AAW missiles. FCS controls the continuous wave illuminating radar, SPG-62, providing a very high probability of kill.
- IRST Shipboard integrated sensor designed to detect and report low flying ASCMs by their heat plumes. It scans the horizon +/- a few degrees but can be manually changed to search higher. Provides accurate bearing, elevation angle, and relative thermal intensity readings.
- AN/SRS-1A(V) Combat DF (Direction Finding)- Automated long range hostile target signal acquisition and direction finding system. Can detect, locate, categorize and archive data into the ship's tactical data system. Provides greater flexibility against a wider range of threat signals. Provides warship commanders near-real-time indications and warning, situational awareness, and cueing information for targeting systems
- AN/UPX-36(V) CIFF-SD - Centralized, controller processor-based, system that associates different sources of target information – IFF and SSDS. Accepts, processes, correlates and combines IFF sensor inputs into one IFF track picture. Controls the interrogations of each IFF system

3.1.4.2 NSFS/ASUW

The Anti-Surface Warfare and the Naval Surface Fire Support system alternatives are listed in Table 12. The different alternatives include AN/SPS-73(V)12 Radar Set, AN/SPQ-9B Radar, TISS Thermal Imaging Sensor System, MK 34 Gun Fire Control System (GFCS), MK 45 5"/62 MK MOD 4 Gun Mount.

Table 12 – NSFS/ASUW System Alternatives

Warfighting system	Options	Components
NSFS/ ASUW	Option 1) MK 45 5IN/62 Mod 4 gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker	29,33,68,140,143,67,75,150,79,164
	Option 2) MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker	29,33,68,140,143,144,145,146,147,79,164

Sub systems descriptions are as follows:

- AN/SPS-73(V)12 Radar Set - Short-range, two-dimensional, surface-search/navigation radar system. Short-range detection and surveillance of surface units and low-flying air units. Provides contact range and bearing information. Enables quick and accurate determination of ownship position relative to nearby vessels and navigational hazards. The SPS-73 replaces SPS-64, 55 and 67 and is shown in Figure 10.

Figure 10 – AN/SPS-73(V)12 Surface Search Radar

- AN/SPQ-9B Radar- Surface surveillance and tracking radar. Has a high resolution, X-band. From the Mk 86 5 inch 54 caliber gun fire control system (GFCS). For missile AAW - provides cueing to other ship self defense systems and excellent detection of low sea-skimming cruise missiles in heavy clutter. The SPQ-9B is shown in Figure 11.

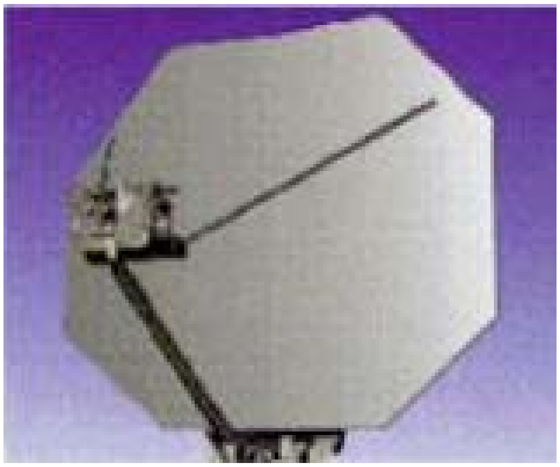


Figure 11 – AN/SPQ-9B Radar

- TISS Thermal Imaging Sensor System- The Thermal Imaging Sensor System (TISS) AN/SAY-1 is a stabilized imaging system which provides a visual infrared (IR) and television image to assist operators in identifying a target by its contrast or infrared characteristics. The AN/SAY-1 detects, recognizes, laser ranges, and automatically tracks targets under day, night, or reduced visibility conditions, complementing and augmenting existing shipboard sensors. The AN/SAY-1 is a manually operated system which can receive designations from the command system and designate to the command system providing azimuth, elevation, and range for low cross section air targets, floating mines, fast attack boats, navigation operations, and search and rescue missions. The sensor suite consists of a high-resolution Thermal

Imaging Sensor (TIS), two Charged Coupled Devices (CCDs) daylight imaging Television Sensors (TVS), and an Eye-Safe Laser Range Finder (ESLRF). The AN/SAY-1 also incorporates an Automatic Video Tracker (AVT) that is capable of tracking up to two targets within the TISS field of view. The TISS Thermal Imaging Sensor System is shown in Figure 12.

Figure 12 – TISS Thermal Imaging Sensor System

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

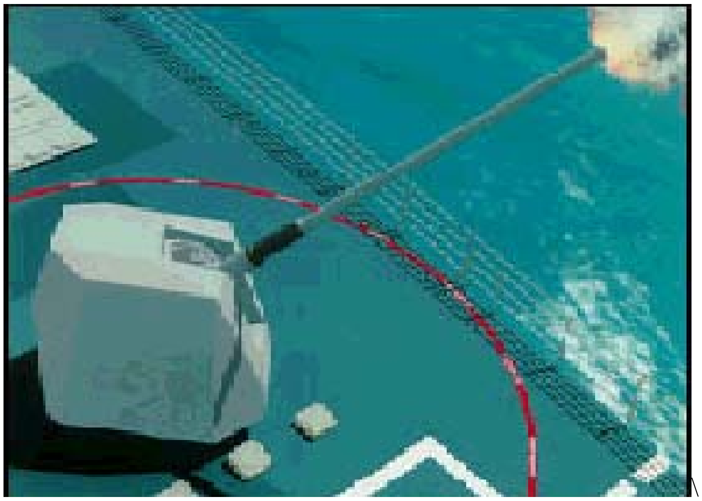


Figure 13 – MK 45 5"/62 MK MOD 4 Gun Mount

3.1.4.3 ASW and MCM

The Anti-Submarine Warfare and the Mine Counter Measures system alternatives are listed in Table 13. The different alternatives include SQS-56 (AN/SQS-56), MK 32 Surface Vessel Torpedo Tube (SVTT), Control Systems (ASWCS), and Mine Avoidance Sonar.

Table 13 – ASW/MSM System Alternatives

Warfighting system	Options	Components
ASW/MCM	Option 1) SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar	35,38,39,41,42,44,51,58,63
	Option 2) LFA/VDS, SQQ 89, 2xMK 32 Triple Tubes, NIXIE	41,42,44,51,153,63

Sub systems descriptions are as follows:

- SQS-56 (AN/SQS-56)- hull-mounted sonar (1.5m) with digital implementation, system control by a built-in mini computer, and an advanced display system. Extremely flexible and easy to operate. Active/passive, preformed beam, digital sonar providing panoramic echo ranging and panoramic (DIMUS) passive surveillance. A single operator can search, track, classify and designate multiple targets from the active system while simultaneously maintaining anti-torpedo surveillance on the passive display. The location of the SQS-56 is shown in Figure 14.

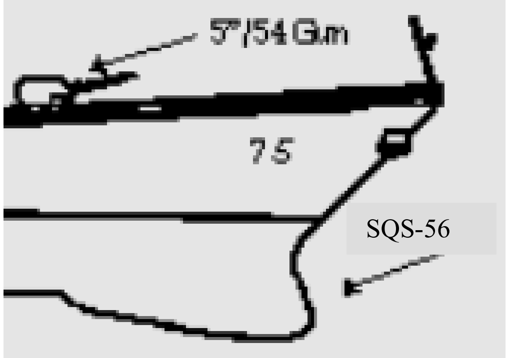


Figure 14 – SQS-56 (AN/SQS-56)- hull-mounted sonar

- MK 32 Surface Vessel Torpedo Tube (SVTT)- ASW launching system which pneumatically launches torpedoes over-the-side of own ship. Handles the MK-46 and MK-50 torpedoes. Capable of stowing and launching up to three torpedoes. Launches torpedoes under local control or remote control from an ASW fire control system. The MK 32 SVTT is shown in Figure 15.

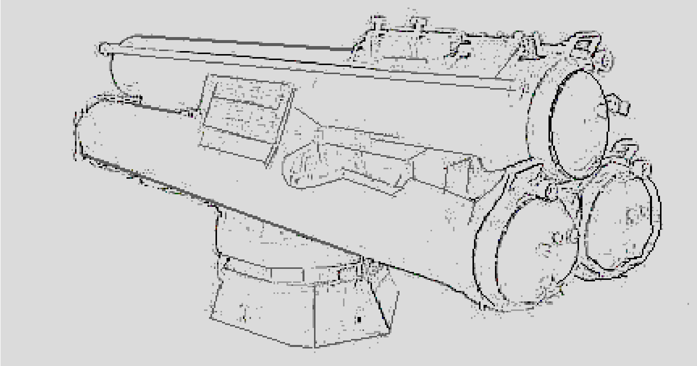


Figure 15 – MK 32 Surface Vessel Torpedo Tube (SVTT)

- Control Systems (ASWCS)- AN-SQQ-89 - integrated undersea warfare detection, classification, display, and targeting capability. Supports SQQ-89 tactical sonar suite, SQS-53C and Tactical Towed Array Sonar (TACTAS), and is fully integrated with Light Airborne Multi-Purpose System (LAMPS MK III) helicopter, MK116 MK116 ASWCS and MK 309 Torpedo Fire Control System. (SQQ-89 is used on all current USN SC)
- Mine Avoidance Sonar (MAS)- The Multi-purpose Sonar System VANGUARD is a versatile two frequency active and broadband passive sonar system conceived for use on surface vessels to assist navigation and permit detection of dangerous objects. The system is designed primarily to detect mines but will also be used to detect other mobbing or stationary underwater objects. It can be used as a navigation sonar, i.e. as a navigational aid in narrow dangerous waters. In addition it can complement the sensors on board anchoring surface vessels with regard to surveillance and protection against divers. The effect of the Mine Avoidance Sonar is shown in Figure 16.

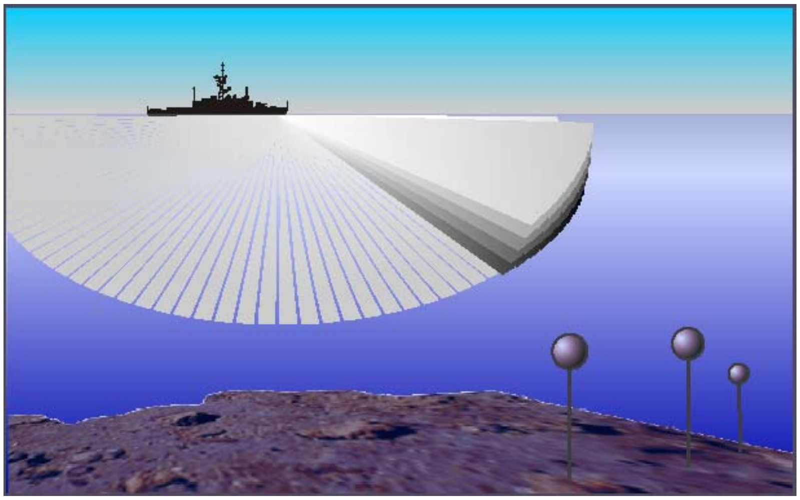


Figure 16 – MAS

3.1.4.4 CCC

The Command Control Communication system alternatives are listed in Table 14. The different alternatives include an enhanced CCC or a basic CCC.

Table 14 – CCC System Alternatives

Warfighting system	Options	Components
CCC	Option 1) Enhanced CCC	2
	Option 2) Basic CCC	106

The Command, Control, and Communications include the following systems with the option of future upgrades.

- Global Broadcast System (GBS)
- EHF SATCOM
- UHF SATCOM
- IMARSAT
- Link 11
- Link 16
- Low Observable Multi Function Stack

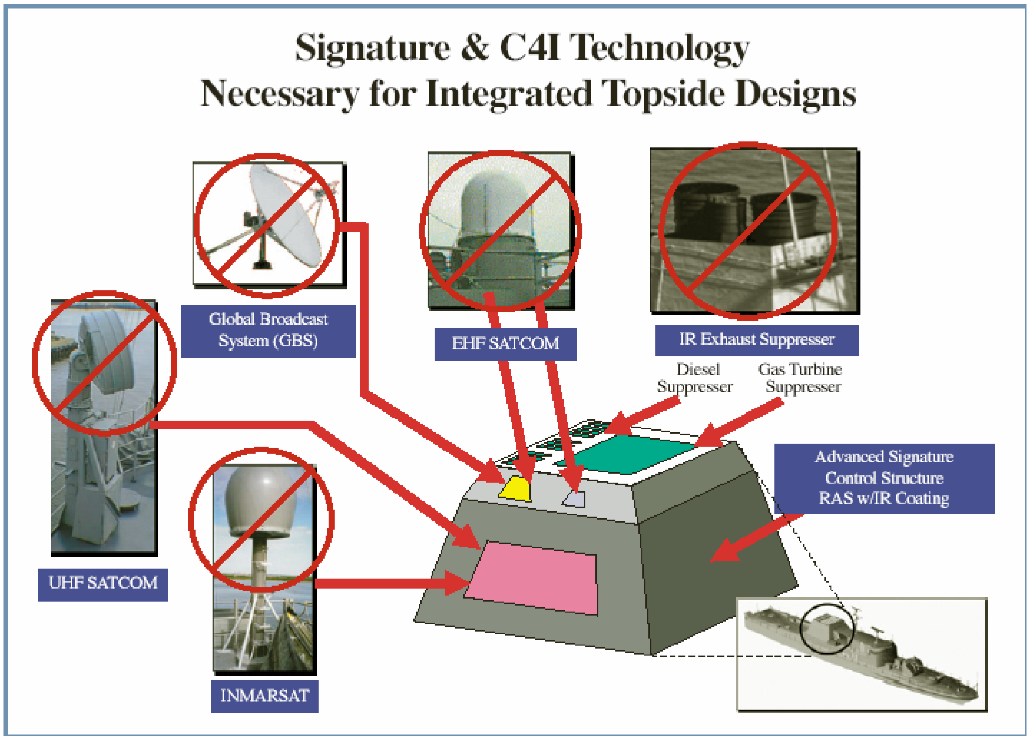


Figure 17 – CCC Components Installed in a Low Observable Multifunction Stack

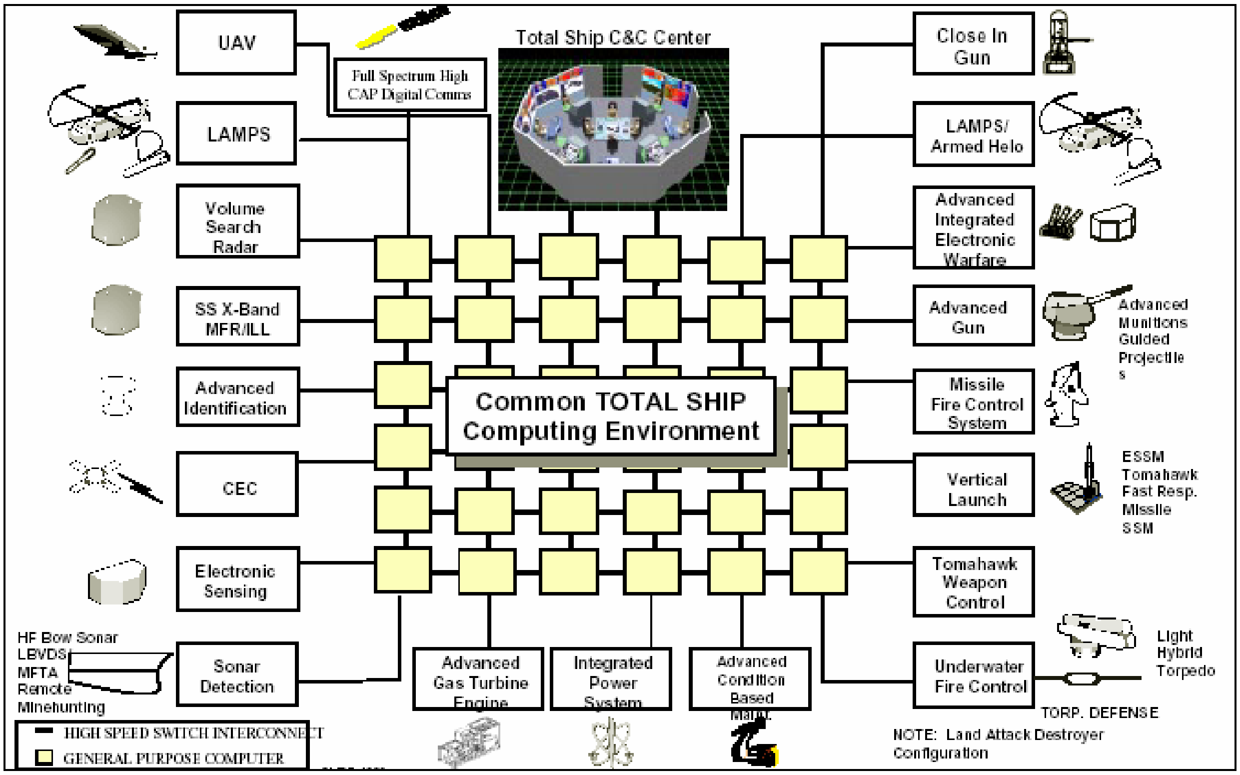


Figure 18 – The computing system of the ship

3.1.4.5 SDS

The Self Defense System (SDS) system alternatives are listed in Table 15. Some of the different alternatives include AN/SLQ-32(V), MK53 SRBOC, NULKA, and CIWS Close-in Weapon System.

Table 15 – SDS System Alternatives

Warfighting system	Options	Components
SDS	Option 1) 2xCIWS, SLQ-32(V) 3, SRBOC, NULKA	12,22,24,24,77,151,152
	Option 2) 1xCIWS, SLQ-32(V) 3, SRBOC, NULKA	12,24,123,77,151,152
	Option 3) SLQ-32(V) 3, SRBOC, NULKA	77,151,152

Sub systems descriptions are as follows:

- AN/SLQ-32(V)3- provides early warning of threats and automatic dispensing of chaff decoys. The electronic warfare system is shown in Figure 19.

Figure 19 – AN/SQS-32(V)3 Electronic Warfare System

- MK 36 DLS SRBOC -Super Rapid Bloom Offboard Countermeasures Chaff and Decoy launching system - provides decoys launched at a variety of altitudes to confuse a variety of missiles by creating false signals. The MK 36 DLS SRBOC is shown in Figure 20.

Figure 20 – MK 36 DLS SRBOC

- MK53 SRBOC and NULKA- The Decoy Launching System (DLS) Mk 53 (NULKA) is a rapid response Active Expendable Decoy (AED) System capable of providing highly effective defense for ships of cruiser size and below against modern radar homing anti-ship missiles. The DLS MK 53 NULKA is shown in Figure 21.

Figure 21 – MK 53 DLS NULKA

- CIWS Close-in Weapon System- Hydraulically driven 20 mm gatling gun capable of firing 4500 rounds per minute. Magazine capacity is 1550 rounds of tungsten ammunition. Computer controlled to automatically correct aim errors. Defense against low altitude ASCMs. Phalanx Surface Mode (PSUM) incorporates side mounted Forward Looking Infrared Radar (FLIR) to engage low, slow or hovering aircraft and surface craft. The CIWS is shown in Figure 22.

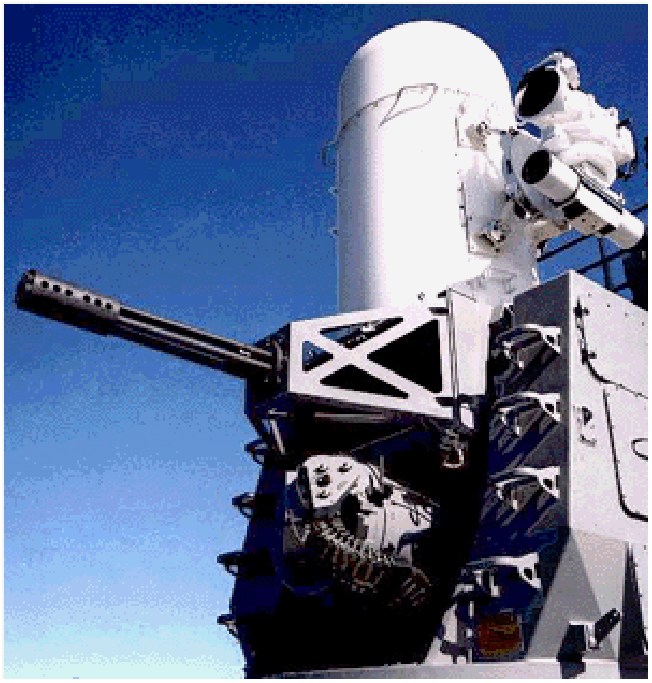


Figure 22 – CIWS Close-in Weapon System

3.1.4.6 GMLS

The Guided Missile Launch system alternatives are listed in Table 16. The different alternatives include 32 cell or 64 cell MK 41 vertical launch system or the MK 57 Peripheral vertical launch system.

Table 16 – GMLS System Alternatives

Warfighting system	Options	Components
GMLS	Option 1) 64 cells, MK 41 and/or MK57 PVLS	80,82,83,85,89
	Option 2) 32 cells, MK 41 and/or MK57 PVLS	81,82,84,86,90

Sub systems descriptions are as follows:

- MK 41 Vertical Launch System (VLS) or MK57 Peripheral vertical launch system - The MK 41 and MK 57 have AAW, ASW, and ASUM mission capabilities. The MKs allow for a fast reaction time to several different threats at once. With the various cells multiple targets are allowed to be targeted and fired upon continuously. The VLSs are capable of surviving high degrees of damage and have the capability of carrying various types of missiles for different missions. The MK 57 PVLS is shown in Figure 23 and the VLS arrangement is shown in Figure 24 and Figure 25.

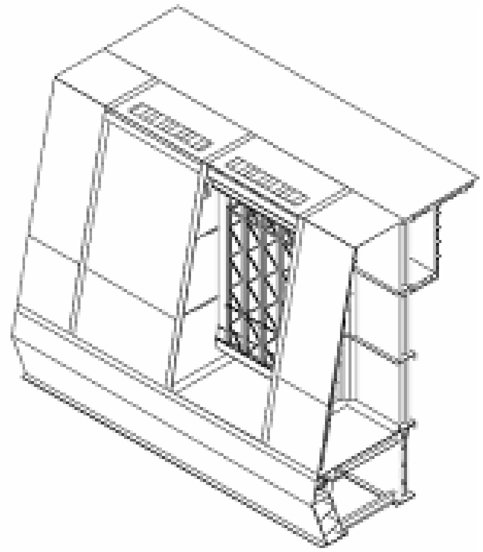


Figure 23 – MK57 PVLS

Figure 24 – VLS Topside

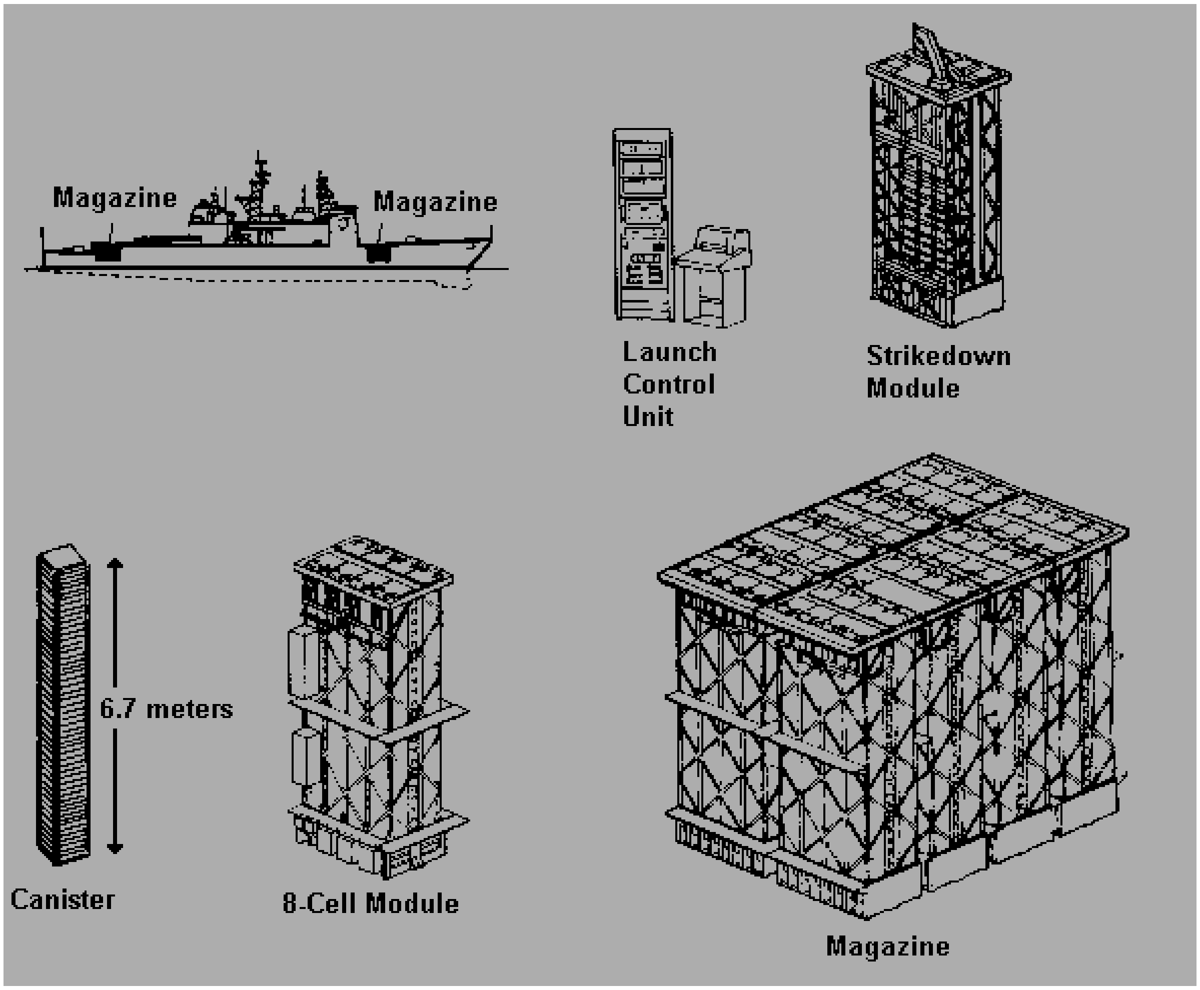


Figure 25 – MK41 VLS

3.1.4.7 MODULES

The MODULES system alternatives are listed in Table 17. The different alternatives include 1 or 2 LCS suites.

Table 17 – MODULES System Alternatives

Warfighting system	Options	Components
MODULES	Option 1) 2xLCS	154-163, 154-163
	Option 2) 1xLCS	154-163

3.1.4.8 LAMPS

The Light Airborne Multi Purpose system alternatives are listed in Table 18.

Table 18 – LAMPS System Alternatives

Warfighting system	Options	Components
LAMPS	Option 1) Embarked 2xLAMPS w/Hangar	36,46,47,50,52,53,54,55,57
	Option 2) LAMPS haven	36,46,48,52,53,55,57,149
	Option 3) LAMPS refueling	45,46,57

Sub systems descriptions are as follows:

- The SH-60 Seahawk (LAMPS MK III) has the capability of performing a several different roles including ASW, search and rescue, ASUW, SPECOPS, cargo lift, deploys sonobuoys and torpedoes, and extending ship's radar capabilities. The SH-60 comes equipped with a retractable in-flight fueling probe, two 7.62mm machine guns, AGM-119 Penguin missiles (shown in Figure 26), and Mk46 or Mk50 torpedoes.

Figure 26 – SH-60 LAMPS Firing an AGM-119 Penguin Anti-Ship Missile

3.1.4.9 Combat Systems Payload Summary

The combat system component data table shown in Table 19 includes all the different alternatives for the combat systems and various properties including weights and areas. The table is included in the ship synthesis model database.

Table 19 – Combat Systems Components Summary

ID	NAME	AREA	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
3	DATA DISPLAY GROUP - BASIC	AAW	411	3	400	5.74	12.19	1086	0	45	45
4	AAW INTERFACE EQUIPMENT - BASIC	AAW	413	4	400	0.3	-3.30	50	0	5	5
5	AAW DATA PROCESSING GROUP - BASIC	AAW	413	5	400	1.47	-3.30	210	0	10	10
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
8	RADAR, MFAR, SPY-1D, SINGLE TRANSMITTER (2CH, 2FACE)	AAW	456	8	400	54.3	14.5	0	1594	269	474.3
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

16	WEAPON SYSTEM SWITCHBOARDS	AAW	489	16	400	2.24	7.28	55	0	4	4
17	COMBAT DF	AAW	495	17	400	8.26	21	0	448	15.47	19.34
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	960.8	0	0	0
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	1500	382.7	382.7
29	HARPOON, AN/SWG-1, WCS, LNCH CONTROL SYSTEM IN CIC	ASUW	482	29	400	1.1	-3.3	0	100	0	15
33	SMALL ARMS AMMO, DDG51 - 7.62MM + 50 CAL + PYRO	ASUW	21	33	20	4.1	-6	0	0	0	0
68	GFCS, MK86	ASUW	481	68	400	7.18	-5.6	0	168	6	15.4
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
164	1X 7M RHIB	ASUW	23	164	20	3.50	-3.00	19.01	0.00	0.00	0.00
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
41	NIXIE, AN/SLQ-25	ASW	473	41	400	3.6	-5.72	172	0	3	4.2
42	TORPEDO DECOYS	ASW	473	42	400	4.52	-4.89	0	0	0	0
44	ASW, CONTROL SYSTEM [ASWCS], SQQ-89	ASW	483	44	400	4.8	-11	185	0	19.5	19.5
51	SVTT, MK32, 2X, ON DECK	ASW	750	51	700	2.7	1.14	0	0	0.6	1.1
58	SONAR, BOW, SQS-56, SONAR DOME HULL DAMPING	ASW	636	58	600	2.01	-37.07	0	0	0	0
153	LFA/VDS w/ELEX	ASW	462	153	400	43	-25.72	373	0	46	46
2	CIC, DDG51	CCC	411	2	400	17.34	-3.3	1989	0	74.5	74.5
106	CIC, FFG7	CCC	411	106	400	10	3.30	1200		60	60
80	VLS, 64 CELL, ARMOR - LEVEL III HY-80	GMLS	164	80	100	21.1	-6.17	0	0	0	0
81	VLS, 32 CELL, ARMOR - LEVEL III HY-80	GMLS	164	81	100	14	-6.17	0	0	0	0
82	VLS, WEAPON CONTROL SYSTEM (1 MODULE)	GMLS	482	82	400	0.7	-9.66	56	0	15	18

83	VLS, 64 CELL MAGAZINE DEWATERING SYSTEM	GMLS	529	83	500	3	-6.97	0	0	0	0
84	VLS, 32 CELL MAGAZINE DEWATERING SYSTEM	GMLS	529	84	500	3	-6.97	0	0	0	0
85	VLS, 64 CELL	GMLS	721	85	700	147.8	-13.66	2245	0	63.4	63.4
86	VLS, 32-CELL	GMLS	721	86	700	82.8	-7.97	1123	0	31.1	31.1
89	VLS, 64 CELL, MISSILES - 64	GMLS	21	89	20	98.4	-11.06	0	0	0	0
90	VLS MISSILES - 32	GMLS	21	90	20	49.2	-5.37	0	0	0	0
36	LAMPS, SQQ-28 ELECTRONICS	LAMPS	460	36	400	3.4	3	15	0	5.3	5.5
45	LAMPS, IN-FLIGHT REFUEL SYS	LAMPS	542	45	500	7.6	-7.35	44	0	1.3	1.3
46	LAMPS, AVIATION FUEL SYS	LAMPS	542	46	500	4.86	-11	30	0	2	2.9
47	LAMPS, RAST/RAST CONTROL/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
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
55	LAMPS, AVIATION SUPPORT AND SPARES	LAMPS	26	55	20	9.42	5	357	0	0	0
57	LAMPS, AVIATION FUEL [JP-5]	LAMPS	42	57	40	64.4	-28.81	0	0	0	0
149	LAMPS MKIII 1 X SH-60B HELO (ON DECK)	LAMPS	23		20	6.36	4.5	0	0	0	0
63	MINE AVOIDANCE SONAR	MCM	462	63	400	11.88	-18.03	350	0	5	5
67	GUN, 5IN MK45, HY-80 ARMOR	NSFS	164	67	100	20.2	-0.35	0	0	0	0
75	GUN, 5IN/62 MK 45, MOD 4, AMMO W/ERGM - 600RDS	NSFS	21	75	20	41.1	-10.75	905	0	0	0
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
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
150	GUN, 5IN/62 MOD 4	NSFS	710	150	700	39	1.44	300	0	36.6	50.2
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
24	CIWS, 20MM AMMO - 16000 RDS	SDS	21	24	20	8.3	20	0	257	0	0
123	CIWS, 1X & WORKSHOP	SDS	711	123	700	9.2	21	0	221	8	32
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
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
154	1x 11M MODULAR SPARTAN DET USV VEHICLE and STOWAGE	SPARTAN	23	154	20	10.54	-3.00	37.52	0.00	0.00	0.00
155	1X 11M MODULAR SPARTAN (USV) DET - 1 MAINT MODULE	SPARTAN	26	155	20	2.60	-3.00	37.52	0.00	0.00	0.00
156	1X 11M MODULAR SPARTAN DET - 1 CONTROL MODULE	SPARTAN	495	156	400	2.96	-3.00	37.52	0.00	2.40	2.40
157	1X 11M MODULAR SPARTAN DET - 1 MIW SUPPORT MODULE	SPARTAN	29	157	20	3.84	-3.00	37.52	0.00	0.00	0.00
158	1X 11M MODULAR SPARTAN DET - 1 WEAPON (ASUW) MODULE	SPARTAN	791	158	700	2.59	-3.00	37.52	0.00	0.00	0.00
159	MODULAR SPARTAN DET - MISSION FUEL	SPARTAN	42	159	40	4.50	-6.00	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
160	VTUAV DET - MODULAR - HANGAR AND 3 VEHICLES	VTUAV	23	160	20	3.41	-3.00	0.00	73.00	0.00	0.00
161	VTUAV DET - MODULAR - MAINTENANCE MODULE	VTUAV	26	161	20	3.06	3.00	0.00	37.52	0.00	0.00
162	VTUAV DET - MODULAR - MISSION COMMAND MODULE	VTUAV	492	162	400	3.01	3.00	0.00	37.52	0.00	0.00
163	VTUAV DET - MODULAR - MISSION FUEL	VTUAV	42	163	40	11.00	-6.00	0.00	0.00	0.00	0.00

3.2 Design Space

The ADF design space includes twenty-five design variables. Trade-off studies are performed within the design space using a multi-objective genetic optimization to search for all feasible non-dominated combinations of design variable values based on cost, risk and overall effectiveness. Table 20 lists the design variables that comprise the ADF design space.

Table 20 – ADF Design Variables

DV #	DV Name	Description	Design Space
1	LWL	Waterline Length	100-150m
2	LtoB	Length to Beam ratio	7.0-10.0
3	LtoD	Length to Depth ratio	10.5-17.8
4	BtoT	Beam to Draft ratio	2.8-3.2
5	Cp	Prismatic coefficient	0.56 – 0.64
6	Cx	Maximum section coefficient	0.75 – 0.85
7	Crd	Raised deck coefficient	0.7 – 1.0
8	VD	Deckhouse volume	2000-4000 m^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
11	BALtype	Ballast/fuel system type	0 = clean ballast, 1 = compensated fuel tanks
12	PSYS	Propulsion system alternative	Option 1) 1 shaft, mechanical, CRP, 2xLM2500+
			Option 2) 1 shaft, mechanical, CRP, 2xMT30
			Option 3) 1 shaft, mechanical, CRP, CODOG 1xLM2500+, 1x PC2/16
			Option 4) 1 shaft, mechanical, CRP, CODOG 1xMT30, 1x PC2/16
			Option 5) 1 shaft. mechanical, CRP, CODAG 1xLM2500+, 1x PC2/16
			Option 6) 1 shaft. mechanical, CRP, CODAG 1xMT30, 1x PC2/16
			Option 7) 1 shaft. mechanical, CRP, COGAG 1xLM2500+, 1x WR21/29
			Option 8) 1 shaft. mechanical, CRP, COGAG 1xMT30, 1x WR21/29
			Option 9) 1 shaft. mechanical, FPP, CODLAG 1x LM2500+, 1x PC2/16DG
			Option 10) 1 shaft. mechanical, FPP, CODLAG 1x MT30, 1x PC2/16DG
			Option 11) 2 shafts, mechanical, CRP, GT 2x LM2500+ 2x Epicycle gear
			Option 12) 2 shafts, mechanical, CRP, GT 2xMT30, 2x Epicycle gear
			Option 13) 2 shafts, mechanical, CRP, GT 4x LM2500+
			Option 14) 2 shafts, mechanical, CRP, CODOG 2x LM2500+, 2x PC2/16
			Option 15) 2 shafts, mechanical, CRP, CODAG 2x LM2500+, 2x PC2/16
			Option 16) 2 shafts, mechanical, CRP, COGAG 2x LM2500+, 2x WR21/29
			Option 17) 2 shafts, mechanical, FPP, CODLAG 2x LM2500+, 1x PC2/16DG
			Option 18) 2 shafts, mechanical, FPP, CODLAG 2x MT30, 1x PC2/16DG

			Option 19) 2 shafts, IPS, FPP, 2x LM2500+GTG, 1x PC2/16DG
			Option 20) 2 shafts, IPS, FPP, 2x MT30GTG, 1x PC2/16DG
			Option 21) 2 shafts, IPS, FPP, 3x LM2500+GTG, 1x PC2/16DG
			Option 22) 2 shafts, IPS, FPP, 3x MT30GTG, 1xPC2/16DG
			Option 23) 2 pods, IPS, 2x LM2500+GTG, 1x PC2/16DG
			Option 24) 2 pods, IPS, 2xMT30GTG, 1x PC2/16DG
			Option 25) 2 pods, IPS, 3xLM2500+GTG, 1x PC2/16DG
			Option 26) 2 pods, IPS, 3x MT30 GTG, 1x PC2/16DG
13	GSYS	Ship Service Generator system alternatives	Option 1) 3 x DDA Allison 501K34 GTG (@3,500 kW)
			Option 2) 4 x CAT 3515V16 DG
			Option 3) 4 x CAT3608 IL8 DG
			Option 4) 3 x CAT3608 IL8 DG
			Option 5) 2 x DDA Allison 501K34 GTG (@3,500 kW)
			Option 6) 2 x CAT3516V16 DG
			Option 7) 2 x CAT3608 IL8 DG For PSYS=9,10,17-26: GSYS=5,6or7
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), AEGIS MK 99 FCS
			Option 2) SPY-3 (3 panel), AEGIS MK 99 FCS
			Option 3) SPY-1D (2 panel), AEGIS MK 99 FCS
19	ASW/MCM	Anti-Submarine Warfare and Mine Countermeasures alternatives	Option 1) SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar
			Option 2) LFA/VDS, SQQ 89, 2xMK 32 Triple Tubes, NIXIE
20	NSFS/ ASUW	Naval Surface Fire Support / ASUW alternatives	Option 1) MK 45 5IN/62 Mod 4 gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
			Option 2) MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
21	CCC	Command Control Communication alternatives	Option 1) Enhanced CCC
			Option 2) Basic CCC
22	LAMPS	LAMPS alternatives	Option 1) Embarked 2xLAMPS w/Hangar
			Option 2) LAMPS haven
			Option 3) LAMPS refueling
23	SDS	Self Defense System alternatives	Option 1) 2xCIWS, SLQ-32(V) 3, SRBOC, NULKA
			Option 2) 1xCIWS, SLQ-32(V) 3, SRBOC, NULKA
			Option 3) SLQ-32(V) 3, SRBOC, NULKA
24	GMLS	Guided Missile Launching System alternatives	Option 1) 64 cells, MK 41 and/or MK57 PVLS
			Option 2) 32 cells, MK 41 and/or MK57 PVLS
25	MODULES	LCS-equivalent Modules	Option 1) 2xLCS
			Option 2) 1xLCS

Design variables 1 through 10 pertain to hull dimensions and attributes. Ballast system type (DV 11) determines whether clean ballast or compensated fuel tanks should be used. The propulsion and generator system options (DV 12 and 13) are discussed in Section 3.1.2. Provisions duration (DV 14) is discussed in Section 3.2.2. Weapons system options (DV 18-25) are in Section 3.1.4 of the report.

3.3 Ship Synthesis Model

A ship synthesis model was created in Model Center using several modules of FORTRAN code. The modules are linked together in a cascading fashion, and each module deals with an aspect of the baseline design. The purpose of the ship synthesis model is to assess an array of candidate designs based on feasibility, cost, risk, and effectiveness. The synthesis model is made up of fourteen modules:

1) Input
2) Combat
3) Propulsion
4) Hull
5) Space Available
6) Electric
7) Resistance
8) Weight
9) Tankage
10) Space Required
11) Feasibility
12) Cost
13) Risk
14) OMOE

Figure 27 is a schematic of the synthesis process. Notice how the process begins with an input module, and as synthesis proceeds there is a cascade affect that terminates at the last three modules; cost, risk, and Overall Measure of Effectiveness (OMOE). Each module is interconnected to other modules as indicated in Table 21 and as detailed below:

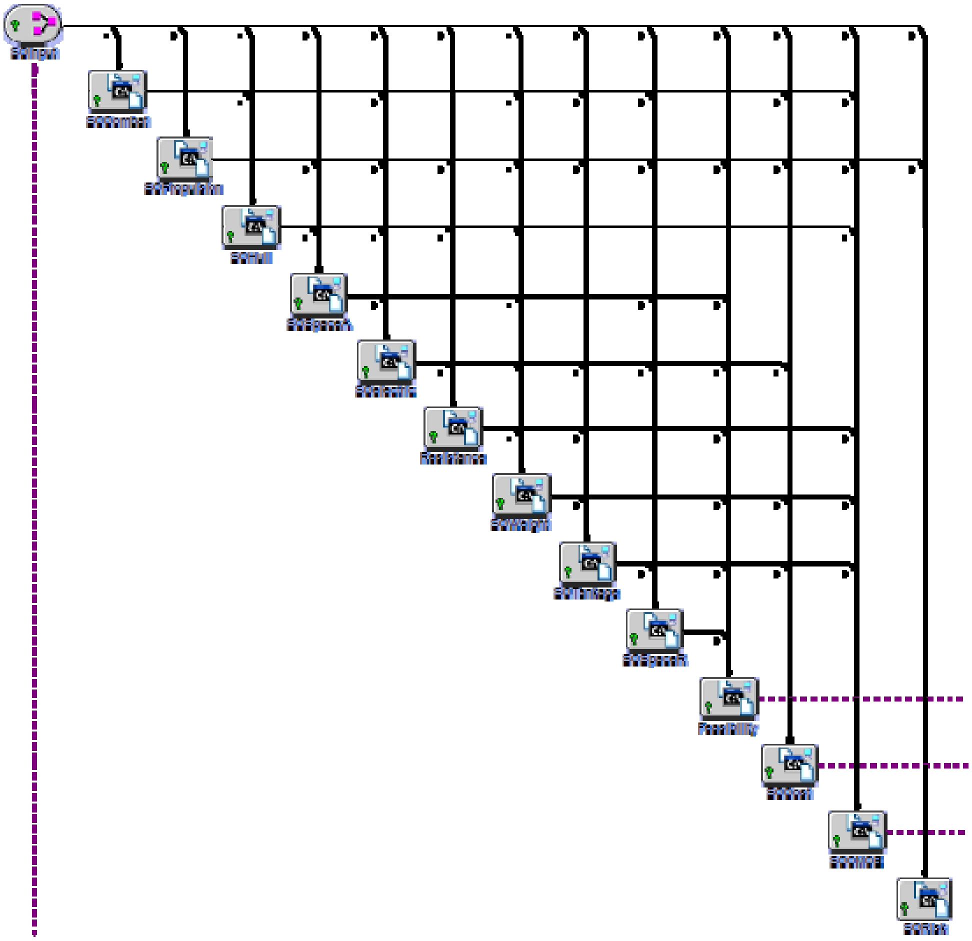


Figure 27 – Ship Synthesis Model in Model Center (MC)

Table 21 – The Interrelationship between Modules

Module Name		**Modules**												
		Combat	*Propulsion*	*Hull*	*SpaceA*	*Electric*	*Resistance*	*Weight*	*Tankage*	*SpaceR*	*Feasibility*	*Cost*	*OMOE*	*Risk*
Input	feeds into	x	x	x	x	x	x	x	x	x	x	x	x	x
Combat	feeds into		x	x	x	x	x	x	x	x		x	x	
Propulsion	feeds into			x	x	x	x	x	x	x	x	x	x	x
Hull	feeds into				x	x	x	x					x	
SpaceA	feeds into					x		x		x	x			
Electric	feeds into						x	x	x	x	x	x		
Resistance	feeds into							x	x		x		x	
Weight	feeds into								x		x	x	x	
Tankage	feeds into									x	x	x	x	
SpaceR	feeds into										x			
Feasibility	feeds into													
Cost	feeds into													
OMOE	feeds into													
Risk	feeds into													

- *Input Module*

  The purpose of this module is to distribute the necessary variables to the other modules. The design variables that make up the design space are stored in this module as well as a set of governing design parameters. These variables and design parameters are subsequently passed into the following modules:

- *Combat Module*

  This module calculates payload characteristics based on the selected combat system alternatives. The depth at station 10 is calculated and a payload for each combat system alternative is found and ultimately summed. Vertical centers of gravity, and the required deckhouse and hull volume associated with the combat system selection are determined. The module finally estimates the required electrical and power payload.

- *Propulsion Module*

  The propulsion module calculates the propulsion and generator system characteristics based on the selected propulsion and generator alternatives. This entails referencing a spreadsheet of propulsion characteristics. The efficiency is then calculated based on the propulsion type selected and a set of updated propulsion characteristics is outputted. Further, an area allocated to inlet and exhaust is found, as well as the number of hull decks.

- *Hull Module*

  The hull form module calculates hull characteristics including block, volume, and water-plane coefficients. Hull geometry is inputted into the module, and using a Taylor Series surface area is calculated. The module ensures that the particular sonar type chosen meets the minimum surface area and volume requirements. Additionally, the module calculates the total hull displacement including appendages.

- *Space Available Module*

  This module calculates the available space from hull and deckhouse characteristics. The minimum depth at station 10 is calculated to prevent flooding, maintain hull strength, and to accommodate the machinery box. Freeboard is calculated at various stations along the length of the ship and total hull, ship, and machinery box volume is outputted. By subtracting the volume allocated to machinery space and tankage, the space available is calculated.

- *Electric Module*

  This module calculates the total electrical load and the volume of the auxiliary machinery room. It does so by first determining the amount of required manning. Electrical power is next summed for each auxiliary source (firefighting, fuel handling, maximum heating, AC, etc). The required electrical power required per generator is then predicted and the 24 hour average electrical load is calculated.

- *Resistance Module*

  The resistance module calculates hull resistance using the Holtrop-Mennen and ITTC equations which require resistance to be broken down into components. Bare hull total resistance is calculated from viscous, wave-making, bulb, and transom resistance with an associated correlation allowance. Shaft horsepower, endurance and sustained speed are estimated by this module. An appropriate propeller diameter is also estimated.

- *Weight Module*

  Weight and vertical center of gravity estimates are calculated in this module. Weight is found according to SWBS number. For instance, in Machinery Weight (W200), weight largely is dependent on propulsion type, power, and the number of shafts. A margin is added to each SWBS group and a total ship weight is found. Vertical centers of gravity are then found for each weight group using parametric equations. Finally, a deckhouse weight and fluid weights (fuel, lube oil, fresh water, etc) are estimated and hydrostatic stability (GM) is calculated.

- *Tankage Module*

  In this module, tankage requirements are found using Navy DDS 200-1 to estimate endurance fuel. Inputs such as endurance speed, specific fuel consumption, and other properties that have effect on the amount of required fuel are entered into the module. Volume of tanks such as sewage, waste oil, ballast, and compensated fuel are calculated. The annual number of gallons of fuel used is then determined based on 2500 hours of operation.

- *Space Required Module*

  This module estimates space requirements and the amount of arrange-able area. Based on deckhouse volume, tankage volume, inlet and exhaust area, and manning requirements, the module calculates habitability, the available volume, and the total available area.

- *Feasibility Module*

  This module is vital because it determines whether a ship is balanced and feasible. From a set of design characteristics, this module determines whether a concept ship can meet its minimum requirements. Will it float at its design waterline? Does it have sufficient space, electric power and stability? It does this by creating ratios of the difference between available and required values to the required value. For a given ship design to be feasible, every ratio must be positive and with in a tolerance of five percent. Feasibility ratios are created for endurance speed, sustained speed, endurance range, electrical power, hull depth, deckhouse arrange-able area, total arrange-able area, a minimum stability ratio and maximum stability ratio.

