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Monterey, California. Naval Postgraduate School

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

TECHNICAL REPORT

"SEA ARCHER"
Distributed Aviation Platform

by

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December 2001

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2001	**3. REPORT TYPE AND DATES COVERED** Technical Report	
4. TITLE AND SUBTITLE: "Sea Archer" Distributed Aviation Platform			**5. FUNDING NUMBERS**
6. AUTHOR(S) Charles Calvano, Robert Harney, David Byers, Fotis Papoulias, John Ciezki, LT Joe Keller, LCDR Rabon Cooke, CDR (sel) James Ivey, LT Brad Stallings, LT Scot Searles, LT Ryan Kuchler, Ivan Ng, LTjg Orhan Okan, LTjg Mersin Gokce, LT Antonios Dalakos, LT Pete Lashomb.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release, distribution unlimited			**12b. DISTRIBUTION CODE**

Currently, no system exists that provides a sea-based distributed aviation platform capability. The emergence of Unmanned Air Vehicles (UAVs) / Unmanned Combat Air Vehicles (UCAVs), the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combine to support the requirement to re-evaluate how littoral operations will be conducted in the future. Given this background, a bottom-up design of a ship supporting a primarily UAV / UCAV air wing in a low to medium threat environment, is of significant interest. SEA ARCHER meets this interest.

This report outlines a design that meets the future needs for distributed aviation with a high-speed, highly automated platform. Large gains in reduced manning through automated systems for both operation and damage control help meet the demanding needs for the future of the Navy at reduced operational costs.

The report will outline both the Mission Needs Statement (MNS) and Operational Requirements Document (ORD) for the ship that was developed. The analysis of alternatives that was conducted to determine relative size requirements for the ships is presented in the next section. The concept design that resulted as a result of the Total Ship Systems Engineering process is then presented. Finally, a detailed look at the analysis and trade studies that were conducted is presented in order to show the more detailed analysis that was conducted in designing the ship.

14. SUBJECT TERMS Ship Design, Total Ship Systems Engineering, SEA ARCHER, Distributed Aviation, Littoral Warfare ship			**15. NUMBER OF PAGES**
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

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This report outlines the results of a two quarter Total Ship Systems Engineering (TSSE) Capstone design project undertaken by the students at the Naval Postgraduate School. The project was under the direction of Professors C.N. Calvano and R.Harney. The design team consisted of: LT Joe Keller, USN; LCDR Rabon Cooke, USN; CDR (sel) James Ivey, USN; LT Brad Stallings, USN; LT Scot Searles, USN; LT Ryan Kuchler, USN; Ivan Ng, Singapore Defense Science and Technology Agency; LTjg Orhan Okan, Turkish Navy; LTjg Mersin Gokce, Turkish Navy; LT Antonios Dalakos, Helenic Navy; LT Pete Lashomb, USN.

ABSTRACT

Currently, no system exists that provides a sea-based distributed aviation platform capability. The emergence of Unmanned Air Vehicles (UAVs) / Unmanned Combat Air Vehicles (UCAVs), the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combine to support the requirement to re-evaluate how littoral operations will be conducted in the future. Given this background, a bottom-up design of a ship supporting a primarily UAV / UCAV air wing in a low to medium threat environment, is of significant interest. SEA ARCHER meets this interest.

This report outlines a design that meets the future needs for distributed aviation with a high-speed, highly automated platform. Large gains in reduced manning through automated systems for both operation and damage control help meet the demanding needs for the future of the Navy at reduced operational costs.

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FACULTY COMMENTS

By
Professors C. N. Calvano, and R. C. Harney, NPS

TSSE PROGRAM

A purpose of the TSSE capstone design project is to give experience in the design process as applied to a large, complex system, using a Navy ship as the system of interest. An additional major goal is to require the students to develop and exercise the leadership and cooperative skills needed to perform a complex task as a team. It is also hoped that the design produced will be interesting, innovative and, possibly, spur discussion and thought in Navy and industry circles.

The program is made up of students enrolled in three curricula: Mechanical Engineering, Electrical and Computer Engineering, and Combat Systems. The faculty strives to ensure that all design projects provide an opportunity for students from each of these curricula to apply what they have learned in their individual domains while participating in a wider-scope team design.

The 2001 capstone design project was the 10th since the program's inception, but the first to be run within a broader, campus-wide collaborative environment. The project grew out of a Naval War College initiative exploring a concept called CORSAIR, a small aviation-capable ship carrying STOVL JSFs for littoral operations. CORSAIR was envisioned as contributing to a USN capability to defeat an adversary's access-denial capability and, in this role, would essentially be providing air cover for small littoral combatants, such as the SEA LANCE, which was the subject of the 2000 TSSE capstone project, a response to another NWDC initiative.

CAMPUS-WIDE COLLABORATIVE PROJECT

The lead in the operational aspects of this collaborative project went to students in the Systems Engineering and Integration curriculum. They were tasked to explore the concept operationally, and their analysis resulted in a FORCE-level approach that had the following salient features:

- The FORCE was intended for operation in low to moderate threat areas in the littorals (where it could relieve or substitute for a CVBG that was needed elsewhere where the threat was high).

- Unmanned air vehicles (UCAVs and UAVs), were employed exclusively to permit exploration of their utility. The air vehicles provide a primarily reconnaissance, surveillance, and target acquisition (RSTA) mission capability, though it was seen as useful to give the UCAVs the ability to carry a limited amount of ordnance.

- The aviation capability of the force would be widely distributed across a number of platforms (notionally quantified as eight). The loss or incapacitation of any platform would not result in the loss of a major part of the aviation capability.

- Because strike capability was not a major part of the force's purpose and because the aviation capability of the FORCE was the capability of interest, individual platforms would not conduct high-tempo air ops (if several aircraft needed to be launched or recovered in a short period of time, several of the eight platforms would share the task).

- Survivability of the FORCE's capability is the survivability characteristic of interest. The individual platforms would be looked upon as "combat consumable". (This, of course, played a big part in the thinking that minimum manning was needed. And, frankly, the idea of considering individual platforms to be "combat consumable" arose when it was hoped the aviation ships would be less than 8000 MT; our design showed that size to be unachievable, given the requirements.)

- The force would be capable of significantly higher speed than current forces, with exploration of a 60 knot maximum speed capability as a prime feature of interest.

- The force would consist of 8 aviation platforms carrying a combination of UCAVs, UAVs and, in very small numbers, helos. There would be 20 escorts, based on a notional extension of the 2000 TSSE SEA LANCE design (with increased displacement, additional missiles for strike and defense, and speed comparable to the aviation platform), referred to as SEA LANCE II. There would be a replenishment capability, hoped to be high-speed-capable, as well.

It was decided to approach this collaborative project in the following manner:

- The SEI students would continue to explore operational matters and would explore the technological developments necessary to make the concept work (e.g. C^2 for large numbers of unmanned air vehicles). The SEI team would coordinate the preparation of a top-level report of the collaborative project.
- The Aeronautical and Astronautical Engineering Department's students, in their capstone aircraft design project, would design the UCAV that would be part of the force.
- The TSSE students would design the aviation ship platform.
- The logistic support system would be defined by participating students from the Operations Logistics curriculum. The logistics ship would be notionally described, but not designed.

- The combatant escort would be SEA LANCE II, notionally described, but not designed.

The teams decided to use the following project names:

- The FORCE would be called CROSSBOW
- The UCAV would be called SEA ARROW
- The aviation ship would be called SEA ARCHER (the subject of this report)
- The escorts, as mentioned, would be SEA LANCE II
- The logistics ship system would be called SEA QUIVER.

THE TSSE SEA ARCHER DESIGN

Based on SEI mission analyses, the TSSE faculty established a Design Reference Mission to guide the design process. The Design Reference Mission for SEA ARCHER called for:

- An unreplenished transit leg of 4000 nm @ 50 kts
- SEA ARCHER to refuel 2 SEA LANCEs at 2000 nm
- SEA ARCHER to have 20% fuel remaining after 4000 nm
- At 4000 nm the force would be replenished. (There might be an identical second 4000 nm transit leg.)
- After replenishment, 7 days in littoral combat operations, to include:
  a. 2 refuelings of 2 SEA LANCEs
  b. Normal aircraft sortie rate operations (as defined in the ORD and AOA)
  c. 2 days @ 20 kts
  d. 1 day @ 25 kts
  e. 3 sprints of 2 hours at 60 kts
  f. Remaining time at loiter speeds (10-15 kts)

It was clear from the beginning that the 60kt maximum speed capability for SEA ARCHER would be a major driver. It quickly became evident that 60 knots could not be sustained for extended periods due to excessive fuel consumption. However, the advantage in maneuver warfare provided by a limited duration sprint capability was deemed important enough to keep 60 knots as the top speed requirement. This led to the choice of the HARLEY SES hull form over the other alternatives seriously considered (high speed catamaran and pentamaran). The result of the design process also highlighted the significant penalty that must be paid for such speed. Indeed, the propulsion system required to propel the nominal 15,000 LT SEA ARCHER at 60 knots

is larger than the propulsion system required to propel a nominal 100,000 LT aircraft carrier at 35 knots. In light of this penalty, the necessity of 60 kt top speed remains a question for further analysis.

