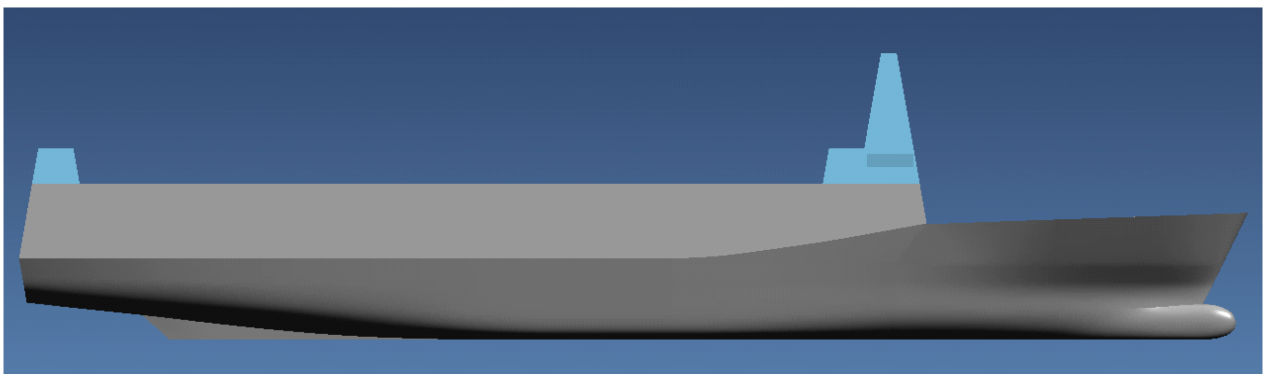
CUVX Design Report

Unmanned Combat Air Vehicle Carrier

VT Total Ship Systems Engineering Approach



CUVX HI2 Option

Ocean Engineering Design Project

AOE 4065/4066

Fall 2002 – Spring 2003

Virginia Tech Team 1

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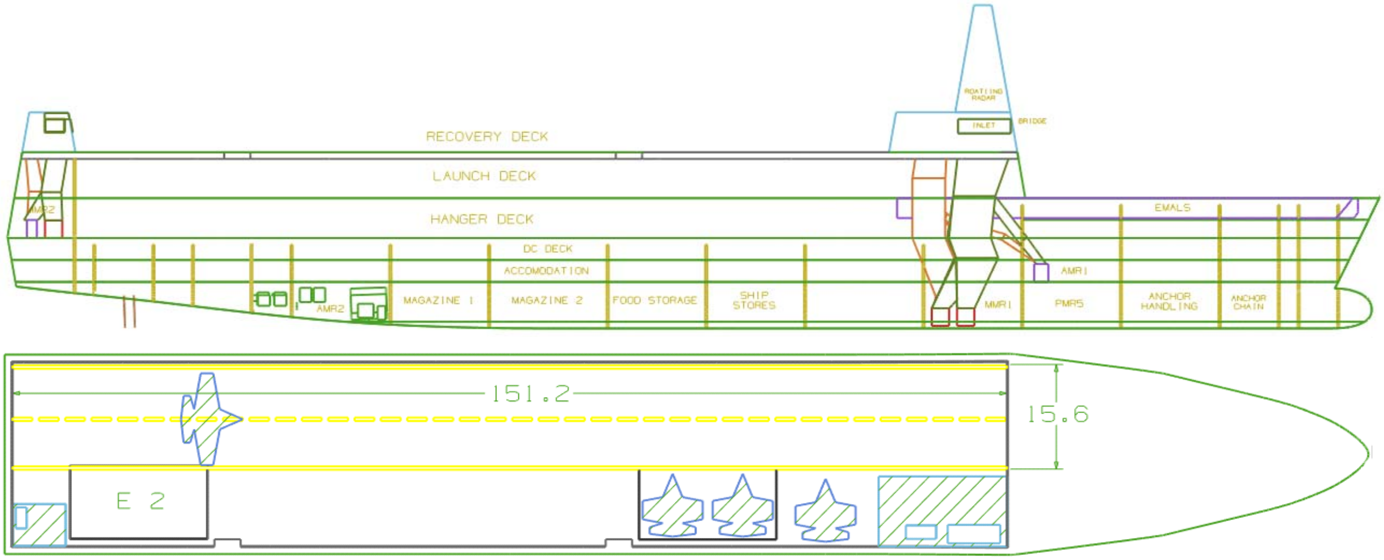
Executive Summary



This report describes the Concept Exploration and development of an unmanned combat air vehicle carrier (CUVX) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech.

The CUVX requirement is based on a CUVX Mission Need Statement and Acquisition Decision Memorandum (ADM). CUVX will operate in littoral areas, close-in, depend on stealth, with high endurance and low manning (for an aircraft carrier). It will support UCAV's, UAV's and LAMPS, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The UAV's will provide surface, subsurface, shore, and deep inland surveillance, reconnaissance and electronic warfare. LAMPS will provide Anti-Submarine Warfare (ASW) and Anti-Surface Ship Warfare (ASUW) defense. UCAV'S will provide initial/early conflict Suppression of Enemy Air Defenses (SEAD) and Strike.

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

CUVX HI2 is a high-end alternative on the lead-ship acquisition cost frontier. This high-end design was chosen to provide a challenging design project using higher risk technology. CUVX HI2 characteristics are listed below. This is a (very) modified-repeat LPD-17 design. It has a unique launch deck arrangement to enable simultaneous launch and recovery of UCAVs. It uses significant automation technology including an electromagnetic aircraft launching system (EMALS) with pulse power from the integrated power system (IPS) propulsion bus, autonomous spotting dollies, and automated pit stops. Concept Development included hull form development and analysis for intact and damage stability, structural finite element analysis, IPS system development and arrangement, aviation system analysis and arrangements, general arrangements, combat system selection, seakeeping analysis, cost analysis and risk analysis. The final concept design satisfies critical operational requirements within cost and risk constraints with additional work being required to improve seakeeping and further reduce manning and cost.

Ship Characteristic	Value
LBP [m]	201.0
Beam [m]	29.54
Draft [m]	7.00
D10 [m]	26.63
Lightship weight [MT]	21140
Full load weight [MT]	25943
Block Coefficient, CB	0.609
Prismatic Coefficient, CP	0.647
Sustained Speed [knots]	24.5
Endurance speed [knots]	20
Range at 20 knots [nm]	4000
Propulsion and Power	Integrated Power System (IPS), 2 shafts, 3 x WR-21 29 ICR
Propellers	2 x FPP
BHP [hp]	55352
Manning	691
Effectiveness OMOE	0.878
Risk OMOR	0.182
Lead ship acquisition cost	$952M
Follow ship acquisition cost	$775M
Combat Systems	SSDS, AN/SPS-49A(V)1, AN/SPS-73(V)12, AN/SLQ-32A(V)2, CIFF, 2xCIWS; Mk36 DLS, Combat DF, IRST, ESSM w/VLS, AN/SPQ-9B, MK91 MFCS
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1 Introduction, Design Process and Plan

1.1 Introduction

This report describes the Concept Exploration and development of an unmanned combat air vehicle carrier (CUVX) for the United States Navy. This concept design was completed in a two-semester ship design course at Virginia Tech. CUVX is required to support unmanned combat air vehicles (UCAV's), unmanned air vehicles (UAV's) and LAMPS helicopters to perform the following missions:

1. Intelligence, Surveillance, and Reconnaissance (ISR)
2. Suppression of Enemy Air Defenses (SEAD)
3. Anti Submarine Warfare (ASW) self-defense
4. Anti Surface Ship Warfare (ASuW) self-defense
5. Electronic Countermeasures (ECM)
6. Mine Warfare (MIW)
7. Time-sensitive UCAV strikes

The Mission Need Statement (MNS) and Acquisition Decision Memorandum (ADM) developed for the Virginia Tech CUVX are provided in Appendices A and B. CUVX will support 10-30 UCAV's and 5-20 UAV's, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. CUVX will operate independently or in conjunction with small Surface Attack Groups (SAGs). It will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict.

CUVX is likely to be forward-deployed in peacetime, conducting extended cruises to sensitive littoral regions. It will provide its own defense with significant dependence on passive survivability and stealth. As a conflict proceeds to conclusion, CUVX will continue to monitor all threats. It will likely be the first to arrive and last to leave the area of conflict.

The carrier must minimize life cycle costs through the application of producibility enhancements and manning reduction. The design must minimize personnel vulnerability in combat through increased automation.

The concepts introduced in the design include moderate to high-risk alternatives. Concepts are explored in parallel with UCAV-N Concept Exploration and development also performed by Virginia Tech students using a Total Ship Systems (ship and aircraft) Engineering approach.

1.2 Design Philosophy, Process, and Plan

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

The scope of this project includes the first two phases in the ship design process, Concept Exploration and Concept Development, as illustrated in Figure 1. The Concept Exploration process is shown in Figure 2. The results of this process are a preliminary Operational Requirements Document (ORD1) that specifies performance and cost requirements, and a baseline concept design. The CUVX ORD1 is provided in Appendix C.

In Concept Exploration, a multiple-objective design optimization is used to search the design space. CUVX Concept Exploration considers various combinations of hull form, propulsion systems, weaponry and automation within the design space using mission effectiveness, risk and acquisition cost as objective attributes. A ship synthesis model is used to balance these parameters in total ship designs. The model is then used to assess feasibility and to calculate cost, risk and effectiveness. The final design combinations are ranked by cost, risk and effectiveness, and presented as a series of non-dominated frontiers, Figure 29 and Figure 30. A non-dominated frontier (NDF) represents ship designs in the design space that have the highest effectiveness for a given cost and risk. Concepts for further study and development are chosen from this frontier. This process is described in Chapter 3.

Figure 3 shows the more traditional design spiral process followed in Concept Development for this project. A complete circuit around the design spiral at this stage is frequently called a Feasibility Study. It investigates each stop in the design spiral at a level of detail necessary to demonstrate that assumptions and results obtained in Concept Exploration are not only balanced, but feasible. In the process, a second layer of detail is added to the design and risk is reduced. CUVX Concept Development is described in Chapter 4.

1.3 Work Breakdown

The CUVX team consists of six students from Virginia Tech. Each student was assigned an area of work according to his or her interests and special skills as listed in Table 1. This specialization allows members to concentrate efforts on thoroughly understanding a subject. A team leader was also selected to effectively coordinate the efforts of the team. Although each team member had his/her own area of expertise there was generally a great deal of overlap, this is a team effort.

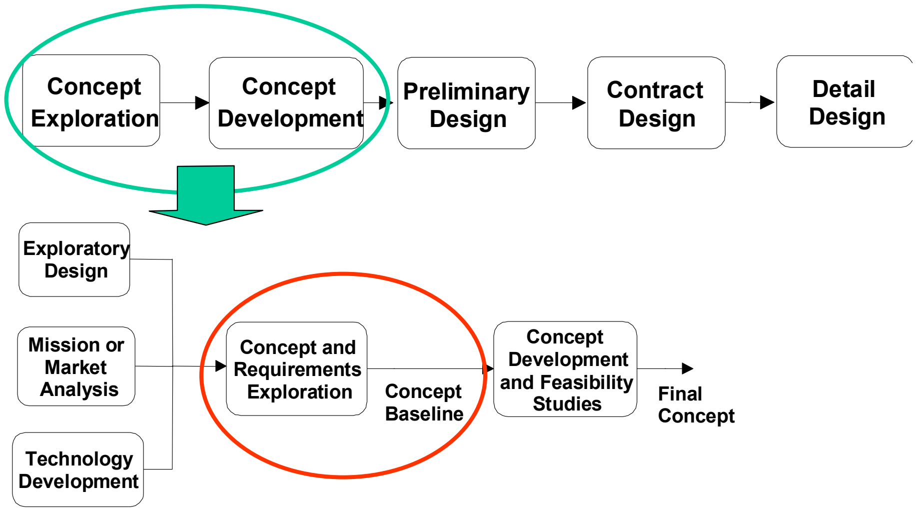

Figure 1. Design Process

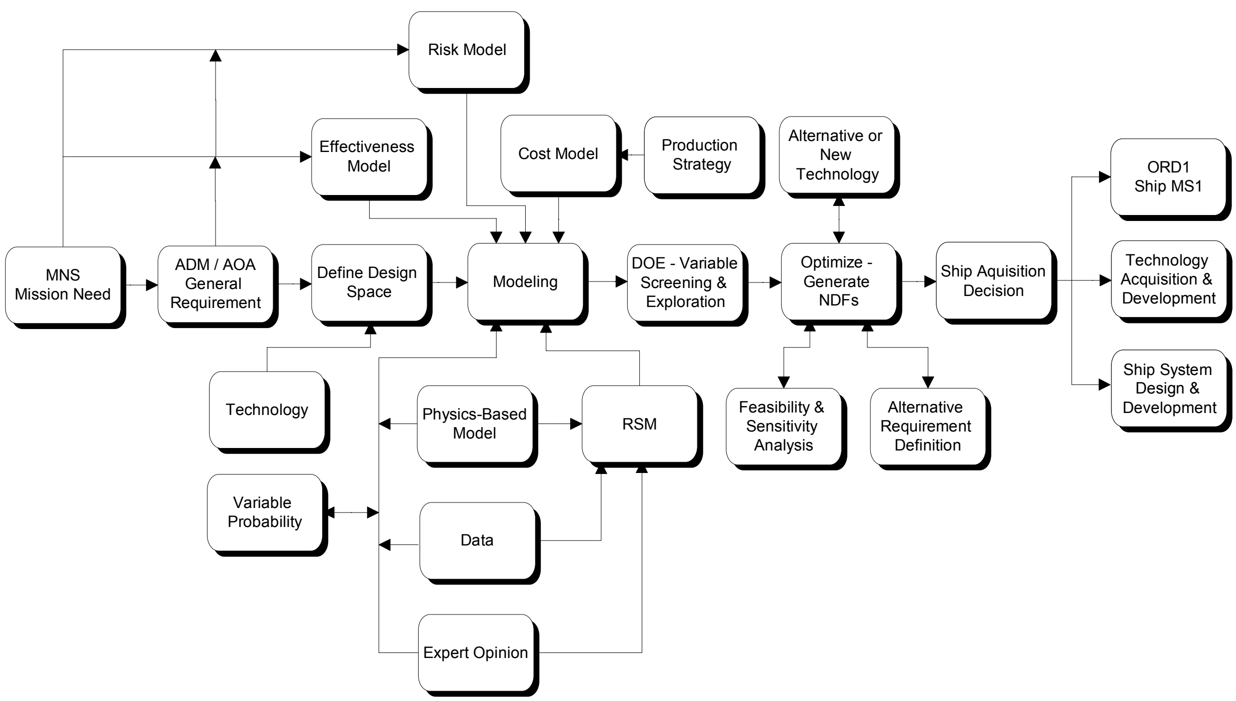

Figure 2. Concept Exploration Process

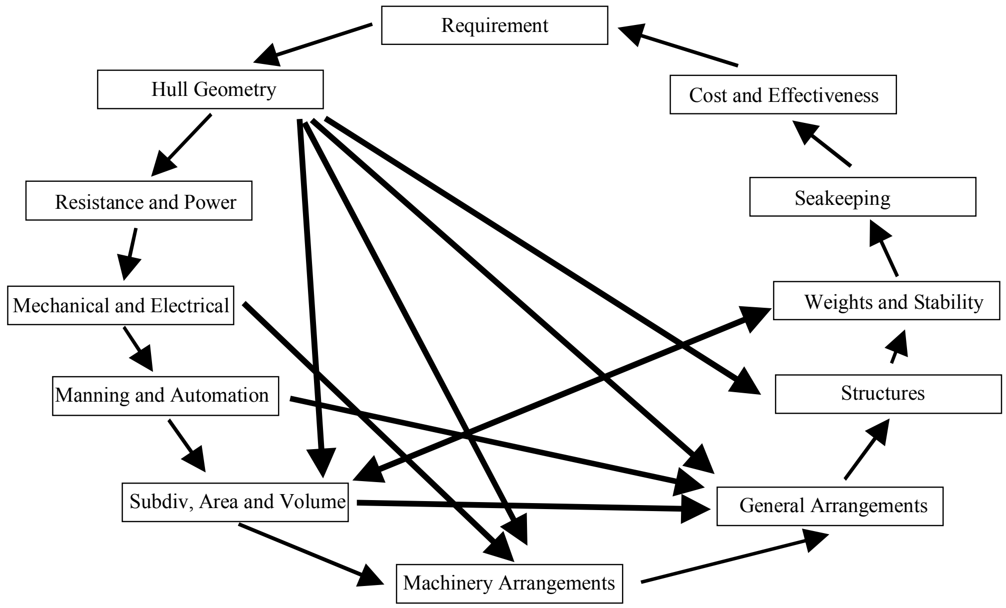

Figure 3. Concept Development Design Spiral (Chapter 4)

Table 1. Work Breakdown

Name	Specialization
Jason Cordell (Team Leader)	Hull / Resistance / Cost / Editor
Erdem Agan	Power / Propulsion / Machinery Arrgts
Sam Dippold	Weights / Hydrostatics / Manning
Wenonah Sumner	Structures / Producibility / Risk
Alec Gosse	Arrangements / Mission Integration
Will Whitacre	Seakeeping / Mission Systems

1.4 Resources

Table 2. Tools

Analysis	Software Package
Arrangement Drawings	AutoCAD, Unigraphics
Hullform Development	FASTSHIP
Hydrostatics	HECSALV
Resistance/Power	MathCad
Ship Motions	SMP
Ship Synthesis Model	MathCad/Fortran
Structure Model	MAESTRO, HECSALV

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

2 Mission Definition

The CUVX mission definition presented here was developed from the CUVX Mission Need Statement (MNS), Appendix A, and Acquisition Decision Memorandum (ADM), Appendix B, with elaboration and clarification obtained by discussion and correspondence with the customer, and reference to pertinent documents and web sites referenced in the following sections.

2.1 Concept of Operations

The CUVX concept of operations (CONOPS) is based on the CUVX Mission Need Statement and Acquisition Decision Memorandum (ADM). CUVX will operate in littoral areas, close-in, depend on stealth, with high endurance, minimum external support, and low manning. It will support 20-30 UCAV's and UAV's, and 2-4 LAMPS helicopters, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The UAV's will provide surface, subsurface, shore, and deep inland surveillance, reconnaissance and electronic warfare. The LAMPS will provide Anti-Submarine Warfare (ASW) and Anti-Surface Ship Warfare (ASUW) defense. UCAV'S will provide initial/early conflict Suppression of Enemy Air Defenses (SEAD), Strike and mining. CUVX will operate independently or in conjunction with small Surface Attack Groups (SAGs). It will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict. CUVX is likely to be forward deployed in peacetime, conducting extended cruises to sensitive littoral regions. Small crew size and limited logistics requirements will facilitate efficient forward deployment. It will provide own defense with significant dependence on passive survivability and stealth. As a conflict proceeds to conclusion, CUVX will continue to monitor all threats. CUVX will likely be the first to arrive and last to leave the conflict area.

2.2 Projected Operational Environment (POE) and Threat

CUVX will provide worldwide operation with two distinct classes of threats. These threats include: (1) Threats from nations with a major military capability, or the demonstrated interest in acquiring such a capability, i.e. China, India, Russia, and North Korea. Specific weapons systems that could be encountered include ballistic missiles, land and surface launched cruise missiles, and significant land based air assets and submarines; and (2) Threats from smaller nations who support, promote, and perpetrate activities that cause regional instabilities detrimental to international security and/or have the potential development of nuclear weapons, i.e. Pakistan and Iran. Specific weapons systems include diesel/electric submarines, land-based air assets, submarines, and chemical/biological weapons.

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

2.3 Missions

CUVX mission types include the following:

- Pre-conflict
  - Surveillance and Reconnaissance (ISR)
- Conflict
  - Continue ISR
  - SEAD
  - Mining
  - Pre-position and support UCAV's for time-sensitive air and missile strikes (HARM and JDAM)
  - SPECOPS
  - ECM
  - ASW / ASuW / with LAMPS
- Post-conflict
  - Continue ISR

2.4 Mission Scenarios

Mission scenarios for CUVX are provided in Table 3, Table 4, and Table 5.

Table 3. CUVX Pre-Conflict Mission Scenario

Day	Mission scenario for Pre-conflict
1-21	Transit from homeport to station independently or in SAG
21	Unrep
22-25	Proceed to station
25-49	ASW/ASuW/AAW, ISR and EW with UAV's and LAMPS Mk3
22-50	Standby on-station offshore independently or in SAG
50-60	Transit and Unrep / port call
60-65	Return to station
65-100	Standby on-station offshore independently or in SAG
100	Commence hostilities or port call

Table 4. CUVX Escalating crisis and regional conflict Mission Scenario

Day	Mission scenario for Escalating crisis and regional conflict
1-30	Continue ASW / ASuW / AAW, ISR and EW with UAV's and LAMPS
1-3	Preposition UCAV's for time sensitive strike bringing precise, lethal effects to bear in decisive quantity on operationally significant targets within minutes
7	Unrep
1-3	SEAD w/HARM and JDAM
1-3	UCAV conduct mining operations, defend against biological weapons
2	Conduct ASW operation against enemy diesel submarine w/LAMPS and torpedoes
5	Conduct ASuW operation against enemy patrol boats w/LAMPS and guns
14	Unrep
4-30	Continue the preposition of UCAV's for time sensitive strike
4-20	Conduct precision strike w/JDAM
21	Unrep
28	Unrep
30	Cease hostilities

Table 5. CUVX Post-Conflict Mission Scenario

Day	Mission scenario for Post-conflict
1-30	Continue ASW / ASuW / AAW, ISR and EW with UAV's and LAMPS
1-30	Continue the preposition of UCAV's for time sensitive strike
1-30	Enforce no-fly zone
1-30	Standby on-station offshore independently or in SAG
31-40	Transit and Unrep / port call
41-45	Return to station
45-60	Standby on-station offshore independently or in SAG
60	Port call / return home

2.5 Required Operational Capabilities

In order to support the missions and mission scenarios described in Sections 2.3 and 2.4, the capabilities listed in

Table 6 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 an explicit Measure of Performance (MOP). MOPs and the process to develop an Overall Measure of Effectiveness (OMOE) are presented in Section 3.5.1 and Table 23.

Table 6. List of Critical CUVX Required Operational Capabilities (ROC's)

ROC's	Description
MOB 1	Steam to design capacity in most fuel efficient manner
MOB 3	Prevent and control damage
MOB 3.2	Counter and control NBC contaminants and agents
MOB 5	Maneuver in formation
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)
MOB 10	Replenish at sea
MOB 12	Maintain health and well being of crew
MOB 13	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support
MOB 16	Operate in day and night environments
MOB 17	Operate in heavy weather
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations
CV 1	Operate and support unmanned aircraft in land attack offensive missions, independent of land facilities
CV2	Operate and support unmanned aircraft in ISR missions (UAV, UCAV), independent of land facilities
CV3	Operate and support unmanned aircraft (LAMPS) in defensive missions against enemy surface and submerged forces, independent of land facilities
CV4	Shelter, transport, launch, recover and maintain unmanned aircraft and helicopters
CV5	Provide weapons storage and handling for embarked unmanned aircraft
AAW 1.2	Provide unit self defense
AAW 5	Provide passive and softkill anti-air defense
AAW 6	Detect, identify and track air targets
ASU 1	Engage surface threats with anti-surface armaments
ASU 1.2	Engage surface ships at medium range (LAMPS)
ASU 1.3	Engage surface ships at close range (guns)
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 4.1	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 (LAMPS)
ASW 1.2	Engage submarines at medium range (LAMPS)
ASW 1.3	Engage submarines at close range (torpedo)
ASW 4	Conduct airborne ASW/recon (LAMPS)
ASW 5	Support airborne ASW/recon
MIW 7	Deploy mines using UCAV
CCC 1.6	Provide a Helicopter/ UCAV Direction Center (HDC)
CCC 3	Provide own unit CCC
CCC 4	Maintain data link capability
SEW 2	Conduct sensor and ECM operations
SEW 3	Conduct sensor and ECCM operations
FSO 5	Conduct towing/search/salvage rescue operations
FSO 6	Conduct SAR operations
INT 1	Support/conduct intelligence collection
INT 2	Provide intelligence
INT 3	Conduct surveillance and reconnaissance
NCO 3	Provide upkeep and maintenance of own unit
NCO 19	Conduct maritime law enforcement operations
LOG 1	Conduct underway replenishment
LOG 2	Transfer/receive cargo and personnel

3 Concept Exploration

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

3.1 Standards and Specifications

Based on the ADM and Program Manager guidance, CUVX shall be designed and constructed using commercial standards wherever possible, with the exception of specialized mission systems and survivability enhancements, or as required for LPD-17 commonality. This guidance is driven by the stringent cost threshold. Additional military standards may be incorporated into subsequent CUVX platforms once the CUVX/UCAV mission concept has been demonstrated. CUVX shall comply with American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels including requirements for classification as A1, AMS, ACCU, and unrestricted service as applicable and where military specifications are not applied.

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

- General Specifications for Ships of the USN (1995)
- Longitudinal Strength: DDS 100-6
- Stability and Buoyancy: DDS 079-1
- Freeboard: DDS 079-2
- Endurance Fuel: DDS 200-1
- Electric Load Analysis: DDS 310-1
- Aircraft Handling Deck Structure: DDS 130-1

If the LPD-17 modified repeat alternative is selected, LPD standards and specifications shall be used for those portions of the CUVX design that are common with the LPD.

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

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

3.2.1 Hull Form Alternatives

Six different hull form type alternatives were considered for CUVX:

- Catamaran
- SWATH
- Trimaran
- Conventional monohull
- Wave piercing tumblehome (WPTH) monohull
- Modified-repeat LPD-17 monohull

The selected hull form must satisfy the following requirements: 1) displacement between 20,000 and 30,000 MT; 2) low radar cross-section (RCS) where possible; 3) good low speed endurance; 4) low cost; 5) good volume for large object spaces (such as hangars); 6) a recovery deck length greater than 150 meters for recovering UCAVs; and 7) good seakeeping characteristics. Each of the hull form types was assessed based on these requirements with the following conclusions:

- Catamaran

The Catamaran or twin-hull concept has been employed in high-speed craft design for several years. The component hulls (demihulls) usually have V-type sections and a cut-off transom stern. The division of displacement and waterplane area between two relatively slender hulls results in a large deck area, good stability, and smaller roll angles than monohulls of similar displacement. However, seakeeping qualities in terms of angle and rate of pitch are poor compared to a monohull. This problem can be eliminated via active control of pitching motions.

The wetted surface area ratio, slenderness ratio, and the hull spacing mainly affect the resistance of a catamaran. The wetted surface area ratio is relatively high compared with planing monohulls of the same displacement. Thus, catamarans have relatively high resistance at low speeds (Fn < 0.35) where skin friction is dominant. At higher speeds, the low wave-making resistance provides relatively low resistance. Beneficial wave interference can be achieved by the cancellation of part of the divergent wave systems of each demihull, whereas adverse wave interference arises in interaction of the transverse wave systems.

Catamarans have a relatively high radar cross section, especially end-on. The displacement to length ratio is high and the large object volume is relatively low compared to a monohull. There is still considerable structural risk with a catamaran as they generate significant transverse bending moments which tend to pry apart the hulls. The cost for building a catamaran is higher than that for a monohull of the same displacement.

- SWATH

The SWATH (Small Waterplane Area Twin Hull) hull form consists of two cylindrical lower hulls that are completely submerged. The upper hull rides above the water and is connected to the lower hulls by vertical struts. The small waterplane area of the vertical struts greatly improves seakeeping for a given displacement, but increases the load sensitivity. SWATH's are considered load sensitive due to the fact that for a small loads added to the ship, a relatively large change in draft occurs. Typically, SWATH ships have 50% less waterplane area compared to monohull ships of equal displacement. Deck length available for landing and takeoff is smaller on a SWATH ship since SWATH ships are generally shorter than monohulls of equal displacement. This would require greater forces on aircraft in takeoff and landing. SWATHs have a relatively high radar cross section, especially end-on unless special provisions are made to reduce it, as with Sea Shadow. In order to lower the radar cross section by incorporating a tumblehome, the SWATH would have to be wider, increasing the transverse bending moment and reducing structural efficiency.

While the reduction in waterplane area decreases wave-making resistance, it leads to an increase in frictional resistance. The increase in frictional resistance is due to an increase in the wetted surface area of the hull. The thin vertical struts also present structural problems. SWATH ships generally experience large transverse bending moments that must be countered with expensive structural support. SWATH ships are more expensive to build and have less large object volume than monohulls of equal displacement.

- Trimaran

The trimaran hull form consists of a very slender monohull with shorter slender hulls attached to each side. The trimaran hull form has some advantages over a conventional monohull such as decreased resistance for Froude numbers greater than 0.3, increased stability and more deck area for flight operations. The decreased resistance of the trimaran hull form is important for CUVX when the ship is going faster than 10 knots. Since the endurance speed of CUVX is greater than 10 knots, the reduced resistance is an advantage for fuel savings. The U.K. and U.S. have developed a trimaran research vessel and the concept is currently being tested.

Trimarans could reduce heat signatures by ducting exhausts between the hulls. The radar cross-section of a trimaran is comparable or greater than a conventional monohull of similar displacement. Given that a trimaran has slender hulls, the large-object arrangeable volume is relatively small and limited. The cost of a trimaran would be greater than a conventional monohull of similar displacement.

- Modified-Repeat LPD-17

As required by the ADM, the modified-repeat LPD-17 is an alternative for CUVX. The LPD-17 is a 25,000-ton displacement, bulbous bow, amphibious assault and transport ship that is currently being constructed at Northrop Grumman Ship Systems, Avondale Division. This ship is designed to reduce radar cross-section and to meet top level requirements for survivability. It has a very robust and survivable hull structure. The current design includes stern flaps, which increase fuel efficiency and speed.

The greatest advantage of using a modified-repeat LPD-17 is that the design has already been completed and would only need to be modified. This reduces design cost, improves producibility through commonality, and reduces the cost of logistics support and training. LPD-17 has more large object arrangeable volume than a multi-hull hullform of the same displacement.

The main disadvantage of using this hull form is that the principal dimensions of the ship can not be altered. This limits optimization of the design for the CUVX mission.

- Conventional Monohull

An optimized conventional monohull hull form with bow flare is the most traditional design considered. Shipyards have more experience in building monohulls and this could improve producibility and reduce construction cost. Monohulls have larger object space than any of the other hullform alternatives for a given displacement. Optimizing a conventional monohull has an advantage over an LPD-17 mod-repeat in that it can be optimized for this particular use. The structural characteristics are well known. Conventional monohulls have a large residuary resistance at high speeds. The radar cross-section for a ship with bow flare and vertical or flared sides may be significant. Compared to multi-hulls there is less usable deck area.

- Wave Piercing Tumblehome Monohull

The Wave Piercing Tumblehome Hull form (WPTH) has negative flare for all sections of the hull above the waterline. It is designed to penetrate waves, reducing the potential for slamming and extreme bow and stern accelerations, and decreasing resistance in waves. The tumblehome hull form offers a 10° inward sloping ruled freeboard to potential threats, minimizing RCS. Since the WPTH hullform is a monohull, the construction cost would be lower than multi-hulls of the same displacement. There is more large object space than in multi-hulls of the same displacement.

The negative flare reduces arrangeable volume and area high in the ship. Area is of particular concern for flight operations where the recovery and launch decks must be of sufficient size. Flare also provides an increasing righting moment with heel; tumblehome exhibits the opposite, limiting the acceptable operational envelope to prevent capsize. Damage stability also suffers. The risk associated with this hull form is significant, since no large naval WPTH has been built.

Table 7. Hullform Advantages (+) / Disadvantages (-)

	Low RCS	Endurance @ Low Speed	Low Cost	Resistance at Sustained Speed	Good Large-Object Spaces	Recovery Deck	Good Seakeeping	Survivability
Catamaran	-		-	++	-	++	++	
SWATH	-	-	--	-	-	++	+++	
Trimaran	-		-	++	-	++	++	+
Conventional Monohull		+	++		++	+	-	++
WPTH	+++	+	+	+	+	-	+	?
Modified-Repeat LPD-17	+	+	+++		++	+	+	++

Based on this preliminary assessment of hull forms, the conventional monohull, WPTH and LPD-17 mod-repeat hull forms were selected for further investigation and trade-off in Concept Exploration and optimization.

3.2.2 Sustainability Alternatives

Sustainability characteristics for CUVX include endurance range, endurance stores duration, aircraft weapons storage, and aircraft fuel storage. A threshold value of 4000 nm is a typical minimum for surface-combatant endurance range. Auxiliary and amphibious ships typically have values closer to 12000 nm. These values are used as the threshold and goal values, respectively. In the CUVX trade-off study, the values of 4000 nm, 8000 nm, and 12000 nm are considered.

Endurance stores duration is typically 60-120 days for naval ships. Values of 60, 90 and 120 days are considered for CUVX. CV 67 data is used to specify goals and thresholds for CUVX space required for aircraft ammo and fuel. CV 67 is non-nuclear and more similar to CUVX than CVNs. CV 67 carries 49 aircraft, 609.6 MT of ammo, and 3353 MT of fuel. CV 67 aircraft ammo and fuel weights per aircraft are: 12.4 MT for ammo and 68.4 MT for fuel. The CUVX threshold value for ammo storage was determined to be 5 MT/UCAV and the goal value 15 MT/UCAV. The threshold value for fuel was determined to be 30 MT/UCAV and the goal value 60 MT/UCAV.

3.2.3 Propulsion and Electrical Machinery Alternatives

3.2.3.1 Machinery Requirements

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

General Requirements - The propulsion engines must be non-nuclear, grade A shock certified, and Navy qualified. The machinery system alternatives must span a total power range of 40000–80000 SHP with total ship service power greater than 8000 kW MFLM. The IPS options must provide 30000-60000 kW pulse power for aircraft launch. The propulsion engines should have a low IR signature, and cruise/boost options should be considered for high endurance.

LPD-17 Machinery Plant – Based on the ADM requirement to consider an LPD-17 modified-repeat as one of the design options, **the LPD-17 machinery plant shall be one of the CUVX machinery plant alternatives**.

Sustained Speed and Propulsion Power - The ship shall be capable of a minimum sustained speed of 20 knots in the full load condition, calm water, and clean hull using no more than 80% of the installed engine rating (maximum continuous rating, MCR) of the main propulsion engine(s) or motor(s), as applicable for mechanical drive plants or electric propulsion plants. For integrated electric propulsion plants, the power required to achieve this speed must not be greater than 80% of the installed generator set rating following deductions for at-sea ship service power requirements and electric plant growth margins. To satisfy this requirement, and assuming a full load displacement of 20000 to 30000 MT, **machinery plant options with total propulsion brake horsepower in the range of 40000 to 80000 SHP shall be considered**.

Range and Endurance- The ship shall have sufficient burnable fuel in the full load condition for a minimum range of 4000 nautical miles at 20 knots. Endurance options up to 12000 nautical miles shall be considered. The total fuel rate for the propulsion engines, generator sets, and auxiliary boilers to be used in determining the endurance fuel requirements shall be calculated using methods described in References [5] and [6]. **Fuel efficient propulsion options such as diesel engines and ICR gas turbines shall be considered.**

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

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

Temperature and Humidity – Design environmental conditions shall be based on the requirement for extended vessel operations in the Persian Gulf. For internal combustion engines which draw combustion air from the weather, the propulsion engine ratings shall be based on the ship operating temperatures listed in Table 8.

Table 8. Ship Operating Temperatures

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

For IC engines that draw combustion air from the surrounding machinery space, engines shall be rated at the air temperature of the machinery space and sea water temperature based on the summer conditions in Table 8.

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

Steam - Steam shall not be used as a means of providing power for main propulsion. Auxiliary steam may be considered for catapult launch in mechanical drive alternatives.

3.2.3.2 Machinery Plant Alternatives

Fourteen machinery plant alternatives are considered in the CUVX trade-off study. These alternatives are shown in Figure 4. Alternatives 1-5 are mechanical drive systems and Alternatives 6-14 are electric drive systems (IPS). Alternatives 1-3 are single shaft configurations that require two gas turbine engines with greater than 20000 BHP each with single reduction gears. The fourth alternative is the same as the configuration used in the LPD-17, and the fifth alternative is a two shaft CODAG configuration, combining the efficiency of a diesel and the power of a gas turbine. Alternatives 6-9 are single shaft IPS configurations that have the same propulsion engines as Alternatives 1-3, but Alternatives 6, 7 and 9 only require two generators instead of three because they use the propulsion generators for primary ship service power. Alternative 8 uses five diesel engines. Alternatives 10 – 14 are two shaft configurations using different combinations of diesel, gas turbine, and ICR engines to span the target propulsion power range.

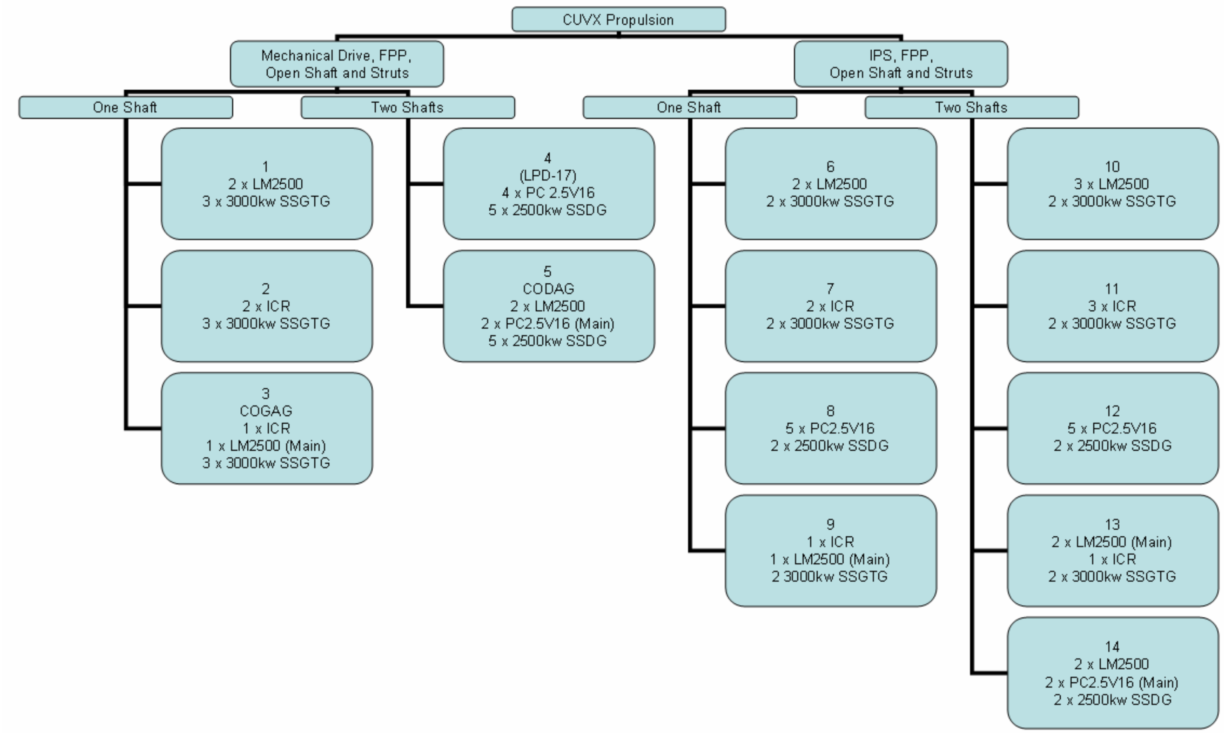

Figure 4. CUVX Machinery Alternatives

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

Single vs. twin shaft – Both single and twin shaft arrangements are considered in the machinery trade-off. The important benefits of having a single shaft are that it is lighter and costs less. The disadvantages of a single shaft are that there is no redundancy, less maneuverability, larger risk of total propulsion loss, and increased vulnerability. The benefits of having two shafts are redundancy, increased maneuverability and survivability. The disadvantages to having two shafts are the need for more maintenance and increased cost, weight and volume.

Propulsion Engine Alternatives - Three propulsion engines were chosen for trade-off in CUVX. The Colt-Pielstick 2.5V16 medium speed diesel engine was selected from medium speed diesels listed in Table 9 because of its commonality with LPD-17. The advantages of using a medium speed diesel engine are its inherent reliability, fuel efficiency, and low cost. Disadvantages are its high weight and volume, and low power density relative to gas turbine engines. Two gas turbine engines were selected for trade-off in CUVX, the LM-2500 and WR-21 ICR. LM-2500 is the US Navy's standard gas turbine engine with good power range and high power density. The disadvantage of this engine is that it has high fuel consumption, particularly at part loads. The WR-21 ICR has much lower fuel consumption, lower IR signature and high power density. However, this engine is not yet Navy qualified. ICR will have a higher acquisition cost, weigh a bit more than LM2500 and, at least initially, require more maintenance. Characteristics for these engines are provided in Table 10, Table 11, and Table 12.

Alternatives are included for selection in the ship synthesis model with characteristics listed in Table 13. This data was developed in ASSET and supplemented with manufacturer's data.

Table 9. Medium Speed Diesels

Model	Type	KW	RPM	SFC	Weight
F 38D8-1/8-10C	D DIESEL	1715.11	900	0.231145	18.5973
F 38D8-1/8-12	D DIESEL	1677.82	900	0.243311	21.9539
F 38D8-1/8-12C	D DIESEL	2058.13	900	0.225063	21.9539
F 38D8-1/8-6	D DIESEL	820.27	900	0.225063	11.5666
F 38D8-1/8-8	D DIESEL	1043.98	900	0.243311	8.39146
F 38TD8-1/8-10	D DIESEL	2237.1	900	0.225063	20.956
F 38TD8-1/8-12	D DIESEL	2609.95	900	0.200732	22.1807
F 38TD8-1/8-9	D DIESEL	1957.46	900	0.220805	16.2613
F PC2/12-DD	D DIESEL	5816.46	520	0.206814	65.408
F PC2/14-DD	D DIESEL	6785.87	520	0.206814	73.1191
F PC2/16-DD	D DIESEL	7755.28	520	0.206814	80.8302
F PC2/18-DD	D DIESEL	8724.69	520	0.206814	88.5412
PC 2.5V12	D DIESEL	5816.46	520	0.206814	65.408
PC 2.5V14	D DIESEL	6785.87	520	0.212897	73.1191
PC 2.5V16	D DIESEL	7755.28	520	0.214114	80.8302
PC 2.5V18	D DIESEL	8724.69	520	0.206814	88.5412
PC 4.2V10	D DIESEL	12132.5	400	0.190391	192.323
PC 4.2V12	D DIESEL	14559	400	0.188566	229.518
PC 4.2V14	D DIESEL	16985.6	400	0.188566	261.269
PC 4.2V16	D DIESEL	19412.1	400	0.188566	289.392
PC 4.2V18	D DIESEL	21838.6	400	0.188566	317.515

Table 10. LM-2500 Specifications and Dimensions

Engine Reference Characteristics

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

Table 11. ICR Specifications and Dimensions

Engine Reference Characteristics

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

Table 12. PC2.5V16 Specifications and Dimensions

Rating				Size		
Model	PC 2.5V16			Length	8.74	m
Power	7755	bkW		Width	3.70	m
Speed	520	rpm		Height	3.58	m
Mass Flow	14.83	kg/s		Weight	80.83	mton
Exhaust Temp	454.44	deg C				
SFC	0.2141	kg/kW-hr		Scale Fac	0.9	

Table 13. Propulsion Alternative Data

Propulsion Options	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Description	2x LM2500 3x 3000kw SSGTG	2x ICR 3x 3000kw SSGTG	COGAG 1xICR 1xLM2500 3x3000kw SSGTG	(LPD-17) 4x PC2.5V16 5x2500kw SSDG	CODAG 2xLM2500 2xPC2.5V16 5x2500kw SSDG	2x LM2500 2x 3000kw SSGTG	2x ICR 2x 3000kw SSGTG	5x PC2.5V16 2x 2500kw SSDG	1xICR 1x LM2500 2x3000kw SSGTG	3x LM2500 2x 3000kw SSGTG	3x ICR 2x 3000kw SSGTG	5x PC2.5V16 2x2500kw SSDG	2x LM2500 1xICR 2x3000kw SSGTG	2xLM2500 2xPC2.5V16 2x2500kw SSDG
Propulsion System Type $PSYS_{TYP}$	Mech.	Mech.	Mech.	Mech.	Mech.	IPS	IPS	IPS	IPS	IPS	IPS	IPS	IPS	IPS
Propeller Shafts, N_{prop}	1	1	1	2	2	1	1	1	1	2	2	2	2	2
Total Propulsion Engine BHP $P_{BPENGTOT}$(hp)	52500	58100	55300	41600	73300	52500	58100	52000	55300	78800	87100	52000	81500	73300
SSG Power (ea) KW_G(kW)	3000	3000	3000	2500	2500	3000	3000	2500	3000	3000	3000	2500	3000	2500
Number of SSGs N_{SSG}	3	3	3	5	5	2	2	2	2	2	2	2	2	2
Endurance Propulsion SFC_{ePE} (kg/kwhr)	0.264	0.199	0.202	0.210	0.266	0.261	0.198	0.213	0.198	0.264	0.198	0.211	0.264	0.210
Endurance SSG SFC_{eG} (kg/kwhr)	0.300	0.298	0.299	0.187	0.186	0.301	0.299	0.192	0.300	0.298	0.296	0.193	0.297	0.193
Machinery Box Minimum Length L_{MBreq}(m)	15.86	15.87	16.13	15.96	16.39	16.16	16.36	13.91	16.36	16.16	16.36	13.91	16.36	16.16
Machinery Box Minimum Width w_{MBreq}(m)	6.63	6.63	6.63	16.07	16.07	6.83	6.83	17.94	6.83	6.83	6.83	17.94	6.83	17.94
Machinery Box Minimum Height H_{MBreq}(m)	6.14	6.22	6.22	6.67	6.67	6.62	6.63	7.59	6.63	6.62	6.63	7.59	6.63	7.59
Basic Electric Machinery Weight W_{BMG}(MT)	198.9	198.9	198.9	304.8	304.8	132.9	132.9	122.6	132.9	132.9	132.9	122.6	132.9	122.6
Basic Propulsion Machinery Weight W_{BM}(MT)	655.2	745.8	767.2	902.9	1187.6	651.1	740.8	1934.5	705.2	935.5	1069.9	2051.0	981.1	1746.1
Propulsion Uptake Area $A_{PIE}(m^2)$	28.0	27.2	27.7	11.6	33.8	28.0	27.2	14.5	27.7	42.0	41.55	14.5	41.9	33.8
SSG Uptake Area $A_{GIE}(m^2)$	10.8	10.8	10.8	1.0	1.0	7.2	7.2	0.4	7.2	7.2	7.2	0.4	7.2	0.4
Machinery Box Required Volume $V_{MBreq}(m^3)$	5888	6536	6285	7816	7852	5138	5261	9487	5217	6982	7189	11127	7069	8514

Ship Service Generator Options – Two alternatives are selected for ship service generator sets, one diesel and one gas turbine. The diesel generator alternative uses the CAT 3608 IL8 engine. This is a Navy standard, shock qualified generator set that is used in AOE-6 and LPD-17. This generator set has excellent fuel consumption. The gas turbine generator option is the DDA 501-K34. This is the newer version of the DDA 501-K17 with a higher power output. This generator is Grade A shock qualified and US Navy certified. It has a high power density. The CAT 3608 engine is heavier and larger than the DDA 501-K34, but is more fuel efficient. Characteristics for the generator sets engines are listed in Table 14 and Table 15.

Table 14. CAT 3608 Specifications and Dimensions

Rating				Size		
Model	CAT 3608 IL8			Length	4.82	m
Power	2528	bkW		Width	1.75	m
Speed	900	rpm		Height	2.63	m
Mass Flow	3.45	kg/s		Weight	18.96	mton
Exhaust Temp	443.89	deg C				
SFC	0.1886	kg/kW-hr		Scale Fac	0.9	

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

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

3.2.4 Automation and Manning Parameters

To minimize CUVX acquisition costs, life cycle costs and personnel vulnerability during combat, it is very important to reduce manning. A number of automation technologies for aircraft launch and recovery, handling, maintenance, and weapons handling were considered including an electromagnetic aircraft launching system (EMALS), advanced arresting gear (AAG) or electromagnetic aircraft recovery system (EARS), pit stop concepts for fueling and rearming aircraft, shipboard weapons loader (SWL), and the use of fuel and weapons aircraft modules.

In Concept Exploration it is difficult to deal with automation manning reductions explicitly, so ship and aviation manning factors are used. These factors represent reductions from “standard” manning levels that result from automation. Standard manning equations are regression-based (Figure 5). Manning factor values (CManShip and CManAir = 0.5-1.0) are used for CUVX (DP14 and DP19). These manning factors are applied using simple expressions based on expert opinion to ship accommodations and support, automation cost, automation risk, damage control performance and repair capability performance as shown in Figure 5, Figure 6 and Figure 7. A more detailed manning analysis is performed in Concept Development.

Current steam catapults and cable arresting gear systems require significant manning for operation and maintenance. EMALS, AAG, and EARS all reduce manning. EMALS will require fewer men to setup and operate the launching sequence of aircraft. EMALS, AAG and EARS will require fewer men to maintain the systems.

Automation and manning reduction is also possible for aircraft weapons loading and fueling. A pit-stop concept is being considered where aircraft are brought to a specialized location to be refueled and reloaded. Safety procedures prohibit simultaneous weapons loading and fueling of aircraft, but even sequential loading and fueling can benefit from automation. A shipboard weapons loader (SWL) is in development that only requires two people to operate it. It has a maximum capacity of 3000 pounds, and is predicted to reduce loading times for JDAM and

HARM missiles from 6-13 minutes to 1 minute. Currently fueling rates are limited to prevent explosive vapors, but a vacuum-jacket fueling method is being developed that could increase safe fueling rates. Fully loaded aircraft can be parked in the hangar decks, but weapons cannot be armed until just prior to launch.

2g. Manning, other requirements, constraints and margins, constant for all designs:

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

$$N_{OShip} := 3 + \mathrm{ceil}\left(N_{prop} + \frac{N_{SSG}}{5} + \frac{W_P - W_{VP}}{15 \cdot lton} + \frac{V_{FL} + V_D}{80000\,ft^3}\right)$$

$$N_{EShip} := \mathrm{ceil}\left[CManShip \cdot \left(N_{prop} \cdot 6 + N_{SSG} \cdot 3 + \frac{W_P - W_{VP}}{10 \cdot lton} + \frac{V_{FL} + V_D}{4450\,ft^3}\right)\right]$$

$$N_{OAir} := \mathrm{ceil}\left(\frac{.1}{MT} \cdot W_{F23}\right)$$

$$N_{EAir} := \mathrm{ceil}\left(CManAir \cdot \frac{1.5}{MT} \cdot W_{F23}\right)$$

$$N_O := N_{OAir} + N_{OShip} \qquad N_E := N_{EAir} + N_{EShip}$$

N_T defines the total crew size, N_A the additional accommodations:

$$N_T := N_{EShip} + N_{OShip} + N_{EAir} + N_{OAir} \qquad N_A := \mathrm{ceil}(.1 \cdot N_T)$$

Figure 5. CUVX "Standard" Manning Calculation

Repair - MOP14:

$$VOP_{14} := \frac{CManShip + CManAir}{2}$$

DC - MOP22:

$$VOP_{22} := \frac{CManShip + CManAir}{2}$$

Figure 6. VOPs for Repair and Damage Control (DC)

+ Cost - Command, Control, Surveillance: (less payload GFM cost)

$$W_4 := \frac{W_{P400} + W_{IC} + W_{CO} + W_{CC}}{.5 \cdot (CManShip + CManAir)}$$

$$K_{N4} := \frac{Mdol}{lton^{.617}} \qquad C_{L_4} := .10857 F_I \cdot K_{N4} \cdot (W_4)^{.617}$$

$$OMOR := \frac{.5 \cdot PERFRISK + .3 \cdot COSTRISK + .2 \cdot SCHEDRISK}{(CManShip + CManAir)}$$

Figure 7. Impact of Manning Factors (Automation) on Cost and Risk

A fuel and weapons module concept was also considered to simplify fueling and weapons load out. This module would be similar to the magazine of a firearm. It would contain fuel for the aircraft and weapons for a specific mission. The module would be brought to the aircraft in an assembly line fashion and loaded into the body of the aircraft. This could greatly reduce manning requirements and possibly improve safety, but it was found that a module would overly constrain the UCAV-N aircraft design.

3.2.5 Aviation (Mission) Systems

Important CUVX aviation system characteristics include: concept of CUVX aviation operations; number, type, size and weight of aircraft to be supported; systems for UCAV launch and recovery (number, size and location of aircraft elevators, number and type of catapults, number and location of recovery wires and equipment); hangar deck and flight deck arrangements and minimum dimensions; systems, weights and area requirements for UCAV refueling, weapons load-out, aircraft support and maintenance including number, size and location of weapons elevators, shops and support equipment; ship aircraft fuel storage capacity; and aircraft weapons magazine capacity.

Characteristics for these systems in CUVX are based on existing and prior CV and CVN characteristics with adjustments made for supporting the UCAV-N vice manned combat and attack aircraft.

3.2.5.1 Virginia Tech UCAV-N

A Virginia Tech Aerospace Engineering UCAV-N design team is currently designing the UCAV-N for CUVX. The UCAV-N and CUVX teams are working in collaboration to effectively integrate the ship and the aircraft as an overall system. The UCAV-N will be a revolutionary aircraft in that it will be the first aircraft capable of landing on an aircraft carrier autonomously. Not only will the UCAV-N be fully autonomous during the mission but also in launch and recovery. The UCAV-N will be used for three missions: SEAD, strike and reconnaissance. When performing a SEAD or strike mission the UCAV-N will be armed with two JDAMs, two HARMs, or one of each. The strike range required to effectively perform a SEAD mission is 500 nm. In order to carry these weapons the UCAV-N will have a payload capacity of 4,300 lbs. Since the UCAV-N has no air-to-air combat capabilities and is a subsonic aircraft, it will rely on stealth as its main defense. When on a reconnaissance mission the UCAV-N must remain aloft for long periods of time without refueling in order to be effective and thus, the endurance requirement for the UCAV-N is 10 hours. The sensor suite to be used in the UCAV-N is the Global Hawk Integrated Sensor Suite manufactured by Raytheon and is the same as on the UAV Global Hawk. Some of the design requirements for the UCAV-N are listed in Table 16. The UCAV-N characteristics that are most important to ship operations are listed in Table 17. A three dimensional graphic of the UCAV-N is shown in Figure 8.

Table 16. UCAV-N Requirements

RFP Requirement	Specification
Mission 1, Strike Range	500 nm
Mission 2, Endurance	10 Hrs.
Payload	4,300 lbs
Cruise Speed	> Mach 0.7
Ceiling	> 45,000 ft
Sensor Suite	Global Hawk

Table 17. UCAV-N General Characteristics with F/A-18 C/D Comparison

Characteristic	UCAV-N	F/A-18C/D
Length	31 ft	56 ft
Span (Wings Unfolded)	45 ft	40 ft 5 in
Span (Wings Folded)	30 ft	27 ft 6 in
Height (Wings Unfolded)	10 ft	15 ft 4 in
Height (Wings Folded)	15 ft	15 ft 4 in
Weight (Max Gross Take Off)	25,000 lbs	51,900 lbs
Launch Acceleration	5 g's	4 g's
Takeoff Speed (Minimum)	160 knots	
Approach Speed	150 knots	135 knots
Wheel Track	12 ft	10 ft 3 in

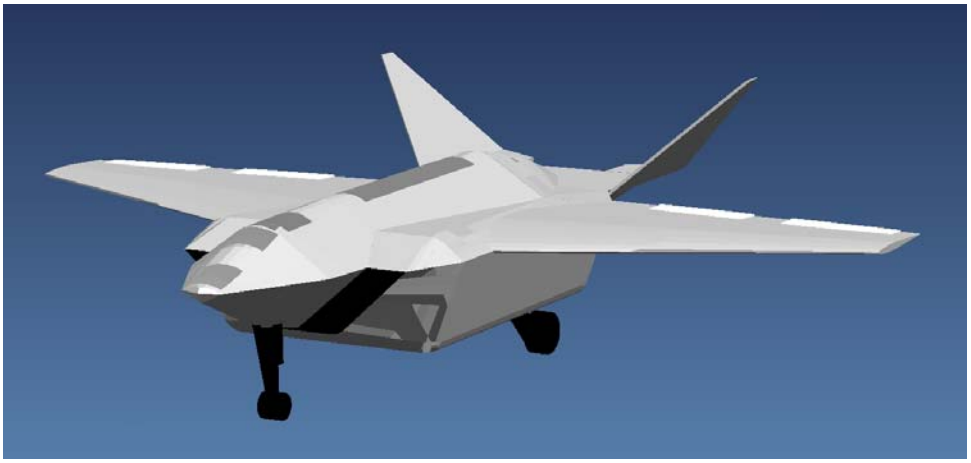

Figure 8. Three Dimensional Graphic of UCAV-N

3.2.5.2 Concept of CUVX Aviation Operations

Aviation operations on CUVX will be similar to aviation operations on a CVN in some respects, but there will also be significant changes due to size constraints and increased automation.

Aviation operations include the following functions.

- Aircraft launch
- Aircraft recovery
- Aircraft spotting and turnaround
- Aircraft crash, fire and rescue
- Aircraft weapons loading and fueling

CVN aircraft launch is accomplished using steam catapults. The CUVX ADM directs that steam propulsion not be considered, and therefore steam catapults in CUVX would require an auxiliary steam system. A preferred option is to use EMALS. A separate launch deck below the recovery deck would enable simultaneous launch and recovery on the size-constrained CUVX, but this is a novel concept and inherently high risk. Launch procedures must differ from CVNs since launch will take place on a partially-covered deck. Jet blast deflectors must direct the flow of hot gas from the aircraft engines out the side of the ship. Large ventilation fans will continuously purge this deck maintaining a positive internal pressure.

Recovery procedures will also vary from CVNs due to the limited size of CUVX. A typical CVN angled recovery deck is shown in Figure 9. The minimum required width for a clear runway on CVN is 100 feet, which is nearly the full beam of the recovery deck on CUVX. The clear runway width on CUVX must be smaller, but because UCAV-N will be autonomous with smaller aircraft and slower approach speeds it is predicted that closer tolerances can be maintained without added risk. Since the UCAV-N will land autonomously there is no need for a Landing Signal Officer (LSO) or a Fresnel Lens Optical Landing System (FLOLS). In place of the LSO and FLOLS, an array of sensors on the aircraft and on CUVX will be used to guide the aircraft to a safe landing. When landing, the aircraft will catch one of two or three arresting cables to stop.

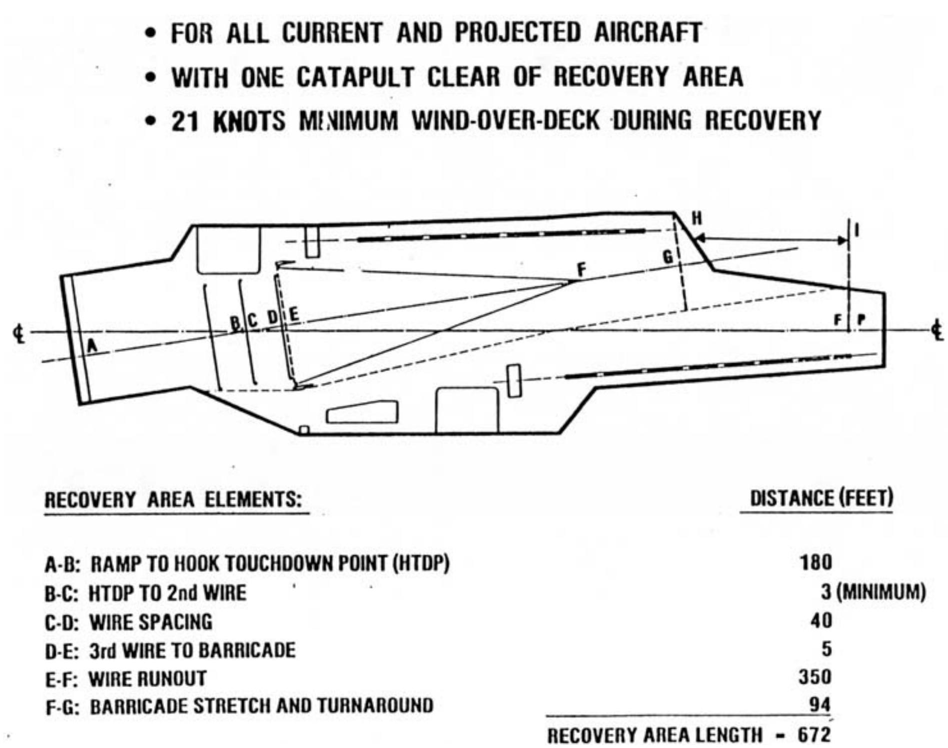

Figure 9. CVN Recovery and Launch Deck

Spotting and turnaround includes all movement and support of aircraft on the ship with the exception of recovering and launching. Spotting is the onboard arrangement of aircraft to provide for efficient launch and recovery. Turnaround refers to the movement and support of aircraft for fueling, weapons loading and unloading, and maintenance. After aircraft are recovered on CUVX they will be towed to a spot near an aircraft elevator and eventually onto an elevator. An automated (unmanned) aircraft-spotting dolly could be used for this purpose enabling an entirely unmanned recovery deck. Technologies capable of accomplishing this are used in commercial warehouses. This technology has not been used in naval aviation operations so it is considered a high-risk alternative. The level of automation when using an automated aircraft spotting dolly could range from one person commanding the tasks of each dolly to the dollies using an automated procedure to decide what dolly takes what task and how each task is accomplished.

Aircraft crash, fire, and rescue (CFR) procedures are not all encompassing since each aircraft crash presents its own special problems. The following equipment are available on a CVN for the salvage of crashed aircraft.

- Aircraft Crash Crane/Crash Forklift
- Aircraft Specific Hoisting Slings
- Universal Aircraft Fabric Hoisting Slings (Bellybands)
- Aircraft Crash Dolly/Tailhook Dolly

Since there are no pilots to rescue from crashed aircraft on CUVX, the procedures for dealing with these situations will be different from procedures on CVNs. If an aircraft has significant damage, it may not be salvaged. Severely damaged aircraft can be removed from the flight deck by pushing them over the side using automated tractors. Aircraft fires on the recovery deck will be handled using automated Mobile Firefighting Vehicles (MFFVs), and installed water/foam systems. Aircraft fires in the hangar decks will be fought using MFFVs and installed water/foam misting and deluge systems.

Fueling and weapons load-out will be accomplished on the first hangar deck at pit stop locations as described in the previous section.

3.2.5.3 CUVX Aviation System Characteristics

The Navy is developing an electromagnetic aircraft launching system (EMALS) to replace steam catapults, Figure 10. Recent advances in pulse-power, energy storage, power conditioning, and controls have made EMALS possible. Current EMALS technology is based on roller coaster and magnetic levitation train technologies. EMALS uses an electromagnetic pulse that propels a shuttle, typically a plate comprised of magnetic materials, over the distance of the track. Figure 11 shows two concepts for a shuttle: inverted U shuttle and blade shuttle. EMALS is expected to reduce weight, maintenance, and transient loads to the aircraft frames. Current CVN EMALS is required to provide 122 MJ of launch energy with a total cycle time between launches of 45 seconds to restore power. CUVX requirements are well within these limits. The CUVX launching system is required to have an end speed of 150 knots and launch energy of 40 MJ in order to launch a UCAV-N. Energy storage methods are currently being developed to provide the three-second high-power pulse necessary for launch. Large capacitors and rotational energy storage devices are being considered, but on CUVX a pulse-power system taking power directly from the IPS propulsion bus is proposed.

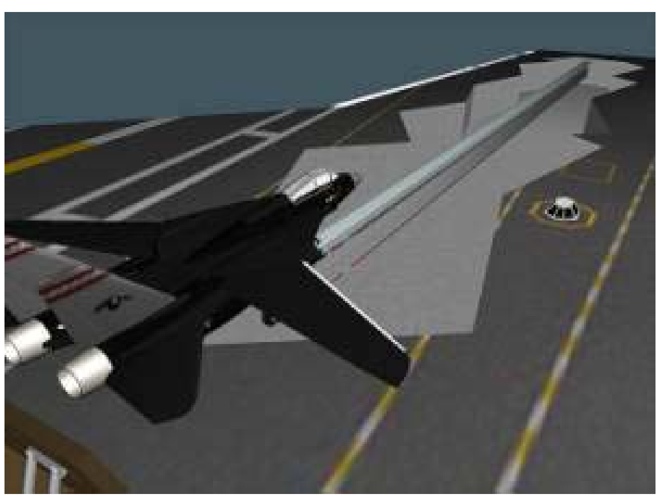

Figure 10. EMALS positioned on an aircraft carrier

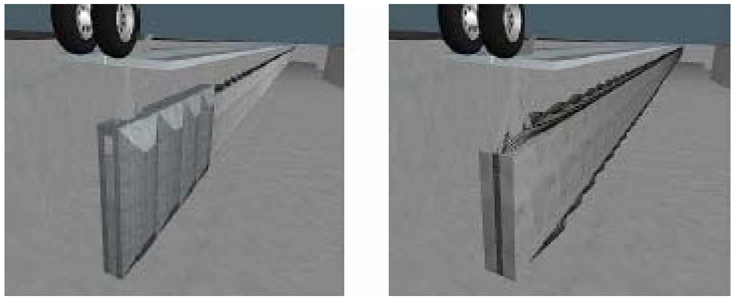

Figure 11. Inverted U Shuttle (left) and Blade Shuttle (right)

EMALS has a number of advantages compared to steam catapults. It is projected to weigh less than a steam catapult, which makes it ideal for a ship that is significantly smaller than a CVN. EMALS is also projected to reduce the manning required to operate and maintain the system. Since the system uses electromagnetic power and no longer requires a steam piston, boilers and steam can be eliminated. When a steam catapult is ready for launch, the appropriate amount of steam must be stored to assure that the aircraft will take-off with the correct speed. Once the catapult is released, there is no way to stop or modify the piston and aircraft travel. One of the main advantages of EMALS is that it provides feedback control. The system will adjust the acceleration curve of the aircraft continuously as it takes off. When this curve is compared to an ideal acceleration curve, the aircraft acceleration can be updated immediately to assure the aircraft will take-off at the optimum speed with minimum forces on the airframe. EMALS has been shown to have a low electromagnetic signature and will not create electromagnetic interference (EMI) problems for other ship equipment and operations. EMALS is easily upgradeable due to its modular design

For aircraft recovery the alternatives include conventional cable recovery systems, advanced arresting gear (AAG) and an electromagnetic aircraft recovery system (EARS). On CUVX, the existing cable arresting gear system can be used with fewer cables than the conventional four cables on a CVN. Since the UCAV-Ns are unmanned, and will have more accurate and precise landing capabilities, fewer cables may be sufficient. Four cables are used on CVNs to allow for human error and to make recovery operations easier on aircraft pilots. The conventional cable system requires a maintenance crew of 24 people to keep the system operational; the other alternatives require less maintenance. AAG and EARS are currently being developed, and will utilize the same technology as EMALS. It may be possible to combine EARS and EMALS to use only one electromagnetic system.

The ship synthesis model uses the equations in Figure 12 to model the impact of aviation systems in CUVX. The weight of UAVs (W_{UAV}), UCAVs (W_{UCAV}), and helicopters (W_{HELO}) was determined from information provided by the Virginia Tech UCAV-N Team or by online sources of existing aircraft. The area each aircraft requires was also provided by the UCAV-N team. L_{FltReq} and B_{FltReq}, the required length and beam of the main deck for flight operations, were adapted from CVN dimensions considering the lighter UCAV-N's. L_{FltReq} was based on the distances found in Figure 9, which shows CVN recovery area elements with a breakdown of the total recovery area length. The hook touch down point (HTDP) is the nominal target for the aircraft when landing. The distance to the hook touchdown point (HTDP) on a CVN is 54.864 meters. This was decreased to 15.24 meters for CUVX since the aircraft are unmanned, lighter, slower and have more accurate landing capabilities. On a CVN, the HTDP is located between the first and second wires. On CUVX the HTDP is located before the first wire. The distance from the HTDP to the first wire on CUVX is 0.914 meters. The distance between wires on CUVX is the same as on a CVN, 12.192 meters. Since there is no barricade on the recovery deck of CUVX, the barricade stretch and turnaround length is not required. The wire run-out required for the UCAV-N is 71.628 meters. With this configuration the minimum length of the flight deck on CUVX is 100 meters. The minimum beam of the flight deck is 25 meters to allow for the UCAV-N's to land with adequate clearance on each side of its wings. In the ship synthesis model, the length of the flight deck, L_{Flt}, is estimated to be 75% of the LWL to give adequate space for aviation operations, combat systems and other ship main deck features.

W_{F23} is the total aircraft weight for the entire ship, including UCAV's, UAV's, and HELO's. Since weights for various aviation systems were not available during the initial stages of Concept Exploration, approximations were made using CV 67 data. The minimum number of aircraft elevators was determined to be two for a ship of this size. These elevators can only be internal elevators because a deck edge elevator would be detrimental to the RCS of CUVX. The weight of an aircraft elevator, W_{ACElev}, is based on a linear approximation where each elevator is 10 times the weight of a UCAV.

The minimum number of weapons elevators is determined to be three to provide redundancy and separation. The weight of a weapons elevator, $W_{WeapElev}$, is 100 MT. The area of a weapons elevator, $A_{WeapElev}$, is taken from CV 67 data where the area of each elevator is 16.7 square meters.

The minimum number of catapults is determined to be two to provide redundant systems in case one of the systems breaks down. Two types of aircraft catapulting systems are considered, steam catapults and EMALS. The weight of a steam catapult system, $W_{AirSCat}$, is based on a linear approximation where each system is 15 times the weight of a UCAV. Given that EMALS is supposed to be lighter than a steam catapult, the weight of EMALS, $W_{AirEMALS}$, is based on a linear approximation where each system is 10.1 times the weight of a UCAV. The weight of the aircraft recovery system, W_{AirRec}, is based on a linear approximation where the system is 5.5 times the weight of a UCAV. The area required for launch and recovery equipment rooms is linearly approximated as the weight of a UCAV multiplied by 42.8 square meters per MT.

Aircraft require space for maintenance shops on the hangar decks. The area required for the aircraft maintenance shop, $W_{AirMaintShops}$, is linearly approximated by the area of a UCAV multiplied by the total number of HELO's and UCAV's divided by 10. The weight of all air supply equipment, $W_{AirSupE}$, is approximated by multiplying the total number of HELO's and UCAV's by 3.4 MT.

The weights of UAV fuel and HELO fuel per aircraft in the synthesis model is 45.7 and 5.1 MT, respectively. The weight of UCAV fuel storage per aircraft is a design parameter discussed in Section 3.2.2. The total ship aircraft fuel weight, W_{F42}, is the sum of the number of specific aircraft multiplied by their fuel weight per aircraft. The area required for fuel systems supplying aircraft fuel is 90 square meters per UCAV.

AVIATION

$$W_{UAV} = 0.227 \cdot MT \qquad A_{UAV} = 18.581\,m^2$$

$$W_{UCAV} = 11.793 \cdot MT \qquad A_{UCAV} = 72.464\,m^2$$

$$W_{HELO} = 6.462 \cdot MT \qquad A_{HELO} = 74.322\,m^2$$

$$L_{FltReq} := 100 \cdot m \qquad B_{FltReq} := 25 \cdot m \qquad L_{Flt} := 0.75 \cdot LWL$$

$$W_{F23} := N_{HELO} \cdot W_{HELO} + N_{UAV} \cdot W_{UAV} + N_{UCAV} \cdot W_{UCAV} \qquad \text{(ordinance delivery-aircraft)}$$

$$N_{AirElev} := 2 \quad \text{(internal, not D/E)} \qquad N_{cat} := 2 \qquad N_{WeapElev} := 3$$

$$W_{WeapElev} := 100 \cdot MT \cdot N_{WeapElev} \qquad A_{WeapElev} := 16.7 \cdot m^2 \cdot N_{WeapElev}$$

$$W_{ACElev} := 10 \cdot W_{UCAV} \cdot N_{AirElev}$$

$$W_{AirSCat} := 15 \cdot N_{cat} \cdot W_{UCAV} \qquad W_{AirEMALS} := 10.1 \cdot N_{cat} \cdot W_{UCAV}$$

$$W_{AirRec} := 5.5 \cdot W_{UCAV}$$

$$A_{LandR} := 42.8 \cdot \frac{m^2}{MT} \cdot W_{UCAV} \qquad A_{AirMaintShops} := A_{UCAV} \cdot \frac{N_{UCAV} + N_{HELO}}{10}$$

$$W_{AirSupE} := 3.4 \cdot MT \cdot (N_{UCAV} + N_{HELO})$$

$$W_{UCAVF} = 45.722 \cdot MT \qquad W_{UAVF} = 5.08 \cdot MT \qquad W_{HELOF} = 32.717 \cdot MT$$

$$W_{F42} := N_{HELO} \cdot W_{HELOF} + N_{UAV} \cdot W_{UAVF} + N_{UCAV} \cdot W_{UCAVF} \qquad \text{(total ship aircraft fuel weight)}$$

$$A_{AirFuel} := 90 \cdot m^2 \cdot N_{UCAV}$$

Figure 12. CUVX Aviation System Characteristics

The available hangar deck area for CUVX is approximated as shown in Figure 13. The ship synthesis model assumes a total of three hangar decks. The total hangar deck area, A_{HANGDK}, is calculated from the waterplane area (C_w*LWL*B) of the ship multiplied by the number of hangar decks. When the ship has tumblehome, the hangar decks above the waterline have less area due to the decrease in beam.

$$N_{HANGDK} := 3$$
$$A_{HANGDK} := C_W \cdot LWL \cdot B \cdot N_{HANGDK}$$
$$A_{HANGmax} := .75 \cdot A_{HANGDK}$$

Figure 13. CUVX Available Hangar Deck Area

The equations for hangar deck requirements for CUVX are shown in Figure 14. There must be enough room in the hangar decks to have a parking spot for every aircraft, a fueling and weapons loading pit stop area, an aircraft maintenance space, room for two aircraft elevators and three weapons elevators and room for the inlet and exhaust stacks for the engines and generators. If the concept of a launch deck located below the recovery deck is used, then the area for launching aircraft must be included in the hangar deck required area. If every aircraft is parked at one time in the hangars, $A_{AirPark}$ is the area of each aircraft multiplied by the number of the specific aircraft. The aircraft elevators should each hold two UCAV-N's at any time. The total hangar deck area for aircraft elevators, $A_{AirElev}$, is two times the area of a UCAV-N times the number of elevators times the number of hangar decks. If a launch deck is used, the area of the pit stop, A_{AirPit}, is 3 times the area taken up by a UCAV-N; otherwise, a pit stop will not be used in the hangars. The aircraft maintenance shops, $A_{AirMaint}$, must be large enough for two UCAV-N's. The total hangar deck area required for CUVX, $A_{HangarReq}$, is the sum of the areas for a launch deck, inlet and exhaust stacks and a factor of 1.3 times the areas for parking, elevators, pit-stops, and maintenance spaces. The margin of 1.3 is included to allow aircraft movement between stations. The total hangar deck volume required, V_{HANG}, is the total hangar deck area multiplied by the hangar deck height.

Hangar Deck Area

$$A_{AirPark} := N_{UAV} \cdot A_{UAV} + N_{UCAV} \cdot A_{UCAV} + N_{HELO} \cdot A_{HELO}$$

$$A_{AirElev} := 2 \cdot A_{UCAV} \cdot N_{AirElev} \cdot N_{HANGDK}$$

$$A_{AirPit} := \begin{cases} 3 \cdot A_{UCAV} & \text{if } DP_8 = 1 \\ 0 \cdot m^2 & \text{otherwise} \end{cases} \qquad A_{AirLaunch} := \begin{cases} 100 \cdot m \cdot B_{FltReq} + 3 \cdot A_{UCAV} & \text{if } DP_8 = 1 \\ 0 \cdot m^2 & \text{otherwise} \end{cases}$$

$$A_{AirMaint} := 2 \cdot A_{UCAV}$$

$$A_{HangarReq} := \left(A_{AirPark} + A_{AirElev} + A_{AirPit} + A_{AirMaint} + A_{WeapElev}\right) \cdot 1.3 + A_{AirLaunch} + A_{HIE}$$

$$V_{HANG} := A_{HangarReq} \cdot H_{HANGDK}$$

Figure 14. CUVX Hangar Deck Area Requirements

3.2.6 Combat System Alternatives

3.2.6.1 Combat System Requirements

The primary requirement for CUVX shipboard combat systems is self-defense. CUVX primary offensive presence is provided by its airwing. CUVX has a very low budget for combat systems, and must depend largely on passive defense.

3.2.6.2 AAW

AAW systems on CUVX are integrated by the Ship Self Defense System (SSDS). This system is intended for installation on all non-Aegis ships. The SSDS improves effectiveness by coordinating hard kill and soft kill and employing them to their optimum tactical advantage. However, SSDS does not improve the performance of any sensor or weapon beyond its stand-alone capability. The SSDS is a versatile system that can be used as a tactical decision aid or an automatic weapon system.

SSDS uses mostly Commercial Off-the-Shelf (COTS) products, including a fiber optic Local Area Network (LAN). SSDS employs single or multiple Local Access Unit (LAU) cabinets with an Uninterruptible Power Supply (UPS) and VME card cage. Processor cards are identical and interchangeable, so spares can be stocked.