- *Cost Module*

  This module predicts the lead and the follow ship acquisition cost and life cycle cost. It estimates cost based on ship weight by SWBS group, propulsion power, number of crew, number of enlisted, inflation and a margin among other variables. A total ownership cost is then found by summing lifecycle fuel, manning, and a ship delivery cost. In these calculations, the life of the ship is considered to be 30 years.

- *Risk Module*

  This module is used in order to assess the risk involved in building a particular ship design. Risk is calculated in three forms: performance, cost and scheduling. These terms are then used in calculating an Overall Measure Of Risk (OMOR) of the concept design. Major influences on risk are variables like deckhouse material, propulsion option, manning reduction factor, and combat systems options. The OMOR process is detailed in Section 3.4.2.

- *OMOE Module*

  Finally, this module quantifies the effectiveness of a particular concept using an Overall Measure Of Effectiveness (OMOE). An OMOE value is obtained by creating a weighted sum of ship design characteristics. Each characteristic or Measure Of Performance (MOP) is assigned a Value Of Performance (VOP) between a threshold value of zero and goal value of one. OMOE is calculated as in Section 3.4.1. The OMOE is calculated based on the seventeen MOPs in this module.

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_i), Values of Performance (VOP_i), and weighting factor (w_i). The equation for this OMOE is:

$$OMOE = g\left[VOP_i(MOP_i)\right] = \sum_i w_i VOP_i(MOP_i) \qquad \textbf{(1)}$$

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 28) 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. 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. Figure 29 shows the overall pairwise comparison results, and Figures D1 – D16 in Appendix D show the lower level pairwise comparison results.

Table 22 – ROC/MOP/DV Summary

ROCs	Description	MOP	Related DV	Goal	Threshold
AAW 1	Provide anti-air defense	AAW	AAW, GMLS, SEW	AAW=1 GMLS=1 SEW=1	AAW=3 GMLS=2 SEW=1
AAW 1.1	Provide area anti-air defense	AAW	AAW GMLS SEW	AAW=1 GMLS=1 SEW=1	AAW=3 GMLS=2 SEW=1
AAW 1.2	Support area anti-air defense	AAW	AAW GMLS SEW	AAW=1 GMLS=1 SEW=1	AAW=3 GMLS=2 SEW=1

AAW 1.3	Provide unit anti-air self defense	AAW, RCS, IR	SSD, VD, PSYS	SDS=1 VD=1500 m3	SDS=2 VD=2000 m3
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	SEW VD PSYS	SEW=1 VD=1500 m3	SEW=1 VD=2000 m3
AAW 6	Detect, identify and track air targets	AAW, IR, RCS	SEW VD PSYS	SEW=1 VD=1500 m3	SEW=1 VD=2000 m3
AAW 9	Engage airborne threats using surface-to-air armament	AAW, IR, RCS	SEW VD PSYS	SEW=1 VD=1500 m3	SEW=1 VD=2000 m3
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
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=3
ASW 1.1	Engage submarines at long range	ASW	ASW	ASW=1	ASW=3
ASW 1.2	Engage submarines at medium range	ASW	ASW	ASW=1	ASW=3
ASW 1.3	Engage submarines at close range	ASW	ASW, PSYS	ASW=1 PSYS=5-16	ASW=3 PSYS=1-4
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=3 LAMPS=3 CCC=2
ASW 7.6	Engage submarines with torpedoes	ASW	ASW LAMPS CCC	ASW=1 LAMPS=1 CCC=1	ASW=3 LAMPS=3 CCC=2
ASW 8	Disengage, evade, avoid and deceive submarines	ASW	ASW	ASW=1	ASW=3
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			
INT 2	Provide intelligence	INT			
INT 3	Conduct surveillance and reconnaissance	INT	LAMPS	LAMPS=1	LAMPS=3

INT 8	Process surveillance and reconnaissance information	INT, CCC			
INT 9	Disseminate surveillance and reconnaissance information	INT, CCC			
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)	INT, CCC			
MIW 4	Conduct mine avoidance	MIW	Degauss	Yes	Yes
MIW 6	Conduct magnetic silencing (degaussing, deperming)	Magnetic Signature	Degauss	Yes	Yes
MIW 6.7	Maintain magnetic signature limits	Magnetic Signature	Degauss	Yes	Yes
MOB 1	Steam to design capacity in most fuel efficient manner	Sustained Speed, Endurance Range	Hullform PSYS	Vs = 30 knts E=5000	Vs = 20 knt E = 3500 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	Cdhmat =1 Composite	Cdhmat = 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=1	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 = 1 NSFS = 2
SEW 2	Conduct sensor and ECM operations	AAW	SEW	SEW=1	SEW=1
SEW 3	Conduct sensor and ECCM operations	AAW	SEW	SEW=1	SEW=1
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=2 CCC=2

Table 23 – MOPs

MOP #	MOP	Metric	Goal	Threshold
1	AAW	AAW option GMLS option SDS option CCC option	AAW=1 GMLS=1 SDS=1 CCC=1	AAW=3 GMLS=2 SDS=3 CCC=2
2	ASW	ASW option LAMPS option GMLS option CCC option	ASW=1 LAMPS=1 GMLS=1 CCC=1	ASW=2 LAMPS=3 GMLS=2 CCC=2
3	Modules (xLCS)	MODULE option	MODULE=1	MODULE=2
4	NSFS/ASUW	NSFS option	NSFS=1	NSFS=2
5	CCC/ISR	CCC option	CCC=1	CCC=2
6	STK	STK option GMLS option	CCC=1 GMLS=1	CCC=2 GMLS=2
7	Seakeeping	McCreight index	McC=15	McC=4
8	E	nm	E=5000nm	E=3500nm
9	Ts	days	Ts=60	Ts=45
10	Vs	knots	Vs=35knt	Vs=30knt
11	Environmental	Ballast option	BALtype=1	BALtype=0
12	RCS	Deckhouse volume	VD=2500m3	VD=3300m3
13	Acoustic Signature	PSYS option	PSYS=9,10, 17-26	PSYS=1-8, 11-16
14	Magnetic Signature	Degaussing option	Ndegaus = 1	Ndegaus = 0
15	IR Signature	PSYS option	PSYS=9,10, 17-26	PSYS=1-8, 11-16
16	VUL	Deckhouse material	Cdhmat=3	Cdhmat=1
17	NBC	CPS option	Ncps=2	Ncps=1

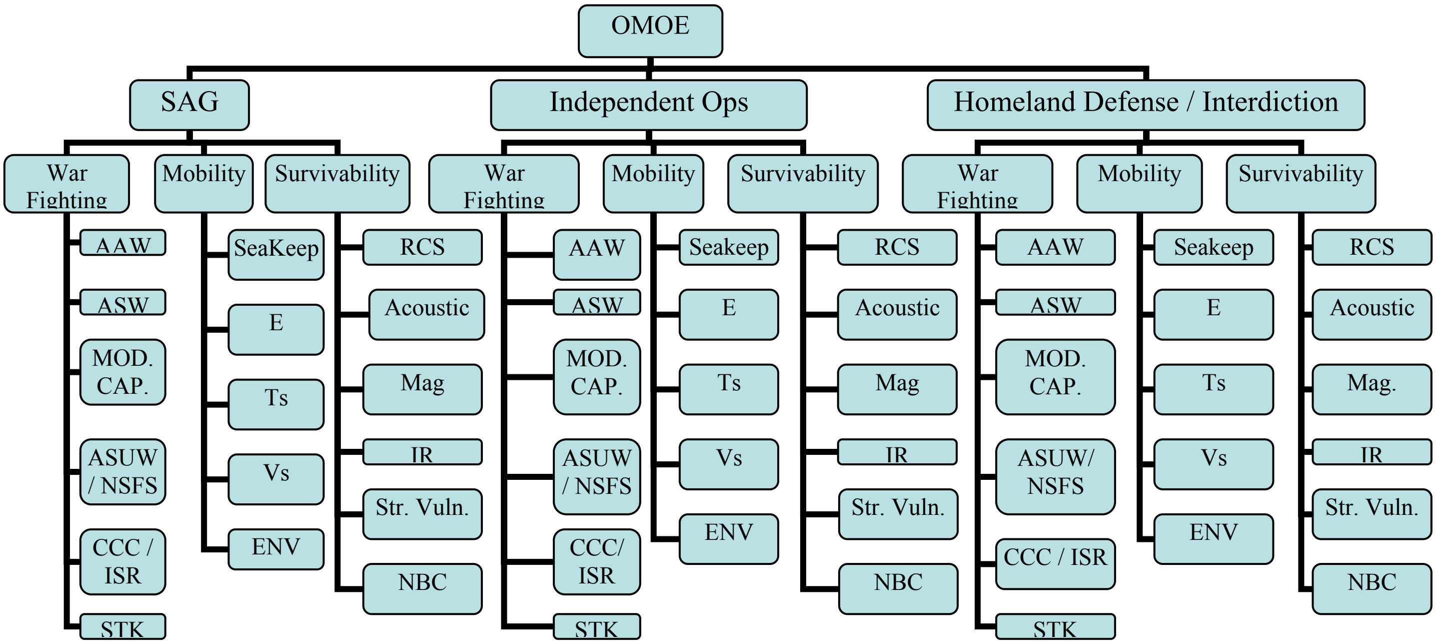


Figure 28 – OMOE Hierarchy

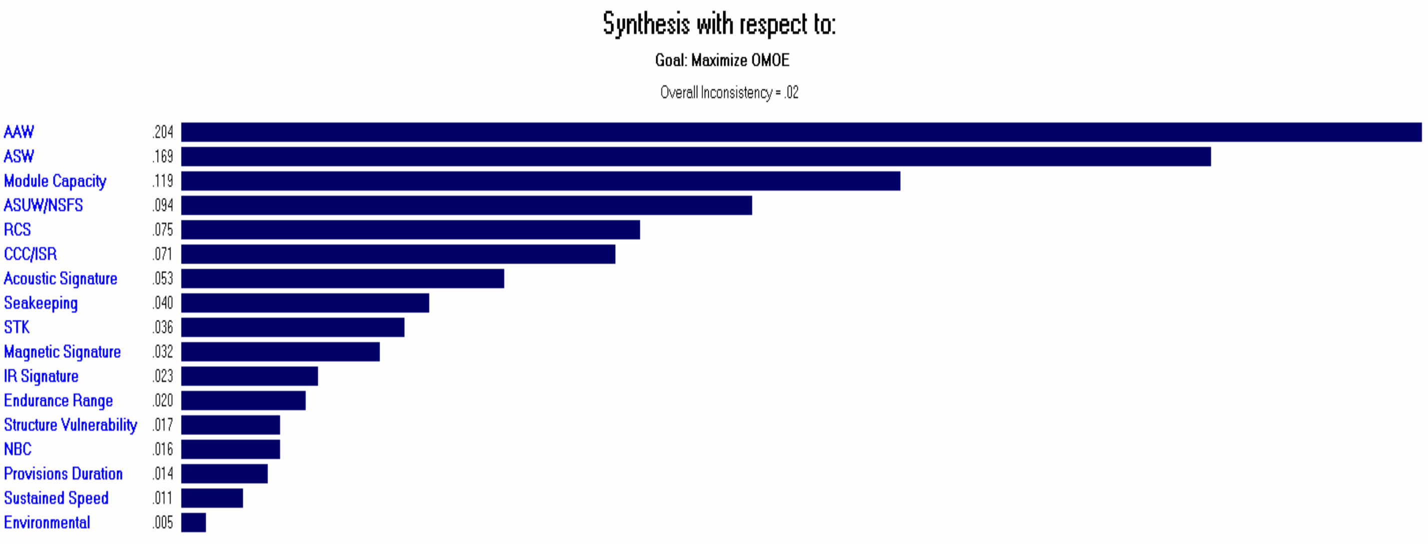


Figure 29 – Bar Chart Showing MOP Weights

3.4.2 Overall Measure of Risk (OMOR)

In the design of naval ships there are systems and new technologies that have not yet undergone thorough testing. Each ship system and design variables present a certain amount of risk in the overall ship. The overall measure of risk (OMOR) is the numerical value of risk involved in the overall ship design. Consider three types of risk: performance, cost, and schedule. The risk for a selected technology is found by the following equation where P_i is the probability that risk event *i* will occur, and C_i is the consequence of risk event *i*.

$$Risk = R_i = P_i \cdot C_i$$

Table 24 shows the estimates for the probability of a risk event occurring. Table 25 show the consequence level of that risk when it occurs. Table 26 is the risk register, which lists the risk events for schedule, cost, and performance of each DV option. Pair wise comparison is used to calculate the hierarchy weights (performance, cost, and schedule) as required.

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

Table 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

Related DV #	DV Options	DV Description	Risk Event Ei	Risk Description	Event #	Pi	Ci	Ri
DV9	3	Deckhouse Material	Composite material producibility problems	USN lack of experience with material	1	0.5	0.6	0.3
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
DV9	3	Deckhouse Material	Composite material cost overruns impact program	In development and test	3	0.5	0.3	0.15
DV9	3	Deckhouse Material	Composite material schedule delays impact program	In development and test	4	0.5	0.2	0.1
DV10	2	Hull Type	Tumblehome Seakeeping Performance	Seakeeping not satisfactory	5	0.7	0.8	0.56
DV12	19-26	Propulsion Systems	IPS Development and Implementation	Reduced reliability and performance (un-proven)	6	0.3	0.6	0.18
DV12	19-26	Propulsion Systems	IPS Development, acquisition and integration cost overruns	Research and Development cost overruns	7	0.4	0.4	0.16
DV12	19-26	Propulsion Systems	IPS Schedule delays impact program	In development and test	8	0.3	0.4	0.12
DV12	9,10,17,18	Propulsion Systems	CODLAG Development and Implementation	Unproven USN Ships	9	0.4	0.5	0.2
DV12	9,10,17,18	Propulsion Systems	CODLAG Development, acquisition and integration cost overruns	Unproven USN Ships	10	0.4	0.4	0.16
DV12	9,10,17,18	Propulsion Systems	CODLAG Schedule delays impact program	Unproven USN Ships	11	0.4	0.5	0.2
DV12	PENGtype =2	Propulsion Systems	ICR Development and Implementation	Unproven, recuperator problems	12	0.6	0.5	0.3
DV12	PENGtype =2	Propulsion Systems	ICR Development, acquisition and integration cost overruns	Unproven, recuperator problems	13	0.6	0.4	0.24
DV12	PENGtype =2	Propulsion Systems	ICR Schedule delays impact program	Unproven, recuperator problems	14	0.6	0.5	0.3
DV12	23-26	Propulsion Systems	Development and Implementation of podded propulsion	Reduced Reliability (un-proven)	15	0.7	0.4	0.28
DV12	23-26	Propulsion Systems	Development and Implementation of podded propulsion	Shock and vibration of full scale system unproven	16	0.7	0.6	0.42
DV12	23-26	Propulsion Systems	Podded Propulsion Implementation Problems	Unproven for USN, large size	17	0.6	0.5	0.27
DV12	23-26	Propulsion Systems	Podded Propulsion Schedule delays impact program	Unproven for USN, large size	18	0.6	0.6	0.36

DV18	1,2	AAW Systems	SPY-3 and AEGIS MK 99 FCS Development and implementation	Reduced Reliability and Performance (un-proven)	19	0.3	0.8	0.24
DV18	1,2	AAW Systems	SPY-3 and AEGIS MK 99 FCS Development, acquisition and integration cost overruns	Research and Development cost overruns	20	0.4	0.5	0.2
DV18	1,2	AAW Systems	SPY-3 and AEGIS MK 99 FCS Schedule delays impact program	Research and Development schedule delays	21	0.4	0.7	0.28
DV17	0.5	Automation	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	22	0.6	0.7	0.42
DV17	0.5	Automation	Automation systems development, acquisition and integration cost overruns	Research and Development cost overruns	23	0.5	0.5	0.25
DV17	0.5	Automation	Automation systems schedule delays impact program	Research and Development schedule delays	24	0.5	0.7	0.35
DV24	1	GMLS	PVLS	Vulnerability performance	25	0.3	0.6	0.18
DV24	1	GMLS	PVLS	Research overruns cost	26	0.4	0.3	0.12
DV24	1	GMLS	PVLS	Research overruns time	27	0.4	0.3	0.12

3.4.3 Cost

The lead ship and follow ship acquisition cost are estimated using a weight-based approach with producibility and complexity factors. The total lead ship acquisition cost is illustrated in Figure 30. The sum of the SWBS costs is used to estimate the basic construction cost. The material furnished by the government and the program manager's cost are accounted for in the total government cost. The post delivery cost accounts for any changes or update from new technology that occur during the construction of the ship. The total life cycle cost is a sum of the total ship cost, manning, fuel, maintenance, and disposal fee that the ship will need for operation.

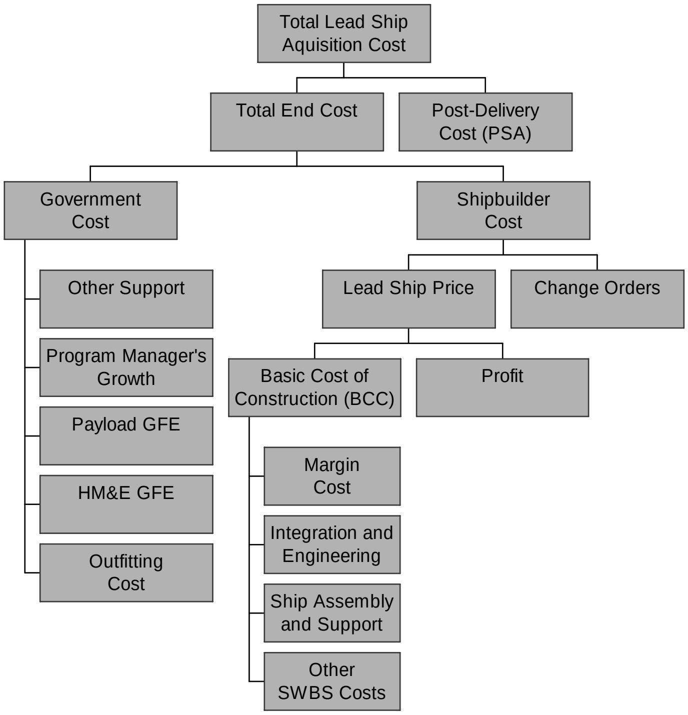


Figure 30 – Naval Ship Acquisition Cost Components

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 31 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 (Section 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 33. 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 optimal design is determined by the customer's preferences for effectiveness, cost and risk.

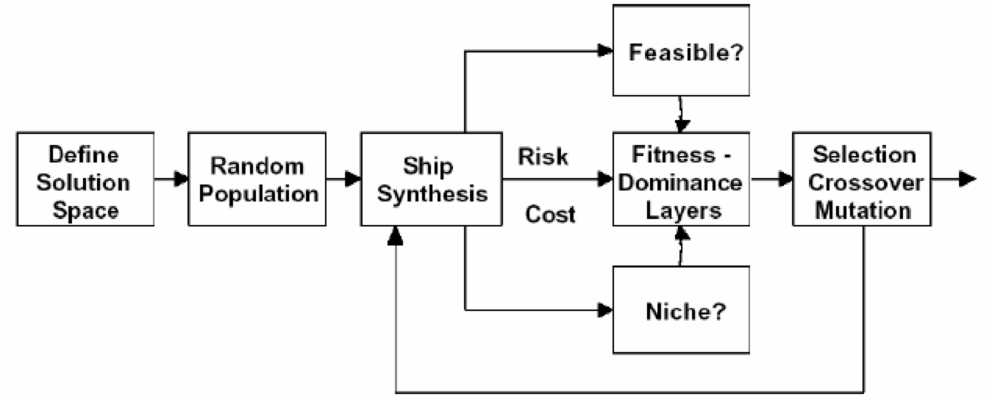


Figure 31 – Multi-Objective Genetic Optimization (MOGO)

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 32 and described in Sections 3.4.1 and 3.4.2.

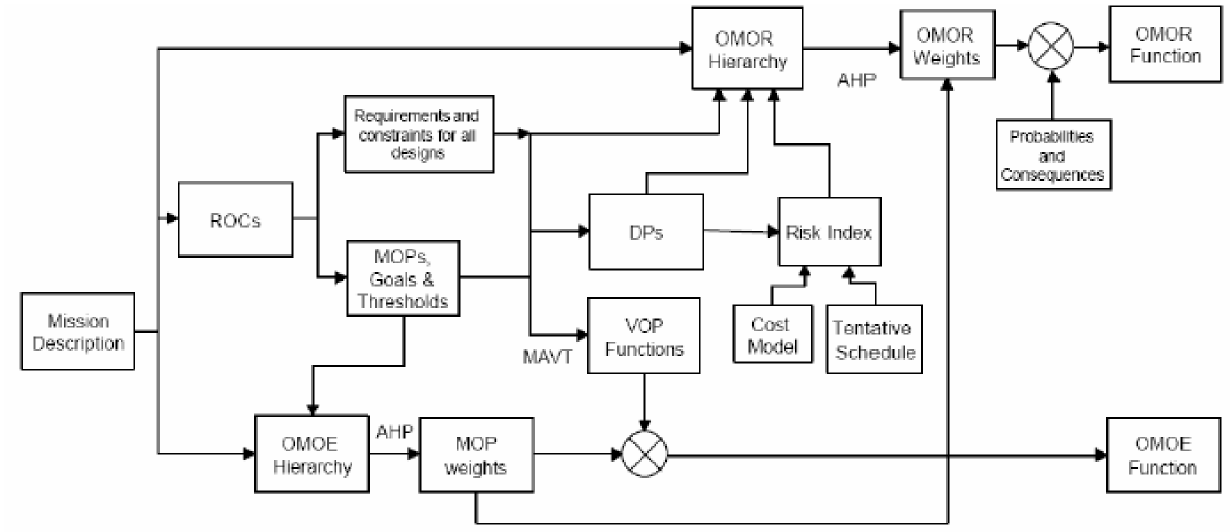
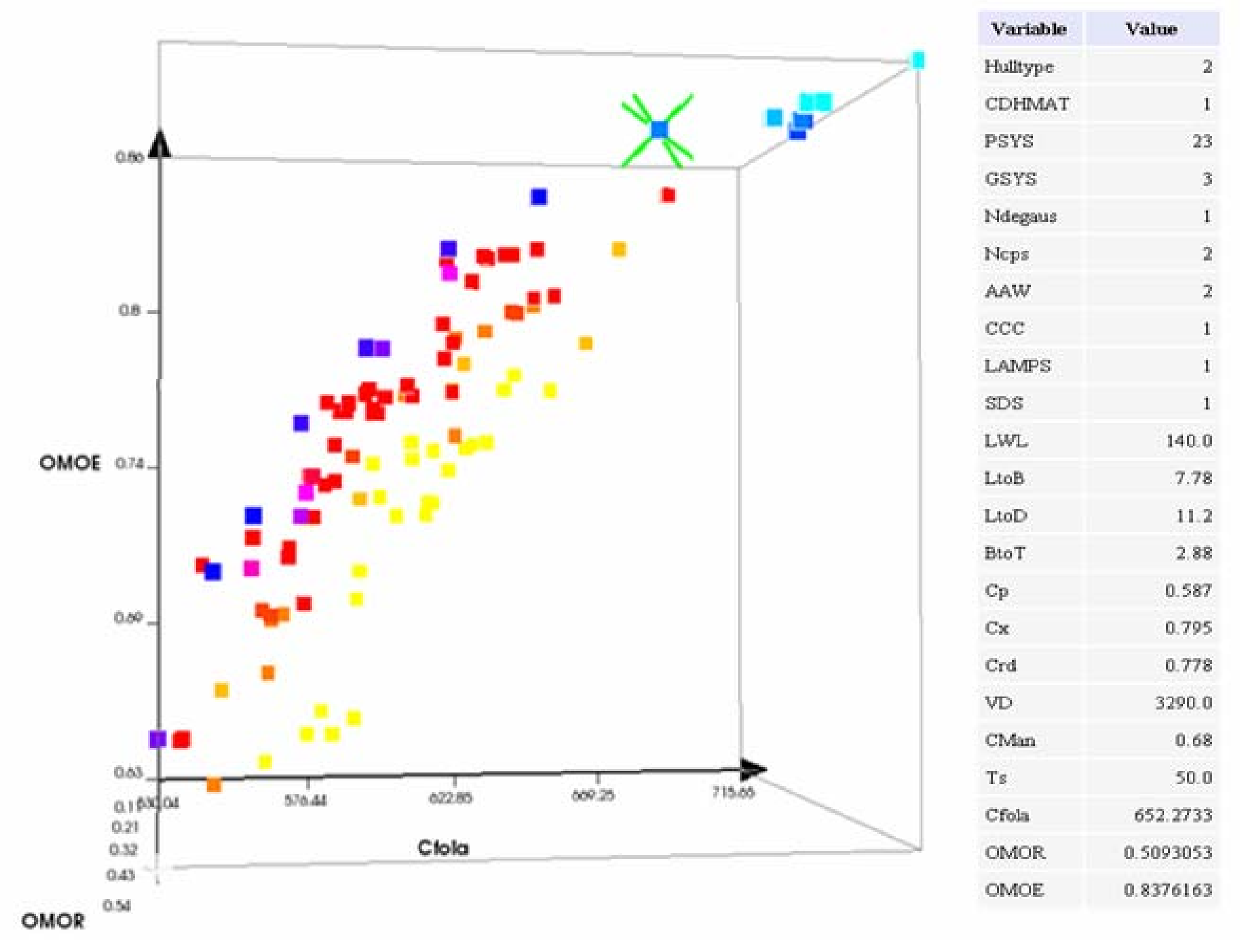


Figure 32 – OMOE and OMOR Development Process

3.6 Optimization Results

The multi-objective genetic optimization (MOGO) (Figure 33) calculates the non-dominated frontier for the cost, risk and effectiveness for several ships. The X-axis represents the ship cost, the Y-axis represents the effectiveness, and the Z-axis represents the risk. Close attention is paid to the "knees" of the curve. The "knee" of the curve is where there can be a large increase in overall effectiveness with a small cost or risk increase. The design that was chosen for Team 5 is represented on the graph by a large X. This design has high risk, high cost, and a high overall effectiveness.



Variable	Value
Hulltype	2
CDHMAT	1
PSYS	23
GSYS	3
Ndegaus	1
Ncps	2
AAW	2
CCC	1
LAMPS	1
SDS	1
LWL	140.0
LtoB	7.78
LtoD	11.2
BtoT	2.88
Cp	0.587
Cx	0.795
Crd	0.778
VD	3290.0
CMan	0.68
Ts	50.0
Cfola	652.2733
OMOR	0.5093053
OMOE	0.8376163

Figure 33 – Non-Dominated Frontier, Design # 95

3.7 Baseline Concept Design

The baseline design that was chosen from the non-dominated frontier for Team 5 was a concept with high cost, high risk and high effectiveness. It is a high-end non-dominated design. It has the highest effectiveness in the design space for this level of cost and risk. The high cost and high risk were likely due to the IPS propulsion system, the tumblehome hull form, and the extensive combat systems onboard. High effectiveness was achieved from a good compromise of the seventeen Measures of Performance (MOP). Table 30 shows these MOPs and the weight that each one carries to ultimately yield a favorable Overall Measure of Effectiveness (OMOE).

Table 27 shows the design options that were chosen in this baseline design. Weights and vertical centers of gravity for each SWBS subgroup appear in Table 28 and a ship area summary appears in Table 29. Finally, the baseline principal characteristics appear in Table 31.

Table 27 – Design Variables Summary

DV #	Description	Design Range/Option	ADF Baseline Value
1	Waterline Length	100-150m	139m
2	Length to Beam ratio	7.0-10.0	8.09
3	Length to Depth ratio	10.5-17.8	11.11
4	Beam to Draft ratio	2.8-3.2	2.96
5	Prismatic coefficient	0.56 – 0.64	0.579
6	Maximum section coefficient	0.75 – 0.85	0.779
7	Raised deck coefficient	0.7 – 1.0	0.783
8	Deckhouse volume	2000-4000 m^3	3413
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, -10 deg flare
11	Ballast/fuel system type	0 = clean ballast, 1 = compensated fuel tanks	Compensated fuel tanks
12	Propulsion system alternative	Option 1) 1 shaft, mechanical, CRP, 2xLM2500+	Option 23) 2 pods, IPS, 2 x LM2500+GTG, 1 x PC2/16DG
		Option 2) 1 shaft, mechanical, CRP, 2xMT30	
		Option 3) 1 shaft, mechanical, CRP, CODOG 1xLM2500+, 1x PC2/16	
		Option 4) 1 shaft, mechanical, CRP, CODOG 1xMT30, 1x PC2/16	
		Option 5) 1 shaft. mechanical, CRP, CODAG 1xLM2500+, 1x PC2/16	
		Option 6) 1 shaft. mechanical, CRP, CODAG 1xMT30, 1x PC2/16	
		Option 7) 1 shaft. mechanical, CRP, COGAG 1xLM2500+, 1x WR21/29	
		Option 8) 1 shaft. mechanical, CRP, COGAG 1xMT30, 1x WR21/29	
		Option 9) 1 shaft. mechanical, FPP, CODLAG 1x LM2500+, 1x PC2/16DG	
		Option 10) 1 shaft. mechanical, FPP, CODLAG 1x MT30, 1x PC2/16DG	
		Option 11) 2 shafts, mechanical, CRP, GT 2x LM2500+ 2x Epicycle gear	
		Option 12) 2 shafts, mechanical, CRP, GT 2xMT30, 2x Epicycle gear	
		Option 13) 2 shafts, mechanical, CRP, GT 4x LM2500+	
		Option 14) 2 shafts, mechanical, CRP, CODOG 2x LM2500+, 2x PC2/16	
		Option 15) 2 shafts, mechanical, CRP, CODAG 2x LM2500+, 2x PC2/16	
		Option 16) 2 shafts, mechanical, CRP, COGAG 2x LM2500+, 2x WR21/29	
		Option 17) 2 shafts, mechanical, FPP, CODLAG 2x LM2500+, 1x PC2/16DG	
		Option 18) 2 shafts, mechanical, FPP, CODLAG 2x MT30, 1x PC2/16DG	
		Option 19) 2 shafts, IPS, FPP, 2x LM2500+GTG, 1x PC2/16DG	
		Option 20) 2 shafts, IPS, FPP, 2x MT30GTG, 1x PC2/16DG	
		Option 21) 2 shafts, IPS, FPP, 3x LM2500+GTG, 1x PC2/16DG	
		Option 22) 2 shafts, IPS, FPP, 3x MT30GTG, 1xPC2/16DG	
		Option 23) 2 pods, IPS, 2x LM2500+GTG, 1x PC2/16DG	
		Option 24) 2 pods, IPS, 2xMT30GTG, 1x PC2/16DG	
		Option 25) 2 pods, IPS, 3xLM2500+GTG, 1x PC2/16DG	
		Option 26) 2 pods, IPS, 3x MT30 GTG, 1x PC2/16DG	
13	Ship Service Generator system alternatives	Option 1) 3 x DDA Allison 501K34 GTG (@3,500 kW)	Option 3) 4 x CAT3608 IL8 DG
		Option 2) 4 x CAT 3515V16 DG	
		Option 3) 4 x CAT3608 IL8 DG	
		Option 4) 3 x CAT3608 IL8 DG	
		Option 5) 2 x DDA Allison 501K34 GTG (@3,500 kW)	
		Option 6) 2 x CAT3516V16 DG	
		Option 7) 2 x CAT3608 IL8 DG	
		For PSYS=9,10,17-26: GSYS=5,6or7	
14	Provisions duration	45-60 days	50 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	0.68
18	Anti-Air Warfare alternatives	Option 1) SPY-3 (4 panel), AEGIS MK 99 FCS	Option 2) SPY-3 (3 panel), AEGIS MK 99 FCS
		Option 2) SPY-3 (3 panel), AEGIS MK 99 FCS	
		Option 3) SPY-1D (2 panel), AEGIS MK 99 FCS	
19	Anti-Submarine Warfare and Mine Countermeasures alternatives	Option 1) SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar	Option 1) SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar
		Option 2) LFA/VDS, SQQ 89, 2xMK 32 Triple Tubes, NIXIE	
20	Naval Surface Fire Support / ASUW alternatives	Option 1) MK 45 5IN/62 Mod 4 gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker	Option 2) MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
		Option 2) MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker	
21	Command Control Communication alternatives	Option 1) Enhanced CCC	Option 1) Enhanced CCC
		Option 2) Basic CCC	
22	LAMPS alternatives	Option 1) Embarked 2xLAMPS w/Hangar	Option 1) Embarked 2xLAMPS w/Hangar

		Option 2) LAMPS haven	
		Option 3) LAMPS refueling	
23	Self Defense System alternatives	Option 1) 2xCIWS, SLQ-32(V) 3, SRBOC, NULKA	Option 1) 2xCIWS, SLQ-32(V) 3, SRBOC, NULKA
		Option 2) 1xCIWS, SLQ-32(V) 3, SRBOC, NULKA	
		Option 3) SLQ-32(V) 3, SRBOC, NULKA	
24	Guided Missile Launching System alternatives	Option 1) 64 cells, MK 41 and/or MK57 PVLS	Option 2) 32 cells, MK 41 and/or MK57 PVLS
		Option 2) 32 cells, MK 41 and/or MK57 PVLS	
25	LCS-equivalent Modules	Option 1) 2xLCS	Option 2) 1xLCS
		Option 2) 1xLCS	

Table 28 – Concept Exploration Weights and VCG Summary

Group	Weight (MT)
SWBS 100	2516
SWBS 200	532
SWBS 300	286
SWBS 400	283
SWBS 500	749
SWBS 600	504
SWBS 700	116
Payload	530
Lightship	5483
Lightship w/ Margin	5982
Full Load w/ Margin	7029

Table 29 – Concept Exploration Area Summary

Area	Required	Available
Total-Arrangeable	5155	5158
Deck House	1128	1138

Table 30 – MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Metric	Value of Performance	MOP Weight	Measure of Effectiveness
MOP 1	AAW	AAW = 2, GMLS = 2, SDS = 1, CCC = 1	0.863	0.204	0.176
MOP 2	ASW	ASW =1, LAMPS = 1, GMLS = 2, CCC = 1	0.978	0.169	0.165
MOP 3	Modules (xLCS)	MODULES = 2	0.641	0.119	0.076
MOP 4	ASUW/NSFS	NSFS = 2	0.845	0.094	0.079
MOP 5	CCC/ISR	CCC = 1	1.000	0.071	0.071
MOP 6	STK	CCC = 1, GMLS =2	0.830	0.036	0.030
MOP 7	Seakeeping	MCC = 11.08, Hulltype = 2	0.087	0.040	0.003
MOP 8	Endurance Range, E	E = 5362	1.000	0.020	0.020
MOP 9	Provisions Duration, Ts	Ts = 60	1.000	0.014	0.014
MOP 10	Sustained Speed, Vs	Vs = 31.78	0.623	0.011	0.007
MOP 11	Environmental	BALtype = 1	0.286	0.005	0.001
MOP 12	RCS	VD = 3413	1.000	0.075	0.075
MOP 13	Acoustic Signature	PSYS = 23	1.000	0.053	0.053
MOP 14	Magnetic Signature	Ndegaus = 1	0.800	0.032	0.026
MOP 15	IR Signature	PSYS = 23	0.619	0.023	0.014
MOP 16	Vulnerability	Cdhmat = 1	0.778	0.017	0.013
MOP 17	NBC	Ncps = 2	1.000	0.016	0.016
OMOE	Overall Measure of Effectiveness				0.841
OMOR	Overall Measure of Risk				0.509
Cfola	Follow-Ship Acquisition Cost				641.99

Table 31 – Concept Exploration Baseline Design Principal Characteristics

Characteristic	Baseline Value
Hull form	Wave-Piercing Tumblehome, -10 deg Flare
D (MT)	12.5
LWL (m)	139.0
Beam (m)	17.2
Draft (m)	5.8
D10 (m)	12.5
Displacement to Length Ratio, C_{DL} (lton/ft)	14.10
Beam to Draft Ratio, C_{BT}	2.96
W1 (MT)	2516
W2 (MT)	532
W3 (MT)	286
W4 (MT)	283
W5 (MT)	749
W6 (MT)	504
W7 (MT)	116
Lightship D (MT)	5483
KG (m)	7.28635
GM/B=	0.08055
Propulsion system	2 Pods, IPS, 2 x LM2500+GTG, 1 x PC2/16DG
Engine inlet and exhaust Area (m^2)	178.8
ASW/MCM system	SQD-56, SQQ 89, 2 x MK 32 Triple Tubes, NIXIE, SQR-19 TACTAS
ASUW system	MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
AAW system	SPY-3 (2 panel), AEGIS MK 99 FCS
Number of LAMPS	1
Average deck height (m)	3
Total Officers	23
Total Enlisted	223
Total Manning	246
Lead Ship Acquisition Cost ($M)	919.35
Average Follow Ship Acquisition Cost ($M)	641.99
Life Cycle Cost ($M)	1119.46

3.8 ASSET Final Concept Baseline

The hullform of ADF 95 is based on a conventional DD-1000 Wave-Piercing Tumblehome (WPTH) 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). Baseline characteristics were chosen according to mission requirements, standard naval combatant vessel requirements, expert opinion, and the multi-objective genetic optimization results stemming from the ship synthesis model. Once all ship parameters were entered into Asset, the program returned baseline values for propulsion, combat, electrical, and mechanical systems that were modified throughout the design spiral to best address the needs of the Initial Capabilities Document and the Acquisition Decision Memorandum.

Views of the hull, machinery arrangements, pods, hull midsection, and their respective data summaries are shown in Figure 34 -

Figure 41. Additional ASSET data summaries are given in Appendix E.

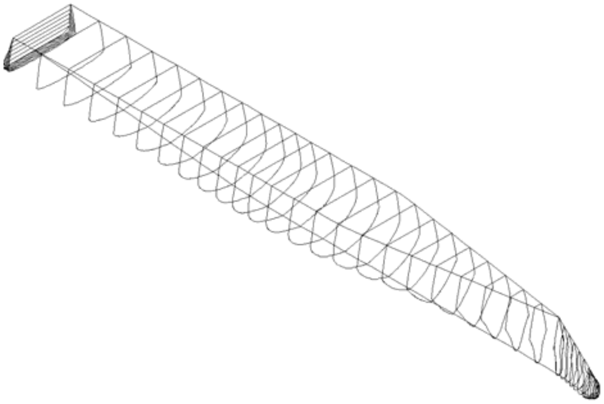
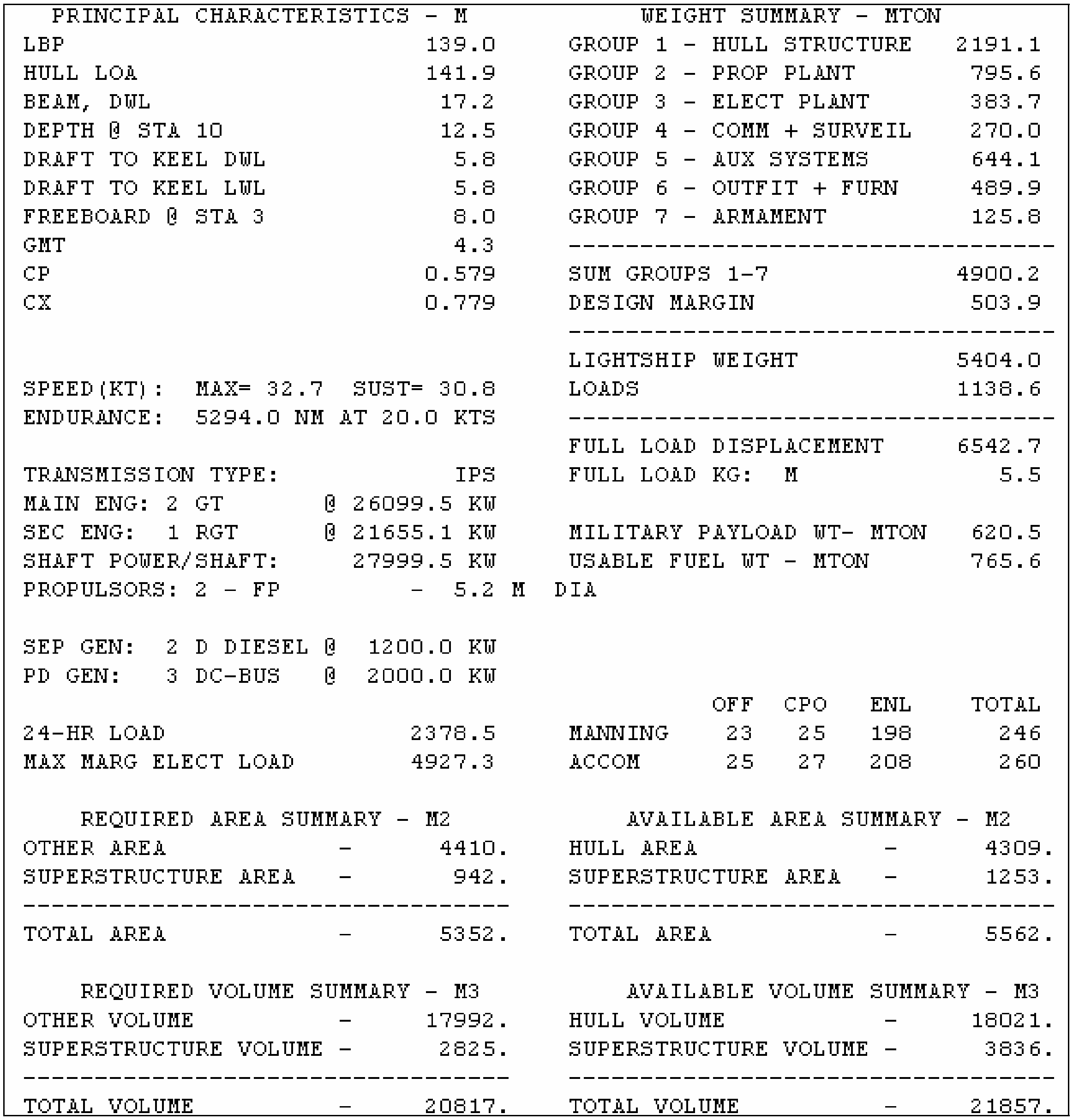


Figure 34 – Hull Isometric View



```
  PRINCIPAL CHARACTERISTICS - M             WEIGHT SUMMARY - MTON
 LBP                           139.0    GROUP 1 - HULL STRUCTURE   2191.1
 HULL LOA                      141.9    GROUP 2 - PROP PLANT        795.6
 BEAM, DWL                      17.2    GROUP 3 - ELECT PLANT       383.7
 DEPTH @ STA 10                 12.5    GROUP 4 - COMM + SURVEIL    270.0
 DRAFT TO KEEL DWL               5.8    GROUP 5 - AUX SYSTEMS       644.1
 DRAFT TO KEEL LWL               5.8    GROUP 6 - OUTFIT + FURN     489.9
 FREEBOARD @ STA 3               8.0    GROUP 7 - ARMAMENT          125.8
 GMT                             4.3    ----------------------------------
 CP                            0.579    SUM GROUPS 1-7             4900.2
 CX                            0.779    DESIGN MARGIN               503.9
                                        ----------------------------------
                                        LIGHTSHIP WEIGHT           5404.0
 SPEED(KT):  MAX= 32.7  SUST= 30.8      LOADS                      1138.6
 ENDURANCE:  5294.0 NM AT 20.0 KTS      ----------------------------------
                                        FULL LOAD DISPLACEMENT     6542.7
 TRANSMISSION TYPE:              IPS    FULL LOAD KG:  M              5.5
 MAIN ENG: 2 GT       @ 26099.5 KW
 SEC ENG:  1 RGT      @ 21655.1 KW      MILITARY PAYLOAD WT- MTON   620.5
 SHAFT POWER/SHAFT:     27999.5 KW      USABLE FUEL WT - MTON       765.6
 PROPULSORS: 2 - FP         -  5.2 M  DIA

 SEP GEN:  2 D DIESEL @  1200.0 KW
 PD GEN:   3 DC-BUS   @  2000.0 KW
                                                  OFF  CPO  ENL    TOTAL
 24-HR LOAD                   2378.5    MANNING    23   25  198      246
 MAX MARG ELECT LOAD          4927.3    ACCOM      25   27  208      260

    REQUIRED AREA SUMMARY - M2              AVAILABLE AREA SUMMARY - M2
 OTHER AREA            -       4410.    HULL AREA              -      4309.
 SUPERSTRUCTURE AREA   -        942.    SUPERSTRUCTURE AREA    -      1253.
 -----------------------------------    -----------------------------------
 TOTAL AREA            -       5352.    TOTAL AREA             -      5562.

    REQUIRED VOLUME SUMMARY - M3            AVAILABLE VOLUME SUMMARY - M3
 OTHER VOLUME          -      17992.    HULL VOLUME            -     18021.
 SUPERSTRUCTURE VOLUME -       2825.    SUPERSTRUCTURE VOLUME -       3836.
 -----------------------------------    -----------------------------------
 TOTAL VOLUME          -      20817.    TOTAL VOLUME           -     21857.
```

Figure 35 – Design Summary Report

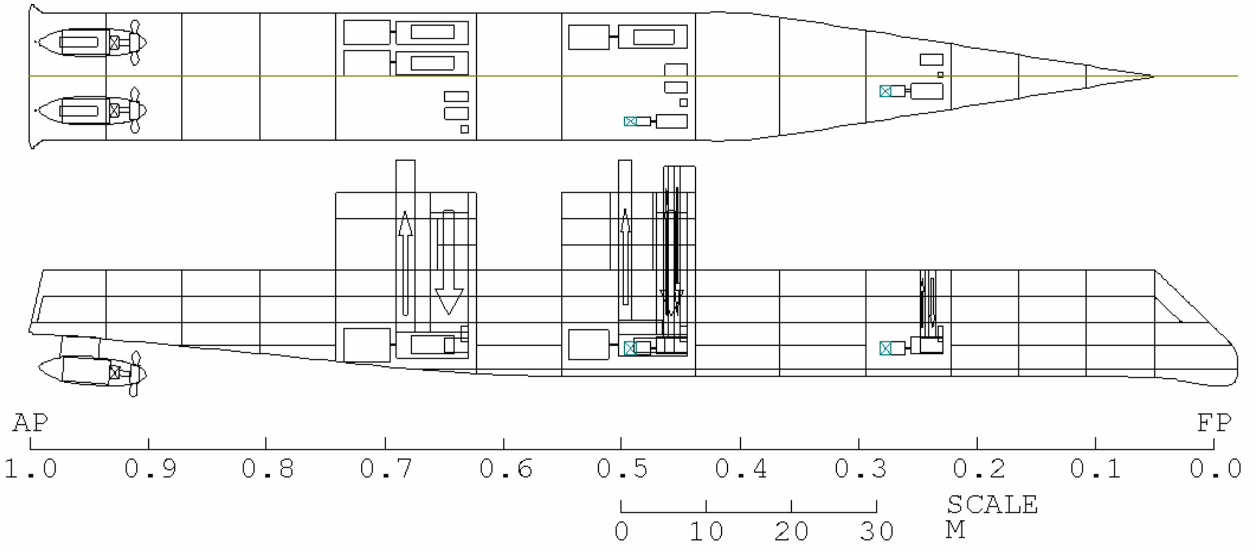
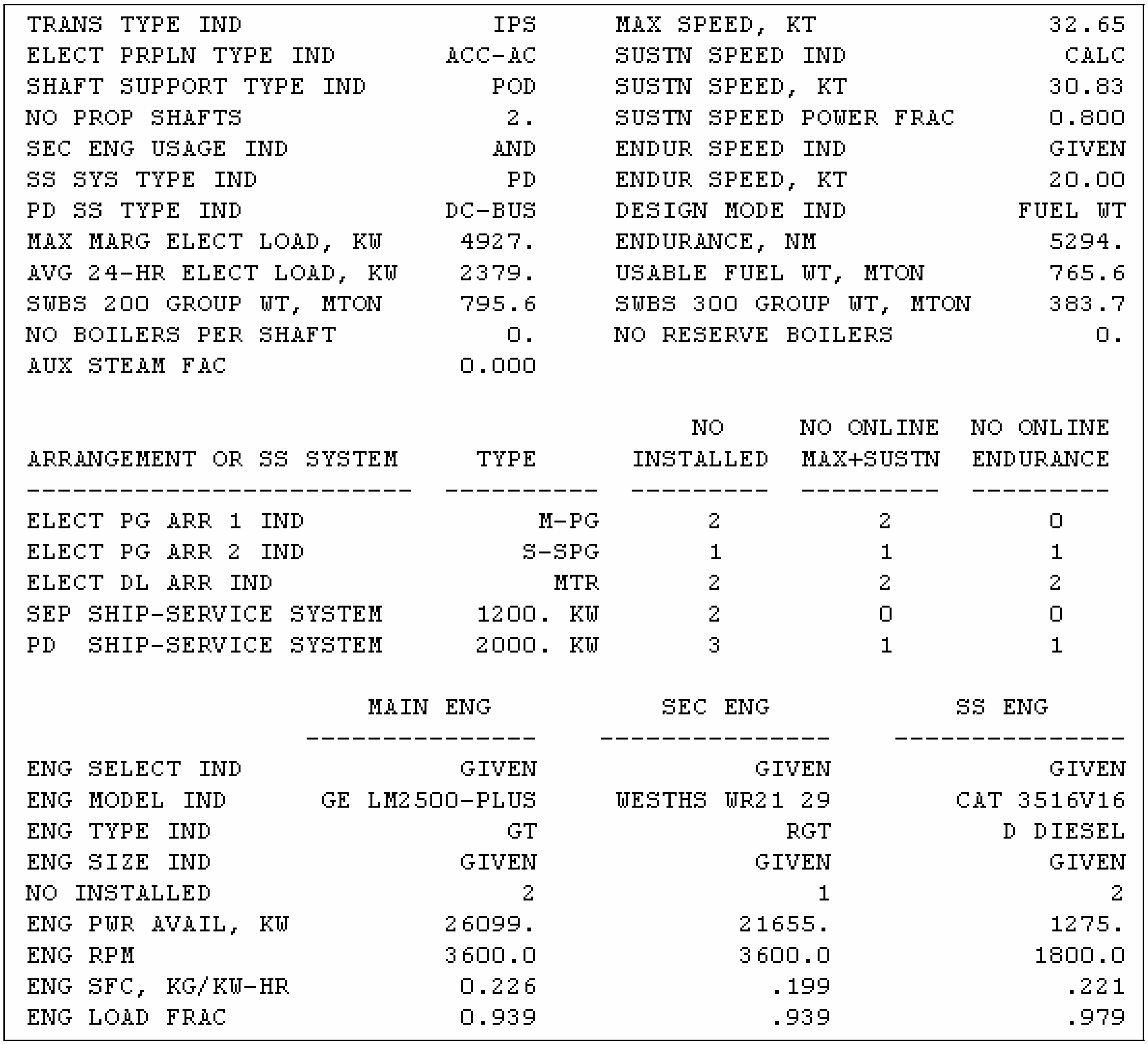