Because the SEA ARROW UCAV had the ability to take off (with 40 kts wind over deck) in 400 ft, it was desired to provide that take off length on the flight deck so that UCAV operation would not be dependent on launcher availability. Also, the only resistance and powering data available to the team for this hull type was based on specific combinations of naval architectural characteristics, such as length-to-beam ratio. In order to enhance the validity of the major "scaling up" required for the hull, the same ship geometry was maintained and this, coupled with the 400 ft take off length resulted in a ship that has excess volume for its payload. (The payload of 8 UCAVs, 10 notional UAVs and 2 helos, with minimal ordnance, is relatively small.)

While the payload was light, the fuel load required to meet the mission profile for the SEA ARCHER (and to refuel its escorts) was a major weight challenge. In the end, the ship is weight (not volume) limited – and further design integration would be expected to reduce the excess volume in the ship.

The design turned out to be one of the most challenging faced yet by a TSSE student team – and one of the most educationally effective. The goals of an unmanned flight and hangar deck introduced the need to consider how automation could replace crew in the aircraft and ordnance handling functions. These automated systems, in turn, made arrangements of ordnance handling and aircraft movement paths crucial design considerations. When coupled with the fact that the high speed capability required an enormous engineering plant, with large volumes devoted to air handling, the ship's arrangements proved to be highly inter-dependent. One of the team members was overheard to say "every time he changes something in the propulsion plant, I have to re-design the hangar deck". While this is a slight overstatement, the sentiment is valid and is indicative of the fact that the students had to make numerous tradeoffs at the "total ship" level – a major goal of the TSSE program.

The final design produced by the TSSE team has several innovative and unique features that deserve special mention. These include:

- A large displacement ship incorporating surface effect technology to permit attainment of high speeds and acceptable endurance.
- The incorporation of numerous advanced sensors along the edges of the hull has eliminated the need for an island. This significantly eases design for reduced observability (stealth). It also increases survivability by eliminating an obvious aimpoint loaded with sensors that represent single points of failure.
- Aircraft are not stored on the flight deck. This is possible due to the reduced sortie rate (from each platform) permitted by distributing the aviation assets over many platforms coupled with reduced numbers of aircraft on each platform. The normally empty flight deck further reduces observability and enhances survivability.
- The flight deck is completely unmanned. Robotic transport equipment handles all movement of aircraft. This permits elimination of a major driver of manpower. It also eliminates the most dangerous jobs associated with naval aviation.
- Operations in the hangar deck are also mostly automated with minimal manpower requirements. Only highly specialized maintenance will involve human interaction. Refueling, rearming, and much avionics maintenance will be performed by robotic actors at specialized pit stops.
- All handling of ordnance (from withdrawal from the magazines to uploading onto aircraft) will be performed by automated systems. This eliminates another large manpower driver that is present on current aircraft carriers.
- The aircraft elevators are fully enclosed. When they are in the down position, a cover may be moved into position to seal the elevator both from the flight deck and from

the hangar deck. This improves the ability of this smaller ship to conduct operations in high sea states. It also permits the elevators to act as airlocks for a full ship collective protection system and as locations for nuclear, chemical, and biological (NBC) agent decontamination to be performed on aircraft when they return from missions. The SEA ARCHER is the first aviation capable ship design that has the potential for sustained and unrestricted combat operations in continuously contaminated NBC environments. This is a major deficiency in current naval forces.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY 1

II. REQUIREMENTS 3
- A. MISSION NEEDS STATEMENT 3
  - 1. Defense Planning Guidance Element. 3
  - 2. Mission Threat Analyses. 4
  - 3. Non-material Alternatives. 8
  - 4. Potential Material Alternatives. 9
  - 5. Constraints 9
- B. OPERATIONAL REQUIREMENTS DOCUMENT 12
  - 1. General Description of Operational Capability 12
  - 2. Threat 18
  - 3. Shortcomings of Existing Systems 19
  - 4. Capabilities Required 20
  - 5. Force Structure 27
  - 6. Schedule 27
  - 7. Program Affordability 27

III. ANALYSIS OF ALTERNATIVES 29
- A. ALTERNATIVES UNDER REVIEW 29
- B. PAYLOAD 30
- C. RESULTING HULL SIZES 31
- D. MEASURES OF EFFECTIVENESS 32
- E. RECOMMENDATIONS AND ALTERNATIVE SELECTION 37
- F. FACULTY DECISION FOR DESIGN 37
  - Design Reference Mission 38

IV. CONCEPT DESIGN 39
- A. HULL 40
  - 1. Hull Design 40
  - 2. Lift System 44
  - 3. Space Upgradeability 45
  - 4. Hull Characteristics 46
  - 5. Hull Construction 52
- B. PROPULSION 54
  - 1. Propulsion 54
  - 2. Propulsors 57
  - 3. Propulsion Plant Cost And Weight Data 60
  - 4. Fuel Requirements 60
  - 5. Engine Changeout 63
- C. ELECTRICAL 65
  - 1. Power Loads 65
  - 2. Power Distribution 67
  - 3. Power Conversion 70
  - 4. Power Generation 72

5. Weight and Volume Data 74
D. AVIATION OPERATIONS 75
1. Flight Deck 75
2. Hangar Bay 78
3. Magazines and Ordnance 81
4. Cyclic Operations 85
E. COMBAT SYSTEMS 89
1. Combat Systems Overview 89
2. Combat Engagement Flow 103
3. C4ISR 106
4. UAV Control & Communications 109
F. DAMAGE CONTROL 113
1. Detectors 113
2. Data Network, Processing Centers, and Evaluation Tools 115
3. Control Station Display and Interface 115
4. Isolation System 116
5. Reactive System 116
6. Chemical, Biological and Radiation (CBR) System 118
7. Personal Locator Device (PLD) 118
8. Damage Control Party Organization 118
9. Damage Control Elements and Scenarios 119
10. Crew Egression 120
G. AUXILIARIES 121
H. HABITABILITY 123
1. Accommodations 123
2. Food Services 125
3. Other Services for Reduced Manning 126
I. TOTAL SHIP SYSTEM 127
1. Construction and Methodology 129
2. Operations Support 130
3. Arrangements 132
4. Manning 136
5. Logistics and Maintenance 139
6. Modularity/Upgradeability 140
7. Survivability 141
8. Cost Estimation 142

V. ANALYSIS AND TRADE STUDIES 145
A. HULL 145
1. Hull Type Selection 145
2. Hydrostatic Calculations 156
B. PROPULSION 159
1. Main Engine Analysis and Trade Studies 159
2. Propulsion Motors 170
3. Propulsors 171
4. Main Reduction Gears 174
C. ELECTRICAL 177
1. Power Loads 177

2. Power Distribution 179
3. Power Conversion 181
4. Power Generation 183
D. AVIATION OPERATIONS 185
1. Aircraft Stowage and Service 185
2. Aircraft Launch and Recovery 186
3. Aircraft Movement 188
4. Ordnance Handling 189
5. Sizing/Scaling of Systems and Equipment 190
E. COMBAT SYSTEMS 195
1. Radars 195
2. Vertical Launch System 198
3. Free Electron Laser Weapon System 200
4. Small Calibre Gun System 219
5. Radar Crossection 224
6. Electro Optical Sensors 226
7. IRST 227
8. Mine Detection 228
9. Mine Clearance 229
F. DAMAGE CONTROL 231
1. Detectors 231
2. Reactive System 239
3. Damage Control Party Organization 244
G. TOTAL SHIP SYSTEMS 245
VI. CONCLUSIONS 251
REFERENCES 256
APPENDIX A 1
TYPICAL RESULTS OF THE ANALYTICAL TOOL DURING THE ANALYSIS OF ALTERNATIVES PHASE 1
APPENDIX B 7
HYDROSTATICS 7
Cross Curves of Stability 9
Hydrostatic Properties 11
Longitudinal Strength (0.01 deg.) 13
Righting Arms vs Heel Angle 15
Floodable Length Calculation 16
Floodable Length Calculation 18
APPENDIX C 20
PROPULSION 20
Gas Turbine Engine Parameters 23
PROPULSION LAYOUT OPTIONS EXPLORED 27
APPENDIX D 33
COMBAT SYSTEMS PAYLOAD 33
INITIAL DISTRIBUTION LIST 38

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LIST OF FIGURES

Figure 1 SEA ARCHER's role in the CROSSBOW FORCE....17
Figure 2 Harley SES Design from Vibtech Website....40
Figure 3 SEA ARCHER Hull Design....41
Figure 4 SEA ARCHER Speed verses Power Curve....42
Figure 5 Fan Module General Arrangement....44
Figure 6 Bell Aerospace-Textron SES Underwater Shock Test and Keel Shock Response from Reference [1]....47
Figure 7 SEA ARCHER Propulsion Unit Locations....48
Figure 8 Maneuvering waterjet equipped vessels with Steering and Reversing Systems from Reference [5]....49
Figure 9 High Length/Beam Ratio SES Wake Comparison to Monohull from Reference [6]....50
Figure 10 SEA ARCHER Bulkhead Arrangement....51
Figure 11 Typical Wave Piercing Bow from Reference [7]....52
Figure 12 SEA ARCHER Propulsion Plant.....55
Figure 13 Propulsion Plant Volume Requirements.....56
Figure 14 SEA ARCHER's Engineroom.....56
Figure 15 SEA ARCHER Steering (From Ref [9])....58
Figure 16 Waterjet/Hydro-Air Drive Inlet Duct....59
Figure 17 Waterjet/Hydro-Air Drive Stern View....59
Figure 18 Engine Changeout.....64
Figure 19 Notional Layout for One Zone....68
Figure 20 Notional Layout of Electrical Source Components....69
Figure 21 Notional Ship Layout....70
Figure 22 Flight Deck Layout....76
Figure 23 Flight Deck Towbot....77
Figure 24 Hangar Bay Layout....79
Figure 25 Hangar Bay Trackbot....80
Figure 26 Pit Stop Layout....80
Figure 27 Magazine Layout....82
Figure 28 Aircraft Flow from Recovery to Launch....87
Figure 29 Flight Deck Arrangement for Surge Operations....88
Figure 30 SEA ARCHER Combat System Layout....91
Figure 31 Ship Self Defense Sequence....105
Figure 32 UAV Communications and Control....111
Figure 33 A Typical Life Raft for Sea Archer....120
Figure 34 Typical Officer Stateroom Arrangement....123
Figure 35 Typical CPO Stateroom Arrangement....124
Figure 36 Sit-up Berth....124
Figure 37 Wireframe View of SEA ARCHER....128
Figure 38 Hull Exterior Profile....130
Figure 39 Hull Profile Aft View....131
Figure 40 Internal Arrangements....133

