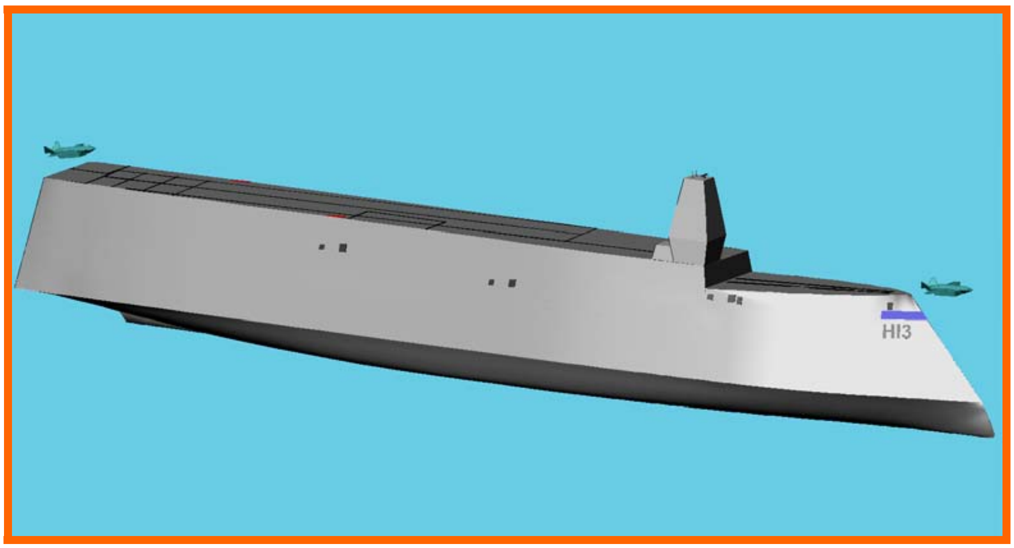
Virginia Tech Aerospace & Ocean Engineering

CUVX Design Report

Unmanned Combat Air Vehicle Carrier

VT Total Ship Systems Engineering



CUVX HI3 Option

Ocean Engineering Design Project

AOE 4065/4066

Fall 2002 – Spring 2003

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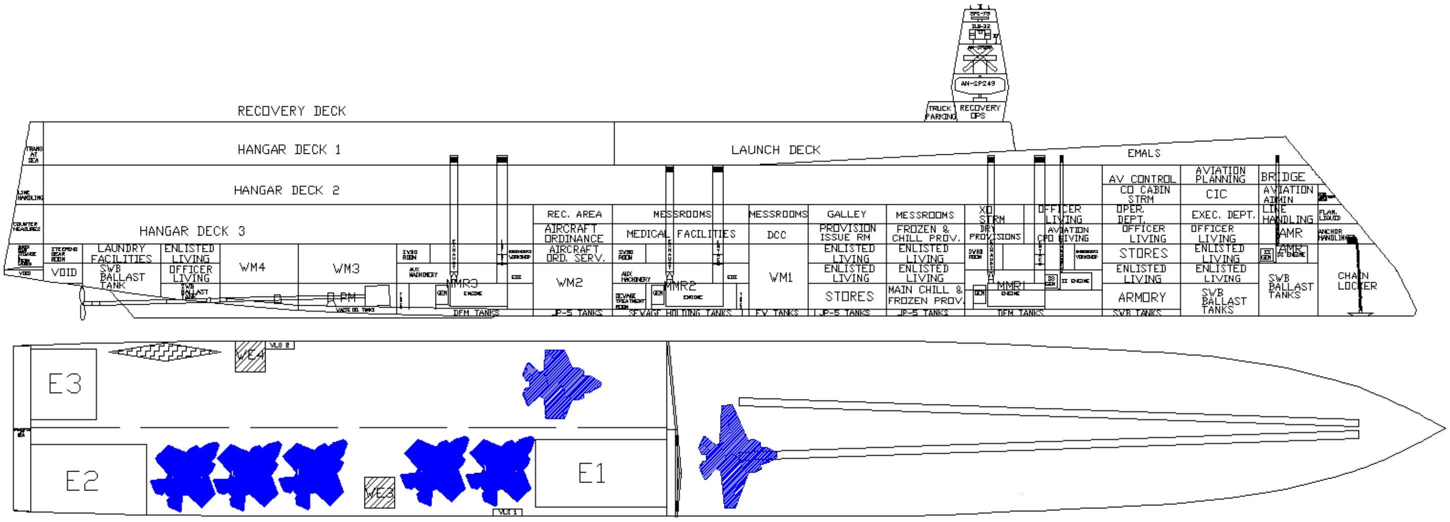
Executive Summary



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 is required to 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 intelligence, surveillance, reconnaissance (ISR) 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), ISR 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 HI3 Baseline Concept Design and define Operational Requirements (ORD1) based on the customer's preference for cost, risk and effectiveness in this baseline.

CUVX HI3 is the highest-end alternative on the follow-ship acquisition cost frontier. This design was chosen to provide a challenging design project using higher risk technology. CUVX HI3 characteristics are listed below. CUVX HI3 has a wave-piercing tumblehome (WPTH) hullform to reduce radar cross section, and 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 arrangement, general arrangements, combat system selection, seakeeping analysis, cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements within cost and risk constraints with additional work required to improve seakeeping and further reduce manning and cost.

Ship Characteristic	Value
LWL	213 m
Beam	29.04 m
Draft	7.01 m
D10	29.58 m
Lightship weight	24770 Mton
Full load weight	29640 Mton
Block Coefficient, C_B	0.667
Prismatic Coefficient, C_P	0.702
Sustained Speed	20.6 knots
Endurance Speed	20 knots
Range at 20 kts	4000 nm
Propulsion and Power	Integrated Power System (IPS), 2 shafts FPP, 5 x PC2.5V16
BHP	52000 Hp
Personnel	898
OMOE (Effectiveness)	0.902
OMOR (Risk)	0.288
Lead ship acquisition cost	$1196M
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
Catapaults	2 x EMALS
UCAV-N's	28
UAV's	18
LAMPS	4

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1 Introduction, Design Process and Plan

1.1 Introduction

This report describes concept exploration and development of an unmanned combat air vehicle carrier (CUVX) for the United States Navy. The CUVX requirement is based on a CUVX Mission Need Statement, Appendix A, and Acquisition Decision Memorandum (ADM), Appendix B. This concept design was completed in a two-semester ship design course at Virginia Tech. 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 strike

Current assets supporting ISR, SEAD and time-sensitive strike capabilities include:

(1) Land and carrier-based manned aircraft and UAVs

(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 CVNs. This fails to address the problems of numbers, cost and risk identified above.

CUVX is an alternative support platform for UCAV-N that offers the possibility to significantly reduce cost and personnel vulnerability. 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 concepts introduced in the CUVX 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 Engineering approach.

1.2 Design Philosophy, Process, and Plan

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

The scope of this project includes the first two phases in the ship design process, Concept Exploration and Concept Development, as illustrated in Figure 1. The concept exploration process is shown in Figure 2. The results of this process are a preliminary Operational Requirements Document (ORD1) that specifies performance and cost requirements, 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 and perform trade-offs. CUVX Concept Exploration considers various combinations of hull form, propulsion systems, combat systems 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, 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 step in the traditional design spiral at a level of detail necessary to demonstrate that assumptions and results obtained in concept exploration are not only balanced, but 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!

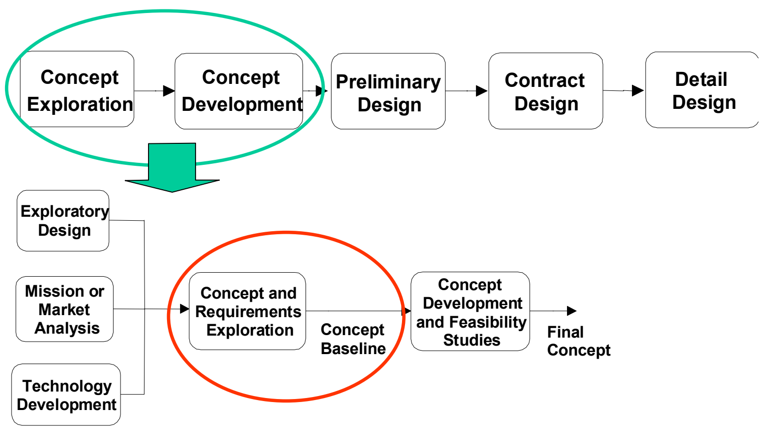


Figure 1. Design Process

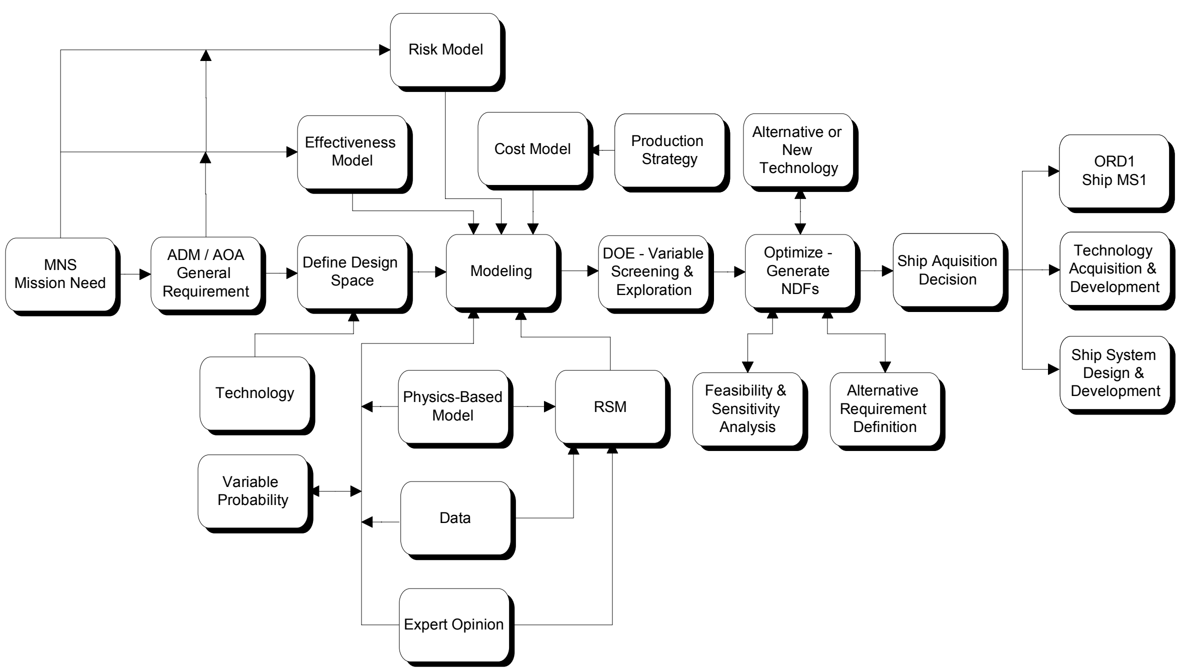


Figure 2. Concept Exploration Process

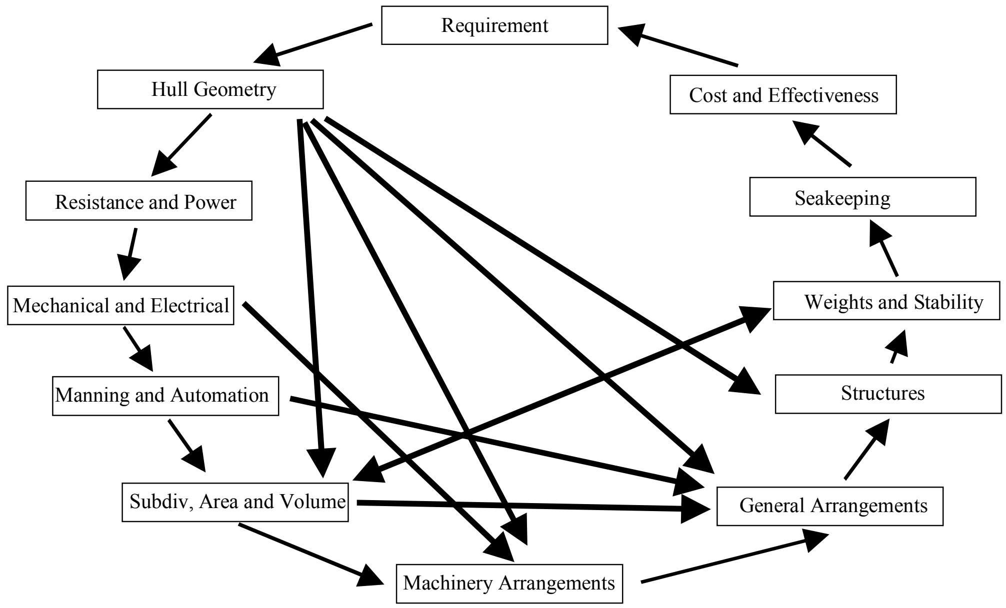


Figure 3. Concept Development Design Spiral (Chapter 4)

Table 1. Work Breakdown

Name	Specialization
Daniel Demko (Team Leader)	Hull / Hydrostatics / Hydrodynamics
Matthew Hecht	Power / Propulsion / Resistance
Jason Albright	Weights / Synthesis
Gregory Morrow	Structures / Producibility
John Leek	Combat Systems / Editor
Keith Webster	Subdivision / Arangements

1.4 Resources

Table 2. Tools

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

When any software 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 UCAVs and UAVs, and 2-4 LAMPS helicopters, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The UAVs 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. UCAVS 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. Specific weapons systems that could be encountered include land and surface launched cruise missiles, and significant land based air assets and submarines; and (2) Threats from smaller nations who support, promote, and perpetrate activities that cause regional instabilities detrimental to international security and/or have the potential development of nuclear weapons. Specific weapons systems include diesel/electric submarines, land-based air assets, 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 UCAVs 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 UAVs 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 UAVs and LAMPS
1-3	Preposition UCAVs 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 UCAVs 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 UAVs and LAMPS
1-30	Continue the preposition of UCAVs 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, design space exploration and optimization 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 in a multi-objective genetic optimization (MOGO) for the total ship design. Technology and concept trade spaces and parameters are described in the following sections.

3.2.1 Hull Form Alternatives

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 (machinery spaces, hangar decks, weapons magazines); 6) a recovery deck length greater than 150 meters for recovering UCAV's; 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 under similar sea conditions. However, seakeeping qualities in terms of angle and rate of pitch are poor compared to a monohull. This problem can be reduced using active control of pitching motions.

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

Catamarans have a relatively high radar cross section, especially end-on. The displacement to length ratio is high and the large object volume is relatively low compared to a monohull. The cost for building a catamaran is higher than that for a monohull of the same displacement.

- 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. SWATHs are considered load sensitive due to the fact that for a small load added to the ship, a relatively large change in draft occurs. Typically, SWATH ships have 50% less waterplane area than 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 result in greater forces being exerted on aircraft to takeoff and land on the shorter deck. 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 added 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 and Bath Iron Works. 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 large-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 an 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. Deck area is a 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	+	+	+++		++	+	+	++

Table 7 summarizes the preliminary assessment of hull forms for CUVX. 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 DDS 200-1. **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, and control the systems from the MCC and local controllers.

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

Temperature and Humidity – Design environmental conditions shall be based on the requirement for extended vessel operations in the Persian Gulf. 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.

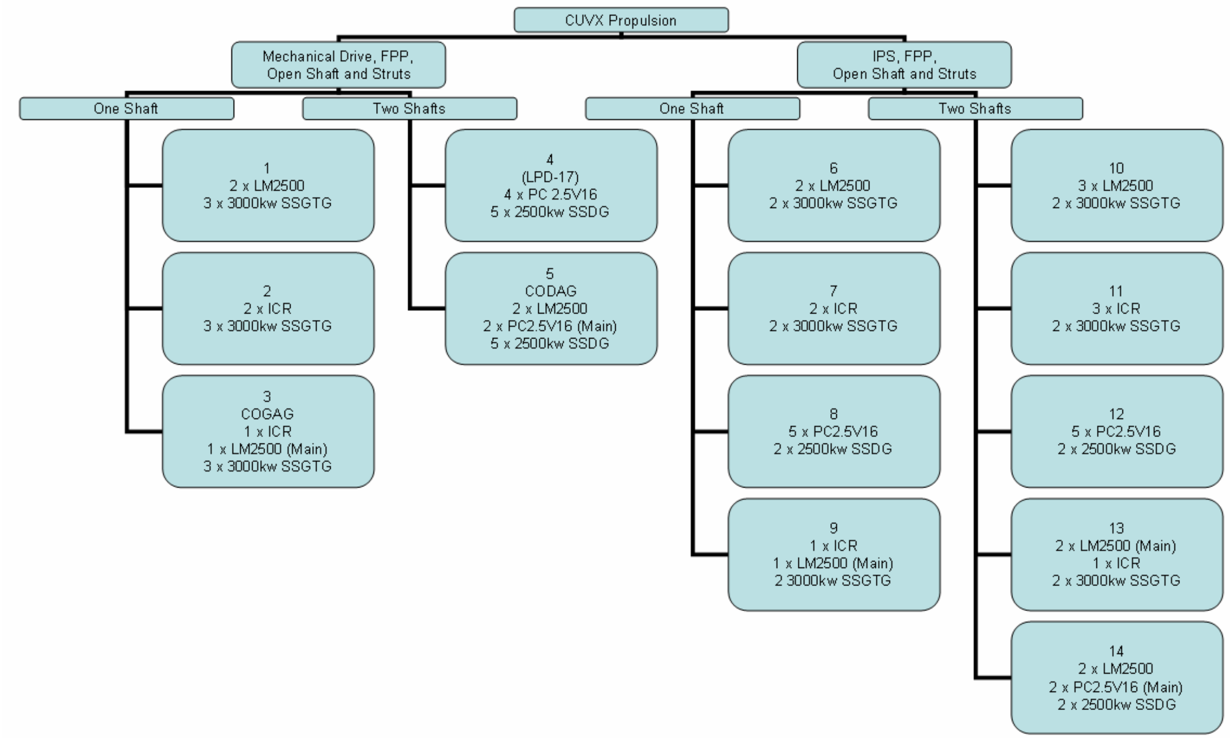


Figure 4. CUVX Machinery Alternatives

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 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 2x3000k w 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 cost, life cycle cost 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 for CUVX including an electromagnetic aircraft launching system (EMALS), advanced arresting gear (AAG) or electromagnetic aircraft recovery system (EARS), pit stop concepts for fueling and arming aircraft, a 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. This leads to the regression based manning equations shown in Figure 5. The manning factors CManShip and CManAir, which vary from 0.5 to 1.0, are used as CUVX design parameters DP14 and DP19. A ship manning factor, CManShip, of 1.0 corresponds to CV-like manning. A ship manning factor of 0.5 correlates to a 50% reduction in manning compared to a CV. These manning factors are also applied using simple expressions based on expert opinion for ship accommodations and support, automation cost, automation risk, damage control performance and repair capability performance. The standard manning calculations are shown in Figure 5. The values of performance for repairs and damage control are shown in Figure 6. The calculation for automation impact on cost and risk is shown in Figure 7. A more detailed manning analysis is performed in concept development.

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

- W_P : total payload weight
- W_{VP} : variable payload weight
- W_{F23} : total weight of aircraft
- V_{FL} : full load hull displacement volume
- N_{SSG} : number of ship service generators
- V_D : deckhouse volume
- N_{prop} : number of propellers

The simple regression-based equations calculate the following:

- N_{EShip} : number of ship enlisted men (including CPO-Chief Petty Officers)
- N_{EAir} : number of air enlisted men (including CPO-Chief Petty Officers)
- N_{OShip} : number of ship officers
- N_{OAir} : number of air officers
- N_E : total number of enlisted men
- N_O : total number of officers

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:

$$CManShip = 1 \qquad N_{OShip} := 3 + \mathrm{ceil}\left(N_{prop} + \frac{N_{SSG}}{5} + \frac{W_P - W_{VP}}{15 \cdot lton} + \frac{V_{FL} + V_D}{80000 \cdot ft^3}\right) \qquad N_{OShip} = 30$$

$$N_{EShip} := \mathrm{ceil}\left[CManShip \cdot \left(N_{prop} \cdot 6 + N_{SSG} \cdot 3 + \frac{W_P - W_{VP}}{10 \cdot lton} + \frac{V_{FL} + V_D}{4450 \cdot ft^3}\right)\right] \qquad N_{EShip} = 275$$

$$CManAir = 1 \qquad N_{OAir} := \mathrm{ceil}\left(\frac{.1}{MT} \cdot W_{F23}\right) \qquad N_{OAir} = 39 \qquad N_O := N_{OAir} + N_{OShip} \qquad N_O = 69$$

$$N_{EAir} := \mathrm{ceil}\left(CManAir \cdot \frac{1.5}{MT} \cdot W_{F23}\right) \qquad N_{EAir} = 576 \qquad N_E := N_{EAir} + N_{EShip} \qquad N_E = 851$$

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

$$N_T := N_{EShip} + N_{OShip} + N_{EAir} + N_{OAir} \qquad N_T = 920$$

$$N_A := \mathrm{ceil}(.1 \cdot N_T) \qquad N_A = 92$$

Figure 5. CUVX "Standard" Manning Calculation

Repair - MOP14:

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

DC - MOP22:

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

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

The repair and damage control values of performances (VOP) are influenced by the ship and air manning factors, CManShip and CManAir, respectively. Figure 7 shows the calculations from the math model of cost and risk that are affected by the manning factors.

$$W_4 := W_{P400} + W_{IC} + W_{CO} + W_{CC} \qquad W_4 = 321.89 \cdot MT$$

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

$$K_{N4} := \frac{2.0 \cdot Mdol}{lton^{.617} \cdot (CManShip + CManAir)} \qquad C_{L_4} := .10857 \cdot F_I \cdot K_{N4} \cdot (W_4)^{.617} \qquad C_{L_4} = 6.542 \cdot Mdol$$

$$OMOR := \frac{.5 \cdot PERFRISK + .3 \cdot COSTRISK + .2 \cdot SCHEDRISK}{(CManShip + CManAir)} \qquad OMOR = 0.169$$

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

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.

Aircraft weapons loading and fueling are also manpower intensive. By regulation, weapons loading and fueling cannot take place at the same time. Aircraft loaded with fuel and weapons can sit in the hangar, but the arming pin on the weapons cannot be pulled until the aircraft is loaded on the launching system and ready for takeoff. Aircraft can be loaded and fueled in the hangars. Automation of fueling could be accomplished using a system which locates the fuel tank, identifies the type of vehicle, and then pumps the fuel. This concept is not new, but the application to a ship is new. For weapons loading, a vehicle called the shipboard weapons loader (SWL) is being developed that only requires two people to operate it. The SWL has a maximum payload of 3000 pounds and eliminates unsafe manual loading practices. The use of this vehicle would greatly reduce the number of personnel required for loading weapons. The SWL is predicted to reduce the loading times for JDAM and HARM missiles from 6-13 minutes to no more than 1 minute. SWL is predicted to reduce the number of operators from 6 to 2.

The concept of a pit stop provides a single point turnaround of aircraft. At this stop the aircraft would be refueled and reloaded. Weapons could be loaded by an automated system similar to factory assembly lines. Although this would require one person to oversee proper loading, it would greatly reduce manning. However, this technology does not currently exist for shipboard use. Fueling would still take a considerable amount of time since the fueling rates would have to be limited to prevent explosive vapors; but there may be the possibility to use a vacuum jacket fueling port to trap the vapors and this would allow fuelling in less time.

A fuel and weapons module concept was also considered to simplify fueling and weapons load out, and reduce manning. This module would be similar to the magazine of a firearm. The module would be preloaded to contain fuel for the aircraft and weapons for a specific mission. The module would be lifted to the aircraft at a pit stop in an assembly line fashion, and loaded into the body of the aircraft. It was concluded that a module would not work well with the UCAV-N, as it greatly restricts other design requirements of the aircraft. There were also concerns with module survivability and transport.

3.2.5 Aviation (Mission) System Parameters

Important CUVX aviation system characteristics include: concept of CUVX aviation operations; sortie rates; number, type, size and weight of aircraft to be supported; 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 the aviation 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. They are discussed in the following sections.

3.2.5.1 Virginia Tech UCAV-N

A separate Virginia Tech design team designed UCAV-N for CUVX in parallel with the CUVX teams. The UCAV-N and CUVX teams worked in collaboration to effectively integrate the ship and the aircraft as an overall system. The UCAV-N is a revolutionary aircraft. It will be the first aircraft capable of landing on an aircraft carrier autonomously.

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 kn	
Approach Speed	150 kn	135 kn
Wheel Track	12 ft	10 ft 3 in

The UCAV-N is required for three missions: SEAD, strike and reconnaissance. When performing a SEAD or strike mission the UCAV-N may be armed with two JDAMs, two HARMs, or one of each. To carry these weapons the UCAV-N requires a payload capacity of 4,300 lbs. The strike range required to effectively perform a SEAD mission is 500 nautical miles. 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. UCAV-N must remain aloft for long periods of time without refueling to support time-sensitive strike and reconnaissance. 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, the same as on the UAV Global Hawk. Design requirements for the UCAV-N are listed in Table 16. UCAV-N characteristics most important to ship operations are listed in Table 17. Figure 8 is a three dimensional graphic of the Virginia Tech UCAV-N.

Figure 8. Three Dimensional Graphic of Virginia Tech UCAV-N

3.2.5.2 Concept of CUVX Aviation Operations

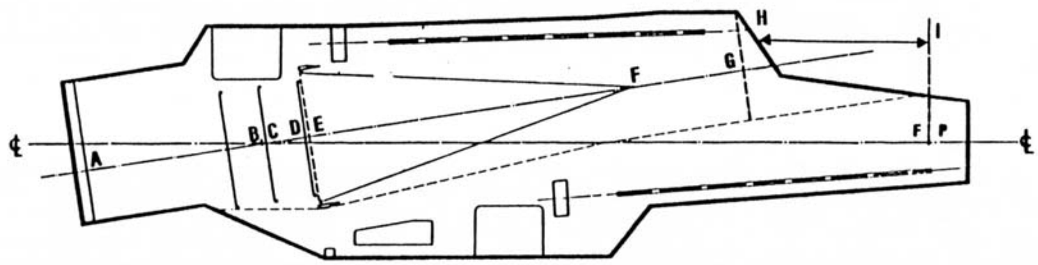
Aviation operations on CUVX will be similar to aviation operations on CVN in some respects, but changes are required due to size constraints and increased automation on CUVX. CUVX aviation operations include:

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

CVN aircraft launch is accomplished using steam catapults. The CUVX ADM directs that steam propulsion not be considered for CUVX, and therefore steam catapults would require an auxiliary steam system. A preferred option is to use EMALS. Since CUVX is small and simultaneous launch and recovery of aircraft is important, a separate (lower) deck is considered for aircraft launch in addition to the recovery (upper) deck. Otherwise simultaneous launch and recovery may not be possible. Launching from a partially covered deck drastically changes the way jet blast deflectors must be used. Since the flow of hot gas from the aircraft engines can not be directed up and away from personnel and equipment as on CVNs they must be exhausted out the side of the ship.

Recovery procedures must 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 strip on CVN is 100 feet, which is nearly the entire beam of the recovery deck on CUVX. UCAVs are smaller than most CVN tactical aircraft and tighter recovery clearances are required and possible for the autonomous aircraft. Since 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 the 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.

Spotting and turnaround includes movement of aircraft in and on the ship with the exceptions of landing and launching. Spotting refers to the arrangement of aircraft in a way to provide for the most efficient launch and servicing of aircraft. Turnaround refers to movement of the aircraft for fueling, weapons loading and unloading, and maintenance. On CVNs aircraft are moved using a tow tractor called a spotting dolly. The tow tractor is driven by a person riding on the tractor. After aircraft are recovered on CUVX they are 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 dollies using an automated procedure to decide what dolly takes what task and how each task is accomplished.



RECOVERY AREA ELEMENTS:	DISTANCE (FEET)
A-B: RAMP TO HOOK TOUCHDOWN POINT (HTDP)	180
B-C: HTDP TO 2nd WIRE	3 (MINIMUM)
C-D: WIRE SPACING	40
D-E: 3rd WIRE TO BARRICADE	5
E-F: WIRE RUNOUT	350
F-G: BARRICADE STRETCH AND TURNAROUND	94
RECOVERY AREA LENGTH	672

Figure 9 - CVN Flight Deck [2]

Aircraft crash, fire, and rescue (CFR) procedures must be flexible since each crash presents its own special problems. On CVNs the Crash, Salvage and Rescue Team handles aircraft crash, fire, and rescue situations using the following equipment:

- 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 can 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 can be handled using automated Mobile Firefighting Vehicles (MFFVs), and installed water/foam systems. Aircraft fires in the hangar decks can be fought using MFFVs and installed water/foam misting and deluge systems.

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.

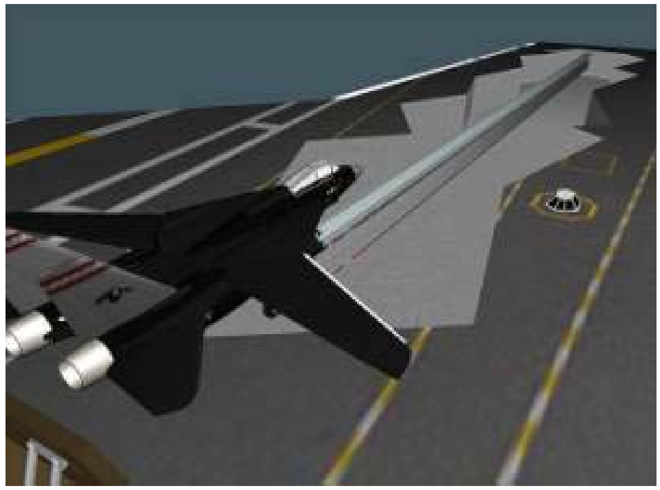


Figure 10. EMALS positioned on an aircraft carrier

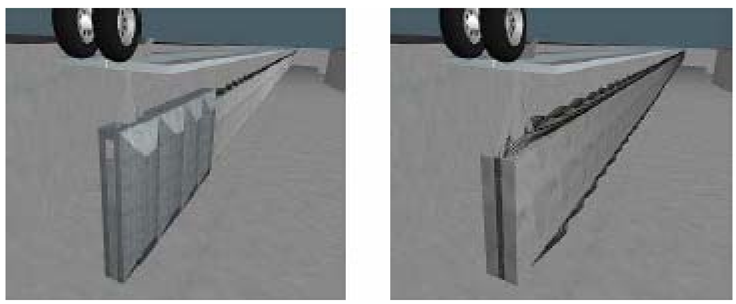


Figure 11. Inverted U Shuttle (left) and Blade Shuttle (right)

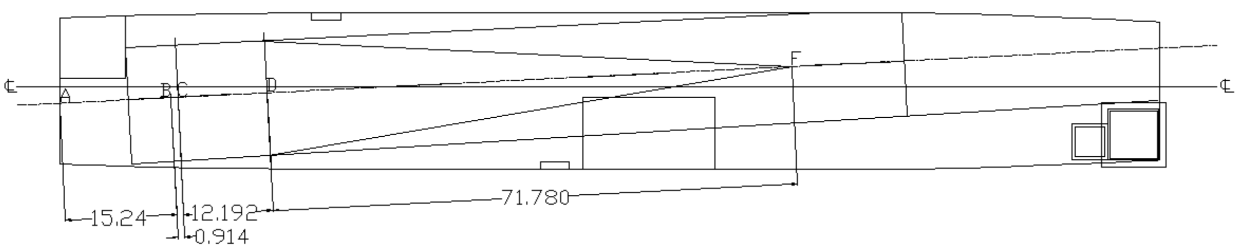


Figure 12. CUVX Recovery Deck

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 scalable due to its modular design

Aircraft recovery 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 make recovery operations safer. 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 components of EARS and EMALS into one electromagnetic system.

The ship synthesis model uses the equations in Figure 13 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 55 meters. This was decreased to 15 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 0.9 meters. The distance between wires on CUVX is the same as on a CVN, 12 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 72 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 the UCAV-Ns to land with adequate clearance on each side of its wings and wheels. 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 on CUVX is 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 adapted from CV 67 data where the area of each elevator is 16.7 square meters.

AVIATION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 13. CUVX Aviation System Characteristics

The minimum number of catapults on CUVX is two. This provides 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 shops, $A_{AirMaintShops}$, 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. 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

The available hangar deck area for CUVX is approximated as shown in Figure 14. 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 14. CUVX Available Hangar Deck Area

The equations for hangar deck requirements for CUVX are shown in Figure 15. 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 15. CUVX Hangar Deck Area Requirements

3.2.6 Combat System Alternatives

3.2.6.1 Combat System Requirements

CUVX shipboard combat systems are primarily for self-defense. CUVX offensive capabilities are provided by its airwing.

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. SVTT is capable of stowing and launching up to three torpedoes under local control or remote control from the 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

Electronic Warfare 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 16.

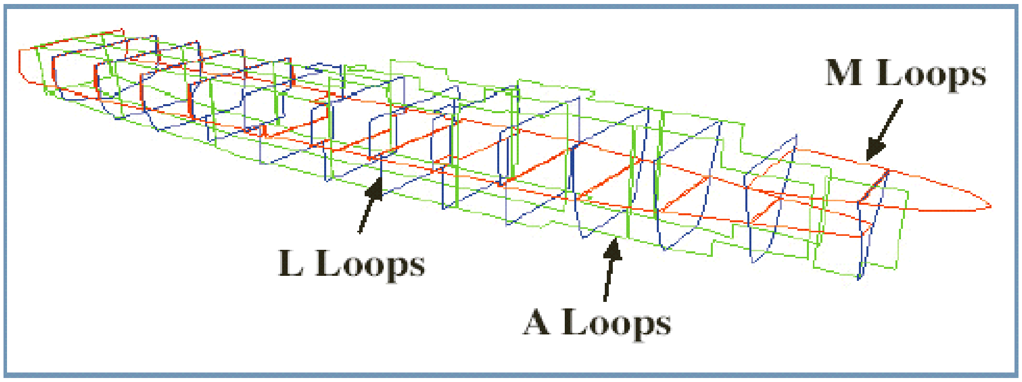


Figure 16. Degaussing

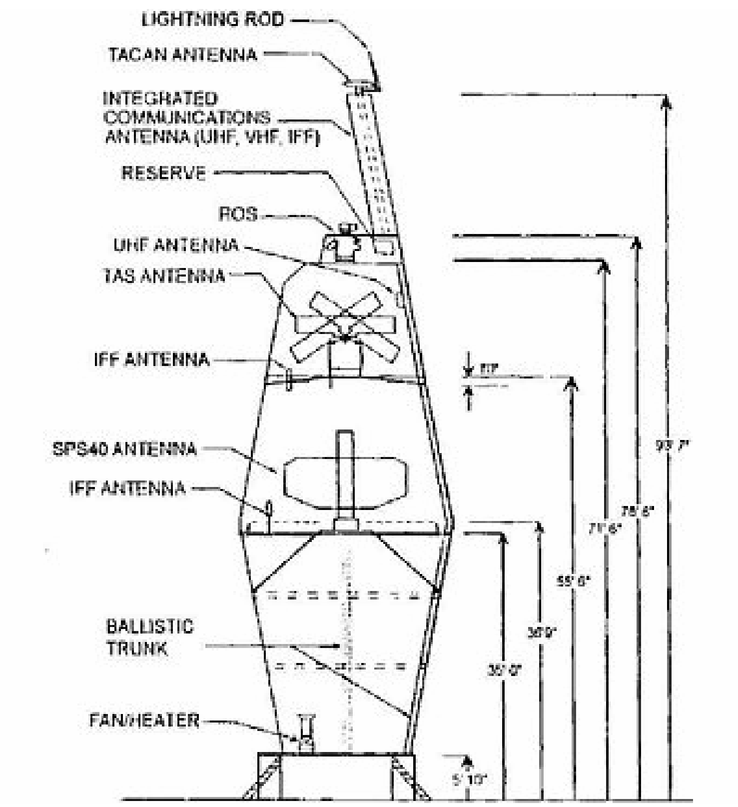


Figure 17. Advance Enclosed Mast Sensor System

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 17. It uses a polarization technique to allow CUVX 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 18 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.

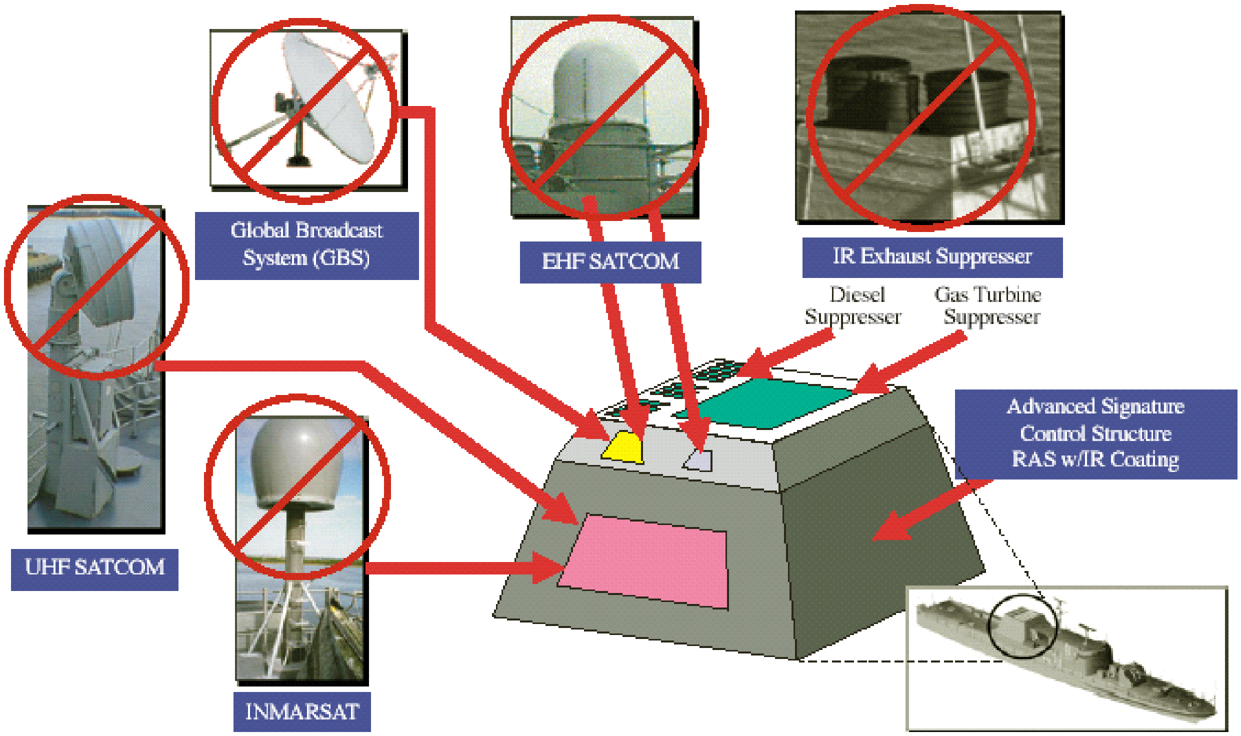


Figure 18. Multi-Function Stack [10]

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 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 Variables

	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
7	Aircraft launch deck?	y/n	0,1	2
8	Deckhouse volume ratio	ND	.05-.3	25
9	AAW system	alternative	1,2	2
10	LAMPS helos	#	2,4	2
11	Endurance range	nm	4000,8000,12000	3
12	Stores duration	days	60,90,120	3
13	Propulsion system	alternative	1-14	14
14	Ship manning and automation factor	ND	.5-1.0	5
15	Hull structure type	type	Conventional, ADH	2
16	CPS	extent	None, partial, full	3
17	UAVs	#	5-20	15
18	UCAVs	#	10-30	20
19	Aviation manning and automation factor	ND	.5-1.0	5
20	Ship aircraft fuel	MT/UCAV	30.-60.	10
21	Ship aircraft weapons	MT/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 1-8) are described in Section 3.2.1. Aviation-related design parameters (DP 7, 10, and 17-21) are described in Section 3.2.5. Combat system design parameters (DP 9 and 10) 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 19. 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 selected 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 19. 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.

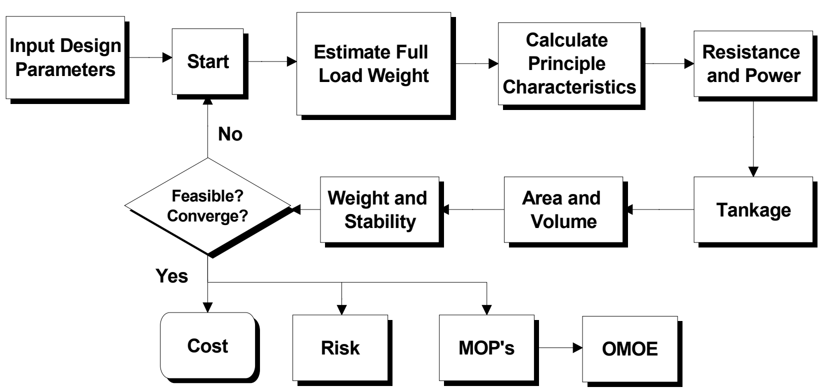


Figure 19. Ship Synthesis Model

The following sections describe the synthesis model calculations.

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 Appendix D.1 CUVX Ship Synthesis Model.

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 Appendix D.1 CUVX Ship Synthesis Model. 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 Appendix D.1 CUVX Ship Synthesis Model. 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 Appendix D.1 CUVX Ship Synthesis Model. 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 Appendix D.1 CUVX Ship Synthesis Model. 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 Appendix D.1 CUVX Ship Synthesis Model. 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 19, 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:	$A_{DR} = 545.731$m^2	$A_{DA} = 671.705$m^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:	$H_{MBreq} = 6.67$m	$H_{MB} = 7.63$m	
Depth:	$D_{10MIN} = 84.219$ft	$D_{10} = 87.369$ft	
Sustained Speed:	$V_e = 20$knt	$V_S \equiv 21.4$knt	
Stability:	.07-.2	$C_{GMB} = 0.155$	
Length of Flight Deck:	$L_{FltReq} = 100$m	$L_{Flt} = 150$m	
Breadth of Flight Deck:	$B_{FltReq} = 25$m	$B = 29.54$m	

Weight and displacement are iterated until convergence. A design is considered feasible if feasibility requirements and thresholds are satisfied simultaneously. 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 variable values. A very small percentage of randomly selected design variable values are mutated or replaced with a new random value. As each generation of ships is selected, the ships spread across the effectiveness/cost/risk design space and frontier. After 300 generations of evolution, the non-dominated frontier (or surface) of designs is defined as shown in Figure 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.

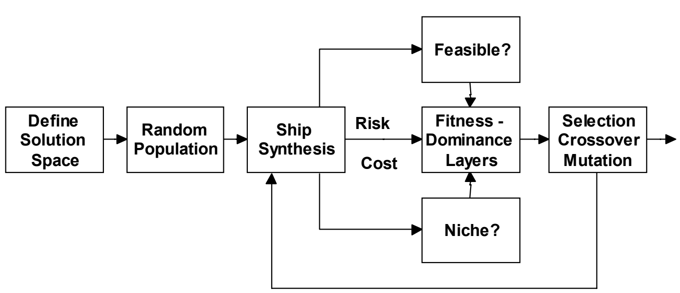


Figure 20. Multi-Objective Genetic Optimization

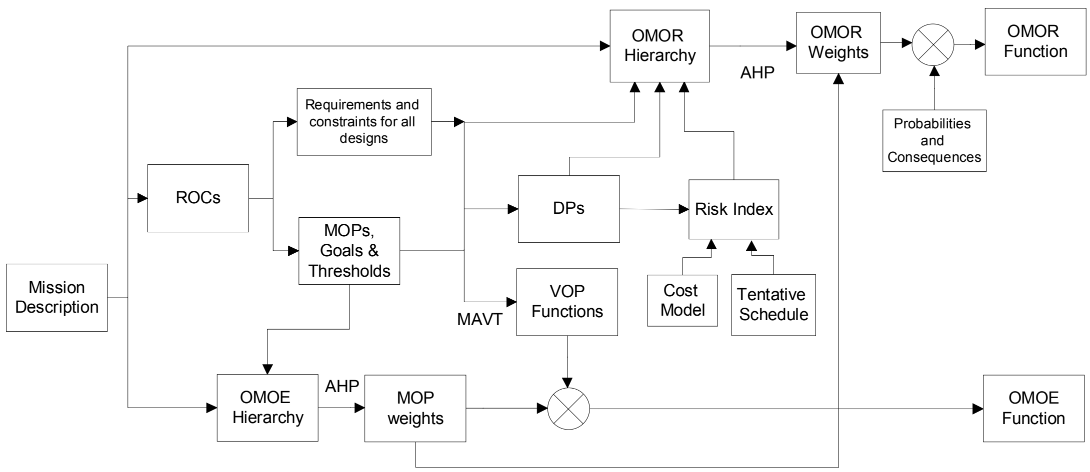


Figure 21. OMOE and OMOR Development Process

3.5.1 Overall Measure of Effectiveness (OMOE) (Appendix D.1 CUVX Ship Synthesis Model, 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 [1]. This can be structured as a multi-attribute decision problem. Two methods for structuring these problems dominate the literature: Multi-Attribute Utility Theory and the Analytical Hierarchy Process. In the past, supporters of these theories have been critical of each other, but recently there have been efforts to identify similarities and blend the best of both for application in Multi-Attribute Value (MAV) functions. This approach is adapted here for deriving an OMOE.

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 (DVs). 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, DV 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:

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

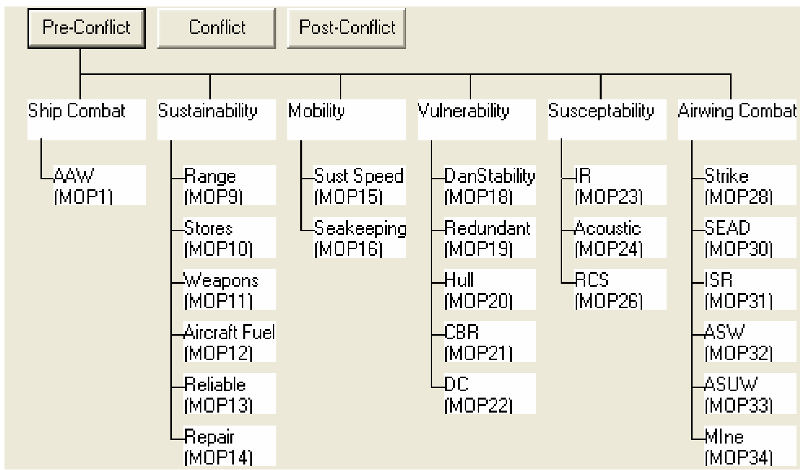


Figure 22. OMOE Hierarchy

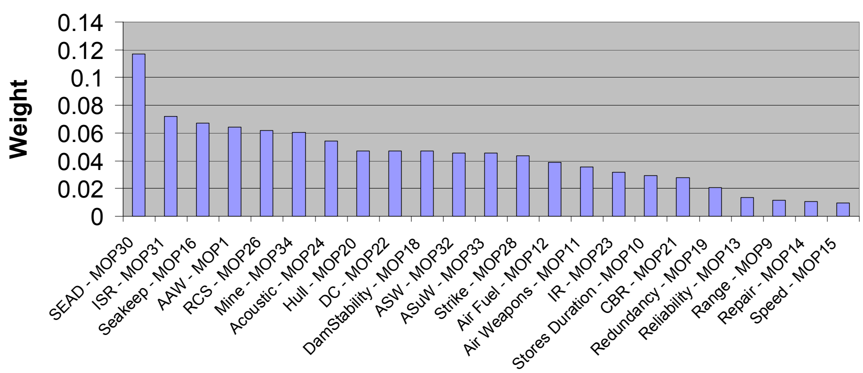


Figure 23. MOP Weights

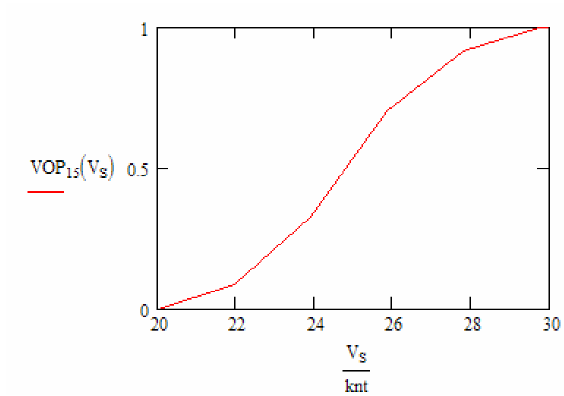


Figure 24. Value of Performance Function for Sustained Speed

Table 23. ROC/MOP/DV Summary

ROC	MOP or Constraint	Threshold or Constraint	Goal	Related DV
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	DV1-DV7 – Hull form DV18 - Range (nm) DV20 – 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	DV1 - Hull form type DV20 – Propulsion system (1-14) DV7 - Hull structure type DV21,26 – ShipManFac, AirManFac DV20 – Propulsion system (1-14) DV20 – Propulsion system (1-14) DV1 - Hull form type
MOB 3.2 - Counter and control NBC contaminants and agents	MOP21 - collective protection system?	none	full	DV23 – 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 5MT / UCAV 30MT/UCAV 1 shaft 50% manning w/automation	12000 nm 120 days 15MT/UCAV 60MT/UCAV 2 shafts Full manning	DV18 - Range (nm) DV19 - Stores Endurance DV28 - Aircraft weapons capacity DV27 - Aircraft fuel capacity DV20 – Propulsion system (1-14) DV21,26 – 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	DV1-DV7 - 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	DV8-separate launch deck DV25-number of UCAVs
CV2 - Operate and support unmanned aircraft in ISR missions independent of land	MOP31 - ISR	5 UAVs	20 UAVs	DV24-number of UAVs
CV3 - Operate and support aircraft (LAMPS) in defensive missions against enemy surface and submerged forces, independent of land facilities	MOP32-ASW MOP33-ASUW MOP34-Mining	2 LAMPS	4 LAMPS	DV11-ASW/ASUW LAMPS
CV4 - Shelter, transport, launch, recover and maintain unmanned aircraft and helicopters	Various / all			DV11-ASW/ASUW LAMPS DV24-number of UAVs DV8-separate launch deck DV25-number of UCAVs DV26-AirManFac
CV5 - Provide weapons storage and handling for embarked unmanned aircraft	MOP11 - Weapons capacity	5MT/UCAV	15MT/UCAV	DV28 - Aircraft weapons capacity
AAW 1.2 - Provide unit self defense	MOP1 - Ship AAW	SSDS w/RAM, CIWS	SSDS w/ESSM, CIWS	DV10 - AAW system
AAW 5 - Provide passive and softkill anti-air defense	All designs – DLS/SRBOC and EW	DLS/SRBOC and SLQ-32		None

ROC	MOP or Constraint	Threshold or Constraint	Goal	Related DV
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	DV10 - 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 +	DV11-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	DV1-DV7 – Hull form DV20 – Propulsion system
ASW 1.1 - Engage submarines at long range	MOP32-ASW	2 LAMPS	4 LAMPS	DV11-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	DV11-ASW/ASUW LAMPS
ASW 5 - Support airborne ASW/recon	MOP32-ASW	2 LAMPS	4 LAMPS	DV11-ASW/ASUW LAMPS
MIW 7 – Deploy mines using UCAVs	MOP34-Mine	10 UCAVs	30 UCAVs	DV25-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	DV24-number of UAVs DV11-ASW/ASUW LAMPS
INT 1 - Support/conduct intelligence collection	MOP8 - number of UAVs and LAMPS	10 UAVs 2 LAMPS	30 UAVs 4 LAMPS	DV24-number of UAVs DV11-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	DV24-number of UAVs DV11-ASW/ASUW LAMPS
NCO 3 - Provide upkeep and maintenance of own unit	MOP14 - Repair	50% manning w/automation	Full manning	DV21,26 – 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) (Appendix D.1 CUVX Ship Synthesis Model, 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 variables 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:

$$OMOR = W_{perf} \sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{\cos t} \sum_j w_j P_j C_j + W_{sched} \sum_k w_k P_k C_k \tag{3-1}$$

Once the OMOR variables 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	DV#	DV Description	DV Value	Risk Event E_i	Risk Description	P_i	C_i	R_i
Armament	Performance	1	DV_{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	DV_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	DV_{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	DV_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	DV_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	DV_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	DV_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	DV_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	DV_{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	DV_{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	DV_{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	DV_{20}	EMALS	>5	Development and integration of new EMALS system will have cost overuns	Unexpected problems with new equipment and systems and integration with IPS pulse power	0.5	0.6	0.3
Armament	Cost	13	DV_{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	DV_{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	DV_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	DV_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%

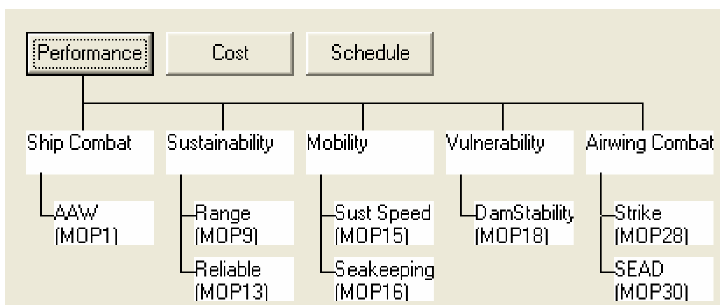


Figure 25. Performance Risk

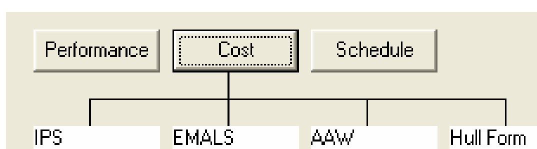


Figure 26. Cost Risk

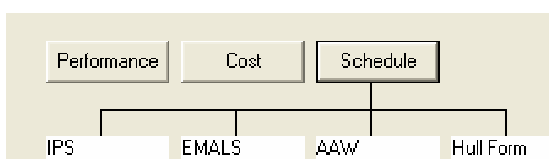


Figure 27. Schedule Risk

3.5.3 Cost (Appendix D.1 CUVX Ship Synthesis Model, 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.

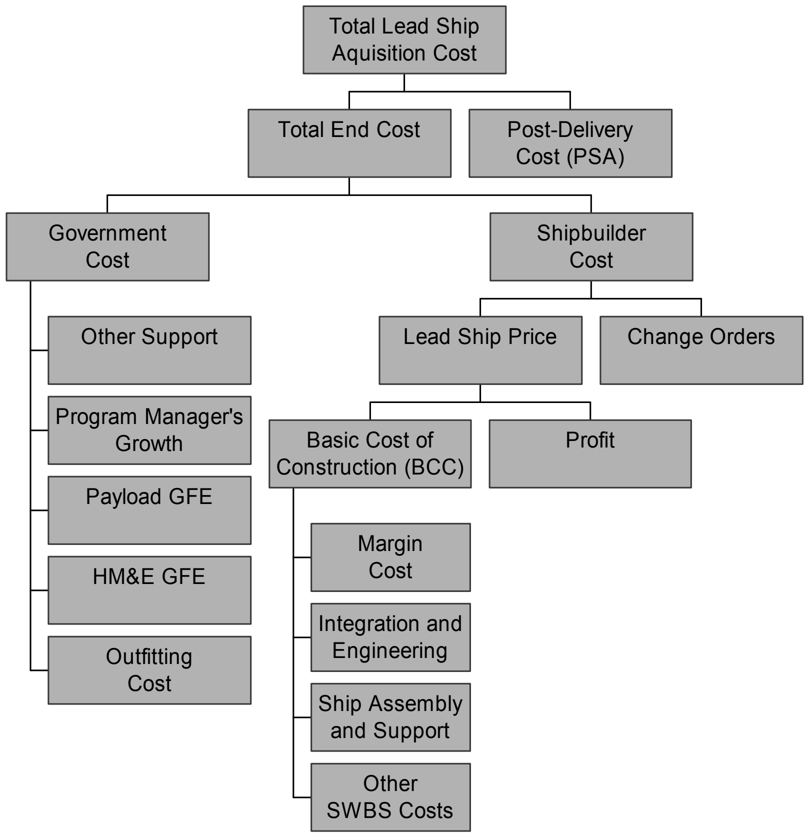


Figure 28. Naval Ship Acquisition Cost Components

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.