CUVX AAW trade-off alternatives include goal and threshold systems listed in Table 18. The alternatives are identical except for the missile systems. Both include: AN/SPS-49A(V)1, Very Long-Range Air Surveillance Radar; AN/SPS-73(V)12, Surface Search Radar; AN/SLQ 32A(V)2, Electronic Warfare System; Centralized

Identification Friend or Foe (CIFF); Phalanx Close-In Weapons System (CIWS); Mk36 Decoy Launching System (DLS); Combat Direction Finding (DF); and Infrared Search and Track (IRST). The AAW goal missile system is an Enhanced Sea Sparrow Missile (ESSM) 2x4 cell Peripheral Vertical Launching System (VLS). This is supported by the Mk91 Guided Missile Fire Control System (GMFCS) w/Mk93 Target Acquisition System (TAS) and AN/SPQ-9B Radar. The AAW threshold missile system is the Rolling Airframe Missile (RAM). All sensors and weapons in each suite are integrated using SSDS. Specific sub-system descriptions are as follows:

- AN/SPS-49A(V)1 Very Long-Range Air Surveillance Radar is a long-range, two-dimensional, air-search radar system. It provides automatic detection and reporting of targets within its surveillance volume. It operates in the presence of clutter, chaff, and electronic counter-measures. It has a line of sight / horizon stabilized antenna for low altitude targets and an upshot feature for high-diving threats.
- AN/SPS-73(V)12 Radar is a short-range, two-dimensional, surface-search/navigation radar system. It provides contact range and bearing information. It also enables quick and accurate determination of ownship position relative to nearby vessels and navigational hazards, making it valuable for navigation and defense.
- AN/SLQ-32 Electronic Warfare (EW) System provides warning, identification, and direction-finding of incoming anti-ship cruise missiles (ASCM). It provides early warning, identification, and direction-finding against targeting radars. It also provides jamming capability against targeting radars.
- CIFF (Centralized Id. Friend or Foe) is a centralized, controller processor-based system that associates different sources of target information. It accepts, processes, correlates and combines IFF sensor inputs into one IFF track picture. It controls the interrogations of each IFF system and ultimately identifies all targets as a friend or foe.
- DLS (Decoy Launching System) defends against ASCMs which have penetrated to the terminal-defense area. It can launch an array of chaff cartridges against a variety of threats by projecting decoys aloft at specific heights and ranges. It confuses hostile missile guidance by creating false signals.
- Combat DF (Direction Finding) is an automated long range hostile target signal acquisition and direction finding system. It can detect, locate, categorize and archive data into the ship's tactical data system. It provides greater flexibility against a wider range of threat signals. Combat DF also provides warship commanders near-real-time indications and warning, situational awareness, and cueing information for targeting systems to make timely decisions.
- MK91 GMFCS(Guided Missile Fire Control System) provides an additional layer of ship missile defense. It combines the Firing Officer Console and Radar Set Console functionality into a single Advanced Display System Console. It detects, tracks, identifies, evaluates, and assigns weapons for use against high-speed, small cross-section targets.
- Phalanx Close-In Weapons System (CIWS) provides defense against low altitude ASCMs. It is a hydraulically driven 20 mm gatling gun capable of firing 4500 rounds per minute. CIWS magazine capacity is 1550 rounds of tungsten ammunition. CIWS is computer controlled to automatically correct aim errors. Phalanx Surface Mode (PSUM) incorporates its side mounted Forward Looking Infrared Radar (FLIR) to engage low, slow or hovering aircraft and surface craft.
- Infrared Search and Track (IRST) is a shipboard integrated sensor designed to detect and report low flying ASCMs by their heat plumes. IRST scans the horizon +/- a few degrees but can be manually changed to search higher. It provides accurate bearing, elevation angle, and relative thermal intensity readings.
- The AAW goal missile system is the ESSM. ESSM (Evolved Sea Sparrow Missiles) are high speed and acceleration air-to-air missiles with high explosive warheads. They are short range missiles intended to provide self-protection for surface ships. They can engage and provide defense against a variety of ASCMs and aircraft. They are capable against low observable highly maneuverable missiles. An ESSM quad-pack fits in a single VLS cell, providing 32 missiles total in each of two 4-cell MK41 VLS halves.
- Vertical Launching System (VLS) is a fixed, vertical, multi-missile storage and firing system. It simultaneously supports multiple warfighting capabilities, including AAW, ASW, SSD, SW, and ASuW. Simultaneous preparation of missiles in each half of launcher module allows for fast reaction to multiple threats with concentrated, continuous firepower.

- AN/SPQ-9B Radar also supports the ESSM. Its most important feature is the ability to detect surface skimming ASCMs. It provides cueing to ship self defense systems. It may also function as the primary surface search radar.
- Rolling Airframe Missile (RAM) is the threshold missile. It is cued from SSDS. RAM is a self contained package. It can use Active Optical Target Detector (AOTD) for improved effectiveness in presence of aerosols. RAM also features Infrared Modular Update (IRMU) to provide capability against non-RF radiating threats. It is comprised of the GMLS (launching system) and GMRP (round pack). RAM is effective and lethal against most current ASCMs. Its capability against LAMPS, aircraft, and surface targets is being developed.

Table 18. AAW System Alternatives

AAW System Alternatives	Goal	Threshold
SSDS MK2 MOD2	X	X
AN/SPS-49A(V)1 Air Search Radar	X	X
AN/SPS-73(V)12 Surface Search Radar		X
AN/SLQ 32A(V)2 Electronic Warfare System	X	X
Centralized ID Friend or Foe (CIFF)	X	X
Mk36 Decoy Launching System (DLS)	X	X
Combat DF	X	X
IRST	X	X
CIWS Mk15 BLK 1B	X	X
ESSM w/ 2x4 cell Peripheral MK 41 VLS	X	
Mk91 MFCS	X	
AN/SPQ-9B Radar	X	
RAM		X

3.2.6.3 ASuW

CUVX ASuW trade-off alternatives both include LAMPS, Penguin Missiles, two MK 46 Mod 1 30mm machine guns, two MK 26 Mod 17 .50 cal. machine guns, and small arms as listed in Table 19. The goal ASuW system has 4 LAMPS. The threshold ASuW system has only 2 LAMPS. Specific sub-system descriptions are as follows:

- SH-60 Seahawk can perform ASW, ASuW, search and rescue, SPECOPS, and cargo lift. It also deploys sonobuoys and torpedoes and extends ship's radar capabilities. It has a retractable in-flight fueling probe for prolonged loitering time. Self defense is provided by two 7.62mm machine guns. It is capable of carrying and launching AGM-114 Hellfire missiles,AGM-119 Penguin missiles, and Mk46 or Mk50 torpedoes.
- The Penguin Missile is a helicopter launched anti-ship missile. It can operate in "Fire and Forget" mode to allow multiple target acquisition.

Table 19. ASuW System Alternatives

ASuW System Alternatives	Goal	Threshold
AN/SPS – 73(V)12 Surface Search Radar	X	X
LAMPS MK3 SH-60 Seahawk Helo	4	2
AGM-119 Penguin Missiles	X	X
MK 46 Mod 1 30mm Machine Gun	2	2
MK 26 Mod 17 .50 Cal Machine Guns	2	2
Small arms	X	X

3.2.6.4 ASW

CUVX ASW systems include LAMPS MK3 SH-60 Seahawk Helo, MK50 Torpedoes, SSTD (Surface Ship Torpedo Defense), AN/SLQ-25 NIXIE, and SVTT (Surface Vessel Torpedo Tube) as listed in Table 20. Specific sub-system descriptions are as follows:

- The Mk 50 Torpedo is an advanced lightweight torpedo used against fast, deep-diving, sophisticated submarines. It can be launched from all ASW aircraft and ship torpedo tubes.
- Surface Ship Torpedo Defense (SSTD) includes countermeasures and acoustic sensors to detect, track, and divert incoming torpedoes. It provides torpedo defense against all threatening torpedoes. SSTD consists

of detection, control, and counter-weapon subsystems. A layered-attrition approach utilizes outer (hardkill) and inner (softkill) subsystems for defense.

- AN/SLQ-25 NIXIE is a tow-behind decoy that employs an underwater acoustic projector. It provides deceptive countermeasures against acoustic homing torpedoes. NIXIEs can be used in pairs or as singles.
- The MK 32 Surface Vessel Torpedo Tube (SVTT) provides an ASW launching system which pneumatically launches both MK-46 and MK-50 torpedoes over-the-side of ownship. SVTT is capable of stowing and launching up to three torpedoes under local control or remote control from an ASW fire control system.

Table 20. ASW System Alternatives

ASW System Alternatives	Goal	Threshold
LAMPS MK3 SH-60 Seahawk Helo	4	2
MK50 Torpedoes	X	X
SSTD (Surface Ship Torpedo Defense)	X	X
AN/SLQ-25 NIXIE	X	X
SVTT (Surface Vessel Torpedo Tube)	2	2

3.2.6.5 SEW

Space and Electronic Warfare (SEW) systems include AN/SLQ-32 and DLS. Descriptions of the specific sub-systems are as follows:

- AN/SLQ-32 is a sensor system that provides early detection and identification of threats. It serves as the electronic eyes of the SSDS. It also provides radar jamming.
- The Decoy Launching System (DLS) launches chaff at an angle of either 45 or 60 degrees from horizontal. The chaff can be launched to confuse a variety of missiles coming from any angle.

3.2.6.6 MCM

Mine Countermeasures (MCM) is defined as any activity used to prevent or reduce the danger of enemy mines. Passive countermeasures operate by reducing a ship's acoustic and magnetic signatures, while active countermeasures include mine-hunting and minesweeping.

CUVX MCM systems include Mine Avoidance Sonar (MAS) and degaussing. Descriptions of the specific sub-systems are as follows:

- Mine Avoidance Sonar determines the type and presence of mines. MAS is an active MCM that detects mines and allows CUVX to avoid dangerous areas.
- Degaussing is a passive MCM that reduces CUVX magnetic signature. Degaussing works by passing a current through a mesh of wires to generate a magnetic field that cancels the ship's magnetic field as shown in Figure 15.

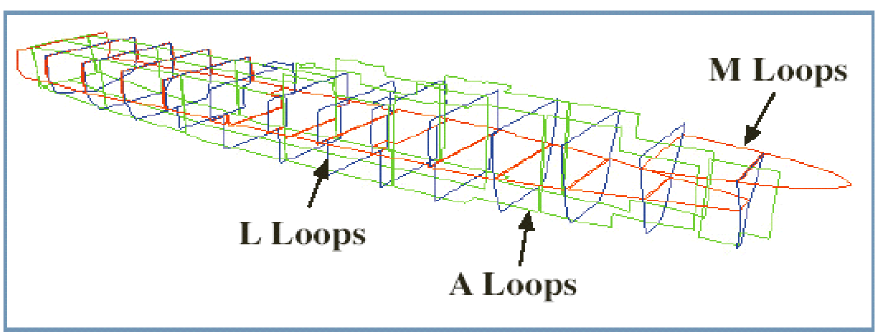

Figure 15. Degaussing

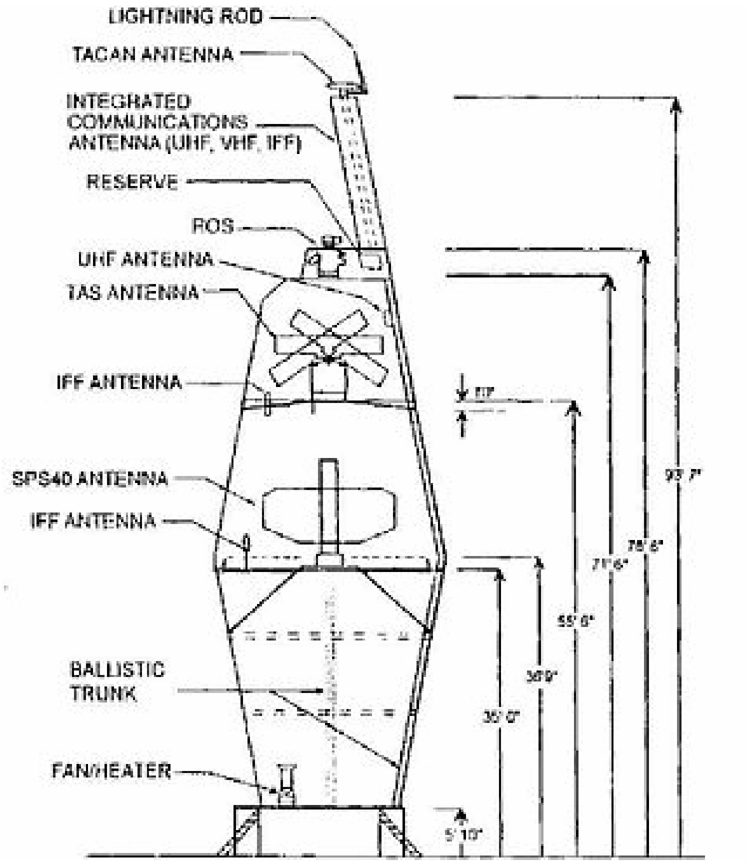

Figure 16. Advance Enclosed Mast Sensor System

3.2.6.7 Topside Design

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

- Advanced Enclosed Mast Sensor System is a low RADAR Cross Section (RCS) enclosure that hides CUVX's sensors in one structure as shown in Figure 16. It uses a polarization technique to allow ownship sensor radiation in and out while screening and reflecting enemy sensor radiation. It also protects CUVX's sensors from the environment and provides for 360 degree radiation and sensing without mast blanking.
- The Low Observable Multi Function Stack shown in Figure 17 is another low RCS structure for antennas and stacks. It incorporates active ventilation to reduce CUVX's heat signature and houses Global Broadcast System (GBS), EHF SATCOM, UHF SATCOM, IMARSAT, Link 11, and Link 16 antennas.

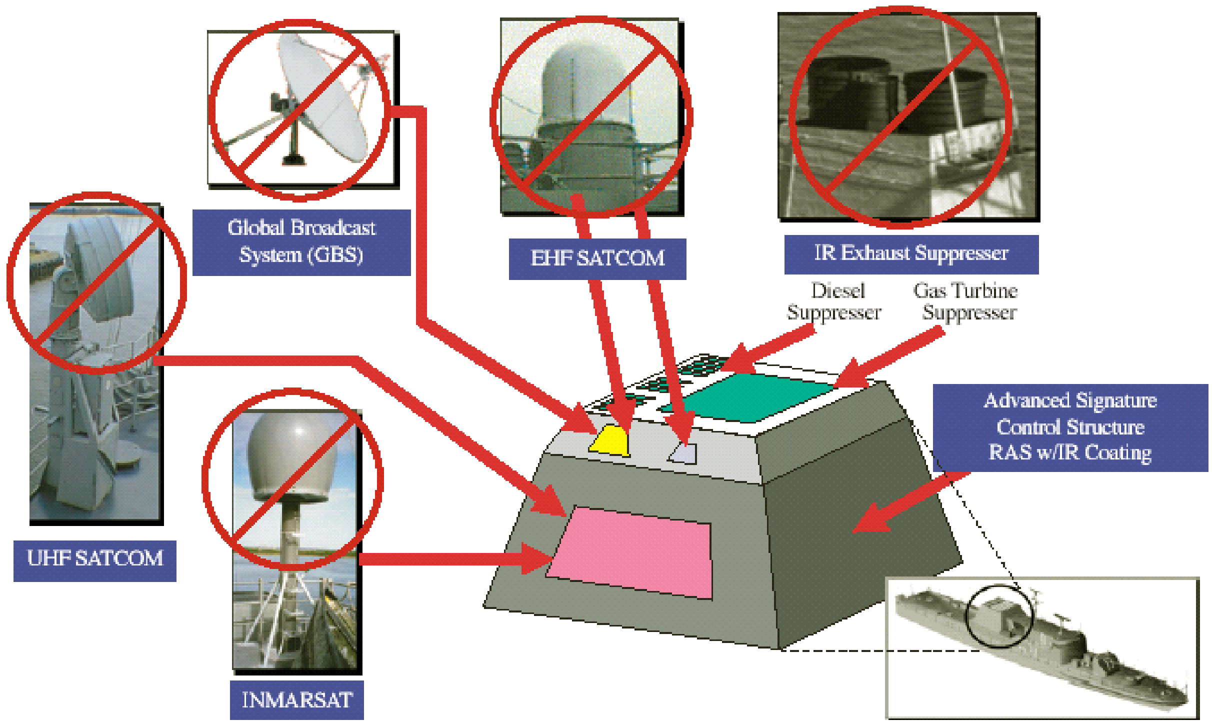

Figure 17. Multi-Function Stack

3.2.6.8 UCAV Weapons

UCAV weapons include the AGM-88 High-speed Anti-Radiation Missiles (HARM), AIM-120 Advanced Medium-Range Air-to-Air Missiles (AMRAAM) Slammer, Joint Direct Attack Munitions (JDAM), and aircraft-deployed mines. Specific descriptions of these weapons are as follows:

- The AGM-88 High-speed Anti-Radiation Missile (HARM) is a supersonic air-to-surface tactical missile. Its primary mission is to seek and destroy enemy radar-equipped air defense systems. It can detect, attack and destroy a target with minimum aircrew input.
- The AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM) Slammer is a supersonic, air-launched guided missile with aerial intercept capabilities. It provides an autonomous launch-and-leave capability against single and multiple targets in all environments.
- Joint Direct Attack Munitions (JDAM) are highly-accurate, all-weather, autonomous, conventional bombing weapons. They are capable of independent target and launch from up to 15 miles. JDAM automatically begins initialization process during captive carry when power is applied by the aircraft.
- MK 67 Quickstrike Mines are aircraft-deployed, shallow water mines. They lie on the ocean bottom and detect targets using magnetic, seismic, and pressure Target Detection Devices (TDD).
- MK 60 CAPTOR Mines are deep water mines that are anchored to the ocean floor. They can be deployed from aircraft, ships, or submarines. They serve as the Navy's primary anti-submarine weapon. Upon detection of a target, the MK 60 deploys a MOD 4 torpedo. They use the Reliable Acoustic Path (RAP) Target Detection Device (TDD).
- The MK 56 Mine is an aircraft-deployed moored mine for use in moderate water depths. It uses a total field magnetic exploder Target Detection Device (TDD).

3.2.6.9 Combat Systems Payload Summary

In order to trade-off combat system alternatives along with other alternatives in the total ship design, combat system characteristics listed in Table 21 are included in the ship synthesis model data base.

Table 21. Combat System Ship Synthesis Characteristics

ID	NAME	WARAREA	WTGRP	WT (lton)	HD10	AREAGRP	HAREA	DHAREA	CRSKW	BATKW
3	DATA DISPLAY GROUP - BASIC	AAW	411	5.74	12.19	1131	1086	0	45	45
4	INTERFACE EQUIPMENT - BASIC	AAW	413	0.3	5.72	1131	50	0	5	5
5	DATA PROCESSING GROUP - BASIC	AAW	413	1.47	6.47	1131	210	0	10	10
6	SPS-49A (V)1 2-D AIR SEARCH RADAR	AAW	452	6.91	17.19	1121	52	0	79	79
7	CENTRALIZED IDENTIFICATION FRIEND OR FOE (CIFF)	AAW	455	2.3	29.2	0	0	0	3.2	4
9	AN/SPQ-9B RADAR FOR HORIZON AND SURFACE SEARCH	AAW	456	4.11	59	0	0	0	220.16	220.16
12	SSDS MK 2 SHIP SELF DEFENSE SYSTEM	AAW	481	1	14.5	1210	0	464	3.2	10.4
13	MK91 MFCS w/MK93 TAS (FOR ESSM)	AAW	482	4.96	22.35	1221	0	122	50.3	85.8
16	WEAPON SYSTEM SWITCHBOARDS	AAW	489	2.24	7.28	1142	55	0	4	4
17	COMBAT DF	AAW	495	8.26	21	1141	0	448	15.47	19.34
18	COOLING EQUIPMENT FOR AN/SPQ-9B X-BAND RADAR	AAW	532	4.43	-21.81	1121	47.85	0	13.64	13.64
22	2X MK15 BLK 1B 20MM CIWS & WORKSHOP	AAW	711	13.2	21	1210	0	321	14	42
23	2X MK31 BLK1 RAM LAUNCHERS (RIM 116 MISSILES)	AAW	720	8.2	14	1222	0	536	10	32
24	MK15 BLK1B CIWS 20MM AMMO - 16000 RDS	AAW	21	8.3	20	1210	0	257	0	0
25	MK36 DLS SRBOC CANNISTERS - 100 RDS	AAW	21	2.2	13.6	0	0	0	0	0
26	RIM-116 RAM BLK1 - 42 RDS	AAW	22	3.86	14	0	0	0	0	0
27	SPS-73 SURFACE SEARCH RADAR	ASUW	451	1.7	29.6	1121	0	70	8	8
31	SC SMALL ARMS AND PYRO STOWAGE	ASUW	760	5.8	-6.3	1900	203	0	0	0
33	SC SMALL ARMS AMMO - 7.62MM + 50 CAL + PYRO	ASUW	21	4.1	-6	0	0	0	0	0
36	SQQ-28 LAMPS MK III ELECTRONICS	ASW	460	3.4	3	1122	15	0	5.3	5.5
41	AN/SLQ-25A NIXIE TOWED ASW DECOY SYSTEM	ASW	473	3.6	-5.72	1142	172	0	3	4.2
42	TORPEDO DECOYS	ASW	473	4.52	-4.89	0	0	0	0	0
43	UNDERWATER FIRE CONTROL SYSTEM w/SSTD - BASIC	ASW	483	0.4	8.32	1142	124	0	11.5	11.5
51	2X MK32 SVTT ON DECK	ASW	750	2.7	1.14	0	0	0	0.6	1.1
53	LAMPS MKIII 18 X MK50 TORP & SONOBUOYS & PYRO	ASW	22	9.87	4.8	1374	0	588	0	0
54	LAMPS MKIII 2 X SH-60B HELOS	ASW/ASUW	23	12.73	4.5	1340	0	3406	5.6	5.6
55	LAMPS MKIII AVIATION SUPPORT AND SPARES	ASW/ASUW	26	9.42	5	1390	357	0	0	0
56	BATHYTHERMOGRAPH PROBES	ASW	29	0.2	-16.11	0	0	0	0	0
63	MINE AVOIDANCE SONAR	MCM	462	11.88	-18.03	1122	350	0	5	5
76	AN/SLQ-32A [V]2 PASSIVE ECM	SEW	472	3	21.5	1141	40	132	6.4	6.4
78	MK36 DLS W/4 LAUNCHERS	SEW	474	1	13.6	0	0	0	2.4	2.4
82	VLS WEAPON CONTROL SYSTEM	AAW	482	0.7	-9.66	1220	56	0	15	18
92	2X MK15 BLK 1B 20MM CIWS & WORKSHOP	AAW	711	13.20	21	1210	0	321	14	42
94	RIM-7M SEA SPARROW MISSILES X 32	WEAP	21	7.16	0	0	0	0	0	0
98	MK-50 ADCAP TORPEDOS X 8	ASW	21	2.68	0	0	0	0	0	0
100	SC ADVANCED C4I SYSTEM	C4I	440	32.3	-7.9	1111	1270	95	93.3	96.4
102	2x4 CELL VLS DEWATERING SYSTEM	WEAP	529	3	-6.97	0	0	0	0	0
103	2x4 CELL VLS ARMOR - LEVEL III HY-80	WEAP	164	4	-6.17	0	0	0	0	0
104	MK41 VLS 2x4-CELL	WEAP	721	20.7	-7.97	1220	1123	0	31.1	31.1
105	LAMPS MKIII PENGUIN MISSILES X 4	ASUW	21	1.79	0	0	0	0	0	0

Table 22. CUVX Design Parameters

	Description	Metric	Range	Increments
1	Hull form	type	General monohull, LPD-17, WPTH	3
2	Prismatic coefficient	ND	.6-.8	20
3	Max section coefficient	ND	.9-.99	9
4	Displacement to length ratio	lton/ft2	50-90	20
5	Beam to Draft Ratio	ND	3-5	20
6	Length to Depth Ratio	ND	6-8	20
8	Aircraft launch deck?	y/n	0,1	2
9	Deckhouse volume ratio	ND	.05-.3	25
10	AAW system	alternative	1,2	2
11	LAMPS helos	#	2,4	2
18	Endurance range	nm	4000,8000,12000	3
19	Stores duration	days	60,90,120	3
20	Propulsion system	alternative	1-14	14
21	Ship manning and automation factor	ND	.5-1.0	5
22	Hull structure type	type	Conventional, ADH	2
23	CPS	extent	None, partial, full	3
24	UAVs	#	5-20	15
25	UCAVs	#	10-30	20
26	Aviation manning and automation factor	ND	.5-1.0	5
27	Ship aircraft fuel	lton/UCAV	30.-60.	10
28	Ship aircraft weapons	lton/UCAV	5.-15.	10

3.3 Design Space

Each ship design is described using 21 design parameters (Table 22). Design-parameter values are selected by the optimizer from the range indicated, and are input into the ship synthesis model. The ship is then balanced, checked for feasibility, and ranked based on risk, cost and effectiveness. Hull form alternatives and other hull form design parameters (DP 1-6 and 9) are described in Section 3.2.1. Aviation-related design parameters (DP 8, 11, and 24-28) are described in Section 3.2.5. Combat system design parameters (DP 10 and 11) are described in Section 3.2.6.

3.4 Ship Synthesis Model

In the Concept Exploration phase of the design process, a simple ship synthesis model is required to support the optimization. This model was developed using MathCad software. A flow chart for the model is shown in Figure 18. It balances the ship in terms of weight, displacement, volume, area and power. The model allows variation of design parameters, while maintaining a balanced ship. Measures of Performance (MOPs) are calculated based on the design parameters and their predicted performance in a balanced design. Values of Performance (VOPs) and effectiveness (OMOE) are calculated as described in Section 3.5.1. An Overall Measure of Risk (OMOR) is calculated as described in Section 3.5.2. Ship acquisition cost is calculated using a weight and producibility-based cost model as described in Section 3.5.3.

The ship synthesis model is organized into a number of modules as shown in Figure 18. These include:

- Module 1 inputs necessary unit conversions and physical constants.
- Module 2 inputs, decodes and processes the design parameter vector and other design parameters that are constant for all designs.
- Module 3 calculates hull resistance and required shaft horsepower at endurance and sustained speeds.
- Module 4 calculates available volume and area.
- Module 5 calculates maximum functional electrical load and average 24-hour electrical load.
- Module 6 calculates tankage, volume and area requirements.
- Module 7 calculates SWBS weights and total ship weight.
- Module 8 calculates ship KG and GM.
- Module 9 calculates hull form principal characteristics and is used to summarize, balance and assess design feasibility.
- Module 10 calculates cost.
- Module 11 calculates effectiveness.
- Module 12 calculates risk.

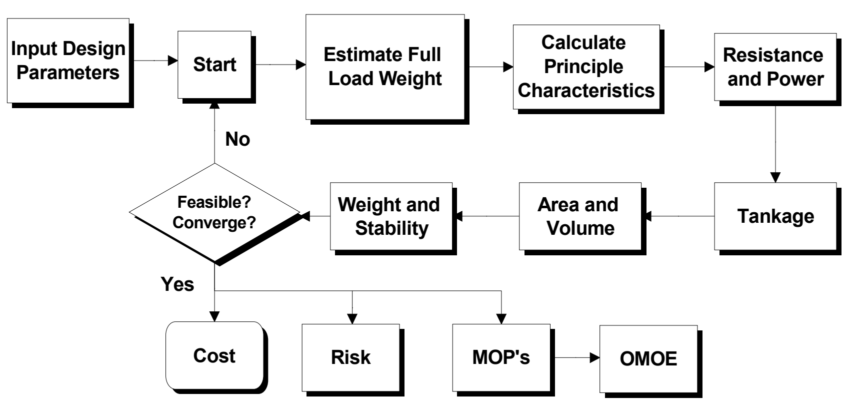

Figure 18. Ship Synthesis Model

The following sections describe the synthesis model calculations. The entire model is provided in Appendix D.1.

3.4.1 Modules 1 and 2 – Input, Decoding

Module 1 inputs necessary unit conversions and physical constants including liquid specific volumes, air and seawater properties. Module 2 inputs, decodes, and processes the design variable vector and sets other design parameters values that are constant for all designs. Payload (combat system) weights, centers of gravity, areas and electric power requirements are read from data files and summed by SWBS group. Combat system values of performance (VOPs) are calculated. For CUVX, aviation-related design characteristics are input and processed. Propulsion system characteristics listed in Table 13 are specified for the propulsion system selected. Standard manning is calculated and modified based on the level of automation specified in the ship and aviation manning factors. Propulsion, power and other design margins are set.

3.4.2 Module 3 - Resistance and Required SHP

Resistance is calculated using the Holtrop and Mennon Method with estimated worm curve factors applied for the WPTH hullform. Viscous drag is calculated using the 1957 International Towing Tank Conference (ITTC) equation with a form factor. Bare hull, appendage and wind drag are added to calculate total resistance and Effective Horsepower (EHP). An Overall Propulsive Coefficient (PC=0.7) is applied to calculate Shaft Horsepower (SHP). In Concept Development a more complete propeller and propulsion analysis are performed. SHP is calculated at endurance speed to determine endurance fuel requirements (10% margin) and at sustained speed to determine required shaft horsepower (25% margin). The Concept Exploration resistance and power calculation is shown in Module 3 of **Error! Reference source not found.**.

3.4.3 Module 4 – Available Volume and Area

Available hull volume is calculated using displaced volume, an area projection of the freeboard and the waterplane area coefficient. Deckhouse volume is calculated as a fraction of total hull volume using the deckhouse coefficient, DP8. The depth at Station 10, D10, is assessed for structural adequacy, freeboard at a 25 degree heel angle, and accommodation of large object spaces and machinery rooms. Machinery box volume is calculated. Concept Exploration volume and area calculations are shown in Module 4 of **Error! Reference source not found.**. More accurate area and volume measurements and arrangements are performed in AutoCad during Concept Development.

3.4.4 Module 5 - Electric Power

Ship service electric power requirements are calculated using regression-based equations. Loads for propulsion, steering, lighting, HVAC, combat systems, other auxiliaries and services are calculated, summed and margins are applied. The regression equations include load factors so this total represents Maximum Functional Load with Margins (MFLM). Electric load calculations are shown in Module 5 of **Error! Reference source not found.**. A more complete Electric Load Analysis is performed in Concept Development. The MFLM is used in to size and determine the number of ship service generators. It is also used to estimate an average 24-hour electric load for the endurance fuel calculation.

3.4.5 Module 6 – Tankage, Required Volume and Area

Module 6 performs a standard endurance fuel calculation using the required endurance BHP calculated in Module 3 and the 24-hour average electric load calculated in Module 5. Required fuel tank volume is calculated based on the endurance fuel weight required to satisfy the endurance range requirement (DP11). Other tank volumes and ship functional area requirements are calculated using regression equations. Volume requirements including tanks and machinery rooms are subtracted from available volume and the remaining arrangeable area is compared to required area. Volume and area calculations are shown in Module 6 of **Error! Reference source not found.**. A more complete space calculation is performed using an Excel spreadsheet in Concept Development.

3.4.6 Module 7 - Weight

SWBS weights are calculated using regression equations as a function of propulsion power, MFLM, ship volume and other ship dimensions. Weight calculations are shown in Module 7 of **Error! Reference source not found.**. A more complete weight and center of gravity calculation is performed using an Excel spreadsheet in Concept Development.

3.4.7 Module 8 - Stability

KG is calculated based on the weights from Module 7 and regression equations for SWBS group vertical centers of gravity. Simple equations are used to estimate KB and BM. A KG margin is applied. The GM/B ratio is used to assess stability by comparison to minimum and maximum limits. These calculations are shown in Module 8 of **Error! Reference source not found.**. No estimate is made for longitudinal center of gravity or trim.

3.4.8 Module 9 - Calculate Principal Characteristics, Summary, Assess Feasibility

As shown in Figure 18, ship displacement is estimated at the beginning of a design iteration. Resistance, power, area, and weight requirements are calculated based on this estimate. Weight must equal displacement and other requirements listed below must be met in a balanced design.

	Required/Minimal	Available	Error
Weight:	$W_T = 2.582\times 10^4\,MT$	$W_{FL} = 2.584\times 10^4\,MT$	$ERR = 7.214\times 10^{-4}$
Arrangeable area:	$A_{TR} = 1.846\times 10^5\,ft^2$	$A_{TA} = 2.057\times 10^5\,ft^2$	$ERR_A = 0.114$
Hangar Area:	$A_{HangarReq} = 8.273\times 10^3\,m^2$	$A_{HANGmax} = 1.089\times 10^4\,m^2$	
Deckhouse area:	$A_{DR} = 545.731m^2$	$A_{DA} = 671.705m^2$	$V_D \equiv C_{vd}\cdot V_{FL}$
Propulsion power:	$P_{IREQ} = 4.114\times 10^4\,hp$	$P_{IPRP} = 4.16\times 10^4\,hp$	$N_T = 658$
Electrical plant:	$KW_{GREQmech} = 2.15\times 10^3\,kW$	$KW_G = 2.5\times 10^3\,kW$	
Mach. box height:	$H_{MBreq} = 6.67m$	$H_{MB} = 7.63m$	
Depth:	$D_{10MIN} = 84.219ft$	$D_{10} = 87.369ft$	
Sustained Speed:	$V_e = 20\,knt$	$V_S \equiv 21.4\,knt$	
Stability:	.07-.2	$C_{GMB} = 0.155$	
Length of Flight Deck:	$L_{FltReq} = 100m$	$L_{Flt} = 150m$	
Breadth of Flight Deck:	$B_{FltReq} = 25m$	$B = 29.54m$	

Figure 19. Feasibility Requirements

Weight and displacement are iterated until convergence. A design is considered feasible if feasibility requirements and thresholds are satisfied simultaneously as shown in Figure 19. If a design is feasible, the synthesis model continues to calculate cost, effectiveness and risk as described in Sections 3.5.1, 3.5.2 and 3.5.3. These characteristics are the objective attributes for a Multi-Objective Genetic Optimization (MOGO) that is used to search the design space and identify non-dominated designs as described in Section 3.5.

3.5 Multi-Objective Optimization

Objective attributes for this optimization are cost (lead ship acquisition cost and mean follow ship acquisition cost, performed separately), risk (technology cost, schedule and performance risk) and military effectiveness. A flow chart for the Multi-Objective Genetic Optimization (MOGO) is shown in Figure 20. In the first design generation, the optimizer randomly defines 1200 balanced ships using the ship synthesis model to balance each ship and to calculate cost, effectiveness and risk. Each of these designs is ranked based on their fitness or dominance in effectiveness, cost and risk relative to the other designs in the population. Penalties are applied for infeasibility and niching or bunching-up in the design space. The second generation of the optimization is randomly selected from the first generation, with higher probabilities of selection assigned to designs with higher fitness. Twenty-five percent of these are selected for crossover or swapping of some of their design parameter values. A very small percentage of randomly selected design parameter values are mutated or replaced with a new random value. As each generation of ships is selected, the ships spread across the effectiveness/cost/risk design space and frontier. After 300 generations of evolution, the non-dominated frontier (or surface) of designs is defined as shown in Figure 29 and Figure 30. Each ship on the non-dominated frontier provides the highest effectiveness for a given cost and risk compared to other designs in the design space. The "best" design is determined by the customer's preferences for effectiveness, cost and risk.

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 21 and described in Sections 3.5.1 and 3.5.2. Cost is calculated using a modified weight-based regression approach as described in Section 3.5.3.

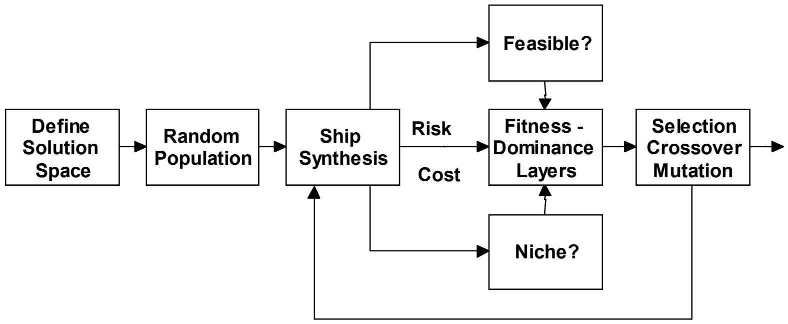

Figure 20. Multi-Objective Genetic Optimization

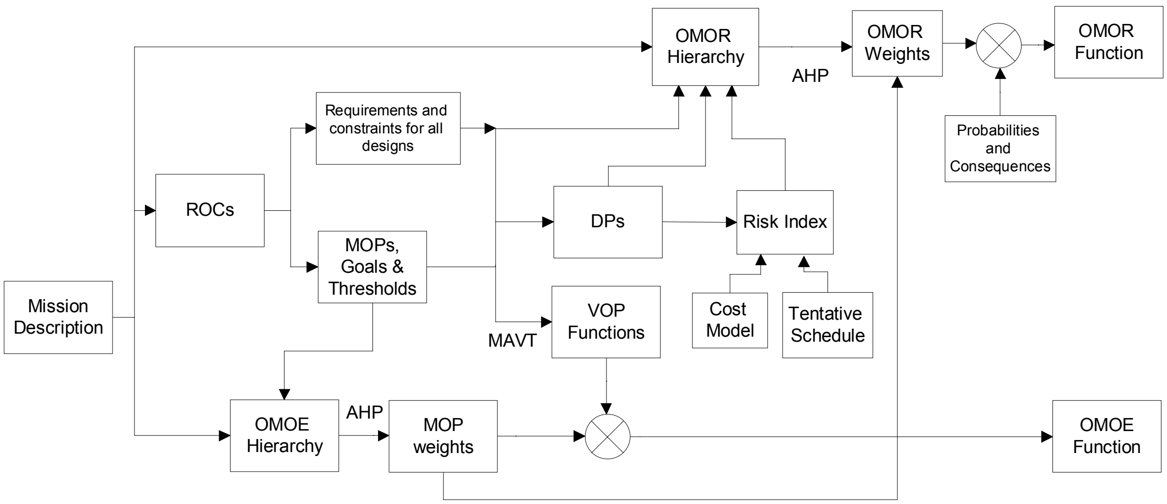

Figure 21. OMOE and OMOR Development Process

3.5.1 Overall Measure of Effectiveness (OMOE) Error! Reference source not found. Module 11

Figure 21 illustrates the process used to develop the CUVX OMOE and OMOR. Important terminology used in describing this process includes:

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

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

An alternative to modeling and simulation is to use expert opinion directly to integrate these diverse inputs, and assess the value or utility of ship MOPs in an OMOE function. This can be structured as a multi-attribute decision problem. Two methods for structuring these problems dominate the literature: Multi-Attribute Utility

Theory [2] and the Analytical Hierarchy Process [3]. In the past, supporters of these theories have been critical of each other, but recently there have been efforts to identify similarities and blend the best of both for application in Multi-Attribute Value (MAV) functions [4]. This approach is adapted here for deriving an OMOE.

The process described in Figure 21 begins with the Mission Need Statement and mission description presented in Chapter 2. Required capabilities (ROCs) are identified to perform the ship's mission(s) and measures of performance (MOPs) are specified for those capabilities that will vary in the designs as a function of the ship design variables (DPs). Each MOP is assigned a threshold and goal value. Capability requirements and constraints applicable to all designs are also specified. Table 23 summarizes the ROCs, DP and MOPs definition for CUVX. An Overall Measure of Effectiveness (OMOE) hierarchy is developed for the MOPs using the Analytical Hierarchy Process (AHP) to calculate MOP weights and Multi-Attribute Value Theory (MAVT) to develop individual MOP value functions. The result is a weighted overall effectiveness function (OMOE) that is used as one of three objectives in the multi-objective optimization. In the AHP, pair-wise comparison questionnaires are produced to solicit expert and customer opinion, required to calculate AHP weights. Value of Performance (VOP) functions (generally S-curves) are developed for each MOP and VOP values are calculated using these functions in the ship synthesis model. A particular VOP has a value of zero corresponding to the MOP threshold, and a value of 1.0 corresponding to the MOP goal.

Figure 22 illustrates the OMOE hierarchy for CUVX derived from Table 23. Separate hierarchies are developed for each mission or condition (pre-conflict, conflict and post-conflict) for CUVX. MOPs are grouped into six categories (ship combat, sustainability, mobility, vulnerability, susceptibility and airwing combat) under each mission. MOP weights calculated using expert opinion are compared in Figure 23. The CUVX VOP curve for sustained speed (MOP 15) is illustrated in Figure 24. Other VOP curves and functions are similar. MOP weights and value functions are finally assembled in a single OMOE function:

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

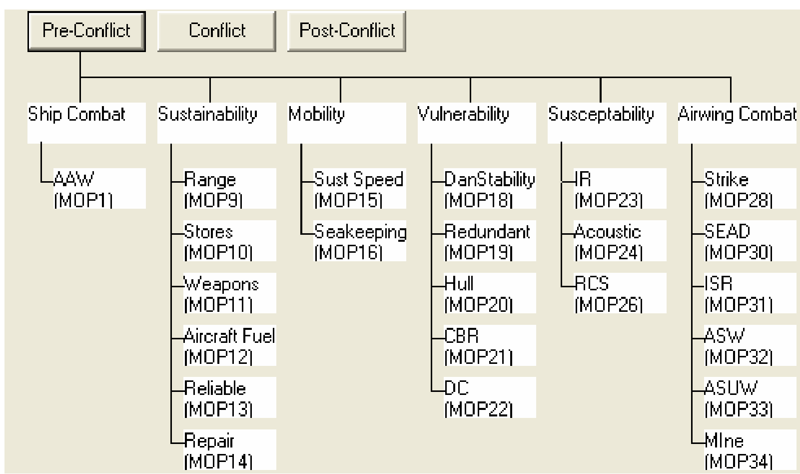

Figure 22. OMOE Hierarchy

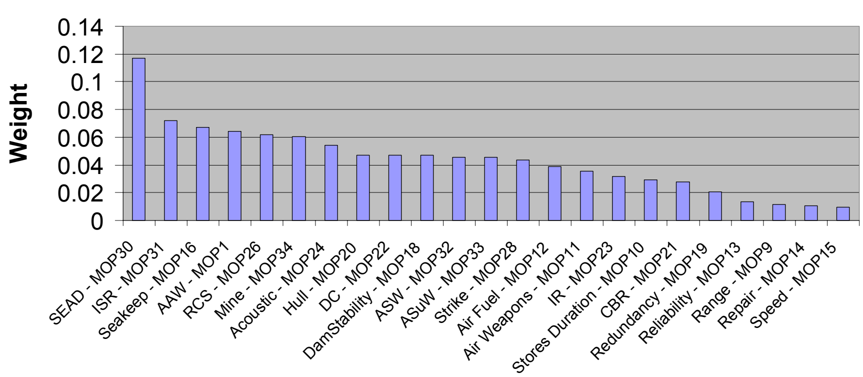

Figure 23. MOP Weights

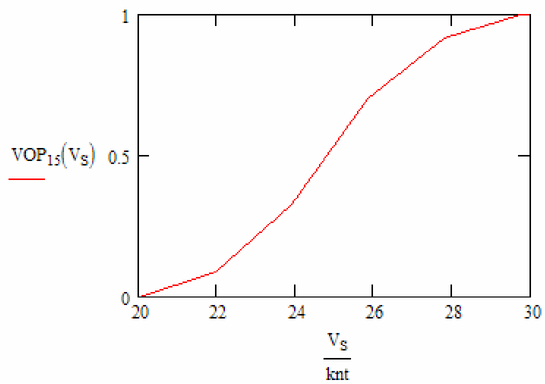

Figure 24. Value of Performance Function for Sustained Speed

Table 23. ROC/MOP/DP Summary

ROC	MOP or Constraint	Threshold or Constraint	Goal	Related DP
MOB 1 - Steam to design capacity in most fuel efficient manner	MOP15 - sustained speed MOP9 - range at endurance speed	20 knots 4000 nm	25 knots 12000nm	DP1-DP7 – Hull form DP18 - Range (nm) DP20 – Propulsion system
MOB 3 - Prevent and control damage	MOP18 - Damage stability MOP19 - Redundancy MOP20 - Hull structure MOP22 - Damage control MOP23 – IR Signature MOP24 – Acoustic Signature MOP26-RCS	tumblehome 1 shaft conventional Automation LM2500 Mechanical drive flare	flare 2 shafts ADH Full manning ICR/diesel IPS tumblehome	DP1 - Hull form type DP20 – Propulsion system (1-14) DP7 - Hull structure type DP21,26 – ShipManFac, AirManFac DP20 – Propulsion system (1-14) DP20 – Propulsion system (1-14) DP1 - Hull form type
MOB 3.2 - Counter and control NBC contaminants and agents	MOP21 - collective protection system?	none	full	DP23 – CPS (none,part,full)
MOB 5 - Maneuver in formation	Turning radius – required all designs	1000 ft		
MOB 7 - Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	Required all designs			
MOB 10 - Replenish at sea	Required all designs			
MOB 12 - Maintain health and well being of crew	Required all designs			
MOB 13 - Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support	MOP9 - range at endurance speed MOP10 - Stores MOP11 – Weapons capacity MOP12 – Ship's aircraft fuel capacity MOP13/19 Reliability/redund MOP14 - Repair	4000 nm 60 days 5lton / UCAV 30lton/UCAV 1 shaft 50% manning w/automation	12000 nm 120 days 15lton/UCAV 60lton/UCAV 2 shafts Full manning	DP18 - Range (nm) DP19 - Stores Endurance DP28 - Aircraft weapons capacity DP27 - Aircraft fuel capacity DP20 – Propulsion system (1-14) DP21,26 – ShipManFac, AirManFac
MOB 16 - Operate in day and night environments	Required all designs			
MOB 17 - Operate in heavy weather	MOP16 - McCreight index Launch and recover maximum seastate	25.0 SS 4	35.0 SS 5	DP1-DP7 - Hull form fins
MOB 18 - Operate in full compliance of existing US and international pollution control laws and regulations	Required all designs			None
CV1 - Operate and support unmanned aircraft (UCAV) in land attack offensive missions, independent of land facilities including SEAD	MOP28-Strike capability MOP30-SEAD capability MOP34-Mining	No launch deck 10 UCAVs	Launch deck (simultaneous launch & t/o) 30 UCAVs	DP8-separate launch deck DP25-number of UCAVs
CV2 - Operate and support unmanned aircraft in ISR missions independent of land	MOP31 - ISR	5 UAVs	20 UAVs	DP24-number of UAVs
CV3 - Operate and support	MOP32-ASW	2 LAMPS	4 LAMPS	DP11-ASW/ASUW LAMPS

ROC	MOP or Constraint	Threshold or Constraint	Goal	Related DP
aircraft (LAMPS) in defensive missions against enemy surface and submerged forces, independent of land facilities	MOP33-ASUW MOP34-Mining			
CV4 - Shelter, transport, launch, recover and maintain unmanned aircraft and helicopters	Various / all			DP11-ASW/ASUW LAMPS DP24-number of UAVs DP8-separate launch deck DP25-number of UCAVs DP26-AirManFac
CV5 - Provide weapons storage and handling for embarked unmanned aircraft	MOP11 - Weapons capacity	5lton/UCAV	15lton/UCAV	DP28 - Aircraft weapons capacity
AAW 1.2 - Provide unit self defense	MOP1 - Ship AAW	SSDS w/RAM, CIWS	SSDS w/ESSM, CIWS	DP10 - AAW system
AAW 5 - Provide passive and softkill anti-air defense	All designs – DLS/SRBOC and EW	DLS/SRBOC and SLQ-32		None
AAW 6 - Detect, identify and track air targets	MOP1 - Ship AAW	AN/SPS-49A(V)1 Air Search Radar	AN/SPS-49A AN/SPQ-9B TAS	DP10 - AAW system
ASU 1 - Engage surface threats with anti-surface armaments at medium and close range	MOP33-ASUW	2 LAMPS; 30mm Machine Guns; .50 Cal Machine Guns	4 LAMPS +	DP11-ASW/ASUW LAMPS
ASU 2 - Engage surface ships in cooperation with other forces	All designs – data link	Link 11 / 16		
ASU 4.1 - Detect and track a surface target with radar	All designs – surface radar	AN/SPS – 73(V)		
ASU 6 - Disengage, evade and avoid surface attack	MOP15 - sustained speed	20 knots	25 knots	DP1-DP7 – Hull form DP20 – Propulsion system
ASW 1.1 - Engage submarines at long range	MOP32-ASW	2 LAMPS	4 LAMPS	DP11-ASW/ASUW LAMPS
ASW 1.3 - Engage submarines at close range	All designs – torpedo tubes	SSTD (Surface Ship Torpedo Defense); SVTT (Surface Vessel Torpedo Tube)		
ASW 4 - Conduct airborne ASW/recon	MOP32-ASW	2 LAMPS	4 LAMPS	DP11-ASW/ASUW LAMPS
ASW 5 - Support airborne ASW/recon	MOP32-ASW	2 LAMPS	4 LAMPS	DP11-ASW/ASUW LAMPS
MIW 7 – Deploy mines using UCAVs	MOP34-Mine	10 UCAVs	30 UCAVs	DP25-number of UCAVs
CCC 1.6 - Provide a Helicopter/ UCAV Direction Center (HDC)	All designs			
CCC 3 - Provide own unit CCC	All designs			
CCC 4 - Maintain data link capability	All designs	Link11/16		
SEW 2 - Conduct sensor, ECM and ECCM operations	All designs	SLQ-32		
FSO 5 - Conduct towing/search/rescue operations	All designs			
FSO 6 - Conduct SAR operations	MOP8 - number of UAVs and LAMPS	10 UAVs 2 LAMPS	30 UAVs 4 LAMPS	DP24-number of UAVs DP11-ASW/ASUW LAMPS
INT 1 - Support/conduct intelligence collection	MOP8 - number of UAVs and LAMPS	10 UAVs 2 LAMPS	30 UAVs 4 LAMPS	DP24-number of UAVs DP11-ASW/ASUW LAMPS
INT 2 - Provide intelligence	All designs			
INT 3 - Conduct surveillance and reconnaissance (ISR)	MOP8 - number of UAVs	10 UAVs 2 LAMPS	30 UAVs 4 LAMPS	DP24-number of UAVs DP11-ASW/ASUW LAMPS
NCO 3 - Provide upkeep and maintenance of own unit	MOP14 - Repair	50% manning w/automation	Full manning	DP21,26 – ShipManFac, AirManFac
NCO 19 - Conduct maritime law enforcement operations	All designs			
LOG 1 - Conduct underway replenishment	All designs			

3.5.2 Overall Measure of Risk (OMOR) Error! Reference source not found. **Module 12**

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

Three types of risk events are considered in the CUVX risk calculation: performance, cost and schedule. The initial assessment of risk performed in Concept Exploration, as illustrated in Figure 21, is a very simplified first step in the overall Risk Plan and the Systems Engineering Management Plan (SEMP) for CUVX. Referring to Figure 21, after the ship's missions and required capabilities are defined and technology options identified, these options and other design parameters are assessed for their potential contribution to overall risk. MOP weights, tentative ship and technology development schedules and cost predictions are also considered. Possible risk events identified for CUVX are listed in Table 24. To calculate an OMOR, these risk events are organized in a Risk hierarchy similar to the hierarchy used to calculate the OMOE (Figure 25, Figure 26 and Figure 27). The AHP and expert pair-wise comparison are then used to calculate OMOR hierarchy weights, W_{perf}, W_{cost}, W_{sched}, w_j and w_k. The OMOE performance weights calculated previously that are associated with risk events are normalized to a total of 1.0, and reused for calculating the OMOR. Once possible risk events are identified, a probability of occurrence, P_i, and a consequence of occurrence, C_i, are estimated for each event using Table 25 and Table 26. The OMOR is calculated using these weights and probabilities in Equation 3-1:

$$OMOR = W_{perf} \sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{cost} \sum_j w_j P_j C_j + W_{sched} \sum_k w_k P_k C_k \qquad (3\text{-}1)$$

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

Table 24. CUVX Risk Register

SWBS	Risk Type	Risk ID	DP#	DP Description	DP Value	Risk Event E_i	Risk Description	P_i	C_i	R_i
Armament	Performance	1	DP_{10}	Peripheral VLS	1	Failure of PVLS EDM test	Will require use of VLS or RAM with impact on flight deck and hangar deck area and ops	0.3	0.5	0.15
Hull	Performance	2	DP_1	WPTH hull form	2	Unable to accurately predict endurance resistance	Will over-predict endurance range.	0.2	0.3	0.06
Propulsion	Performance	3	DP_{20}	Integrated power system	>5	Development and use of new IPS system	New equipment and systems will have reduced reliability	0.4	0.4	0.16
Hull	Performance	4	DP_1	WPTH hull form	2	Unable to accurately predict sustained speed resistance	Will over-predict sustained speed.	0.2	0.5	0.1
Hull	Performance	5	DP_1	WPTH hull form	2	Unable to accurately predict WPTH seakeeping performance	Seakeeping performance will not be acceptable	0.5	0.5	0.25
Hull	Performance	6	DP_1	WPTH hull form	2	Unable to accurately predict WPTH extreme motions and stability	Damaged stability performance will not be acceptable	0.7	0.7	0.49
Hull	Performance	7	DP_8	Separate launch deck	1	Concept doesn't work preventing simultaneous launch and recovery for SEAD mission	Unforeseen problems with dedicated launch deck (launch, fuel, weapons)	0.4	0.8	0.32
Hull	Performance	8	DP_8	Separate launch deck	1	Concept doesn't work preventing simultaneous launch and recovery for Strike mission	Unforeseen problems with dedicated launch deck (launch, fuel, weapons)	0.4	0.9	0.36
Propulsion	Schedule	9	DP_{20}	Integrated power system	>5	Development and integration of new IPS system will be behind schedule	Unexpected problems with new equipment and systems	0.3	0.3	0.09
Propulsion	Cost	10	DP_{20}	Integrated power system	>5	Development and integration of new IPS system will have cost overuns	Unexpected problems with new equipment and systems	0.3	0.6	0.18
Auxiliary	Schedule	11	DP_{20}	EMALS	>5	Development and integration of new EMALS system will be behind schedule	Unexpected problems with new equipment and systems and integration with IPS pulse power	0.5	0.4	0.20
Auxiliary	Cost	12	DP_{20}	EMALS	>5	Development and	Unexpected problems with new	0.5	0.6	0.3

SWBS	Risk Type	Risk ID	DP#	DP Description	DP Value	Risk Event E_i	Risk Description	P_i	C_i	R_i
						integration of new EMALS system will have cost overuns	equipment and systems and integration with IPS pulse power			
Armament	Cost	13	DP_{10}	Peripheral VLS	1	PVLS EDM test and development system will have cost overuns	Unexpected problems with new equipment and systems	0.2	0.4	0.08
Armament	Schedule	14	DP_{10}	Peripheral VLS	1	PVLS EDM test and development will be behind schedule	Unexpected problems with new equipment and systems	0.2	0.2	0.04
Hull	Schedule	15	DP_1	WPTH hull form	2	Delays and problems with WPTH testing	Unexpected problems or unsatisfactory performance of new hull form	0.5	0.7	0.35
Hull	Cost	16	DP_1	WPTH hull form	2	Delays and problems with WPTH testing	Unexpected problems or unsatisfactory performance of new hull form	0.5	0.6	0.3

Table 25. 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 26. Event Consequence Estimate

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

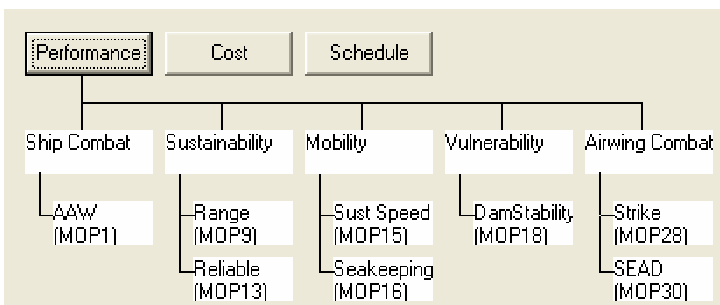

Figure 25. Performance Risk

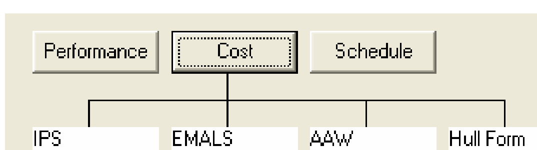

Figure 26. Cost Risk

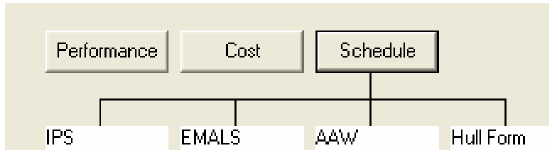

Figure 27. Schedule Risk

3.5.3 Cost (Error! Reference source not found. Module 10)

Lead ship acquisition cost, and follow ship acquisition cost are particularly important for getting the concept of a CUVX carrier "off the ground". Two separate multi-objective optimizations are performed for CUVX, the first using lead ship acquisition cost, and the second using mean follow-ship acquisition cost.

CUVX construction costs are estimated for each SWBS group using weight-based equations adapted from an early ASSET cost model and US Navy cost data. Historical costs are inflated to the base year using a 2.3% average annual inflation rate from 1981 data. The CUVX base year is assumed to be 2005. Figure 28 illustrates total lead ship acquisition cost components calculated in the model. Lead ship costs include detail design engineering and plans for the class (SWBS 800 – Integration and Engineering) and all tooling, jigs and special facilities for the class (SWBS 900 - Ship Assembly and Support). The Basic Cost of Construction (BCC) is the sum of all SWBS group costs. Ship price includes profit. In naval ships, the Total Shipbuilder Portion is the sum of the projected cost of change orders and the BCC. The Total Government Portion is the sum of the cost of Government-Furnished Material (GFM) and Program Managers Growth. The Total End Cost is the Sum of the Total Shipbuilder Portion and the Total Government Portion.

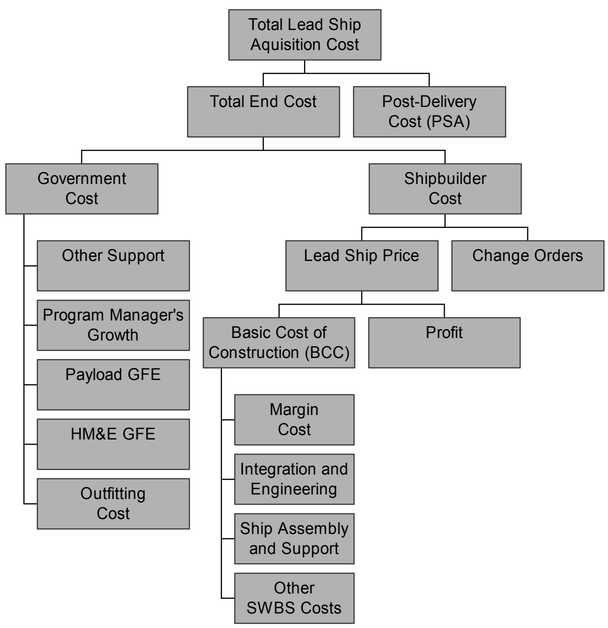

Figure 28. Naval Ship Acquisition Cost Components

Basic follow-ship costs for SWBS groups 100-600 are equal to lead ship costs, but reduced by a learning factor and inflated to the follow-ship award year. Follow-ships have significantly lower SWBS 800 and 900 costs. Follow-ship construction cost benefits from a learning curve that reduces the cost as the work force becomes more efficient at the various production processes repeated from ship to ship. The learning rate represents the percent cost reduction for every doubling of the number of ships produced. Total follow-ship acquisition cost is the sum of shipbuilder and government portions. A learning rate of 98%, total ship acquisition of 30 and production rate of two ships per year are assumed for calculating CUVX follow-ship acquisition costs.

3.4 Optimization Results

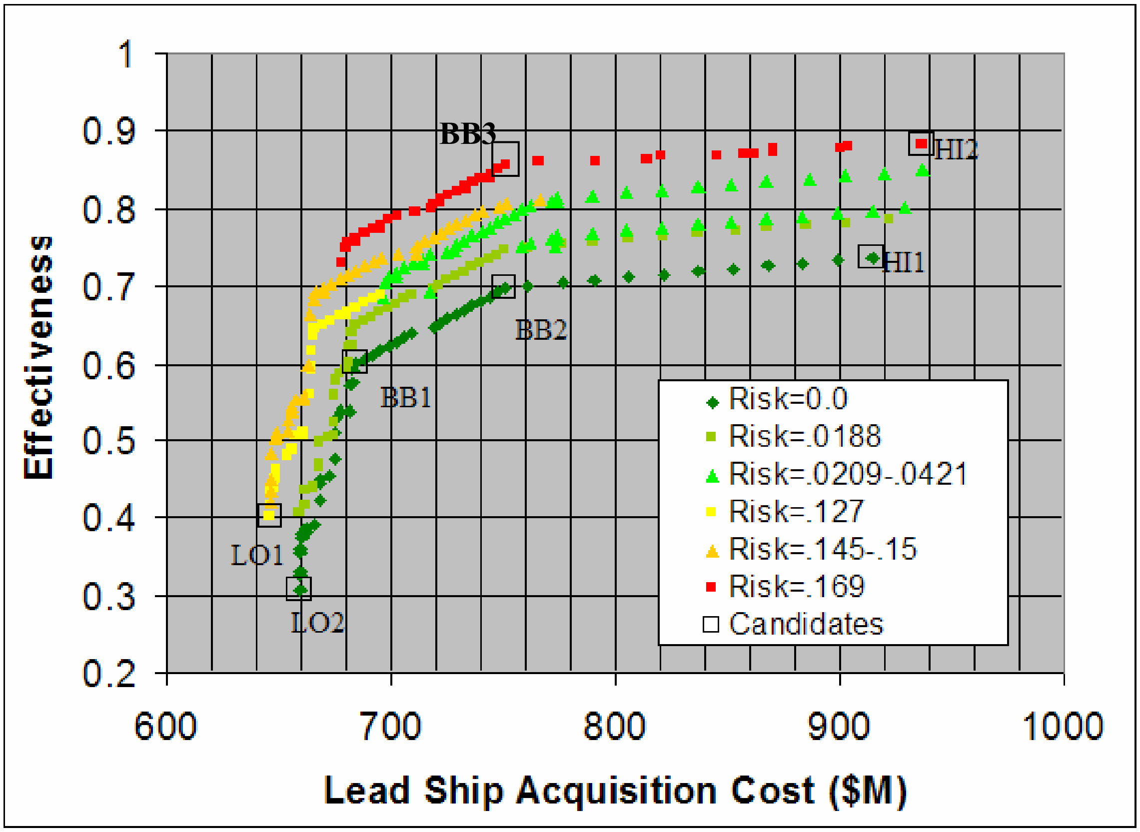

Figure 29. Non-Dominated Frontier based on Lead Ship Acquisition Cost

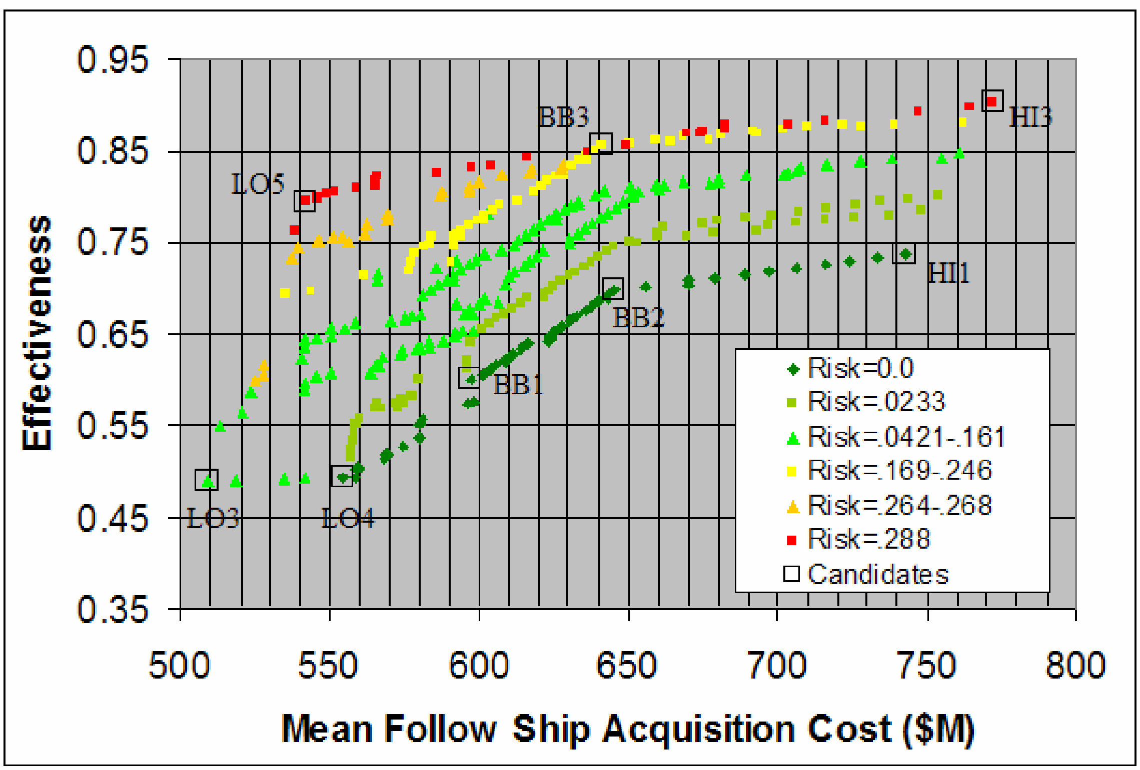

Figure 30. Non-Dominated Frontier based on Average Follow Ship Acquisition Cost

Table 27. Non-Dominated Design Candidates

	Team 4						Team 4			Team 1	Team 2
	LO1	LO2	LO3	LO4	LO5	BB1	BB2	BB3	HI1	HI2	HI3
Cfol ($M)	562.60	574.82	509.21	554.67	542.18	597.10	645.44	641.39	742.49	760.29	772.24
Clead ($M)	641.93	654.56	770.79	840.10	822.39	682.55	750.92	751.79	914.55	937.07	1192.30
OMOR	0.1271	0.0000	0.1185	0.0000	0.2877	0.0000	0.0000	0.1692	0.0000	0.1692	0.2877
OMOE	0.4003	0.3055	0.4889	0.4931	0.7946	0.6005	0.6977	0.8553	0.7367	0.8820	0.9021
Hullform	LPD	LPD	WPTH	MH	WPTH	LPD	LPD	LPD	LPD	LPD	WPTH
Δ (lton)	25711.1	25295.7	20412.9	22495.8	21412.2	25143.8	25873.0	25880.4	25170.8	25294.6	28995.6
LWL (ft)	656.17	656.17	614.46	629.96	634.05	656.17	656.17	656.17	656.17	656.17	696.01
Beam (ft)	96.92	96.92	74.20	82.21	89.96	96.92	96.92	96.92	96.92	96.92	94.12
Draft (ft)	23.23	22.85	20.61	22.22	21.94	22.72	23.38	23.38	22.74	22.85	22.96
D10 (ft)	87.37	87.37	83.04	82.89	88.06	87.37	87.37	87.37	87.37	87.37	96.67
Cp	0.647	0.647	0.800	0.720	0.630	0.647	0.647	0.647	0.647	0.647	0.710
Cx	0.941	0.941	0.950	0.950	0.950	0.941	0.941	0.941	0.941	0.941	0.950
Cdl (lton/ft3)	90.012	90.012	88.000	90.000	84.000	90.012	90.012	90.012	90.012	90.012	86.000
Cbt	4.220	4.220	3.600	3.700	4.100	4.220	4.220	4.220	4.220	4.220	4.100
CD10	7.510	7.510	7.400	7.600	7.200	7.510	7.510	7.510	7.510	7.510	7.200
NLaunDk	0	0	0	0	1	0	0	1	0	1	1
Cvd	0.080	0.080	0.290	0.140	0.180	0.110	0.110	0.120	0.110	0.210	0.150
Range (nm)	12000	12000	12000	12000	8000	12000	8000	4000	4000	4000	4000
Duration (days)	120	120	120	120	120	120	120	120	120	120	120
NCPS	3	3	3	1	1	1	1	1	1	1	1
PSYS	8	1	1	1	12	4	4	12	4	11	12
Shafts	1	1	1	1	2	2	2	2	2	2	2
PSYStype	IPS	Mech	Mech	Mech	IPS	Mech	Mech	IPS	Mech	IPS	IPS
AAW	2	2	2	2	1	2	2	1	2	1	1
ADHull	0	0	0	0	1	0	0	0	0	0	1
Nhelo	2	2	4	4	4	4	4	4	4	4	4
CManShip	1	1	1	1	1	1	1	1	1	1	1
NUAV	13	9	20	18	20	20	20	20	20	19	18
NUCAV	10	10	10	10	11	10	28	29	30	30	28
CManAir	1	1	1	1	1	1	1	1	1	1	1
WFUCAV	60.0	60.0	57.0	57.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
WWUCAV	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	15.0	15.0	14.0
W1	10835.0	10761.1	7036.2	8636.5	8697.0	10823.4	10853.2	10926.3	10857.6	10922.0	13061.8
W2	1963.9	773.3	759.5	766.8	2130.1	1093.5	1093.5	2138.9	1093.5	1172.9	2143.0
W3	634.9	712.1	585.5	668.9	598.4	848.7	895.7	745.6	901.1	778.6	816.7
W4	301.2	301.2	247.0	270.4	270.0	302.1	302.1	313.5	302.1	316.2	328.8
W5	3355.7	3469.9	2813.5	3152.6	2909.1	3552.2	3633.5	3539.1	3642.6	3599.2	3739.9
W6	1406.0	1399.4	1118.1	1239.2	1208.1	1452.8	1730.0	1760.6	1776.1	1810.6	1838.8
W7	29.9	29.9	29.9	29.9	42.4	29.9	29.9	42.4	29.9	42.4	42.4
Wp	933.1	912.2	1070.9	1060.5	1162.3	1070.9	2179.8	2271.3	2603.0	2627.7	2451.2
Δ LS (lton)	20379.3	19191.5	13848.7	16240.8	17440.7	19912.9	20391.7	21413.1	20463.1	20506.1	24168.5
KG (ft)	30.73	30.17	27.38	28.10	32.28	31.36	33.90	34.89	35.35	35.62	38.81
GM/B=	0.186	0.190	0.105	0.133	0.131	0.177	0.154	0.144	0.136	0.133	0.084
Vs (knt)	20.95	22.63	22.14	22.62	21.92	21.28	21.28	20.95	21.28	24.63	20.18
McC	46.88	46.55	40.66	43.47	40.82	46.48	47.13	47.18	46.68	46.78	53.14
Manning	476	481	496	490	514	523	863	880	901	917	901

Figure 3.2.2.1 shows the final cost-risk frontier with generations 1,30 80, 100, and 200 plotted. The first generation shows an exploration of the design space. As successive generations are formed, the trend is to move toward a lower risk and cost while still exploring the design space. Finally the generations converge on a non-dominated frontier. The frontier shows four distinctive "knees" in the curve, illustrated in the figure as LO, BBL, BBH, and HI (Characteristics shown in Table 3.2.2.1). These "Knees" are distinct irregularities in the curve where substantial risk reduction can occur for a slight increase in cost. LO represents a knee at the lowest cost. These knees each represent a ship design. These designs were assigned for feasibility study by the four teams participating in this project. Our team is assigned the LO design variant.

Several ships have unique characteristics which would be addressed in their feasibility studies. The low Cp in the BBH ORT created problems for cargo volume and machinery space. The fine hull caused the ship to be unable to accommodate the required cargo capacity of 140K DWT and made it difficult to fit the engine into the machinery space. The HI ORT had a very large W1 cost which exceeds the valid range of the weight parametric. The LO ORT has a low number of cargo divisions which increases the risk associated with mean oil outflow.

3.5 Baseline Concept Design

Our CUVX concept design is chosen to be the LPD-17 modified-repeat alternative HI2. HI2 is a high-end alternative on the lead-ship acquisition cost non-dominated high-risk frontier shown in Figure 29. This high-end design was chosen in order to provide a more interesting design project with a wider array of alternatives. The following tables provide summaries of the design parameters, principal characteristics, SWBS group weights, areas, electrical power, manning, cost, risk, and performance. A figure of the speed-power curve is also provided below.

Table 28. Design Parameters Summary

Design Parameter	Description	Range	Values
DP 1	Hull Form type	1. General Monohull 2. LPD-17 3. WPTH	(2)
DP 2	Hull Form	$C_P = 0.6 – 0.8$	0.647
DP 3	Hull Form	$C_X = 0.9 – 0.99$	0.941
DP 4	Hull Form	$C_{\Delta L} = 50 – 90$ lton/ft^3	88.294
DP 5	Hull Form	$C_{BT} = 3.0 – 5.0$	4.22
DP 6	Hull Form	$C_{D10} = 6 – 8$	6.2
DP 8	Launch Deck	1. Yes 2. No	(1)
DP 9	Hull Form	C_{vd}	0.21
DP 10	AAW System	1. ESSM + CIWS2 2. RAM + CIWS2	(1)
DP 11	ASuW	1. 4 LAMPS w/ 4 Machine Guns 2. 2 LAMPS w/ 4 Machine Guns	(1)
DP 18	Range	1. 12000 nm 2. 8000 nm 3. 4000 nm	(3)
DP 19	Stores Duration	1. 120 day 2. 90 day 3. 60 day	(1)
DP 20	Propulsion	1. 2 LM2500, 1 shaft, mech 2. 2 ICR, 1 shaft, mech 3. 1 ICR, 1 LM2500, 1 shaft, mech 4. LPD-17 5. 2 LM2500, 2 PC2.5V16, 2 shaft, mech 6. 2 LM2500, 1 shaft, IPS 7. 2 ICR, 1 shaft, IPS 8. 5 PC2.5V16, 1 shaft, IPS 9. 1 ICR, 1 LM2500, 1 shaft, IPS 10. 3 LM2500, 2 shaft, IPS	(11)

Design Parameter	Description	Range	Values
		11. 3 ICR, 2 shaft, IPS 12. 5 PC2.5V16, 2 shaft, IPS 13. 2 LM2500, 1 ICR, 2 shaft, IPS 14. 2 PC2.5V16, 2 LM2500, 2 shaft, IPS	
DP 21	Ship Manning Factor	0.5 – 1.0	1.0
DP 22	Advanced Double Hull	0. No 1. Yes	(0)
DP 23	CPS – Collective Protection System	1. Full Ship – 60 lton 2. Partial Ship (Citadel) – 30 lton 3. None – 0 lton	(1)
DP 24	Number of UAV's	4 – 20	19
DP 25	Number of UCAV's	9 – 30	30
DP 26	Air Manning Factor	0.5 – 1.0	1.0
DP 27	Aircraft Fuel Weight/ UCAV	15 lton – 45 lton	45 lton
DP 28	Aircraft Weapons Weight/ UCAV	5 lton – 15 lton	15 lton

Table 29. Principal Characteristics

Characteristic	Baseline Value
Hullform	LPD Modified-Repeat
Δ (MT)	25370
LWL (m)	201
Beam (m)	29.54
Draft (m)	6.938
Depth (m)	26.63
Cp	0.647
Cx	0.941
Cdl (lton/ft^3)	88.292
Cbt	4.22
CD10	6.2
Cvd	0.21
W1 (MT)	11140
W2 (MT)	1192
W3 (MT)	796
W4 (MT)	322
W5 (MT)	3665
W6 (MT)	1846
W7 (MT)	43
Wp (MT)	2670
Lightship Δ (MT)	20907
KG (m)	10.827
GM/B=	0.139
Seakeeping (McC Index)	46.78
Sustained Speed (knots)	24.5
Endurance Speed (knots)	20.0
Hull structure	Conventional
Propulsion system	Alternative 11: 2 shafts, IPS, 3xICR.5V16 main propulsion gas turbines, 2x3000kW SSGTG

Characteristic	Baseline Value
Engine inlet and exhaust	Deckhouse Stack
Combat system	SSDS, AN/SPS-49A(V)1, AN/SPS-73(V)12, AN/SLQ-32A(V)2, CIFF, 2xCIWS; Mk36 DLS, Combat DF, IRST, ESSM w/VLS, AN/SPQ-9B, MK91 MFCS
Aircraft elevators	2
Weapons elevators	3
Catapults	2
Number of LAMPS	4
Average deck height (m)	3.0
Hangar deck height (m)	6.0

Table 30. Weights and Vertical Center of Gravity Summary

Group	Weight	VCG
SWBS 100	11140 MT	10.25 m
SWBS 200	1192 MT	6.578 m
SWBS 300	796 MT	9.32 m
SWBS 400	322 MT	15.683 m
SWBS 500	3665 MT	6.633 m
SWBS 600	1846 MT	12.787 m
SWBS 700	43 MT	21.196 m
Lightship	20907 MT	9.646 m
Variable Loads	4665 MT	10.637 m
Total	25571 MT	10.827 m

Table 31. Area Summary

Area	Required	Available
Arrangeable	20964 m^2	21014 m^2
Hangar	8260 m^2	10940 m^2
Deckhouse	972 m^2	1756 m^2

Table 32. Electric Power Summary

Group	Description	Power
SWBS 200	Propulsion	281 kW
SWBS 561	Steering	125 kW
SWBS 300	Electric Plant Lighting	961 kW
SWBS 430, 475	Misc.	101 kW
CPS	Collective Protection System	609 kW
SWBS 517	Aux Boiler	216 kW
SWBS 521	Firemain	438 kW
SWBS 540	Fuel Handling	766 kW
SWBS 530, 550	Misc. Aux	598 kW
SWBS 600	Services	363 kW
KW_{MFLM}	Max. Functional Load w/ Margins	8945 kW
KW_{24AVG}	24 Hour Electrical Load	5143 kW

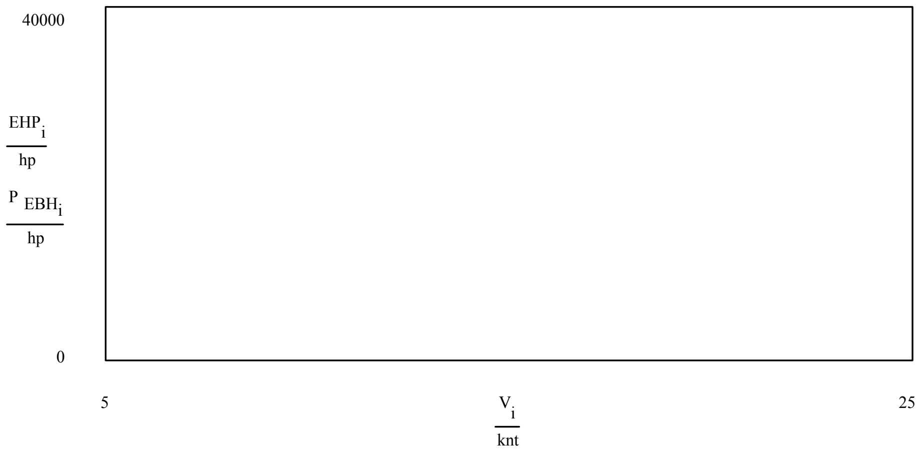

Figure 31. Speed-Power Curve

Table 33. Manning Summary

Group	Number
Ship Officers	30
Ship Enlisted	275
Air Officers	39
Air Enlisted	576
Total Officers	69
Total Enlisted	851
Total Manning	920

Table 34. Cost Summary

	Acquisition Cost
Lead Ship	937 $M
Follow Ship	760 $M

Table 35. MOP/ VOP/ OMOE Summary

Item	MOP Number	MOP Weight	Value of Performance
AAW	MOP 1	0.0642	1
VLS & Weapons	MOP 9	0.0113	0
Stores Duration	MOP 10	0.0294	1
Aircraft Weapons Capacity	MOP 11	0.0354	1
Aircraft Fuel Capacity	MOP 12	0.0389	1
Reliability	MOP 13	0.0133	1
Repair	MOP 14	0.0105	1
Sustained Speed	MOP 15	0.0097	0.95
Seakeeping	MOP 16	0.0671	1
Damage Stability	MOP 18	0.0469	1
Redundancy	MOP 19	0.0208	1
Hull Type (ADH)	MOP 20	0.0469	0
CPS	MOP 21	0.0276	1
Damage Control	MOP 22	0.0469	1

Item	MOP Number	MOP Weight	Value of Performance
IR Signature	MOP 23	0.0318	0.239
Acoustic	MOP 24	0.0542	1
RCS	MOP 26	0.0618	0.5
Strike Mission	MOP 28	0.0434	1
SEAD Mission	MOP 30	0.1168	1
ISR Mission	MOP 31	0.072	0.933
Aircraft ASW Capabilities	MOP 32	0.0457	1
Aircraft ASuW Capabilities	MOP 33	0.0457	1
Aircraft MCM Capabilities	MOP 34	0.0602	1
OMOE = 0.882			

Table 36. Risk/OMOR Summary

Item	Cost Risk	Schedule Risk	Performance Risk
AAW	0.08	0.04	0.15
IPS	0.18	0.09	---
Hullform	0	0	---
EMALS	0.3	0.2	---
Range	---	---	0
Reliability	---	---	0.16
Sustained Speed	---	---	0
Seakeeping	---	---	0
Dynamic Stability	---	---	0
Strike	---	---	0.36
SEAD	---	---	0.32
Total	0.651	0.485	0.092
OMOR = 0.169			

4 Concept Development (Feasibility Study)

Concept development of CUVX follows the design spiral in sequence after Concept Exploration. Here the general concepts for the hull, aircraft launch and recovery, and arrangements are determined. These general concepts are refined into specific systems and subsystems that meet the requirements of CUVX.