Figure 36 – Ship Machinery Layout



```
TRANS TYPE IND                  IPS     MAX SPEED, KT                32.65
ELECT PRPLN TYPE IND         ACC-AC     SUSTN SPEED IND               CALC
SHAFT SUPPORT TYPE IND          POD     SUSTN SPEED, KT              30.83
NO PROP SHAFTS                   2.     SUSTN SPEED POWER FRAC       0.800
SEC ENG USAGE IND               AND     ENDUR SPEED IND              GIVEN
SS SYS TYPE IND                  PD     ENDUR SPEED, KT              20.00
PD SS TYPE IND               DC-BUS     DESIGN MODE IND            FUEL WT
MAX MARG ELECT LOAD, KW       4927.     ENDURANCE, NM                5294.
AVG 24-HR ELECT LOAD, KW      2379.     USABLE FUEL WT, MTON         765.6
SWBS 200 GROUP WT, MTON       795.6     SWBS 300 GROUP WT, MTON      383.7
NO BOILERS PER SHAFT             0.     NO RESERVE BOILERS              0.
AUX STEAM FAC                 0.000


                                                 NO     NO ONLINE  NO ONLINE
ARRANGEMENT OR SS SYSTEM        TYPE       INSTALLED   MAX+SUSTN  ENDURANCE
-------------------------   ----------   ---------   ---------  ---------
ELECT PG ARR 1 IND                M-PG         2           2          0
ELECT PG ARR 2 IND               S-SPG         1           1          1
ELECT DL ARR IND                   MTR         2           2          2
SEP SHIP-SERVICE SYSTEM      1200. KW          2           0          0
PD  SHIP-SERVICE SYSTEM      2000. KW          3           1          1

                       MAIN ENG            SEC ENG              SS ENG
                   ---------------    ---------------    ---------------
ENG SELECT IND               GIVEN              GIVEN              GIVEN
ENG MODEL IND       GE LM2500-PLUS      WESTHS WR21 29       CAT 3516V16
ENG TYPE IND                    GT                RGT           D DIESEL
ENG SIZE IND                 GIVEN              GIVEN              GIVEN
NO INSTALLED                     2                  1                  2
ENG PWR AVAIL, KW           26099.             21655.              1275.
ENG RPM                     3600.0             3600.0             1800.0
ENG SFC, KG/KW-HR            0.226               .199               .221
ENG LOAD FRAC                0.939               .939               .979
```

Figure 37 – Machinery Module Summary

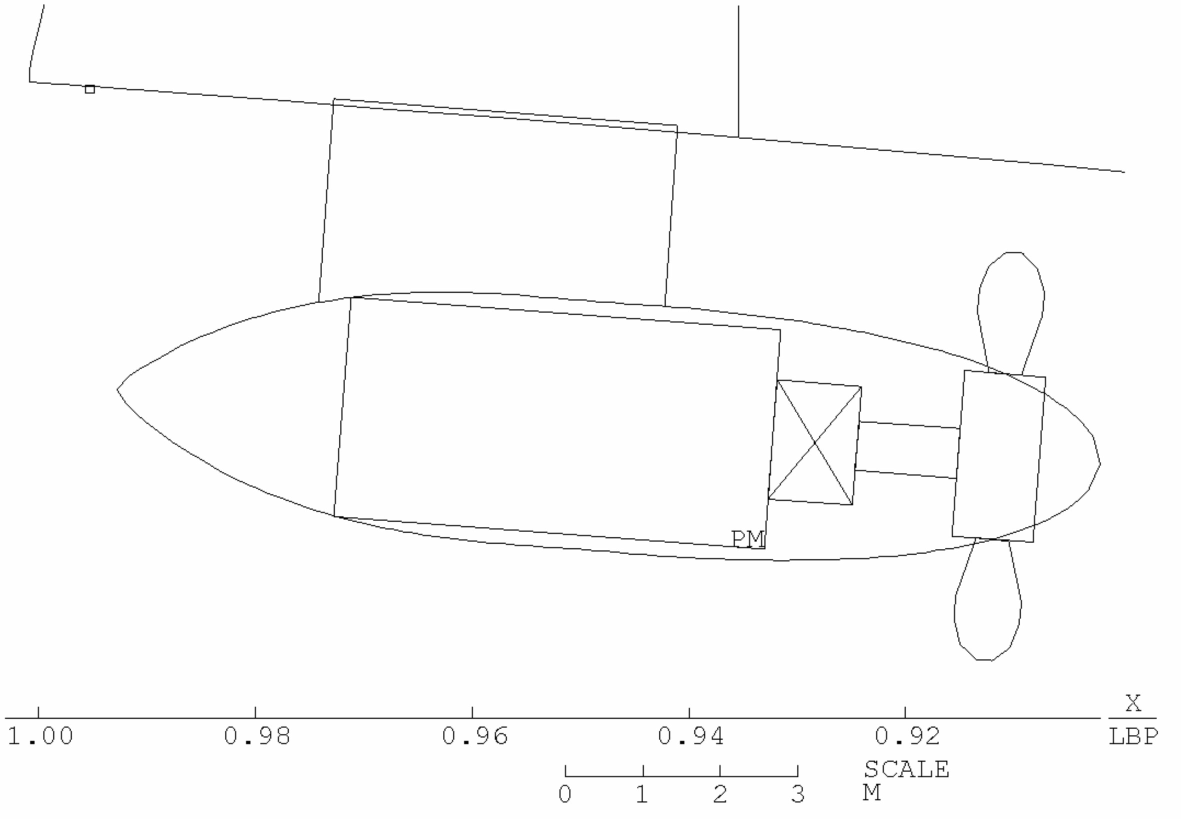
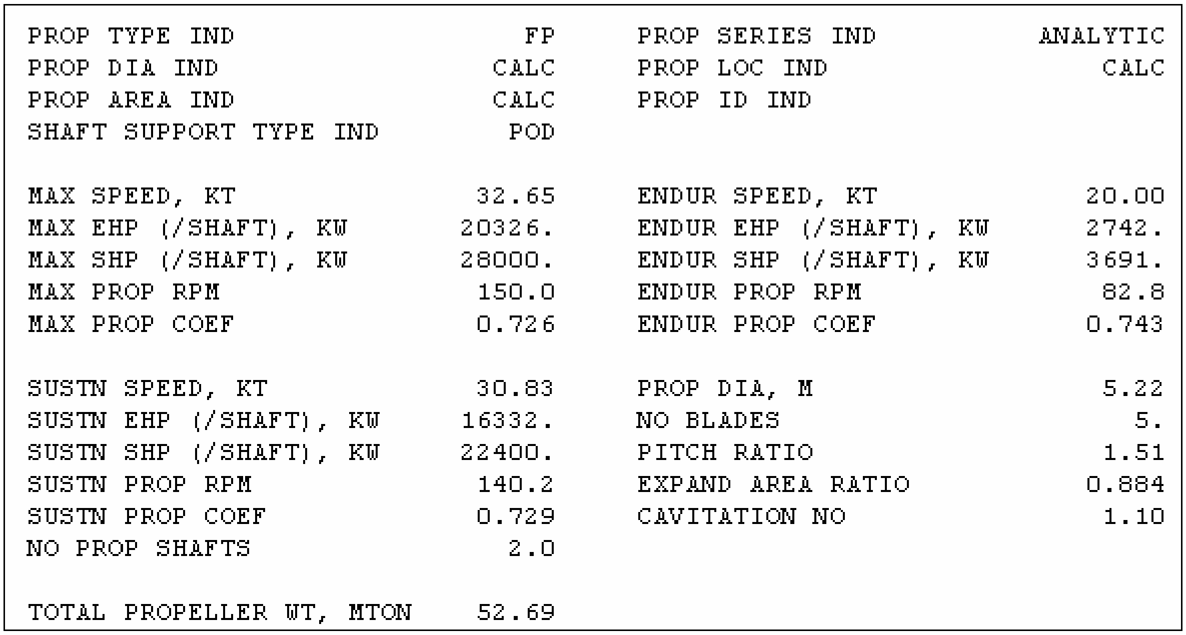


Figure 38 – Propulsion Inboard Appendages Profile View



```
PROP TYPE IND                    FP     PROP SERIES IND          ANALYTIC
PROP DIA IND                   CALC     PROP LOC IND                 CALC
PROP AREA IND                  CALC     PROP ID IND
SHAFT SUPPORT TYPE IND          POD

MAX SPEED, KT                 32.65     ENDUR SPEED, KT             20.00
MAX EHP (/SHAFT), KW         20326.     ENDUR EHP (/SHAFT), KW      2742.
MAX SHP (/SHAFT), KW         28000.     ENDUR SHP (/SHAFT), KW      3691.
MAX PROP RPM                  150.0     ENDUR PROP RPM               82.8
MAX PROP COEF                 0.726     ENDUR PROP COEF             0.743

SUSTN SPEED, KT               30.83     PROP DIA, M                  5.22
SUSTN EHP (/SHAFT), KW       16332.     NO BLADES                      5.
SUSTN SHP (/SHAFT), KW       22400.     PITCH RATIO                  1.51
SUSTN PROP RPM                140.2     EXPAND AREA RATIO           0.884
SUSTN PROP COEF               0.729     CAVITATION NO                1.10
NO PROP SHAFTS                  2.0

TOTAL PROPELLER WT, MTON      52.69
```

Figure 39 – Propulsor Module Summary

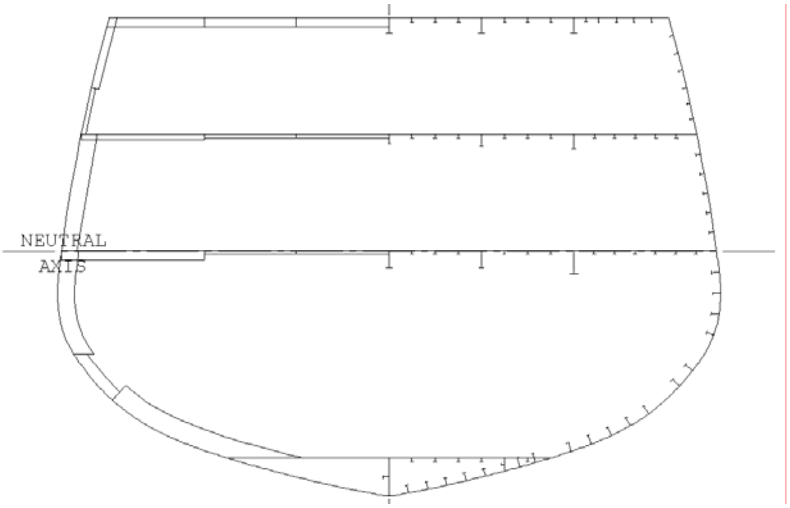
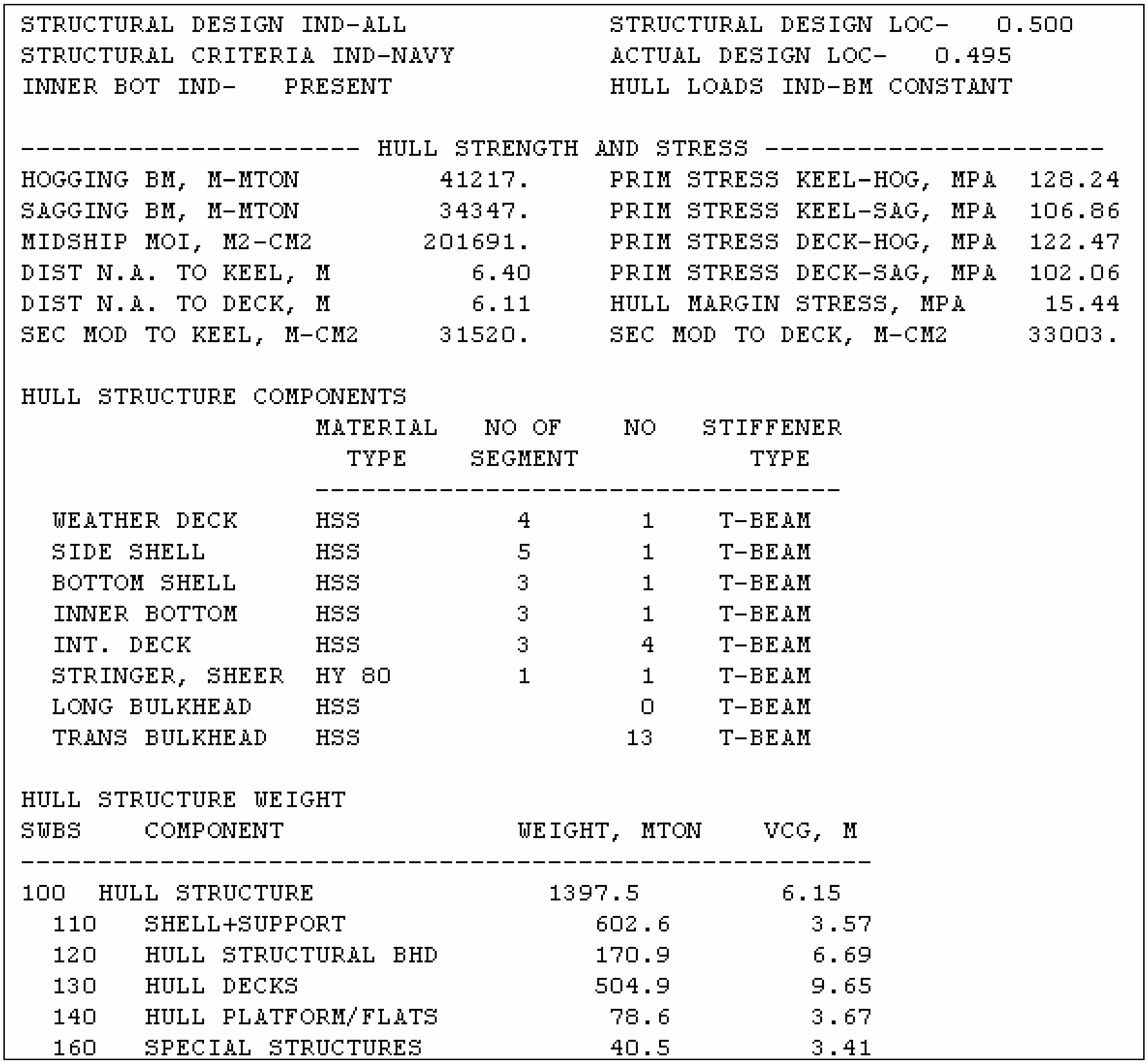


Figure 40 – Section View at the Structural Design Location



```
STRUCTURAL DESIGN IND-ALL             STRUCTURAL DESIGN LOC-   0.500
STRUCTURAL CRITERIA IND-NAVY          ACTUAL DESIGN LOC-   0.495
INNER BOT IND-   PRESENT              HULL LOADS IND-BM CONSTANT

---------------------- HULL STRENGTH AND STRESS ----------------------
HOGGING BM, M-MTON          41217.     PRIM STRESS KEEL-HOG, MPA  128.24
SAGGING BM, M-MTON          34347.     PRIM STRESS KEEL-SAG, MPA  106.86
MIDSHIP MOI, M2-CM2        201691.     PRIM STRESS DECK-HOG, MPA  122.47
DIST N.A. TO KEEL, M          6.40     PRIM STRESS DECK-SAG, MPA  102.06
DIST N.A. TO DECK, M          6.11     HULL MARGIN STRESS, MPA     15.44
SEC MOD TO KEEL, M-CM2      31520.     SEC MOD TO DECK, M-CM2     33003.

HULL STRUCTURE COMPONENTS
                   MATERIAL   NO OF    NO   STIFFENER
                     TYPE    SEGMENT          TYPE
                   ----------------------------------
  WEATHER DECK     HSS          4       1    T-BEAM
  SIDE SHELL       HSS          5       1    T-BEAM
  BOTTOM SHELL     HSS          3       1    T-BEAM
  INNER BOTTOM     HSS          3       1    T-BEAM
  INT. DECK        HSS          3       4    T-BEAM
  STRINGER, SHEER  HY 80        1       1    T-BEAM
  LONG BULKHEAD    HSS                  0    T-BEAM
  TRANS BULKHEAD   HSS                 13    T-BEAM

HULL STRUCTURE WEIGHT
SWBS    COMPONENT              WEIGHT, MTON    VCG, M
-------------------------------------------------------
100  HULL STRUCTURE              1397.5         6.15
  110   SHELL+SUPPORT               602.6         3.57
  120   HULL STRUCTURAL BHD         170.9         6.69
  130   HULL DECKS                  504.9         9.65
  140   HULL PLATFORM/FLATS          78.6         3.67
  160   SPECIAL STRUCTURES           40.5         3.41
```

Figure 41 – Hull Structure Module Summary

4 Concept Development (Feasibility Study)

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

4.1 Preliminary Arrangement (Cartoon)

As a preliminary step in finalizing hull form geometry, deck house geometry, and all general arrangements, an arrangement cartoon was developed for areas supporting mission operations, propulsion, and other critical constrained functions. The arrangement cartoon was created to ensure all the necessary volumes, areas and large objects would fit into the ship. To accomplish this, transverse bulkheads, decks, major tanks, and primary spaces were determined. While creating the cartoon, many things were taken into consideration including stability, trim, radar cross section, damage stability, large object placement, engine intake and exhaust, structural efficiency, survivability, and function.

The first step in creating the cartoon was to create profile and plan views of our ship in Rhino and then print them out to use as an outline. Required areas and volumes were determined from the baseline synthesis model and were used to help determine arrangements. The transverse bulkheads and decks were sketched by hand on the profile and plan views along with topside arrangements, mission spaces, machinery spaces, inlet and exhaust trunks and major tanks. The preliminary arrangement cartoon is shown in Figure 42.

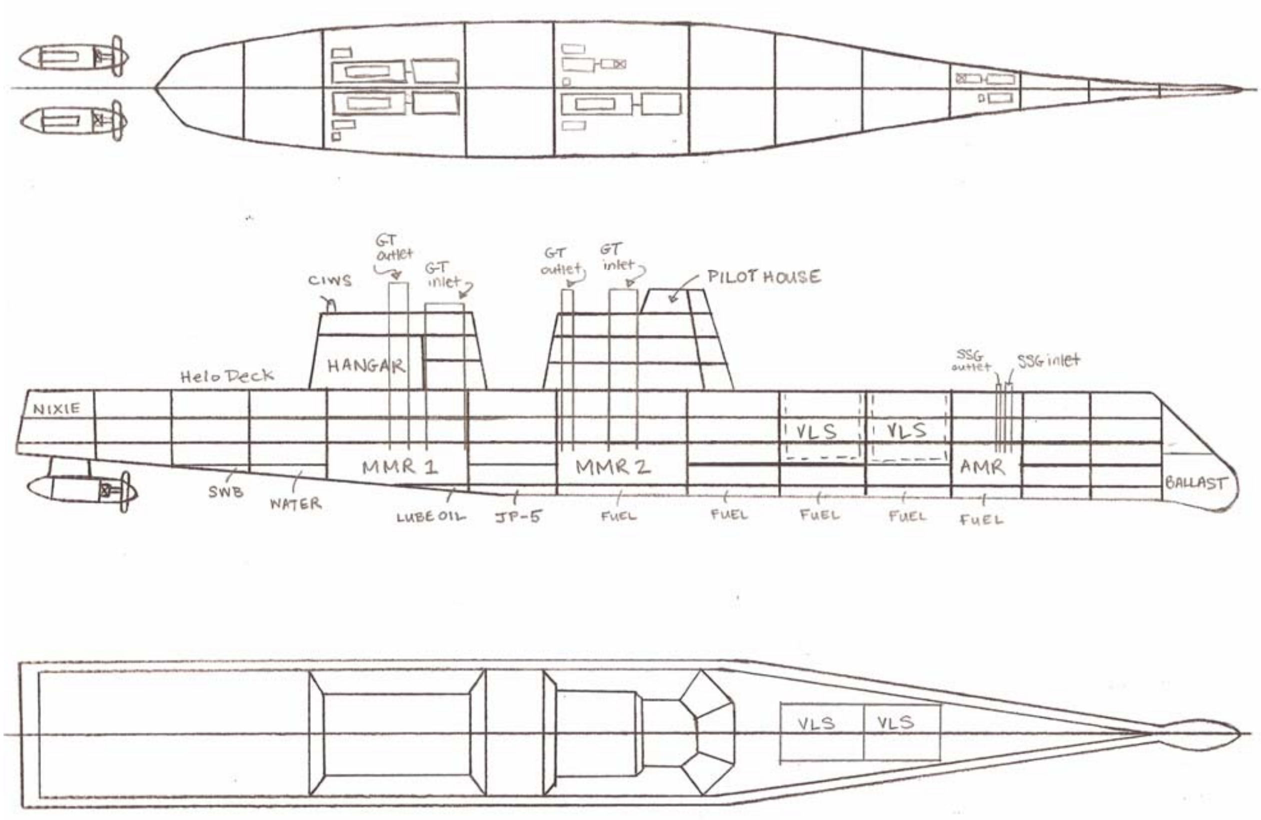


Figure 42 – Preliminary Arrangement Cartoon

After reviewing the cartoon, several corrections were required including a continuous deckhouse, a reduction in Vertical Launch System (VLS) space, the re-orientation of engines, and the addition of more combat systems topside.

4.2 Design for Producibility

The ideal build strategy for ADF 95 is to create a highly producible hull form. Wherever possible, flat plates and straight frames will be used in place of contoured members. Single curvature plates will be used to create most contours, and in circumstances in which double curvature plates are required, only slight contours will be used. The deckhouse will also be comprised predominately of flat plates and straight frames to maximize producibility. The shape of the bulb at the bow will be a constant elliptical cross-section, and a lengthy parallel midbody will also be used for ease of production. The performance penalty of these production-favorable attributes will be minimal as shown in model testing.

For construction purposes, a block breakout, claw chart, and master construction schedule were created. For the block breakout, the ship was section according to groups. Blocks within the bow were given numbers in 1000, blocks in the stern 4000, blocks containing hull cargo 2000, blocks containing machinery 3000, on board construction blocks 5000, and high-skill construction blocks were 6000. The claw chart is the construction of blocks by week, and the master construction schedule is the process from contract to delivery. The block breakout is shown in Figure 43, the claw chart in Table 32, and the master construction schedule in Table 33.

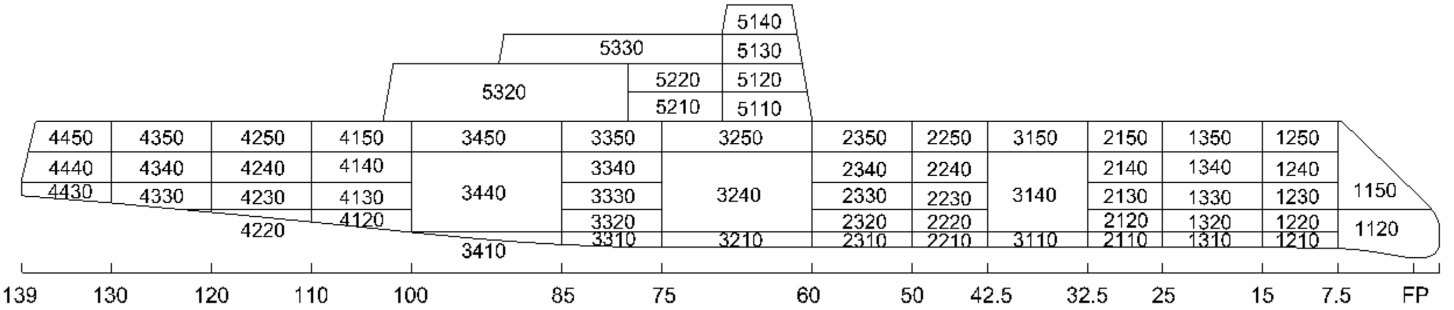


Figure 43 – Block Breakout

Table 32 – Claw Chart

Week	4400	4300	4200	4100	5300 3400	5200 3300	5100 3200	2300	2200	2100	3100	1300	1200	1100
1						3320	3210							
2					3440			2320						
3					GEN #1				2220					
4				4130			3240							
5								2330		2120				
6					ENG #1						3110			
7			4240			3330								
8									2230		3140			
9							GEN #2			2130				
10		4350										1320		
11				4150									1220	
12							ENG #2					1330		
13			4250		3450									
14	4450													1120
15						3350					GEN #3			
16					5320		3250							
17						5220					ENG #3			
18							5220		2250				1230	
19								2350		2150				
20											3150		1250	
21												1350		1150
22	POD				5330									
23	POD						5120							
24	POD						5130							

25	POD						5140							

Table 33 – Master Construction Schedule

EVENT	DESCRIPTION	DURATION (MONTHS)	MBD
001	AWARD CONTRACT (M)	0	60
002	DETAIL PROCUREMENT	38	60
003	MATERIAL PROCUREMENT	42	59
004	MFG/PRODUCTION PLANNING	40	58
005	LOFTING	21	52
006	START CONSTRUCTION (M)	0	42
007	STRUCTURAL FAB/ASSEMBLY	24	42
008	LAY KEEL (M)	0	38
009	STRUCTURAL ERECTION	20	38
010	MACHINERY INSTALLATION	30	37
011	PIPING INSTALLATION	32	35
012	ELECT/ELEX INSTALLATION	30	34
013	HVAC INSTALLATION	25	32
014	TANK/VOID CLOSEOUTS	16	24
015	STERN RELEASE (M)	0	23
016	SYSTEMS TESTING	20	22
017	LAUNCH (M)	0	20
018	ON-BOARD OUTFITTING	14	19
019	COMPARTMENT CLOSEOUTS	14	17
020	DRYDOCKING	1	14
021	INCLINING	0	13
022	DOCK TRIALS (M)	0	7
023	BUILDER'S TRIALS (M)	0	5
024	ACCEPTANCE TRIALS (M)	0	3
025	DELIVERY (M)	0	0

4.3 Hull Form and Deck House

4.3.1 Hullform

There were several objectives for designing the hull including minimum drag by having a fair hullform, minimum radar cross section (RCS), large enough deck and volume areas to support propulsion and mission systems, and good sea keeping ability. The hullform for ADF 95 was created to ASSET baseline characteristics using DD 1000 as a parent hull. The hull surface was lofted in Rhino and the transom, top deck, and sonar dome were modified. The baseline hull characteristics are given in Table 34.

Table 34 – Baseline Hull Characteristics

Characteristic	Value
Full Load Displacement	6530 MT
LWL	139 m
B	17.18
T	5.81
D10	12.51
Cp	.579
Cx	.779
Topside Flare	-10°
Deckhouse Volume	3836 m^3

The hull form of ADF 95 is a wave piercing tumblehome (WPTH). The hull above the water line, the transom, and the deckhouse are angled at 10 degrees to reduce radar cross section. Originally ADF 95 was designed with a raised deck, however for structural strength to support the pods, the entire top deck was made continuous. The body view in Figure 44 and the profile view of the hullform in Figure 45 show the 10 degree flare, the 45 degree rake of the bow, the shape of the deckhouse, the pilot house and the angled transom. A lines drawing is shown in Figure 46.

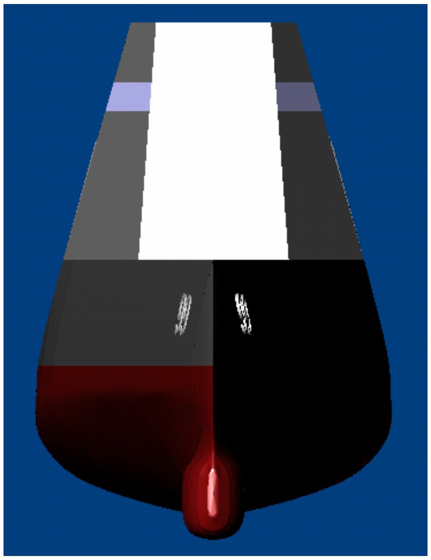


Figure 44 – Body View

Figure 45 – Profile View

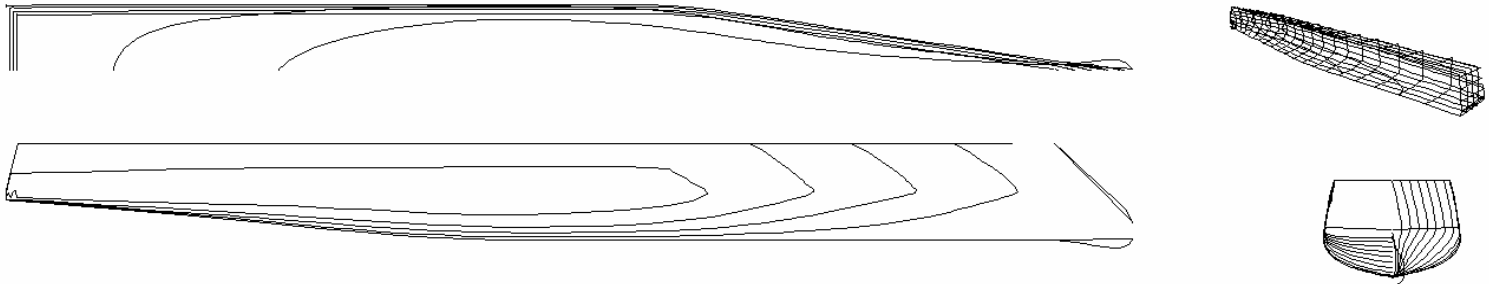


Figure 46 – Lines Drawing

4.3.2 Deck House

The deckhouse for ADF 95 is made of steel and has four levels. The top level, deck 03, contains the Spy-3 and other radar equipment. Deck 02 contains the pilot house and communications room and deck 01 contains the captain and XO living quarters. The helicopter hangar is two stories tall and is located on the aft portion of the deckhouse. An isometric view of the deckhouse is shown in Figure 47.

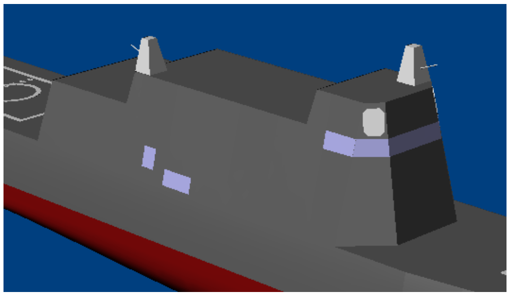


Figure 47 – Isometric View of Deckhouse

4.4 Structural Design and Analysis

4.4.1 Procedure

The midship section and two boarding hull sections were originally modeled in MAESTRO. This model reflects the second main machinery room section and two neighboring sections. Notice that continuous decks were accounted for however non-continuous platforms like those found in the machinery room were omitted. Figure 48 shows a rendering of the model that was created.

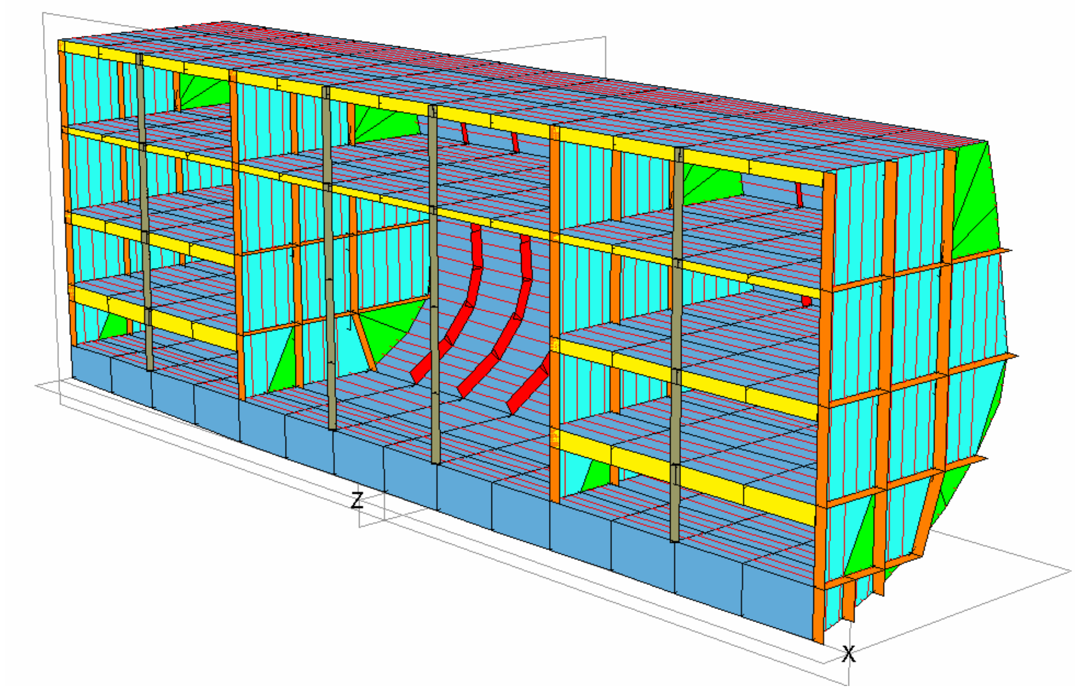


Figure 48 – MAESTRO Model Showing Mid and Neighboring Sections

Due to limitations in MAESTRO, the model would not analyze loads properly with only a section of the ship. In order to still assess the structural integrity, a more basic method was adopted. In this method, a 2D midsection was created using plates, stiffeners, and longitudinal girders. By calculating moments of inertia and using the parallel axis theorem, the section modulus for the keel and strength deck were calculated. Knowing the Section Modulus and bending moment values, the longitudinal stress due to bending was found and compared to the yield values for the hull material type. Figure 49 shows the 2D midsection model that was created in HECSALV Section Modulus Editor and

Table 35 shows the values of Section Modulus and other associated properties of the cross-section.

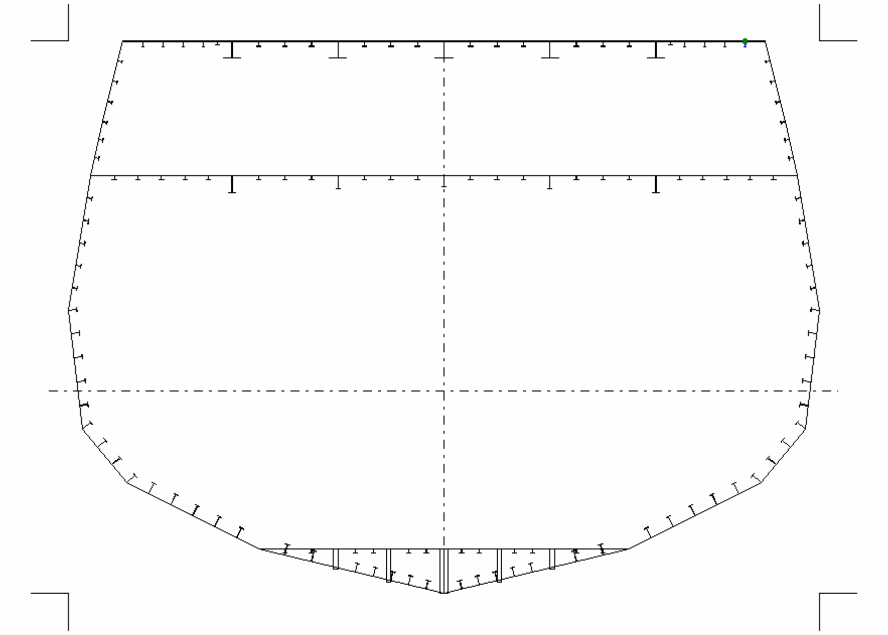


Figure 49 – 2D Cross-Section at Midships

Table 35 – Properties of the Midsection

Property	Value
Total Area (m^2)	1.306
NA from Bottom (m)	4.590
I (m^4)	30.350
Section Modulus at Keel (m^3)	6.612
Section Modulus at Strength Deck (m^3)	3.831

4.4.2 Materials and Geometry

ADF 95 is constructed predominately of HSS with HY80 steel used as the stringer plate where high bending stress is expected and greater yield strength is required. Table 36 shows the material properties of these two types of steel.

Table 36 – Material Properties

Material Properties	HSS	HY80
Modulus (GPa)	204.1	204.1
Density (kg/m^3)	7833	7833
Yield Strength (MPa)	352	552

The hull structure geometry is composed of weather deck, stringer, deck, side shell and bottom shell plating. Each of these plates is stiffened using T-stiffeners. Longitudinal girders are located below the lowest internal deck and extend across the length of the ship. Transverse deck beams and side frames are spaced 2.5m apart and are used to provide adequate support to decks and shell plating.

The scantlings of these stiffeners, girder supports, and frames appear in the list of materials arranged by catalog number shown in Table 37. Note that “S” designates that a particular member is a stiffener; “G” designates a girder, “B” a deck beam, and “F” a transverse frame.

Table 37 – Dimensions of Scantlings

Catalog #	Web Height (mm)	Flange Width (mm)	Web Thickness (mm)	Flange Thickness (mm)
1 S/B	95.12	100.08	4.32	5.21
2 S/B	120.14	100.58	4.83	5.33
3 S	99.57	50.80	3.05	4.57
4 S	124.97	50.80	3.05	4.57
5 S	145.67	100.84	5.08	5.72
6 S/F/B	195.20	100.08	4.32	5.21
7 B	144.40	100.08	4.32	5.46
9 S	145.70	101.35	5.59	6.73
14 S/B	245.36	100.58	4.83	5.33
21 S	197.99	102.11	6.22	8.00
33 G	250.06	102.11	6.35	10.03
35 F	299.97	101.85	5.97	8.89
40 S	340.49	127.00	5.84	8.51
41 G	301.88	102.36	6.60	10.80
51 G/S	389.76	139.70	6.35	8.76
67 G	391.92	177.55	7.49	10.92
69 G	438.79	152.40	7.62	10.80
75 G	441.33	152.91	8.00	13.34
80 F	397.00	179.58	9.65	16.00
81 F	442.47	190.50	9.02	14.48
87 F	517.53	209.30	10.16	15.62
88 F	171.20	171.20	25.40	6.35
89 F	664.50	317.50	4.76	6.35
99 G	589.79	228.09	10.67	17.27
109 G	664.21	253.75	12.45	19.05
127 G	823.98	293.12	16.26	26.92
128 G	986.59	317.50	10.32	6.35
129 G	341.79	317.50	101.60	6.35

4.4.3 Loads

Shear Force and Bending Moment Diagrams were found using HECSALV for three conditions. The first condition is still water and it represents the shear force and bending moment experienced by the hull under full load with no waves. The second and third conditions represent the worst case hogging and sagging scenarios whereby severe waves are used to assess these conditions. In the case of conditions two and three, the wave height, $H = 1.1 \times \sqrt{L_{WL}}$ (in feet), and the wave length, $L = L_{WL}$. Note that for the hogging condition, the crest location occurs at amidships, and for the sagging condition, the crest location occurs at the forward perpendicular. The three conditions are pictured below with their associated Shear Force and Bending Moment Diagrams in Figure 50 – Figure 52.

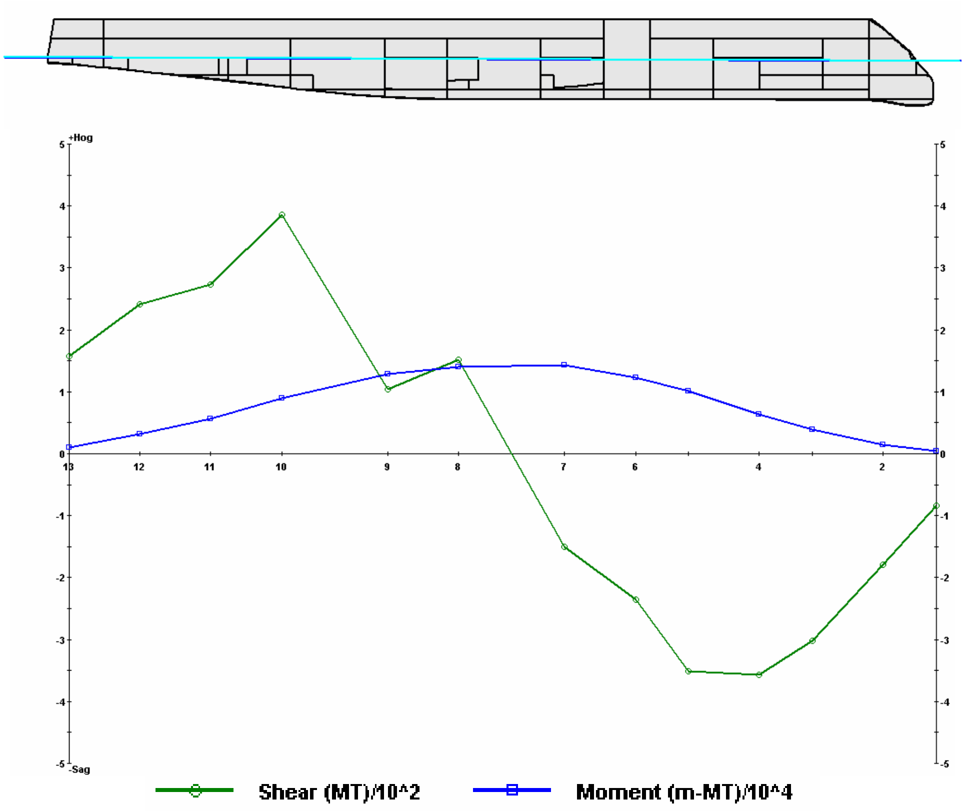


Figure 50 – Condition 1: Still Water at Full Load, Shear Force and Bending Moment

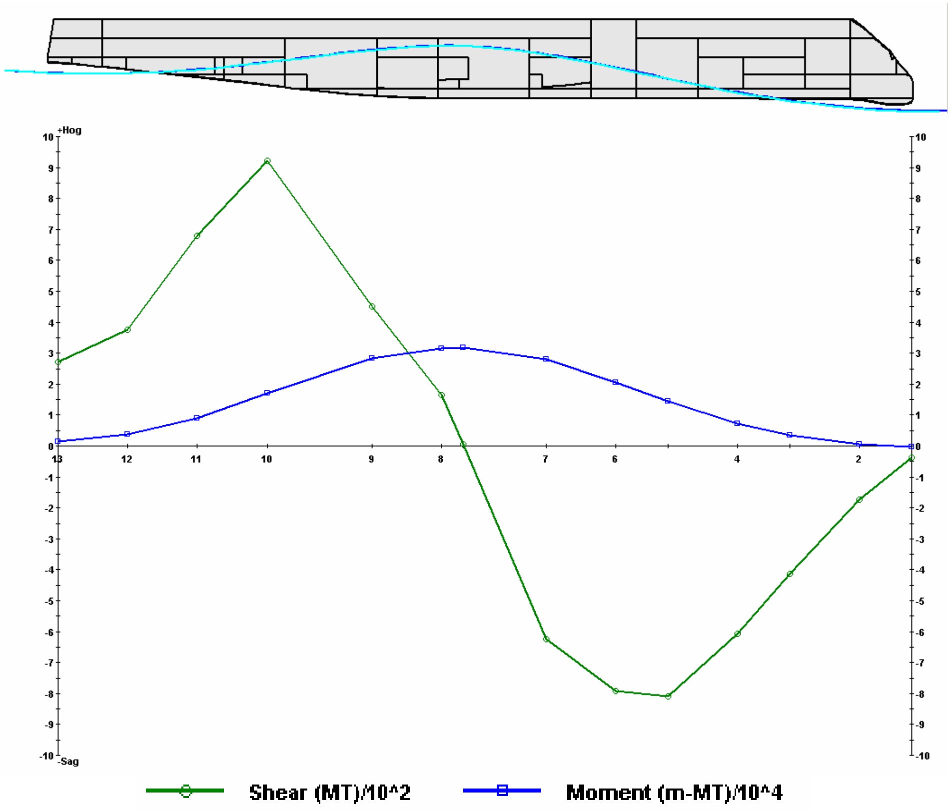


Figure 51 – Condition 2: Severe Hogging at Full Load, Shear Force and Bending Moment

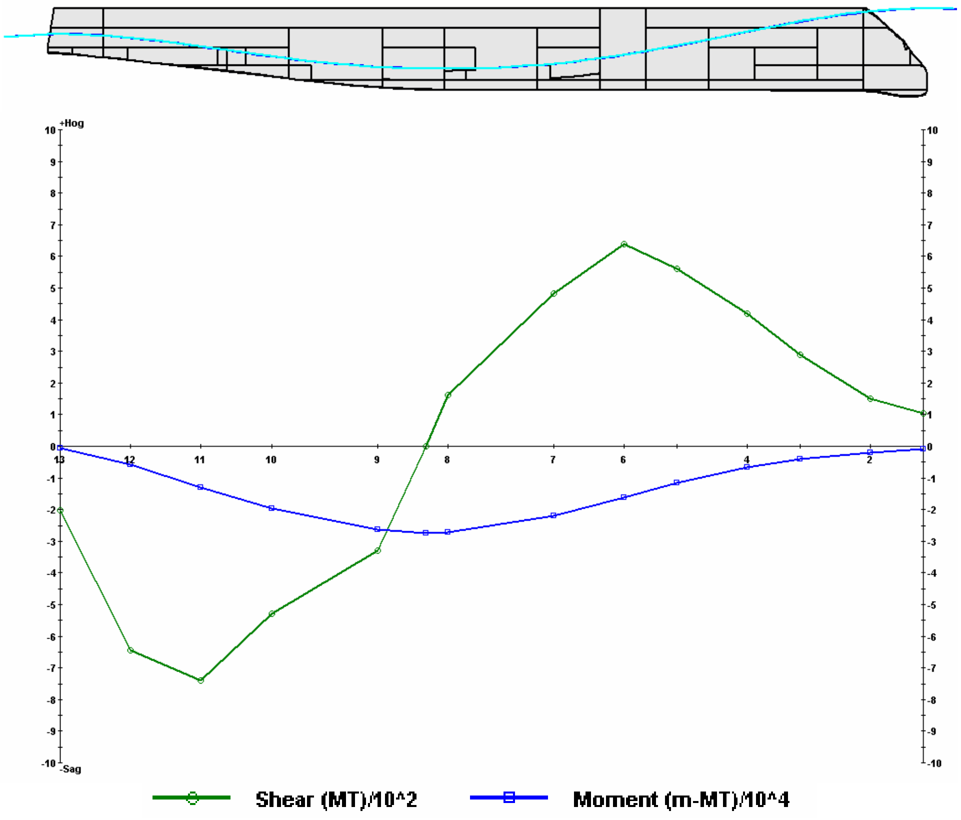


Figure 52 – Condition 3: Severe Sagging at Full Load, Shear Force and Bending Moment

4.4.4 Adequacy

These conditions were used to determine the moment acting on the midships section and the maximum bending stress produced for each condition was found. Table 38 shows the bending stresses on the deck and keel panels.

Table 38 – Moments and Stresses Based on Condition Number

Condition 1: Still Water	
M_{max} (m*MT)	-14291
σ_{max} at Keel (MPa)	-21.2
σ_{max} at Strength Deck (MPa)	36.6
Condition 2: Severe Hogging	
M_{max} (m*MT)	-31655
σ_{max} at Keel (MPa)	-47.0
σ_{max} at Strength Deck (MPa)	81.1
Condition 3: Severe Sagging	
M_{max} (m*MT)	27400
σ_{max} at Keel (MPa)	40.7
σ_{max} at Strength Deck (MPa)	-70.2

Since all the bending stresses produced were substantially below 351.6 MPa, the accepted yield stress of HSS, other possible modes of failure were examined. Portions of the hull girder were chosen and treated as panel and plate elements to check for structural adequacy. The portions of the hull shown in Figure 53 were chosen in regions likely to experience high bending or shear stress. The appropriate panel/plate regions are highlighted in blue.