3.6 Optimization Results

Figure 29 and Figure 30 show the final effectiveness-cost-risk frontiers generated by the genetic optimization. Each point in Figure 29 and Figure 30 represents objective attribute values for a feasible non-dominated ship design. Non-dominated frontiers for different levels of risk (OMORs) are represented by different colors. Extreme designs (LO and HI) and distinctive "knees" in the curve (Best Buy - BB) are labeled as candidate designs for discussion. Alternative designs at the extremes of the frontiers (HI and LO) and at knees in the curve (BB1, 2 and 3, etc.) are often the most interesting possibilities for the customer. Characteristics for these ships are shown in Table 27. The "Knees" are distinct irregularities in the curves at the top of steep slopes where substantial effectiveness improvement occurs for a small increase in cost. The HI3 design variant shown in Figure 30 was assigned to Team 2.

Non-dominated ships include all three hullform types. The LPD modified-repeat hullform offers cost advantages and dominates the center region of the design space, but since the modified-repeat requires a specific displacement (25000 MT +/- 2%), low end ships with displacements less than 25000 MT and high-end ships with displacements greater than 25000 MT must be either general monohulls or WPTH. Low-end (cost) variants have one shaft, high-end variants have two shafts. The rising slopes seen in each frontier between acquisition costs of $550M and $650M represent an increase in the number of UCAVs and UAVs with their necessary support and manning. The higher risk frontiers represent a greater use of higher risk alternatives: WPTH, peripheral vertical launch, separate launch deck, IPS and EMALS. HI3 has all of these alternatives, LO4 and BB2 have none. HI3 is the largest ship with the most aircraft and crew. It has the lowest signatures, advanced double hull, and high-end combat system. It has the lowest endurance because it is weight-constrained (29000 MT). Adding weight for aircraft and survivability provides a greater increase in effectiveness than adding fuel weight, but it costs more.

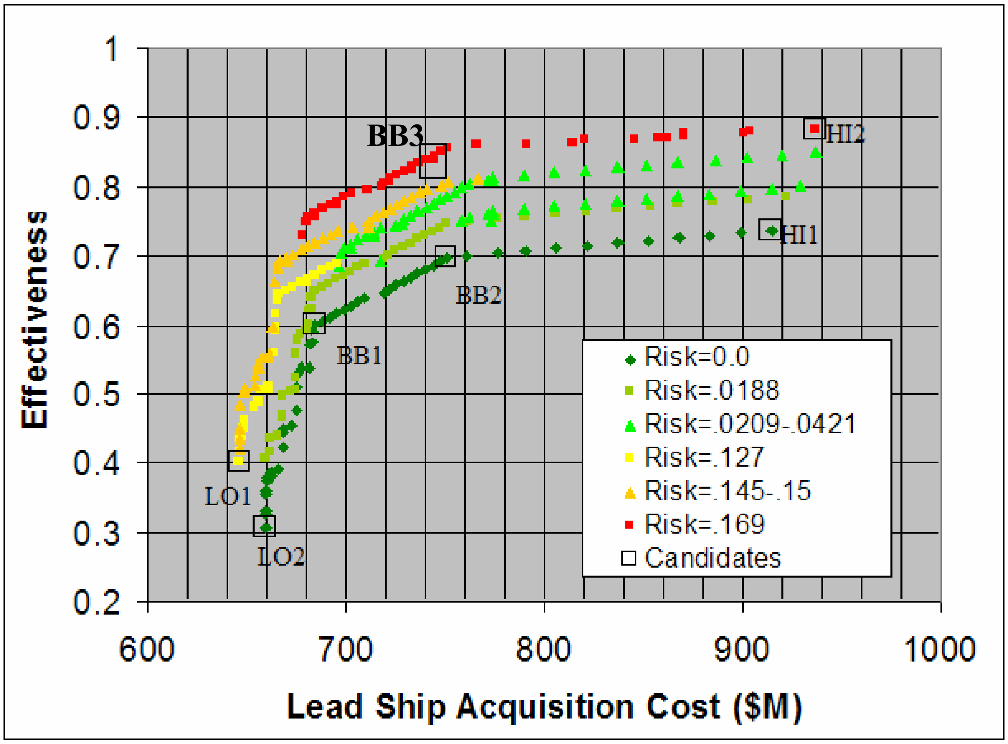


Figure 29. Non-Dominated Frontier based on Lead Ship Acquisition Cost

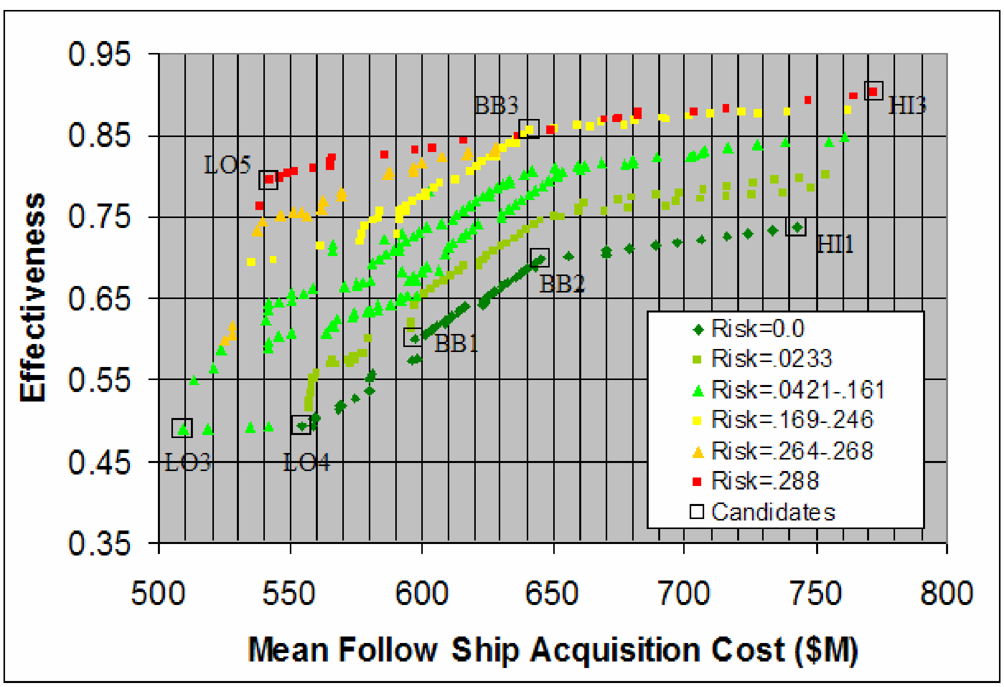


Figure 30. Non-Dominated Frontier based on Average Follow Ship Acquisition Cost

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
Cost Follow ($M)	562.60	574.82	509.21	554.67	542.18	597.10	645.44	641.39	742.49	760.29	772.24
Cost Lead ($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
Launch Deck	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
CPS	3	3	3	1	1	1	1	1	1	1	1
Prop. System	8	1	1	1	12	4	4	12	4	11	12
Shafts	1	1	1	1	2	2	2	2	2	2	2
Prop. System Type	IPS	Mech	Mech	Mech	IPS	Mech	Mech	IPS	Mech	IPS	IPS
AAW	2	2	2	2	1	2	2	1	2	1	1
Advanced Double Hull	0	0	0	0	1	0	0	0	0	0	1
# of Helos	2	2	4	4	4	4	4	4	4	4	4
CManShip	1	1	1	1	1	1	1	1	1	1	1
# of UAV	13	9	20	18	20	20	20	20	20	19	18
# of UCAV	10	10	10	10	11	10	28	29	30	30	28
CManAir	1	1	1	1	1	1	1	1	1	1	1
Weight Fuel UCAV	60.0	60.0	57.0	57.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Weight Weap. UCAV	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
W Payload	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
Sustained Speed (knt)	20.95	22.63	22.14	22.62	21.92	21.28	21.28	20.95	21.28	24.63	20.18
McCreigh Index	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

3.7 HI3 Baseline Concept Design

The HI3 design is the highest risk, follow-ship acquisition cost and effectiveness non-dominated design identified by the MOGO. The high OMOR of 0.288 is due to the Advanced Double Hull, Wave Piercing Tumblehome, Launch Deck, Full Ship Collective Protection System, Electromagnetic Launching System, and Integrated Power System. These are all higher risk alternatives. Table 28 - Table 33 summarize the baseline ship characteristics. Table 28 shows the design variables and ranges considered for CUVX and the design variable values selected for HI3. The endurance range tankage volume was limited due to the reduced volume in the WPTH hull form. Flight deck area was also reduced due to the tumblehome. The propulsion system uses 5 propulsion diesels (see Table 13 propulsion system details), and was necessary to achieve the threshold range. Table 29 lists the ship weights and vertical centers of gravity by SWBS groups with margins. Table 30 summarizes arrangeable area. Table 31 is an electric power summary by SWBS group. Table 32 lists principal characteristics with descriptions of the propulsion system and combat systems. The dimensions were altered slightly from the ship synthesis model to accommodate an even frame spacing of 3 m. This table also contains information about number of elevators, manning broken down by ship/air officers and enlisted, deck heights, and lead/follow ship costs. Table 33 summarizes the values given to each Measure of Performance in determining HI3's Overall Measure of Effectiveness and Risk. All values are at the goal or close to it except for the threshold endurance range and damage stability because of the wave piercing tumblehome.

Table 28. Design Variables Summary

Design Variable	Description	Trade-off Range	HI3 Values
DV 1	Hull Form type	1. General Monohull 2. LPD-17 3. WPTH	(3.) WPTH
DV 2	Prismatic Coefficient	$C_P = 0.6 – 0.8$	0.7
DV 3	Max. Section Coefficient	$C_X = 0.9 – 0.99$	0.95
DV 4	Displacement to Length Ratio	$C_{\Delta L} = 50 – 90$	86
DV 5	Beam to Draft Ratio	$C_{BT} = 3.0 – 5.0$	4.1
DV 6	Length to Depth Ratio	$C_{D10} = 6 – 8$	7.2
DV 7	Launch Deck	1. Yes 2. No	(1)
DV 8	Deck House Volume Ratio	$C_{vd} = 0.05 – 0.3$	0.105
DV 9	AAW System	1. ESSM + CIWS2 2. RAM + CIWS2	(1.)
DV 10	ASuW	1. 2 HELOS 2. 4 HELOS	(2.)
DV 11	Endurance Range	1. 12000 nm 2. 8000 nm 3. 4000 nm	(3.)
DV 12	Stores Duration	1. 120 day 2. 90 day 3. 60 day	(1.)
DV 13	Propulsion System	1. 2 LM2500, 1 shaft, mechanical 2. 2 ICR, 1 shaft, mechanical 3. 1 ICR, 1 LM2500, 1 shaft, mechanical 4. LPD-17 5. 2 LM2500, 2 PC2.5V16, 2 shaft, mechanical 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. 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	(12.)
DV 14	Ship Manning Factor	0.5 – 1.0	1.0
DV 15	Advanced Double Hull	1. Yes 2. No	(1.)
DV 16	Collective Protection System (CPS)	1. Full Ship 2. Partial Ship (Citadel) 3. None	(1.)
DV 17	Number of UAVs	4 – 20	18
DV 18	Number of UCAVs	9 – 30	28
DV 19	Air Manning Factor	0.5 – 1.0	1.0
DV 20	Aircraft Fuel Weight – ship capacity	30 MTs – 60 MTs	45 MTs
DV 21	Aircraft Weapons Weight - ship capacity	5 MTs – 15 MTs	14 MTs

Table 29. Concept Exploration Weights and Vertical Center of Gravity Summary

Group	Weight	VCG
SWBS 100	13445 MT	11.29 m
SWBS 200	2179 MT	8.38 m
SWBS 300	835 MT	10.37 m
SWBS 400	335 MT	17.47 m
SWBS 500	3927 MT	14.97 m
SWBS 600	1870 MT	14.14 m
SWBS 700	43 MT	24.19 m
Lightship	22634 MT	11.76 m
Lightship w/Margin	24886 MT	11.67 m
Minop Weight w/Margin	29691 MT	10.24 m
Full Load w/Margin	29959 MT	10.29 m

Table 30. Concept Exploration Area Summary

Area	Required	Available
Total-Arrangeable	20670 m^2	20810 m^2
Hanger	7906 m^2	12030 m^2
Deck House	972 m^2	1022 m^2

Table 31. Concept Exploration Electric Power Summary

Group	Description	Power
SWBS 200	Propulsion	168 kW
SWBS 300	Electric Plant, Lighting	1018 kW
SWBS 430, 475	Misc.	101 kW
SWBS 521	Firemain	464 kW
SWBS 540	Fuel Handling	827 kW
SWBS 530, 550	Misc. Aux	684 kW
SWBS 561	Steering	135 kW
SWBS 600	Services	355 kW
CPS	CPS	645 kW
KW_{NP}	Non-Payload Functional Load	4608 kW
KW_{MFLM}	Max. Functional Load w/Margins	9129 kW
KW_{24AVG}	24 Hour Electrical Load	5187 kW

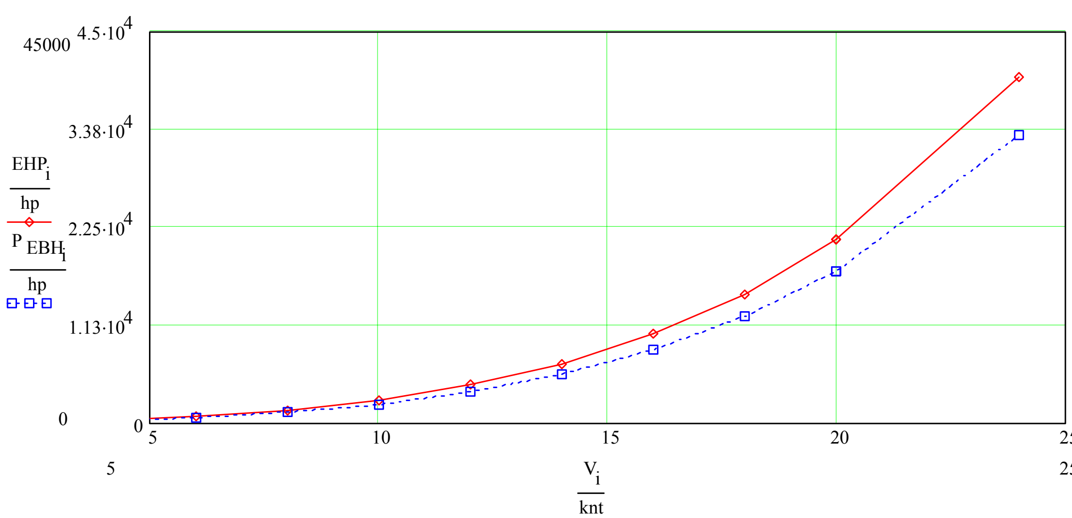


Figure 31. Speed-Power Curve

Table 32. Concept Exploration Baseline Design Principal Characteristics

Characteristic	Baseline Value
Hullform	WPTH
Δ (MT)	29640
LWL (m)	213
Beam (m)	29.04
Draft (m)	7.01
D10 (m)	29.58
Prismatic Coefficient, C_P	0.702
Max. Sectional Coefficient, C_X	0.950
Displacement to Length Ratio, $C_{\Delta L}$ (lton/ft^3)	86
Beam to Draft Ratio, C_{BT}	4.100
Length to Depth Ratio, C_{D10}	7.200
Deck House Volume Ratio, C_{vd}	0.105
W1 (MT)	13450
W2 (MT)	2179
W3 (MT)	839
W4 (MT)	335
W5 (MT)	3808
W6 (MT)	1870
W7 (MT)	43
Wp (MT)	2491
Lightship Δ (MT)	24770
KG (m)	11.84
GM/B=	0.088
Hull structure	Advanced Double Hull
Propulsion system	Alternative 12: 2 shafts, IPS, 5xPC2.5V16 main propulsion diesels, 2x2500kW SSDG
Engine inlet and exhaust	Side or stern
AAW system	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 w/MK93 TAS, SSDS
Aircraft elevators	3
Weapons elevators	3
Catapults	2
Average deck height (m)	3.0
Hangar deck height (m)	6.0
Ship Officers	30
Ship Enlisted	290
Air Officers	37
Air Enlisted	541
Total Officers	67
Total Enlisted	831
Total Manning	898
Number of UCAVs	28
Number of UAVs	18
Lead Ship Cost	1196 $M
Follow Ship Cost	775 $M

Table 33. MOP/ VOP/ OMOE/ OMOR Summary

Measure	Description	Value of Performance
MOP 1	AAW systems	1
MOP 9	Range at endurance speed	0
MOP 10	Stores	1
MOP 11	Weapons	0.9
MOP 12	Aircraft Fuel	1
MOP 13	Reliability	1
MOP 14	Repair	1
MOP 15	Sustained Speed	1
MOP 16	Seakeeping	1
MOP 18	Damage Stability	0
MOP 19	Redundancy	1
MOP 20	Hull Form	1
MOP 21	CBR	1
MOP 22	Damage Control	1
MOP 23	IR signature	0.8
MOP 24	Acoustic Signature	1
MOP 26	RCS	1
MOP 28	Strike	0.93
MOP 30	SEAD	0.93
MOP 31	ISR	0.867
MOP 32	ASW	1
MOP 33	ASuW	1
MOP 34	Mine Countermeasures	1
OMOE	Overall Measure of Effectiveness	0.902
OMOR	Overall Measure of Risk	0.288

4 Concept Development (Feasibility Study)

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

4.1 General Arrangement and UCAV Operations Concept (Cartoon)

As a preliminary step to determine hull form geometry, deck house geometry and general arrangements, an arrangement cartoon was developed for the vital mission flight deck and hangar deck areas (Figure 32). UCAV operations and support were primary considerations. Scaled layouts of the three hangar decks and the recovery deck are shown. Paper cutout UCAVs, and HELOs were made based on the Virginia Tech UCAV-N design team's dimensions. These cutouts were laid over the four decks, and different arrangements for the aircraft elevators, weapons elevators, aircraft maintenance, and aircraft storage were considered. Since this ship is designed to incorporate a wave piercing tumble home hull form, the usable deck area is limited. The 10 degree angled sides necessary to minimize radar cross-section decrease the beam of each successive deck moving higher in the ship. Due to these limitations and the need for simultaneous take-off and landing, separate launch and recovery decks are required. Take-off and recovery occur on the same deck (flight deck) on a CVN where the size of the ship and sponsons make this possible. CUVX aviation operations and system design are described more fully in Section 4.6.

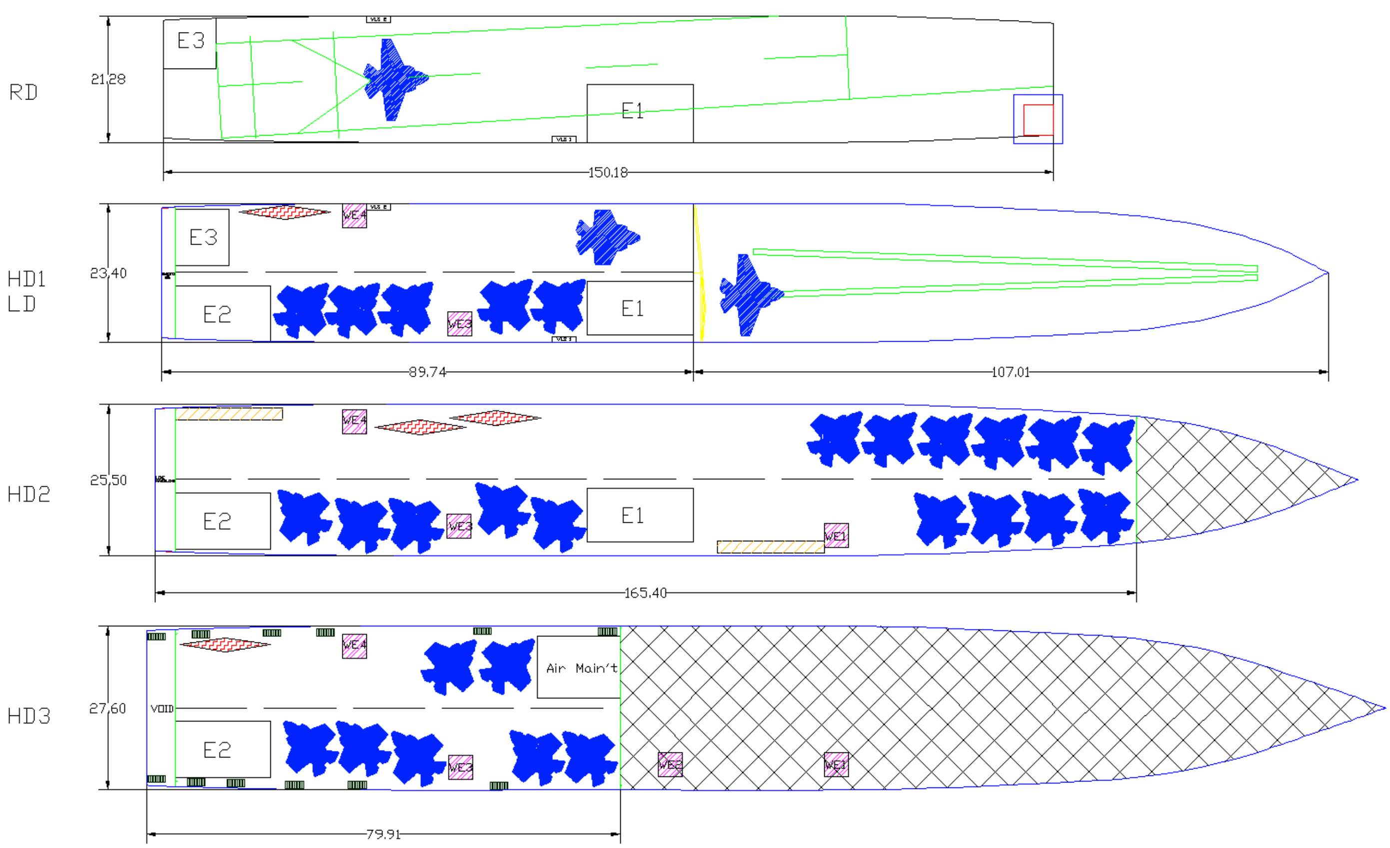


Figure 32. Hangar Deck Arrangements

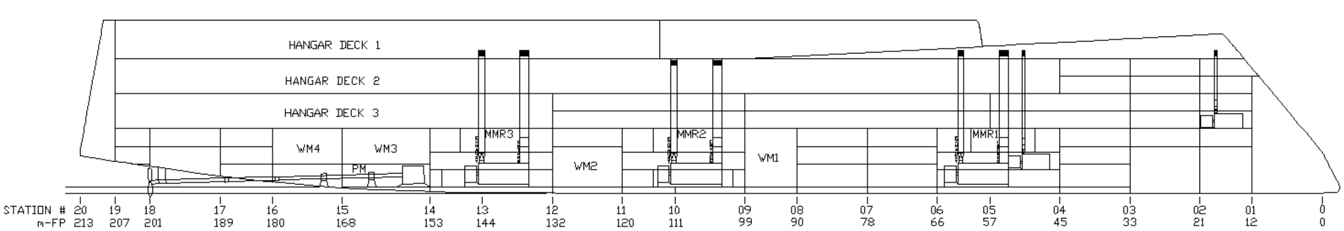


Figure 33. Profile - Intake/Exhaust and Weapons Magazine Locations

4.1.1 Recovery Deck

The function of the Recovery Deck is to provide an area where UCAVs, UAVs, and HELOS can land, park, and await transport below deck. The Recovery Deck on CUVX is 150.2 meters long and 21.3 meters wide. This deck is serviced by Aircraft Elevator 1 on the starboard side forward and by Aircraft Elevator 3 on the port side aft. The recovery strip is 106 meters long, 15.8 meters wide at the start of the strip and 14.2 meters wide at the end of the strip. The only deck obstacle is the deckhouse all the way forward with a one meter clearance on the right side of the landing aircraft's wingspan when on the center of the strip. Otherwise, the deck is completely clear with no obstacles to deck edge overhang. There are 6 meters of deck on each side of the aircraft's wheels on touchdown. The UAVs are smaller than the UCAVs and there is ample clearance for wings and landing gear. The width is tapered since space is limited toward the forward end of the deck. The strip is canted at a 3 degree angle to the centerline to further avoid the deck house and parking. This requires aircraft to approach slightly from starboard. The first arresting cable is 15 meters forward of the rear edge of the deck. There are two more cables, spaced 7 meters and 14 meters from the first cable. After an aircraft has landed and while the arresting cable is being retracted, the wings are folded and it is moved to the starboard side directly behind the deck house. There is room to safely park four UCAVs while a fifth UCAV is landing, after which all are moved below decks. If Elevator 1 is unable to bring planes below deck, Elevator 3 becomes the primary aircraft elevator. VLS cells are located on the port deck edge 172 meters from the forward perpendicular and along the starboard deck edge 142 meters from the forward perpendicular, out of the way of landing aircraft. The two modules have been separated for survivability. The deckhouse is located forward on the starboard side. The deck house is similar in shape and uses the same technology as the Advanced Electronic Mast (AEM) enclosure on LPD-17; it first flares out and 10.6 meters above the deck it tapers in at a 10 degree angle. This keeps the footprint as small as possible, maximizing the usable deck area while maintaining a minimum radar cross section (RCS). The footprint for the deckhouse is 26 m^2. Electro-hydraulic covers will be provided for Elevator 1 and 3, to allow aircraft recovery in the event an elevator is stuck down, and for between-deck CBN decontamination. With the WPTH hullform and narrow deck area, there was no alternative to locating these elevators clear of the recovery strip.

4.1.2 Launch Deck/Hangar Deck 1

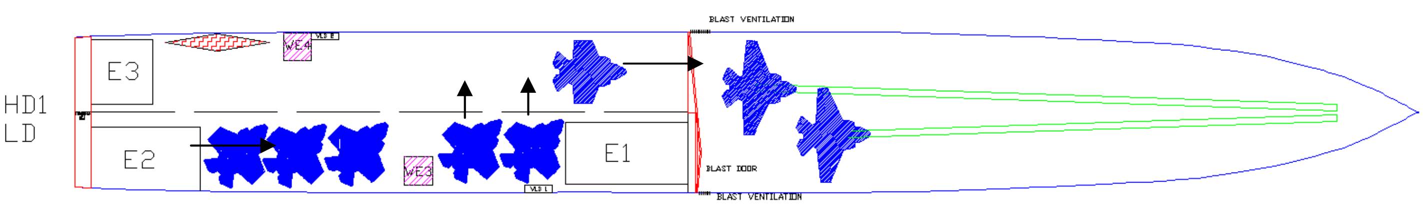


Figure 34. Hangar Deck 1 Aircraft Flow Pattern

Hangar Deck 1 is divided into two sections separated by a jet blast deflector door. The forward 107 meters is the launch deck. In this area there are two EMALS catapults on a launch ramp inclined at three degrees. The starboard track is 75 meters long and the port track is 85 meters long. This stagger allows for two UCAVs to be brought through the blast door before closing. The starboard EMALS will launch first followed by the port, increasing the sortie rate. The incline launches the aircraft at an initial angle of attack allowing them to take-off in a shorter distance. The aft portion of this deck is a hangar. This area is used to load weapons and fuel, and to prepare the aircraft for takeoff. The aircraft are brought up Aircraft Elevator 2 and moved forward into line along the starboard side where there is room for five UCAVs to park. Each of these spots is equipped as a pit stop for fueling and loading weapons. Once the UCAVs are fueled and loaded with appropriate weapons, they move to the port side of the ship, around Aircraft Elevator 1 and out onto the Launch Deck. There is room on this deck along the port side behind the rear weapons elevator to store one LAMPS always ready to be sent out on short notice.

4.1.3 Hangar Deck 2

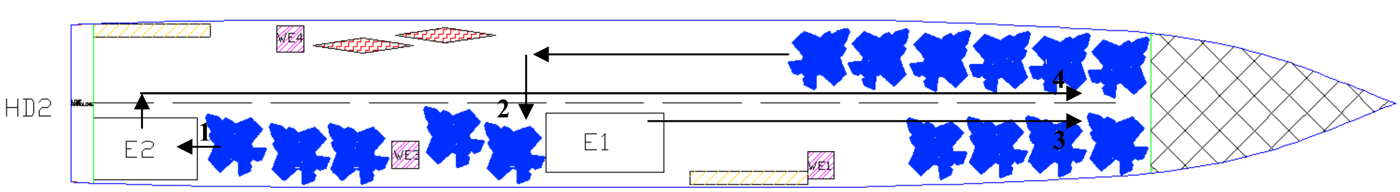


Figure 35. Hangar Deck 2 Aircraft Flow Pattern

Hangar Deck 2 is 165.4 meters long and 25.5 meters wide; it is the largest hangar space on the ship. This deck is a holding deck for UCAVs, UAVs, and LAMPS that are waiting to be sent up to Hangar Deck 1 and prepared for launch. Preliminary preparations can be made on this deck if for some reason more than 5 UCAVs need to be launched in a short period of time. In the forward end of the deck, six UCAVs may be positioned along the port side and four on the starboard side. Two LAMPs may be stored on the port side side forward of Weapons Elevator 4. Further aft along the starboard side between Aircraft Elevators 1 and 2 there is room for five UCAVs; these five UCAVs are the first UCAVs to be moved up to Hangar Deck 1 as spaces become available (arrow #1, Figure 35). As these five UCAVs are moved up to Hangar Deck 1, the ten UCAVs forward are moved aft filling the newly vacated spaces (arrow #2, Figure 35). As UCAVs are recovered they are brought down and moved into the ten forward spaces that were cleared. When UCAVS or UAVs return from a mission, ideally they will be brought down to this deck on Aircraft Elevator 1 and moved into any of the open positions (arrow #3, Figure 35). If for some reason a large number of UCAVs need to be recovered quickly, UCAVs can be brought down to Hangar Deck 1 temporarily so that Aircraft Elevator 1 can be raised again to recover more UCAVs. If this occurs, the UCAVs brought to Hangar Deck 1 can be moved down to Hangar Deck 2 on Aircraft Elevator 2 and then moved forward into the lineup (arrow #4, Figure 35). All 18 of the UAVs are stored on this deck for use in pre-conflict surveillance missions. Nine of them are along the port side in the far rear corner; the other nine are along the starboard side just forward of Aircraft Elevator 1 along the side.

4.1.4 Hangar Deck 3

Hangar Deck 3 is 79.9 meters long and 27.6 meters wide and it is the smallest of the three hangar decks. This deck is only used for aircraft maintenance and storage. There is enough room on this deck to store seven UCAVs and one LAMPS. The ship is required to have enough maintenance area to service two UCAVs simultaneously. This space is located all the way forward on Hangar Deck 3 on the port side. There is a total maintenance area of 147 m^2.

4.1.5 Elevators

There are three aircraft elevators on CUVXHI3. Aircraft Elevator 1 is capable of carrying two UCAVs with wings and tails folded or two LAMPS, and operates from the Recovery Deck down to Hangar Deck 2. This elevator is 18 meters long and 9 meters wide and the center of the elevator is 130 meters aft of the forward perpendicular. It is placed as far forward as possible on the starboard side; constraining its location is the requirement to be behind the jet blast deflector on the Launch Deck. Elevator 1 has a mechanical door on the recovery deck to cover the opening while the elevator is in the down position. This door is electric-hydraulic with a manual override. This allows for aircraft landing while the elevator is down and for decontamination of aircraft before entering the hangar. Aircraft Elevator 2 is capable of carrying two UCAVs with wings and tails folded and it operates from Hangar Deck 1 to Hangar Deck 3. This elevator is 16 m long by 9.5 m wide and it is located at the rear edge of the ship on the starboard side. This is the main interior elevator on the ship. Aircraft Elevator 3 can carry one UCAV with folded wings and tail. It operates from the recovery deck down to Hangar Deck 1. It is located at the rear edge of the ship on the port side and is 9 meters long by 9.5 meters wide. UCAVs taken down to Hangar Deck 1 on this elevator can be moved across the deck to Aircraft Elevator 2 and then down to Hangar Deck 2. This elevator is as small as possible to limit the amount of recovery deck used. It is intended as a backup only to Aircraft Elevator 1. Elevator 3 has the same mechanical door as Elevator 1.

There are three weapons elevators on CUVX HI3. Two of the weapons elevators run all the way up from the weapons magazines to the Hangar Deck 1. One of these elevators (WE3) is located behind Aircraft Elevator 1 on the starboard side 160 meters aft of the forward perpendicular. The other (WE4) is further aft on the port side 177 meters from the forward perpendicular. Placing it here leaves enough room between it and Aircraft Elevator 2 to park one LAMPS out of the way. Weapons Elevator 2, WE2, only runs up to Deck 6. This elevator is located 124 m from the forward perpendicular along the starboard side. Weapons Elevator 1, WE1, is located along the starboard side 95 meters from the forward perpendicular. This elevator services Weapons Magazine 1, Deck 6, and Hangar Deck 2. Weapons from WE2 are transferred to WE1 on Deck 6 and continue up to HD2.

4.1.6 Other Primary Arrangement Considerations

Main engines use side air intakes and exhausts as shown in Figure 33. This is specified in the Concept Baseline characteristics, Table 32. This minimizes the impact on available area in the hangar decks and recovery deck. The side intakes and exhausts use louvered panels with a plenum to prevent water entry and maintain the 10 degree tumblehome.

Capacities for weapons magazines are specified in the Concept Baseline characteristics to support UCAVs, LAMPs, and ship weapons. Considerations for placement of weapons magazines include redundancy, survivability, and weight distribution. The placement of weapons magazines is also driven by the location of weapons elevators to support weapons load-out on Hangar Deck 1 as shown in Figure 33.

4.2 Hull Form, Appendages and Deck House

4.2.1 Hull Form

The baseline Concept Development hullform was created using FastShip software in conjunction with FastGen. The principle dimensions of a parametric model of LPD-17 including length, beam, depth, draft, prismatic coefficient, cross sectional coefficient, and block coefficient were modified using Parametric FastShip macros. These dimensions were iterated to achieve the values specified for CUVX HI3 by the optimization in Concept Exploration as listed in Table 34.

Table 34. CUVX HI3 Hullform Characteristics

	LPD-17	CUVX HI3
LWL	200 m	213 m
B	29.51 m	29.04 m
D	19.0 m	29.58 m
T	7.00 m	7.01 m
C_P	.647	.702
C_X	.941	.95
C_B	.609	.667

A wave-piercing tumblehome (WPTH) hullform was selected for CUVX HI3 in Concept Exploration. The modified LPD hullform was left untouched below the waterline except for reshaping the bulbous bow into a wave-piercing bow. Above the waterline the hullform was modified to have a tumblehome of ten degrees to reduce radar cross section (RCS). Figure 36 shows this modification. A hard chine was created at the waterline where single curvature or flat angled plates on the side of the ship meet the round bilge radius. This also improves the producibility of the design. The transom was modified to have a ten degree incline, as shown in Figure 37.

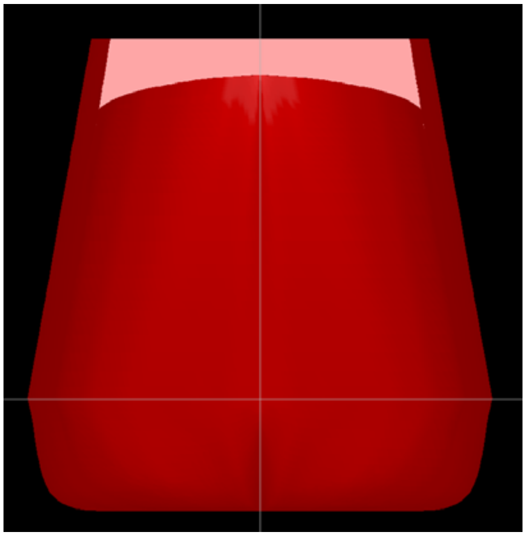


Figure 36. CUVX Body View

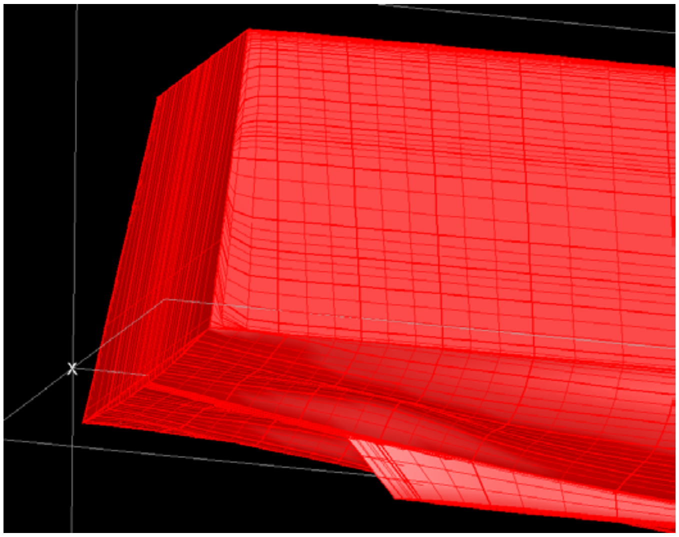


Figure 37. CUVX Isometric View of Transom

The bow was raked back at forty degrees as shown in Figure 38 to give good wave piercing qualities. This angle and shape were estimated based on expert opinion and comparison to pictures and drawings of wave-piercing tumblehome hullforms in the literature. Detailed hullform data is proprietary and could not be obtained. Because no data was available, a model was built and a resistance test performed to measure the resistance of this hullform and compare to the estimate made in Concept Exploration. This is described in Appendix D.3 .

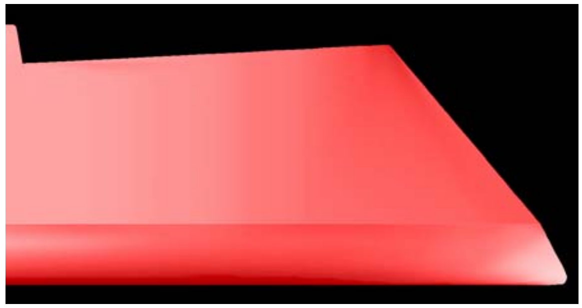


Figure 38. Profile close-up of bow section

Concept Exploration specified the requirement for simultaneous takeoff and landing in CUVX HI3. Due to the LWL constraints and launch/recovery distance requirements specified by the VT UCAV-N team, launch and recovery could not be incorporated on the single weather deck. It is only possible using two separate decks. This varies from traditional CVN launch and recovery and is therefore high risk. The weather deck was selected as the recovery deck and the hullform and sheer line were modified to incorporate a launch deck below the recovery deck, angled up and off the bow of the ship. Working with the VT UCAV-N team, a ramp launch was found to decrease the launch distance required by imparting a vertical component to the launch velocity and giving the UCAV-N a more optimal launch angle of attack. An angle of 3 degrees was chosen because it fit best the ship geometry. This decrease in strip length is very valuable in terms of added hangar deck area. Figure 39 shows a labeled profile view of the finished baseline hullform concept. Figure 40 shows CUVX HI3's floodable length curve. Figure 41 shows the curves of form for CUVX HI3. Also see attached lines drawings.

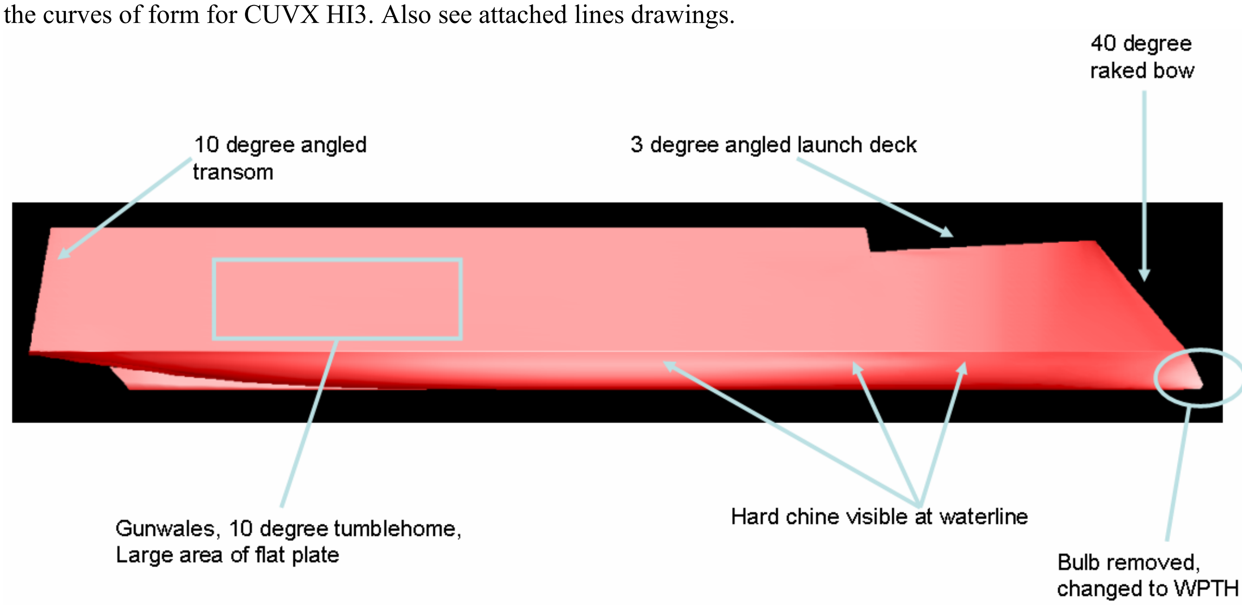


Figure 39. CUVX HI3 wave piercing tumblehome in profile view

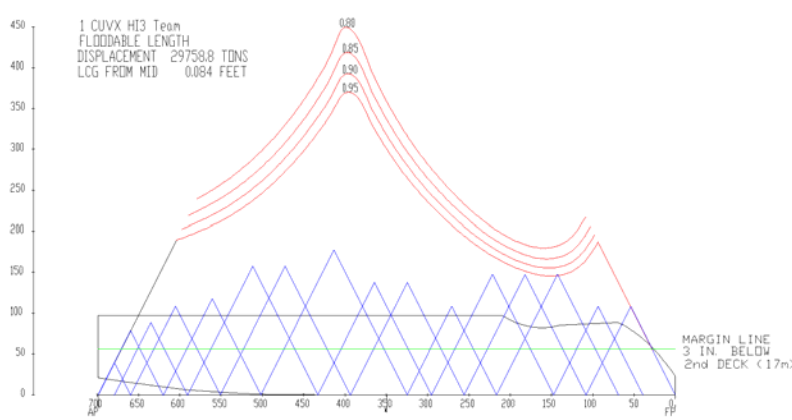


Figure 40. Floodable Length Curve

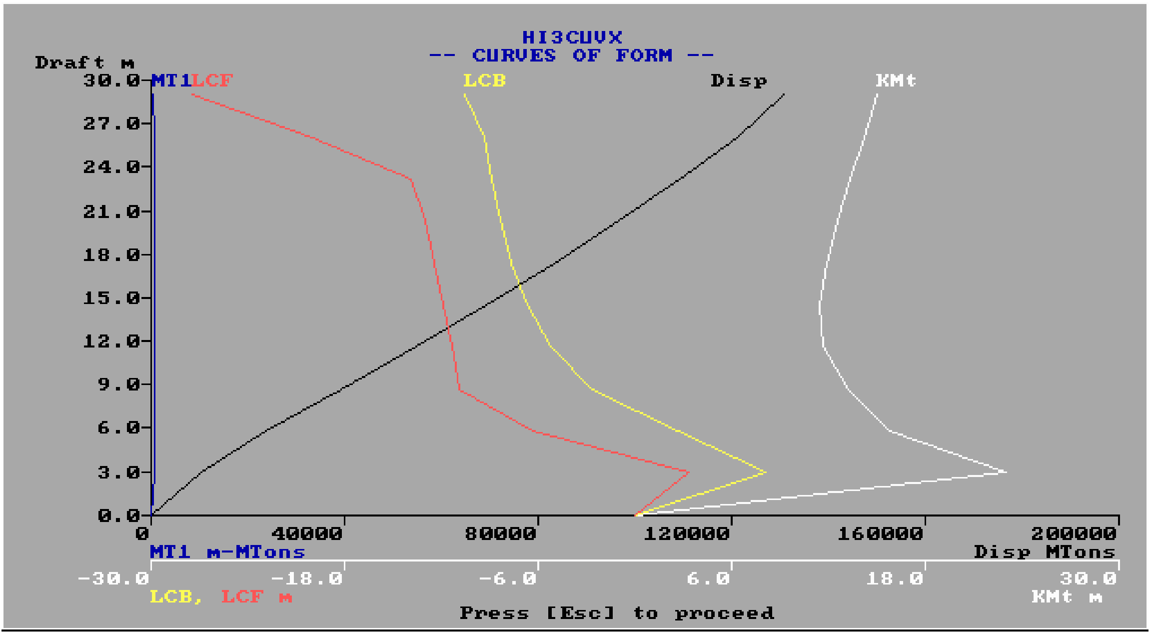


Figure 41. CUVX HI3 Curves of Form

4.2.2 Deck House

The island on a CVN contains the flight operations center, recovery operations center, pilot house, combat systems center, communications center, and supports many of the ship's electronics and sensors. It is also very high for optimal forward visibility. One large structure is not possible in CUVX because of limited recovery deck area and the low RCS requirement. Trade-offs must be made between forward visibility, recovery deck visibility, usable area on recovery deck, and low RCS. This requires CUVX to have separate facilities for each of three groups of operations, located to satisfy their own needs and those of the total ship.

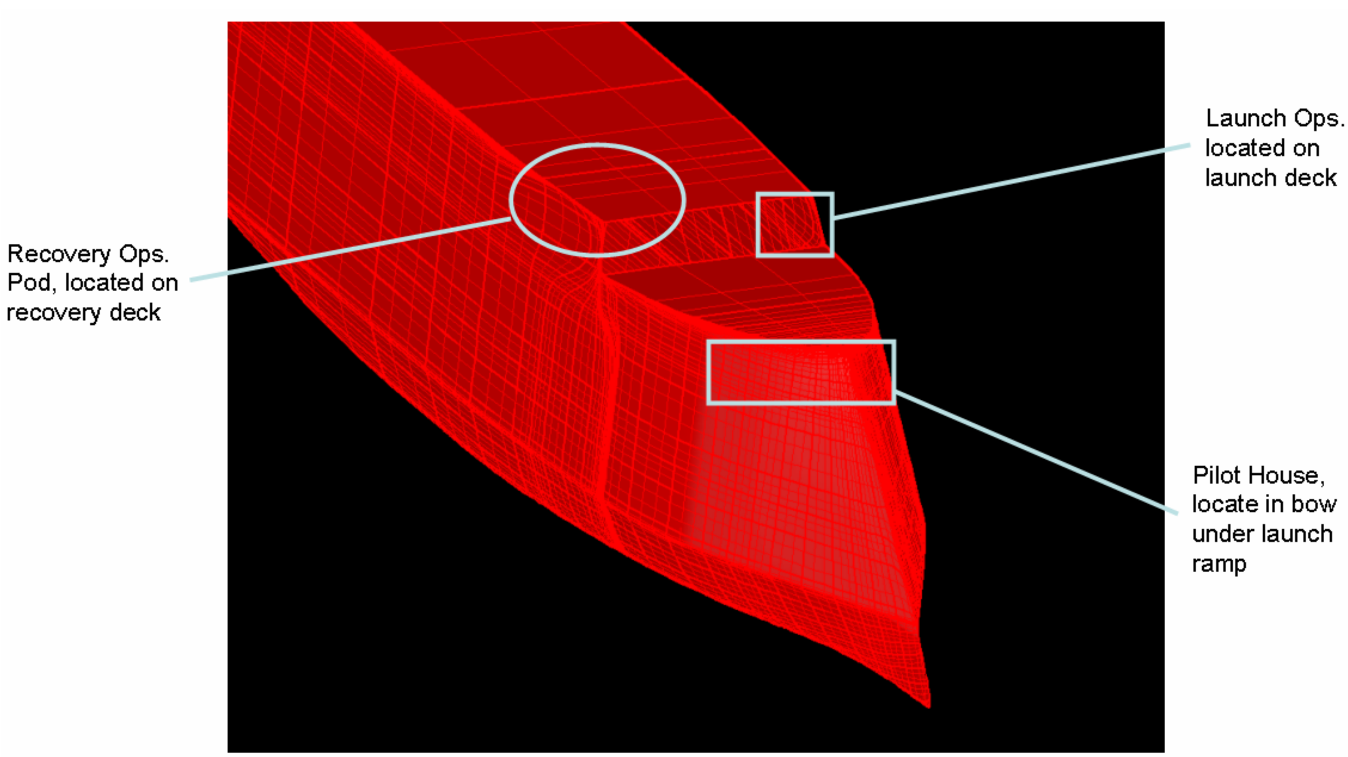


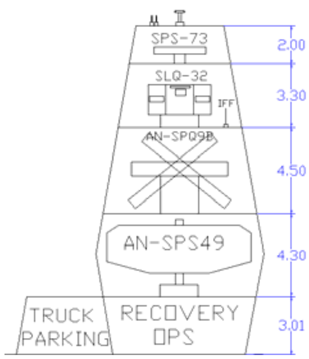
Figure 42. Isometric bow section showing locations of Pilot House, Launch Ops., and Recovery Ops

The pilot house and combat control on CUVX is located under the launch ramp in the bow of the ship. This satisfies the requirement for forward visibility and does not waste valuable recovery deck space. This space includes steering, navigation, communications, combat information center, and flight operations. Figure 42 shows the location of the Pilot House.

Launch Operations is located adjacent to the launch ramp on the launch deck. This control space supports the EMALS operator. This operator is responsible for monitoring and controlling the final launch preparations for the UCAVs and UAVs. Figure 42 shows the location of Launch Operations.

Recovery Operations control is located on the recovery deck in the forward deckhouse. The structure of this facility is based on the Advanced Enclosed Mast (AEM) concept, and also houses the antennas for the radar and other electronic sensors. It is located on the starboard side at the forward end of the recovery deck. This placement maximizes maneuverability, recovery area, parking area, and elevator redundancy within the confines of the small recovery deck. Figure 42 shows the location of Recovery Operations.

Radar domes, antennas, and recovery deck flight operations are all housed in the CUVX-HI3's Advanced Enclosed Mast (AEM). This tower is located forward on the starboard side of the recovery deck. There is also an area inside to park trucks and equipment needed for recovery operations and crash emergencies. The mast has a footprint of 48.5 m^2 that flares up and out on all sides at an angle of 10 degrees to a maximum area of 76.7 m^2. Figure 43 shows a profile view and 3-D view of the AEM. The lower section will support personnel and is 3 m high. The four upper sections' heights and widths are governed by the radars enclosed. The truck parking section has a footprint of 25 m^2, height of 3 m, and a 10 degree taper for low RCS signature. The lower portion of this mast is constructed of radar absorbent material to maintain the ships stealth characteristics. The upper portion will slope in at 10 degrees like the hull sides giving it low RCS signature and is constructed with an advanced hybrid frequency-selective surface that allows CUVX-HI3's own radar in and out, but not foreign radar.



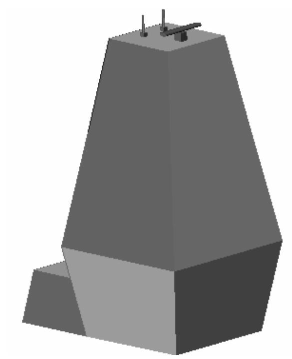


Figure 43. Advanced Enclosed Mast System (AEM)

4.3 Structural Design and Analysis

The structural design process for CUVX HI3 is illustrated in Figure 44. Loads were defined using the full load and minimum operating weight distributions generated in HECSALV, design wave and other hydrostatic pressure criteria from the Structural Design Manual for Naval Surface Ships and aircraft deck criterion from DDS 130-1, Aircraft Handling Deck Structure.

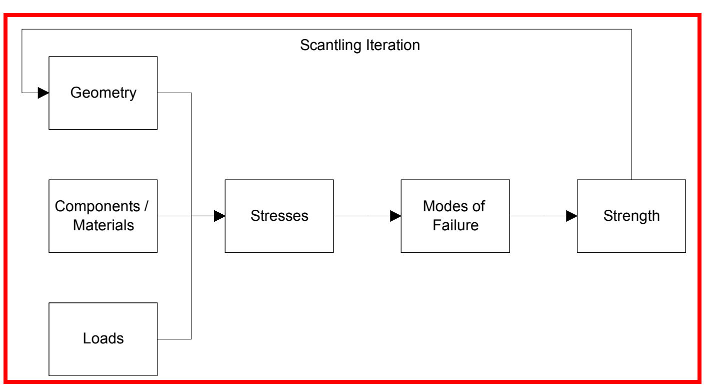


Figure 44. CUVX Structural Design Process

AH36 steel was selected for the hull with HY-80 for the sheer and stringer strakes at deckedge. A standard catalog of shapes and plate thicknesses was selected using I-Ts, Ts and a limited number of fabricated shapes. The catalog was kept as small as possible to maximize producibility. The geometry was modeled in MEASTRO, a coarse-mesh finite element solver with the additional ability to assess individual failure modes. After assessing adequacy, a few iterations of scantling changes to correct inadequacies and reduce weight were performed.

4.3.1 Geometry and Modeling Procedure

A three-dimensional mesh of CUVXHI3's shell is created in FastShip. This mesh was imported into a MAESTRO file. The coordinate axes are adjusted such that the origin is coincident with the forward perpendicular of the imported mesh and the X-axis is positive in the aft direction, the Y-axis is positive vertically upward, and the Z-axis was positive in the port direction. Using the vertices of the imported mesh as reference points, the hull form is created in MAESTRO. Figure 45 shows the completed MAESTRO model.

CUVX HI3 is a longitudinally stiffened ship with transverse frames every three meters. Initial scantlings were chosen based on similar designs. Figure 46 and Drawing D6 show the CUVX HI3 midship section. The structure below the damage control deck and in the middle two thirds of the ship uses an Advanced Double Hull design. Above this deck, the structure is a more traditional single hull design, with the decks and side shells supported by longitudinal stiffeners, girders and transverse frames with tee-shaped cross-sections. Deep deck beams are used to support aircraft decks and the large transverse unsupported spans required over hangar decks.

The Advanced Double Hull (ADH) is a cellular type of structural design that increases hull damage tolerance and producibility. A single average cell from the ADH section of the ship is approximately 9 meters long, 1.5 meters in breadth, and 1 meter deep. In the right half of Figure 46, the cross sections of 17 of these cells are shown below the damage control deck. On the left side, a transverse web is shown below the damage control deck. These transverse webs occur approximately every nine to twelve meters in the ADH vice the standard 3-meter frame spacing used in the remainder of the structure. Figure 47 shows the portion of the hull that is constructed of Advanced Double Hull. The outer skin of the ADH is shown in the flat green color, and the inner skin is shown in yellow.

Figure 48 shows the interior of the MAESTRO model. As shown in the figure, the Advanced Double Hull starts and ends at 33 and 168 meters aft of the forward perpendicular, respectively. Note that there are very few centerline bulkheads in the ship, requiring that the hangar deck beams be very large. One of the ship's aircraft elevators is visible in the aft section of this figure.

The model includes eight substructures. There are short substructures in the bow and the stern, and six main substructures between them, each averaging about 33 meters. Each of the six main substructures is divided into three port and three starboard modules. There is also an additional module for each bulkhead

4.3.2 Loads

Full Load and Minimum Operating weight distributions from HECSALV were applied in MAESTRO load cases as illustrated in Figure 49. The resulting shear force and bending moment diagrams for the full load hogging wave load case are shown in Figure 50 and Figure 51. The ship is balanced on hogging and sagging trochoidal waves. Wave lengths in hogging (crest at midship) and sagging (crests at FP and AP) are equal to the ship length. The wave height is $1.1L^{1/2}$. Other quasi-static sea loads including passing wave ($0.675L^{1/2}$), wave slap, green seas, flooding and aircraft loads are also applied in a series of load cases.