4.1 General Arrangement and UCAV-N Operations Concept (Cartoon)

Initial design concepts were formed around two basic requirements. The first was the simultaneous launch and recovery of aircraft. The second was to minimize RCS within the limits of the LPD-17 hull form. RCS consideration eliminated the possibility of the flared topsides seen on the Nimitz class carriers. This led to the conclusion that there would not be adequate deck area to support simultaneous flight operations on a single deck. Our solution is to incorporate a launch deck directly below the recovery deck. RCS is minimized by using 10° tumblehome ruled surfaces wherever additions to the basic LPD-17 hull were required.

Prime movers

Survivability is approached through the use of separation and redundant systems where possible. Three prime movers were selected for this ship. Two are placed forward near the EMALS; a location which is ideal for pulse power catapult operation. The third is placed well aft for maximum separation. The aft prime mover is also then in close proximity to the propulsion motors. This enhances survivability in the event of damage near amidships. Exhaust from the prime movers is routed above deck level on the recovery deck to protect personnel who may be on the recovery deck.

Primary Subdivision

The transverse bulkheads of LPD-17 are retained to create the primary longitudinal subdivision of this ship. Transverse subdivision is accomplished with centerline and 10 meter offset longitudinal bulkheads running the length of the ship wherever possible. The propulsion motors are located in the auxiliary machinery rooms 1 and 2 that can be seen in Figure 32.

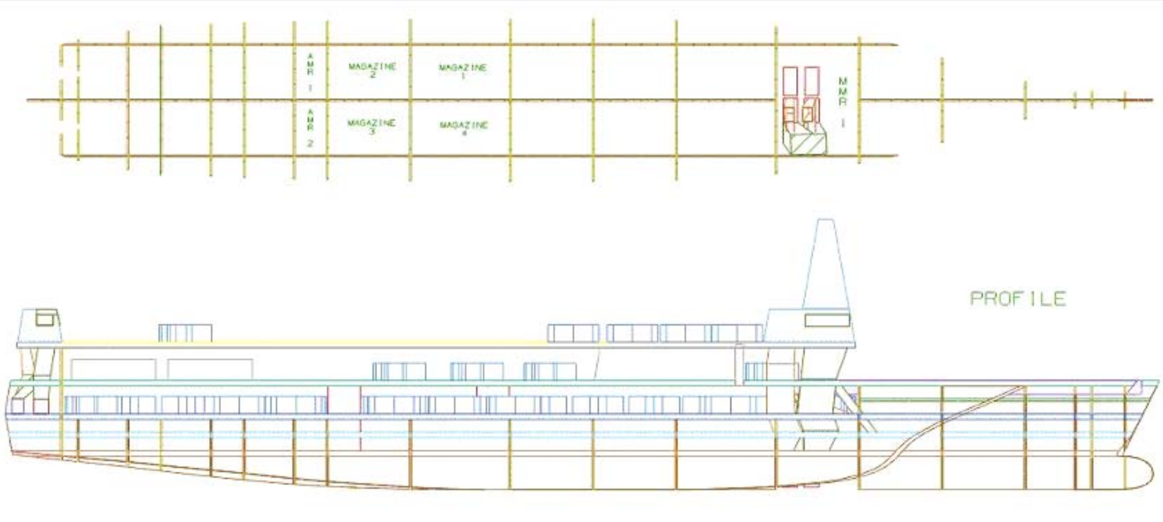

Figure 32. Inboard profile and primary subdivision of the lowest machinery level

Recovery Deck

The ship has three aircraft levels. The uppermost is the recovery deck. Figure 33 shows the recovery deck, and includes the recovery strip, the two aircraft elevators, parked aircraft and the deckhouses. The UCAV-N shown in Figure 33 is on the recovery strip has just caught the first of two arresting wires. The recovery strip is placed to port in accordance with US Navy tradition, with all other recovery deck obstructions to starboard. The elevators are outside the bounds of the recovery strip, allowing the aircraft to be recovered regardless of elevator configuration. This allows aircraft operations to continue in the event of an elevator malfunction. Once recovered, aircraft will be taken below using the forward elevator, E1. This elevator can fit two folded UCAV-N's, as shown in Figure 33.

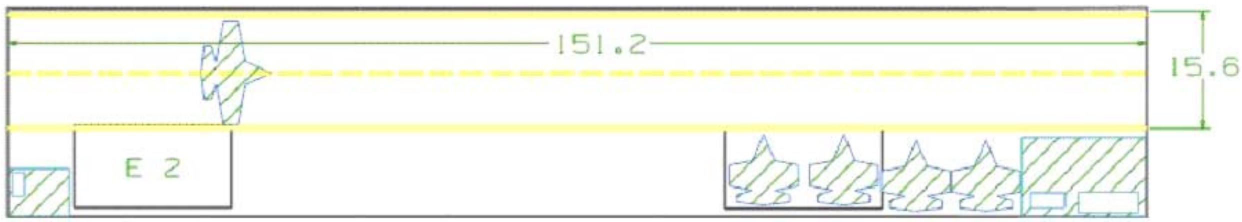

Figure 33. Recovery deck (all dimensions in meters)

Deckhouses

Two deckhouses are needed, one forward and one aft, to accommodate the inlet and exhaust requirements of the prime movers. The aft deckhouse size is minimized in order to reduce its impact on aircraft recovery. This deckhouse is only large enough to include the inlet/exhaust of the rear prime mover and flat array radar and communications equipment. The forward deckhouse is larger in order to incorporate a bridge area and to house the rotating radar arrays in a low RCS structure. Dimensions of this extension were based on the advanced enclosed mast of LPD-17. Locating the bridge at the forward extent of the recovery deck also allows good forward visibility.

Launch Deck

Aircraft launching is accomplished through two EMALS catapults at the forward end of the launch deck, shown in Figure 34. Maintenance shops will be placed all the way aft. HELO's will be stored at the aft end of the launch deck. Maintenance on HELO's and UCAV-N's will also be maintained in this area. Aircraft fueling and arming will take place near amidships and aft of E1. A large door in the JBD will allow UCAV-N's to enter the Launch area. The interference shown in the section view of the UCAV-N's on the catapult illustrates that two EMALS are only included for redundancy. Only one UCAV-N may launch at a time.

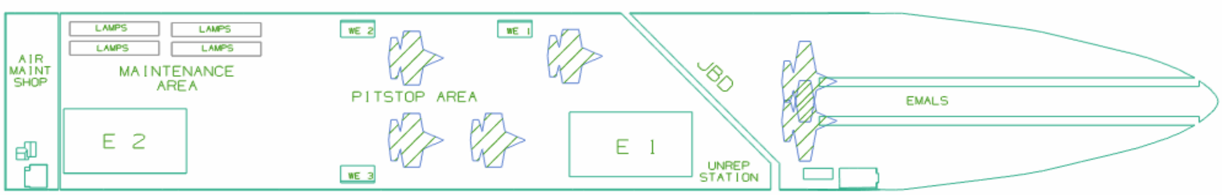

Figure 34. Launch Deck

Hangar Deck

Only a single hangar deck is used, in order to provide a damage control deck above the DWL. The hangar deck is serviced by both platforms of E1 and E2. Aircraft will be parked in the highest density configuration, with the ability to store the full UCAV-N airwing on this deck. A plan of the hangar deck is shown in Figure 35. The aft main machinery room is also located on this level aft of the hangar area. Forward of the hangar are, accommodations and operations spaces are arranged.

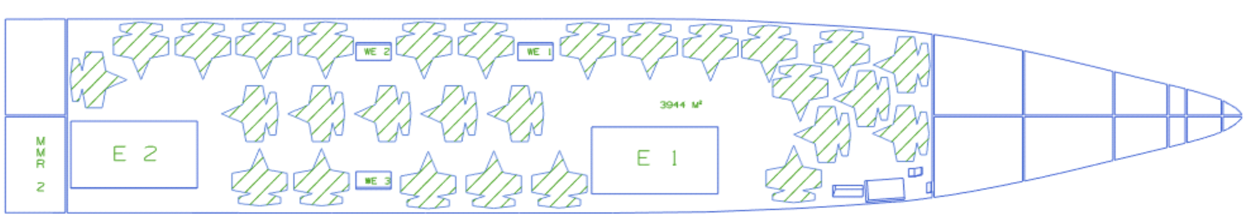

Figure 35. The hangar deck showing 28 UCAV-N's in storage

Elevators

Two aircraft elevators servicing the recovery deck are needed for redundancy. Both were sized such that they could accommodate two LAMPS or UCAV-N's in their folded configuration. The elevators need to be located inboard for RCS considerations. Three aircraft decks required additional elevators to move aircraft efficiently. Additional elevator locations would have impacted available hangar deck area. The solution is to employ two independent elevator platforms per shaft. This system allows internal aircraft movement while maintaining the integrity of the recovery deck. Electric elevators were chosen in order to lower maintenance effort and allow their self contained operation. Three weapons elevators are required. They are placed as far outboard as the magazine spaces allow. The shafts are also angled outboard in order to further minimize their impact on the hangar and launch decks.

Automated Aircraft Spotting

In order to reduce manning and provide efficient and coordinated aircraft movement in the small spaces available on this ship, an autonomous spotting dolly, or SPOT, was developed, shown in Figure 36. It has the capability to lift the nose gear of aircraft in order to translate in any direction. Movement is accomplished through 4 independently controllable and moveable wheels. The dolly is entirely electric and will position itself on the ship through the use of a camera array and pattern recognition software on the dolly's onboard computer system. A visual grid on the aircraft decks will facilitate this cheaply and flexibly.

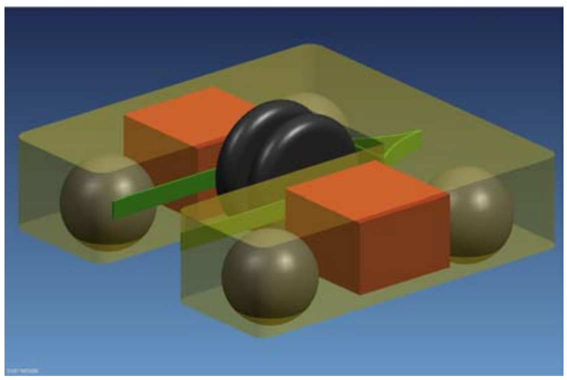

Figure 36. SPOT

4.2 Hull Form, Appendages and Deck House

The concept design hull form is created using the FastShip software program. A parametric LPD-17 model is used in FastShip as our parent hullform. Figure 37 and Figure 38 show the original hullform of LPD-17 as seen in FastShip.

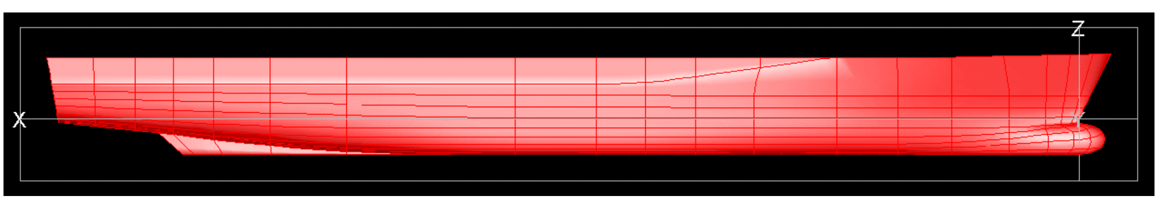

Figure 37. Profile of LPD-17 Original Hullform

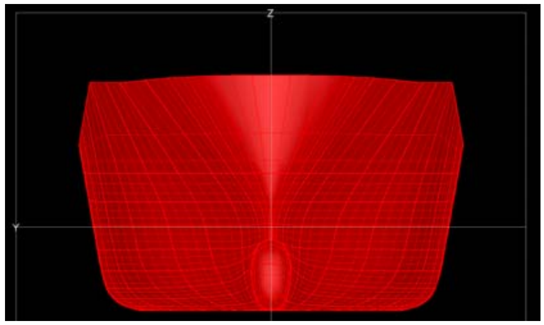

Figure 38. Body Plan of LPD-17 Original Hullform

The design concept for CUVX is to create a LPD Modified Repeat. All features of the original LPD are kept from the waterline down to the keel. The length along the waterline is altered from 200 meters to 201 meters to accommodate an equal spacing of 3 meters between structural frames. To effectively increase the length along the waterline by one-meter, one meter of parallel midbody is added just aft of amidships. In general, the form coefficients remain the same with only a small effect due to the increased length. A comparison of the LPD-17 and CUVX HI2 hullform characteristics can be seen in Table 37.

Table 37. Hullform Characteristics Comparison for LPD-17 and CUVX

	LPD-17	CUVX HI2
LWL	200 m	201 m
B	29.51 m	29.54 m
D	19.0 m	26.63 m
T	7.00 m	7.00 m
C_P	0.647	0.647
C_X	0.941	0.941
C_B	0.609	0.609

The bulbous bow of the parent hullform was kept in order to reduce the amount of wake-making resistance. A skeg is present on LPD-17, as seen in Figure 37, and will therefore be included in the design of CUVX. Keeping the skeg and bulbous bow will help to keep the hullform below the waterline as similar as possible to that of LPD-17.

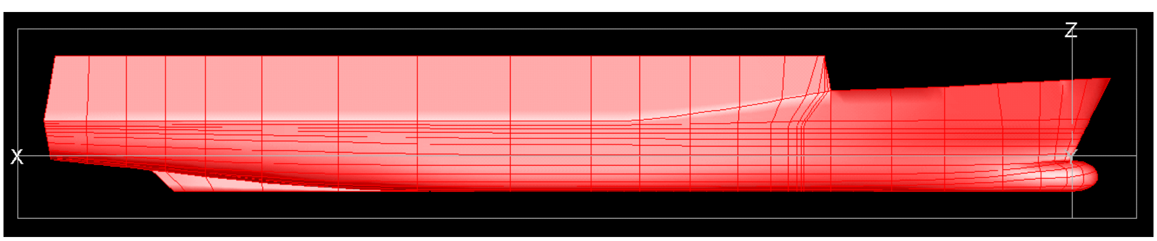

Figure 39. Profile of CUVX HI2 Hullform

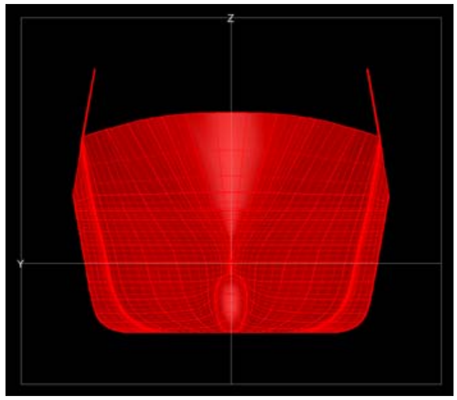

Figure 40. Body Plan of CUVX HI2 Hullform

To allow for an additional deck for aircraft operations, 7.63 meters is added above the topmost deck of the parent hull form as shown in Figure 39. The additional freeboard is added only onto the aft 75% of the ship to allow the recovery strip to be an adequate length for aircraft recovery. With this design, it is possible to accommodate simultaneous take-off and landings. The topmost deck will be used solely for recovering aircraft and so is called the recovery deck. The deck below the recovery deck, extending up to the bow tip, will be used for aircraft preparation and launching. This deck is called the launch deck. The freeboard is added as tumblehome angled at 10° in order to reduce the ships radar cross-section (RCS) as can be seen in Figure 40. The angle of 10° is based upon expert opinion.

The transom above the waterline of LPD-17 originally raked aft. In CUVX HI2, the transom is left alone up to the hard chine, which is located 6 meters above the waterline. Above the hard chine, the transom is raked forward at a 10° angle. The forward connection of the recovery deck to the launch deck is also at a 10° inclination. These angles are provided to maintain a RCS reduction.

The launch deck at the bow, where the launching systems are located, is raised at a 2° angle from the horizontal. Not only does this effectively add more flare to the bow to protect the launching area from greenwater, but it also provides the aircraft with launching conditions that are slightly closer to its optimum angle of attack.

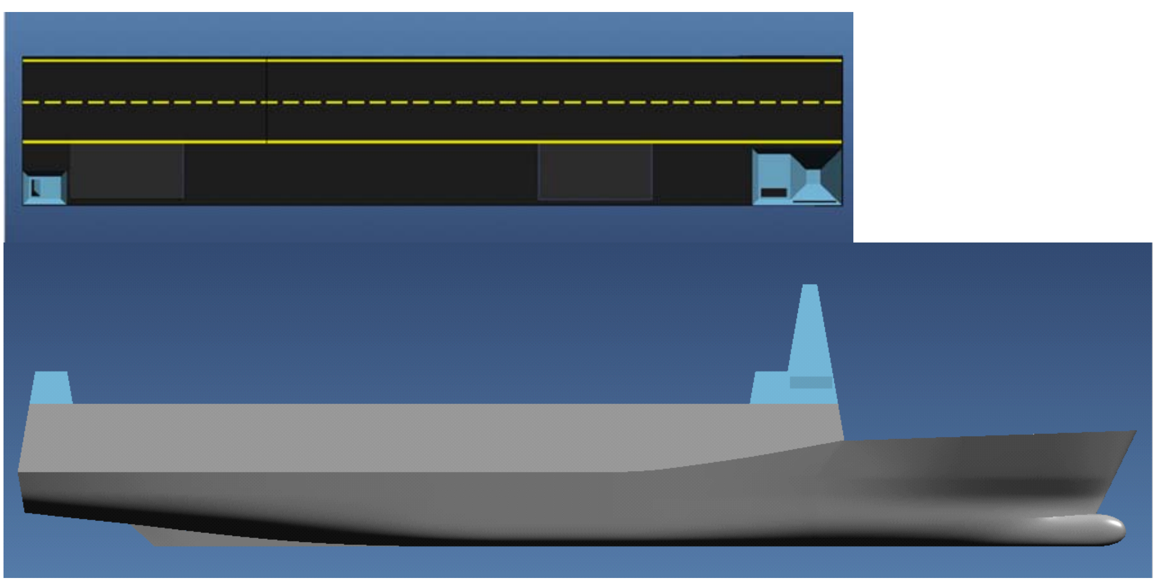

Figure 41. Plan View of Recovery Deck and Profile View of CUVX HI2 Hullform

Two main superstructures are present on the final concept design of CUVX, shown in Figure 41. The forward superstructure is the deckhouse and the advanced enclosed radar mast. The inlet and exhaust stacks for all of the gas turbines are present on the side of the forward deckhouse. The location for the deckhouse was chosen in order to minimize obstruction to landing aircraft and to provide the maximum line of sight for the helm. The exhaust stacks were directed as high as possible to place the exhaust fumes as far out of the way of the crew on the recovery deck. The enclosed mast system is placed on top of the forward deckhouse to get the radars as high into the air as possible. The aft superstructure is used solely for inlet and exhaust stacks. Both of the deck superstructures are created with 10° inclines to further provide a low RCS.

The curves of form for CUVX HI2, obtained from HECSALV, can be seen in Figure 42. Figure 43 shows the cross curves for the final concept design and Figure 44 shows the Bonjean curves for CUVX HI2.

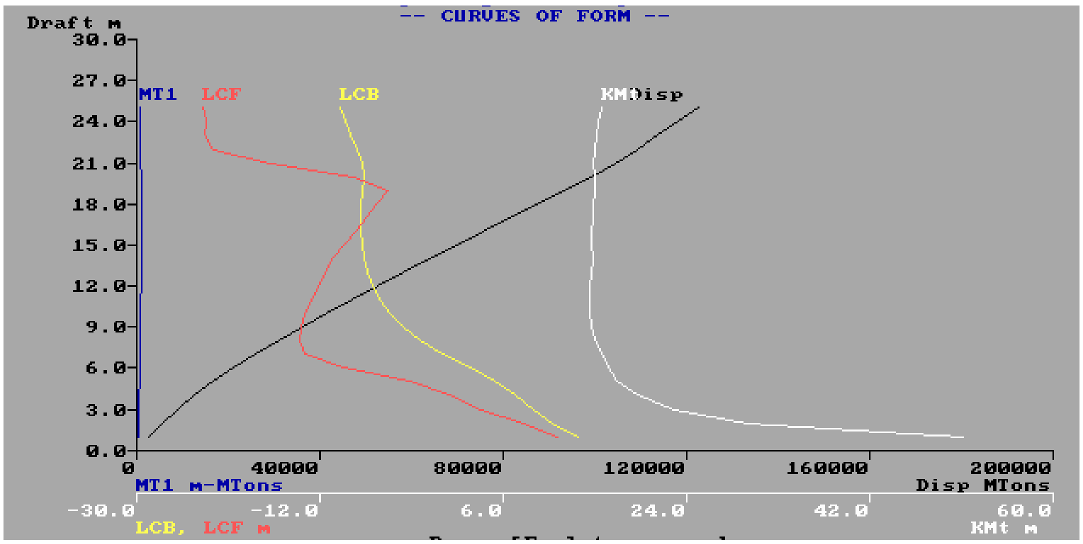

Figure 42. Curves of Form for CUVX HI2

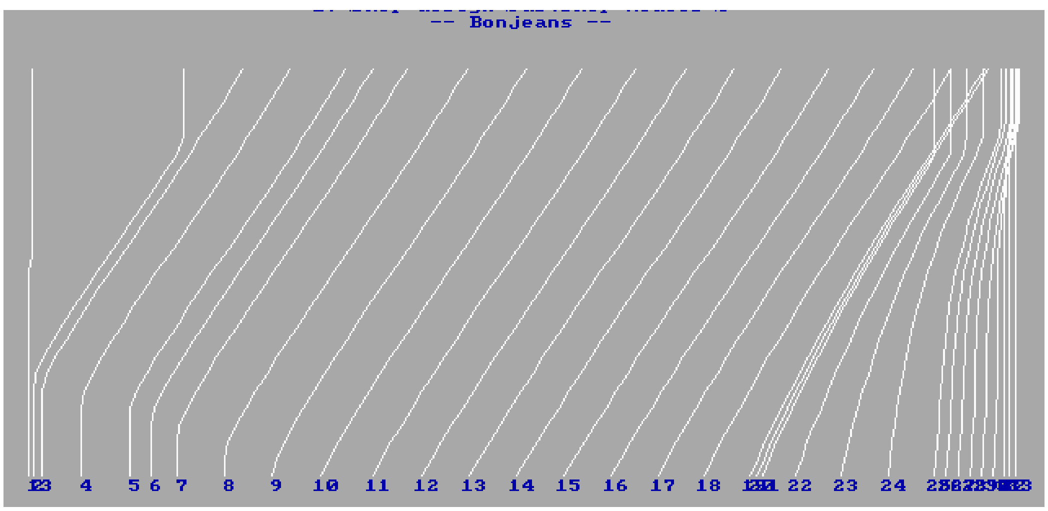

Figure 43. Cross Curves for CUVX HI2

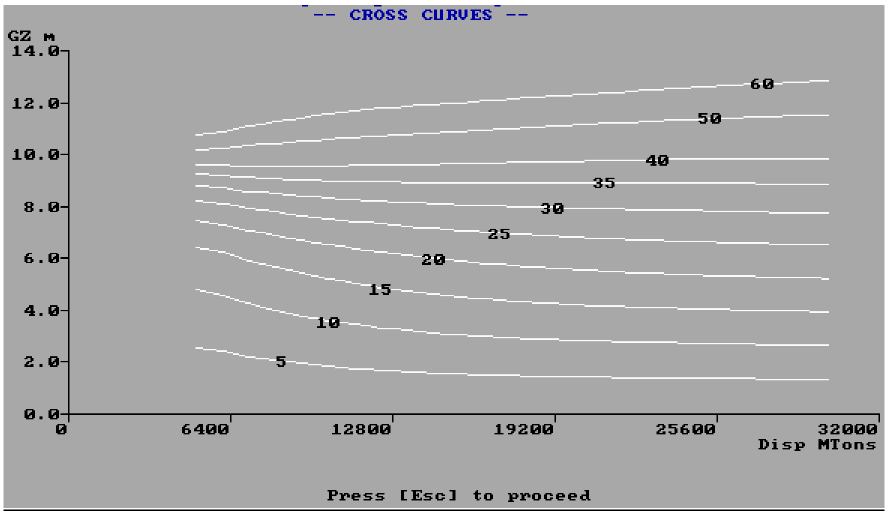

Figure 44. Bonjean Curves for CUVX HI2

4.3 Structural Design and Analysis

4.3.1 Procedures

Concurrent with arrangement design, the structural design was undertaken. The scantlings were chosen to a default of 12 millimeters. The arrangement of the ship's available area led the structural design with the placement of transverse and longitudinal bulkheads as well as the various decks. Finite Element Analysis using Maestro is used to fine-tune the initial structural design. The process begins with the importing the shell of the ship from FASTSHIP into Maestro. Endpoints are created to represent the hull, with the length between stations varying depending on the usage of that particular space. Additional endpoints are then added to represent the decks and bulkheads. Since it is a coarse-mesh model, some slight approximations are made, specifically with the bow. The bulbous bow that is present on our ship is left off because of its lack of structural importance and the complexity of adding it into the model. The final model is shown in Figure 45. A coarse mesh model is all that is necessary for this concept design phase of analysis, but the hull is modeled relatively accurately through this method. This can be seen in Figure 46. Stiffeners can be seen in the right view in this figure. Maestro allows the user to view stiffeners to ensure that the proper layout is presented, either longitudinal or transverse. Plate thickness and the sizes for beams and stiffeners are specified before modeling the structure.

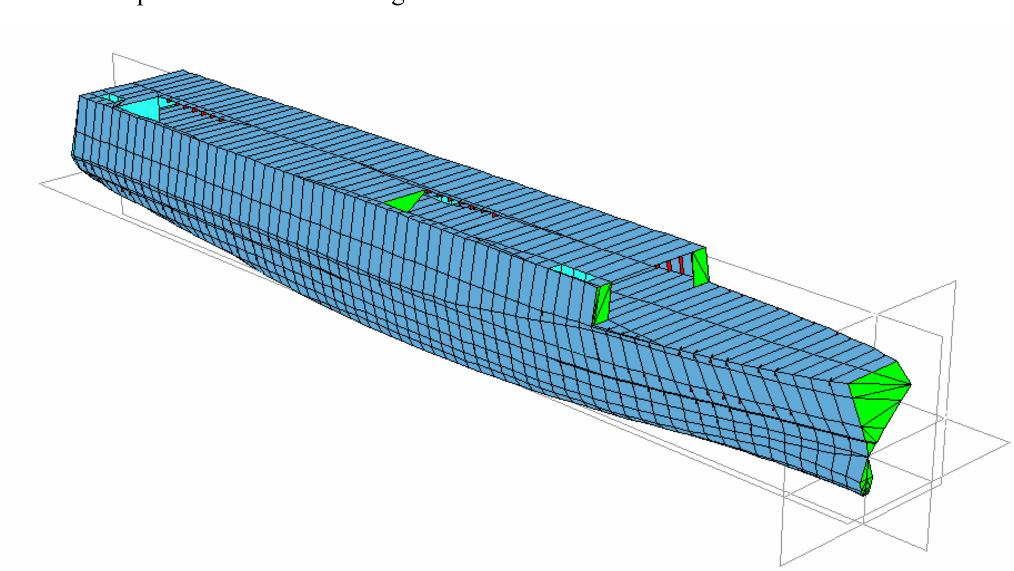

Figure 45. CUVX Maestro Model

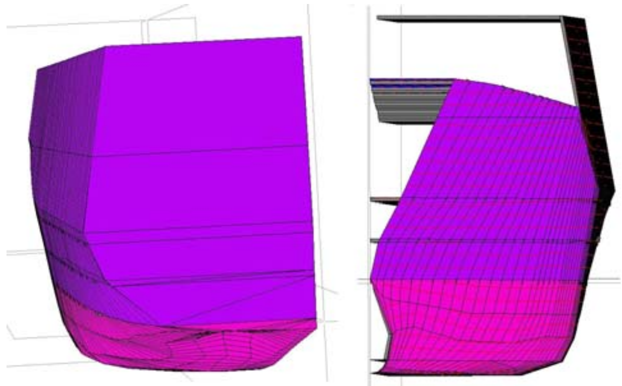

Figure 46. Stern and bow views of Maestro Model

4.3.2 Scantlings

The CUVX is a longitudinally stiffened ship, with transverse frames every three meters along the length of the ship. High strength steel was used in all cases. All of the steel has yield strength of 355 MPa (AH36). Figure 47 shows the midships section, where the hangar deck, food storage, and berthing are located on their respective decks. The double bottom is visible in the figure, with solid floors to provide strength in the keel.

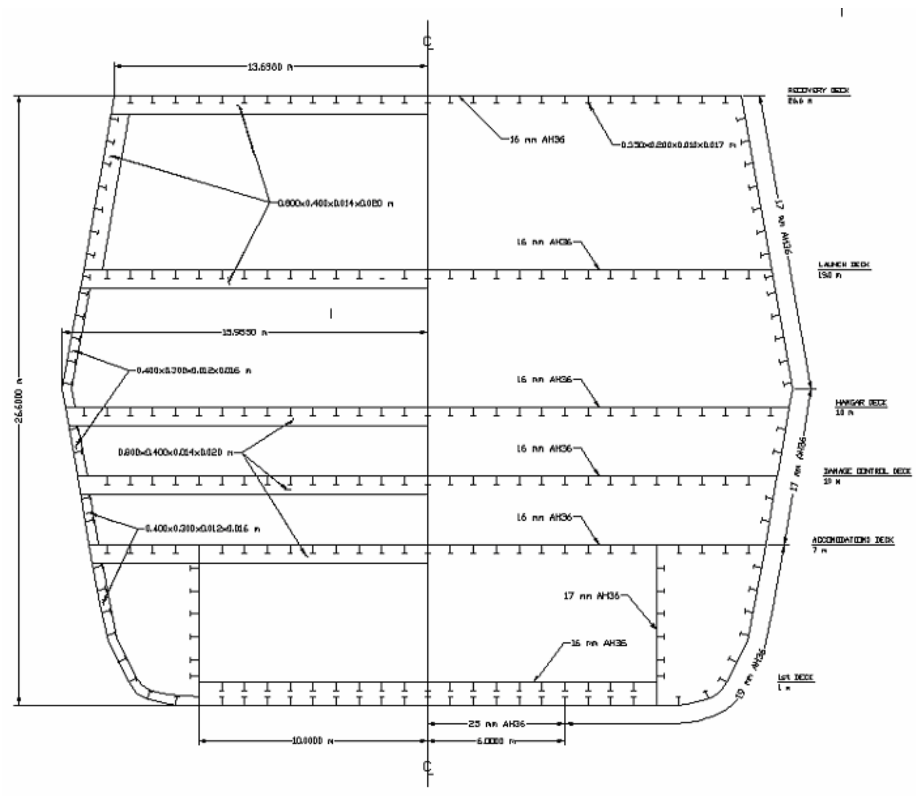

Figure 47. Midships Section

Figure 48 shows the interior of the Maestro model. The software assigns specific colors for each element type in order to distinguish them from each other. Maestro is designed to model half of the ship and then mirror the modules before performing analysis and making detailed modifications to the structure.

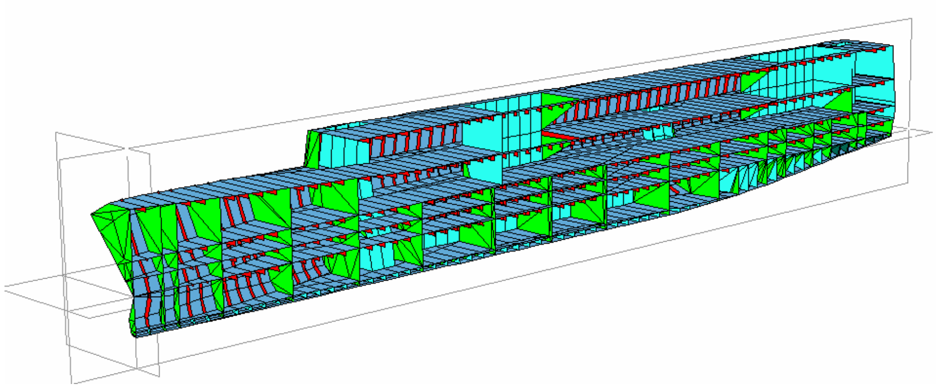

Figure 48. Interior of CUVX Maestro model

Within the model there are various areas of structure worth noting. Deep frames were placed on the launch and recovery decks in order to alleviate some of the stresses caused by having extended lengths with no vertical supports. Large stresses and deformations were present around the two aircraft elevators. This problem was initially solved by placing a triangle element for support in addition to the original set of walls placed on two sides of the elevator shaft. The double bottom suffered many extraordinary stresses where it tapers at the aft end of the ship, initially creating inadequacies in much of the keel. Increasing the thickness up a reasonable increment until it was considered adequate in the Maestro structural analysis solved this problem.

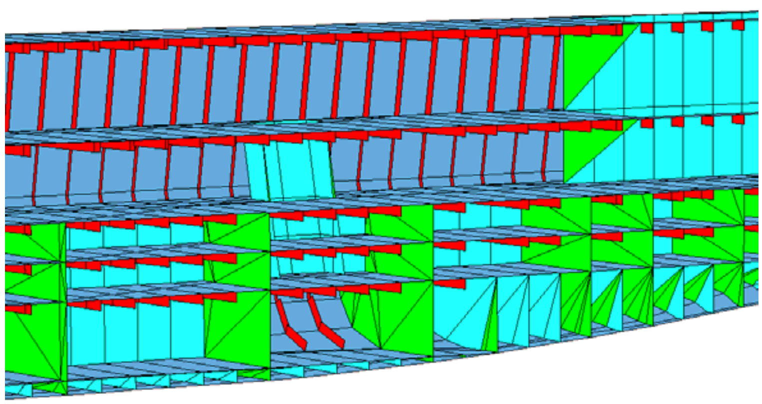

Figure 49. Close-up view of the interior of Maestro model

Transverse bulkheads are located between each module, sectioning the ship into subdivisions. The decks in between the bulkheads have been strengthened with frames in order to endure the stresses from the unsupported expanse. The frames are visible below each deck in Figure 49. In the double bottom seen in the figure above, there are three longitudinal bulkheads running the length of the ship. The centerline longitudinal bulkhead, shown in Figure 50, is located only in the double bottom and, towards the stern, from the keel to the Accommodations Deck. The other two longitudinal bulkheads are located 10 meters to port and starboard of the centerline, running the entire length of the ship up to the bottom of the Hangar Deck. The original thickness of the centerline bulkhead is not adequate where it intersected the transverse bulkheads and it had to be increased slightly.

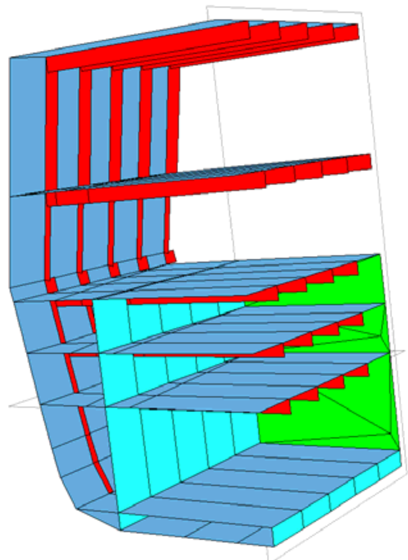

Figure 50. Close-up view of the interior of Maestro model, port side showing centerline longitudinal bulkhead

Figure 51 shows the weight distribution for the lightship stillwater load case. This load case includes structural weight in addition to major machinery. Figure 52 shows the shear force and bending moment diagrams for lightship weight condition taken from HECSALV.

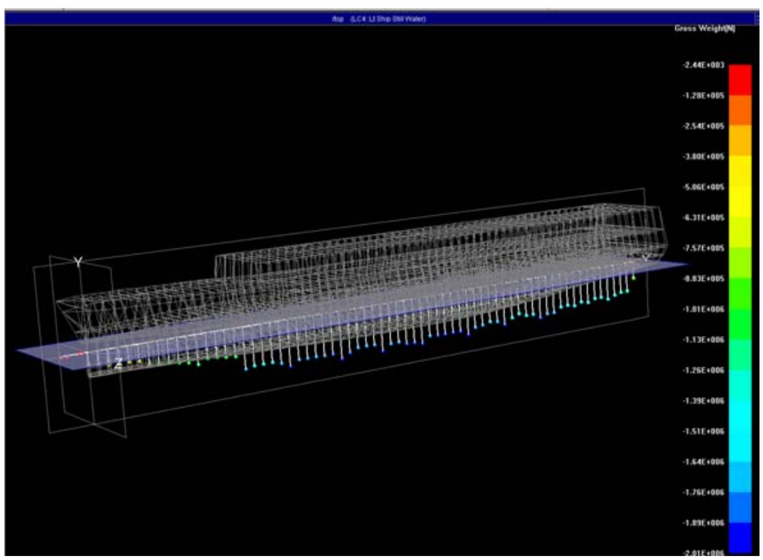

Figure 51. Lightship stillwater weight distribution

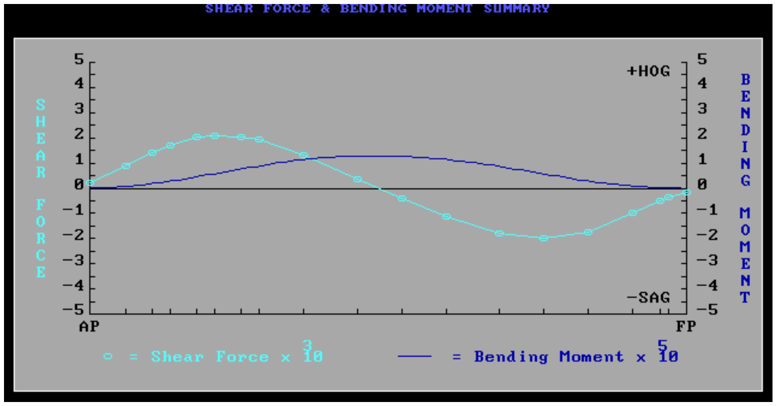

Figure 52. Lightship shear and bending moment diagrams

Figure 53 and Figure 54 show the shear force and bending moment diagrams for the full load hogging wave cases. Hogging was found to be the worst load case as far as stresses on the ship are concerned. A sagging load case analysis was also performed.

Figure 53. Shear force diagram for full load case, hogging wave condition

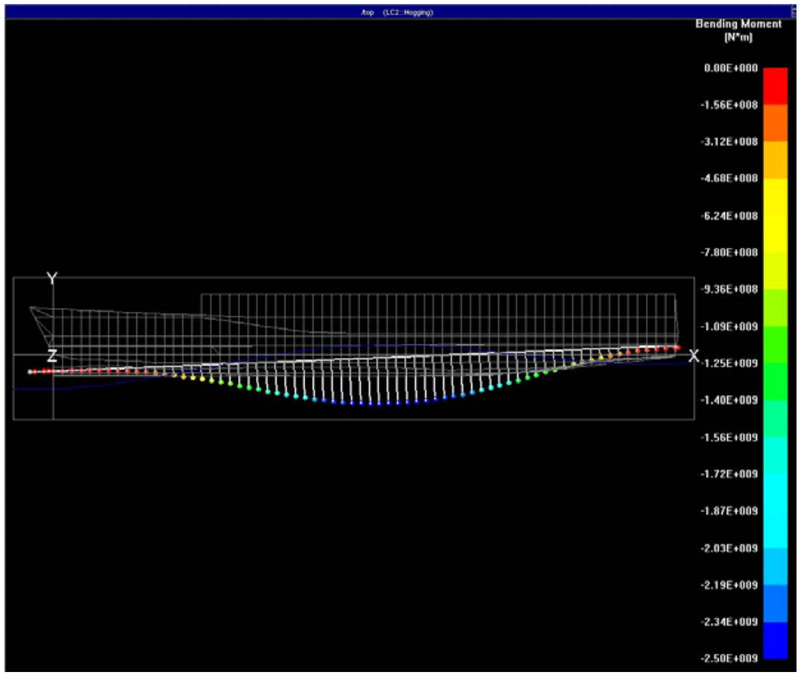

Figure 54. Bending moment diagram for full load case, hogging wave condition

4.3.3 Midships Region Analysis

The Maestro program breaks the ship model down by modules. The module shown in Figure 55 is the midship section. This is equivalent to the section shown in Figure 47, where beams have been modeled in a similar orientation. The solid floor on the double bottom is visible as well. This approximation of the longitudinal bulkheads and subdivisions is adequate for concept design level of analysis. In the next cycle around the design spiral, a much more detailed, finer mesh would be required. For our purposes, the coarse mesh model will serve appropriately for the structural analysis required.

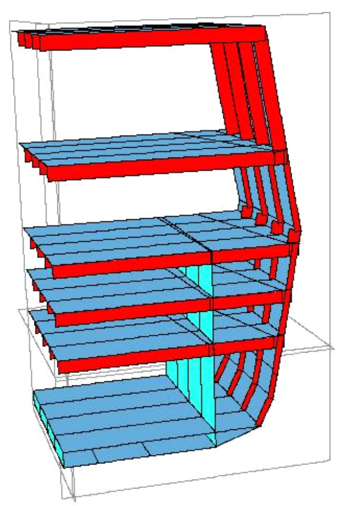

Figure 55. Maestro midships section

Figure 56 shows a full ship region of the midships section. It is followed by Figure 57 which is an exaggerated deformation of the region under the hogging load case. All modules were corrected until all components were adequate in all three load cases (stillwater, sagging, and hogging).

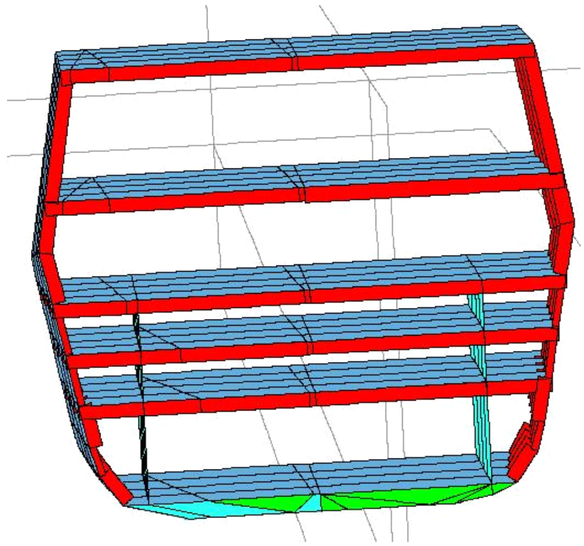

Figure 56. Maestro midships section showing both port and starboard

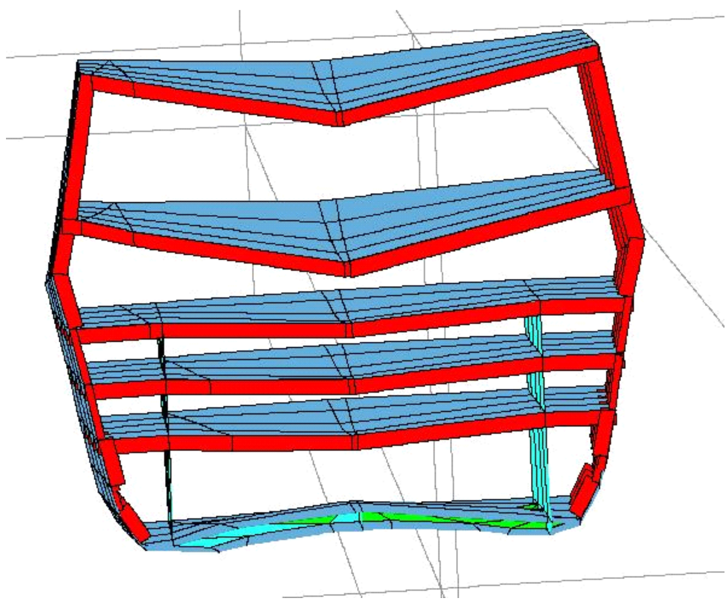

Figure 57. Exaggerated deformation of the Maestro midships section in hogging wave load case

4.3.4 Load cases and analysis

In order to define load cases, Maestro requires masses be defined throughout the ship. To define masses, loaded nodes are designated for major machinery and any significant loads in the structure. Specific regions of nodes are given a weight, which is then evenly spread among them.

With the masses defined, they can be selected to define various load cases. Six load cases are defined with varying wave conditions for each. The cases are lightship and full load. Figure 58 shows the lightship weight distribution graph taken from HECSALV. Ballast, or minimum operating condition, is not necessary because of the compensated fuel system employed on the ship. The displacement of the ship does not change significantly from that of the full load case.

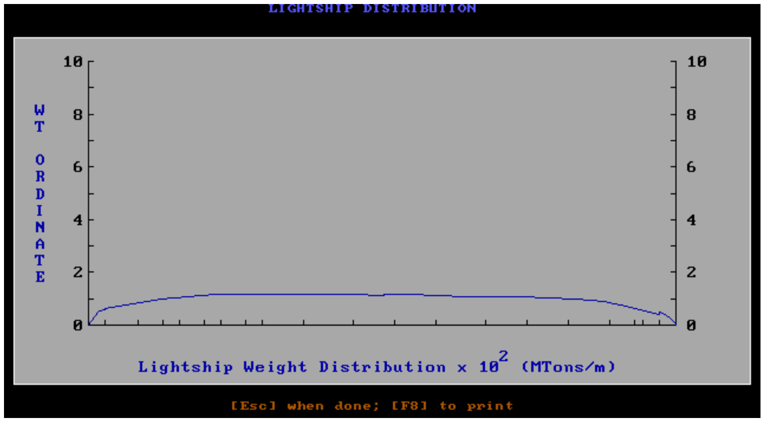

Figure 58. Lightship weight distribution

Figure 59 and Figure 60 illustrate the shear force and bending moment diagrams for full load and minimum operations load cases taken from HECSALV.

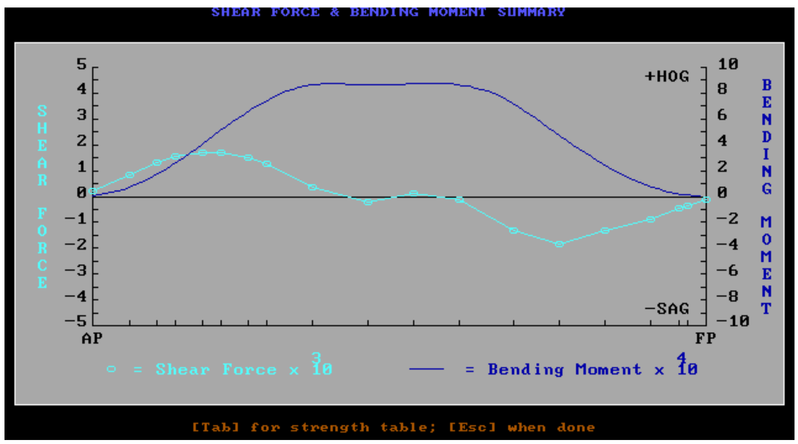

Figure 59. Shear force and bending moment diagrams for full load case

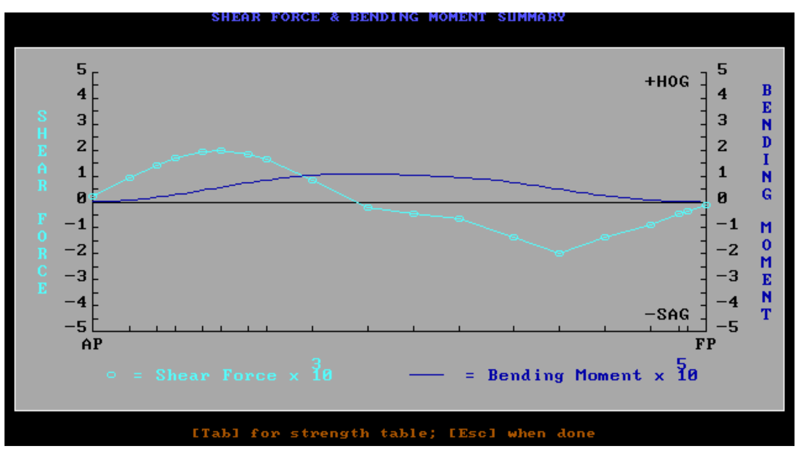

Figure 60. Shear force and bending moment diagrams for minimum operation load case

For each load case, three wave conditions were defined, stillwater, hogging, and sagging. The colors define the adequacy of the element with an adequacy of zero being ideal, a negative adequacy meaning that the structure fails, and a positive adequacy means that it is overbuilt as it gets farther from zero. As previously mentioned, our worst case is full load, hogging wave. Figure 61 and Figure 62 show the adequacy of the structure for the hogging wave, full load case. Areas of major concern are located in the keel and the top deck amidships. The keel was in severe compression while the top deck was under tension. The areas were addressed and are now adequate. The sagging wave can be seen in either of the figures below. The second figure shows the plate adequacy in the interior of the ship. The sagging wave condition proved to cause fewer inadequacy problems and those were addressed and corrected.

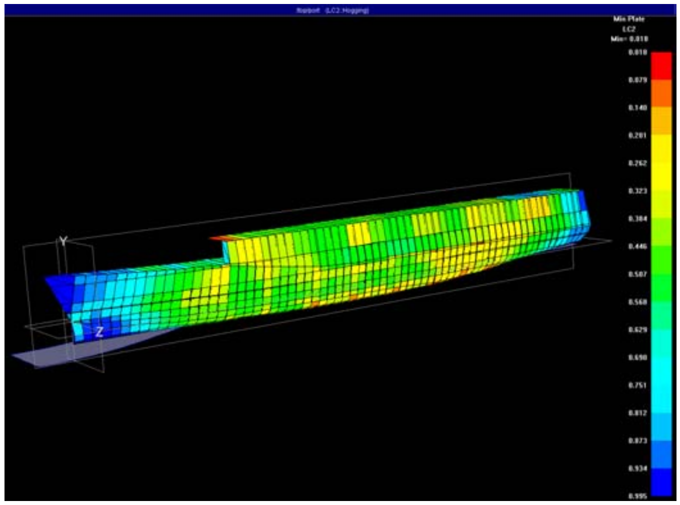

Figure 61. Plate adequacy for full load case in hogging wave condition

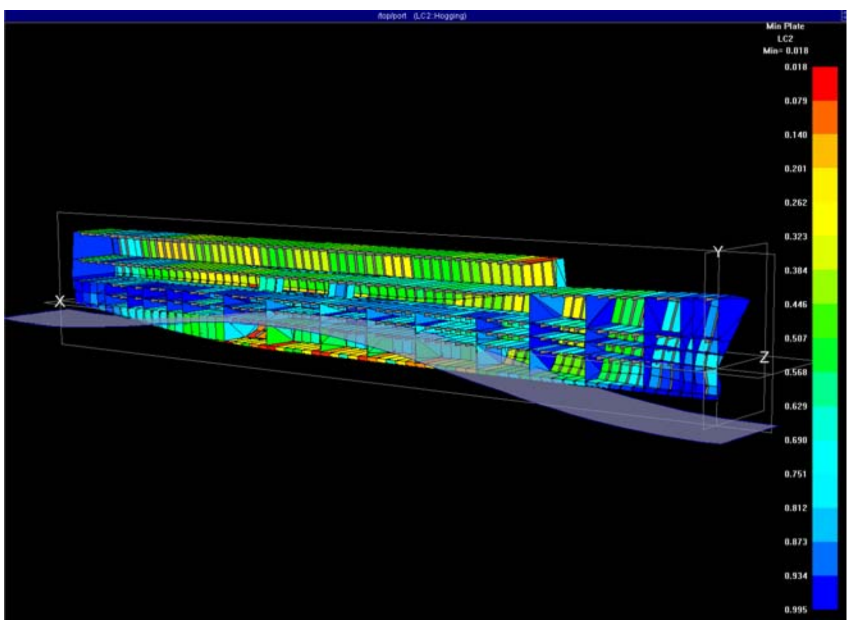

Figure 62. Shear Plate adequacy for full load case in hogging wave condition

In the next iteration in the design phase, optimization of the areas that are blue, which are well above adequate, will be performed by decreasing their thickness in order to conserve weight. The areas in red are adequate enough for this case. Figure 63 shows the adequacy of the starboard side in stillwater.

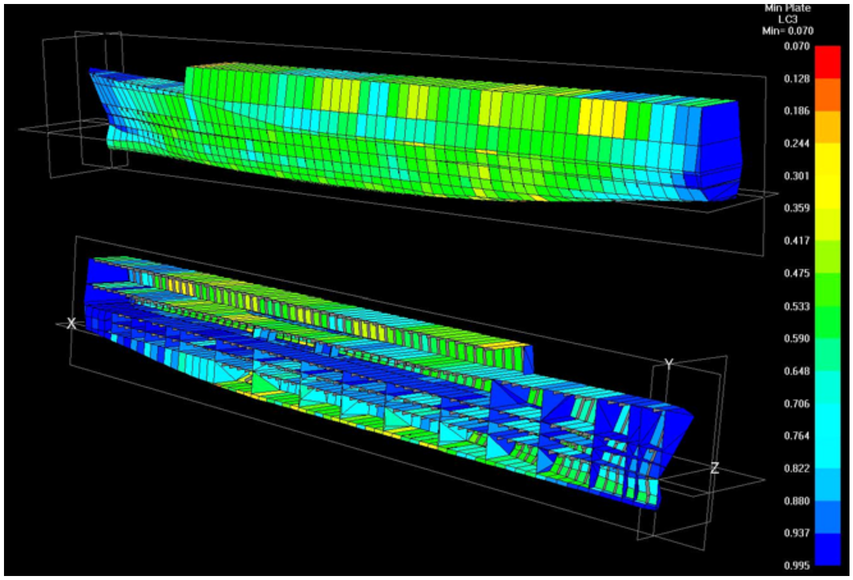

Figure 63. Adequacy of the entire ship (starboard shown here)

4.4 Resistance, Power and Propulsion

4.4.1 Resistance Analysis

The resistance calculations are performed using the Holtrop-Mennen and the ITTC methods. The Holtrop-Mennen method is used with a correlation allowance of 0.0005 to calculate the bare-hull resistance. Inputs for this method include ship principal characteristics such as LWL, beam, draft, and coefficients of form, as well as other data such as full load displaced volume, appendage information, wetted surface area, transverse bulb section area at the forward perpendicular, and ship speeds. The hull characteristics that are used in the resistance calculation are shown in Table 38. Most of the information in this table is found from calculations using the hullform in FastShip. The analysis is performed over the range of operating speeds in calm seas. The components that were analyzed for resistance are bare hull, appendage, and wind. These results are shown in Figure 64 and Table 39.

Table 38. Hull Form Parameters for Holtrop-Mennen Calculation

Input Parameters	Values
LWL (m)	201
B (m)	29.54
T (m)	7.00
V_{FL} (m^3)	24847
Prismatic Coefficient (C_P)	0.647
Maximum Area Coefficient (C_X)	0.941
Block Coefficient (C_B)	0.609
Waterplane Coefficient (C_W)	0.819
Wetted Surface Area (m^2)	6598
Total Rudder Surface Area (m^2)	19.6
Total Bilge Keel Surface Area (m^2)	76.828
Transom Area (m^2)	11.822
Bulb Area at FP (m^2)	14.811
Bulb center above BL (m)	3.018

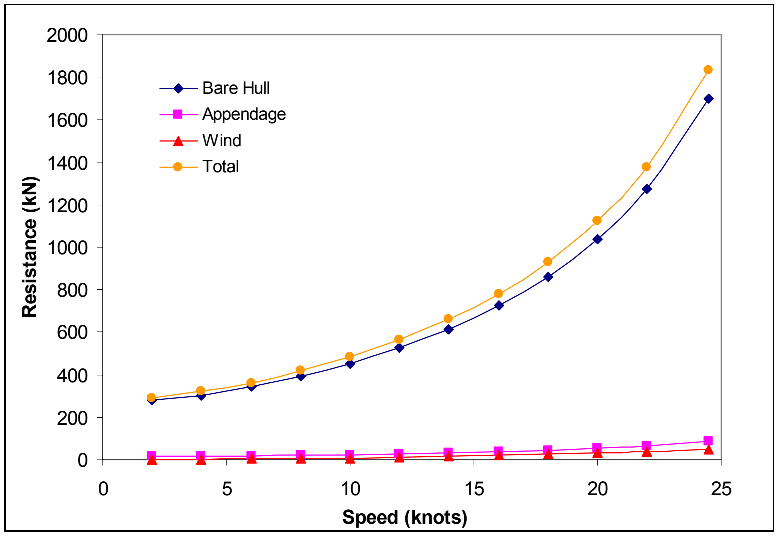

Figure 64. Resistance Curves for Full Load Condition

Table 39. Resistance Summary for Full Load Condition

Speed (knots)	Bare Hull (kN)	Appendage (kN)	Wind (kN)	Total (kN)
2	278.61	13.93	0.32	292.86
4	303.48	15.17	1.28	319.94
6	341.75	17.09	2.88	361.72
8	392.08	19.60	5.12	416.80
10	453.58	22.68	8.00	484.26
12	526.79	26.34	11.52	564.65
14	614.85	30.74	15.68	661.27
16	723.95	36.20	20.48	780.62
18	862.51	43.13	25.91	931.55
20	1038.57	51.93	31.99	1122.49
22	1275.42	63.77	38.71	1377.90
24.5	1699.12	84.96	48.01	1832.08

LPD-17 was originally designed with a five bladed propeller, so the propeller of LPD-17 is used since the specific propeller was optimized for this specific hullform. The LPD-17 propeller optimization was based on the propeller efficiency at an endurance speed of 20 knots. Since the endurance speed of CUVX is 20 knots and the CUVX hullform does not change below the waterline compared to that of LPD-17, the propeller of LPD-17 is used for CUVX. The propeller's characteristics are summarized in Table 40. Given the propeller characteristics and the total thrust required at endurance speed, the chosen propeller does not cavitate, as shown in a calculation found in Appendix D.2 CUVX Power and Propulsion Analysis

Table 40. Propeller Characteristics

Blades	Pitch Type	Diameter	Pitch	EAR	Immersion	Open Water Efficiency	Advance Ratio	K_T	K_Q
5	FPP	4.88 m	5.86 m	0.94	4.56 m	0.691	0.925	0.279	5.8

The propulsion system chosen in the optimization of the ship is an IPS plant with three main ICR propulsion engines, two gas turbine ship service generators and two propulsion motors. Based on generalized performance, a motor and transmission efficiency of 0.93 is used. From this efficiency and the shaft horsepower of the propulsion shafts, the brake horsepower required from the propulsion motors is found. The total brake horsepower required for the ship with two shafts at sustained speed is 55,352 hp. Since the main propulsion engines provide the power to the propulsion motors and the ship's service power, the required maximum functional electrical load with margins is included to find the required power for the ICR generator sets. The required total installed power for the main propulsion generator sets at sustained speed is found to be 93,587 hp. Figure 65 shows the power versus ship speed for the total propulsion motor BHP and the total propulsion engine BHP. The three Westinghouse WR-21 29 ICR engines are rated at 33,794 hp each, giving a total MCR of 101,381 hp.

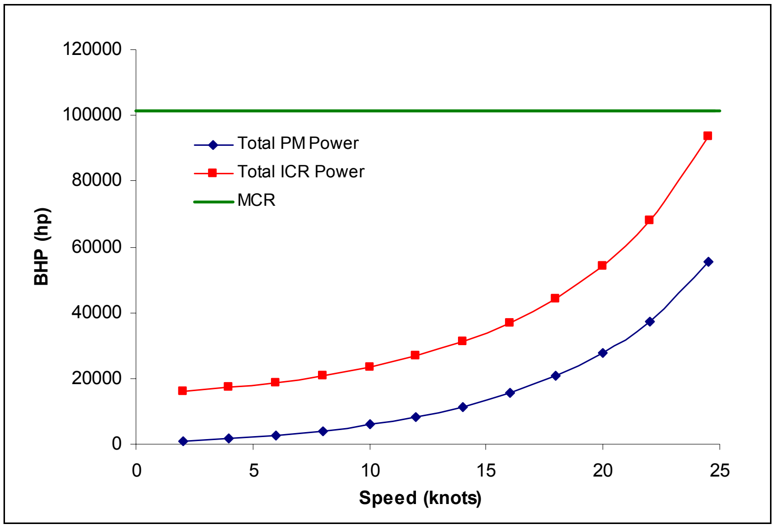

Figure 65. Total BHP vs. Speed

4.4.2 Electrical Power Analysis

The average electrical load required to service the ship over one full trip is needed to determine fuel weight and volume. The main gas turbine generators are used to provide the electrical power that is driven to the propulsion motors and electromagnetic launching system (EMALS) as well as to the zonal buses to provide power for the large loads. The ship service gas turbine generators provide the power for ship service such as lighting, firemain, heating, ventilation, etc. The electrical loads take into account for every equipment list for each SWBS group. From the ship synthesis model, the maximum functional load with margins was 8925 kW. The 24 hour average electrical load was found to be 5132 kW.

4.4.3 Endurance Fuel Calculation

An endurance fuel calculation is performed with CUVX running at endurance speed, 20 knots, over the endurance range, 4000 nm. At endurance speeds, only two ICR's will be online to provide the ship propulsion and ship service generators. At this speed and range, CUVX will be expected to run at least 200 hours and therefore carry at least this much fuel for such a mission. Based on ICR performance, CUVX should carry at least 1785 cubic meters of fuel (DFM) to operate at endurance speed while providing adequate ship service capabilities. Given that only two main engines are online during endurance speed, only two fuel service tanks are needed, one in each main machinery room next to a running ICR. Assuming each tank should hold up to 8 hours worth of fuel, each tank was sized to hold 120.63 cubic meters of fuel. The endurance fuel calculation can be found in Appendix D.2 CUVX Power and Propulsion Analysis.

4.5 Mechanical and Electrical Systems

The machinery equipment list is developed according to the ship mission and our Concept Exploration. The equipment list is determined by the optimization process, equipment from similar ships, and expert opinion. The equipment list is composed of auxiliary, mechanical, and electrical parts. A complete list of the pertinent mechanical and electrical systems for this ship containing capacities, dimensions, locations, and weights is shown in Appendix D.6 CUVX Machinery Equipment. Most of the equipment is located in the main and auxiliary machinery rooms.

There are pump rooms next to each machinery room that are also used to put the machinery related parts such as pumps, etc. close to the machinery rooms that are detailed in Section 4.9.2.

4.5.1 Mechanical Systems

Several mechanical systems are categorized under main, auxiliary, and propulsion systems. The auxiliary system contains all the ship service related systems as well as deck machinery, and other miscellaneous equipment. The propulsion system is mainly located in two of the auxiliary machinery rooms that are located next to each other between the 11^{th} and the 12^{th} transverse bulkheads as seen in Section 4.9.2. The power is delivered to the AC-DC-AC power conversion motors directly from the main switchboards and converted to required voltage and current by the converters and then delivered to propulsion motors.

The main propulsion is fed by three main ICR gas turbine generator sets that can provide 21MW each. The delivered power and required power is discussed in the next section.

4.5.2 Electrical Systems

The electric loads are analyzed using the results from the electrical load section of Appendix D.5 Electric Load Analysis for all equipment in each SWBS group that includes all the equipment that use power. This analysis is used to determine the power requirements during the six operating conditions; UCAV launch (EMALS), Other Aircraft Operations, Cruise, Inport, Anchor, and Emergency. A summary table of these conditions can be seen in Table 41. The integrated power system (IPS) is designed so that the main three gas turbines and two ship service gas turbines can provide enough power to all electrical needs in each operating state.

Table 41. Electric Load Summary

SWBS	Description	Connected (kW)	UCAV Launch (kW)	Other Aircraft Ops (kW)	Cruise (kW)	Inport (kW)	Anchor (kW)	Emergency (kW)
100	Deck	451.1	0.0	0.0	0.0	12.1	8.0	5.3
200	Propulsion	48489.4	47403.1	47481.5	21220.5	248.7	284.0	0.0
230	Engines - Mechanical Drive		0.0	0.0	0.0	0.0	0.0	0.0
235	Elecric Propulsion Drive	46905.0	46905.0	46905.0	20644.0	0.0	0.0	0.0
250&260	Support	1584.4	498.1	576.5	576.5	248.7	284.0	0.0
300	Electric	680.2	322.9	322.9	322.9	214.7	335.7	149.5
310	Power Generation	334.2	126.6	126.6	126.6	37.1	135.1	58.5
330	Lighting	346.0	196.3	196.3	196.3	177.6	200.6	91.0
400	C&S	746.7	597.7	597.7	577.9	71.5	218.4	373.5
410	C&C	65.0	48.7	48.7	43.6	6.0	42.2	34.4
420	Navigation	5.0	4.6	4.6	4.6	0.4	3.6	5.0
430	IC	41.5	31.2	31.2	31.2	4.6	16.0	33.9
440	Ex Comm	192.9	96.5	96.5	96.5	57.9	57.9	57.9
450	Radar	303.0	303.0	303.0	303.0	0.0	2.0	224.0
460	UW Surveillance	6.9	5.5	5.5	1.4	0.0	1.4	0.0
470	Countermeasures	80.7	63.0	63.0	61.1	0.0	58.8	13.1
480	Fire Control	32.4	25.9	25.9	17.3	2.6	17.3	5.2
490	Special	19.3	19.3	19.3	19.3	0.0	19.3	0.0
500	Auxiliary Systems	9841.3	4746.9	4513.0	4767.7	4122.1	4286.5	581.6
510	HVAC	6291.6	3864.4	3864.4	3945.1	3748.7	3864.4	0.0
520	Seawater Systems	2139.7	208.8	208.8	357.9	101.4	113.4	246.1
530	Fresh Water Sys	575.1	247.4	247.4	247.4	212.7	230.6	335.6
540	Fuel Handling	311.6	77.1	77.1	77.1	21.8	37.4	0.0
550	Air and Gas	217.2	21.7	21.7	21.7	21.7	21.7	0.0
560	Ship Control	200.6	29.9	0.0	29.9	0.0	0.0	0.0
580	Mechanical		280.0	76.0	71.0	0.0	0.0	0.0
584	Mechanical Doors		21.0	21.0	21.0	0.0	0.0	0.0
586	Aircraft Recovery		5.0	5.0	0.0	0.0	0.0	0.0
587	Aircraft Launch (Boiler)		204.0	0.0	0.0	0.0	0.0	0.0
588	Aircraft Handling		50.0	50.0	50.0	50.0	50.0	0.0
593	Environmental	105.4	17.5	17.5	17.5	15.8	19.0	0.0
600	Services	677.0	342.1	342.1	342.1	342.1	342.0	50.0
700	Armament		10.0	10.0	10.0	0.0	10.0	0.0
	Max Functional Load		53422.7	53267.2	27241.1	5011.1	5484.5	1160.0
	MFL w/ Margins		54686.9	54482.2	28505.5	6011.2	6576.7	1403.6
	24 Hour Average		51059.9	50981.8	24877.9	3129.9	3430.3	1403.6
Number	**Generator**	**Rating (kW)**	**UCAV Launch**	**Other Aircraft Ops**	**Cruise**	**Inport**	**Anchor**	**Emergency**
3	Propulsion Generators	21000.0	3	3	2	0	0	0
2	SSDGs	3430.0	0	0	0	2	2	2
0	EDG	0.0	0	0	0	0	0	0
	Power Available (kW)		63000.0	63000.0	42000.0	6860.0	6860.0	6860.0

The three main gas turbine engines have the capacity to provide 21MW power each while the ship service gas turbine generators can provide 3.43MW each. The ship does not contain an additional generator that can be used for emergency because one of the ship service generators is capable of providing the required power. The generators are placed as far away from each other as possible to maintain the survivability incase of a hit.

The main generators contained onboard are capable of providing the propulsion maximum functional loads. The ship service generators are also capable of providing the ship service maximum functional loads in all conditions.

Within the analysis, the electrical load is combined with two margin factors producing the maximum functional load.

As you can see below in Figure 66, the ship contains three main switchboards and two ship service switchboards. The power generated by the ship service generator goes directly to the ship service switchboard and is delivered to main zonal buses on the port and starboard sides of the ship. The current generated by ship service generators (SSG) is clean so that power converters and transformers are not necessary. The current that is delivered to each zonal bus is 480 V 3-Phase AC at 60 Hz frequency. Two main generators that are located at the first main machinery room are connected to the main switchboard and the one at the aft is connected to the other main switchboard. The current on the main switchboards is high voltage, 4160V, 3-Phase AC current at 60Hz. These main switchboards are connected to both zonal buses as well as to the propulsion motors. Power Conversion Modules (PCM AC-DC-AC Power Converters) are used to reduce the high voltage from 4160V to 480V, 3-Phase clean AC at 60 Hz frequency as it goes to the zonal buses. Propulsion power converters are connected to the propulsion motors to obtain the desired current and voltage. An EMALS switch directs the current that is coming to the propulsion motors to the EMALS.

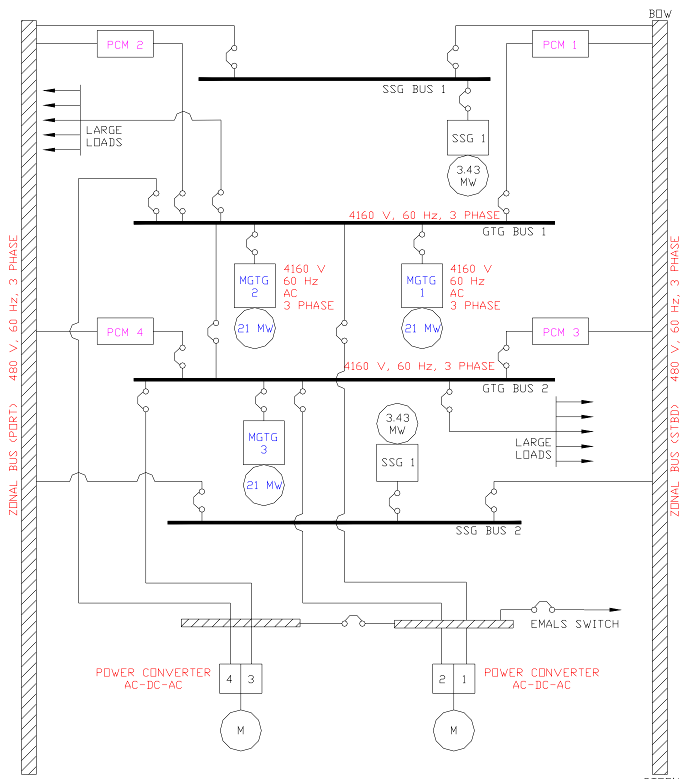

Figure 66. IPS 1-Line Diagram

4.6 Aircraft Systems

4.6.1 Unmanned Combat Air Vehicles

4.6.1.1 Description

A Virginia Tech Aerospace Engineering UCAV-N design team is currently designing the UCAV-N for CUVX. The UCAV-N and CUVX teams are working in collaboration to effectively integrate the ship and the aircraft as an overall system. The UCAV-N will be a revolutionary aircraft in that it will be the first aircraft capable of landing on an aircraft carrier autonomously. Not only will the UCAV-N be fully autonomous during the mission but also in launch and recovery. The UCAV-N will be used for three missions: SEAD, strike, and reconnaissance. When performing a SEAD or strike mission the UCAV-N will be armed with two JDAM's, two HARM's, or one of each. The strike range required to effectively perform a SEAD or strike mission is 500 nm or greater. In order to carry these weapons the UCAV-N will have a payload capacity of 4,300 lbs. Since the UCAV-N has no air-to-air combat capabilities and is a subsonic aircraft, it will rely on stealth as its main defense. When on a reconnaissance mission the UCAV-N must remain aloft for long periods of time without refueling in order to be effective and thus, the endurance requirement for the UCAV-N is 10 hours. The above mentioned requirements for the UCAV-N were met or exceeded and are shown in Table 16. The sensor suite to be used in the UCAV-N is the Global Hawk Integrated Sensor Suite manufactured by Raytheon and is the same as on the UAV Global Hawk. The UCAV-N characteristics that are most important to ship operations can be found in Table 17. A three dimensional graphic of the UCAV-N can be seen in Figure 67.

Table 42. UCAV-N Specifications

Specification	Value
Strike Range	550 nm
Endurance	10 Hrs.
Payload	4,600 lbs
Cruise Speed	Mach 0.7
Ceiling	> 45,000 ft
Sensor Suite	Global Hawk

Table 43. UCAV-N General Characteristics with F/A-18 C/D Comparison

Characteristic	UCAV-N	F/A-18C/D
Length	32 ft	56 ft
Span (Wings Unfolded)	45 ft	40 ft 5 in
Span (Wings Folded)	30 ft	27 ft 6 in
Height (Wings Unfolded)	10 ft	15 ft 4 in
Height (Wings Folded)	15 ft	15 ft 4 in
Weight (Max Gross Take Off)	34,500 lbs	51,900 lbs
Launch Acceleration	5 g's	4 g's
Approach Speed	135 kn	135 kn
Wheel Track	10 ft	10 ft 3 in

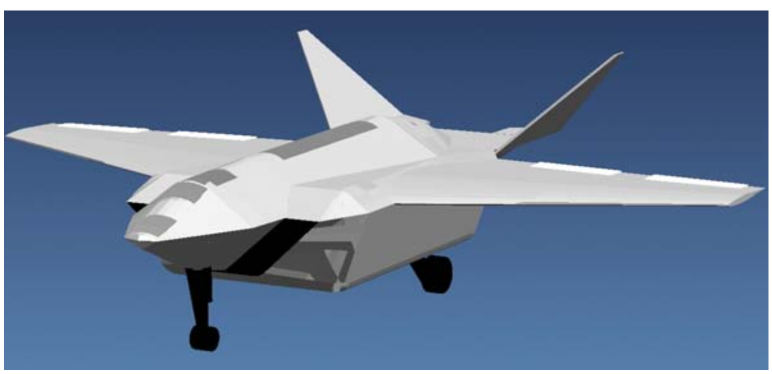

Figure 67. Three Dimensional Graphic of UCAV-N

4.6.1.2 Spotting Turnaround and Stowage

Autonomous aircraft spotting dollies termed SPOT's will be used for all UCAV spotting and turnaround. This is not commercial of the shelf but is essential to various aspects of aircraft operations aboard CUVX such as the unmanned launch area and the efforts to reduce manning. The SPOT's will be autonomous and navigate based on image recognition of deck features. The use of SPOT's will allow for coordinated movement of the UCAV's and helicopters. They will be electric drive and will charge in the weapons assembly area as needed. They will move the UCAV's by lifting at the forward landing gear and towing the aircraft. There will be twenty SPOT's.