Panels were chosen at the deck and keel where the maximum stress due to bending occurs. Also, a panel was chosen at the neutral axis. These regions of the hull were assessed for plate buckling, the combined bending and compressive stress of a panel, the ultimate stress of a panel and panel tension. The calculation of the second section tested, the side shell plating, is shown in Appendix I. Table 39 shows the factor or safety for each of the failure modes and panel locations where a value greater than one is representative of a safe structure.

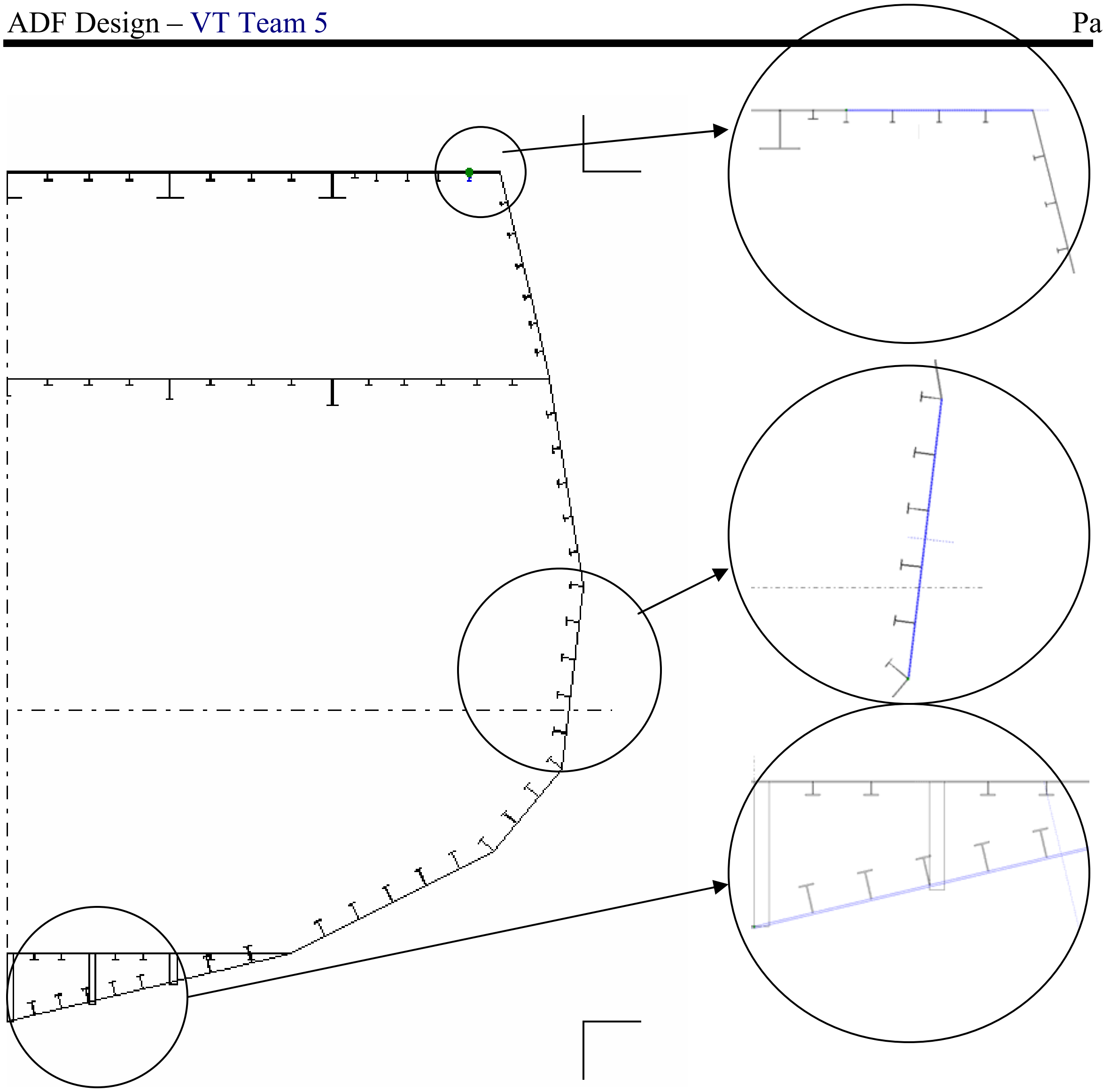


Figure 53 – Regions Checked for Failure

Table 39 – Factors of Safety for Various Failure Modes

Plate Buckling	FOS
Stringer Plate (at Deck)	22.60
Side Shell Panel (at NA)	2.14
Bottom Shell Panel (at Keel)	3.64

Panel Ultimate Strength	FOS
Stringer Plate (at Deck)	11.69
Side Shell Panel (at NA)	3.25
Bottom Shell Panel (at Keel)	3.11

Panel Comb. Bending And Comp. Stress	FOS
Stringer Plate (at Deck)	3.10
Side Shell Panel (at NA)	1.39
Bottom Shell Panel (at Keel)	0.95

Panel Tension	FOS
Stringer Plate (at Deck)	2.99
Side Shell Panel (at NA)	1.78
Bottom Shell Panel (at Keel)	1.36

For all three panels, the most critical modes appear to be panel combined bending and compressive stress, and panel tension. Panel combined bending and compressive stress is especially critical for the bottom shell plating nearest to the keel. The factor of safety of 0.95 indicates structural inadequacy. A possible solution to this problem is to increase the size of the stiffeners and given another design iteration, larger stiffeners would be used for this plate. The final midship section drawing of the hull is shown in Figure 54.

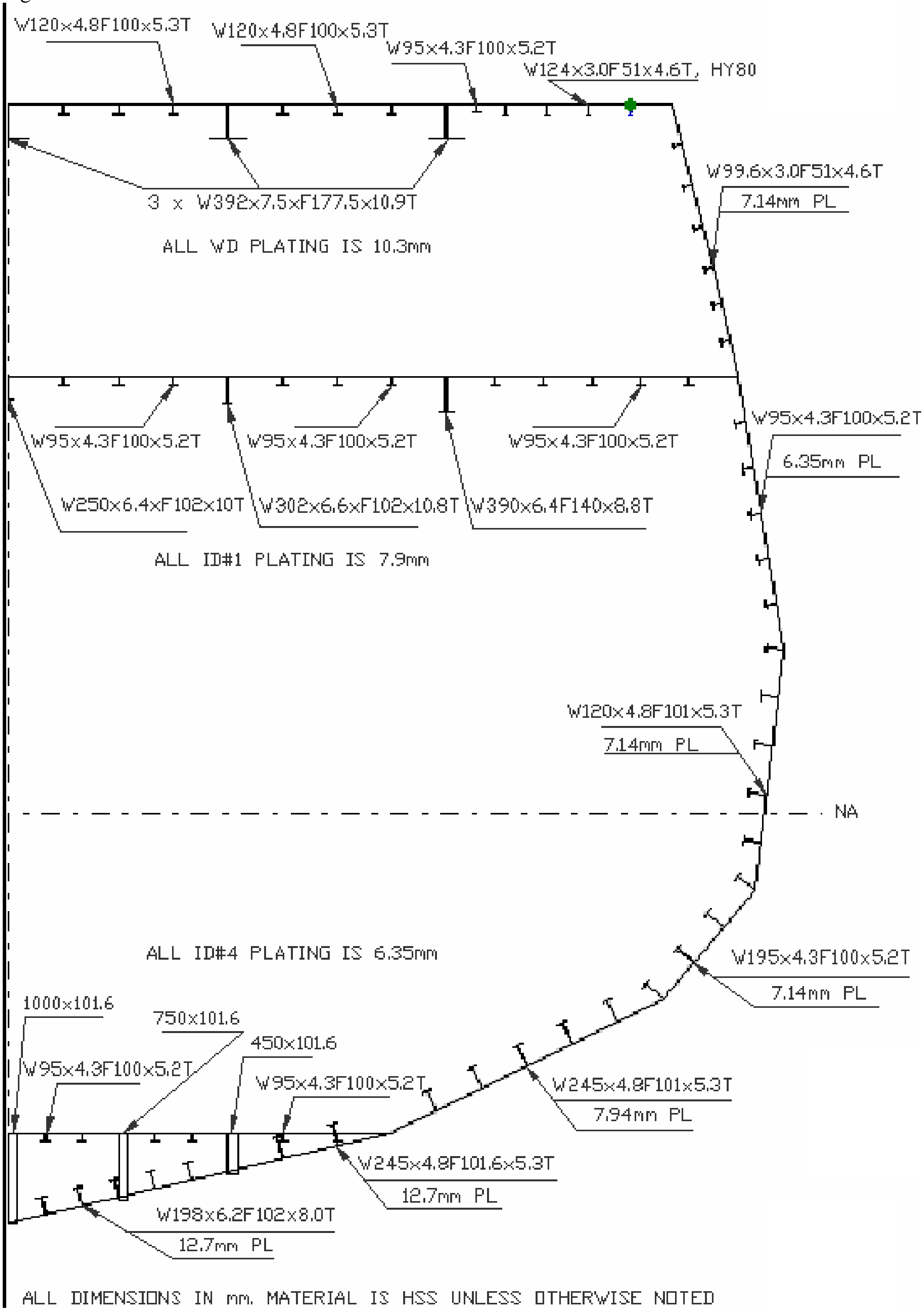


Figure 54 – Midship Section Drawing

4.5 Power and Propulsion

ADF 95 uses an Integrated Power System (IPS) with two pods and fixed pitch propellers for propulsion. The IPS is driven by two LM2500+ gas turbine engines and one ICR. There are also two back up generators that are driven by two CAT 3516V16 diesel engines.

4.5.1 Resistance

Ship resistance calculations were made using the Holtrop-Mennen equations. Values for length between perpendiculars, beam, draft, block coefficient, prismatic coefficient, endurance speed, and propeller diameter were used to compute the ship's bare hull resistance, wave making drag, and viscous drag. Figure 55 shows a plot of the bare hull resistance versus ship speed. The total effective horsepower was then calculated for ship speeds ranging from 20 to 35 knots in 1 knot increments. Figure 56 shows tables of the effective horsepower versus the ship speed and Figure 57 shows a plot of effective horsepower versus ship speed. Supporting calculations can be found in Appendix I.

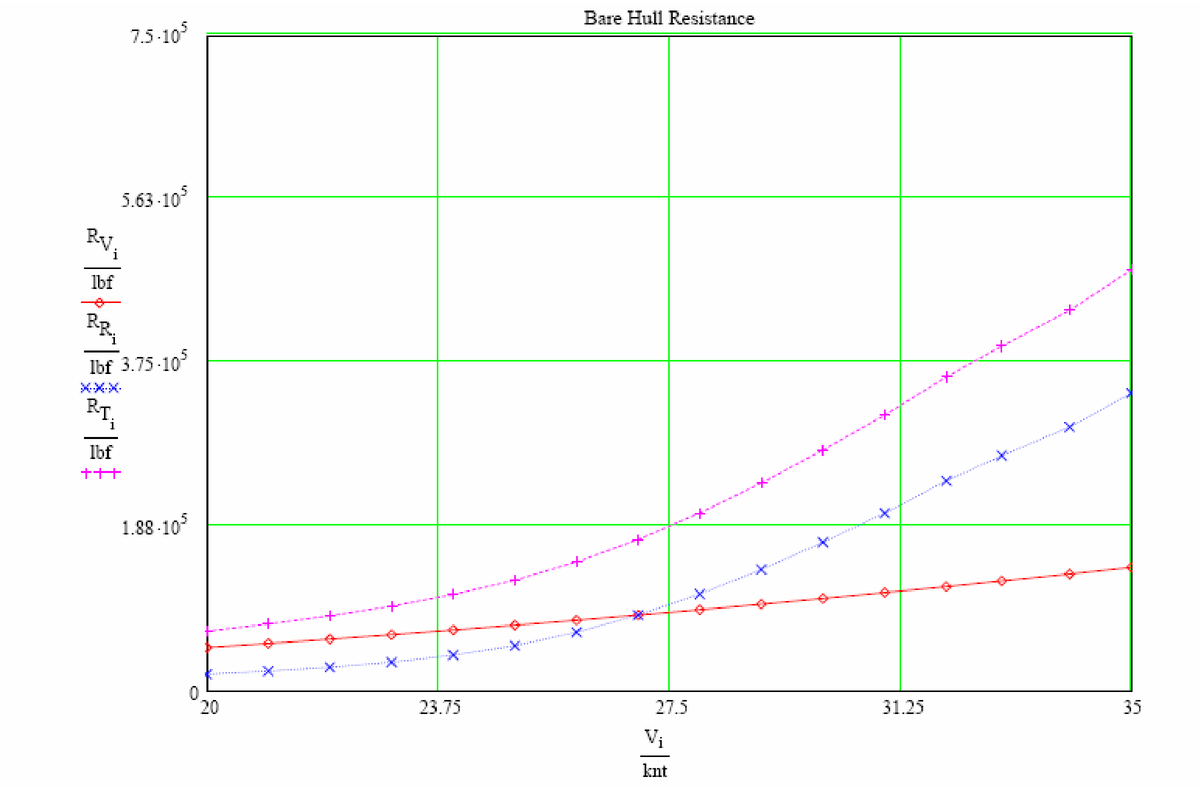
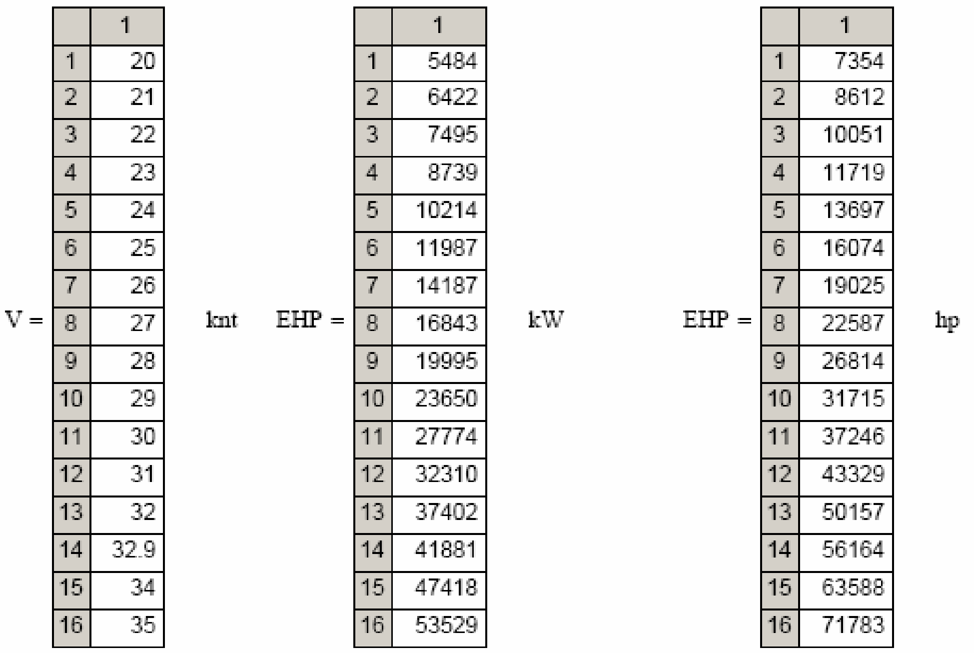


Figure 55 – Resistance vs. Ship Speed



V = knt

	1
1	20
2	21
3	22
4	23
5	24
6	25
7	26
8	27
9	28
10	29
11	30
12	31
13	32
14	32.9
15	34
16	35

EHP = kW

	1
1	5484
2	6422
3	7495
4	8739
5	10214
6	11987
7	14187
8	16843
9	19995
10	23650
11	27774
12	32310
13	37402
14	41881
15	47418
16	53529

EHP = hp

	1
1	7354
2	8612
3	10051
4	11719
5	13697
6	16074
7	19025
8	22587
9	26814
10	31715
11	37246
12	43329
13	50157
14	56164
15	63588
16	71783

Figure 56 – EHP vs. Ship Speed

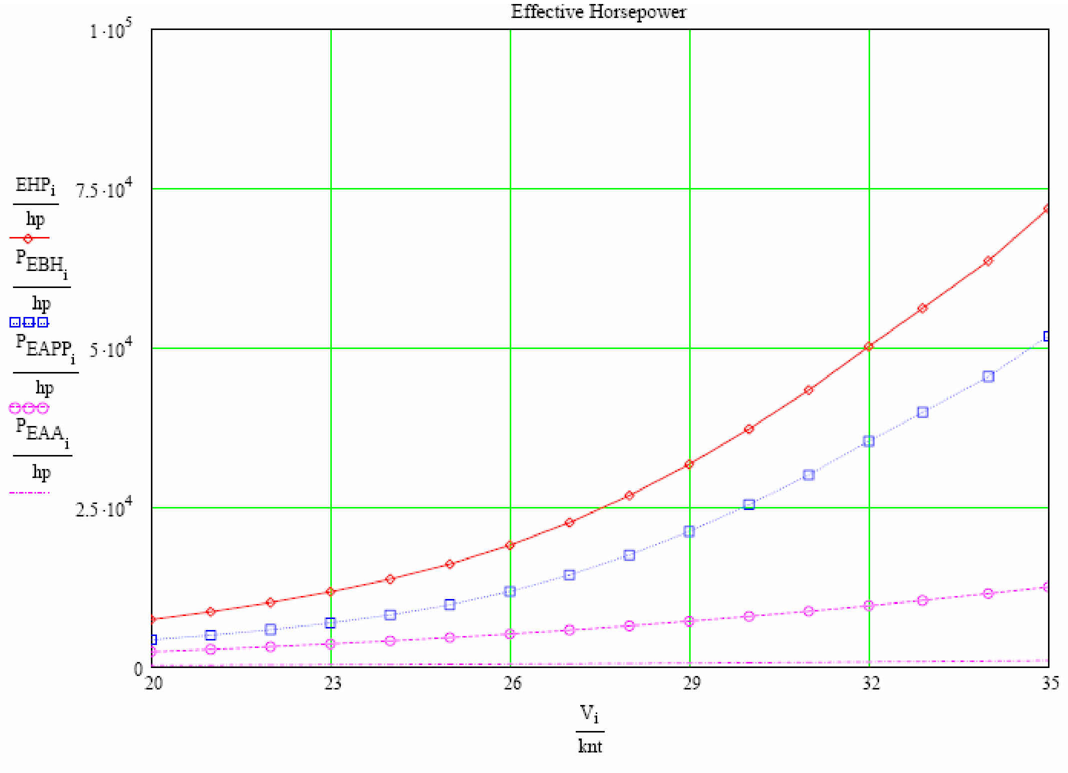


Figure 57 – EHP vs. Ship Speed

4.5.2 Propulsion

ADF 95 is propelled by two pods with fixed pitch propellers. The characteristics of the propellers were determined by iterating Michigan's Propeller Optimization Program (POP) to achieve the highest possible open water efficiency at endurance speed. Using these characteristics, POP was rerun to determine if sustained speed could be achieved. The propeller design with the highest open water efficiency at endurance speed and with the ability to reach sustained speed was the design chosen.

A diameter of 5.59m was used in the propeller design because it was the largest diameter that would allow sufficient clearance to avoid interference between the screw and the hull. Table 40 – Table 42 show the design characteristics from POP including the pitch to diameter ratio, BHP, RPM, and open water efficiency. Table 40 shows the propeller characteristics of each fixed propeller and Table 41 and Table 42 show the performance characteristics of the propeller at endurance and sustained speed.

Table 40 – Optimum Propeller Characteristics

Propeller Characteristics	
Z	4 blades
z	5.41 m
EAR	0.5929
P/Dp	1.3956
Dp	5.59 m
Type	Fixed Pitch

Table 41 – Propeller Performance Characteristics at Endurance Speed

Ve	20 knt
EHPe	7354 hp
Te	296.5 kN
THP	3848.4 hp
DHP	4834.7 hp
SHP	4834.7 hp
BHP	5980.5 hp
PROP RPM	87 RPM
open water efficiency	0.796

Table 42 – Propeller Performance Characteristics at Sustained Speed

Vs	32.9 knt
EHPs	56164 hp
Ts	1263.8 kN
THP	29391.3 hp
DHP	38621.9 hp
SHP	38621.9 hp
BHP	95549.4 hp
PROP RPM	153 RPM
open water efficiency	0.761

4.5.3 Electric Load Analysis (ELA)

Throughout the design spiral, an ASSET electric load baseline was updated with expert advice and design considerations to a final electric load analysis. The analysis is shown in

Table 43 and is broken down into major ship operating conditions by SWBS group. Table 44 shows which generators will need to be in use during the different operating conditions.

Table 43 - Electric Load Analysis Summary

SWBS	Description	Connected Load (kW)	Battle Power Factor	Battle (kW)	Cruise Power Factor	Cruise (kW)	Anchor Power Factor	Anchor (kW)	Inport Power Factor	Inport (kW)	Emergency Power Factor	Emergency (KW)
200	**Propulsion Plant**	**1831.2**	**0.5**	**915.6**	**0.3**	**461.1**	**0.05**	**85.4**	**0.0**	**0.0**	**0.17**	**305.2**
230	Propulsion Units	1329.5	0.4	531.8	0.2	224.0	0.02	30.0	0.0	0.0	0.12	224.0
235	Electric Propulsion	58671.0	1.0	58671.0	0.3	17601.3	0.00	0.0	0.0	0.0	0.00	0.0
240	Transmission + Propulsors	6.5	0.4	2.6	0.4	2.6	0.00	0.8	0.0	0.0	0.00	0.0
250	Support Systems	950.5	0.4	380.2	0.2	224.3	0.03	52.1	0.0	0.0	0.04	81.2
260	Propulsion Fuel & Lube Oil	2.5	0.4	1.0	4.1	10.2	0.00	2.5	0.0	0.0	0.00	0.0
300	**Electric**	**327.8**	**0.6**	**196.7**	**0.5**	**174.3**	**0.08**	**152.7**	**0.4**	**131.1**	**0.05**	**96.7**
310	Electric Power Generator	132.3	0.6	79.4	0.4	57.0	0.02	35.4	0.4	52.9	0.01	18.5
330	Lighting System	195.5	0.6	117.3	0.6	117.3	0.06	117.3	0.4	78.2	0.04	78.2
400	**Command + Surveillance**	**2264.4**	**0.5**	**1132.2**	**0.4**	**980.0**	**0.26**	**484.4**	**0.4**	**905.8**	**0.27**	**499.2**
410	Command + Control Sys.	124.2	0.6	74.5	0.6	74.5	0.01	14.9	0.0	0.0	0.00	0.0
430	Interior Communications	89.5	0.4	35.8	0.4	35.8	0.02	28.6	0.1	9.0	0.01	17.9
450	Surf Surv Sys (RADAR)	1545.5	0.4	618.2	0.4	617.4	0.17	308.7	0.1	154.6	0.17	309.1
460	Underwater Surveillance	191.3	0.4	76.5	0.4	76.3	0.01	22.9	0.1	19.1	0.02	38.2
470	Countermeasures	347.5	0.4	139.0	0.2	57.2	0.03	49.6	0.1	34.8	0.02	45.6
480	Fire Control Sys.	387.5	0.4	155.0	0.2	89.9	0.02	45.0	0.1	38.8	0.04	77.5
490	Special Purpose Sys.	83.3	0.4	33.3	0.3	29.0	0.01	14.7	0.1	8.3	0.01	10.9
500	**Auxiliary Systems**	**1792.0**	**0.5**	**896.0**	**0.6**	**1160.7**	**0.69**	**1254.7**	**0.1**	**179.2**	**0.22**	**396.4**
510	Climate Control	1630.3	0.4	652.1	0.5	826.6	0.50	912.3	0.0	0.0	0.14	260.6
520	Sea Water Sys.	142.9	0.7	100.0	0.6	86.4	0.05	86.1	0.4	57.1	0.05	100.0
530	Fresh Water Sys	510.8	0.4	77.8	0.4	204.3	0.11	204.3	0.4	204.3	0.02	35.7
540	Fuels/Lubricants, Handling	102.0	0.4	40.8	0.2	20.9	0.02	28.5	0.1	10.2	0.00	0.0
550	Air, Gas + Misc Fluid Sys.	39.8	0.4	15.9	0.3	13.0	0.01	13.0	0.0	0.0	0.00	0.0
560	Ship Control Sys.	0.3	0.4	0.1	0.4	0.1	0.00	0.0	0.1	0.0	0.00	0.1
580	Mechanical Handling Sys.	11.0	0.4	4.4	0.4	4.4	0.00	4.4	0.1	1.1	0.00	0.0
590	Special Purpose Sys.	12.5	0.4	5.0	0.4	5.0	0.00	6.0	0.1	1.3	0.00	0.0
600	**Outfit + Furnishing, General**	**129.8**	**0.4**	**51.9**	**1.4**	**185.4**	**0.10**	**184.6**	**0.4**	**51.9**	**0.00**	**4.0**
620	Hull Compartmentation	10.5	0.4	4.2	0.4	4.2	0.00	3.4	0.4	4.2	0.00	0.0
630	Preservatives + Coverings	18.3	0.4	7.3	0.4	7.3	0.00	7.3	0.4	7.3	0.00	0.0
650	Service Spaces	418.5	0.4	40.4	0.4	167.4	0.09	167.4	0.4	167.4	0.00	4.0
660	Working Spaces	6.5	0.4	0.0	1.0	6.5	0.00	6.5	0.4	2.6	0.00	0.0
700	**Armament**	**147.7**	**0.6**	**88.6**	**0.3**	**49.7**	**0.02**	**40.7**	**0.0**	**0.0**	**0.03**	**52.0**
710	Guns + Ammunition	86.7	0.6	52.0	0.2	18.0	0.00	9.0	0.0	0.0	0.03	52.0
720	Missiles + Rockets	51.8	0.6	31.1	0.6	31.1	0.02	31.1	0.0	0.0	0.00	0.0
750	Torpedoes	1.8	0.6	1.1	0.3	0.6	0.00	0.6	0.0	0.0	0.00	0.0
780	Aircraft Related Weapons	7.3	0.6	4.4	0.0	0.0	0.00	0.0	0.0	0.0	0.00	0.0
	Total Required	65163.9		61952.0		20612.5		2202.5		1268.0		1353.5
	24 Hour Average			25448.2		8626.2		1023.9		585.9		782.5

Table 44 – Generator Power Usage

Number	Generator	Rating (kW)	Avertage Connected (kW)	Online	Battle (kW)	Online	Cruise (kW)	Online	Anchor (kW)	Online	Port (kW)	Online	Emergency (KW)
2	GE LM2500+	26099.0	52198.0	2	52198.0	0	0.0	0	0.0	0	0.0	0	0.0
1	WESTHS WR21 29	21655.0	21655.0	1	21655.0	1	21655.0	0	0.0	0	0.0	0	0.0
2	CAT 3516V16	1275.0	2550.0	0	0.0	0	0.0	2	2550.0	2	2550.0	2	2550.0
	Total		76403.0		73853.0		21655.0		2550.0		2550.0		2550.0

4.5.4 Fuel Calculation

A fuel calculation was performed for endurance range and sprint range in accordance with DDS 200-1. The range of the IPS system was calculated based on its maximum rating of 3600 RPM. Next, the specific fuel rate was read from the Engine Performance Curve in Figure 58 as $0.33 \frac{lbf}{hp * hr}$. This equates to an average fuel rate of $0.357\dfrac{lbf}{hp*hr}$ when accounting for propulsion plant deterioration over two years. From fuel consumption, endurance speed, and volume of fuel available, an endurance range of 6005 nm was calculated. This calculation can be found in the "Prop Selection, Engine Match, and Fuel Calculation" file in Appendix I.

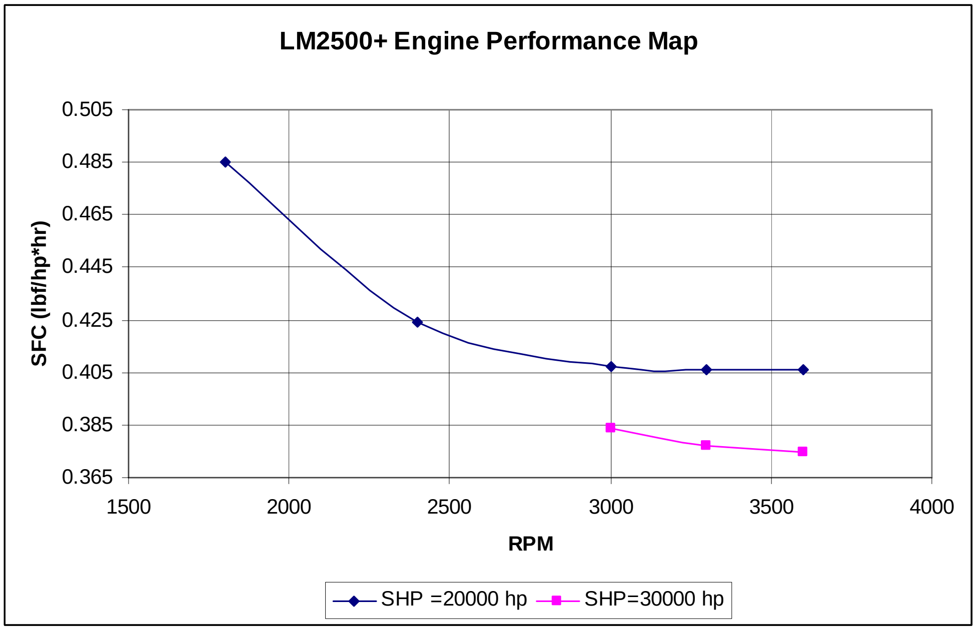


Figure 58 – Engine Performance Curve

4.6 Mechanical and Electrical Systems

Mechanical and electrical systems were selected according to mission requirements, standard naval combatant vessel requirements, and expert opinion. The machinery equipment list (MEL) includes weights, dimensions, and locations by compartment for all major non-mission mechanical and electrical equipment to support propulsion, ship service, and habitability systems. The complete MEL is provided in Appendix F. The following subsections 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.

4.6.1 Integrated Power System (IPS)

Figure 59 is an electrical diagram that represents a basic one-line connection of generators, propulsors, and ship service power buses in an Integrated Power System (IPS), in which the ship service power is distributed from any of the three propulsion generators or SSDG's via a zonal bus. Power Control Modules (PCMs) are located in each zone to convert power, and these units direct ship service power where it is needed. They are able to convert AC to DC and DC to AC as required. Two Ship Service Gas Turbine Generators (SSGTGs) provide 480V AC 60 HZ power to a ship service switchboard which has direct connection to port and starboard ship service zonal buses. Two Main Gas Turbine Generators (MGTGs) and one Secondary RGT Generator 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. Electric power is taken from the zonal buses in each zone through the power conversion modules. If there is a vital system in a zone it draws power from both the port and starboard buses through a power conversion module and an ABT which is an automated switch to either bus in case of power loss of one of the zonal buses.

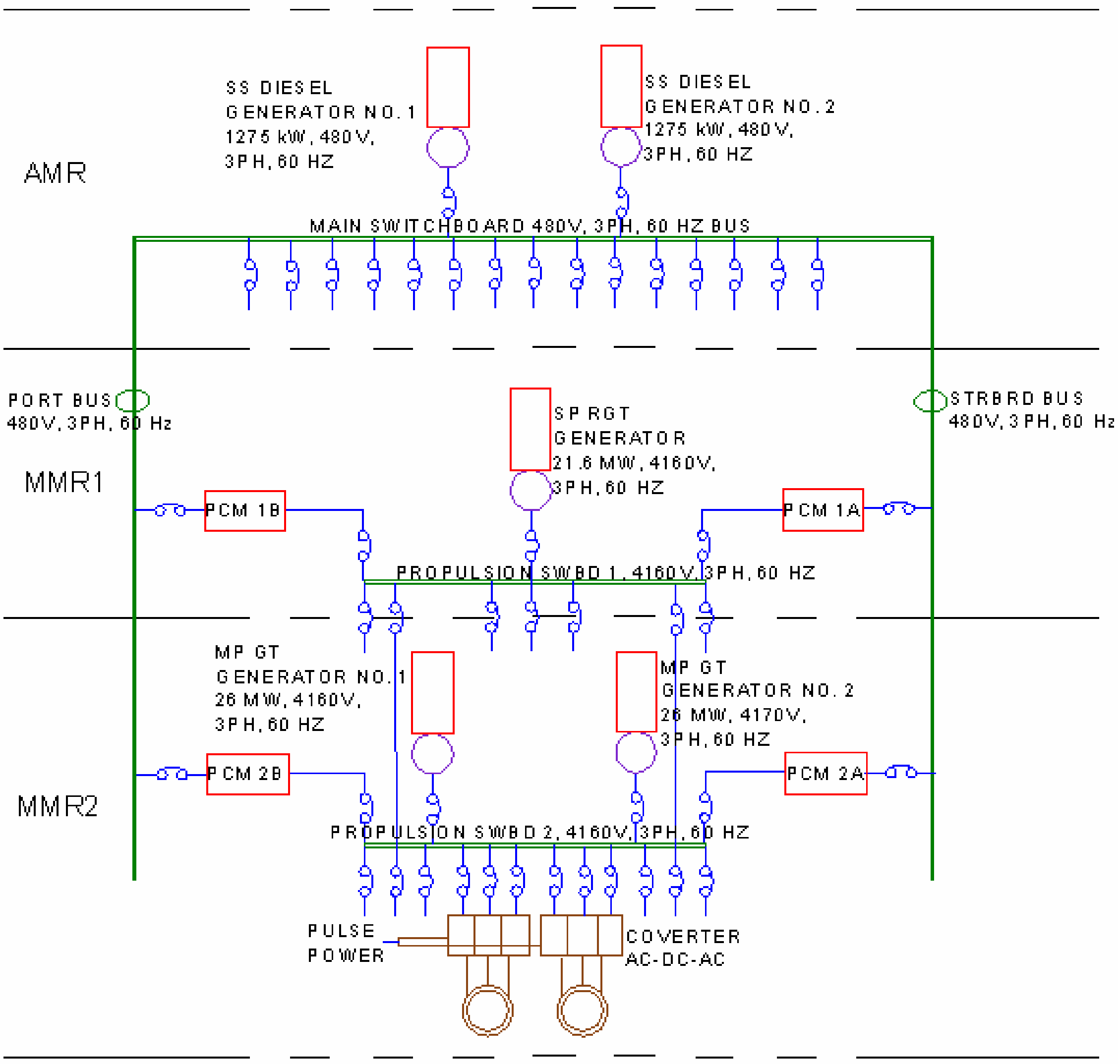


Figure 59 – One-Line Electrical Diagram

4.6.2 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 in the main machinery rooms (MMR1 and MMR2). Two distillers are used to produce potable water from seawater at a capacity of 76 cubic meters each per day. 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.

4.6.3 Ship Service Electrical Distribution

Ship service power is distributed from either of the switchboards to port and starboard zonal buses. Electric power is taken from the zonal buses in each zone through the power conversion modules. If there is a vital system in a zone it draws power from both the port and starboard buses through a power conversion module and an ABT which is an automated switch to either bus in case of power loss of one of the zonal buses.

4.7 Manning

ADF 95 was designed to meet the current Navy guidelines for ship manning. Through the use of automation and unmanned systems the total ship manning has been significantly reduced. The manning for ADF 95 is broken down into 5 departments: Executive/Administration, Operations, Weapons, Engineering, and Supply. ADF 95 will accommodate 25 Officers, 27 CPO and 208 enlisted men for a total crew size of 260 members. Table 45 shows a breakdown of the number of required crew members for each department.

Table 45 - Manning Summary

Departments	Division	Officers	CPO	Enlisted	Total Department
	CO/XO	2			2
	Department Heads	4			
Executive/Admin	Executive/Admin	0	1	5	6
Operations	Communications	1	2	11	57
	Navigation and Control	1	1	11	
	Electronic Repair	1	1	8	
	CIC,EW,Intelligence	1	2	16	
Weapons	Air	2	2	10	73
	Boat and Vehicle	1	2	11	
	Deck	1	2	16	
	Ordnance/Gunnery	1	2	9	
	ASW/MCM	1	1	11	
Engineering	Main Propulsion	1	2	20	68
	Electrical/IC	1	1	11	
	Auxiliaries	1	1	11	
	Repair/DC	1	1	16	
Supply	Stores	1	2	8	40
	Material/Repair	1	1	8	
	Mess	1	1	16	
	Total	23	25	198	246
	Accommodations	25	27	208	260

Figure 60 – Manning Organization

4.8 Space and Arrangements

HECSALV and AutoCAD were used to produce the general arrangements for ADF 95. HECSALV was used for primary subdivision to create tanks, unassigned spaces, and loading. Rhino was used to create a 2-D profile drawing of the decks, platforms, and locations of rooms inside the unassigned spaces from HECSALV. A profile showing the internal arrangements is shown in Figure 61.

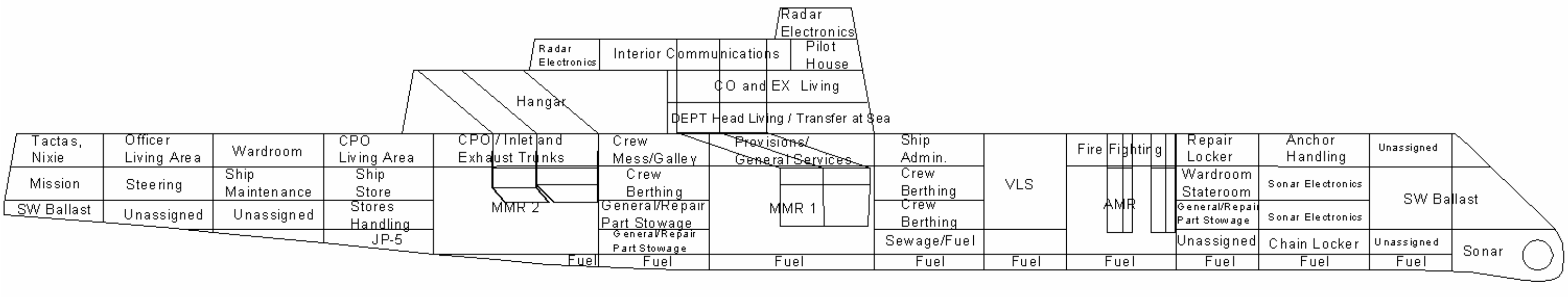


Figure 61 - Profile View of Internal Arrangements

4.8.1 Volume

The initial volume requirements for the ship were found using the ship synthesis model. HECSALV was used to create tanks which were arranged for producibility, accessibility, stowage, survivability, damage stability, floodable length, trim and heel. A floodable length curve was developed to adjust subdivision so that the ship was capable of surviving if three continuous sections were flooded. The floodable length curve is shown in Figure 62 and the primary subdivision and tank capacities are shown in Figure 63.

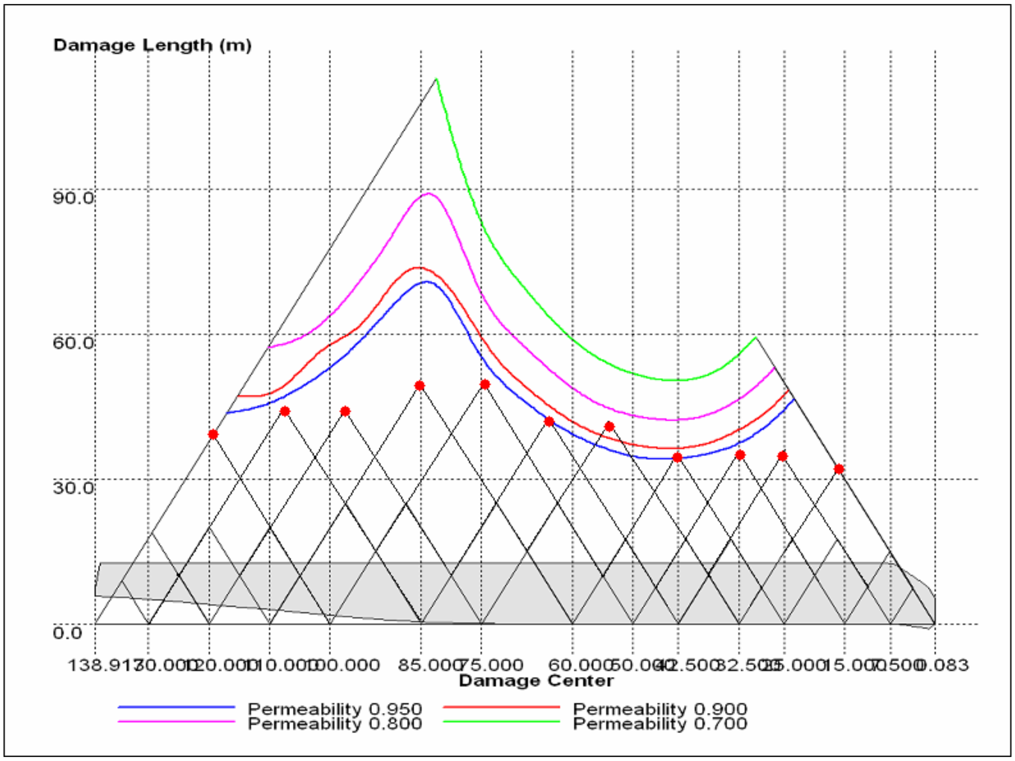
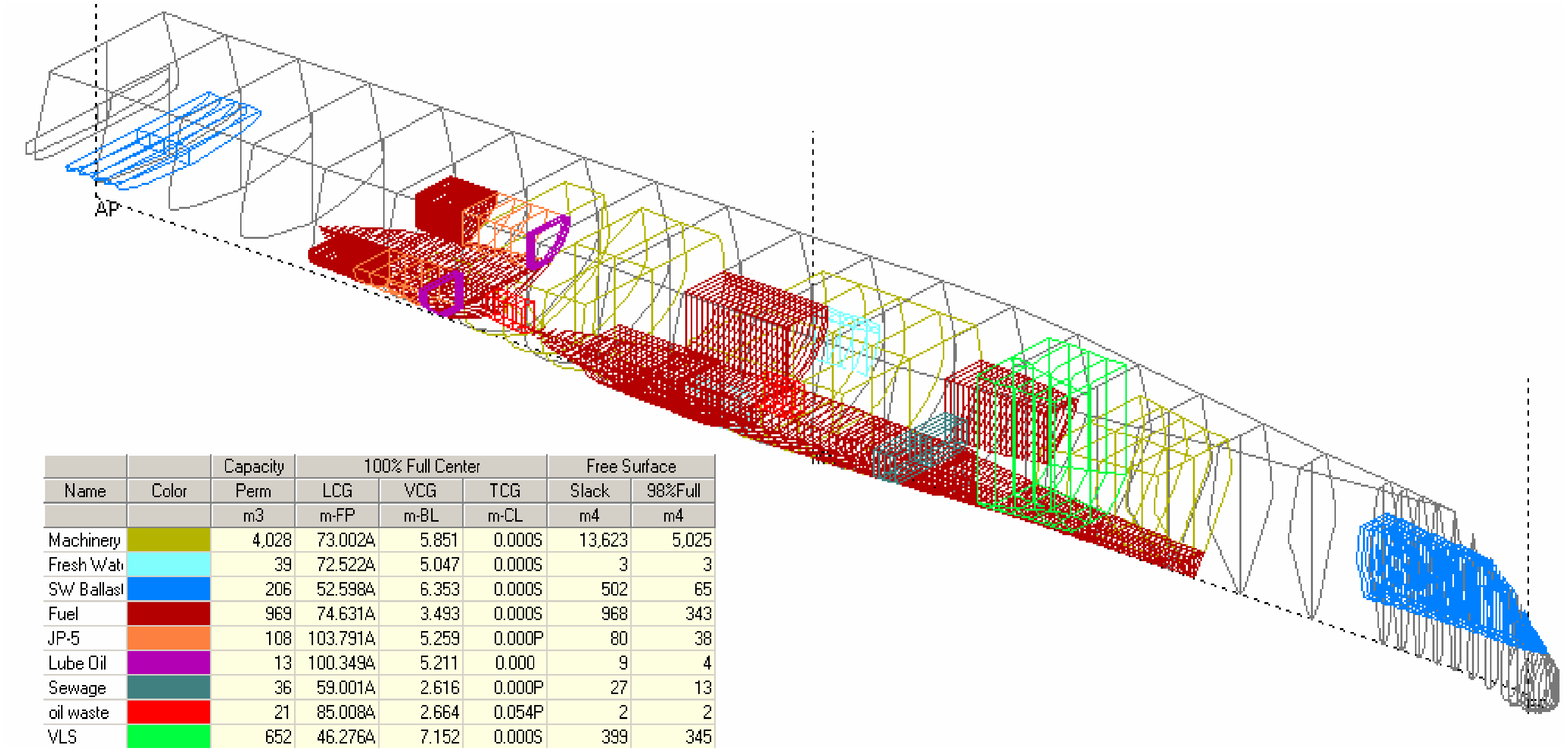


Figure 62 – Floodable Length Curve



		Capacity	100% Full Center			Free Surface	
Name	Color	Perm	LCG	VCG	TCG	Slack	98%Full
		m3	m-FP	m-BL	m-CL	m4	m4
Machinery	🟨	4,028	73.002A	5.851	0.000S	13,623	5,025
Fresh Wat	🟦	39	72.522A	5.047	0.000S	3	3
SW Ballast	🟦	206	52.598A	6.353	0.000S	502	65
Fuel	🟥	969	74.631A	3.493	0.000S	968	343
JP-5	🟧	108	103.791A	5.259	0.000P	80	38
Lube Oil	🟪	13	100.349A	5.211	0.000	9	4
Sewage	🟦	36	59.001A	2.616	0.000P	27	13
oil waste	🟥	21	85.008A	2.664	0.054P	2	2
VLS	🟩	652	46.276A	7.152	0.000S	399	345

Figure 63 – Primary Subdivision

4.8.2 Main and Auxiliary Machinery Spaces and Machinery Arrangement

There are three machinery compartments in ADF 95. These spaces include two main machinery rooms (MMR1 and MMR2) and one auxiliary machinery room (AMR). All machinery equipment is arranged to produce port and 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 0.3 meters. A profile drawing of the machinery arrangements is shown in Figure 64, and arrangement drawings of MMR1 and MMR2 are shown in Figure 65 and Figure 66. Two LM2500+ Main Gas Turbine Generators rated at 26 MW each are located in MMR1, while one ICR Secondary Gas Turbine Generator rated at 21.6 MW is located in MMR2. The AMR contains two Caterpillar 3516V16 Diesel Generators rated at 1275 kW each. A machinery arrangement drawing of the AMR is shown in Figure 67.