Figure 41 Internal Arrangements - Forward....134
Figure 42 Internal Arrangements - Aft....135
Figure 43 Hull Form Candidates Characterization Based on Means of Support....145
Figure 44 Generic Power versus Speed Curve....146
Figure 45 Speed Degradation with Sea State for Various Hullforms. 147
Figure 46 Displacement vs. Payload Graph Comparing SES, Catamaran, Trimaran and Pentamaran. 149
Figure 47 Graph Displaying the Displacement Crossover Point Between Pentamaran and ACC....153
Figure 48 Graph Displaying the Required Horsepower Crossover Point Between Pentamaran and ACC....154
Figure 49 Power Curve for Harley SES Based on All the Data Compared to Catamaran 155
Figure 50 SEA ARCHER's Hull Body Plan View 156
Figure 51 SEA ARCHER's Hull Top Isometric View....157
Figure 52 SEA ARCHER's Hull Bottom Isometric View....158
Figure 53 Power to Weight Ratio Comparison. 161
Figure 54 SFC Comparison. 162
Figure 55 LM2500 GTE (From Ref [34]). 163
Figure 56 WR21 GTE (From Ref [37])....164
Figure 57 LM6000 GTE (From Ref [34]). 165
Figure 58 Trent 50 GTE (From Ref [40]). 166
Figure 59 LM2500+ GTE (From Ref [34]). 167
Figure 60 Trent 30 GTE (From Ref [43]). 168
Figure 61 SFC Performance Predictions (From Ref.[45]). 169
Figure 62 Far Term SFC Predictions (From Ref [45])....170
Figure 63 Kamewa 50MW Waterjet (From Ref [48]). 172
Figure 64 Hydro-Air Half Submerged (from Ref [48]). 173
Figure 65 Typical Hydro-Air Drive Install (from Ref[48]). 173
Figure 66 Scaled Waterjet/Hydro-Air drive Data (data from Ref [49]). 174
Figure 67 Available Catapult Energies 188
Figure 68 Ordnance Handling System 190
Figure 69 Size and Weight for SPY 3 197
Figure 70 SEA ARCHER Radar Blind Zones....198
Figure 71 Combat Engagement Sequence....204
Figure 72 Radar Horizon with target at different target heights 205
Figure 73 Time Engagement Analysis for Mach 2 ASCM 206
Figure 74 Time Engagement with Mach 3 ASCM....207
Figure 75 FEL System Location 210
Figure 76 FEL System Architecture....211
Figure 77 Beam Director for Sea Archer 212
Figure 78 Beam Director Location....214
Figure 79 SEA ARCHER Prime Power Layout....216
Figure 80 Energy Required for Vaporization of Rain for a 5 km Engagement 219
Figure 81 Overview of Small Calibre Gun Systems 223
Figure 82 Radar Cross Section against Aspect Angle θ....225
Figure 83 Thermal Imaging Sighting System (TISS) (from [23]) 227

Figure 84 Notional IRST system (from [23])....227
Figure 85 Source Level Calculation....228
Figure 86 RAMICS Concept....230
Figure 87 Typical Hydrocarbon Fire Spectrum....233
Figure 88 Schematic Video Smoke and Flame....234
Figure 89 Principle of Fiber Optical Detector....236
Figure 90 High Performance Optical Detector....237
Figure 91 Smart Microsensor....237
Figure 92 Relative System Cylinder/Space Requirements (from [71])....243

LIST OF TABLES

Table 1 Aircraft Planning Factors 18
Table 2 Key Performance Parameters 21
Table 3 Notional SEA ARCHER Air Wing, 1 Squadron 29
Table 4 Payload Summary 30
Table 5 AOA Ship sizes 32
Table 6 MOE Matrix Evaluation. 37
Table 7 SEA ARCHER Design Characteristics 43
Table 8 Fan Module Specifications 44
Table 9 Propulsion Weight And Cost Data. 60
Table 10 Speed Profile For SEA ARCHER 61
Table 11 Speed Versus Horsepower Requirements. 62
Table 12 Fuel Required at Various Speeds. 63
Table 13 Required Electrical Power 65
Table 14 Power Types for Major Components 66
Table 15 Electrical Generator Casualties 72
Table 16 Propulsion Casualties 73
Table 17 Electrical Weights and Volumes 74
Table 18 Airwing Weapons Loadout 85
Table 19 Hypothetical Airplan 86
Table 20 Layered Air Defense for CROSSBOW Taskforce 89
Table 21 Layered Surface Defense for CROSSBOW Taskforce 89
Table 22 Layered Sub-Surface Defense for CROSSBOW Taskforce 90
Table 23 Super Sea Sparrow Missile Characteristics 97
Table 24 Small Caliber Gun System Specifications 98
Table 25 Estimated Bandwidth Requirement 109
Table 26 Installation of the Detectors Onboard 114
Table 27 Installation of the Fire Suppression Systems Onboard 117
Table 28 Accommodation Arrangement 125
Table 29 Habitability Compartments Other Than Accommodations 125
Table 30 Ship Design Philosophy Priorities 129
Table 31 Ships Manning Matrix 138
Table 32 Aviation Manning Matrix 138
Table 33 Provisions Capacity 139
Table 34 AOA Payload Summary 150
Table 35 AOA Hull Dimensions Results 151
Table 36 New SEA LANCE Concept Characteristics 151
Table 37 Final Payload for SEA ARCHER Design. 152
Table 38 Induction Propulsion Motors (From ref [46]). 171
Table 39 Gas Turbine and Power Conversion Module Weights 181
Table 40 Gas Turbine and Power Conversion Module Volumes 182
Table 41 Available Gas Turbine Generators 183
Table 42 Weights and Volumes of EMALS Components 192
Table 43 Magazine Loadout 194

Table 44 Comparison of Inner Layer Defense Systems (from [23] & [25]).....201
Table 45 Table of ASCM assumptions.....206
Table 46 Properties of Aluminum.....208
Table 47 Radar Cross Section of SEA ARCHER for Surface Based Radar.....225
Table 48 Radar Cross Section of SEA ARCHER for Air Based Radar 226
Table 49 Comparison of Fire Suppression Systems (from [74]) 243
Table 50 Manhors Summary.....245
Table 51 Manhours Summary (Continued) 246
Table 52 SEA ARCHER Specialized Equipment.....247
Table 53 SEA ARCHER Cost Estimate 248

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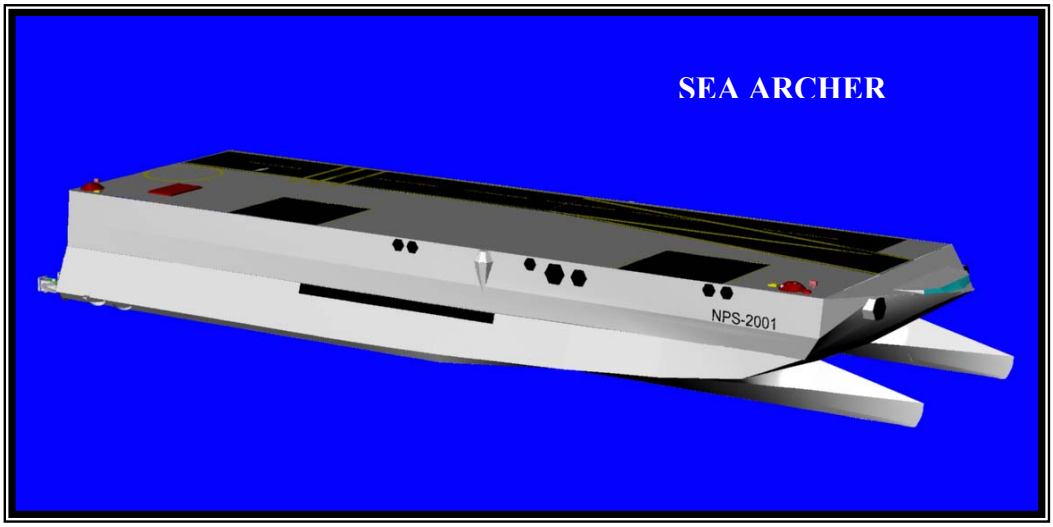
I. EXECUTIVE SUMMARY

Currently, no system exists that provides a sea-based distributed aviation platform capability. The emergence of Unmanned Air Vehicles (UAVs) / Unmanned Combat Air Vehicles (UCAVs), the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combine to support the requirement to re-evaluate how littoral operations will be conducted in the future. Given this background, a bottom-up design of a ship supporting a primarily UAV / UCAV air wing in a low to medium threat environment, is of significant interest. SEA ARCHER meets this interest.