4.3.3 Adequacy

MAESTRO calculates stresses for each load case and compares them to limit state values for various failure modes. Stress divided by failure stress for various modes of failure results in a strength ratio, r. This value can range between zero and infinity. An adequacy parameter is defined as: $(1 - r)/(1 + r)$. This parameter is always between negative one and positive one. A negative adequacy parameter indicates that the element will fail in a particular failure mode and load case. A positive adequacy parameter indicates that it should not fail. An element with an adequacy parameter of positive one is over-designed. At this level of analysis, the main objective is to make as many of the adequacy parameters positive as possible without too much over-design. In a more detailed analysis, the objective would be to adjust the scantlings such that all adequacy parameters were positive, but not much higher than zero. A safety factor of 1.25 is used for serviceability limit states and 1.5 for collapse limit states.

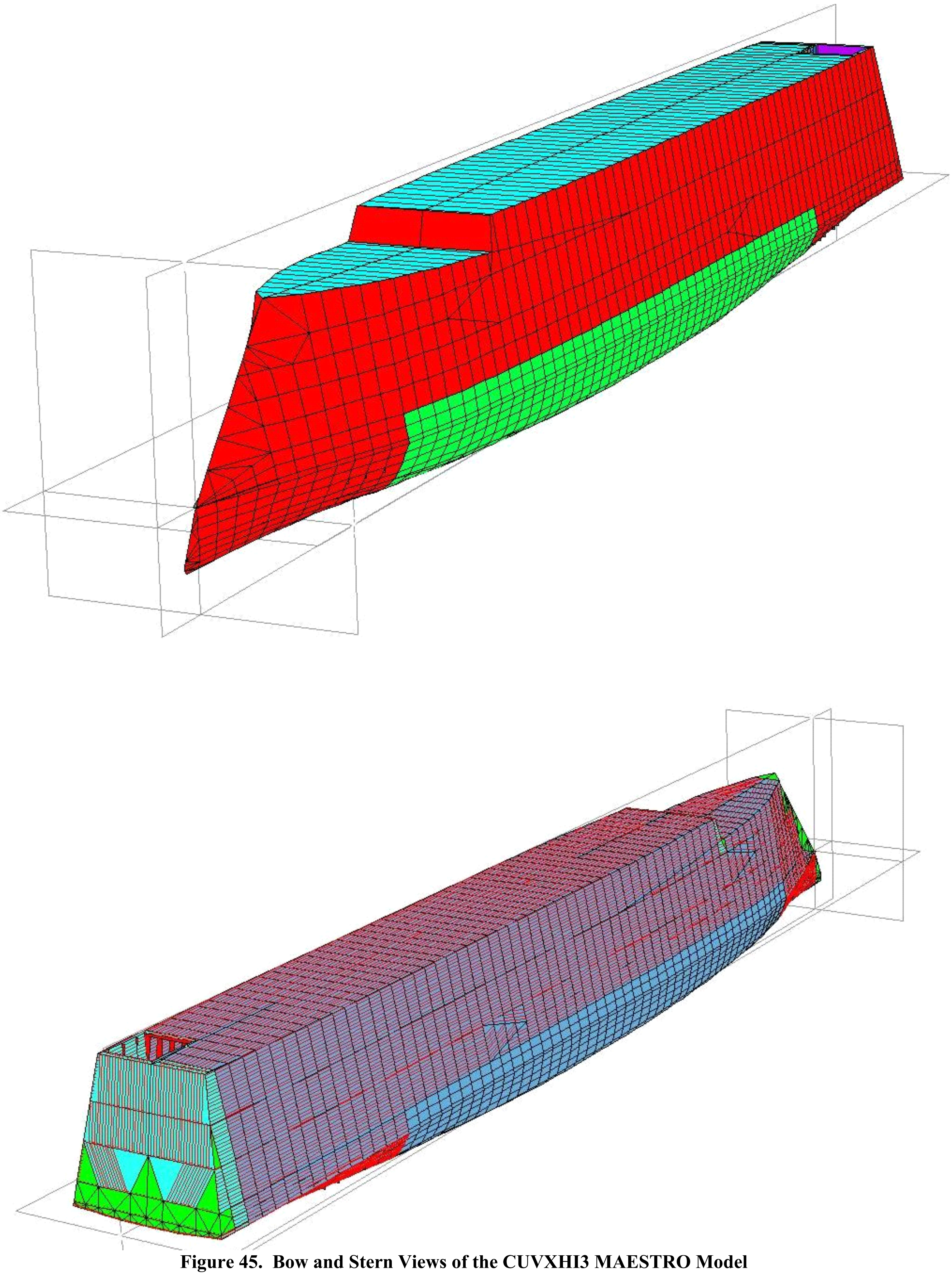


Figure 45. Bow and Stern Views of the CUVXHI3 MAESTRO Model

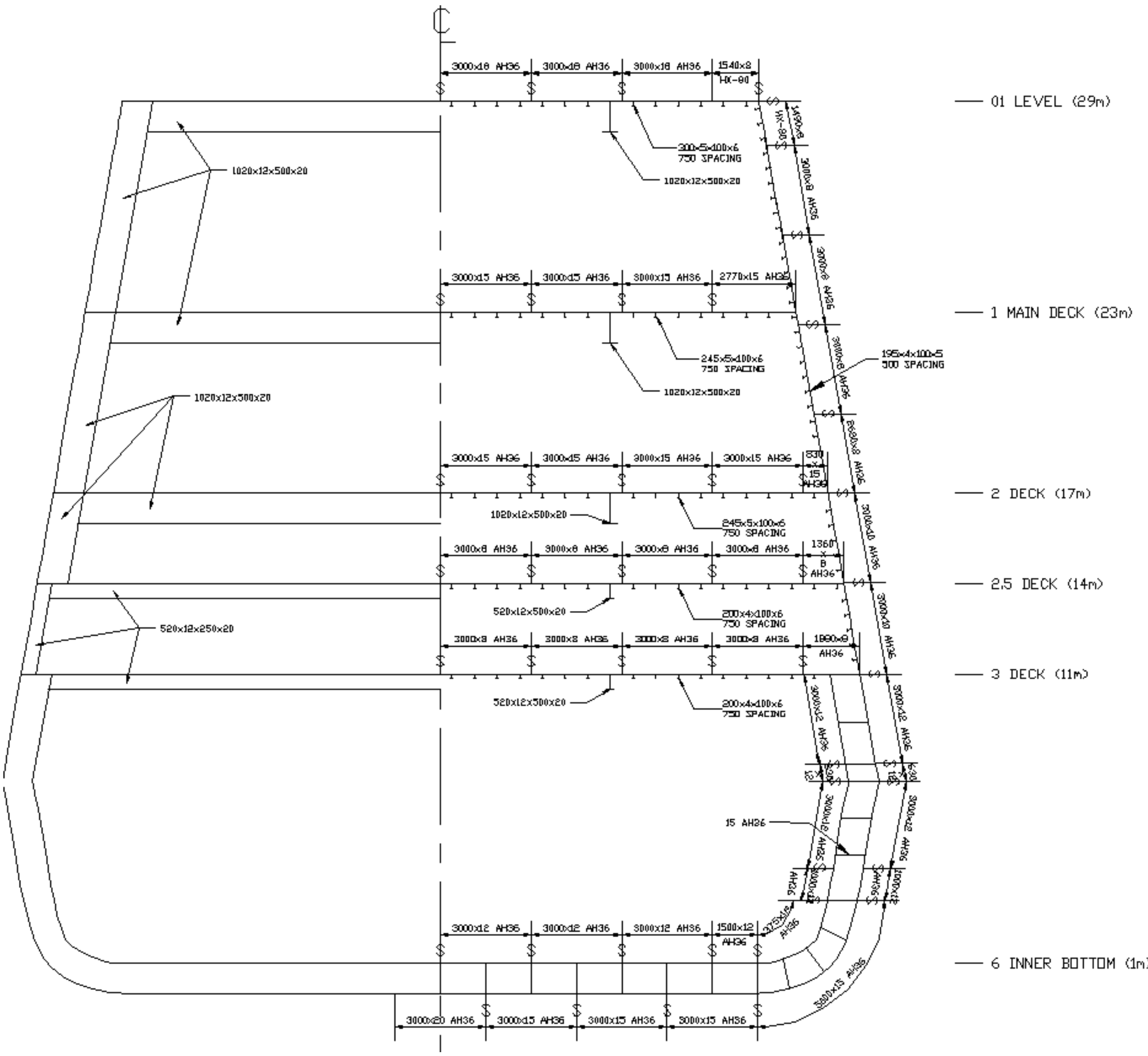


Figure 46. CUVX HI3 Midship Section Drawing

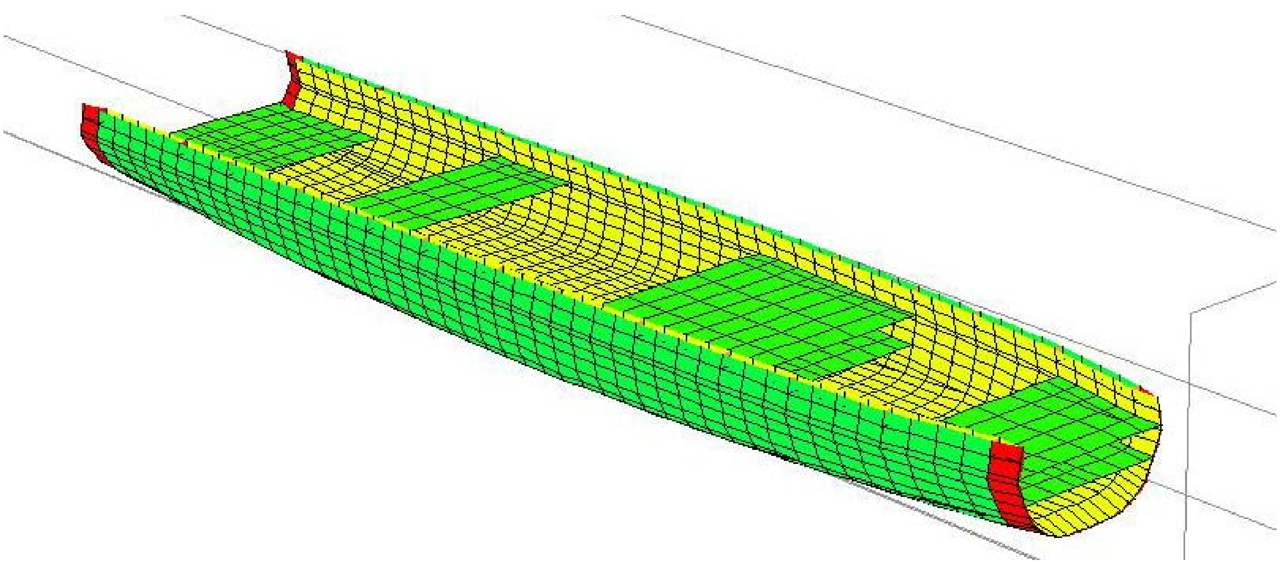


Figure 47. Advanced Double Hull

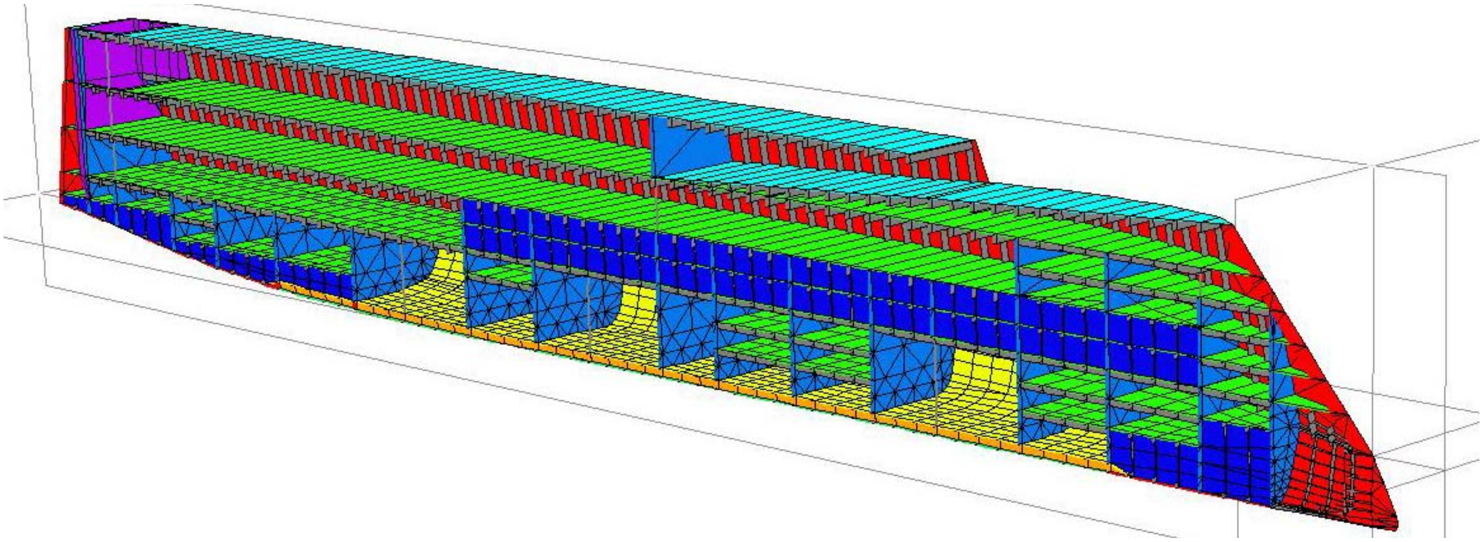


Figure 48. Interior of MAESTRO model

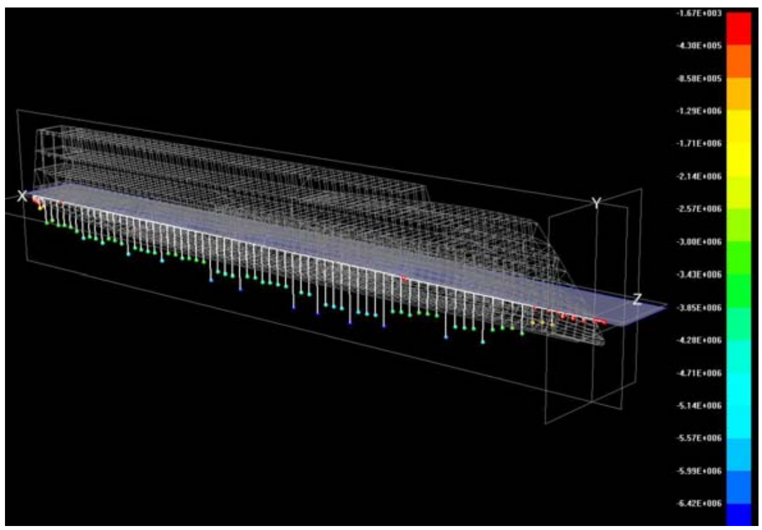


Figure 49. Full Load Stillwater Weight Distribution in MAESTRO

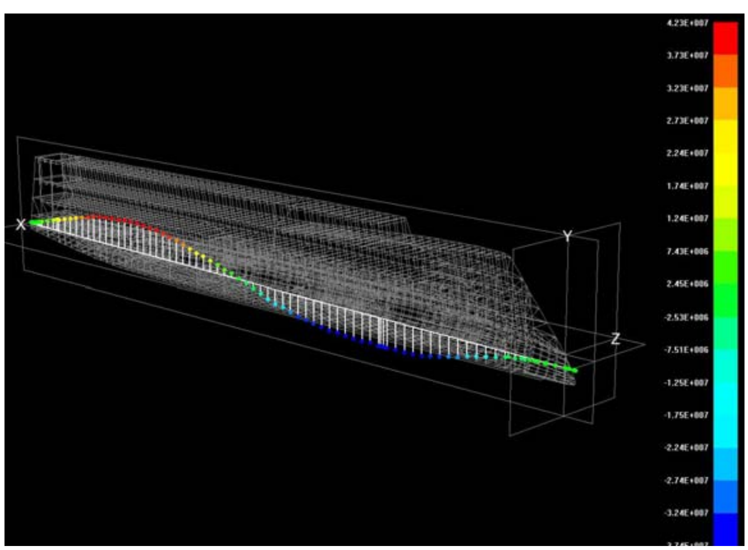


Figure 50. Shear force diagram for full load hogging load case

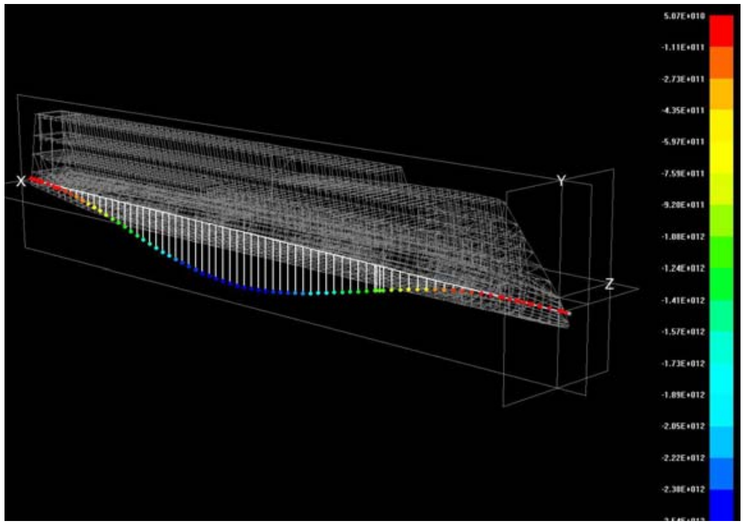


Figure 51. Bending moment diagram for full load hogging load case

CUVX HI3 adequacy parameters shown in Figure 52 and Figure 53 show the final minimum negative values for panel failure modes for all load cases. These were the only areas of negative adequacy. In all cases, both for panels and beams, the worst values occurred in the sagging load case.

Only two side shell strakes, a small region near midship in the bottom and a few scattered panels have slightly negative adequacy parameters. In most cases the failure modes are panel collapse stiffener flexure (PCSF) with the stiffener in tension. An increase in stiffener size is the likely solution. This will be accomplished in the next design iteration at the same time as scantling reduction in over-designed areas to reduce structural weight. Otherwise the structure has adequate strength to satisfy the USN quasi-static load criteria. A probabilistic analysis using North Atlantic wave energy spectra will also be performed in the next design iteration.

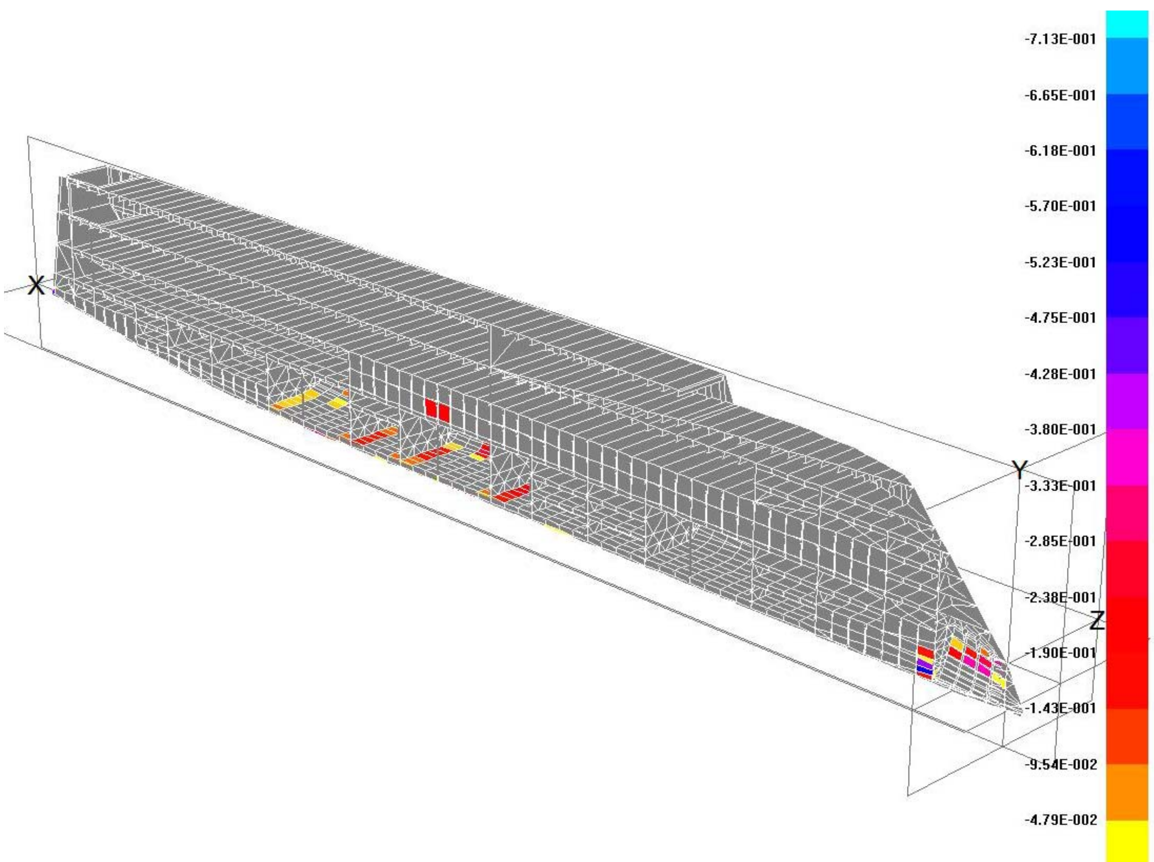


Figure 52. Negative panel adequacy for all load cases

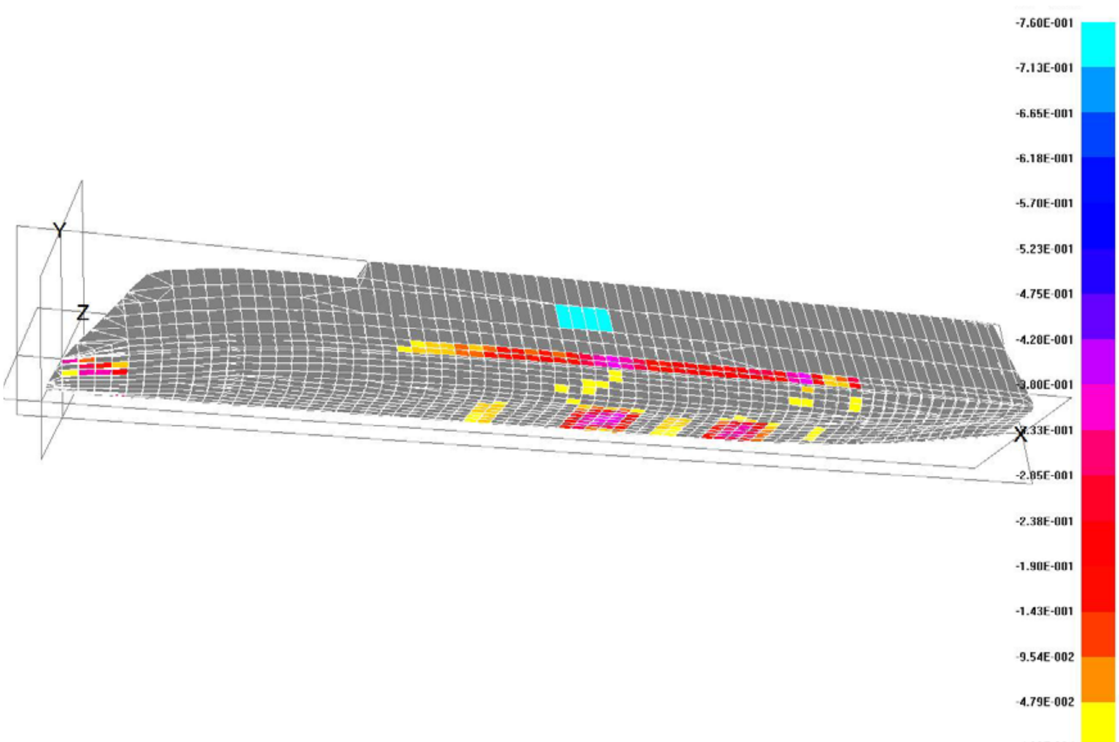


Figure 53. Negative Panel Adequacy for All Load Cases

4.4 Power and Propulsion

CUVX HI3 uses an Integrated Power System (IPS) for propulsion and ship service power. Power from propulsion engines and ship service generators are shared between propulsion, aircraft operations, and ship service loads as required.

4.4.1 Resistance

The calculations for CUVX HI3's resistance, speed, and power are shown in Appendix D.2. The Holtrop-Mennen Method with a WPTH worm-curve factor is used. The resulting resistance vs. speed curve is shown in Figure 54. The upper curve in Figure 54 represents the results of a model test performed at Virginia Tech for this project. Because of the small model size and crude test rig the Holtrop-Mennen results were used for the propulsion calculations; not the model test results. The model test provided an excellent educational opportunity.

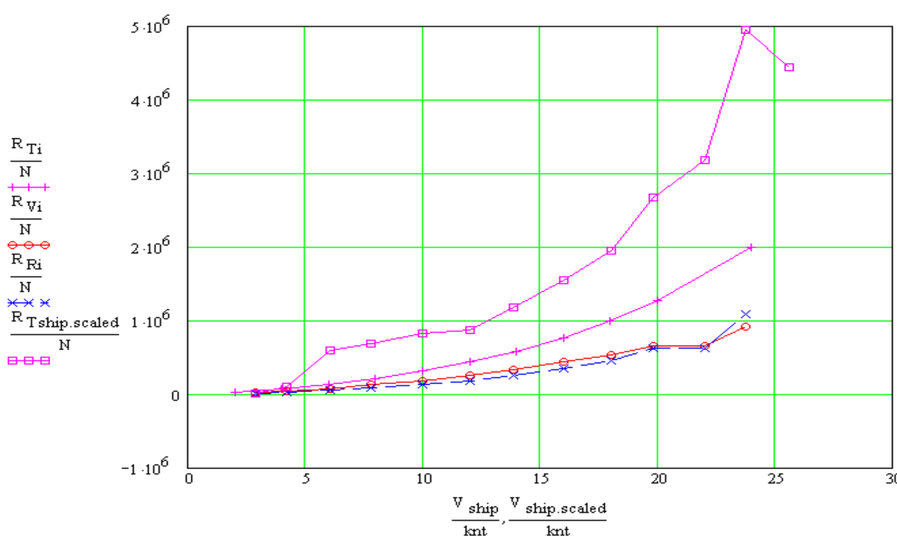


Figure 54. Resistance vs. Speed Curve

4.4.2 Propulsion

A five-bladed fixed-pitch propeller design is used. The largest practical propeller diameter (5m) is selected for maximum efficiency. The ANALYTIC2 method, based on empirical Gawn-series correlations of Levedahl, is used for the propeller performance calculations. Propeller calculations are shown in Figure 55 and Figure 56. Cavitation performance is predicted using the Keller criterion. The BAR for this propeller is equal to 0.94, greater than the minimum required to minimize cavitation at endurance speed (0.72).

$V_e := 20 \cdot knt$ $V_S := 20.64 \cdot knt$ $E := 4000nm$ $C_B := .667$ $Draft := 7.01 \cdot m$ $PMF_e := 1.1$ $PMF_S := 1.25$

$EHP_e := 14120 \cdot kW$ $KW_{24AVG} := 4569 \cdot kW$

Solution: $V := V_e$ $EHP := EHP_e$ $EHP = 1.412 \times 10^4 \, kW$

$w := 2 \cdot C_B^5 \cdot (1 - C_B) + .04$ $w = 0.128$ wake fraction

$V_A := V \cdot (1 - w)$ $V_A = 17.442 \, knt$ speed of advance - average wake velocity seen by prop

$t := .7 \cdot w + .06$ $t = 0.15$ thrust deduction fraction - prop changes pressure distribution around hull which effectively changes the resistance of towed hull

$T := \frac{EHP}{V \cdot (1 - t)}$ $T = 3.623 \times 10^5 \, lbf$

$\eta_H := \frac{1 - t}{1 - w}$ $\eta_H = 0.975$ hull efficiency = EHP/THP = $R_T V / T V_A$

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

$\eta_O := .691$ assume & iterate — open water efficiency = THP/DHPo

$\eta_B := \eta_O \cdot \eta_R$ $\eta_B = 0.691$ prop efficiency behind ship = THP/DHP

$\eta_D := \eta_H \cdot \eta_B$ $\eta_D = 0.674$ quasi-propulsive efficiency

$\eta_S := .99$ estimate — transmission efficiency (mechanical external to hull - stern tube and struts)

$\eta_P := \eta_S \cdot \eta_D$ $\eta_P = 0.667$ propulsive efficiency

$\eta_{elec} := .93$ estimate — mechanical transmission efficiency (inside hull)

$THP := \frac{EHP}{\eta_H}$ $THP = 1.942 \times 10^4 \, hp$

$DHP := \frac{THP}{\eta_B}$ $DHP = 2.81 \times 10^4 \, hp$ $DHP_O := \eta_R \cdot DHP$ $DHP_O = 2.81 \times 10^4 \, hp$

$SHP := \frac{DHP}{\eta_S}$ $SHP = 2.117 \times 10^4 \, kW$

$BHP_{ereq} := \frac{SHP}{\eta_{elec}}$ $BHP_{ereq} = 2.276 \times 10^4 \, kW$ for endurance fuel calculation

From propeller data: $PD := 1.20$ $BAR := 0.94$ $D := 5 \cdot m$ $Z := 5$ $N_{shaft} := 2$

$J_e := 0.925$ $K_T := 0.279$ $K_Q := 5.8$ $\eta_O := 0.691$ checks

$n_{eSHAFT} := \frac{V_A}{D \cdot J_e}$ $n_{eSHAFT} = 116.554 \frac{1}{min}$

$z := Draft - \frac{D}{2}$ $z = 4.51 \, m$ $z = 14.797 \, ft$

$p_v := 1750 \cdot \frac{newton}{m^2}$ $p_v = 0.254 \, psi$

$p_{atm} := 101400 \cdot \frac{newton}{m^2}$ $p_{atm} = 14.707 \, psi$

$p_0 := p_{atm} + \rho_{SW} \cdot g \cdot z$ $p_0 = 1.468 \times 10^5 \frac{newton}{m^2}$ $p_0 = 21.29 \, psi$

$BAR_{min} := \frac{(1.3 + .3 \cdot Z) \cdot \frac{T}{N_{shaft}}}{(p_0 - p_v) \cdot D^2} + .1$ $BAR_{min} = 0.72$

Figure 55. Endurance Propulsion Calculation

$$V := V_S \qquad V = 20.64\,\text{knt}$$

$$J_S := 0.93 \qquad n_{sSHAFT} := \frac{V_S \cdot (1 - w)}{D \cdot J_S} \qquad n_{sSHAFT} = 119.637\,\frac{1}{\text{min}} \qquad \eta_O := .67$$

$$EHP := 15735 \cdot kW \qquad EHP := \frac{PMF_S}{PMF_e} \cdot EHP \qquad EHP = 2.398 \times 10^4\,\text{hp}$$

$$T := \frac{EHP}{V \cdot (1 - t)} \qquad T = 4.446 \times 10^5\,\text{lbf} \qquad V_A := V \cdot (1 - w) \qquad V_A = 18\,\text{knt}$$

$$THP := \frac{EHP}{\eta_H} \qquad THP = 2.459 \times 10^4\,\text{hp}$$

$$\eta_B := \eta_O \cdot \eta_R \qquad \eta_B = 0.67$$

$$DHP := \frac{THP}{\eta_B} \qquad DHP = 3.67 \times 10^4\,\text{hp} \qquad DHP_O := \eta_R \cdot DHP \qquad DHP_O = 3.67 \times 10^4\,\text{hp}$$

$$SHP := \frac{DHP}{\eta_S} \qquad SHP = 2.764 \times 10^4\,\text{kW} \qquad \frac{SHP}{2} = 1.382 \times 10^4\,\text{kW} \quad \text{(power required for propulsion motors)}$$

$$BHP_{Sreq} := \frac{SHP}{\eta_{elec}} \qquad BHP_{Sreq} = 2.972 \times 10^4\,\text{kW}$$

Figure 56. Sustained Speed Propeller Calculations

4.4.3 Electrical Load Analysis (ELA)

Power requirements for SWBS groups 100 through 700 equipment and machinery are summarized in the Electric Load Analysis Summary, Table 35. Load factors are used to estimate the electric power requirement for each component in each of five operating conditions, including UCAV Launch, other aircraft operations, cruise, anchor, and in-port. The electric output of the ships propulsion engines and ship service diesel generators are also summarized for each operating condition. The complete ELA data is provided in Appendix D.3.

Table 35. Electric Load Analysis 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
250&260	Support	2473.6	908.4	908.4	908.4	285.4	290.2	27.8
300	Electric	1748.6	501.6	501.6	500.8	887.2	1008.2	819.5
310	Power Generation	1402.6	305.3	305.3	304.5	709.6	807.6	728.5
330	Lighting	346.0	196.3	196.3	196.3	177.6	200.6	91.0
400	C&S	830.8	699.1	699.1	681.0	61.4	211.4	364.6
410	C&C	74.0	56.8	56.8	50.8	6.9	49.4	38.0
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	158.0	79.0	79.0	79.0	47.4	47.4	47.4
450	Radar	311.0	311.0	311.0	311.0	0.0	3.0	224.0
460	UW Surveillance	10.5	8.4	8.4	5.1	0.0	1.1	0.0
470	Countermeasures	99.8	82.2	82.2	80.3	0.0	57.8	12.1
480	Fire Control	111.7	106.5	106.5	99.6	2.1	13.8	4.2
490	Special	19.3	19.3	19.3	19.3	0.0	19.3	0.0
500	Auxiliary Systems	69017.2	7999.8	7969.9	4974.8	4692.5	4836.7	823.9
510	HVAC	4688.5	3913.5	3913.5	3913.5	3796.0	3913.5	0.0
520	Seawater Systems	2613.5	257.6	257.6	257.6	166.1	192.0	718.7
530	Fresh Water Sys	664.8	598.3	598.3	598.3	586.1	586.1	0.0
540	Fuel Handling	435.3	113.4	113.4	113.4	105.7	105.7	97.2
550	Air and Gas	182.5	13.1	13.1	13.1	13.1	13.1	8.0
560	Ship Control	200.6	29.9	0.0	29.9	0.0	0.0	0.0
580	Mechanical	60076.0	3046.0	3046.0	21.0	0.0	0.0	0.0
584	Mechanical Doors	21.0	21.0	21.0	21.0	0.0	0.0	0.0
586	Aircraft Recovery	5.0	5.0	5.0	0.0	0.0	0.0	0.0
587	Aircraft Launch (EMALS)	60000.0	3000.0	3000.0	0.0	0.0	0.0	0.0
588	Blast Deflector	50.0	20.0	20.0	0.0	0.0	0.0	0.0
593	Environmental	155.9	28.0	28.0	28.0	25.5	26.3	0.0
600	Services	677.0	342.1	342.1	342.1	342.1	342.0	50.0
700	Armament	75.3	47.1	47.1	47.1	0.0	0.0	0.0
	Max Functional Load	75273.6	10498.1	10468.1	7454.1	6280.6	6696.5	2091.2
	MFL w/ Margins	82801.0	11547.9	11514.9	8199.6	6908.7	7366.2	2300.3
235	Elecric Propulsion Drive	29727.0	29727.0	29727.0	22760.0	0.0	0.0	0.0
	Total Load w/margins		41274.9	41241.9	30959.6	6908.7	7366.2	2300.3
	24 Hour Ship Service Average		7025.7	6211.7	4569.0	3908.6	3825.8	1295.3
Number	**Generator**	**Rating (kW)**	**UCAV Launch**	**Other Aircraft Ops**	**Cruise**	**Inport**	**Anchor**	**Emergency**
5	Diesel Generator, Main	7755.0	5	5	4	1	1	0
2	Diesel Generator, Aux.	2500.0	1	1	1	0	0	1
	Power Available (kW)		41275.0	41275.0	33520.0	7755.0	7755.0	2500.0

4.4.4 Endurance Fuel Calculation

An endurance fuel calculation is performed for the endurance range of 4000 nm at endurance speed in accordance with DDS 200-1. The endurance range was selected in concept exploration. The 24 hour average electric load is used to estimate the fuel required for ship service electrical power. The endurance fuel calculation is shown in Figure 57.

4.5 Mechanical and Electrical Systems

Mechanical and electrical systems are selected based on mission requirements, standard naval requirements for combat ships, and expert opinion. The Machinery Equipment List (MEL) of major mechanical and electrical systems for CUVX HI3 including quantities, dimensions, weights, and locations is included in Appendix D.2. The major components of the mechanical and electrical systems and the methods used to size them are described in the following two subsections. The arrangement of these systems is detailed in Section 4.9.

4.5.1 Integrated Power System (IPS)

Due to the Navy's commitment in all-electric ships and the potential synergy with electro-magnetic catapults, integrated power system options were considered for CUVX and selected for CUVX HI3. Solid-state power electronics devices utilizing programmable microprocessor based digital control, such as silicon controlled rectifiers, thyristors, and more recently, isolated gate bipolar transistors (IGBTs), make it possible to utilize fixed frequency alternating current generator sets supplying a common bus which feeds both propulsion and ship service loads. The application of fixed frequency AC input, variable voltage DC output propulsion motor drives became common in icebreakers, tugs and offshore supply vessels in the 1970's. In the early 1980's, fixed frequency AC input, variable frequency AC output propulsion motor drives began to be applied in icebreakers, ferries and passenger cruise vessels. It is this type of plant which has become increasingly popular in commercial and naval ships for both new construction and conversions, the most notable conversion being the 1987 re-powering of the Queen Elizabeth 2 from geared steam-turbine propulsion to AC diesel electric propulsion utilizing two 60,000 HP propulsion motors. Major cruise lines such as Carnival, Royal Caribbean and P&O Princess Cruise Lines are ordering increasingly larger ships with integrated AC electric propulsion plants.

Figure 58 shows the one-line diagram for CUVX propulsion and ship service power. CUVX's 5 main diesel engines (MGDs) and generators provide electrical power to the propulsion switchboards. The electric power distributed from the propulsion switchboards for propulsion is sent to propulsion power converters which control the speed of the ship by varying the frequency to the 2 propulsion motors. Each propulsion switchboard is connected to both propulsion motors for redundancy and survivability and the power converters have 3 parallel elements. The pulse power for EMALS is taken from a switch at the power converters.

To support the IPS power specified in the ELA, Table 35, the main diesel generator sets are rated at 7755 kW each. The propulsion motors are AMS A/C synchronous motors from ABB rated at 14000 kW each as specified in Section 4.4.2. This satisfies the power requirement with a 1.25 margin on CUVX HI3's shaft horsepower for sustained speed. There is one propulsion motor per shaft. Each MDG set provides 4160 volt, 3-phase, 60 Hz power to its main switchboard. The ADG sets provide 480 volt, 3-phase, 60 Hz power to separate ship service switchboards but this power may also be routed to the propulsion bus. The generator sets each have a generator control panel for local control, and may be automatically or manually started both locally and remotely from the EOS. Automatic paralleling and load sharing capability are provided for each set. The propulsion motors are capable of infinite speed control from 0 to full rpm. Two shafts may be operated at all times thereby eliminating the need for trailing a shaft during low speed operations. Each propulsion motor includes an integral thrust bearing; shaft lock; turning gear; and dual stator windings. Power to each propulsion motor is supplied from two 60 Hz fixed voltage and frequency input, variable voltage and frequency output, IGBT propulsion drives with associated isolation transformers. In addition, harmonic filters are provided for compliance with the ship service distribution system power quality requirements. The total efficiency of this electric propulsion system is estimated to be 93% at full power.

4.5.2 Service and Auxiliary Systems

Tanks for lube oil, fuel oil, and waste oil are sized based on requirements from the Ship Synthesis model. Fuel service tank requirements are based on a capacity to run for 18 hours. The pumps needed for fuel and lube oil service and transfer are based on similar ships. Where necessary, two pumps are installed, one for use and another for redundancy. These pumps are located either in the Main Machinery Rooms or the Auxiliary Machinery Room.

Endurance Fuel Calculation

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

Fuel Tankage

$lton := 2240 \cdot lbf$ $\quad \delta_F := 43.6 \cdot \frac{ft^3}{lton}$ $\quad \delta_{AF} := 42 \cdot \frac{ft^3}{lton}$ $\quad \delta_{LO} := 39 \cdot \frac{ft^3}{lton}$ $\quad \delta_W := 36 \cdot \frac{ft^3}{lton}$

Average endurance brake horsepower required with 10% margin for fouling and sea state:

$P_{eBAVG} := BHP_e$ $\quad P_{eBAVG} = 3.069 \cdot 10^4 \, hp$ $\quad E = 4 \cdot 10^3 \, nm$ $\quad V_e = 20 \, knt$

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: $FR_{SP} := f_1 \cdot SFC_{ePErated}$ $\quad FR_{SP} = 0.216 \, \frac{kg}{kW \cdot hr}$

Average fuel rate allowing for plant deterioration over 2 years: $FR_{AVG} := 1.05 \cdot FR_{SP} \cdot g$ $\quad FR_{AVG} = 2.264 \cdot 10^{-4} \, \frac{MT}{kW \cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e} \cdot P_{eBAVG} FR_{AVG}$ $\quad W_{BP} = 1.036 \cdot 10^3 \, MT$

Tailpipe allowance: $TPA := 0.95$

Required propulsion endurance fuel load (weight): $W_{FP} := \frac{W_{BP}}{TPA}$ $\quad W_{FP} = 1.091 \cdot 10^3 \, MT$

Required propulsion fuel tank volume (including allowance for expansion, 5%, and tank internal structure, 2%):

$V_{FP} := 1.02 \cdot 1.05 \cdot W_{FP} \cdot \delta_F$ $\quad V_{FP} = 1.42 \cdot 10^3 \, m^3$ (for 200 hours of propulsion - endurance range)

Average 24 hour electrical load for the ship service diesel generators

$KW_{24AVG} := 4569 \, kW$ $\quad N_{GENAVG} := 2$

$P_{GENAVG} := \frac{PMF_e \cdot KW_{24AVG}}{N_{GENAVG}}$ $\quad P_{GENAVG} = 3.37 \cdot 10^3 \, hp$ $\quad SFC_{GE} := 0.62 \cdot \frac{lbf}{hp \cdot hr}$ (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: $FR_{GAVG} := 1.05 \cdot FR_{GSP}$ $\quad FR_{GAVG} = 3.071 \cdot 10^{-4} \, \frac{MT}{hp \cdot hr}$

Burnable electrical endurance fuel weight: $W_{Be} := \frac{E}{V_e} \cdot KW_{24AVG} FR_{GAVG}$ $\quad W_{Be} = 376.329 \, MT$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $\quad W_{Fe} = 396.135 \, MT$

Required electrical fuel volume: $V_{Fe} := 1.02 \cdot 1.05 \cdot \delta_F \cdot W_{Fe}$ $\quad V_{Fe} = 515.526 \, m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $\quad W_{F41} = 1.487 \cdot 10^3 \, MT$

$V_F := V_{FP} + V_{Fe}$ $\quad V_F = 1.935 \cdot 10^3 \, m^3$ total tankage required for endurance speed and range with 24 average electrical load

$Hour := 8$ (number of hours of fuel required in tanks)

$$V_{FuelServiceTank} := \frac{V_{FP}}{\frac{200}{8}} + \frac{V_{Fe}}{\frac{24}{8}}$$

$V_{FuelServiceTank} = 228.632 \, m^3$ total required capacity for fuel service tank located in the MMR's

$\frac{V_{FuelServiceTank}}{3} = 76.211 \, m^3$ per tank (1 in each MMR)

Other Tanks

$N_T := 898$ $\quad N_A := 90$ (Total crew size and total accomodations) $\quad BAL_{TYP} := 1$

Aircraft fuel: $W_{F42} := 1503 \cdot MT$ $\quad V_{AF} := 1.02 \cdot 1.05 \cdot W_{F42} \cdot \delta_{AF}$ $\quad V_{AF} = 1.884 \cdot 10^3 \, m^3$

Lubrication oil: $W_{F46} := 17.6 \cdot lton$ $\quad V_{LO} := 1.02 \cdot 1.05 \cdot W_{F46} \cdot \delta_{LO}$ $\quad V_{LO} = 20.817 \, m^3$

Potable water: (Water does not expand). $W_{F52} := N_T \cdot 0.45 \cdot lton$ $\quad W_{F52} = 410.585 \, MT$

$V_W := 1.02 \cdot W_{F52} \cdot \delta_W$ $\quad V_W = 420.181 \, m^3$

Sewage: $V_{SEW} := (N_T + N_A) \cdot 2.005 \, ft^3$ $\quad V_{SEW} = 56.094 \, m^3$

Waste oil: $V_{WASTE} := 0.02 \cdot V_F$ $\quad V_{WASTE} = 38.705 \, m^3$

Clean ballast: (compensated ballast) $V_{BAL} := if(BAL_{TYP} = 1, 0.19 \cdot V_F, 0.275 \cdot V_F)$ $\quad V_{BAL} = 367.7 \, m^3$

Total tankage volume required: $V_{TK} := V_F + V_{AF} + V_{LO} + V_W + V_{SEW} + V_{WASTE} + V_{BAL}$ $\quad V_{TK} = 4.723 \cdot 10^3 \, m^3$

Figure 57. Endurance Fuel Calculation

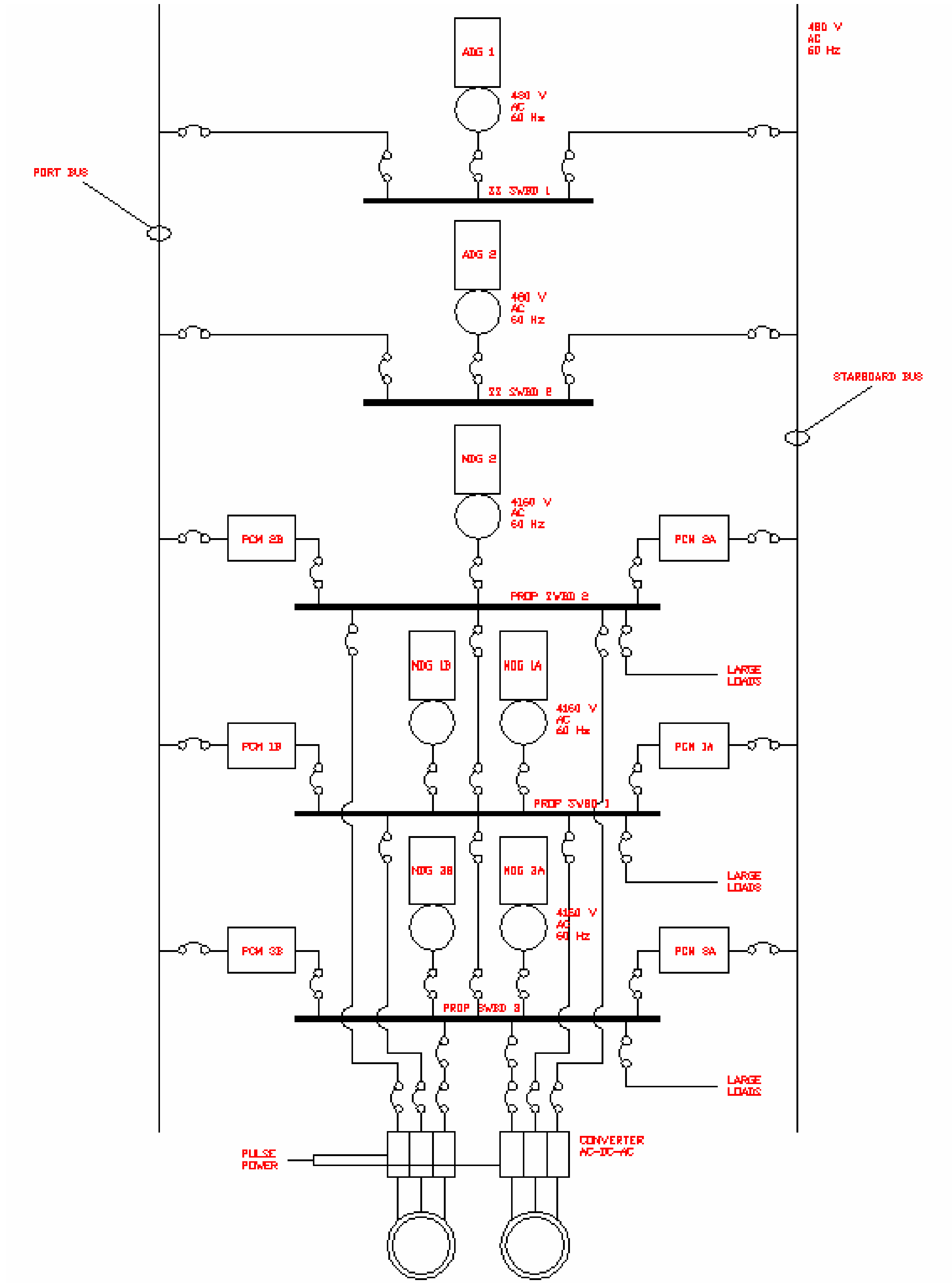


Figure 58. 1 Line Electrical Diagram

Fuel and lube oil purifiers are sized relative to the fuel and oil consumption of each engine. There are two purifiers per Main Machinery Room. One is for normal use and the other is for redundancy

Six distillers are used to produce potable water from seawater. Reverse osmosis distillers are used. They are located in the MMRs. They are sized based on 0.24 m^3 of water per man per day requirement. For CUVX HI3's 900 man crew, six 40 m^3 per day distillers were needed. Potable water pumps are used to pump water from the distillers to the potable water tanks.

Six air conditioning plants and two refrigeration plants are required for CUVX HI3. The air conditioning plants are sized based on crew size and arrangeable area, with 6 a/c plants at 450 tons each. The refrigeration plants are sized at 10 tons per 200 crew, so two refrigeration plants at 25 tons each were needed with 2 additional plants for redundancy. JP-5 pumps and filters are located in the JP-5 pump rooms located in MMR1 and MMR2

4.5.3 Ship Service Electrical Distribution

CUVX HI3 has an integrated power system (IPS) in which the ship service power is distributed from any of the five propulsion buses or SSDG's via a zonal bus, as shown in Figure 59. Power Control Modules (PCMs) are located in each zone to convert ship service power as required, provide circuit protection and automatic reconfiguration. They are able to convert AC to DC and DC to AC as required. Electric power may be taken from any of the 3 propulsion switchboards, one in each main machinery room or 2 ship service switchboards. Power from the main switchboards is converted from 4,160 volt, 3-phase, 60 Hz to ship service 480 volt, 3-phase, 60 Hz by power conversion modules supplying also the port and starboard ship service zonal buses. The SSDG buses are connected to the zonal buses but supply 480 volt, 3-phase, 60 Hz directly and do not need power conversion modules. Figure 59 shows the power takeoff from the zonal ship service buses to the vital and non-vital ship loads. The ship is divided into 10 CPS and Electrical Distribution Zones (Hangar Decks are a zone and AEM is another zone not pictured). Electric power is taken from the zonal buses in each zone through the power conversion modules. If there is a vital system in a zone it draws power from both the port and starboard buses through a power conversion module and an ABT which is an automated switch to either bus in case of power loss of one of the zonal buses.

Zonal systems are also used for the ship's fire system and Collective Protection System. Fire mains are located on the Damage Control Deck and fire pumps in each zone. CPS zones are separated by air locks with airlocks on all external accesses. The hangar decks are within CPS zones. Aircraft Elevators 1 and 3 both have external covers with the space between elevator and cover acting as an airlock and aircraft decontamination station. The unmanned launch deck serves as one large airlock with an external access door and internal door/jet blast deflector.

4.6 Aircraft Systems

4.6.1 Aircraft

There are 28 UCAVs carried on CUVX-HI3. The UCAVs chosen for this ship are designed by the Virginia Tech UCAV-N Design Team as described in Section 3.2.5.1. When the wings and tail of the UCAV are folded it has the dimensions of 9.2 m wingspan x 9.7 m long x 4.4 m high. The wings and tail are unfolded only when the plane is ready to launch. When the wings and tail are unfolded the wingspan increases to 13.7 m and length to 10.7 m. The aircraft has a weight of 12 MT. The maintenance facilities for these planes are located on Hangar Deck 3 with the ability to service two planes at a time. These aircraft are launched using the EMALS and recovered on the recovery deck. Fueling and weapons load-out take place on Hangar Deck 1.

CUVX-HI3 carries 18 UAVs. The UAVs selected for use on this ship are the Shadow 400. The Shadow 400 was selected because it a proven aircraft already in military use. These UAVs are stored in individual boxes with dimensions 3 m long x 1.5 m wide x 2 m high. When they are assembled these aircraft have the dimensions 3.8 m long x 5.1 m high x 2 m high. The assembly process for these aircraft will take place next to their storage areas on Hanger Deck 2. These aircraft will be fueled at the same fueling stations used for the UCAVs and launched using either of the EMALS. If for some reason the EMALS are down these aircraft have a compatible portable launching system approximately the size of a shipping container that can be used. These aircraft are recovered on the recovery deck in the same fashion as the UCAVs. This aircraft is shown in Figure 60.

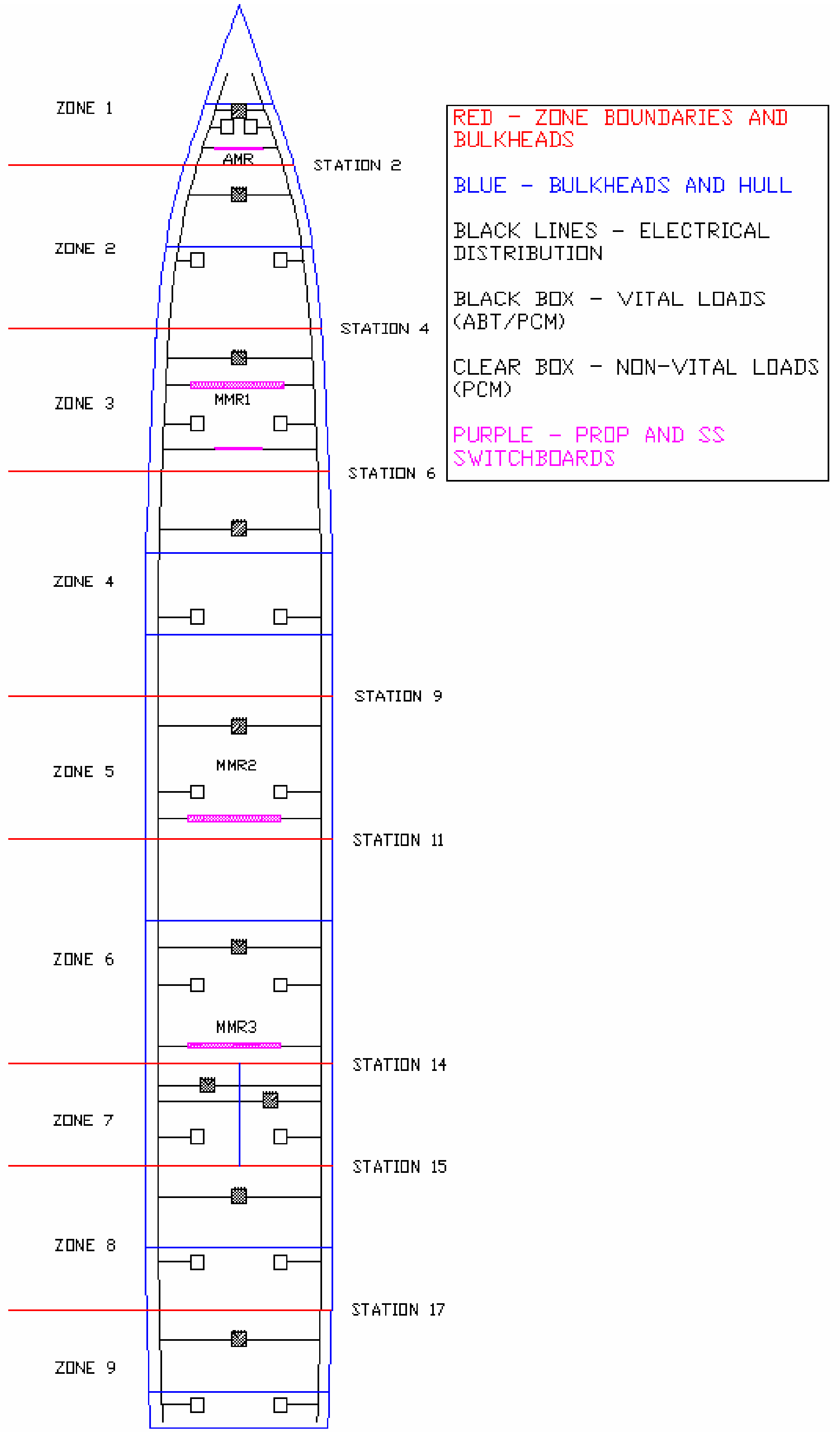


Figure 59. 1 Line Diagram Zonal Electric Power Distribution System (ZEDS)

Figure 60. Shadow 400 (UAV)

There are four LAMPS Helos on the CUVX-HI3 that are responsible for the ships ASW, ASuW, and MCM. While inside the ship the LAMPS rotor blades are folded giving the aircraft the dimensions 15.3 m long x 2.4 m wide x 3.8 m high. Before deployment the LAMPS are fueled and outfitted with weapons on Hanger Deck 1 in the same pit stop area as the UCAVs and UAVs. LAMPS are launched and recovered on the recovery deck.