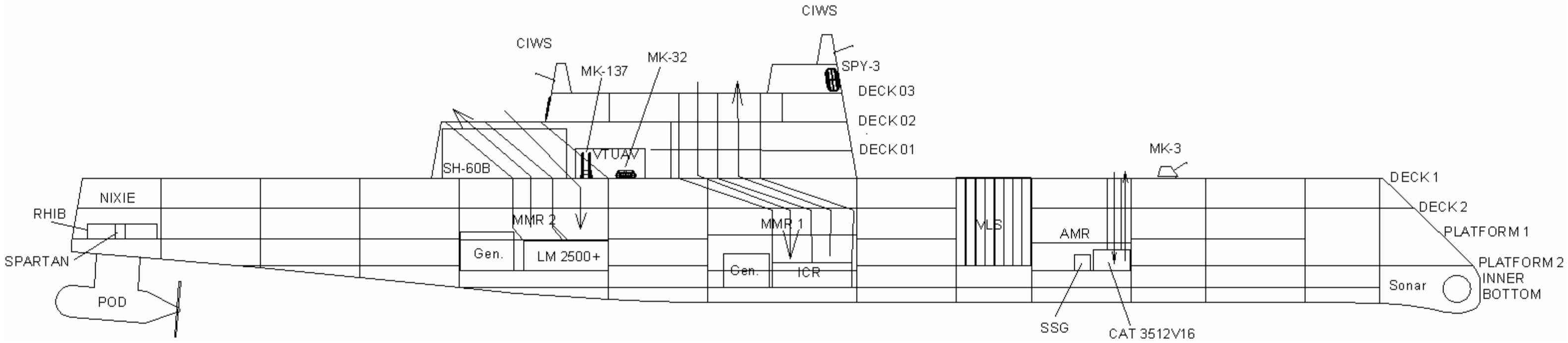
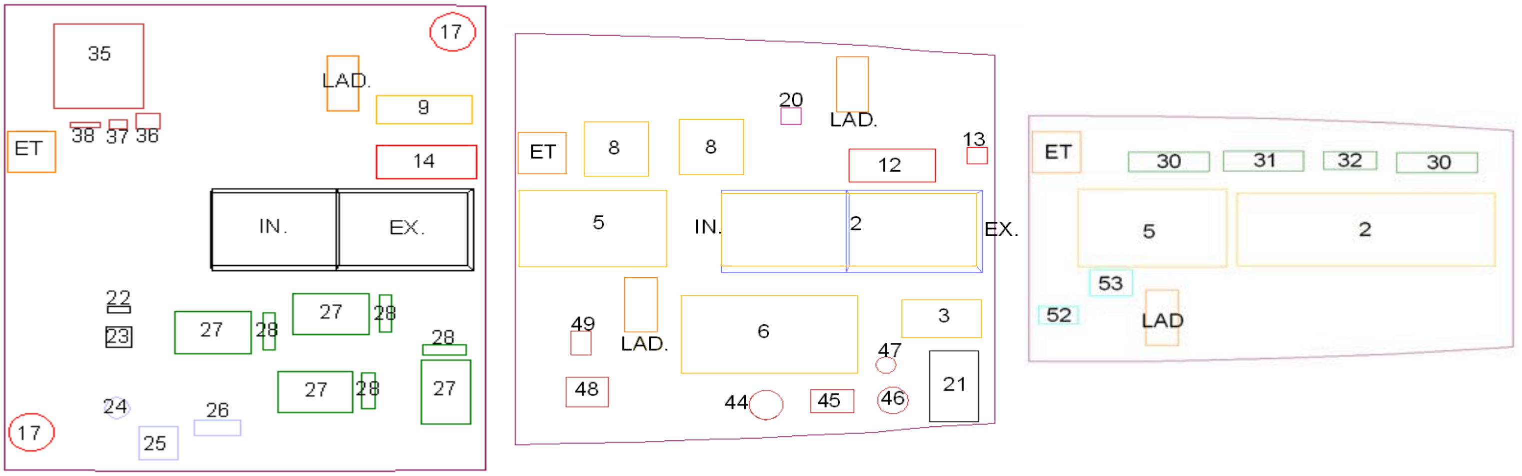
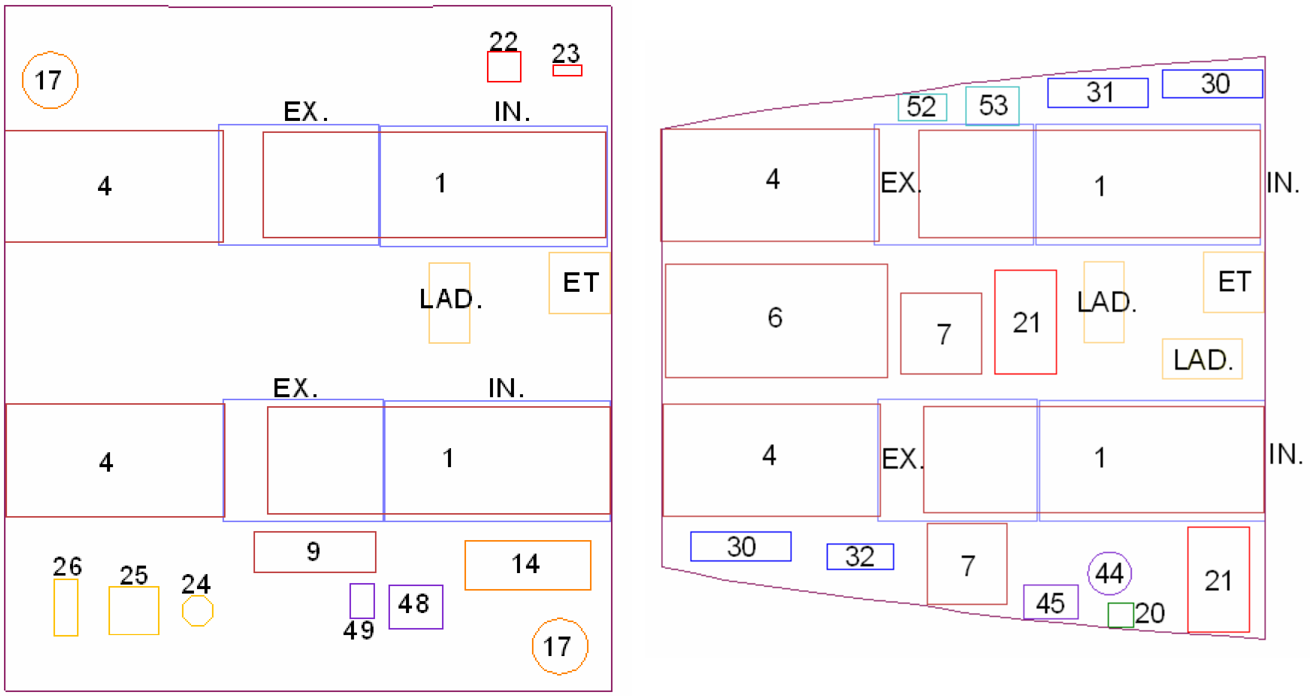


Figure 64 – Profile View Showing Arrangements



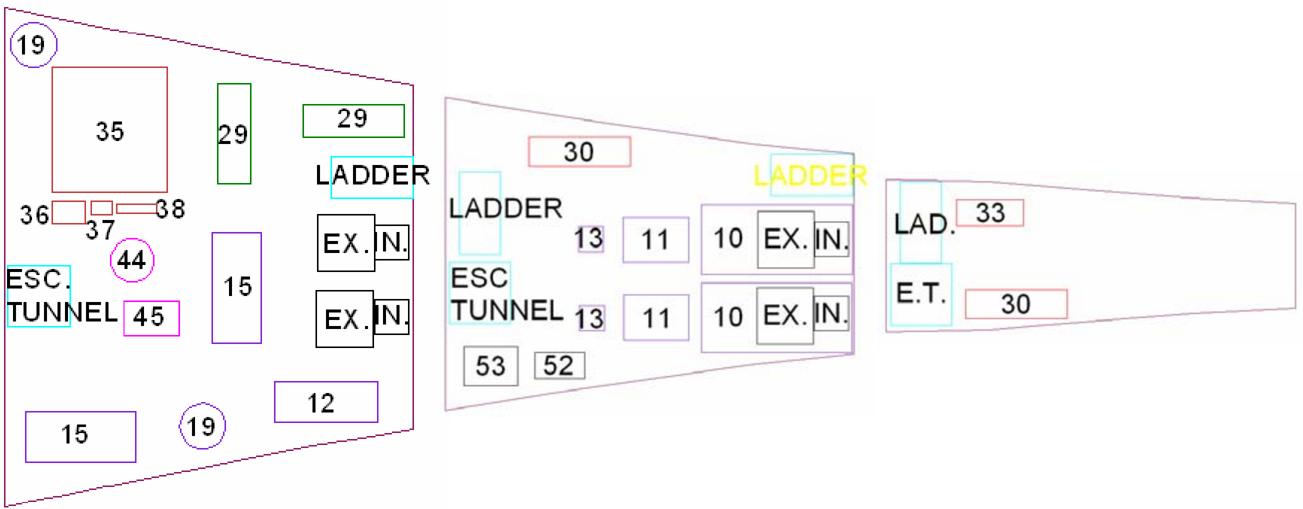
Platform 3 **Platform 4** **Inner Bottom**

Figure 65 – MMR 1 Platform Arrangements



Platform 3 **Platform 4**

Figure 66 – MMR 2 Platform Arrangements



Platform 3 **Platform 4** **Inner Bottom**

Figure 67 – AMR Platform Arrangements

4.8.3 Internal Arrangements

ADF 95 contains 5 decks, 3 platforms, and a holding area below the third platform. AutoCAD was used to layout areas for the 6 different classifications in the internal arrangements including combat systems, mission support, human support, ship support, hangar space, and machinery rooms. The volumes and areas required for each were found using the ship synthesis model and relevant areas are given in the SSCS Space Summary in Appendix H.

The human support area is located the damage control deck, Deck 2. This deck includes the crew's berthing, CPOs berthing, officers berthing, mess rooms, and other basic human support areas. Platform 1 consists of ship support and storage areas. The ships maintenance areas and stores are located throughout the platform. Each department requires its own storage which is arranged in the bow of Platform 1.

Mission support is located in the stern of Deck 2 and Platform 1 for close proximity to the RHIB, Spartan, NIXIE, and TACTAS. The machinery rooms run vertically from the inner bottom of the hull to the Damage Control Deck. The inlet and exhaust ducts for the engines move vertically through the ship and are located along the centerline to reduce the heat signature along the hull. The slopes of the ducts are small to ensure maximum flow. The general arrangements of the ship are shown in Figure 68 – Figure 73.

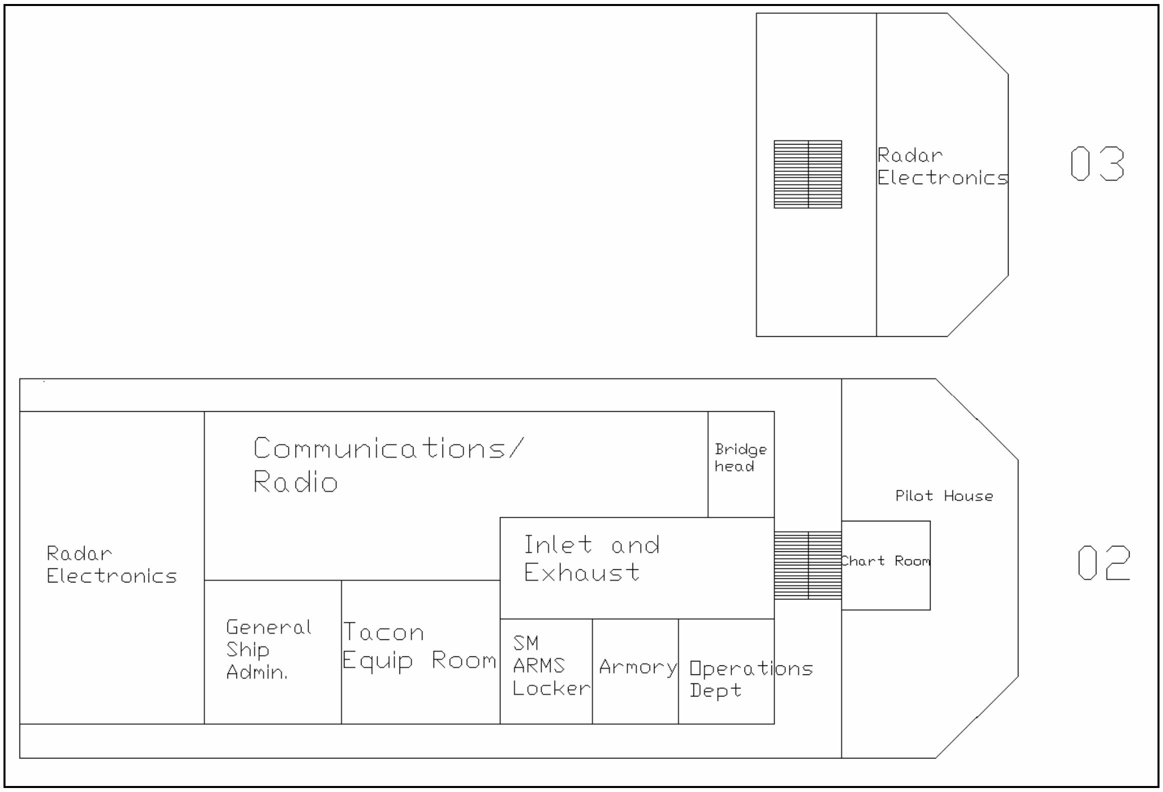


Figure 68 – Deck 03 and Deck 02 Arrangements

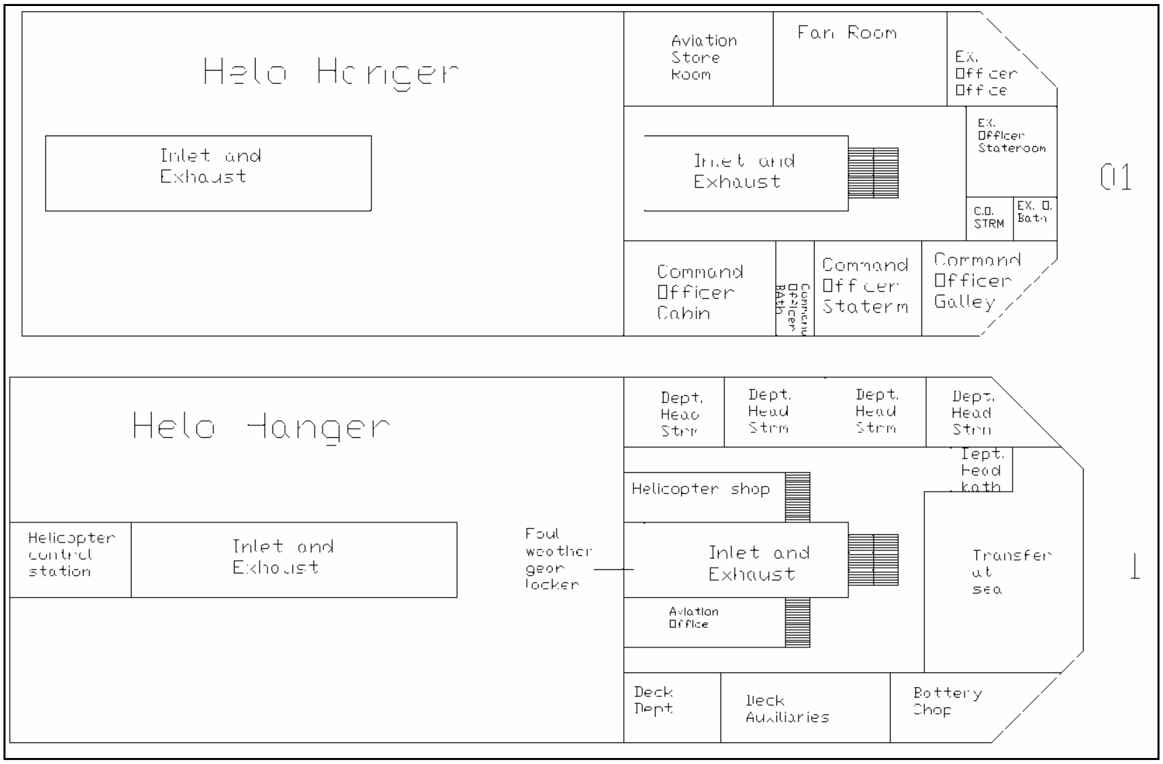


Figure 69 – Deck 01 and Deck 1 Arrangements

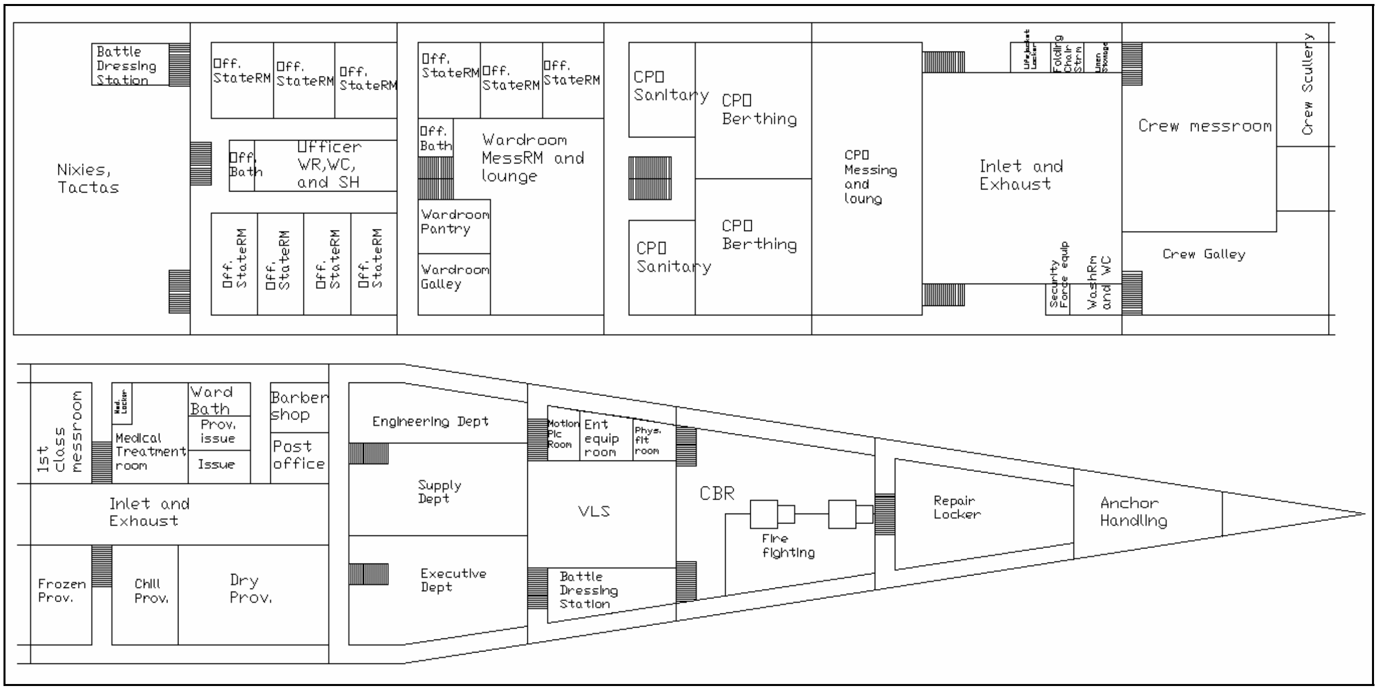


Figure 70 – Deck 2 Arrangements

Figure 71 – Platform 1 Arrangements

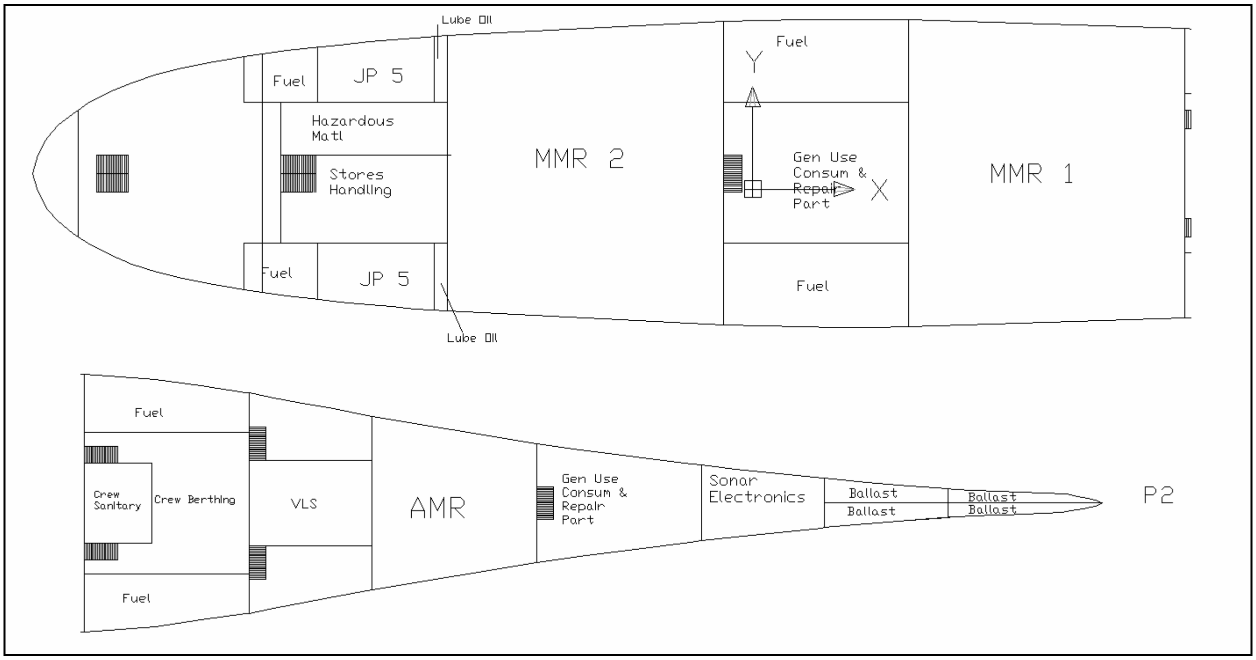


Figure 72 – Platform 2 Arrangements

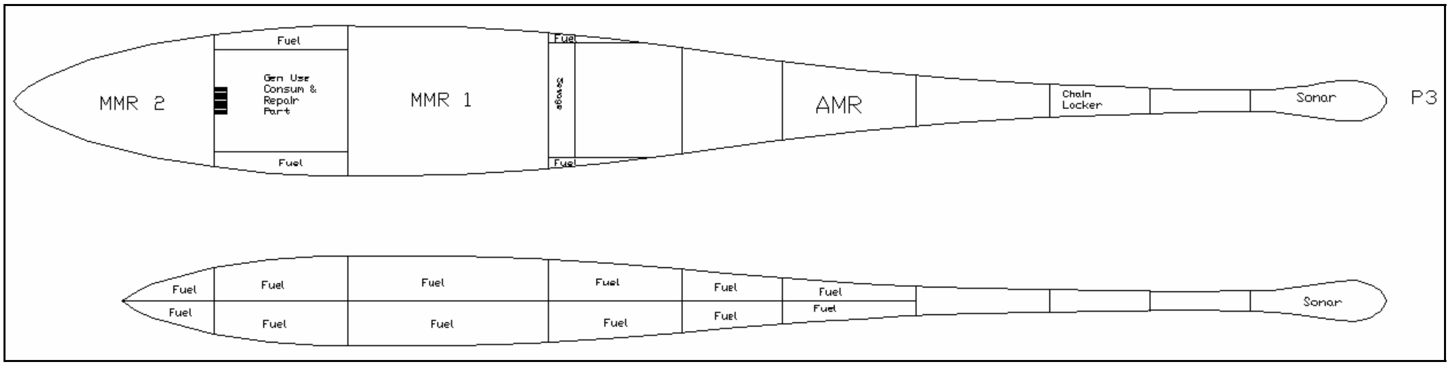


Figure 73 – Platform 3 and Holding Area Arrangements

4.8.4 Living Arrangements

The initial volume requirements for the living areas were found using the ship synthesis model. There were 6 different living areas included on the ship for: the commanding officer (CO), the executive officer (XO), department heads, officers, Chief Petty Officers (CPO), and the enlisted crew. Each area was arranged to maximize protection, privacy, and functional ability. The manning accommodation space is summarized in Table 46.

Table 46 – Manning Accommodations

Item	Accommodation Quantity	Per Space	Number of Spaces	Area Each (m^2)	Total Area (m^2)
CO	1	1	1	22.9	22.9
XO	1	1	1	13.9	13.9
Department Head	4	1	4	11.15	44.6
Other Officer	19	2	10	10.68	106.8
CPO	26	13	2	34.5	69
Enlisted	208	23	9	41.87	376.8

The CO and XO accommodations are on Deck 01 and the four department heads' housing is on Deck 1. The 19 officer rooms and 26 CPO spaces are arranged on Deck 2 and crew accommodations are located on Platform 3.

4.8.5 External Arrangements

The primary objective for external arrangements is to maximize effectiveness of combat systems. To do this, all combat systems are placed in areas that give the system the highest productivity, with minimum effect on radar cross section.

To ensure 360 degrees of coverage for the Spy-3 radar, two panels are placed on the front of the deckhouse and one is on the aft end of Deck 02. Two CIWS are located off center on top of the deckhouse to guarantee complete coverage of the hull. The placement is designed to protect against incoming missiles and aircraft at different angles of attack. A 57mm MK3 is placed forward on the bow to achieve maximum shooting range.

To minimize radar cross section, the SVTTs and DLSs are placed inside the hanger. Hatches are on both sides of the hangar that allow the systems to be fired when needed, but still maintain the low radar cross section when stowed. An isometric view of the external arrangements is shown in Figure 74.

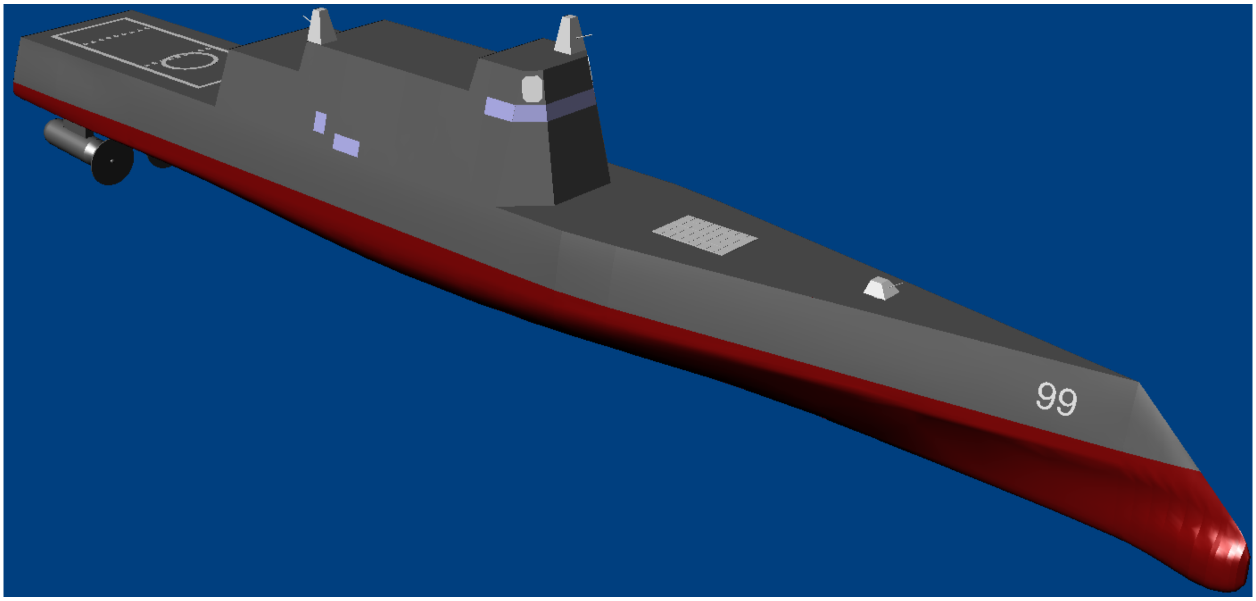


Figure 74 – Isometric View of External Arrangements

4.9 Weights and Loading

4.9.1 Weights

ADF 95's weights are grouped together by SWBS number. The value of weight for each SWBS group was obtained either from manufacturer's specifications or derived from ASSET. The vertical and horizontal centers of gravity were calculated based on component locations in the machinery and general arrangements models. Weights and centers of gravity were then used to calculate moments. Table 47 shows a summary of the lightship weights, centers of gravity, and moments. A more detailed weights summary is given in Appendix G with the LCGs measured from the forward perpendicular.

Table 47 – Lightship Weight Summary

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
100	HULL STRUCTURES	2191.20	6.55	14345.52	77.18	169116.51	0.00	0.00
200	PROPULSION PLANT	795.60	3.48	2770.38	106.07	84389.54	0.00	0.00
300	ELECTRIC PLANT, GENERAL	383.80	6.03	2313.08	67.02	25722.10	0.00	0.00
400	COMMAND+SURVEILLANCE	270.10	11.17	3018.11	61.23	16538.40	0.28	75.56
500	AUXILIARY SYSTEMS, GENERAL	643.90	7.26	4674.03	56.23	36205.79	0.28	180.48

600	OUTFIT+FURNISHING,GENERAL	489.90	6.69	3278.46	81.61	39981.56	-0.44	-214.24
700	ARMAMENT	125.70	7.57	951.76	67.87	8531.80	0.27	34.14
	LIGHTSHIP WEIGHT	4900.20	6.40	31351.33	77.65	380485.71	0.02	75.94
	MARGIN	490.02	6.40	3135.13	77.65	38048.57	0.02	7.59
	LIGHTSHIP WEIGHT + MARGIN	5390.22	6.40	34486.47	77.65	418534.28	0.02	83.53

4.9.2 Loading Conditions

The U.S. Navy's DDS 079-1 defines two independent loading conditions that were evaluated for ADF 95. The first condition is the Full Load Condition and the second is the Minimum Operating Condition. Each load condition uses the Lightship weight combined with a percentage of the load weight, as specified in the DDS 079-1. In Full Load Conditions; the ammunitions, provisions and personnel stores, general stores, reserve feed, fresh water, and diesel fuel marine are at 100% capacity. The lube oil, aviation fuels are at 95% capacity and the sewage and ballast tanks are empty. In the Minimum Operating Condition; the ammunition, provisions, personnel stores, general stores, lube oil, and aviation fuel are at 33% capacity. The diesel fuel marine is at 50% capacity, and the reserve feed and fresh water are at 67% capacity. The aviation fuel is at 95% capacity, the sewage tanks are at 95% capacity and the ballast tanks are empty. Table 48 shows the weights, centers of gravity and moments for the Full Load condition, and Table 49 shows weights, centers of gravity and moments for the Minimum Operating Condition.

Table 48 – Full Load Condition Weight Summary

	FULL LOAD CONDITION	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F00	LOADS	1119.90	2.85	3187.14	62.24	69703.47	0.14	153.10
F10	SHIPS FORCE	29.00	8.19	237.51	65.33	1894.57	1.80	52.20
F21	SHIP AMMUNITION	77.90	7.80	607.62	121.80	9488.22	0.00	0.00
F22	ORD DEL SYS AMMO	10.00	7.50	75.00	48.00	480.00	0.00	0.00
F23	ORD DEL SYS (AIRCRAFT)	30.70	13.90	426.73	89.00	2732.30	0.00	0.00
F31	PROVISIONS+PERSONNEL STORES	30.80	10.00	308.00	65.00	2002.00	4.06	125.05
F32	GENERAL STORES	6.90	7.30	50.37	103.00	710.70	-3.50	-24.15
F41	DIESEL FUEL MARINE	805.90	1.00	805.90	50.00	40295.00	0.00	0.00
F42	JP-5	81.20	5.26	427.11	103.80	8428.56	0.00	0.00
F46	LUBRICATING OIL	8.20	6.15	50.43	100.35	822.87	0.00	0.00
F47	SEA WATER	0.00	6.10	0.00	57.70	0.00	0.00	0.00
F52	FRESH WATER	39.30	5.05	198.47	72.50	2849.25	0.00	0.00
	Total Weight	6510.12	5.79	37673.60	75.00	488237.75	0.04	236.63

Table 49 – Minimum Operating Condition Weight Summary

	MINIMUM OPERATING CONDITION	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F00	LOADS	426.16	3.59	1529.05	64.07	27305.64	0.19	80.39
F10	SHIPS FORCE	29.00	8.19	237.51	65.33	1894.57	0.00	0.00
F21	SHIP AMMUNITION	25.97	7.80	202.57	121.80	3163.15	1.80	46.75
F22	ORD DEL SYS AMMO	3.33	7.50	24.98	48.00	159.84	0.00	0.00
F23	ORD DEL SYS (AIRCRAFT)	30.70	13.90	426.73	89.00	2732.30	0.00	0.00
F31	PROVISIONS+PERSONNEL STORES	10.27	6.00	61.62	75.06	770.87	4.06	41.70
F32	GENERAL STORES	2.30	6.79	15.62	75.06	172.64	-3.50	-8.05
F41	DIESEL FUEL MARINE	268.60	1.00	268.60	50.00	13430.00	0.00	0.00
F42	JP-5	27.06	5.26	142.34	103.80	2808.83	0.00	0.00
F46	LUBRICATING OIL	2.73	6.15	16.79	100.35	273.96	0.00	0.00
F47	SEA WATER	0.00	6.10	0.00	57.70	0.00	0.00	0.00
F52	FRESH WATER	26.20	5.05	132.31	72.50	1899.50	0.00	0.00
	Total Weight	5816.38	6.19	36015.52	76.65	445839.92	0.03	163.93

4.10 Hydrostatics and Stability

The hydrostatics, intact stability, and the damage stability of ADF 95 were calculated using HECSALV. The hullform of the ship was imported from RHINO and tanks and unassigned compartments were then defined within bulkheads. Loading and damage conditions were created in HECSALV and analyzed.

4.10.1 Intact Stability

In each condition, trim, stability and righting arm data are calculated. All conditions are assessed using DDS 079-1 stability standards for beam winds with rolling. For intact stability analysis, the full load and minimum operating conditions were evaluated. The tanks and compartments were filled to the Navy's DDS 079-1 standards and the stability and trim were determined for each condition. The righting arm curve was used to ensure that the area under the curve was greater than 1.4 times the area under the heeling arm curve. Table 50 shows the stability and trim calculations for the full load condition, and Figure 75 shows the righting and heeling arm curve for the full load condition. Table 51 shows the stability and trim calculations for the minimum operating condition, and Figure 76 shows the righting and heeling arm curve for the minimum operating condition.

Table 50 – Full Load Condition Trim and Stability Table

Stability Calculation		Trim Calculation	
KMt	10.507 m	LCF Draft	6.384 m
VCG	5.804 m	LCB (even keel)	74.636A m-FP
GmT (solid)	4.703 m	LCF	83.224a m-FP
FSc	0.009 m	MT1cm	150 m-MT/cm
GMt (corrected)	4.694 m	Trim	0.541 m-A
Specific Gravity	1.0250	List	0.0 deg

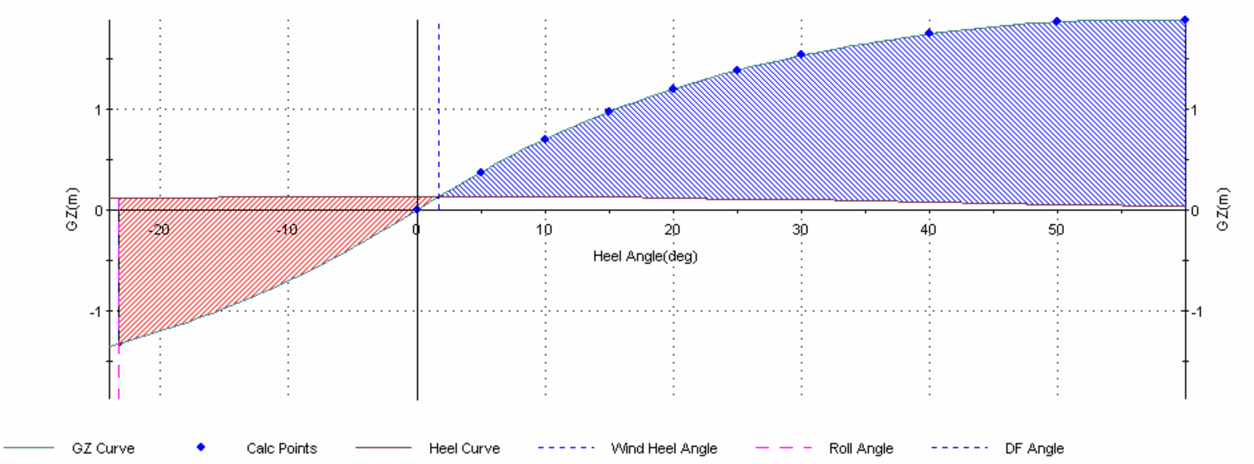


Figure 75 – Full Load Condition Righting Arm and Heeling Arm Curve

Table 51 – Minimum Operating Condition Trim and Stability Table

Stability Calculation		Trim Calculation	
KMt	10.746 m	LCF Draft	6.154 m
VCG	5.890 m	LCB (even keel)	74.003A m-FP
GmT (solid)	4.856 m	LCF	83.321a m-FP
FSc	0.103 m	MT1cm	147 m-MT/cm
GMt (corrected)	4.753 m	Trim	0.653 m-A
Specific Gravity	1.0250	List	0.0 deg

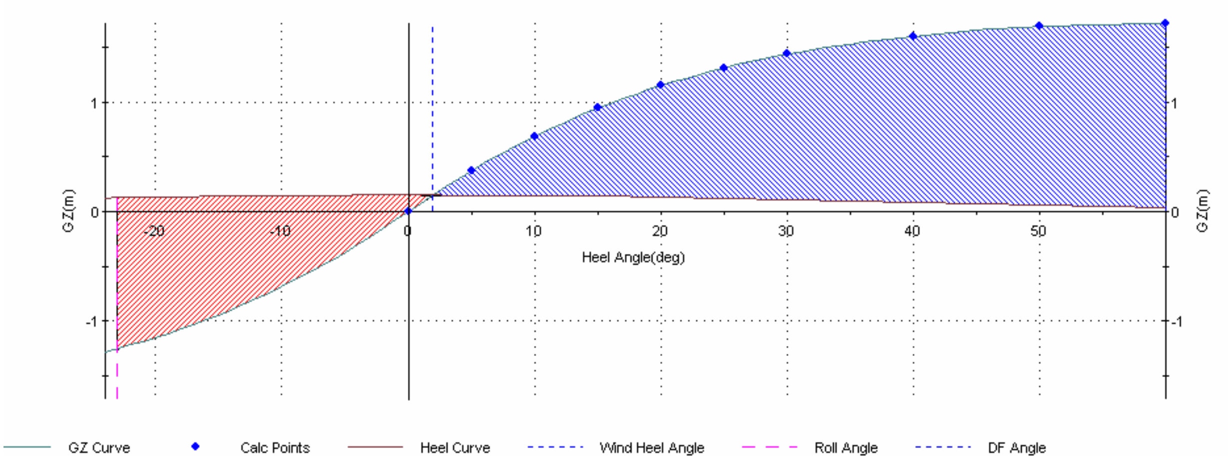


Figure 76 – Minimum Operating Condition Righting Arm and Heeling Arm Curve

4.10.2 Damage Stability

The damage stability of ADF 95 was checked under both full load and minimum operating conditions. In accordance with DDS 079-1, ADF 95 should be able to flood a section of the ship that is 15% of the length along the waterline (21 meters) at any longitudinal position along the hull. Starting at the forward perpendicular, 21 meter sections were flooded and analyzed under both loading conditions. Under both load conditions the worst case scenario occurred when ADF 95 was flooded from 100m to 130m aft of the forward perpendicular.
The righting and heeling arm curve was also examined for each load condition. The ship passed the damage stability test because the waterline did not rise above the flood deck for either load condition under any damage scenario.

Figure 77 shows the worst case damage scenario at full load and Table 52 gives the corresponding stability data. Figure 79 shows the worst case damage scenario at minimum operating conditions and Table 53 gives the corresponding stability data. Figure 78 shows the righting arm curve for the full load condition and Figure 80 shows the righting arm curve for the minimum operating condition.

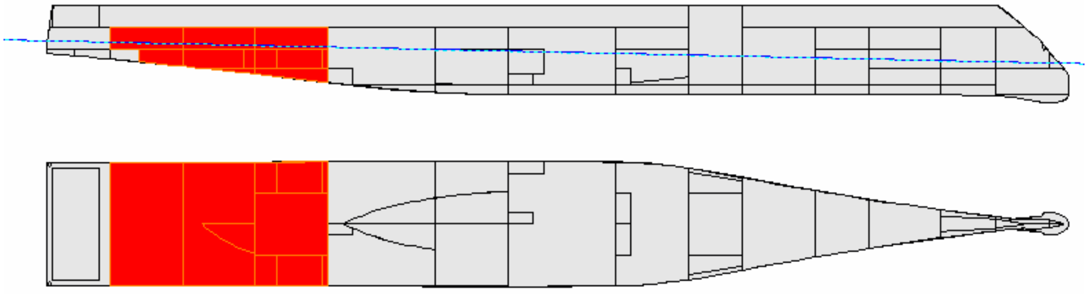


Figure 77 – Full Load Condition Worst Case Damage Scenario

Table 52 – Full Load Worst Case Damage Stability Calculations

Stability	Calculations
Draft FP	4.425m
Draft AP	7.547m
Trim	3.123m AFT
GMt	2.019m

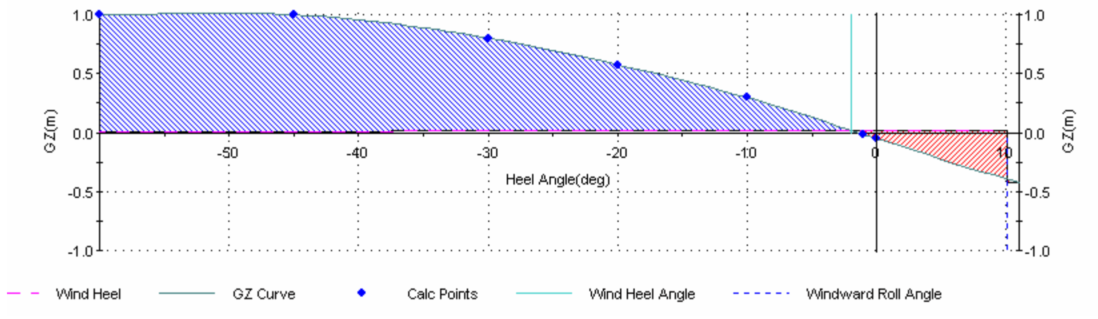


Figure 78 – Full Load Condition Worst Case Damage Righting Arm Curve

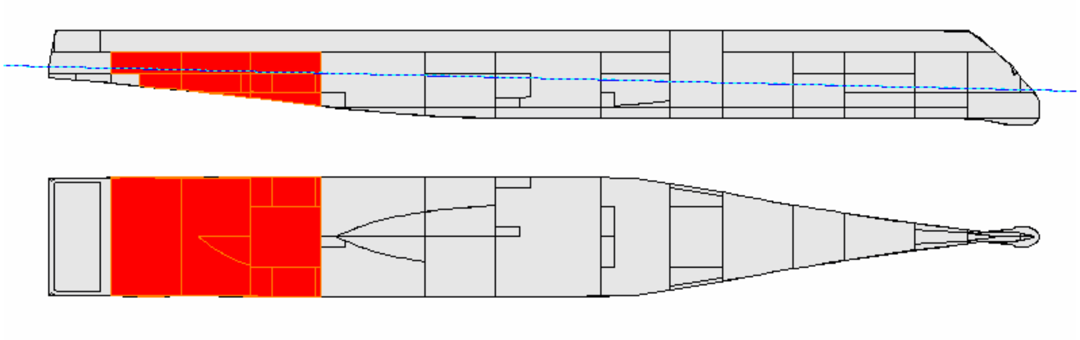


Figure 79 – Minimum Operating Condition Worst Case Damage Scenario

Table 53 – Minimum Operating Worst Case Damage Stability Calculations

Stability	Calculations
Draft FP	4.143m
Draft AP	7.416m
Trim	3.222m AFT
GMt	1.941m

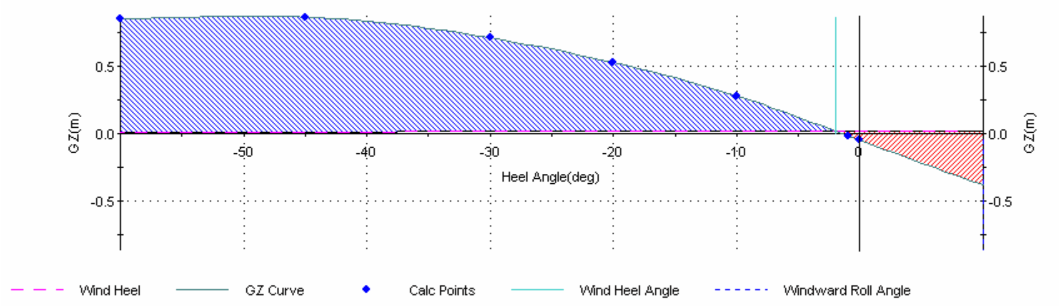


Figure 80 – Minimum Operating Condition Worst Case Damage Righting Arm Curve

4.11 Seakeeping

A seakeeping analysis in the full load condition was performed using ….. How was it modeled? Sea states? Speeds? Headings? Velocities and accelerations at what locations? Tables. ORD and US Navy Motion Limit

Criteria by subsystem. Polar plots show the ship response for various headings and forward speeds. Significant amplitude criteria are listed in Table 54. Describe and discuss. Include all limiting polar plots. Assess.

Table 54 - Limiting Motion Criteria (Significant Amplitude) and Results

Application	Roll	Pitch	Yaw	Longitudinal Acceleration	Transverse Acceleration	Vertical Acceleration	ORD Threshold SeaState	Sea State Achieved

4.12 Cost Analysis

Cost was estimated using parametric models for both the lead ship and follow ship acquisition as part of the multi-objective genetic optimization within the concept exploration phase (see sections 3.4.3, 3.5, and 3.6). These models used rough estimates for the weight of SWBS groups determined by parametric math models to estimate the basic cost of construction. Other factors that were 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 other capital-consuming aspects were added to this cost to come up with the final cost estimates. In concept development, many of the assumptions on which the original cost estimate was based were re-calculated as new numbers were determined or as the design changed. Therefore, a re-estimation of cost was performed at the end of concept development by using the MATHCAD model given in Appendix G. Table 55 shows the results of the re-calculated cost model.

Table 55 – Revised Cost Estimates

Cost Factor		Values
Lightship Weight (lton)		5319
Crew	Officers	23
	CPOs	25
	Enlisted	198
Ship Service Life (yrs)		40
Initial Operational Capability		2015
Base Year		2010
Total Lead Ship Cost (Billion Dollars)		1.3
Total Follow-Ship Acquisition Cost (Million Dollars)		824.08
Total Life Cycle Cost (Undiscounted, Billion Dollars)		60.12
Total Discounted Life Cycle Cost (Billion Dollars)		10.2

5 Conclusions and Future Work

5.1 Assessment

Discuss Table 56. Compare to ORD goals and thresholds and to baseline.

Table 56 - Compliance with Operational Requirements

Technical Performance Measure	ORD TPM (Threshold)	Original Goal	Concept BL	Final Concept BL

5.2 Future Work

Provide a list of things to be done next time around spiral. All areas.

5.3 Conclusions

Sell your design based on assessment.

********this section will be completed before submission to SNAME********

6 References

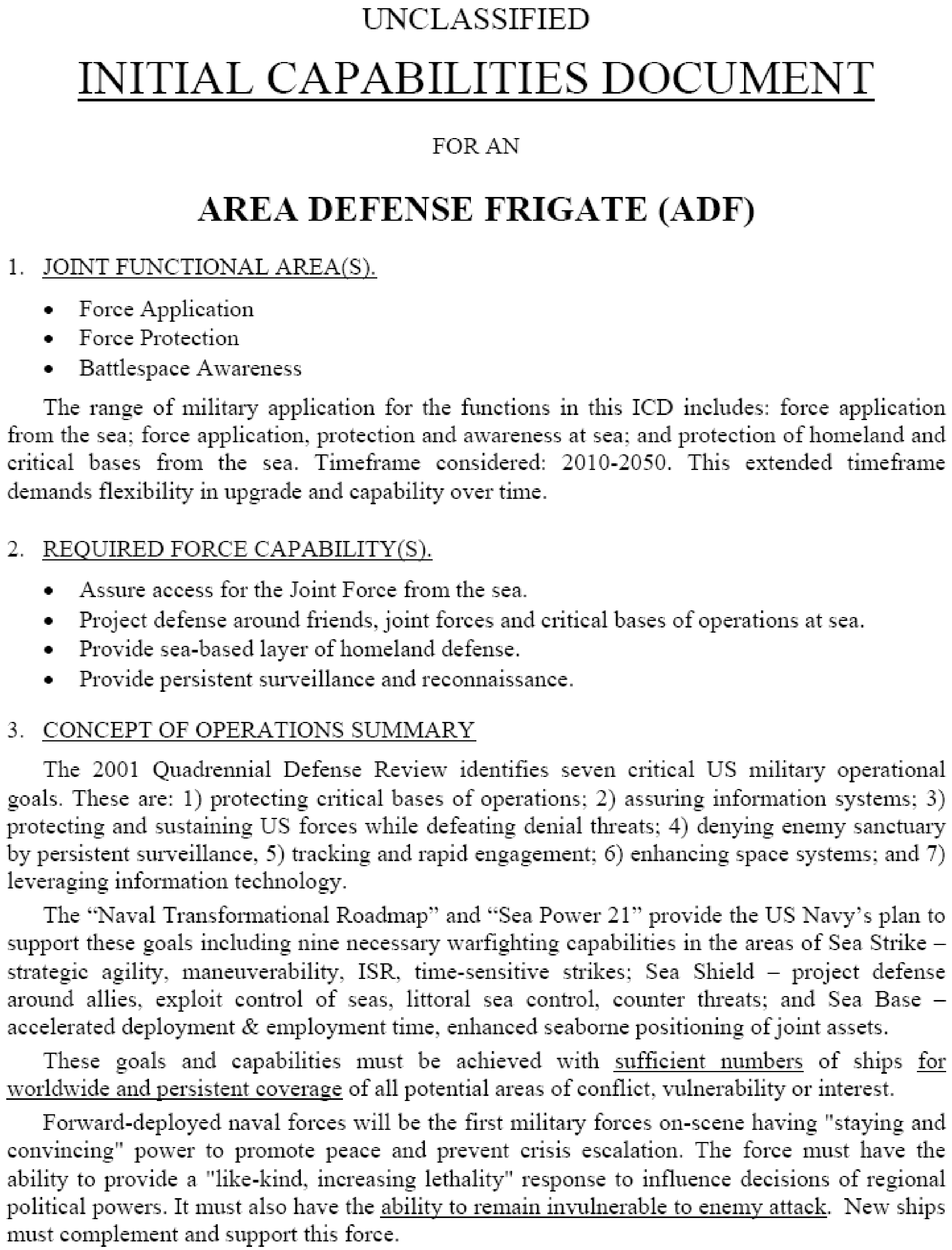
1. Brown, Dr. Alan and LCDR Mark Thomas, USN. "Reengineering the Naval Ship Concept Design Process." 1998.