Due to the limited number of different aircraft aboard CUVX spotting will not be as coordination intensive as aboard current CVN's. Spotting will consist of placing recovered aircraft back in stowage with the exception of two or three which will remain on the launch deck in the fueling and weapons loading area for deployment on a moments notice. Since each UCAV will be capable of performing the same missions as long as they are functional and there will be no pilot-aircraft connection without pilots there is no need to choose one UCAV over another. This concept also affects the stowage of the UCAV's, which will be stowed on the hangar deck as shown in Figure 68.

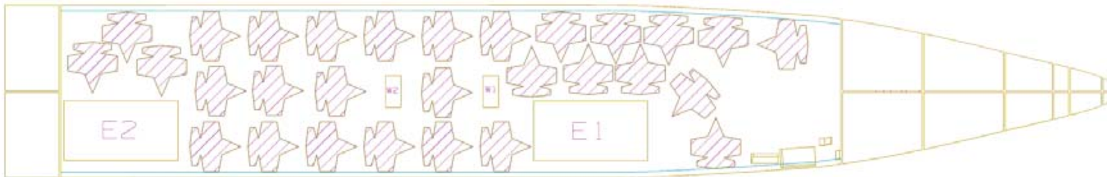

Figure 68. CUVX Hangar Deck

This diagram shows the UCAV's stowed in a way conducive to a star pattern of extraction over a linear method. This means that four or more UCAV's are free to be placed on each elevator without the movement of any of the other UCAV's. This will greatly reduce the required movement of aircraft on the hangar deck. While in the hangar deck it may be necessary to chock and chain the aircraft. This will be done manually since it is not an easy task to automate and will not be required in great amount.

4.6.1.3 Fueling

The UCAV's will be fueled in the area aft of the jet blast deflector (JBD) on the launch deck. This can be seen in Figure 69. The fueling will be done with fuel lines extending from the underside of the recovery deck. There will be 4 of these lines which will together be able to cover the entire fueling area so that an aircraft can be fueled using these lines any where in the fueling area. Hot fueling will not be an option aboard CUVX since the all UCAV fueling will be done below decks. The UCAV's will be refueled directly after recovery to decrease the likelihood of explosion. The fueling time for a UCAV will be 30 minutes when filling a completely empty tank.

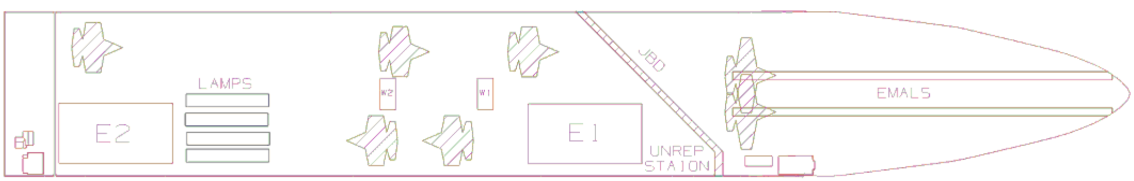

Figure 69. CUVX Launch Deck

4.6.1.4 Weapons Load-out

The UCAV's will be loaded with weapons, if necessary, in the weapons load-out area aft of the JBD as shown in Figure 68. The weapons load-out will be done autonomously by a vehicle termed BLT. The BLTs will be loaded in the magazine. They will then take the elevator to the damage control deck. On the damage control deck in the weapons assembly room the weapons will be assembled. The BLTs will then take different elevators to the launch deck. The weapons will be armed remotely by the UCAV's when in the launch area.

4.6.1.5 Launch

UCAV launching can be broken into two parts: positioning and hookup, and launch. In keeping with the policy of maintaining an unmanned launch area the hook up and positioning of the UCAV's must be done autonomously and will thus be accomplished using SPOT. Launch of the UCAV's will be accomplished using an Electromagnetic Launching System (EMALS). Every aspect of the launching of UCAV's will be monitored from the control room located on the damage control deck. The people in the control room will be able to see into the launch area using a variety of cameras.

4.6.1.6 Recovery

The UCAV's will be recovered on the recovery deck where they will catch one of two wires of a conventional wire arresting system. They will then run out a distance of approximately 100m to the port side of the deckhouse. The UCAV's will then be released from the wire and the engines will be cut off. A SPOT will then attach to the UCAV and tow it to the forward aircraft elevator to be taken below deck. If for some reason the forward elevator is not usable the UCAV will be taken to the aft elevator. If for some reason the UCAV does not catch the arresting wire it will bolter and circle for another landing attempt.

4.6.1.7 Crash Fire and Rescue

CUVX will be equipped to deal with the various possible crash scenarios for a UCAV, which include damage to landing gear and aircraft inversion. If the aircraft is salvageable with only landing gear damage, SPOT's will be used to move the aircraft by taking the place of the damage landing gear. If the aircraft is inverted or burning the Crashed Aircraft Removal Vehicle (CARV) will be used to push the aircraft overboard. CARV will be outfitted with fire fighting equipment including aqueous film forming foam hoses.

4.6.1.8 Maintenance/ Inspections

Maintenance and inspection of UCAV's will be performed in the aft end of the launch deck. The maintenance for the UCAV's will exclude anything involving engine tests as there will be no place to fire the engines other than the launch area. The maintenance will include only servicing, repairs and adjustments. Inspections will be done before and after each flight.

4.6.2 UAV Systems

The unmanned aerial vehicles or UAV's to be used aboard CUVX are the Shadow 400s, which are produced by AAI Corp. These UAV's were designed for use aboard aircraft carriers and will therefore be able to endure the harsh environment at sea. The UAV's are not only light but also structurally sound enough to be launched at 8gs. The physical characteristics and performance specifications of the Shadow 400 can be found in Table 44.

Table 44. Physical Characteristic and Performance Specifications of Shadow 400

Characteristic	Value
Length	12.54 ft. (3.82 m)
Wingspan	16.80 ft. (5.1) m
Max Payload	66 lbs. (30 kg)
Empty Weight	147 kg
Max Gross Weight	442 lbs. (201 kg)
Endurance	5 hours
Max Altitude	12,000 ft. (3,660 m)
Cruise Speed	75 kts (139 kph)
Max Dash Speed	100 kts (185 kph)
Loiter Speed	65 kts (120 kph)

4.6.2.1 Spotting Turnaround and Stowage

The UAV's are stowed in small containers that allow them to be placed wherever convenient. This will allow for greater stowage flexibility. The UAV's are assembled before use, which is a simple procedure since it is a modular design. A small number of the UAV's will be stowed fully assembled so they can be launched on a moments notice. The UAV's are also small relative to the UCAV's and in fact are small enough to be transported about the ship by way of manpower instead of using SPOT. The UAV launch track will also be stored at the aft end of the hangar deck.

4.6.2.2 Fueling

The UAV's will be fueled in the aft end of the launch deck before launch if the tanks are not already full. The fuel will be brought from the fueling and weapons loading area using fuel cans. The UAV's will be fueled directly upon recovery in the weapons and fueling area before they are taken back to stowage.

4.6.2.3 Launch

The launch of the UAV's is flexible. They can be launched either using the EMALS or using their own portable launching track. Each method has good and bad qualities. It would be preferable in most cases to launch the UAV's without interfering with the launch of the UCAV's which will require the EMALS to launch. For that reason it is desirable to launch the UAV's using the portable launching system. The main drawback to using the UAV's portable launching system is the detrimental effect this will have on the radar cross section of the ship. The portable launch system is small enough to be taken from the hangar deck to the recovery deck via the aircraft elevators. This launch system will unfold on the recovery deck to a length of a flat bed trailer. This system can be placed on the starboard side out of the way of the recovery strip, which will allow for launch of the UAV's during the recovery of the UCAV's.

4.6.2.4 Recovery

The UAV's will be recovered in a way similar to the UCAV's. They will catch a smaller arresting wire than the UCAV's, since catching the large wire would be equivalent to the UAV hitting a brick wall. The large wires will be lower to be flush with the deck and the smaller wires will be raised to catch the UAV's. This method of autonomous landing will require an avionics upgrade to the UAV, as they are currently designed to fly into a large net for recovery. The large net was not an option for CUVX since it would be a huge radar signature negating all of the efforts to reduce the radar cross-section of the ship.

4.6.2.5 Crash Fire and Rescue

Crash procedures for the UAV's will be similar to the crash procedures for the other aircraft. If the crashed UAV is salvageable (not burning) it will be manually removed from the flight deck. If it is not salvageable then it will be removed from the recovery deck as soon as possible using CARV.

4.6.3 Helicopter Systems

4.6.3.1 Description

The helicopters to be used aboard CUVX will be the SH-60 helicopters, shown in Figure 70.

Figure 70. SH-60 Helicopter

There will be four of these. Some of the important characteristics of these helicopters can be found in Table 45.

Table 45. SH-60 Physical Characteristics

Characteristic	Value
Length	64' 10"
Height	13'
Rotor Diameter	53' 8"
Weight	21,000 lbs

4.6.3.2 Spotting Turnaround and Stowage

The helicopters will be stowed on the launch deck near the aft aircraft elevator as shown in Figure 71. The helicopters will be moved about the ship using SPOT's. Since there is only one type of helicopter on board, helicopter spotting will be relatively simple. The helicopters will be spotted near the aft elevator at all times which will allow them to be taken to the recovery deck with minimal movement. While in stowage it may be necessary to chock and chain the helicopters in which case this will be done manually.

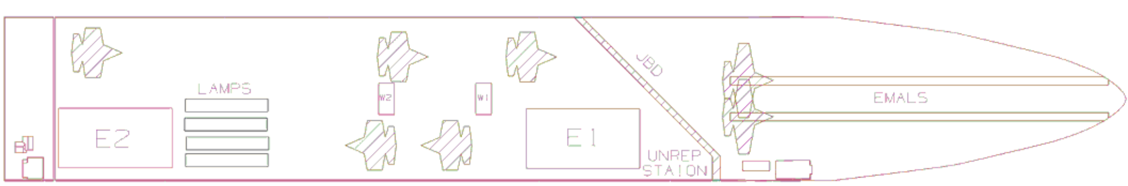

Figure 71. CUVX Launch Deck

4.6.3.3 Fueling

The helicopters will be fueled directly after recovery and stowed with full tanks. This will be beneficial in two ways. First the full fuel tank lessens the chance of explosion due to fuel vapors. Second this will allow the helicopters to be deployed without the wait associated with fueling. Since the helicopters will be brought from the recovery deck to the launch deck via the forward aircraft elevator fueling will be done on the way to stowage or maintenance/inspection.

4.6.3.4 Weapons Load-out

The weapons load-out for the helicopters will be similar to that for the UCAV's. They will be loaded using the BLTs just like the UCAV's. The main difference is that the helicopters will be loaded with weapons in the aft section of the launch deck instead of the forward section like the UCAV's.

4.6.3.5 Deployment

The helicopters will be deployed from the recovery deck near or from the aft aircraft elevator. It will be on the recovery deck prior to launch that the weapons aboard the helicopters will be armed. The helicopters make it impossible to maintain an unmanned recovery deck. Attempts will be made to minimize the manning on the recovery deck.

4.6.3.6 Recovery

The helicopters will be recovered on the recovery deck near the forward aircraft elevator. This will lend well to fueling them before placing them back into stowage. When recovered, the pilots of the helicopters will ride the elevator to the launch deck while inside the helicopter.

4.6.3.7 Crash Fire and Rescue

Each crash presents its own specific problems so there is no recipe for dealing with crashed aircraft but there are some basic guidelines that can aid in crash cases. Primarily a decision must be made on whether or not to salvage the helicopter. If the helicopter is burning for example it may be necessary remove it from the recovery deck by any means necessary. If only the landing gear is damaged and the helicopter is otherwise in good condition then the SPOT's will be used to secure and transport the aircraft.

4.6.3.8 Maintenance/ Inspections

The maintenance and inspection procedures for the helicopters will be exactly the same as for the UCAV's. Only minor maintenance functions can be accomplished aboard CUVX. No engine testing will be performed.

4.7 Manning

Manning on CUVX is broken down into two conditions: Conditions I & III. The ship is in Condition I when all hands are at battle stations. Condition III is when the ship is in normal operating conditions. Condition I consists of two 12 hour shifts, while Condition III consists of three 8 hour shifts. Condition I is the limiting factor for manning on CUVX as it will require the most personnel.

The total number of officers and enlisted personnel for CUVX can be seen in Table 46. Manning is broken down by department as shown in Table 47. Manning for the ships crew for LPD-17 was used as a guideline in determining the manning for the ships crew for CUVX. CUVX has a total ships crew of 433, while LPD-17's total manning for ships crew is 448. Ships crew includes all of the departments in Table 47 minus Aviation.

Table 46. Total Manning

Personnel	Number Present
Officers	59
Enlisted	632
Total	691

Table 47. Departmental Manning

Department	Officers	Enlisted	Total
Aviation	29	229	258

Weapons	3	30	33
Deck	6	80	86
Engineering	10	180	190
Operations	6	30	36
Supply	4	50	54
Medical	2	8	10
Navigation	1	6	7
Administration	1	15	16
Total	59	632	691

Aviation can be broken down into six divisions: Launch & Recovery Deck, Launch & Recovery Systems, Hangar Bay, Aircraft Loading, Maintenance, and Helicopters. Launch & Recovery Deck encompasses all the crew responsible for handling the aircraft on the launch and recovery decks. Due to the fact that the launch and recovery decks will be automated, manning numbers cannot be extrapolated from current aircraft carriers, which use manpower to handle the aircraft. As stated above in 4.6.1.2, autonomous spotting dollies will be used to transport aircraft around the ship. Manning is significantly reduced as only SPOT operators will be needed in order to move the aircraft on the launch and recovery decks. This section of Aviation also includes the Crash & Salvage (C&S) Team. The C&S team is responsible for handling emergencies on the launch and recovery decks. To reduce manning, burning aircraft will be removed from the recovery deck using the CARV putting personnel out of harms way. Firefighters are still required, and will use firefighting equipment attached to the CARV. Total manning for Launch & Recovery Deck is 43 enlisted personnel, and 4 officers. Launch & Recovery Systems includes catapult and arresting gear operators and maintenance. EMALS reduces manning from conventional steam driven catapults to a total of 21 enlisted personnel and 1 officer. The conventional cable arresting gear requires 24 enlisted personnel and 1 officer. Total manning for Launch & Recovery Systems is 45 enlisted personnel, and 2 officers. Hangar Bay covers aircraft handling in the hangar bay. Using the same reasoning as stated before for Launch & Recovery Deck, automation reduces the manning required for this section. Hangar Bay requires 21 enlisted personnel and 1 officer. Aircraft Loading includes aircraft refueling and weapons loading of the UCAV's and LAMPS. Automation, in the form of BLT's, reduces manpower that is required for the loading of weapons on the aircraft. Aircraft refueling will not be automated and will require personnel to connect the fuel lines to the aircraft. Automated refueling will not occur because there are currently no technologies to accommodate such maneuvers. However, the possibility of automated refueling should still be considered with following ships. Such automation would further reduce the amount of personnel put in harms way. Currently, Aircraft Loading requires 30 enlisted personnel and 3 officers. Maintenance requires the most personnel in the Aviation department. Although the maintenance shop will have limited capabilities, 90 enlisted personnel and 6 officers will be required to service all of the aircraft. Each helo requires 2 officers and 1 enlisted personnel to perform their duties. Therefore, the requirements for the 4 helicopters onboard are 8 officers and 4 enlisted personnel. The six divisions for Aviation require a total of 233 enlisted personnel and 25 officers.

The ships crew is broken up into eight different departments: Weapons, Deck, Engineering, Operations, Supply, Medical, Navigation, and Administration. Weapons manning includes the personnel necessary to operate and maintain ship weapons. These include the two CIWS and the two VLS. The required manning for Weapons is 30 enlisted personnel and 3 officers.

Deck manning includes personnel necessary for maintenance and/or special evolution (UNREP, small boat operations, etc.) related. Numbers from CVX were used as a guideline, with the condition that a reduction in manning is possible due to technological advances. This results in a total number of enlisted personnel of 80 and officers of 6.

Engineering manning is based on "The Gas Turbine Propulsion for the Fleet" study which states that manning could be reduced to 150 enlisted personnel. This number was increased however because it seemed relatively low for a ship with an integrated power system. The study does not state how many officers would be required, but a factor of approximately 1 officer per 15 enlisted personnel is used. Using these numbers, the manning for engineering was divided into the divisions shown below in Table 48.

Table 48. Engineering Manning

	Enlisted	Officers	Total
Eng Officer	0	1	1

Main Prop	50	2	52
Prop Aux	40	2	42
Aviation Support	30	2	32
DC/Repair/Aux	40	2	42
Elec Dist	20	2	22
Total	180	11	191

Manning numbers for operations are based on CVX manning numbers, but include a large reduction due to automation. Personnel in operations are required to forecast the weather, analyze tactical combat and operational information, operate communications equipment, maintain and operate ship self defense systems, and maintain all computers and networks. The total number of enlisted personnel was reduced to 30 with officers down to 6.

The supply department is responsible for the ship's stores and mess. The manning number for this department is based on CVX to be 50 enlisted personnel and 4 officers.

The Medical department includes both the doctors and dentists. The manning numbers for this department are based on the total manning for the ship and are 8 enlisted personnel and 2 officers.

Manning for navigation is based on CVX and reduced due to technological advances. Required manning is 6 enlisted personnel and 1 officer.

Administration is based on CVX manning, and is reduced to 15 enlisted personnel and 1 officer. The officer in administration is the XO.

Since automation is a currently being developed for naval use, CUVX is designed to support such automation advances. Automation could be used more for UCAV weapons and moving aircraft around, increasing the effectiveness of CUVX. The lead ship of CUVX is designed with some automation using the 691 manning number as the compliment. However, if the automation does not appear to be working properly on the lead ship, then more men can be added to CUVX to replace the faulty automation. When it comes to accommodation spaces, the ship synthesis model manning estimate of 916 men is used to provide enough space within the ship. When broken down into ships crew and aviation men, the new manning estimate for aviation are 258 compared 615 of the ship synthesis model giving a new air manning factor, CManAir, of 0.42. The new manning estimate for ships crew is 433 compared to 301 of the ship synthesis model giving a new ship manning factor, CManShip, of 1.439. Overall, the combination of CManAir and CManShip provides less manning compared to the original ship synthesis model.

4.8 Space and Arrangements

4.8.1 Tankage

The tankage for CUVX is based on tankage requirements provided by the math model. Tanks were positioned in available locations in order to provide the best trim and heel possible. The Tankage Capacity Plan showing the volumes, capacities, and contents of the tanks is shown below in Table 49.

Table 49. Tankage Capacity Plan

Tank	Content	Volume (m^3)	Capacity (MT)
0-48-1-J	JP-5	152	127
0-48-2-J	JP-5	152	127
0-96-3-J	JP-5	406	385
0-96-4-J	JP-5	406	385
0-111-3-J	JP-5	462	439
0-111-4-J	JP-5	462	439
Total JP-5	JP-5	2040	1902
0-33-3-F	DFM	401	334
0-33-4-F	DFM	401	334
0-81-3-F	DFM	395	330
0-81-4-F	DFM	395	330
Total DFM	DFM	1592	1328
0-81-1-W	Potable Water	150	150

0-81-2-W	Potable Water	150	150
0-96-1-W	Potable Water	150	150
0-96-2-W	Potable Water	150	150
Total PW	Potable Water	600	600
0-63-1-W	SW Ballast	176	181
0-63-2-W	SW Ballast	176	181
Total SW	SW Ballast	352	362
Total		4584	4192

Table 50. Hull Required, Available, Actual Parameters from MathCad

Parameter	Required	Available	Actual
Machinery Box Height	6.63 m	7.63 m	?? m
Machinery Box Length	16.36 m	?? m	?? m
Machinery Box Width	6.83 m	?? m	?? m
Machinery Box Volume	7189 m^3	8273 m^3	?? m^3
Waste Oil	31.54 m^3	N/A	35.703 m^3
Lube Oil	20.817 m^3	N/A	20.817 m^3
Sewage	57.457 m^3	N/A	57.229 m^3

4.8.2 Main and Auxiliary Machinery Spaces and Machinery Arrangement

Spacing and arrangements are modeled using Unigraphics with the actual 3D dimensions. The machinery equipments are grouped and located into three different types of rooms, which are the main machinery, auxiliary machinery, and pump rooms. The ship contains two main machinery rooms (MMR1, MMR2), three auxiliary machinery room (AMR1, AMR2, AMR3), and five pump rooms (PMR1, PMR2, PMR3, PMR4, PMR5), which are shown in Figure 72. The ship also has a steering gear room that is located above the rudders.

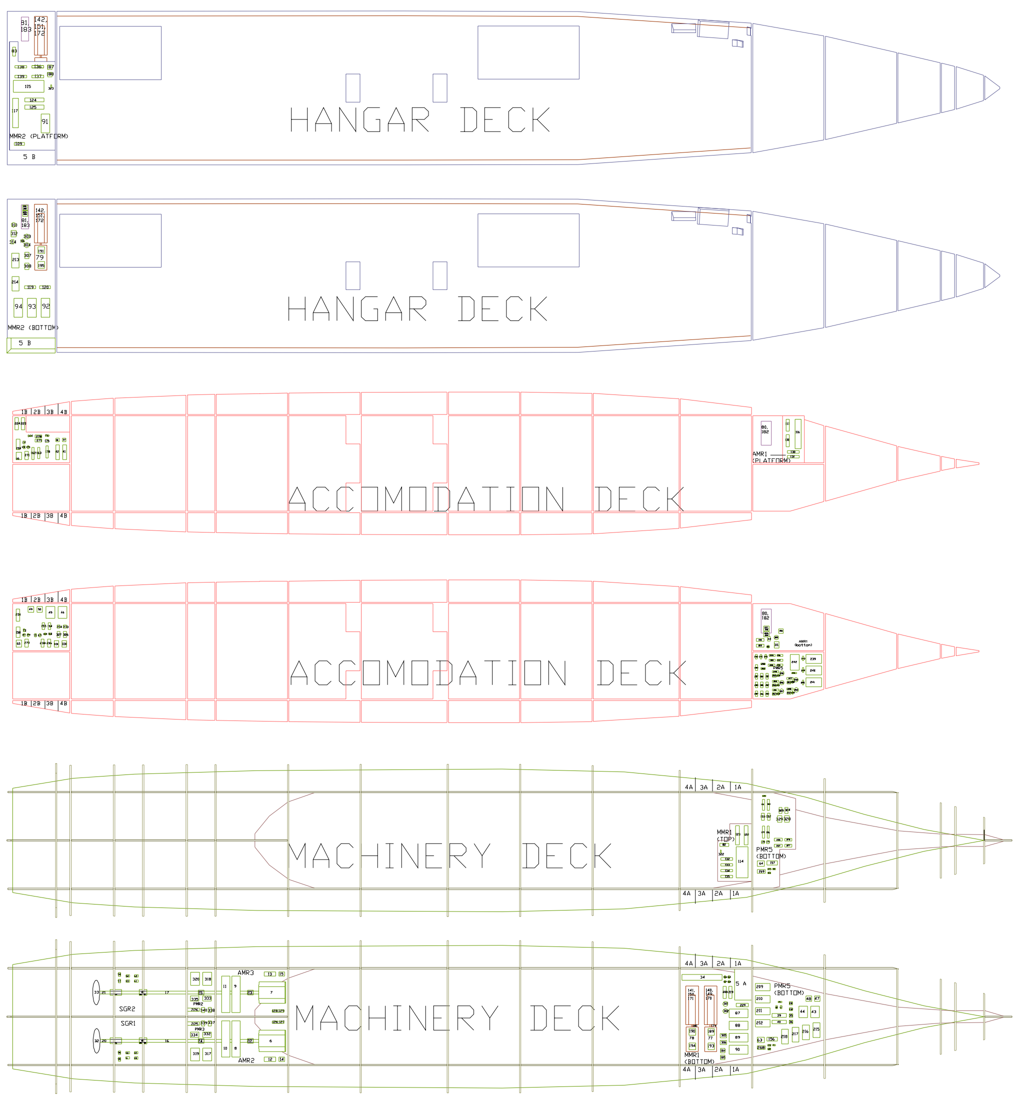

Figure 72. Plan View of Machinery Arrangements

Most of the tiny components are placed at a minimum distance of 0.8 meters from each other and the walls. This clearance is even higher in most major components for maintenance purposes. Many heavy components are placed aft and forward, starboard and port oppositely in the machinery rooms to balance the weight distribution over the area.

The machinery equipment list is developed and located in the machinery and pump rooms. The detailed list of machinery equipment is shown in Appendix D.6 CUVX Machinery Equipment. Platforms are placed to increase the usable area in the machinery and pump rooms.

Two of the main gas turbine generators and the ICR's are located at the MMR1, shown in Figure 73 and Figure 74, which is located between the 5th and 6th bulkhead (between 48 and 63 meters aft of the FP) on the machinery deck. AMR1 is located close to MMR1 in order to have the ability to use the same air intake and exhaust. The radar cross section is a high concern in the design; therefore, the number of exhaust systems is limited to two.

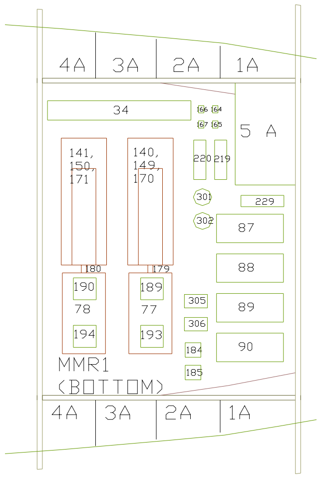

Figure 73. Plan View of MMR1 (Bottom Platform)

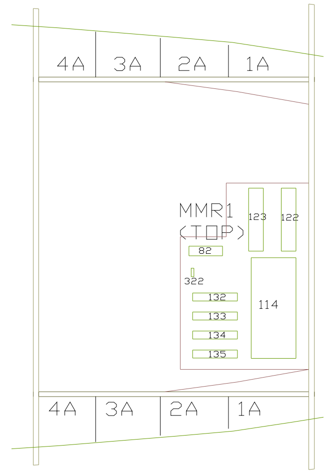

Figure 74. Plan View of MMR1 (Top Platform)

The other main gas turbine generator with the ICR, plus ship service gas turbine generator are located in the MMR2, which is at the aft end of the ship (189 meters aft of the FP) on the hanger deck level. The main and ship service generator sets are put in the same place in MMR2, shown in Figure 75 and Figure 76, for the same reason explained in the paragraph above.

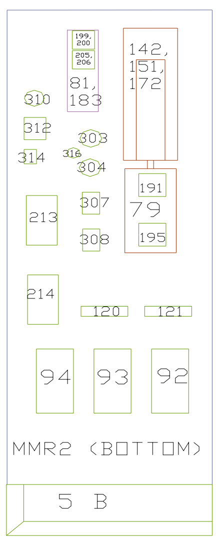

Figure 75. Plan View of MMR2 (Bottom Platform)

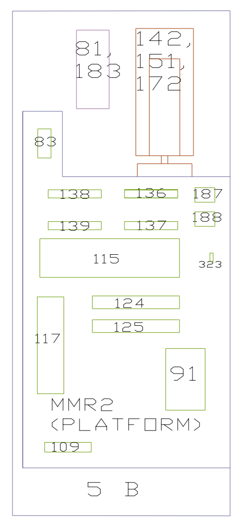

Figure 76. Plan View of MMR2 (Top Platform)

One of the ship service gas turbine generators is located in AMR1, shown in Figure 77 and Figure 78, which is forward of MMR1, one level up on the accommodation deck on the starboard side (between 33 and 48 meters aft of the FP).

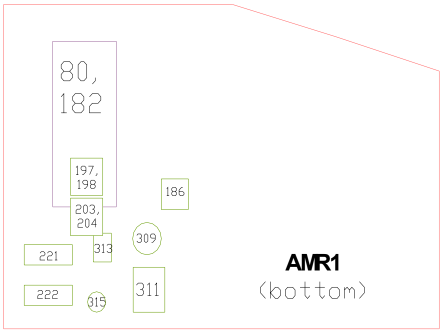

Figure 77. Plan View of AMR2 (Bottom Platform)

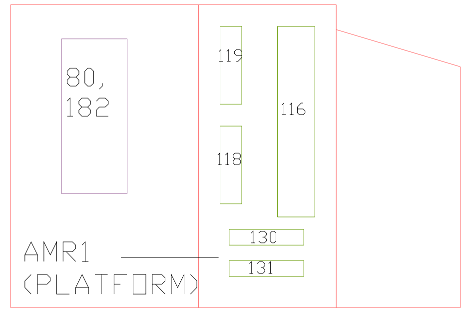

Figure 78. Plan View of AMR2 (Top Platform)

The potable water pumps, distillers, and related equipment are stored in PMR1, shown in Figure 79, which is next to AMR1 and the JP-5 Room. All JP-5 pumps and related equipments are placed in the JP-5 room.

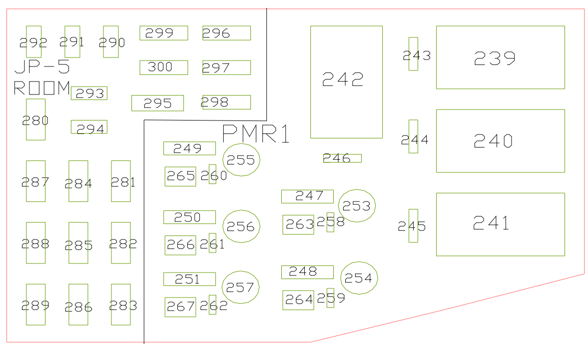

Figure 79. Plan View of PMR1

PMR5 is the room below PMR1 on the machinery deck and it contains the equipment related to the main gas turbine engines. All of our refrigeration plants and some of the AC plants are placed in PMR5, shown in Figure 80 and Figure 81.

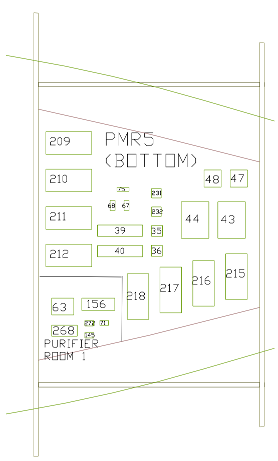

Figure 80. Plan View of PMR5 (Bottom Platform)

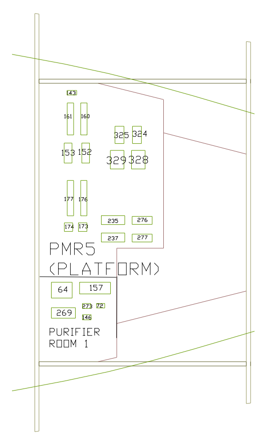

Figure 81. Plan View of PMR5 (Top Platform)

AMR2 and AMR3, shown in Figure 82, are located between the 11th and 12th bulkheads on the machinery deck (between 144 and 159 meters aft of the FP). The rooms contain the propulsion motors, power converters, control units, the exciters, shafts, and shaft bearings. AMR2 and AMR3 are symmetrical about the centerline.

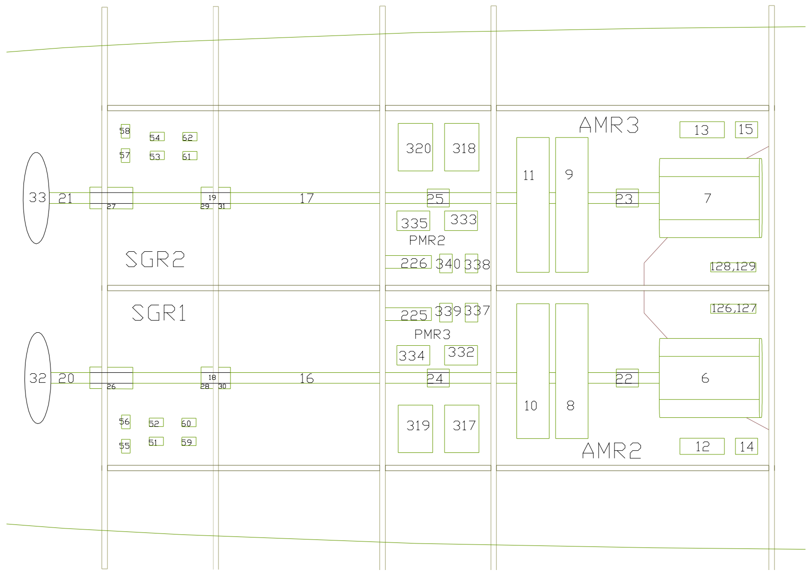

Figure 82. Plan View of AMR2, AMR3, PMR2, PMR3, SGR1, and SGR2

PMR2 and PMR3 are located aft of the AMRs (between 159 and 165 meters aft of the FP). The sewage units, wastewater discharging units, and fire pumps are located symmetrically in these pump rooms.

PMR4, shown in Figure 83 and Figure 84, is located below the MMR2 (189 meters aft of the FP) on the accommodation deck level.

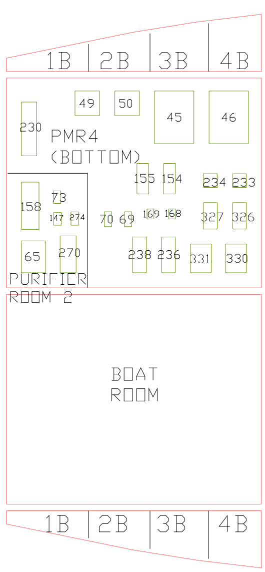

Figure 83. Plan View of PMR4 (Bottom Platform)

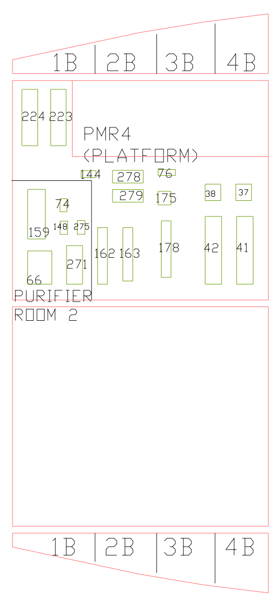

Figure 84. Plan View of PMR4 (Top Platform)

Most of the components that are related to each other are placed within close proximity in the rooms, such as low temperature fresh water cooler and low temperature fresh water-cooling pump are placed close together so that there will be no unnecessary or excess cables or hoses. The location and placement of the components is based on stability, functionality, and survivability. Most equipment is arranged about the centerline, having one component situated on the port side of the ship and the second component on the starboard.

The main switchboards, power conversion modules and other power related electronic type components are placed on the platforms to be kept clean and dry. Pumps and related equipment are placed in the pump rooms, as well as equipment that do not need to be in the machinery rooms. Exact locations of this equipment can be seen in the figures above. Our ship contains only one platform, which is connected to the main floor by stairs.

4.8.3 Internal Arrangements

Inboard Profile:

Figure 85. Inboard Profile showing the internal arrangements

Launch Deck:

The launch deck is located immediately below the recovery deck, and also serves as the weather deck of the parent hull form. It is a full 6-meter deck for aircraft operations. The Forward 75m of this deck is devoted to the EMALS. The Launch space is partially enclosed with a door at the terminus of the recovery deck. The space is divided from the pit stop and maintenance space aft of it by the jet blast deflector (JBD). A second door is provided on the port side to allow the egress of hot exhaust gasses from launching UCAV's. The JBD itself is largely moveable to allow transfer of prepared UCAV's from the pit stop area to the catapults. Just aft of the JBD and inlet/exhaust area for MMR1 is the UNREP station for CUVX. Aircraft elevators are carried through the deck vertically with their positions being defined by their location on the recovery deck. Weapons elevators are located centrally in the pit stop area to facilitate UCAV's following a semicircular path from the forward elevator to the opening in the JBD. Peripheral vertical launch missile units are placed to starboard to ensure they do not interfere with aircraft recovery. Aircraft maintenance is performed near the aft elevator with shops located aft of the aft-most transverse bulkhead. A plan of the Launch deck is shown in Figure 86.

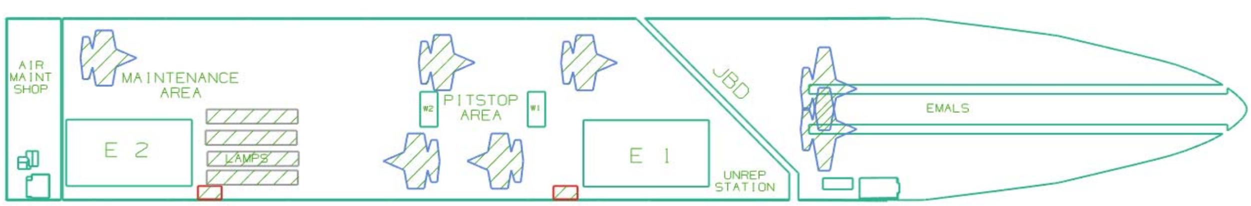

Figure 86. Plan View of Launch Deck

EMALS deck:

Located forward of the hangar space and beneath the foredeck, the EMALS deck, shown in Figure 87, houses all forward line handling apparatus. The boatswain's department is housed here, as well as the ancillary components associated with the EMALS. The hangar deck below is a 6-meter deck. This height is not required in the forward spaces so the EMALS deck was added to provide additional arrangeable space.

Figure 87. Plan View of EMALS Deck

Hangar Deck:

Normal operations will likely not involve the UCAV's; they will be activated for strike activities but will not engage in missions such as combat air patrol, which would require their continuous operation. In light of this, they will be stored on the hangar deck. The main hangar space, shown in Figure 88, extends from the aft-most transverse bulkhead forward to the #5 transverse bulkhead, even with the forward edge of the recovery deck. This space occupies the full breadth of the ship and is large enough to accommodate the ship's compliment of UCAV's. The red line seen in the drawing represents a one meter setback from the shell plating; this is taken as the boundary of the area in which aircraft may be placed. Aft of the hangar space is MMR2, which houses a ship service turbine and the third prime mover. The hangar space represents a collective protection zone; forward spaces are included with those spaces below them in the forward CPS zone.

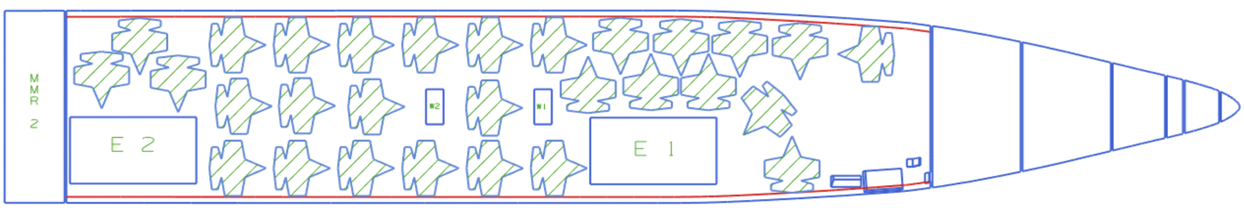

Figure 88. Plan View of Hangar Deck

Damage Control Deck:

The damage control (DC) deck is located directly below the hangar deck. It is a 3-meter deck designed for personnel. Two main longitudinal passageways, two meters in width to allow passage of medical equipment, are located inboard of the main longitudinal bulkheads. Central weapons elevator transition spaces require the full width between longitudinal bulkheads so the passageways shift outboard of the longitudinal bulkheads for two compartment lengths amidships. This jog is utilized as airlocks between CPS zones. The mess spaces are located just forward of amidships for the best motions. All messing spaces are grouped using the centralized galley concept described in the US Navy habitability criteria. Medical spaces are located just aft of amidships and are accessible from both major passageways. Command and Control is centrally located forward of the messing spaces. This large space is designed to centralize many of the diverse ship functions, specifically ship operations with aviation operations. Damage control lockers are located one per CPS zone with DC central located to starboard at amidships. The DC deck does not extend all the way aft in order to accommodate full height auxiliary spaces aft of the final transverse bulkhead. Figure 89 shows the plan view of the damage control deck where the heavy lines represent CPS zones and longitudinal bulkheads.

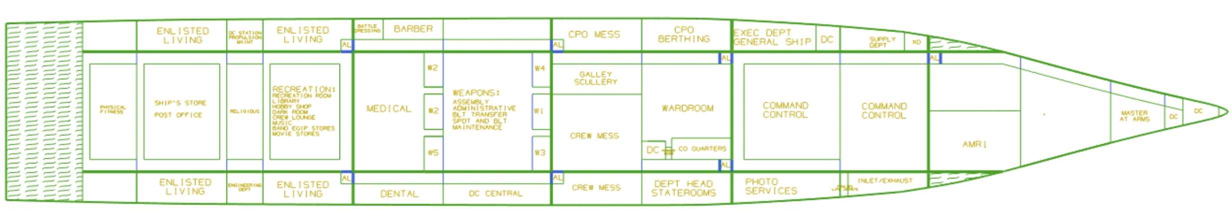

Figure 89. Plan View of Damage Control Deck

Accommodations Deck:

The accommodations deck, shown in Figure 90, is also a 3-meter deck, located beneath the DC deck, making it the first deck without provisions for passage through transverse bulkheads. The avionics and other repair shops of the ship are located in the spaces interrupted by weapons elevators in order that material may be transported to these spaces using the elevators. The remainder of the deck is a mixture of Enlisted and Officer berthing spaces. The garage for the ship's two rigid inflatable auxiliary boats is located aft on the port side. The accommodations deck is coincident with the waterline allowing effective launch and recovery of the ship's boats. Other vessels with a similar garage approach have shown the system to be functional even in high sea states. Traditional cranes were an impossible RCS problem. The aft starboard area is a pump room, which services the aft main machinery room as well as general ship services. Immediately forward of this are the laundry facilities.

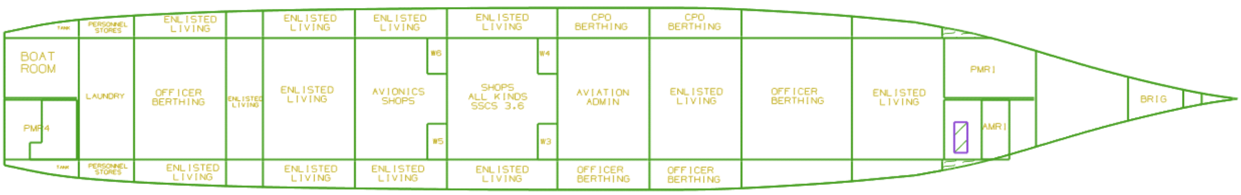

Figure 90. Plan View of Accommodations Deck

Machinery Deck:

The lowest deck of the CUVX, shown in Figure 91, extends from one meter above the baseline to the accommodations deck, a total height of six meters. Forward is MMR1, which houses two of the three ICR prime movers. The forepeak houses the anchor and its chain and handling gear. Amidships are the magazines. This location is ideal from a weapons elevator perspective; separation was not deemed necessary on the assumption that a casualty in either space would cause the loss of the ship. Food storage is located forward of the magazines, directly below the galley space. The main propulsion motors are located aft of the magazines and separated longitudinally for survivability. The volume outboard of the longitudinal bulkheads is used as tankage.

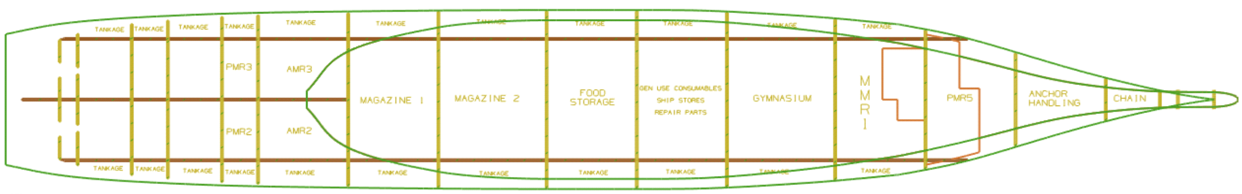

Figure 91. Plan View of Machinery Deck

Deckhouse:

The deckhouse has two 3-meter decks. The upper of the two includes the bridge, chart room and the Captain's sea cabin. The lower level will house the meteorological and visual communication department. Figure 92 shows the plan view of the deckhouse decks, where the bow of the ship is pointing to the left. The captain's sea cabin and the chart room are not shown in these plan views.

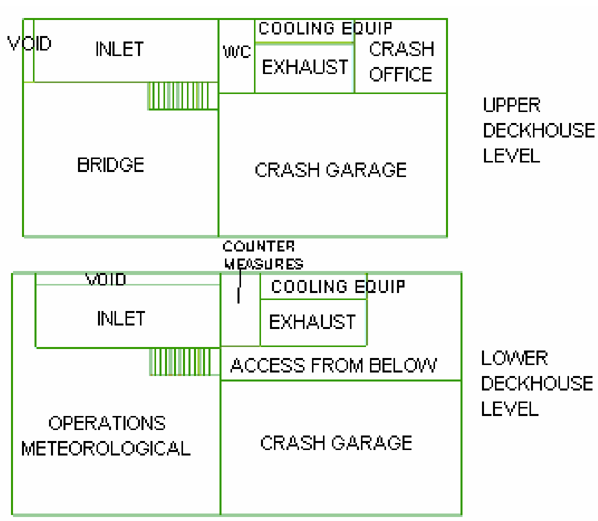

Figure 92. Plan View of Deckhouse Decks

Habitability:

Accommodations, shown in Figure 93 and Figure 94, were based on the 1994 Navy Habitability Criteria. There is ample space on CUVX after this first design iteration to make the accommodations more lavish. Likewise they were designed to accommodate the original crew size of 916 defined in the Ship Synthesis Model. The final crew size is actually smaller by 225 people, down to 691 people. However, the ship will accommodate 916 people since the loss of crew is dependant upon automation. As more automation is used on CUVX, fewer men are needed. If the automation is found to be unsatisfactory, then more people can be added to replace the troublesome robots. A sample crew berthing space and group of double officer staterooms are shown below.

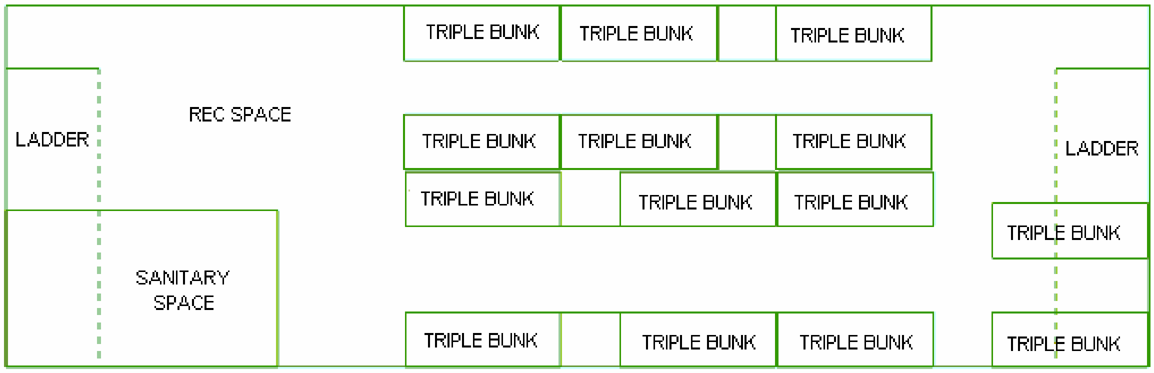

Figure 93. Sample Crew Quarters

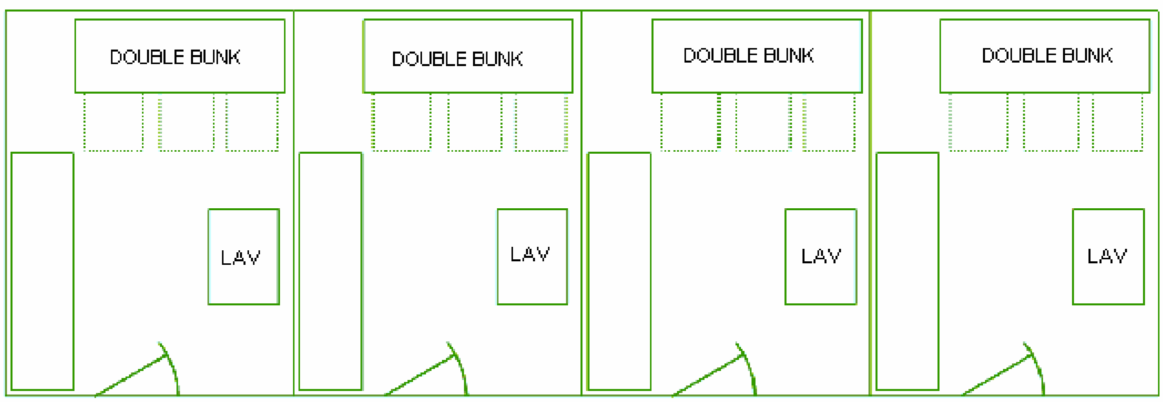

Figure 94. Plan View of Double Occupancy Officer Staterooms

4.8.4 External Arrangements

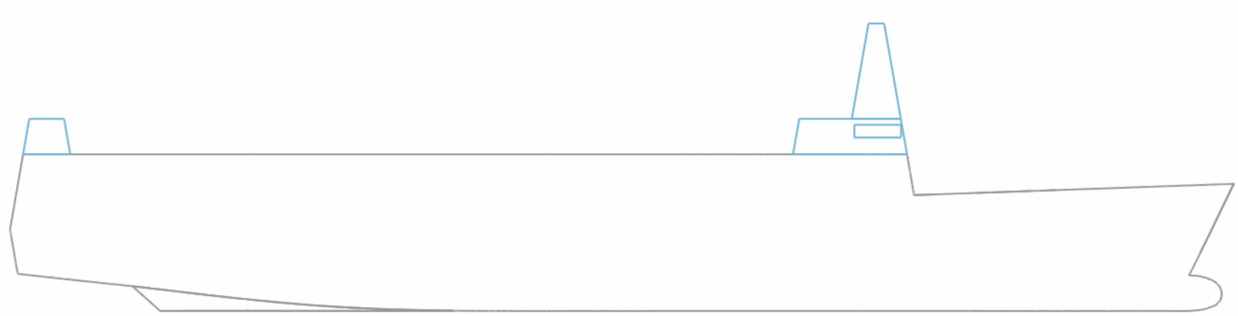

Figure 95. Outboard Profile View showing external arrangements

The primary considerations in external arrangements were aviation operations and minimizing RCS. The parent hull form was extended vertically from 46m aft of the FP to create the recovery deck space. Deckhouses were created using 10° rectangular pyramids. The forward and aft deckhouse configuration was chosen in order to facilitate inlet and exhaust from the prime movers, which are separated longitudinally. The bridge is located on the second of two personnel levels located in the forward deckhouse. This location provides excellent visibility. The vertical extension of the forward deckhouse is an unmanned advanced enclosed mast structure housing rotating radar arrays. The 10° slope of the deckhouses, and any other exterior structures, was chosen based on expert opinion. The anchor is of the mushroom type and is retracted into the hull near the bulbous bow. This system will be similar to that used on ballistic missile submarines. RCS considerations excluded the use of traditional bow anchors.

The chief compromise to the RCS is the CIWS. Our requirements specified two CIWS units. In order to ensure adequate coverage one unit needed to be placed forward to port and the other aft and starboard. These units will also be housed in trapezoidal structures similar to the deckhouse in order to make the best of a difficult design situation. The other alternative was to place the units at the top of the forward deckhouse; this was deemed to great a weight penalty, maintenance problem, and reduction of the unit's capability to detect surface skimming threats.

Flat panel communications arrays are located on the aft deckhouse. CUVX has two peripheral vertical launch missile cells. These are both placed to starboard but separated longitudinally. It was deemed too great a risk place one cell at the edge of the recovery strip. CUVX itself is lightly armed and has no deck gun, which greatly aided in the topside design.

Exhaust is accomplished through the top of the aft deckhouse and the top of the rear section of the forward deckhouse. The height of these stacks are limited to the present values in order to ensure there are no blind spots in the field of view of the rotating radars housed in the enclosed mast.

Recovery Deck:

Central to aviation operations is the recovery deck. Its recovery strip must be large enough, and free of hazards, to allow the effective recovery of aircraft in all operating environments. The recovery strip is 151.2m long and 15.6m wide. It was placed to port in accordance with US Navy tradition. Aircraft elevators were sized to accommodate two folded UCAV's or LAMP's. They are 21m long and 11m wide. All associated machinery is contained within the structure of the elevator platforms, so they could be placed 1m from the deck edges and main transverse bulkheads. The elevators needed to be separated longitudinally for survivability purposes. They are not separated transversely in order to allow an unobstructed recovery strip in the event of elevator malfunction, where an elevator is not able to remain in the up position. Internal elevators are used for RCS considerations; the survivability and space consequences are necessary in order for the ship to be able to perform the ship's primary mission of low observable operations. A parking space sufficient for a single UCAV is provided forward of Elevator 1. Many more UCAV's may be accommodated parked on the recovery deck but will be much closer to landing aircraft than is likely reasonable for normal operations.

Given the nature of the autonomous control system of the UCAV's, namely that pilot confidence is not an issue, only two arresting cables will be installed on the ship. The UCAV's will aim to pick up the first cable with the second as a backup. A control system will also be installed on the UCAV arresting hook to prevent skipping over the arresting wire. A plan view of the recovery deck can be seen below in Figure 96.

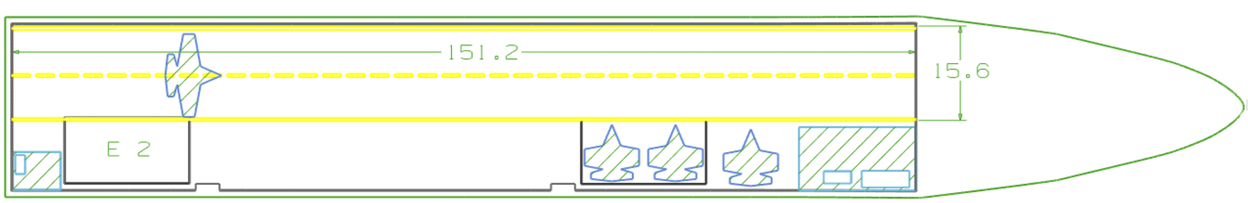

Figure 96. Plan View of Recovery Deck

4.9 Weights and Loading

4.9.1 Weights

After arranging the permanent equipment in CUVX the light ship center of gravity is found for stability and trim calculations. To do this, weights of all equipment are found and organized in a spreadsheet by SWBS groups. This spreadsheet is shown in **table**. The locations of the centers of gravity of each piece of equipment are also present in this table. The vertical distance was measured from the baseline of the ship. The longitudinal distance was measured from the forward perpendicular aft. The transverse distance was measured from the centerline of the ship with starboard positive. A summary of the weights spreadsheet including only lightship weights is in Table 51.

Table 51. Lightship Weight Summary

SWBS	Weight (MT)	VCG (m)	LCG (m)	TCG (m)
100	11062.59	10.18	105.69	0.10
200	526.80	8.48	94.17	1.28
300	733.81	14.81	105.64	0.97
400	407.86	17.64	92.29	2.66
500	5600.87	12.85	100.24	-0.41
600	1761.20	9.21	106.05	0.00
700	40.34	13.45	133.99	0.00
Total	20133.46	11.12	103.69	0.06

4.9.2 Loading Conditions

4.9.2.1 Full Load

For the full load condition the diesel fuel marine (DFM) and JP5 tanks were taken to be 95% full. The ballast was taken to be zero and all other loads were taken to be the maximum value. The individual loads can be seen in Table 52 and the trim conditions resulting from this loading are shown in Table 53.

Table 52. Weight Summary: Full Load Condition

Label	Identification	Weight (MT)	VCG (m)	LCG (m)	TCG (m)
F00	LOADS	5083.70	6.40	83.68	-0.28
F10	SHIPS FORCE	88.17	15.98	105.00	0.00
F21	SHIP AMMUNITION	26.64	2.50	117.00	0.00
F22	ORD DEL SYS AMMO	13.95	2.50	117.00	-6.00
F23	ORD DEL SYS (AIRCRAFT)	360.60	17.00	105.00	0.00
F26	LAMPS MKIII AVIATION SUPPORT AND SPARES	9.57	20.00	190.00	0.00
F29	BATHYTHERMOGRAPH PROBES	0.20	20.00	190.00	0.00
F31	PROVISIONS+PERSONNEL STORES	258.69	11.43	110.00	0.00
F32	GENERAL STORES	79.28	11.35	110.00	0.00
F41	DIESEL FUEL MARINE	1321.00	9.99	64.17	0.00
F42	JP-5	1808.00	4.04	104.81	0.00
F46	LUBRICATING OIL	17.60	2.00	150.00	0.00
F47	SEA WATER	500.00	0.00	0.00	-2.70
F52	FRESH WATER	600.00	0.50	96.00	0.00

Table 53. Trim Summary: Full Load Condition

Item	Value
FP Draft	6.923 m
AP Draft	7.074 m
MS Draft	6.998 m
LCB (even keel)	100.51 m-Aft
LCF	114.025 m-Aft

MT1cm	601 m-MT/cm
Trim	0.151 m-Aft
Prop Immersion	145%
List	0.01 deg-STBD

4.9.2.2 Minimum Operating Load

The minimum operating load was defined based on DDS 079-1. These guidelines require that for minimum operation, diesel fuel marine, ship ammunition, aircraft ammunition, personal stores, general stores, lube oil, and the JP5 be at 1/3 of the full load condition and the potable water must be at 2/3 of the full load amount. Since CUVX has compensated fuel tanks the seawater ballast is taken to be the difference in volume of diesel fuel marine and JP5 between the full load and minimum operating load replaced with seawater. The minimum operating loads can be seen in Table 54 and the trim conditions corresponding to these loads can be seen in Table 55.

Table 54. Weight Summary: Minimum Operating Load Condition

Label	Identification	Weight (MT)	VCG (m)	LCG (m)	TCG (m)
F00	LOADS	4446.84	6.35	100.53	-0.33
F10	SHIPS FORCE	88.17	15.98	105.00	0.00
F21	SHIP AMMUNITION	8.88	2.50	117.00	0.00
F22	ORD DEL SYS AMMO	4.65	2.50	117.00	0.00
F23	ORD DEL SYS (AIRCRAFT)	360.60	17.00	105.00	0.00
F26	LAMPS MKIII AVIATION SUPPORT AND SPARES	9.57	20.00	190.00	0.00
F29	BATHYTHERMOGRAPH PROBES	0.20	20.00	190.00	0.00
F31	PROVISIONS+PERSONNEL STORES	86.23	11.43	110.00	0.00
F32	GENERAL STORES	26.43	11.35	110.00	0.00
F41	DIESEL FUEL MARINE	440.33	4.29	127.32	0.00
F42	JP-5	602.67	8.34	78.72	0.00
F46	LUBRICATING OIL	5.87	2.00	150.00	0.00
F47	SEA WATER	2413.24	5.78	100.00	-0.60
F52	FRESH WATER	400.00	0.50	96.00	0.00

Table 55. Trim Summary: Minimum Operating Load Condition

Item	Value
FP Draft	6.733 m
AP Draft	6.824 m
MS Draft	6.779 m
LCB (even keel)	99.89 m-Aft
LCF	113.21 m-Aft
MT1cm	582 m-MT/cm
Trim	0.091 m-Aft
Prop Immersion	140%
List	0.01 deg STBD

4.10 Hydrostatics and Stability

4.10.1 General

HECSALV software is used to analyze the intact and damage stability for CUVX. Light Ship, Full Load, and Minimum Operating conditions are analyzed using the software and previously calculated Hydrostatic Curves, Cross Curves, and Bonjean curves. All criteria are met for these cases in intact and damage stability.

4.10.2 Intact Stability

The static righting arm curves are shown below for light ship, full load and minimum operating conditions in Figure 97, Figure 98, and Figure 99, respectively. The static stability summary for each condition is summarized in Table 56. The static stability curves are required to meet U.S. Navy Design Data Sheet DDS 079-1.

Table 56. Static Stability Summary

Item	Light Ship	Full Load	Min Op
Weight (MT)	22147	26722	25639
KMt (m)	16.125	15.536	15.664
VCG (m)	11.120	10.474	10.679
LCG (m)	103.330	101.195	100.482
TCG (m)	0.060S	0.050S	0.052S
GMt	5.005	5.056	4.985
F.S. Correction (m)	0.000	0.032	0.632
GMt Corrected	5.005	5.024	4.353

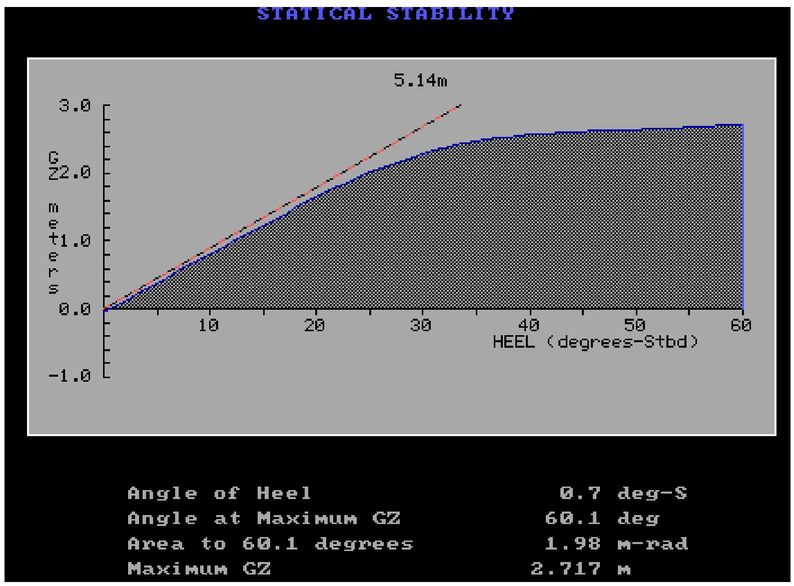

Figure 97. Light Ship Righting Arm Curve

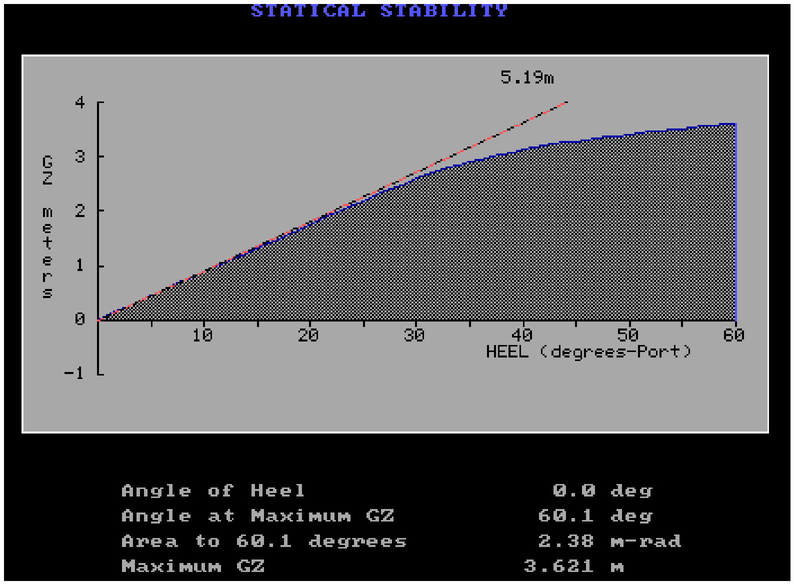

Figure 98. Static Full Load Righting Arm Curve

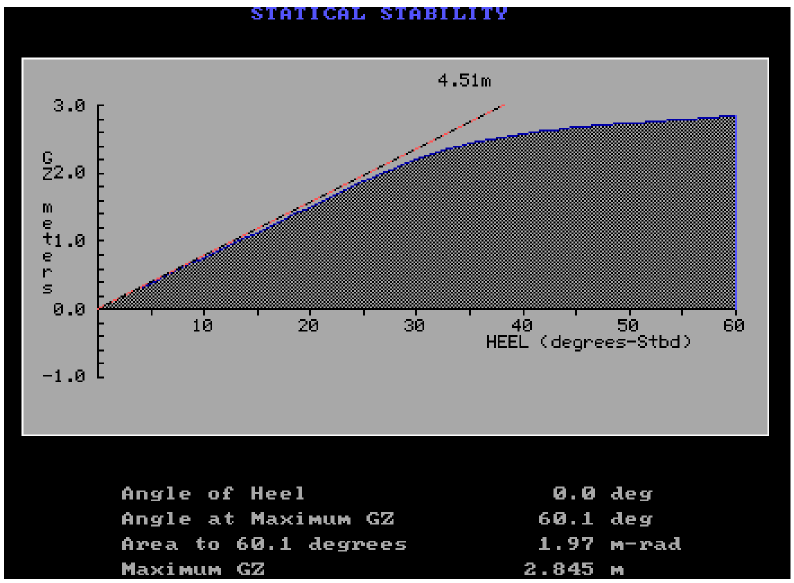

Figure 99. Static Minimum Operation Righting Arm Curve

The DDS 079-1 Beam Wind and Rolling criteria are used as the limiting case for the Intact Loading cases. In order for the ship to be considered satisfactory in this case, the wind and roll must be considered to be acting simultaneously. This is expected for high velocity winds producing considerable waves. HECSALV uses the wind velocity, reference draft for the projected sail area, projected sail area above the reference draft, and the vertical center of the sail area above the base line to analyze this case. These parameters are shown below in Table 57.

Full load and minimum operating conditions are analyzed for beam wind and rolling stability. Light ship is not analyzed because the ship will not be operating at sea in this condition. The full load condition consists of fuel at maximum volume and a full weapons load out. The minimum operating condition consists of fuel at one third maximum volume and one third full weapons load out.

Table 57. Stability Constant Summary

Parameter	Value
Wind Velocity	100 knots
Reference Draft	7 m
Projected Sail Area	3900 m^2
Center of Sail	16.75 m

All requirements for both the full load and minimum operating conditions are met as shown in Figure 100 and Figure 101. These requirements include that the intersection of the righting are and healing arm curves is no greater than six-tenths of the maximum righting are. It is also required that the area between the two curves to the right of the intersection must not be less than 1.4 times the area between the curves to the left of the intersection.

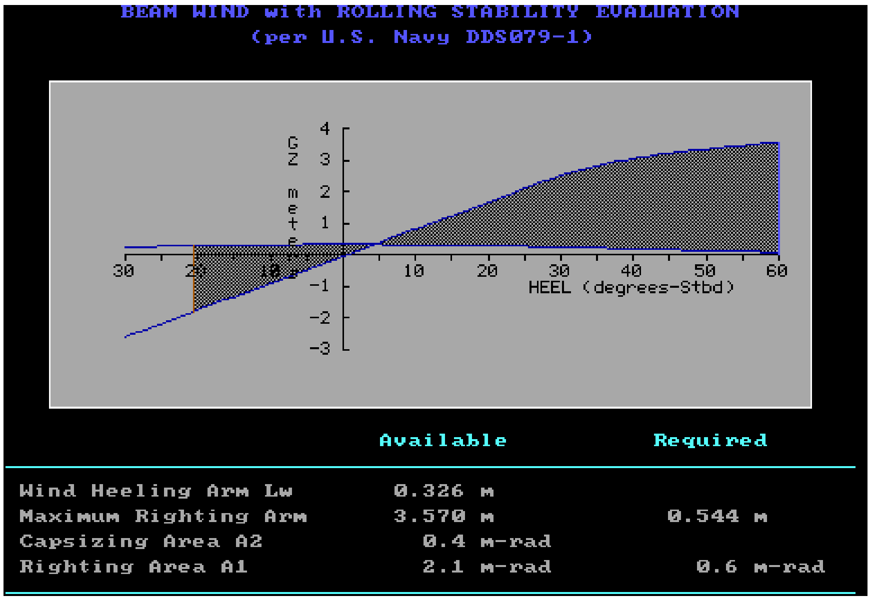

Figure 100. Full Load Beam Wind with Rolling

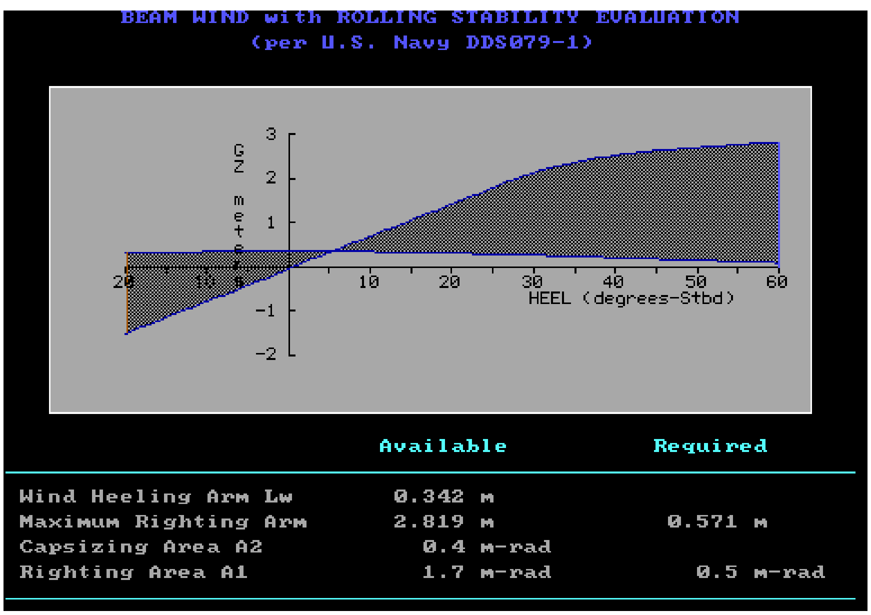

Figure 101. Minimum Operations Beam Wind with Rolling

4.10.3 Damage Stability

Full load and minimum operating conditions are both checked for damage stability using HECSALV. DDS 079-1 dictates that a ship of length greater than 300 ft must survive damage to 15% of the length of the ship. Twenty three damage cases are analyzed for each loading condition in which a 30 m portion of the ship is damaged. The cases are run assuming damage to the starboard side of the ship. Twelve cases are run with the starboard longitudinal bulkhead intact, and eleven with it destroyed. The damage runs complete from the baseline through the recovery deck. The two worst damage cases for each loading condition are shown below. The remaining cases can be seen in Appendix D.3 Damage Stability.

The worst case damage scenarios for full load are shown below in Table 58 and Table 59, as well as in Figure 102 thru Figure 105. In Damage Case 3B, flooding occurs on the starboard side of the ship between the four most forward bulkheads with the starboard longitudinal bulkhead being destroyed. This leads to an extreme trim by the bow of 11.133 m. Damage Case 7 includes starboard flooding between bulkheads 9 and 11 with the starboard longitudinal bulkhead remaining intact. This leads to an extreme static heel angle of 5.1ºS. All damage cases for the full load condition meet the requirements of DDS 079-1.

Table 58. Full Load Damage Case 3

	Intact	Damage
Draft AP (m)	7.074	3.823
Draft FP (m)	6.923	14.956
Trim on LBP (m)	0.151A	11.133F
Total Weight (MT)	25943	36017
Static Heel (deg)	0.0S	1.6P
Wind Heel (deg)	3.8	5.5P
GMt (upright) (m)	5.191	4.297
Maximum GZ		4.410
Max.GZ Angle (deg)		60.1P
GZ Pos. Range (deg)		>58.4

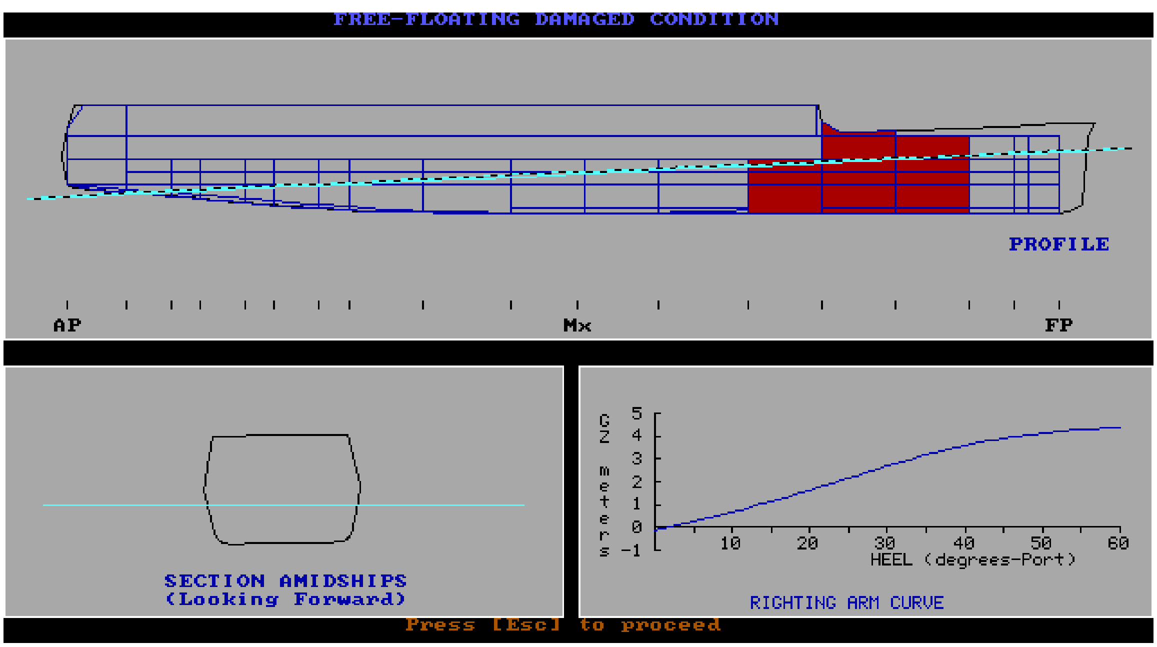

Figure 102. Full Load Damage Case 3

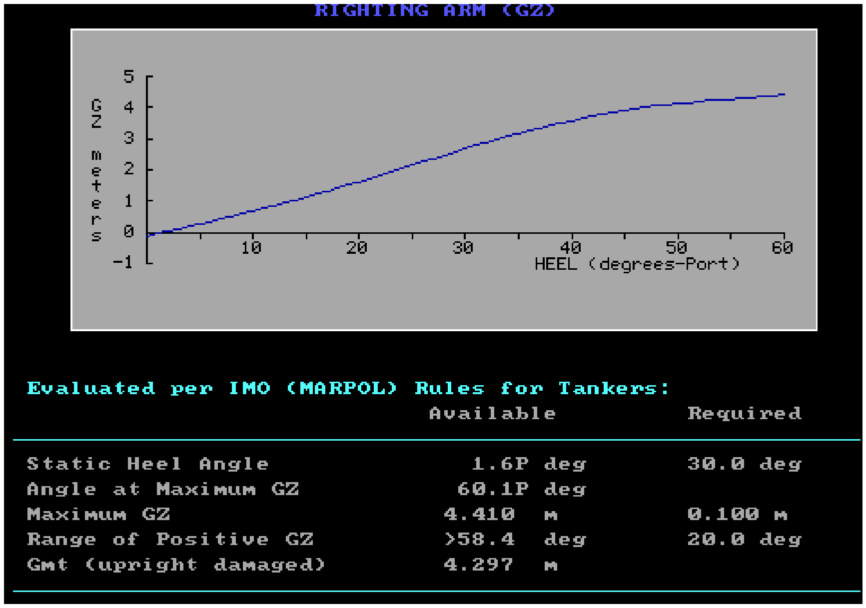

Figure 103. Righting Arm for Full Load Damage Case 3

Table 59. Full Load Damage Case 7

	Intact	Damage
Draft AP (m)	7.074	7.346
Draft FP (m)	6.923	7.076
Trim on LBP (m)	0.151A	0.270A
Total Weight (MT)	25943	27134
Static Heel (deg)	0.0S	5.1S
Wind Heel (deg)	3.8	10.6S
GMt (upright) (m)	5.191	1.724
Maximum GZ		3.903
Max.GZ Angle (deg)		60.1S
GZ Pos. Range (deg)		>54.9

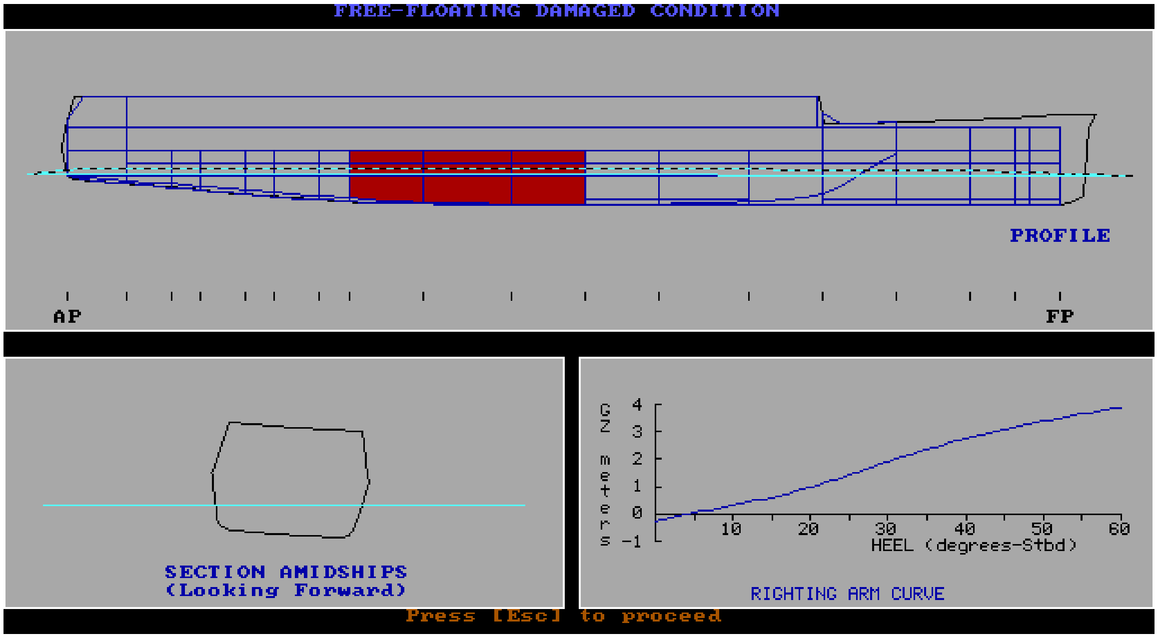

Figure 104. Full Load Damage Case 7

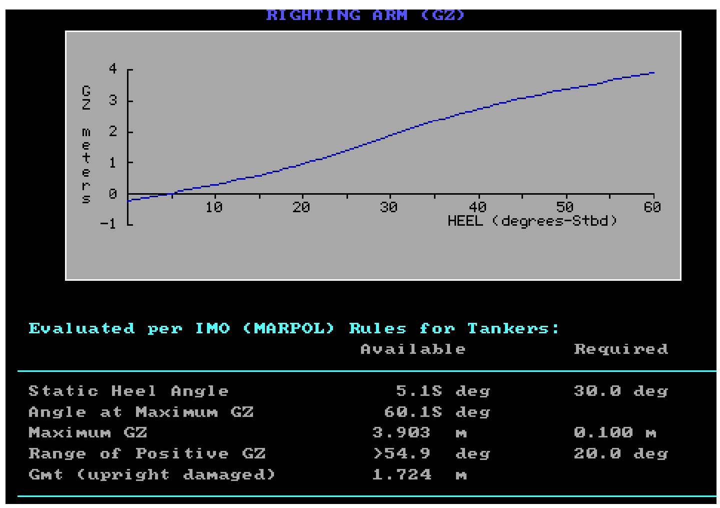

Figure 105. Righting Arm for Full Load Damage Case 7

The worst case damage scenarios for the minimum operating condition are shown below in Table 60 and Table 61, as well as in Figure 106 thru Figure 109. In Damage Case 3B, flooding occurs between the four most forward bulkheads with the starboard bulkhead being destroyed. This leads to an extreme trim by the bow of 11.417 m. Damage Case 7 includes starboard flooding between bulkheads 9 and 11 with the starboard longitudinal bulkhead remaining intact. This leads to an extreme static heel angle of 10.0ºS. All damage cases for the minimum operating condition meet the requirements of DDS 079-1.