SEA ARCHER Characteristics

Displacement	13,500 mT
Length	181 m
Beam	59 m
Draft – w/air cushion	2m
off air cushion	4m
Installed HP	327,000 HP
Manning	128

Reductions in manning were achieved through a high degree of automation, including the damage control architecture. In further support of reduced manning, a maintenance concept that calls for much of SEA ARCHER's maintenance to be performed by outside activities is utilized.

Operational Requirements

- Range: 4000 nm @ 50 kts
- Maximum speed: 60 kts
- Maximum manning: 150
- Airwing: 8 UCAVs, 2 Helos, 10 UAVs

SEA ARCHER was designed as part of a wider interdisciplinary project, with teams from the Systems Engineering and Integration Program, the Department of Aeronautics and Astronautics, and the Total Ship Systems Engineering program. Students from the Logistics Management and Aviation Maintenance Curricula also participated.

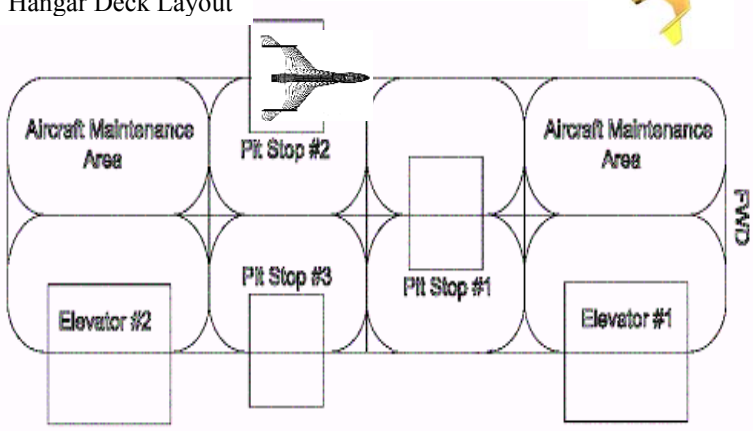
CROSSBOW – Is the force level structure that includes:
SEA ARCHER – Aviation ship
SEA ARROW – Unmanned Combat Air Vehicle
SEA LANCE – Small Combatant (2000 TSSE design)
SEA QUIVER – Logistics Support Subsystem

Aviation Systems

Significant manning reductions were achieved through the use of an unmanned flight deck and a computer-controlled, automated hangar deck. The fully enclosed hangar bay provides storage for all aircraft as well as maintenance areas and a pit stop system where refueling, rearming, and reconfiguring functions occur. Other automated functions include the use of robotic trackbots and towbots for aircraft movement, as well as automated weapons handling and loading. Aircraft are launched with an Electromagnetic Aircraft Launching System (EMALS) catapult or can be launched without catapult assistance when SEA ARCHER's speed capabilities are used to create a wind over deck greater than 40 knots. Fully enclosed elevators allow for corrosion-control waterwash and CBR decontamination of aircraft in the elevator.

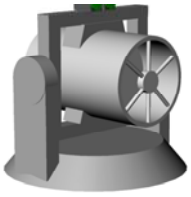
SEA ARROW UCAV

Hangar Deck Layout

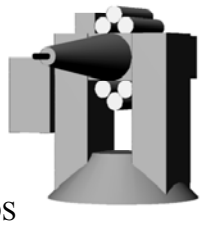


Track system for handling aircraft in Hangar

Free electron laser



Stabilized small caliber gun



Super Sea Sparrow Missiles

IRST

EOS

USC

Combat Systems

SEA ARCHER has an inner layer defense provided by a free electron laser (primary air defense) and stabilized small caliber gun system (primary surface role) with enclosed decoy launchers. Medium layer defense employs air/surface capable missiles. This is supported by a new, small, unmanned surface craft (USC) capable of air and surface engagement as well as forward mine detection. SEA ARROW, helicopters and SEA LANCE provide outer layer defenses. Sensor suites include 3D Volume Search Radar, Multi-Function Radar, Infra-Red Search & Track System and Electro-Optical Systems. Command & Control is supported by an Enhanced Cooperative Engagement Capability integrated with a ship self defense system for air, surface and subsurface warfare.

Hull/Propulsion

SEA ARCHER meets the demanding speed requirements of the Operational Requirements Document by merging a catamaran hull with a surface effect ship's air cavities. When filled with air by high volume compressors, the cavities in each hull support up to 85% of the ship's weight, cutting the ship's draft in half and greatly reducing underwater resistance. The ship is propelled by a combination of six gas turbine engines driving six hydro-air drive propulsors. These vectored-thrust propulsors give the ship the ability to get underway without tugs. The propulsion plant can be operated in various lineups to achieve a top speed of over 60 kts without sacrificing fuel efficiency at lower speeds.

II. REQUIREMENTS

A. MISSION NEEDS STATEMENT

1. Defense Planning Guidance Element.

This Mission Needs Statement (MNS) provides requirements for a platform to deliver distributed aviation for access assurance in the littorals. It addresses the Department of Defense "Defense Planning Guidance, FY-1997-2001," dated 9 May 1995, which states:

> "The primary mission of the United States military forces has always been, and will continue to be, to protect the nation from direct threats and to deter, and, if necessary, fight and win the nation's wars … deter and, if required decisively defeat aggression by projecting and sustaining U.S. power in two nearly simultaneous Major Regional Conflicts (MRCs); … Some U.S. forces must be forward-deployed or stationed in key overseas regions in peacetime … This demands highly qualified and motivated people, modern, well maintained equipment, viable joint doctrine, realistic training, strategic mobility and sufficient support and sustainment capabilities." (pp. 4&5)

This mission need also addresses the guidance and requirements validated by the Naval War College and Navy Warfare Doctrine Command in the "CORSAIR Concept". The planning, guidance, and mission needs for the "CORSAIR" initiative amplify new mission roles and priorities which the Navy and Marine Corps must meet to ensure success in 2010 and beyond.

Key demands on the future United States military capability requires assured access to all regions of the world. The concepts and doctrine to maintain this access include:

The ability for "knock down the door" (i.e., opposed entry) initial access using the combined capabilities of strike and power projection with reduced risk.

Denying enemy's targeting sequence through:

- Speed, maneuver, stealth, and distributed counter targeting.

- Enhanced Anti-Ship Missile Defense (ASMD), Cruise Missile Defense, Anti Submarine Warfare (ASW), and Mine Counter Measure (MCM).
- Defensive warfare strategies used by the total force in a fully Network Centric Warfare (NCW) environment.

Some level of active self-defense may still be required.

This MNS should guide initiatives to investigate potential solutions to include design, research, development, and acquisition of a new platform for the attainment of distributed sea-based tactical air.

2. Mission Threat Analyses.

Mission.

The general missions of distributed sea-based tactical air are to:

Provide credible, sustainable, and independent forward presence during peacetime without access to land bases,

Operate primarily in the littoral environment as a complement to the Carrier Battle Group (CVBG) and yet be capable of operations independent of the CVBG during certain Military Operations Other Than War (MOOTW) and low intensity conflicts to ensure access to littoral regions.

Provide a credible force to harass and suppress enemy forces, while awaiting CVBG arrival.

Carry the war to the enemy through joint multi-mission offensive operations by:

- being able to operate and support aircraft in attacks on enemy forces ashore, afloat, or submerged independent of forward-based land facilities,
- protecting friendly forces from enemy attack, through the establishment and maintenance of battlespace dominance independent of forward-based land facilities,
- engaging in sustained operations in support of the United States and its Allies independent of forward-based land facilities.

Capabilities.

The primary function of a sea-based distributed aviation platform is to shelter, transport, launch, recover, and maintain multi-mission aircraft and tactical airborne systems suitable for sea-based operations. The core capabilities required for this platform to perform the above missions include:

Strategic mobility – it must have the ability to independently deploy/respond quickly and operate with sufficient tactical flexibility, whenever and wherever required, to enable joint maritime expeditionary force operations.

Sustainability – it must have the capacity to sustain itself, its aircraft and escort for extended periods without direct access to shore facilities.

Survivability – it must be able to operate aircraft in hostile environments, protect itself from attack by threat weapons, and if hit, degrade gracefully.

Firepower –it must be able to operate sufficient numbers of tactical aircraft, and carry sufficient ordnance and fuel to conduct, in concert with other platforms in the distributed sea-based tactical aviation force, simultaneous power projection, battle space dominance and surveillance operations for extended periods and to deliver precise, high-volume firepower.

Joint command and control – while not envisioned to be a command and control flagship, it must be interoperable and its communications suite must be fully compatible with other naval, expeditionary, interagency, joint, and allied forces. In addition, it must be able to operate as a Command and Control center, integrate information to develop a coherent tactical picture to support Joint Force, Battle Force, Battle Group and Air Wing planning, coordinate actions with other forces, and communicate the force's actions to appropriate commanders. Connectivity must include seamless integration of both organic and off-ship sensor inputs for power projection actions.