Figure 61. LAMPS

4.6.2 Aircraft Elevators

There are three aircraft elevators on CUVX-HI3. Refer to Figure 32 and Section 4.1.5. The technical data for these elevators is estimated based on current aircraft elevator data supplied by Jered Inc. Sizes and weights are scaled to the dimensions of CUVX-HI3's elevators. Specifications for the three aircraft elevators and weapons elevators are listed in Table 36.

Table 36. Aircraft and Weapons Elevator Specifications

	Distance from FP	Distance from CL	Side	Size (m)	Weight	Capacity	Weight Capacity	Power Requirement	Cycle Time	Decks Serviced
E1	130.6 m	6.1 m	Stbd	18 long x 9 wide	48 MT	2 UCAV or 2 LAMPS or 2 UAV	32 MT	300 kW (Installed)	180 s	HD1 HD2 RD
E2	201.0 m	7.0 m	Stbd	16 long x 9.5 wide	48 MT	2 UCAV or 2 LAMPS or 2 UAV	32 MT	300 kW (Installed)	180 s	HD1 HD2 HD3
E3	204.5 m	5.8 m	Port	9 long x 9.5 wide	24 MT	1 UCAV (f) or 1 LAMPS	16 MT	150 kW (Installed)	90 s	HD1 RD
WE1	95.6 m	10.4 m	Stbd	4 x 4	10 MT	-	2.5 MT	50 kW (Installed)	-	HD2 Deck6 WM1
WE2	124.4 m	10.4 m	Stbd	4 x 4	10 MT	-	2.5 MT	50 kW (Installed)	-	Deck6 WM2
WE3	159 m	7.92 m	Stbd	4 x 4	10 MT	-	2.5 MT	50 kW (Installed)	-	HD1,2,3 WM3
WE4	128.0 m	9.7 m	Port	4 x 4	10 MT	-	2.5 MT	50 kW (Installed)	-	HD1,2,3 WM4

4.6.3 EMALS

Two Electro-Magnetic Aircraft Launching Systems (EMALS) are used for launching aircraft. The launch deck is fully automated and unmanned. Both the UCAVs and UAVs are launched using EMALS. This new technology replaces the standard steam driven catapults currently in use on CVNs. CUVX-HI3 has two EMALS positioned side-by-side and staggered on the launch deck. The EMALS are 75 meters (starboard) and 85 meters (port) long, 3 meters deep, 1 meter wide, and weighs approximately 220 MT. The 75 meter length is sufficient for the take-off requirements of VT UCAV-N and Shadow 400. The aircraft shuttle starts 1.5 meters from the beginning of the track. It is estimated that 30 MW of power will be required to launch a single UCAV and the cycle time between successive launches is around 45 seconds depending on the amount of cooling. The tracks are spaced at a 2 degree angle about the centerline and taper to 1.5 meters apart at the end. The machinery required for the system is located underneath the launch deck in the area above the pilot house. The control systems for EMALS are accessible from the pilot house, but located in a low profile enclosed control center situated on the port side of the launch deck. This allows the flight control operator to view launch operations while protected by an enclosed environment. One EMALS will be used as the primary launcher; the second system is available for redundancy. Figure 62 shows critical dimensions of the EMALS on the launch deck. Refer to Section 3.2.5.3 for additional information.

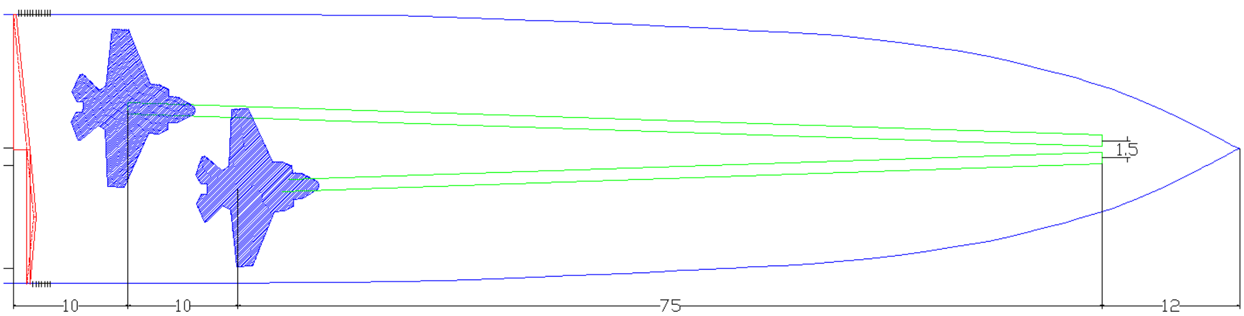


Figure 62. Dimensioned Launch Deck and EMALS

4.6.4 Jet Blast Deflectors

There is a jet blast deflector/door 10 meters aft of the launch ramp on the ship's launch deck that separates the launch deck from Hangar Deck 1. The port side of the deflector is a movable door that slides behind the starboard side of the deflector to allow aircraft through from Hangar Deck 1 out onto the launch deck. Both sides of the deflector are angled down and aft from the centerline to direct the exhaust from launch out the vented sides of the ship. The doors remain closed when there are no aircraft operations taking place, and must be closed before planes can be launched. The deflector has chilled water piped through it to dissipate the jet exhaust heat. It is estimated that this deflector will weigh 30 MT and will require 100 kW of power to open and close during aircraft launch operations. A rendering of the jet blast deflector is shown in Figure 63. Refer to Figure 62 for its location on the launch deck.

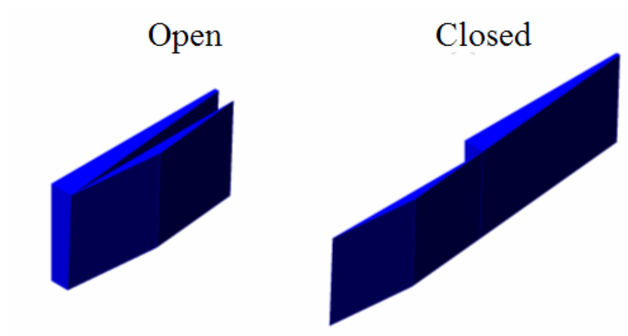


Figure 63. Jet Blast Deflector

4.6.5 Arresting Gear and Recovery Deck

Cable arresting gear is used to recover aircraft on the recovery deck. There are three cables in this system for the aircraft to catch, evenly spaced seven meters apart. The first arresting cable is 15 meters from the aft deck edge. Limitations in the length of the recovery deck limit the spacing between these cables to be closer than on CVN. However, the spacing is sufficient for the landing of precision computer-controlled aircraft with the lower landing speeds of VT-UCAV-N and Shadow 400. The cables have run-outs of 100, 93 and 86 meters. Figure 64 shows a dimensioned plan view of the recovery deck. The arresting gear machinery is located in the overhead of Hangar Deck 1 and weighs 76 MT. This system requires 500 kW of power during aircraft recovery operations. There are 6 meters of deck on each side of the aircraft's wheels on touchdown. There are no wingtip obstructions for 75% of the landing strip and a 1 meter starboard clearance for the last 25% due to the AEM/Deckhouse and aircraft parking. Table 37 compares CUVX and CVN recovery system dimensions. CUVX bolters would automatically clear to port.

Table 37. Recovery System Comparison

	CVN	CUVX
Minimum Landing Wingtip Clearance	3 m	Clear most of length; 1m end of recovery strip
Cable Run-Out	103.6 m	100 m
Cable Spacing	12 m	7 m

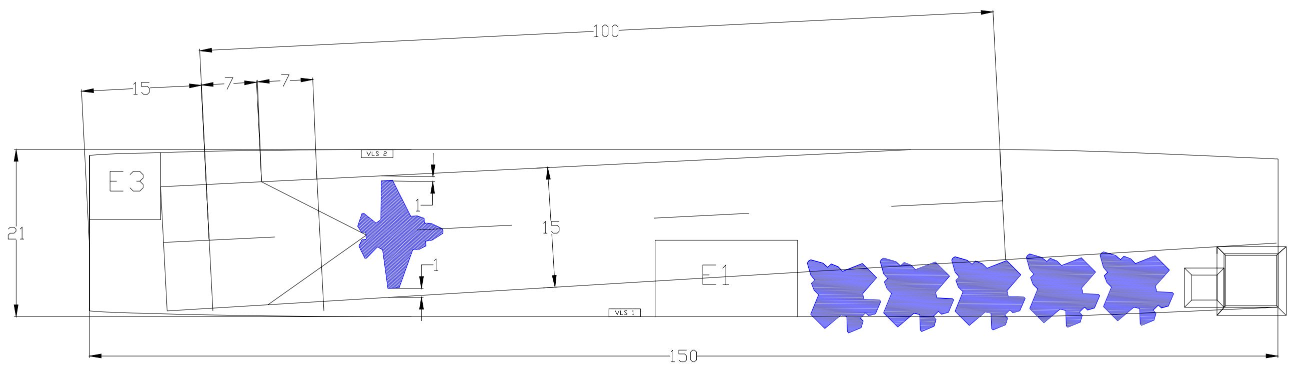


Figure 64. Recovery Deck with dimensions

4.6.6 Weapons Magazines

CUVX HI3 has a total weapons magazine volume of 8304 m^3 capable of holding 432.5 MT of munitions. The total magazine capacity is divided into four weapons magazines. These magazines are located separately for redundancy and survivability and so that their elevators are within proximity of the aircraft. All the weapons magazines are protected by the advanced double hull. Weapons Magazine 1 is the largest; it is 9 meters long and starts 90 meters aft of the forward perpendicular. This magazine, like all four magazines, spans the entire beam of the ship inside the double hull. It is 10 meters high, 2364 m^3 in volume, and is capable of storing 123 MT of munitions. Weapons Magazine 2 is the next largest magazine. This space is 12 meters long starting 99 meters aft of the forward perpendicular. It is 7 meters high, 2207 m^3 in volume, and is capable of storing 115 MT of munitions. Weapons Magazine 3 is the smallest of the four compartments. It is 12 meters long, 6 meters high, and starts 156 meters aft of the forward perpendicular. This magazine is 1824 m^3 in volume and can hold 95 MT of munitions. Weapons Magazine 4 is 12 meters long, 6 meters high, and starts 168 meters aft of the forward perpendicular. This magazine is 1909 m^3 in volume and can hold 99.5 MT of munitions. Weapons Magazines 1 and 2 (Group A) are loaded with the same munitions as Weapons Magazines 3 and 4 (Group B) for redundancy. Weapons are used incrementally from Group A and Group B so that either can support any combination of weapons load-out in the event of a weapons elevator malfunction. Figure 65 is a top view of the weapons magazines, highlighted in red.

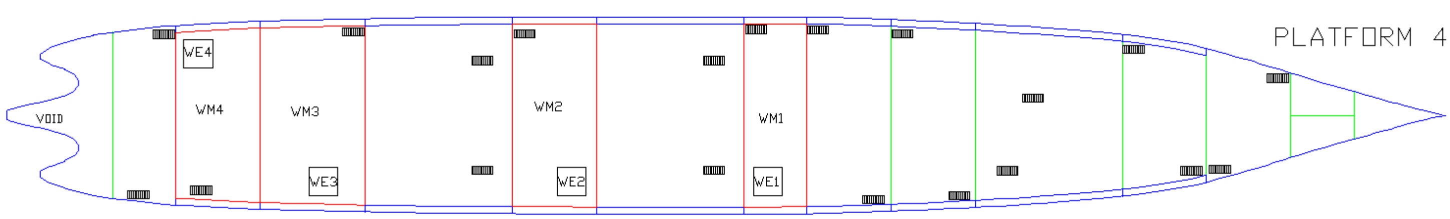


Figure 65. CUVX Plan View Showing Weapons Magazines

4.6.7 Weapons Elevators

Each weapons magazine is serviced by a separate weapons elevator. Weapons elevators deliver weapons from the magazines up to Hangar Decks 1, 2, or 3. Aircraft weapons are loaded into the aircraft on Hangar Deck 1. Only Weapons Elevators 3 and 4 go directly from the magazines up to Hangar Deck 1. The weapons stop at Hangar Deck 3 for assembly before continuing up to Hangar Deck 1. Weapons Elevator 1 goes only as high as Hangar Deck 2 where the weapons have are unloaded, assembled and carted back to Weapons Elevator 3 or 4 to be transported to Hangar Deck 1. Weapons Elevator 2 stops on Hangar Deck 3 where the weapons are unloaded, moved forward to Weapons Elevator 1, moved up to Hangar Deck 2, assembled, and then moved up to Hangar Deck 1 on Weapons Elevator 3 or 4. This staggered elevator shaft system improves ship survivability by avoiding a vertical shaft from Hangar Deck 1 to the magazine. A summary of the weapons elevator specifications is given in Table 36. Figure 66 shows the flow of weapons from magazine to weapons loading; the green arrows are for unassembled weapons and the red arrows are for assembled weapons.

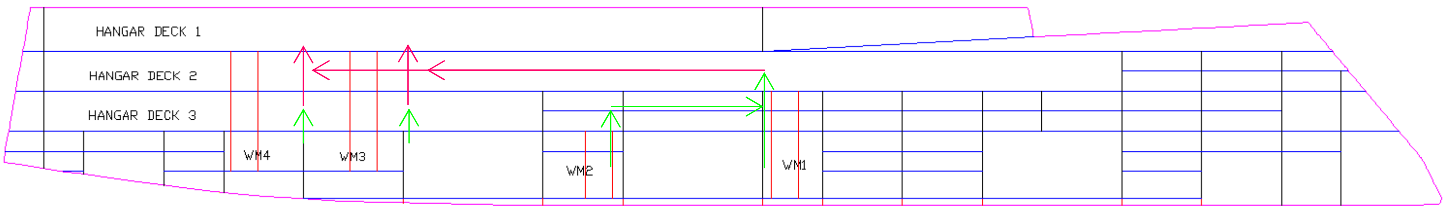


Figure 66. CUVX Profile Showing Weapons Flow

4.6.8 Sortie Rate

Sortie rates for CUVX HI3 are determined primarily by 3 operations: fueling and weapons loading, launching, and recovery. Fueling and weapons loading occurs on Hangar Deck 1. The time required to service four aircraft is dependant on the fuel and weapons needed for a particular mission. A maximum of 45 minutes is estimated. Two aircraft are then hooked up to a track behind the blast deflector door to pull and connect them to the EMALS. This will take five minutes for each aircraft. Total time to service four aircraft and prep for launch takes 65 minutes. Launching consists of opening the blast deflector door, bringing two aircraft through and into the ready position (5 minutes), and closing the door. The blast deflector door takes 10 minutes to open and close. The starboard EMALS launches immediately and 2 minutes later the port EMALS launches. Total time to launch two aircraft takes 17 minutes. Recovery takes 3 minutes for one aircraft to land, unhook, and clear the landing strip, while the arresting gear retracts. Six aircraft can land before needing to clear the deck. Three aircraft are taken down in Elevators 1 and 3 at a time. The greatest cycle time is 180 seconds (3 minutes) for Elevator 1 without decontamination. It takes 10 minutes to load and offload the elevator. The recovery deck can be cleared in 26 minutes. Total time to recover 6 aircraft takes 32 minutes. The sortie rates are summarized in Table 38.

Table 38. Sortie Rate Summary

Sortie	Aircraft/Hour
Service	4
Launch	8
Recovery	12

4.7 Combat Systems

The Mission Need Statement (Appendix A) requires CUVX-HI3 to be capable of operating independently n littoral warfare environments. For this reason, CUVX-HI3 must be passively defensive. CUVX HI3 must avoid detection whenever possible, and when detected must be able to defend itself against the threat. Many of the combat system sensors require an elevated position to detect targets. These sensors, because of their intrinsic radar signature, are housed in a special low AEM/deckhouse. Refer to Section 3.2.6 for information on the combat systems and 4.2 for a description of the AEM/deckhouse. Drawing D5 shows the CUVX HI3 topside arrangement with topside combat systems and sensors.

4.8 Manning

An important goal for CUVX is to reduce manning by 85% from current CVN carriers (including its airwing) by utilizing automation and unmanned aircraft. CUVX-HI3 has a crew of 898 men. This is 15.8% of CVN76 manning. The use of unmanned aircraft is a significant factor in this reduction. CUVX original manning estimates were made using the ship synthesis model. These estimates were based on ship and aviation scaling factors for the size of the ship, number of propulsion systems, and ship displacement. These estimates were further refined by comparison to the manning of other naval ships. The total manning is allocated by department and resized based on the CUVX unique mission and by analogy with other ships. Aviation is the most manning intensive department on CUVX-HI3. Watch Condition I (General Quarters) is the most manning intensive watch requirement.

4.8.1 Aviation Department

A number of automated systems are introduced for aircraft handling. This automation reduces manning associated with the movement of aircraft, EMALS hook-up, signalmen, and recovery handling. The aircraft within the hangar decks, on the recovery deck, or on the launch deck are handled by robotic tractors. Men previously needed to operate tractor equipment are no longer necessary. Aircraft elevators are manned by 1 person. There are **303** enlisted men and **19** officers in the aviation department in four divisions on CUVX:

The first division is responsible for aircraft weapons handling. Automation eliminates many jobs in this division; however there are still jobs that require men. The weapons need to be unloaded from their casings, assembled, transported to the waiting aircraft, armed, and loaded. There are **117** enlisted men and **3** officers designated for this division.

The second division is responsible for EMALS and arresting gear operations. This division will only be fully active during emergency situations when the catapults and arresting gear are in constant use; at other times these men will be working in other divisions of the aviation department. There are **48** enlisted men and **3** officers designated for this division.

The third division is responsible for handling aircraft in the hangar bays and on the flight and recovery decks. These men monitor and control the flow patterns of incoming and outgoing aircraft within the ship and the movement of aircraft on the launch and recovery decks. Automated tractors reduce the number of men needed to physically move the aircraft. There are **75** enlisted men and **3** officers designated for this division.

The fourth division is responsible for aircraft fueling. This division is continuously busy refueling UCAVs, LAMPS, and UAVs. The idea of automated fueling was considered, but it is currently to risky for actual operation. Therefore, this division has 5**9** enlisted men and **2** officers.

There are 4 aircrews, one for each LAMPS. Each consists of 2 officers and 1 enlisted. The pilot and copilot are both officers, and the systems operator is enlisted. These 12 crewmen make up the rest of the officers and enlisted in the aviation department.

4.8.2 Weapons Department

The weapons department is responsible for the assembly, loading, and transportation of shipboard weapons to their place of use, weapons maintenance, and some specialized weapons use. The weapons department is also required to organize, maintain, and oversee the supply of all weapons magazines. This department also issues ammunition from the ships arsenal. During normal cruise conditions this department stands watch 8 hours per day on average. There are **6** officers and **40** enlisted in this department.

4.8.3 Deck Department

The Deck department is responsible for line handling, anchoring, life boat maintenance, topside maintenance, and helmsmen. Line handling and anchoring occur only when the ship is in port. Most men are assigned to maintenance work and switched to line handling and anchoring as needed. There are 3 to 4 enlisted helmsmen who alternate watches. There are **8** officers and **100** enlisted men assigned to this department.

4.8.4 Engineering Department

The engineering department is responsible for operating and maintaining the five Colt-Pielstic Main Diesel Engines, their support systems, the two CAT 3608 Ship Service Diesel Generators, all of their support systems, the electrical systems of the ship, aircraft elevators, weapons elevators, and most other major mechanical or electrical equipment on the ship. This department has **198** enlisted men and **12** officers assigned.

This department consists of five divisions: Main Propulsion, Ship Service, Electrical, Auxiliary, and Damage Control. The Main Propulsion division is responsible for maintenance and repair of the main propulsion engines and their support systems. This division consists of 68 enlisted and 4 officers. The Ship Service division is responsible for the care of the ship service diesel generators and their support systems. This division consists of 40 enlisted and 3 officers. The Electrical division is responsible for all of the ships electrical systems. This division includes 50 enlisted and 3 officers. Finally the Auxiliary division is in charge of major auxiliary equipment including aircraft and weapons elevators, motorized doors and hatches, pumps, and damage control equipment. This division is assigned 40 enlisted and 2 officers.

4.8.5 Operations Department

The operations department is responsible for sensor and combat systems, radio operations, communications, watch standing, and the maintenance of electronic and communication equipment. This department is mainly comprised of Operations Specialists and Electronics Technicians. Operations Specialists are required to interpret the electronic output of the systems and relay any important information gathered. The Electrical Technicians maintain electronics equipment. The men operating the electronics equipment stand 8 hours of watch per day during normal cruise conditions. During times of heightened readiness, watch standing may be increased to 12 hours per day. This department is assigned **60** enlisted and **8** officers.

4.8.6 Supply Department

The supply department is responsible for ordering, receiving, organizing, and storing food, spare parts, equipment and other material. They are also responsible for food preparation, including cooking, cleaning, beverages, and inventory. These men are in charge of the ships laundry, retail, tailoring, and dry cleaning. They man the ships store, barbershop, and postal service and they are responsible for distributing pay. This department is assigned 95 enlisted and 8 officers.

4.8.7 Medical Department

Because of the projected littoral environment that CUVX-HI3 will be operating in and the fact that it carries LAMPS capable of rescuing people injured in combat, this ship could act as a small temporary medical facility. For this reason the Medical department is slightly oversized on CUVX-HI3 in comparison with other ships of this size. The medical department is assigned 2 doctors, 20 corpsmen, and one dentist.

4.8.8 Navigation Department

The navigation department is responsible for navigating and meteorology. Navigation watches will require three men working 8 hour days at each position. This department is assigned 5 enlisted and 1 officer.

4.8.9 Administration Department

The administration department maintains personnel records and manages. The Executive Officer (XO) is included in this department. His job is to make sure that all departments are running smoothly and efficiently on the ship. This department is assigned 10 enlisted and 2 officers including the XO.

The total number of enlisted men and officers on CUVX-HI3 are summarized in Table 39. Figure 67 illustrates the allocation of personnel to each department.

Table 39. Manning Summary Table

	Number of Officers	Percentage of Officers	Number of Enlisted	Percentage of Enlisted	Total Number	Total Percentage
Aviation	19	28.3 %	303	36.5 %	322	35.9 %
Weapons	6	8.9 %	40	4.8 %	46	5.1 %
Deck	8	11.9 %	100	12.0 %	108	12.0 %
Engineering	12	17.9 %	198	23.8 %	210	23.4 %
Operations	8	11.9 %	60	7.2 %	67	7.5 %
Supply	8	11.9 %	95	11.4 %	97	11.5 %
Medical	3	4.5 %	20	2.4 %	25	2.6 %
Navigation	1	1.5 %	5	0.6 %	15	0.67 %
Administration	2	2.9 %	10	1.2 %	20	1.3 %
Total	67		831		898	

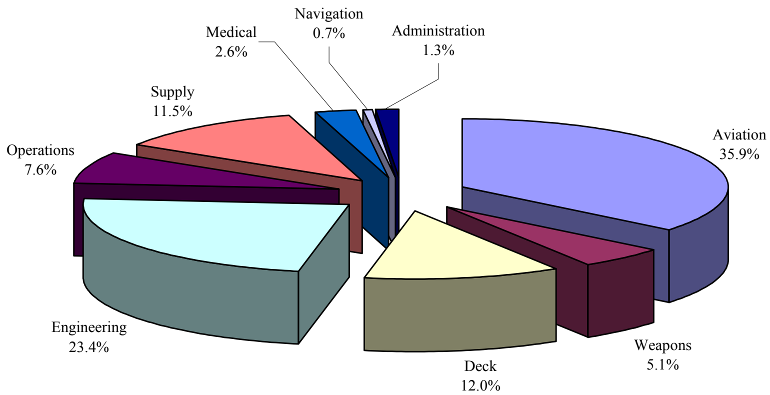


Figure 67. Total Manning Distribution by Department

4.9 Space and Arrangements

HECSALV and AutoCAD are used to generate and assess the subdivision and arrangements of CUVX-HI3. HECSALV is used for subdivision, tank arrangements and loading. AutoCAD is used to construct 2-D models of the inboard and outboard profiles, deck and platform plans, detailed drawings of the berthing, sanitary, and mess rooms, and a 3-D model of the ship. A profile of CUVX-HI3 showing the internal arrangements is shown in Figure 68 and in Drawing D3. Primary transverse subdivision is based on stack-up length and damage stability requirements, initially using the floodable length curve, Figure 40.

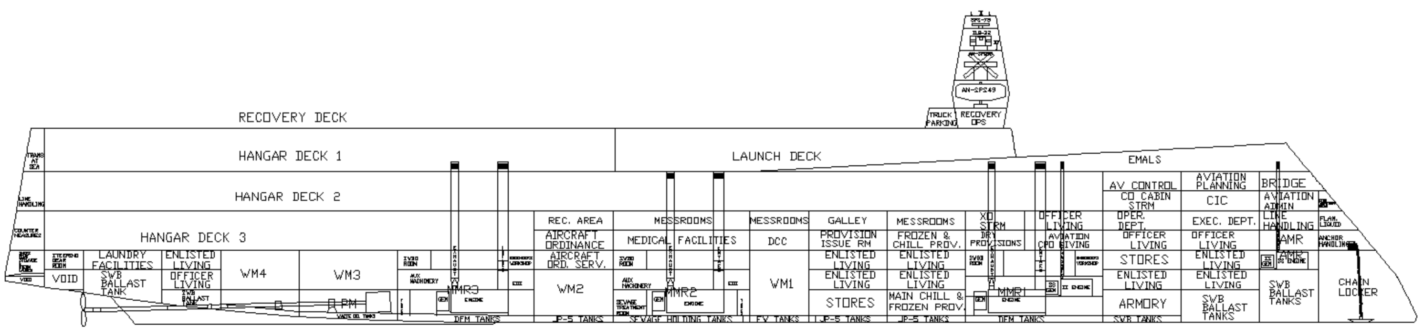


Figure 68. Profile View Showing Arrangements

4.9.1 Space

Initial space requirements and availability in the ship are determined in the ship synthesis model (Appendix D.1 CUVX Ship Synthesis Model). Parameters output by the ship synthesis model are as follows: the machinery box height, length, width, and volumes, and volumes of the waste oil, lube oil, potable water, sewage, aircraft fuel, clean ballast, and propulsion fuel. These are shown in Table 40. Given the volumes and hull form, tanks are arranged in HECSALV. Lightship weight, load cases, and ballast locations are coordinated with weight and stability analysis for proper placement. Complete space and volume data are shown in Appendix D.5.

Table 40. Required, Available, Actual Space Variables from Ship Synthesis Model

Variable	Required	Actual
Machinery Box Height	7.59 m	10 m
Machinery Box Length	16.36 m	21 m
Machinery Box Width	17.94 m	24.01 m
Machinery Box Volume	1.113×10^4 m^3	1.329×10^4 m^3
Waste Oil	37.793 m^3	40.0 m^3
Lube Oil	20.82 m^3	20.82 m^3
Potable Water	420.18 m^3	438.0 m^3
Sewage	56.09 m^3	58.0 m^3
Aircraft Fuel	1884.0 m^3	1962.0 m^3
Clean Ballast	359.04 m^3	2786.0 m^3
Propulsion Fuel	1572.0 m^3	2014.0 m^3

CUVX-HI3 has five decks and six platforms, accommodating 898 total personnel: 831 enlisted crew and 67 officers. The decks and platforms are divided into the following areas: human support, machinery, weapons storage, ship support, mission support, and hangar. HD1 is the main deck and the Recovery Deck is the 01 level. Deck 3 is the Damage Control Deck. Details of each deck and platform are discussed in Section 4.9.3.

4.9.2 Main and Auxiliary Machinery Spaces and Machinery Arrangement

The primary propulsion, auxiliary, and electrical machinery are arranged in six compartments. There are three main machinery rooms, MMR1, MMR2, and MMR3, one auxiliary machinery room, AMR, and two propulsion motor rooms, MPM1 and 2 separated by a centerline bulkhead. Details are shown in Drawings D2.

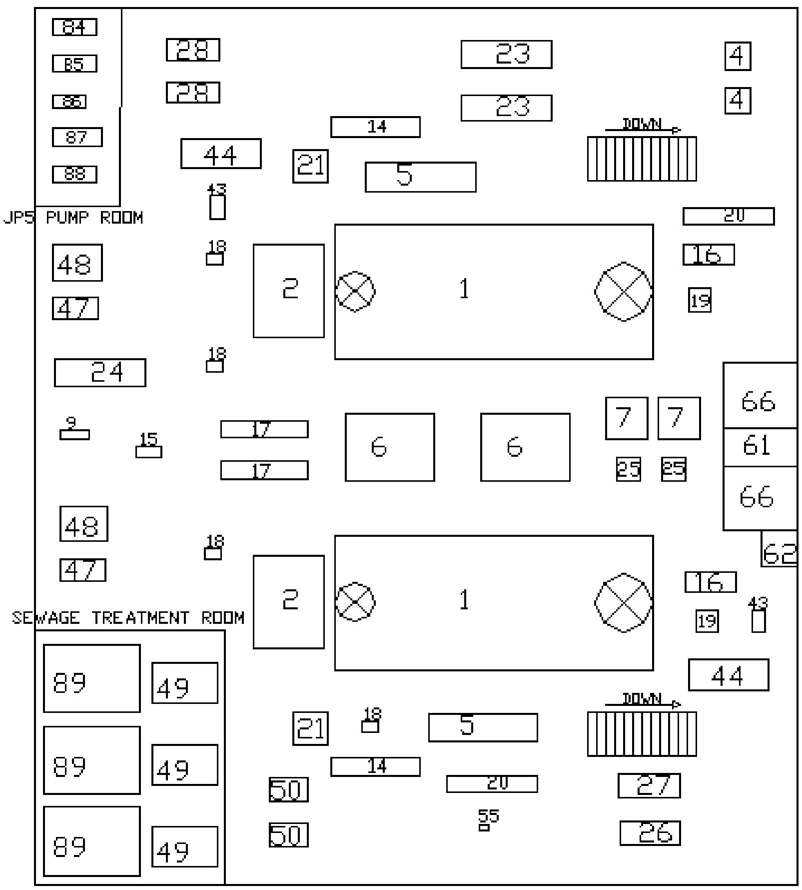
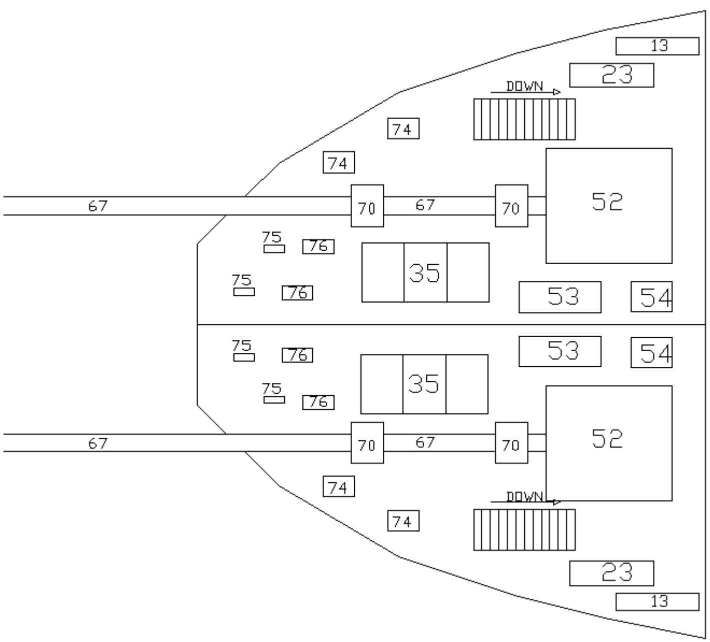


Figure 69. MMR2 Lower Level Machinery Arrangement

No.	Equipment	Capacity
1	Diesel Engine	
2	Generator	7755 kW, 6600V, 60 Hz
4	FW Cooling Pump	600 m^3/hr @ 4bar
5	FW Cooler	
6	Seawater strainer	
7	Main SW Circ Pump	
9	LO Feed Pump	
13	Prop Motor control	
14	Motor control	
15	Fuel Service Pump	
16	LO Service Pump	
17	Lube oil cooler	
18	Lube oil strainer	
19	HT FW cooling pmp	
20	MDG FW preheater	
21	Generator control	
23	Fire pump	2000 gpm @ 9 bar
24	Fire and ballast pump	2000 gpm @ 9 bar
25	Aux SW pump	1000 gpm @ 3 bar
26	Bilge pump	1000 gpm @ 3.8 bar
27	Bilge/ballast pump	1000 gpm @ 3.8 bar
28	Fuel transfer pump	200 gpm @ 4.2 bar
44	MDG lube oil filter	
47	Oily waste pump	100 gpm @ 7.6 bar
48	Oil/water separator	20 gpm
49	Sewage treatment	
50	Waste water pump	250 gpm @ 2.4 bar
55	Oil content monitor	15 ppm
61	LO storage tank	6.39 m^3
62	LO settling tank	1.52 m^3
66	Fuel service tank	21 m^3
84	JP-5 transfer pump	
85	JP-5 service pump	
86	JP-5 stripping pump	
87	JP-5 filter/separator	
88	JP-5 filter/separator	
89	Sewage treatment	

Figure 69 shows lower level machinery arrangements in MMR2. The complete machinery arrangement and MEL is in Drawing D2 and Appendix D.2. The location of components is based on ship stability, functionality, producibility, and survivability. Most equipment is arranged evenly about the centerline, with one component on the port side of the ship and a second similar component on the starboard side. Components near bulkheads have a minimum clearance of 0.5 meters. The spaces are arranged with the main engines and generators placed first on the lowest level of each machinery room about the centerline with 4.8 meters between them for maintenance accessibility and 4 meters from the forward transverse bulkhead. In MMR1 there is 1 power generation module (PGM) including diesel engine, generator, generator lube system, engine fuel system, start air system, fire suppression system, bus switchgear, sub base, seawater cooling system, engine lube system, and 1 auxiliary diesel. These are arranged to balance the ship, longitudinally and transversely. The day tanks and settling tanks are arranged along the bulkhead in the lowest level. The sewage treatment machinery and JP-5 system are placed in separate rooms within the main machinery rooms on the lowest level for safety and sanitation. Next the pumps and ladders are arranged on the lowest level in the remaining space with necessary room around each for producibility and maintenance. The seawater strainers are placed on the lowest flat in between the engines. Most of the large auxiliary machinery is placed on the 1st platform. This includes air conditioning plants, refrigeration plants, distillers, brominators, and their associated equipment. These are arranged around the opening for the engines and ladders along with an engineer's operating station and purifier equipment. The purifier equipment is also placed inside a separate room for safety. Sensitive equipment such as switchboards and power conversion modules are located on the 2nd platform away from the bilge. Also on the 2nd platform are machinery room ventilation fans. MMR2 and MMR3 are arranged in a similar manner. (Auxiliary engines and generators are located on the 1st platform of MMR1 and the auxiliary machinery room.)

Figure 70 shows the general machinery arrangements in the propulsion motor rooms (PMR1 and PMR2). Drawing D2 shows a complete profile and plan view of PM1 and PM2. The PMRs are separated by a centerline bulkhead for survivability in the case that one side takes a hit or floods (with care taken to check for the effect of off-center flooding). The motors are arranged as close to the forward bulkhead as clearance restrictions allow. This keeps the shaft angle less than 2 degrees. The propulsion power converters are arranged close to the motors. Each consists of 3 parallel units, one for each propulsion power bus. The motor control and exciter units are placed near the motors and support equipment is arranged in the remaining space.



No.	Equipment	Capacity
13	Local Control Panel	
23	Fire Pump	2000 gpm @ 9 bar
35	Power Converter	3 x 5000 kW
52	Propulsion Motor	14000 kW @ 117 rpm
53	Motor Control	
54	Motor Exciter	
67	Propulsion (Line) Shaft	520 mm diameter
70	Line Shaft Bearing	
74	Strut and Stern Tube Lube Oil Pump	1.1 m^3/hr @ 2 bar
75	Lube Oil Cooler	1.1 m^3/hr
76	Lube Oil Filter	1.1 m^3/hr

Figure 70. Propulsion Motor Room Machinery Arrangements

4.9.3 Internal Arrangements

Six space classifications are considered in the internal arrangements: hangar space, machinery rooms, weapons magazines, human support, ship support, and mission support. Area and volume estimates for these spaces were initially taken from the ship synthesis model and refined in the process of arranging the ship. The arrangements are shown in drawings D3, D4, D5.

Hangar decks require the largest area in the ship. The upper three decks of the ship are used primarily for aircraft operations. These decks are located to most easily service, recover and launch aircraft. Hangar deck areas are used to service, store, and prepare aircraft for missions. Hangar decks are interconnected by three aircraft elevators and four weapons elevators. Multiple elevators are used to provide redundancy.

Machinery rooms are located on the lowest deck of the ship enclosed by the ADH and sized for the ships mechanical and electrical systems. Three main machinery rooms and one auxiliary machinery room contain the diesel propulsion engines and ship service generators. Other mechanical and electrical systems including air conditioning, distillers, firemain, etc., are fit in remaining space. These machinery rooms are spaced as evenly as possible about the LCB to aid in balancing the ship and as far apart as possible for survivability. These rooms are positioned as low as possible for overall ship stability. The intake and exhaust ducts for each machinery room exit the side of the ship just below the recovery deck. The intake and exhaust locations are chosen to minimize the area lost to ducting through the ship.

CUVX-HI3 has four weapons magazines located on the lowest deck of the ship enclosed by the ADH. The magazines store the aircraft weapons and ship weapons. Each magazine spans the breadth of the ship within the ADH to meet volume requirements. The magazines are separated by the main machinery rooms and are staggered along the length of the ship for better ship survivability.

Living area requirements are estimated based on crew size using the ship synthesis model. The model estimates areas for enlisted living, officer living, mess areas, and human support facilities. Living areas are located primarily in the forward half of the ship and placed in close proximity to messing spaces and other human support spaces to simplify the flow of day-to-day traffic. Some enlisted and officer berthing is located aft for separation and survivability.

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

Mission Support areas are primarily in the forward part of the ship where the command and control operations take place. These areas include the pilothouse, flight operations control, and CIC.

All tankage for CUVX-HI3 is located in the ADH. Having the tankage in the ADH puts the weight associated with the ships fuel, oil, etc., as low as possible, which helps the stability and seakeeping of the ship. Table 40 lists the required and actual tankage for CUVX-HI3. Propulsion fuel tanks are located in the ADH sections surrounding the machinery rooms for easier transfer of fuel to the engines. Ballast tanks are placed in the extreme fore and aft of the ship. This requires less volume to correct trim or heel conditions.

Main passageways are located against the hull and run longitudinally from the bow of the ship to the hangar decks. This provides a buffer space near the hull to reduce personnel casualties and damage in the event of a weapons strike. Secondary passageways run transversely through the ship and are positioned just behind the watertight bulkheads. Passageways are only required above the damage control deck. Main Passageways are 2 meters wide and secondary passageways are 1.2 meters wide. All main passageways have watertight doors located at the watertight bulkheads. Below the damage control deck there is no longitudinal access to compartments. Ladders provide vertical access through watertight hatches to the damage control deck and the main passageways. Main passageways can be seen on the third deck in Figure 71 and Drawing D4.

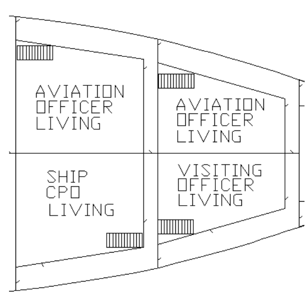


Figure 71. Main and Secondary Passageways on Third Deck

4.9.4 External Arrangements

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

The AEM is positioned at the forward starboard end of the recovery deck. This location was selected to keep the stern of the ship open for incoming aircraft to land. It is positioned on the starboard edge to allow clearance for boltering aircraft to continue off the port side. The lower portion of the AEM is angled out at ten degrees to minimize its footprint, saving area on the recovery deck.

The VLS tubes are located on the recovery deck with four tubes on the starboard side and four on the port side for redundancy. The port side tubes are positioned further aft than the starboard tubes. Refer to Section 4.7 for arrangements of topside sensors and antennas and to Section 4.6.5 for Recovery Deck arrangements.

4.10 Weights and Loading

4.10.1 Weights

Ship weights are grouped by SWBS number. Weights were obtained from manufacturer information, when possible, and from ASSET parametrics. Weight values calculated by the ship synthesis model are used when no other values are available. LCGs, TCGs and VCGs for each weight were estimated from machinery and ship arrangements. These centers were used to find moments and the lightship COG. A summary of lightship weights and centers of gravity by SWBS group is listed in Table 41. Weights grouped by SWBS number with centers of gravity are listed in Appendix D.4.

Table 41. Lightship Weight Summary

SWBS Group	Weight (MT)	VCG (m-BL)	LCG (m-FP)	TCG (m-CL)
100	13445	11.29	115.26	0.02
200	2179	4.48	118.02	-0.68
300	835	14.24	58.40	0.23
400	335	17.47	85.73	4.46
500	3433	13.75	99.99	-0.61
600	1870	14.14	60.35	1.00
700	43	24.19	80.00	-10.00
Margin	2252	10.77	105.56	0.00
Total	24393	11.41	105.70	0.00

Figure 72 shows the lightship weight distribution curve. It is used with the following loading conditions to calculate still water bending moment.

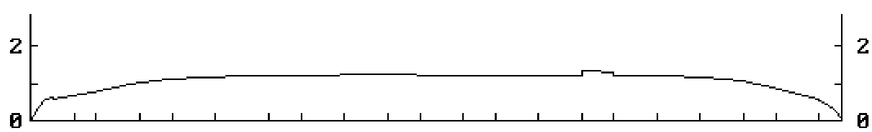


Figure 72. Lightship Weight Distribution for CUVX-HI3 (100MT/m)

4.10.2 Loading Conditions

Two loading conditions are considered for CUVX: Full Load and Minimum Operating (Minop) as defined in DDS 079-1. The centers of gravity for the two loading conditions are calculated using the lightship weight and center and loads weights and centers. Weights for the Full Load condition are estimated with all fuel oil and potable water tanks filled to 95% and full provisions, general stores, and weapons. The Minimum Operating condition assumes that all fuel, stores, and weapons are at 33% of their full load capacity, and that potable water tanks are 66% full. Compensated fuel ballast is included in this condition. The full airwing and the total weight for the crew are used in both conditions. A summary of the weights for the Full Load condition is provided in Table 42, and a summary for the Minimum Operating condition is provided in Table 43.

4.11 Hydrostatics and Stability

To assess the hydrostatics, intact stability, and damage stability of CUVX-HI3, ship offsets are imported into HECSALV. Hydrostatics are calculated using a range of drafts from 0 to 29 meters. From this information, the curves of form, coefficients of form and cross curves are calculated. Using the data obtained from these calculations, intact stability is calculated in the two loading conditions. The ballast tanks are filled for correct trim and heel. With intact load conditions created and balanced, intact stability and damage stability are examined.

Table 42. Weight Summary: Full Load Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship	24392	11.41	105.7
Ships Force	101	15.98	105.00
Total Weapons Loads	832	16.65	105.00
Aircraft	360	17.00	105.00
Provisions	268	11.43	110.00
General Stores	82	11.35	110.00
Diesel Fuel Marine	1421	2.37	105.08
JP-5	1428	3.24	95.17
Lubricating Oil	17	2.00	150.00
SW Ballast	19	4.89	88.54
Fresh Water	411	2.95	94.49
Total	29332	10.68	105.03

Table 43. Weight Summary: Minop Condition

Item	Weight (MT)	VCG (m-BL)	LCG (m-FP)
Lightship	24392	11.41	105.7
Ships Force	101	15.98	105.00
Total Weapons Loads	275	16.65	105.00
Aircraft	360	17.00	105.00
Provisions	89	11.43	110.00
General Stores	27	11.35	110.00
Diesel Fuel Marine	469	2.37	105.08
JP-5	471	3.24	95.17
Lubricating Oil	6	2.00	150.00
Compensated Fuel-Ballast	1280	2.37	105.08
SW Ballast	1934	4.89	88.54
Fresh Water	271	2.95	94.49
Total	29671	10.22	103.52

Table 44. Minop Trim and Stability Summary

Vessel Displacement and Centers of Gravity					
Item	Weight MT	VCG - m	LCG - m - FP	TCG - m	FSmom m - MT
Lightship	24393	11.41	105.7	0	
Constant	0	0	106.5	0	0
Misc. Weight	1565	17.332	135.617	0.406S	0
Aircraft Fuel	531	3.23	94.308	0	8403
Propulsion Fuel	0	0	106.5	0	0
Comp. Fuel/Ballast	1913	2.335	104.635	0	10473
Potable Water	288	2.95	94.493	0	2319
Clean Ballast	1568	4.72	93.239	0.438P	7191
TOTALS	30259	10.572	106.227	0.002P	28386
Stability Calculation		Trim Calculation			
KMt	14.676	m	LCF Draft	7.041	m
VCG	10.572	m	LCB (even keel)	106.16	m - AFT
GMt	4.104	m	LCF	114.813	m - AFT
F.S. Correction	0.938	m	MT1cm	693	m - MT/cm
GMt Corrected	3.166	m	Trim	0.031	m - AFT
			Prop. Immersion	133	%
			List	0.03	Deg. - PORT
Drafts					
A.P.				7.055	m
M.S.				7.039	m
F.P.				7.024	m
Strength Calculation					
Shear Force at 33 m - FP				2234	MT
Bending Moment at 111 m - FP				140615	m - MT [HOG]

Table 45. Full Load Trim and Stability Summary

Vessel Displacement and Centers of Gravity					
Item	Weight MT	VCG - m	LCG - m - FP	TCG - m	FSmom m - MT
Lightship	24393	11.41	105.7	0	
Constant	0	0	106.5	0	0
Misc. Weight	2361	16.58	125.791	0.269S	0
Aircraft Fuel	1529	3.23	94.308	0	8403
Propulsion Fuel	1818	2.335	104.635	0	9950
Comp. Fuel/Ballast	0	0	106.5	0	0
Potable Water	437	2.95	94.493	0	0
Clean Ballast	149	5.077	115.505	4.747P	3596
TOTALS	30687	10.712	106.503	0.002P	21949
Stability Calculation		**Trim Calculation**			
KMt	14.604	m	LCF Draft	7.119	m
VCG	10.712	m	LCB (even keel)	106.3	m - AFT
GMt	3.893	m	LCF	114.936	m - AFT
F.S. Correction	0.715	m	MT1cm	696	m - MT/cm
GMt Corrected	3.177	m	Trim	0.089	m - AFT
			Prop. Immersion	135	%
			List	0.04	Deg. - PORT
Drafts					
A.P.				7.16	m
M.S.				7.116	m
F.P.				7.071	m
Strength Calculation					
Shear Force at 180 m - FP				1522	MT
Bending Moment at 123 m - FP				86421	m - MT [HOG]

4.11.1 Intact Stability

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

Figure 73 and Table 46 describe the righting arm and wind heeling arm curve and data for the minimum operating condition.

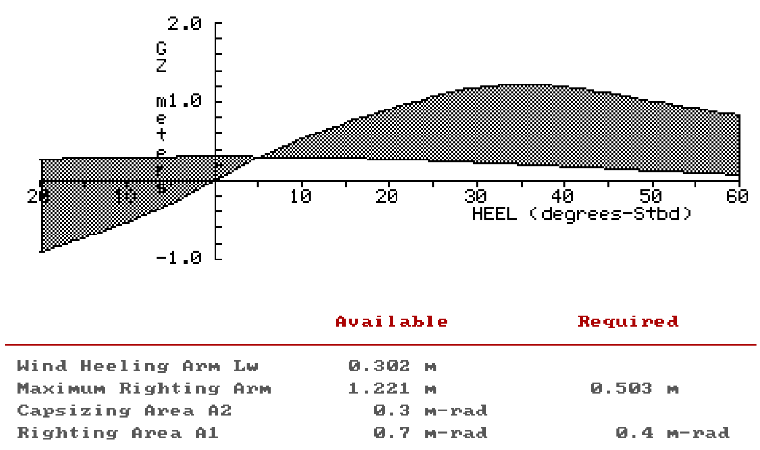
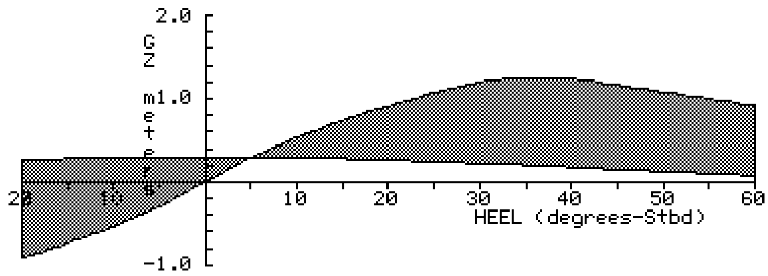


Figure 73. Righting Arm (GZ) and Heeling Arm Curve for Minop Condition

Table 46. Righting Arm (GZ) and Heeling Arm Data for Minop Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Wind Heeling Arm Lw	0.302 m	Displacement	30259 MT
Maximum Righting Arm	1.221 m	GMt (corrected)	3.166 m
Capsizing Area A2	0.3 m-rad	Mean Draft	7.039 m
Righting Area A1	0.7 m-rad	Roll Angle	25.0 deg
Wind Pressure Factor	0.0035	Angle at Intercept	60.0 deg
Wind Pressure	0.1709 MT/m2	Wind Heel Arm Lw	0.302 m
Wind Velocity	100 knts	Wind Heel Angle	5.1 deg
Projected Sail Area	3993.8 m2	Maximum GZ	1.221 m
Vertical Arm	17.016 m ABL	Angle at Maximum GZ	35.3 deg
Heeling Arm at 0 deg	0.304		

Figure 74 and Table 47 describe the righting arm and heeling arm curve for the full load condition.



	Available	Required
Wind Heeling Arm Lw	0.297 m	
Maximum Righting Arm	1.252 m	0.494 m
Capsizing Area A2	0.3 m-rad	
Righting Area A1	0.7 m-rad	0.4 m-rad

Figure 74. Righting Arm (GZ) and Heeling Arm Curve for Full Load Condition

Table 47. Righting Arm (GZ) and Heeling Arm Data for Full Load Condition

Beam Wind with Rolling Stability Evaluation (per US Navy DDS079-1)			
Wind Heeling Arm Lw	0.297 m	Displacement	30686 MT
Maximum Righting Arm	1.252 m	GMt (corrected)	3.177 m
Capsizing Area A2	0.3 m-rad	Mean Draft	7.116 m
Righting Area A1	0.7 m-rad	Roll Angle	25.0 deg
Wind Pressure Factor	0.0035	Angle at Intercept	60.0 deg
Wind Pressure	0.1709 MT/m2	Wind Heel Arm Lw	0.297 m
Wind Velocity	100 knts	Wind Heel Angle	5.0 deg
Projected Sail Area	3977.5 m2	Maximum GZ	1.252 m
Vertical Arm	17.056 m ABL	Angle at Maximum GZ	36.2 deg
Heeling Arm at 0 deg	0.299		

CUVX-HI3 intact stability is satisfactory for both minimum operating and full load conditions.

4.11.2 Damage Stability

In addition to the locating transverse bulkheads to satisfy floodable length requirements, the two load cases, Minimum Operation (Minop) and Full Load, are checked for damage stability using a 15% LWL damage length in accordance with DDS 079-01. This is equal to a 32 meter damage length which is systematically applied along the length of the ship starting from the bow and moving aft. Worse case penetration to the centerline is used. 28 damage cases were assessed for each loading condition. In all cases, the flooded angle of heel must be less than 15 degrees, the margin line must not be submerged, and remaining dynamic stability must be adequate ($A_1 > 1.4\ A_2$).

Table 48. Minop Damage Results

	Intact	Damage BH 21-66	Damage BH 132-180
Draft AP (m)	7.055	3.995	9.546
Draft FP (m)	7.024	14.855	6.739
Trim on LBP (m)	0.031A	10.860F	2.807A
Total Weight (MT)	30259	40356	36876
Static Heel (deg)	0.0P	2.8S	11.4S
Wind Heel (deg)	5.5P	8.7S	18.1S
GM_t (upright) (m)	3.166	2.796	1.701
Maximum GZ		1.80	1.545
Maximum GZ Angle (deg)		60.1S	60.1S
GZ Pos. Range (deg)		> 57.2	> 48.6

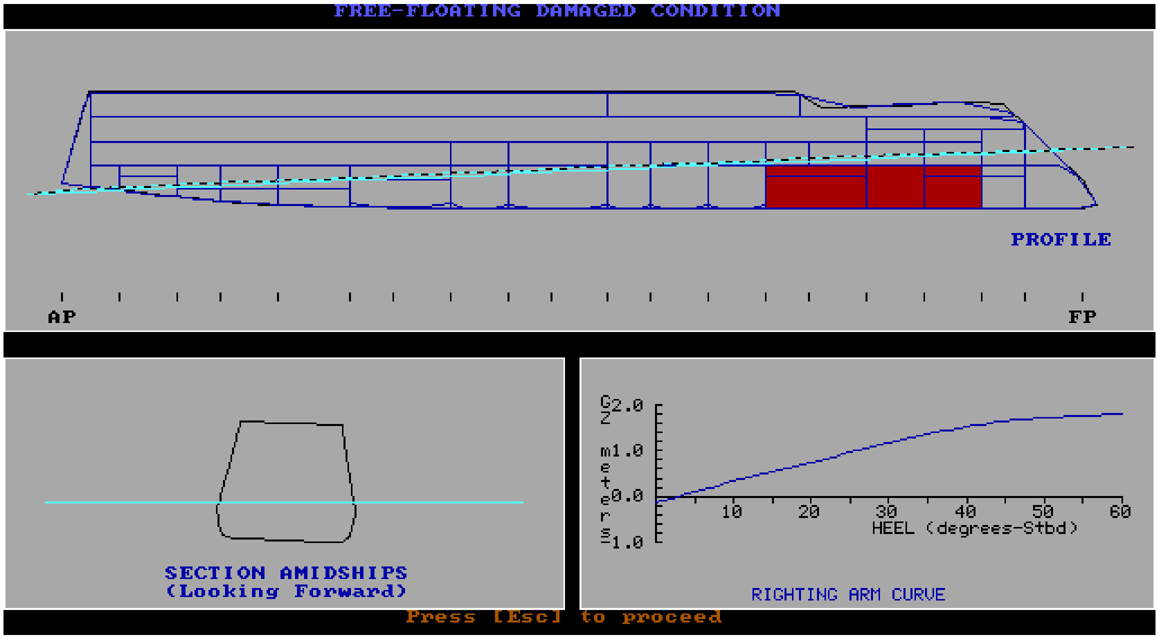


Figure 75. Limiting Trim Case for Minop

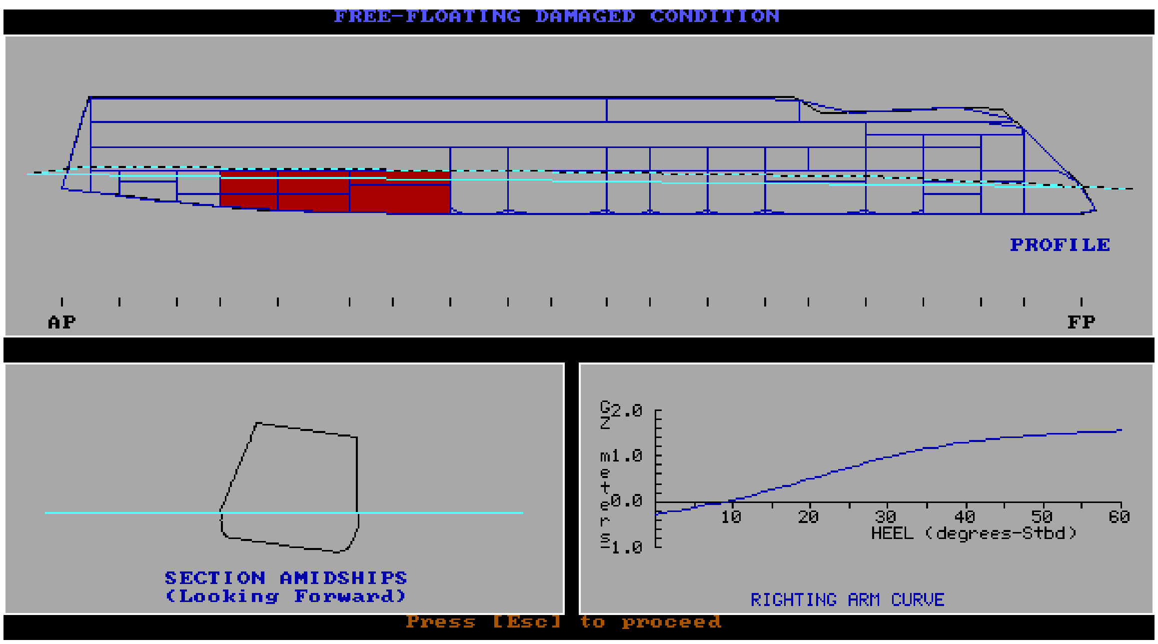


Figure 76. Limiting Heel Case for Minops

The limiting trim case in the Minop condition is for flooding between bulkheads at frames 21 and 66. The limiting heel case is for flooding between bulkheads at frames 132 and 180. The results are shown in Table 48. Figure 75 shows the results with the damaged compartments in red, the heel of the ship and the Righting Arm curve when there is flooding between bulkheads at frames 21 and 66. Figure 76 shows the results in the limiting heel case, bulkhead 132 to 180. CUVX HI3 damaged stability is satisfactory in the Minop condition.