Table 60. Full Load Damage Case 3B

	Intact	Damage
Draft AP (m)	6.824	3.418
Draft FP (m)	6.733	14.836
Trim on LBP (m)	0.091A	11.417F

Total Weight (MT)	24860	34796
Static Heel (deg)	0.0S	1.7P
Wind Heel (deg)	4.6	6.8P
GMt (upright) (m)	4.507	3.442
Maximum GZ		3.657
Max.GZ Angle (deg)		60.1P
GZ Pos. Range (deg)		>58.3

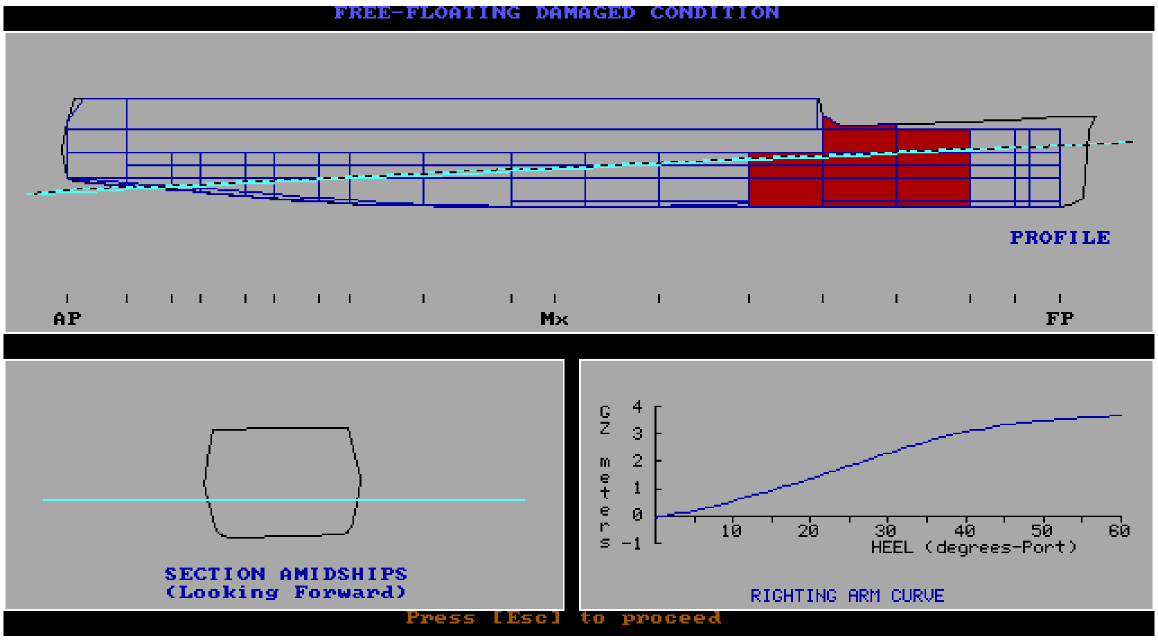

Figure 106. Full Load Damage Case 3B

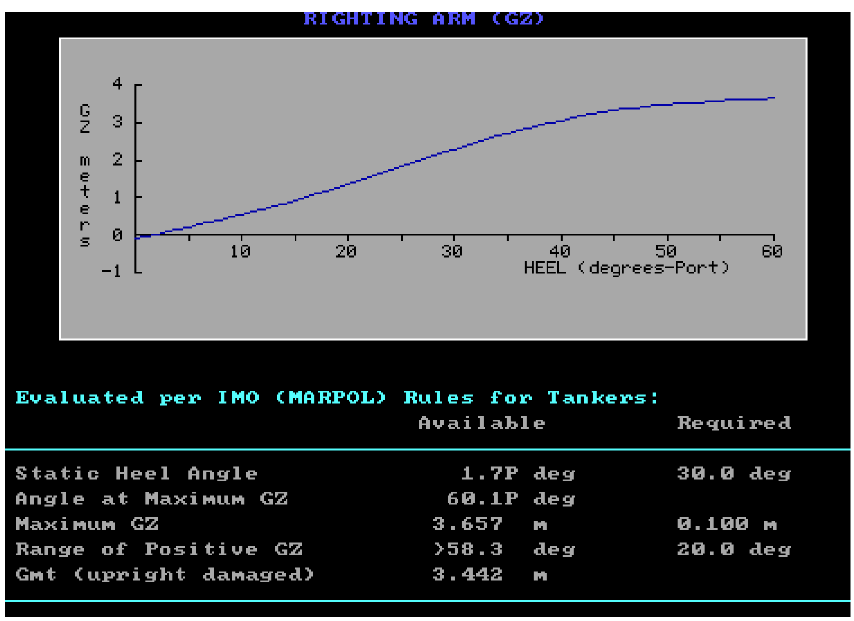

Figure 107. Righting Arm for Full Load Damage Case 3B

Table 61. Full Load Damage Case 7B

	Intact	Damage
Draft AP (m)	6.824	7.127
Draft FP (m)	6.733	7.109
Trim on LBP (m)	0.091A	0.018A
Total Weight (MT)	24860	26890
Static Heel (deg)	0.0S	10.0S
Wind Heel (deg)	4.6	17.1S
GMt (upright) (m)	4.507	2.598
Maximum GZ		3.126
Max.GZ Angle (deg)		60.1S
GZ Pos. Range (deg)		>50.0

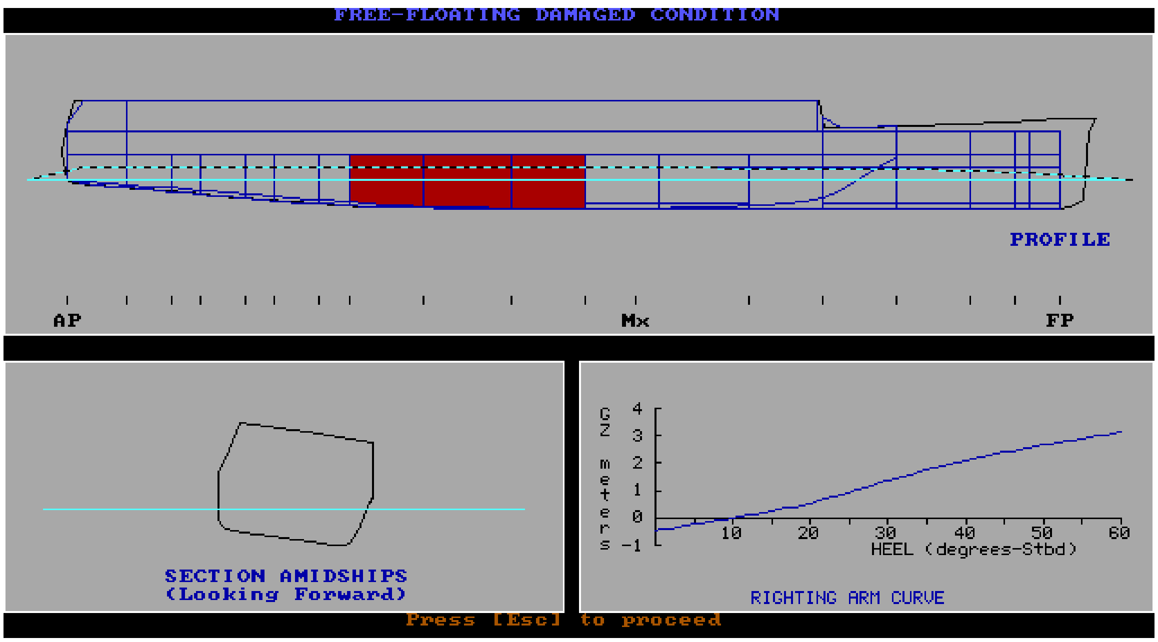

Figure 108. Full Load Damage Case 7B

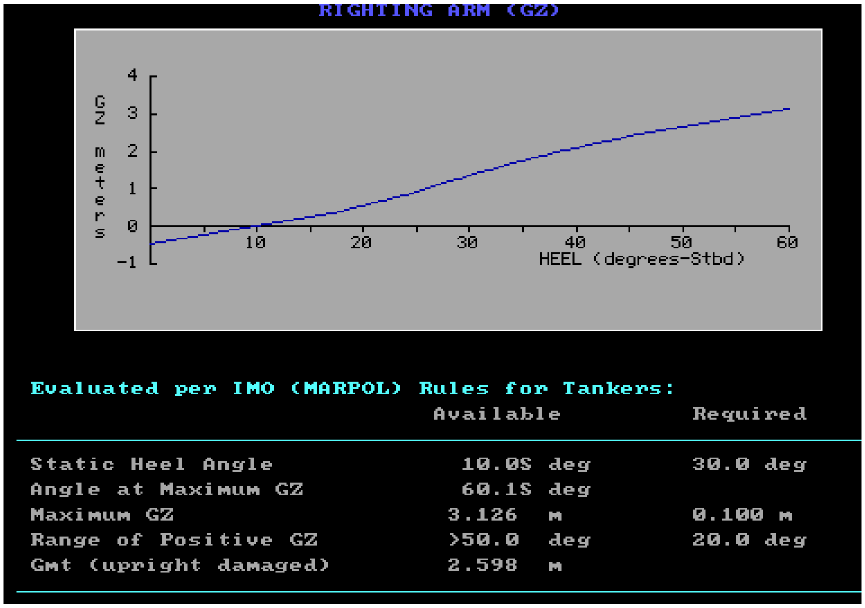

Figure 109. Righting Arm for Full Load Damage Case 7B

4.11 Seakeeping and Maneuvering

4.11.1 Seakeeping

The seakeeping analysis for CUVX was done with a six degree of freedom model using Visual SMP produced by Proteus Engineering. For use in the analysis six areas of the ship operations were considered: Personnel, ASW and ASuW, AAW, ISR and SEAD, Transit, Underway Replenishment (UnRep). For all of the above areas personnel limitations and transit limitations had to be met to allow for operation in the other areas. These areas were analyzed in sea states (SS) ranging from 3 to 7. For the analysis the sea states were taken to be as shown in Table 62.

Table 62. Sea States Used for Seakeeping Analysis

Sea State	Significant Wave Height (m)	Modal Period (sec.)
3	0.88	8
4	1.88	9
5	3.25	10
6	5	12
7	7.5	14

4.11.2 Personnel

Table 63. Personnel Performance Limitations

Motion	Limit	Location
Roll	8°	CG
Pitch	3°	CG
Vertical Acceleration	0.4g	Bridge
Lateral Acceleration	0.2g	Bridge

The requirements shown in Table 63 were to be met in SS7. Due to the poor roll performance of the ship and the location of the bridge, this was not achieved and should be addressed the next time around the design spiral. A dynamic roll stabilization system should be implemented to increase the range of operability of this ship. The requirements were able to be met in SS6 but only for a small area of operability. The polar plots are shown below for both SS6 and SS7. In all polar plots shown zero degrees indicates head seas.

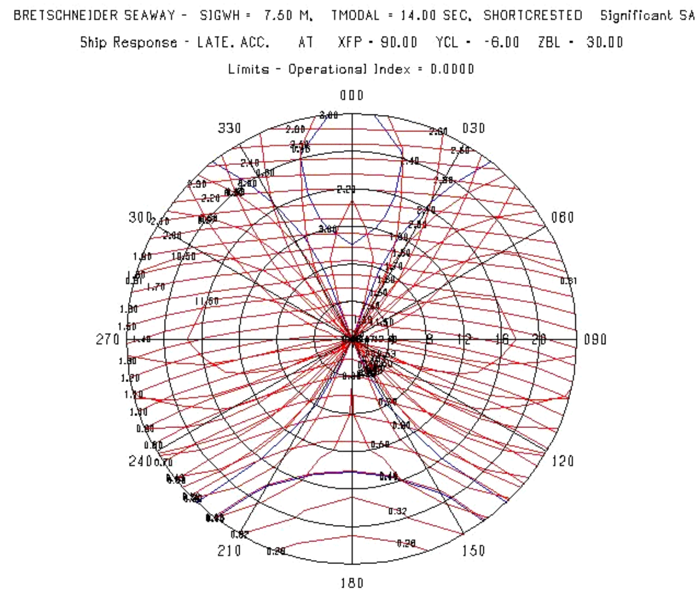

Figure 110. Polar Plot for Personnel Limitations in Sea State 7

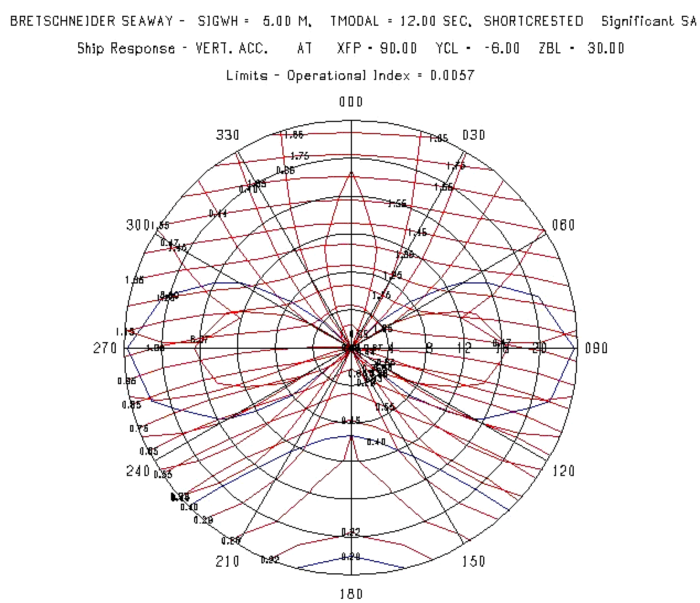

Figure 111. Polar Plot for Personnel Limitations in Sea State 6

4.11.3 ASW and ASuW

The analysis for AAW only considered the systems required for ASW and ASuW and not the personnel. Future trips around the design spiral will address the system issues separately from the personnel issues. The requirements for ASW and ASuW are shown in Table 64 and were required to be met in SS5. This was not accomplished. These requirements could be met in SS4 using the forward helicopter pad. The polar plot for the forward helicopter pad in SS4 is shown in Figure 112. The requirements using the aft helicopter pad could be satisfied in SS3 and the polar plot to verify this can be found in Figure 113.

Table 64. ASW and ASuW Performance Limitations

Motion	Limit	Location
Roll	8º	CG
Pitch	3º	CG
Vertical Velocity	2.5 m/s	Each Helo Pad

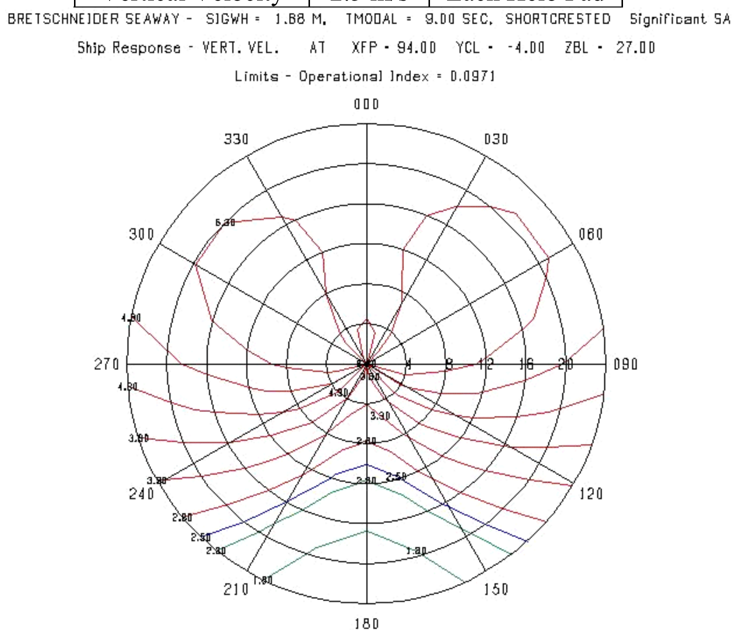

Figure 112. Helicopter Operations Using Forward Helicopter Pad in SS4

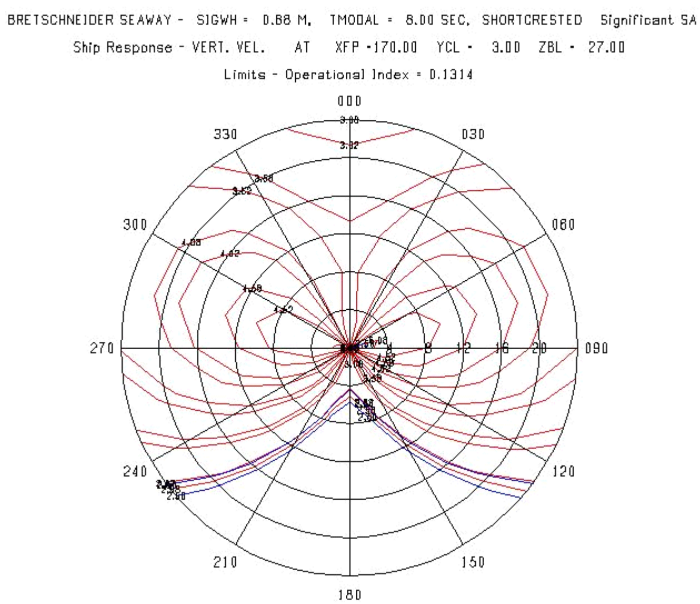

Figure 113. Helicopter Operations Using the Aft Helicopter Pad in SS3

4.11.4 AAW

The AAW analysis was of the ESSM VLS and did not include the personnel limitations. The requirements shown in Table 65 were required to be met in SS6. The forward VLS was able to meet these requirements in SS7.

Both the fore and aft VLS were able to meet these requirements in SS6. The polar plots for these conditions can be found in Figure 114 and Figure 115, respectively.

Table 65. Vertical Launch System Performance Limitations

Motion	Limit	Location
Roll	17.5º	CG
Pitch	3º	CG
Yaw	1.5º	CG
Vertical Acceleration	0.6g	Outboard Corner
Lateral Acceleration	0.7g	Outboard Corner
Longitudinal Acceleration	0.6g	Outboard Corner

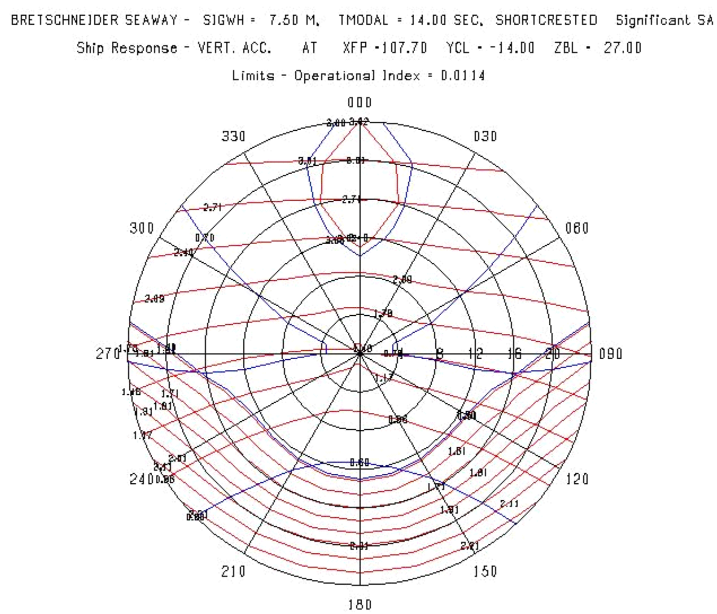

Figure 114. Forward Vertical Launch System in SS7

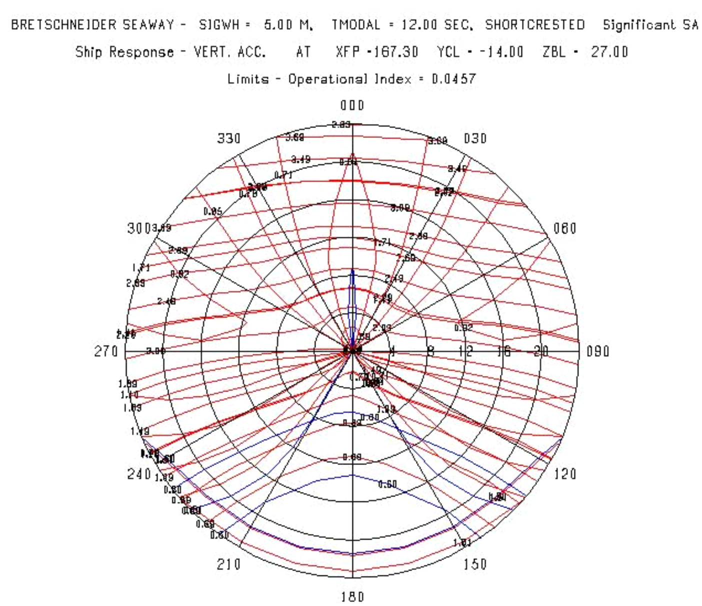

Figure 115. Forward and Aft Vertical Launch Systems in SS6

4.11.5 ISR and SEAD

The ISR and SEAD requirements correspond to UCAV operations. The analysis of UCAV operations did not include personnel limitations. The requirements for UCAV operations are shown in Table 66 and were required to be met in SS5. This requirement was not met. The highest sea state in which UCAV operations can be done is sea state 3. This is unacceptable and will have to be improved in the next time around the design spiral. The polar plot for UCAV operations in SS3 is shown in Figure 116.

Table 66. UCAV Performance Limitations

Motion	Limit	Location
Roll	8º	CG
Pitch	3º	CG
Vertical Velocity	2.5 m/s	TDP and Launch Point

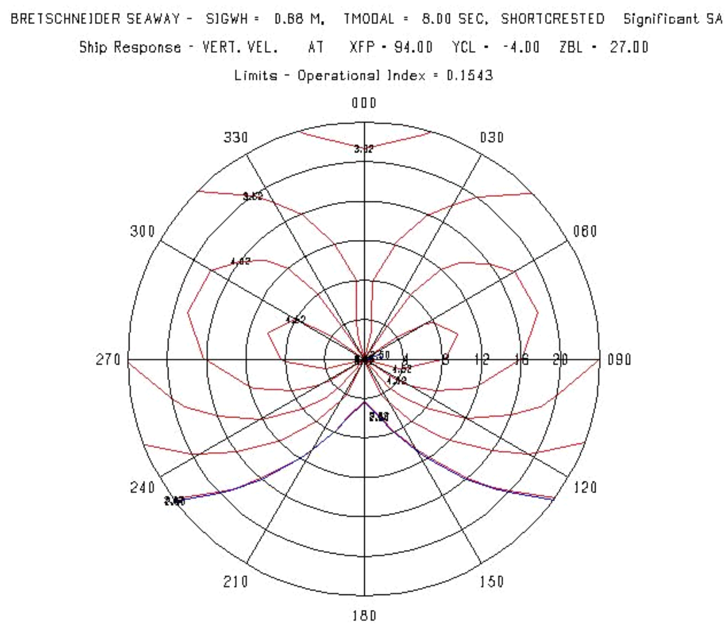

Figure 116. UCAV Operations in SS3

4.11.6 Transit

The transit analysis was based on slamming and bow immersion only and did not include personnel limitations. The requirements are shown in Table 67 and were met in SS7, which was required. The polar plot showing that the requirements were met can be found in Figure 117.

Table 67. Transit Performance Limitations

Motion	Limit	Location
Wetness (Bow)	30/hr	Bow STA 0
Slamming (Keel)	20/hr	Keel STA 3

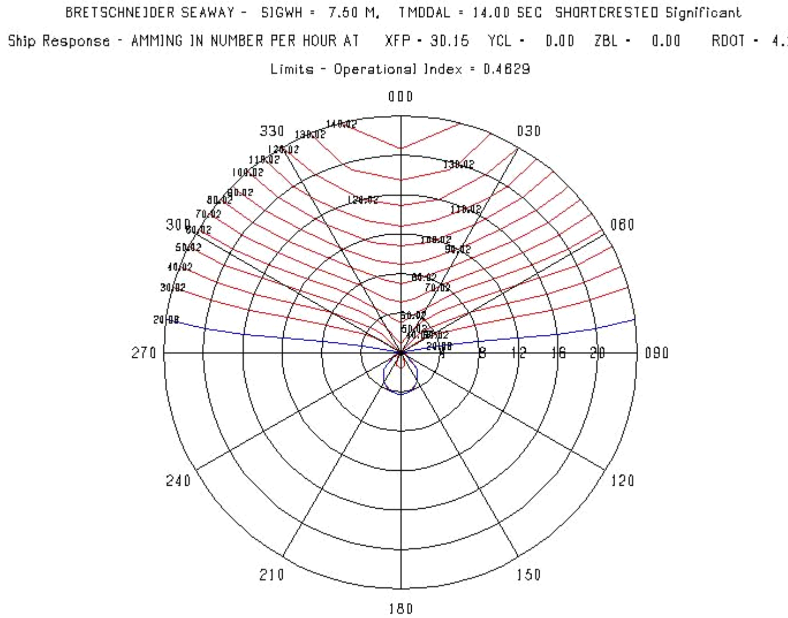

Figure 117. Polar Plot for Transit Performance Limitations in SS7

4.11.7 Underway Replenishment

The underway replenishment was based on roll and pitch angles and did not consider personnel. The requirements are shown in Table 68. They were only required to be met in SS5 but were able to be met up to SS6. The polar plot showing that the requirements were met in SS6 is shown in Figure 118

Table 68. Underway Replenishment Performance Limitations

Motion	Limit	Location
Roll	4º	CG
Pitch	1.5º	CG

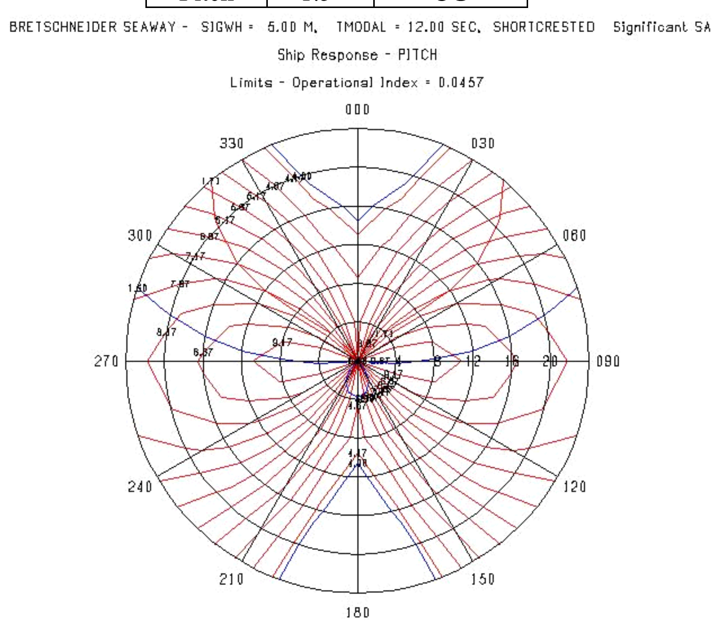

Figure 118. Polar Plot for Underway

4.12 Cost and Risk Analysis

4.12.1 Cost Analysis

Cost calculations for CUVX are regression based and use weight, power and manning to determine the lead ship and follow ship cost. These calculations are shown in Appendix C Operational Requirements Document. The components contributing to the manufactures portion of the cost of the ship are structure, propulsion, electric, command, control and surveillance, auxiliary, outfit armament, margin cost, integration, ship assembly and support. The integration and ship assembly and support costs for CUVX are reduced since CUVX is based on the LPD-17 hullform which is already being produced. Structure, electric, auxiliary, outfit, armament, and margin cost are all based on their respective weights. The command control and surveillance costs are all based on manning. The margin included in the analysis accounts for additional cost due to design error, added equipment and added cost common in production. There is an additional portion of the total lead ship acquisition cost which is due to the government portion. The government portion includes ordnance and electrical GFE, and outfitting costs. The ordnance and electrical GFE include the military payload.

The cost for the follow ship is based on a learning curve. Each time a ship is built the manufacturer becomes more efficient at producing that type of ship. The follow ship cost calculation also accounts for inflation based on the inflation rates in the previous years. The lead ship acquisition cost and the follow ship cost are shown in Table 69. The table shows two categories for the CUVX concept where one accounts for automation and the other does not account for automation. CUVX without manning uses the compliment manning estimate of 691 to calculate the total acquisition costs. CUVX with manning assumes that no automation is used throughout the ship and this corresponds to the 916 man estimate. As we add more men to the ship and decrease the amount of automation, the cost of the ship starts to increase slightly. In this case, it can be seen why automation would benefit CUVX. If the automation happens to work on CUVX, and as more technologies are updated and developed, the life cycle cost of CUVX can potentially decrease.

Table 69. Cost Comparison

Cost Type	CUVX w/out Manning ($ mil)	CUVX w/ Manning ($ mil)
Total Lead Ship Acquisition	937.86	952.00
Total Follow Ship Acquisition	761.09	774.75

4.12.2 Risk Analysis

The risk associated with the CUVX concept design, determined by the overall measure of risk, OMOR, is based on three main areas: cost, schedule, and performance. Each of these areas has several contributing components of the ship that factored into the total risk. For this design, the cost risk is associated with AAW, IPS, the type of hull form, and EMALS. Each of these factors has an associated risk that is shown in Table 70. Schedule risk also has these same factors, which are shown in Table 71. The factors for performance risk include AAW, range, reliability, damage stability, strike, and SEAD. The risk associated with performance is shown in Table 72.

Table 70. Cost-based Risk Factors

Cost	Risk
AAW	0.08
IPS	0.18
Hull Form	0.00
EMALS	0.30

Table 71. Schedule-based Risk Factors

Schedule	Risk
AAW	0.04
IPS	0.09

Hull Form	0.00
EMALS	0.20

Table 72. Performance-based Risk Factors

Performance	Risk
AAW	0.15
Range	0.00
Reliability	0.16
Dynamic Stability	0.00
Strike	0.36
SEAD	0.32

These risk assessment values are then added up and divided by the total possible risk for each of the three areas. The OMOR is then calculated by added the risk associated with each area multiplied by their weighting factors and then divided by the total manning factor. Therefore as manning decreases, the overall risk increases. The weighting for each area is as follows: 0.5 for performance, 0.3 for cost, and 0.2 for schedule. The OMOR for the concept with no automation was found to be 0.169. By using automation, the risk increases to 0.182. Since CUVX has enough accommodation spaces for 916 men, but is scheduled to carry 691 men, a risk mitigation schedule is adopted. If the automation of CUVX turns out to do more harm than good, then more men could be added to do the jobs of the robots. However, if the automation works out well, then the extra accommodation spaces could be utilized for more aircraft, fuel or weapons, thereby increasing the effectiveness of CUVX.

5 Conclusions and Future Work

5.1 Assessment

Table 73 outlines the major specifications for CUVX as required by the ORD. This table also shows the actual design specifications as developed for the ship. The majority of the key specifications are met by the CUVX design, including the aircraft complement as well as endurance range and speed. Some requirements such as displacement and draft are not met, but future iterations of the design spiral would most likely achieve these goals. Automation aided in reducing the manning numbers in order to meet and surpass the manning requirements.

Table 73. Compliance with Operational Requirements

Requirement	Specification	CUVX HI2
Number of UAVs	20	20
Number of UCAVs	30	30
Number of LAMPS	4	4
Aircraft Fuel Capacity	2005.0 m^3	2040.0 m^3
Endurance Range	4000 nm at 20 knots	4000 nm at 20 knots
Endurance Speed	20 knots at 100% MCR	20 knots at 100% MCR
Sustained Speed	24.63 knots at 100% MCR	24.5 knots at 100% MCR
Full Load Draft	6.938 m	6.998 m
Depth	26.63 m	26.63 m
Beam	29.54 m	29.54 m
Δ (MT)	25730 MT	26722 MT
Lightship Δ (MT)	20910 MT	22147 MT
Manning	917	691
Lead-Ship Acquisition Cost	937.1 Million dollars	937.86 Million dollars
Follow-Ship Acquisition Cost	760.3 Million dollars	761.09 Millions dollars
Risk	0.169	0.169

5.2 Next Time Around Design Spiral

There are a few major changes that should be made to CUVX in the next iteration through the design spiral. The following areas merit further consideration.

5.2.1 Hull Form, Appendages and Deckhouse

In future iterations of the design process, it will be possible to further optimize the hullform for CUVX. More in depth analyses of the tankage and space requirements will lead to more precise requirements for the hullform. If these requirements change significantly, then the volume of the hullform can be increased or decreased accordingly. The hullform can also be changed to better satisfy the seakeeping requirements. Appendages can be added or modified to produce a more seaworthy ship in rough water. This would greatly help in aircraft operations when a steady ship is desired. A more seaworthy ship can be attained through optimization of the bilge keels as well as the exploration of active stabilization, similar to stabilizing fins used on cruise ships. It might also be possible to further optimize the deckhouse in future iterations of the design spiral. As more precise requirements for space are developed, the area enclosed by the deckhouse can be decreased or increased as a result.

5.2.2 Structural Design and Analysis

MAESTRO performs structural analysis on the model by using a deterministic approach which optimizes the hull structure based on an ultimate bending moment criteria. It does not account for the cyclic dynamic loads which lead to fatigue caused failures. Rationally based statistical design methods would be very useful in accounting for fatigue life issues which are important to this design. The MAESTRO structural analysis is sufficient for the first trip around the design spiral; however, statistical structural analysis methods would mitigate the risk of hull failure during the ship's service life. The current MAESTRO model also requires optimization of the structural effectiveness to reduce weight.

For the structure there are multiple things that need to change in order to account for the fact that this ship will accommodate the launching and recovery of aircraft. The recovery deck and launch deck, where the EMALS are located, need to have thicker plating as well as more accommodating girders.

5.2.3 Power and Propulsion

Model testing of CUVX would provide the design with far more accurate resistance data compared to regression-based methods. Propellers could also be optimized more accurately for our ship, as opposed to using the existing fixed pitch propellers of LPD-17. Other propulsion alternatives could have been reviewed more closely to provide the most optimum operating conditions for propelling CUVX through the water.

5.2.4 Mechanical and Electrical Systems

A more in-depth electrical analysis could be performed to assure that enough power is provided to CUVX under different operating conditions. After the electrical analysis is reviewed in-depth, the prime movers could be better picked to ensure enough power is provided to the ship without having too much excess power. If more time were permitted, every mechanical system could be optimized for its purpose to fully optimize the final concept design.

5.2.5 Mission Systems

The main changes in mission systems will serve the purpose to either reduce the manning or increase the operation area for aircraft operations. This may include increasing the level of automation through out the range of aircraft operations, such as a completely automated fueling system. Some changes in the arrangements and flow for aircraft operations may result from changes in the location of certain activities such as helicopter launch and recovery to be able to perform helicopter operations in higher sea states. Changes in the other mission systems such as radars are not foreseen.

5.2.6 Manning

To improve the manning numbers, a more in depth analysis can be done in the next time around the design spiral. In this breakdown, each person's position on the ship can be defined in order to fill all necessary posts and to avoid assigning too many personnel. A more thorough investigation of automation can also help to increase the accuracy of the manning number. Knowing to what extent the ship will be automated is also a very important factor in determining the manning.

5.2.7 Space and Arrangements

Tankage, as is, fulfills all requirements. It provides enough fuel for the ship and aircraft, as well as enough fresh water for the ships personnel. The tankage is located ideally in order to reduce trim and heel. In the second time around the design spiral, tankage only needs to be reconsidered if the weights on the ship are adjusted, or the tankage requirements change.

5.3 Conclusion

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Appendix A – Mission Need Statement

MISSION NEED STATEMENT

FOR

UNMANNED COMBAT AIR VEHICLE CARRIER (CUVX)

1. DEFENSE PLANNING GUIDANCE ELEMENT.

The Department of the Navy's 1992 white paper, "From the Sea", outlined a significant change in priorities from a "Blue Water Navy fighting a traditional Super Power". The rapidly changing global political climate prompted the Department of the Navy to publish a revised white paper, "Forward From the Sea", in December 1994. Most recently, the Quadrennial Defense Review Report and the Department of the Navy's new whitepaper, "Naval Transformational Roadmap," provide additional unclassified guidance and clarification on current DoD and USN defense policies and priorities.

The Quadrennial Defense Review Report identifies six critical US military operational goals. These are: 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; and leveraging information technology.

The Naval "Transformational Roadmap" provides 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.

This Mission Need Statement specifically addresses four of these warfighting capabilities. These are: Intelligence, Surveillance and Reconnaissance (ISR); time-sensitive strike; accelerated deployment and employment time; enhanced seaborne positioning of joint assets. While addressing these capabilities, there is also a need to reduce cost and minimize personnel in harms way.

2. MISSION AND THREAT ANALYSIS.

a. Threat.

(1) Adversaries may range from Super Powers to numerous regional powers, and as such the US requires increased flexibility to counter a variety of threat scenarios that may rapidly develop. There are two distinct classes of threats to US national security interests:

(a) Threats from nations with a major military capability, or the demonstrated interest in acquiring such a capability, i.e. China, India, Russia, and North Korea. Specific weapons systems that could be encountered include ballistic missiles, land and surface launched cruise missiles, significant land based air assets and submarines.

(b) Threats from smaller nations who support, promote, and perpetrate activities which cause regional instabilities detrimental to international security and/or have the potential for development of nuclear weapons, .i.e. Iraq and Iran. Specific weapon systems include diesel/electric submarines, land-based air assets, submarines and chemical/biological weapons.

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

b. Mission Capabilities.
Enhance our ability to provide the following capabilities specified in the Defense Planning Guidance:

(1) Deny the enemy sanctuary by persistent intelligence, surveillance, reconnaissance (ISR), tracking, and rapid engagement.
(2) Execute and support flexible time sensitive strike missions with speed measured in minutes and precision measured in meters through appropriately positioned "shooters" to seize the initiative and disrupt enemy timelines.
(3) Support, maintain and conduct operations with the most technologically advanced unmanned/remotely controlled tactical and C^4/I reconnaissance vehicles.
(4) Provide sufficient mobility and endurance to perform these missions on extremely short notice, at locations far removed from home port.
(5) Provide enhanced seaborne positioning of joint assets.

Given the following significant constraints:

(1) Minimize personnel in harms way.
(2) Reduce cost.

c. Need.
Current assets supporting these capabilities include:

(1) Land and carrier-based manned aircraft and UAV's
(2) Cruise missiles launched from submarines and surface ships
(3) Space-based and long-range aircraft

These assets are costly and/or put significant numbers of personnel in harms way. Their cost does not allow for sufficient worldwide coverage of all potential regions of conflict necessary to support continuous ISR and sea-based positioning for immediate time-sensitive strike. Manned aircraft are particularly vulnerable to First Day of War scenarios until enemy defenses are sufficiently suppressed and the risk of loss of life is reduced.

The Unmanned Combat Air Vehicle (UCAV-N) is a transformational technology in development with the potential to effectively address some of these problems. "Transformation is about seizing opportunities to create new capabilities by radically changing organizational relationships, implementing different concepts of warfighting and inserting new technology to carry out operations in ways that profoundly improve current capabilities and develop desired future capabilities." The current concept of operations for UCAV-N is to provide support and delivery using existing CVN's. This plan fails to address the problems of cost and risk identified above. UCAV-N and its support system must be developed as a **total transformational system**.

There is a mission need for a UCAV-N support and delivery system or platform to provide the mission capabilities specified in paragraph (b.) above. This transformational system must be developed in parallel with UCAV-N to maximize mission effectiveness and minimize cost.

3. <u>NON-MATERIAL ALTERNATIVES</u>.

a. Change the US role in the world by reducing international involvement.

b. Increase reliance on foreign military facilities and support to meet the interests of US policy.

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

d. Make increased use of foreign air bases.

4. <u>POTENTIAL MATERIAL ALTERNATIVES</u>.

a. Increase the production and numbers of *Nimitz* Class CVN's for support of manned and unmanned aircraft.

b. Provide a surface ship specifically designed or modified to support UAV's and UCAV's in ISR, First Day of War (FDOW) and Suppression of Enemy Air Defenses (SEAD) missions. Deploy in larger numbers than current CVN's. Alternatives include:

- Convert existing LHD or LHA class ships to UCAV carriers
- Design and build a modified-repeat LHD or LPD-17 as a UCAV carrier
- Design and build an entirely new class of UCAV carrier (CUVX)

5. CONSTRAINTS

a. The cost of the platforms must be kept to an absolute minimum, allowing sufficient numbers for worldwide coverage.

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

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

d. Inter-service and Allied C^4/I (inter-operability) must be considered in the development of any new platform or the upgrade of existing assets.

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

(1) A dense contact and threat environment
(2) Conventional and nuclear weapons environments
(3) Survivable in Sea State 9
(4) Operable in Sea State 5
(5) Littoral regions
(6) All weather, battle group environments
(7) Independent operations

f. The platform must have absolute minimum manning.

Appendix B – Acquisition Decision Memorandum

Aerospace and Ocean Engineering

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

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September 25, 2003

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

Subj: ACQUISITION DECISION MEMORANDUM FOR an Unmanned Combat Air Vehicle (UCAV) Carrier (CUVX)

Ref: (a) CUVX Mission Need Statement

1. This memorandum authorizes Concept Exploration of two material alternatives for an Unmanned Combat Air Vehicle Carrier (CUVX), as proposed to the Virginia Tech Naval Acquisition Board in Reference (a). These alternatives are: 1) a modified-repeat LPD-17 design; and 2) an entirely new CUVX design. Additional material and non-material alternatives supporting this mission may be authorized in the future.

2. Concept exploration is authorized for a CUVX consistent with the mission requirements and constraints specified in Reference (a). CUVX will operate primarily in littoral areas, depending on stealth, with high endurance, minimum external support, low cost and low manning. It must support 20-30 UCAV's and UAV's, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The UAV's will provide surface, subsurface, shore, and deep inland surveillance, reconnaissance and electronic warfare. UCAV's and LAMPS will provide initial/early conflict Anti-Submarine Warfare (ASW), Anti-Surface Ship Warfare (ASUW), Suppression of Enemy Air Defenses (SEAD) and mining. CUVX will operate independently or in conjunction with small Surface Attack Groups (SAG). It will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict. CUVX is likely to be forward deployed in peacetime, conducting extended cruises to sensitive littoral regions. It will provide own defense with significant dependence on passive survivability and stealth. As a conflict proceeds to conclusion, CUVX will continue to monitor all threats. CUVX will likely be the first to arrive and last to leave the conflict area. The ship shall be designed to minimize life cycle cost through the application of producibility enhancements and manning reduction. The design must minimize personnel vulnerability in combat through automation. Average follow-ship acquisition cost shall not exceed $500M ($FY2005), not including aircraft. It is expected that 30 ships of this type will be built with IOC in 2012. Concepts will be explored in parallel with UCAV-N Concept Exploration and development using a Total Ship Systems Engineering approach.

A.J. Brown
VT Acquisition Executive

Appendix C – Operational Requirements Document

Operational Requirements Document (ORD1)
Unmanned Combat Air Vehicle Carrier (CUVX)
HI2 Alternative

1. Mission Need Summary.

CUVX is required to support unmanned combat air vehicles (UCAVs), unmanned air vehicles (UAVs) and LAMPS helicopters to perform the following missions:

1. Intelligence, Surveillance, and Reconnaissance (ISR)
2. Suppression of Enemy Air Defenses (SEAD)
3. Anti Submarine Warfare (ASW) self-defense
4. Anti Surface Ship Warfare (ASuW) self-defense
5. Electronic Countermeasures (ECM)
6. Mine Warfare (MIW)
7. Time-sensitive UCAV strikes

The Mission Need Statement (MNS) and Acquisition Decision Memorandum (ADM) developed for the Virginia Tech CUVX are provided in Appendices A and B. CUVX will operate primarily in littoral areas, depending on stealth, high endurance, minimum external support, low cost and low manning. It will support 10-30 UCAV's and 5-20 UAV's, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. CUVX will operate independently or in conjunction with small Surface Attack Groups (SAGs). It will be capable of performing unobtrusive peacetime presence missions in an area of hostility, and immediately respond to escalating crisis and regional conflict.

CUVX is likely to be forward deployed in peacetime, conducting extended cruises to sensitive littoral regions. It will provide its own defense with significant dependence on passive survivability and stealth. As a conflict proceeds to conclusion, CUVX will continue to monitor all threats. It will likely be the first to arrive and last to leave the area of conflict.

The UAV's will provide surface, subsurface, shore, and deep inland surveillance, reconnaissance and electronic warfare. The UCAV's and LAMPS will provide initial/early conflict ASW, ASuW, SEAD, and MIW.

2. Acquisition Decision Memorandum (ADM)

The CUVX ADM authorizes Concept Exploration of two material alternatives for an Unmanned Combat Air Vehicle Carrier (CUVX). These alternatives are: 1) a modified-repeat LPD-17 design; and 2) an entirely new CUVX design. The concepts considered in Concept Exploration are required to include moderate to high-risk alternatives. Average follow-ship acquisition cost shall not exceed $650M ($FY2005) and lead ship acquisition cost shall not exceed $750M, not including aircraft. CUVX Concepts will be explored in parallel with UCAV-N Concept Exploration and development using a Total Ship Systems Engineering approach.

3. Results of Concept Exploration

Concept exploration was performed using a multi-objective genetic optimization (MOGO). A broad range of non-dominated CUVX alternatives within the scope of the ADM was identified based on lead and follow ship acquisition cost, effectiveness and risk. **This ORD specifies a requirement for Concept Development of CUVX alternative HI2, an LPD-17 modified-repeat design.** This high end design was chosen in order to provide a more interesting design project with a wider array of alternatives. Other alternatives are specified in separate ORDs. HI2 is a high-end alternative on the lead-ship acquisition cost ND high-risk frontier (Figure 1). It is also on the follow-ship cost ND frontier. It has a lead ship acquisition cost of $937M and a follow-ship acquisition cost of $760M with excellent effectiveness (OMOE=.882) and high risk (OMOR=0.169). It carries 30 UCAVs, 19 UAVs, has excellent commonality with LPD-17, excellent aircraft weapons and fuel capacity, and medium endurance range.

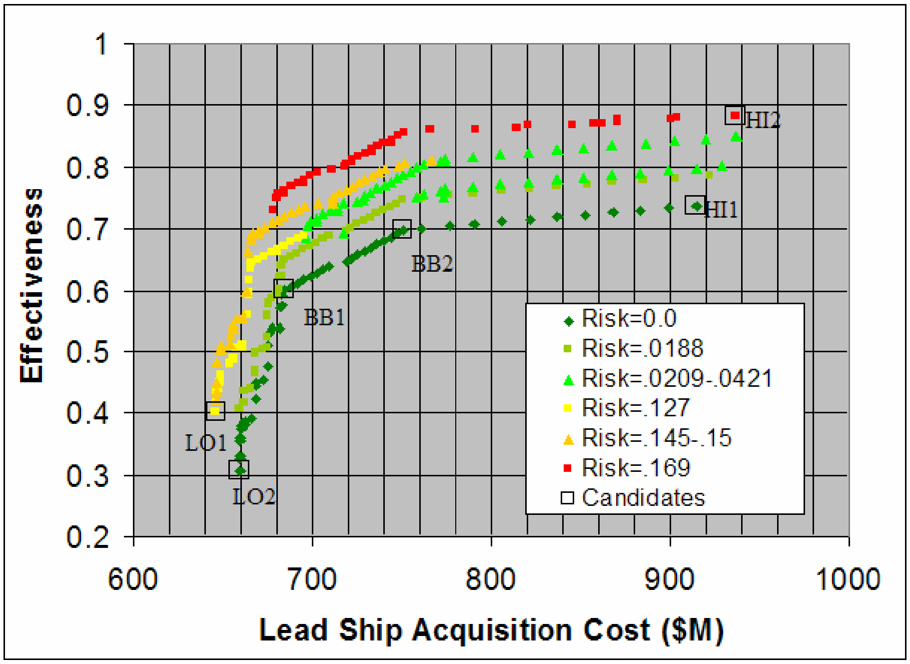


Figure 1. CUVX Non-Dominated (ND) Frontier

4. Technical Performance Measures (TPMs)

TPM	Threshold	Goal
Number of UAVs	19	20
Number of UCAVs	30	30
Number of LAMPS	4	4
Aircraft fuel capacity (MT)	1599.0	2032.0
Aircraft weapons capacity (MT)	467.6	450.0
Aircraft fuel capacity (m3)	2005.0	2549.0
Aircraft weapons magazine capacity (m3)	8978.0	8600.0
Endurance range (nm)	4000	12000
Stores duration (days)	120	120
CPS	full	full
Vs (knt)	24.63	25.00
Seakeeping (McC index)	46.78	50.00
Crew size	917	800
OMOE	0.882	0.9
Aircraft Launch and Recovery	SS4	SS5
Unrep	SS4	SS4

5. Program Requirements

Program Requirement	Threshold	Goal
Mean follow-ship acquisition cost ($M)	760.3	650.0
Lead-ship acquisition cost ($M)	937.1	750.0
Maximum level of risk (OMOR)	0.169	0.169

6. Baseline Ship Characteristics (HI2 Alternative)

Hullform	LPD-17 modified-repeat
Δ (MT)	25730
LWL (m)	201
Beam (m)	29.54
Draft (m)	6.938
D10 (m)	26.63
Cp	0.647
Cx	0.941
Cdl (lton/ft^3)	88.28
Cbt	4.220
CD10	6.2
Cvd	0.21
W1 (MT)	11140
W2 (MT)	1192
W3 (MT)	795.607
W4 (MT)	321.888
W5 (MT)	3665
W6 (MT)	1846
W7 (MT)	43.08
Wp (MT)	2670
Lightship Δ (MT)	20910
KG (m)	10.827
GM/B=	0.139
Hull structure	Conventional
Propulsion system	Alternative 11: 2 shafts, IPS, 3xICR main propulsion, 2x3000kW SSGTG
Engine inlet and exhaust	Side or stern
AAW system	ESSM w/ VLS; X-band, Very Long-Range Air Search, and Short-Range Surface Search Radars; Electronic Warfare System, CIFF, DLS, DF, IRST, CIWS, GMFCS
Aircraft elevators	2
Weapons elevators	3
Catapults	2
Average deck height (m)	3.0
Hangar deck height (m)	6.0

7. Other Design Requirements, Constraints and Margins

KG margin (m)	1.0
Propulsion power margin (design)	10 %
Propulsion power margin (fouling and seastate)	25% (0.8 MCR)
Electrical margins	10%
Weight margin (design and service)	10%
Blast pressure	3 psi
Length of flight deck	> 100 meters
Breadth of flight deck	> 25 meters

8. Special Design Considerations and Standards

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

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

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

- General Specifications for Ships of the USN (1995)
- Longitudinal Strength: DDS 100-6
- Stability and Buoyancy: DDS 079-1
- Freeboard: DDS 079-2
- Endurance Fuel: DDS 200-1
- Electric Load Analysis: DDS 310-1
- Aircraft Handling Deck Structure: DDS 130-1

Use the following cost and life cycle assumptions:

- Ship service life = L_S = 30 years
- Base year = 2005
- IOC = 2011
- Total ship acquisition = N_S = 30 ships
- Production rate = R_P = 2 per year

Appendix D – Technical Appendices

D.1 CUVX Ship Synthesis Model

Aircraft Carrier (CUVX) Ship Synthesis Model (4/7/03) - CUVXHI2

Module 1 - Units and Physical Constants

$hp \equiv 33000 \cdot \frac{ft \cdot lbf}{min}$ $knt \equiv 1.69 \cdot \frac{ft}{sec}$ $nm \equiv knt \cdot hr$ $lton \equiv 2240 \cdot lbf$

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

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

Liquids specific volumes: $\delta_F := 42.3 \cdot \frac{ft^3}{lton}$ $\delta_{AF} := 42 \cdot \frac{ft^3}{lton}$ $\delta_{LO} := 39 \cdot \frac{ft^3}{lton}$ $\delta_W := 36 \cdot \frac{ft^3}{lton}$

Module 2 - Input, Design Parameters Decoding and Processing:

$DP := [DES_1, DES_2, DES_3, DES_4, DES_5, DES_6, 0, DES_7, DES_8, DES_9, DES_{10}, 0, 0, 0, 0, 0, 0, DES_{11}, DES_{12}, DES_{13}, DES_{14}, DES_{15}, DES_{16}, DES_{17}, DES_{18}, DES_{19}, DES_{20}, DES_{21}]^T$

DP1 - Hull form (4,5,6 only) $HullForm = 5$

Hull Form: 1 = Fastship Geosim; 2 = SS United States geosim; 3 = semiplaning (Mercier-Savitsky); 4= general monohull (Holtrop-Mennen); 5 = LPD-17 (Holtrop-Mennen) 6=WPTH monohull (H-M w/worm curve)

DP2 - C_P = .6-.8 $C_P = 0.647$

DP3 - C_X = .9-.99 $C_X = 0.941$

DP4 - $C_{\Delta L}$ $C_{\Delta L} = 87.471 \cdot \frac{lton}{ft^3}$

DP5 - C_{BT} = 3.0-5.0 $C_{BT} = 4.22$

DP6 - C_{D10} = 6-8 $C_{D10} = 6.2$

$C_B = 0.598$

DP7 = ie = 5 - 15 deg

DP8 = Launch Deck $DP_8 = 1$

0 = DP not used

DP9 = Cvd $C_{vd} = 0.21$

DP10 = AAW(1,2) $DP_{10} = 1$

$D_{10} = 26.63 \; m$

DP11 = ASUW(1,2) $DP_{11} = 1$

DP12 = ASW(0)

DP13 = C4I(0)

DP14 = NSFS(0)

DP15 = SEW(0)

DP16 = MCM(0)

DP17 = VLS(0)

DP18 = RANGE(1-4) $E = 4 \cdot 10^3 \; nm$

DP19 = STORES DURATION(1,2) $T_S = 120 \cdot day$

DP20 = PROP (1-13) $DP_{20} = 11$

DP21 = SHIP MANNING FACTOR $CManShip = 1$

DP22 = HULL STRUCTURE $DP_{22} = 0$ $Hull := DP_{22}$

DP23 = CPS (1-3) $W_{CPS} = 60 \cdot lton$

DP24 = NUMBER OF UAVS $N_{UAV} = 19$

DP25 = NUMBER OF UCAVS $N_{UCAV} = 30$

DP26 = AVIATION MANNING FACTOR $CManAir = 1$

DP27 = AIRCRAFT FUEL WEIGHT PER UCAV $W_{UCAVF} = 4.5 \cdot lton$

DP28 = AIRCRAFT WEAPONS WEIGHT PER UCAV $W_{UCAVW} = 1.5 \cdot lton$

$DES = [2, 11, 5, 16, 2, 2, 1, 16, 1, 1, 3, 1, 11, 5, 0, 1, 15, 21, 5, 10, 10]^T$

$PAY := [DP_{10}, DP_{11}, DP_{12}, DP_{13}, DP_{14}, DP_{15}, DP_{16}, DP_{17}]^T$

PAY1(4,5) = DP10(1,2) = AAW

PAY2(1,2) = DP11(1,2) = ASUW

PAY3 = DP12 = ASW(0)

PAY4 = DP13 = C4I(0)

PAY5 = DP14 = NSFS(0)

PAY6 = DP15 = SEW(0)

PAY7 = DP16 = MCM(0)

PAY8 = DP17 = VLS(0)

$$PAY_1 := \begin{cases} 4 & \text{if } DP_{10} = 1 \\ 5 & \text{if } DP_{10} = 2 \\ 0 & \text{otherwise} \end{cases}$$

2a. Hull form design parameters and parent hulls:

Input - Design Parameter Range and Resolution (Input from Summary Page at End of Model)

$$HullForm := \begin{cases} 4 & \text{if } DP_1 = 1 \\ 5 & \text{if } DP_1 = 2 \\ 6 & \text{if } DP_1 = 3 \\ 4 & \text{otherwise} \end{cases}$$

DP # 2 (0-20)
$NCp \equiv 21$
$Cpmin \equiv .6$
$Cpmax \equiv .8$

DP # 3 (0-9)
$NCx \equiv 10$
$Cxmin \equiv .9$
$Cxmax \equiv .99$

DP # 4 (0-20)
$NCdl \equiv 21$
$Cdlmin \equiv 50.$
$Cdlmax \equiv 90.$

DP # 5 (0-10)
$NCbt \equiv 21$
$Cbtmin \equiv 3.0$
$Cbtmax \equiv 5.0$

DP # 6 (0-100)
$NCD10 \equiv 21$
$CD10min \equiv 6.0$
$CD10max \equiv 8.0$

DP # 7(0-10)
$Nei \equiv 0$
$eimin \equiv 5.$
$eimax \equiv 15.$

DP # 8(0-10)
$NCrd \equiv 0$
$Crdmin \equiv 0.$
$Crdmax \equiv .5$

DP # 9(0-25)
$NCvd \equiv 26$
$Cvdmin \equiv .05$
$Cvdmax \equiv .3$

DP # 21(0-5)
$NCManShip \equiv 6$
$CManShipmin \equiv .5$
$CManShipmax \equiv 1.$

DP # 26 (0-5)
$NCManAir \equiv 6$
$CManAirmin \equiv .5$
$CManAirmax \equiv 1.$

DP # 27 (0-10)
$NWUCAVF \equiv 11$
$WUCAVFmin \equiv 1.5$
$WUCAVFmax \equiv 4.5$

DP # 28 (0-10)
$NWUCAVW \equiv 11$
$WUCAVWmin \equiv .5$
$WUCAVWmax \equiv 1.5$

Average non-hangar deck height (hull and deckhouse): $H_{DK} := 3 \cdot m$

Average hangar deck height: $H_{HANGDK} = 6 \cdot m$

$$\iota_E = \left[eimin + DP_7 \cdot \frac{(eimax - eimin)}{Nei - 1} \right] \qquad C_{rd} = \left[Crdmin + DP_8 \cdot \frac{(Crdmax - Crdmin)}{NCrd - 1} \right] \qquad C_{D10} = CD10min + DP_6 \cdot \frac{(CD10max - CD10min)}{NCD10 - 1}$$

$$C_{vd} = \left[Cvdmin + DP_9 \cdot \frac{(Cvdmax - Cvdmin)}{NCvd - 1} \right] \qquad CManShip = \left[CManShipmin + DP_{21} \cdot \frac{(CManShipmax - CManShipmin)}{NCManShip - 1} \right]$$

$$W_{UCAVF} = \left[WUCAVFmin + DP_{27} \cdot \frac{(WUCAVFmax - WUCAVFmin)}{NWUCAVF - 1} \right] \cdot lton$$

$$W_{UCAVW} = \left[WUCAVWmin + DP_{28} \cdot \frac{(WUCAVWmax - WUCAVWmin)}{NWUCAVW - 1} \right] \cdot lton$$

$$CManAir = \left[CManAirmin + DP_{26} \cdot \frac{(CManAirmax - CManAirmin)}{NCManAir - 1} \right]$$

$$N_{HANGDK} := 3$$

$$A_{HANGDK} := C_{W} \cdot LWL \cdot B \cdot N_{HANGDK}$$

$$A_{HANGmax} := .75 \cdot A_{HANGDK}$$

$$A_{HANGDK} = 1.459 \cdot 10^{4} m^{2}$$

$$A_{HANGmax} = 1.094 \cdot 10^{4} m^{2}$$

2b. Payload design parameters and Warfighting MOPs:

AAW

$$PAY1 = \begin{cases} (2\ 7\ 10\ 11\ 15\ 17\ 19\ 20\ 25\ 12\ 22\ 24) & \text{if } PAY_1 = 1 \\ (2\ 7\ 8\ 11\ 14\ 17\ 21\ 20\ 25\ 12\ 22\ 24) & \text{if } PAY_1 = 2 \\ (2\ 7\ 8\ 9\ 12\ 14\ 17\ 18\ 21\ 22\ 24\ 25) & \text{if } PAY_1 = 3 \\ (3\ 4\ 5\ 6\ 7\ 13\ 16\ 17\ 25\ 9\ 18\ 12\ 22\ 24) & \text{if } PAY_1 = 4 \\ (3\ 4\ 5\ 6\ 7\ 16\ 17\ 25\ 12\ 22\ 24\ 23\ 26) & \text{otherwise} \end{cases}$$

$$VOP_1 = \begin{cases} 1.0 & \text{if } PAY_1 = 1 \\ 1.0 & \text{if } PAY_1 = 2 \\ 1.0 & \text{if } PAY_1 = 3 \\ 1.0 & \text{if } PAY_1 = 4 \\ 0.0 & \text{otherwise} \end{cases}$$

$$PAY_1 = 4$$

$$VOP_1 = 1$$

ASUW

$$PAY2 := \begin{cases} (27\ 31\ 33\ 53\ 54\ 55\ 56\ 105\ 54\ 55\ 56\ 105) & \text{if } PAY_2 = 1 \\ (27\ 31\ 33\ 53\ 54\ 55\ 56\ 105) & \text{otherwise} \end{cases}$$

$$PAY_2 = 1$$

$$N_{HELO} := \begin{cases} 4 & \text{if } PAY_2 = 1 \\ 2 & \text{if } PAY_2 = 2 \end{cases} \qquad VOP_{33} := \begin{cases} 1.0 & \text{if } PAY_2 = 1 \\ 0.0 & \text{if } PAY_2 = 2 \end{cases}$$

$$N_{HELO} = 4 \qquad VOP_{33} = 1$$

C4I

$$PAY4 := \begin{cases} (0\ 58) & \text{if } PAY_4 = 2 \\ (0\ 100) & \text{otherwise} \end{cases}$$

$$PAY_4 = 0$$

NSFS

$$PAY5 = \begin{cases} (66\ 69\ 70\ 72\ 74) & \text{if } PAY_5 = 1 \\ (67\ 68\ 70\ 71\ 75) & \text{if } PAY_5 = 2 \\ (67\ 68\ 71\ 75) & \text{if } PAY_5 = 3 \\ (0\ 0) & \text{otherwise} \end{cases}$$

$$PAY_5 = 0$$

ASW

$$PAY3 := \begin{cases} \text{if } DP_1 = 4 \\ \quad \begin{cases} (34\ 36\ 37\ 40\ 41\ 42\ 45\ 46\ 47\ 48\ 49\ 50\ 51\ 53\ 54\ 55\ 56\ 57) & \text{if } PAY_3 = 1 \\ (34\ 36\ 40\ 41\ 43\ 45\ 46\ 47\ 48\ 49\ 50\ 51\ 53\ 54\ 55\ 56\ 57) & \text{if } PAY_3 = 2 \\ (34\ 38\ 40\ 41\ 44\ 46\ 48\ 49\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 3 \\ (34\ 37\ 38\ 41\ 44\ 46\ 48\ 49\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 4 \\ (35\ 39\ 41\ 44\ 46\ 48\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 5 \\ (36\ 41\ 42\ 51) & \text{otherwise} \end{cases} \\ \text{otherwise} \\ \quad \begin{cases} (35\ 36\ 39\ 41\ 44\ 45\ 46\ 47\ 48\ 50\ 51\ 53\ 54\ 55\ 56\ 57) & \text{if } PAY_3 = 1 \\ (35\ 36\ 39\ 41\ 43\ 45\ 46\ 47\ 48\ 50\ 51\ 53\ 54\ 55\ 56\ 57) & \text{if } PAY_3 = 2 \\ (35\ 38\ 39\ 41\ 44\ 46\ 48\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 3 \\ (35\ 39\ 41\ 44\ 46\ 48\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 4 \\ (38\ 41\ 44\ 46\ 48\ 51\ 52\ 56\ 57) & \text{if } PAY_3 = 5 \\ (36\ 41\ 42\ 51) & \text{otherwise} \end{cases} \end{cases}$$

$$PAY_3 = 0 \qquad PAY_2 = 1$$

ASW and ASUW MOP:

$$VOP_{32} := VOP_{33}$$

SEW

$$PAY6 = \begin{cases} (101\ 78) & \text{if } PAY_6 = 1 \\ (77\ 78) & \text{if } PAY_6 = 2 \\ (76\ 78) & \text{otherwise} \end{cases}$$

$$PAY_6 = 0$$

$$SON_{TYP} := \begin{cases} 0 & \text{if } (DP_1 = 1 \vee DP_1 = 3) \wedge PAY_3 = 5 \\ 1 & \text{if } (DP_1 = 2 \vee DP_1 = 4) \wedge PAY_3 \neq 5 \\ 2 & \text{otherwise} \end{cases}$$

$$SON_{TYP} = 0$$

STK

$$PAY7 := (0\ 0) \qquad VOP_5 = 0$$

MCM

$$PAY8 = \begin{cases} (63\ 64\ 65) & \text{if } PAY_7 = 1 \\ (63\ 64) & \text{if } PAY_7 = 2 \\ (0\ 63) & \text{otherwise} \end{cases} \qquad VOP_8 = \begin{cases} 1.0 & \text{if } PAY_7 = 1 \\ 0.9 & \text{if } PAY_7 = 2 \\ 0.0 & \text{otherwise} \end{cases}$$

$$PAY_7 = 0$$

$$VOP_8 = 0$$

MCM and ASUW MOP:

$$VOP_{34} = VOP_{33}$$

VLS & VLS WEAPONS

$$PAY9 := \begin{cases} (102\ 103\ 104\ 82\ 94) & \text{if } PAY_1 = 4 \\ (0\ 0) & \text{otherwise} \end{cases}$$

$$PAY_1 = 4 \qquad PAY_8 = 0$$

AVIATION

$N_{UAV} \equiv DP_{24}+4$ $N_{UAV}=19$ $W_{UAV}:=500 \cdot lbf$ $A_{UAV}:=200 \cdot ft^2$

$N_{UCAV} \equiv DP_{25}+9$ $N_{UCAV}=30$ $W_{UCAV}:=26000 \cdot lbf$ $A_{UCAV}:=780 \cdot ft^2$ $A_{HELO}:=800 \cdot ft^2$

$N_{HELO}=4$ $W_{HELO}:=6.36 \cdot lton$ $L_{FltReq}:=100 \cdot m$ $B_{FltReq}:=25 \cdot m$ $L_{Flt}:=.75 \cdot LWL$ $W_{UCAV}=11.793 \cdot MT$

$W_{F23}:=N_{HELO} \cdot W_{HELO}+N_{UAV} \cdot W_{UAV}+N_{UCAV} \cdot W_{UCAV}$ $W_{F23}=383.959 \cdot MT$ (ordnance delivery -aircraft)

$N_{AirElev}:=2$ (internal, not D/E) $N_{cat}:=2$ $N_{WeapElev}:=3$

$W_{WeapElev}:=100. \cdot MT \cdot N_{WeapElev}$ $A_{WeapElev}:=16.7 \cdot m^2 \cdot N_{WeapElev}$ $W_{WeapElev}=300 \cdot MT$ $A_{WeapElev}=50.1\ m^2$

$W_{ACElev}:=10. \cdot W_{UCAV} \cdot N_{AirElev}$ $W_{ACElev}=235.868 \cdot MT$

$W_{AirSCat}:=15. \cdot N_{cat} \cdot W_{UCAV}$ $W_{AirSCat}=353.802 \cdot MT$ $W_{AirEMALS}:=10.1 \cdot N_{cat} \cdot W_{UCAV}$ $W_{AirEMALS}=238.227 \cdot MT$

$W_{AirRec}:=5.5 \cdot W_{UCAV}$ $W_{AirRec}=64.864 \cdot MT$

$A_{LandR}:=42.8 \cdot \frac{m^2}{MT} \cdot W_{UCAV}$ $A_{LandR}=504.758\ m^2$ $A_{AirMaintShops}:=A_{UCAV} \cdot \frac{N_{UCAV}+N_{HELO}}{10}$

$W_{AirSupE}:=3.4 \cdot MT \cdot (N_{UCAV}+N_{HELO})$ $W_{AirSupE}=115.6 \cdot MT$ $A_{AirMaintShops}=246.379\ m^2$

$W_{UCAVF}=45.722 \cdot MT$ $W_{UAVF}:=5.0 \cdot lton$ $W_{HELOF}:=32.2 \cdot lton$

$W_{F42}:=N_{HELO} \cdot W_{HELOF}+N_{UAV} \cdot W_{UAVF}+N_{UCAV} \cdot W_{UCAVF}$ $W_{F42}=1.599 \cdot 10^3 \cdot MT$ (total ship aircraft fuel weight)

$A_{AirFuel}:=90 \cdot m^2 \cdot N_{UCAV}$

Strike Mission MOP: $VOP_{28}:=.3 \cdot DP_8+.7 \cdot if\left(\frac{N_{UCAV}-10}{20} \le 1, \frac{N_{UCAV}-10}{20}, 1.0\right)$ $VOP_{28}=1$ $DP_8=1$

SEAD Mission MOP: $VOP_{30}:=VOP_{28}$ $VOP_{30}=1$

ISR Mission MOP: $VOP_{31}:=if\left(\frac{N_{UAV}-5}{15} \le 1, \frac{N_{UAV}-5}{15}, 1.0\right)$ $VOP_{31}=0.933$

Ship Aircraft Fuel Capacity MOP: $VOP_{12}:=\frac{DP_{27}}{NWUCAVF-1}$ $VOP_{12}=1$

Ship Aircraft Weapons Capacity MOP: $VOP_{11}:=\frac{DP_{28}}{NWUCAVW-1}$ $VOP_{11}=1$

2c. Build payload vector and extract data from data files:

PAY := augment(PAY1 ,PAY2) PAY := augment(PAY ,PAY3) PAY := augment(PAY ,PAY4)
PAY := augment(PAY ,PAY5) PAY := augment(PAY ,PAY6) PAY := augment(PAY ,PAY7)
PAY := augment(PAY ,PAY8) PAY := augment(PAY ,PAY9) $PAY := PAY^T$

Read payload SWBS weights:

P100 := READPRN ("p100.csv") P400 := READPRN ("p400.csv") P500 := READPRN ("p500.csv")
P600 := READPRN ("p600.csv") P700 := READPRN ("p700.csv") PF20 := READPRN ("pf20.csv")
PF42 := READPRN ("pf42.csv")

$$W_{P100}:=\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P100)} if\left(P100_{m,1}=PAY_n, P100_{m,2}, 0\right) \cdot lton$$

$$VCD_{P100}:=\frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P100)} if\left(P100_{m,1}=PAY_n, P100_{m,2} \cdot P100_{m,3}, 0\right) \cdot ltonft}{W_{P100}}-H_{HANGDK}$$

$$W_{P400}:=\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P400)} if\left(P400_{m,1}=PAY_n, P400_{m,2}, 0\right) \cdot lton$$

$$VCG_{P600} := \frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P600)} if\left(P600_{m,1} = PAY_n, P600_{m,2} \cdot P600_{m,3}, 0\right) \cdot lton \cdot ft}{W_{P600}} - H_{HANGDK}$$

$$BATKW_{600} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P600)} if\left(P600_{m,1} = PAY_n, P600_{m,6}, 0\right) \cdot kW$$

$$TRANKW_{600} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P600)} if\left(P600_{m,1} = PAY_n, P600_{m,7}, 0\right) \cdot kW$$

$$A_{HPC} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P600)} if\left(P600_{m,1} = PAY_n, P600_{m,4}, 0\right) \cdot ft^2$$

$$A_{DPC} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P600)} if\left(P600_{m,1} = PAY_n, P600_{m,5}, 0\right) \cdot ft^2 \qquad A_{HPC} := A_{HPC} + A_{DPC} \qquad A_{DPC} := 0 \cdot m^2$$

$$W_{P500} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,2}, 0\right) \cdot lton$$

$$VCG_{P500} := \frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,2} \cdot P500_{m,3}, 0\right) \cdot lton \cdot ft}{W_{P500}} - H_{HANGDK}$$

$$BATKW_{500} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,6}, 0\right) \cdot kW$$

$$TRANKW_{500} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,7}, 0\right) \cdot kW$$

$$AHULL_{500} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,4}, 0\right) \cdot ft^2$$

$$ADH_{500} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P500)} if\left(P500_{m,1} = PAY_n, P500_{m,5}, 0\right) \cdot ft^2 \qquad AHULL_{500} := AHULL_{500} + ADH_{500} \qquad ADH_{500} := 0 \cdot m^2$$

$$W_{P400} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P400)} if\left(P400_{m,1} = PAY_n, P400_{m,2}, 0\right) \cdot lton$$

$$VCG_{P400} := \frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P400)} if\left(P400_{m,1} = PAY_n, P400_{m,2} \cdot P400_{m,3}, 0\right) \cdot lton \cdot ft}{W_{P400}} - H_{HANGDK}$$

$$AHULL_{400} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P400)} if\left(P400_{m,1} = PAY_n, P400_{m,4}, 0\right) \cdot ft^2$$

$$ADH_{400} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P400)} if\left(P400_{m,1} = PAY_n, P400_{m,5}, 0\right) \cdot ft^2 \qquad AHULL_{400} := AHULL_{400} + ADH_{400} \qquad ADH_{400} := 0 \cdot m^2$$

$$W_7 := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,2}, 0\right) \cdot lton$$

$$VCG_{700} := \frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,2} \cdot P700_{m,3}, 0\right) \cdot lton \cdot ft}{W_7} - H_{HANGDK}$$

$$BATKW_{700} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,6}, 0\right) \cdot kW$$

$$TRANKW_{700} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,7}, 0\right) \cdot kW$$

$$AHULL_{700} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,4}, 0\right) \cdot ft^2$$

$$ADH_{700} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(P700)} if\left(P700_{m,1} = PAY_n, P700_{m,5}, 0\right) \cdot ft^2$$

$$W_{F50} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF50)} if\left(PF50_{m,1} = PAY_n, PF50_{m,2}, 0\right) \cdot lton + W_{F55} + W_{UCAVW} \cdot N_{UCAV}$$

$$VCG_{F50} := \frac{\sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF50)} if\left(PF50_{m,1} = PAY_n, PF50_{m,2} \cdot PF50_{m,3}, 0\right) \cdot lton \cdot ft - W_{F55} \cdot 1.5 \cdot H_{HANGDK} - 3.0 \cdot N_{UCAV} \cdot W_{UCAVW} \cdot H_{HANGDK}}{W_{F50}}$$

$$BATKW_{F50} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF50)} if\left(PF50_{m,1} = PAY_n, PF50_{m,6}, 0\right) \cdot kW \qquad VCG_{F50} = -13.427 \cdot m$$

$$TRANKW_{F20} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF20)} if(PF20_{m,1} = PAY_n, PF20_{m,7}, 0) \cdot kW$$

$$AHULL_{F20} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF20)} if(PF20_{m,1} = PAY_n, PF20_{m,4}, 0) \cdot ft^2 + N_{UCAV} \cdot W_{UCAVW} \cdot 6.4 \cdot \frac{m^2}{MT}$$

$$ADH_{F20} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF20)} if(PF20_{m,1} = PAY_n, PF20_{m,5}, 0) \cdot ft^2 \qquad AHULL_{F20} = 2.993 \cdot 10^3 \cdot m^2$$

$VCD_{F42} := -1.5 \cdot H_{HANGDK}$ $\quad VCD_{F42} = -9 \cdot m$

$W_{VP} := W_{F20} + W_{F42}$ $\quad VCD_{VP} := \dfrac{W_{F20} \cdot VCD_{F20} + W_{F42} \cdot VCD_{F42}}{W_{VP}}$ $\quad VCD_{VP} = -10.32 \cdot m$

$W_P := W_{VP} + W_{P100} + W_{P400} + W_{P500} + W_{P600} + W_7$

$$VCD_P := \frac{W_{VP} \cdot VCD_{VP} + W_{P100} \cdot VCD_{P100} + W_{P400} \cdot VCD_{P400} + W_{P500} \cdot VCD_{P500} + W_{P600} \cdot VCD_{P600} + W_7 \cdot VCD_{700}}{W_P}$$

$BATKW_{PAY} := BATKW_{400} + BATKW_{500} + BATKW_{700} + BATKW_{F20}$ $\quad VCD_P = -10.024 \ m$

$TRANKW_{PAY} := TRANKW_{400} + TRANKW_{500} + TRANKW_{700} + TRANKW_{F20}$ $\quad BATKW_{PAY} = 696.54 \cdot kW$

$A_{HPA} := AHULL_{500} + AHULL_{600} + AHULL_{700} + AHULL_{F20}$ $\quad A_{HPA} = 3.129 \cdot 10^3 \cdot m^2$ $\quad TRANKW_{PAY} = 636.27 \cdot kW$

$A_{DPA} := ADH_{500} + ADH_{600} + ADH_{700} + ADH_{F20}$ $\quad D_{10} = 26.63 \ m$

$VCG_{P100} := VCD_{P100} + D_{10}$ $\quad VCG_{P400} := VCD_{P400} + D_{10}$ $\quad VCG_{P500} := VCD_{P500} + D_{10}$ $\quad VCG_{P600} := VCD_{P600} + D_{10}$

$VCG_P := VCD_P + D_{10}$ $\quad VCG_{VP} := VCD_{VP} + D_{10}$ $\quad VCG_{700} := VCD_{700} + D_{10}$ $\quad D_{10} = 26.63 \cdot m$ $\quad VCG_{VP} = 16.31 \cdot m$

Payload Weights and VCG Summary

$W_P = 2.67 \cdot 10^3 \cdot MT$ $\quad VCG_P = 16.606 \ m$

$W_{VP} = 2.514 \cdot 10^3 \cdot MT$ $\quad VCG_{VP} = 53.51 \cdot ft$ $\quad$ (Variable Payload = WF20+WF42)

$W_{P100} = 4.064 \cdot MT$ $\quad W_{P400} = 100.985 \cdot MT$ $\quad W_{P500} = 7.549 \cdot MT$ $\quad W_{P600} = 0 \cdot MT$ $\quad W_7 = 43.08 \cdot MT$

$VCG_{P100} = 18.749 \ m$ $\quad VCG_{P400} = 21.993 \ m$ $\quad VCG_{P500} = 15.809 \ m$ $\quad VCG_{P600} = 20.63 \ m$ $\quad VCG_{700} = 21.196 \ m$

$W_{F42} = 1.599 \cdot 10^3 \cdot MT$ (aircraft fuel) $\quad W_{F20} = 915.098 \cdot MT$

$W_{F23} = 383.959 \cdot MT$ (aircraft)

Payload Area Requirements

Required payload deck areas in deckhouse: $\quad A_{DPC} = 0 \ m^2$ $\quad A_{DPA} = 845.511 \ m^2$

In hull: $\quad A_{HPC} = 435.437 \ m^2$ $\quad A_{HPA} = 3.129 \cdot 10^3 \ m^2$

Where 'PC' index stands for Command & Surveilance (swbs 400) and 'PA' for armament (swbs 500, 600, 700 and F20).