Flexibility and growth potential – it must have the versatility to operate manned aircraft, unmanned aerial vehicles (UAVs), unmanned combat aerial vehicles (UCAVs), short take-off and vertical landing (STOVL) and short take-

off and landing aircraft (STOL). It must have the ability to perform simultaneous multi-mission tasking and readily adapt to changing operational needs. In addition, it must have the flexibility to adapt to changes in future threats, missions and technologies.

Threat

The anticipated threat to naval forces in 2020 will be the proliferation of high-tech/low-cost weaponry and sensors. These systems will be employed to inflict maximum damage by simple saturation of own-ship sensors and defensive measures. Anticipated threat objectives will be the coordinated effort to use all target acquisition and force support agencies available for the purpose of denying the combat power of the littoral force during the initial stages of ship movement. Central to the threat's defensive plan is the early identification and rapid denial in the littorals. Enemy systems will be found in multiple major threat areas. These include threats from space, air, surface, undersea, and info-sphere.

Common threads amongst these threats include:

- Enhanced multi-source intelligence collection and Information Warfare Operations
- Enhanced tactical mobility systems that reduce reaction time, protect the littorals, and improve firepower and sea protection.
- Higher-volume, longer-range targeting, command, control, and communications.
- Enhanced counter mobility capability by using land and shallow water mines.
- Increased availability, numbers, and accuracy of precision-guided munitions.
- Increased lethality and reliability of weapon systems, and the possible use of Weapons of Mass Destruction (WMD) / Nuclear, Biological, and Chemical (NBC) weapons.
- Electronic Warfare (EW) capabilities to monitor, direct, find, jam and deceive in the Radio Frequency (RF) and electro-optical spectrums.
- Early attack and disruption of supplies and logistics.

- The ability to reach outside the littorals with submarines, smart mines and aircraft carriers.
- Ability to take advantage of the sea and land terrain.
- With numerous aircraft, missiles, and rockets in the air at the same time, the probability of attrition is high.

Current Deficiencies – Shortfalls

There is no existing system to provide the sea-based distributed aviation platform capability. The emergence of UAVs / UCAVs, the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combined to support a requirement to re-think how future warfare will be waged in the littoral. A ship has never before been designed, from the bottom up, to support the operation of a primarily UAVs / UCAVs air wing in a low to medium threat environment. The sea-based distributed aviation platform will be the first. The object of the distributed aviation battle group is to augment CVBG capabilities in the contested littorals of the world.

Current programs and acquisitions fail to:

- Maintain required force levels for forward presence, crisis response and warfighting,
- Maintain an effective industrial base to assure continued support for sea-based tactical aviation, and
- Take advantage of new technologies and design concepts that offer opportunities to develop sea-based platforms that are capable, but more affordable than current platforms.

Timing and Priority

Low intensity conflicts throughout the world have increased dramatically in the past decade. In addition, the gross domestic products (GDP) of potential threat countries have increased at rates faster than that of the United States. Future conflicts will be fought against countries with credible defensive and offensive capabilities, especially in the littorals. The need for high tech/low cost, quick response air platforms is essential for ensuring access to the littoral regions of the world. Currently there are no programs being developed and funded that meet these needs for littoral access assurance.

Therefore, high priority must be placed on developing a sea-based distributed aviation system.

3. Non-material Alternatives.

US or Allied Doctrine. Doctrinal changes would include: Acceptance of a decreased quick response capability to deter/contain regional crises; A greater risk involved in placing high value assets in littoral regions; no customized naval platform to leverage on unmanned air systems; and, inability to increase US presence in low level conflicts.

Operational Concepts. The possibility of converting LHAs or LHDs was deliberated. The payload criteria could be fulfilled without major conversions to the platform but the higher speeds required cannot be achieved by the LHA/LHD, which have a maximum speed of well under 30 knots. Notwithstanding, the platforms are already currently utilized for other Operational Requirements and nearing the end of their life cycle.

The utilization of CVBGs to respond to lower levels of conflicts was also considered but this would entail increasing the current number of CVBGs.

Tactics. Multiple conflicts, calling for the application of sea-based forces into the littorals to enable US follow on forces and to ensure US presence, will place naval assets at greater risk with increased technological improvements in the enemy's offensive weaponry. Deployment of capital assets or High Value Units (HVUs) is unacceptable since the risk is very high and the mission would not be accomplished without accepting the loss of the HVUs.

Training. No training solutions were found to be feasible to fulfill requirements.

Organization. Organizational changes, such as to forward deploy air assets and increasing forward bases, have been considered. This would then reduce the response time for US action in the region of conflict. However, trends indicate an inability to forward base air assets due to base closures. It also raises complications such as increased defense spending and the dependence on allies for deployment but most of all, the acceptance that there would be insufficient assets to engage in two simultaneous MRCs.

All the alternatives considered were deemed not viable and as such justify a need for distributed sea-based tactical aviation platforms.

4. Potential Material Alternatives.

Alternative design concepts.

- New ship, aircraft or space-based designs, which may include nuclear or non-nuclear propulsion or advanced/unconventional hull forms
- Deployed space based designs including future pulsed laser or missile weapons systems
- Mobile Offshore Basing (MOB) Concepts

Modification of current assets

- Upgrade or modification of current naval/commercial assets
- Modification/increased procurement and employment of current Air Force assets

Cooperative allied programs.

Various allies have combat, hull, mechanical and electrical system programs ongoing or under development that offer possible cooperative opportunities. These subsystem designs will be examined. All meaningful cooperative opportunities can be realized without a formal cooperative development program for a 21st century sea-based distributed-air platform.

5. Constraints.

Overarching Constraints.

Operations. The ship design must extend the operational envelope beyond the capabilities of current sea-based aviation platforms to include significant increases in the distribution of aviation assets and in maximum and sustained speeds. Consideration should be given to ease risk management of assets in the littoral warfare environment. The platform must provide landing facilities and at least minimal hangar facilities commensurate with mission needs and cost, and ammunition storage for operational support of required aviation assets.

Architecture. The ship design must employ a total ship, aircraft, and weapons system architecture/engineering approach that optimizes total ownership cost and performance; allows computational and communications resources to keep

technological pace with commercial capabilities and allows for full realization of the "Command, Control, Communications, Computers and Intelligence (C4I) for the Warrior" (C4IFTW) concept; and provides the capability to survive and fight hurt in all operational environments. More specifically this implies physical element modularity; functional sharing of hardware (across all services); open systems information architecture; ship-wide resource management; automation of C4I, combat, aircraft support, ordnance and aircraft handling; automation and minimization of maintenance and administrative functions; integrated systems security; and embedded training.

Design. Consideration should be given to the maximum use of modular construction design in the platform's infrastructure. Emerging technologies through 2012 must be accounted for and incorporated during the developmental phase to support an Initial Operational Capability (IOC) date of 2021. Modern, flexible information processing must be built into any new weapons system. Since communication and data systems hold the greatest potential for future growth, and therefore obsolescence, their installations must be modularized as much as possible to allow for future upgrades. The inherent vulnerabilities of communications and data systems require information systems security to be engineered into the design. Use standard man-to-machine interfaces among the systems onboard. The man-to-machine interfaces should be standardized to the maximum extent possible to be consistent with existing user-friendly systems. For comparable capabilities, the total life cycle cost of the design should not exceed that of existing sea-based aviation platforms.

Personnel. The platform should be automated to a sufficient degree to realize significant manpower reductions in engineering, damage control, combat systems, ship support and Condition III watchstanding requirements. Reduced manning concepts used by other Navies should be reviewed to leverage advanced technologies and future advanced technology concepts in an effort to minimize shipboard manning requirements. Preventive maintenance manpower requirements must be reduced by incorporating self-analysis features in equipment designs, and by selecting materials and preservatives that minimize corrosion. The design should exploit the use of technology to reduce Manpower, Personnel and Training (MPT) requirements. Trade-offs that reduce MPT requirements shall be favored during design and development.

Infrastructure. The platform shall be able to use current U.S. Navy port facilities and shipyards.

Interoperability. All ship and combat systems elements must make use of standard subsystems and meet required development practices. The platform must be fully integrated with other U.S. Navy, Marine Corps, joint and allied forces, and other agencies in combined, coordinated operations. Joint goals for standardization and interoperability will be achieved to the maximum feasible extent. The platform must be able to embark Special Operations Forces (SOF) and Joint Forces when required for selected missions.

Logistics and Environmental, Safety, and Occupational Health Concerns.

The platform must be able to operate in U.S., foreign, and international waters in full compliance with existing U.S. and international pollution control laws and regulations. Consideration must be given to logistics that support meeting the constraints of high operational speeds and reduced manning.

Survivability.

The platform must meet the survivability requirements of Level III as defined in OPNAVINST 9070.1. A system capable of decontaminating the platform topsides after exposure to a Chemical, Biological & Radiological (CBR) warfare agents must be provided.

Operational environment.

The platform must remain functional and operational in all environments regardless of time of day, whether operating independently, in heavy weather or in the presence of electromagnetic, nuclear, biological and chemical contamination and/or shock effects from nuclear and conventional weapon attack.