2. Brown, A.J., "Ship Design Notes", Virginia Tech AOE Department, 2006.

3. Comstock, John P., ed. Principles of Naval Architecture, New Jersey: Society of Naval Architects and Marine Engineers (SNAME), 1967.

4. *U.S. NavyFact File*. 2004. U.S. Navy Home Page. http://www.chinfo.navy.mil/navpalib/factfile/ffiletop.html

Appendix A – Initial Capabilities Document (ICD)



UNCLASSIFIED

INITIAL CAPABILITIES DOCUMENT

FOR AN

AREA DEFENSE FRIGATE (ADF)

1. JOINT FUNCTIONAL AREA(S).

- Force Application
- Force Protection
- Battlespace Awareness

The range of military application for the functions in this ICD includes: force application from the sea; force application, protection and awareness at sea; and protection of homeland and critical bases from the sea. Timeframe considered: 2010-2050. This extended timeframe demands flexibility in upgrade and capability over time.

2. REQUIRED FORCE CAPABILITY(S).

- Assure access for the Joint Force from the sea.
- Project defense around friends, joint forces and critical bases of operations at sea.
- Provide sea-based layer of homeland defense.
- Provide persistent surveillance and reconnaissance.

3. CONCEPT OF OPERATIONS SUMMARY

The 2001 Quadrennial Defense Review identifies seven critical US military operational goals. These are: 1) protecting critical bases of operations; 2) assuring information systems; 3) protecting and sustaining US forces while defeating denial threats; 4) denying enemy sanctuary by persistent surveillance, 5) tracking and rapid engagement; 6) enhancing space systems; and 7) leveraging information technology.

The “Naval Transformational Roadmap” and “Sea Power 21” provide the US Navy’s plan to support these goals including nine necessary warfighting 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.

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

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

Power Projection requires the execution and support of flexible strike missions and support of naval amphibious operations. This includes protection to friendly forces from enemy attack, unit self defense against littoral threats, area defense, mine countermeasures and support of theater ballistic missile defense. Ships must be able to support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C^4/I reconnaissance vehicles. Naval forces must possess sufficient mobility and endurance to perform all missions on extremely short notice, at locations far removed from home port. To accomplish this, they must be pre-deployed, virtually on station in sufficient numbers around the world.

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

4. CAPABILITY GAP(S)

The overarching capability gap addressed by this ICD is:

- Provide and support functional areas specified above with sufficient numbers of reconfigurable-mission (modular, open systems architecture) ships for worldwide and persistent coverage of all potential areas of conflict, vulnerability or interest. – Projected force numbers of US Navy ships will not provide this coverage. LCS ships will contribute, but are not able to support adequate inherent core capabilities for AAW/BMD (with queuing), and blue/green water ASW necessary for many strike group and independent operations. DDG-51 class ships are too costly for this force-multiplier.

Specific capability gaps resulting from insufficient force numbers with adequate inherent core capabilities include: AAW/BMD (with queuing); blue/green water ASW. Additional capabilities include capacity and interfaces for special mission packages and personnel (mine countermeasures, ISR, ASUW, special operations, maritime interdiction and limited disaster relief).

Priority	**Capability Description**	**Threshold Systems or metric**	**Goal Systems or metric**
1	Core AAW/BMD (with queuing)	SPY-3 w/32 cell VLS, Nulka/ SRBOC, SLQ-32V2	SPY-3 w/64 cell VLS, Nulka/ SRBOC, SLQ-32V3
2	Core Blue/green water ASW	SQS-56 sonar, TACTAS, NIXIE, 2xSH-2G, SSTD	SQS-53C sonar, TACTAS, NIXIE, 2xSH-60, SSTD
3	Special-Mission Packages (MCM, SUW, ASW, ISR, Special Forces)	1xLCS Mission Packages with UAVs, USVs and stern launch	2xLCS Mission Packages with UAVs, USVs and stern launch
4	Core ISR	2xSH-2G, advanced C4I	2xSH-60, advanced C4I
5	Mobility	30knt, full SS4, 3500 nm, 45days	35knt, full SS5, 5000 nm, 60days
6	Survivability and self-defense	DDG-51 signatures, mine detection sonar, CIWS or CIGS	DD1000 signatures, mine detection sonar, CIWS or CIGS
7	Maritime interdiction, ASUW	2xSH-2G, 57mm gun, 2x.50 caliber guns	2xSH-60, 57mm gun, 2x.50 caliber guns, Netfires

5. THREAT AND OPERATIONAL ENVIRONMENT

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

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

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

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

- Open ocean (sea states 0 through 9) and littoral
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture
- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather Battle Group
- All-Weather Independent operations

6. FUNCTIONAL SOLUTION ANALYSIS SUMMARY.

a. *Ideas for Non-Materiel Approaches (DOTMLPF Analysis).*

- Change the U.S. role in the world by reducing U.S. international involvement.
- Keep ships forward-deployed and rotate crews.
- Increase reliance on foreign political and military activity to meet the interests of the U.S.
- 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.

b. *Ideas for Materiel Approaches.*

- Retain and upgrade current fleet assets as necessary. Possibilities include a service life extension to current assets. Continue production of the DDG-51 class mixed with LCS ships at a rate that provides sufficient surface force numbers and sufficient inherent capability.

- Design and build a new frigate or corvette-sized ship design, larger than LCS, but smaller and much less expensive than DDG-51 class. This ship would use the same mission packages as LCS, but with additional AAW/BMD (with queuing) and blue/green water ASW capabilities.
- Purchase and build an existing corvette or frigate design such as the Israeli Eilat Class (Sa'ar 5), Swedish Visby Plus or MEKO D Frigate.

7. FINAL RECOMMENDATIONS.

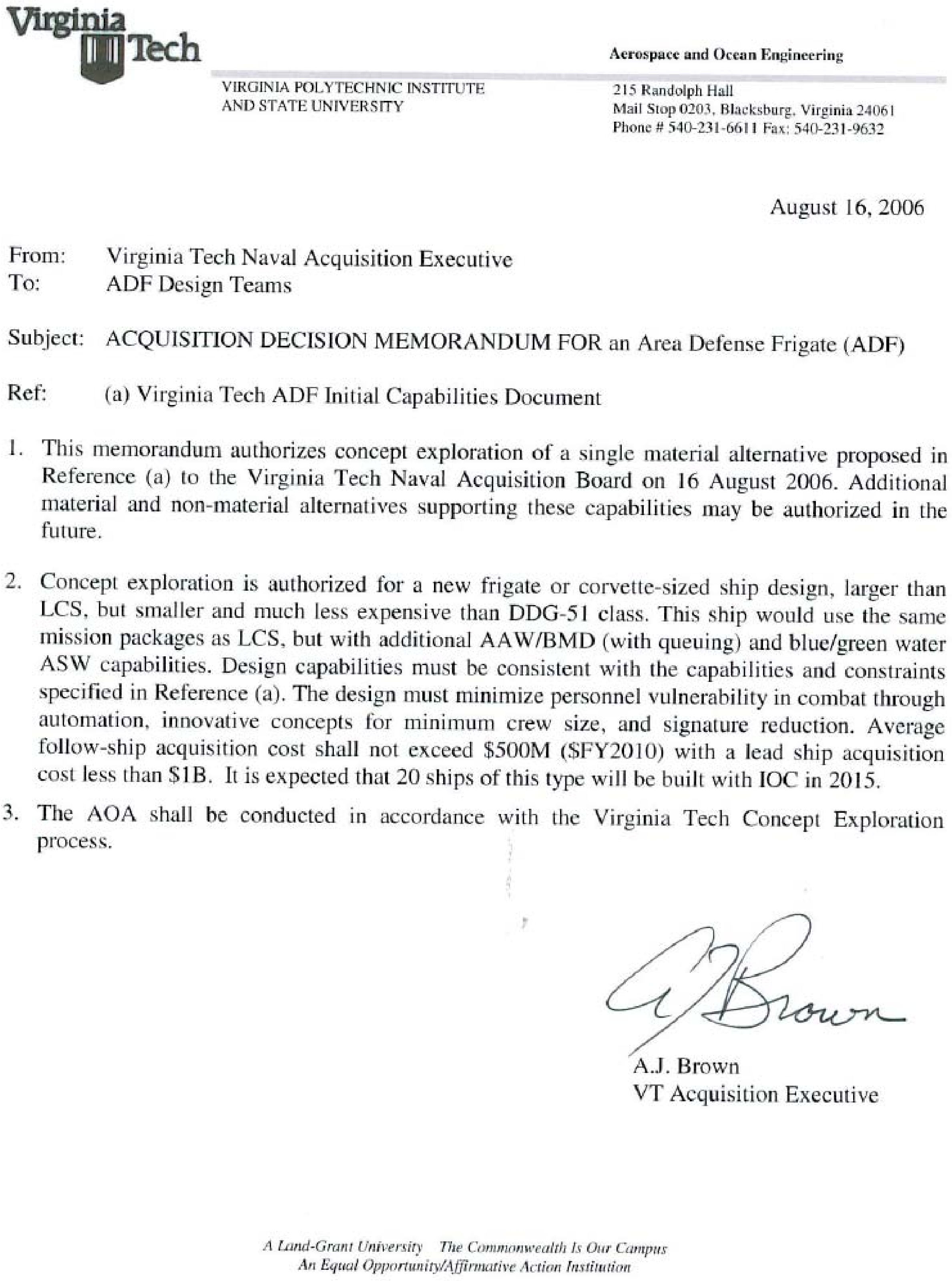
a. Maintaining LCS and possibly ADFs forward-deployed with crew rotation has the potential to provide a significant low cost effective force multiplier and should be tested.

b. Upgrade and service life extension of existing assets has the undesirable effect of maintaining larger crews and resulting life cycle costs.

c. Existing foreign navy designs do not provide the right mix or flexibility of core and modular capabilities.

d. A new frigate-sized ship with more capable core systems and the same modular systems as LCS provides the potential for significant acquisition and life cycle cost savings while providing core systems more consistent with independent missions and direct support of CSGs and ESGs. These core capabilities are AAW/BMD (with queuing) and blue/green water ASW. It is essential that the acquisition cost of a new frigate be kept to the absolute minimum, no more than 50% of a DDG-51 class ship. The platforms must be highly producible, minimizing the time from concept to delivery to the fleet and maximizing system commonality with LCS. The platforms must operate within current logistics support capabilities. Inter-service and Allied C^4/I (inter-operability) must be considered. The new ship must have absolute minimum manning.

Appendix B – Acquisition Decision Memorandum (ADM)



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

August 16, 2006

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

Subject: ACQUISITION DECISION MEMORANDUM FOR an Area Defense Frigate (ADF)

Ref: (a) Virginia Tech ADF Initial Capabilities Document

1. This memorandum authorizes concept exploration of a single material alternative proposed in Reference (a) to the Virginia Tech Naval Acquisition Board on 16 August 2006. Additional material and non-material alternatives supporting these capabilities may be authorized in the future.

2. Concept exploration is authorized for a new frigate or corvette-sized ship design, larger than LCS, but smaller and much less expensive than DDG-51 class. This ship would use the same mission packages as LCS, but with additional AAW/BMD (with queuing) and blue/green water ASW capabilities. Design capabilities must be consistent with the capabilities and constraints specified in Reference (a). The design must minimize personnel vulnerability in combat through automation, innovative concepts for minimum crew size, and signature reduction. Average follow-ship acquisition cost shall not exceed $500M ($FY2010) with a lead ship acquisition cost less than $1B. It is expected that 20 ships of this type will be built with IOC in 2015.

3. The AOA shall be conducted in accordance with the Virginia Tech Concept Exploration process.

A.J. Brown
VT Acquisition Executive

Appendix C – Capability Development Document (CDD)

UNCLASSIFIED

CAPABILITY DEVELOPMENT DOCUMENT

FOR

AREA DEFENSE FRIGATE (ADF) Variant #95
VT Team 5

1. Capability Discussion.

The Initial Capabilities Document (ICD) for this CCD was issued by the Virginia Tech Acquisition Authority on 31 August 2006. The overarching capability gaps addressed by this ICD are: Provide and support functional areas with sufficient numbers of reconfigurable-mission (modular, open systems architecture) ships for worldwide and persistent coverage of all potential areas of conflict, vulnerability or interest. Projected force numbers of US Navy ships will not provide this coverage. LCS ships will contribute, but are not able to support adequate inherent core capabilities for AAW/BMD (with queuing), and blue/green water ASW necessary for many strike group and independent operations. DDG-51 and DD-1000 class ships are too costly for this force-multiplier.

Specific capability gaps resulting from insufficient force numbers with adequate inherent core capabilities include: AAW/BMD (with queuing); blue/green water ASW. Additional capabilities include capacity and interfaces for special mission packages and personnel (mine countermeasures, ISR, ASUW, special operations, maritime interdiction and limited disaster relief).

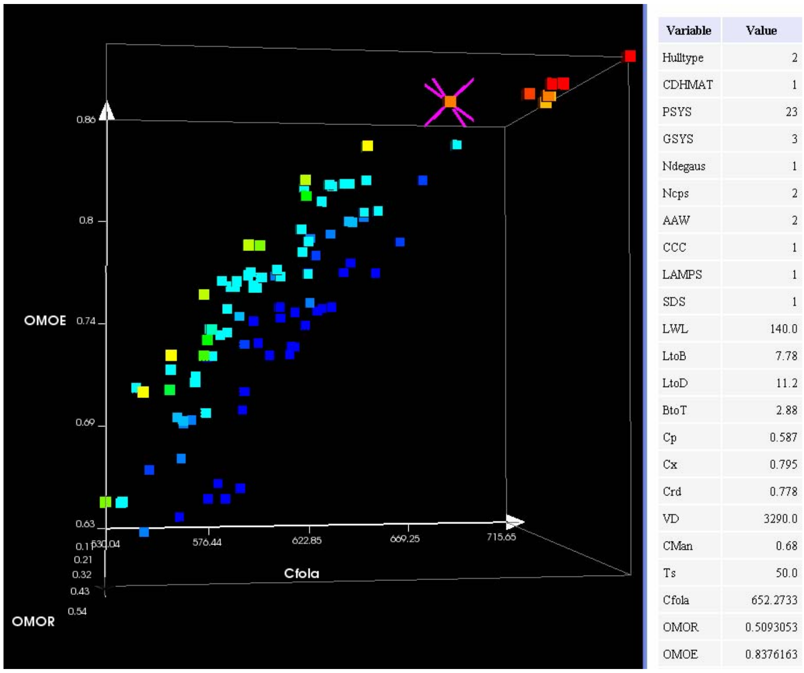
Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	Core AAW/BMD (with queuing)	SPY-3 w/32 cell VLS, Nulka/ SRBOC, SLQ-32V2	SPY-3 w/64 cell VLS, Nulka/ SRBOC, SLQ-32V3
2	Core Blue/green water ASW	SQS-56 sonar, TACTAS, NIXIE, 2xSH-2G, SSTD	SQS-53C sonar, TACTAS, NIXIE, 2xSH-60, SSTD
3	Special-Mission Packages (MCM, SUW, ASW, ISR, Special Forces)	1xLCS Mission Packages with UAVs, USVs and stern launch	2xLCS Mission Packages with UAVs, USVs and stern launch
4	Core ISR	2xSH-2G, advanced C4I	2xSH-60, advanced C4I
5	Mobility	30knt, full SS4, 3500 nm, 45days	35knt, full SS5, 5000 nm, 60days
6	Survivability and self-defense	DDG-51 signatures, mine detection sonar, CIWS or CIGS	DD1000 signatures, mine detection sonar, CIWS or CIGS
7	Maritime interdiction, ASUW	2xSH-2G, 57mm gun, 2x.50 caliber guns	2xSH-60, 57mm gun, 2x.50 caliber guns, Netfires

2. Analysis Summary.

An Acquisition Decision Memorandum issued on 7 September 2006 by the Virginia Tech Acquisition Authority directed Concept Exploration and Analysis of Alternatives (AoA) for a new frigate-sized ship with more capable core systems and modular systems similar to LCS. Required core capabilities are AAW/BMD (with queuing) and blue/green water ASW. The platforms must be highly producible, minimizing the time from concept to delivery and maximizing system commonality with LCS. The platforms must operate within current logistics support capabilities. Inter-service and Allied C^4/I (inter-operability) must be considered. The new ship must have minimum manning.

Concept Exploration was conducted from 12 September 2006 through 5 December 2006. A Concept Design and Requirements Review was conducted on 23 January 2007. This CDD presents the baseline requirements approved in this review.

Available technologies and concepts necessary to provide required functional capabilities were identified and defined in terms of performance, cost, risk and ship impact (weight, area, volume, power). Trade-off studies were performed using technology and concept design parameters to select trade-off options in a multi-objective genetic optimization (MOGO) for the total ship design. The result of this MOGO was a non-dominated frontier, Figure 1. This frontier includes designs with a wide range of risk and cost, each having the highest effectiveness for a given risk and cost. Preferred designs are often “knee in the curve” designs at the top of a large increase in effectiveness for a given cost and risk, or designs at high and low extremes. The design selected for Virginia Tech Team 5, and specified in this CDD, is the low-cost and low-risk design shown with an X in Figure 1. Selection of a point on the non-dominated frontier specifies requirements, technologies and the baseline design.



Variable	Value
Hulltype	2
CDHMAT	1
PSYS	23
GSYS	3
Ndegaus	1
Ncps	2
AAW	2
CCC	1
LAMPS	1
SDS	1
LWL	140.0
LtoB	7.78
LtoD	11.2
BtoT	2.88
Cp	0.587
Cx	0.795
Crd	0.778
VD	3290.0
CMan	0.68
Ts	50.0
Cfola	652.2733
OMOR	0.5093053
OMOE	0.8376163

Figure 1 – ADF Non-Dominated Frontier

3. Concept of Operations Summary.

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

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

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

Power Projection requires the execution and support of flexible strike missions and support of naval amphibious operations. This includes protection to friendly forces from enemy attack, unit self defense against littoral threats, area defense, mine countermeasures and support of theater ballistic missile defense. Ships must be able to support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C^4/I reconnaissance vehicles. Naval forces must possess sufficient mobility and endurance to perform all missions on extremely short notice, at locations far removed from home port. To accomplish this, they must be pre-deployed, virtually on station in sufficient numbers around the world.

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

Expected operations for ADF include:

- Escort (CSG, ESG, MCG, Convoy)
  - Provide Area AAW, ASW and ASUW defense
- SAG (Surface Action Group)
  - With CGs, DDGs and/or LCSs
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
  - Support BMD (w/ queuing)
  - Provide MCM and additional ISR/ASW/ASUW w/ mission modules
- Independent Ops
  - Provide Area AAW, ASW and ASUW
  - Provide ISR
  - Support UAVs, USVs and UUVs
  - Support BMD (w/ queuing)
  - Provide MCM and additional ISR/ASW/ASUW w/ mission modules
  - Support Special Operations
  - Humanitarian Support and Rescue
  - Peacetime Presence
- Homeland Defense/Interdiction
  - Support AAW, ASW and ASUW
  - Provide surveillance and reconnaissance, support UAVs
  - Interdict, board and inspect

4. Threat Summary.

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

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

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

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

- Open ocean (sea states 0 through 8) and littoral, fully operational through SS4
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture

- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather Battle Group
- All-Weather Independent operations

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

Key Performance Parameter (KPP)	Development Threshold or Requirement
AAW	SPY-3 (2 panel), Aegis MK 99 FCS
ASUW/NSFS	MK 3 57 mm gun, MK86 GFCS, SPS-73(V)12, 1 RHIB, Small Arms Locker
ASW	SQS-56, SQQ 89, 2xMK 32 Triple Tubes, NIXIE, SQR-19 TACTAS, mine avoidance sonar
CCC	Enhanced CCC
LAMPS	2 LAMPS w/ hanger (flight deck, refueling, rearming), SQQ-28
SDS	2x CIWS, SLQ-32(V) 3, SRBOC, NULKA
GMLS	32 cells, MK 41 VLS
LCS Modules	1x LCS
Hull	Wave-piercing Tumblehome
Power and Propulsion	2 pods, LM 2500+ GT, ICR
Endurance Range (nm)	5595 nm
Sustained Speed (knots)	30.8 knots
Endurance Speed (knots)	20 knots
Stores Duration (days)	50
Collective Protection System	full
Crew Size	246
RCS (m^3)	3836
Maximum Draft (m)	5.8 m
Vulnerability (Hull Material)	Steel
Ballast/fuel system	Compensated fuel tanks
Degaussing System	Yes
McCreight Seakeeping Index	11.08

KG margin (m)	0.2m
Propulsion power margin (design)	10%
Propulsion power margin (fouling and seastate)	25% (0.8 MCR)
Electrical margins	5%
Net Weight margin (design and service)	10%

6. Program Affordability.

Average follow-ship acquisition cost shall not exceed $530M ($FY2010) with a lead ship acquisition cost less than $1B. It is expected that 30 ships of this type will be built with IOC in 2015.

Appendix D – Lower Level Pair-wise Comparison Results

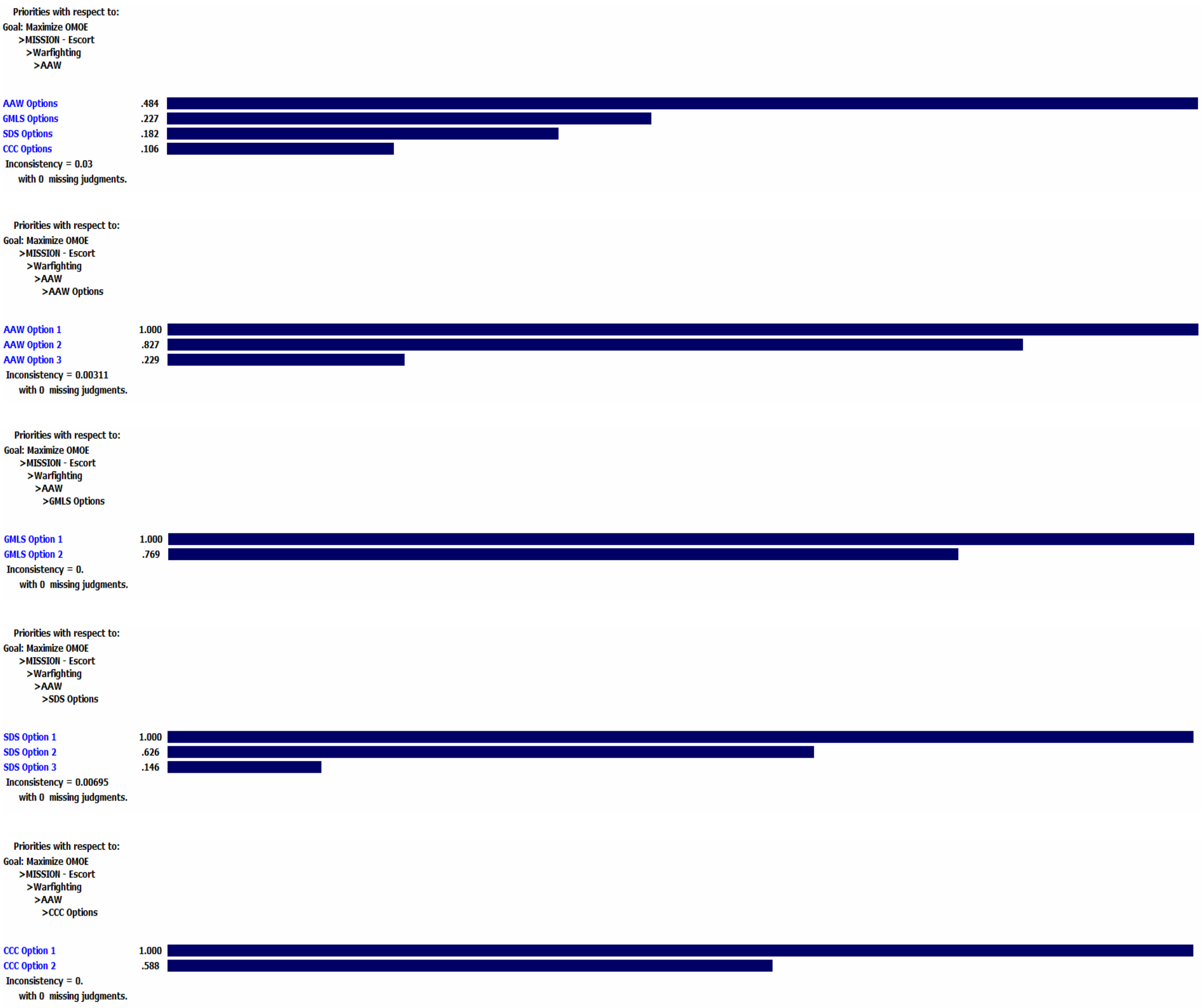


Figure D1 – MOP1 AAW

```
Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >ASW

ASW Options       .445
LAMPS Options     .395
GMLS Options      .097
CCC Options       .063
 Inconsistency = 0.01
    with 0  missing judgments.

Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >ASW
          >ASW Options

ASW Option 1     1.000
ASW Option 2      .340
 Inconsistency = 0.
    with 0  missing judgments.

Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >ASW
          >LAMPS Options

LAMPS Option1    1.000
LAMPS Option 2    .474
LAMPS Option 3    .128
 Inconsistency = 0.02
    with 0  missing judgments.

Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >ASW
          >GMLS Options

GMLS Option 1    1.000
GMLS Option 2     .885
 Inconsistency = 0.
    with 0  missing judgments.

Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >ASW
          >CCC Options

CCC Option 1     1.000
CCC Option 2      .690
 Inconsistency = 0.
    with 0  missing judgments.

Priorities with respect to:
Goal: Maximize OMOE
    >MISSION - Escort
      >Warfighting
        >Module Capacity

2 LCS            1.000
1 LCS             .641
 Inconsistency = 0.
    with 0  missing judgments.
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Figure D2 – MOP2 ASW

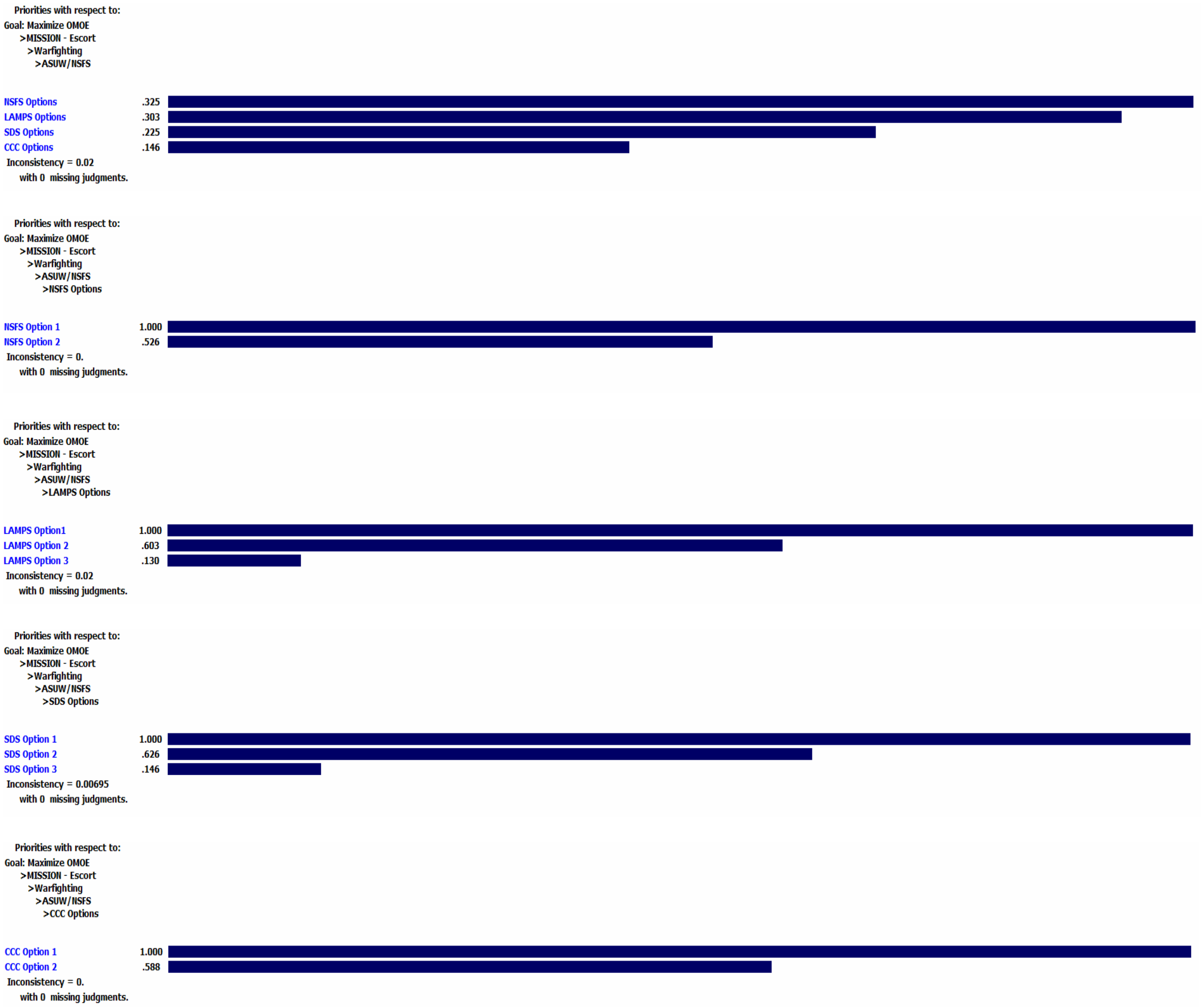


Figure D3 – MOP3 ASUW/NSFS

Figure D4 – MOP3 CCC/ISR

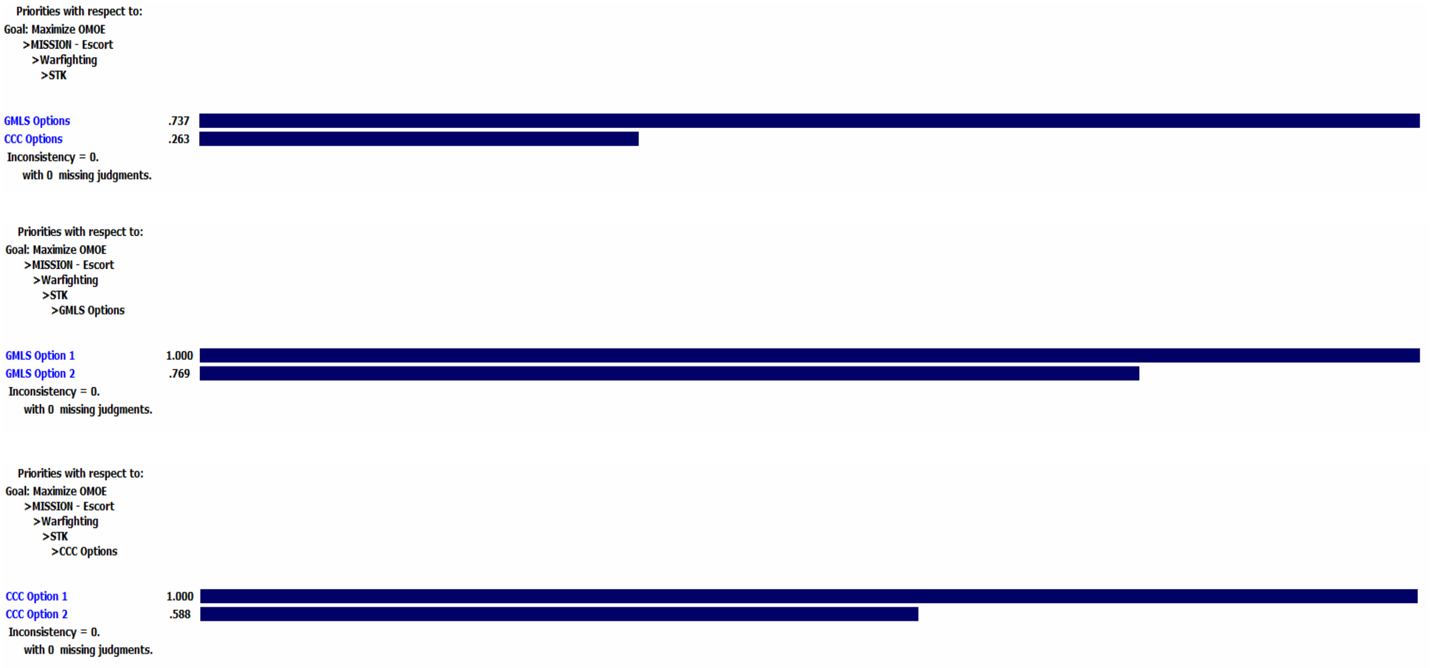


Figure D5 – MOP4 STK

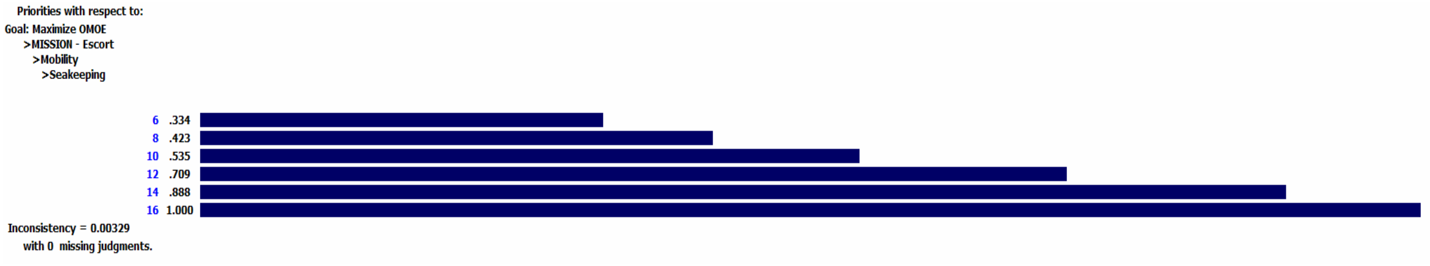


Figure D6 – MOP5 SeaKeep

Figure D7 – MOP6 E

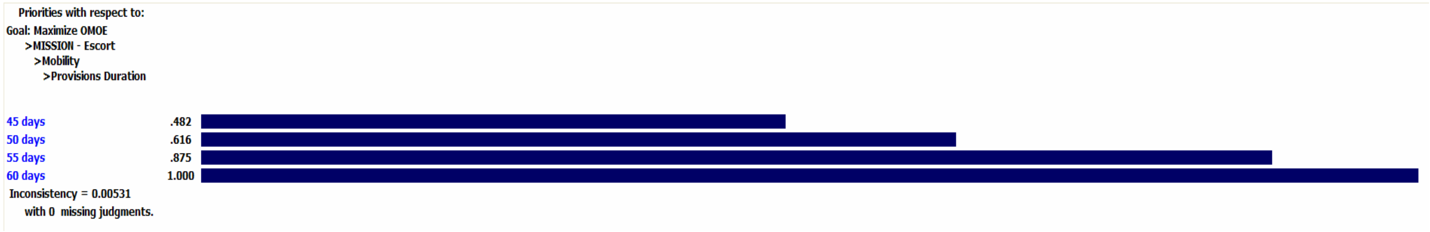


Figure D8 – MOP7 Ts

Figure D9 – MOP8 Vs

Figure D10 – MOP9 ENV

Figure D11 – MOP10 RCS

Figure D12 – MOP11 Acoustic

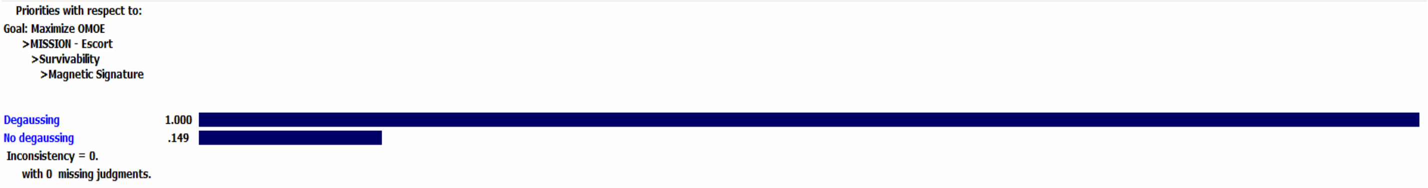


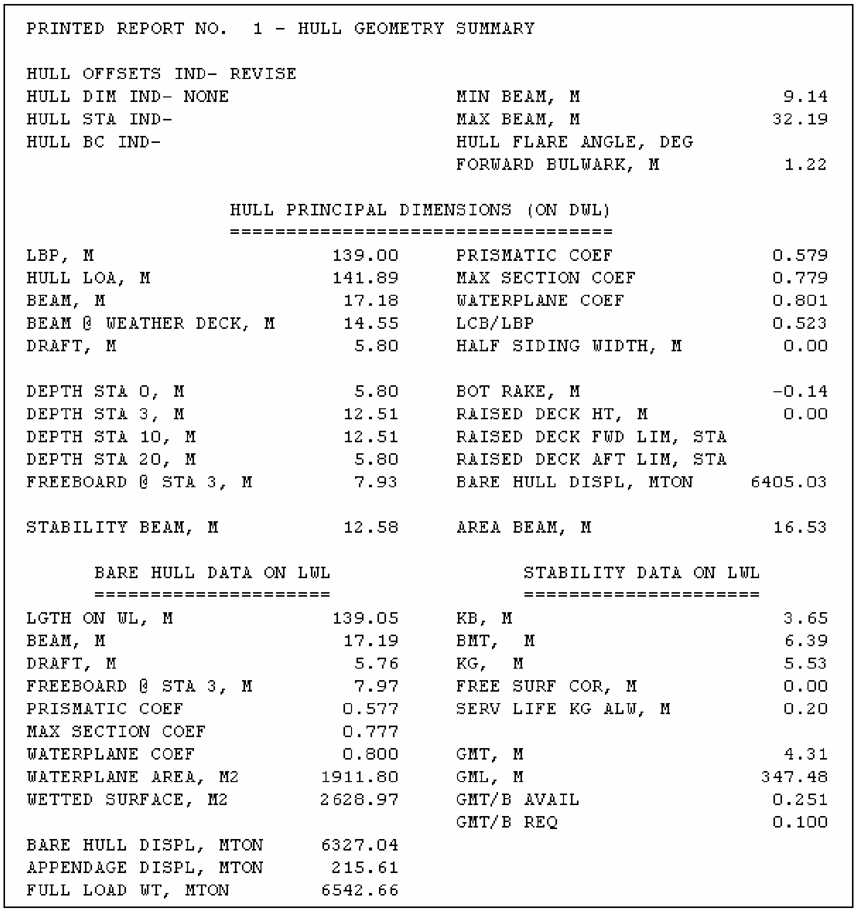
Figure D13 – MOP12 Mag

Figure D14 – MOP13 IR

Figure D15 – MOP14 Str. Vuln.

Figure D16 – MOP15 NBC

APPENDIX E – ASSET Data Summaries



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HULL OFFSETS IND- REVISE
HULL DIM IND- NONE                    MIN BEAM, M                 9.14
HULL STA IND-                         MAX BEAM, M                32.19
HULL BC IND-                          HULL FLARE ANGLE, DEG
                                      FORWARD BULWARK, M          1.22

                  HULL PRINCIPAL DIMENSIONS (ON DWL)
                  ==================================
LBP, M                      139.00    PRISMATIC COEF             0.579
HULL LOA, M                 141.89    MAX SECTION COEF           0.779
BEAM, M                      17.18    WATERPLANE COEF            0.801
BEAM @ WEATHER DECK, M       14.55    LCB/LBP                    0.523
DRAFT, M                      5.80    HALF SIDING WIDTH, M        0.00

DEPTH STA 0, M                5.80    BOT RAKE, M                -0.14
DEPTH STA 3, M               12.51    RAISED DECK HT, M           0.00
DEPTH STA 10, M              12.51    RAISED DECK FWD LIM, STA
DEPTH STA 20, M               5.80    RAISED DECK AFT LIM, STA
FREEBOARD @ STA 3, M          7.93    BARE HULL DISPL, MTON    6405.03

STABILITY BEAM, M            12.58    AREA BEAM, M               16.53

      BARE HULL DATA ON LWL                 STABILITY DATA ON LWL
      =====================                 =====================
LGTH ON WL, M               139.05    KB, M                       3.65
BEAM, M                      17.19    BMT,  M                     6.39
DRAFT, M                      5.76    KG,   M                     5.53
FREEBOARD @ STA 3, M          7.97    FREE SURF COR, M            0.00
PRISMATIC COEF               0.577    SERV LIFE KG ALW, M         0.20
MAX SECTION COEF             0.777
WATERPLANE COEF              0.800    GMT, M                      4.31
WATERPLANE AREA, M2        1911.80    GML, M                    347.48
WETTED SURFACE, M2         2628.97    GMT/B AVAIL                0.251
                                      GMT/B REQ                  0.100
BARE HULL DISPL, MTON      6327.04
APPENDAGE DISPL, MTON       215.61
FULL LOAD WT, MTON         6542.66
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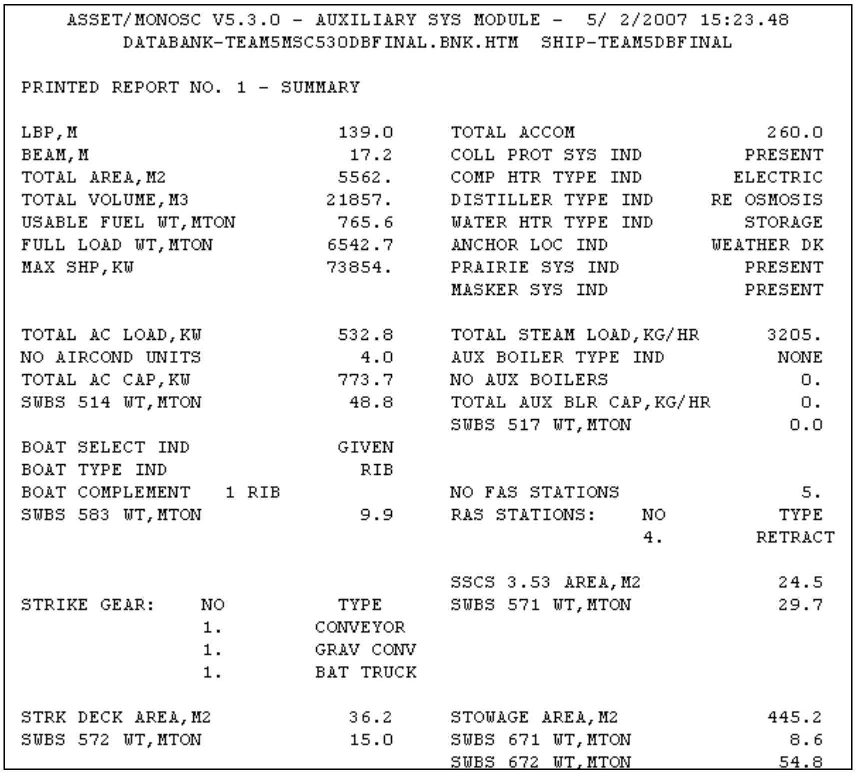

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PRINTED REPORT NO. 1 - SUMMARY

LBP,M                         139.0     TOTAL ACCOM               260.0
BEAM,M                         17.2     COLL PROT SYS IND       PRESENT
TOTAL AREA,M2                 5562.     COMP HTR TYPE IND      ELECTRIC
TOTAL VOLUME,M3              21857.     DISTILLER TYPE IND   RE OSMOSIS
USABLE FUEL WT,MTON           765.6     WATER HTR TYPE IND      STORAGE
FULL LOAD WT,MTON            6542.7     ANCHOR LOC IND       WEATHER DK
MAX SHP,KW                   73854.     PRAIRIE SYS IND         PRESENT
                                        MASKER SYS IND          PRESENT

TOTAL AC LOAD,KW              532.8     TOTAL STEAM LOAD,KG/HR    3205.
NO AIRCOND UNITS                4.0     AUX BOILER TYPE IND        NONE
TOTAL AC CAP,KW               773.7     NO AUX BOILERS               0.
SWBS 514 WT,MTON               48.8     TOTAL AUX BLR CAP,KG/HR      0.
                                        SWBS 517 WT,MTON            0.0

BOAT SELECT IND               GIVEN
BOAT TYPE IND                   RIB
BOAT COMPLEMENT    1 RIB                NO FAS STATIONS              5.
SWBS 583 WT,MTON                9.9     RAS STATIONS:    NO        TYPE
                                                         4.      RETRACT

                                        SSCS 3.53 AREA,M2          24.5
STRIKE GEAR:    NO          TYPE        SWBS 571 WT,MTON           29.7
                1.        CONVEYOR
                1.        GRAV CONV
                1.        BAT TRUCK

STRK DECK AREA,M2              36.2     STOWAGE AREA,M2           445.2
SWBS 572 WT,MTON               15.0     SWBS 671 WT,MTON            8.6
                                        SWBS 672 WT,MTON           54.8
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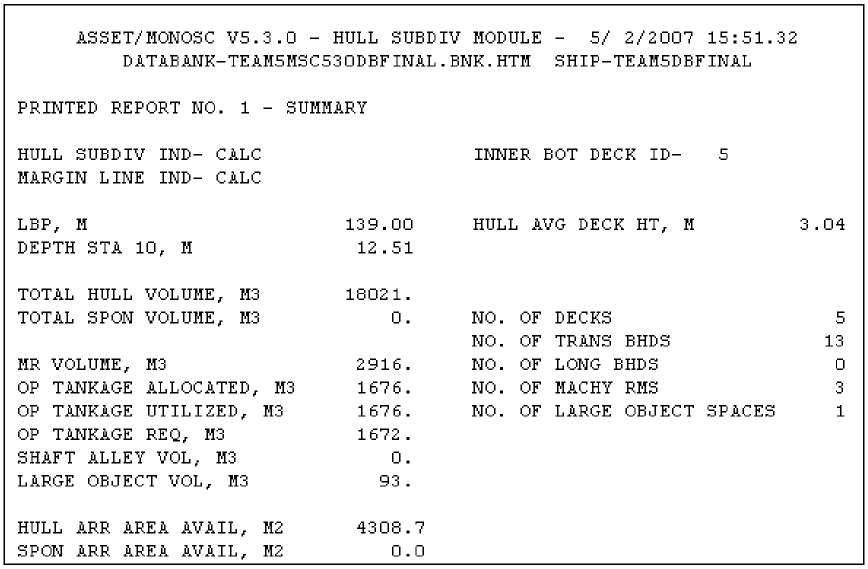

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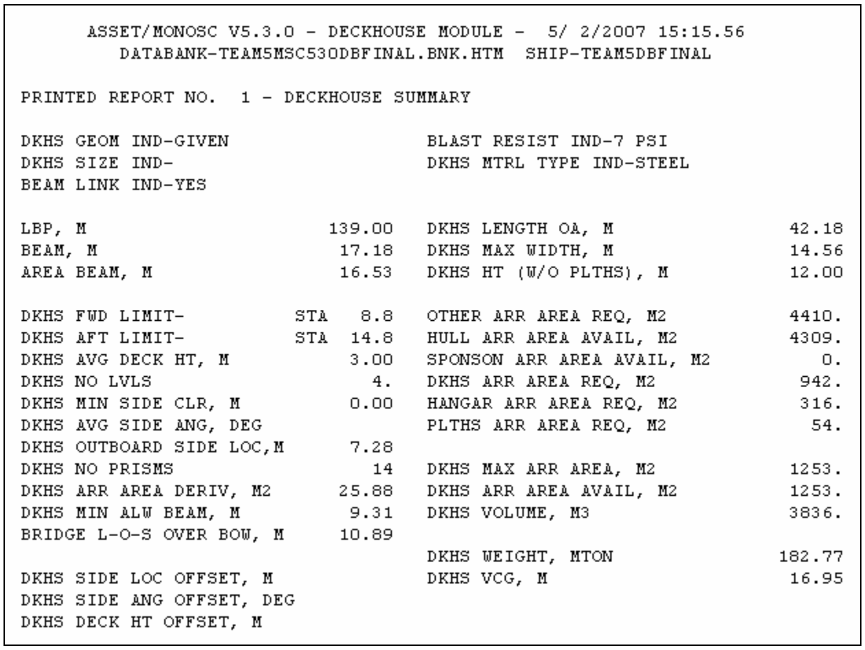
PRINTED REPORT NO. 1 - SUMMARY

HULL SUBDIV IND- CALC                  INNER BOT DECK ID-   5
MARGIN LINE IND- CALC

LBP, M                      139.00     HULL AVG DECK HT, M        3.04
DEPTH STA 10, M              12.51

TOTAL HULL VOLUME, M3       18021.
TOTAL SPON VOLUME, M3           0.     NO. OF DECKS                  5
                                       NO. OF TRANS BHDS            13
MR VOLUME, M3                2916.     NO. OF LONG BHDS              0
OP TANKAGE ALLOCATED, M3     1676.     NO. OF MACHY RMS              3
OP TANKAGE UTILIZED, M3      1676.     NO. OF LARGE OBJECT SPACES    1
OP TANKAGE REQ, M3           1672.
SHAFT ALLEY VOL, M3             0.
LARGE OBJECT VOL, M3           93.

HULL ARR AREA AVAIL, M2      4308.7
SPON ARR AREA AVAIL, M2         0.0
```