Sonar model (0 for SQR-19 only, 1 for SQS-53C or combination, 2 for SQS-56 or combination): $\quad SON_{TYP} = 0$

Payload Electrical Requirements

$BATKW_{PAY} = 696.54 \cdot kW$

$TRANKW_{PAY} = 636.27 \cdot kW$ (For winter cruise condition, with sonar)

Fin stabilizers: $\quad N_{fins} := if(DP_1 = 3, 1, 0)$ $\quad KW_{fins} := \begin{cases} 0 \cdot kW & \text{if } N_{fins} = 0 \\ 100 \cdot kW & \text{otherwise} \end{cases}$ $\quad KW_{fins} = 0 \cdot kW$

2d. Endurance parameters and MOPs:

$E := \begin{cases} (12000 \cdot nm) & \text{if } DP_{18} = 1 \\ (8000 \cdot nm) & \text{if } DP_{18} = 2 \\ (4000 \cdot nm) & \text{if } DP_{18} = 3 \end{cases}$ $\quad VOP_9 := \begin{cases} 1.0 & \text{if } DP_{18} = 1 \\ .667 & \text{if } DP_{18} = 2 \\ 0.0 & \text{otherwise} \end{cases}$ $\quad V_e := 20 \cdot knt$ $\quad E = 4 \cdot 10^3 \cdot nm$

$T_S := \begin{cases} (120 \cdot day) & \text{if } DP_{19} = 1 \\ (90 \cdot day) & \text{if } DP_{19} = 2 \\ (60 \cdot day) & \text{if } DP_{19} = 3 \end{cases}$ $\quad VOP_{10} := \begin{cases} 1.0 & \text{if } DP_{19} = 1 \\ .7 & \text{if } DP_{19} = 2 \\ 0.0 & \text{otherwise} \end{cases}$

2e. CBR Protection and MOP:

Collective Protection System : $\quad W_{CPS} := \left| \begin{cases} 60 \cdot lton & \text{if } DP_{23} = 1 \\ 30 \cdot lton & \text{if } DP_{23} = 2 \\ 0.0 \cdot lton & \text{if } DP_{23} = 3 \end{cases} \right|$ $\quad VOP_{21} := \begin{cases} 1.0 & \text{if } DP_{23} = 1 \\ .7 & \text{if } DP_{23} = 2 \\ 0.0 & \text{if } DP_{23} = 3 \end{cases}$ $\quad W_{CPS} = 60.963 \cdot MT$

21. Propulsion System:

$$PSYS_{TYP} := \begin{cases} 1 & \text{if } 1 \le DP_{20} \le 5 \\ 2 & \text{otherwise} \end{cases} \qquad \eta := \begin{cases} .98 & \text{if } 1 \le DP_{20} \le 5 \\ .92 & \text{otherwise} \end{cases}$$

(Propulsion System Type
1 - Mechanical
2 - IPS

$$N_{prop} := \begin{cases} 1 & \text{if } 1 \le DP_{20} \le 3 \\ 1 & \text{if } 6 \le DP_{20} \le 9 \\ 2 & \text{otherwise} \end{cases} \qquad N_{prop} = 2 \qquad W_{AirL} := \begin{cases} W_{AirSCat} & \text{if } PSYS_{TYP} = 1 \\ W_{AirEMALS} & \text{otherwise} \end{cases}$$

$$P_{BPENGTOT} := \begin{cases} 52500 \cdot hp & \text{if } (DP_{20} = 1) + (DP_{20} = 6) \\ 58100 \cdot hp & \text{if } (DP_{20} = 2) + (DP_{20} = 7) \\ 55300 \cdot hp & \text{if } (DP_{20} = 3) + (DP_{20} = 9) \\ 41600 \cdot hp & \text{if } (DP_{20} = 4) \\ 52000 \cdot hp & \text{if } (DP_{20} = 8) + (DP_{20} = 12) \\ 78800 \cdot hp & \text{if } (DP_{20} = 10) \\ 87100 \cdot hp & \text{if } (DP_{20} = 11) \\ 81500 \cdot hp & \text{if } (DP_{20} = 13) \\ 73300 \cdot hp & \text{otherwise} \end{cases}$$

$$SFC_{ePE} := \begin{cases} 0.264 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 1) \\ 0.199 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 2) \\ 0.202 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 3) \\ 0.210 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 4) + (DP_{20} = 14) \\ 0.210 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 5) \\ 0.261 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 6) \\ 0.198 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 7) + (DP_{20} = 11) + (DP_{20} = 9) \\ 0.213 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 8) \\ 0.264 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 10) + (DP_{20} = 13) \\ 0.211 \cdot \frac{kg}{kW \cdot hr} & \text{otherwise} \end{cases}$$

$$P_{BPENGTOT} = 8.71 \cdot 10^{4} \cdot hp$$

$$SFC_{ePE} = 0.198 \cdot \frac{kg}{kW \cdot hr}$$

$$H_{MBreq} := \begin{cases} 6.14 \cdot m & \text{if } (DP_{20} = 1) \\ 6.22 \cdot m & \text{if } (DP_{20} = 2) + (DP_{20} = 3) \\ 6.67 \cdot m & \text{if } (DP_{20} = 4) + (DP_{20} = 5) \\ 6.62 \cdot m & \text{if } (DP_{20} = 6) + (DP_{20} = 10) \\ 6.63 \cdot m & \text{if } (DP_{20} = 7) + (DP_{20} = 9) + (DP_{20} = 11) + (DP_{20} = 13) \\ 7.59 \cdot m & \text{otherwise} \end{cases} \qquad H_{MBreq} = 6.63 \cdot m$$

$$w_{MBreq} := \begin{cases} 6.63 \cdot m & \text{if } (DP_{20} = 1) + (DP_{20} = 2) + (DP_{20} = 3) \\ 16.07 \cdot m & \text{if } (DP_{20} = 4) + (DP_{20} = 5) \\ 6.83 \cdot m & \text{if } (DP_{20} = 6) + (DP_{20} = 7) + (DP_{20} = 9) + [(DP_{20} = 10) + (DP_{20} = 11) + (DP_{20} = 13)] \\ 17.94 \cdot m & \text{otherwise} \end{cases} \qquad w_{MBreq} = 6.83\ m$$

$$L_{MBreq} := \begin{cases} 15.86 \cdot m & \text{if } (DP_{20} = 1) \\ 15.87 \cdot m & \text{if } (DP_{20} = 2) \\ 16.13 \cdot m & \text{if } (DP_{20} = 3) \\ 15.96 \cdot m & \text{if } (DP_{20} = 4) \\ 16.39 \cdot m & \text{if } (DP_{20} = 5) \\ 16.16 \cdot m & \text{if } (DP_{20} = 6) + (DP_{20} = 10) + (DP_{20} = 14) \\ 16.36 \cdot m & \text{otherwise} \end{cases} \qquad L_{MBreq} = 16.36\ m$$

$$V_{MBreq} := \begin{cases} 5888 \cdot m^3 & \text{if } (DP_{20} = 1) \\ 6536 \cdot m^3 & \text{if } (DP_{20} = 2) \\ 6285 \cdot m^3 & \text{if } (DP_{20} = 3) \\ 7816 \cdot m^3 & \text{if } (DP_{20} = 4) \\ 7852 \cdot m^3 & \text{if } (DP_{20} = 5) \\ 5138 \cdot m^3 & \text{if } (DP_{20} = 6) \\ 5261 \cdot m^3 & \text{if } (DP_{20} = 7) \\ 9487 \cdot m^3 & \text{if } (DP_{20} = 8) \\ 5217 \cdot m^3 & \text{if } (DP_{20} = 9) \\ 6982 \cdot m^3 & \text{if } (DP_{20} = 10) \\ 7189 \cdot m^3 & \text{if } (DP_{20} = 11) \\ 11127 \cdot m^3 & \text{if } (DP_{20} = 12) \\ 7069 \cdot m^3 & \text{if } (DP_{20} = 13) \\ 8514 \cdot m^3 & \text{otherwise} \end{cases}$$

$$A_{PIE} := \begin{cases} 28 \cdot m^2 & \text{if } (DP_{20} = 1) + (DP_{20} = 6) \\ 27.2 \cdot m^2 & \text{if } (DP_{20} = 2) + (DP_{20} = 7) \\ 27.7 \cdot m^2 & \text{if } (DP_{20} = 3) + (DP_{20} = 9) \\ 11.6 \cdot m^2 & \text{if } (DP_{20} = 4) \\ 33.8 \cdot m^2 & \text{if } (DP_{20} = 5) + (DP_{20} = 14) \\ 42 \cdot m^2 & \text{if } (DP_{20} = 10) \\ 41.55 \cdot m^2 & \text{if } (DP_{20} = 11) \\ 41.9 \cdot m^2 & \text{if } (DP_{20} = 13) \\ 14.5 \cdot m^2 & \text{otherwise} \end{cases}$$

$$A_{PIE} = 41.55\ m^2$$

$$V_{MBreq} = 7.189 \cdot 10^{3}\ m^3$$

$$W_{BM} = \begin{cases} 655.2 \cdot MT & \text{if } (DP_{20} = 1) \\ 745.8 \cdot MT & \text{if } (DP_{20} = 2) \\ 767.2 \cdot MT & \text{if } (DP_{20} = 3) \\ 902.3 \cdot MT & \text{if } (DP_{20} = 4) \\ 1187.6 \cdot MT & \text{if } (DP_{20} = 5) \\ 651.1 \cdot MT & \text{if } (DP_{20} = 6) \\ 740.8 \cdot MT & \text{if } (DP_{20} = 7) \\ 1934.5 \cdot MT & \text{if } (DP_{20} = 8) \\ 705.2 \cdot MT & \text{if } (DP_{20} = 9) \\ 935.5 \cdot MT & \text{if } (DP_{20} = 10) \\ 1069.9 \cdot MT & \text{if } (DP_{20} = 11) \\ 2051.0 \cdot MT & \text{if } (DP_{20} = 12) \\ 981.9 \cdot MT & \text{if } (DP_{20} = 13) \\ 1746.1 \cdot MT & \text{otherwise} \end{cases} \qquad W_{BM} = 1.07 \cdot 10^{3} \cdot MT$$

$$KW_{G} := \begin{cases} 2500 \cdot kW & \text{if } (DP_{20} = 4) + (DP_{20} = 5) + (DP_{20} = 8) + (DP_{20} = 12) + (DP_{20} = 14) \\ 3000 \cdot kW & \text{otherwise} \end{cases} \qquad KW_{G} = 3 \cdot 10^{3} \cdot kW$$

$$N_{SSG} := \begin{cases} 5 & \text{if } (DP_{20} = 4) + (DP_{20} = 5) \\ 3 & \text{if } (DP_{20} = 1) + (DP_{20} = 2) + (DP_{20} = 3) \\ 2 & \text{otherwise} \end{cases} \qquad N_{SSG} = 2$$

$$SFC_{eG} = \begin{cases} 0.3 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 1) \\ 0.298 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 2) \\ 0.299 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 3) \\ 0.187 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 4) \\ 0.186 \cdot \frac{kg}{kW \cdot hr} & \text{if } (DP_{20} = 5) \\ SFC_{ePE} & \text{otherwise} \end{cases}$$

$$W_{BMG} = \begin{cases} 198.9 \cdot MT & \text{if } (DP_{20} = 1) + (DP_{20} = 2) + (DP_{20} = 3) \\ 304.8 \cdot MT & \text{if } (DP_{20} = 4) + (DP_{20} = 5) \\ 587.6 \cdot MT & \text{if } (DP_{20} = 3) \\ 122.6 \cdot MT & \text{if } (DP_{20} = 8) + (DP_{20} = 12) + (DP_{20} = 14) \\ 132.9 \cdot MT & \text{otherwise} \end{cases}$$

$$A_{GIE} := \begin{cases} 10.8 \cdot m^2 & \text{if } (DP_{20} = 1) + (DP_{20} = 2) + (DP_{20} = 3) \\ 10 \cdot m^2 & \text{if } (DP_{20} = 4) + (DP_{20} = 5) \\ 0.4 \cdot m^2 & \text{if } (DP_{20} = 8) + (DP_{20} = 12) + (DP_{20} = 14) \\ 7.2 \cdot m^2 & \text{otherwise} \end{cases}$$

$W_{BMG} = 132.9 \cdot MT$ $\quad SFC_{eG} = 0.198 \cdot \frac{kg}{kW \cdot hr}$

$A_{GIE} = 7.2 \ m^2$

Deckhouse decks impacted by propulsion and generator inlet/exhaust: $N_{DIE} := ceil\left(\frac{V_D}{H_{DK} \cdot B \cdot \frac{LWL}{3}}\right)$ $\quad N_{DIE} = 1$

Hull decks impacted by propulsion inlet/exhaust:
(assumes 2m inner bottom in MB) $N_{HPIE} := floor\left(\frac{D_{10} - H_{MBreq} - 1 \cdot m}{H_{HANGDK}}\right)$ $\quad N_{HPIE} = 3$

$H_{MB} = D_{10} - N_{HANGDK} \cdot H_{HANGDK} - 1 \cdot m$ $\quad H_{MB} = 7.63 \ m$ $\quad H_{MBreq} = 6.63 \ m$

Hull decks impacted by generator inlet/exhaust: $N_{HGIE} := floor\left(\frac{D_{10} - H_{MBreq} - 1 \cdot m}{H_{HANGDK}}\right)$ $\quad N_{HGIE} = 3$

Total inlet/exhaust arrangeable area required (assumes 2 SSG outside MB):

$A_{HIE} := 1.4 \cdot (N_{HPIE} \cdot A_{PIE} + N_{HGIE} \cdot A_{GIE})$ $\quad A_{HIE} = 204.75 \ m^2$

$A_{DIE} := 0 \cdot m^2$ (side or stern exhaust)

2g. Manning, other requirements, constraints and margins, constant for all designs:

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

$CManShip = 1$ $\quad N_{OShip} := 3 + ceil\left(N_{prop} + \frac{N_{SSG}}{5} + \frac{W_P - W_{VP}}{15 \cdot lton} + \frac{V_{FL} + V_D}{80000 \cdot ft^3}\right)$ $\quad N_{OShip} = 29$

$N_{EShip} := ceil\left[CManShip \cdot \left(N_{prop} \cdot 6 + N_{SSG} \cdot 3 + \frac{W_P - W_{VP}}{10 \cdot lton} + \frac{V_{FL} + V_D}{4450 \cdot ft^3}\right)\right]$ $\quad N_{EShip} = 272$

$CManAir = 1$ $\quad N_{OAir} := ceil\left(\frac{1}{MT} \cdot W_{F23}\right)$ $\quad N_{OAir} = 39$ $\quad N_O := N_{OAir} + N_{OShip}$ $\quad N_O = 68$

$N_{EAir} := ceil\left(CManAir \cdot \frac{15}{MT} \cdot W_{F23}\right)$ $\quad N_{EAir} = 576$ $\quad N_E := N_{EAir} + N_{EShip}$ $\quad N_E = 848$

N_T defines the total crew size, N_A the additional accommodations: $N_T := N_{EShip} + N_{OShip} + N_{EAir} + N_{OAir}$ $N_T = 916$

Repair - MOP14: $N_A := ceil(.1 \cdot N_T)$ $N_A = 92$

$VOP_{14} := \frac{CManShip + CManAir}{2}$ $VOP_{14} = 1$

DC - MOP22:

$VOP_{22} := \frac{CManShip + CManAir}{2}$ $VOP_{22} = 1$

Ballast type (1 for compensated, 2 otherwise): $BAL_{TYP} := 1$

Margins: $KG_{MARG} := 1.0 \cdot m$ power: $PMF := 1.1$ weight: $WMF := 0.1$

electrical load: $EDMF := 1.1$ $EFMF := 1.1$ $E24MF := 1.1$

Hull material (will be used for hull structure weight calculation in the weight section later; 1.0 for OS or 0.93 for HTS/HSS) and deckhouse material (1 for aluminum and 2 for steel): $C_{HMAT} := 0.93$ $C_{DHMAT} := 2$

Hull Type (ADH or Conventional): $V_{ADH} := \begin{cases} 0.0 \cdot m^3 & \text{if } [(HullForm = 5) \cdot (DP_{22} = 0)] \\ ((B + 2 \cdot T) \cdot .6 \cdot LWL \cdot 1 \cdot m) & \text{otherwise} \end{cases}$ $VOP_{20} := \begin{cases} 0.0 & \text{if } HullForm = 5 \\ DP_{22} & \text{otherwise} \end{cases}$ $V_{ADH} = 0\ m^3$

$Hull = 0$ $VOP_{20} = 0$

Module 3 - Ship Resistance and Powering

$i := 1, 2 .. 12$ $V_i := i \cdot 2 \cdot knt$ $V_{10} := V_e$ $V_{11} := V_S$

	1
1	2
2	4
3	6
4	8
5	10
6	12
7	14
8	16
9	18
10	20
11	24.5
12	24

$V = $ (table above) $\cdot knt$

3a. Hull Surface Area, Coefficients and Dimensions:

$S_{SD} := \begin{cases} 10 \cdot ft^2 & \text{if } SON_{TYP} = 0 \\ 1400 \cdot ft^2 & \text{if } SON_{TYP} = 1 \\ 80 \cdot ft^2 & \text{if } SON_{TYP} = 2 \end{cases}$ $S_{SD} = 0 \cdot ft^2$ $S_{SD} = 0 \cdot ft^2$

$A_{BT} := \frac{S_{SD}}{5}$ $A_{BT} := 14.811 \cdot m^2$ (bulb section area at FP)

$L_R := (1 - C_P) \cdot LWL$ $L_R = 70.953\ m$ (Run length)

$C_V := \frac{V_{FL}}{LWL^3}$ $C_V = 3.06 \cdot 10^{-3}$ $T_F := T$ $T_F = 7\ m$

$h_B := \sqrt{\frac{A_{BT}}{\pi}}$ $h_B := 3.012 \cdot m$ (height of bulb center)

$C_W = 0.819$

$A_T := \frac{B \cdot T \cdot C_X}{5}$ $A_T := 11.822 \cdot m^2$ (transom area)

$S_i := \begin{cases} (-280.29 \cdot V_i \cdot ft \cdot sec + 81540 \cdot ft^2) \cdot R_{FS}{}^2 + S_{SD} & \text{if } DP_1 = 1 \\ LWL \cdot (2 \cdot T + B) \cdot \sqrt{C_M} \cdot \left(.453 + .4425 \cdot C_B - .2862 \cdot C_M - .003467 \cdot \frac{B}{T} + .3696 \cdot C_W\right) + 2.38 \cdot \frac{A_{BT}}{C_B} + S_{SD} & \text{otherwise} \end{cases}$

$S_1 = 6.31 \cdot 10^3 \cdot m^2$

3b. Viscous Drag

Coefficient of friction:

$R_{N_i} := LWL \cdot \frac{V_i}{\upsilon_{SW}}$ $C_{F_i} := \frac{0.075}{\left(\log(R_{N_i}) - 2\right)^2}$ (ITTC) $C_{f_i} := \frac{0.066}{\left(\log(R_{N_i}) - 2.03\right)^2}$ (ATTC) $R_i := \frac{V_i}{\sqrt{LWL}}$

$formfac := 1.03 \cdot \left[.93 + \left(\frac{T}{LWL}\right)^{.22284} \cdot \left(\frac{B}{L_R}\right)^{.92497} \cdot (.95 - C_P)^{-.521448} \cdot (1 - C_P + .05)^{.6906}\right] + 2.7 \cdot \frac{S_{SD}}{S_1}$

3c. Wave Making Drag

$Fn_{V_i} := \frac{V_i}{\sqrt{V_{FL}{}^{\frac{1}{3}} \cdot g}}$ $Fn_i := \frac{V_i}{\sqrt{g \cdot LWL}}$

FS and US Geosim

$C_{RUS_i} := .0279 \cdot (Fn_{V_i})^2 - .0438 \cdot Fn_{V_i} + .0174$

$C_{RFS_i} := \begin{cases} 0.0411 \cdot (Fn_{V_i})^3 - 0.1019 \cdot (Fn_{V_i})^2 + 0.0858 \cdot Fn_{V_i} - 0.0225 & \text{if } Fn_{V_i} < 1.05 \\ 0.0005 \cdot e^{1.6912 \cdot Fn_{V_i}} & \text{otherwise} \end{cases}$

$C_{RLPD} := 1.0$

$C_{R1} := C_{RFS}$ $\quad C_{R2} := C_{RUS}$

Mercier-Savitsky $\qquad x := Fn_V$

$$A_1 := \begin{cases} -2.5777\cdot(x)^2 + 5.826\cdot x - 3.183 & \text{if } x < 1.3 \\ 0.306\cdot(x)^2 - 0.8724\cdot x + 0.6517 & \text{if } 1.3 \le x < 1.5 \\ -2.6233\cdot(x)^3 + 13.151\cdot(x)^2 - 21.851\cdot x + 12.072 & \text{otherwise} \end{cases}$$

$$A_2 := \begin{cases} 25.957\cdot(x)^2 - 57.89\cdot x + 31.533 & \text{if } x < 1.3 \\ 0 & \text{otherwise} \end{cases}$$

$$A_4 := \begin{cases} 0.1289\cdot(x)^2 - 0.2977\cdot x + 0.1572 & \text{if } x < 1.5 \\ 0 & \text{otherwise} \end{cases}$$

$$A_5 := \begin{cases} 3.8592\cdot(x)^2 - 8.8358\cdot x + 4.9126 & \text{if } x < 1.3 \\ -2.28\cdot(x)^2 + 6.1117\cdot x - 4.143 & \text{if } 1.3 \le x < 1.5 \\ 15.027\cdot(x)^3 - 75.445\cdot(x)^2 + 125.73\cdot x - 69.667 & \text{otherwise} \end{cases}$$

$$A_6 := \begin{cases} 0 & \text{if } x \le 1.1 \\ 4.6418\cdot(x)^2 - 12.243\cdot x + 7.8504 & \text{if } 1.1 < x < 1.4 \\ -2.8417\cdot(x)^3 + 13.864\cdot(x)^2 - 22.39\cdot x + 11.775 & \text{otherwise} \end{cases}$$

$$A_7 := \begin{cases} 6.5917\cdot(x)^3 - 26.223\cdot(x)^2 + 34.006\cdot x - 14.268 & \text{if } x < 1.3 \\ -1.3915\cdot(x)^2 + 3.6749\cdot x - 2.3213 & \text{if } 1.3 \le x < 1.5 \\ 2.0067\cdot(x)^3 - 10.076\cdot(x)^2 + 16.786\cdot x - 9.2203 & \text{otherwise} \end{cases}$$

$$A_8 := \begin{cases} 45.873\cdot(x)^3 - 207.82\cdot(x)^2 + 293.16\cdot x - 130.24 & \text{if } x \le 1.3 \\ -0.95\cdot(x)^2 + 3.396\cdot x - 2.3742 & \text{if } 1.3 < x < 1.5 \\ 16.164\cdot(x)^2 - 50.725\cdot x + 40.302 & \text{if } 1.5 \le x < 1.7 \\ 1.4664\cdot x - 1.7109 & \text{otherwise} \end{cases}$$

$$A_9 := \begin{cases} -0.2767\cdot(x)^3 + 1.0115\cdot(x)^2 - 1.2201\cdot x + 0.4825 & \text{if } x < 1.3 \\ -0.07\cdot(x)^2 + 0.1873\cdot x - 0.1272 & \text{if } 1.3 < x < 1.5 \\ 0.003\cdot(x)^2 - 0.0077\cdot x + 0.0011 & \text{otherwise} \end{cases}$$

$$A_{10} := \begin{cases} 0.818\cdot(x)^2 - 1.68\cdot x + 0.8729 & \text{if } x < 1.2 \\ 0.0632\cdot x - 0.041 & \text{if } 1.2 \le x \le 1.3 \\ 0.5525\cdot(x)^2 - 1.513\cdot x + 1.0742 & \text{if } 1.3 < x < 1.5 \\ 0.0705\cdot(x)^2 - 0.2556\cdot x + 0.2728 & \text{otherwise} \end{cases}$$

$$A_{15} := \begin{cases} 0 & \text{if } x \le 1.4 \\ -4.634\cdot(x)^2 + 14.27\cdot x - 10.89 & \text{if } 1.4 < x < 1.6 \\ -(x)^2 + 3.7781\cdot x - 3.4113 & \text{otherwise} \end{cases}$$

$$A_{18} := \begin{cases} -75.202\cdot(x)^3 + 316.6\cdot(x)^2 - 426.52\cdot x + 183.71 & \text{if } x < 1.3 \\ 13.497\cdot(x)^2 - 36.703\cdot x + 23.978 & \text{if } 1.3 \le x < 1.5 \\ 50.555\cdot(x)^3 - 254.02\cdot(x)^2 + 422.84\cdot x - 234.05 & \text{otherwise} \end{cases}$$

$$A_{19} := \begin{cases} 18.759\cdot(x)^2 - 37.577\cdot x + 19.109 & \text{if } x < 1.2 \\ -6.0175\cdot(x)^2 + 15.384\cdot x - 8.7654 & \text{if } 1.2 \le x < 1.4 \\ 26.448\cdot(x)^3 - 132.36\cdot(x)^2 + 219.25\cdot x - 119.13 & \text{otherwise} \end{cases}$$

$$A_{24} := \begin{cases} -1.4737\cdot(x)^2 + 3.36\cdot x - 1.8559 & \text{if } x \le 1.3 \\ -1.3085\cdot(x)^2 + 3.5534\cdot x + -2.3859 & \text{if } 1.3 < x < 1.5 \\ 0 & \text{otherwise} \end{cases}$$

$$A_{27} := \begin{cases} 0.101\cdot(x)^2 - 0.2304\cdot x + 0.1279 & \text{if } x < 1.3 \\ 0.0875\cdot(x)^2 - 0.2398\cdot x + 0.1628 & \text{if } 1.3 \le x < 1.5 \\ 0 & \text{otherwise} \end{cases}$$

$U := \sqrt{2\cdot i_E}$ $\qquad X := \dfrac{V_{FL}^{\frac{1}{3}}}{LWL}$ $\qquad Y := \dfrac{A_T}{A_X}$ $\qquad Z := \dfrac{V_{FL}}{B^3}$ $\qquad W_m := 100000\ lb$

$$R_{eq} := W_m\cdot\left(A_1 + A_2\cdot X + A_4\cdot U + A_5\cdot Y + A_6\cdot X\cdot Z + A_7\cdot X\cdot U + A_8\cdot X\cdot Y + A_9\cdot Z\cdot U + A_{10}\cdot Z\cdot Y + A_{15}\cdot Y^2 \ldots + A_{18}\cdot X\cdot Y^2 + A_{19}\cdot Z\cdot X^2 + A_{24}\cdot U\cdot Y^2 + A_{27}\cdot Y\cdot U^2\right)$$

$$S_{eq} := \left[2.262\cdot\sqrt{\frac{LWL}{V_{FL}^{\frac{1}{3}}}}\cdot\left[1 + 0.046\cdot\frac{B}{T} + 0.00287\cdot\left(\frac{B}{T}\right)^2\right]\cdot\left(V_{FL}\right)^{\frac{2}{3}}\right] + S_{SD}$$

Holtrop

$c_3 := \dfrac{.56\cdot A_{BT}^{1.5}}{B\cdot T\cdot\left(.31\cdot\sqrt{A_{BT}} + T_F - h_B\right)}$ $\qquad c_3 = 0.03$ $\qquad c_2 := \exp\left(-1.89\cdot\sqrt{c_3}\right)$ $\qquad c_2 = 0.722$

$c_5 := 1 - \dfrac{.8\cdot A_T}{B\cdot T\cdot C_M}$ $\qquad c_5 = 0.951$

$$\lambda_R := \begin{cases} 1.446\cdot C_P - .03\cdot\dfrac{LWL}{B} & \text{if } \dfrac{LWL}{B} < 12 \\ 1.446\cdot C_P - .036 & \text{otherwise} \end{cases}$$ $\qquad \lambda_R = 0.731$

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

$$c_7 := \begin{cases} .229577 \cdot \left(\frac{B}{LWL}\right)^{.33333} & \text{if } \frac{B}{LWL} < .11 \\ .5 - .0625 \cdot \frac{LWL}{B} & \text{if } \frac{B}{LWL} > .25 \\ \frac{B}{LWL} & \text{otherwise} \end{cases} \qquad c_7 = 0.147$$

$$c_{16} := \begin{cases} 8.07981 \cdot C_P - 13.8673 \cdot C_P^2 + 6.984388 \cdot C_P^3 & \text{if } C_P < .8 \\ 1.73014 - .7067 \cdot C_P & \text{otherwise} \end{cases} \qquad c_{16} = 1.314$$

$$i_E := 1 + 89 \cdot \exp\left[-\left(\frac{LWL}{B}\right)^{.80856} \cdot (1 - C_W)^{.30484} \cdot (1 - C_P)^{.6367} \cdot \left(\frac{L_R}{B}\right)^{.34574} \cdot \left(\frac{100 \cdot V_{FL}}{LWL^3}\right)^{.16302}\right] \qquad i_E = 18.787$$

$$c_1 := 2223105 \cdot c_7^{3.78613} \cdot \left(\frac{T}{B}\right)^{1.07961} \cdot (90 - i_E)^{-1.37565} \qquad c_1 = 0.934$$

$$m_1 := .0140407 \cdot \frac{LWL}{T} - 1.75254 \cdot \frac{V_{FL}^{\frac{1}{3}}}{LWL} - 4.79323 \cdot \frac{B}{LWL} - c_{16} \qquad m_1 = -1.87$$

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

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

$$P_B := \frac{.56 \cdot A_{BT}^{.5}}{(T_F - 1.5 \cdot h_B)} \qquad P_B = 0.868$$

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

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

3d. Bare Hull Resistance

$$C_A := .0005 \qquad R_{A_i} := .5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_A$$

$$R_{V_i} := \begin{cases} 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{F_i} & \text{if HullForm} = 1 \\ 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{F_i} & \text{if HullForm} = 2 \\ \left[(C_{F_i} - C_{f_i} + C_A) \cdot \frac{1}{2} \cdot \frac{S_{eq}}{V_{FL}^{\frac{2}{3}}} \cdot (x_i)^2\right] \cdot W_{FL} & \text{if HullForm} = 3 \\ 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{F_i} \cdot formfac & \text{otherwise} \end{cases}$$

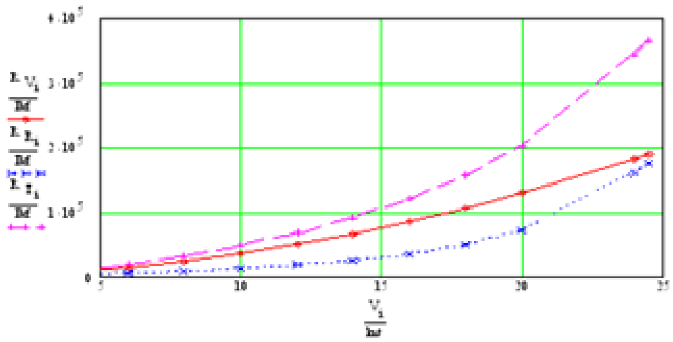
$$RR_i := \frac{R_i}{\left(\frac{knt}{\sqrt{ft}}\right)}$$

$$A := READPRN\ (\text{"worm.prn"})$$

$$WCF_i := \begin{array}{l} j \leftarrow 1 \\ \text{while } RR_i > A_{j+1,1} \\ \quad j \leftarrow j + 1 \\ A_{j,2} + \frac{A_{j+1,2} - A_{j,2}}{0.05} \cdot (RR_i - A_{j,1}) \end{array}$$

$$R_{R_i} := \begin{cases} 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{R1_i} & \text{if HullForm} = 1 \\ 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{R2_i} & \text{if HullForm} = 2 \\ \frac{R_{eq_i}}{W_m} \cdot W_{FL} & \text{if HullForm} = 3 \\ WCF_i \cdot (R_{w_i} + R_{B_i} + R_{TR_i} + R_{A_i}) & \text{if HullForm} = 6 \\ R_{w_i} + R_{B_i} + R_{TR_i} + R_{A_i} & \text{otherwise} \end{cases}$$

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



3e. Ship Effective Horsepower

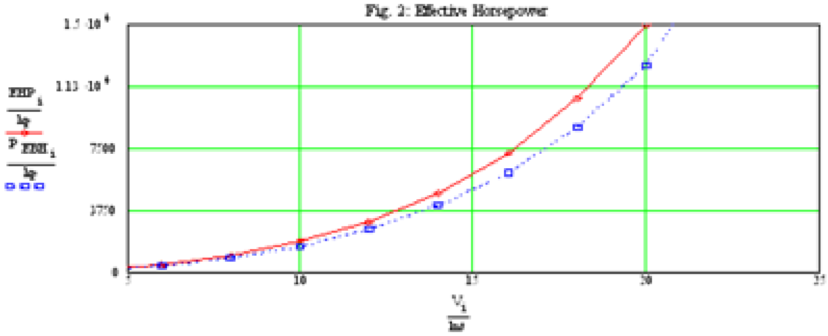
Bare hull: $P_{EBH_i} := R_{T_i} \cdot V_i$ $P_{Efins_i} := \begin{cases} 0 \cdot hp & \text{if } N_{fins} = 0 \\ 0.02 \cdot P_{EBH_i} & \text{otherwise} \end{cases}$ $P_{EAPP_i} := \begin{cases} 0 \cdot hp & \text{if HullForm} = 1 \\ 0.05 \cdot P_{EBH_i} & \text{otherwise} \end{cases}$

Air frontal area (+5% for masts, equip., etc): $A_W := 1.05 \cdot B \cdot (D_{10} - T + H_{DK})$ $A_W = 701.915 \; m^2$

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

Total effective horsepower: $P_{ET_i} := P_{EBH_i} + P_{EAA_i} + P_{EAPP_i} + P_{Efins_i}$ $EHP_i := PMF \cdot P_{ET_i}$ $PMF = 1.1$

Fig. 2: Effective Horsepower



3f. Propulsion Power Balance

Approximate propulsive coefficient: $PC := 0.72$ $V_{10} = 20 \cdot knt$ $V_{11} = 24.5 \cdot knt$

$SHP_i := \frac{EHP_i}{PC}$ $SHP_S := SHP_{11}$ $SHP_S = 4.54 \cdot 10^4 \; hp$ $SHP_e := SHP_{10}$ $SHP_e = 2.066 \cdot 10^4 \; hp$

Required installed power (with 25% for fouling and sea state): $P_{IREQ} := \frac{1.25 \cdot SHP_S}{\eta}$ $P_{IREQ} = 61684.3 \; hp$

Module 4 - Space Available

4a. Underwater available hull volume: $V_{HUW} := V_{FL}$

4b. Above waterline available hull volume:

For sheer line, choose from 3 criteria: - keep deck edge above water at 25 ^{0} heel (DDS-079-1).
- ensure longitudinal strength.
- contain machinery box (in height).

$M := \begin{bmatrix} 0.21 \cdot B + T \\ \frac{LWL}{15} \\ H_{MBreq} + N_{HANGDK} \cdot H_{HANGDK} + 1 \cdot m \end{bmatrix}$ $M = \begin{pmatrix} 13.203 \\ 13.4 \\ 25.63 \end{pmatrix} m$ $D_{10MIN} := \max(M)$ $D_{10MIN} = 25.63 \; m$

$D_{0MIN} := 2.011827 \cdot T - \frac{6.36215 \cdot 10^{-6}}{ft} \cdot LWL^2 + 2.780649 \cdot 10^{-2} \cdot LWL$ $D_{0MIN} = 18.829 \; m$ $D_0 := D_{10}$ $D_0 = 26.63 \; m$

$D_{20MIN} := 0.014 \cdot LWL \cdot \left(2.125 + \frac{1.25 \cdot 10^{-3}}{ft} \cdot LWL\right) + T$ $D_{20MIN} = 15.299 \; m$ $D_{20} := D_{10}$ $D_{20} = 26.63 \; m$

$F_0 := D_0 - T$ $F_{10} := D_{10} - T$ $F_{20} := D_{20} - T$ (Assuming zero trim)

$A_{PRO} := \frac{LWL}{0.98} \cdot \frac{F_0 + 4 \cdot F_{10} + F_{20}}{6}$ (Trapezoidal rule) $flare := \begin{cases} -10 \cdot deg & \text{if HullForm} = 6 \\ 0 \cdot deg & \text{otherwise} \end{cases}$ $C_W = 0.819$

$F_{AV} := \frac{A_{PRO}}{LWL}$ $F_{AV} = 20.031 \; m$ $D_{AV} := F_{AV} + T$ $D_{AV} = 27.031 \; m$ $F_{AV} = 65.717 \; ft$

Above water hull volume: $V_{HAW} := F_{AV}^2 \cdot \tan(\text{flare}) \cdot LWL + LWL \cdot B \cdot C_W \cdot F_{AV}$ $V_{HAW} = 9.741 \cdot 10^4\ m^3$

Total hull volume: $V_{HT} = V_{HUW} + V_{HAW}$ $V_{HT} = 1.223 \cdot 10^5\ m^3$ $V_{HUW} = 2.485 \cdot 10^4 \cdot m^3$

Cubic number: $CN := \frac{V_{HT}}{10^5 \cdot ft^3}$ $CN = 43.173$

Total ship volume: $V_T = V_{HT} + V_D$ $V_T = 127470.34\ m^3$

Machinery box

$H_{MB} = 7.63\ m$ $V_{MB} := \frac{H_{MB}}{H_{MBreq}} \cdot V_{MBreq}$ $V_{MB} = 8.273 \cdot 10^3\ m^3$

Module 5 - Electrical Load

Based on DDS 310-1. Estimate maximum functional load for winter cruise condition:

(SWBS 200, propulsion). $KW_P := 0.00323 \cdot \frac{kW}{hp} \cdot P_{BPENGTOT}$ $KW_P = 281.333 \cdot kW$

(SWBS 561, steering). $KW_S := 0.00826 \cdot \frac{kW}{ft^2} \cdot LWL \cdot T$ $KW_S = 125.096 \cdot kW$

$V_T = 1.275 \cdot 10^5\ m^3$

(SWBS 300, electric plant, lighting). $KW_E = 0.000213 \cdot \frac{kW}{ft^3} \cdot V_T$ $KW_E = 958.835 \cdot kW$

(SWBS 430+475, miscelaneous). $KW_M := 101.4 \cdot kW$ $KW_M = 101.4 \cdot kW$

(Collective Protection System) $KW_{CPS} = 0.000135 \cdot \frac{kW}{ft^3} \cdot V_T$ $KW_{CPS} = 607.712 \cdot kW$

(SWBS 517, aux boiler). $KW_B := 0.235 \cdot N_T \cdot kW$ $KW_B = 215.26 \cdot kW$

(SWBS 521, firemain). $KW_F = 0.000097 \cdot \frac{kW}{ft^3} \cdot V_T$ $KW_F = 436.653 \cdot kW$

(SWBS 540, fuel handling). $KW_{HN} := 0.000177 \cdot \frac{kW}{ft^3} \cdot V_{HT}$ $KW_{HN} = 764.163 \cdot kW$

(SWBS 530+550, misc aux). $KW_A = 0.65 \cdot N_T \cdot kW + KW_{fins}$ $KW_A = 595.4 \cdot kW$

(SWBS 600, services). $KW_{SERV} := 0.395 \cdot N_T \cdot kW$ $KW_{SERV} = 361.82 \cdot kW$

The calculations are iterative, because KW_H, KW_V and KW_{AC} depend on V_{AUX}, which depends on the maximal functional load. Non payload functional load (without the above mentioned loads):

$KW_{NP} := KW_P + KW_S + KW_E + KW_M + KW_B + KW_F + KW_{HN} + KW_A + KW_{SERV}$ (non-Payload)

Maximum Functional Load: (Summer AC assumed worse case) $KW_{NP} = 3.84 \cdot 10^4\ W$

$$KW_{MFL} = \begin{array}{|l} KW_{MFL} \leftarrow 1000 \cdot kW \\ KW_X \leftarrow 0 \cdot kW \\ \text{while } \left|\frac{KW_{MFL} - KW_X}{KW_{MFL}}\right| > 0.01 \\ \quad \begin{array}{|l} KW_X \leftarrow KW_{MFL} \\ V_{AUX} \leftarrow 40000 \cdot \frac{ft^3}{kW} \cdot \frac{KW_X}{3411} \\ KW_{AC} \leftarrow 0.67 \cdot \left[0.1 \cdot kW \cdot N_T + 0.00067 \cdot \frac{kW}{ft^3} \cdot (V_T - V_{MB} - V_{AUX}) + 0.1 \cdot BATKW_{PAY}\right] \\ KW_V \leftarrow 0.103 \cdot (KW_{AC} + BATKW_{PAY}) + KW_{CPS} \\ KW_{MFL} \leftarrow KW_{NP} + KW_V + KW_{AC} + BATKW_{PAY} \end{array} \\ KW_{MFL} \end{array}$$

$KW_{MFL} = 7.376 \cdot 10^3 \cdot kW$ $EDMF = 1.1$ $EFMF = 1.1$

$KW_{MFLM} := EDMF \cdot EFMF \cdot KW_{MFL}$ $KW_{MFLM} = 8.925 \cdot 10^3 \cdot kW$ (MFL w/margins)

The iterative process yields: $TRANKW_{PAY} = 636.27 \cdot kW$

$V_{AUX} = 40000 \cdot \frac{ft^3}{kW} \cdot \frac{KW_{MFL}}{3411}$

$KW_{AC} = 0.67 \cdot \left[0.1 \cdot kW \cdot N_T + 0.00067 \cdot \frac{kW}{ft^3} \cdot (V_T - V_{MB} - V_{AUX}) + 0.1 \cdot BATKW_{PAY}\right]$ $KW_{AC} = 1.959 \cdot 10^3 \cdot kW$

$KW_V := 0.103 \cdot (KW_{AC} + BATKW_{PAY}) + KW_{CPS}$ (Ventilation) $KW_V = 881.213 \cdot kW$

Power required per generator for mechanical drive system, with one in stand-by:

$$KW_{GREQmech} := \begin{array}{|l} \frac{KW_{MFLM}}{(N_{SSG} - 1) \cdot 0.9} \text{ if } PSYS_{TYP} = 1 \\ 0.0 \cdot kW \text{ otherwise} \end{array}$$ $KW_{GREQmech} = 0 \cdot kW$

The 0.9 compensates for possible voltage fluctuations. 24 hour electrical load:

$KW_{24} := 0.5\cdot(KW_{MFLM} - KW_P - KW_S) + 1\cdot(KW_P + KW_S)$ $\quad KW_{24} = 4.666\cdot10^3\cdot kW$

Including design margin: $KW_{24AVG} := E24MF\cdot KW_{24}$ $\quad KW_{24AVG} = 5.132\cdot10^3\cdot kW$

Maximal continuous brake horsepower for propulsion: $PSYS_{TYP} = 2$

$P_{IPRP} := \begin{cases} P_{BPENGTOT} & \text{if } PSYS_{TYP}=1 \\ P_{BPENGTOT} - KW_{MFLM} & \text{otherwise} \end{cases}$ $\quad P_{BPENGTOT} = 6.495\cdot10^4\cdot kW$ $\quad P_{IPRP} = 5.603\cdot10^4\cdot kW$ $\quad P_{IPRP} = 7.513\cdot10^4\cdot hp$

Module 6 - Tankage, Required Volume and Area

6a. Fuel Tankage Based on [3]. Start with fuel for propulsion systems.

Average endurance brake horsepower required (includes 10% margin for fouling and sea state):

$P_{eBAVG} := \frac{1.1\cdot SHP_e}{\eta}$ $\quad P_{eBAVG} = 2.47\cdot10^4\cdot hp$

Correction for instrumentation inaccuracy and machinery design changes:

$f_1 := \begin{cases} 1.04 & \text{if } 1.1\cdot SHP_e \le \frac{1}{3}\cdot\frac{P_{BPENGTOT}}{2} \\ 1.03 & \text{if } 1.1\cdot SHP_e \ge \frac{2}{3}\cdot\frac{P_{BPENGTOT}}{2} \\ 1.02 & \text{otherwise} \end{cases}$ $\quad SFC_{ePE} = 0.326\cdot\frac{lb}{hp\cdot hr}$ $\quad \frac{lb}{hp\cdot hr} = 1.341\cdot\frac{lb}{kW\cdot hr}$

Specified fuel rate: $FR_{SP} := f_1\cdot SFC_{ePE}\cdot\epsilon$ $\quad FR_{SP} = 1.506\cdot10^{-4}\cdot\frac{MT}{hp\cdot hr}$

Average fuel rate allowing for plant deterioration: $FR_{AVG} := 1.05\cdot FR_{SP}$ $\quad FR_{AVG} = 1.581\cdot10^{-4}\cdot\frac{MT}{hp\cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e}\cdot P_{eBAVG}\cdot FR_{AVG}$ $\quad W_{BP} = 781.087\cdot MT$

Tailpipe allowance: $TPA := 0.95$

Required propulsion fuel weight: $W_{FP} := \frac{W_{BP}}{TPA}$ $\quad W_{FP} = 822.197\cdot MT$

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

$V_{FP} := 1.02\cdot1.05\cdot\delta_F\cdot W_{FP}$ $\quad V_{FP} = 1.038\cdot10^3\ m^3$

Fuel for generator systems: $SFC_{GE24} := SFC_{ePE}$ $\quad SFC_{GE24} = 0.198\cdot\frac{kg}{kW\cdot hr}$

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

Specified fuel rate: $FR_{GSP} := f_{1e}\cdot SFC_{GE24}\cdot\epsilon$

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05\cdot FR_{GSP}$ $\quad FR_{GAVG} = 2.162\cdot10^{-4}\cdot\frac{MT}{kW\cdot hr}$

Burnable electrical endurance fuel weight: $W_{Be} := \frac{E}{V_e}\cdot KW_{24AVG}\cdot FR_{GAVG}$ $\quad W_{Be} = 221.944\cdot MT$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $\quad W_{Fe} = 233.626\cdot MT$

Required electrical fuel volume: $V_{Fe} := 1.02\cdot1.05\cdot\delta_F\cdot W_{Fe}$ $\quad V_{Fe} = 294.973\ m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $\quad W_{F41} = 1.056\cdot10^3\cdot MT$

$V_F := V_{FP} + V_{Fe}$ $\quad V_F = 1.333\cdot10^3\ m^3$

6b. Other Tanks

Aircraft fuel: $V_{AF} := 1.02\cdot1.05\cdot W_{F42}\cdot\delta_{AF}$ $\quad V_{AF} = 2.005\cdot10^3\ m^3$

Lubrication oil: $W_{F46} := 17.6\cdot lton$ $\quad V_{LO} := 1.02\cdot1.05\cdot W_{F46}\cdot\delta_{LO}$ $\quad V_{LO} = 20.817\ m^3$

Potable water: (Water does not expand). $W_{F52} := N_T\cdot0.45\cdot lton$ $\quad W_{F52} = 418.815\cdot MT$

$V_W := 1.02\cdot W_{F52}\cdot\delta_W$ $\quad V_W = 428.603\ m^3$

Sewage: $V_{SEW} := (N_T + N_A)\cdot2.005\cdot ft^3$ $\quad V_{SEW} = 57.229\ m^3$

Waste oil: $V_{WASTE} := 0.02\cdot V_F$ $\quad V_{WASTE} = 26.661\ m^3$

Clean ballast: $V_{BAL} := \text{if}(BAL_{TYP}=1, 0.19\cdot V_F, 0.275\cdot V_F)$ $\quad V_{BAL} = 253.283\ m^3$

Total tankage volume required: $V_{TK} := V_F + V_{AF} + V_{LO} + V_W + V_{SEW} + V_{WASTE} + V_{BAL}$ $\quad V_{TK} = 4.124\cdot10^3\ m^3$

6c. Required Area $V_{TK} := \mathrm{if}(5 \cdot V_{ADH} > V_{TK}, V_{ADH}, V_{TK} + 5 \cdot V_{ADH})$

Ship Warfighting Payload Deck Areas:

Deckhouse payload area (including access): $A_{DPR} := 1.15 \cdot A_{DPA} + 1.23 \cdot A_{DPC}$ $A_{DPR} = 972.337\ m^2$

Hull payload area (including access): $A_{HPR} := 1.15 \cdot A_{HPA} + 1.23 \cdot A_{HPC}$ $A_{HPR} = 4.134 \cdot 10^3\ m^2$

Hangar Deck Area

$A_{AirPark} := N_{UAV} \cdot A_{UAV} + N_{UCAV} \cdot A_{UCAV} + N_{HELO} \cdot A_{HELO}$ $A_{AirPark} = 2.824 \cdot 10^3\ m^2$ $DP_s = 1$

$A_{AirElev} := 2 \cdot A_{UCAV} \cdot N_{AirElev} \cdot N_{HANGDK}$ $A_{AirElev} = 849.572\ m^2$ $A_{AirPr} := \begin{cases} 3 \cdot A_{UCAV} & \text{if } DP_s = 1 \\ 0 \cdot m^2 & \text{otherwise} \end{cases}$

$A_{AirPr} = 217.393\ m^2$

$A_{AirMaint} := 2 \cdot A_{UCAV}$ $A_{AirMaint} = 144.929\ m^2$ $A_{AirLaunch} := \begin{cases} 100 \cdot m \cdot B_{FMreq} + 3 \cdot A_{UCAV} & \text{if } DP_s = 1 \\ 0 \cdot m^2 & \text{otherwise} \end{cases}$

$A_{AirLaunch} = 2.717 \cdot 10^3\ m^2$ $A_{HIF} = 204.75\ m^2$

$A_{HangarReq} := (A_{AirPark} + A_{AirElev} + A_{AirPr} + A_{AirMaint} + A_{WeapElev}) \cdot 1.3 + A_{AirLaunch} + A_{HIF}$

$A_{HangarReq} = 8.24 \cdot 10^3\ m^2$ $A_{HANGmax} = 1.094 \cdot 10^4\ m^2$ $V_{HANG} := A_{HangarReq} \cdot H_{HANGDK}$ $V_{HANG} = 4.956 \cdot 10^4\ m^3$

Living Deck Area

Assumption is that officers live at deckhouse, and enlisted at hull. At deckhouse:

$A_{COXO} := 225 \cdot ft^2$ $A_{DO} := 75 \cdot N_O \cdot ft^2$ $A_{DL} := A_{COXO} + A_{DO}$ $A_{DL} = 494.789\ m^2$

At hull: $A_{HAB} := 50 \cdot ft^2$ $A_{HL} := A_{HAB} \cdot (N_T + N_A) - A_{DL}$ $A_{HL} = 4.188 \cdot 10^3\ m^2$

Other Ship areas:

Hull stores: $A_{HS} := 300 \cdot ft^2 + 0.0155 \cdot \frac{ft^2}{lb} \cdot N_T \cdot 9 \cdot \frac{lb}{day} \cdot T_S$ $A_{HS} = 1.48 \cdot 10^3\ m^2$

Ship Maintenance: $A_{DM} := 0.05 \cdot (A_{DPR} + A_{DL})$ $A_{DM} = 73.352\ m^2$

Bridge and chart room: $A_{DB} := 14 \cdot ft \cdot (B - 18 \cdot ft)$ $A_{DB} = 117.305\ m^2$

Ship functions in hull: $A_{HSF} := 1500 \cdot ft^2 \cdot CN$ $A_{HSF} = 6.016 \cdot 10^3\ m^2$

6d. Total Required Area/Volume

Hull: $A_{HR} := A_{HPR} + A_{HL} + A_{HS} + A_{HSF} + A_{LandR} + A_{AirMaintShop} + A_{AirFuel} + (A_{DL} + A_{DM} + A_{DB})$

$A_{HR} = 1.995 \cdot 10^4\ m^2$

$V_{HR} := H_{DK} \cdot A_{HR}$ $V_{HR} = 5.904 \cdot 10^4\ m^3$

Deckhouse: $A_{DR} := A_{DPR}$ $A_{DR} = 972.337\ m^2$

$V_{DR} := H_{DK} \cdot A_{DR}$ $V_{DR} = 2.917 \cdot 10^3\ m^3$

Total: $A_{TR} := A_{HR} + A_{DR}$ $A_{TR} = 2.093 \cdot 10^4\ m^2$

$V_{TR} := V_{HR} + V_{DR}$ $V_{TR} = 6.278 \cdot 10^4\ m^3$

Available hull volume: $V_{HA} := V_{HT} - V_{MB} - V_{AUX} - V_{TK} - V_{HANG}$ $V_{HA} = 5.784 \cdot 10^4\ m^3$

Available hull area: $A_{HA} := \frac{V_{HA}}{H_{DK}}$ $A_{HA} = 1.928 \cdot 10^4\ m^2$

Available deckhouse area: $A_{DA} := \frac{V_D}{H_{DK}}$ $A_{DA} = 1.739 \cdot 10^3\ m^2$

Total available area: $A_{TA} := A_{HA} + A_{DA}$ $V_{TA} := H_{DK} \cdot A_{TA}$ $A_{TA} = 2.102 \cdot 10^4\ m^2$

Area effectiveness: $ERR_A := \frac{A_{TA} - A_{TR}}{A_{TR}}$ $ERR_A = 4.473 \cdot 10^{-3}$

Module 7 - Weight

SWBS 200

$W_{BM} = 1.07 \cdot 10^3 \cdot MT$ (SWBS 200 minus 243-245)

Shafting (SWBS 243): $f_S := \mathrm{if}(N_{prop} = 1, 0.3, 0.45)$ $f_S := \mathrm{if}(PSYS_{TYP} = 1, f_S, N_{prop} \cdot 1)$ $f_S = 0.2$

$W_S := 0.47 \cdot \frac{lton}{ft} \cdot LWL \cdot f_S$ $W_S = 62.983\ MT$

$D_P := 7 \cdot T$ $D_P = 4.9\ m$

Propellors (245): FP: $f_{PR} := 0.08$ $W_{PR} := f_{PR} \cdot lbf \cdot \left(\frac{D_P}{ft}\right)^{5.497 - \frac{0.0433}{ft} \cdot D_P} \cdot N_{prop}$ $W_{PR} = 47.049\ MT$

Bearings (244): $W_B := 0.11 \cdot (W_S + W_{PR})$ $W_B = 12.106\ MT$ CRP: $f_{PR} = 1.27$

Total 243-245: $W_{ST} := W_S + W_B + W_{PR}$ $W_{ST} = 122.138\ MT$

Total for propulsion: $W_2 := W_{BM} + W_{ST}$ $W_2 = 1.192 \cdot 10^3 \cdot MT$ $KW_{MFLM} = 8.905 \cdot 10^3 \cdot kW$

SWBS 300

$W_{BMG} = 133.9\ MT$ (SWBS 300 minus 320-330) $LWL = 659.449\ ft$

$W_{dist} := 0.003 \cdot \frac{MT}{kW \cdot m} \cdot KW_{MFLM} \cdot LWL$ $W_{dist} = 538.198\ MT$ $0.003 \cdot \frac{MT}{kW \cdot m} = 9 \cdot 10^{-5} \cdot \frac{lton}{kW \cdot ft}$

$W_{lght} := 0.01 \cdot \frac{MT}{m^3} \cdot (V_T - V_{TK})$ $W_{lght} = 123.344\ MT$ $0.01 \cdot \frac{MT}{m^3} = 2.787 \cdot 10^{-5} \cdot \frac{lton}{ft^3}$

$W_3 := W_{BMG} + W_{dist} + W_{lght}$ $W_3 = 794.444\ MT$

SWBS 400 - Command and Surveillance

Gyro/IC/Navigation (420+430): $W_{IC} := 2.95 \cdot 10^{-5} \cdot \frac{lton}{ft^3} \cdot V_T$ $W_{IC} = 134.927 \cdot MT$

Other/Misc: $W_{CO} := 1.05 \cdot CN \cdot lton$ $W_{CO} = 46.059 \cdot MT$

Cabling: $W_{CC} := 0.14 \cdot (W_{P400} + W_{IC} + W_{CO})$ $W_{CC} = 39.476 \cdot MT$

Total (less W498): $W_4 := W_{P400} + W_{IC} + W_{CO} + W_{CC}$ $W_4 = 321.447 \cdot MT$

SWBS 500

Aux system operating fluids: $W_{598} := 0.0000745 \cdot V_T \cdot \frac{lton}{ft^3}$ $W_{598} = 340.749 \cdot MT$

$$W_{AUX} := \left[0.000772 \cdot \left(\frac{V_T}{ft^3}\right)^{1.443} + 5.14 \cdot \frac{V_T}{ft^3} + 6.19 \cdot \left(\frac{V_T}{ft^3}\right)^{0.7224} + 377 \cdot N_T + 2.74 \cdot \frac{P_{BPENGTOT}}{hp}\right] \cdot 10^{-4} \cdot lton \cdot 82$$

$W_{AirAux} := W_{WeapElev} + W_{ACElev} + W_{AirL} + W_{AirRec} + W_{AirSupE}$ $W_{AirAux} = 939.483 \cdot lton$ $W_{AUX} = 2.266 \cdot 10^3 \cdot MT$

Environmental support: $W_{593} := .032 \cdot MT \cdot N_T$ $W_{593} = 29.312 \cdot MT$ $.032 \cdot MT = 0.031 \cdot lton$

Total: $W_5 := W_{AUX} + W_{P500} + W_{593} + W_{598} + W_{CPS} + W_{AirAux}$ $W_5 = 3.659 \cdot 10^3 \cdot MT$

SWBS 600

Hull fittings (610+620+630): $W_{OFH} := \frac{0.00025}{ft^3} \cdot (V_T - V_{TK}) \cdot lton$ $W_{OFH} = 1.106 \cdot 10^3 \cdot MT$

Personnel related (640+650+660+670): $W_{OFP} := 0.8 \cdot (N_T - 9.5) \cdot lton$ $W_{OFP} = 736.837 \cdot MT$

Total: $W_6 := W_{OFH} + W_{OFP} + W_{P600}$ $W_6 = 1.843 \cdot 10^3 \cdot MT$

SWBS 100

Hull (110 .. 140,160,190):

$W_{BH} := C_{HMAT} \cdot 1.0 \cdot (1.68341 \cdot CN^2 + 167.1721 \cdot CN - 103.283) \cdot lton$ $CN = 43.173$

$W_{BH} := \begin{cases} 1.1 \cdot W_{BH} & \text{if } DP_{22} = 1 \\ W_{BH} & \text{otherwise} \end{cases}$ $DP_{22} = 0$ $W_{BH} = 9.687 \cdot 10^3 \cdot MT$

Deckhouse (150): $\rho_{DH} := \text{if}(C_{DHMAT} = 1, 0.00168, .0007)$ $C_{DHMAT} = 2$

$W_{DH} := \rho_{DH} \cdot \frac{lton}{ft^3} \cdot V_D$ $W_{DH} = 131.056 \cdot MT$

Masts (171): (Assuming the same mast). $W_{171} := 2 \cdot lton$

Foundations (180): $W_{180} := 0.0735 \cdot (W_{BH} + W_2 + W_3 + W_4 + W_5 + W_6 + W_7)$ $W_{180} = 1.289 \cdot 10^3 \cdot MT$

Total: $W_1 := W_{BH} + W_{DH} + W_{171} + W_{180} + W_{P100}$ $W_1 = 1.111 \cdot 10^4 \cdot MT$

Weight Summary

SWBS weight: $W_{SWBS} := \sum_{i=1}^{7} W_i$ $W_{SWBS} = 1.897 \cdot 10^4 \cdot MT$

Margin for future growth: $W_{M24} := WMF \cdot \left(\sum_{i=1}^{7} W_i\right)$ $W_{M24} = 1.897 \cdot 10^3 \cdot MT$

Lightship weight: $W_{LS} := \sum_{i=1}^{7} W_i + W_{M24}$ $W_{LS} = 2.086 \cdot 10^4 \cdot MT$

Provisions: $W_{F31} := N_T \cdot 2.45 \cdot 10^{-3} \cdot \frac{lton}{day} \cdot T_S$ $W_{F31} = 273.625 \cdot MT$

General stores: $W_{F32} := 0.00071 \cdot \frac{lton}{day} \cdot T_S \cdot N_T + 0.0049 \cdot lton \cdot N_T$ $W_{F32} = 83.856 \cdot MT$

Crew: $W_{F10} := 236 \cdot lbf \cdot N_E + 400 \cdot lbf \cdot (N_O + 1)$ $W_{F10} = 103.296 \cdot MT$

Total weight:

$W_T := W_{LS} + W_P + W_{F41} + W_{F46} + W_{F52} + W_{F31} + W_{F32} + W_{F10}$ $W_T = 2.549 \cdot 10^4 \cdot MT$

$ERR := \frac{W_{FL} - W_T}{W_T}$ $ERR = 7.952 \cdot 10^{-6}$ $F_P := \frac{W_P}{W_T}$ $F_P = 0.105$

Module 8 - Stability

Calculate light ship weight groups center of gravity and moment.

$VCG_{BH} := 0.4 \cdot D_{10}$ $\quad VCG_{BH} = 10.652\ m$ $\quad P_1 := W_{BH} \cdot VCG_{BH}$ $\quad P_1 = 1.032 \cdot 10^5 \cdot MT \cdot m$

$VCG_{DH} := D_{10} + .5 \cdot H_{DK}$ $\quad VCG_{DH} = 28.13\ m$ $\quad P_2 := W_{DH} \cdot VCG_{DH}$ $\quad P_2 = 3.687 \cdot 10^3 \cdot MT \cdot m$

$VCG_{180} := 0.2 \cdot D_{10}$ $\quad VCG_{180} = 5.326\ m$ $\quad P_3 := W_{180} \cdot VCG_{180}$ $\quad P_3 = 6.866 \cdot 10^3 \cdot MT \cdot m$

$VCG_{171} := D_{10} + 0.05 \cdot LWL$ $\quad VCG_{171} = 36.68\ m$ $\quad P_4 := W_{171} \cdot VCG_{171}$ $\quad P_4 = 74.537 \cdot MT \cdot m$

$P_{100} := P_1 + P_2 + P_3 + P_4 + W_{P100} \cdot VCG_{P100}$ $\quad VCG_{100} := \frac{P_{100}}{W_1}$ $\quad VCG_{100} = 10.248\ m$

$VCG_{200} := .6 \cdot H_{MB} + 2 \cdot m$ $\quad VCG_{200} = 6.578\ m$ $\quad P_{200} := W_2 \cdot VCG_{200}$ $\quad P_{200} = 7.841 \cdot 10^3 \cdot MT \cdot m$

$VCG_{300} := 0.35 \cdot D_{10}$ $\quad VCG_{300} = 9.32\ m$ $\quad P_{300} := W_3 \cdot VCG_{300}$ $\quad P_{300} = 7.405 \cdot 10^3 \cdot MT \cdot m$

$VCG_{IC} := .5 \cdot D_{10}$ $\quad VCG_{IC} = 13.315\ m$ $\quad P_9 := W_{IC} \cdot VCG_{IC}$ $\quad P_9 = 1.797 \cdot 10^3 \cdot MT \cdot m$

$VCG_{CO} := 0.45 \cdot D_{10}$ $\quad VCG_{CO} = 11.983\ m$ $\quad P_{10} := W_{CO} \cdot VCG_{CO}$ $\quad P_{10} = 551.95 \cdot MT \cdot m$

$VCG_{CC} := 0.45 \cdot D_{10}$ $\quad VCG_{CC} = 11.983\ m$ $\quad P_{11} := W_{CC} \cdot VCG_{CC}$ $\quad P_{11} = 473.061 \cdot MT \cdot m$

$P_{400} := P_9 + P_{10} + P_{11} + W_{P400} \cdot VCG_{P400}$ $\quad VCG_{400} := \frac{P_{400}}{W_4}$ $\quad VCG_{400} = 15.687\ m$

$VCG_{AUX} := 0.4 \cdot D_{10}$ $\quad VCG_{AUX} = 10.652\ m$ $\quad P_{13} := W_{AUX} \cdot VCG_{AUX}$ $\quad P_{13} = 2.414 \cdot 10^4 \cdot MT \cdot m$

$P_{500} := P_{13} + W_{P500} \cdot VCG_{P500}$ $\quad VCG_{500} := \frac{P_{500}}{W_5}$ $\quad VCG_{500} = 6.629\ m$

$VCG_{OFH} := 0.4 \cdot D_{10}$ $\quad VCG_{OFH} = 10.652\ m$ $\quad P_{15} := W_{OFH} \cdot VCG_{OFH}$ $\quad P_{15} = 1.179 \cdot 10^4 \cdot MT \cdot m$

$VCG_{OFP} := 0.6 \cdot D_{10}$ $\quad VCG_{OFP} = 15.978\ m$ $\quad P_{16} := W_{OFP} \cdot VCG_{OFP}$ $\quad P_{16} = 1.177 \cdot 10^4 \cdot MT \cdot m$

$P_{600} := P_{15} + P_{16} + W_{P600} \cdot VCG_{P600}$ $\quad VCG_{600} := \frac{P_{600}}{W_6}$ $\quad VCG_{600} = 12.781\ m$

Total light ship vertical moment is (note that variable payload is deducted):

$P_{WG} := P_{100} + P_{200} + P_{300} + P_{400} + P_{500} + P_{600} + W_7 \cdot VCG_{700}$ $\quad P_{WG} = 1.829 \cdot 10^5 \cdot MT \cdot m$

Vertical CG of light ship: $\quad VCG_{LS} := \frac{P_{WG}}{W_{LS} - W_{M24}}$ $\quad VCG_{LS} = 9.644\ m$ $\quad VCD_{VP} = -10.32\ m$

Here we assume that the 10% weight margin's CG location is at the CG of light ship.

$KG_{LS} := VCG_{LS}$ $\quad KG_{LS} = 9.644\ m$ $\quad W_{LS} = 2.086 \cdot 10^4 \cdot MT$ $\quad W_{VP} = 2.514 \cdot 10^3 \cdot MT$ $\quad VCG_{VP} = 16.31\ m$ $\quad D_{10} = 26.63\ m$

Calculate variable loads weight group center of gravity and moment:

$VCG_{F10} := 0.6 \cdot D_{10}$ $\quad VCG_{F10} = 15.978\ m$ $\quad P_{17} := W_{F10} \cdot VCG_{F10}$ $\quad P_{17} = 1.65 \cdot 10^3 \cdot MT \cdot m$

$VCG_{F31} := 0.423 \cdot D_{AV}$ $\quad VCG_{F31} = 11.434\ m$ $\quad P_{18} := W_{F31} \cdot VCG_{F31}$ $\quad P_{18} = 3.129 \cdot 10^3 \cdot MT \cdot m$

$VCG_{F32} := 0.42 \cdot D_{AV}$ $\quad VCG_{F32} = 11.353\ m$ $\quad P_{19} := W_{F32} \cdot VCG_{F32}$ $\quad P_{19} = 952.005 \cdot MT \cdot m$

$VCG_{F41} := 1 \cdot m$ $\quad VCG_{F41} = 1\ m$ $\quad P_{20} := W_{F41} \cdot VCG_{F41}$ $\quad P_{20} = 1.056 \cdot 10^3 \cdot MT \cdot m$

$VCG_{F46} := 2 \cdot m$ $\quad VCG_{F46} = 2\ m$ $\quad P_{21} := W_{F46} \cdot VCG_{F46}$ $\quad P_{21} = 35.765 \cdot MT \cdot m$

$VCG_{F52} := 0.138 \cdot D_{AV}$ $\quad VCG_{F52} = 3.73\ m$ $\quad P_{22} := W_{F52} \cdot VCG_{F52}$ $\quad P_{22} = 1.562 \cdot 10^3 \cdot MT \cdot m$

Total loads moment: $\quad P_{WGL} := P_{17} + P_{18} + P_{19} + P_{20} + P_{21} + P_{22} + W_{VP} \cdot VCG_{VP}$ $\quad P_{WGL} = 4.939 \cdot 10^4 \cdot MT \cdot m$

Total variable loads weight: $\quad W_L := W_{F10} + W_{F31} + W_{F32} + W_{F41} + W_{F46} + W_{F52} + W_{VP}$ $\quad W_L = 4.467 \cdot 10^3 \cdot MT$

Vertical center of gravity: $\quad VCG_L := \frac{P_{WGL}}{W_L}$ $\quad VCG_L = 11.056\ m$

$KG := \frac{W_{LS} \cdot KG_{LS} + W_L \cdot VCG_L}{W_{LS} + W_L} + KG_{MARG}$ $\quad KG_{MARG} = 1\ m$ $\quad KG = 10.893\ m$

$C_{IT} := -0.537 + 1.44 \cdot C_W$ $\quad C_{IT} = 0.642$ $\quad C_W = 0.819$

$KB := \frac{T}{3} \cdot \left(2.4 - \frac{C_P \cdot C_X}{C_W}\right)$ $\quad KB = 3.865\ m$ $\quad BM := \frac{LWL \cdot B^3 \cdot C_{IT}}{12 \cdot V_{FL}}$ $\quad BM = 11.162\ m$

$GM := KB + BM - KG$ $\quad GM = 4.135\ m$ $\quad C_{GMB} := \frac{GM}{B}$ $\quad C_{GMB} = 0.14$

Module 9 - Design Balance / Summary

$W_{FL1} := \frac{W_P}{0.1}$ $\quad W_{FL1} = 2.67 \cdot 10^4 \cdot MT$ $\quad$ (First iteration only).