B. OPERATIONAL REQUIREMENTS DOCUMENT

1. General Description of Operational Capability

Mission Area

The U.S. National Security Strategy has shifted from a focus on a global threat to a focus on regional challenges and interests in the littoral. While the prospect of global war has receded, we are entering a period of enormous uncertainty in regions critical to our national interests. Our forces can help to shape the future in ways favorable to our interests by underpinning our alliances, precluding threats, and helping to preserve the strategic position we won with the end of the Cold War. Naval forces will be full participants in the principal elements of this strategy--strategic deterrence and defense, forward presence, crisis response, and reconstitution. The Naval White Papers, "Forward From the Sea" and Operational Maneuver From the Sea (OMFFTS), provide direction to the U.S. Navy (USN) and the U.S. Marine Corps (USMC) concerning the challenges of the post-Cold War world and shift the operational focus of naval forces from the open ocean to the world's littorals. The concept of Littoral Warfare emphasizes the capability of naval forces as a forward deployed crisis response force to deter conflict in the littorals, and to prevent escalation and restore stability where deterrence has failed. These naval forces will meet far greater threats in number, quality and intelligence of weapons. As simultaneous coordinated attacks come with larger numbers of all types of weapons (from subsurface, surface, air and space), any naval force will have far less time to plan and carry out defensive and offensive operations. This view of a combat operation in the time frame of 2020 will require a mix of all types of airborne platforms both manned and unmanned operating from the SEA ARCHER class ship. All new missions, technologies, equipment, and operations strategies must have Follow on Operational Test and Evaluation completed by the summer of 2021.

With a far greater emphasis on joint and combined operations, the Navy, Marine Corps, Army and Air Force will provide unique capabilities of indispensable value in meeting our future security challenges especially in the littorals. Ready, relevant, and capable American Naval Expeditionary Forces provide: a powerful yet unobtrusive presence, strategic deterrence, control of the seas, extended and continuous

on-scene crisis response, precise power projection from the sea, and sea lift if larger scale war-fighting scenarios emerge. These maritime capabilities are particularly well tailored for the forward presence and crisis response missions articulated in the emerging National Security Strategy. The requirement for the capability to deploy, transport, and project landing forces in sufficient strength and capacity for the conduct of amphibious operations, up through Marine Expeditionary Force (MEF) level, without nearby land bases for support has been identified in the Marine Corps Master Plan (MCMP) 1996-2006.

Our ability to command the seas in areas where we anticipate future operations allows us to resize our naval forces and to concentrate on those capabilities required in the complex operating environment of the littoral or coastlines of the earth. Naval Expeditionary Forces maneuver from the sea using their dominance of littoral areas to amass forces rapidly and generate high intensity, precise offensive firepower at the time and location of their choosing, under any weather conditions, day or night. Operating in the Littorals requires mobility, flexibility and technology to amass strength against weakness in a timely manner.

Our National Security Strategy requires a strong forcible entry capability into the littoral areas and adjacent land. As discussed in detail in the Department of the Navy's concept of "From the Sea", America's interests will continue to dictate the necessity to influence events on the other side of our protective oceans. While even the viability of political reinforcement, by uncontested forward-presence forces, requires a credible forcible entry capability, the requirement to respond against an invader or international outlaw requires the unquestionable ability to place power in the littorals and ashore. In 2020 with few adjacent land bases in the world, the requisite sustainable, forcible entry capability can only come from the sea. In this time frame, allied forces will be required to enter areas defended by integrated systems of modern space, air, sea, and ground weapons. While some defenses will consist of relatively immobile forces and fixed positions, others will include mobile, combined-arms units backed by space weapons, naval and air craft (manned and unmanned) and employing the newest unmanned vehicles, missiles and mines against our planes, ships, and landing forces.

Design of operations and forces to defeat these opponents must accommodate our societal intolerance of attrition and demands for victory.

"Forward From the SEA"(FFTS) is a concept for projecting naval power in the littorals and ashore in support of a strategic objective. Essentially, FFTS is the application of maneuver warfare principles to the maritime portion of a theater campaign, capitalizing on the ever-expanding capabilities of modern naval airborne forces (manned and unmanned) to project power in an increasingly sophisticated and lethal environment. Operations are designed to break the cohesion and integration of enemy defenses while avoiding attrition oriented attacks. Emphasis will be placed on speed, mobility, deception, surprise, and other measures of battlefield preparation that confuse or create uncertainty and delay in the enemy's actions. Our ultimate desire is to destroy his will to fight or carry out actions contrary to the interests of the United States.

FFTS is a single, seamless operation extending from homeports to secure sea bases across the littoral to dominate a critical enemy center of gravity. The FFTS concept requires a single force that can change its character with its environment but always operate with a single objective. FFTS brings all facets of sea power to bear; it replaces our recent history of separately controlled movement, supporting operations, landings, and maneuver ashore. The next generation of technology provides our opportunity to close the batt1efield mobility gap between space assets, airborne operations, ship firepower and on shore forces, to link maneuver in ships, space assets, airborne operations with maneuver ashore.

Increased operational speed will be the sum of more rapid decisions of command, faster methods of control, quicker execution, higher speed of sea borne systems, and blurring distinction between maneuver at sea and maneuver in the littorals. Relative operational speed (the difference between our speed and that of the enemy) will increase as enemy operations are degraded by simultaneous surprise, deception, strikes, fires, and special and information operations. The moment of achieving superior operational tempo will be reached when the frequency of our operations do not allow our opponent to respond effectively or maintain cohesion of his forces.

While strike and special operations are complementary forms of sea power projection, new technologies, equipment, and tactics will be required to allow the Navy after Next to gain superiority in the littorals. The conduct of a littoral operation encompasses almost all types of ships, aircraft, weapons, and landing forces of the U.S. Navy and Marine Corps in a collaborative military effort. The salient requirement of the littoral operation is the necessity of rapidly building up combat power from an initial level of zero to full coordinated striking power to gain success and maintain objectives.

Future naval forces will be structured and equipped to project combat power in the littorals to seize control of the crisis arena for follow-on joint operations. Power projection requires air, space and water mobility, speed, firepower, and a versatile mix of survivable vehicles that enable launch in nearly all weather from a sea base of versatile ships. The force provides standoff (Battlespace) for the Naval Task Force to enable the effective employment of active / passive defense systems against enemy air and surface-fired weapons, avoids the major sea mine threat and avoids attrition. The Battlespace will be very complex around the task force with large numbers of enemy and friendly manned and unmanned vehicles in the air.

Type of System Proposed

Title 10, U.S. Code, directs the Navy to develop equipment used for maritime operations. This ORD addresses the specific operational capabilities and design considerations for SEA ARCHER, the centerpiece ship of the CROSSBOW Battle Group.

Operational Concept

As part of the Navy after Next initiative, the Navy is considering a new Battle Group concept called CROSSBOW (Figure 1), designed from the bottom up for littoral operation. This new force should operate primarily in the littoral environment as a complement to the Carrier Battle Group (CVBG) and yet be capable of operations independent of the CVBG during certain Military Operations Other Than War (MOOTW) and low intensity conflicts. CROSSBOW should provide additional assets to assist in the penetration of the littorals to suppress and soften enemy Integrated Air Defenses (IAD) and area denial capability to provided CVBG access. When low

intensity or MOOTW activities lead to escalation, CROSSBOW provides a credible force to harass and suppress enemy forces, while awaiting CVBG arrival. CROSSBOW forces may consist of squadrons of SEA ARCHERs, small expeditionary aircraft carriers, operating in concert with up to 20 SEA LANCE, which are small, low cost, high-speed combatants capable of deploying the Expeditionary Warfare Grid (EWG) and providing offensive and defensive missile fires. By using distributed sea based air assets, CROSSBOW should be capable of supporting continuous, rather than pulsed, air operations. The SEA ARCHER air wing, CV air wing, SEA LANCE, and other escorts operating in the area of action will provide force protection and offensive firepower. One or more SEA QUIVERs, which are high-speed support ships, should provide logistic and maintenance support for the CROSSBOW Battle Group. The smallest CROSSBOW operational element is envisioned to consist of two SEA ARCHERs and four SEA LANCEs capable of operating independently.

The SEA ARCHER air wing should consist of manned aircraft and Unmanned Air Vehicles (UAVs), and Unmanned Combat Air Vehicles (UCAVs). For air vehicle quantities and other planning factors see Table 1 Flight deck design should focus on automation. High-speed launch and recovery operations should take place from an unmanned flight deck. The SEA ARCHER air wing provides the eyes and ears of the CROSSBOW force. Targeting and reconnaissance information should be provided via appropriate data links to SEA LANCE and armed airborne units for a coordinated engagement. A significant number of airborne missions must be launched from the SEA ARCHER to support a CROSSBOW Battle Group operating in the littoral environment. No single airborne platform is expected to accomplish all of the required missions and all missions do not need to be launched from a single SEA ARCHER. It is recognized that some missions may require the simultaneous operation of more than one airborne platform type.

SEA ARCHER may have the ability to act as a “Lily pad” (recover, refuel, & launch) for AV-8s, VTOL JSFs, and helicopters under 30,000 pounds maximum gross weight. SEA ARCHER is not intended to deploy without an air wing aboard.