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      ASSET/MONOSC V5.3.0 - DECKHOUSE MODULE -  5/ 2/2007 15:15.56
         DATABANK-TEAM5MSC530DBFINAL.BNK.HTM  SHIP-TEAM5DBFINAL

PRINTED REPORT NO.  1 - DECKHOUSE SUMMARY

DKHS GEOM IND-GIVEN                  BLAST RESIST IND-7 PSI
DKHS SIZE IND-                       DKHS MTRL TYPE IND-STEEL
BEAM LINK IND-YES

LBP, M                      139.00   DKHS LENGTH OA, M             42.18
BEAM, M                      17.18   DKHS MAX WIDTH, M             14.56
AREA BEAM, M                 16.53   DKHS HT (W/O PLTHS), M        12.00

DKHS FWD LIMIT-         STA   8.8    OTHER ARR AREA REQ, M2        4410.
DKHS AFT LIMIT-         STA  14.8    HULL ARR AREA AVAIL, M2       4309.
DKHS AVG DECK HT, M           3.00   SPONSON ARR AREA AVAIL, M2       0.
DKHS NO LVLS                    4.   DKHS ARR AREA REQ, M2          942.
DKHS MIN SIDE CLR, M          0.00   HANGAR ARR AREA REQ, M2        316.
DKHS AVG SIDE ANG, DEG               PLTHS ARR AREA REQ, M2          54.
DKHS OUTBOARD SIDE LOC,M      7.28
DKHS NO PRISMS                  14   DKHS MAX ARR AREA, M2         1253.
DKHS ARR AREA DERIV, M2      25.88   DKHS ARR AREA AVAIL, M2       1253.
DKHS MIN ALW BEAM, M          9.31   DKHS VOLUME, M3               3836.
BRIDGE L-O-S OVER BOW, M     10.89
                                     DKHS WEIGHT, MTON            182.77
DKHS SIDE LOC OFFSET, M              DKHS VCG, M                   16.95
DKHS SIDE ANG OFFSET, DEG
DKHS DECK HT OFFSET, M
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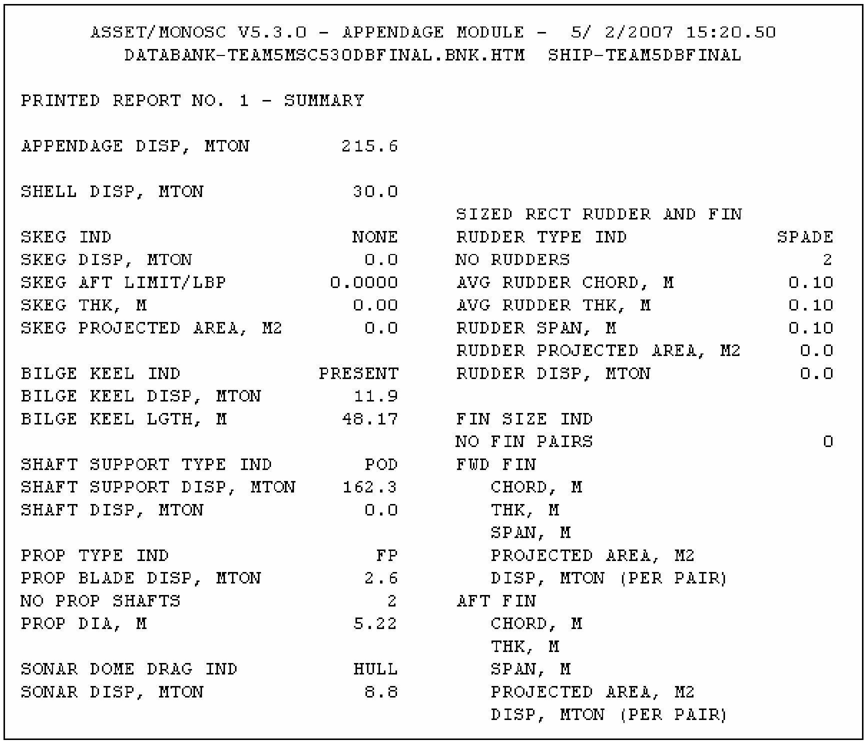

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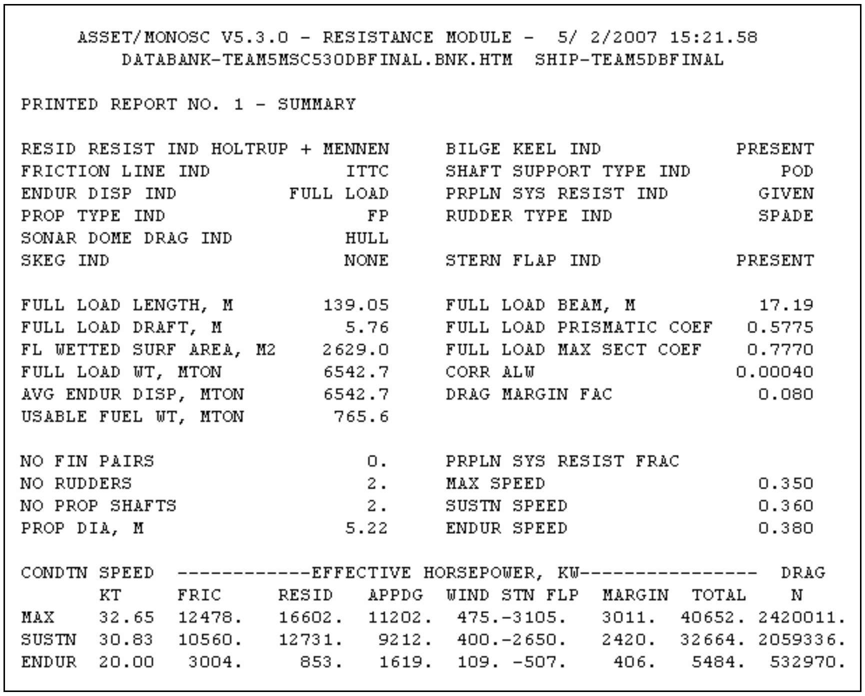
      ASSET/MONOSC V5.3.0 - APPENDAGE MODULE -  5/ 2/2007 15:20.50
         DATABANK-TEAM5MSC530DBFINAL.BNK.HTM  SHIP-TEAM5DBFINAL