$W_T = 2.549 \cdot 10^4 \cdot MT$ $\quad W_{FL} := 25487 \cdot MT$ $\quad V_{FL} := W_{FL} \cdot 34.98 \cdot \frac{ft^3}{lton}$ $\quad V_{FL} = 2.485 \cdot 10^4\ m^3$

Froude Scaling Factors: $\quad R_{FS} := \sqrt[3]{\frac{V_{FL}}{V_{FS}}}$ $\quad R_{FS} = 0.945$ $\quad R_{US} := \sqrt[3]{\frac{V_{FL}}{V_{US}}}$ $\quad R_{US} = 0.864$ $\quad R_{LPD} := \sqrt[3]{\frac{V_{FL}}{V_{LPD}}}$ $\quad R_{LPD} = 0.995$

$$C_X := \begin{cases} C_{XFS} & \text{if } HullForm = 1 \\ C_{XUS} & \text{if } HullForm = 2 \\ C_{XLPD} & \text{if } HullForm = 5 \\ Cxmin + DP_3 \cdot \frac{(Cxmax - Cxmin)}{NCx - 1} & \text{otherwise} \end{cases}$$

$$C_P := \begin{cases} \frac{V_{FL}}{L_{FS} \cdot R_{FS}^3 \cdot A_{XFS}} & \text{if } HullForm = 1 \\ \frac{V_{FL}}{L_{US} \cdot R_{US}^3 \cdot A_{XUS}} & \text{if } HullForm = 2 \\ C_{PLPD} & \text{if } HullForm = 5 \\ Cpmin + DP_2 \cdot \frac{(Cpmax - Cpmin)}{NCp - 1} & \text{otherwise} \end{cases}$$

$$C_{\Delta L} := \begin{cases} \frac{W_{FL}}{\left(\frac{L_{FS} \cdot R_{FS}}{100}\right)^3} & \text{if } HullForm = 1 \\ \frac{W_{FL}}{\left(\frac{L_{US} \cdot R_{US}}{100}\right)^3} & \text{if } HullForm = 2 \\ \frac{W_{FL}}{\left(\frac{L_{LPD}}{100}\right)^3} & \text{if } HullForm = 5 \\ \left[Cdlmin + DP_4 \cdot \frac{(Cdlmax - Cdlmin)}{NCdl - 1}\right] \cdot \frac{lton}{ft^3} & \text{otherwise} \end{cases}$$

$$C_{BT} \equiv \begin{cases} C_{BTFS} & \text{if HullForm} = 1 \\ C_{BTUS} & \text{if HullForm} = 2 \\ C_{BTLPD} & \text{if HullForm} = 5 \\ \left[Cbtmin + DP_5 \cdot \frac{(Cbtmax - Cbtmin)}{NCbt - 1} \right] & \text{otherwise} \end{cases}$$

$C_M \equiv C_X$

$C_M = 0.941$ $CN = 43.173$

$$LWL \equiv \begin{cases} L_{FS} \cdot R_{FS} & \text{if HullForm} = 1 \\ L_{US} \cdot R_{US} & \text{if HullForm} = 2 \\ L_{LPD} & \text{if HullForm} = 5 \\ 100 \cdot \sqrt[3]{\frac{W_{FL}}{C_{\Delta L}}} & \text{otherwise} \end{cases}$$

$$B \equiv \begin{cases} B_{FS} \cdot R_{FS} & \text{if HullForm} = 1 \\ B_{US} \cdot R_{US} & \text{if HullForm} = 2 \\ B_{LPD} & \text{if HullForm} = 5 \\ \sqrt{\frac{C_{BT} \cdot V_{FL}}{C_p \cdot C_X \cdot LWL}} & \text{otherwise} \end{cases}$$

$$T \equiv \begin{cases} T_{FS} \cdot R_{FS} & \text{if HullForm} = 1 \\ T_{US} \cdot R_{US} & \text{if HullForm} = 2 \\ T_{LPD} & \text{if HullForm} = 5 \\ \frac{V_{FL}}{C_p \cdot C_X \cdot LWL \cdot B} & \text{otherwise} \end{cases}$$

$A_X \equiv C_X \cdot B \cdot T$ $C_B \equiv \frac{V_{FL}}{LWL \cdot B \cdot T}$

$$C_W \equiv \begin{cases} C_{WFS} & \text{if HullForm} = 1 \\ C_{WUS} & \text{if HullForm} = 2 \\ C_{WLPD} & \text{if HullForm} = 5 \\ 0.278 + 0.836 \cdot C_p & \text{otherwise} \end{cases}$$

$$D_{10} \equiv \begin{cases} D_{LPD} & \text{if HullForm} = 5 \\ \frac{LWL}{C_{D10}} & \text{otherwise} \end{cases}$$

$LWL = 201\ m$ $B = 29.54\ m$ $T = 6.873\ m$ $D_{10} = 26.63\ m$ $A_X = 194.58\ m^2$ $\frac{LWL}{B} = 6.804$

$C_p = 0.647$ $C_X = 0.941$ $C_{\Delta L} = 87.471 \cdot \frac{lton}{ft^3}$ $C_{BT} = 4.22$ $C_{D10} = 6.2$ $C_{vd} = 0.21$ $C_B = 0.598$ $C_W = 0.819$

Balance Check:

	Required/Minimal	Available	Error
Weight:	$W_T = 2.549 \cdot 10^4 \cdot MT$	$W_{FL} = 2.549 \cdot 10^4 \cdot MT$	$ERR = 7.952 \cdot 10^{-4}$
Arrangeable area:	$A_{TR} = 2.093 \cdot 10^4 \cdot m^2$	$A_{TA} = 2.102 \cdot 10^4\ m^2$	$ERR_A = 4.473 \cdot 10^{-3}$
Hangar Area:	$A_{HangarReq} = 8.26 \cdot 10^3\ m^2$	$A_{HANGmax} = 1.094 \cdot 10^4\ m^2$	
Deckhouse area:	$A_{DR} = 972.337\ m^2$	$A_{DA} = 1.739 \cdot 10^3\ m^2$	$V_D \equiv C_{vd} \cdot V_{FL}$ $V_D = 5.218 \cdot 10^3 \cdot m^3$
Propulsion power:	$P_{IREQ} = 6.168 \cdot 10^4 \cdot hp$	$P_{IPRP} = 7.513 \cdot 10^4 \cdot hp$	$N_T = 916$
Electrical plant:	$KW_{GREQmech} = 0 \cdot kW$	$KW_G = 3 \cdot 10^3 \cdot kW$	
Mach. box height:	$H_{MBreq} = 6.63\ m$	$H_{MB} = 7.63\ m$	
Depth:	$D_{10MIN} = 25.63 \cdot m$	$D_{10} = 26.63 \cdot m$	
Sustained Speed:	$V_s = 20 \cdot knt$	$V_S = 24.5 \cdot knt$	
Stability:	.05-.2	$C_{GMB} = 0.14$	
Length of Flight Deck:	$L_{FltReq} = 100\ m$	$L_{Flt} = 150.75\ m$	
Breadth of Flight Deck:	$B_{FltReq} = 25\ m$	$B = 29.54\ m$	

$V_{airwep} := AHULL_{F20} \cdot \frac{H_{DK}}{3}$

$W_{airwep} := \frac{V_{airwep}}{\left(6.4 \cdot \frac{m^2}{MT}\right) \cdot H_{DK}}$

$V_{airwep} = 2.993 \cdot 10^3 \cdot m^3$

$W_{airwep} = 155.862 \cdot MT$

$W_{F42} = 1.599 \cdot 10^3 \cdot MT$

$V_{AF} = 2.005 \cdot 10^3\ m^3$

Module 10 - SIMPLIFIED COST MODEL

$Mdol := coul$ $Bdol := 1000 \cdot Mdol$ $Kdol := \frac{Mdol}{1000}$ $dol := \frac{Kdol}{1000}$ $i1 := 1, 2..7$

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

$W_{MP} := \left[(W_4 + W_7) - W_{IC} \right] + W_{F20} - W_{F23}$ $W_{MP} = 760.739 \cdot MT$

10a. Inflation:

Base Year: $Y_B := 2005$ $iy := 1..Y_B - 1981$

Average Inflation Rate (%): (from 1981-2005) $R_I := 2.3$ $F_I := \prod_{iy} \left(1 + \frac{R_I}{100}\right)$ $F_I = 1.726$

10b. Lead Ship Cost:

Lead Ship Cost - Shipbuilder Portion:

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

Structure: $K_{N1} := \frac{.8 \cdot Mdol}{lton^{.772}}$ $C_{L_1} := .03395 \cdot F_I \cdot K_{N1} \cdot (W_1)^{.772}$ $C_{L_1} = 61.518 \cdot Mdol$

+ Propulsion: $K_{N2} := \frac{1.0 \cdot Mdol}{hp^{.808}}$ $C_{L_2} := .00186 \cdot F_I \cdot K_{N2} \cdot P_{BPENGTOT}^{.808}$ $C_{L_2} = 31.482 \cdot Mdol$

+ Electric: $K_{N3} := \frac{1.0 \cdot Mdol}{lton^{.91}}$ $C_{L_3} := .07505 \cdot F_I \cdot K_{N3} \cdot (W_3)^{.91}$ $C_{L_3} = 55.607 \cdot Mdol$

+ Command, Control, Surveillance: (less payload GFM cost)

$K_{N4} := \frac{2.0 \cdot Mdol}{lton^{.617} \cdot (CManShip + CManAir)}$ $C_{L_4} := .10857 \cdot F_I \cdot K_{N4} \cdot (W_4)^{.617}$ $C_{L_4} = 6.537 \cdot Mdol$

+ Auxiliary: $K_{N5} := \frac{2.0 \cdot Mdol}{lton^{.782} \cdot (CManShip + CManAir)}$ $C_{L_5} := .09487 \cdot F_I \cdot K_{N5} \cdot (W_5)^{.782}$ $C_{L_5} = 98.923 \cdot Mdol$

+ Outfit: $K_{N6} := \frac{1.0 \cdot Mdol}{lton^{.784}}$ $C_{L_6} := .09859 \cdot F_I \cdot K_{N6} \cdot (W_6)^{.784}$ $C_{L_6} = 61.035 \cdot Mdol$

+ Armament: (Less payload GFM cost)

$K_{N7} := \frac{1.0 \cdot Mdol}{lton^{.987}}$ $C_{L_7} := .00838 \cdot F_I \cdot K_{N7} \cdot (W_7)^{.987}$ $C_{L_7} = 0.584 \cdot Mdol$

+ Margin Cost: $C_{LM} := \frac{W_{M24}}{(W_{LS} - W_{M24})} \cdot \left(\sum_{i1} C_{L_{i1}}\right)$ $C_{LM} = 31.568 \cdot Mdol$

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

$$K_{N8} := \begin{cases} \frac{2. \cdot Mdol}{Mdol^{1.099}} & \text{if HullForm} = 5 \\ \frac{10. \cdot Mdol}{Mdol^{1.099}} & \text{otherwise} \end{cases} \quad K_{N8} = 2 \cdot \frac{Mdol}{Mdol^{1.099}} \quad C_{L_8} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099} \quad C_{L_8} = 42.138 \cdot Mdol$$

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

$$K_{N9} := \begin{cases} \frac{.5 \cdot Mdol}{(Mdol)^{.839}} & \text{if HullForm} = 5 \\ \frac{2. \cdot Mdol}{(Mdol)^{.839}} & \text{otherwise} \end{cases} \quad K_{N9} = 0.5 \cdot \frac{Mdol}{(Mdol)^{.839}} \quad C_{L_9} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839} \quad C_{L_9} = 9.139 \cdot Mdol$$

= Total Lead Ship Construction Cost (BCC) :

$C_{LCC} := \sum_{i1} C_{L_{i1}} + C_{L_8} + C_{L_9} + C_{LM}$ $C_{LCC} = 398.529 \cdot Mdol$

+ Profit: $F_P := .10$ $C_{LP} := F_P \cdot C_{LCC}$ $C_{LP} = 39.853 \cdot Mdol$

= Lead Ship Price : $P_L := C_{LCC} + C_{LP}$ $P_L = 438.382 \cdot Mdol$

+ Change Orders: $C_{LCORD} := .12 \cdot P_L$ $C_{LCORD} = 52.606 \cdot Mdol$

= Total Shipbuilder Portion: $C_{SB} := P_L + C_{LCORD}$ $C_{SB} = 490.988 \cdot Mdol$

Lead Ship Cost - Government Portion

Other support: $C_{LOTH} := .025 \cdot P_L$ $C_{LOTH} = 10.96 \cdot Mdol$

+ Program Manager's Growth: $C_{LPMG} := 0 \cdot P_L$ $C_{LPMG} = 0 \cdot Mdol$

+ Ordnance and Electrical GFE: (Military Payload GFE or include actual cost if known)

$C_{LMPG} := \left(3 \cdot \frac{Mdol}{lton} \cdot W_{MP}\right) \cdot F_I$ $C_{LMPG} = 387.667 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{LHMEG} := .02 \cdot P_L$ $C_{LHMEG} = 8.768 \cdot Mdol$

+ Outfittimg Cost : $C_{LOUT} := .04 \cdot P_L$ $C_{LOUT} = 17.535 \cdot Mdol$

= Total Government Portion: $C_{LGOV} := C_{LOTH} + C_{LPMG} + C_{LMPG} + C_{LHMEG} + C_{LOUT}$ $C_{LGOV} = 424.929 \cdot Mdol$

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

* Total End Cost: $C_{LEND} := C_{SB} + C_{LGOV}$ $C_{LEND} = 915.917 \cdot Mdol$

Total Lead Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{LPDEL} := .05 \cdot P_L$ $C_{LPDEL} = 21.919 \cdot Mdol$

= Total Lead Ship Acquisition Cost: $C_{LA} := C_{LEND} + C_{LPDEL}$ $C_{LA} = 937.836 \cdot Mdol$ ($FY2005)

10c. Follow-Ship (N_S/2 th ship) Cost:

Total Ship Acquisition: $N_S := 30$ Production Rate (per year): $R_P := 2$

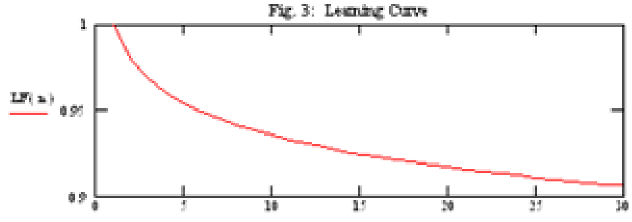
Learning Rate: (for every doubling of number of units) $R_L := .98$

$LF(n) := R_L^{\frac{\ln(n)}{\ln(2)}}$ $n := 1 .. N_S$

Average Follow Ship Learning Cost Factor:

$$F_{LAV} := \frac{\sum_{n=2}^{N_S} LF(n)}{N_S - 1} \qquad F_{LAV} = 0.928$$

Fig. 3: Learning Curve



Ship N_S/2 Learning Cost Factor:

$F_L := LF\left(\frac{N_S}{2}\right)$ $F_L = 0.924$

Follow Ship (N_S/2) Inflation from Program Base Year: (assume follow ship awards start in Base Year + 2)

$Y_{Award} := Y_B + 1 + \frac{N_S}{2 \cdot R_P}$ $Y_{Award} = 2.014 \cdot 10^3$ $iy := 1 .. \frac{N_S}{2 \cdot R_P} + 1$

Average Inflation Rate (%): (from 2011 to 2020) $R_I := 2.$ $F_{IFOL} := \prod_{iy} \left(1 + \frac{R_I}{100}\right)$ $F_{IFOL} = 1.172$

Follow Ship Cost - Shipbuilder Portion

$C_{FOL_{i1}} = F_L \cdot F_{IFOL} \cdot C_{L_{i1}}$ $C_{FM} = F_L \cdot F_{IFOL} \cdot C_{LM}$ $C_{FM} = 34.18 \cdot Mdol$

$C_{FOL_x} = \frac{.03 \cdot Mdol}{Mdol^{1.099}} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM} \right)^{1.099}$ $C_{FOL_x} = 18.59 \cdot Mdol$ $C_{FOL_x} = 18.59 \cdot Mdol$

$C_{FOL_y} := F_L \cdot F_{IFOL} \cdot .5 \cdot C_{L_y}$

Total Follow Ship Construction Cost: (BCC) $C_{FCC} = \sum_{i1} C_{FOL_{i1}} + C_{FOL_x} + C_{FOL_y} + C_{FM}$ $C_{FCC} = 399.52 \cdot Mdol$

+ Profit: $F_P = .1$ $C_{FP} = F_P \cdot C_{FCC}$ $C_{FP} = 39.952 \cdot Mdol$

= Follow Ship Price : $P_F := C_{FCC} + C_{FP}$ $P_F = 439.472 \cdot Mdol$

+ Change Orders: $C_{FCORD} := .08 \cdot P_F$ $C_{FCORD} = 35.158 \cdot Mdol$

= Total Follow Ship Shipbuilder Portion: $C_{FSB} := P_F + C_{FCORD}$ $C_{FSB} = 474.629 \cdot Mdol$

Follow Ship Cost - Government Portion

Other support: $C_{FOTH} := .025 \cdot P_F$ $C_{FOTH} = 10.987 \cdot Mdol$

+ Program Manager's Growth: $C_{FPMG} := 0 \cdot P_F$

+ Ordnance and Electrical GFE: (Military Payload GFE) number of helo's: $N_{HELO} = 4$

$C_{FMPG} = \left(.15 \cdot \frac{Mdol}{lton} \cdot W_{MP} \right) \cdot F_{IFOL} \cdot F_I$ $C_{FMPG} = 227.107 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{FHMEG} = .02 \cdot P_F$ $C_{FHMEG} = 8.789 \cdot Mdol$

+ Outfitting Cost: $C_{FOUT} := .04 \cdot P_F$ $C_{FOUT} = 17.579 \cdot Mdol$

= Total Follow Ship Government Cost: $C_{FGOV} := C_{FOTH} + C_{FPMG} + C_{FMPG} + C_{FHMEG} + C_{FOUT}$ $C_{FGOV} = 264.462 \cdot Mdol$

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

* Total Follow Ship End Cost: $C_{FEND} = C_{FSB} + C_{FGOV}$ $C_{FEND} = 739.091 \cdot Mdol$

Total Follow Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{FPDEL} := .05 \cdot P_F$ $C_{FPDEL} = 21.974 \cdot Mdol$

= Total Follow Ship Aquisition Cost: $C_{FA} := C_{FEND} + C_{FPDEL}$ $C_{FA} = 761.065 \cdot Mdol$

Module 11 - Effectiveness

11a. Sustained Speed - MOP15

$$VOP_{15} = \begin{cases} 0 & \text{if } V_S < 20 \cdot knt \\ \left(\frac{V_S - 20 \cdot knt}{knt} \cdot .1 \right) & \text{if } (V_S \geq 20 \cdot knt) \cdot (V_S < 21 \cdot knt) \\ \left(\frac{V_S - 21 \cdot knt}{knt} \cdot .2 + .1 \right) & \text{if } (V_S \geq 21 \cdot knt) \cdot (V_S < 22 \cdot knt) \\ \left(\frac{V_S - 22 \cdot knt}{knt} \cdot .25 + .3 \right) & \text{if } (V_S \geq 22 \cdot knt) \cdot (V_S < 23 \cdot knt) \\ \left(\frac{V_S - 23 \cdot knt}{knt} \cdot .35 + .55 \right) & \text{if } (V_S \geq 23 \cdot knt) \cdot (V_S < 24 \cdot knt) \\ \left(\frac{V_S - 24 \cdot knt}{knt} \cdot .1 + .9 \right) & \text{if } (V_S \geq 24 \cdot knt) \cdot (V_S < 25 \cdot knt) \\ 1.0 & \text{otherwise} \end{cases}$$

$VOP_{15} = 0.95$ $V_S = 24.5 \cdot knt$

11b. SeaKeeping - MOP16

$x := \begin{cases} .483 & \text{if } HullForm = 2 \\ .492 & \text{otherwise} \end{cases}$ $y := \begin{cases} .416 & \text{if } HullForm = 2 \\ .431 & \text{otherwise} \end{cases}$ $z := \begin{cases} .509 & \text{if } HullForm = 2 \\ .498 & \text{otherwise} \end{cases}$

$m := \begin{cases} .557 & \text{if } HullForm = 2 \\ .552 & \text{otherwise} \end{cases}$ $xx := \begin{cases} 2.398 & \text{if } HullForm = 2 \\ 2.187 & \text{otherwise} \end{cases}$

$$a := \begin{bmatrix} 9.43595 \\ 3.10450 \cdot 10^{-6} \\ -8.42980 \\ -37.5995 \\ 590.435 \\ .287418 \\ -57.3460 \\ -6.08436 \\ 9.18775 \cdot 10^{-5} \\ -6.03225 \\ -6.41495 \cdot 10^{-3} \end{bmatrix}$$

$A_{WP} := C_{WP} \cdot B \cdot LWL$ $A_{WP} = 4.863 \cdot 10^3 \, m^2$ $C_{VPF} := \frac{x \cdot V_{FL}}{y \cdot A_{WP} \cdot T}$ $C_{VPF} = 0.848$

$C_{VPA} := \frac{(1-x) \cdot V_{FL}}{(1-y) \cdot A_{WP} \cdot T}$ $C_{VPA} = 0.663$ $A_{WA} := (1-y) \cdot A_{WP}$ $A_{WA} = 2.767 \cdot 10^3 \, m^2$

$LCB = z \cdot LWL$ $LCB = 100.098 \, m$ $LCF = m \cdot LWL$ $LCF = 110.952 \, m$

$BM_L := xx \cdot LWL + KG - KB$ $BM_L = 446.604 \, m$

$$AA = a_1 + \frac{a_2 \cdot BM_L \cdot V_{FL}}{m^4} + a_3 \cdot C_{VPF} + a_4 \cdot C_{VPA} + a_5 \cdot \frac{BM_L \cdot V_{FL}}{B \cdot LWL^3} + a_6 \cdot \frac{LWL}{m} + a_7 \cdot \frac{T}{B} + a_8 \cdot \frac{A_{WA}}{V_{FL}^{\frac{2}{3}}} + \frac{a_9 \cdot (LCB - LCF) \cdot V_{FL}}{m^4}$$

$$MkR := AA + a_{10} \cdot \left[\frac{\frac{LWL}{2} - LCB}{V_{FL}^{\frac{1}{3}}} \right] + a_{11} \cdot \frac{LWL^2}{B \cdot T}$$

$MkR = 37.632$

$$VOP_{14} = \begin{cases} 0 & \text{if } MkR < 25 \\ \left(\frac{MkR - 25}{2} \cdot .1\right) & \text{if } (MkR \ge 25) \cdot (MkR < 27) \\ \left(\frac{MkR - 27}{2} \cdot .2 + .1\right) & \text{if } (MkR \ge 27) \cdot (MkR < 29) \\ \left(\frac{MkR - 29}{2} \cdot .25 + .3\right) & \text{if } (MkR \ge 29) \cdot (MkR < 31) \\ \left(\frac{MkR - 31}{2} \cdot .35 + .55\right) & \text{if } (MkR \ge 31) \cdot (MkR < 33) \\ \left(\frac{MkR - 33}{2} \cdot .1 + .9\right) & \text{if } (MkR \ge 33) \cdot (MkR < 35) \\ 1 & \text{if } (MkR \ge 35) \end{cases}$$

$VOP_{14} = \text{if}\left(VOP_{14} < 0., 0., VOP_{14}\right)$

$VOP_{14} = 1$

11c. RCS - MOP26

$$VOP_{26} := \begin{cases} 1.0 & \text{if } HullForm = 6 \\ .5 & \text{if } HullForm = 5 \\ 0.0 & \text{otherwise} \end{cases}$$

11d. IR Signature - MOP23

$$VOP_{23} := \begin{cases} 0.0 & \text{if } (DP_{20} = 1) + (DP_{20} = 6) + (DP_{20} = 10) \\ .25 & \text{if } (DP_{20} = 3) + (DP_{20} = 9) + (DP_{20} = 13) \\ 1.0 & \text{if } (DP_{20} = 4) + (DP_{20} = 8) + (DP_{20} = 12) \\ 0.5 & \text{otherwise} \end{cases}$$

$VOP_{23} := VOP_{23} \cdot \frac{41600 \cdot hp}{P_{BPENGTOT}}$ $VOP_{23} = 0.239$

11e. Acoustic - MOP24

$$VOP_{24} := \begin{cases} 1.0 & \text{if } PSYS_{TYP} = 2 \\ 0.0 & \text{otherwise} \end{cases}$$

11f. Reliability - MOP13

$$VOP_{13} := \begin{cases} 1.0 & \text{if } N_{prop} = 2 \\ 0.0 & \text{otherwise} \end{cases}$$

11g. Redundancy - MOP19

$$VOP_{19} := \begin{cases} 1.0 & \text{if } N_{prop} = 2 \\ 0.0 & \text{otherwise} \end{cases}$$

11h. Damage Stability - MOP18

$$VOP_{18} = \begin{cases} 0.0 & \text{if } HullForm = 6 \\ 1.0 & \text{otherwise} \end{cases}$$

$HullForm = 5$

11d. OMOE

$OMOE := WEIGHT^T \cdot VOP$

$OMOE = (0.882\ )$

VOP =

	1
1	1
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	1
11	1
12	1
13	1
14	1
15	0.95
16	1
17	0
18	1
19	1
20	0
21	1
22	1
23	0.239
24	1
25	0
26	0.5
27	0
28	1
29	0
30	1
31	0.933
32	1
33	1
34	1

WEIGHT =

.0642
0
0
0
0
0
0
0
.0113
.0294
.0354
.0389
.0133
.0105
.0097
.0671
0
.0469
.0208
.0469
.0276
.0469
.0318
.0542
0
.0618
0
.0434
0
.1168
.072
.0457
.0457
.0602

12. OMOR

$$COSTRISK_{AAW} := \begin{cases} .08 & \text{if } DP_{10}+3=4 \\ 0.0 & \text{otherwise} \end{cases} \quad COSTRISK_{IPS} := \begin{cases} 0 & \text{if } 1 \le DP_{20} \le 5 \\ .18 & \text{otherwise} \end{cases} \quad COSTRISK_{HullForm} := \begin{cases} .3 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$COSTRISK_{EMALS} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .3 & \text{otherwise} \end{cases} \quad .08 + .18 + .3 + .3 = 0.86$$

$$SCHEDRISK_{AAW} := \begin{cases} .04 & \text{if } DP_{10}+3 \\ 0.0 & \text{otherwise} \end{cases} \quad SCHEDRISK_{IPS} := \begin{cases} 0 & \text{if } 1 \le DP_{20} \le 5 \\ .09 & \text{otherwise} \end{cases} \quad SCHEDRISK_{HullForm} := \begin{cases} .35 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$SCHEDRISK_{EMALS} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .2 & \text{otherwise} \end{cases} \quad .04 + .09 + .35 + .2 = 0.68$$

$$PERFRISK_{AAW} := \begin{cases} .15 & \text{if } DP_{10}+3 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{Range} := \begin{cases} .06 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{Reliab} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .16 & \text{otherwise} \end{cases}$$

$$PERFRISK_{VS} := \begin{cases} .1 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{SK} := \begin{cases} .25 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{DStab} := \begin{cases} .49 & \text{if } HullForm = 6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$PERFRISK_{Strike} := \begin{cases} .36 & \text{if } DP_{8}=1 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{SEAD} := \begin{cases} .32 & \text{if } DP_{8}=1 \\ 0.0 & \text{otherwise} \end{cases} \quad .15 + .06 + .16 + .1 + .25 + .49 + .36 + .32 = 1.89$$

$$COSTRISK := \frac{COSTRISK_{AAW} + COSTRISK_{IPS} + COSTRISK_{HullForm} + COSTRISK_{EMALS}}{.86} \quad COSTRISK = 0.651$$

$$SCHEDRISK := \frac{SCHEDRISK_{AAW} + SCHEDRISK_{IPS} + SCHEDRISK_{HullForm} + SCHEDRISK_{EMALS}}{.68} \quad SCHEDRISK = 0.485$$

$$PERFRISK := \frac{\begin{array}{l} WEIGHT_{1} \cdot PERFRISK_{AAW} + WEIGHT_{9} \cdot PERFRISK_{Range} + WEIGHT_{13} \cdot PERFRISK_{Reliab} \cdots \\ + WEIGHT_{15} \cdot PERFRISK_{VS} + WEIGHT_{16} \cdot PERFRISK_{SK} + WEIGHT_{18} \cdot PERFRISK_{DStab} \cdots \\ + WEIGHT_{28} \cdot PERFRISK_{Strike} + WEIGHT_{30} \cdot PERFRISK_{SEAD} \end{array}}{1.89 \cdot \left(WEIGHT_{1} + WEIGHT_{9} + WEIGHT_{13} + WEIGHT_{15} + WEIGHT_{16} + WEIGHT_{18} + WEIGHT_{28} + WEIGHT_{30}\right)}$$

$$PERFRISK = 0.092$$

$$OMOR := \frac{.5 \cdot PERFRISK + .3 \cdot COSTRISK + .2 \cdot SCHEDRISK}{(CMenShip + CMenAir\ )} \quad OMOR = 0.169$$

Notes:

A_{DPC} = communications deck house area required

A_{HPC} = communications hull area required

$AHULL_{500}$ = auxiliaries hull area required

$AHULL_{600}$ = payload furnishings hull area required

$AHULL_{700}$ = fixed weapons hull area required

$AHULL_{F20}$ = weapons loads hull area required

ADH_{500} = auxiliaries deck house area required

ADH_{600} = payload furnishings deck house area required

ADH_{700} = fixed weapons deck house area required

ADH_{F20} = weapons loads deck house area required

A_W = Waterline Area

A_X = Maximum or Midship Section Area

$BATKW_{400}$ = payload SWBS 400 battle electric power

$BATKW_{500}$ = payload auxiliaries battle electric power

$BATKW_{700}$ = fixed weapons battle electric power

$BATKW_{F20}$ = weapons loads battle electric power

C_B = Block Coefficient

C_{BT} = Beam to Draft Ratio

C_{LB} = Length to Beam Ratio

C_M = Midship Coefficient

C_P = Prismatic Coefficient

C_W = Waterline Area Coefficient

C_X = Maximum Section Area Coefficient

E = Range at endurance speed

EDMF = Electrical Design and Growth Margin Factor

EFMF = Electrical Fault Margin Factor

E24MF = Electrical 24 hour Design Load Margin

H_{DK} = Deckhouse deck height

H_{MBMIN} = Minimum Machinery Box Height

L_{MB} = Minimum Machinery Box Length

LWL = Length Waterline = LBP

MOP = Measures of Performance

MRedFac = Manning Reduction Factor - multiplies standard crew size

N_P = Number of Propulsion Engines

P_{BPENG} = Brake HP per Propulsion Engine

PC = Propulsive coefficient

P_I = Total Installed Propulsion Engine Brake HP

PMF = Propulsion Margin Factor - includes sea and fouling margin

SFC_{PE} = Propulsion Engine Endurance Specific Fuel Consumption

$TRANKW_{400}$ = payload SWBS 400 transit electric power

$TRANKW_{500}$ = payload auxiliaries transit electric power

$TRANKW_{700}$ = fixed weapons transit electric power

$TRANKW_{F20}$ = weapons loads transit electric power

T_S = Number of days capacity for crew stores/food

VCD_{700} = height of fixed weapons weight above deck edge

VCD_{F20} = height of weapons loads weight above deck edge

VCD_{F42} = height of helo fuel weight above deck edge

VCD_P = height of total payload weight above deck edge

VCD_{P100} = height of payload SWBS 100 weight above deck edge

VCD_{P400} = height of payload SWBS 400 weight above deck edge

VCD_{P500} = height of payload auxiliaries weight above deck edge

VCD_{P600} = height of payload furnishings weight above deck edge

VCD_{VP} = height of variable payload loads weight above deck edge

VCG_P = vertical center of gravity of total payload weight above baseline

V_e = Endurance speed

V_{FL} = Full load hull displaced volume

W_{FL} = Full Load Weight

WMF = Weight Margin Factor

W_7 = total fixed weapons weight

W_{F20} = total weapons loads weight

W_{F42} = helo fuel weight

W_P = total payload weight

W_{P100} = total payload SWBS 100 weight

W_{P400} = total payload SWBS 400 weight

W_{P500} = total payload auxiliaries weight

W_{P600} = total payload furnishings weight

W_{VP} = variable payload loads weight

η = power conversion efficiency (bearings, gears, etc)

ρ_{SW} =salt water density
υ SW=salt water viscosity
ρ_{A} =air density
δ_{F} =DFM specific volume
δ_{HF} =JP-5 specific volume
δ_{LO} =lube oil specific volume
δ_{W} =fresh water specific volume

η_{I} = power conversion efficiency (bearings, gears, etc)
W_{PENG} = Propulsion Engine weight (each)
V_{MBreq} = Required Machinery Box Volume
W_{ENG} = Total Propulsion Engine weight
L_{MBreq} = Required Machinery Box Length
w_{MBreq} = Required Machinery Box width
H_{MBreq} = Required Machinery Box Height
P_{I} = Total Installed Propulsion Engine Brake HP

N_{prop} = Number of Propulsors

N_{PENG} = Number of Propulsion Engines

SFC_{PE} = Generator Engine Endurance Specific Fuel Consumption

L_{ENG} = Propulsion Engine Length
w_{ENG} = Propulsion Engine width
P_{BPENG} = Brake HP per Propulsion Engine
H_{ENG} = Propulsion Engine height

SFC_{PE} = Propulsion Engine Endurance Specific Fuel Consumption

D.2 CUVX Power and Propulsion Analysis

CUVX HI2 Resistance and Powering (4/29/2003)

$knt := 0.515 \cdot \frac{m}{sec}$ $V_e := 20 \cdot knt$ $V_s := 24.5 \cdot knt$ $\nu_{SW} := 1.2817 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ $nm := knt \cdot hr$

$LWL := 201 \cdot m$ $B := 29.54 \cdot m$ $Draft := 7 \cdot m$ $V_{FL} := 25310 \cdot m^3$ $\rho_{SW} := 1025 \cdot \frac{kg}{m^3}$

$C_P := 0.647$ $C_X := 0.941$ $C_B := 0.609$ $C_W := 0.819$ $C_M := C_X$

$i := 1, 2 .. 12$ $V_i := i \cdot 2 \cdot knt$ $V_{10} := V_e$ $V_{12} := V_s$ $MT := g \cdot tonne$ $\rho_A := 0.0023817 \cdot \frac{slug}{ft^3}$

$D_{10} := 26.63 \cdot m$ $H_{DK} := 3 \cdot m$ $PMF_e := 1.1$ $PMF_s := 1.25$ $E := 4000 \cdot nm$

V = (·knt)

	0
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	14
8	16
9	18
10	20
11	22
12	24.5

a. Hull Surface Area, Coefficients and Dimensions:

$A_{BT} := \frac{\pi}{4} \cdot (6.9585 \cdot m - 1.0050 \cdot m) \cdot (2 \cdot 1.5838 \cdot m)$ $A_{BT} = 14.811\ m^2$ (bulb section area at FP)

$L_R := (1 - C_P) \cdot LWL$ $L_R = 70.953\ m$ (Run length)

$C_V := \frac{V_{FL}}{LWL^3}$ $C_V = 3.117 \cdot 10^{-3}$ $T_F := Draft$ $T_F = 7\ m$

$h_B := (7 - 6.9585) \cdot m + 0.5 \cdot (6.9585 - 1.005) \cdot m$ $h_B = 3.018\ m$ (height of bulb center)

$A_T := 0.5 \cdot \left[\frac{\pi}{4} \cdot (0.7 \cdot m \cdot 2) \cdot (2 \cdot 10.7517 \cdot m)\right]$ $A_T = 11.822\ m^2$ (transom area)

$S_1 := 6598 \cdot m^2$ (does not account for additional appendages such as bilge keels and rudders)

b. Viscous Drag

Coefficient of friction:

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

$$formfac := 1.03 \cdot \left[.93 + \left(\frac{Draft}{LWL}\right)^{.22284} \cdot \left(\frac{B}{L_R}\right)^{.92497} \cdot \left(.95 - C_P\right)^{-.521448} \cdot \left(1 - C_P + .05\right)^{.6906}\right] + \frac{\left(1.4 \cdot S_{BK} + 2.8 \cdot S_{rudder}\right)}{S_1}$$

c. Wave Making Drag

$Fn_{V_i} := \frac{V_i}{\sqrt{V_{FL}^{\frac{1}{3}} \cdot g}}$ $Fn_i := \frac{V_i}{\sqrt{g \cdot LWL}}$

Holtrop

$$c_3 := \frac{.56 \cdot A_{BT}^{1.5}}{B \cdot Draft \cdot \left(.31 \cdot \sqrt{A_{BT}} + T_F - h_B\right)} \qquad c_3 = 0.03 \qquad c_2 := \exp\left(-1.89 \cdot \sqrt{c_3}\right) \qquad c_2 = 0.721$$

$$c_5 := 1 - \frac{.8 \cdot A_T}{B \cdot Draft \cdot C_M} \qquad c_5 = 0.951$$

$$\lambda_R := \begin{cases} 1.446 \cdot C_P - .03 \cdot \frac{LWL}{B} & \text{if } \frac{LWL}{B} < 12 \\ 1.446 \cdot C_P - .036 & \text{otherwise} \end{cases} \qquad \lambda_R = 0.731$$

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

$$c_7 := \begin{cases} .229577 \cdot \left(\frac{B}{LWL}\right)^{.33333} & \text{if } \frac{B}{LWL} < .11 \\ .5 - .0625 \cdot \frac{LWL}{B} & \text{if } \frac{B}{LWL} > .25 \\ \frac{B}{LWL} & \text{otherwise} \end{cases} \qquad c_7 = 0.147$$

$$c_{16} := \begin{cases} 8.07981 \cdot C_P - 13.8673 \cdot C_P^2 + 6.984388 \cdot C_P^3 & \text{if } C_P < .8 \\ 1.73014 - .7067 \cdot C_P & \text{otherwise} \end{cases} \qquad c_{16} = 1.314$$

$$i_E := 1 + 89 \cdot \exp\left[-\left(\frac{LWL}{B}\right)^{.80856} \cdot \left(1 - C_W\right)^{.30484} \cdot \left(1 - C_P\right)^{.6367} \cdot \left(\frac{L_R}{B}\right)^{.34574} \cdot \left(\frac{100 \cdot V_{FL}}{LWL^3}\right)^{.16302}\right] \qquad i_E = 18.701$$

$$c_1 := 2223105 \cdot c_7^{3.78613} \cdot \left(\frac{Draft}{B}\right)^{1.07961} \cdot \left(90 - i_E\right)^{-1.37565} \qquad c_1 = 0.932$$

$$m_1 := .0140407 \cdot \frac{LWL}{Draft} - 1.75254 \cdot \frac{V_{FL}^{\frac{1}{3}}}{LWL} - 4.79323 \cdot \frac{B}{LWL} - c_{16} \qquad m_1 = -1.872$$

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

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

$$P_B := \frac{.56 \cdot A_{BT}^{.5}}{\left(T_F - 1.5 \cdot h_B\right)} \qquad P_B = 0.872$$

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

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

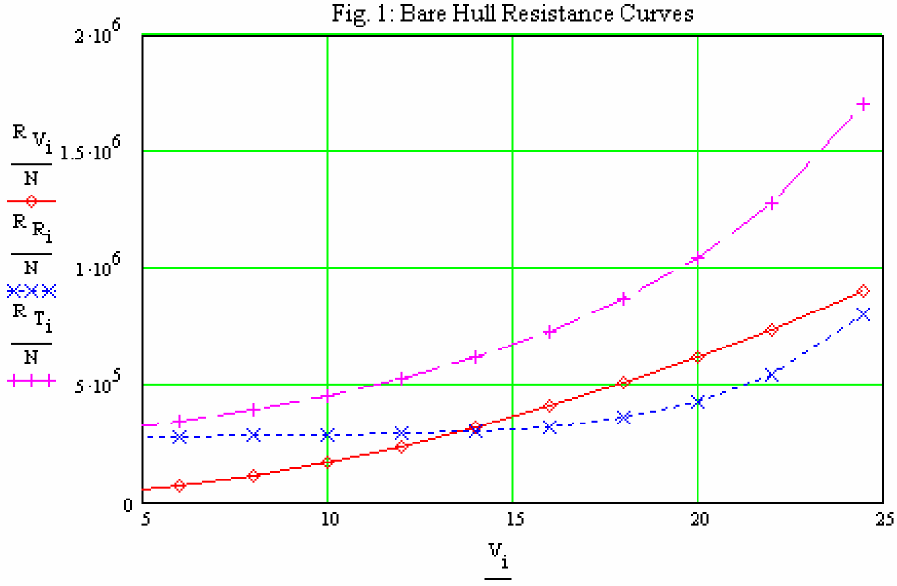
d. Bare Hull Resistance

$$C_A := .0005 \qquad R_A := .5 \cdot \rho_{SW} \cdot \left(V_s\right)^2 \cdot S_1 \cdot C_A \qquad RR_i := \frac{R_i}{\left(\frac{knt}{\sqrt{ft}}\right)}$$

$$R_{V_i} := 0.5 \cdot \rho_{SW} \cdot \left(V_i\right)^2 \cdot S_1 \cdot C_{F_i} \cdot formfac$$

$$R_{R_i} := R_{w_i} + R_{B_i} + R_{TR_i} + R_A \qquad R_{T_i} := R_{V_i} + R_{R_i}$$

Fig. 1: Bare Hull Resistance Curves



e. Ship Effective Horsepower

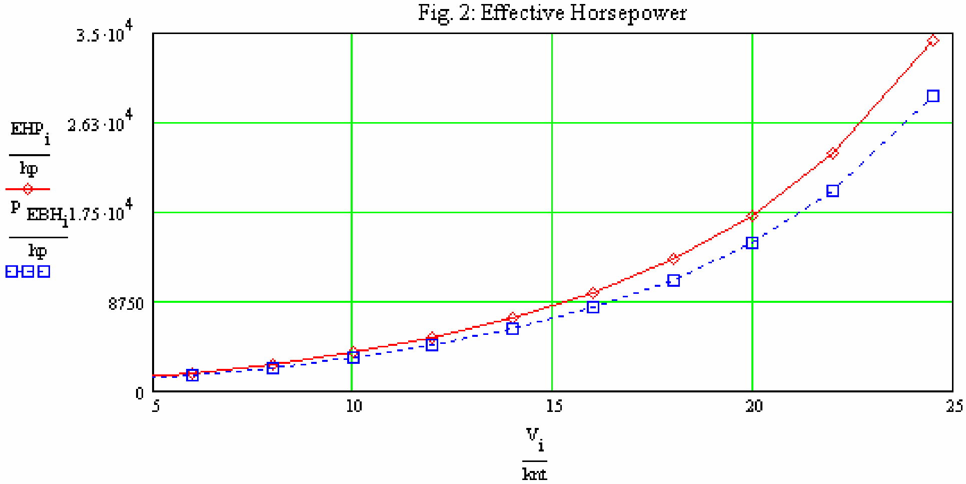
Bare hull: $P_{EBH_i} := R_{T_i} \cdot V_i$ $P_{Efins_i} := 0 \cdot hp$ $P_{EAPP_i} := 0.05 \cdot P_{EBH_i}$

Air frontal area (+5% for masts, equip., etc): $A_W := 1.05 \cdot B \cdot (D_{10} - Draft + H_{DK})$ $A_W = 701.915\ m^2$

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

Total effective horsepower: $P_{ET_i} := P_{EBH_i} + P_{EAA_i} + P_{EAPP_i} + P_{Efins_i}$ $EHP_i := PMF_e \cdot P_{ET_i}$

Fig. 2: Effective Horsepower



f. Propulsion Efficiencies and Horse Powers

$R_{T_{10}} = 1.039 \cdot 10^6 \cdot N$ $EHP_{10} = 1.705 \cdot 10^4 \cdot hp$ $EHP_e := EHP_{10}$ $R_{Te} := R_{T_{10}}$ $N_{shaft} := 2$

$w := 2 \cdot C_B^5 \cdot (1 - C_B) + 0.04$ $w = 0.106$ (wake fraction)

$t := 0.7 \cdot w + 0.06$ $t = 0.134$ (thrust deduction fraction)

$V_A := V_e \cdot (1 - w)$ $V_A = 17.89 \cdot knt$ (speed of advance)

$T := \frac{EHP_{10}}{V_e \cdot (1 - t)}$ $T = 1.426 \cdot 10^6\ N$ (total for two screws)

$\eta_H := \frac{1 - t}{1 - w}$ $\eta_H = 0.968$ (hull efficiency)

$\eta_R := 1.0$ from Asset (relative rotative efficiency)

$\eta_O := 0.691$ from Asset (open water efficiency)

$\eta_B := \eta_O \cdot \eta_R$ $\eta_B = 0.691$ (prop efficiency behind ship)

$\eta_D := \eta_H \cdot \eta_B$ $\eta_D = 0.669$ (quasi-propulsive efficiency)

$\eta_S := 0.99$ estimate (transmission efficiency - mech external to hull)

$\eta_P := \eta_S \cdot \eta_D$ $\eta_P = 0.662$ (propulsive efficiency)

$\eta_{elec} := 0.93$ estimate (mechanical transmission efficiency - inside hull)

$THP_e := \frac{EHP_e}{\eta_H}$ $THP_e = 1.761 \cdot 10^4 \cdot hp$

$DHP_e := \frac{THP_e}{\eta_B}$ $DHP_e = 2.549 \cdot 10^4 \cdot hp$

$DHP_{Oe} := DHP_e \cdot \eta_R$ $DHP_{Oe} = 2.549 \cdot 10^4 \cdot hp$

g. Propeller Information and Cavitation Check

The following propeller characteristics are taken from Asset:

$J_e := 0.925$ $K_T := 0.279$ $K_Q := 5.8$ $\eta_O := 0.691$ $\eta_P = 0.662$ $J_s := 0.93$ from trendline

$PD := 1.20$ $EAR := 0.94$ $D := 4.88 \cdot m$ $Z := 5$

$n_{eSHAFT} := \frac{V_A}{D \cdot J_e}$ $n_{eSHAFT} = 122.463 \cdot \frac{1}{min}$ $n_{sSHAFT} := \frac{V_s \cdot (1-w)}{D \cdot J_s}$ $n_{sSHAFT} = 149.21 \cdot \frac{1}{min}$

$z := Draft - \frac{D}{2}$ $z = 4.56\ m$

$p_{atm} := 101400 \cdot Pa$ $p_v := 1750 \cdot Pa$ $p_o := p_{atm} + z \cdot g \cdot \rho_{SW}$ $p_o = 1.472 \cdot 10^5\ Pa$

$BAR_{min} := \frac{(1.3 + .3 \cdot Z) \cdot T}{D^2 \cdot (p_o - p_v) \cdot N_{shaft}} + 0.1$ $BAR_{min} = 0.676$ This shows that our propeller will not cavitate at the endurance speed.

h. Propulsion Power Balance

Approximate propulsive coefficient: $\eta_P = 0.662$ $V_{10} = 20 \cdot knt$ $V_{12} = 24.5 \cdot knt$

$SHP_i := \frac{EHP_i}{\eta_P}$ $SHP_S := SHP_{12}$ $SHP_S = 5.148 \cdot 10^4 \cdot hp$ $SHP_e := SHP_{10}$ $SHP_e = 2.575 \cdot 10^4 \cdot hp$

$BHP_e := \frac{SHP_e}{\eta_{elec}}$ $BHP_e = 2.768 \cdot 10^4 \cdot hp$

$BHP_s := \frac{SHP_S}{\eta_{elec}}$ $BHP_s = 5.5352 \cdot 10^4 \cdot hp$ (total brake horsepower required for propulsion motors)

i. Engine/Motor Selection and Check

Endurance Speed: $N_{ePMotor} := 2$ $n_{eSHAFT} = 122.463 \cdot \frac{1}{min}$ $P_{eBPMotor} := \frac{BHP_e}{N_{ePMotor}}$ $P_{eBPMotor} = 1.3842 \cdot 10^4 \cdot hp$

$N_{eENG} := 2$

Sustained Speed: $N_{sPMotor} := 2$ $n_{sSHAFT} = 149.21 \cdot \frac{1}{min}$ $P_{sBPMotor} := \frac{PMF_s \cdot BHP_s}{N_{sPMotor} \cdot PMF_e}$ $P_{sBPMotor} = 3.145 \cdot 10^4 \cdot hp$

$N_{sENG} := 3$

The propulsion motors are integrated into IPS. The motors that are used are PMM 8.

$P_{BPMotorrated} := 29330 \cdot kW$ $P_{BPMotorrated} = 3.9332 \cdot 10^4 \cdot hp$ $n_{PMotorrated} := 150 \cdot \frac{1}{min}$ $P_{BPMotor} := P_{BPMotorrated}$

The ICRs are Westinghouse WR-21 29 engines.

$n_{ePErated} := \frac{3600}{min}$ $SFC_{ePErated} := 0.1991 \cdot \frac{kg}{kW \cdot hr}$ $P_{BPENGrated} := 25200 \cdot kW$ $P_{BPENGrated} = 3.3794 \cdot 10^4 \cdot hp$

engine speed for sustained speed:

$n_{sPMotor} := n_{sSHAFT}$ $n_{sPMotor} = 149.21 \cdot \frac{1}{min}$ $KW_{MFLM} := 8.92533 \cdot 10^3 \cdot kW$ from MM

$P_{BPENGe} := \frac{BHP_e + KW_{MFLM}}{.8 \cdot (N_{eENG})}$ $P_{BPENGe} = 2.4784 \cdot 10^4 \cdot hp$

$P_{BPENGreq} := \frac{\frac{PMF_s}{PMF_e} \cdot BHP_s + KW_{MFLM}}{.8 \cdot (N_{sENG})}$ $P_{BPENGreq} = 3.1196 \cdot 10^4 \cdot hp$ (required power for each ICR)

j. Endurance Fuel Calculation

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

Fuel Tankage

$1ton := 2240 \cdot lbf$ $\delta_F := 43.6 \cdot \frac{ft^3}{1ton}$ $\delta_{AF} := 42 \cdot \frac{ft^3}{1ton}$ $\delta_{LO} := 39 \cdot \frac{ft^3}{1ton}$ $\delta_W := 36 \cdot \frac{ft^3}{1ton}$

Average endurance brake horsepower required with 10% margin for fouling and sea state:

$P_{eBAVG} := BHP_e$ $P_{eBAVG} = 2.768 \cdot 10^4 \cdot hp$ $E = 4 \cdot 10^3 \cdot nm$ $V_e = 20 \cdot knt$

Correction for instrumentation inaccuracy and machinery design changes:

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

Specified fuel rate: $FR_{SP} := f_1 \cdot SFC_{ePErated}$ $\qquad FR_{SP} = 0.203 \cdot \frac{kg}{kW \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years: $FR_{AVG} := 1.05 \cdot FR_{SP} \cdot g$ $\qquad FR_{AVG} = 2.132 \cdot 10^{-4} \cdot \frac{MT}{kW \cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e} \cdot P_{eBAVG} \cdot FR_{AVG}$ $\qquad W_{BP} = 880.429 \cdot MT$

Tailpipe allowance: $TPA := 0.95$

Required propulsion endurance fuel load (weight): $W_{FP} := \frac{W_{BP}}{TPA}$ $\qquad W_{FP} = 926.768 \cdot MT$

Required propulsion fuel tank volume (including allowance for expansion, 5%, and tank internal structure, 2%):

$V_{FP} := 1.02 \cdot 1.05 \cdot W_{FP} \cdot \delta_F$ $\qquad V_{FP} = 1.206 \cdot 10^3 \, m^3$ (for 200 hours of propulsion - endurance range)

Average 24 hour electrical load for the ship service gas turbine generators

$KW_{24AVG} := 5.132 \cdot 10^3 \, kW$ $\qquad N_{GENAVG} := 2$

$P_{GENAVG} := \frac{PMF_e \cdot KW_{24AVG}}{N_{GENAVG}}$ $\qquad P_{GENAVG} = 3.785 \cdot 10^3 \cdot hp$ $\qquad SFC_{GE} := 0.62 \cdot \frac{lbf}{hp \cdot hr}$ (from MEN, Ch. 6, Figure 10)

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

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

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05 \cdot FR_{GSP}$ $\qquad FR_{GAVG} = 3.071 \cdot 10^{-4} \cdot \frac{MT}{hp \cdot hr}$

Burnable electrical endurance fuel weight: $W_{Be} := \frac{E}{V_e} \cdot KW_{24AVG} \cdot FR_{GAVG}$ $\qquad W_{Be} = 422.7 \cdot MT$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $\qquad W_{Fe} = 444.948 \cdot MT$

Required electrical fuel volume: $V_{Fe} := 1.02 \cdot 1.05 \cdot \delta_F \cdot W_{Fe}$ $V_{Fe} = 579.05\ m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $W_{F41} = 1.372 \cdot 10^3 \cdot MT$

$V_F := V_{FP} + V_{Fe}$ $V_F = 1.785 \cdot 10^3\ m^3$ total tankage required for endurance speed and range with 24 average electrical load

Hour := 8 (number of hours of fuel required in tanks)

$$V_{FuelServiceTank} := \begin{cases} \dfrac{V_{FP}}{\frac{200}{8}} + \dfrac{V_{Fe}}{\frac{24}{8}} & \text{if Hour=8} \\ \dfrac{V_{FP}}{\frac{200}{12}} + \dfrac{V_{Fe}}{\frac{24}{12}} & \text{if Hour=12} \\ \dfrac{V_{FP}}{\frac{200}{16}} + \dfrac{V_{Fe}}{\frac{24}{16}} & \text{if Hour=16} \\ \dfrac{V_{FP}}{\frac{200}{24}} + \dfrac{V_{Fe}}{\frac{24}{24}} & \text{if Hour=24} \end{cases}$$

$V_{FuelServiceTank} = 241.26\ m^3$

total required capacity for fuel service tank located in the MMR's

$\dfrac{V_{FuelServiceTank}}{2} = 120.63\ m^3$ per tank (1 in each MMR)

Other Tanks

$N_T := 916$ $N_A := 92$ (Total crew size and total accomodations) $BAL_{TYP} := 1$

Aircraft fuel: $W_{F42} := 1600 \cdot MT$ $V_{AF} := 1.02 \cdot 1.05 \cdot W_{F42} \cdot \delta_{AF}$ $V_{AF} = 2.006 \cdot 10^3\ m^3$

Lubrication oil: $W_{F46} := 17.6 \cdot lton$ $V_{LO} := 1.02 \cdot 1.05 \cdot W_{F46} \cdot \delta_{LO}$ $V_{LO} = 20.817\ m^3$

Potable water: (Water does not expand). $W_{F52} := N_T \cdot 0.45 \cdot lton$ $W_{F52} = 418.815 \cdot MT$

$V_W := 1.02 \cdot W_{F52} \cdot \delta_W$ $V_W = 428.603\ m^3$

Sewage: $V_{SEW} := (N_T + N_A) \cdot 2.005 \cdot ft^3$ $V_{SEW} = 57.229\ m^3$

Waste oil: $V_{WASTE} := 0.02 \cdot V_F$ $V_{WASTE} = 35.703\ m^3$

Clean ballast: (compensated ballast) $V_{BAL} := \mathrm{if}(BAL_{TYP}=1, 0.19 \cdot V_F, 0.275 \cdot V_F)$ $V_{BAL} = 339.176\ m^3$

Total tankage volume required: $V_{TK} := V_F + V_{AF} + V_{LO} + V_W + V_{SEW} + V_{WASTE} + V_{BAL}$ $V_{TK} = 4.672 \cdot 10^3\ m^3$

D.3 Damage Stability

Case	1	2	3	4	5	6	7	8	9	10	11
Forward Blkhd	1	2	4	5	7	8	9	11	12	13	14
Aft Blkhd	5	6	7	8	9	11	12	15	17	18	19
Draft AP (m)	6.829	6.481	6.659	7.153	7.019	7.146	7.346	7.527	7.504	7.536	7.561
Draft FP (m)	7.461	8.216	7.897	6.792	7.264	7.088	7.076	6.823	6.729	6.678	6.622
Trim on LBP (m)	0.632F	1.735F	1.238F	0.361A	0.245F	0.058A	0.270A	0.705A	0.775A	0.858A	0.939A
Total Weight (MT)	26403	27092	26898	25879	26549	26526	27134	27091	26783	26755	26691
Static Heel (deg)	0.0S	1.9P	2.0P	0.3P	2.7S	2.5S	5.1S	4.8S	3.2S	2.8S	1.9S
Wind Heel (deg)	3.8S	5.6P	6.3P	5.4p	7.85	8.7S	10.6S	9.5S	8.2S	8.1S	7.6S
GMt (upright) (m)	5.189	5.245	4.479	4.403	3.144	2.373	1.724	2.555	2.656	2.558	2.614
Maximum GZ	3.707	3.775	3.653	3.505	3.725	3.863	3.903	3.843	3.827	3.840	3.825
Max.GZ Angle (deg)	60.15	60.1P	60.1P	60.1p	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S
GZ Pos. Range (deg)	>60.0	>58.1	>58.0	>59.7	>57.3	>57.5	>54.9	>55.2	>56.8	>57.2	>58.1

Case	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B
Forward Blkhd	2	4	5	7	8	9	11	12	13	14
Aft Blkhd	6	7	8	9	11	12	15	17	18	19
Draft AP (m)	4.897	3.823	4.542	6.767	8.343	9.364	9.897	10.063	10.420	10.895
Draft FP (m)	11.818	14.956	15.707	10.333	9.482	8.344	6.334	5.634	5.211	4.601
Trim on LBP (m)	6.921F	11.133F	11.165F	3.566F	1.140F	1.020A	3.563A	4.428A	5.209A	6.295A
Total Weight (MT)	31087	36017	39621	32602	35230	35767	62944	31907	32049	32140
Static Heel (deg)	1.9P	1.6P	0.3S	2.4S	2.0S	3.9S	3.9S	2.7S	2.4S	1.7S
Wind Heel (deg)	5.9P	5.5P	4.0S	7.0S	7.1S	8.3S	8.1S	7.5S	7.7S	7.6S
GMt (upright) (m)	4.660	4.297	4.270	3.975	3.565	3.778	4.139	3.834	3.535	3.192
Maximum GZ	4.088	4.410	4.924	4.325	4.709	4.840	4.434	4.214	4.161	4.032
Max.GZ Angle (deg)	60.1P	60.1P	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S
GZ Pos. Range (deg)	>58.1	>58.4	>59.7	>57.6	>58.0	>56.2	>56.1	>57.3	>57.6	>58.3

Case	1	2	3	4	5	6	7	8	9	10	11
Forward Blkhd	1	2	4	5	7	8	9	11	12	13	14
Aft Blkhd	5	6	7	8	9	11	12	15	17	18	19
Draft AP (m)	5.965	6.236	6.421	6.898	6.768	6.941	7.127	7.202	7.138	7.116	7.019
Draft FP (m)	8.624	7.981	7.662	6.636	7.012	7.147	7.109	6.667	6.608	6.596	6.625
Trim on LBP (m)	2.659F	1.745F	1.241F	0.262A	0.244F	0.206F	0.018A	0.534A	0.530A	0.520A	0.394A
Total Weight (MT)	26577	25929	25737	24837	25309	26258	26890	25858	25491	25930	25166
Static Heel (deg)	0.0S	2.4P	2.1P	0.1P	2.5S	7.2S	10.0S	5.1S	3.3S	2.7S	1.6S
Wind Heel (deg)	4.8S	7.0P	7.5P	6.5P	9.5S	15.7S	17.1S	11.4S	9.7S	9.5S	8.7S
GMt (upright) (m)	4.268	4.506	3.725	4.149	3.584	2.977	2.598	3.199	3.281	3.226	3.447
Maximum GZ	3.054	2.978	2.883	2.727	2.922	3.074	3.126	3.051	3.032	3.043	3.022
Max.GZ Angle (deg)	60.1	60.1P	60.1P	60.1P	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S
GZ Pos. Range (deg)	>60.0	>57.6	>57.9	>59.9	>57.5	>52.8	>50.0	>54.9	>56.7	>57.3	>58.4

Case	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B
Forward Blkhd	2	4	5	7	8	9	11	12	13	14
Aft Blkhd	6	7	8	9	11	12	15	17	18	19
Draft AP (m)	4.589	3.418	4.252	6.539	8.118	9.137	9.530	9.636	9.911	10.177
Draft FP (m)	11.583	14.836	15.196	9.841	9.443	8.254	6.171	5.531	5.168	4.715
Trim on LBP (m)	6.994F	11.417F	10.944F	3.302F	1.325F	0.883A	3.359A	4.105A	4.743A	5.462A
Total Weight (MT)	29814	34796	37625	30855	34590	35011	31522	30428	30542	30255
Static Heel (deg)	2.6P	1.7P	0.8S	2.7S	5.4S	7.5S	4.7S	3.4S	3.2S	2.3S
Wind Heel (deg)	7.6P	6.8P	6.1S	8.2S	10.0S	11.6S	9.6S	9.1S	9.6S	9.8S
GMt (upright) (m)	3.882	3.442	3.162	3.370	3.546	3.441	3.430	3.125	2.823	2.482
Maximum GZ	3.299	3.657	3.993	3.680	4.538	4.360	3.626	3.404	3.349	3.240
Max.GZ Angle (deg)	60.1P	60.1P	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S	60.1S
GZ Pos. Range (deg)	>57.4	>58.3	>59.2	>57.3	>54.6	>52.5	>55.3	>56.6	>56.8	>57.7

D.4 Weights Spreadsheet

COMPONENT	WT-MT	VCG-m	Moment	LCG-m	Moment	TCG-m	Moment
FULL LOAD WEIGHT + MARGIN	25942.83	10.40	269850.02	100.95	2618955.97	0.00	95.29
MINOP WEIGHT AND MARGIN	24835.89	10.33	256448.90	102.43	2543988.59	0.00	92.36
LIGHTSHIP WEIGHT + MARGIN	21140.13	11.13	235331.21	103.37	2185310.25	0.06	1334.38
LIGHTSHIP WEIGHT	20133.46	11.13	224124.96	103.37	2081247.86	0.06	1270.83
MARGIN	1006.67	11.13	11206.25	103.37	104062.39	0.06	63.54
HULL STRUCTURES	11062.59	10.18	112614.88	105.69	1169181.10	0.10	1099.85
BARE HULL	9672.00	10.65	103026.14	104.00	1005888.00	0.00	0.00
SHELL + SUPPORTS			0.00		0.00		0.00
HULL STRUCTURAL BULKHDS			0.00		0.00		0.00
HULL DECKS			0.00		0.00		0.00
HULL PLATFORMS/FLATS			0.00		0.00		0.00
DECK HOUSE STRUCTURE	69.59	28.13	1957.57	90.00	6263.10	15.00	1043.85
SPECIAL STRUCTURES	2.00	21.00	42.00	107.70	215.40	14.00	28.00
SPECIAL STRUCTURES	2.00	21.00	42.00	167.30	334.60	14.00	28.00
SPECIAL STRUCTURES	30.00	21.00	630.00	70.00	2100.00	0.00	0.00
MASTS+KINGPOSTS+SERV PLATFORM	2.00	36.63	73.26	90.00	180.00	0.00	0.00
FOUNDATIONS	1285.00	5.33	6843.91	120.00	154200.00	0.00	0.00
SPECIAL PURPOSE SYSTEMS			0.00		0.00		0.00
PROPULSION PLANT	526.80	8.48	4465.63	94.17	49608.04	1.28	672.30
PROPULSION UNITS			0.00		0.00		0.00
DIESEL ENGINES			0.00		0.00		0.00
ICR I	49.80	3.00	149.40	56.00	2788.80	3.00	149.40
ICR II	49.80	3.00	149.40	59.00	2938.20	3.00	149.40
ICR III	49.80	13.50	672.30	195.00	9711.00	7.50	373.50
ELECTRIC PROPULSION	75.32	2.50	188.30	148.00	11147.36	0.00	0.00
TRANSMISSION+PROPULSOR SYSTEMS			0.00		0.00		0.00
REDUCTION GEARS			0.00		0.00		0.00
CLUTCHES + COUPLINGS			0.00		0.00		0.00
SHAFTING	62.90	3.00	188.70	180.00	11322.00	0.00	0.00
SHAFT BEARINGS	12.11	3.00	36.32	185.00	2239.61	0.00	0.00
PROPULSORS	47.07	3.00	141.21	201.00	9461.07	0.00	0.00
SUPPORT SYSTEMS, UPTAKES, EXHAUST, FORWARD	100.00	15.00	1500.00		0.00		0.00
SUPPORT SYSTEMS, UPTAKES, EXHAUST, AFT	80.00	18.00	1440.00		0.00		0.00
PROPUL SUP SYS- FUEL, LUBE OIL			0.00		0.00		0.00
SPECIAL PURPOSE SYSTEMS			0.00		0.00		0.00
ELECTRIC PLANT, GENERAL	733.81	14.81	10865.49	105.64	77523.00	0.97	709.20
ELECTRIC POWER GENERATION			0.00		0.00		0.00
SHIP SERVICE POWER GENERATION, FORWARD	29.55	9.00	265.95	45.50	1344.53	11.00	325.05
SHIP SERVICE POWER GENERATION, AFT	29.55	15.00	443.25	194.00	5732.70	13.00	384.15
EMERGENCY GENERATORS			0.00		0.00		0.00
POWER CONVERSION EQUIPMENT	14.30	5.00	71.50	100.00	1430.00	0.00	0.00
POWER DISTRIBUTION SYS	486.91	15.00	7303.65	105.00	51125.55	0.00	0.00
LIGHTING SYSTEM	118.70	20.00	2374.00	101.00	11988.70	0.00	0.00
POWER GENERATION SUPPORT SYS	33.70	9.27	312.40	108.00	3639.60	0.00	0.00
SPECIAL PURPOSE SYS	21.10	4.49	94.74	107.20	2261.92		0.00
COMMAND+SURVEILLANCE	407.86	17.64	7193.50	92.29	37641.36	2.66	1084.90
PAYLOAD	91.06	20.96	1908.89	95.00	8650.70	5.00	455.30
CABLING	37.70	11.98	451.70	103.00	3882.59	3.00	113.09
MISC	46.01	11.98	551.28	105.00	4830.53	3.00	138.02
COMMAND+CONTROL SYS	5.60	12.00	67.20	65.00	364.00	0.00	0.00
NAVIGATION SYS	6.60	28.67	189.22	60.11	396.73		0.00
INTERIOR COMMUNICATIONS	75.70	13.32	1007.95	110.00	8327.00	5.00	378.50
EXTERIOR COMMUNICATIONS	30.70	27.97	858.68	55.71	1710.30		0.00
SURF SURVEILLANCE SYS (RADAR)	16.40	27.56	451.98	80.12	1313.97		0.00
UNDERWATER SURVEILLANCE SYSTEMS	10.00	1.00	10.00	15.00	150.00		0.00
COUNTERMEASURES	58.30	16.24	946.79	98.49	5741.97		0.00
FIRE CONTROL SYS	14.40	29.74	428.26	88.92	1280.45		0.00
SPECIAL PURPOSE SYS	15.40	20.88	321.55	64.49	993.15		0.00
AUXILIARY SYSTEMS, GENERAL	5600.87	12.85	71963.66	98.97	554339.15	-0.41	-2295.42
WAUX	2207.00	10.65	23508.96	100.00	220700.00	-1.70	-3751.90
PAYLOAD	0.00		0.00		0.00		0.00
CLIMATE CONTROL	411.10	16.37	6729.71	80.09	32925.00		0.00
SEA WATER SYSTEMS	336.00	12.12	4072.32	95.67	32145.12		0.00
FRESH WATER SYSTEMS	196.00	9.94	1948.24	92.03	18037.88		0.00
FUELS/LUBRICANTS,HANDLING+STORAGE	171.70	7.52	1291.18	125.34	21520.88		0.00
AIR,GAS+MISC FLUID SYSTEM	188.00	11.65	2190.20	98.78	18570.64		0.00
SHIP CNTL SYS	108.60	6.14	666.80	189.91	20624.23		0.00
UNDERWAY REPLENISHMENT SYSTEMS	244.10	19.58	4779.48	89.00	21724.90		0.00
ANCHOR HANDLING+STOWAGE SYSTEMS	224.20	14.02	3143.28	9.77	2190.43		0.00
MOORING+TOWING SYSTEMS	74.80	16.97	1269.36	113.26	8471.85		0.00
BOATS,HANDLING+STOWAGE SYSTEMS	74.50	9.00	670.50	192.00	14304.00		0.00
AIRCRAFT WEAPONS ELEVATORS 1	40.00	6.00	240.00	108.00	4320.00		0.00

AIRCRAFT WEAPONS ELEVATORS 2	40.00	15.00	600.00	108.00	4320.00		0.00
AIRCRAFT WEAPONS ELEVATORS 3	40.00	6.00	240.00	108.00	4320.00		0.00
AIRCRAFT WEAPONS ELEVATORS 4	40.00	6.00	240.00	141.00	5640.00		0.00
AIRCRAFT WEAPONS ELEVATORS 5	40.00	15.00	600.00	141.00	5640.00		0.00
AIRCRAFT WEAPONS ELEVATORS 6	40.00	6.00	240.00	141.00	5640.00		0.00
AIRCRAFT RECOVERY SUPPORT SYS	64.86	26.00	1686.46	150.00	9729.60	-3.00	-194.59
AIRCRAFT LAUNCH SUPPORT SYSTEM	353.80	19.00	6722.20	40.00	14152.00	0.00	0.00
AIRCRAFT ELEVATORS	117.93	23.00	2712.48	180.00	21228.12	7.00	825.54
AIRCRAFT ELEVATORS	117.93	23.00	2712.48	94.00	11085.80	7.00	825.54
AIRCRAFT HANDLING, SUPPORT	108.80	17.00	1849.60	100.00	10880.00	0.00	0.00
ENVIRONMENTAL POLLUTION CNTL SYS	27.71	10.65	295.13	100.00	2771.20	0.00	0.00
AUX SYSTEMS OPERATING FLUIDS	333.83	10.65	3555.26	130.00	43397.51	0.00	0.00
OUTFIT+FURNISHING,GENERAL	1761.20	9.21	16217.75	106.05	186769.50	0.00	0.00
SHIP FITTINGS	1065.00	10.65	11344.38	110.00	117150.00	0.00	0.00
LIVING SPACES	696.20	7.00	4873.37	100.00	69619.50	0.00	0.00
ARMAMENT	40.34	19.93	804.06	153.36	6185.71	0.00	0.00
GUNS+AMMUNITION	6.71	21.00	140.82	45.00	301.75	0.00	0.00
	6.71	21.00	140.82	200.00	1341.12	0.00	0.00
MISSLES+ROCKETS	21.03	24.00	504.75	180.00	3785.62	0.00	0.00
TORPEDOES	0.00	2.50	0.00	117.00	0.00	0.00	0.00
SMALL ARMS+PYROTECHNICS	5.89	3.00	17.68	128.50	757.22	0.00	0.00
FULL LOAD CONDITION							
LOADS	4802.70	7.19	34518.82	90.29	433645.72	-0.26	-1239.09
SHIPS FORCE	88.17	15.98	1408.78	105.00	9257.85	0.00	0.00
SHIP AMMUNITION	26.64	2.50	66.60	117.00	3116.88	0.00	0.00
ORD DEL SYS AMMO	13.95	2.50	34.87	117.00	1632.11	0.00	0.00
ORD DEL SYS (AIRCRAFT)	360.60	17.00	6130.18	105.00	37862.90	-1.00	-360.60
LAMPS MKIII AVIATION SUPPORT AND SPARES	9.57	20.00	191.41	190.00	1818.43	0.00	0.00
BATHYTHERMOGRAPH PROBES	0.20	20.00	4.06	190.00	38.61	0.00	0.00
PROVISIONS+PERSONNEL STORES	258.69	11.43	2957.86	110.00	28455.90	0.00	0.00
GENERAL STORES	79.28	11.35	900.05	110.00	8720.69	0.00	0.00
DIESEL FUEL MARINE	1504.00	9.99	15023.46	64.17	96517.70	0.00	0.00
JP-5	1617.00	4.04	6532.68	104.81	169481.00	0.00	0.00
LUBRICATING OIL	17.60	2.00	35.20	150.00	2640.00	0.00	0.00
SEA WATER	227.00	4.11	933.65	72.70	16502.45	-3.87	-878.49
FRESH WATER	600.00	0.50	300.00	96.00	57601.20	0.00	0.00
MINIMUM OPERATING CONDITION							
LOADS	3695.76	5.71	21117.69	97.05	358678.34	-0.34	-1242.01
SHIPS FORCE	88.17	15.98	1408.78	105.00	9257.85	0.00	0.00
SHIP AMMUNITION	8.88	2.50	22.20	117.00	1038.96	0.00	0.00
ORD DEL SYS AMMO	4.65	2.50	11.62	117.00	544.04	0.00	0.00
ORD DEL SYS (AIRCRAFT)	360.60	17.00	6130.18	105.00	37862.90	-1.00	-360.60
LAMPS MKIII AVIATION SUPPORT AND SPARES	9.57	20.00	191.41	190.00	1818.43	0.00	0.00
BATHYTHERMOGRAPH PROBES	0.20	20.00	4.06	190.00	38.61	0.00	0.00
PROVISIONS+PERSONNEL STORES	86.23	11.43	985.95	110.00	9485.30	0.00	0.00
GENERAL STORES	26.43	11.35	300.02	110.00	2906.90	0.00	0.00
DIESEL FUEL MARINE	496.32	4.29	0.00	127.32	63191.46	0.00	0.00
JP-5	533.61	8.34	4450.31	78.72	42005.78	0.00	0.00
LUBRICATING OIL	5.87	2.00	11.73	150.00	880.00	0.00	0.00
SEA WATER COMPENSATED	1087.23	5.78	6284.21	100.00	108723.37	0.00	0.00
SEA WATER	588.00	1.90	1117.20	72.32	42524.75	-1.50	-881.41
FRESH WATER	400.00	0.50	200.00	96.00	38400.00	0.00	0.00

D.5 Electric Load Analysis

SWBS	Description	Connected (kW)	UCAV Launch (kW)	Other Aircraft Ops (kW)	Cruise (kW)	Inport (kW)	Anchor (kW)	Emergency (kW)
100	Deck	451.1	0.0	0.0	0.0	12.1	8.0	5.3
200	Propulsion	48489.4	47403.1	47481.5	21220.5	248.7	284.0	0.0
230	Engines - Mechanical Drive		0.0	0.0	0.0	0.0	0.0	0.0
235	Elecric Propulsion Drive	46905.0	46905.0	46905.0	20644.0	0.0	0.0	0.0
250&260	Support	1584.4	498.1	576.5	576.5	248.7	284.0	0.0
300	Electric	680.2	322.9	322.9	322.9	214.7	335.7	149.5
310	Power Generation	334.2	126.6	126.6	126.6	37.1	135.1	58.5
330	Lighting	346.0	196.3	196.3	196.3	177.6	200.6	91.0
400	C&S	746.7	597.7	597.7	577.9	71.5	218.4	373.5
410	C&C	65.0	48.7	48.7	43.6	6.0	42.2	34.4
420	Navigation	5.0	4.6	4.6	4.6	0.4	3.6	5.0
430	IC	41.5	31.2	31.2	31.2	4.6	16.0	33.9
440	Ex Comm	192.9	96.5	96.5	96.5	57.9	57.9	57.9
450	Radar	303.0	303.0	303.0	303.0	0.0	2.0	224.0
460	UW Surveillance	6.9	5.5	5.5	1.4	0.0	1.4	0.0
470	Countermeasures	80.7	63.0	63.0	61.1	0.0	58.8	13.1
480	Fire Control	32.4	25.9	25.9	17.3	2.6	17.3	5.2
490	Special	19.3	19.3	19.3	19.3	0.0	19.3	0.0
500	Auxiliary Systems	9841.3	4746.9	4513.0	4767.7	4122.1	4286.5	581.6
510	HVAC	6291.6	3864.4	3864.4	3945.1	3748.7	3864.4	0.0
520	Seawater Systems	2139.7	208.8	208.8	357.9	101.4	113.4	246.1
530	Fresh Water Sys	575.1	247.4	247.4	247.4	212.7	230.6	335.6
540	Fuel Handling	311.6	77.1	77.1	77.1	21.8	37.4	0.0
550	Air and Gas	217.2	21.7	21.7	21.7	21.7	21.7	0.0
560	Ship Control	200.6	29.9	0.0	29.9	0.0	0.0	0.0
580	Mechanical		280.0	76.0	71.0	0.0	0.0	0.0
584	Mechanical Doors		21.0	21.0	21.0	0.0	0.0	0.0
586	Aircraft Recovery		5.0	5.0	0.0	0.0	0.0	0.0
587	Aircraft Launch (Boiler)		204.0	0.0	0.0	0.0	0.0	0.0
588	Aircraft Handling		50.0	50.0	50.0	50.0	50.0	0.0
593	Environmental	105.4	17.5	17.5	17.5	15.8	19.0	0.0
600	Services	677.0	342.1	342.1	342.1	342.1	342.0	50.0
700	Armament		10.0	10.0	10.0	0.0	10.0	0.0
	Max Functional Load		53422.7	53267.2	27241.1	5011.1	5484.5	1160.0
	MFL w/ Margins		54686.9	54482.2	28505.5	6011.2	6576.7	1403.6
	24 Hour Average		51059.9	50981.8	24877.9	3129.9	3430.3	1403.6
Number	**Generator**	**Rating (kW)**	**UCAV Launch**	**Other Aircraft Ops**	**Cruise**	**Inport**	**Anchor**	**Emergency**
3	Propulsion Generators	21000.0	3	3	2	0	0	0
2	SSDGs	3430.0	0	0	0	2	2	2
0	EDG	0.0	0	0	0	0	0	0
	Power Available (kW)		63000.0	63000.0	42000.0	6860.0	6860.0	6860.0

SWBS 100

Equipment	Qty	Rated	Conn (Demand)	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
100 - DECK MACHINERY															
Anchor Windlass PORT	1	100.00	79.62	0.00	0	0.00	0	0.00	0	0.00	0	0.10	7.96	0.00	0
Anchor Windlass STBD	1	100.00	79.62	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
C.T. Winch #1	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.10	4.024	0.00	0	0.00	0
C.T. Winch #2	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
C.T. Winch #3	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.10	4.024	0.00	0	0.00	0
C.T. Winch #4	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
C.T. Winch #5	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.10	4.024	0.00	0	0.00	0
C.T. Winch #6	1	50.00	40.24	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Rescue Boat FR 50 (S)	1	25.00	20.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Rescue Boat FR 39 (P)	1	25.00	20.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Accommodition Ladder Port	1	1.50	1.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Accommodition Ladder Stbd	1	1.50	1.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Side Port (Port)	1	1.00	0.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Side Port (Stbd)	1	1.00	0.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Water Tight Doors #1	1	2.00	1.78	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.78
Water Tight Doors #2	1	2.00	1.78	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.78
Water Tight Doors #3	1	2.00	1.78	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.78
Total			451.10		0.00		0.00		0.00		12.07		7.96		5.34

SWBS 200

Equipment	Qty	Rated	Conn	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	(Demand) KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
235 - Electric Propulsion															
MOTOR, PROPULSION (PORT)	1	29330.00	23692.00	1.00	23692	1.00	23692	1.00	10850	0.00	0	0.00	0	0.00	0
MOTOR, PROPULSION (STBD)	1	29330.00	23692.00	1.00	23692	1.00	23692	1.00	10850	0.00	0	0.00	0	0.00	0
Total			47384.00		47384		47384		21700		0		0		0
240 - Propellers, Shafts, & Bearings															
250&260 - Support															
CONSOLE, MAIN CONTROL	1														
PURIFIER, MGTG LUBE OIL #1	1	16.10	12.00	0.40	4.8	0.90	10.8	0.90	10.8	0.20	2.4	0.90	10.8	0.00	0
PURIFIER, MGTG LUBE OIL #2	1	16.10	12.00	0.00	0	0.90	10.8	0.90	10.8	0.20	2.4	0.90	10.8	0.00	0
PURIFIER, MGTG LUBE OIL #3	1	16.10	12.00	0.40	4.8	0.90	10.8	0.90	10.8	0.20	2.4	0.90	10.8	0.00	0
PURIFIER, MGTG LUBE OIL #4	1	16.10	12.00	0.00	0	0.90	10.8	0.90	10.8	0.20	2.4	0.90	10.8	0.00	0
PUMP, MGTG LUBE OIL PURIFIER FEED #1	1	1.50	1.20	0.90	1.08	0.90	1.08	0.90	1.08	0.20	0.24	0.90	1.08	0.00	0
PUMP, MGTG LUBE OIL PURIFIER FEED #2	1	1.50	1.20	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL PURIFIER FEED #3	1	1.50	1.20	0.90	1.08	0.90	1.08	0.90	1.08	0.20	0.24	0.90	1.08	0.00	0
PUMP, MGTG LUBE OIL PURIFIER FEED #4	1	1.50	1.20	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PURIFIER HEATER, MGTG LUBE OIL #1	1	75.10	56.00	0.40	22.4	0.40	22.4	0.40	22.4	0.20	11.2	0.20	11.2	0.00	0
PURIFIER HEATER, MGTG LUBE OIL #2	1	75.10	56.00	0.00	0	0.40	22.4	0.40	22.4	0.20	11.2	0.20	11.2	0.00	0
PURIFIER HEATER, MGTG LUBE OIL #3	1	75.10	56.00	0.40	22.4	0.40	22.4	0.40	22.4	0.20	11.2	0.20	11.2	0.00	0
PURIFIER HEATER, MGTG LUBE OIL #4	1	75.10	56.00	0.00	0	0.40	22.4	0.40	22.4	0.20	11.2	0.20	11.2	0.00	0
PUMP, LUBE OIL TRANSFER #1	1	5.00	3.73	0.10	0.373	0.10	0.373	0.10	0.373	0.10	0.373	0.10	0.373	0.00	0
PUMP, LUBE OIL TRANSFER #2	1	5.00	3.73	0.10	0.373	0.10	0.373	0.10	0.373	0.10	0.373	0.10	0.373	0.00	0
PUMP, MAIN SEAWATER CIRC #1	1	150.00	111.86	0.90	100.67	0.90	100.674	0.90	100.67	0.00	0	0.00	0	0.00	0
PUMP, MAIN SEAWATER CIRC #2	1	150.00	111.86	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MAIN SEAWATER CIRC #3	1	150.00	111.86	0.90	100.67	0.90	100.674	0.90	100.67	0.00	0	0.00	0	0.00	0
PUMP, MAIN SEAWATER CIRC #4	1	150.00	111.86	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Motor Turning Gear (S)	1	10.00	8.43	0.00	0	0.00	0	0.00	0	0.10	0.843	0.10	0.843	0.00	0
Motor Turning Gear (P)	1	10.00	8.43	0.00	0	0.00	0	0.00	0	0.10	0.843	0.10	0.843	0.00	0
Motor Heater Port	1	0.00	12.00	0.00	0	0.00	0	0.00	0	0.90	10.8	0.90	10.8	0.00	0
Motor Heater Stbd	1	0.00	12.00	0.00	0	0.00	0	0.00	0	0.90	10.8	0.90	10.8	0.00	0
Motor Blowers Port	1	20.00	16.27	0.90	14.643	0.90	14.643	0.90	14.643	0.00	0	0.00	0	0.00	0
Motor Blowers Stbd	1	20.00	16.27	0.90	14.643	0.90	14.643	0.90	14.643	0.00	0	0.00	0	0.00	0
PUMP, LOW TEMPERATURE FW COOLING #1	1	125.00	93.21	0.90	83.889	0.90	83.889	0.90	83.889	0.90	83.889	0.90	83.889	0.00	0
PUMP, LOW TEMPERATURE FW COOLING #2	1	125.00	93.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, LOW TEMPERATURE FW COOLING #3	1	125.00	93.21	0.90	83.889	0.90	83.889	0.90	83.889	0.90	83.889	0.90	83.889	0.00	0
PUMP, LOW TEMPERATURE FW COOLING #4	1	125.00	93.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
AGTG LO Settling Tank	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.00	0	0.00	0	0.00	0
MGTG LO Settling Tank	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.20	0.4	0.20	0.4	0.00	0
MTGT LO Storage Tank	1	0.00	8.00	0.20	1.6	0.20	1.6	0.20	1.6	0.20	1.6	0.20	1.6	0.00	0
MGTG Starting Unit	1	0.00	150.00	0.10	15	0.10	15	0.10	15	0.00	0	0.00	0	0.00	0
Pre-Heating Unit, MGTG HT FW	3	0.00	243.00	0.10	24.3	0.10	24.3	0.10	24.3	0.00	0	0.00	0	0.00	0
PUMP, MAIN STRUT AND STERN TUBE LUBE OIL #1	1	0.50	0.37	0.90	0.333	0.90	0.333	0.90	0.333	0.00	0	0.00	0	0.00	0
PUMP, MAIN STRUT AND STERN TUBE LUBE OIL #2	1	0.50	0.37	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MAIN STRUT AND STERN TUBE LUBE OIL #3	1	0.50	0.37	0.90	0.333	0.90	0.333	0.90	0.333	0.00	0	0.00	0	0.00	0
PUMP, MAIN STRUT AND STERN TUBE LUBE OIL #4	1	0.50	0.37	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Total			1584.42		498.08		576.48		576.48		248.69		283.97		0.00