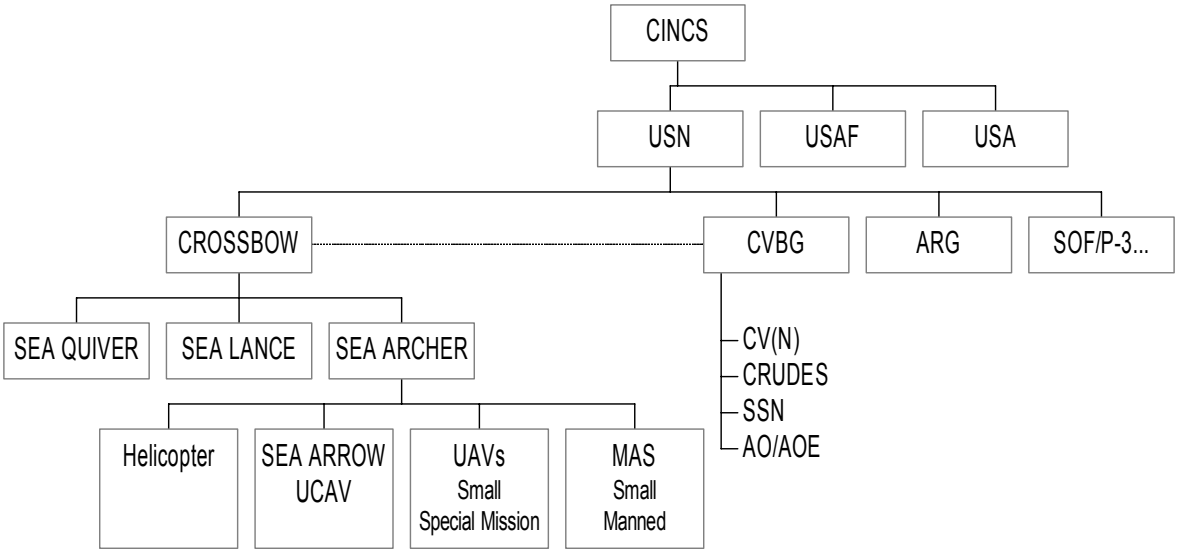


Figure 1 SEA ARCHER's role in the CROSSBOW FORCE

Air Vehicle Type	No.	Unit Weight (lbs)	Total – Type Weight (lbs)	Sortie* Rate Per Day	Sortie* Rate (Surge) Per Day	Aircrew / Seat Factor	Total Aircrew
Helicopter • Utility or • Attack	2 or 3	23K or 15K	46K or 45K	8 12	12 18	2.5 2	5 6
UCAV • Sea Arrow	8	15K	120K	28	42	1.5	12
UAVs •	10	3.5K	35K	32	50	.25	3
TOTAL	**20** **21**		**201K** **200K**	**68** **72**	**104** **110**		**20** **21**

Table 1 Aircraft Planning Factors

2. Threat

The anticipated threat to naval forces in 2020 will be the proliferation of high-tech/low-cost weaponry and sensors. These systems will be employed to inflict maximum damage by simple saturation of own-ship sensors and defensive measures. Anticipated threat objectives will be the coordinated effort to use all target acquisition and force support agencies available for the purpose of denying the combat power of the littoral force during the initial stages of ship movement. Central to the threat's defensive plan is the early identification and rapid denial in the littorals. Enemy systems will be found in multiple major threat areas. These include threats from space, air, surface, undersea, and info-sphere.

Common threads amongst these threats include:

- Enhanced multi-source intelligence collection and Information Warfare Operations
- Enhanced tactical mobility systems that reduce reaction time, protect the littorals, and improve firepower and sea protection.
- Higher-volume, longer-range targeting, command, control, and communications.
- Enhanced counter mobility capability by using land and shallow water mines.
- Increased availability, numbers, and accuracy of precision-guided munitions.
- Increased lethality and reliability of weapon systems, and the possible use of Weapons of Mass Destruction (WMD) / Nuclear, Biological, and Chemical (NBC) weapons.
- Electronic Warfare (EW) capabilities to monitor, direct, find, jam and deceive in the Radio Frequency (RF) and electro-optical spectrums.
- Early attack and disruption of supplies and logistics.
- The ability to reach outside the littorals with submarines, smart mines and aircraft carriers.
- Ability to take advantage of the sea and land terrain.
- With numerous aircraft, missiles, and rockets in the air at the same time, the probability of attrition is high

3. Shortcomings of Existing Systems

There is no existing system to provide the sea-based distributed aviation platform capability. The emergence of UAVs / UCAVs, the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combined to support a requirement to re-think how future warfare will be waged in the littoral. A ship has never before been designed, from the bottom up, to support the operation of a primarily UAVs / UCAVs air wing in a high threat environment. The sea-based distributed aviation platform will be the first. The object of the distributed aviation battle group is to augment CVBG capabilities in the contested littorals of the world.

Current programs and acquisitions fail to:

- Provide support for UAV and UCAV fixed wing aircraft.
- Provide large capacity, highly distributed, sea based combat aviation.
- Maintain required force levels for forward presence, crisis response and war fighting.

- Maintain an effective industrial base to assure continued support for sea-based tactical aviation.
- Take advantage of new technologies and design concepts that offer opportunities to develop sea-based platforms that are capable, but more affordable than current platforms.

4. Capabilities Required

Key Performance Parameters.

The SEA ARCHER squadron of ships must have certain performance requirements in order to facilitate the key concept of distributed aviation in a littoral warfare environment. The requirements of Table 2are deemed Key Performance Parameters (KPP) and must be met within threshold requirements for the SEA ARCHER platform to be deemed effective.

KPP	Threshold	Objective
Speed		
Endurance	40 knots. This assures the ship can meet an aggressive sustained transit speed in order to reach the theater of operations quickly.	50 knots. This will allow unprecedent response times to regional conflicts.
Max operational	40 knots. This is the minimum speed allowable for launching Sea Arrow aircraft in a zero wind condition.	60 knots. This assures maximum speed for aircraft operations as well as for in theater tactical manueveribility.
Manning	150 personnel. This includes the airwing onboard and is in keeping with the goal of significantly reducing manning requirements on future naval ships.	120 personnel. This will require an aggressive step toward reliance on automation and increases in reliability of equipement on the ship.
Range	4000 nm. This range is based on transiting to regional conflicts with minimal need to stop and refuel.	4500 nm
Sortie Rate		
Sustained	80 sorties per day. Need to have ability to sustain this rate for 7 days.	note:see Table 1 for more detailed sortie breakdown
Surge	120 sorties per day. Need to have the ability to maintain this rate for 3 days.	note:see Table 1 for more detailed sortie breakdown
Operational Availability*	0.9. Based on concepts of distributed air each ship can have a reduced availibility as long as the Crossbow system has an overall higher availibility.	0.99.
Sustainability		
Combat	Loadout capable of supporting 7 days sustained combat operations.	Loadout capable of supporting 7 days surge rate combat operations.
Peacetime	30 days self sustained operations.	90 days self-sustained operations.

Table 2 Key Performance Parameters

Operational Availability is defined by the ability to launch and recover aircraft.

Design Philosophy

In conjunction with meeting the above key performance parameters the ship design should incorporate the following into the design philosophy. Factors are listed in order of priority:

Category	Weight
Survivability	HI
Automation	HI
Reduced manning	HI
Upgradeability	HI
Maintainability	MED
Reliability	MED
Manufacturability	MED
COTS	LOW
Affordability	LOW

The following are additional system performance requirements:

Humanitarian Operations

SEA ARCHER should provide empty shelter space for accommodating 30-50 non-combatants in an emergency. This space may be used for crew recreation or enhanced survivability; it must not interfere with the ability of the ship to conduct normal functions, even with the additional passenger load onboard. At the Battle Group commander's earliest convenience, these non-combatants should be ferried to a SEA QUIVER, CV(N), or other large combatant for longer-term support and transport.

Survivability / Vulnerability

SEA ARCHER must be able to operate aircraft in hostile environments, protect itself from enemy attack, and if hit, degrade gracefully and remain afloat (threshold). The desired objective is to be able to remain afloat and launch air wing for recovery on sister ships, a SEA QUIVER, or a CV(N). The ship survivability performance must support damage control operations in a reduced manning environment. To reduce vulnerability in the littorals, the ship should be equipped with enhanced survivability features, such as in-stride mine avoidance capability and full-spectrum signature reduction (Radio Frequency/Infra-Red/Electro-Optical/Communications Conformal Apertures, reduced clutter, geometric shaping). Attention should be given to acoustic quieting and magnetic signature reduction for both equipment and propulsion systems. Inclusion of a damage-tolerant design, and an integrated magazine protection system should also be considered.

Self-protection

The ability to assess terminal threat situations quickly and correctly will be an essential element of SEA ARCHER's weapon systems. Shipboard defense capabilities should provide a protective shield against cruise missiles, submarines, torpedoes, mines, aircraft and other future threats. The defensive weapon systems selected must have high precision and accuracy, high probability of kill and high repetitive fire rates. The generation after next (2020) Close In Weapon System (CIWS) replacement and a shipboard version of something akin to the new Rapid Airborne Mine Clearance System (RAMICS) could be candidates for consideration. SEA ARCHER should have integrated Electronic Warfare (EW) capability to support ship defense.

Special Operations

SEA ARCHER should have the capability to embark one SEAL platoon and their equipment. SEAL platoons should be embarked as required by the operational scenario. When SEALs are embarked, the multi-mission helicopters (e.g. H-60) needs to be a part of the air wing (rather than the attack helicopters) to provide an airborne insertion capability.

Inport Force Protection, Mooring, and Ship Access

SEA ARCHER should have the means to provide adequate Inport Force Protection and ship access control. SEA ARCHER should be able to be made fast to the ground, buoy, or pier and safely remain made fast in up to 30 knots of wind. These systems should be as automated as possible to minimize manning requirements.