The limiting case for trim in the Full Load condition is flooding between bulkheads at frames 21 and 66. The limiting heel case is for flooding between bulkheads 132 and 180. The results are shown in Table 49. Figure 77 shows the results with the damaged compartments in red, the heel of the ship and the Righting Arm curve for the ship. Figure 78 shows the results for the limiting heel case. CUVX HI3 is satisfactory in the Full Load condition.

Table 49. Full Load Damage Results

	Intact	Damage BH 21-66	Damage BH 132-180
Draft AP (m)	7.160	4.112	9.228
Draft FP (m)	7.071	14.781	6.804
Trim on LBP (m)	0.089A	10.669F	2.424A
Total Weight (MT)	30686	40472	36101
Static Heel (deg)	0.0P	2.5S	11.2S
Wind Heel (deg)	5.4P	8.1S	18.3S
GM_t (upright) (m)	3.177	2.910	1.811
Maximum GZ		1.892	1.463
Maximum GZ Angle (deg)		60.1S	60.1S
GZ Pos. Range (deg)		> 57.5	> 48.8

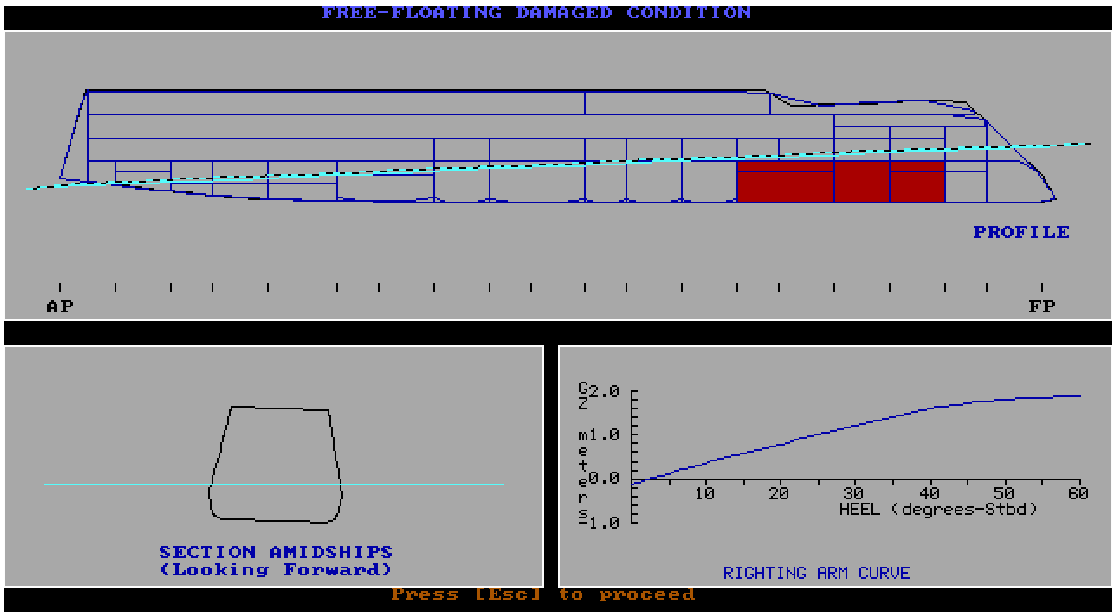


Figure 77. Limiting Trim Case for Full Load

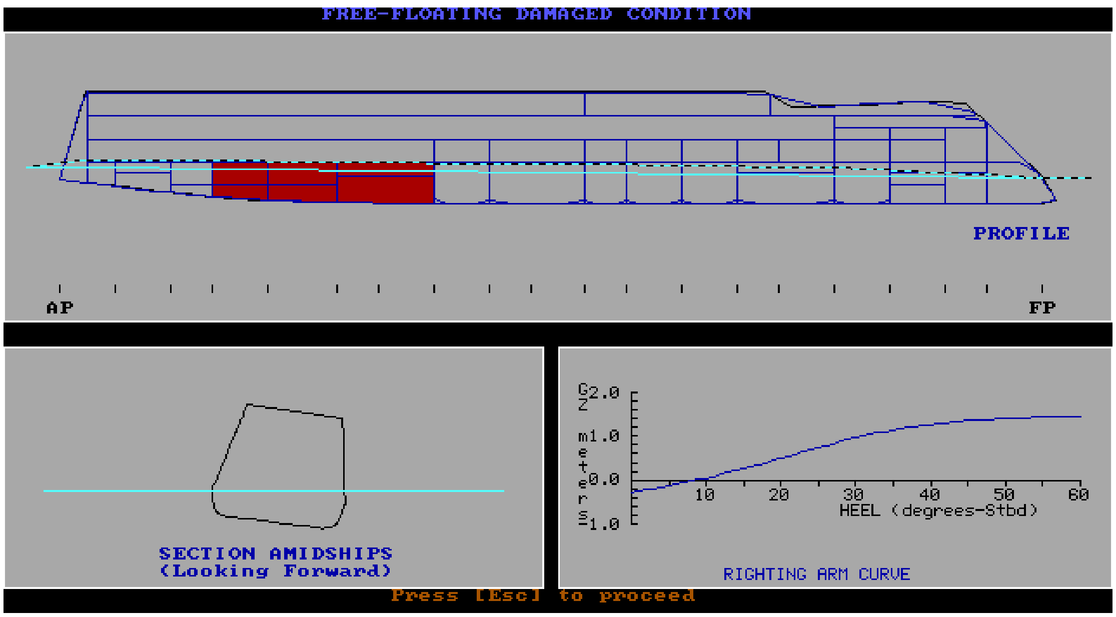


Figure 78. Limiting Heel Case for Full Load

4.12 Seakeeping

A seakeeping analysis in the full load condition was performed using the Ship Motion Program (SMP). The hull was modeled using offsets from Fastship. Ship responses were calculated for a Bretschneider wave spectrum in Sea States 3, 4, 5, 6, and 7 (significant wave heights of 0.88, 1.88, 3.25, 5, and 7.5 meters). Ship motions were analyzed at 8 locations. These locations are described in Table 50 below. The Post-Processing module of SMP was used to create Speed-Polar plots showing the operating envelopes of the ship for Required Operational Capabilities (ROCs) using Navy criteria for operational limits. The plots show the regions in which the criteria are met as blank. The bold lines are the limit contour lines. The regions in which the ship did not pass the criteria are shown with contour lines plotted in them. The numbers shown on each contour line are the value of the plotted criteria for the particular Speed-polar plot. Significant amplitude criteria are listed in Table 51.

Table 50. Sea Keeping Analysis Locations

Description	Longitudinal Location (mFP)	Vertical Location (m basline)	Transverse Location (m CL port pos)
Bridge Center	16.5	20.1	0
Outboard Corner of VLS Starboard	169.31	29.31	-10.61
Outboard Corner of VLS Port	138.31	29.31	10.61
Keel @ Sta. 3	33	0	0
Bow/UCAV Launch	17.02	27.3	0
UCAV Recovery	181	29.31	1
Generic LAMP Aft Landing/Launch	168	29.31	-2
Generic LAMP Forward Landing/Launch	123	29.31	-1

Table 51. Limiting Sea Keeping Criteria for CUVXHI3 (Significant Amplitude)

Mission	Roll (deg)	Pitch (deg)	Yaw (deg)	Vert Vel (m/s)	Vertical Acc (g)	Lateral Acc (g)	Long Acc (g)	Wetness per Hour @ Bow	Slams per Hour @Sta. 3	Sea State Goal	Threshold Sea State	Sea State Achieved
AAW (VLS)	17.5	3	1.5		0.6	0.7	0.3			7	6	6 (limited)
ASW (LAMPS)	5	3		2.5						5	4	4 (limited)
ASuW (LAMPS)	5	3		2.5						5	4	4 (limited)
ISR (UAV)	5	3		2.5						5	4	4 (limited)
SEAD (UCAV)	5	3		2.5						5	4	4 (limited)
UNREP	4	1.5								5	4	5 - 6 (limited)
Personnel	8	3			0.4	0.2				8	7	7 (limited)
Hull								30	20	8	7	7 (limited)

CUVX marginally satisfies seakeeping requirements. It provides only limited operations in the threshold sea states except for UNREP where it is fully operable.

VLS (the primary AAW system) criteria are 17.5 degrees roll, 3 degrees pitch, and 1.5 degrees yaw. Longitudinal acceleration must be less than 0.3g, transverse acceleration less than 0.7g, and vertical acceleration less than 0.6g. The AAW operating envelope for Sea State 6 is shown in Figure 79. In CUVX, AAW operations are limited by yaw and vertical acceleration. The regions in which the vertical acceleration and the angle of yaw exceed the criteria for VLS launch are shown in the Speed-polar plot. The acceptable operating range requires a heading of 150-210 at a speed of 20 knots.

ASW and ASUW missions are performed using LAMPS helos. The performance criteria for helo flight operations are 5 degrees roll and 3 degrees pitch. Vertical velocity at the helo takeoff and landing locations must not exceed 2.5 m/s. The seakeeping analysis indicates that helicopter flight operations are not possible in Sea State 5. The limiting factor for Sea State 5 is the vertical velocity at the aft landing spot. Figure 80 is a Speed-polar plot showing the helo operating envelope for Sea State 4. Flight operations are possible in Sea State 4 in all conditions from the forward takeoff and landing spot. The vertical velocities at the aft landing and takeoff locations are not within operational limits for all conditions. The acceptable operating range from the aft landing spot for Sea State 4 requires a heading of 150-210 at a speed of 20 knots.

The ISR and SEAD missions are performed by UAVs and UCAVs. The performance criteria for flight operations are 5 degrees roll, 3 degrees pitch, and vertical velocities at the touchdown and the launch locations must not exceed 2.5 m/s. Seakeeping analysis shows that UCAV and UAV flight operations are not possible during Sea State 5 and operation is very limited in Sea State 4. The limiting criteria for UCAV and UAV flight operations above Sea State 3 are vertical velocities at the launch point and landing spot. Figure 81 and Figure 82 show the operating envelope for ISR and SEAD in Sea State 4 and Sea State 3. The acceptable operating range for Sea State 4 requires a heading of 175-185 at a speed of 22 knots. The operating range for Sea State 3 requires a heading of 135-225 at a speed of 20 knots.

The criteria for Underway Replenishment are a maximum roll of 4 degrees or pitch of 1.5 degrees. CUVX is fully operational in Sea State 4 and limited in Sea State 5 and 6. The speed-polar plot for Sea State 5 is shown in Figure 83. A heading of 040-340 (following seas) or 125-235 (head seas) is required to be within the criteria in Sea State 5. The operating envelope for UNREP in Sea State 6 is shown in Figure 84. The ship is able to perform underway replenishment in Sea State 6, but the envelope is very narrow. The ship must be traveling in following seas at greater than 12 knots or in heads seas at greater than 18 knots.

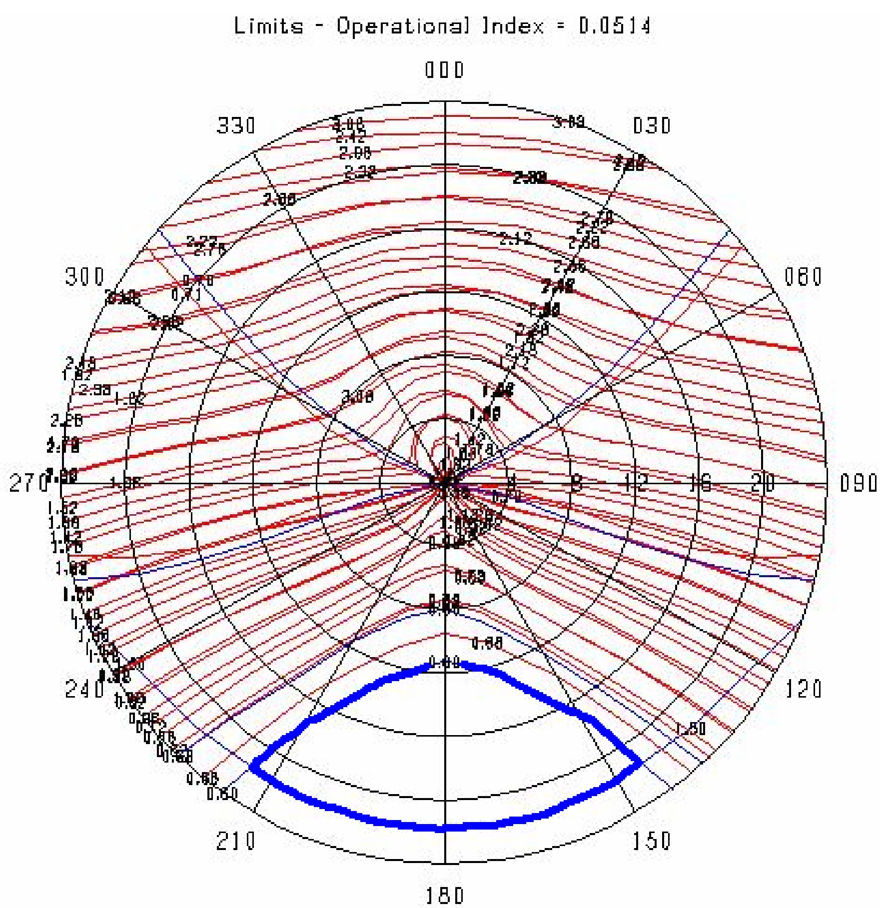


Figure 79. AAW (VLS) Speed-polar Plot for Vertical Acceleration and Yaw in Sea State 6

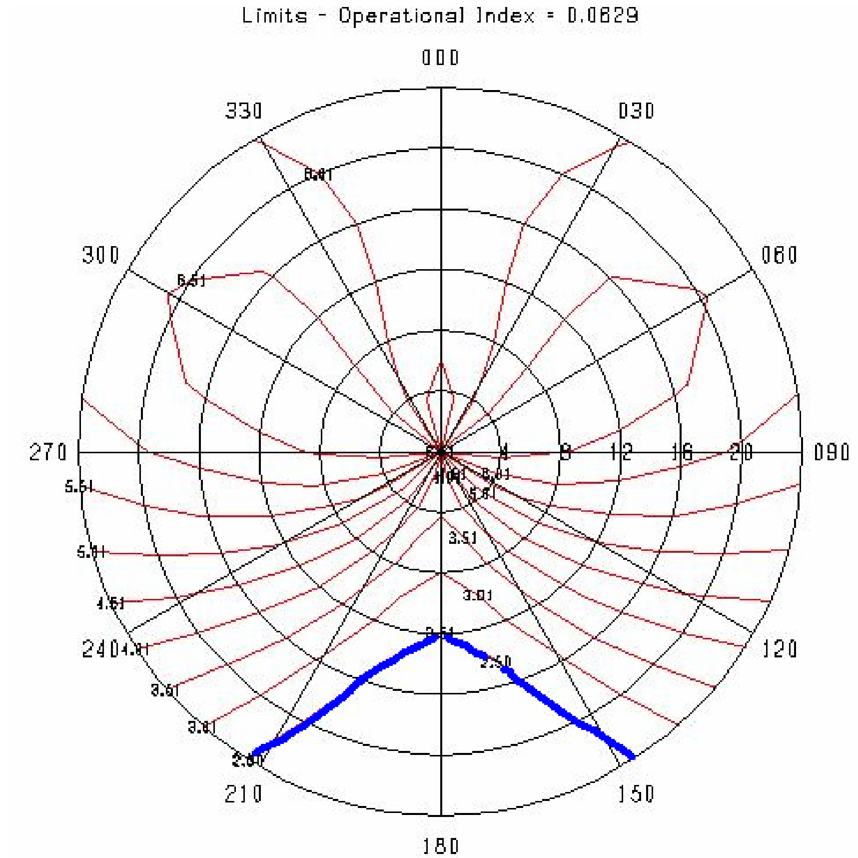


Figure 80. ASW and ASuW Speed-polar Plot for Vertical Velocity in Sea State 4

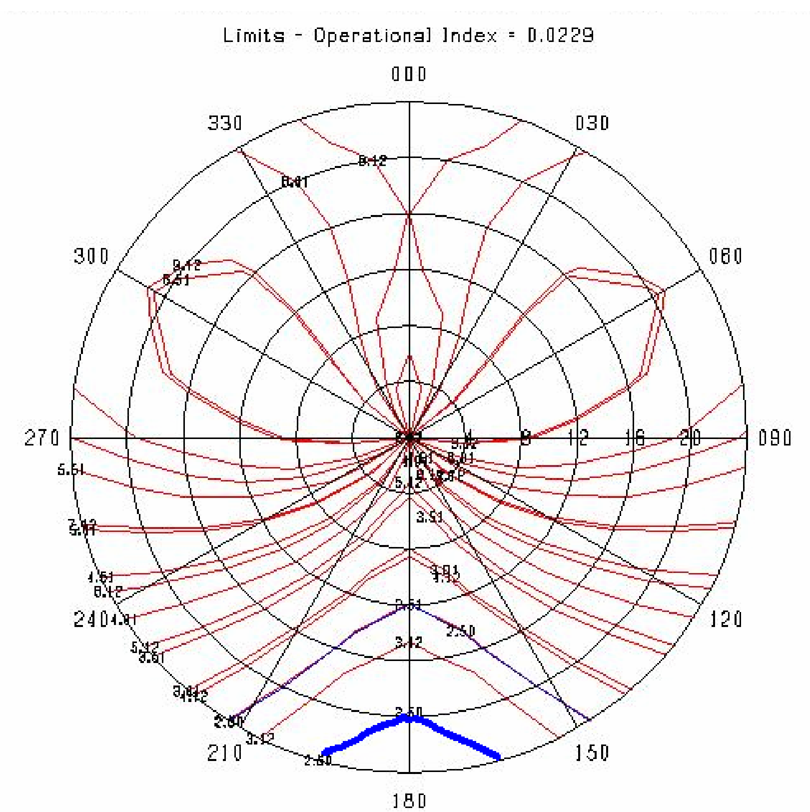


Figure 81. ISR and SEAD Speed-polar Plot for Vertical Velocity in Sea State 4

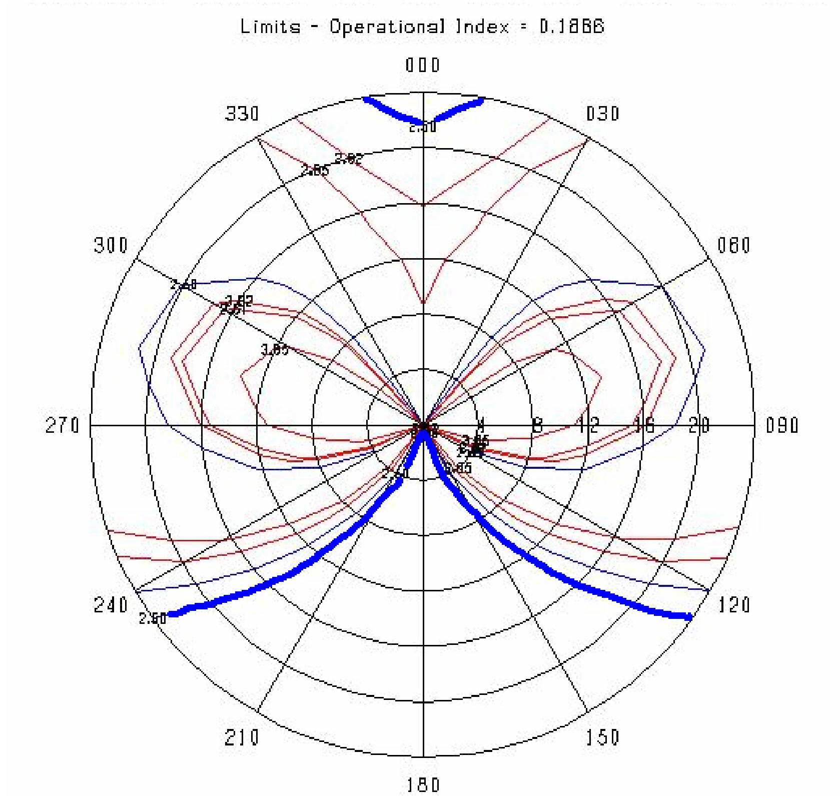


Figure 82. ISR, SEAD, ASW and ASuW Speed-polar Plot for Vertical Velocity in Sea State 3

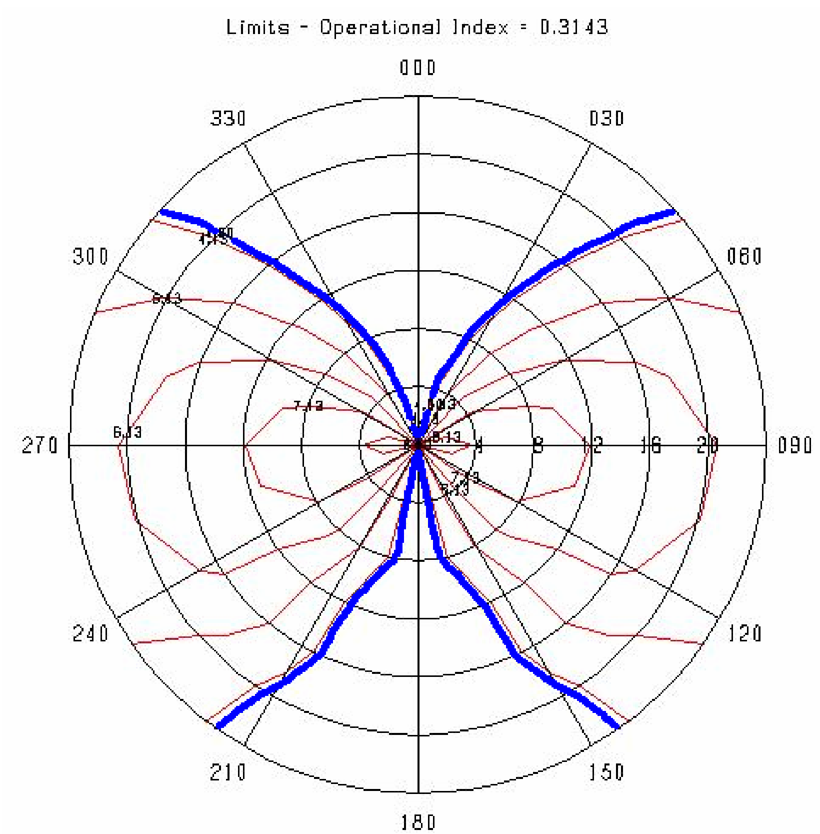


Figure 83. UNREP Speed-polar Plot for Roll in Sea State 5

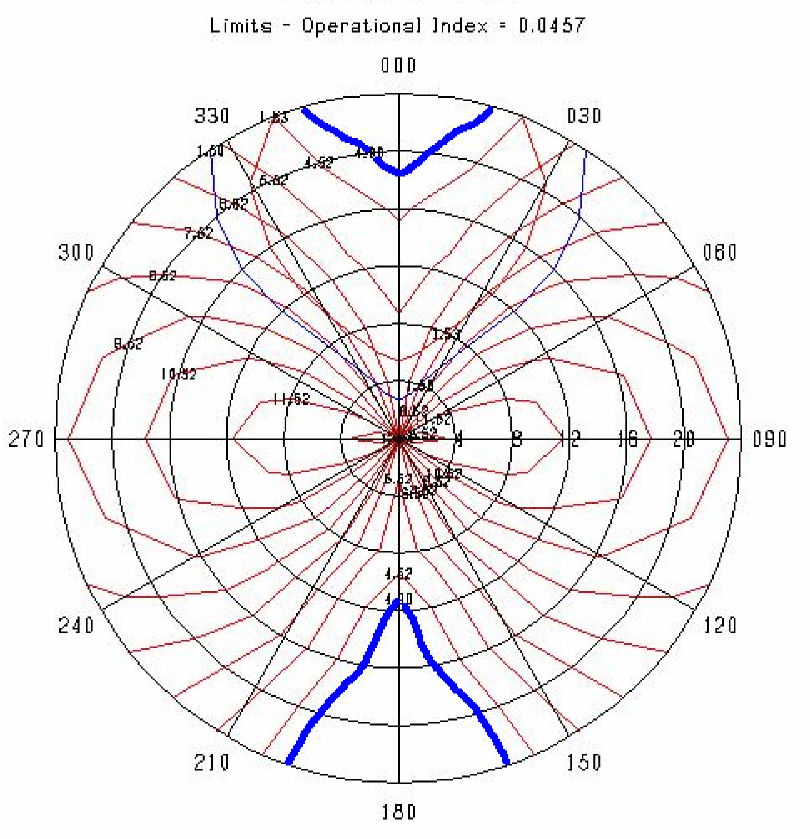


Figure 84. UNREPs Speed-polar Plot for Roll in Sea State 6

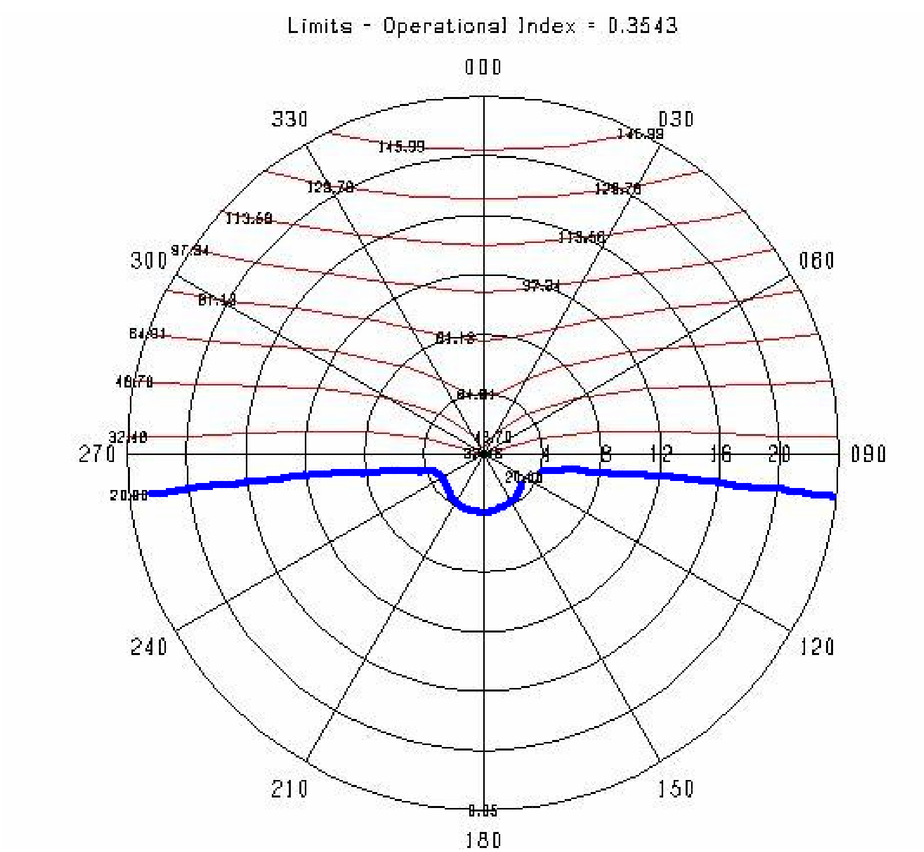


Figure 85. Hull Limitations Speed-polar Plot for Slamming in Sea State 7

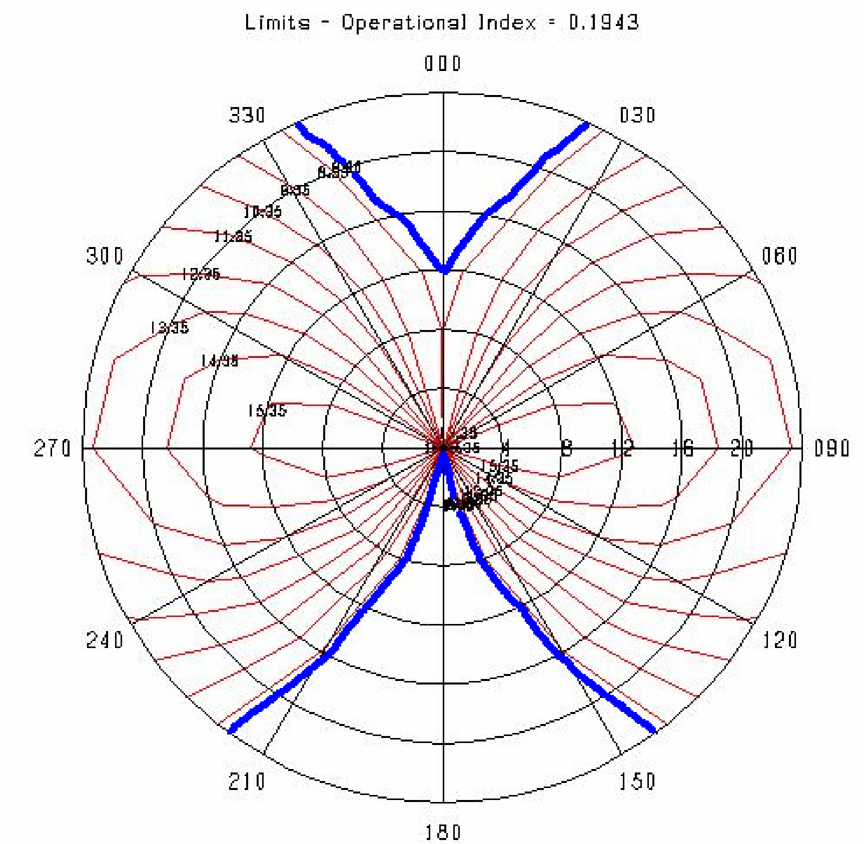


Figure 86. Personnel Speed-polar Plot for Roll in Sea State 7

The performance degradation criteria for personnel are 8 degrees roll and 3 degrees pitch. Crew on the bridge must only be subjected to 0.2g lateral acceleration and 0.4g vertical acceleration. Figure 86 is a Speed Polar plot showing the operating envelope for personnel in Sea State 7. The limiting criterion in Sea State 7 is roll. The acceptable operating range requires a heading of 030-330 (following seas) or 150-210 (head seas).

Hull sea keeping criteria are 30 bow submergences per hour, and 20 slams per hour. CUVX can perform limited operations in Sea State 7. Slamming at Station 3 is the limiting criterion. The contours for slams/hour in Sea State 7 are plotted on the Speed-polar plot in Figure 79. The acceptable operating range requires a heading of 100-270.

4.13 Cost and Risk Analysis

4.13.1 Cost and Producibility

Cost calculations for CUVX HI3 are based on weight and producibility. These calculations are shown in Figure 87. The cost is analyzed for each SWBS group by weight and multiplied by a producibility factor. With the latest iteration of the design some variables differ from the original values in Concept Exploration. These changes result in a lower cost than originally estimated. A comparison of the costs is shown in Table 52. These acquisition costs satisfy the threshold values as specified in the ORD, but because this is a very high end ship, they are well above cost goals.

CUVX HI3 is a producible design. Its hull form has significant parallel midbody. A chine at the waterline transitions the curved wetted surfaces to a low-curvature freeboard. The entire hull above the waterline consists of single curvature or flat plating as does the transom. The Advanced Double Hull uses cell production techniques. The centerline skeg also uses single curvature plate. The cost of outfitting and installation is reduced by generous deck heights and the use of zonal distribution systems for electric power, firemain and ventilation. The variety of structural materials (plate and shapes) was kept to a minimum.

Module 10 - SIMPLIFIED COST MODEL

$Mdol := coul \quad Bdol := 1000 \cdot Mdol \quad Kdol := \frac{Mdol}{1000} \quad dol := \frac{Kdol}{1000} \quad i1 := 1, 2 .. 7$

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

$W_{MP} := \left[\left(W_4 + W_7\right) - W_{IC}\right] + W_{F20} - W_{F23} \quad W_{MP} = 695.755 \cdot lton$

10a. Inflation:

Base Year: $Y_B := 2005 \quad iy := 1 .. Y_B - 1981$

Average Inflation Rate (%): (from 1981-2005) $R_I := 2.3 \quad F_I := \prod_{iy}\left(1 + \frac{R_I}{100}\right) \quad F_I = 1.726$

10b. Lead Ship Cost:

Lead Ship Cost - Shipbuilder Portion:

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

Structure: $K_{N1} := \frac{.8 \cdot Mdol}{lton^{.772}} \quad C_{L_1} := .03395 \cdot F_I \cdot K_{N1} \cdot \left(W_1\right)^{.772} \quad C_{L_1} = 71.262 \cdot Mdol$

+ Propulsion: $K_{N2} := \frac{1.0 \cdot Mdol}{hp^{.808}} \quad C_{L_2} := .00186 \cdot F_I \cdot K_{N2} \cdot P_{BPENGTOT}^{.808} \quad C_{L_2} = 20.752 \cdot Mdol$

+ Electric: $K_{N3} := \frac{1.0 \cdot Mdol}{lton^{.91}} \quad C_{L_3} := .07505 \cdot F_I \cdot K_{N3} \cdot \left(W_3\right)^{.91} \quad C_{L_3} = 58.185 \cdot Mdol$

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

$K_{N4} := \frac{2.0 \cdot Mdol}{lton^{.617} \cdot (CManShip + CManAir)} \quad C_{L_4} := .10857 \cdot F_I \cdot K_{N4} \cdot \left(W_4\right)^{.617} \quad C_{L_4} = 6.705 \cdot Mdol$

+ Auxiliary: $K_{N5} := \frac{2.0 \cdot Mdol}{lton^{.782} \cdot (CManShip + CManAir)} \quad C_{L_5} := .09487 \cdot F_I \cdot K_{N5} \cdot \left(W_5\right)^{.782} \quad C_{L_5} = 94.11 \cdot Mdol$

+ Outfit: $K_{N6} := \frac{1.0 \cdot Mdol}{lton^{.784}} \quad C_{L_6} := .09859 \cdot F_I \cdot K_{N6} \cdot \left(W_6\right)^{.784} \quad C_{L_6} = 61.738 \cdot Mdol$

+ Armament: (Less payload GFM cost)

$K_{N7} := \frac{1.0 \cdot Mdol}{lton^{.987}} \quad C_{L_7} := .00838 \cdot F_I \cdot K_{N7} \cdot \left(W_7\right)^{.987} \quad C_{L_7} = 0.583 \cdot Mdol$

+ Margin Cost: $C_{LM} := \frac{W_{M24}}{\left(W_{LS} - W_{M24}\right)} \cdot \left(\sum_{i1} C_{L_{i1}}\right) \quad C_{LM} = 31.278 \cdot Mdol$

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

$K_{N8} := \begin{cases} \frac{2. \cdot Mdol}{Mdol^{1.099}} & \text{if } HullForm = 5 \\ \frac{10. \cdot Mdol}{Mdol^{1.099}} & \text{otherwise} \end{cases} \quad K_{N8} = 10 \cdot \frac{Mdol}{Mdol^{1.099}} \quad C_{L_8} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099}$

$C_{L_8} = 208.932 \cdot Mdol$

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

$K_{N9} := \begin{cases} \frac{.5 \cdot Mdol}{(Mdol)^{.839}} & \text{if } HullForm = 5 \\ \frac{2. \cdot Mdol}{(Mdol)^{.839}} & \text{otherwise} \end{cases} \quad K_{N9} = 2 \cdot \frac{Mdol}{(Mdol)^{.839}} \quad C_{L_9} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839}$

$C_{L_9} = 36.323 \cdot Mdol$

= Total Lead Ship Construction Cost: (BCC)

$C_{LCC} := \sum_{i1} C_{L_{i1}} + C_{L_8} + C_{L_9} + C_{LM} \quad C_{LCC} = 589.868 \cdot Mdol$

+ Profit: $F_P := .10 \quad C_{LP} := F_P \cdot C_{LCC} \quad C_{LP} = 58.987 \cdot Mdol$

= Lead Ship Price: $P_L := C_{LCC} + C_{LP} \quad P_L = 648.855 \cdot Mdol$

+ Change Orders: $C_{LCORD} := .12 \cdot P_L \quad C_{LCORD} = 77.863 \cdot Mdol$

= Total Shipbuilder Portion: $C_{SB} := P_L + C_{LCORD} \quad C_{SB} = 726.718 \cdot Mdol$

Lead Ship Cost - Government Portion

Other support: $C_{LOTH} := .025 \cdot P_L \quad C_{LOTH} = 16.221 \cdot Mdol$

+ Program Manager's Growth: $C_{LPMG} := 0 \cdot P_L \quad C_{LPMG} = 0 \cdot Mdol$

+ Ordnance and Electrical GFE: (Military Payload GFE or include actual cost if known)

$C_{LMPG} := \left(.3 \cdot \frac{Mdol}{lton} \cdot W_{MP}\right) \cdot F_I \quad C_{LMPG} = 360.241 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{LHMEG} := .02 \cdot P_L \quad C_{LHMEG} = 12.977 \cdot Mdol$

+ Outfittimg Cost : $C_{LOUT} := .04 \cdot P_L \quad C_{LOUT} = 25.954 \cdot Mdol$

= Total Government Portion: $C_{LGOV} := C_{LOTH} + C_{LPMG} + C_{LMPG} + C_{LHMEG} + C_{LOUT}$

$C_{LGOV} = 415.393 \cdot Mdol$

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

* Total End Cost: $C_{LEND} := C_{SB} + C_{LGOV} \quad C_{LEND} = 1.142 \cdot 10^3 \cdot Mdol$

Total Lead Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{LPDEL} := .05 \cdot P_L \quad C_{LPDEL} = 32.443 \cdot Mdol$

= Total Lead Ship Acquisition Cost: $C_{LA} := C_{LEND} + C_{LPDEL} \quad C_{LA} = 1.175 \cdot 10^3 \cdot Mdol$ ($FY2005)

Figure 87. Simplified CUVX HI3 Cost Model (Lead Ship)

Table 52. Cost Comparison

Cost Type	Concept Exploration Lead ($ mil)	Concept Exploration Follow ($ mil)	Concept Development Lead ($ mil)	Concept Development Follow ($ mil)
Structure	71.3	71.3	71.3	71.3
Propulsion	20.8	20.8	20.8	20.8
Electrical	58.2	58.2	58.2	58.2
CCS	6.7	6.7	6.7	6.7
Auxiliary Systems	102.1	102.1	94.1	94.1
Services	61.7	61.7	61.7	61.7
Armament (non-GFM)	0.58	0.58	0.58	0.58
Engineering	214.8	18.95	208.9	18.4
Assembly and Support	37.1	20.1	36.3	19.7
BCC	605.3	421.7	589.9	411.2
Profit	60.5	42.2	58.99	41.1
Price	665.9	463.9	648.9	452.3
Acquisition Cost	1196 (threshold) 750 (goal)	775 (threshold) 650 (goal)	1175	760

4.13.2 Risk Analysis

CUVX-HI3 is a high risk ship. This risk is due to the unproven cutting edge technology and concepts integrated into the design. The Wave Piercing Tumble Home (WPTH) hull form, EMALS, Advanced Double Hull, Integrated Power System, Unmanned Aircraft, automated systems, forward pilot house location, and separate launch and recovery decks are all high risk alternatives as described in Table 24. Additional technology demonstrations and tests are required to reduce this risk. An integrated test using the lead CUVX HI3 alternative would assess all high risk technologies simultaneously and could be considered as a lead (test) ship. This is a revolutionary approach. Another possibility is to select a less risky LPD-17 mod-repeat alternative, and gradually incorporate high risk alternatives later in the class. This is an evolutionary approach.

5 Conclusions and Future Work

5.1 Assessment

CUVX HI3 meets and exceeds the requirements specified in the ORD as shown in Table 53. In most of the performance measures HI3 reached the original goal values or very close to it.

Table 53. Compliance with Operational Requirements

Technical Performance Measure	Threshold	Goal	HI3
Number of UAVs	4	20	18
Number of UCAVs	9	30	28
Number of LAMPS	2	4	4
Ship Aircraft fuel capacity (MT)	996	2032	1514
Ship Aircraft weapons capacity (MT)	150	450	409
Ship Aircraft fuel capacity (m3)	1273	2549	1911
Ship Aircraft weapons magazine capacity	2867	8600	7846
Endurance range (nm)	4000	12000	4000
Stores duration (days)	60	120	120
CPS	none	full	full
Vs (knt)	20	25.00	20.6
Crew size		800	898
OMOE		0.95	0.9021
Aircraft Launch and Recovery	SS4	SS5	Limited SS4
Unrep	SS4	SS5	Limited SS5
Mean follow-ship acquisition cost ($M)	775	650	760
Lead-ship acquisition cost ($M)	1196	750	1175
Maximum level of risk (OMOR)		0.288	0.288

CUVX incorporates proven technology and new cutting edge technology. It integrates a non-traditional separate launch and recovery deck which enables simultaneous take-off and landing. A rapid turnaround of aircraft is expected due to the efficient flow of operations in the hangar decks. A stealthy, low radar cross section design is effectively incorporated in the hullform to satisfy the requirement for passive defense. A non-conventional pilot house in the bow of the ship increases the available recovery deck area. The advanced enclosed mast maintains CUVX HI3's low radar cross section while protecting the ship's electronic sensors. The integrated power system in provides the ability to operate the engines at optimum efficiencies and provides flexibility in electric plant configuration and load distribution. The 5 diesels provide a threshold value for sustained speed and excellent fuel efficiency. Manning is significantly reduced compared to other aircraft carriers while maintaining a high integrity of operations. CUVX exceeds Navy damage stability requirements.

5.2 Future Work

- A sensitivity study to increase beam should be performed to decrease recovery deck risk.
- Actual dimensions and angles for the Wave Piercing Tumble Home design were estimated because information about this design was not available. A more tested and proven geometry should be used.
- Refine the AEM deckhouse design to increase recovery deck area and improve aircraft clearances.
- Scantlings should be optimized making all adequacy parameters positive and closer to zero to reduce unnecessary weight.
- Further investigation of IPS pulse power for EMALS should be performed.
- Design and test the blast deflector door and ventilation system to continuously clear the launch deck of exhaust.

- Design a system that automates the hook-up of the aircraft to the EMALS. A possibility for this would be a track starting inside the hangar deck where the aircraft could be hooked up to and then towed out into place on the launch deck. This would eliminate the need for men on the launch deck.
- Design a retractable cover on the recovery deck for Aircraft Elevator 1 and 3. This cover will allow recovery operations to continue in the event of an elevator malfunction.
- Consider a third EMALS catapult located on the forward end of the recovery deck. This catapult could be used if the other two catapults fail; the blast deflector door is stuck in the closed position; or just to launch planes more rapidly. More investigation of the cost and benefit from a third catapult is required.
- Investigate the use of Electro-Magnetic Aircraft Recovery.
- Consider dynamic roll stabilizers to allow flight operations in Sea State 4 and possibly Sea State 5.

5.3 Conclusion

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 is required to 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 intelligence, surveillance, reconnaissance (ISR) 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), ISR 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 HI3 Baseline Concept Design and define Operational Requirements (ORD1) based on the customer's preference for cost, risk and effectiveness in this baseline.

CUVX HI3 is the highest-end alternative on the follow-ship acquisition cost frontier. This design was chosen to provide a challenging design project using higher risk technology. CUVX HI3 has a wave-piercing tumblehome (WPTH) hullform to reduce radar cross section, and 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 arrangement, general arrangements, combat system selection, seakeeping analysis, cost and producibility analysis and risk analysis. The final concept design satisfies critical operational requirements within cost and risk constraints with additional work required to improve seakeeping and further reduce manning and cost.CUVX-HI3 meets or exceeds the requirements for this design.

The WPTH design reduces resistance and vertical motion in waves and reduces RCS. The Advanced Double Hull provides the ship with a high level of damage protection in the mid body around magazines and machinery spaces. The ADH also provides tankage for the ships fuel, oil, waste, and aircraft fuel in a producible design. It increases the ships structural strength to under hull explosion. The propulsion system includes five medium-speed Colt-Pielstic diesel engines, proven and Navy shock qualified. These engines supply power to an Integrated Power System which is used for propulsion and all other ship electrical needs including pulse power for the EMALS. Hangar space is sufficient to house, repair, and safely operate the required 28 UCAVs, 18 UAVs, and 4 LAMPS. Separate Launch and Recovery decks are provided for the ship to perform simultaneous takeoff and landing operations. Two EMALS integrated into the launch deck have sufficient power to launch the UAVs and UCAVs. The pilot house is located in the bow of the ship on the deck below the launch deck. This location allows an unobstructed view around the forward end of the ship while opening up valuable space on the recovery deck for aircraft operations. A low-RCS Advanced Enclosed Mast System is the only structure on the recovery deck. It is located at the forward starboard end of the deck and houses all the radar masts, aircraft recovery operations facilities, and aircraft recovery support equipment.

CUVX-HI3 is a unique and capable design that should be considered as lead/test ship for a revolutionary CUVX class of ships.

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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:

(4) Land and carrier-based manned aircraft and UAVs
(5) Cruise missiles launched from submarines and surface ships
(6) 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 CVNs. 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 UAVs and UCAVs in ISR, First Day of War (FDOW) and Suppression of Enemy Air Defenses (SEAD) missions. Deploy in larger numbers than current CVNs. 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 Tech 1872

VIRGINIA POLYTECHNIC INSTITUTE
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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 UCAVs and UAVs, providing for takeoff and landing, fueling, maintenance, weapons load-out, planning and control. The UAVs will provide surface, subsurface, shore, and deep inland surveillance, reconnaissance and electronic warfare. UCAVs 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)
HI3 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 Air and Missile 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 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. Only low to middle alternatives satisfied the follow-ship acquisition cost requirement, and only LPD-17 modified-repeat alternatives satisfied both the follow-ship and lead-ship acquisition cost requirements. **This ORD specifies the requirement for Concept Development of CUVX alternative HI3, a Wave-Piercing Tumblehome Monohull design.** Other alternatives are specified in separate ORDs. Based on the follow-ship acquisition cost ND frontier (Figure 1), HI3 is the non-dominated design at the highest cost, risk, and effectiveness end of the design space. It has a lead ship acquisition cost of $1.19B and a follow-ship acquisition cost of $772M with excellent effectiveness (OMOE=.9021) for the risk (OMOR=0.2877). It carries 28 UCAVs, has stealth characteristics, excellent aircraft weapons and fuel capacity, an Integrated Power System (IPS), and is protected by an Advanced Double Hull (ADH). Its cost and risk are above the customer's threshold, but is an excellent alternative for a challenging and innovative student project and will provide important insights into the application and benefits of potential transformational technologies.

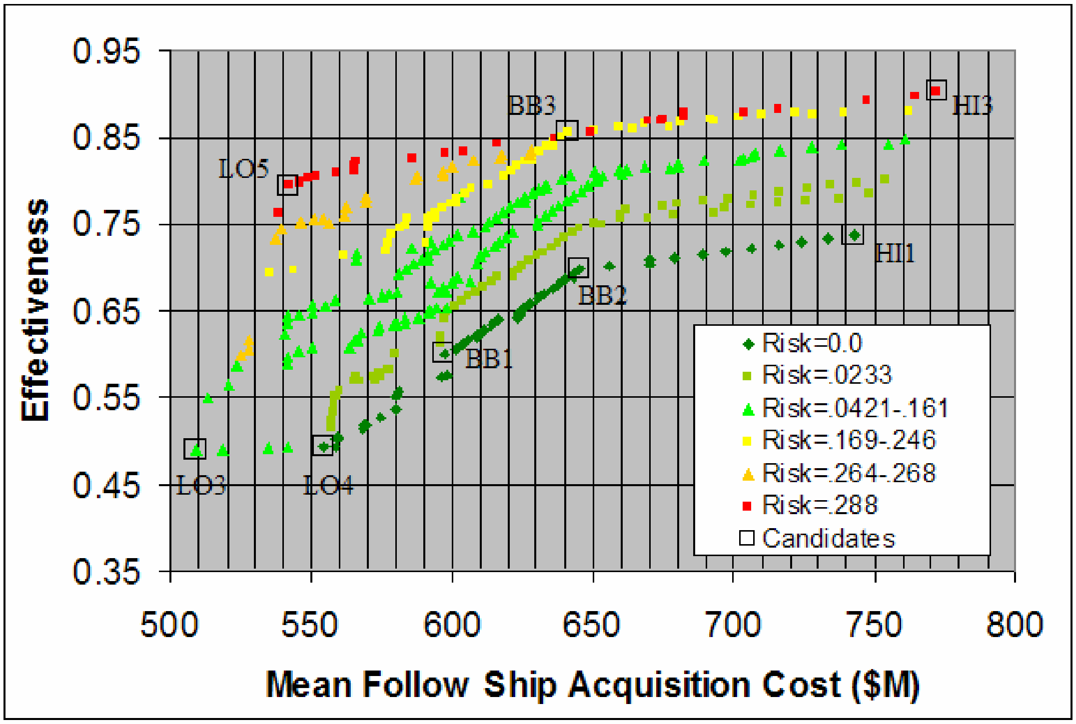


Figure 1. CUVX Non-Dominated (ND) Frontier

4. Technical Performance Measures (TPMs)

TPM	Threshold	Goal
Number of UAVs	18	20
Number of UCAVs	28	30
Number of LAMPS	4	4
Aircraft fuel capacity (MT)	1514	2032
Aircraft weapons capacity (MT)	409	450
Aircraft fuel capacity (m3)	1911	2549
Aircraft weapons magazine capacity (m3)	7846	8600
Endurance range (nm)	4000	12000
Stores duration (days)	120	120
CPS	full	full
Vs (knt)	20.00	25.00
Seakeeping (McC index)	43.36	50.00
Crew size	898	800
OMOE	0.9021	0.95
Aircraft Launch and Recovery	SS4	SS5
Unrep	SS4	SS4

5. Program Requirements

Program Requirement	Threshold	Goal
Mean follow-ship acquisition cost ($M)	775	650
Lead-ship acquisition cost ($M)	1196	750
Maximum level of risk (OMOR)	0.288	0.288

6. Baseline Ship Characteristics (HI3 Alternative)

Hullform	WPTH
Δ (MT)	29640
LWL (m)	213
Beam (m)	29.04
Draft (m)	7.01
D10 (m)	29.58
Cp	0.702
Cx	0.950
Cdl (lton/ft^3)	86
Cbt	4.100
CD10	7.200
Cvd	0.105
W1 (MT)	13450
W2 (MT)	2179
W3 (MT)	839
W4 (MT)	335
W5 (MT)	3808
W6 (MT)	1870
W7 (MT)	43
Wp (MT)	2491
Lightship Δ (MT)	24770
KG (m)	11.84
GM/B=	0.088
Hull structure	Advanced Double Hull
Propulsion system	Alternative 12: 2 shafts, IPS, 5xPC2.5V16 main propulsion diesels, 2x2500kW SSDG
Engine inlet and exhaust	Side or stern
AAW system	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 w/MK93 TAS, SSDS
Aircraft elevators	3
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 (CV) Ship Synthesis Model - CUVXHI3

Module 1 - Units and Physical Constants

$hp \equiv \frac{33000 \cdot ft \cdot lbf}{min}$ $knt \equiv 1.69 \cdot \frac{ft}{sec}$ $nm \equiv knt \cdot hr$ $lton \equiv 2240 \cdot lbf$ Air properties: $\rho_A := 0.0023817 \cdot \frac{slug}{ft^3}$ $MT \equiv g \cdot tonne$

Sea water properties: $\rho_{SW} := 1.9905 \cdot \frac{slug}{ft^3}$ $\upsilon_{SW} := 1.2817 \cdot 10^{-5} \cdot \frac{ft^2}{sec}$ Liquids specific volumes: $\delta_F := 42.3 \cdot \frac{ft^3}{lton}$

Module 2 - Input, Design Parameters Decoding and Processing:

$\delta_{AF} := 42 \cdot \frac{ft^3}{lton}$ $\delta_{LO} := 39 \cdot \frac{ft^3}{lton}$ $\delta_W := 36 \cdot \frac{ft^3}{lton}$

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

DP2 - C_P =.6-.8 $C_P = 0.7$

DP3 - C_X = .9-.99 $C_X = 0.95$

DP4 - $C_{\Delta L}$ $C_{\Delta L} = 86 \cdot \frac{lton}{ft^3}$

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)

DP5 - C_{BT} = 3.0-5.0 $C_{BT} = 4.1$

DP6 - C_{D10} = 10-15 $C_{D10} = 7.2$

DP7 = ie = 5 - 15 deg

DP8 = Launch Deck $DP_8 = 1$ 0 = DP not used

DP9 = Cvd $C_{vd} = 0.105$ $D_{10} = 29.624\ m$

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

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) $E = 4 \cdot 10^3 \cdot nm$

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

DP20 = PROP (1-13) $DP_{20} = 12$

DP21 = SHIP MANNING FACTOR $CManShip = 1$

DP22 = HULL STRUCTURE $DP_{22} = 1$ $Hull := DP_{22}$

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

DP24 = NUMBER OF UAVS $N_{UAV} = 18$

DP25 = NUMBER OF UCAVS $N_{UCAV} = 28$

DP26 = AVIATION MANNING FACTOR $CManAir = 1$

DP27 = AIRCRAFT FUEL WEIGHT PER UCAV $W_{UCAVF} = 45 \cdot lton$

DP28 = AIRCRAFT WEAPONS WEIGHT PER UCAV $W_{UCAVW} = 14 \cdot lton$

$$DP \equiv \begin{bmatrix} DES_1 & DES_2 & DES_3 & DES_4 & DES_5 & DES_6 & 0 & DES_7 & DES_8 & DES_9 & DES_{10} & 0 & 0 & 0 & 0 & 0 & 0 & DES_{11} & DES_{12} & DES_{13} & DES_{14} & DES_{15} & DES_{16} & DES_{17} & DES_{18} & DES_{19} & DES_{20} & DES_{21} \end{bmatrix}^T$$

$$DES \equiv \begin{bmatrix} 3 & 10 & 5 & 18 & 11 & 12 & 1 & 5.5 & 1 & 1 & 3 & 1 & 12 & 5 & 1 & 1 & 14 & 19 & 5 & 10 & 9 \end{bmatrix}^T$$

$$PAY \equiv \begin{bmatrix} DP_{10} & DP_{11} & DP_{12} & DP_{13} & DP_{14} & DP_{15} & DP_{16} & DP_{17} \end{bmatrix}^T$$

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)

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

DP # 2 (0-20)	DP # 3 (0-9)	DP # 4 (0-20)	DP # 5 (0-10)	
NCp ≡ 21	NCx ≡ 10	NCdl ≡ 21	NCbt ≡ 21	
Cpmin ≡ .6	Cxmin ≡ .9	Cdlmin ≡ 50.	Cbtmin ≡ 3.0	
Cpmax ≡ .8	Cxmax ≡ .99	Cdlmax ≡ 90.	Cbtmax ≡ 5.0	
DP # 6 (0-100)	**DP # 7(0-10)**	**DP # 8(0-10)**	**DP # 9(0-25)**	**DP # 21(0-5)**
NCD10 ≡ 21	Nei ≡ 0	NCrd ≡ 0	NCvd ≡ 26	NCManShip ≡ 6
CD10min ≡ 6.0	eimin ≡ 5.	Crdmin ≡ 0.	Cvdmin ≡ .05	CManShipmin ≡ .5
CD10max ≡ 8.0	eimax ≡ 15.	Crdmax ≡ .5	Cvdmax ≡ .3	CManShipmax ≡ 1.