SWBS 300

Equipment	Qty	Rated	Connected	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
310 - Power Generation															
GAS TURBINE GENRATOR, MAIN #1															
PUMP, MGTG FUEL SERVICE STBY	1	5.00	3.73	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL SERVICE STBY	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
GAS TURBINE GENRATOR, MAIN #2															
PUMP, MGTG FUEL SERVICE STBY	1	5.00	3.73	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL SERVICE STBY	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
GAS TURBINE GENRATOR, MAIN #3															
PUMP, MGTG FUEL SERVICE STBY	1	5.00	3.73	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL SERVICE STBY	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
GAS TURBINE GENERATOR, AUXILIARY #1															
PUMP, MGTG FUEL SERVICE STBY	1	5.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL SERVICE STBY	1	40.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
GAS TURBINE GENERATOR, AUXILIARY #2															
PUMP, MGTG FUEL SERVICE STBY	1	5.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, MGTG LUBE OIL SERVICE STBY	1	40.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Engine Rm Cont. Console UPS	1	0.00	20.00	0.30	6	0.30	6	0.30	6	0.10	2	0.20	4	1.00	20
Cathodic Protection Sys	1	0.00	20.00	0.70	14	0.70	14	0.70	14	0.70	14	0.70	14	0.00	0
Degaussing	1	0.00	120.00	0.80	96	0.80	96	0.80	96	0.00	0	0.80	96	0.00	0
Motor and Controller Htrs	1	0.00	35.00	0.20	7	0.20	7	0.20	7	0.50	17.5	0.50	17.5	0.00	0
Emerg. DG Jacket Water Heater	1	0.00	5.00	0.50	2.5	0.50	2.5	0.50	2.5	0.50	2.5	0.50	2.5	1.00	5
IC Battery Charger	1	0.00	2.50	0.25	0.625	0.25	0.625	0.25	0.625	0.25	0.63	0.25	0.625	1.00	2.5
SUBM Pump	1	5.00	4.34	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	4.34
Whistle Heater (Air)	1	0.00	2.50	0.20	0.5	0.20	0.5	0.20	0.5	0.20	0.5	0.20	0.5	1.00	2.5
Heated Window Sig Shelt	1	0.00	4.95	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	4.95
Heated Window P.H.	1	0.00	9.75	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	9.75
Heated Window Chart Rm	1	0.00	9.45	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	9.45
Total			334.17		126.63		126.63		126.63		37.13		135.13		58.49
330 - Lighting															
Engine Room LTG	1	0.00	40.00	0.70	28	0.70	28	0.70	28	0.70	28	0.70	28	0.00	0
Living Quarters LTG	1	0.00	120.00	0.60	72	0.60	72	0.60	72	0.40	48	0.60	72	0.00	0
MISC LTG	1	0.00	50.00	0.20	10	0.20	10	0.20	10	0.20	10	0.20	10	0.00	0
Floodlights (White)	1	0.00	15.00	0.10	1.5	0.10	1.5	0.10	1.5	0.70	10.5	0.40	6	0.00	0
Replenishing FLD LTS (Red)	1	0.00	30.00	0.10	3	0.10	3	0.10	3	0.00	0	0.10	3	0.00	0
Emergency Lights	1	0.00	90.00	0.90	81	0.90	81	0.90	81	0.90	81	0.90	81	1.00	90
Navigational Lights	1	0.00	1.00	0.80	0.8	0.80	0.8	0.80	0.8	0.10	0.1	0.60	0.6	1.00	1
Total			346.00		196.3		196.3		196.3		178		200.6		91

SWBS 400

Equipment Description	Qty	Rated HP Ea	Conn (Demand KW	UCAV Launch LF	KW	Other Aircraft Ops LF	KW	Cruise LF	KW	Inport LF	KW	Anchor LF	KW	Emergency LF	KW
410 - C&C															
INT. BRIDGE CONSOLE	1	0.00	5.00	0.40	2	0.40	2	0.40	2	0.10	0.5	0.20	1	1.00	5
Whistle (Electric)	1	0.00	5.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	5
BRIDGE WING CONSOLE (P	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.10	0.2	0.10	0.2	1.00	2
BRIDGE WING CONSOLE (S	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.10	0.2	0.10	0.2	1.00	2
Data Processing	1		1.00	0.90	0.9	0.90	0.9	0.80	0.8	0.10	0.1	0.80	0.8	0.40	0.4
Data Display	1		45.00	0.90	40.5	0.90	40.5	0.80	36	0.10	4.5	0.80	36	0.40	18
Data Interface	1		5.00	0.90	4.5	0.90	4.5	0.80	4	0.10	0.5	0.80	4	0.40	2
Total			65.00		48.7		48.7		43.6		6		42.2		34.4
420 - Navigation															
Collision Avoidance	1	0.00	2.00	1.00	2	1.00	2	1.00	2	0.00	0	1.00	2	1.00	2
Doppler Speed Log	1	0.00	1.00	1.00	1	1.00	1	1.00	1	0.00	0	0.00	0	1.00	1
Gyrocompass Sys. #1	1	0.00	1.00	0.80	0.8	0.80	0.8	0.80	0.8	0.20	0.2	0.80	0.8	1.00	1
Gyrocompass Sys. #2	1	0.00	1.00	0.80	0.8	0.80	0.8	0.80	0.8	0.20	0.2	0.80	0.8	1.00	1
Total			5.00		4.60		4.60		4.60		0.40		3.60		5.00
430 - IC															
Ship Miscelaneous	1		38	0.8	30.4	0.8	30.4	0.8	30.4	0.1	3.8	0.4	15.2	0.8	30.4
Gen Alarm Beacon Lts	1	0.00	1.50	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.5
CRT DISPLAY CH. ENG.	1	0.00	1.00	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	1.00	1
CRT DISPLAY CAPTAIN	1	0.00	1.00	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	1.00	1
Total			41.50		31.2		31.2		31.2		4.6		16		33.9
440 - Ex Comm															
AN/URT-23C (V) XIMR Set #	1	0.00	9.00	0.50	4.5	0.50	4.5	0.50	4.5	0.30	2.7	0.30	2.7	0.30	2.7
AN/URT-23C (V) XIMR Set #	1	0.00	9.00	0.50	4.5	0.50	4.5	0.50	4.5	0.30	2.7	0.30	2.7	0.30	2.7
AN/WSC-3 (V) 7 UHF XCVR	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
Advanced C4I Systems			131.30	0.50	65.65	0.50	65.65	0.50	65.65	0.30	39.39	0.30	39.39	0.30	39.4
MT-6069/WSC-3 (V) Rack	1	0.00	5.60	0.50	2.8	0.50	2.8	0.50	2.8	0.30	1.68	0.30	1.68	0.30	1.68
SA-2000A / WSC-1 (V) ANT	1	0.00	1.60	0.50	0.8	0.50	0.8	0.50	0.8	0.30	0.48	0.30	0.48	0.30	0.48
AN/WSC-3 (V) 3 UHF Sat.	1	0.00	1.40	0.50	0.7	0.50	0.7	0.50	0.7	0.30	0.42	0.30	0.42	0.30	0.42
Total			192.90		96.45		96.45		96.45		57.87		57.87		57.9
450 - Radar															
SPS-49A	1	0.00	79.00	1.00	79	1.00	79	1.00	79	0.00	0	0.00	0	0.00	0
SPQ-9B	1	0.00	220.00	1.00	220	1.00	220	1.00	220	0.00	0	0.00	1	1.00	220
CIFF	1	0.00	4.00	1.00	4	1.00	4	1.00	4	0.00	0	0.00	1	1.00	4
Total			303.00		303		303		303		0		2		224
460 - UW Surveillance															
LAMPS Electronics	1		6.90	0.80	5.52	0.80	5.52	0.20	1.38	0.00	0	0.20	1.38	0.00	0
470 - Countermeasures															
AN/SLQ-25 Winch	1	5.00	4.34	0.10	0.434	0.10	0.434	0.10	0.434	0.00	0	0.00	0	1.00	4.34
AN/SLQ-25 Transmitter	1	0.00	3.80	1.00	3.8	1.00	3.8	0.50	1.9	0.00	0	0.00	0	0.00	0
Degaussing	1	0.00	62.50	0.80	50	0.80	50	0.80	50	0.00	0	0.80	50	0.00	0
DLS	4	0.00	3.00	0.80	2.4	0.80	2.4	0.80	2.4	0.00	0	0.80	2.4	0.80	2.4
SLQ-32	1	0.00	7.10	0.90	6.39	0.90	6.39	0.90	6.39	0.00	0	0.90	6.39	0.90	6.39
Total			80.74		63.02		63.02		61.12		0.00		58.79		13.13
480 - Fire Control															
UW Fire Control	1		14.40	0.80	11.52	0.80	11.52	0.20	2.88	0.00	0	0.20	2.88	0.00	0
SSDS	1		13.00	0.80	10.4	0.80	10.4	0.80	10.4	0.20	2.6	0.80	10.4	0.40	5.2
Weapons Switchboards	2		5.00	0.80	4	0.80	4	0.80	4	0.00	0	0.80	4	0.00	0
Total			32.40		25.92		25.92		17.28		2.6		17.28		5.2
490 - Misc															
Combat DF	1	0	19.3	1	19.3	1	19.3	1	19.3	0	0	1	19.3	0	0

SWBS 500

Equipment	Qty	Rated	Connected	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
410 - C&C															
INT. BRIDGE CONSOLE	1	0.00	5.00	0.40	2	0.40	2	0.40	2	0.10	0.5	0.20	1	1.00	5
Whistle (Electric)	1	0.00	5.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	5
BRIDGE WING CONSOLE (P)	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.10	0.2	0.10	0.2	1.00	2
BRIDGE WING CONSOLE (S)	1	0.00	2.00	0.20	0.4	0.20	0.4	0.20	0.4	0.10	0.2	0.10	0.2	1.00	2
Data Processing	1		1.00	0.90	0.9	0.90	0.9	0.80	0.8	0.10	0.1	0.80	0.8	0.40	0.4
Data Display	1		45.00	0.90	40.5	0.90	40.5	0.80	36	0.10	4.5	0.80	36	0.40	18
Data Interface	1		5.00	0.90	4.5	0.90	4.5	0.80	4	0.10	0.5	0.80	4	0.40	2
Total			65.00		48.7		48.7		43.6		6		42.2		34.4
420 - Navigation															
Collision Avoidance	1	0.00	2.00	1.00	2	1.00	2	1.00	2	0.00	0	1.00	2	1.00	2
Doppler Speed Log	1	0.00	1.00	1.00	1	1.00	1	1.00	1	0.00	0	0.00	0	1.00	1
Gyrocompass Sys. #1	1	0.00	1.00	0.80	0.8	0.80	0.8	0.80	0.8	0.20	0.2	0.80	0.8	1.00	1
Gyrocompass Sys. #2	1	0.00	1.00	0.80	0.8	0.80	0.8	0.80	0.8	0.20	0.2	0.80	0.8	1.00	1
Total			5.00		4.60		4.60		4.60		0.40		3.60		5.00
430 - IC															
Ship Miscelaneous	1		38	0.8	30.4	0.8	30.4	0.8	30.4	0.1	3.8	0.4	15.2	0.8	30.4
Gen Alarm Beacon Lts	1	0.00	1.50	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.5
CRT DISPLAY CH. ENG.	1	0.00	1.00	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	1.00	1
CRT DISPLAY CAPTAIN	1	0.00	1.00	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	0.40	0.4	1.00	1
Total			41.50		31.2		31.2		31.2		4.6		16		33.9
440 - Ex Comm															
AN/URT-23C (V) XIMR Set #1	1	0.00	9.00	0.50	4.5	0.50	4.5	0.50	4.5	0.30	2.7	0.30	2.7	0.30	2.7
AN/URT-23C (V) XIMR Set #2	1	0.00	9.00	0.50	4.5	0.50	4.5	0.50	4.5	0.30	2.7	0.30	2.7	0.30	2.7
AN/WSC-3 (V) 7 UHF XCVR #1	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR #2	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR #3	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR #4	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
AN/WSC-3 (V) 7 UHF XCVR #5	1	0.00	7.00	0.50	3.5	0.50	3.5	0.50	3.5	0.30	2.1	0.30	2.1	0.30	2.1
Advanced C4I Systems			131.30	0.50	65.65	0.50	65.65	0.50	65.65	0.30	39.4	0.30	39.4	0.30	39.4
MT-6069/WSC-3 (V) Rack	1	0.00	5.60	0.50	2.8	0.50	2.8	0.50	2.8	0.30	1.68	0.30	1.68	0.30	1.68
SA-2000A / WSC-1 (V) ANT	1	0.00	1.60	0.50	0.8	0.50	0.8	0.50	0.8	0.30	0.48	0.30	0.48	0.30	0.48
AN/WSC-3 (V) 3 UHF Sat.	1	0.00	1.40	0.50	0.7	0.50	0.7	0.50	0.7	0.30	0.42	0.30	0.42	0.30	0.42
Total			192.90		96.45		96.45		96.45		57.9		57.9		57.9
450 - Radar															
SPS-49A	1	0.00	79.00	1.00	79	1.00	79	1.00	79	0.00	0	0.00	0	0.00	0
SPQ-9B	1	0.00	220.00	1.00	220	1.00	220	1.00	220	0.00	0	0.00	1	1.00	220
CIFF	1	0.00	4.00	1.00	4	1.00	4	1.00	4	0.00	0	0.00	1	1.00	4
Total			303.00		303		303		303		0		2		224
460 - UW Surveillance															
LAMPS Electronics	1		6.90	0.80	5.52	0.80	5.52	0.20	1.38	0.00	0	0.20	1.38	0.00	0
470 - Countermeasures															
AN/SLQ-25 Winch	1	5.00	4.34	0.10	0.434	0.10	0.434	0.10	0.434	0.00	0	0.00	0	1.00	4.34
AN/SLQ-25 Transmitter	1	0.00	3.80	1.00	3.8	1.00	3.8	0.50	1.9	0.00	0	0.00	0	0.00	0
Degaussing	1	0.00	62.50	0.80	50	0.80	50	0.80	50	0.00	0	0.80	50	0.00	0
DLS	4	0.00	3.00	0.80	2.4	0.80	2.4	0.80	2.4	0.00	0	0.80	2.4	0.80	2.4
SLQ-32	1	0.00	7.10	0.90	6.39	0.90	6.39	0.90	6.39	0.00	0	0.90	6.39	0.90	6.39
Total			80.74		63.02		63.02		61.12		0.00		58.79		13.13
480 - Fire Control															
UW Fire Control	1		14.40	0.80	11.52	0.80	11.52	0.20	2.88	0.00	0	0.20	2.88	0.00	0
SSDS	1		13.00	0.80	10.4	0.80	10.4	0.80	10.4	0.20	2.6	0.80	10.4	0.40	5.2
Weapons Switchboards	2		5.00	0.80	4	0.80	4	0.80	4	0.00	0	0.80	4	0.00	0
Total			32.40		25.92		25.92		17.28		2.6		17.3		5.2
490 - Misc															
Combat DF	1	0	19.3	1	19.3	1	19.3	1	19.3	0	0	1	19.3	0	0

SWBS 500 (cont.)

Equipment	Qty	Rated	Conn (Demand)	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
500 - AUXILIARY MACHINERY															
510 - HVAC, Aux Boilers, Refer															
AIR CONDITIONING PLANTS #1	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
AIR CONDITIONING PLANTS #2	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
AIR CONDITIONING PLANTS #3	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
AIR CONDITIONING PLANTS #4	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
AIR CONDITIONING PLANTS #5	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
AIR CONDITIONING PLANTS #6	1	670.00	500.00	0.80	400	0.80	400	0.80	400	0.80	400	0.80	400	0.00	0
MN MCHNRY SPACE FAN (EXHAUST	1	75.00	22.40	0.90	20.16	0.90	20.16	0.90	20.16	0.50	11.2	0.90	20.16	0.00	0
MN MCHNRY SPACE FAN (EXHAUST	1	75.00	22.40	0.00	0	0.00	0	0.90	20.16	0.00	0	0.00	0	0.00	0
MN MCHNRY SPACE FAN (EXHAUST	1	75.00	22.40	0.90	20.16	0.90	20.16	0.90	20.16	0.50	11.2	0.90	20.16	0.00	0
MN MCHNRY SPACE FAN (EXHAUST	1	75.00	22.40	0.00	0	0.00	0	0.90	20.16	0.00	0	0.00	0	0.00	0
AUX MCHNRY SPACE FAN (EXHAUS	1	75.00	22.40	0.90	20.16	0.90	20.16	0.90	20.16	0.50	11.2	0.90	20.16	0.00	0
AUX MCHNRY SPACE FAN (EXHAUS	1	75.00	22.40	0.00	0	0.00	0	0.90	20.16	0.00	0	0.00	0	0.00	0
AUX MCHNRY SPACE FAN (EXHAUS	1	75.00	22.40	0.90	20.16	0.90	20.16	0.90	20.16	0.50	11.2	0.90	20.16	0.00	0
AUX MCHNRY SPACE FAN (EXHAUS	1	75.00	22.40	0.00	0	0.00	0	0.90	20.16	0.50	11.2	0.00	0	0.00	0
MN MCHNRY SPACE FAN (SUPPLY)	1	30.00	56.93	0.90	51.237	0.90	51.237	0.90	51.237	0.50	28.465	0.90	51.237	0.00	0
MN MCHNRY SPACE FAN (SUPPLY)	1	30.00	56.93	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
MN MCHNRY SPACE FAN (SUPPLY)	1	30.00	56.93	0.90	51.237	0.90	51.237	0.90	51.237	0.50	28.465	0.90	51.237	0.00	0
MN MCHNRY SPACE FAN (SUPPLY)	1	30.00	56.93	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
AUX MCHNRY SPACE FAN (SUPPLY	1	30.00	56.93	0.90	51.237	0.90	51.237	0.90	51.237	0.50	28.465	0.90	51.237	0.00	0
AUX MCHNRY SPACE FAN (SUPPLY	1	30.00	56.93	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
AUX MCHNRY SPACE FAN (SUPPLY	1	30.00	56.93	0.90	51.237	0.90	51.237	0.90	51.237	0.50	28.465	0.90	51.237	0.00	0
AUX MCHNRY SPACE FAN (SUPPLY	1	30.00	56.93	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Reheaters	173	0.00	295.95	0.40	118.38	0.40	118.38	0.40	118.38	0.40	118.38	0.40	118.38	0.00	0
Preheaters	8	0.00	1472.00	0.40	588.8	0.40	588.8	0.40	588.8	0.40	588.8	0.40	588.8	0.00	0
Heaters	11	0.00	440.00	0.40	176	0.40	176	0.40	176	0.40	176	0.40	176	0.00	0
Convectors	36	0.00	38.20	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Cooling Coil #1	1	0.33	0.34	0.50	0.17	0.50	0.17	0.50	0.17	0.50	0.17	0.50	0.17	0.00	0
Cooling Coil #2	1	0.33	0.34	0.50	0.17	0.50	0.17	0.50	0.17	0.50	0.17	0.50	0.17	0.00	0
REFRIG PLANTS, SHIP SERVICE #1	1	110.00	82.03	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.00	0
REFRIG PLANTS, SHIP SERVICE #2	1	110.00	82.03	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.00	0
REFRIG PLANTS, SHIP SERVICE #3	1	110.00	82.03	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.00	0
REFRIG PLANTS, SHIP SERVICE #4	1	110.00	82.03	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.70	57.421	0.00	0
Control RM A/C	1	0.00	82.03	0.80	65.624	0.80	65.624	0.80	65.624	0.80	65.624	0.80	65.624	0.00	0
Total			6291.62		3864.42		3864.4		3945.1		3748.7		3864.42		0

Equipment	Qty	Rated	Conn (Demand)	UCAV Launch		Other Aircraft Ops		Cruise		Inport		Anchor		Emergency	
Description		HP Ea	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW
520 - Seawater Systems															
PUMP, FIRE #1	1	250.00	186.43	0.20	37.286	0.20	37.286	0.20	37.286	0.10	18.643	0.10	18.643	0.00	0
PUMP, FIRE #2	1	250.00	186.43	0.00	0	0.00	0	0.20	37.286	0.00	0	0.00	0	0.00	0
PUMP, FIRE #3	1	250.00	186.43	0.20	37.286	0.20	37.286	0.20	37.286	0.10	18.643	0.10	18.643	0.00	0
PUMP, FIRE #4	1	250.00	186.43	0.00	0	0.00	0	0.20	37.286	0.00	0	0.00	0	0.00	0
PUMP, FIRE #5	1	250.00	186.43	0.20	37.286	0.20	37.286	0.20	37.286	0.10	18.643	0.10	18.643	0.00	0
PUMP, FIRE #6	1	250.00	186.43	0.00	0	0.00	0	0.20	37.286	0.00	0	0.00	0	0.00	0
PUMP, FIRE #7	1	250.00	186.43	0.20	37.286	0.20	37.286	0.20	37.286	0.10	18.643	0.10	18.643	0.00	0
PUMP, FIRE #8	1	250.00	186.43	0.00	0	0.00	0	0.20	37.286	0.00	0	0.00	0	0.00	0
PUMP, FIRE/BALLAST #1	1	250.00	186.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, FIRE/BALLAST #1	1	250.00	186.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	186
PUMP, BILGE/BALLAST #1	1	40.00	29.83	0.10	2.983	0.10	2.983	0.10	2.983	0.00	0	0.20	5.966	1.00	29.8
PUMP, BILGE/BALLAST #2	1	40.00	29.83	0.10	2.983	0.10	2.983	0.10	2.983	0.00	0	0.20	5.966	1.00	29.8
PUMP. BILGE #1	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP. BILGE #1	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, AUX. SEAWATER #1	1	40.00	29.83	0.90	26.847	0.90	26.847	0.90	26.847	0.90	26.847	0.90	26.847	0.00	0
PUMP, AUX. SEAWATER #2	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, AUX. SEAWATER #3	1	40.00	29.83	0.90	26.847	0.90	26.847	0.90	26.847	0.00	0	0.00	0	0.00	0
PUMP, AUX. SEAWATER #4	1	40.00	29.83	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Foam Pump (Fwd)	1	30.00	24.33	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	24.3
Foam Pump (Aft)	1	15.00	12.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	12.5
Total			2139.73		208.80		208.80		357.95		101.42		113.35		246

SWBS 500 (cont.)

530 - Fresh Water Systems

PUMP, POTABLE WATER #1	1	10.00	7.46	0.30	2.238	0.30	2.238	0.30	2.238	0.20	1.492	0.30	2.238	0.00
PUMP, POTABLE WATER #2	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PUMP, POTABLE WATER #3	1	10.00	7.46	0.30	2.238	0.30	2.238	0.30	2.238	0.20	1.492	0.30	2.238	0.00
PUMP, POTABLE WATER #4	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PUMP, POTABLE WATER #5	1	10.00	7.46	0.30	2.238	0.30	2.238	0.30	2.238	0.20	1.492	0.30	2.238	0.00
PUMP, HOT WATER RECIRC #1	1	15.00	11.20	0.60	6.72	0.60	6.72	0.60	6.72	0.30	3.36	0.30	3.36	0.00
PUMP, HOT WATER RECIRC #2	1	15.00	11.20	0.60	6.72	0.60	6.72	0.60	6.72	0.30	3.36	0.30	3.36	0.00
PUMP, HOT WATER RECIRC #3	1	15.00	11.20	0.60	6.72	0.60	6.72	0.60	6.72	0.30	3.36	0.30	3.36	0.00
PUMP, HOT WATER RECIRC #4	1	15.00	11.20	0.60	6.72	0.60	6.72	0.60	6.72	0.30	3.36	0.30	3.36	0.00
PUMP, HOT WATER RECIRC #5	1	15.00	11.20	0.60	6.72	0.60	6.72	0.60	6.72	0.30	3.36	0.30	3.36	0.00
PUMP, DISTILLER #1	1	2.00	11.20	0.70	7.84	0.70	7.84	0.70	7.84	0.00	0	0.70	7.84	0.00
PUMP, DISTILLER #2	1	2.00	11.20	0.70	7.84	0.70	7.84	0.70	7.84	0.00	0	0.70	7.84	0.00
BROMINATOR #1	1	0.00	0.10	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
BROMINATOR #2	1	0.00	0.10	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PUMP, CHILLED WATER #1	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.00
PUMP, CHILLED WATER #2	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	1.00
PUMP, CHILLED WATER #3	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	2.00
PUMP, CHILLED WATER #4	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	3.00
PUMP, CHILLED WATER #5	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	4.00
PUMP, CHILLED WATER #6	1	30.00	22.37	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	0.70	15.659	5.00
HEATER, WATER #1	1	88.00	65.00	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.00
HEATER, WATER #2	1	88.00	65.00	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.00
HEATER, WATER #3	1	88.00	65.00	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.00
HEATER, WATER #4	1	88.00	65.00	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.00
HEATER, WATER #5	1	88.00	65.00	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.30	19.5	0.00
Total			575.12		247.448		247.45		247.45		212.73		230.648	

540 - Fuel Handling

PURIFIER, FUEL #1	1	8.05	6.00	0.40	2.4	0.40	2.4	0.40	2.4	0.10	0.6	0.20	1.2	0.00
PURIFIER, FUEL #2	1	8.05	6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PURIFIER, FUEL #3	1	8.05	6.00	0.40	2.4	0.40	2.4	0.40	2.4	0.10	0.6	0.20	1.2	0.00
PURIFIER, FUEL #4	1	8.05	6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
HEATER, FUEL #1	1	48.28	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.10	3.6	0.20	7.2	0.00
HEATER, FUEL #2		48.28	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.10	3.6	0.20	7.2	0.00
HEATER, FUEL #3		48.28	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.10	3.6	0.20	7.2	0.00
HEATER, FUEL #4		48.28	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.10	3.6	0.20	7.2	0.00
PUMP, FUEL TRANSFER #1	1	30.00	22.37	0.10	2.237	0.10	2.237	0.10	2.237	0.10	2.237	0.10	2.237	0.00
PUMP, FUEL TRANSFER #2	1	30.00	22.37	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PUMP, FUEL TRANSFER #3	1	30.00	22.37	0.10	2.237	0.10	2.237	0.10	2.237	0.10	2.237	0.10	2.237	0.00
PUMP, FUEL TRANSFER #4	1	30.00	22.37	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
PUMP, JP-5 TRANSFER #1	1	3.00	2.24	0.20	0.448	0.20	0.448	0.20	0.448	0.10	0.224	0.10	0.224	0.00
PUMP, JP-5 TRANSFER #2	1	3.00	2.24	0.20	0.448	0.20	0.448	0.20	0.448	0.10	0.224	0.10	0.224	0.00
PUMP, JP-5 TRANSFER #3	1	3.00	2.24	0.20	0.448	0.20	0.448	0.20	0.448	0.10	0.224	0.10	0.224	0.00
PUMP, JP-5 TRANSFER #4	1	3.00	2.24	0.20	0.448	0.20	0.448	0.20	0.448	0.10	0.224	0.10	0.224	0.00
PUMP, JP-5 TRANSFER #5	1	3.00	2.24	0.20	0.448	0.20	0.448	0.20	0.448	0.10	0.224	0.10	0.224	0.00
PUMP, JP-5 SERVICE #1	1	10.00	7.46	0.20	1.492	0.20	1.492	0.20	1.492	0.00	0	0.00	0	0.00
PUMP, JP-5 SERVICE #2	1	10.00	7.46	0.20	1.492	0.20	1.492	0.20	1.492	0.00	0	0.00	0	0.00
PUMP, JP-5 SERVICE #3	1	10.00	7.46	0.20	1.492	0.20	1.492	0.20	1.492	0.00	0	0.00	0	0.00
PUMP, JP-5 SERVICE #4	1	10.00	7.46	0.20	1.492	0.20	1.492	0.20	1.492	0.00	0	0.00	0	0.00
PUMP, JP-5 SERVICE #5	1	10.00	7.46	0.20	1.492	0.20	1.492	0.20	1.492	0.00	0	0.00	0	0.00
PUMP, JP-5 SREIPPING #1	1	1.50	1.12	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.00
PUMP, JP-5 SREIPPING #2	1	1.50	1.12	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.00
PUMP, JP-5 SREIPPING #3	1	1.50	1.12	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.00
PUMP, JP-5 SREIPPING #4	1	1.50	1.12	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.00
PUMP, JP-5 SREIPPING #5	1	1.50	1.12	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.10	0.112	0.00
Total			311.58		77.13		77.13		77.13		21.75		37.35	

SWBS 500 (cont.)

550 - Air and Gas													
COMPRESSOR, START AIR #1	1	22.80	17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7
COMPRESSOR, START AIR #2	1	22.80	17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7
COMPRESSOR, START AIR #3	1	22.80	17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7
COMPRESSOR, START AIR #4	1	22.80	17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7
COMPRESSOR, AIR, LP SHIP SERVI	1	50.00	37.29	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729
COMPRESSOR, AIR, LP SHIP SERVI	1	50.00	37.29	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729
COMPRESSOR, AIR, LP SHIP SERVI	1	50.00	37.29	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729
COMPRESSOR, AIR, LP SHIP SERVI	1	50.00	37.29	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729	0.10	3.729
Total			217.16		21.716		21.716		21.716		21.716		21.716
560 - Ship Control													
Steering Gear Stbd	1	125.00	99.52	0.30	29.856	0.30	29.856	0.30	29.856	0.00	0	0.00	0
Steering Gear Port	1	125.00	99.52	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Steering Control Stbd	1	0.00	0.80	0.10	0.08	0.10	0.08	0.10	0.08	0.00	0	0.00	0
Steering Control Port	1	0.00	0.80	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Total			200.64		29.936		0.00		29.936		0		0
593 - Environmental Pollution													
SEPARATOR, OIL/WATER #1	1	1.35	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2
SEPARATOR, OIL/WATER #2	1	1.35	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2
SEPARATOR, OIL/WATER #3	1	1.35	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2
SEPARATOR, OIL/WATER #4	1	1.35	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2
PUMP, OILY WASTE TRANSFER #1	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.10	0.746	0.10	0.746
PUMP, OILY WASTE TRANSFER #2	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
PUMP, OILY WASTE TRANSFER #3	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.10	0.746	0.10	0.746
PUMP, OILY WASTE TRANSFER #4	1	10.00	7.46	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
SEWAGE COLLECTION UNIT #1	1	5.40	4.03	0.40	1.612	0.40	1.612	0.40	1.612	0.20	0.806	0.40	1.612
SEWAGE COLLECTION UNIT #2	1	5.40	4.03	0.40	1.612	0.40	1.612	0.40	1.612	0.20	0.806	0.40	1.612
SEWAGE COLLECTION UNIT #3	1	5.40	4.03	0.40	1.612	0.40	1.612	0.40	1.612	0.20	0.806	0.40	1.612
SEWAGE COLLECTION UNIT #4	1	5.40	4.03	0.40	1.612	0.40	1.612	0.40	1.612	0.20	0.806	0.40	1.612
SEWAGE TREATMENT UNIT #1	1	8.58	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56
SEWAGE TREATMENT UNIT #2	1	8.58	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56
SEWAGE TREATMENT UNIT #3	1	8.58	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56
SEWAGE TREATMENT UNIT #4	1	8.58	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56
PUMP, WASTE WATER DISCH #1	1	10.00	7.46	0.10	0.746	0.10	0.746	0.10	0.746	0.10	0.746	0.00	0
PUMP, WASTE WATER DISCH #2	1	10.00	7.46	0.10	0.746	0.10	0.746	0.10	0.746	0.10	0.746	0.00	0
PUMP, WASTE WATER DISCH #3	1	10.00	7.46	0.10	0.746	0.10	0.746	0.10	0.746	0.10	0.746	0.00	0
PUMP, WASTE WATER DISCH #4	1	10.00	7.46	0.10	0.746	0.10	0.746	0.10	0.746	0.10	0.746	0.00	0
Total			105.40		17.488		17.488		17.488		15.756		18.98

D.6 CUVX Machinery Equipment List

CUV(X) MASTER EQUIPMENT LIST
Option 11 - Twin FPP's, ICR Gas Turbine with IPS Electric Option

ITEM	QTY.	EQUIPMENT NOMENCLATURE	DESCRIPTION	CAPACITY RATING (each)	PWR REQD (each)	UNIT WEIGHT (MT)	DIMENSIONS LxWxH (mm)	LOCATION	SWBS	REMARKS
1	2	TANK, L.O. STORAGE	STRUCTURAL	10.5 m^3	-	8.95	-	VARIOUS	123	
2	2	TANK, L.O. SETTLING	STRUCTURAL	10.5 m^3	20 kW	-	-	VARIOUS	123	WITH ELECTRIC HEATER
3	2	TANK, OILY WASTE HOLDING	STRUCTURAL	13.8 m^3	-	-	-	VARIOUS	123	
4	2	TANK, WASTE OIL	STRUCTURAL	13.8 m^3	-	-	-	VARIOUS	123	
5	2	TANK, FUEL SERVICE	STRUCTURAL	121 m^3	-	-	-	MMR	123	12 HOUR SUPPLY
6	1	MOTOR, PROPULSION		29330 kW @ 150 rpm		45	5400 x 4700 x 4400	AMR2	235	INCLUDES THRUST BEARING, TURNING GEAR AND SPACE HEATER
7	1	MOTOR, PROPULSION		29330 kW @ 150 rpm		45	5400 x 4700 x 4400	AMR3	235	INCLUDES THRUST BEARING, TURNING GEAR AND SPACE HEATER
8	1	CONVERTER, PRPLN POWER		14665 kW	-	4	7500 x 1750 x 2140	AMR2	235	
9	1	CONVERTER, PRPLN POWER		14665 kW	-	4	7500 x 1750 x 2140	AMR2	235	
10	1	CONVERTER, PRPLN POWER		14665 kW	-	4	7500 x 1750 x 2140	AMR3	235	
11	1	CONVERTER, PRPLN POWER		14665 kW	-	4	7500 x 1750 x 2140	AMR3	235	
12	1	CONTROL UNIT, PRPLN MOTOR		-	-	0.85	2400 x 900 x 2080	AMR2	235	
13	1	CONTROL UNIT, PRPLN MOTOR		-	-	0.85	2400 x 900 x 2080	AMR3	235	
14	1	EXCITER UNIT, PRPLN MOTOR		-	605kW	8.75	1200 x 900 x 2080	AMR2	235	STBY UNITS
15	1	EXCITER UNIT, PRPLN MOTOR		-	605kW	8.75	1200 x 900 x 2080	AMR3	235	STBY UNITS
16	1	SHAFT, LINE	520 mm (OD), 345 mm (ID)	-	-	15	15,200	AMR2	243	ABS GRADE 2 STEEL
17	1	SHAFT, LINE	520 mm (OD), 345 mm (ID)	-	-	15	15,200	AMR3	243	ABS GRADE 2 STEEL
18	1	SHAFT, STERN TUBE	600 mm (OD), 400 mm (ID)	-	-	25	19,000	STERN TUBE (P/S)	243	ABS GRADE 2 STEEL
19	2	SHAFT, STERN TUBE	600 mm (OD), 400 mm (ID)	-	-	25	19,000	STERN TUBE (P/S)	243	ABS GRADE 2 STEEL
20	1	SHAFT, TAIL	625 mm (OD), 400 mm (ID)	-	-	15	10,000	FRAME 180 -190 (P/S)	243	ABS GRADE 2 STEEL
21	1	SHAFT, TAIL	625 mm (OD), 400 mm (ID)	-	-	15	10,000	FRAME 180 -190 (P/S)	243	ABS GRADE 2 STEEL
22	1	BEARING, LINE SHAFT	DISK TYPE	520 mm LINE SHAFT	-	1.61	940 x 1220 x 1181	AMR2	244	
23	1	BEARING, LINE SHAFT	DISK TYPE	520 mm LINE SHAFT	-	1.61	940 x 1220 x 1181	AMR2	244	
24	1	BEARING, LINE SHAFT	DISK TYPE	520 mm LINE SHAFT	-	1.61	940 x 1220 x 1181	AMR3	244	
25	1	BEARING, LINE SHAFT	DISK TYPE	520 mm LINE SHAFT	-	1.61	940 x 1220 x 1181	AMR3	244	
26	1	BEARING, MAIN STRUT	OIL LUBRICATED	625 mm TAIL SHAFT	-	0.9	1250 (L) x 680 (OD)	MAIN STRUT (P/S)	244	
27	1	BEARING, MAIN STRUT	OIL LUBRICATED	625 mm TAIL SHAFT	-	0.9	1250 (L) x 680 (OD)	MAIN STRUT (P/S)	244	
28	1	BEARING, STERN TUBE	OIL LUBRICATED	600 mm STERN TUBE SHAFT	-	0.438	600 (L) x 680 (OD)	STERN TUBE (P/S)	244	
29	1	BEARING, STERN TUBE	OIL LUBRICATED	600 mm STERN TUBE SHAFT	-	0.438	600 (L) x 680 (OD)	STERN TUBE (P/S)	244	

30	1	BEARING, STERN TUBE	OIL LUBRICATED	600 mm STERN TUBE SHAFT	-	0.438	600 (L) x 680 (OD)	STERN TUBE (P/S)	244	
31	1	BEARING, STERN TUBE	OIL LUBRICATED	600 mm STERN TUBE SHAFT	-	0.438	600 (L) x 680 (OD)	STERN TUBE (P/S)	244	
32	1	PROPELLER, FIXED PITCH	5 BLADES, Ni-Al-Bronze		-	23	4880 (D)	FRAME 190 (P/S)	245	
33	1	PROPELLER, FIXED PITCH	5 BLADES, Ni-Al-Bronze		-	23	4880 (D)	FRAME 190 (P/S)	245	
34	1	CONSOLE, MAIN CONTROL			5 kW	3.632	8334 x 1219 x 2134	MMR1	252	
35	1	PUMP, LOW TEMPERATURE FW COOLING	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	600 m^3/hr @ 4 bar	125 HP	1.287	724 x 724 x 1905	PMR5	256	1 DUTY / 1 STBY PER CENTRAL COOLING LOOP
36	1	PUMP, LOW TEMPERATURE FW COOLING	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	600 m^3/hr @ 4 bar	125 HP	1.287	724 x 724 x 1905	PMR5	256	1 DUTY / 1 STBY PER CENTRAL COOLING LOOP
37	1	PUMP, LOW TEMPERATURE FW COOLING	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	600 m^3/hr @ 4 bar	125 HP	1.287	724 x 724 x 1905	PMR4	256	1 DUTY / 1 STBY PER CENTRAL COOLING LOOP
38	1	PUMP, LOW TEMPERATURE FW COOLING	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	600 m^3/hr @ 4 bar	125 HP	1.287	724 x 724 x 1905	PMR4	256	1 DUTY / 1 STBY PER CENTRAL COOLING LOOP
39	1	COOLER, LT FW	PLATE TYPE	-	-	2.724	2997 x 762 x 1499	PMR5	256	
40	1	COOLER, LT FW	PLATE TYPE	-	-	2.724	2997 x 762 x 1499	PMR5	256	
41	1	COOLER, LT FW	PLATE TYPE	-	-	2.724	2997 x 762 x 1499	PMR4	256	
42	1	COOLER, LT FW	PLATE TYPE	-	-	2.724	2997 x 762 x 1499	PMR4	256	
43	1	STRAINER, SEAWATER	SIMPLEX BASKET		-	6.577	2438 x 1829 x 3626	PMR5	256	
44	1	STRAINER, SEAWATER	SIMPLEX BASKET		-	6.577	2438 x 1829 x 3626	PMR5	256	
45	1	STRAINER, SEAWATER	SIMPLEX BASKET		-	6.577	2438 x 1829 x 3626	PMR4	256	
46	1	STRAINER, SEAWATER	SIMPLEX BASKET		-	6.577	2438 x 1829 x 3626	PMR4	256	
47	1	PUMP, MAIN SEAWATER CIRC	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	1300 m^3/hr @ 2 bar	150 HP	2.286	1143 x 1143 x 2777	PMR5	256	STBY FOR AUX SW PUMPS
48	1	PUMP, MAIN SEAWATER CIRC	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	1300 m^3/hr @ 2 bar	150 HP	2.286	1143 x 1143 x 2777	PMR5	256	STBY FOR AUX SW PUMPS
49	1	PUMP, MAIN SEAWATER CIRC	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	1300 m^3/hr @ 2 bar	150 HP	2.286	1143 x 1143 x 2777	PMR4	256	STBY FOR AUX SW PUMPS
50	1	PUMP, MAIN SEAWATER CIRC	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	1300 m^3/hr @ 2 bar	150 HP	2.286	1143 x 1143 x 2777	PMR4	256	STBY FOR AUX SW PUMPS
51	1	PUMP, MAIN STRUT AND STERN TUBE LUBE OIL	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	1.1 m^3/hr @2bar	0.5 HP	0.082	914 x 610 x 1219	SGR1	262	TWO DUTY, TWO STBY
52	1	PUMP, MAIN STRUT AND STERN TUBE LUBE OIL	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	1.1 m^3/hr @2bar	0.5 HP	0.082	914 x 610 x 1219	SGR1	262	TWO DUTY, TWO STBY
53	1	PUMP, MAIN STRUT AND STERN TUBE LUBE OIL	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	1.1 m^3/hr @2bar	0.5 HP	0.082	914 x 610 x 1219	SGR2	262	TWO DUTY, TWO STBY
54	1	PUMP, MAIN STRUT AND STERN TUBE LUBE OIL	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	1.1 m^3/hr @2bar	0.5 HP	0.082	914 x 610 x 1219	SGR2	262	TWO DUTY, TWO STBY
55	1	COOLER, LUBE OIL	PLATE TYPE		-	0.091	610 x 204 x 533	SGR1	262	FOR STERN TUBES AND STRUTS
56	1	COOLER, LUBE OIL	PLATE TYPE		-	0.091	610 x 204 x 533	SGR1	262	FOR STERN TUBES AND STRUTS
57	1	COOLER, LUBE OIL	PLATE TYPE		-	0.091	610 x 204 x 533	SGR2	262	FOR STERN TUBES AND STRUTS
58	1	COOLER, LUBE OIL	PLATE TYPE		-	0.091	610 x 204 x 533	SGR2	262	FOR STERN TUBES AND STRUTS
59	1	FILTER / COALESCER, LUBE OIL		1.1 m^3/hr	-	.068 (DRY WEIGHT)	914 (L) x 410 (OD)	SGR1	262	FOR STERN TUBES AND STRUTS
60	1	FILTER / COALESCER, LUBE OIL		1.1 m^3/hr	-	.068 (DRY WEIGHT)	914 (L) x 410 (OD)	SGR1	262	FOR STERN TUBES AND STRUTS
61	1	FILTER / COALESCER, LUBE OIL		1.1 m^3/hr	-	.068 (DRY WEIGHT)	914 (L) x 410 (OD)	SGR2	262	FOR STERN TUBES AND STRUTS
62	1	FILTER / COALESCER, LUBE OIL		1.1 m^3/hr	-	.068 (DRY WEIGHT)	914 (L) x 410 (OD)	SGR2	262	FOR STERN TUBES AND STRUTS
63	1	PURIFIER, MGTG LUBE OIL	CENTRIFUGAL, SELF CLEANING, PARTIAL DISCHARGE TYPE	2.9 m^3/hr	12 kW	1.62	1120 x 1470 x 1420	PR1	264	
64	1	PURIFIER, MGTG LUBE OIL	CENTRIFUGAL, SELF CLEANING, PARTIAL DISCHARGE TYPE	2.9 m^3/hr	12 kW	1.62	1120 x 1470 x 1420	PR1	264	
65	1	PURIFIER, MGTG LUBE OIL	CENTRIFUGAL, SELF CLEANING, PARTIAL DISCHARGE TYPE	2.9 m^3/hr	12 kW	1.62	1120 x 1470 x 1420	PR2	264	
66	1	PURIFIER, MGTG LUBE OIL	CENTRIFUGAL, SELF CLEANING, PARTIAL DISCHARGE TYPE	2.9 m^3/hr	12 kW	1.62	1120 x 1470 x 1420	PR2	264	
67	1	PUMP, MGTG LUBE OIL PURIFIER FEED	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	2.9 m^3/hr @ 5bar	1.5HP	0.12	683 x 330 x 232	PMR5	264	
68	1	PUMP, MGTG LUBE OIL PURIFIER FEED	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	2.9 m^3/hr @ 5bar	1.5HP	0.12	683 x 330 x 232	PMR5	264	
69	1	PUMP, MGTG LUBE OIL PURIFIER FEED	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	2.9 m^3/hr @ 5bar	1.5HP	0.12	683 x 330 x 232	PMR4	264	
70	1	PUMP, MGTG LUBE OIL PURIFIER FEED	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	2.9 m^3/hr @ 5bar	1.5HP	0.12	683 x 330 x 232	PMR4	264	
71	1	PURIFIER HEATER, MGTG LUBE OIL	ELECTRIC		56 kW	0.106	580 x 355 x 895	PR1	264	

72	1	PURIFIER HEATER, MGTG LUBE OIL	ELECTRIC		56 kW	0.106	580 x 355 x 895	PR1	264	
73	1	PURIFIER HEATER, MGTG LUBE OIL	ELECTRIC		56 kW	0.106	580 x 355 x 895	PR2	264	
74	1	PURIFIER HEATER, MGTG LUBE OIL	ELECTRIC		56 kW	0.106	580 x 355 x 895	PR2	264	
75	1	PUMP, LUBE OIL TRANSFER	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	6.5 m3/hr@5bar	5 HP	0.165	800 x 267 x 318	PMR5	264	
76	1	PUMP, LUBE OIL TRANSFER	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	6.5 m3/hr@5bar	5 HP	0.165	800 x 267 x 318	PMR4	264	
77	1	GAS TURBINE GENERATOR, MAIN	SULZER 12ZA40S 4-STROKE, TURBOCHARGED, OR EQUAL	21000 kW, 514 RPM, 4160 V, 3 PHASE, 60 Hz, 0.8 PF	60 HP	51	4600 x 2800 x 1040	MMR1	311	INCLUDES INTAKE AIR FILTERS, TURNING GEAR AND AIR COOLERS
78	1	GAS TURBINE GENERATOR, MAIN	SULZER 12ZA40S 4-STROKE, TURBOCHARGED, OR EQUAL	21000 kW, 514 RPM, 4160 V, 3 PHASE, 60 Hz, 0.8 PF	60 HP	51	4600 x 2800 x 1040	MMR1	311	INCLUDES INTAKE AIR FILTERS, TURNING GEAR AND AIR COOLERS
79	1	GAS TURBINE GENERATOR, MAIN	SULZER 12ZA40S 4-STROKE, TURBOCHARGED, OR EQUAL	21000 kW, 514 RPM, 4160 V, 3 PHASE, 60 Hz, 0.8 PF	60 HP	51	4600 x 2800 x 1040	MMR2	311	INCLUDES INTAKE AIR FILTERS, TURNING GEAR AND AIR COOLERS
80	1	GAS TURBINE GENERATOR, AUXILIARY	DDA 501-K34	3430 kW, 14300 RPM, 600V, 3 PHASE, 60 Hz, 0.8 PF	-	0.6	2290 x 850 x 790	AMR1	311	INCLUDES INTAKE AIR FILTERS, TURNING GEAR AND AIR COOLERS
81	1	GAS TURBINE GENERATOR, AUXILIARY	DDA 501-K34	3430 kW, 14300 RPM, 600V, 3 PHASE, 60 Hz, 0.8 PF	-	0.6	2290 x 850 x 790	MMR2	311	INCLUDES INTAKE AIR FILTERS, TURNING GEAR AND AIR COOLERS
82	1	UPS	CENTRALIZED CONTROL	100 A	-	0.15	1829 x 610 x 610	MMR1	313	
83	1	UPS	CENTRALIZED CONTROL	100 A	-	0.15	1829 x 610 x 610	MMR2	313	
87	1	POWER CONVERSION MODULES	1 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1622 x 610 x 915	MMR1	314	
88	1	POWER CONVERSION MODULES	2 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1623 x 610 x 915	MMR1	314	
89	1	POWER CONVERSION MODULES	3 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1624 x 610 x 915	MMR1	314	
90	1	POWER CONVERSION MODULES	4 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1625 x 610 x 915	MMR1	314	
91	1	POWER CONVERSION MODULES	5 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1626 x 610 x 915	MMR2	314	
92	1	POWER CONVERSION MODULES	6 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1626 x 610 x 915	MMR2	314	
93	1	POWER CONVERSION MODULES	7 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1626 x 610 x 915	MMR2	314	
94	4	POWER CONVERSION MODULES	8 PHASE PCM BANK 3 SINGLE PHASE UNITS	37.5 KVA, 600V/480V 3 PHASE, 60 Hz	-	4.05	1626 x 610 x 915	MMR2	314	
109	1	SHORE POWER FACILITY		2400 A	-	0.363	2134 x 610 x 2286	MMR2	321	INCLUDES RECEPTACLES, BREAKERS AND CONTROLS
114	1	SWITCHBOARD, MAIN POWER				12	6400 x 2439 x 2286	MMR1	324	
115	1	SWITCHBOARD, MAIN POWER				12	6400 x 2439 x 2286	MMR2	324	
116	1	SWITCHBOARD, SHIPS SERVICE	GENERATOR CONTROL POWER DISTRIBUTION	-	-	12	6096 x 1220 x 2286	AMR1	324	
117	1	SWITCHBOARD, SHIPS SERVICE	GENERATOR CONTROL POWER DISTRIBUTION	-	-	12	6096 x 1220 x 2286	MMR2	324	
118	1	SWITCHBOARD, LOAD CENTER	POWER DISTRIBUTION	-	-	3.632	2286 x 610 x 2286	VARIOUS	324	
119	1	SWITCHBOARD, LOAD CENTER	POWER DISTRIBUTION	-	-	3.632	2286 x 610 x 2286	VARIOUS	324	
120	1	SWITCHBOARD, LOAD CENTER	POWER DISTRIBUTION	-	-	3.632	2286 x 610 x 2286	MMR2	324	
121	1	SWITCHBOARD, LOAD CENTER	POWER DISTRIBUTION	-	-	3.632	2286 x 610 x 2286	MMR2	324	
122	1	FILTER, HARMONIC		-	-	3.8	4000 x 800 x 2000	MMR1	324	
123	1	FILTER, HARMONIC		-	-	3.8	4000 x 800 x 2000	MMR1	324	
124	1	FILTER, HARMONIC		-	-	3.8	4000 x 800 x 2000	MMR2	324	
125	1	FILTER, HARMONIC		-	-	3.8	4000 x 800 x 2000	MMR2	324	
126	1	PROPULSION MOTOR CONTROL CENTER	460V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR2	324	
127	1	PROPULSION MOTOR CONTROL CENTER	460V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR2	324	
128	1	PROPULSION MOTOR CONTROL CENTER	460V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR3	324	
129	1	PROPULSION MOTOR CONTROL CENTER	460V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR3	324	
130	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR1	324	
131	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	AMR1	324	
132	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR1	324	
133	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR1	324	
134	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR1	324	
135	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR1	324	
136	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR2	324	
137	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR2	324	
138	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR2	324	
139	1	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR2	324	

140	1	PUMP, MGTG FUEL SERVICE	ENGINE DRIVEN	6.8 m3/hr	-	-	-	MMR1	342	INCLUDED WITH MGTG SET
141	1	PUMP, MGTG FUEL SERVICE	ENGINE DRIVEN	6.8 m3/hr	-	-	-	MMR1	342	INCLUDED WITH MGTG SET
142	1	PUMP, MGTG FUEL SERVICE	ENGINE DRIVEN	6.8 m^3/hr	-	-	-	MMR2	342	INCLUDED WITH MGTG SET
143	1	PUMP, MGTG FUEL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	6.8 m^3/hr @ 6.2 bar	5 HP	0.163	686 x 305 x 284	MMR1	342	1 STBY PER 2 MGTG SETS
144	1	PUMP, MGTG FUEL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	6.8 m^3/hr @ 6.2 bar	5 HP	0.163	686 x 305 x 284	PMR4	342	1 STBY PER 2 MGTG SETS
145	1	FILTER, MGTG FUEL FILTER	DUPLEX		-	0.145	356 x 610 x 686	PR1	342	
146	1	FILTER, MGTG FUEL FILTER	DUPLEX		-	0.145	356 x 610 x 686	PR1	342	
147	1	FILTER, MGTG FUEL FILTER	DUPLEX		-	0.145	356 x 610 x 686	PR2	342	
148	1	FILTER, MGTG FUEL FILTER	DUPLEX		-	0.145	356 x 610 x 686	PR2	342	
149	1	PUMP, MGTG LUBE OIL SERVICE	ENGINE DRIVEN	110 m^3/hr	-	-	-	MMR1	342	INCLUDED WITH MGTG SET
150	1	PUMP, MGTG LUBE OIL SERVICE	ENGINE DRIVEN	110 m^3/hr	-	-	-	MMR1	342	INCLUDED WITH MGTG SET
151	1	PUMP, MGTG LUBE OIL SERVICE	ENGINE DRIVEN	110 m^3/hr	-	-	-	MMR2	342	INCLUDED WITH MGTG SET
152	1	PUMP, MGTG LUBE OIL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	110 m^3/hr	40 HP	0.44	1410 x 546 x 686	MMR1	342	1 STBY PER MGTG SET
153	1	PUMP, MGTG LUBE OIL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	110 m^3/hr	40 HP	0.44	1410 x 546 x 686	MMR1	342	1 STBY PER MGTG SET
154	1	PUMP, MGTG LUBE OIL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	110 m^3/hr	40 HP	0.44	1410 x 546 x 686	MMR2	342	1 STBY PER MGTG SET
155	1	PUMP, MGTG LUBE OIL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	110 m^3/hr	40 HP	0.44	1410 x 546 x 686	MMR2	342	1 STBY PER MGTG SET
156	1	FILTER, MGTG LUBE OIL	AUTOMATIC CLEANING	110 m^3/hr	-	1.86	2190 x 820 x 1508	PR1	342	WITH BYPASS FILTER
157	1	FILTER, MGTG LUBE OIL	AUTOMATIC CLEANING	110 m^3/hr	-	1.86	2190 x 820 x 1508	PR1	342	WITH BYPASS FILTER
158	1	FILTER, MGTG LUBE OIL	AUTOMATIC CLEANING	110 m^3/hr	-	1.86	2190 x 820 x 1508	PR2	342	WITH BYPASS FILTER
159	1	FILTER, MGTG LUBE OIL	AUTOMATIC CLEANING	110 m^3/hr	-	1.86	2190 x 820 x 1508	PR2	342	WITH BYPASS FILTER
160	1	COOLER, MGTG LUBE OIL	PLATE TYPE		-	0.908	2363 x 457 x 1067	MMR1	342	
161	1	COOLER, MGTG LUBE OIL	PLATE TYPE		-	0.908	2363 x 457 x 1067	MMR1	342	
162	1	COOLER, MGTG LUBE OIL	PLATE TYPE		-	0.908	2363 x 457 x 1067	PMR4	342	
163	1	COOLER, MGTG LUBE OIL	PLATE TYPE		-	0.908	2363 x 457 x 1067	PMR4	342	
164	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	MMR1	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
165	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	MMR1	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
166	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	MMR1	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
167	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	MMR1	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
168	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	PMR4	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
169	1	STRAINER, MGTG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	PMR4	342	FOUR MOUNTED ON MDGs AND FOUR MOUNTED OFF
170	1	PUMP, MGTG HT FW COOLING	ENGINE DRIVEN	113 m^3/hr	-	-	-	MMR1	342	INCLUDED WITH MDG SET
171	1	PUMP, MGTG HT FW COOLING	ENGINE DRIVEN	113 m^3/hr	-	-	-	MMR1	342	INCLUDED WITH MDG SET
172	1	PUMP, MGTG HT FW COOLING	ENGINE DRIVEN	113 m^3/hr	-	-	-	MMR2	342	INCLUDED WITH MDG SET
173	1	PUMP, MGTG HT FW COOLING STBY	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	113 m3/hr @ 5 bar	40 HP	528	600 x 600 x 1498	PMR5	342	1 STBY PER MGTG SET
174	1	PUMP, MGTG HT FW COOLING STBY	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	113 m3/hr @ 5 bar	40 HP	528	600 x 600 x 1498	PMR5	342	1 STBY PER MGTG SET
175	1	PUMP, MGTG HT FW COOLING STBY	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	113 m3/hr @ 5 bar	40 HP	528	600 x 600 x 1498	PMR4	342	1 STBY PER MGTG SET
176	1	PRE-HEATING UNIT, MGTG HT FW	CENTRIFUGAL PUMP / HEATER	6 m^3 /hr	150 kW	800	2500 x 450 x 1400	PMR5	342	1 PER MGTG SET
177	1	PRE-HEATING UNIT, MGTG HT FW	CENTRIFUGAL PUMP / HEATER	6 m^3 /hr	150 kW	800	2500 x 450 x 1400	PMR5	342	1 PER MGTG SET
178	1	PRE-HEATING UNIT, MGTG HT FW	CENTRIFUGAL PUMP / HEATER	6 m^3 /hr	150 kW	800	2500 x 450 x 1400	PMR4	342	1 PER MGTG SET
179	1	SILENCER, MGTG	SPARK ARRESTING TYPE	-	-	3.273	4166 (L) x 2438 (dia)	UPTAKE	342	
180	1	SILENCER, MGTG	SPARK ARRESTING TYPE	-	-	3.273	4166 (L) x 2438 (dia)	UPTAKE	342	
181	1	SILENCER, MGTG	SPARK ARRESTING TYPE	-	-	3.273	4166 (L) x 2438 (dia)	UPTAKE	342	
182	1	SILENCER, AGTG	SPARK ARRESTING TYPE	-	-	0.794	2159(L) x 1372 (dia)	UPTAKE	342	
183	1	SILENCER, AGTG	SPARK ARRESTING TYPE	-	-	0.794	2159(L) x 1372 (dia)	UPTAKE	342	
184	1	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	MMR1	342	
185	1	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	MMR1	342	
186	1	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	AMR1	342	
187	1	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	MMR2	342	
188	1	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	MMR2	342	

189	1	MN MCHNRY SPACE FAN	SUPPLY	119,796 m^3/hr	75 HP	0.568	1321 (L) x 1384 (dia)	MMR1 INTAKE	513	
190	1	MN MCHNRY SPACE FAN	SUPPLY	119,796 m^3/hr	75 HP	0.568	1321 (L) x 1384 (dia)	MMR1 INTAKE	513	
191	1	MN MCHNRY SPACE FAN	SUPPLY	119,796 m^3/hr	75 HP	0.568	1321 (L) x 1384 (dia)	MMR2 INTAKE	513	
192	1	MN MCHNRY SPACE FAN	SUPPLY	119,796 m^3/hr	75 HP	0.568	1321 (L) x 1384 (dia)	MMR2 INTAKE	513	
193	1	MN MCHNRY SPACE FAN	EXHAUST	93,445 m^3/hr	30 HP	0.522	1321 (L) x 1397 (dia)	MMR1 UPTAKE	513	
194	1	MN MCHNRY SPACE FAN	EXHAUST	93,445 m^3/hr	30 HP	0.522	1321 (L) x 1397 (dia)	MMR1 UPTAKE	513	
195	1	MN MCHNRY SPACE FAN	EXHAUST	93,445 m^3/hr	30 HP	0.522	1321 (L) x 1397 (dia)	MMR2 UPTAKE	513	
196	1	MN MCHNRY SPACE FAN	EXHAUST	93,445 m^3/hr	30 HP	0.522	1321 (L) x 1397 (dia)	MMR2 UPTAKE	513	
197	1	AUX MCHNRY SPACE FAN	SUPPLY	61,164 m^3/hr	30 HP	0.477	1092 (L) x 1118 (dia)	AMR1 INTAKE	513	
198	1	AUX MCHNRY SPACE FAN	SUPPLY	61,164 m^3/hr	30 HP	0.477	1092 (L) x 1118 (dia)	AMR1 INTAKE	513	
199	1	AUX MCHNRY SPACE FAN	SUPPLY	61,164 m^3/hr	30 HP	0.477	1092 (L) x 1118 (dia)	MMR2 INTAKE	513	
200	1	AUX MCHNRY SPACE FAN	SUPPLY	61,164 m^3/hr	30 HP	0.477	1092 (L) x 1118 (dia)	MMR2 INTAKE	513	
203	1	AUX MCHNRY SPACE FAN	EXHAUST	61,164 m^3/hr	20 HP	0.477	1092 (L) x 1118 (dia)	AMR1 UPTAKE	513	
204	1	AUX MCHNRY SPACE FAN	EXHAUST	61,164 m^3/hr	20 HP	0.477	1092 (L) x 1118 (dia)	AMR1 UPTAKE	513	
205	1	AUX MCHNRY SPACE FAN	EXHAUST	61,164 m^3/hr	20 HP	0.477	1092 (L) x 1118 (dia)	MMR2 UPTAKE	513	
206	1	AUX MCHNRY SPACE FAN	EXHAUST	61,164 m^3/hr	20 HP	0.477	1092 (L) x 1118 (dia)	MMR2 UPTAKE	513	
209	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	PMR5	514	
210	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	PMR5	514	
211	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	PMR5	514	
212	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	PMR5	514	
213	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	MMR2	514	
214	1	AIR CONDITIONING PLANTS	500 TON, CENTRIFUGAL UNITS	500 TON	670 HP	16.647	5010 x 2240 x 3585	MMR2	514	
215	1	REFRIG PLANTS, SHIPS SERVICE	R-134a	12 TON	110 HP	6.405	3040 x 1430 x 3150	PMR5	516	
216	1	REFRIG PLANTS, SHIPS SERVICE	R-134a	12 TON	110 HP	6.405	3040 x 1430 x 3150	PMR5	516	
217	1	REFRIG PLANTS, SHIPS SERVICE	R-134a	12 TON	110 HP	6.405	3040 x 1430 x 3150	PMR5	516	
218	1	REFRIG PLANTS, SHIPS SERVICE	R-134a	12 TON	110 HP	6.405	3040 x 1430 x 3150	PMR5	516	
219	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	MMR1	521	
220	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	MMR1	521	
221	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	AMR1	521	
222	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	AMR1	521	
223	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	MMR2	521	
224	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	MMR2	521	
225	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	PMR2	521	
226	1	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	PMR3	521	
229	1	PUMP, FIRE/ BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr @ 9 bar	250 HP	1.458	2490 x 711 x 864	MMR1	521	
230	1	PUMP, FIRE/ BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr @ 9 bar	250 HP	1.458	2490 x 711 x 864	MMR2	521	
231	1	PUMP, AUX. SEAWATER	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	227 m^3/hr @ 3 bar	40 HP	0.803	635 x 635 x 1702	PMR5	524	
232	1	PUMP, AUX. SEAWATER	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	227 m^3/hr @ 3 bar	40 HP	0.803	635 x 635 x 1702	PMR5	524	
233	1	PUMP, AUX. SEAWATER	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	227 m^3/hr @ 3 bar	40 HP	0.803	635 x 635 x 1702	PMR4	524	
234	1	PUMP, AUX. SEAWATER	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	227 m^3/hr @ 3 bar	40 HP	0.803	635 x 635 x 1702	PMR4	524	
235	1	PUMP, BILGE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	PMR1	529	
236	1	PUMP, BILGE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	PMR4	529	
237	1	PUMP, BILGE/BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	PMR1	529	
238	1	PUMP, BILGE/BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	PMR4	529	

239	1	DISTILLER	REVERSE OSMOSIS TYPE	65 m^3/day	30 kW	2.722	3266 x 1830 x 1830	PMR1	531
240	1	DISTILLER	REVERSE OSMOSIS TYPE	65 m^3/day	30 kW	2.722	3266 x 1830 x 1830	PMR1	531
241	1	DISTILLER	REVERSE OSMOSIS TYPE	65 m^3/day	30 kW	2.722	3266 x 1830 x 1830	PMR1	531
242	1	DISTILLER	REVERSE OSMOSIS TYPE	65 m^3/day	30 kW	2.722	3266 x 1830 x 1830	PMR1	531
243	1	BROMINATOR	PROPORTIONING	1.5 m^3/hr	-	0.0115	965 x 203 x 406	PMR1	531
244	1	BROMINATOR	PROPORTIONING	1.5 m^3/hr	-	0.0115	965 x 203 x 406	PMR1	531
245	1	BROMINATOR	PROPORTIONING	1.5 m^3/hr	-	0.0115	965 x 203 x 406	PMR1	531
246	1	BROMINATOR	PROPORTIONING	1.5 m^3/hr	-	0.0115	965 x 203 x 406	PMR1	531
247	1	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	PMR1	532
248	1	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	PMR1	532
249	1	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	PMR1	532
250	1	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	PMR1	532
251	1	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	PMR1	532
253	1	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	PMR1	533
254	1	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	PMR1	533
255	1	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	PMR1	533
256	1	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	PMR1	533
257	1	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	PMR1	533
258	1	PUMP, HOT WATER RECIRC	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	4.5 m^3/hr @ 1 bar	1.5 HP	0.091	559 x 178 x 178	PMR1	533
259	1	PUMP, HOT WATER RECIRC	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	4.5 m^3/hr @ 1 bar	1.5 HP	0.091	559 x 178 x 178	PMR1	533
260	1	PUMP, HOT WATER RECIRC	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	4.5 m^3/hr @ 1 bar	1.5 HP	0.091	559 x 178 x 178	PMR1	533
261	1	PUMP, HOT WATER RECIRC	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	4.5 m^3/hr @ 1 bar	1.5 HP	0.091	559 x 178 x 178	PMR1	533
262	1	PUMP, HOT WATER RECIRC	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	4.5 m^3/hr @ 1 bar	1.5 HP	0.091	559 x 178 x 178	PMR1	533
263	1	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	PMR1	533
264	1	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	PMR1	533
265	1	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	PMR1	533
266	1	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	PMR1	533
267	1	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	PMR1	533
268	1	PURIFIER, FUEL	SELF CLEANING, CENTRIFUGAL, partial discharge type	3.4 m^3/hr	6 kW	0.7	1300 x 720 x 1500	PR1	541
269	1	PURIFIER, FUEL	SELF CLEANING, CENTRIFUGAL, partial discharge type	3.4 m^3/hr	6 kW	0.7	1300 x 720 x 1500	PR1	541
270	1	PURIFIER, FUEL	SELF CLEANING, CENTRIFUGAL, partial discharge type	3.4 m^3/hr	6 kW	0.7	1300 x 720 x 1500	PR2	541
271	1	PURIFIER, FUEL	SELF CLEANING, CENTRIFUGAL, partial discharge type	3.4 m^3/hr	6 kW	0.7	1300 x 720 x 1500	PR2	541
272	1	HEATER, FUEL	ELECTRIC		36 kW	0.076	580 x 319 x 895	PR1	541
273	1	HEATER, FUEL	ELECTRIC		36 kW	0.076	580 x 319 x 895	PR1	541
274	1	HEATER, FUEL	ELECTRIC		36 kW	0.076	580 x 319 x 895	PR2	541
275	1	HEATER, FUEL	ELECTRIC		36 kW	0.076	580 x 319 x 895	PR2	541
276	1	PUMP, FUEL TRANSFER	GEAR, MOTOR DRIVEN	45.4 m^3/hr @ 4.2 bar	30 HP	0.4	1423 x 559 x 686	PMR1	541
277	1	PUMP, FUEL TRANSFER	GEAR, MOTOR DRIVEN	45.4 m^3/hr @ 4.2 bar	30 HP	0.4	1423 x 559 x 686	PMR1	541
278	1	PUMP, FUEL TRANSFER	GEAR, MOTOR DRIVEN	45.4 m^3/hr @ 4.2 bar	30 HP	0.4	1423 x 559 x 686	PMR4	541
279	1	PUMP, FUEL TRANSFER	GEAR, MOTOR DRIVEN	45.4 m^3/hr @ 4.2 bar	30 HP	0.4	1423 x 559 x 686	PMR4	541

280	1	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
281	1	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
282	1	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
283	1	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
284	1	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
285	1	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
286	1	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
287	1	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
288	1	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
289	1	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	JP-5 PUMP ROOM	542	
290	1	PUMP, JP-5 STRIPPING	ROTARY, MOTOR DRIVEN	5.7 m^3/hr @ 3.4 bar	1.5 HP	0.386	915 x 381 x 381	JP-5 PUMP ROOM	542	
291	1	PUMP, JP-5 STRIPPING	ROTARY, MOTOR DRIVEN	5.7 m^3/hr @ 3.4 bar	1.5 HP	0.386	915 x 381 x 381	JP-5 PUMP ROOM	542	
292	1	PUMP, JP-5 STRIPPING	ROTARY, MOTOR DRIVEN	5.7 m^3/hr @ 3.4 bar	1.5 HP	0.386	915 x 381 x 381	JP-5 PUMP ROOM	542	
293	1	PUMP, JP-5 STRIPPING	ROTARY, MOTOR DRIVEN	5.7 m^3/hr @ 3.4 bar	1.5 HP	0.386	915 x 381 x 381	JP-5 PUMP ROOM	542	
294	1	PUMP, JP-5 STRIPPING	ROTARY, MOTOR DRIVEN	5.7 m^3/hr @ 3.4 bar	1.5 HP	0.386	915 x 381 x 381	JP-5 PUMP ROOM	542	
295	1	FILTER/SEPAR., JP-5 TRANSFER	STATIC, TWO-STAGE	17 m^3/hr	-	0.363	457 (L) x 1321 (dia)	JP-5 PUMP ROOM	542	
296	1	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	JP-5 PUMP ROOM	542	
297	1	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	JP-5 PUMP ROOM	542	
298	1	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	JP-5 PUMP ROOM	542	
299	1	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	JP-5 PUMP ROOM	542	
300	1	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	JP-5 PUMP ROOM	542	
301	1	RECEIVER, START AIR	STEEL, CYLINDRICAL	2.27 m^3	-	0.97	1067 (dia) x 2540 (H)	MMR1	551	
302	1	RECEIVER, START AIR	STEEL, CYLINDRICAL	2.27 m^3	-	0.97	1067 (dia) x 2540 (H)	MMR1	551	
303	1	RECEIVER, START AIR	STEEL, CYLINDRICAL	2.27 m^3	-	0.97	1067 (dia) x 2540 (H)	MMR2	551	
304	1	RECEIVER, START AIR	STEEL, CYLINDRICAL	2.27 m^3	-	0.97	1067 (dia) x 2540 (H)	MMR2	551	
305	1	COMPRESSOR, START AIR	RECIPROCATING	80 m3/hr @ 30 bar	17 kW	0.57	1334 x 841 x 836	MMR1	551	
306	1	COMPRESSOR, START AIR	RECIPROCATING	80 m3/hr @ 30 bar	17 kW	0.57	1334 x 841 x 836	MMR1	551	
307	1	COMPRESSOR, START AIR	RECIPROCATING	80 m3/hr @ 30 bar	17 kW	0.57	1334 x 841 x 836	MMR2	551	
308	1	COMPRESSOR, START AIR	RECIPROCATING	80 m3/hr @ 30 bar	17 kW	0.57	1334 x 841 x 836	MMR2	551	
309	1	RECEIVER, SHIP SERVICE AIR	STEEL, CYLINDRICAL	1.7 m^3	-	0.726	1830 (H) x 965 (dia)	AMR1	551	
310	1	RECEIVER, SHIP SERVICE AIR	STEEL, CYLINDRICAL	1.7 m^3	-	0.726	1830 (H) x 965 (dia)	MMR2	551	
311	1	COMPRESSOR, AIR, LP SHIP SERVICE	LOW PRESSURE, ROTARY SCREW	194 SCFM @ 8.6 bar	50 HP	1	1346 x 1067 x 1829	AMR1	551	
312	1	COMPRESSOR, AIR, LP SHIP SERVICE	LOW PRESSURE, ROTARY SCREW	194 SCFM @ 8.6 bar	50 HP	1	1346 x 1067 x 1829	MMR2	551	
313	1	DRYER, AIR	REFRIGERANT TYPE	250 SCFM	-	0.259	610 x 864 x 1473	AMR1	551	
314	1	DRYER, AIR	REFRIGERANT TYPE	250 SCFM	-	0.259	610 x 864 x 1473	MMR2	551	
315	1	RECEIVER, CONTROL AIR	STEEL, CYLINDRICAL	1 m^3	-	0.427	3421 (H) x 610 (dia)	AMR1	551	
316	1	RECEIVER, CONTROL AIR	STEEL, CYLINDRICAL	1 m^3	-	0.427	3421 (H) x 610 (dia)	MMR2	551	
317	1	SEWAGE COLLECTION UNIT	VACUUM COLLECTION TYPE W/ PUMPS	28 m^3	5.4 HP	1.567	2642 x 1854 x 1575	PMR2	593	
318	1	SEWAGE COLLECTION UNIT	VACUUM COLLECTION TYPE W/ PUMPS	28 m^3	5.4 HP	1.567	2642 x 1854 x 1575	PMR2	593	
319	1	SEWAGE COLLECTION UNIT	VACUUM COLLECTION TYPE W/ PUMPS	28 m^3	5.4 HP	1.567	2642 x 1854 x 1575	PMR3	593	
320	1	SEWAGE COLLECTION UNIT	VACUUM COLLECTION TYPE W/ PUMPS	28 m^3	5.4 HP	1.567	2642 x 1854 x 1575	PMR3	593	
322	1	MONITOR, OIL CONTENT		15 PPM	TBD	0.0082	254 x 153 x 305	VARIOUS	593	
323	1	MONITOR, OIL CONTENT		15 PPM	TBD	0.0082	254 x 153 x 305	VARIOUS	593	
324	1	PUMP, OILY WASTE TRANSFER	SLIDING SHOE, MOTOR DRIVEN	12.3 m^3/hr @ 7.6 bar	10 HP	0.286	1219 x 635 x 813	PMR1	593	
325	1	PUMP, OILY WASTE TRANSFER	SLIDING SHOE, MOTOR DRIVEN	12.3 m^3/hr @ 7.6 bar	10 HP	0.286	1219 x 635 x 813	PMR1	593	
326	1	PUMP, OILY WASTE TRANSFER	SLIDING SHOE, MOTOR DRIVEN	12.3 m^3/hr @ 7.6 bar	10 HP	0.286	1219 x 635 x 813	PMR4	593	
327	1	PUMP, OILY WASTE TRANSFER	SLIDING SHOE, MOTOR DRIVEN	12.3 m^3/hr @ 7.6 bar	10 HP	0.286	1219 x 635 x 813	PMR4	593	
328	1	SEPARATOR , OIL/WATER	COALESCER PLATE TYPE	2.7 m^3/hr	1 kW	0.5	1321 x 965 x 1473	PMR1	593	
329	1	SEPARATOR , OIL/WATER	COALESCER PLATE TYPE	2.7 m^3/hr	1 kW	0.5	1321 x 965 x 1473	PMR1	593	
330	1	SEPARATOR , OIL/WATER	COALESCER PLATE TYPE	2.7 m^3/hr	1 kW	0.5	1321 x 965 x 1473	PMR4	593	
331	1	SEPARATOR , OIL/WATER	COALESCER PLATE TYPE	2.7 m^3/hr	1 kW	0.5	1321 x 965 x 1473	PMR4	593	
332	1	SEWAGE TREATMENT UNIT			6.4 kW	0.98	1778 x 1092 x 2007	PMR2	593	
333	1	SEWAGE TREATMENT UNIT			6.4 kW	0.98	1778 x 1092 x 2007	PMR2	593	
334	1	SEWAGE TREATMENT UNIT			6.4 kW	0.98	1778 x 1092 x 2007	PMR3	593	
335	1	SEWAGE TREATMENT UNIT			6.4 kW	0.98	1778 x 1092 x 2007	PMR3	593	
337	1	PUMP, WASTE WATER DISCH	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 2.4 bar	10 HP	0.563	1042 x 686 x 356	PMR2	593	
338	1	PUMP, WASTE WATER DISCH	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 2.4 bar	10 HP	0.563	1042 x 686 x 356	PMR2	593	
339	1	PUMP, WASTE WATER DISCH	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 2.4 bar	10 HP	0.563	1042 x 686 x 356	PMR3	593	
340	1	PUMP, WASTE WATER DISCH	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 2.4 bar	10 HP	0.563	1042 x 686 x 356	PMR3	593	