PRINTED REPORT NO. 1 - SUMMARY

APPENDAGE DISP, MTON        215.6

SHELL DISP, MTON             30.0
                                      SIZED RECT RUDDER AND FIN
SKEG IND                     NONE     RUDDER TYPE IND            SPADE
SKEG DISP, MTON               0.0     NO RUDDERS                     2
SKEG AFT LIMIT/LBP         0.0000     AVG RUDDER CHORD, M         0.10
SKEG THK, M                  0.00     AVG RUDDER THK, M           0.10
SKEG PROJECTED AREA, M2       0.0     RUDDER SPAN, M              0.10
                                      RUDDER PROJECTED AREA, M2    0.0
BILGE KEEL IND            PRESENT     RUDDER DISP, MTON            0.0
BILGE KEEL DISP, MTON        11.9
BILGE KEEL LGTH, M          48.17     FIN SIZE IND
                                      NO FIN PAIRS                   0
SHAFT SUPPORT TYPE IND        POD     FWD FIN
SHAFT SUPPORT DISP, MTON    162.3        CHORD, M
SHAFT DISP, MTON              0.0        THK, M
                                         SPAN, M
PROP TYPE IND                  FP        PROJECTED AREA, M2
PROP BLADE DISP, MTON         2.6        DISP, MTON (PER PAIR)
NO PROP SHAFTS                  2     AFT FIN
PROP DIA, M                  5.22        CHORD, M
                                         THK, M
SONAR DOME DRAG IND          HULL        SPAN, M
SONAR DISP, MTON              8.8        PROJECTED AREA, M2
                                         DISP, MTON (PER PAIR)
```



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     ASSET/MONOSC V5.3.0 - RESISTANCE MODULE -  5/ 2/2007 15:21.58
         DATABANK-TEAM5MSC530DBFINAL.BNK.HTM  SHIP-TEAM5DBFINAL

PRINTED REPORT NO. 1 - SUMMARY

RESID RESIST IND HOLTRUP + MENNEN     BILGE KEEL IND           PRESENT
FRICTION LINE IND              ITTC     SHAFT SUPPORT TYPE IND       POD
ENDUR DISP IND            FULL LOAD     PRPLN SYS RESIST IND       GIVEN
PROP TYPE IND                    FP     RUDDER TYPE IND            SPADE
SONAR DOME DRAG IND            HULL
SKEG IND                       NONE     STERN FLAP IND           PRESENT

FULL LOAD LENGTH, M          139.05     FULL LOAD BEAM, M          17.19
FULL LOAD DRAFT, M             5.76     FULL LOAD PRISMATIC COEF  0.5775
FL WETTED SURF AREA, M2      2629.0     FULL LOAD MAX SECT COEF   0.7770
FULL LOAD WT, MTON           6542.7     CORR ALW                 0.00040
AVG ENDUR DISP, MTON         6542.7     DRAG MARGIN FAC            0.080
USABLE FUEL WT, MTON          765.6

NO FIN PAIRS                     0.     PRPLN SYS RESIST FRAC
NO RUDDERS                       2.     MAX SPEED                  0.350
NO PROP SHAFTS                   2.     SUSTN SPEED                0.360
PROP DIA, M                    5.22     ENDUR SPEED                0.380

CONDTN SPEED  ------------EFFECTIVE HORSEPOWER, KW----------------  DRAG
        KT    FRIC     RESID   APPDG  WIND STN FLP  MARGIN  TOTAL     N
MAX    32.65  12478.   16602.  11202.  475.-3105.   3011.  40652. 2420011.
SUSTN  30.83  10560.   12731.   9212.  400.-2650.   2420.  32664. 2059336.
ENDUR  20.00   3004.     853.   1619.  109. -507.    406.   5484.  532970.
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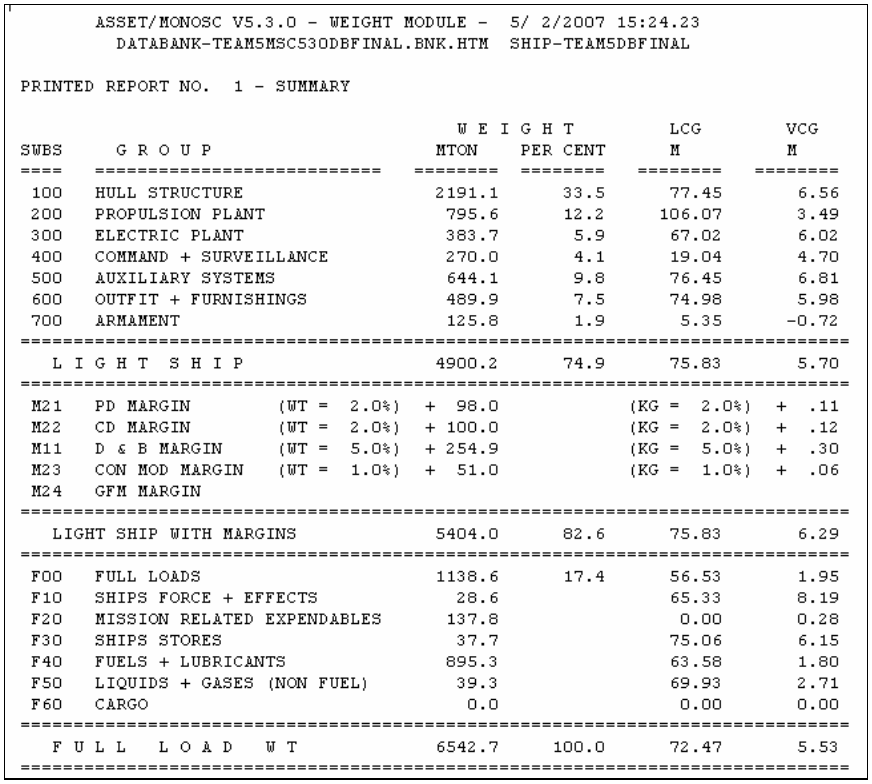

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      ASSET/MONOSC V5.3.0 - WEIGHT MODULE -  5/ 2/2007 15:24.23
        DATABANK-TEAM5MSC530DBFINAL.BNK.HTM  SHIP-TEAM5DBFINAL

PRINTED REPORT NO.  1 - SUMMARY

                                             W E I G H T        LCG        VCG
SWBS     G R O U P                         MTON    PER CENT      M          M
====   ===========================       ========  ========   ========   ========
 100   HULL STRUCTURE                      2191.1      33.5      77.45       6.56
 200   PROPULSION PLANT                     795.6      12.2     106.07       3.49
 300   ELECTRIC PLANT                       383.7       5.9      67.02       6.02
 400   COMMAND + SURVEILLANCE               270.0       4.1      19.04       4.70
 500   AUXILIARY SYSTEMS                    644.1       9.8      76.45       6.81
 600   OUTFIT + FURNISHINGS                 489.9       7.5      74.98       5.98
 700   ARMAMENT                             125.8       1.9       5.35      -0.72
===============================================================================
   L I G H T  S H I P                      4900.2      74.9      75.83       5.70
===============================================================================
 M21   PD MARGIN        (WT =  2.0%)  +  98.0            (KG =  2.0%)  +  .11
 M22   CD MARGIN        (WT =  2.0%)  + 100.0            (KG =  2.0%)  +  .12
 M11   D & B MARGIN     (WT =  5.0%)  + 254.9            (KG =  5.0%)  +  .30
 M23   CON MOD MARGIN   (WT =  1.0%)  +  51.0            (KG =  1.0%)  +  .06
 M24   GFM MARGIN
===============================================================================
   LIGHT SHIP WITH MARGINS                 5404.0      82.6      75.83       6.29
===============================================================================
 F00   FULL LOADS                          1138.6      17.4      56.53       1.95
 F10   SHIPS FORCE + EFFECTS                 28.6                65.33       8.19
 F20   MISSION RELATED EXPENDABLES          137.8                 0.00       0.28
 F30   SHIPS STORES                          37.7                75.06       6.15
 F40   FUELS + LUBRICANTS                   895.3                63.58       1.80
 F50   LIQUIDS + GASES (NON FUEL)            39.3                69.93       2.71
 F60   CARGO                                  0.0                 0.00       0.00
===============================================================================
   F U L L   L O A D   W T                 6542.7     100.0      72.47       5.53
===============================================================================
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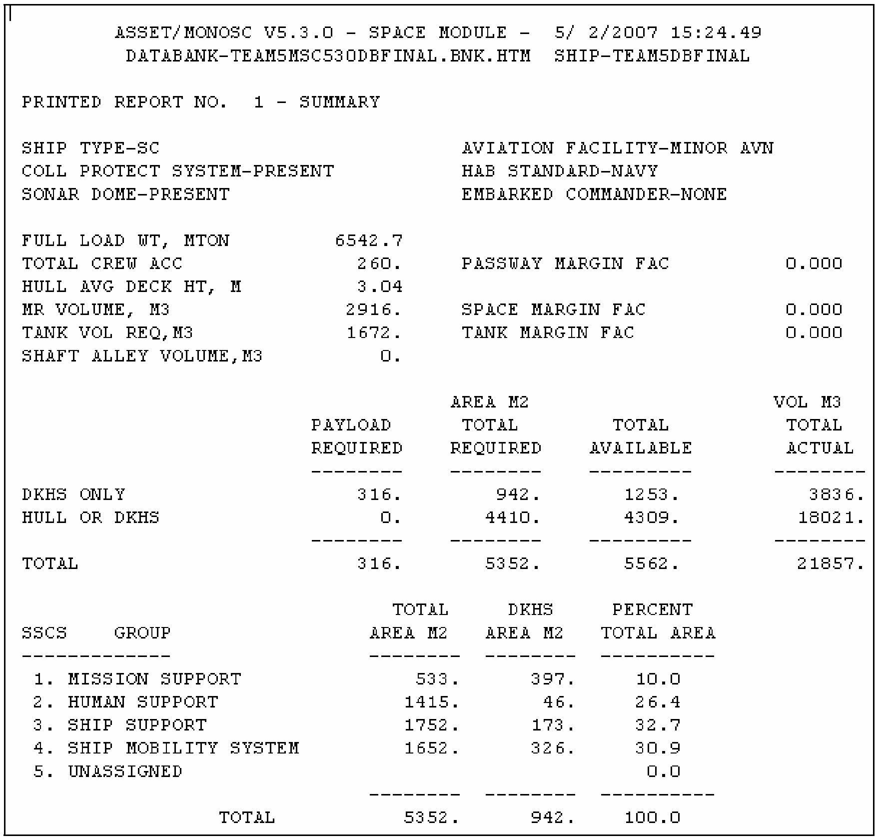

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        ASSET/MONOSC V5.3.0 - SPACE MODULE -  5/ 2/2007 15:24.49
         DATABANK-TEAM5MSC530DBFINAL.BNK.HTM  SHIP-TEAM5DBFINAL

PRINTED REPORT NO.  1 - SUMMARY

SHIP TYPE-SC                          AVIATION FACILITY-MINOR AVN
COLL PROTECT SYSTEM-PRESENT           HAB STANDARD-NAVY
SONAR DOME-PRESENT                    EMBARKED COMMANDER-NONE

FULL LOAD WT, MTON         6542.7
TOTAL CREW ACC               260.     PASSWAY MARGIN FAC          0.000
HULL AVG DECK HT, M          3.04
MR VOLUME, M3               2916.     SPACE MARGIN FAC            0.000
TANK VOL REQ,M3             1672.     TANK MARGIN FAC             0.000
SHAFT ALLEY VOLUME,M3          0.

                                     AREA M2                     VOL M3
                         PAYLOAD      TOTAL       TOTAL           TOTAL
                         REQUIRED    REQUIRED    AVAILABLE        ACTUAL
                         --------    --------    ---------       --------
DKHS ONLY                    316.        942.       1253.          3836.
HULL OR DKHS                   0.       4410.       4309.         18021.
                         --------    --------    ---------       --------
TOTAL                        316.       5352.       5562.         21857.

                                TOTAL     DKHS     PERCENT
SSCS    GROUP                  AREA M2   AREA M2  TOTAL AREA
-------------                  --------  --------  ----------
 1. MISSION SUPPORT               533.      397.      10.0
 2. HUMAN SUPPORT                1415.       46.      26.4
 3. SHIP SUPPORT                 1752.      173.      32.7
 4. SHIP MOBILITY SYSTEM         1652.      326.      30.9
 5. UNASSIGNED                                         0.0
                               --------  --------  ----------
                 TOTAL           5352.      942.     100.0
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Appendix F – Machinery Equipment List

ITEM	QTY	NOMENCLATURE	CAPACITY RATING	LOCATION	SWBS #	REMARKS	DIMENSIONS LxWxH (m)
1	2	Gas Turbine, Main LM2500+	26MW	MMR2	234	Includes Acoustic Enclosure	8.48x2.65x3.00
2	1	Gas Turbine, Sec ICR	21.6MW	MMR1	234	Includes Acoustic Enclosure	8.00x2.64x2.64
3	1	Secondary Engine Intercooler	-	MMR1	234	Located next to Secondary Engine	2.48x1.37x1.74
4	2	Main Propulsion Generator	26MW	MMR2	234	Located next to Main Engine	5.41 x 2.80 x 3.89
5	1	Secondary Propulsion Generator	21MW	MMR1	234	Located next to Secondary Engine	4.60 x 2.80 x 3.40
6	2	Propulsion Motors	28MW	MMR1, MMR2	234	Pods	5.53 x 2.80 x 2.80
7	2	Unit, MGT Hydraulic Starting	14.8 m^3/hr @ 414 bar	MMR2	556	near end ME away from RG	2x2x2
	2	Main Engine Exhaust Duct	90.5 kg/sec	MMR2 and up	234	Needs to follow almost vertical path up through hull, deckhouse and out stack	5.8 m2
	2	Main Engine Inlet Duct	6.10 m/s	MMR2 and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	11.9 m2
8	2	Unit, MGT Hydraulic Starting	14.8 m^3/hr @ 414 bar	MMR1	556	near end ME away from RG	2x2x2
	2	Secondary Engine Exhaust Duct	74.4 kg/sec	MMR1 and up	234	Needs to follow almost vertical path up through hull, deckhouse and out stack	3.8 m2
	2	Secondary Engine Inlet Duct	6.10 m/s	MMR1 and up	234	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	9.8 m2
9	2	Console, Main Control	NA	MMR1 and MMR2 Engineering Operation Station (EOS)	252	MMR 2nd or upper level in EOS looking down on RG	3x1x2
10	2	Diesel Engine, Ships Service CAT 3516V16	1275kW, 480 V, 3 phase, 60 Hz, 0.8 PF	AMR	311	Includes enclosure, 2nd or upper level, orient F&A	3.69 x 1.70 x 2.05
11	2	D Generator, Ships Service	1275kW, 480 V, 3 phase, 60 Hz, 0.8 PF	AMR	311	Includes enclosure, 2nd level if possible, orient F&A	1.60 x 1.10 x 1.55
	2	SSD Exhaust Duct	2.4 kg/sec	AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out stack	0.1 m2
	2	SSD Inlet Duct	6.1 m/sec	AMR and up	311	Needs to follow almost vertical path up through hull, deckhouse and out side of stack or deckhouse	0.4 m2
12	5	PD SS DC-BUS Rectifier	6.1 m/sec	MMR2, MMR1, AMR	311		2.68 x 1.22 x 1.83
13	5	PD SS DC-BUS .25MW Inverter	0.25MW	MMR2, MMR1, AMR	311		0.61 x 0.61 x 1.83
14	2	Switchboard, Ships Service	-	MMR1, MMR2	324	MMR upper level in EOS	3.096 x 1.220 x 2.286
15	1	Switchboard, Ships Service	-	AMR	324	AMR upper level	2.5x1x2
	6	MMR and AMR ladders	-	MMR2, MMR1, AMR		May have single or double inclined ladders between levels depending on space	1.0x2.0
	3	MMR and AMR escape trunks	-	MMR2, MMR1, AMR		One per space in far corners, bottom to main deck	1.5x1.5
16	2	MN Machinery Space Fan	94762 m^3/hr	FAN ROOM	512	above, outside MMR	1.118 (H) x 1.384 (dia)
17	4	MN Machinery Space Fan	91644 m^3/hr	MMR1, MMR2	512	Upper level in corners	1.118 (H) x 1.384 (dia)
18	2	Aux Machinery Space Fan	61164 m^3/hr	FAN ROOM	512	above, outside AMR	1.092 (H) x 1.118 (dia)
19	2	Aux Machinery Space Fan	61164 m^3/hr	AMR	512	Upper level in corners	1.092 (H) x 1.118 (dia)
20	2	Pump, Main Seawater Circ	230 m^3/hr @ 2 bar	MMR1, MMR2	256	P&S MMR lower level near hull and ME	.622 x .622 x 1.511
21	3	Assembly, MGT Lube Oil Storage and Conditioning	NA	MMR1, MMR2	262	next to each engine	1.525 x 2.60 x 1.040
22	2	Purifier, Lube Oil	1.1 m^3/hr	MMR	264	next to LO transfer pump, 2nd or upper level MMR	.830 x .715 x 1.180
23	2	Pump, Lube Oil Transfer	4 m^3/hr @ 5 bar	MMR	264	next to LO purifier	.699 x .254 x .254

24	2	Filter Separator, MGT Fuel	30 m^3/hr	MMR1, MMR2	541	next to FO purifiers	1.6 (L) x.762 (dia)
25	2	Purifier, Fuel Oil	7.0 m^3/hr	MMR1, MMR2	541	2nd or upper level MMR	1.2 x 1.2 x 1.6
26	2	Pump, Fuel Transfer	45.4 m^3/hr @ 5.2 bar	MMR1, MMR2	541	next to FO purifiers	1.423 x .559 x .686
	2	Fuel Oil Service Tanks	-	MMR1, MMR2		lower level MMR P&S	size for 4 hours at endurance speed
27	4	Air Conditioning Plants	150 ton	AMR	514	either level, side by side	2.353 x 1.5 x 1.5
28	4	Pump, Chilled Water	128 m^3/hr @4.1 bar	AMR	532	next to AC plants	1.321 x .381 x .508
29	2	Refrig Plants, Ships Service	4.3 ton	AMR	516	either level, side by side	2.464 x .813 x 1.5
30	6	Pump, Fire	454 m^3/hr @ 9 bar	MMR2, MMR1, AMR	521	lower levels	2.490 x .711 x .864
31	2	Pump, Fire/Ballast	454 m^3/hr @ 9 bar	MMR2, MMR1	521	lower levels	2.490 x .711 x .864
32	2	Pump, Bilge	227 m^3/hr @3.8 bar	MMR2, MMR1	529	lower levels	1.651 x .635 x 1.702
33	1	Pump, Bilge/Ballast	227 m^3/hr @3.8 bar	AMR	529	lower levels	1.651 x .635 x .737
34	3	Station, AFFF	227 m^3/hr @3.8 bar	above MMR2, MMR1, AMR	555	for entering space	2.190 x 1.070 x 1.750
35	2	Distiller, Fresh Water	76 m^3/day (3.2 m^3/hr)	AMR	531	lower or 2nd level	2.794 x 3.048 x 2.794
36	2	Brominator	1.5 m^3/hr	AMR	531	next to distillers	.965 x .203 x .406
37	2	Brominator	5.7 m^3/hr	AMR	533	next to distillers	.533 x.356 x 1.042
38	2	Pump, Potable Water	22.7 m^3/hr @ 4.8 bar	AMR	533	next to distillers	.787 x .559 x .356
39	2	Pump, JP-5 Transfer	11.5 m^3/hr @ 4.1 bar	JP-5 PUMP ROOM	542	in JP-5 pump room	1.194 x.483 x .508
40	2	Pump, JP-5 Service	22.7 m^3/hr @ 7.6 bar	JP-5 PUMP ROOM	542	in JP-5 pump room	1.194 x .483 x .508
41	1	Pump, JP-5 Stripping	5.7 m^3/hr @ 3.4 bar	JP-5 PUMP ROOM	542	in JP-5 pump room	.915 x .381 x .381
42	2	Filter/Separ., JP-5 Transfer	17 m^3/hr	JP-5 PUMP ROOM	542	in JP-5 pump room	.457 (L) x 1.321 (dia)
43	2	Filter/Separ., JP-5 Service	22.7 m^3/hr	JP-5 PUMP ROOM	542	in JP-5 pump room	.407 (L) x 1.219 (dia)
44	3	Receiver, Starting Air	2.3 m^3	MMR2, MMR1, AMR	551	near ME, compressors and bulkhead	1.067 (dia) x 2.185 (H)
45	3	Compressor, MP Air	80 m^3/hr FADY @ 30 bar	MMR2, MMR1, AMR	551	2nd or upper level	1.334 x .841 x .836
46	1	Receiver, Ship Service Air	1.7 m^3	MMR1	551	near ME, compressors and bulkhead	1.830 (H) x .965 (dia)
47	1	Receiver, Control Air	1 m^3	MMR1	551	near ME, compressors and bulkhead	3.421 (H) x .610 (dia)
48	2	Compressor, Air, LP Ship Service	8.6 bar @ 194 SCFM	MMR1, MMR2	551	2nd or upper level	1.346 x 1.067 x 1.829
49	2	Dryer, Air	250 SCFM	MMR1, MMR2	551	near LP air compressors	.610 x .864 x 1.473
50	2	Hydraulic Pump and Motor	-	aft Steering Gear Room	561	next to ram	0.5x0.8x0.8
51	1	Hydraulic Steering Ram	-	aft Steering Gear Room	561	over pods	1.2x8.5x1.5
52	3	Pump, Oily Waste Transfer	12.3 m^3/hr @ 7.6 bar	MMR2, MMR1, AMR	593	lower level	1.219 x .635 x .813
53	3	Separator, Oil/Water	2.7 m^3/hr	MMR2, MMR1, AMR	593	lower level near oily waste transfer pump	1.321 x .965 x 1.473
54	1	Unit, Sewage Collection	28 m^3	SEWAGE TREATMENT ROOM	593	sewage treatment room	2.642 x 1.854 x 1.575
55	1	Sewage Plant	225 people	SEWAGE TREATMENT ROOM	593	sewage treatment room	1.778 x 1.092 x 2.007

Appendix G – Weights and Centers

	FULL LOAD CONDITION	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F00	LOADS	1119.9	2.8	3187.1	62.2	69703.5	0.1	153.1
F10	SHIPS FORCE	29.0	8.2	237.5	65.3	1894.6	1.8	52.2
F21	SHIP AMMUNITION	77.9	7.8	607.6	121.8	9488.2	0.0	0.0
F22	ORD DEL SYS AMMO	10.0	7.5	75.0	48.0	480.0	0.0	0.0
F23	ORD DEL SYS (AIRCRAFT)	30.7	13.9	426.7	89.0	2732.3	0.0	0.0
F31	PROVISIONS+PERSONNEL STORES	30.8	10.0	308.0	65.0	2002.0	4.1	125.0
F32	GENERAL STORES	6.9	7.3	50.4	103.0	710.7	-3.5	-24.2
F41	DIESEL FUEL MARINE	805.9	1.0	805.9	50.0	40295.0	0.0	0.0
F42	JP-5	81.2	5.3	427.1	103.8	8428.6	0.0	0.0
F46	LUBRICATING OIL	8.2	6.2	50.4	100.4	822.9	0.0	0.0
F47	SEA WATER	0.0	6.1	0.0	57.7	0.0	0.0	0.0
F52	FRESH WATER	39.3	5.1	198.5	72.5	2849.3	0.0	0.0
	Total Weight	6510.1	5.8	37673.6	75.0	488237.7	0.0	236.6

	MINIMUM OPERATING CONDITION	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
F00	LOADS	426.2	3.6	1529.1	64.1	27305.6	0.2	80.4
F10	SHIPS FORCE	29.0	8.2	237.5	65.3	1894.6	0.0	0.0
F21	SHIP AMMUNITION	26.0	7.8	202.6	121.8	3163.1	1.8	46.7
F22	ORD DEL SYS AMMO	3.3	7.5	25.0	48.0	159.8	0.0	0.0
F23	ORD DEL SYS (AIRCRAFT)	30.7	13.9	426.7	89.0	2732.3	0.0	0.0
F31	PROVISIONS+PERSONNEL STORES	10.3	6.0	61.6	75.1	770.9	4.1	41.7
F32	GENERAL STORES	2.3	6.8	15.6	75.1	172.6	-3.5	-8.1
F41	DIESEL FUEL MARINE	268.6	1.0	268.6	50.0	13430.0	0.0	0.0
F42	JP-5	27.1	5.3	142.3	103.8	2808.8	0.0	0.0
F46	LUBRICATING OIL	2.7	6.2	16.8	100.4	274.0	0.0	0.0
F47	SEA WATER	0.0	6.1	0.0	57.7	0.0	0.0	0.0
F52	FRESH WATER	26.2	5.1	132.3	72.5	1899.5	0.0	0.0
	Total Weight	5816.4	6.2	36015.5	76.7	445839.9	0.0	163.9

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
100	HULL STRUCTURES	2191.2	6.5	14345.5	77.2	169116.5	0.0	0.0
200	PROPULSION PLANT	795.6	3.5	2770.4	106.1	84389.5	0.0	0.0
300	ELECTRIC PLANT, GENERAL	383.8	6.0	2313.1	67.0	25722.1	0.0	0.0
400	COMMAND+SURVEILLANCE	270.1	11.2	3018.1	61.2	16538.4	0.3	75.6
500	AUXILIARY SYSTEMS, GENERAL	643.9	7.3	4674.0	56.2	36205.8	0.3	180.5
600	OUTFIT+FURNISHING,GENERAL	489.9	6.7	3278.5	81.6	39981.6	-0.4	-214.2
700	ARMAMENT	125.7	7.6	951.8	67.9	8531.8	0.3	34.1
	LIGHTSHIP WEIGHT	4900.2	6.4	31351.3	77.6	380485.7	0.0	75.9
	MARGIN	490.0	6.4	3135.1	77.6	38048.6	0.0	7.6
	LIGHTSHIP WEIGHT + MARGIN	5390.2	6.4	34486.5	77.6	418534.3	0.0	83.5

SWBS	COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
	FULL LOAD WEIGHT + MARGIN	6510.12	5.79	37673.60	75.00	488237.75	0.04	236.63
	MINOP WEIGHT AND MARGIN	5816.38	6.19	36015.52	76.65	445839.92	0.03	163.93
	LIGHTSHIP WEIGHT + MARGIN	5390.22	6.40	34486.47	77.65	418534.28	0.02	83.53
	LIGHTSHIP WEIGHT	4900.20	6.40	31351.33	77.65	380485.71	0.02	75.94
	MARGIN	490.02	6.40	3135.13	77.65	38048.57	0.02	7.59
100	HULL STRUCTURES	2191.20	6.55	14345.52	77.18	169116.51	0.00	0.00
110	SHELL + SUPPORTS	615.70	3.55	2185.74	70.77	43573.09	0.00	0.00
120	HULL STRUCTURAL BULKHDS	170.90	6.69	1143.32	79.61	13605.35	0.00	0.00
130	HULL DECKS	504.90	9.65	4872.29	81.18	40987.78	0.00	0.00
140	HULL PLATFORMS/FLATS	78.60	3.67	288.46	70.79	5564.09	0.00	0.00
150	DECK HOUSE STRUCTURE	182.80	16.80	3071.04	78.40	14331.52	0.00	0.00
160	SPECIAL STRUCTURES	192.10	4.96	952.82	76.08	14614.97	0.00	0.00
170	MASTS+KINGPOSTS+SERV PLATFORM	2.00	28.45	56.90	81.97	163.94	0.00	0.00
180	FOUNDATIONS	332.00	3.18	1055.76	83.09	27585.88	0.00	0.00
190	SPECIAL PURPOSE SYSTEMS	112.20	6.41	719.20	77.45	8689.89	0.00	0.00
200	PROPULSION PLANT	795.60	3.48	2770.38	106.07	84389.54	0.00	0.00
230	PROPULSION UNITS	584.60	2.49	1455.65	108.29	63306.33	0.00	0.00
234	GAS TURBINES			0.00		0.00		0.00
235	ELECTRIC PROPULSION			0.00		0.00		0.00

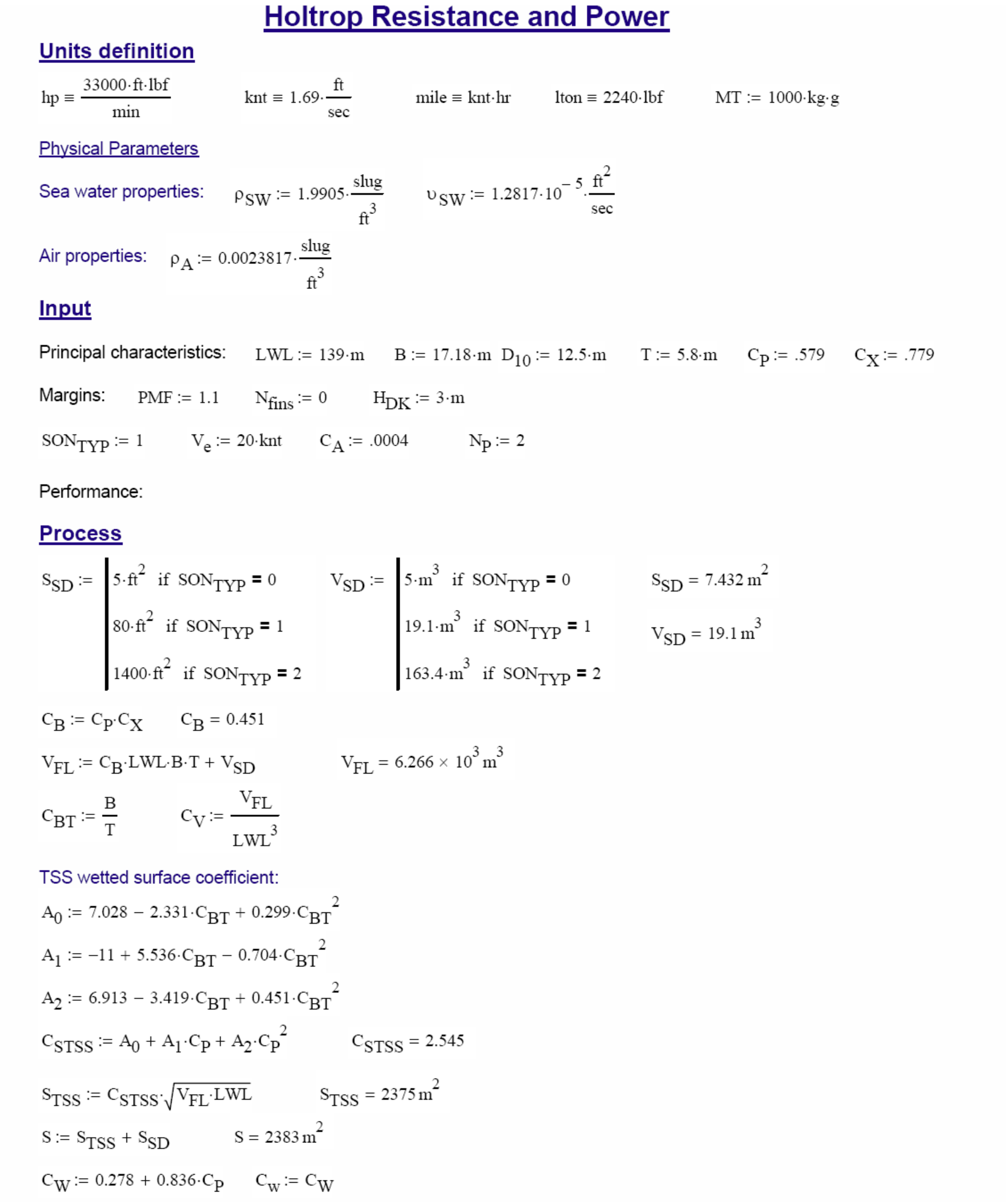
240	TRANSMISSION+PROPULSOR SYSTEMS	78.90	0.40	31.56	127.37	10049.49	0.00	0.00
241	REDUCTION GEARS			0.00		0.00		0.00
242	CLUTCHES + COUPLINGS			0.00		0.00		0.00
243	SHAFTING			0.00		0.00		0.00
244	SHAFT BEARINGS			0.00		0.00		0.00
245	PROPULSORS			0.00		0.00		0.00
250	SUPPORT SYSTEMS, UPTAKES	112.40	10.74	1207.18	83.97	9438.23	0.00	0.00
260	PROPUL SUP SYS- FUEL, LUBE OIL	6.70	4.88	32.70	78.64	526.89	0.00	0.00
290	SPECIAL PURPOSE SYSTEMS	13.00	3.33	43.29	82.20	1068.60	0.00	0.00
300	ELECTRIC PLANT, GENERAL	383.80	6.03	2313.08	67.02	25722.10	0.00	0.00
310	ELECTRIC POWER GENERATION	179.20	3.10	555.52	59.69	10696.45	0.00	0.00
311	SHIP SERVICE POWER GENERATION			0.00		0.00		0.00
312	EMERGENCY GENERATORS			0.00		0.00		0.00
314	POWER CONVERSION EQUIPMENT			0.00		0.00		0.00
320	POWER DISTRIBUTION SYS	146.40	8.64	1264.90	74.21	10864.34	0.00	0.00
330	LIGHTING SYSTEM	31.50	10.26	323.19	73.11	2302.97	0.00	0.00
340	POWER GENERATION SUPPORT SYS	13.50	8.31	112.19	50.77	685.40	0.00	0.00
390	SPECIAL PURPOSE SYS	13.20	4.34	57.29	88.86	1172.95	0.00	0.00
400	COMMAND+SURVEILLANCE	270.10	11.17	3018.11	61.23	16538.40	0.28	75.56
410	COMMAND+CONTROL SYS	17.60	19.20	337.92	64.8	1140.48	0.00	0.00
420	NAVIGATION SYS	9.20	19.20	176.64	64.8	596.16	0.00	0.00
430	INTERIOR COMMUNICATIONS	28.90	19.20	554.88	81.8	2364.02	-2.70	-78.03
440	EXTERIOR COMMUNICATIONS	0.00	19.20	0.00	81.8	0.00	-2.70	0.00
450	SURF SURVEILLANCE SYS (RADAR)	45.60	22.10	1007.76	64.5	2941.20	0.00	0.00
460	UNDERWATER SURVEILLANCE SYSTEMS	57.90	-0.50	-28.95	-1.4	-81.06	0.00	0.00
470	COUNTERMEASURES	49.10	7.41	363.83	122.4	6009.84	2.30	112.93
480	FIRE CONTROL SYS	21.40	10.46	223.84	37.4	800.36	1.90	40.66
490	SPECIAL PURPOSE SYS	40.40	9.46	382.18	68.5	2767.40	0.00	0.00
500	AUXILIARY SYSTEMS, GENERAL	643.90	7.26	4674.03	56.23	36205.79	0.28	180.48
510	CLIMATE CONTROL	144.20	6.81	982.00	38.3	5522.86	0.00	0.00
	CPS		6.81	0.00	38.3	0.00	0.00	0.00
520	SEA WATER SYSTEMS (FORWARD)	77.25	6.50	502.13	9	695.25	0.00	0.00
520	SEA WATER SYSTEMS (AFT)	25.75	5.90	151.93	132.4	3409.30	0.00	0.00
530	FRESH WATER SYSTEMS	67.70	5.00	338.50	72.5	4908.25	0.00	0.00
540	FUELS/LUBRICANTS,HANDLING+STORAGE	44.40	5.30	235.32	101	4484.40	0.00	0.00
550	AIR,GAS+MISC FLUID SYSTEM	70.70	10.46	739.52	37.4	2644.18	1.90	134.33
560	SHIP CNTL SYS	0.00	0.00	0.00	139	0.00	0.00	0.00
570	UNDERWAY REPLENISHMENT SYSTEMS	44.70	7.41	331.23	119.5	5341.65	0.00	0.00
581	ANCHOR HANDLING+STOWAGE SYSTEMS	49.60	10.46	518.82	28	1388.80	0.00	0.00
582	MOORING+TOWING SYSTEMS	13.80	10.46	144.35	28	386.40	0.00	0.00
583	BOATS,HANDLING+STOWAGE SYSTEMS	9.90	7.41	73.36	119.5	1183.05	0.00	0.00
585	AIRCRAFT WEAPONS ELEVATORS	0.00	0.00	0.00	139	0.00	0.00	0.00
586	AIRCRAFT RECOVERY SUPPORT SYS	0.00	0.00	0.00	139	0.00	0.00	0.00
587	AIRCRAFT LAUNCH SUPPORT SYSTEM	0.00	0.00	0.00	139	0.00	0.00	0.00
588	AIRCRAFT HANDLING, STOWAGE	31.60	14.50	458.20	84	2654.40	0.00	0.00
589	MISC MECH HANDLING SYS	0.00	0.00	0.00	139	0.00	0.00	0.00
593	ENVIRONMENTAL POLLUTION CNTL SYS	12.60	4.26	53.68	76.5	963.90	0.00	0.00
598	AUX SYSTEMS OPERATING FLUIDS	44.60	2.50	111.50	39	1739.40	0.00	0.00
599	AUX SYSTEMS REPAIR TOOLS + PARTS	7.10	4.72	33.51	124.5	883.95	6.50	46.15
600	OUTFIT+FURNISHING,GENERAL	489.90	6.69	3278.46	81.61	39981.56	-0.44	-214.24
610	SHIP FITTINGS	12.50	1.73	21.63	99	1237.50	0.00	0.00
620	HULL COMPARTMENTATION	95.30	7.00	667.10	77.35	7371.46	0.00	0.00
630	PRESERVATIVES + COVERINGS	195.00	5.73	1117.35	72.45	14127.75	0.00	0.00
640	LIVING SPACES	49.40	6.41	316.65	60	2964.00	0.00	0.00
650	SERVICE SPACES	20.20	8.00	161.60	65	1313.00	-1.70	-34.34
660	WORKING SPACES	49.00	10.46	512.54	122.2	5987.80	-1.50	-73.50
670	STOWAGE SPACES	63.40	7.00	443.80	100	6340.00	-2.00	-126.80
690	SPECIAL PURPOSE SYS	5.10	7.41	37.79	125.5	640.05	4.00	20.40
700	ARMAMENT	125.70	7.57	951.76	67.87	8531.80	0.27	34.14
710	GUNS+AMMUNITION	23.10	7.80	180.18	121.80	2813.58	1.80	41.58
720	MISSLES+ROCKETS	84.90	7.15	607.04	46.28	3929.17	0.00	0.00
750	TORPEDOES	2.70	4.20	11.34	10.00	27.00	0.00	0.00
760	SMALL ARMS+PYROTECHNICS	2.00	13.00	26.00	89.00	178.00	6.00	12.00
780	AIRCRAFT RELATED WEAPONS	2.70	18.50	49.95	75.50	203.85	-7.20	-19.44
790	SPECIAL PURPOSE SYSTEMS	10.30	7.50	77.25	134.00	1380.20	0.00	0.00

Appendix H – SSCS Space Summary

SSCS	GROUP	AREA
1.113	VISUAL COM	5.9
1.122	UNDERWATER SURV (SONAR)	23.3
1.13201	PILOT HOUSE	46.8
1.13202	CHART ROOM	7.0
1.15	INTERIOR COMMUNICATIONS	49.9
1.321201	HELICOPTER CONTROL STATION	9.3
1.332202	TACAN EQUIP RM	11.1
1.35306	AVIATION OFFICE	8.4
1.36106	BATTERY SHOP	5.9
1.36905	HELICOPTER SHOP	11.6
1.391102	AVIATION STORE RM	21.4
1.91	SM ARMS (LOCKER)	6.9
1.94	ARMORY	8.1
1.95	SECURITY FORCE EQUIP	1.0
2.1111101	COMMANDING OFFICER CABIN	22.9
2.1111104	COMMANDING OFFICER STATEROOM	16.3
2.1111206	EXECUTIVE OFFICER STATEROOM	13.9
2.111123	DEPARTMENT HEAD STATEROOM	44.6
2.1111302	OFFICER STATEROOM (DBL)	106.8
2.1121101	COMMANDING OFFICER BATH	4.6
2.1121201	EXECUTIVE OFFICER BATH	2.8
2.1121203	OFFICER BATH	4.2
2.1121303	OFFICER WR, WC & SH	16.4
2.1211	SHIP CPO	21.2
2.131101	LIVING SPACE	376.8
2.132101	SANITARY	78.8
2.14002	BRIDGE WASHRM & WC	2.3
2.14003	DECK WASHRM & WC	2.3
2.14004	ENGINEERING WR & WC	2.3
2.15101	ENTERTAINMENT EQUIP STRM	4.8
2.15201	PROJECTION EQUIP RM	1.9
2.15302	ATHLETIC GEARM STRM	2.9
2.16002	RECOGNITION TRAINING LKR	3.3
2.21101	WARDROOM MESSRM & LOUNGE	53.4
2.21201	CPO MESSROOM AND LOUNGE	55.7
2.21301	1ST CLASS MESSROOM	13.8
2.21303	CREW MESSROOM	78.3
2.22201	COMMANDING OFFICER GALLEY	10.7
2.22202	WARD ROOM GALLEY	9.8
2.22204	CREW GALLEY	44.6
2.22302	WARDROOM PANTRY	7.4
2.22403	CREW SCULLERY	16.7
2.231	CHILL PROVISIONS	15.7
2.232	FROZEN PROVISIONS	15.4
2.233	DRY PROVISIONS	33.1
2.234	ISSUE	5.6
2.23401	PROVISION ISSUE ROOM	5.6
2.31012	MEDICAL TREATMENT ROOM	16.1
2.31024	WARD	4.6
2.31025	WARD BATH	5.5
2.33201	FWD BATTLE DRESSNIG STA	7.0
2.33203	AFT BATTLE DRESSING STA	7.0
2.34103	MEDICAL LOCKER	2.0
2.41001	SHIP STORE	15.5
2.41006	SHIP STORE STORERM	21.8
2.42001	LAUNDRY	48.3
2.44002	BARBER SHOP	7.0
2.46001	POST OFFICE	6.5
2.51001	OFFICER BAGGAGE STRM	4.6
2.51002	CPO BAGGAGE STRM	2.5
2.51003	CREW BAGGAGE STRM	9.7
2.52001	WARDROOM STOREROOM	2.3

2.52002	CPO STOREROOM	5.0
2.52003	COMMANDING OFFICER STRM	1.9
2.55001	FOUL WEATHER GEAR LOCKER	1.9
2.56	LINEN STOWAGE	2.2
2.57	FOLDING CHAIR STOREROOM	1.4
2.61	CBR DECON STATIONS	18.1
2.62001	CBR DEFENSE EQP STRMS	25.5
2.63	CPS AIRLOCKS	18.5
2.71	LIFEJACKET LOCKER	1.9
3.11	STEERING GEAR	73.1
3.22	REPAIR STATIONS	39.8
3.25	FIRE FIGHTING	23.9
3.301	GENERAL SHIP	16.9
3.302	EXECUTIVE DEPT	38.9
3.303	ENGINEERING DEPT	23.8
3.304	SUPPLY DEPT	34.3
3.305	DECK DEPT	10.3
3.306	OPERATIONS DEPT	15.7
3.5	DECK AUXILIARIES	16.6
3.51	ANCHOR HANDLING	35.4
3.53	TRANSFER AT SEA	16.6
		7.9
3.611	AUX (FILTER CLEANING)	10.6
3.612	ELECTRICAL	25.0
3.613	MECH (GENERAL WK SHOP)	35.2
3.614	PROPULSION MAINTENANCE	9.9
3.62	OPERATIONS DEPT (ELECT SHOP)	32.5
3.63	WEAPONS DEPT (ORDINANCE SHOP)	5.8
3.711	HAZARDOUS MATL (FLAM LIQ)	26.3
3.712	SPECIAL CLOTHING	11.6
3.713	GEN USE CONSUM+REPAIR PART	168.0
3.714	SHIP STORE STORES	6.7
3.715	STORES HANDLING	36.2
3.72	ENGINEERING DEPT	5.5
3.73	OPERATIONS DEPT	7.7
3.74	DECK DEPT (BOATSWAIN STORES)	68.3
3.75	WEAPONS DEPT	4.9
3.76	EXEC DEPT (MASTER-AT-ARMS STORE)	5.7
3.78	CLEANING GEAR STOWAGE	3.7
3.821	NORMAL ACCESS	154.5
		773.9
3.822	ESCAPE ACCESS	2.0
		9.2
3.941	SEWAGE TANKS	4.9
3.942	OILY WASTE TANKS	7.4
4.132	COMBUSITION AIR	2.9
		1.4
4.133	EXHAUST	7.4
		3.7
4.134	CONTROL	50.2
4.142	COMBUSTION AIR	119.5
		39.8
4.143	EXHAUST	139.1
		46.4
4.144	CONTROL	87.3
4.31	GENERAL (AUX MACH DELTA)	778.4
4.321	A/C (INCL VENT)	59.5
4.332	PWR DIST & CNTRL	21.4
4.334	DEGAUSSING	8.7
4.341	SEWAGE	12.1
4.342	TRASH	6.0
4.35	MECHANICAL SYSTEMS	14.7
4.36	VENTILATION SYSTEMS	57.1
		196.4

Appendix I – MathCAD Models



Holtrop Resistance and Power

Units definition

$hp \equiv \dfrac{33000 \cdot ft \cdot lbf}{min}$ $\quad knt \equiv 1.69 \cdot \dfrac{ft}{sec}$ $\quad mile \equiv knt \cdot hr$ $\quad lton \equiv 2240 \cdot lbf$ $\quad MT := 1000 \cdot kg \cdot g$

Physical Parameters

Sea water properties: $\rho_{SW} := 1.9905 \cdot \dfrac{slug}{ft^3}$ $\quad \upsilon_{SW} := 1.2817 \cdot 10^{-5} \cdot \dfrac{ft^2}{sec}$

Air properties: $\rho_A := 0.0023817 \cdot \dfrac{slug}{ft^3}$

Input

Principal characteristics: $LWL := 139 \cdot m$ $\quad B := 17.18 \cdot m$ $\quad D_{10} := 12.5 \cdot m$ $\quad T := 5.8 \cdot m$ $\quad C_P := .579$ $\quad C_X := .779$

Margins: $PMF := 1.1$ $\quad N_{fins} := 0$ $\quad H_{DK} := 3 \cdot m$

$SON_{TYP} := 1$ $\quad V_e := 20 \cdot knt$ $\quad C_A := .0004$ $\quad N_P := 2$

Performance:

Process

$$S_{SD} := \left| \begin{array}{l} 5 \cdot ft^2 \ \text{ if } SON_{TYP} = 0 \\ 80 \cdot ft^2 \ \text{ if } SON_{TYP} = 1 \\ 1400 \cdot ft^2 \ \text{ if } SON_{TYP} = 2 \end{array} \right. \qquad V_{SD} := \left| \begin{array}{l} 5 \cdot m^3 \ \text{ if } SON_{TYP} = 0 \\ 19.1 \cdot m^3 \ \text{ if } SON_{TYP} = 1 \\ 163.4 \cdot m^3 \ \text{ if } SON_{TYP} = 2 \end{array} \right.$$

$S_{SD} = 7.432\,m^2$

$V_{SD} = 19.1\,m^3$

$C_B := C_P \cdot C_X$ $\quad C_B = 0.451$

$V_{FL} := C_B \cdot LWL \cdot B \cdot T + V_{SD}$ $\quad V_{FL} = 6.266 \times 10^3\,m^3$

$C_{BT} := \dfrac{B}{T}$ $\quad C_V := \dfrac{V_{FL}}{LWL^3}$

TSS wetted surface coefficient:

$A_0 := 7.028 - 2.331 \cdot C_{BT} + 0.299 \cdot C_{BT}^{\,2}$

$A_1 := -11 + 5.536 \cdot C_{BT} - 0.704 \cdot C_{BT}^{\,2}$

$A_2 := 6.913 - 3.419 \cdot C_{BT} + 0.451 \cdot C_{BT}^{\,2}$

$C_{STSS} := A_0 + A_1 \cdot C_P + A_2 \cdot C_P^{\,2}$ $\quad C_{STSS} = 2.545$

$S_{TSS} := C_{STSS} \cdot \sqrt{V_{FL} \cdot LWL}$ $\quad S_{TSS} = 2375\,m^2$

$S := S_{TSS} + S_{SD}$ $\quad S = 2383\,m^2$

$C_W := 0.278 + 0.836 \cdot C_P$ $\quad C_w := C_W$

Pre-Process

$T_F := T$ $C_M := C_X$ $C_V := \dfrac{V_{FL}}{LWL^3}$ $C_V = 2.333 \times 10^{-3}$

$A_{BT} := \dfrac{S_{SD}}{6}$ $A_{BT} = 1.239\,m^2$ (bulb section area at FP)

$h_B := \sqrt{\dfrac{A_{BT}}{\pi}}$ $h_B = 0.628\,m$ (height of bulb center)

$A_T := \dfrac{B \cdot T \cdot C_X}{20}$ $A_T = 3.881\,m^2$ (transom area)

$L_R := (1 - C_P) \cdot LWL$ $L_R = 58.519\,m$ (Run length)

$$formfac := 1.03 \cdot \left[.93 + \left(\frac{T}{LWL}\right)^{.22284} \cdot \left(\frac{B}{L_R}\right)^{.92497} \cdot (.95 - C_P)^{-.521448} \cdot (1 - C_P + .05)^{.6906}\right] + 2.7 \cdot \frac{S_{SD}}{S} \qquad formfac = 1.129$$

Appendages drag coefficient:

$$C_{DAPP} := \left(-4 \cdot 10^{-9} \cdot \frac{LWL^3}{ft^3} + 9 \cdot 10^{-6} \cdot \frac{LWL^2}{ft^2} - 0.0081 \cdot \frac{LWL}{ft} + 5.0717\right) \cdot \frac{hp \cdot 10^{-5}}{ft^2 \cdot knt^3} \qquad C_{DAPP} = 5.946 \times 10^{-6} \frac{hp}{ft^2 \cdot \left(\frac{ft}{sec}\right)^3}$$

Estimate propeller size:

$C_{PROP} := if(N_P > 1, 1, 1.2)$ $C_{PROP} = 1$ $D_P := (0.64 \cdot T + 0.013 \cdot$ 5.519 m

$i := 1 .. 16$ $V_i := (i - 1) \cdot knt + V_e$ $V_{14} := 32.9 \cdot knt$

$R_{A_i} := .5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S \cdot C_A$

$V =$

	1
1	20
2	21
3	22
4	23
5	24
6	25
7	26
8	27
9	28
10	29
11	30
12	31
13	32
14	32.9
15	34
16	35

knt

Viscous Drag

Coefficient of friction:

$R_{N_i} := LWL \cdot \dfrac{V_i}{\upsilon_{SW}}$ $C_{F_i} := \dfrac{0.075}{\left(\log(R_{N_i}) - 2\right)^2}$ (ITTC)

$R_{V_i} := 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S \cdot C_{F_i} \cdot formfac$

Wave Making Drag

$Fn_i := \dfrac{V_i}{\sqrt{g \cdot LWL}}$

$c_3 := \dfrac{.56 \cdot A_{BT}^{1.5}}{B \cdot T \cdot \left(.31 \cdot \sqrt{A_{BT}} + T_F - h_B\right)}$ $c_3 = 1.404 \times 10^{-3}$ $c_2 := \exp\left(-1.89 \cdot \sqrt{c_3}\right)$ $c_2 = 0.932$

$c_5 := 1 - \dfrac{.8 \cdot A_T}{B \cdot T \cdot C_M}$ $c_5 = 0.96$

$$\lambda_R := \begin{vmatrix} 1.446 \cdot C_P - .03 \cdot \dfrac{LWL}{B} & \text{if } \dfrac{LWL}{B} < 12 \\ 1.446 \cdot C_P - .036 & \text{otherwise} \end{vmatrix} \qquad \lambda_R = 0.595$$

$$c_{15} := \begin{cases} -1.69385 & \text{if } \dfrac{LWL^3}{V_{FL}} < 512. \\ 0.0 & \text{if } \dfrac{LWL^3}{V_{FL}} > 1726.91 \\ -1.69385 + \dfrac{\dfrac{LWL}{V_{FL}^{\frac{1}{3}}} - 8}{2.36} & \text{otherwise} \end{cases} \qquad c_{15} = -1.694$$

$$c_7 := \begin{cases} .229577 \cdot \left(\dfrac{B}{LWL}\right)^{.33333} & \text{if } \dfrac{B}{LWL} < .11 \\ .5 - .0625 \cdot \dfrac{LWL}{B} & \text{if } \dfrac{B}{LWL} > .25 \\ \dfrac{B}{LWL} & \text{otherwise} \end{cases} \qquad c_7 = 0.124$$

$$c_{16} := \begin{cases} 8.07981 \cdot C_P - 13.8673 \cdot C_P^{\,2} + 6.984388 \cdot C_P^{\,3} & \text{if } C_P < .8 \\ 1.73014 - .7067 \cdot C_P & \text{otherwise} \end{cases} \qquad c_{16} = 1.385$$

$$i_E := 1 + 89 \cdot \exp\left[-\left(\frac{LWL}{B}\right)^{.80856} \cdot \left(1 - C_W\right)^{.30484} \cdot \left(1 - C_P\right)^{.6367} \cdot \left(\frac{L_R}{B}\right)^{.34574} \cdot \left(\frac{100 \cdot V_{FL}}{LWL^3}\right)^{.16302} \right] \qquad i_E = 8.824$$

$$c_1 := 2223105 \cdot c_7^{\,3.78613} \cdot \left(\frac{T}{B}\right)^{1.07961} \cdot \left(90 - i_E\right)^{-1.37565} \qquad c_1 = 0.593$$

$$m_1 := .0140407 \cdot \frac{LWL}{T} - 1.75254 \cdot \frac{V_{FL}^{\frac{1}{3}}}{LWL} - 4.79323 \cdot \frac{B}{LWL} - c_{16} \qquad m_1 = -1.873$$

$$m_{4_i} := .4 \cdot c_{15} \cdot \exp\left[-.034 \cdot \left(Fn_i\right)^{-3.29}\right]$$

$$R_{w_i} := V_{FL} \cdot \rho_{SW} \cdot g \cdot c_1 \cdot c_2 \cdot c_5 \cdot \exp\left[m_1 \cdot \left(Fn_i\right)^{-.9} + m_{4_i} \cdot \cos\left[\frac{\lambda_R}{\left(Fn_i\right)^2}\right]\right]$$

$$P_B := \frac{.56 \cdot A_{BT}^{\,.5}}{\left(T_F - 1.5 \cdot h_B\right)} \qquad P_B = 0.128$$

$$WCF := \begin{pmatrix} .588 \\ .6 \\ .62 \\ .64 \\ .66 \\ .68 \\ .71 \\ .74 \\ .77 \\ .8 \\ .83 \\ .86 \\ .9 \\ .92 \\ .94 \\ .99 \end{pmatrix}$$

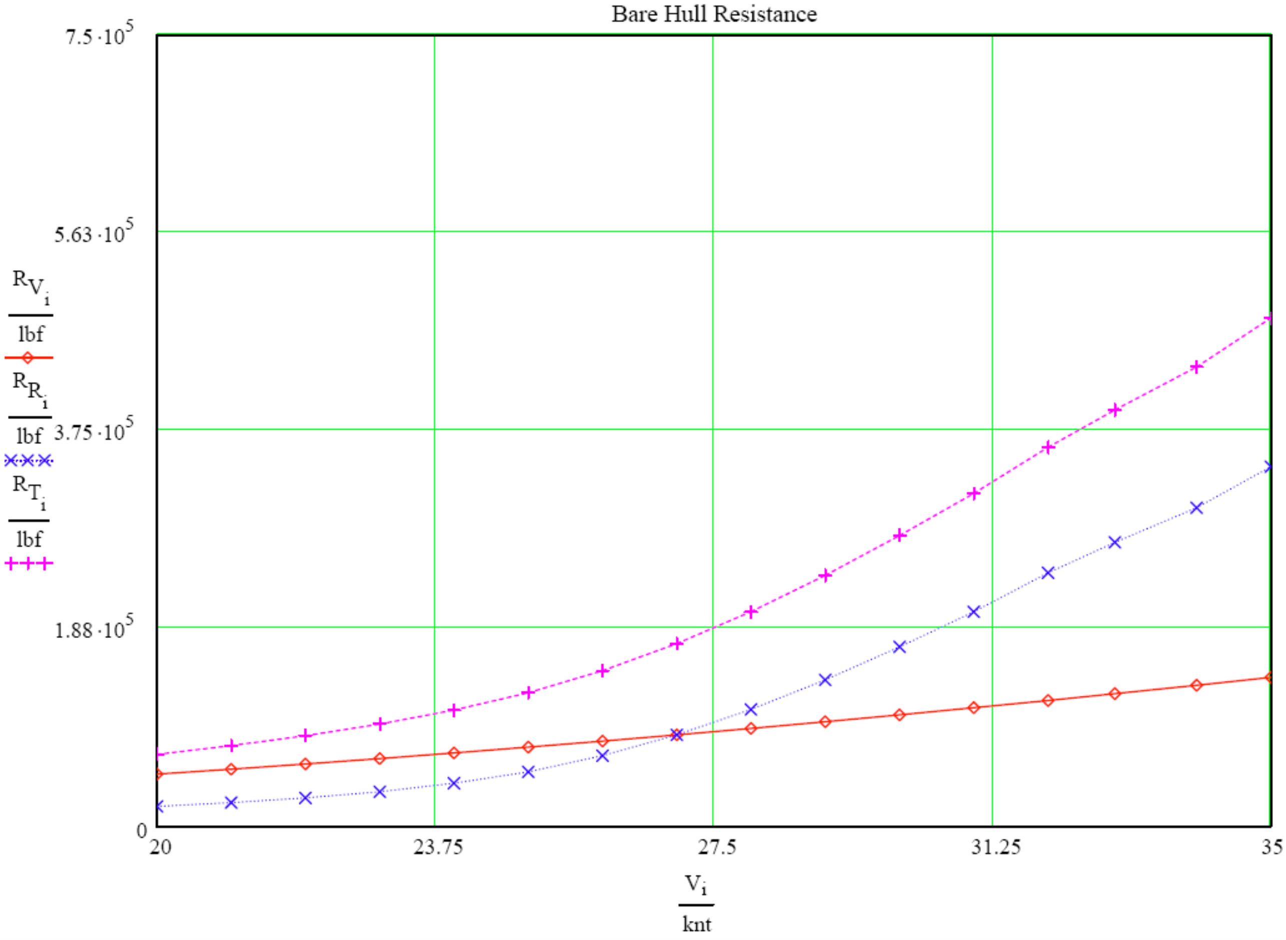
$$Fni_i := \frac{V_i}{\sqrt{g \cdot \left(T_F - h_B - .25 \cdot A_{BT}^{\,.5}\right) + .15 \cdot \left(V_i\right)^2}} \qquad R_{B_i} := \frac{.11 \cdot \exp\left(\dfrac{-3}{P_B^{\,2}}\right) \cdot \left(Fni_i\right)^3 \cdot A_{BT}^{\,1.5} \cdot \rho_{SW} \cdot g}{1 + \left(Fni_i\right)^2}$$

$$FnT_i := \frac{V_i}{\sqrt{\dfrac{2 \cdot g \cdot A_T}{B + B \cdot C_W}}} \qquad c_{6_i} := \begin{cases} .2 \cdot \left(1 - .2 \cdot FnT_i\right) & \text{if } FnT_i < 5 \\ 0. & \text{otherwise} \end{cases} \qquad R_{TR_i} := .5 \cdot \rho_{SW} \cdot \left(V_i\right)^2 \cdot A_T \cdot c_{6_i}$$

Bare Hull Resistance

$$R_{R_i} := \left(R_{w_i} + R_{B_i} + R_{TR_i} + R_{A_i}\right) \cdot WCF_i$$

$$R_{T_i} := R_{V_i} + R_{R_i}$$



Ship Effective Horsepower

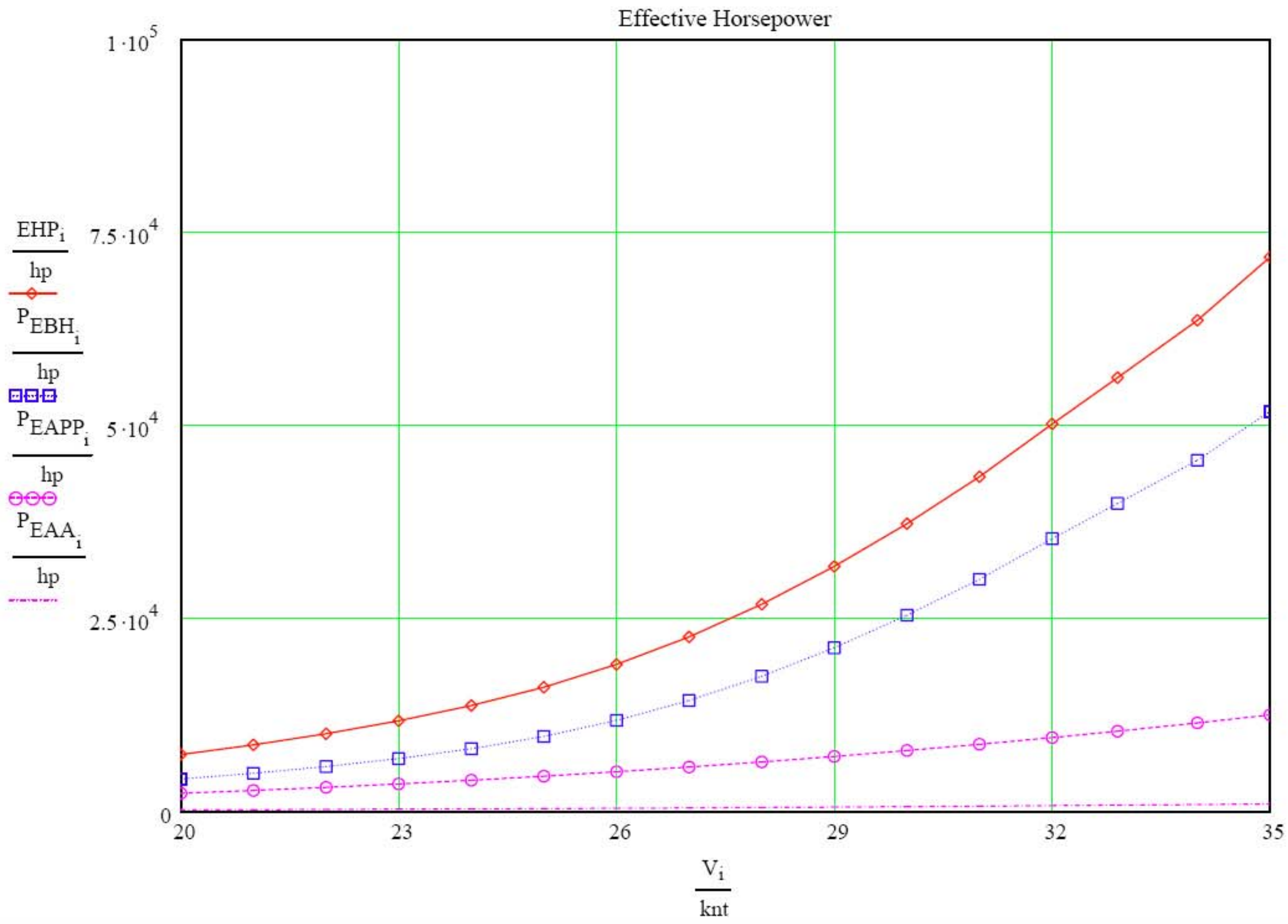
Bare hull: $P_{EBH_i} := R_{T_i} \cdot V_i$

$$P_{Efins_i} := \begin{cases} 0 \cdot hp & \text{if } N_{fins} = 0 \\ 0.025 \cdot P_{EBH_i} & \text{otherwise} \end{cases} \qquad P_{EAPP_i} := 1.23 \cdot LWL \cdot D_P \cdot C_{DAPP} \cdot \left(V_i\right)^3 + P_{Efins_i}$$

Air frontal area (+5% for masts, equip., etc): $A_W := 1.05 \cdot B \cdot \left(D_{10} - T + 3 \cdot H_{DK}\right)$ $A_W = 283.212\ m^2$

$$C_{AA} := 0.7 \qquad P_{EAA_i} := \frac{1}{2} \cdot C_{AA} \cdot A_W \cdot \rho_A \cdot \left(V_i\right)^3$$

Total effective horsepower: $P_{ET_i} := P_{EBH_i} + P_{EAPP_i} + P_{EAA_i}$ $EHP_i := PMF \cdot P_{ET_i}$ $EHP_1 = 7354\ hp$



V = knt

	1
1	20
2	21
3	22
4	23
5	24
6	25
7	26
8	27
9	28
10	29
11	30
12	31
13	32
14	32.9
15	34
16	35

EHP = kW

	1
1	5484
2	6422
3	7495
4	8739
5	10214
6	11987
7	14187
8	16843
9	19995
10	23650
11	27774
12	32310
13	37402
14	41881
15	47418
16	53529

EHP = hp

	1
1	7354
2	8612
3	10051
4	11719
5	13697
6	16074
7	19025
8	22587
9	26814
10	31715
11	37246
12	43329
13	50157
14	56164
15	63588
16	71783

Appendix –

Prop Selection, Engine Match and Fuel Calculation - IPS w/GT

Units and Physical Constants

$knt \equiv 1.69 \cdot \frac{ft}{sec}$ $mile \equiv knt \cdot hr$ $lton \equiv 2240 \cdot lbf$ $nm := knt \cdot hr$ $kN := 1000 \cdot newton$ $RPM := \frac{1}{min}$

Sea water properties: $\rho_{SW} := 1.9905 \cdot \frac{slug}{ft^3}$ $\upsilon_{SW} := 1.2817 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ $\delta_F := 43.6 \cdot \frac{ft^3}{lton}$ $MT := 9810 \cdot kg \cdot \frac{m}{sec^2}$

Air properties: $\rho_A := 0.0023817 \cdot \frac{slug}{ft^3}$

Principal characteristics:

$T := 5.8 \cdot m$ $C_P := .579$ $C_X := .779$ $Draft := T$ $D_P := 5.59 \cdot m$ $D := D_P$

$KW_{24AVG} := 1634.98 \cdot kW$ $KW_{MFLM} := 4927kW$ $V_{F41} := 979 \cdot m^3$

$V_e := 20 \cdot knt$ $V_S := 32.9 \cdot knt$ $C_B := C_P \cdot C_X$ $C_B = 0.451$ $z := 5.41m$

$PMF_e := 1.1$ $PMF_S := 1.1$ $N_P := 2$

$w := 2 \cdot C_B{}^5 \cdot (1 - C_B) + .04$ $w = 0.06$ wake fraction

$t := .7 \cdot w + .06$ $t = 0.102$ thrust deduction fraction - prop changes pressure distribution around hull which effectively changes the resistance of towed hull

1. Maximize Propulsor Efficiency at Endurance Speed - input EHP from Resistance Calculation at Ve

$V := V_e$ $EHP := 7354 \cdot hp$ (total, hull)

$V_A := V \cdot (1 - w)$ $V_A = 18.79\,knt$ speed of advance - average wake velocity seen by prop

$T := \frac{EHP}{V \cdot (1 - t) \cdot N_P}$ $T = 66655\,lbf$ $T = 296.489\,kN$ thrust/shaft

$\eta_H := \frac{1 - t}{1 - w}$ $\eta_H = 0.955$ hull efficiency = $EHP/(THP_* N_P) = R_{T*}V/(T_* V_{A*} N_P)$

$\eta_R := 1.0$ estimate relative rotative efficiency - due to non-uniform flow into prop = DHPo/DHP

2. Determine the efficiency of an optimum standard propeller using the Wageningen B-screw series and the Propeller Optimization Program from the University of Michigan. The inputs for the program are:

Pitch Type = Fixed Pitch $Z := 4$ $EAR := 0.5929$ $PtoD := 1.3956$ $D = 5.59\,m$ $T = 296.489\,kN$

$V_e = 20\,knt$ $w = 0.06$ $z = 5.41\,m$

Output:

$D = 5.59\,m$ $EAR := 0.5929$ $PtoD := 1.3956$ $n_{eSHAFT} := 87RPM$ $\eta_O := .796$ $\sigma := .7402$

$\eta_B := \eta_O \cdot \eta_R$ $\eta_B = 0.796$ prop efficiency behind ship = THP/DHP

$\eta_D := \eta_H \cdot \eta_B$ $\eta_D = 0.761$ quasi-propulsive efficiency

$\eta_S := 1.0$ estimate transmission efficiency (mechanical external to hull - stern tube and struts)

$\eta_P := \eta_S \cdot \eta_D$ $\eta_P = 0.761$ propulsive efficiency

$\eta_{gen} := .973$ generator efficiency

$\eta_{conv} := .955$ convertor efficiency

$\eta_{motor} := .957$ motor efficiency

$\eta_{elec} := \eta_{gen} \cdot \eta_{conv} \cdot \eta_{motor}$

$\eta_{elec} = 0.889$ electrical efficiency

$THP := \frac{EHP}{\eta_H \cdot N_P}$ $THP = 3848.433\,hp$

$DHP := \frac{THP}{\eta_B}$ $DHP = 4834.715\,hp$ $DHP_O := \eta_R \cdot DHP$ $DHP_O = 4835\,hp$

$SHP := \frac{DHP}{\eta_S}$ $SHP = 4834.715\,hp$ (per shaft)

$BHP_{ereq} := \frac{PMF_e \cdot SHP \cdot N_P}{\eta_{elec}}$ $BHP_{ereq} = 11961\,hp$ (total ship)

3. Calculate "off-design" performance (η_O and n) and required BHP at sustained speed

$V := V_S$ $V = 32.9\,knt$ $V := 32knt$ $EHP := 56164 \cdot hp$

$T := \frac{EHP}{V \cdot (1-t) \cdot N_P}$ $T = 318159.83\,lbf$ $T = 1415.215\,kN$ $V_A := V \cdot (1-w)$ $V_A = 30.064\,knt$ (per shaft)

Determine the efficiency of the propeller at sustained speed (off-design):

$\eta_O := .761$ $n_{sSHAFT} := 153RPM$ $\sigma := .2476$ propeller cavitates

$THP := \frac{EHP}{\eta_H \cdot N_P}$ $THP = 29391.273\,hp$

$\eta_B := \eta_O \cdot \eta_R$ $\eta_B = 0.761$ prop efficiency behind ship = THP/DHP

$\eta_D := \eta_H \cdot \eta_B$ $\eta_D = 0.727$ quasi-propulsive efficiency

$\eta_P := \eta_S \cdot \eta_D$ $\eta_P = 0.727$ propulsive efficiency

$DHP := \frac{THP}{\eta_B}$ $DHP = 38621.909\,hp$ $DHP_O := \eta_R \cdot DHP$ $DHP_O = 38621.909\,hp$

$SHP := \frac{DHP}{\eta_S}$ $SHP = 38621.909\,hp$ (per shaft)

$BHP_{Sreq} := \frac{N_P \cdot PMF_S \cdot SHP}{\eta_{elec}}$ $BHP_{Sreq} = 71251.225\,kW$ (total ship)

4. Calculate optimum engine operating characteristics - Electric Propulsion

$P_{BPENG} := 21655 \cdot kW$

Summary, per shaft:

Endurance Speed: $N_{eENG} := 1$ $n_{eSHAFT} = 87\,RPM$

$$P_{BPENGe} := \frac{BHP_{ereq} + \frac{KW_{24AVG}}{.8}}{N_{eENG}}$$

$P_{BPENGe} = 14702\,hp$

Sustained Speed: $N_{sENG} := 1$ $n_{sSHAFT} = 153\,RPM$

$$P_{BPENGreq} := \frac{BHP_{Sreq} + \frac{.4 \cdot KW_{MFLM}}{.8}}{N_{sENG}}$$

$P_{BPENGreq} = 73715\,kW$

4a. Select engine RPM for minimum fuel consumption at endurance speed from the engine performance map. Estimate SFC at endurance speed. Calculate the required (optimum) RG ratio.

$n_{ePEopt} := 3600 \cdot RPM$ $n_{ePE} := n_{ePEopt}$ $P_{BPENGe} = 10963\,kW$ $SFC_{ePE} := .33 \dfrac{lbf}{hp \cdot hr}$

$n_{sPEopt} := 3600 \cdot RPM$ $n_{sPE} := n_{sPEopt}$ $P_{BPENGreq} = 73715\,kW$ $SFC_{sPE} := .375 \dfrac{lbf}{hp \cdot hr}$

5. Endurance Fuel Calculation

Calculate the endurance range for the specified fuel tank volume and average 24 hour electric load.

$P_{eBAVG} := P_{BPENGe}$ $P_{eBAVG} = 10962.999\,kW$ $V_e = 20\,knt$ $P_{BPENG} = 21655\,kW$

Correction for instrumentation inaccuracy and machinery design changes:

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

$f_1 = 1.03$

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{ePE}$ $FR_{SP} = 0.34 \dfrac{lbf}{hp \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years: $FR_{AVG} := 1.05 \cdot FR_{SP}$ $FR_{AVG} = 0.357 \dfrac{lbf}{hp \cdot hr}$

Tailpipe allowance: $TPA := 0.95$

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

$$W_{F41} := \frac{V_{F41}}{1.02 \cdot 1.05 \cdot \delta_F} \qquad E := \frac{W_{F41} \cdot V_e \cdot TPA}{P_{eBAVG} \cdot FR_{AVG}}$$

$E = 6005.618\,nm$

$W_{F41} = 752.016\,MT$

SIMPLIFIED COST MODEL

FFSHI

$\mathrm{Mdol} := \mathrm{coul}$

$\mathrm{Bdol} := 1000 \cdot \mathrm{Mdol}$

$\mathrm{lton} := 2240 \cdot \mathrm{lb}$ $\quad \mathrm{Kdol} := \dfrac{\mathrm{Mdol}}{1000}$

$\mathrm{hp} := \dfrac{33000 \cdot \mathrm{ft} \cdot \mathrm{lb}}{\mathrm{min}}$ $\quad \mathrm{dol} := \dfrac{\mathrm{Kdol}}{1000}$

1. Single Digit Weight Summary:

$i1 := 100, 200 \,..\, 700$

$W_{100} := 2156.494 \cdot \mathrm{lton}$ $\quad W_{400} := 265.735 \cdot \mathrm{lton}$ $\quad W_{500} := 633.927 \cdot \mathrm{lton}$

$W_{200} := 783.0347 \mathrm{lton}$ $\quad W_{420} := 9.2 \cdot \mathrm{lton}$ $\quad W_{600} := 482.162 \mathrm{lton}$ $\quad W_{F_{20}} := 135.62 \mathrm{lton}$

$W_{300} := 377.64 \mathrm{lton}$ $\quad W_{430} := 28.44 \mathrm{lton}$ $\quad W_{700} := 123.813 \mathrm{lton}$ $\quad W_{F_{23}} := 30 \cdot \mathrm{lton}$ [helo]

$N_{HELO} := 2$

Weight margin: $W_M := 495.941 \mathrm{lton}$

2. Additional charcteristics:

Lightship:

$W_{LS} := \sum_{i1} W_{i1} + W_M$ $\quad W_{LS} = 5.319 \times 10^3 \,\mathrm{lton}$

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

$W_{MP} := \left[\left(W_{400} + W_{700}\right) - W_{420} - W_{430}\right] + W_{F_{20}} - W_{F_{23}}$ $\quad W_{MP} = 457.528 \mathrm{lton}$

Installed Propulsion Power: $P_{SUM} := 50157 \mathrm{hp}$

Manning: (crew + air detachment + staff)

Officers: $N_{C_1} := 23$ $\quad$ CPO's: $N_{C_2} := 25$ $\quad$ Enlisted: $N_{C_3} := 198$

Ship Service Life: $L_S := 40$ $\quad$ Initial Operational Capability: $Y_{IOC} := 2015$

Total Ship Acquisition: $N_S := 20$ $\quad$ Production Rate (per year): $R_P := 3$

3. Inflation:

Base Year: $Y_B := 2010$ $\quad iy := 1 \,..\, Y_B - 1981$

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

$F_I := \prod_{iy} \left(1 + \dfrac{R_I}{100}\right)$ $\quad F_I = 2.357$

4. Lead Ship Cost:

a. Lead Ship Cost - Shipbuilder Portion:

SWBS costs: (See Enclosure 1 for K_N factors); includes escalation estimate

Structure $\quad K_{N1} := \dfrac{.55 \cdot \mathrm{Mdol}}{\mathrm{lton}^{.772}}$ $\quad C_{L_{100}} := .03395 \cdot F_I \cdot K_{N1} \cdot \left(W_{100}\right)^{.772}$ $\quad C_{L_{100}} = 16.487 \,\mathrm{Mdol}$

\+ Propulsion $\quad K_{N2} := \dfrac{1.2 \cdot \mathrm{Mdol}}{\mathrm{hp}^{.808}}$ $\quad C_{L_{200}} := .00186 \cdot F_I \cdot K_{N2} \cdot P_{SUM}^{\;.808}$ $\quad C_{L_{200}} = 33.025 \,\mathrm{Mdol}$

\+ Electric $\quad K_{N3} := \dfrac{1.0 \cdot \mathrm{Mdol}}{\mathrm{lton}^{.91}}$ $\quad C_{L_{300}} := .07505 \cdot F_I \cdot K_{N3} \cdot \left(W_{300}\right)^{.91}$ $\quad C_{L_{300}} = 39.154 \,\mathrm{Mdol}$

+ Command, Control, Surveillance

$K_{N4} := \frac{2.0 \cdot Mdol}{lton^{.617}}$ $\quad C_{L_{400}} := .10857 \cdot F_I \cdot K_{N4} \cdot \left(W_{400}\right)^{.617}$ $\quad C_{L_{400}} = 16.029\,Mdol$

(less payload GFM cost)

+ Auxiliary $\quad K_{N5} := \frac{1.5 \cdot Mdol}{lton^{.782}}$ $\quad C_{L_{500}} := .09487 \cdot F_I \cdot K_{N5} \cdot \left(W_{500}\right)^{.782}$ $\quad C_{L_{500}} = 52.083\,Mdol$

+ Outfit $\quad K_{N6} := \frac{1.0 \cdot Mdol}{lton^{.784}}$ $\quad C_{L_{600}} := .09859 \cdot F_I \cdot K_{N6} \cdot \left(W_{600}\right)^{.784}$ $\quad C_{L_{600}} = 29.494\,Mdol$

+ Armament $\quad K_{N7} := \frac{1.0 \cdot Mdol}{lton^{.987}}$ $\quad C_{L_{700}} := .00838 \cdot F_I \cdot K_{N7} \cdot \left(W_{700}\right)^{.987}$ $\quad C_{L_{700}} = 2.297\,Mdol$

(Less payload GFM cost)

+ Margin Cost:

$$C_{LM} := \frac{W_M}{\left(W_{LS} - W_M\right)} \cdot \left(\sum_{i1} C_{L_{i1}}\right) \qquad C_{LM} = 19.391\,Mdol$$

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

$$K_{N8} := \frac{10. \cdot Mdol}{Mdol^{1.099}} \qquad C_{L_{800}} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099} \qquad C_{L_{800}} = 119.932\,Mdol$$

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

$$K_{N9} := \frac{2.0 \cdot Mdol}{(Mdol)^{.839}} \qquad C_{L_{900}} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839} \qquad C_{L_{900}} = 23.776\,Mdol$$

= Total Lead Ship Construction Cost: (BCC):

$$C_{LCC} := \sum_{i1} C_{L_{i1}} + C_{L_{800}} + C_{L_{900}} + C_{LM} \qquad C_{LCC} = 351.667\,Mdol$$

+ Profit:

$F_P := .10 \qquad C_{LP} := F_P \cdot C_{LCC} \qquad C_{LP} = 35.167\,Mdol$

= Lead Ship Price:

$P_L := C_{LCC} + C_{LP} \qquad P_L = 386.834\,Mdol$

+ Change Orders:

$C_{LCORD} := .12 \cdot P_L \qquad C_{LCORD} = 46.42\,Mdol$

= Total Shipbuilder Portion:

$C_{SB} := P_L + C_{LCORD} \qquad C_{SB} = 433.254\,Mdol$

b. Lead Ship Cost - Government Portion

Other support: $C_{LOTH} := .025 \cdot P_L$ $C_{LOTH} = 9.671\,Mdol$

+ Program Manager's Growth: $C_{LPMG} := .1 \cdot P_L$ $C_{LPMG} = 38.683\,Mdol$ $W_{MP} = 457.528\,lton$

+ Ordnance and Electrical GFE: (Military Payload GFE)

$$C_{LMPG} := \left(.319 \cdot \frac{Mdol}{lton} \cdot W_{MP} + N_{HELO} \cdot 18.71 \cdot Mdol\right) \cdot F_I$$

$C_{LMPG} = 432.127\,Mdol$ (or incl actual cost if known)

+ HM&E GFE (boats, IC): $C_{LHMEG} := .02 \cdot P_L$ $C_{LHMEG} = 7.737\,Mdol$

+ Outfittimg Cost : $C_{LOUT} := .04 \cdot P_L$ $C_{LOUT} = 15.473\,Mdol$

= Total Government Portion:

$$C_{LGOV} := C_{LOTH} + C_{LPMG} + C_{LMPG} + C_{LHMEG} + C_{LOUT} \qquad C_{LGOV} = 503.691\,Mdol$$

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

* Total End Cost:

$$C_{LEND} := C_{SB} + C_{LGOV} \qquad C_{LEND} = 936.945\,Mdol$$

d. Total Lead Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{LPDEL} := .05 \cdot P_L$ $C_{LPDEL} = 19.342\,Mdol$

= Total Lead Ship Acquisition Cost: $C_{LA} := C_{LEND} + C_{LPDEL}$ $C_{LA} = 956.286\,Mdol$

5. Follow-Ship Cost:

Learning Rate/Factor: $R_L := .97$ $F := 2 \cdot R_L - 1$ $F = 0.94$ (for $N_s/2$ ship)

a. Follow Ship Cost - Shipbuilder Portion

$CF_{i1} := F \cdot CL_{i1}$ $C_{FM} := F \cdot C_{LM}$ $C_{FM} = 18.227\,Mdol$

$$CF_{800} := \frac{.104 \cdot Mdol}{Mdol^{1.099}} \cdot \left(\sum_{i1} CL_{i1} + C_{LM}\right)^{1.099} \qquad CF_{800} = 36.685\,Mdol$$

$CF_{900} := F \cdot CL_{900}$ $CF_{900} = 22.35\,Mdol$

$\frac{CF_{i1}}{Mdol} =$
15.498
31.043
36.804
15.067
48.958
27.724
2.159

Total Follow Ship Construction Cost: (BCC)

$$C_{FCC} := \sum_{i1} CF_{i1} + CF_{800} + CF_{900} + C_{FM} \qquad C_{FCC} = 254.516\,Mdol$$

+ Profit:

$F_P := .1$ $C_{FP} := F_P \cdot C_{FCC}$ $C_{FP} = 25.452\,Mdol$

= Follow Ship Price:

$P_F := C_{FCC} + C_{FP}$ $P_F = 279.968\,\mathrm{Mdol}$

+ Change Orders:

$C_{FCORD} := .08 \cdot P_L$ $C_{FCORD} = 30.947\,\mathrm{Mdol}$

= Total Follow Ship Shipbuilder Portion:

$C_{FSB} := P_F + C_{FCORD}$ $C_{FSB} = 310.914\,\mathrm{Mdol}$

b. Follow Ship Cost - Government Portion

Other support: $C_{FOTH} := .025 \cdot P_F$ $C_{FOTH} = 6.999\,\mathrm{Mdol}$

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

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

+ Ordnance and Electrical GFE:
(Military Payload GFE)

$$C_{FMPG} := \left(.3 \cdot \frac{\mathrm{Mdol}}{\mathrm{lton}} \cdot W_{MP} + 18.710 \cdot \mathrm{Mdol} \cdot N_{HELO}\right) \cdot F_I$$

$C_{FMPG} = 411.641\,\mathrm{Mdol}$

+ HM&E GFE (boats, IC): $C_{FHMEG} := .02 \cdot P_F$ $C_{FHMEG} = 5.599\,\mathrm{Mdol}$

+ Outfittimg Cost: $C_{FOUT} := .04 \cdot P_F$ $C_{FOUT} = 11.199\,\mathrm{Mdol}$

= Total Follow Ship Government Cost:

$C_{FGOV} := C_{FOTH} + C_{FPMG} + C_{FMPG} + C_{FHMEG} + C_{FOUT}$ $C_{FGOV} = 449.437\,\mathrm{Mdol}$

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

* Total Follow Ship End Cost:

$C_{FEND} := C_{FSB} + C_{FGOV}$ $C_{FEND} = 760.351\,\mathrm{Mdol}$

d. Total Follow Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{FPDEL} := .05 \cdot P_F$ $C_{FPDEL} = 13.998\,\mathrm{Mdol}$

= Total Follow Ship Acquisition Cost: $C_{FA} := C_{FEND} + C_{FPDEL}$ $C_{FA} = 774.349\,\mathrm{Mdol}$

AVERAGE SHIP ACQUISITION COST:

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

$C_{AV} = 760.951\,\mathrm{Mdol}$

6. Life Cycle Cost:

a. Research and development

Ship design and development:

$$C_{SDD} := 1.1\cdot\left(.571\cdot\frac{C_{FSB}}{F} + .072\cdot C_{LMPG}\right) \qquad C_{SDD} = 241.975\,\mathrm{Mdol}$$

+ Ship test and evaluation

$$C_{STE} := 1.2\cdot\left(.499\cdot\frac{C_{FSB}}{F} + .647\cdot C_{LMPG}\right) \qquad C_{STE} = 533.562\,\mathrm{Mdol}$$

= Total Ship R&D Cost:

$$C_{RD} := C_{SDD} + C_{STE} \qquad C_{RD} = 775.537\,\mathrm{Mdol}$$

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

Ship Expected Total Shipbuilding Program Cost:

$$C_{SPE} := C_{AV}\cdot N_S \qquad C_{SPE} = 15.219\,\mathrm{Bdol}$$

+ Support Equipment (shore-based)

ship: $C_{SSE} := .15\cdot C_{SPE} \qquad C_{SSE} = 2.283\,\mathrm{Bdol}$

+ Spares and repair parts (shore supply)

ship: $C_{ISS} := .1\cdot C_{SPE} \qquad C_{ISS} = 1.522\,\mathrm{Bdol}$

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

$$C_{INV} = 19.024\,\mathrm{Bdol}$$

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

Personnel (Pay and Allowances)

$$C_{PAY} := F_I\cdot\left[.026184\cdot N_{C_1} + .01151\cdot\left(N_{C_2} + N_{C_3}\right)\right]\cdot N_S\cdot L_S\cdot \mathrm{Mdol} \qquad C_{PAY} = 5.974\,\mathrm{Bdol}$$

$$C_{TAD} := F_I\cdot\left(N_{C_1} + N_{C_2} + N_{C_3}\right)\cdot N_S\cdot L_S\cdot 2.6\cdot 10^{-6}\cdot \mathrm{Mdol} \qquad C_{TAD} = 1.206\,\mathrm{Mdol}$$

$$C_{PERS} := C_{PAY} + C_{TAD} \qquad C_{PERS} = 5.975\,\mathrm{Bdol}$$

+ Operations:

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

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

$$C_{OPS} = 3.686\,\mathrm{Bdol}$$

+ Maintenance

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

$$C_{MTC} = 10.177\,\mathrm{Bdol}$$

+ Energy

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

$C_{EGY} := N_S \cdot L_S \cdot C_{FUEL} \cdot \frac{H}{6.8 \cdot \frac{\text{lb}}{\text{gal}}} \cdot W$ $C_{EGY} = 1.779\,\text{Bdol}$

+ Replenishment Spares

$C_{REP} := C_{ISS} \cdot \frac{L_S - 4}{4}$ $C_{REP} = 13.697\,\text{Bdol}$

+ Major Support (COH, ROH):

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

$C_{MSP} = 3.64\,\text{Bdol}$

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

$C_{OAS} = 38.954\,\text{Bdol}$

d. Residual Value:

$RES := .5 \cdot C_{SPE} \cdot \left(1 - \frac{2}{L_S}\right)^{L_S}$ $RES = 0.978\,\text{Bdol}$

e. Total Program

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

$C_{LIFE} = 57.775\,\text{Bdol}$

<u>7. Discounted Life Cycle Cost:</u>

Discount Rate: $R_D := .1$

a. Discounted R&D:

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

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

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

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

$C_{DRD} := F_{DRD} \cdot C_{RD}$ $C_{DRD} = 750.721\,\text{Mdol}$

b. Discounted Investment:

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

end: $E_{INV} := B_{INV} + \frac{N_S - 1}{R_P}$ $E_{INV} = 14.333$

$L_{INV} := E_{INV} - B_{INV} + 1$ $L_{INV} = 7.333$

$$F_{DINV} := \frac{\displaystyle\sum_{y=B_{INV}}^{E_{INV}} \frac{1}{(1+R_D)^y}}{L_{INV}} \qquad F_{DINV} = 0.341$$

$C_{DINV} := F_{DINV} \cdot C_{INV}$ $\qquad C_{DINV} = 6.481\ \mathrm{Bdol}$

c. Discounted O&S:

start: $B_{OAS} := E_{INV} + 1$ $\qquad B_{OAS} = 15.333$

end: $E_{OAS} := B_{OAS} + L_S - 1$ $\qquad E_{OAS} = 54.333$

$L_{OAS} := E_{OAS} - B_{OAS} + 1$ $\qquad L_{OAS} = 40$

$$F_{DOAS} := \frac{\displaystyle\sum_{y=B_{OAS}}^{E_{OAS}} \frac{1}{(1+R_D)^y}}{L_{OAS}} \qquad F_{DOAS} = 0.062$$

$C_{DOAS} := F_{DOAS} \cdot C_{OAS}$ $\qquad C_{DOAS} = 2.429\ \mathrm{Bdol}$

d. Discounted Residual Value:

$$RES_D := RES \cdot \left(\frac{1}{1+R_D}\right)^{E_{OAS}+1} \qquad RES_D = 5.011\ \mathrm{Mdol}$$

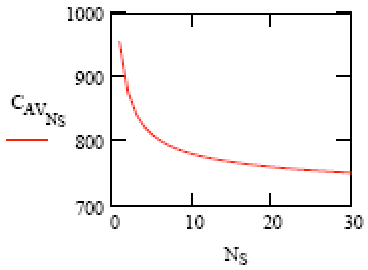
e. Total Discounted Life Cycle Cost:

$C_{DLIFE} := C_{DRD} + C_{DINV} + C_{DOAS} - RES_D$ $\qquad C_{DLIFE} = 9.656\ \mathrm{Bdol}$

LEARNING CURVE:

$N_S := 1 .. 30$

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



$C_{LA} = 956.286\ \mathrm{Mdol}$

$C_{FA} = 774.349\ \mathrm{Mdol}$