DP # 26 (0-5)	DP # 27 (0-10)	DP # 28 (0-10)
NCManAir ≡ 6	NWUCAVF ≡ 11	NWUCAVW ≡ 11
CManAirmin ≡ .5	WUCAVFmin ≡ 15.	WUCAVWmin ≡ 5.
CManAirmax ≡ 1.	WUCAVFmax ≡ 45.	WUCAVWmax ≡ 15.

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

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

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

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

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

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

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

$N_{HANGDK} := 3$

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

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

$A_{HANGDK} = 1.604 \cdot 10^4\ m^2$

$A_{HANGmax} = 1.203 \cdot 10^4\ m^2$

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

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

$PAY_2 = 1$

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

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

C4I

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

$PAY_4 = 0$

NSFS

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

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

$$PAY6 := \begin{cases} (101\ 78) & \text{if } PAY_6 = 1 \\ (77\ 78) & \text{if } PAY_6 = 2 \\ (76\ 78) & \text{otherwise} \end{cases} \qquad PAY_6 = 0$$

$$SON_{TYP} := \begin{cases} 0 & \text{if } (DP_1 = 1 \lor DP_1 = 3) \land PAY_3 = \\ 1 & \text{if } (DP_1 = 2 \lor DP_1 = 4) \land PAY_3 \ne \\ 2 & \text{otherwise} \end{cases}$$

$SON_{TYP} := 0$

STK

$PAY7 := (0\ 0) \qquad VOP_7 = 0$

MCM

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

MCM and ASUW MOP:

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

VLS & VLS WEAPONS

$$PAY9 := \begin{cases} (102\ 103\ 104\ 82\ 94) & \text{if } PAY_1 = 4 \\ (0\ 0) & \text{otherwise} \end{cases} \qquad PAY_1 = 4 \qquad PAY_8 = 0$$

AVIATION

$N_{UAV} \equiv DP_{24} + 4 \qquad N_{UAV} = 18 \qquad W_{UAV} := 440 \cdot lbf \qquad A_{UAV} := 50 \cdot ft^2$

$N_{UCAV} \equiv DP_{25} + 9 \qquad N_{UCAV} = 28 \qquad W_{UCAV} := 26500 \cdot lbf \qquad A_{UCAV} := 960 \cdot ft^2 \qquad A_{HELO} := 800 \cdot ft^2$

$N_{HELO} = 4 \qquad W_{HELO} := 6.36 \cdot lton \qquad L_{FltReq} := 100 \cdot m \quad B_{FltReq} := 25 \cdot m \quad L_{Flt} := .75 \cdot LWL \qquad W_{UCAV} = 11.83 \cdot lton$

$W_{F23} := N_{HELO} \cdot W_{HELO} + N_{UAV} \cdot W_{UAV} + N_{UCAV} \cdot W_{UCAV} \qquad W_{F23} = 360.226 \cdot lton$ (ordnance delivery -aircraft)

$N_{AirElev} := 3$ (internal, not D/E) $\qquad N_{cat} := 2 \qquad N_{WeapElev} := 4$

$W_{WeapElev} := 10. \cdot MT \cdot N_{WeapElev} \qquad A_{WeapElev} := 16. \cdot m^2 \cdot N_{WeapElev} \qquad W_{WeapElev} = 39.368 \cdot lton \qquad A_{WeapElev} = 64\ m^2$

$W_{ACElev} := 48. \cdot MT \cdot N_{AirElev} \qquad W_{ACElev} = 141.726 \cdot lton$

$W_{AirSCat} := 15. \cdot N_{cat} \cdot W_{UCAV} \qquad W_{AirSCat} = 354.911 \cdot lton \qquad W_{AirEMALS} := 10.1 \cdot N_{cat} \cdot W_{UCAV} \qquad W_{AirEMALS} = 242.808 \cdot MT$

$W_{AirRec} := 5.5 \cdot W_{UCAV} \qquad W_{AirRec} = 66.111 \cdot MT$

$A_{LandR} := 42.8 \cdot \frac{m^2}{MT} \cdot W_{UCAV} \qquad A_{LandR} = 514.464\ m^2 \qquad A_{AirMaintShops} := A_{UCAV} \cdot \frac{N_{UCAV} + N_{HELO}}{10}$

$W_{AirSupE} := 3.4 \cdot MT \cdot (N_{UCAV} + N_{HELO}) \qquad W_{AirSupE} = 107.082 \cdot lton \qquad A_{AirMaintShops} = 285.398\ m^2$

$W_{UCAVF} = 45 \cdot lton \qquad W_{UAVF} := 5.0 \cdot lton \qquad W_{HELOF} := 32.2 \cdot lton$

$W_{F42} := N_{HELO} \cdot W_{HELOF} + N_{UAV} \cdot W_{UAVF} + N_{UCAV} \cdot W_{UCAVF} \qquad W_{F42} = 1.479 \cdot 10^3 \cdot lton$ (total ship aircraft fuel weight)

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

Strike Mission MOP: $VOP_{28} := .3 \cdot DP_8 + .7 \cdot \text{if}\left(\frac{N_{UCAV} - 10}{20} \le 1, \frac{N_{UCAV} - 10}{20}, 1.0\right) \qquad VOP_{28} = 0.93 \qquad DP_8 = 1$

SEAD Mission MOP: $VOP_{30} := VOP_{28} \qquad VOP_{30} = 0.93$

ISR Mission MOP: $VOP_{31} := \text{if}\left(\frac{N_{UAV} - 5}{15} \le 1, \frac{N_{UAV} - 5}{15}, 1.0\right) \qquad VOP_{31} = 0.867$

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

Ship Aircraft Weapons Capacity MOP: $VOP_{11} := \frac{DP_{28}}{NWUCAVW - 1} \qquad VOP_{11} = 0.9$

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")

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

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

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

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

$$BATKW_{400} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(P400)} \mathrm{if}\left(P400_{m,1} = PAY_n, P400_{m,6}, 0\right) \cdot \mathrm{kW}$$

$$TRANKW_{400} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(P400)} \mathrm{if}\left(P400_{m,1} = PAY_n, P400_{m,7}, 0\right) \cdot \mathrm{kW}$$

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

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

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

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

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

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

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

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

$$W_{P600} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(P600)} \mathrm{if}\left(P600_{m,1} = PAY_n, P600_{m,2}, 0\right) \cdot \mathrm{lton}$$

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

$$AHULL_{600} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(P600)} \mathrm{if}\left(P600_{m,1} = PAY_n, P600_{m,4}, 0\right) \cdot \mathrm{ft}^2$$

$$ADH_{600} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(P600)} \mathrm{if}\left(P600_{m,1} = PAY_n, P600_{m,5}, 0\right) \cdot \mathrm{ft}^2 \qquad AHULL_{600} := AHULL_{600} + ADH_{600} \qquad ADH_{600} := 0 \cdot \mathrm{m}^2$$

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

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

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

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

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

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

$$W_{F20} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(PF20)} \mathrm{if}\left(PF20_{m,1} = PAY_n, PF20_{m,2}, 0\right) \cdot \mathrm{lton} + W_{F23} + W_{UCAVW} \cdot N_{UCAV}$$

$$VCD_{F20} := \frac{\sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(PF20)} \mathrm{if}\left(PF20_{m,1} = PAY_n, PF20_{m,2} \cdot PF20_{m,3}, 0\right) \cdot \mathrm{lton} \cdot \mathrm{ft} - W_{F23} \cdot 1.5 \cdot H_{HANGDK} - 3.0 \cdot N_{UCAV} \cdot W_{UCAVW} \cdot H}{W_{F20}}$$

$$BATKW_{F20} := \sum_{n=1}^{\mathrm{rows}(PAY)} \sum_{m=1}^{\mathrm{rows}(PF20)} \mathrm{if}\left(PF20_{m,1} = PAY_n, PF20_{m,6}, 0\right) \cdot \mathrm{kW} \qquad VCD_{F20} = -40.444 \cdot \mathrm{ft}$$

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

$$AHULL_{F20} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF20)} if\left(PF20_{m,1} = PAY_n, PF20_{m,4}, 0\right) \cdot ft^2 + N_{UCAV} \cdot W_{UCAVW} \cdot 6.4 \cdot \frac{m^2}{MT} \qquad N_{UCAV} \cdot W_{UCAVW} \cdot 6.4 \cdot \frac{m^2}{MT} = 2.744 \cdot 10^4 \cdot ft^2$$

$$ADH_{F20} := \sum_{n=1}^{rows(PAY)} \sum_{m=1}^{rows(PF20)} if\left(PF20_{m,1} = PAY_n, PF20_{m,5}, 0\right) \cdot ft^2 \qquad AHULL_{F20} = 2.815 \cdot 10^4 \cdot ft^2 \qquad 6.4 \cdot m^2 = 68.8$$

$VCD_{F42} := -1.5 \cdot H_{HANGDK}$ $\quad VCD_{F42} = -29.528 \cdot ft$

$W_{VP} := W_{F20} + W_{F42}$ $\quad VCD_{VP} := \frac{W_{F20} \cdot VCD_{F20} + W_{F42} \cdot VCD_{F42}}{W_{VP}}$ $\quad VCD_{VP} = -33.437 \cdot ft$ $\quad VCD_{F20} = -40.$

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

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

$BATKW_{PAY} := BATKW_{400} + BATKW_{500} + BATKW_{700} + BATKW_{F20}$ $\quad VCD_P = -9.883\ m$

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

$A_{HPA} := AHULL_{500} + AHULL_{600} + AHULL_{700} + AHULL_{F20}$ $\quad A_{HPA} = 2.962 \cdot 10^4 \cdot ft^2$ $\quad TRANKW_{PAY} = 636.27 \cdot kW$

$A_{DPA} := ADH_{500} + ADH_{600} + ADH_{700} + ADH_{F20}$ $\quad D_{10} = 29.624\ m$

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

$VCG_P := VCD_P + D_{10}$ $\quad VCG_{VP} := VCD_{VP} + D_{10}$ $\quad VCG_{700} := VCD_{700} + D_{10}$ $\quad D_{10} = 97.193 \cdot ft$ $\quad VCG_{VP} = 63.756 \cdot ft$

Payload Weights and VCG Summary

$W_P = 2.457 \cdot 10^3 \cdot lton$ $\quad VCG_P = 19.741\ m$

$W_{VP} = 2.304 \cdot 10^3 \cdot lton$ $\quad VCG_{VP} = 63.756 \cdot ft$ (Variable Payload = WF20+WF42)

$W_{P100} = 4 \cdot lton$ $\quad W_{P400} = 99.39 \cdot lton$ $\quad W_{P500} = 7.43 \cdot lton$ $\quad W_{P600} = 0 \cdot lton$ $\quad W_7 = 42.4 \cdot lton$

$VCG_{P100} = 21.744\ m$ $\quad VCG_{P400} = 24.988\ m$ $\quad VCG_{P500} = 18.803\ m$ $\quad VCG_{P600} = 23.624\ m$ $\quad VCG_{700} = 24.19\ m$

$W_{F42} = 1.479 \cdot 10^3 \cdot lton$ (aircraft fuel) $\quad W_{F20} = 824.976 \cdot lton$

$W_{F23} = 360.226 \cdot lton$ (aircraft)

Payload Area Requirements

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

In hull: $A_{HPC} = 435.437\ m^2$ $\quad A_{HPA} = 2.752 \cdot 10^3\ m^2$

Where 'PC' index stands for Command & Surveillance (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): $SON_{TYP} = 0$

Payload Electrical Requirements

$BATKW_{PAY} = 696.54 \cdot kW$

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

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

2d. Endurance parameters and MOPs:

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

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

2e. CBR Protection and MOP:

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

2f. Propulsion System:

$PSYS_{TYP} := \begin{cases} 1 & \text{if } 1 \le DP_{20} \le 5 \\ 2 & \text{otherwise} \end{cases}$ $\quad \eta := \begin{cases} .98 & \text{if } 1 \le DP_{20} \le 5 \\ .92 & \text{otherwise} \end{cases}$ (Propulsion System Type 1 - Mechanical 2 - IPS)

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

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

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

$0.210 \cdot \frac{kg}{kW \cdot hr} = 0.345 \cdot$

$16.16 \cdot m =$

$.4 \cdot m^2 =$

$8514 \cdot m^3 =$

$122.6 \cdot MT =$

$P_{BPENGTOT} = 5.2 \cdot 10^4 \cdot hp$

$SFC_{ePE} = 0.211 \cdot \frac{kg}{kW \cdot hr}$

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

$H_{MBreq} = 7.59\cdot m$

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

$w_{MBreq} = 17.94\ m$

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

$L_{MBreq} = 16.36\ m$

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

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

$A_{PIE} = 14.5\ m^2$

$V_{MBreq} = 1.113\cdot 10^4\ m^3$

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

$W_{BM} = 2.051\cdot 10^3 \cdot MT$

$$KW_G := \begin{cases} 2500\cdot kW & \text{if } (DP_{20}=4)+(DP_{20}=5)+(DP_{20}=8)+(DP_{20}=12)+(DP_{20}=14) \\ 3000\cdot kW & \text{otherwise} \end{cases}$$

$KW_G = 2.5\cdot 10^3 \cdot kW$

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

$N_{SSG} = 2$

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

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

$$A_{GIE} := \begin{cases} 10.8\cdot m^2 & \text{if } (DP_{20}=1)+(DP_{20}=2)+(DP_{20}=3) \\ 1.0\cdot m^2 & \text{if } (DP_{20}=4)+(DP_{20}=5) \\ 0.4\cdot m^2 & \text{if } (DP_{20}=8)+(DP_{20}=12)+(DP_{20}=14) \\ 7.2\cdot m^2 & \text{otherwise} \end{cases}$$

$W_{BMG} = 122.6 \cdot MT$

$SFC_{eG} = 0.211 \cdot \frac{kg}{kW\cdot hr}$

$A_{GIE} = 0.4\ m^2$

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

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

$H_{MB} := D_{10} - N_{HANGDK} \cdot H_{HANGDK} - 1 \cdot m$ $H_{MB} = 10.624 \cdot m$ $H_{MBreq} = 7.59\ m$

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

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

$A_{HIE} := 1.4 \cdot (N_{HPIE} \cdot A_{PIE} + N_{HGIE} \cdot A_{GIE})$ $A_{HIE} = 673.606 \cdot ft^2$

$A_{DIE} := 0 \cdot m^2$ (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:

$CManShip \equiv 1$ $N_{OShip} := 3 + \mathrm{ceil}\left(N_{prop} + \frac{N_{SSG}}{5} + \frac{W_P - W_{VP}}{15 \cdot lton} + \frac{V_{FL} + V_D}{80000 \cdot ft^3}\right)$ $N_{OShip} = 48$

$N_{EShip} := \mathrm{ceil}\left[CManShip \cdot \left(N_{prop} \cdot 6 + N_{SSG} \cdot 3 + \frac{W_P - W_{VP}}{10 \cdot lton} + \frac{V_{FL} + V_D}{4450 \cdot ft^3}\right)\right]$ $N_{EShip} = 534$

$CManAir \equiv 1$ $N_{OAir} := \mathrm{ceil}\left(\frac{.1}{MT} \cdot W_{F23}\right)$ $N_{OAir} = 19$ $N_O := N_{OAir} + N_{OShip}$ $N_O = 67$

$N_{EAir} := \mathrm{ceil}\left(CManAir \cdot \frac{1.5}{MT} \cdot W_{F23}\right)$ $N_{EAir} = 297$ $N_E := N_{EAir} + N_{EShip}$ $N_E = 831$

N_T defines the total crew size, N_A the additional accommodations: $N_T := N_{EShip} + N_{OShip} + N_{EAir} + N_{OAir}$ $N_T = 898$

Repair - MOP14: $N_A := \mathrm{ceil}(.1 \cdot N_T)$ $N_A = 90$

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

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): $V_{ADH} := (B + 2 \cdot T) \cdot .6 \cdot LWL \cdot 1 \cdot m$

$VOP_{20} := \begin{cases} 0.0 & \text{if } HullForm = 5 \\ DP_{22} & \text{otherwise} \end{cases}$ $V_{ADH} = 5.531 \cdot 10^3\ m^3$

$Hull \equiv 1$ $VOP_{20} = 1$

Module 3 - Ship Resistance and Powering

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

3a. Hull Surface Area, Coefficients and Dimensions:

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

$V =$ (knt)

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

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

$L_R := (1 - C_P) \cdot LWL$ $L_R = 63.989\ m$ (Run length)

$C_V := \frac{V_{FL}}{LWL^3}$ $C_V = 3.008 \cdot 10^{-3}$ $T_F := T$ $T_F = 7.085\ m$

$h_B := \sqrt{\frac{A_{BT}}{\pi}}$ $h_B = 0.243\ m$ (height of bulb center)

$C_W = 0.863$

$A_T := \frac{B \cdot T \cdot C_X}{5}$ $A_T = 39.103\ m^2$ (transom area)

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

3b. Viscous Drag

Coefficient of friction: $S_1 = 7.547 \cdot 10^4 \cdot ft^2$

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

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

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

$C_{RLPD_i} := 1.0$

$C_{R1_i} := C_{RFS_i} \quad C_{R2_i} := C_{RUS_i}$

Mercier-Savitsky $\qquad x_i := Fn_{V_i}$

$$A_{1_i} := \begin{cases} -2.5777\,(x_i)^2 + 5.826\,x_i - 3.183 & \text{if } x_i<1.3 \\ 0.306\,(x_i)^2 - 0.8724\,x_i + 0.6517 & \text{if } 1.3\le x_i<1.5 \\ -2.6233\,(x_i)^3 + 13.151\,(x_i)^2 - 21.851\,x_i + 12.072 & \text{otherwise} \end{cases}$$

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

$$A_{4_i} := \begin{cases} 0.1289\cdot(x_i)^2 - 0.2977\cdot x_i + 0.1572 & \text{if } x_i<1.5 \\ 0 & \text{otherwise} \end{cases}$$

$$A_{5_i} := \begin{cases} 3.8592\cdot(x_i)^2 - 8.8358\cdot x_i + 4.9126 & \text{if } x_i<1.3 \\ -2.28\cdot(x_i)^2 + 6.1117\cdot x_i - 4.143 & \text{if } 1.3\le x_i<1.5 \\ 15.027\cdot(x_i)^3 - 75.445\cdot(x_i)^2 + 125.73\cdot x_i - 69.667 & \text{otherwise} \end{cases}$$

$$A_{6_i} := \begin{cases} 0 & \text{if } x_i\le 1.1 \\ 4.6418\,(x_i)^2 - 12.243\,x_i + 7.8504 & \text{if } 1.1<x_i<1.4 \\ -2.8417\,(x_i)^3 + 13.864\,(x_i)^2 - 22.39\,x_i + 11.775 & \text{otherwise} \end{cases}$$

$$A_{7_i} := \begin{cases} 6.5917\,(x_i)^3 - 26.223\,(x_i)^2 + 34.006\,x_i - 14.268 & \text{if } x_i<1.3 \\ -1.3915\,(x_i)^2 + 3.6749\,x_i - 2.3213 & \text{if } 1.3\le x_i<1.5 \\ 2.0067\,(x_i)^3 - 10.076\,(x_i)^2 + 16.786\,x_i - 9.2203 & \text{otherwise} \end{cases}$$

$$A_{8_i} := \begin{cases} 45.873\,(x_i)^3 - 207.82\,(x_i)^2 + 293.16\cdot x_i - 130.24 & \text{if } x_i\le 1.3 \\ -0.95\,(x_i)^2 + 3.396\,x_i - 2.3742 & \text{if } 1.3<x_i<1.5 \\ 16.164\,(x_i)^2 - 50.725\,x_i + 40.302 & \text{if } 1.5\le x_i<1.7 \\ 1.4664\,x_i - 1.7109 & \text{otherwise} \end{cases}$$

$$A_{9_i} := \begin{cases} -0.2767\,(x_i)^3 + 1.0115\,(x_i)^2 - 1.2201\,x_i + 0.4825 & \text{if } x_i<1.3 \\ -0.07\,(x_i)^2 + 0.1873\,x_i - 0.1272 & \text{if } 1.3<x_i<1.5 \\ 0.003\,(x_i)^2 - 0.0077\,x_i + 0.0011 & \text{otherwise} \end{cases}$$

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

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

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

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

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

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

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

$$R_{eq_i} := W_m\cdot\left(A_{1_i} + A_{2_i}\cdot X + A_{4_i}\cdot U + A_{5_i}\cdot Y + A_{6_i}\cdot X\cdot Z + A_{7_i}\cdot X\cdot U + A_{8_i}\cdot X\cdot Y + A_{9_i}\cdot Z\cdot U + A_{10_i}\cdot Z\cdot Y + A_{15_i}\cdot Y^2 \ldots + A_{18_i}\cdot X\cdot Y^2 + A_{19_i}\cdot Z\cdot X^2 + A_{24_i}\cdot U\cdot Y^2 + A_{27_i}\cdot Y\cdot U^2\right)$$

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

Holtrop

$$c_3 := \frac{.56\cdot A_{BT}^{1.5}}{B\cdot T\cdot\left(.31\cdot\sqrt{A_{BT}} + T_F - h_B\right)} \qquad c_3 = 3.124\cdot 10^{-5} \qquad c_2 := \exp\left(-1.89\cdot\sqrt{c_3}\right) \qquad c_2 = 0.989$$

$$c_5 := 1 - \frac{.8\cdot A_T}{B\cdot T\cdot C_M} \qquad c_5 = 0.84$$

$$\lambda_R := \begin{cases} 1.446\cdot C_P - .03\cdot\frac{LWL}{B} & \text{if } \frac{LWL}{B}<12 \\ 1.446\cdot C_P - .036 & \text{otherwise} \end{cases} \qquad \lambda_R = 0.792$$

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

$$c_7 := \begin{cases} .229577\cdot\left(\frac{B}{LWL}\right)^{.33333} & \text{if } \frac{B}{LWL}<.11 \\ .5 - .0625\cdot\frac{LWL}{B} & \text{if } \frac{B}{LWL}>.25 \\ \frac{B}{LWL} & \text{otherwise} \end{cases} \qquad c_7 = 0.136$$

$$c_{16} := \begin{cases} 8.07981\cdot C_P - 13.8673\cdot C_P^2 + 6.984388\cdot C_P^3 & \text{if } C_P<.8 \\ 1.73014 - .7067\cdot C_P & \text{otherwise} \end{cases} \qquad c_{16} = 1.257$$

$$i_E := 1 + 89\cdot\exp\left[-\left(\frac{LWL}{B}\right)^{.80856}\cdot\left(1 - C_W\right)^{.30484}\cdot\left(1 - C_P\right)^{.6367}\cdot\left(\frac{L_R}{B}\right)^{.34574}\cdot\left(\frac{100\cdot V_{FL}}{LWL^3}\right)^{.16302}\right] \qquad i_E = 23.57$$

$$c_1 := 2223105 \cdot c_7^{3.78613} \cdot \left(\frac{T}{B}\right)^{1.07961} \cdot (90 - i_E)^{-1.37565} \qquad c_1 = 0.795$$

$$m_1 := .0140407 \cdot \frac{LWL}{T} - 1.75254 \cdot \frac{V_{FL}^{\frac{1}{3}}}{LWL} - 4.79323 \cdot \frac{B}{LWL} - c_{16} \qquad m_1 = -1.74$$

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

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

$$P_B := \frac{.56 \cdot A_{BT}^{.5}}{(T_F - 1.5 \cdot h_B)} \qquad P_B = 0.036$$

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

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

3d. Bare Hull Resistance

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

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

A := READPRN("worm.prn")

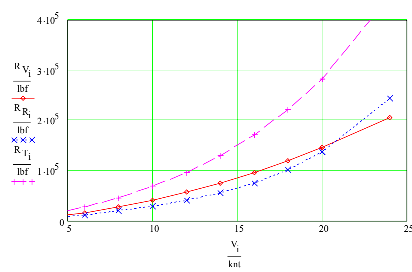
$$R_{V_i} := \begin{cases} 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_i \cdot C_{F_i} & \text{if HullForm} = 1 \\ 0.5 \cdot \rho_{SW} \cdot (V_i)^2 \cdot S_1 \cdot C_{F_i} & \text{if HullForm} = 2 \\ \left[\left(C_{F_i} - C_{f_i} + C_A\right) \cdot \frac{1}{2} \cdot \frac{S_{eq}}{V_{FL}^{\frac{2}{3}}}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

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

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

V = (·knt)

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



3e. Ship Effective Horsepower

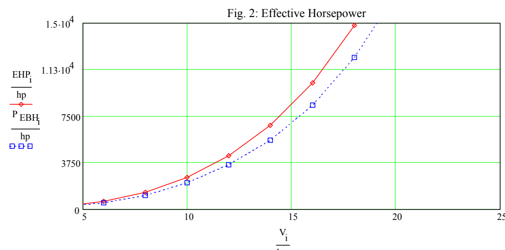
Bare hull: $P_{EBH_i} := R_{T_i} \cdot V_i$ $\qquad P_{Efins_i} := \begin{cases} 0 \cdot hp & \text{if } N_{fins} = 0 \\ 0.02 \cdot P_{EBH_i} & \text{otherwise} \end{cases} \qquad P_{EAPP_i} := \begin{cases} 0 \cdot hp & \text{if HullForm} = 1 \\ 0.05 \cdot P_{EBH_i} & \text{otherwise} \end{cases}$

Air frontal area (+5% for masts, equip., etc): $A_W := 1.05 \cdot B \cdot (D_{10} - T + H_{DK})$ $\qquad A_W = 778.969\ m^2$

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

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

Fig. 2: Effective Horsepower



3f. Propulsion Power Balance

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

$$SHP_i := \frac{EHP_i}{PC} \qquad SHP_S := SHP_{11} \qquad SHP_S = 2.907 \cdot 10^4 \cdot hp \qquad SHP_e := SHP_{10} \qquad SHP_e = 36337 \cdot hp$$

Required installed power (with 25% for fouling and sea state): $P_{IREQ} := \frac{1.25 \cdot SHP_S}{\eta}$ $\qquad P_{IREQ} = 39493.4 \cdot hp$

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 heel (DDS-079-1).
- ensure longitudinal strength.
- contain machinery box (in height).

$$M := \begin{bmatrix} 0.21 \cdot B + T \\ \dfrac{LWL}{15} \\ H_{MBreq} + N_{HANGDK} \cdot H_{HANGDK} + 1 \cdot m \end{bmatrix} \quad M = \begin{bmatrix} 13.185 \\ 14.22 \\ 26.59 \end{bmatrix} m \quad D_{10MIN} := \max(M) \quad D_{10MIN} = 26.59\ m \quad D_{10}$$

$$D_{0MIN} := 2.011827 \cdot T - \frac{6.36215 \cdot 10^{-6}}{ft} \cdot LWL^2 + 2.780649 \cdot 10^{-2} \cdot LWL \quad D_{0MIN} = 19.235\ m \quad D_0 := D_{10} \quad D_0 = 29.624\ m$$

$$D_{20MIN} := 0.014 \cdot LWL \cdot \left(2.125 + \frac{1.25 \cdot 10^{-3}}{ft} \cdot LWL\right) + T \quad D_{20MIN} = 16.043\ m \quad D_{20} := D_{10} \quad D_{20} = 29.624\ m$$

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

$$A_{PRO} := \frac{LWL}{0.98} \cdot \frac{F_0 + 4 \cdot F_{10} + F_{20}}{6}$$ (Trapezoidal rule)

$$flare := \begin{cases} -10 \cdot deg & \text{if } HullForm = 6 \\ 0 \cdot deg & \text{otherwise} \end{cases} \quad C_W = 0.863$$

$$F_{AV} := \frac{A_{PRO}}{LWL} \quad F_{AV} = 22.999\ m \quad D_{AV} := F_{AV} + T \quad D_{AV} = 30.084\ m \quad F_{AV} = 75.457 \cdot ft$$

Above water hull volume: $V_{HAW} := F_{AV}^2 \cdot \tan(flare) \cdot LWL + LWL \cdot B \cdot C_W \cdot F_{AV}$ $\quad V_{HAW} = 1.031 \cdot 10^5\ m^3$ $\quad V_{HAW} = 3.641 \cdot 10^6 \cdot ft^3$

Total hull volume: $V_{HT} := V_{HUW} + V_{HAW}$ $\quad V_{HT} = 1.323 \cdot 10^5\ m^3$ $\quad V_{HUW} = 1.031 \cdot 10^6 \cdot ft^3$

Cubic number: $CN := \dfrac{V_{HT}}{10^5 \cdot ft^3}$ $\quad CN = 46.723$

Total ship volume: $V_T := V_{HT} + V_D$ $\quad V_T = 135369.256\ m^3$

Machinery box

$H_{MB} = 10.624\ m \quad V_{MB} := \dfrac{H_{MB}}{H_{MBreq}} \cdot V_{MBreq} \quad V_{MB} = 1.558 \cdot 10^4\ m^3$

Module 5 - Electrical Load

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

(SWBS 200, propulsion). $KW_P := 0.00323 \cdot \dfrac{kW}{hp} \cdot P_{BPENGTOT}$ $\quad KW_P \equiv 168 \cdot kW$

(SWBS 561, steering). $KW_S := 0.00826 \cdot \dfrac{kW}{ft^2} \cdot LWL \cdot T$ $\quad KW_S \equiv 29.9 \cdot kW$

$V_T = 4.781 \cdot 10^6 \cdot ft^3$

(SWBS 300, electric plant, lighting). $KW_E := 0.000213 \cdot \dfrac{kW}{ft^3} \cdot V_T$ $\quad KW_E \equiv 500.8 \cdot kW$

(SWBS 430+475, miscelaneous). $KW_M := 101.4 \cdot kW$ $\quad KW_M \equiv 111.5 \cdot kW$

(Collective Protection System) $KW_{CPS} := 0.000135 \cdot \dfrac{kW}{ft^3} \cdot V_T$ $\quad KW_{CPS} = 645.37 \cdot kW$

(SWBS 517, aux boiler). $KW_B := 0.235 \cdot N_T \cdot kW$ $\quad KW_B \equiv 3913.5 \cdot kW$

(SWBS 521, firemain). $KW_F := 0.000097 \cdot \dfrac{kW}{ft^3} \cdot V_T$ $\quad KW_F \equiv 257.6 \cdot kW$

(SWBS 540, fuel handling). $KW_{HN} := 0.000177 \cdot \dfrac{kW}{ft^3} \cdot V_{HT}$ $\quad KW_{HN} \equiv 113.4 \cdot kW$

(SWBS 530+550, misc aux). $KW_A := 0.65 \cdot N_T \cdot kW + KW_{fins}$ $\quad KW_A \equiv 626 \cdot kW$

(SWBS 600, services). $KW_{SERV} := 0.395 \cdot N_T \cdot kW$ $\quad KW_{SERV} \equiv 342 \cdot kW$

The calculations are iterative, because KW_M, 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) $\quad KW_{NP} = 6.063 \cdot 10^6\ W$

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

$EDMF = 1.1 \quad EFMF = 1.1$

$KW_{MFL} = 9.633 \cdot 10^3 \cdot kW$

$KW_{MFLM} := EDMF \cdot EFMF \cdot KW_{MFL}$ $\quad KW_{MFLM} = 1.166 \cdot 10^4 \cdot kW$ (MFL w/margins)

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

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

$$KW_{AC} := 0.67 \cdot \left[0.1 \cdot kW \cdot N_T + 0.00067 \cdot \frac{kW}{ft^3} \cdot (V_T - V_{MB} - V_{AUX}) + 0.1 \cdot BATKW_{PAY}\right] \quad KW_{AC} = 1.955 \cdot 10^3 \cdot kW$$

$KW_V := 0.103 \cdot (KW_{AC} + BATKW_{PAY}) + KW_{CPS}$ (Ventilation) $\quad KW_V = 918.498 \cdot kW$

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

$$KW_{GREQmech} := \begin{cases} \dfrac{KW_{MFLM}}{(N_{SSG} - 1) \cdot 0.9} & \text{if } PSYS_{TYP} = 1 \\ 0.0 \cdot kW & \text{otherwise} \end{cases} \quad KW_{GREQmech} = 0 \cdot kW$$

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

$KW_{24} := 0.5\cdot(KW_{MFLM} - KW_P - KW_S) + 1\cdot(KW_P + KW_S)$ $KW_{24} = 5.927\cdot10^3\,kW$

Including design margin: $KW_{24AVG} := E24MF\cdot KW_{24}$ $KW_{24AVG} = 5187\cdot kW$

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

$P_{IPRP} := \begin{cases} P_{BPENGTOT} & \text{if } PSYS_{TYP} = 1 \\ P_{BPENGTOT} - KW_{MFLM} & \text{otherwise} \end{cases}$ $P_{BPENGTOT} = 3.878\cdot10^4\,kW$ $P_{IPRP} = 2.712\cdot10^4\,kW$ $P_{IPRP} = 3.637\cdot10^4\,hp$

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):

$P_{eBAVG} := \frac{1.1\cdot SHP_e}{\eta}$ $P_{eBAVG} = 4.345\cdot10^4\,hp$

Correction for instrumentation inaccuracy and machinery design changes:

$f_1 := \begin{cases} 1.04 & \text{if } 1.1\cdot SHP_e \le \frac{1}{3}\cdot\frac{P_{BPENGTOT}}{2} \\ 1.03 & \text{if } 1.1\cdot SHP_e \ge \frac{2}{3}\cdot\frac{P_{BPENGTOT}}{2} \\ 1.02 & \text{otherwise} \end{cases}$ $SFC_{ePE} = 0.347\,\frac{lb}{hp\cdot hr}$ $\frac{lb}{hp\cdot hr} = 1.341\,\frac{lb}{kW\cdot hr}$

Specified fuel rate: $FR_{SP} := f_1\cdot SFC_{ePE}\cdot g$ $FR_{SP} = 0.357\,\frac{lbf}{hp\cdot hr}$

Average fuel rate allowing for plant deterioration: $FR_{AVG} := 1.05\cdot FR_{SP}$ $FR_{AVG} = 0.375\,\frac{lbf}{hp\cdot hr}$

Burnable propulsion endurance fuel weight: $W_{BP} := \frac{E}{V_e}\cdot P_{eBAVG}\cdot FR_{AVG}$ $W_{BP} = 1.455\cdot10^3\,lton$

Tailpipe allowance: $TPA := 0.95$

Required propulsion fuel weight: $W_{FP} := \frac{W_{BP}}{TPA}$ $W_{FP} = 1.532\cdot10^3\,lton$

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

$V_{FP} := 1.02\cdot1.05\cdot\delta_F\cdot W_{FP}$ $V_{FP} = 1.965\cdot10^3\,m^3$

Fuel for generator systems: $SFC_{GE24} := SFC_{ePE}$ $SFC_{GE24} = 0.465\,\frac{lb}{kW\cdot hr}$

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

Specified fuel rate: $FR_{GSP} := f_{1e}\cdot SFC_{GE24}\cdot g$

Average fuel rate, allowing for plant deterioration: $FR_{GAVG} := 1.05\cdot FR_{GSP}$ $FR_{GAVG} = 0.508\,\frac{lbf}{kW\cdot hr}$

Burnable electrical endurance fuel weight: $W_{Be} := \frac{E}{V_e}\cdot KW_{24AVG}\cdot FR_{GAVG}$ $W_{Be} = 235.254\,lton$

Required electrical fuel weight: $W_{Fe} := \frac{W_{Be}}{TPA}$ $W_{Fe} = 247.636\,lton$

Required electrical fuel volume: $V_{Fe} := 1.02\cdot1.05\cdot\delta_F\cdot W_{Fe}$ $V_{Fe} = 317.679\,m^3$

Total fuel weight and tanks volume: $W_{F41} := W_{FP} + W_{Fe}$ $W_{F41} = 1.779\cdot10^3\,lton$

$V_F := V_{FP} + V_{Fe}$ $V_F = 2.283\cdot10^3\,m^3$

6b. Other Tanks

Aircraft fuel: $V_{AF} := 1.02\cdot1.05\cdot W_{F42}\cdot\delta_{AF}$ $V_{AF} = 1.884\cdot10^3\,m^3$

Lubrication oil: $W_{F46} := 17.6\cdot lton$ $V_{LO} := 1.02\cdot1.05\cdot W_{F46}\cdot\delta_{LO}$ $V_{LO} = 20.817\,m^3$

Potable water: (Water does not expand). $W_{F52} := N_T\cdot0.45\cdot lton$ $W_{F52} = 404.1\,lton$

$V_W := 1.02\cdot W_{F52}\cdot\delta_W$ $V_W = 420.181\,m^3$

Sewage: $V_{SEW} := (N_T + N_A)\cdot2.005\cdot ft^3$ $V_{SEW} = 56.094\,m^3$

Waste oil: $V_{WASTE} := 0.02\cdot V_F$ $V_{WASTE} = 45.656\,m^3$

Clean ballast: $V_{BAL} := if(BAL_{TYP} = 1, 0.19\cdot V_F, 0.275\cdot V_F)$ $V_{BAL} = 433.736\,m^3$

Total tankage volume required: $V_{TK} := V_F + V_{AF} + V_{LO} + V_W + V_{SEW} + V_{WASTE} + V_{BAL}$ $V_{TK} = 5.143\cdot10^3\,m^3$

6c. Required Area $V_{TK} := if(.5\cdot V_{ADH} > V_{TK}, V_{ADH}, V_{TK} + .5\cdot V_{ADH})$

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): $A_{HPR} := 1.15\cdot A_{HPA} + 1.23\cdot A_{HPC}$ $A_{HPR} = 3.7\cdot10^3\,m^2$

Hangar Deck Area

$A_{AirPark} := N_{UAV}\cdot A_{UAV} + N_{UCAV}\cdot A_{UCAV} + N_{HELO}\cdot A_{HELO}$ $A_{AirPark} = 2.878\cdot10^3\,m^2$ $DP_8 = 1$

$A_{AirElev} := 2\cdot A_{UCAV}\cdot N_{AirElev}\cdot N_{HANGDK}$ $A_{AirElev} = 1.605\cdot10^3\,m^2$ $A_{AirPit} := \begin{cases} 3\cdot A_{UCAV} & \text{if } DP_8 = 1 \\ 0\cdot m^2 & \text{otherwise} \end{cases}$

$A_{AirPit} = 267.561\,m^2$

$A_{AirMaint} := 2\cdot A_{UCAV}$ $A_{AirMaint} = 178.374\,m^2$ $A_{AirLaunch} := \begin{cases} 100\cdot m\cdot B_{FltReq} + 3\cdot A_{UCAV} & \text{if } DP_8 = 1 \\ 0\cdot m^2 & \text{otherwise} \end{cases}$

$A_{AirLaunch} = 2.768\cdot10^3\,m^2$ $A_{HIE} = 62.58\,m^2$

$A_{HangarReq} := (A_{AirPark} + A_{AirElev} + A_{AirPit} + A_{AirMaint} + A_{WeapElev})\cdot1.3 + A_{AirLaunch} + A_{HIE}$

$A_{HangarReq} = 1.003\cdot10^5\,ft^2$ $A_{HANGmax} = 1.203\cdot10^4\,m^2$ $V_{HANG} := A_{HangarReq}\cdot H_{HANGDK}$ $V_{HANG} = 1.975\cdot10^6\,ft^3$

Living Deck Area

Assumption is that officers live at deckhouse, and enlisted at hull. At deckhouse:

$A_{COXO} := 225\cdot ft^2$ $A_{DO} := 75\cdot N_O\cdot ft^2$ $A_{DL} := A_{COXO} + A_{DO}$ $A_{DL} = 487.741\,m^2$

At hull: $A_{HAB} := 50\cdot ft^2$ $A_{HL} := A_{HAB}\cdot(N_T + N_A) - A_{DL}$ $A_{HL} = 4.102\cdot10^3\,m^2$

Other Ship areas

Hull stores: $A_{HS} := 300\cdot ft^2 + 0.0158\cdot\frac{ft^2}{lb}\cdot N_T\cdot9\cdot\frac{lb}{day}\cdot T_S$ $A_{HS} = 1.451\cdot10^3\,m^2$

Ship Maintenance: $A_{DM} := 0.05\cdot(A_{DPR} + A_{DL})$ $A_{DM} = 73.004\,m^2$

Bridge and chart room: $A_{DB} := 16\cdot ft\cdot(B - 18\cdot ft)$ $A_{DB} = 114.907\,m^2$

Ship functions in hull: $A_{HSF} := 1500\cdot ft^2\cdot CN$ $A_{HSF} = 6.511\cdot10^3\,m^2$

6d. Total Required Area/Volume

Hull: $A_{HR} := A_{HPR} + A_{HL} + A_{HS} + A_{HSF} + A_{LandR} + A_{AirMaintShops} + A_{AirFuel} + (A_{DL} + A_{DM} + A_{DB})$

$A_{HR} = 1.976 \cdot 10^{4}\ m^{2}$

$V_{HR} := H_{DK} \cdot A_{HR}$ $\quad V_{HR} = 5.928 \cdot 10^{4}\ m^{3}$

Deckhouse: $A_{DR} := A_{DPR}$ $\quad A_{DR} = 972.337\ m^{2}$

$V_{DR} := H_{DK} \cdot A_{DR}$ $\quad V_{DR} = 2.917 \cdot 10^{3}\ m^{3}$

Total: $A_{TR} := A_{HR} + A_{DR}$ $\quad A_{TR} = 2.073 \cdot 10^{4}\ m^{2}$

$V_{TR} := V_{HR} + V_{DR}$ $\quad V_{TR} = 6.22 \cdot 10^{4}\ m^{3}$

Available hull volume: $V_{HA} := V_{HT} - V_{MB} - V_{AUX} - V_{TK} - V_{HANG}$ $\quad V_{HA} = 4.969 \cdot 10^{4}\ m^{3}$

Available hull area: $A_{HA} := \frac{V_{HA}}{H_{DK}}$ $\quad A_{HA} = 1.656 \cdot 10^{4}\ m^{2}$

Available deckhouse area: $A_{DA} := \frac{V_{D}}{H_{DK}}$ $\quad A_{DA} = 1.022 \cdot 10^{3}\ m^{2}$

Total available area: $A_{TA} := A_{HA} + A_{DA}$ $\quad V_{TA} := H_{DK} \cdot A_{TA}$ $\quad A_{TA} = 1.759 \cdot 10^{4}\ m^{2}$

Area effectiveness: $ERR_{A} := \frac{A_{TA} - A_{TR}}{A_{TR}}$ $\quad ERR_{A} = -0.152$

Module 7 - Weight

SWBS 200

$W_{BM} = 2.019 \cdot 10^{3} \cdot lton$ (SWBS 200 minus 243-245)

Shafting (SWBS 243): $f_{S} := if(N_{prop} = 1, 0.3, 0.45)$ $\quad f_{S} := if(PSYS_{TYP} = 1, f_{S}, N_{prop} \cdot .1)$ $\quad f_{S} = 0.2$

$W_{S} := 0.47 \cdot \frac{lton}{ft} \cdot LWL \cdot f_{S}$ $\quad W_{S} = 65.78 \cdot lton$

$D_{P} := .7 \cdot T$ $\quad D_{P} = 16.271 \cdot ft$

Propulsors (245): FP: $f_{PR} := .084$ $\quad W_{PR} := f_{PR} \cdot lbf \left(\frac{D_{P}}{ft}\right)^{5.497 - \frac{0.0433}{ft} \cdot D_{P}} \cdot N_{prop}$ $\quad W_{PR} = 47.945 \cdot lton$

Bearings (244): $W_{B} := 0.11 \cdot (W_{S} + W_{PR})$ $\quad W_{B} = 12.71 \cdot MT$ $\quad$ CRP: $f_{PR} := .127$

Total 243-245: $W_{ST} := W_{S} + W_{B} + W_{PR}$ $\quad W_{ST} = 128.26 \cdot MT$

Total for propulsion: $W_{2} := W_{BM} + W_{ST}$ $\quad W_{2} = 2179 \cdot MT$ $\quad KW_{MFLM} = 1.166 \cdot 10^{4} \cdot kW$

SWBS 300

$W_{BMG} = 120.664 \cdot lton$ (SWBS 300 minus 320-330) $\quad LWL = 699.787 \cdot ft$

$W_{dist} := .0003 \cdot \frac{MT}{kW \cdot m} \cdot KW_{MFLM} \cdot LWL$ $\quad W_{dist} = 734.039 \cdot lton$ $\quad .0003 \cdot \frac{MT}{kW \cdot m} = 9 \cdot 10^{-5} \cdot \frac{lton}{kW \cdot ft}$

$W_{light} := .001 \cdot \frac{MT}{m^{3}} \cdot (V_{T} - V_{TK})$ $\quad W_{light} = 127.461 \cdot MT$ $\quad .001 \cdot \frac{MT}{m^{3}} = 2.787 \cdot 10^{-5} \cdot \frac{lton}{ft^{3}}$

$W_{3} := W_{BMG} + W_{dist} + W_{light}$ $\quad W_{3} = 835 \cdot MT$

SWBS 400 - Command and Surveillance

Gyro/IC/Navigation (420+430): $W_{IC} := 2.95 \cdot 10^{-5} \frac{lton}{ft^{3}} \cdot V_{T}$ $\quad W_{IC} = 141.025 \cdot lton$

Other/Misc: $W_{CO} := 1.05 \cdot CN \cdot lton$ $\quad W_{CO} = 49.059 \cdot lton$

Cabling: $W_{CC} := 0.14 \cdot (W_{P400} + W_{IC} + W_{CO})$ $\quad W_{CC} = 40.526 \cdot lton$

Total (less W498): $W_{4} := W_{P400} + W_{IC} + W_{CO} + W_{CC}$ $\quad W_{4} = 335 \cdot MT$

SWBS 500

Aux system operating fluids: $W_{598} := 0.0000745 \cdot V_{T} \cdot \frac{lton}{ft^{3}}$ $\quad W_{598} = 3.549 \cdot 10^{6}\ N$

$$W_{AUX} := \left[0.000772 \cdot \left(\frac{V_{T}}{ft^{3}}\right)^{1.443} + 5.14 \cdot \frac{V_{T}}{ft^{3}} + 6.19 \cdot \left(\frac{V_{T}}{ft^{3}}\right)^{0.7224} + 377 \cdot N_{T} + 2.74 \cdot \frac{P_{BPENGTOT}}{hp}\right] \cdot 10^{-4} \cdot lton \cdot .82$$

$W_{AirAux} := W_{WeapElev} + W_{ACElev} + W_{AirL} + W_{AirRec} + W_{AirSupE}$ $\quad W_{AirAux} = 592.216 \cdot lton$ $\quad W_{AUX} = 2.364 \cdot 10^{3} \cdot lton$

Environmental support: $W_{593} := .032 \cdot MT \cdot N_{T}$ $\quad W_{593} = 28.282 \cdot lton$ $\quad .032 \cdot MT = 0.031 \cdot lton$

Total: $W_{5} := W_{AUX} + W_{P500} + W_{593} + W_{598} + W_{CPS} + W_{AirAux}$ $\quad W_{5} = 3433 \cdot MT$

SWBS 600

Hull fittings (610+620+630): $W_{OFH} := \frac{0.00025}{ft^{3}} \cdot (V_{T} - V_{TK}) \cdot lton$ $\quad W_{OFH} = 1.125 \cdot 10^{3} \cdot lton$

Personnel related (640+650+660+670): $W_{OFP} := 0.8 \cdot (N_{T} - 9.5) \cdot lton$ $\quad W_{OFP} = 710.8 \cdot lton$

Total: $W_{6} := W_{OFH} + W_{OFP} + W_{P600}$ $\quad W_{6} = 1870 \cdot MT$

SWBS 100 $\quad W_{7} = 43 \cdot MT$

Hull (110 .. 140,160,190):

$W_{BH} := C_{HMAT} 1.0 \cdot (1.68341 \cdot CN^{2} + 167.1721 \cdot CN - 103.283) \cdot lton$ $\quad CN = 46.723$

$W_{BH} := \begin{cases} 1.1 \cdot W_{BH} & \text{if } DP_{22} = 1 \\ W_{BH} & \text{otherwise} \end{cases}$ $\quad DP_{22} = 1$ $\quad W_{BH} = 1.164 \cdot 10^{4} \cdot lton$

Deckhouse (150): $\rho_{DH} := if(C_{DHMAT} = 1, 0.00168, .0007)$ $\quad C_{DHMAT} = 2$

$W_{DH} := \rho_{DH} \cdot \frac{lton}{ft^{3}} \cdot V_{D}$ $\quad W_{DH} = 75.771 \cdot lton$

Masts (171): (Assuming the same mast). $\quad W_{171} := 2 \cdot lton$

Foundations (180): $W_{180} := 0.0735 \cdot (W_{BH} + W_{2} + W_{3} + W_{4} + W_{5} + W_{6} + W_{7})$ $\quad W_{180} = 1549 \cdot MT$

Total: $W_{1} := W_{BH} + W_{DH} + W_{171} + W_{180} + W_{P100}$ $\quad W_{1} = 13445 \cdot MT$

Weight Summary

SWBS weight: $W_{SWBS} := \sum_{i=1}^{7} W_{i}$ $\quad W_{SWBS} = 22140 \cdot MT$

Margin for future growth: $W_{M24} := WMF \cdot \left(\sum_{i=1}^{7} W_{i}\right)$ $\quad W_{M24} = 2214 \cdot MT$

Lightship weight: $W_{LS} := \sum_{i=1}^{7} W_i + W_{M24}$ $\quad W_{LS} = 24393 \cdot MT$

Provisions: $W_{F31} := N_T \cdot 2.45 \cdot 10^{-3} \cdot \frac{lton}{day} \cdot T_S$ $\quad W_{F31} = 264.012 \cdot lton$ $\quad W_{LS} = 2.401 \cdot 10^4 \cdot lton$

General stores: $W_{F32} := 0.00071 \cdot \frac{lton}{day} \cdot T_S \cdot N_T + 0.0049 \cdot lton \cdot N_T$ $\quad W_{F32} = 80.91 \cdot lton$

Crew: $W_{F10} := 236 \cdot lbf \cdot N_E + 400 \cdot lbf \cdot (N_O + 1)$ $\quad W_{F10} = 99.695 \cdot lton$

Total weight:

$W_T := W_{LS} + W_P + W_{F41} + W_{F46} + W_{F52} + W_{F31} + W_{F32} + W_{F10}$ $\quad W_T = 29671 \cdot MT$

$ERR := \frac{W_{FL} - W_T}{W_T}$ $\quad ERR = 9.201 \cdot 10^{-3}$ $\quad F_P := \frac{W_P}{W_T}$ $\quad F_P = 0.084$

Module 8 - Stability

Calculate light ship weight groups center of gravity and moment.

$VCG_{BH} := 0.4 \cdot D_{10}$ $\quad VCG_{BH} = 11.85\ m$ $\quad P_1 := W_{BH} \cdot VCG_{BH}$ $\quad P_1 = 4.527 \cdot 10^5 \cdot lton \cdot ft$

$VCG_{DH} := D_{10} + .5 \cdot H_{DK}$ $\quad VCG_{DH} = 31.124\ m$ $\quad P_2 := W_{DH} \cdot VCG_{DH}$ $\quad P_2 = 7.737 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{180} := 0.2 \cdot D_{10}$ $\quad VCG_{180} = 5.925\ m$ $\quad P_3 := W_{180} \cdot VCG_{180}$ $\quad P_3 = 2.963 \cdot 10^4 \cdot lton \cdot ft$

$VCG_{171} := D_{10} + 0.05 \cdot LWL$ $\quad VCG_{171} = 40.289\ m$ $\quad P_4 := W_{171} \cdot VCG_{171}$ $\quad P_4 = 264.364 \cdot lton \cdot ft$

$P_{100} := P_1 + P_2 + P_3 + P_4 + W_{P100} \cdot VCG_{P100}$ $\quad VCG_{100} := \frac{P_{100}}{W_1}$ $\quad VCG_{100} = 11.301\ m$

$VCG_{200} := .6 \cdot H_{MB} + 2 \cdot m$ $\quad VCG_{200} = 8.375\ m$ $\quad P_{200} := W_2 \cdot VCG_{200}$ $\quad P_{200} = 5.892 \cdot 10^4 \cdot lton \cdot ft$

$VCG_{300} := 0.35 \cdot D_{10}$ $\quad VCG_{300} = 10.369\ m$ $\quad P_{300} := W_3 \cdot VCG_{300}$ $\quad P_{300} = 2.796 \cdot 10^4 \cdot lton \cdot ft$

$VCG_{IC} := .5 \cdot D_{10}$ $\quad VCG_{IC} = 14.812\ m$ $\quad P_9 := W_{IC} \cdot VCG_{IC}$ $\quad P_9 = 6.853 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{CO} := 0.45 \cdot D_{10}$ $\quad VCG_{CO} = 13.331\ m$ $\quad P_{10} := W_{CO} \cdot VCG_{CO}$ $\quad P_{10} = 2.146 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{CC} := 0.45 \cdot D_{10}$ $\quad VCG_{CC} = 13.331\ m$ $\quad P_{11} := W_{CC} \cdot VCG_{CC}$ $\quad P_{11} = 1.772 \cdot 10^3 \cdot lton \cdot ft$

$P_{400} := P_9 + P_{10} + P_{11} + W_{P400} \cdot VCG_{P400}$ $\quad VCG_{400} := \frac{P_{400}}{W_4}$ $\quad VCG_{400} = 17.49\ m$

$VCG_{AUX} := 0.4 \cdot D_{10}$ $\quad VCG_{AUX} = 11.85\ m$ $\quad P_{13} := W_{AUX} \cdot VCG_{AUX}$ $\quad P_{13} = 9.189 \cdot 10^4 \cdot lton \cdot ft$

$P_{500} := P_{13} + W_{P500} \cdot VCG_{P500}$ $\quad VCG_{500} := \frac{P_{500}}{W_5}$ $\quad VCG_{500} = 8.331\ m$

$VCG_{OFH} := 0.4 \cdot D_{10}$ $\quad VCG_{OFH} = 11.85\ m$ $\quad P_{15} := W_{OFH} \cdot VCG_{OFH}$ $\quad P_{15} = 4.375 \cdot 10^4 \cdot lton \cdot ft$

$VCG_{OFP} := 0.6 \cdot D_{10}$ $\quad VCG_{OFP} = 17.775\ m$ $\quad P_{16} := W_{OFP} \cdot VCG_{OFP}$ $\quad P_{16} = 4.145 \cdot 10^4 \cdot lton \cdot ft$

$P_{600} := P_{15} + P_{16} + W_{P600} \cdot VCG_{P600}$ $\quad VCG_{600} := \frac{P_{600}}{W_6}$ $\quad VCG_{600} = 14.11\ m$

Total light ship vertical moment is (note that variable payload is deducted):

$P_{WG} := P_{100} + P_{200} + P_{300} + P_{400} + P_{500} + P_{600} + W_7 \cdot VCG_{700}$ $\quad P_{WG} = 7.773 \cdot 10^5 \cdot lton \cdot ft$

Vertical CG of light ship: $VCG_{LS} := \frac{P_{WG}}{W_{LS} - W_{M24}}$ $\quad VCG_{LS} = 35.61 \cdot ft$ $\quad VCD_{VP} = -33.437 \cdot ft$

Here we assume that the 10% weight margin's CG location is at the CG of light ship.

$KG_{LS} := VCG_{LS}$ $\quad KG_{LS} = 35.61 \cdot ft$ $\quad W_{LS} = 2 \cdot 10^4 \cdot lton$ $\quad W_{VP} = 2.304 \cdot 10^3 \cdot lton$ $\quad VCG_{VP} = 63.756 \cdot ft$ $\quad D_{10} = 97.193 \cdot ft$

Calculate variable loads weight group center of gravity and moment:

$VCG_{F10} := 0.6 \cdot D_{10}$ $\quad VCG_{F10} = 58.316 \cdot ft$ $\quad P_{17} := W_{F10} \cdot VCG_{F10}$ $\quad P_{17} = 5.814 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{F31} := 0.423 \cdot D_{AV}$ $\quad VCG_{F31} = 41.751 \cdot ft$ $\quad P_{18} := W_{F31} \cdot VCG_{F31}$ $\quad P_{18} = 1.102 \cdot 10^4 \cdot lton \cdot ft$

$VCG_{F32} := 0.42 \cdot D_{AV}$ $\quad VCG_{F32} = 41.455 \cdot ft$ $\quad P_{19} := W_{F32} \cdot VCG_{F32}$ $\quad P_{19} = 3.354 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{F41} := 1 \cdot m$ $\quad VCG_{F41} = 3.281 \cdot ft$ $\quad P_{20} := W_{F41} \cdot VCG_{F41}$ $\quad P_{20} = 5.838 \cdot 10^3 \cdot lton \cdot ft$

$VCG_{F46} := 2 \cdot m$ $\quad VCG_{F46} = 6.562 \cdot ft$ $\quad P_{21} := W_{F46} \cdot VCG_{F46}$ $\quad P_{21} = 115.486 \cdot lton \cdot ft$

$VCG_{F52} := 0.138 \cdot D_{AV}$ $\quad VCG_{F52} = 13.621 \cdot ft$ $\quad P_{22} := W_{F52} \cdot VCG_{F52}$ $\quad P_{22} = 5.504 \cdot 10^3 \cdot lton \cdot ft$

Total loads moment: $P_{WGL} := P_{17} + P_{18} + P_{19} + P_{20} + P_{21} + P_{22} + W_{VP} \cdot VCG_{VP}$ $\quad P_{WGL} = 1.785 \cdot 10^5 \cdot ft \cdot lton$

Total variable loads weight: $W_L := W_{F10} + W_{F31} + W_{F32} + W_{F41} + W_{F46} + W_{F52} + W_{VP}$ $\quad W_L = 4.95 \cdot 10^3 \cdot lton$

Vertical center of gravity: $VCG_L := \frac{P_{WGL}}{W_L}$ $\quad VCG_L = 36.069 \cdot ft$

$KG := \frac{W_{LS} \cdot KG_{LS} + W_L \cdot VCG_L}{W_{LS} + W_L} + KG_{MARG}$ $\quad KG_{MARG} = 3.281 \cdot ft$ $\quad KG = 11.878 \cdot m$

$C_{IT} := -0.537 + 1.44 \cdot C_W$ $\quad C_{IT} = 0.706$ $\quad C_W = 0.863$

$KB := \frac{T}{3} \cdot \left(2.4 - \frac{C_P \cdot C_X}{C_W}\right)$ $\quad KB = 12.627 \cdot ft$ $\quad BM := \frac{LWL \cdot B^3 \cdot C_{IT}}{12 \cdot V_{FL}}$ $\quad BM = 34.57 \cdot ft$

$GM := KB + BM - KG$ $\quad GM = 8.227 \cdot ft$ $\quad C_{GMB} := \frac{GM}{B}$ $\quad C_{GMB} = 0.086$

Module 9 - Design Balance / Summary

$W_{FL1} := \frac{W_P}{0.1}$ $\quad W_{FL1} = 2.457 \cdot 10^4 \cdot lton$ $\quad$ (First iteration only).

$W_T = 2.967 \cdot 10^4 \cdot MT$ $\quad W_{FL} = 29944 \cdot MT$ $\quad V_{FL} = W_{FL} \cdot 34.98 \cdot \frac{ft^3}{lton}$ $\quad V_{FL} = 2.919 \cdot 10^4\ m^3$

Froude Scaling Factors: $R_{FS} = \sqrt[3]{\frac{V_{FL}}{V_{FS}}}$ $\quad R_{FS} = 0.997$ $\quad R_{US} = \sqrt[3]{\frac{V_{FL}}{V_{US}}}$ $\quad R_{US} = 0.912$ $\quad R_{LPD} = \sqrt[3]{\frac{V_{FL}}{V_{LPD}}}$ $\quad R_{LPD} = 1.05$

$$C_X = \begin{cases} C_{XFS} & \text{if HullForm} = 1 \\ C_{XUS} & \text{if HullForm} = 2 \\ C_{XLPD} & \text{if HullForm} = 5 \\ Cxmin + DP_3 \cdot \frac{(Cxmax - Cxmin)}{NCx - 1} & \text{otherwise} \end{cases}$$

$$C_{\Delta L} = \begin{cases} \frac{W_{FL}}{\left(\frac{L_{FS} \cdot R_{FS}}{100}\right)^3} & \text{if HullForm} = 1 \\ \frac{W_{FL}}{\left(\frac{L_{US} \cdot R_{US}}{100}\right)^3} & \text{if HullForm} = 2 \\ \frac{W_{FL}}{\left(\frac{L_{LPD}}{100}\right)^3} & \text{if HullForm} = 5 \\ \left[Cdlmin + DP_4 \cdot \frac{(Cdlmax - Cdlmin)}{NCdl - 1}\right] \cdot \frac{lton}{ft^3} & \text{otherwise} \end{cases}$$

$$C_P = \begin{cases} \frac{V_{FL}}{L_{FS} \cdot R_{FS}^3 \cdot A_{XFS}} & \text{if HullForm} = 1 \\ \frac{V_{FL}}{L_{US} \cdot R_{US}^3 \cdot A_{XUS}} & \text{if HullForm} = 2 \\ C_{PLPD} & \text{if HullForm} = 5 \\ Cpmin + DP_2 \cdot \frac{(Cpmax - Cpmin)}{NCp - 1} & \text{otherwise} \end{cases}$$

$$C_{BT} \equiv \begin{cases} C_{BTFS} & \text{if HullForm}=1 \\ C_{BTUS} & \text{if HullForm}=2 \\ C_{BTLPD} & \text{if HullForm}=5 \\ \left[Cbtmin + DP_5 \cdot \frac{(Cbtmax - Cbtmin)}{NCbt - 1}\right] & \text{otherwise} \end{cases} \qquad C_M \equiv C_X \qquad CN = 46.723$$

$$LWL \equiv \begin{cases} L_{FS} \cdot R_{FS} & \text{if HullForm}=1 \\ L_{US} \cdot R_{US} & \text{if HullForm}=2 \\ L_{LPD} & \text{if HullForm}=5 \\ 100 \cdot \sqrt[3]{\frac{W_{FL}}{C_{\Delta L}}} & \text{otherwise} \end{cases} \qquad B \equiv \begin{cases} B_{FS} \cdot R_{FS} & \text{if HullForm}=1 \\ B_{US} \cdot R_{US} & \text{if HullForm}=2 \\ B_{LPD} & \text{if HullForm}=5 \\ \sqrt{\frac{C_{BT} \cdot V_{FL}}{C_P \cdot C_X \cdot LWL}} & \text{otherwise} \end{cases} \qquad T \equiv \begin{cases} T_{FS} \cdot R_{FS} & \text{if HullForm}=1 \\ T_{US} \cdot R_{US} & \text{if HullForm}=2 \\ T_{LPD} & \text{if HullForm}=5 \\ \frac{V_{FL}}{C_P \cdot C_X \cdot LWL \cdot B} & \text{otherwise} \end{cases}$$

$$A_X \equiv C_X \cdot B \cdot T \qquad C_B \equiv \frac{V_{FL}}{LWL \cdot B \cdot T} \qquad C_W \equiv \begin{cases} C_{WFS} & \text{if HullForm}=1 \\ C_{WUS} & \text{if HullForm}=2 \\ C_{WLPD} & \text{if HullForm}=5 \\ 0.278 + 0.836 \cdot C_P & \text{otherwise} \end{cases} \qquad D_{10} \equiv \begin{cases} D_{LPD} & \text{if HullForm}=5 \\ \frac{LWL}{C_{D10}} & \text{otherwise} \end{cases}$$

$LWL = 213.295\,m$ $B = 29.048\,m$ $T = 7.02\,m$ $D_{10} = 29.624\,m$ $A_X = 195.516\ m^2$ $\frac{LWL}{B} = 7.343$

$C_P = 0.7$ $C_X = 0.95$ $C_{\Delta L} = 86\,\frac{lton}{ft^3}$ $C_{BT} = 4.1$ $C_{D10} = 7.2$ $C_{vd} = 0.105$ $C_B = 0.665$ $C_W = 0.863$

Balance Check:

	Required/Minimal	Available	Error
Weight:	$W_T = 2.967 \cdot 10^4\,MT$	$W_{FL} = 2.994 \cdot 10^4\,MT$	$ERR = 9.201 \cdot 10^{-3}$
Arrangeable area:	$A_{TR} = 2.073 \cdot 10^4\,m^2$	$A_{TA} = 1.759 \cdot 10^4\,m^2$	$ERR_A = -0.152$
Hangar Area:	$A_{HangarReq} = 9.322 \cdot 10^3\ m^2$	$A_{HANGmax} = 1.203 \cdot 10^4\ m^2$	
Deckhouse area:	$A_{DR} = 972.337\ m^2$	$A_{DA} = 1.022 \cdot 10^3\ m^2$	$V_D \equiv C_{vd} \cdot V_{FL}$ $V_D = 1.082 \cdot 10^5\,ft^3$
Propulsion power:	$P_{IREQ} = 3.949 \cdot 10^4\,hp$	$P_{IPRP} = 3.637 \cdot 10^4\,hp$	$N_T = 898$
Electrical plant:	$KW_{GREQmech} = 0\,kW$	$KW_G = 2.5 \cdot 10^3\,kW$	
Mach. box height:	$H_{MBreq} = 7.59\ m$	$H_{MB} = 10.624\ m$	
Depth:	$D_{10MIN} = 26.59\,m$	$D_{10} = 29.624\,m$	
Sustained Speed:	$V_e = 20\,knt$	$V_S \equiv 20.\cdot knt$	
Stability:	.07-.2	$C_{GMB} = 0.086$	
Length of Flight Deck:	$L_{FltReq} = 100\ m$	$L_{Flt} = 159.971\ m$	
Breadth of Flight Deck:	$B_{FltReq} = 25\ m$	$B = 29.048\ m$	

$$V_{airweap} := AHULL_{F20} \cdot H_{DK} \qquad W_{airweap} := \frac{V_{airweap}}{\left(6.4 \cdot \frac{m^2}{MT}\right) \cdot H_{DK}}$$

$V_{airweap} = 7.846 \cdot 10^3\,m^3$ $W_{airweap} = 408.655\,MT$

Module 10 - SIMPLIFIED COST MODEL

$Mdol := coul$ $Bdol := 1000 \cdot Mdol$ $Kdol := \frac{Mdol}{1000}$ $dol := \frac{Kdol}{1000}$ $i1 := 1, 2 .. 7$ $W_{F42} = 1.503 \cdot 10^3\,MT$

Costed Military Payload: (helo and helo fuel weight not included) $V_{AF} = 1.884 \cdot 10^3\ m^3$

$W_{MP} := \left[(W_4 + W_7) - W_{IC}\right] + W_{F20} - W_{F23}$ $W_{MP} = 695.755\,lton$

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: $K_{N1} := \frac{.8 \cdot Mdol}{lton^{.772}}$ $C_{L_1} := .03395 \cdot F_I \cdot K_{N1} \cdot (W_1)^{.772}$ $C_{L_1} = 71.262\,Mdol$

+ Propulsion: $K_{N2} := \frac{1.0 \cdot Mdol}{hp^{.808}}$ $C_{L_2} := .00186 \cdot F_I \cdot K_{N2} \cdot P_{BPENGTOT}^{.808}$ $C_{L_2} = 20.752\,Mdol$

+ Electric: $K_{N3} := \frac{1.0 \cdot Mdol}{lton^{.91}}$ $C_{L_3} := .07505 \cdot F_I \cdot K_{N3} \cdot (W_3)^{.91}$ $C_{L_3} = 58.185\,Mdol$

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

$K_{N4} := \frac{2.0 \cdot Mdol}{lton^{.617} \cdot (CManShip + CManAir)}$ $C_{L_4} := .10857 \cdot F_I \cdot K_{N4} \cdot (W_4)^{.617}$ $C_{L_4} = 6.705\,Mdol$

+ Auxiliary: $K_{N5} := \frac{2.0 \cdot Mdol}{lton^{.782} \cdot (CManShip + CManAir)}$ $C_{L_5} := .09487 \cdot F_I \cdot K_{N5} \cdot (W_5)^{.782}$ $C_{L_5} = 94.11\,Mdol$

+ Outfit: $K_{N6} := \frac{1.0 \cdot Mdol}{lton^{.784}}$ $C_{L_6} := .09859 \cdot F_I \cdot K_{N6} \cdot (W_6)^{.784}$ $C_{L_6} = 61.738\,Mdol$

+ Armament: (Less payload GFM cost)

$K_{N7} := \frac{1.0 \cdot Mdol}{lton^{.987}}$ $C_{L_7} := .00838 \cdot F_I \cdot K_{N7} \cdot (W_7)^{.987}$ $C_{L_7} = 0.583\,Mdol$

+ Margin Cost: $C_{LM} := \frac{W_{M24}}{(W_{LS} - W_{M24})} \cdot \left(\sum_{i1} C_{L_{i1}}\right)$ $C_{LM} = 31.278\,Mdol$

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

$$K_{N8} := \begin{cases} \frac{2.\cdot Mdol}{Mdol^{1.099}} & \text{if HullForm}=5 \\ \frac{10.\cdot Mdol}{Mdol^{1.099}} & \text{otherwise} \end{cases} \qquad K_{N8} = 10\,\frac{Mdol}{Mdol^{1.099}} \qquad C_{L_8} := .034 \cdot K_{N8} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099} \qquad C_{L_8} = 208.932\,Mdol$$

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

$$K_{N9} := \begin{cases} \frac{.5 \cdot Mdol}{(Mdol)^{.839}} & \text{if HullForm}=5 \\ \frac{2.\cdot Mdol}{(Mdol)^{.839}} & \text{otherwise} \end{cases} \qquad K_{N9} = 2\,\frac{Mdol}{(Mdol)^{.839}} \qquad C_{L_9} := .135 \cdot K_{N9} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{.839} \qquad C_{L_9} = 36.323\,Mdol$$

= Total Lead Ship Construction Cost: (BCC)

$$C_{LCC} := \sum_{i1} C_{L_{i1}} + C_{L_8} + C_{L_9} + C_{LM} \qquad C_{LCC} = 589.868\,Mdol$$

+ Profit: $F_P := .10$ $C_{LP} := F_P \cdot C_{LCC}$ $C_{LP} = 58.987 \cdot Mdol$

= Lead Ship Price: $P_L := C_{LCC} + C_{LP}$ $P_L = 648.855 \cdot Mdol$

+ Change Orders: $C_{LCORD} := .12 \cdot P_L$ $C_{LCORD} = 77.863 \cdot Mdol$

= Total Shipbuilder Portion: $C_{SB} := P_L + C_{LCORD}$ $C_{SB} = 726.718 \cdot Mdol$

Lead Ship Cost - Government Portion

Other support: $C_{LOTH} := .025 \cdot P_L$ $C_{LOTH} = 16.221 \cdot Mdol$

+ 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)

$C_{LMPG} := \left(.3 \cdot \frac{Mdol}{lton} \cdot W_{MP}\right) \cdot F_I$ $C_{LMPG} = 360.241 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{LHMEG} := .02 \cdot P_L$ $C_{LHMEG} = 12.977 \cdot Mdol$

+ Outfittimg Cost : $C_{LOUT} := .04 \cdot P_L$ $C_{LOUT} = 25.954 \cdot Mdol$

= Total Government Portion: $C_{LGOV} := C_{LOTH} + C_{LPMG} + C_{LMPG} + C_{LHMEG} + C_{LOUT}$

$C_{LGOV} = 415.393 \cdot Mdol$

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

* Total End Cost: $C_{LEND} := C_{SB} + C_{LGOV}$ $C_{LEND} = 1.142 \cdot 10^3 \cdot Mdol$

Total Lead Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{LPDEL} := .05 \cdot P_L$ $C_{LPDEL} = 32.443 \cdot Mdol$

= Total Lead Ship Acquisition Cost: $C_{LA} := C_{LEND} + C_{LPDEL}$ $C_{LA} = 1.175 \cdot 10^3 \cdot Mdol$ ($FY2005)

10c. Follow-Ship (N_S/2 th ship) Cost:

Total Ship Acquisition: $N_S := 30$ Production Rate (per year): $R_P := 2$

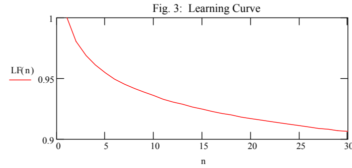
Learning Rate: (for every doubling of number of units) $R_L := .98$

$LF(n) := R_L^{\frac{\ln(n)}{\ln(2)}}$ $n := 1..N_S$

Average Follow Ship Learning Cost Factor:

$F_{LAV} := \frac{\sum_{n=2}^{N_S} LF(n)}{N_S - 1}$ $F_{LAV} = 0.928$

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

$C_{FOL_{i1}} := F_L \cdot F_{IFOL} \cdot C_{L_{i1}}$ $C_{FM} := F_L \cdot F_{IFOL} \cdot C_{LM}$ $C_{FM} = 33.866 \cdot Mdol$

$C_{FOL_8} := \frac{.03 \cdot Mdol}{Mdol^{1.099}} \cdot \left(\sum_{i1} C_{L_{i1}} + C_{LM}\right)^{1.099}$ $C_{FOL_8} = 18.435 \cdot Mdol$ $C_{FOL_8} = 18.435 \cdot Mdol$

$C_{FOL_9} := F_L \cdot F_{IFOL} \cdot .5 \cdot C_{L_9}$

Total Follow Ship Construction Cost: (BCC) $C_{FCC} := \sum_{i1} C_{FOL_{i1}} + C_{FOL_8} + C_{FOL_9} + C_{FM}$ $C_{FCC} = 411.224 \cdot Mdol$

+ Profit: $F_P := .1$ $C_{FP} := F_P \cdot C_{FCC}$ $C_{FP} = 41.122 \cdot Mdol$

= Follow Ship Price: $P_F := C_{FCC} + C_{FP}$ $P_F = 452.346 \cdot Mdol$

+ Change Orders: $C_{FCORD} := .08 \cdot P_F$ $C_{FCORD} = 36.188 \cdot Mdol$

= Total Follow Ship Shipbuilder Portion: $C_{FSB} := P_F + C_{FCORD}$ $C_{FSB} = 488.534 \cdot Mdol$

Follow Ship Cost - Government Portion

Other support: $C_{FOTH} := .025 \cdot P_F$ $C_{FOTH} = 11.309 \cdot Mdol$

+ Program Manager's Growth: $C_{FPMG} := 0 \cdot P_F$

+ Ordnance and Electrical GFE: (Military Payload GFE) number of helo's: $N_{HELO} = 4$

$C_{FMPG} := \left(.15 \cdot \frac{Mdol}{lton} \cdot W_{MP}\right) \cdot F_{IFOL} \cdot F_I$ $C_{FMPG} = 211.04 \cdot Mdol$

+ HM&E GFE (boats, IC): $C_{FHMEG} := .02 \cdot P_F$ $C_{FHMEG} = 9.047 \cdot Mdol$

+ Outfittimg Cost: $C_{FOUT} := .04 \cdot P_F$ $C_{FOUT} = 18.094 \cdot Mdol$

= Total Follow Ship Government Cost: $C_{FGOV} := C_{FOTH} + C_{FPMG} + C_{FMPG} + C_{FHMEG} + C_{FOUT}$

$C_{FGOV} = 249.489 \cdot Mdol$

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

* Total Follow Ship End Cost: $C_{FEND} := C_{FSB} + C_{FGOV}$ $C_{FEND} = 738.023 \cdot Mdol$

Total Follow Ship Acquisition Cost:

+ Post-Delivery Cost (PSA): $C_{FPDEL} := .05 \cdot P_F$ $C_{FPDEL} = 22.617 \cdot Mdol$

= Total Follow Ship Acquisition Cost: $C_{FA} := C_{FEND} + C_{FPDEL}$ $C_{FA} = 760.64 \cdot Mdol$

Module 11 - Effectiveness

11a. Sustained Speed - MOP15

$$VOP_{15} := \begin{cases} 0 & \text{if } V_S < 20 \cdot knt \\ \left(\frac{V_S - 20 \cdot knt}{knt} \cdot .1\right) & \text{if } (V_S \ge 20 \cdot knt) \cdot (V_S < 21 \cdot knt) \\ \left(\frac{V_S - 21 \cdot knt}{knt} \cdot .2 + .1\right) & \text{if } (V_S \ge 21 \cdot knt) \cdot (V_S < 22 \cdot knt) \\ \left(\frac{V_S - 22 \cdot knt}{knt} \cdot .25 + .3\right) & \text{if } (V_S \ge 22 \cdot knt) \cdot (V_S < 23 \cdot knt) \\ \left(\frac{V_S - 23 \cdot knt}{knt} \cdot .35 + .55\right) & \text{if } (V_S \ge 23 \cdot knt) \cdot (V_S < 24 \cdot knt) \\ \left(\frac{V_S - 24 \cdot knt}{knt} \cdot .1 + .9\right) & \text{if } (V_S \ge 24 \cdot knt) \cdot (V_S < 25 \cdot knt) \\ 1.0 & \text{otherwise} \end{cases}$$

$VOP_{15} = 0$ $V_S = 20 \cdot knt$

11b. SeaKeeping - MOP16

$x := \begin{cases} .483 & \text{if HullForm}=2 \\ .492 & \text{otherwise} \end{cases}$ $y := \begin{cases} .416 & \text{if HullForm}=2 \\ .431 & \text{otherwise} \end{cases}$ $z := \begin{cases} .509 & \text{if HullForm}=2 \\ .498 & \text{otherwise} \end{cases}$

$zz := \begin{cases} .557 & \text{if HullForm}=2 \\ .552 & \text{otherwise} \end{cases}$ $xx := \begin{cases} 2.398 & \text{if HullForm}=2 \\ 2.187 & \text{otherwise} \end{cases}$

$$a := \begin{bmatrix} 9.43595 \\ 3.10450\cdot 10^{-6} \\ -8.42980 \\ -37.5995 \\ 590.435 \\ .287418 \\ -57.3460 \\ -6.08436 \\ 9.18775\cdot 10^{-5} \\ -6.03225 \\ -6.41495\cdot 10^{-3} \end{bmatrix}$$

$A_{WP} := C_W \cdot B \cdot LWL$ $A_{WP} = 5.348\cdot 10^3\ m^2$ $C_{VPF} := \frac{x\cdot V_{FL}}{y\cdot A_{WP}\cdot T}$ $C_{VPF} = 0.888$

$C_{VPA} := \frac{(1-x)\cdot V_{FL}}{(1-y)\cdot A_{WP}\cdot T}$ $C_{VPA} = 0.694$ $A_{WA} := (1-y)\cdot A_{WP}$ $A_{WA} = 3.043\cdot 10^3\ m^2$

$LCB := z\cdot LWL$ $LCB = 106.221\ m$ $LCF := zz\cdot LWL$ $LCF = 117.739\ m$

$BM_L := xx\cdot LWL + KG - KB$ $BM_L = 474.506\ m$

$$AA := a_1 + \frac{a_2\cdot BM_L\cdot V_{FL}}{m^4} + a_3\cdot C_{VPF} + a_4\cdot C_{VPA} + a_5\cdot\frac{BM_L\cdot V_{FL}}{B\cdot LWL^3} + a_6\cdot\frac{LWL}{m} + a_7\cdot\frac{T}{B} + a_8\cdot\frac{A_{WA}}{V_{FL}^{\frac{2}{3}}} + \frac{a_9\cdot(LCB - LCF)\cdot V_{FL}}{m^4}$$

$$McR := AA + a_{10}\cdot\left[\frac{\frac{LWL}{2} - LCB}{V_{FL}^{\frac{1}{3}}}\right] + a_{11}\cdot\frac{LWL^2}{B\cdot T}$$ $McR = 43.381$

$$VOP_{16} := \begin{cases} 0 & \text{if } McR<25 \\ \left(\frac{McR-25}{2}\cdot .1\right) & \text{if } (McR\ge 25)\cdot(McR<27) \\ \left(\frac{McR-27}{2}\cdot .2 + .1\right) & \text{if } (McR\ge 27)\cdot(McR<29) \\ \left(\frac{McR-29}{2}\cdot .25 + .3\right) & \text{if } (McR\ge 29)\cdot(McR<31) \\ \left(\frac{McR-31}{2}\cdot .35 + .55\right) & \text{if } (McR\ge 31)\cdot(McR<33) \\ \left(\frac{McR-33}{2}\cdot .1 + .9\right) & \text{if } (McR\ge 33)\cdot(McR<35) \\ 1 & \text{if } (McR\ge 35) \end{cases}$$

$VOP_{16} := \text{if}(VOP_{16}<0., 0., VOP_{16})$

$VOP_{16} = 1$

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

$$VOP_{23} := \begin{cases} 0.0 & \text{if } (DP_{20}=1)+(DP_{20}=6)+(DP_{20}=10) \\ .25 & \text{if } (DP_{20}=3)+(DP_{20}=9)+(DP_{20}=13) \\ 1.0 & \text{if } (DP_{20}=4)+(DP_{20}=8)+(DP_{20}=12) \\ 0.5 & \text{otherwise} \end{cases}$$

$VOP_{23} := VOP_{23}\cdot\frac{41600\cdot hp}{P_{BPENGTOT}}$ $VOP_{23} = 0.8$

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 = 6

VOP =

	1
1	1
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	1
11	0.9
12	1
13	1
14	1
15	0
16	1
17	0
18	0
19	1
20	1
21	1
22	1
23	0.8
24	1
25	0
26	1
27	0
28	0.93
29	0
30	0.93
31	0.867
32	1
33	1
34	1

$$WEIGHT := \begin{bmatrix} .0642 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ .0113 \\ .0294 \\ .0354 \\ .0389 \\ .0133 \\ .0105 \\ .0097 \\ .0671 \\ 0 \\ .0469 \\ .0208 \\ .0469 \\ .0276 \\ .0469 \\ .0318 \\ .0542 \\ 0 \\ .0618 \\ 0 \\ .0434 \\ 0 \\ .1168 \\ .072 \\ .0457 \\ .0457 \\ .0602 \end{bmatrix}$$

11d. OMOE

$OMOE := WEIGHT^T\cdot VOP$

$OMOE = (0.902)$

12. OMOR

$$COSTRISK_{AAW} := \begin{cases} .08 & \text{if } DP_{10}+3=4 \\ 0.0 & \text{otherwise} \end{cases} \quad COSTRISK_{IPS} := \begin{cases} 0 & \text{if } 1 \le DP_{20} \le 5 \\ .18 & \text{otherwise} \end{cases} \quad COSTRISK_{HullForm} := \begin{cases} .3 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$COSTRISK_{EMALS} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .3 & \text{otherwise} \end{cases} \qquad .08 + .18 + .3 + .3 = 0.86$$

$$SCHEDRISK_{AAW} := \begin{cases} .04 & \text{if } DP_{10}+3 \\ 0.0 & \text{otherwise} \end{cases} \quad SCHEDRISK_{IPS} := \begin{cases} 0 & \text{if } 1 \le DP_{20} \le 5 \\ .09 & \text{otherwise} \end{cases} \quad SCHEDRISK_{HullForm} := \begin{cases} .35 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$SCHEDRISK_{EMALS} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .2 & \text{otherwise} \end{cases} \qquad .04 + .09 + .35 + .2 = 0.68$$

$$PERFRISK_{AAW} := \begin{cases} .15 & \text{if } DP_{10}+3 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{Range} := \begin{cases} .06 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{Reliab} := \begin{cases} 0.0 & \text{if } 1 \le DP_{20} \le 5 \\ .16 & \text{otherwise} \end{cases}$$

$$PERFRISK_{VS} := \begin{cases} .1 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{SK} := \begin{cases} .25 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{DStab} := \begin{cases} .49 & \text{if } HullForm=6 \\ 0.0 & \text{otherwise} \end{cases}$$

$$PERFRISK_{Strike} := \begin{cases} .36 & \text{if } DP_{8}=1 \\ 0.0 & \text{otherwise} \end{cases} \quad PERFRISK_{SEAD} := \begin{cases} .32 & \text{if } DP_{8}=1 \\ 0.0 & \text{otherwise} \end{cases} \quad .15 + .06 + .16 + .1 + .25 + .49 + .36 + .32 = 1.89$$

$$COSTRISK := \frac{COSTRISK_{AAW} + COSTRISK_{IPS} + COSTRISK_{HullForm} + COSTRISK_{EMALS}}{.86} \qquad COSTRISK = 1$$

$$SCHEDRISK := \frac{SCHEDRISK_{AAW} + SCHEDRISK_{IPS} + SCHEDRISK_{HullForm} + SCHEDRISK_{EMALS}}{.68} \qquad SCHEDRISK = 1$$

$$PERFRISK := \frac{\begin{gathered} WEIGHT_1 \cdot PERFRISK_{AAW} + WEIGHT_9 \cdot PERFRISK_{Range} + WEIGHT_{13} \cdot PERFRISK_{Reliab} \cdots \\ + WEIGHT_{15} \cdot PERFRISK_{VS} + WEIGHT_{16} \cdot PERFRISK_{SK} + WEIGHT_{18} \cdot PERFRISK_{DStab} \cdots \\ + WEIGHT_{28} \cdot PERFRISK_{Strike} + WEIGHT_{30} \cdot PERFRISK_{SEAD} \end{gathered}}{1.89 \cdot \left(WEIGHT_1 + WEIGHT_9 + WEIGHT_{13} + WEIGHT_{15} + WEIGHT_{16} + WEIGHT_{18} + WEIGHT_{28} + WEIGHT_{30}\right)}$$

$$PERFRISK = 0.151$$

$$OMOR := \frac{.5 \cdot PERFRISK + .3 \cdot COSTRISK + .2 \cdot SCHEDRISK}{(CManShip + CManAir)} \qquad OMOR = 0.288$$

D.2 Machinery Equipment List (MEL)

ITEM	QTY	EQUIPMENT NOMENCLATURE	DESCRIPTION	CAPACITY RATING (each)	PWR REQD (each)	UNIT WEIGHT (MT)	DIMENSIONS LxWxH (mm)	LOCATION	SWBS
1	5	DIESEL ENGINE, MAIN	PC2.5V16			80.8	8740 x 3700 x 3580	MMR	
2	5	DIESEL GEMNERATOR, MAIN	IPS PGM-4	7755 kW, 514 RPM, 6600 V, 3 PHASE, 60 Hz, 0.8 PF	20 HP	16.16	1950 x 2540 x 2840	MMR	311
3	2	CONSOLE, MAIN CONTROL			5 kW	3.632	1500 x 4000 x 3000	MMR- EOS	252
4	6	PUMP, LOW TEMPERATURE FW COOLING	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	600 m^3/hr @ 4 bar	125 HP	1.287	724 x 724 x 1905	MMR	256
5	6	COOLER, LT FW	PLATE TYPE	-	-	2.724	2997 x 762 x 1499	MMR	256
6	7	STRAINER, SEAWATER	SIMPLEX BASKET		-	6.577	2438 x 1829 x 3626	MMR	256
7	7	PUMP, MAIN SEAWATER CIRC	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	1300 m^3/hr @ 2 bar	150 HP	2.286	1143 x 1143 x 2777	MMR	256
8	3	PUMP, MDG LUBE OIL PURIFIER FEED	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	2.9 m^3/hr @ 5bar	1.5HP	0.12	683 x 330 x 232	MMR	264
9	3	PUMP, LUBE OIL TRANSFER	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	6.5 m^3/hr@5bar	5 HP	0.165	800 x 267 x 318	MMR	264
10	3	SWITCHBOARD, MAIN POWER				12	6400 x 2439 x 2286	MMR- SWBD ROOMS	324
11	4	SWITCHBOARD, LOAD CENTER	POWER DISTRIBUTION	-	-	3.632	2286 x 610 x 2286	MMR- SWBD ROOMS	324
12	6	POWER CONVERSION MODULE	PCM4-5000	5000 kW	-	16	3810 x 1830 x 2130	MMR	
13	2	PROPULSION MOTOR CONTROL CENTER	460V/3 PHASE	-	-	0.727	2439 x 508 x 2286	PM	324
14	10	MOTOR CONTROL CENTER	600V/3 PHASE	-	-	0.727	2439 x 508 x 2286	MMR/AMR	324
15	3	PUMP, MDG 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	MMR	342
16	6	PUMP, MDG LUBE OIL SERVICE STBY	POS. DISPL., HORIZONTAL, MOTOR DRIVEN	110 m^3/hr	40 HP	0.44	1410 x 546 x 686	MMR	342
17	6	COOLER, MDG LUBE OIL	PLATE TYPE		-	0.908	2363 x 457 x 1067	MMR	342
18	10	STRAINER, MDG LUBE OIL SUCTION	SIMPLEX BASKET	110 m^3/hr	-	0.1	457 x 318 x 552	MMR	342
19	5	PUMP, MDG HT FW COOLING STBY	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	113 m3/hr @ 5 bar	40 HP	528	600 x 600 x 1498	MMR	342
20	5	PRE-HEATING UNIT, MDG HT FW	CENTRIFUGAL PUMP / HEATER	6 m^3/hr	150 kW	800	2500 x 450 x 1400	MMR	342
21	7	GENERATOR CONTROL UNIT	GENERATOR START/STOP, VOLTAGE/FREQ. CONTROL	-	-	0.341	915 x 915 x 2286	MMR/AMR	342
22	2	REFRIG PLANTS, SHIPS SERVICE	R-134a	25 TON	350 HP	13.3	3879 x 1825 x 3000	MMR	516
23	10	PUMP, FIRE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr	250 HP	1.458	2490 x 711 x 864	MMR/AMR/PM	521
24	3	PUMP, FIRE/ BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	454 m^3/hr @ 9 bar	250 HP	1.458	2490 x 711 x 864	MMR	521
25	6	PUMP, AUX. SEAWATER	CENTRIFUGAL, VERTICAL, MOTOR DRIVEN	227 m^3/hr @ 3 bar	40 HP	0.803	635 x 635 x 1702	MMR	524
26	4	PUMP, BILGE	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	MMR/AMR	529
27	4	PUMP, BILGE/BALLAST	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	227 m^3/hr @ 3.8 bar	40 HP	0.926	1651 x 635 x 737	MMR/AMR	529
28	6	PUMP, FUEL TRANSFER	GEAR, MOTOR DRIVEN	45.4 m^3/hr @ 4.2 bar	30 HP	0.4	1423 x 559 x 686	MMR	541
29	6	RECEIVER, START AIR	STEEL, CYLINDRICAL	2.27 m^3	-	0.97	1067 (dia) x 2540 (H)	MMR	551
30	6	COMPRESSOR, START AIR	RECIPROCATING	80 m3/hr @ 30 bar	17 kW	0.57	1334 x 841 x 836	MMR	551
31	2	RECEIVER, SHIP SERVICE AIR	STEEL, CYLINDRICAL	1.7 m^3	-	0.726	1830 (H) x 965 (dia)	MMR	551
32	2	COMPRESSOR, AIR, LP SHIP SERVICE	LOW PRESSURE, ROTARY SCREW	194 SCFM @ 8.6 bar	50 HP	1	1346 x 1067 x 1829	MMR	551
33	2	DRYER, AIR	REFRIGERANT TYPE	250 SCFM	-	0.259	610 x 864 x 1473	MMR	551
34	2	RECEIVER, CONTROL AIR	STEEL, CYLINDRICAL	1 m^3	-	0.427	3421 (H) x 610 (dia)	MMR	551
35	2	CONVERTER, PRPLN POWER		5500 kW	-	2	3750 x 1750 x 2140	PM	235
36	6	AIR CONDITIONING PLANTS	450 TON, CENTRIFUGAL UNITS	450 TON	600 HP	14.98	4836 x 2163 x 3114	MMR	514
37	6	DISTILLER	REVERSE OSMOSIS TYPE	75 m^3/day	35 kW	3.141	3768 x 2111 x 2111	MMR	531
38	2	SWITCHBOARD, SHIPS SERVICE	GENERATOR CONTROL POWER DISTRIBUTION	-	-	12	6096 x 1220 x 2286	MMR- SWBD ROOMS/AMR	324

ITEM	QTY	EQUIPMENT NOMENCLATURE	DESCRIPTION	CAPACITY RATING (each)	PWR REQD (each)	UNIT WEIGHT (MT)	DIMENSIONS LxWxH (mm)	LOCATION	SWBS
39	2	DIESEL ENGINE, AUXILIARY	CAT 3608 IL8 2-STROKE, TURBOCHARGED, OR EQUAL	2528 kW, 900 RPM, 600V, 3 PHASE, 60 Hz, 0.8 PF	-	18.96	4820x1750x2630	MMR/AMR	311
40	2	DIESEL GENERATOR, AUXILIARY				6.98	1950 x 1550 x 2010	MMR/AMR	
41	3	PURIFIER, MDG LUBE OIL	CENTRIFUGAL, SELF CLEANING, PARTIAL DISCHARGE TYPE	2.9 m^3/hr	12 kW	1.62	1120 x 1470 x 1420	MMR-PURIFIER ROOMS	264
42	3	PURIFIER HEATER, MDG LUBE OIL	ELECTRIC		56 kW	0.106	580 x 355 x 895	MMR-PURIFIER ROOMS	264
43	6	FILTER, MDG FUEL	DUPLEX		-	0.145	356 x 610 x 686	MMR-PURIFIER ROOMS	342
44	6	FILTER, MDG LUBE OIL	AUTOMATIC CLEANING	110 m^3/hr	-	1.86	2190 x 820 x 1508	MMR-PURIFIER ROOMS	342
45	3	PURIFIER, FUEL	SELF CLEANING, CENTRIFUGAL, partial discharge type	3.4 m^3/hr	6 kW	0.7	1300 x 720 x 1500	MMR-PURIFIER ROOMS	541
46	3	HEATER, FUEL	ELECTRIC		36 kW	0.076	580 x 319 x 895	MMR-PURIFIER ROOMS	541
47	6	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	MMR	593
48	6	SEPARATOR , OIL/WATER	COALESCER PLATE TYPE	2.7 m^3/hr	1 kW	0.5	1321 x 965 x 1473	MMR	593
49	5	SEWAGE TREATMENT UNIT			6.4 kW	0.98	1778 x 1092 x 2007	MMR-SEWAGE TRTMNT ROOM	593
50	5	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	MMR	593
51	1	SHORE POWER FACILITY		2400 A	-	0.363	2134 x 610 x 2286	01 XFR DK AFT	321
52	2	MOTOR, PROPULSION	AMS AC Synchronous Motor (from ABB) Power: 2-20 MW at 50 Hz Voltage: 3-15 kV	14,000 kW @ 117 rpm		21	3700 x 3400 x 3100	PM	235
53	2	CONTROL UNIT, PRPLN MOTOR		-	-	0.85	2400 x 900 x 2080	PM	235
54	2	EXCITER UNIT, PRPLN MOTOR		-	40 kW	0.58	1200 x 900 x 2080	PM	235
55	2	MONITOR, OIL CONTENT		15 PPM	TBD	0.0082	254 x 153 x 305	MMR	593
56	6	BROMINATOR	PROPORTIONING	1.5 m^3/hr	-	0.0115	965 x 203 x 406	MMR	531
57	6	PUMP, CHILLED WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	128 m^3/hr @ 4.1 bar	30 HP	0.377	1321 x 381 x 508	MMR	532
58	5	HEATER, WATER	ELECTRIC STORAGE TYPE	1.65 m^3	65 kW	0.993	1854 (H) x 1067 (dia)	MMR	533
59	5	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	MMR	533
60	5	PUMP, POTABLE WATER	CENTRIFUGAL, HORIZONTAL, MOTOR DRIVEN	22.7 m^3/hr @ 4.8 bar	10 HP	0.189	787 x 559 x 356	MMR	533
61	3	TANK, L.O. STORAGE	STRUCTURAL	6.39 m^3	-	-	2000 x 1065 x 3000	MMR	123
62	3	TANK, L.O. SETTLING	STRUCTURAL	1.52 m^3	32 kW	-	1000 x 1000 x 3000	MMR	123
64	3	TANK, OILY WASTE HOLDING	STRUCTURAL	12.7 m^3	-	-	2000 x 2117 x 3000	ADH	123
65	3	TANK, WASTE OIL	STRUCTURAL	12.7 m^3	-	-	2000 x 2117 x 3000	ADH	123
66	6	TANK, FUEL SERVICE	STRUCTUAL	21 m^3	-	-	2000 x 1750 x 3000	MMR	123
67	2	SHAFT, LINE	520 mm (OD), 345 mm (ID)	-	-	15	15,200	PM	243
68	2	SHAFT, STERN TUBE	600 mm (OD), 400 mm (ID)	-	-	25	19,000	STERN TUBE (P/S)	243
69	2	SHAFT, TAIL	625 mm (OD), 400 mm (ID)	-	-	15	10,000	FRAME 180 - 190 (P/S)	243
70	4	BEARING, LINE SHAFT	DISK TYPE	520 mm LINE SHAFT	-	1.61	940 x 1220 x 1181	PM	244
71	2	BEARING, MAIN STRUT	OIL LUBRICATED	625 mm TAIL SHAFT	-	0.9	1250 (L) x 680 (OD)	MAIN STRUT (P/S)	244
72	4	BEARING, STERN TUBE	OIL LUBRICATED	600 mm STERN TUBE SHAFT	-	0.438	600 (L) x 680 (OD)	STERN TUBE (P/S)	244
73	2	PROPELLER, FIXED PITCH	5 BLADES, Ni-Al-Bronze		-	25	5000 (D)	FRAME 190 (P/S)	245
74	4	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	PM	262
75	4	COOLER, LUBE OIL	PLATE TYPE		-	0.091	610 x 204 x 533	PM	262
76	4	FILTER / COALESCER, LUBE OIL		1.1 m^3/hr	-	.068 (DRY WEIGHT)	914 (L) x 410 (OD)	PM	262
77	2	UPS	CENTRALIZED CONTROL	100 A	-	0.15	1829 x 610 x 610	MMR- EOS	313
78	5	SILENCER, MDG	SPARK ARRESTING TYPE	-	-	3.273	4166 (L) x 2438 (dia)	MMR	342
79	2	SILENCER, ADG	SPARK ARRESTING TYPE	-	-	0.794	2159(L) x 1372 (dia)	MMR/AMR	342
80	6	MN MCHNRY SPACE FAN	SUPPLY	119,796 m^3/hr	75 HP	0.568	1321 (L) x 1384 (dia)	MMR	513
81	6	MN MCHNRY SPACE FAN	EXHAUST	93,445 m^3/hr	30 HP	0.522	1321 (L) x 1397 (dia)	MMR	513
82	2	AUX MCHNRY SPACE FAN	SUPPLY	61,164 m^3/hr	30 HP	0.477	1092 (L) x 1118 (dia)	AMR INTAKE	513
83	2	AUX MCHNRY SPACE FAN	EXHAUST	61,164 m^3/hr	20 HP	0.477	1092 (L) x 1118 (dia)	AMR EXHAUST	513
84	3	PUMP, JP-5 TRANSFER	ROTARY, MOTOR DRIVEN	11.5 m^3/hr @ 4.1 bar	3 HP	0.261	1194 x 483 x 508	MMR- JP-5 PUMP ROOM	542
85	3	PUMP, JP-5 SERVICE	ROTARY, MOTOR DRIVEN	22.7 m^3/hr @ 7.6 bar	10 HP	0.261	1194 x 483 x 508	MMR- JP-5 PUMP ROOM	542
86	3	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	MMR- JP-5 PUMP ROOM	542
87	3	FILTER/SEPAR., JP-5 TRANSFER	STATIC, TWO-STAGE	17 m^3/hr	-	0.363	457 (L) x 1321 (dia)	MMR- JP-5 PUMP ROOM	542
88	3	FILTER/SEPAR., JP-5 SERVICE	STATIC, TWO STAGE	22.7 m^3/hr	-	0.316	407 (L) x 1219 (dia)	MMR- JP-5 PUMP ROOM	542
89	5	SEWAGE COLLECTION UNIT	VACUUM COLLECTION TYPE W/ PUMPS	28 m^3	5.4 HP	1.567	2642 x 1854 x 1575	MMR-SEWAGE TRTMNT ROOM	593
	5	PUMP, MDG FUEL SERVICE	ENGINE DRIVEN	6.8 m^3/hr	-	-	-	MMR	342
	5	PUMP, MDG LUBE OIL SERVICE	ENGINE DRIVEN	110 m^3/hr	-	-	-	MMR	342
	5	PUMP, MDG HT FW COOLING	ENGINE DRIVEN	113 m^3/hr	-	-	-	MMR	342

D.3 Electric Load Analysis (ELA)

Equipment	SWBS	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
Tank, L.O. Settling #1	100	1		32	0.1	3.2	0.1	3.2	0.1	3.2	0	0	0	0	0	0
Tank, L.O. Settling #2	100	1		32	0.1	3.2	0.1	3.2	0.1	3.2	0	0	0	0	0	0
Tank, L.O. Settling #3	100	1		32	0.1	3.2	0.1	3.2	0.1	3.2	0	0	0	0	0	0
Anchor Windlass PORT	100	1	100.00	79.62	0.00	0	0.00	0	0.00	0	0.00	0	0.10	7.962	0.00	0
Anchor Windlass STBD	100	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	100	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	100	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	100	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	100	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	100	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	100	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)	100	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)	100	1	25.00	20.27	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Accommidition Ladder Port	100	1	1.50	1.36	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Accommidition Ladder Stbd	100	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)	100	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)	100	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	100	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	100	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	100	1	2.00	1.78	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	1.78
Port Propulsion System	200	1	18169.00	14863.50	1.00	14864	1.00	14864	1.00	11380	0.00	0	0.00	0	0.00	0
Stbd Propulsion System	200	1	18169.00	14863.50	1.00	14864	1.00	14864	1.00	11380	0.00	0	0.00	0	0.00	0
Purifier, Fuel #1A	200	1	20.00	6.00	0.90	5.4	0.90	5.4	0.90	5.4	0.10	0.6	0.20	1.2	0.00	0
FO PUR Supply Pump #1A	200	1	7.50	6.39	0.90	5.751	0.90	5.751	0.90	5.751	0.10	0.639	0.20	1.278	0.00	0
FO Purifier Heater #1A	200	1	0.00	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.10	3.6	0.20	7.2	0.00	0
Purifier, Fuel #1B	200	1	20.00	6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO PUR Supply Pump #1B	200	1	7.50	6.39	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO Purifier Heater #1B	200	1	0.00	36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, Fuel #2A	200	1	20.00	6.00	0.90	5.4	0.90	5.4	0.90	5.4	0.00	0	0.00	0	0.00	0
FO PUR Supply Pump #2A	200	1	7.50	6.39	0.90	5.751	0.90	5.751	0.90	5.751	0.00	0	0.00	0	0.00	0
FO Purifier Heater #2A	200	1	0.00	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.00	0	0.00	0	0.00	0
Purifier, Fuel #2B	200	1	20.00	6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO PUR Supply Pump #2B	200	1	7.50	6.39	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO Purifier Heater #2B	200	1	0.00	36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, Fuel #3A	200	1	20.00	6.00	0.90	5.4	0.90	5.4	0.90	5.4	0.00	0	0.00	0	0.00	0
FO PUR Supply Pump #3A	200	1	7.50	6.39	0.90	5.751	0.90	5.751	0.90	5.751	0.00	0	0.00	0	0.00	0
FO Purifier Heater #3A	200	1	0.00	36.00	0.40	14.4	0.40	14.4	0.40	14.4	0.00	0	0.00	0	0.00	0
Purifier, Fuel #3B	200	1	20.00	6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO PUR Supply Pump #3B	200	1	7.50	6.39	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
FO Purifier Heater #3B	200	1	0.00	36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Starting Air Compressor #1	200	1	0.00	6.20	0.10	0.62	0.10	0.62	0.10	0.62	0.10	0.62	0.10	0.62	0.00	0
Starting Air Compressor #2	200	1	0.00	6.20	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	6.2
Pump, Lube Oil Transfer #1	200	1	5.00	4.30	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.00	0
Pump, Lube Oil Transfer #2	200	1	5.00	4.30	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.00	0
Pump, Lube Oil Transfer #3	200	1	5.00	4.30	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.10	0.43	0.00	0
Oily Waste Transfer Pump #1	200	1	10.00	8.43	0.20	1.686	0.20	1.686	0.20	1.686	0.10	0.843	0.10	0.843	0.00	0
Oily Waste Transfer Pump #2	200	1	10.00	8.43	0.20	1.686	0.20	1.686	0.20	1.686	0.10	0.843	0.10	0.843	0.00	0
Pump, Main Seawater Circ. #1A	200	1	150.00	111.85	0.90	100.665	0.90	100.665	0.90	100.7	0.00	0	0.00	0	0.00	0
Pump, Main Seawater Circ. #1B	200	1	150.00	111.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Main Seawater Circ. #2A	200	1	150.00	111.85	0.90	100.665	0.90	100.665	0.90	100.7	0.00	0	0.00	0	0.00	0
Pump, Main Seawater Circ. #2B	200	1	150.00	111.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Main Seawater Circ. #3A	200	1	150.00	111.85	0.90	100.665	0.90	100.665	0.90	100.7	0.00	0	0.00	0	0.00	0
Pump, Main Seawater Circ. #3B	200	1	150.00	111.85	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Motor Turning Gear (S)	200	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)	200	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	200	1	0.00	12.00	0.00	0	0.00	0	0.00	0	0.90	10.8	0.90	10.8	0.90	10.8
Motor Heater Stbd	200	1	0.00	12.00	0.00	0	0.00	0	0.00	0	0.90	10.8	0.90	10.8	0.90	10.8
Motor Blowers Port	200	1	20.00	16.27	0.90	14.643	0.90	14.643	0.90	14.64	0.00	0	0.00	0	0.00	0
Motor Blowers Stbd	200	1	20.00	16.27	0.90	14.643	0.90	14.643	0.90	14.64	0.00	0	0.00	0	0.00	0
Pump, Low Temp. FW Cooling #1A	200	1	125.00	93.21	0.90	83.889	0.90	83.889	0.90	83.89	0.90	83.89	0.90	83.89	0.00	0
Pump, Low Temp. FW Cooling #1B	200	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 Temp. FW Cooling #2A	200	1	125.00	93.21	0.90	83.889	0.90	83.889	0.90	83.89	0.90	83.89	0.90	83.89	0.00	0
Pump, Low Temp. FW Cooling #2B	200	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 Temp. FW Cooling #3A	200	1	125.00	93.21	0.90	83.889	0.90	83.889	0.90	83.89	0.90	83.89	0.90	83.89	0.00	0
Pump, Low Temp. FW Cooling #3B	200	1	125.00	93.21	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
ADG LO Settling Tank	200	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
MDG LO Settling Tank	200	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
MDG LO Storage Tank	200	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
MDG Starting Unit	200	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, MDG HT FW	200	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 LO #1A	200	1	0.50	0.37	0.90	0.3357	0.90	0.3357	0.90	0.336	0.00	0	0.00	0	0.00	0
Pump, Main Strut and Stern Tube LO #1B	200	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 LO #2A	200	1	0.50	0.37	0.90	0.3357	0.90	0.3357	0.90	0.336	0.00	0	0.00	0	0.00	0
Pump, Main Strut and Stern Tube LO #2B	200	1	0.50	0.37	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Lube Oil Transfer #1	200	1		3.73	0.90	3.3552	0.90	3.3552	0.90	3.355	0.00	0	0.00	0	0.00	0
Pump, Lube Oil Transfer #2	200	1		3.73	0.90	3.3552	0.90	3.3552	0.90	3.355	0.00	0	0.00	0	0.00	0
Pump, Lube Oil Transfer #3	200	1		3.73	0.90	3.3552	0.90	3.3552	0.90	3.355	0.00	0	0.00	0	0.00	0
Console, Main Control	200	1		5.00	0.90	4.5	0.90	4.5	0.90	4.5	0.00	0	0.00	0	0.00	0
Purifier, MDG Lube Oil #1A	200	1		12.00	0.90	10.8	0.90	10.8	0.90	10.8	0.00	0	0.00	0	0.00	0
Purifier, MDG Lube Oil #1B	200	1		12.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, MDG Lube Oil #2A	200	1		12.00	0.90	10.8	0.90	10.8	0.90	10.8	0.00	0	0.00	0	0.00	0
Purifier, MDG Lube Oil #2B	200	1		12.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, MDG Lube Oil #3A	200	1		12.00	0.90	10.8	0.90	10.8	0.90	10.8	0.00	0	0.00	0	0.00	0

Equipment	SWBS	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
Purifier, MDG Lube Oil #3B	200	1		12.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #1A	200	1		1.12	0.90	1.0062	0.90	1.0062	0.90	1.006	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #1B	200	1		1.12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #2A	200	1		1.12	0.90	1.0062	0.90	1.0062	0.90	1.006	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #2B	200	1		1.12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #3A	200	1		1.12	0.90	1.0062	0.90	1.0062	0.90	1.006	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Purifier Feed #3B	200	1		1.12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #1A	200	1		56.00	0.90	50.4	0.90	50.4	0.90	50.4	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #1B	200	1		56.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #2A	200	1		56.00	0.90	50.4	0.90	50.4	0.90	50.4	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #2B	200	1		56.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #3A	200	1		56.00	0.90	50.4	0.90	50.4	0.90	50.4	0.00	0	0.00	0	0.00	0
Purifier Heater, MDG Lube Oil #3B	200	1		56.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Diesel Generator No. 1	300															
Pump, HT FW Cooling Stby	300	1	40.00	37.28	0.90	33.552	0.90	33.552	0.90	33.55	0.00	0	0.00	0	0.00	0
Preheating Unit, HT FW	300	1		150	0.00	0	0.00	0	0.00	0	0.90	135	0.90	135	0.90	135
Main Diesel Generator No. 2	300															
Pump, HT FW Cooling Stby	300	1	40.00	37.28	0.90	33.552	0.90	33.552	0.90	33.55	0.00	0	0.00	0	0.00	0
Preheating Unit, HT FW	300	1		150	0.00	0	0.00	0	0.00	0	0.90	135	0.90	135	0.90	135
Main Diesel Generator No. 3	300															
Pump, HT FW Cooling Stby	300	1	40.00	37.28	0.90	33.552	0.90	33.552	0.90	33.55	0.00	0	0.00	0	0.00	0
Preheating Unit, HT FW	300	1		150	0.00	0	0.00	0	0.00	0	0.90	135	0.90	135	0.90	135
Main Diesel Generator No. 4	300															
Pump, HT FW Cooling Stby	300	1	40.00	37.28	0.90	33.552	0.90	33.552	0.90	33.55	0.00	0	0.00	0	0.00	0
Preheating Unit, HT FW	300	1		150	0.00	0	0.00	0	0.00	0	0.90	135	0.90	135	0.90	135
Main Diesel Generator No. 5	300															
Pump, HT FW Cooling Stby	300	1	40.00	37.28	0.90	33.552	0.90	33.552	0.90	33.55	0.00	0	0.00	0	0.00	0
Preheating Unit, HT FW	300	1		150	0.00	0	0.00	0	0.00	0	0.90	135	0.90	135	0.90	135
Pump, MDG Fuel Service Stby #1	300	1	5.00	4.66	0.10	0.466	0.10	0.466	0.10	0.466	0.00	0	0.00	0	0.00	0
Pump, MDG Fuel Service Stby #2	300	1	5.00	4.66	0.10	0.466	0.10	0.466	0.10	0.466	0.00	0	0.00	0	0.00	0
Pump, MDG Fuel Service Stby #3	300	1	5.00	4.66	0.10	0.466	0.10	0.466	0.10	0.466	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #1A	300	1	40.00	37.28	0.10	4	0.10	4	0.10	3.728	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #1B	300	1	40.00	37.28	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #2A	300	1	40.00	37.28	0.10	4	0.10	4	0.10	3.728	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #2B	300	1	40.00	37.28	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #3A	300	1	40.00	37.28	0.10	4	0.10	4	0.10	3.728	0.00	0	0.00	0	0.00	0
Pump, MDG Lube Oil Service Stby #3B	300	1	40.00	37.28	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Engine Rm Cont. Console UPS	300	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	300	1	0.00	20.00	0.70	14	0.70	14	0.70	14	0.70	14	0.70	14	0.00	0
Degaussing	300	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	300	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
IC Battery Charger	300	1	0.00	2.50	0.25	0.625	0.25	0.625	0.25	0.625	0.25	0.625	0.25	0.625	1.00	2.5
SUBM Pump	300	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)	300	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	300	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.	300	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	300	1	0.00	9.45	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	9.45
Engine Room LTG	300	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	300	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	300	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)	300	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)	300	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	300	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	300	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
INT. BRIDGE CONSOLE	400	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)	400	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)	400	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)	400	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	400	1		10.00	0.90	9	0.90	9	0.80	8	0.10	1	0.80	8	0.40	4
Data Display	400	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	400	1		5.00	0.90	4.5	0.90	4.5	0.80	4	0.10	0.5	0.80	4	0.40	2
Collision Avoidance	400	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	400	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	400	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	400	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
Ship Miscelaneous	400	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	400	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.	400	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	400	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
AN/URT-23C (V) XIMR Set #1	400	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	400	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	400	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	400	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	400	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	400	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	400	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	400			96.40	0.50	48.2	0.50	48.2	0.50	48.2	0.30	28.92	0.30	28.92	0.30	28.92
MT-6069/WSC-3 (V) Rack	400	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	400	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.	400	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
AN/SPS-49A(V)1	400	1	0.00	79.00	1.00	79	1.00	79	1.00	79	0.00	0	0.00	0	0.00	0
AN/SPS-73(V)12	400	1	0.00	8.00	1.00	8	1.00	8	1.00	8	0.00	0	0.00	1	0.00	0
AN-SPQ9B	400	1	0.00	220.00	1.00	220	1.00	220	1.00	220	0.00	0	0.00	1	1.00	220
CIFF	400	1	0.00	4.00	1.00	4	1.00	4	1.00	4	0.00	0	0.00	1	1.00	4
LAMPS Electronics	400	1		5.50	0.80	4.4	0.80	4.4	0.20	1.1	0.00	0	0.20	1.1	0.00	0
Mine Avoidance Sonar	400	1		5.00	0.80	4	0.80	4	0.80	4	0.00	0	0.00	0	0.00	0
Mk 36	400	1		2.40	1.00	2.4	1.00	2.4	1.00	2.4	0.00	0	0.00	0	0.00	0

Equipment	SWBS	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
Mk 36	400	1		2.40	1.00	2.4	1.00	2.4	1.00	2.4	0.00	0	0.00	0	0.00	0
Mk 36	400	1		2.40	1.00	2.4	1.00	2.4	1.00	2.4	0.00	0	0.00	0	0.00	0
Mk 36	400	1		2.40	1.00	2.4	1.00	2.4	1.00	2.4	0.00	0	0.00	0	0.00	0
AN/SLQ-32A [V]2	400	1		6.40	1.00	6.4	1.00	6.4	1.00	6.4	0.00	0	0.00	0	0.00	0
AN/SLQ-25 NIXIE Decoy	400	1		4.20	1.00	4.2	1.00	4.2	1.00	4.2	0.00	0	0.00	0	0.00	0
AN/SLQ-25 Winch	400	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	400	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	400	1	0.00	62.50	0.80	50	0.80	50	0.80	50	0.00	0	0.80	50	0.00	0
DLS	400	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
AN/SLQ 32A(V)2	400	1	0.00	6.00	0.90	5.4	0.90	5.4	0.90	5.4	0.00	0	0.90	5.4	0.90	5.4
UW Fire Control	400	1		11.50	0.80	9.2	0.80	9.2	0.20	2.3	0.00	0	0.20	2.3	0.00	0
SSDS MK2	400	1		10.40	0.80	8.32	0.80	8.32	0.80	8.32	0.20	2.08	0.80	8.32	0.40	4.16
Mk91 MFCS w/Mk93 TAS	400	1		85.80	1.00	85.8	1.00	85.8	1.00	85.8	0.00	0	0.00	0	0.00	0
Weapons Switchboards	400	2		4.00	0.80	3.2	0.80	3.2	0.80	3.2	0.00	0	0.80	3.2	0.00	0
Combat DF	400	1	0	19.3	1	19.3	1	19.3	1	19.3	0	0	1	19.3	0	0
Air Conditioning Plant #1	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Air Conditioning Plant #2	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Air Conditioning Plant #3	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Air Conditioning Plant #4	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Air Conditioning Plant #5	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Air Conditioning Plant #6	500	1	600.00	559.27	0.90	503.343	0.90	503.343	0.90	503.3	0.90	503.3	0.90	503.3	0.00	0
Main Mach. Space Supply Fan #1A	500	1	75.00	69.91	0.90	62.919	0.90	62.919	0.90	62.92	0.50	34.96	0.90	62.92	0.00	0
Main Mach. Space Supply Fan #1B	500	1	75.00	69.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Mach. Space Supply Fan #2A	500	1	75.00	69.91	0.90	62.919	0.90	62.919	0.90	62.92	0.50	34.96	0.90	62.92	0.00	0
Main Mach. Space Supply Fan #2B	500	1	75.00	69.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Mach. Space Supply Fan #3A	500	1	75.00	69.91	0.90	62.919	0.90	62.919	0.90	62.92	0.50	34.96	0.90	62.92	0.00	0
Main Mach. Space Supply Fan #3B	500	1	75.00	69.91	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Mach. Space Exhaust Fan #1A	500	1	30.00	27.96	0.90	25.164	0.90	25.164	0.90	25.16	0.50	13.98	0.90	25.16	0.00	0
Main Mach. Space Exhaust Fan #1B	500	1	30.00	27.96	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Mach. Space Exhaust Fan #2A	500	1	30.00	27.96	0.90	25.164	0.90	25.164	0.90	25.16	0.50	13.98	0.90	25.16	0.00	0
Main Mach. Space Exhaust Fan #2B	500	1	30.00	27.96	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Main Mach. Space Exhaust Fan #3A	500	1	30.00	27.96	0.90	25.164	0.90	25.164	0.90	25.16	0.50	13.98	0.90	25.16	0.00	0
Main Mach. Space Exhaust Fan #3B	500	1	30.00	27.96	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Aux. Mach. Space Supply Fan #1	500	1	30.00	27.96	0.90	25.164	0.90	25.164	0.90	25.16	0.90	25.16	0.90	25.16	0.00	0
Aux. Mach. Space Supply Fan #2	500	1	30.00	27.96	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Aux. Mach. Space Exhaust Fan #1	500	1	20.00	18.64	0.90	16.776	0.90	16.776	0.90	16.78	0.90	16.78	0.90	16.78	0.00	0
Aux. Mach. Space Exhaust Fan #2	500	1	20.00	18.64	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Refrig. Plants, Ship Service #1	500	1	350.00	326.24	0.90	293.616	0.90	293.616	0.90	293.6	0.90	293.6	0.90	293.6	0.00	0
Refrig. Plants, Ship Service #2	500	1	350.00	326.24	0.90	293.616	0.90	293.616	0.90	293.6	0.90	293.6	0.90	293.6	0.00	0
Pump, Fire #1A	500	1	250.00	196.32	0.20	39.264	0.20	39.264	0.20	39.26	0.10	19.63	0.10	19.63	0.00	0
Pump, Fire #1B	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fire #2A	500	1	250.00	196.32	0.20	39.264	0.20	39.264	0.20	39.26	0.10	19.63	0.10	19.63	0.00	0
Pump, Fire #2B	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fire #3A	500	1	250.00	196.32	0.20	39.264	0.20	39.264	0.20	39.26	0.10	19.63	0.10	19.63	0.00	0
Pump, Fire #3B	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fire #4A	500	1	250.00	196.32	0.20	39.264	0.20	39.264	0.20	39.26	0.10	19.63	0.10	19.63	0.00	0
Pump, Fire #4B	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fire/Ballast #1	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	196.32
Pump, Fire/Ballast #2	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	196.32
Pump, Fire/Ballast #3	500	1	250.00	196.32	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.00	196.32
Pump, Bilge/Ballast #1	500	1	40.00	32.43	0.10	3.243	0.10	3.243	0.10	3.243	0.00	0	0.20	6.486	1.00	32.43
Pump, Bilge/Ballast #2	500	1	40.00	32.43	0.10	3.243	0.10	3.243	0.10	3.243	0.00	0	0.20	6.486	1.00	32.43
Pump, Bilge/Ballast #3	500	1	40.00	32.43	0.10	3.243	0.10	3.243	0.10	3.243	0.00	0	0.20	6.486	1.00	32.43
Pump, Bilge/Ballast #4	500	1	40.00	32.43	0.10	3.243	0.10	3.243	0.10	3.243	0.00	0	0.20	6.486	1.00	32.43
Pump, Bilge #1	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Bilge #2	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Bilge #3	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Bilge #4	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Aux. Seawater #1A	500	1	40.00	32.43	0.90	29.187	0.90	29.187	0.90	29.19	0.90	29.19	0.90	29.19	0.00	0
Pump, Aux. Seawater #1B	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Aux. Seawater #2A	500	1	40.00	32.43	0.90	29.187	0.90	29.187	0.90	29.19	0.90	29.19	0.90	29.19	0.00	0
Pump, Aux. Seawater #2B	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Aux. Seawater #3A	500	1	40.00	32.43	0.90	29.187	0.90	29.187	0.90	29.19	0.90	29.19	0.90	29.19	0.00	0
Pump, Aux. Seawater #3B	500	1	40.00	32.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Distiller #1	500	1		35.00	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.00	0
Distiller #2	500	1		35.00	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.00	0
Distiller #3	500	1		35.00	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.90	31.5	0.00	0
Pump, Chilled Water #1	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Pump, Chilled Water #2	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Pump, Chilled Water #3	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Pump, Chilled Water #4	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Pump, Chilled Water #5	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Pump, Chilled Water #6	500	1	30.00	27.93	0.90	25.137	0.90	25.137	0.90	25.14	0.90	25.14	0.90	25.14	0.00	0
Heater, Water #1	500	1		65.00	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.00	0
Heater, Water #2	500	1		65.00	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.00	0
Heater, Water #3	500	1		65.00	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.00	0
Heater, Water #4	500	1		65.00	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.00	0
Heater, Water #5	500	1		65.00	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.90	58.5	0.00	0
Pump, Hot Water Recirc #1	500	1	1.50	1.40	0.90	1.2582	0.90	1.2582	0.90	1.258	0.90	1.258	0.90	1.258	0.00	0
Pump, Hot Water Recirc #2	500	1	1.50	1.40	0.90	1.2582	0.90	1.2582	0.90	1.258	0.90	1.258	0.90	1.258	0.00	0
Pump, Hot Water Recirc #3	500	1	1.50	1.40	0.90	1.2582	0.90	1.2582	0.90	1.258	0.90	1.258	0.90	1.258	0.00	0
Pump, Hot Water Recirc #4	500	1	1.50	1.40	0.90	1.2582	0.90	1.2582	0.90	1.258	0.90	1.258	0.90	1.258	0.00	0
Pump, Hot Water Recirc #5	500	1	1.50	1.40	0.90	1.2582	0.90	1.2582	0.90	1.258	0.90	1.258	0.90	1.258	0.00	0
Pump, Potable Water #1	500	1	10.00	9.32	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.00	0
Pump, Potable Water #2	500	1	10.00	9.32	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.00	0
Pump, Potable Water #3	500	1	10.00	9.32	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.00	0
Pump, Potable Water #4	500	1	10.00	9.32	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.00	0

Equipment	SWBS	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
Pump, Potable Water #5	500	1	10.00	9.32	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.90	8.388	0.00	0
AN/SPQ-9B Cooling Equipment	500	1		13.64	0.90	12.276	0.90	12.276	0.90	12.28	0.00	0	0.00	0	0.00	0
JP-5 Transfer Pump #1	500	1	3.00	2.66	0.20	0.532	0.20	0.532	0.20	0.532	0.10	0.266	0.10	0.266	0.00	0
JP-5 Transfer Pump #2	500	1	3.00	2.66	0.20	0.532	0.20	0.532	0.20	0.532	0.10	0.266	0.10	0.266	0.00	0
JP-5 Transfer Pump #3	500	1	3.00	2.66	0.20	0.532	0.20	0.532	0.20	0.532	0.10	0.266	0.10	0.266	0.00	0
JP-5 Service Pump #1	500	1	10.00	8.43	0.20	1.686	0.20	1.686	0.20	1.686	0.00	0	0.00	0	0.00	0
JP-5 Service Pump #2	500	1	10.00	8.43	0.20	1.686	0.20	1.686	0.20	1.686	0.00	0	0.00	0	0.00	0
JP-5 Service Pump #3	500	1	10.00	8.43	0.20	1.686	0.20	1.686	0.20	1.686	0.00	0	0.00	0	0.00	0
JP-5 Stripping Pump #1	500	1	1.50	1.36	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.00	0
JP-5 Stripping Pump #2	500	1	1.50	1.36	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.00	0
JP-5 Stripping Pump #3	500	1	1.50	1.36	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.10	0.136	0.00	0
Pump, Fuel Transfer #1A	500	1	30.00	24.33	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.00	0
Pump, Fuel Transfer #1B	500	1	30.00	24.33	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fuel Transfer #2A	500	1	30.00	24.33	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.00	0
Pump, Fuel Transfer #2B	500	1	30.00	24.33	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pump, Fuel Transfer #3A	500	1	30.00	24.33	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.10	2.433	0.00	0
Pump, Fuel Transfer #3B	500	1	30.00	24.33	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, Fuel #1A	500	1		6.00	0.10	0.6	0.10	0.6	0.10	0.6	0.00	0	0.00	0	0.00	0
Purifier, Fuel #1B	500	1		6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, Fuel #2A	500	1		6.00	0.10	0.6	0.10	0.6	0.10	0.6	0.00	0	0.00	0	0.00	0
Purifier, Fuel #2B	500	1		6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Purifier, Fuel #3A	500	1		6.00	0.10	0.6	0.10	0.6	0.10	0.6	0.00	0	0.00	0	0.00	0
Purifier, Fuel #3B	500	1		6.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Heater, Fuel #1A	500	1		36.00	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4
Heater, Fuel #1B	500	1		36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Heater, Fuel #2A	500	1		36.00	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4
Heater, Fuel #2B	500	1		36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Heater, Fuel #3A	500	1		36.00	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4	0.90	32.4
Heater, Fuel #3B	500	1		36.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Compressor, Start Air #1A	500	1		17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.00	0
Compressor, Start Air #1B	500	1		17.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Compressor, Start Air #2A	500	1		17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.00	0
Compressor, Start Air #2B	500	1		17.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Compressor, Start Air #3A	500	1		17.00	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.10	1.7	0.00	0
Compressor, Start Air #3B	500	1		17.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Compressor, Air, LP Ship Service	500	1	50.00	40.24	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024
Compressor, Air, LP Ship Service	500	1	50.00	40.24	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024	0.10	4.024
Steering Gear Stbd	500	1	125.00	99.52	0.30	29.856	0.30	29.856	0.30	29.86	0.00	0	0.00	0	0.00	0
Steering Gear Port	500	1	125.00	99.52	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Steering Control Stbd	500	1	0.00	0.80	0.10	0.08	0.10	0.08	0.10	0.08	0.00	0	0.00	0	0.00	0
Steering Control Port	500	1	0.00	0.80	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Aircrtaft Elevator 1	500	1		300.00	0.40	120	0.40	120	0.00	0	0.00	0	0.00	0	0.00	0
Aircrtaft Elevator 2	500	1		150.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Aircrtaft Elevator 3	500	1		300.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Weapons Elevator 1	500	1		50.00	0.40	20	0.40	20	0.00	0	0.00	0	0.00	0	0.00	0
Weapons Elevator 2	500	1		50.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Weapons Elevator 3	500	1		50.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Weapons Elevator 4	500	1		50.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
EMAL track 1	500	1		30000.00	0.10	3000	0.10	3000	0.00	0	0.00	0	0.00	0	0.00	0
EMAL track 2	500	1		30000.00	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Blast Deflector	500	1		50.00	0.40	20	0.40	20	0.00	0	0.00	0	0.00	0	0.00	0
Separator, Oil/Water #1A	500	1	0.00	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.00	0
Separator, Oil/Water #1B	500	1	0.00	1.00	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.00	0
Separator, Oil/Water #2A	500	1	0.00	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.00	0
Separator, Oil/Water #2B	500	1	0.00	1.00	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.00	0
Separator, Oil/Water #3A	500	1	0.00	1.00	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.20	0.2	0.00	0
Separator, Oil/Water #3B	500	1	0.00	1.00	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.10	0.1	0.00	0
Oily Waste XFER Pump #1A	500	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
Oily Waste XFER Pump #1B	500	1	10.00	8.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Oily Waste XFER Pump #2A	500	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
Oily Waste XFER Pump #2B	500	1	10.00	8.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Oily Waste XFER Pump #3A	500	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
Oily Waste XFER Pump #3B	500	1	10.00	8.43	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Sewage Collection Unit #1	500	1	5.40	5.03	0.40	2.012	0.40	2.012	0.40	2.012	0.20	1.006	0.40	2.012	0.00	0
Sewage Collection Unit #2	500	1	5.40	5.03	0.40	2.012	0.40	2.012	0.40	2.012	0.20	1.006	0.40	2.012	0.00	0
Sewage Collection Unit #3	500	1	5.40	5.03	0.40	2.012	0.40	2.012	0.40	2.012	0.20	1.006	0.40	2.012	0.00	0
Sewage Collection Unit #4	500	1	5.40	5.03	0.40	2.012	0.40	2.012	0.40	2.012	0.20	1.006	0.40	2.012	0.00	0
Sewage Collection Unit #5	500	1	5.40	5.03	0.40	2.012	0.40	2.012	0.40	2.012	0.20	1.006	0.40	2.012	0.00	0
Sewage Treatment Unit #1	500	1	10.00	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.00	0
Sewage Treatment Unit #2	500	1	10.00	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.00	0
Sewage Treatment Unit #3	500	1	10.00	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.00	0
Sewage Treatment Unit #4	500	1	10.00	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.00	0
Sewage Treatment Unit #5	500	1	10.00	6.40	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.40	2.56	0.00	0
Pump, Waste Water Disch #1	500	1	10.00	8.43	0.10	0.843	0.10	0.843	0.10	0.843	0.10	0.843	0.00	0	0.00	0
Pump, Waste Water Disch #2	500	1	10.00	8.43	0.10	0.843	0.10	0.843	0.10	0.843	0.10	0.843	0.00	0	0.00	0
Pump, Waste Water Disch #3	500	1	10.00	8.43	0.10	0.843	0.10	0.843	0.10	0.843	0.10	0.843	0.00	0	0.00	0
Pump, Waste Water Disch #4	500	1	10.00	8.43	0.10	0.843	0.10	0.843	0.10	0.843	0.10	0.843	0.00	0	0.00	0
Pump, Waste Water Disch #5	500	1	10.00	8.43	0.10	0.843	0.10	0.843	0.10	0.843	0.10	0.843	0.00	0	0.00	0
CIWS Mk15 BLK 1B	700	1		21.00	1.00	21	1.00	21	1.00	21	0.00	0	0.00	0	0.00	0
CIWS Mk15 BLK 1B	700	1		21.00	1.00	21	1.00	21	1.00	21	0.00	0	0.00	0	0.00	0
VLS Mk-41	700			31.10	0.10	3.11	0.10	3.11	0.10	3.11	0.00	0	0.00	0	0.00	0
MK32 SVTT OnDeck	700	1		1.1	0.9	0.99	0.9	0.99	0.9	0.99	0	0	0	0	0	0
MK32 SVTT OnDeck	700	1		1.1	0.9	0.99	0.9	0.99	0.9	0.99	0	0	0	0	0	0

D.4 Weights

SWBS	Component	Weight (MT)	VCG (m)	Moment	LCG (m)	Moment	TCG (m)	Moment
100	HULL STRUCTURES	13444.99	11.29	151763.02	115.26	1549723.19	0.02	332.28
	BARE HULL	11830.00	11.85	140185.50	115.00	1360450.00	0.00	0.00
110	SHELL + SUPPORTS			0.00		0.00		0.00
120	HULL STRUCTURAL BULKHDS			0.00		0.00		0.00
130	HULL DECKS			0.00		0.00		0.00
140	HULL PLATFORMS/FLATS			0.00		0.00		0.00
150	DECK HOUSE STRUCTURE	76.99	31.12	2396.14	62.00	4773.19	4.32	332.28
160	SPECIAL STRUCTURES			0.00		0.00		0.00
170	MASTS+KINGPOSTS+SERV PLATFORM	2.00	40.29	80.58	90.00	180.00	0.00	0.00
180	FOUNDATIONS	1536.00	5.93	9100.80	120.00	184320.00	0.00	0.00
190	SPECIAL PURPOSE SYSTEMS			0.00		0.00		0.00
200	PROPULSION PLANT	2179.26	4.48	9761.84	118.17	257516.90	-0.68	-1488.02
	BASIC MACHINERY	757.85	6.58	4985.14	90.00	68206.50	-3.00	-2273.55
230	PROPULSION UNITS	369.00	2.00	738.00	162.00	59778.00	0.00	0.00
	Propulsion Motor 1	184.50	2.00	369.00	162.00	29889.00		0.00
	Propulsion Motor 2	184.50	2.00	369.00	162.00	29889.00		0.00
233	DIESEL ENGINES	404.15	2.79	1127.58	110.20	44537.33	0.85	343.53
	Diesel 1	80.83	2.79	225.52	140.00	11316.20	4.25	343.53
	Diesel 2	80.83	2.79	225.52	140.00	11316.20	-4.25	-343.53
	Diesel 3	80.83	2.79	225.52	107.00	8648.81	4.25	343.53
	Diesel 4	80.83	2.79	225.52	107.00	8648.81	-4.25	-343.53
	Diesel 5	80.83	2.79	225.52	57.00	4607.31	4.25	343.53
234	GAS TURBINES			0.00		0.00		0.00
235	ELECTRIC PROPULSION	520.00	5.11	2654.60	116.20	60424.00	0.85	442.00
	Propulsion Generator 1	104.00	5.11	530.92	146.00	15184.00	4.25	442.00
	Propulsion Generator 2	104.00	5.11	530.92	146.00	15184.00	-4.25	-442.00
	Propulsion Generator 3	104.00	5.11	530.92	113.00	11752.00	4.25	442.00
	Propulsion Generator 4	104.00	5.11	530.92	113.00	11752.00	-4.25	-442.00
	Propulsion Generator 5	104.00	5.11	530.92	63.00	6552.00	4.25	442.00
240	TRANSMISSION+PROPULSOR SYSTEMS			0.00		0.00		0.00
241	REDUCTION GEARS			0.00		0.00		0.00
242	CLUTCHES + COUPLINGS			0.00		0.00		0.00
243	SHAFTING	66.84	2.00	133.67	185.00	12364.66	0.00	0.00
244	SHAFT BEARINGS	12.71	2.00	25.42	190.00	2414.90	0.00	0.00
245	PROPULSORS	48.71	2.00	97.43	201.00	9791.51	0.00	0.00
250	SUPPORT SYSTEMS, UPTAKES			0.00		0.00		0.00
260	PROPUL SUP SYS- FUEL, LUBE OIL			0.00		0.00		0.00
290	SPECIAL PURPOSE SYSTEMS			0.00		0.00		0.00
300	ELECTRIC PLANT, GENERAL	834.74	14.24	11886.11	58.40	48751.80	0.23	195.30
310	ELECTRIC POWER GENERATION			0.00		0.00		0.00
	BASIC MACHINERY	60.68	9.32	565.54	75.00	4551.00	0.00	0.00
311	SHIP SERVICE POWER GENERATION	62.00	0.00	0.00	35.50	2201.00	3.15	195.30
		31.00		0	50.00	1550.00	4.00	124.00
		31.00		0	21.00	651.00	2.30	71.30
312	EMERGENCY GENERATORS			0.00		0.00		0.00
314	POWER CONVERSION EQUIPMENT			0.00		0.00		0.00
320	POWER DISTRIBUTION SYS	584.12	15.00	8761.83	50.00	29206.10	0.00	0.00
330	LIGHTING SYSTEM	127.94	20.00	2558.74	100.00	12793.70	0.00	0.00
340	POWER GENERATION SUPPORT SYS			0.00		0.00		0.00
390	SPECIAL PURPOSE SYS			0.00		0.00		0.00
400	COMMAND+SURVEILLANCE	335.30	17.47	5859.22	85.73	28743.76	4.46	1494.43
	PAYLOAD	100.99	24.99	2523.41	90.00	9088.65	5.00	504.93
	CABLING	41.18	13.33	548.93	90.00	3705.93	3.00	123.53
	MISC	49.85	13.33	664.50	90.00	4486.14	3.00	149.54
410	COMMAND+CONTROL SYS			0.00		0.00		0.00
420	NAVIGATION SYS			0.00		0.00		0.00
430	INTERIOR COMMUNICATIONS	143.29	14.81	2122.38	80.00	11463.04	5.00	716.44
440	EXTERIOR COMMUNICATIONS			0.00		0.00		0.00
450	SURF SURVEILLANCE SYS (RADAR)			0.00		0.00		0.00
460	UNDERWATER SURVEILLANCE SYSTEMS			0.00		0.00		0.00
470	COUNTERMEASURES			0.00		0.00		0.00
480	FIRE CONTROL SYS			0.00		0.00		0.00
490	SPECIAL PURPOSE SYS			0.00		0.00		0.00
500	AUXILIARY SYSTEMS, GENERAL	3433.00	13.75	47208.45	99.99	343249.39	-0.61	-2092.54
	WAUX	2402.00	11.85	28463.70	100.00	240200.00	-1.70	-4083.40
	PAYLOAD	7.55	18.80	141.94		0.00		0.00
510	CLIMATE CONTROL			0.00		0.00		0.00
	CPS	60.96	17.00	1036.37	70.00	4267.41	1.00	60.96
520	SEA WATER SYSTEMS			0.00		0.00		0.00
530	FRESH WATER SYSTEMS			0.00		0.00		0.00
540	FUELS/LUBRICANTS,HANDLING+STORAGE			0.00		0.00		0.00
550	AIR,GAS+MISC FLUID SYSTEM			0.00		0.00		0.00
560	SHIP CNTL SYS			0.00		0.00		0.00
570	UNDERWAY REPLENISHMENT SYSTEMS			0.00		0.00		0.00
581	ANCHOR HANDLING+STOWAGE SYSTEMS			0.00		0.00		0.00
582	MOORING+TOWING SYSTEMS			0.00		0.00		0.00
583	BOATS,HANDLING+STOWAGE SYSTEMS			0.00		0.00		0.00
585	AIRCRAFT WEAPONS ELEVATORS	40.00	15.06	602.40	104.67	4186.66	2.16	86.25
	Weapons Elevator 1	10.00	22.08	220.80	178.80	1787.96	-9.72	-97.22
	Weapons Elevator 2	10.00	22.08	220.80	142.31	1423.12	7.92	79.24
	Weapons Elevator 3	10.00	16.08	160.80	97.56	975.58	10.42	104.22
	Weapons Elevator 4	10.00	10.00	100.00	102.41	1024.10	10.42	104.20
586	AIRCRAFT RECOVERY SUPPORT SYS	64.86	29.08	1886.25	186.89	12122.43	1.20	78.00
587	AIRCRAFT LAUNCH SUPPORT SYSTEM	238.23	24.83	5914.70	69.19	16482.93	0.00	0.00
588	AIRCRAFT ELEVATORS	120.00	26.28	3153.60	173.56	20827.20	4.06	487.20
	Elevator 1 (2 UCAV'S)	48.00	29.08	1395.84	130.62	6269.76	6.05	290.40
	Elevator 2 (1 UCAV)	24.00	29.08	697.92	204.52	4908.48	-5.80	-139.20
	Elevator 3(2 UCAV's)	48.00	22.08	1059.84	201.02	9648.96	7.00	336.00
589	AIRCRAFT HANDLING, SUPPORT	108.80	17.00	1849.60	80.00	8704.00	10.00	1088.00
593	ENVIRONMENTAL POLLUTION CNTL SYS	28.74	10.65	306.04	80.00	2298.88	0.00	0.00
598	AUX SYSTEMS OPERATING FLUIDS	361.86	10.65	3853.85	80.00	28949.12	0.00	0.00
600	OUTFIT+FURNISHING,GENERAL	1870.21	14.14	26441.01	60.35	112859.27	1.00	1870.21
610	SHIP FITTINGS	1148.00	11.85	13603.80	70.00	80360.00	1.00	1148.00
640	LIVING SPACES	722.21	17.78	12837.21	45.00	32499.27	1.00	722.21
700	ARMAMENT	43.08	24.19	1042.11	80.00	3446.40	-10.00	-303.80

D.5 Area and Volume

SSCS	GROUP	LAUNCH DK AREA (m2)	RECOVERY DK AREA (m2)	FLT DK AREA (m2)	HANGAR AREA (m2)	HULL AREA (m2)	DH AREA (m2)	HULL VOLUME (m3)
1	MISSION SUPPORT	2102.67	3271.66	5104.25	3860.50	2402.30	97.00	51562.43
1.1	COMMAND,COMMUNICATION+SURV			0.00	0.00	516.81	76.00	1104.69
1.11	EXTERIOR COMMUNICATIONS			0.00	0.00	148.58	0.00	0.00
1.111	RADIO			0	0	117.98	0.00	0
1.115	TTY+FACSIMILE SYS			0	0	12.00	0.00	0
1.116	SECURE SYSTEMS			0	0	18.60	0.00	0
1.12	SURVEILLANCE SYS			0.00	0.00	4.83	76.00	14.49
1.121	SURFACE SURV (RADAR)			0	0	4.83	76.00	14.49
1.13	COMMAND+CONTROL			0.00	0.00	244.78	0.00	734.34
1.131	COMBAT INFO CENTER			0	0	129.87	0.00	389.61
1.132	CONNING STATIONS			0.00	0.00	114.91	0.00	344.73
1.1321	PILOT HOUSE (BRIDGE)			0	0	14.91	0.00	44.73
1.1322	CHART ROOM			0	0	100.00	0.00	300
1.14	COUNTERMEASURES			0	0	36.32	0.00	108.96
1.15	INTERIOR COMMUNICATIONS			0	0	80	0	240
1.16	ENVIORNMENTAL CNTL SUP SYS			0	0	2.30	0.00	6.9
1.2	WEAPONS		8	8.00	8.00	50.00	0.00	1000.00
1.22	MISSILES		8	8	8	0	0	0
1.24	TORPEDOS		0	0	0	50	0	0
1.26	MINE STOWAGE		0	0	0	0	0	1000
1.3	AVIATION	2102.67	3263.66	5096.25	3852.50	1541.90	21.00	48576.97
1.31	AVIATION LAUNCH+RECOVERY	2002.67	2973.76	4806.35	22.30	504.76	0.00	11439.18
1.311	LAUNCHING+RECOVERY AREAS	1810.39	2973.76	4784.15	0.00	0.00	0.00	10862.34
1.3111	LAUNCH DECK AREA	1810.39		1810.39	0.00	0.00	0.00	5431.17
1.3112	RECOVERY DECK AREA		2973.76	2973.76	0.00	0.00	0.00	0.00
1.312	LAUNCHING+RECOVERY EQUIP			0.00	0.00	504.76	0.00	510.24
1.3122	EMALS	170.08		0.00	0.00	0.00	0.00	510.24
1.313	STARTING STATIONS	22.2		22.20	22.30	0.00	0.00	66.60
1.32	AVIATION CONTROL			0.00	0.00	135.93	21.00	407.79
1.321	FLIGHT CONTROL			0.00	0.00	0.00	21.00	0.00
1.322	NAVIGATION			0.00	0.00	46.00	0.00	138.00
1.323	OPERATIONS			0.00	0.00	89.93	0.00	269.79
1.3231	AIR INTELLIGENCE			0.00	0.00	63.30	0.00	189.90
1.3232	AVIATION PHOTOGRAPHIC			0.00	0.00	9.50	0.00	28.50
1.3233	AVIATION PLAN AND READY RO			0.00	0.00	17.13	0.00	51.39
1.33	AVIATION HANDLING		289.9	289.90	869.60	0.00	0.00	5217.60
1.331	AIRCRAFT ELEVATORS		289.9	289.9	869.60	0.00	0.00	5217.60
1.34	AIRCRAFT STOWAGE			0.00	2698.00	0.00	0.00	16188.00
1.341	HANGAR PARKING				2698.00	0.00	0.00	16188.00
1.35	AVIATION ADMINISTRATION			0.00	0.00	203.00	0.00	609.00
1.36	AVIATION MAINTENANCE			0.00	145.00	0.00	0.00	1745.10
1.362	UCAV/UAV SHOPS			0.00	145.00	0.00	0.00	435.00
1.363	AIRCRAFT ORDINANCE MAINTINANCE			0.00	0.00	156.70	0.00	470.10
1.369	ORGANIZATIONAL LEVEL MAINTANENCE			0.00	0.00	280.00	0.00	840.00
1.37	AIRCRAFT ORDINANCE	100		0.00	117.6	418.14	0	9806.02
1.371	AIRCRAFT ORDINANCE SERVICE			0.00	0.00	80.00	0.00	240.00
1.372	CONTROL			0.00	0.00	42.57	0.00	127.71
1.373	HANDLING			0	0.00	127.57	0.00	382.71
1.374	STOWAGE			0.00	0.00	0.00	0.00	7846
1.375	WEAPONS ELEVATORS			0.00	117.60	168.00	0.00	1209.60
1.38	AVIATION FUEL SYS			0.00	0.00	0.00	0.00	2044.00
1.381	JP-5 SYSTEM			0.00	0.00	0.00	0.00	2044.00
1.3811	JP-5 TRANSFER			0.00	10.00	0.00	0.00	20.00
1.3812	JP-5 HANDLING			0.00	70.00	0.00	0.00	140.00
1.3813	AVIATION FUEL			0.00	0.00	0.00	0.00	1884.00
1.39	AVIATION STORES			0.00	0.00	280.07	0.00	1120.28
1.8	MISSION SUPPORT			0	0	78.35	0	235.05
1.86	METEOROLOGICAL FACIL			0.00	0.00	9.90	0.00	29.70
1.87	PHOTOGRAPHIC FACIL			0.00	0.00	68.45	0.00	205.35
1.9	SM ARMS,PYRO+SALU BAT			0.00	0.00	215.24	0.00	645.72
1.91	SM ARMS (LOCKER)			0.00	0.00	12.00	0.00	36.00
1.92	PYROTECHNICS			0.00	0.00	9.22	0.00	27.66
1.94	ARMORY			0.00	0.00	161.33	0.00	483.99
1.95	SECURITY FORCE EQUIP			0.00	0.00	32.69	0.00	98.07
2	HUMAN SUPPORT			0.00	0.00	6205.61	0.00	12118.26
2.1	LIVING			0.00	0.00	3355.54	0.00	3568.05
2.11	OFFICER LIVING			0.00	0.00	469.93	0.00	1409.79
2.111	BERTHING			0	0	388.76	0	1166.28
2.1111	SHIP OFFICER			0	0	138	0	414
2.1112	COMMANDING OFFICER CABIN			0	0	36.8	0	110.4
2.1113	COMMANDING OFFICER STATEROOM			0	0	24.5	0	73.5
2.1114	EXECUTIVE OFFICER STATEROOM			0	0	19.26	0	57.78
2.1115	AVIATION OFFICER			0	0	170.2	0	510.6
2.112	SANITARY			0	0	81.17	0	243.51
2.1121	SHIP OFFICER WR, WC & SH			0	0	31.5	0	94.5
2.1122	COMMANDING OFFICER BATH			0	0	5.97	0	17.91
2.1123	EXECUTIVE OFFICER BATH			0	0	3.8	0	11.4
2.1124	AVIATION OFFICER WR, WC & SH			0	0	39.9	0	119.7
2.12	ENLISTED LIVING			0	0	2655.04	0	1556.55
2.121	BERTHING			0	0	2136.19	0	0
2.1211	SHIP CPO			0	0	125.5	0	376.5

SSCS	GROUP	LAUNCH DK AREA (m2)	RECOVERY DK AREA (m2)	FLT DK AREA (m2)	HANGAR AREA (m2)	HULL AREA (m2)	DH AREA (m2)	HULL VOLUME (m3)
2.1212	AVIATION CPO			0	0	145.45	0	436.35
2.1213	SHIP ENLIST			0	0	675.04	0	2025.12
2.1214	AVIATION ENLIST			0	0	1190.2	0	3570.6
2.122	SANITARY			0	0	518.85	0	1556.55
2.1221	SHIP CPO			0	0	24.6	0	73.8
2.1222	AVIATION CPO			0	0	30.34	0	91.02
2.1223	SHIP ENLIST			0	0	181.755	0	545.265
2.1224	AVIATION ENLIST			0	0	282.155	0	846.465
2.13	CREW RECREATION			0.00	0.00	124.67	0.00	374.01
2.131	RECREATION ROOM			0	0	49.77	0	149.31
2.132	LIBRARY			0	0	47	0	141
2.133	HOBBY SHOP			0	0	3	0	9
2.134	PHOTOGRAPHIC DARK ROOM			0	0	3	0	9
2.135	CREW LOUNGE			0	0	21.9	0	65.7
2.14	GENERAL SANITARY FACILITIES			0.00	0.00	11.90	0.00	35.70
2.141	LADIES RETIRING ROOM			0	0	5.50	0.00	16.50
2.142	BRIDGE WASHRM & WC			0	0	4.10	0.00	12.30
2.143	ENGINEERING WASHRM & WC			0	0	2.30	0.00	6.90
2.155	PHYSICAL FITNESS			0.00	0.00	64.00	0.00	102.00
2.1551	PHYSICAL FITNESS RM			0	0	25.00	0.00	75.00
2.1552	ATHLETIC GEAR STRM			0	0	9.00	0.00	27.00
2.16	TRAINING			0.00	0.00	30.00	0.00	90.00
2.2	COMMISSARY			0	0	2028.16	0	6084.48
2.21	FOOD SERVICE			0	0	326.63	0	979.89
2.211	OFFICER MESSR00M AND LOUNGE			0	0	128.45	0.00	385.35
2.212	CPO MESSROOM AND LOUNGE			0	0	198.18	0.00	594.54
2.213	CREW			0	0	420.07	0	1260.21
2.2131	1ST CLASS MESSROOM			0	0	49.99	0.00	149.97
2.2132	CREW MESSROOM			0	0	370.08	0.00	1110.24
2.22	COMMISSARY SERVICE SPACES			0	0	367.65	0	1102.95
2.221	FOOD PREPARATION SPACES			0	0	48.40	0.00	145.20
2.222	GALLEY			0	0	319.25	0	957.75
2.2221	COMMANDING OFFICER GALLEY			0	0	14.85	0.00	44.55
2.2222	OFFICER GALLEY			0	0	37.27	0.00	111.81
2.2223	CPO GALLEY			0	0	19.19	0.00	57.57
2.2224	CREW GALLEY			0	0	191.16	0.00	573.48
2.2231	CPO PANTRY			0	0	8.96	0.00	26.88
2.2241	CREW SCULLERY			0	0	47.82	0.00	143.46
2.23	FOOD STORAGE+ISSUE			0	0	1333.88	0	4001.64
2.231	CHILL PROVISIONS			0	0	326.71	0.00	980.13
2.232	FROZEN PROVISIONS			0	0	302.89	0.00	908.67
2.233	DRY PROVISIONS			0	0	453.27	0.00	1359.81
2.234	PROVISION ISSUE ROOM			0	0	251.01	0.00	753.03
2.3	MEDICAL+DENTAL			0	0	238.10	0	714.30
2.31	MEDICAL FACILITIES			0	0	214.90	0.00	644.70
2.33	BATTLE DRESSING			0	0	23.2	0	69.60
2.4	GENERAL SERVICES			0	0	424.41	0	1273.23
2.41	SHIP STORE FACILITIES			0	0	150.07	0.00	450.21
2.42	LAUNDRY FACILITIES			0	0	148.34	0.00	445.02
2.44	BARBER SERVICE			0	0	34.80	0.00	104.40
2.46	POST OFFICE			0	0	23.50	0.00	70.50
2.47	BRIG			0	0	30.30	0.00	90.90
2.48	RELIGIOUS			0	0	37.40	0.00	112.20
2.5	PERSONNEL STORES			0	0	94.7	0	284.1
2.51	BAGGAGE STOREROOMS			0	0	80.08	0	240.24
2.511	OFFICER BAGGAGE STRM			0	0	7.86	0.00	23.58
2.512	CPO BAGGAGE STRM			0	0	6.20	0.00	18.60
2.513	CREW BAGGAGE STRM			0	0	66.02	0.00	198.06
2.55	FOUL WEATHER GEAR			0	0	14.62	0.00	43.86
2.61	CBR DECON STATIONS			0	0	78.90	0.00	236.70
2.62	CBR EQUIPMENT			0	0	93.40	0.00	280.20
2.63	CPS AIRLOCKS			0	0	62.80	0.00	188.40
2.71	LIFEJACKET LOCKER			0	0	1.90	0.00	5.70
3	SHIP SUPPORT			0	0	5071.92	0	16618.3
3.1	SHIP CNTL SYS (STEERING&DIVING)			0.00	0.00	166.00	0.00	498.00
3.11	STEERING GEAR			0	0	166.00	0.00	498.00
3.2	DAMAGE CONTROL			0.00	0.00	193.62	0.00	580.86
3.21	DAMAGE CNTRL CENTRAL			0	0	52.42	0.00	157.26
3.22	REPAIR STATIONS			0	0	69.60	0.00	208.80
3.25	FIRE FIGHTING			0	0	71.60	0.00	214.80
3.3	SHIP ADMINISTRATION			0.00	0.00	265.19	0.00	795.57
3.301	GENERAL SHIP			0	0	23.14	0.00	69.42
3.302	EXECUTIVE DEPT			0	0	58.60	0.00	175.80
3.303	ENGINEERING DEPT			0	0	38.00	0.00	114.00
3.304	SUPPLY DEPT			0	0	66.95	0.00	200.85
3.305	DECK DEPT			0	0	15.50	0.00	46.50
3.306	OPERATIONS DEPT			0	0	33.00	0.00	99.00
3.307	WEAPONS DEPT			0	0	30.00	0.00	90.00
3.5	DECK AUXILIARIES			0	0	500.17	0	2099.19
3.51	ANCHOR HANDLING			0	0	29.03	0.00	87.09
3.52	LINE HANDLING			0	0	145.10	0.00	435.30
3.53	TRANSFER-AT-SEA			0	0	51.60	0.00	154.80
3.54	SHIP BOATS STOWAGE			0	0	154.70	0.00	464.10
3.55	CHAIN LOCKER			0	0	119.74	0.00	957.90

SSCS	GROUP	LAUNCH DK AREA (m2)	RECOVERY DK AREA (m2)	FLT DK AREA (m2)	HANGAR AREA (m2)	HULL AREA (m2)	DH AREA (m2)	HULL VOLUME (m3)
3.6	SHIP MAINTENANCE			0.00	0.00	461.04	0.00	990.66
3.61	ENGINEERING DEPT			0	0	330.22	0.00	598.2
3.611	AUX (FILTER CLEANING)			0	0	28.40	0.00	85.20
3.612	ELECTRICAL			0	0	66.80	0.00	200.40
3.613	MECH (GENERAL WK SHOP)			0	0	94.00	0.00	282.00
3.614	PROPULSION MAINTENANCE			0	0	10.20	0.00	30.60
3.62	SHIP OPERATIONS DEPT (ELECT SHOP)			0	0	4.40	0.00	13.20
3.63	SHIP WEAPONS DEPT (ORDINANCE SHOP)			0	0	64.42	0.00	193.26
3.64	DECK DEPT (CARPENTER SHOP)			0	0	62.00	0.00	186.00
3.7	STOWAGE			0	0	787.87	0	2363.61
3.71	SUPPLY DEPT			0	0	721.17	0	2163.51
3.711	HAZARDOUS MATL (FLAM LIQ)			0	0	80.67	0.00	242.01
3.712	SPECIAL CLOTHING			0	0	38.00	0.00	114.00
3.713	GEN USE CONSUM+REPAIR PART			0	0	489.50	0.00	1468.50
3.714	SHIP STORE STORES			0	0	113.00	0.00	339.00
3.715	STORES HANDLING			0	0	0.00	0.00	0.00
3.72	ENGINEERING DEPT			0	0	15.00	0.00	45.00
3.73	OPERATIONS DEPT			0	0	4.40	0.00	13.20
3.74	DECK DEPT (BOATSWAIN STORES)			0	0	39.10	0.00	117.30
3.75	WEAPONS DEPT			0	0	2.80	0.00	8.40
3.76	EXEC DEPT (MASTER-AT-ARMS STOR)			0	0	3.30	0.00	9.90
3.78	CLEANING GEAR STOWAGE			0	0	2.10	0.00	6.30
3.8	ACCESS			0.00	0.00	2029.90	0.00	6089.70
3.82	INTERIOR			0.00	0.00	2029.90	0.00	6089.70
3.821	NORMAL ACCESS			0	0	2000.00	0.00	6000.00
3.822	ESCAPE ACCESS			0	0	29.90	0.00	89.70
3.9	TANKS			0	0	668.13	0	3200.711
3.91	SHIP PROP SYS TANKS			0	0	0	0	1910.49
3.911	SHIP ENDUR FUEL TANKS			0	0	0	0	1889.67
3.9112	FUEL OR BALLAST TANK (COMPENSATED)			0	0	0	0	1889.67
3.912	LUBE OIL TANKS			0	0	0	0	20.82
3.92	SW BALLAST TNKG			0	0	0	0	359.04
3.93	POTABLE WATER TNKG			0	0	0	0	420.181
3.941	SEWAGE TANKS			0	0	0	0	698.7
3.942	OILY WASTE TANKS			0	0	0	0	37.793
3.95	VOIDS			0	0	47.13	0	490
3.96	COFFERDAMS			0	0	21	0	21
3.98	UN OCCUPIED SPACES / EMPTY TANKS			0	0	600	0	1800
4	SHIP MACHINERY SYSTEM			0	0	52.92	0	11355.75
4.1	PROPULSION SYSTEM			0	0	52.92	0	9128.68
	BASIC MACHINERY			0	0	0	0	8940.94
4.13	INTERNAL COMBUSTION			0	0	52.92	0	187.74
4.133	EXHAUST			0	0	62.58	0	187.74
4.3	AUX MACHINERY			0	0	0	0	2227.07
4.31	GENERAL (AUX MACH DELTA)			0	0	0	0	2227.07

D.6 Resistance Model Testing

Model Construction

A scale of 100:1 is used for the model. The overall length of the model is 213 cm, the maximum that can effectively be tested in the Virginia Tech ESM towing tank. A 2 meter model is also realistic for our construction abilities and available tooling.

The model construction method was to frame the hull at its stations much like building a small wooden boat. Stations templates were traced onto balsa frames. Several stations were added in areas where there was more curvature to better define the model surface. Holes were drilled through the frames along a grid that was previously marked with pinholes. The frames were connected using wooded dowels through these holes.

Liquid expanding foam was poured between the frames to create workable surfaces. To contain the liquid expanding foam, a disposable mold was constructed. This mold was made out of cardboard and was roughly the shape of the upside-down hull. Hot glue and duct tape were used to seal the mold. The top of the mold was left open to allow for extra expansion of the foam. Foam was added batch by batch to the mold until it was full as shown in Figure 1. Once the mold was filled and the foam was allowed to dry fully, the cardboard mold was cut away. Sanding boards with higher grit paper, such as 120 or 180, were used to sand through the foam until the frames were reached. This created a surface between the frames that was approximately fair and geometrically similar to our actual hullform.

After fairing, the model was coated with a surface primer. This primer is intended to achieve a watertight seal and also, by applying thick layers, add rigidity to the model.

Testing

The model was tested in Virginia Tech's small student towing tank. To obtain proper trim and displacement, the model was placed in the towing tank and observed. It showed a small amount of trim at the stern and the model was too light. Holes were drilled in the model and weights were placed at locations equidistant from the models' CG along the centerline. This was done to sink the model to the design waterline and to correctly trim the model.

The model was towed using a wire tow line. To measure drag force, the tow line was connected from an eyehook on the model to a strain gage balance located underneath the carriage, Figure 2. The model was towed at speeds scaled to correspond to required ship speeds. Figure 3 and 4 show two model test runs. The color is inverted in Figure 3 to enable better viewing of the waves.

After reviewing the results it was concluded that the due to the unsophisticated test techniques and the small model size, the Holtrop-Mennen resistance prediction provided more reasonable results. Building and testing the model was a good educational experience, but it was understood at the start that the results would be suspect.

Figure 1. Foam surface being added to model frame structure

Figure 2. Tow Tank Apparatus and Model Ship

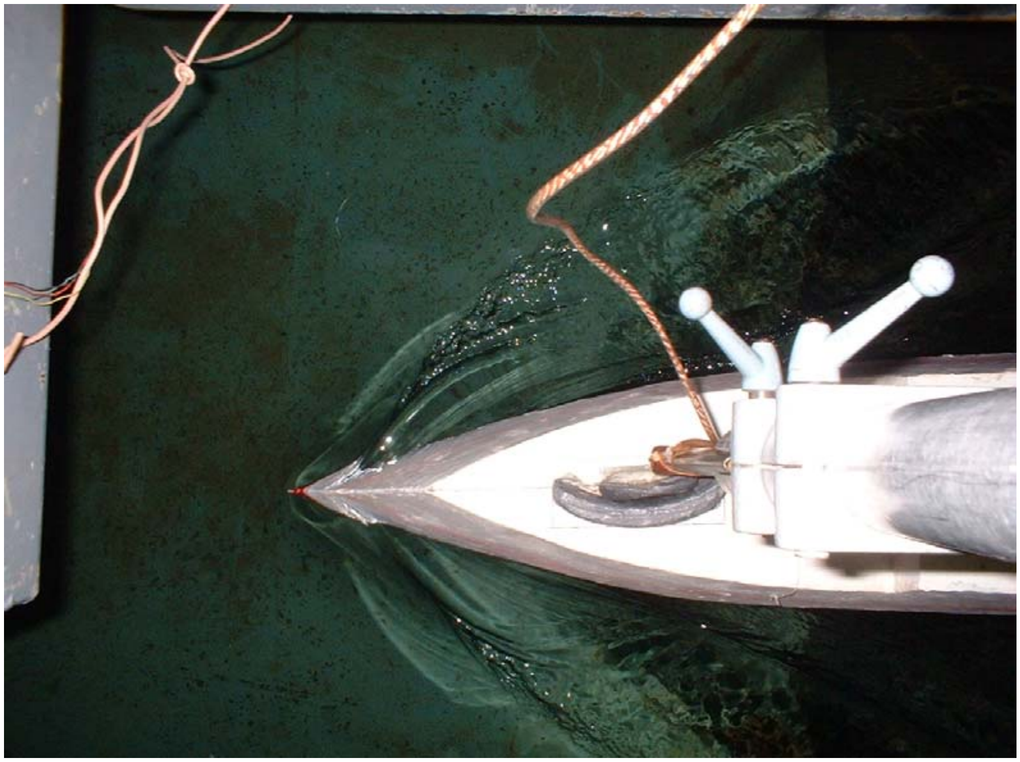


Figure 3. Model Test Run at 3.7 ft/sec

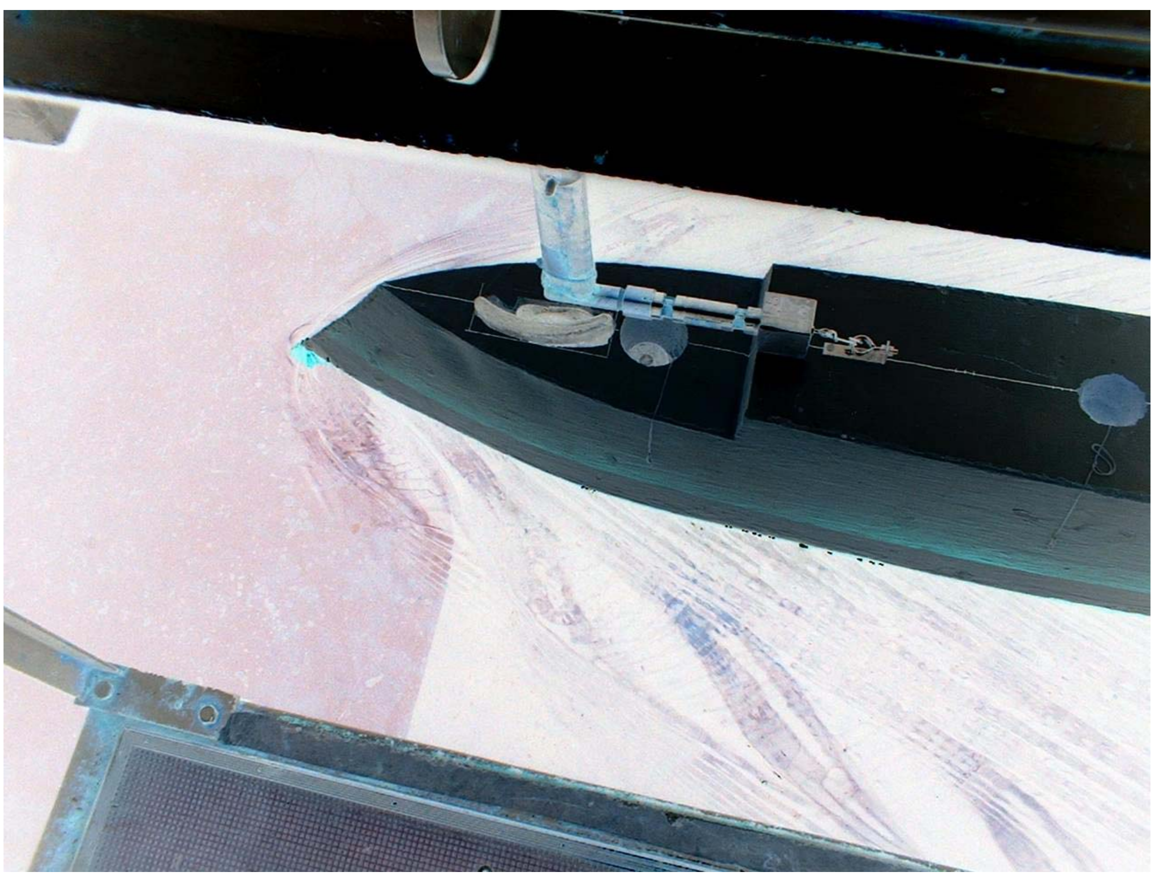


Figure 4. Model Test Run at 4 ft/sec