Information exchange requirements

Network Centric Warfare (NCW). NCW is an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace. Incorporation of NCW concepts is necessary for CROSSBOW to be an effective force. The Distributed Sea-based Air concept demands a highly flexible command and control architecture with system multiplicity, and redundancy built-in to ensure total system availability and enhanced survivability during combat and non-combat operations. Therefore, all SEA ARCHER ships should have the same command and control capability. SEA ARCHER C4ISR should share tactical and administrative information using advanced networks and technologies. These new resources will continue to automate manual processes, but should also improve decision support functions through advanced modeling and simulation. SEA ARCHER's information architecture should be designed to optimize interoperability, data access, information sharing, managed security and reliability of service while reducing data redundancy and costs.

Interoperability. SEA ARCHER's communications architecture must be fully interoperable with other naval, expeditionary, interagency, joint and allied information systems. A coherent tactical picture is necessary to support Joint Force, Battle Force, Battle Group and Air Wing planning, coordinate actions with other forces,

and communicate the force's actions to appropriate commanders. SEA ARCHER must have the necessary command and control architecture to communicate with a Joint Force Commander (JFC). Additionally, it is necessary to leverage NCW to fully integrate sensor and shooter into an effective and potent fighting force. All Integrated Information Systems (IIS) must be compatible with the Defense Information Infrastructure (DII) Common Operating Environment (COE).

Control of UAVs & UCAVs. The SEA ARCHER should have responsibility for control of unmanned air vehicles within its air wing. Direct control may be transferred to other elements or other SEA ARCHERs depending on the mission.

Commander of Task Force (CTF). The size of any given operation will determine who the CTF is and where the CTF and staff are located. All SEA ARCHERs should be equipped to handle command and control, but should not be designed to accommodate a CTF staff.

Information Warfare (IW). IW is the ability to exploit, corrupt, deny, or destroy an adversary's information base while leveraging friendly information and information systems to achieve dominant Battlespace Awareness. As information technology continues to proliferate and as our susceptibility to offensive IW increases, defensive IW enables full spectrum protection. The SEA ARCHER must be capable of 1) protecting its own information systems and 2) leveraging U.S. and allied information to gain a decisive advantage.

Logistics and Readiness

Historically, defined requirements for system logistics and maintenance support have been left until far too late in the acquisition cycle. Early and rigorous logistics analysis is needed to prevent excessive Operations and Support (O&S) costs. Weapon system capability rates have been in a steady decline due to system operation beyond intended design life, inaccurate failure rate projections, and closed/proprietary architectures. SEA ARCHER design must facilitate rapid and cost-controlled incorporation of new technologies as they become available.

Supportability, maintainability, and reliability should be designed into SEA ARCHER. The ship should have an embedded logistics and maintenance system to improve readiness throughout its lifecycle. Significant O&S cost reductions may be realized through decreased repairs, spares, repair man-hours, and support infrastructure. Additionally, adequate bandwidth must be provided to support Network Centric Logistics.

Recognizing that a Level Of Repair Analysis (LORA) has not been completed, the CROSSBOW concept calls for SEA ARCHER to conduct only organizational level maintenance. All higher levels of maintenance are anticipated to be the responsibility of the SEA QUIVER support ship or other force asset, which should act like a tender, Intermediate Maintenance Activity (IMA) or Depot Repair Facility (DRF) for major repairs. Aircraft onboard SEA ARCHER may follow a similar plan and only conduct organizational level servicing, repair and troubleshooting. Remove and replace activities should be the emphasis. The SEA QUIVER should be capable of recovering any SEA ARCHER aircraft on its flight deck.

The following outlines some of the key logistic and support concepts that must be incorporated into the SEA ARCHER design:

- Prognostic and Diagnostic capability for ship and airborne assets through remote sensing and virtual presence.
- Minimize Special tools
- Remote access to Intermediate and Depot level repair information via secure data network.
- Remote access to requisitioning and material support information.
- Maximum use of automation and robotics for aviation support to include movement to/from the flight deck, storage of aircraft, fueling, arming, and other “yellow gear” functions.
- Replenishment at Sea Capability (RAS) to include:
- Port and Starboard RAS staging stations
- Weapons and Munitions Storage for all airborne and ship defensive systems.
- Food stores (dry provisions, chill and freezers):
- Located near food preparation facilities
- Capacity – Enough for crew for 3 months

- Refuse devices to reduce trash maintained onboard
- Biodegradable meal containers
- Self-service crew services to include:
- Laundry, Ship's store, Email center, A/V room…
- Workload reductions to include:
- Wax-less floors, Endurance paints, Paint-less surfaces

Environmental Safety and Occupational Health and Other System Characteristics

- Given the requested speed requirements of the ship, consideration must be given to personnel safety.
- Given the nature of a highly automated, electric ship environment, ship must be designed with appropriate considerations for electromagnetic safety for both personnel and weapons.
- Consideration shall be given to all technologies that will reduce or minimize the impact on the maritime environment.
- The design should employ, to the maximum extent possible, all hazardous material reduction practices.

5. Force Structure

The typical CROSSBOW squadron will consist of 8 SEA ARCHER ships each capable of limited independent operation; or multiple ships operating in a collaborative effort to provide force projection and rapid response capability throughout the world.

6. Schedule

Initial Operating Capability must occur in 2021. An initial technology development date for the first designed SEA ARCHER is established at 2012.

7. Program Affordability

While design and development of this new platform must at all times keep cost as a consideration, many new concept designs will have to be explored and developed, in order to meet the Key Performance Parameters outlined in this ORD. Sea Archer should

be designed in conjunction with current acceptable cost guidelines in order to assure that the program does not become cost prohibitive.

III. ANALYSIS OF ALTERNATIVES

A. ALTERNATIVES UNDER REVIEW

In order to meet the requirements defined by the SEA ARCHER Operational Requirements Document (ORD) it is necessary to consider which alternatives are available to meet these requirements. In an effort to determine the optimal hull platform and architecture, as well as the proper support concept, an Analysis of Alternatives (AOA) was conducted. This AOA explores the effects of varying the air-wing size per ship, the type of aircraft carried, as well as the level and type of logistics support.

The alternatives considered were divided between two teams of engineers. The first team explored the options of having one squadron of aircraft, while the second team explored a ship capable of carrying two squadrons of aircraft (See Table 3for definition of a squadron of aircraft). Each team then had three alternatives to consider. For the first alternative, the notional Unmanned Combat Air Vehicle (UCAV) SEA ARROW was to be utilized in the squadron. In the second alternative, the SEA ARROW was replaced by an equivalent number of Joint Strike Fighter (JSF) aircraft. The third alternative would once again include SEA ARROW but would take away the notional SEA QUIVER logistics support defined in the ORD.

Aircraft Type	Number of Aircraft
SEA ARROW or JSF	8
Helicopters	2
Unmanned Air Vehicle (UAV)	10
Maneuver Air Support (MAS)	3

Table 3 Notional SEA ARCHER Air Wing, 1 Squadron

B. PAYLOAD

Payload Definition

For the AOA, payload was considered the key variable among the six alternatives. Payload was defined as the following: aircraft, aircraft ordnance, aircraft fuel, combat systems, and C4ISR infrastructure, and logistics load out. A breakdown of the payload for each of the alternatives is listed in Table 4.

	1 Squadron			2 Squadron		
	w/Sea Arrow	w/JSF	w/o Sea Quiver	w/Sea Arrow	w/JSF	w/o Sea Quiver
Aircraft (mT)	80	135	80	160	270	160
Aircraft Ordnance(mT)	200	1200	200	400	2400	400
Aircraft Fuel (mT)	1050	1950	1050	2100	3900	2100
Combat Systems (mT)	170	170	170	170	170	170
Logistics (mT)	400	410	780	420	430	800
Total Payload (mT)	**1900**	**3865**	**2280**	**3250**	**7170**	**3630**

Table 4 Payload Summary

Assumptions:

The calculated payload was based on the known number of aircraft listed in Table 3and their known weights. The aircraft ordnance and fuel weights were calculated based on carrying enough fuel and ordnance to support 7 days of operations at the normal sortie rates listed in the SEA ARCHER ORD. The logistics load out was calculated based on carrying enough stores and parts for 90 days of operations.

Some of the assumptions that went into the above calculations are:

Aircraft Weights: MAS and UAV aircraft were not defined at the time of this study, therefore a study of UAV's was conducted and a weight of 3500 lbs was assumed. The MAS aircraft was chosen to be of similar weight to that of the SEA ARROW with a penalty for having to man the aircraft going to a reduced payload. The Helicopter chosen for this payload model was the SH-60 for which accurate weights were attained. Weights for the Marine STOVL version of the JSF were also attained, and the SEA ARROW design weights were used for that aircraft

Aircraft Fuel: For fuel estimation, each aircraft was assumed to have consumed all available fuel for each sortie flown. This is not the expected operational scenario for the aircraft. However, it assists in making a conservative estimate for the payload. The UAV chosen was assumed to have 33% of take-off weight in fuel. The JSF, SEA ARROW, and Helicopters all had known fuel payloads. MAS were considered to carry a 30% reduction in the SEA ARROW fuel payload so as to account for the penalty in having to man the aircraft.

Aircraft Ordnance: The aircraft ordnance calculations are based on the assumption that for each sortie, each aircraft would drop its entire payload. This is more accurate than the fuel assumption since during combat operations it is likely the aircraft will drop all ordnance during each sortie. The UAV's were considered to carry no ordnance payload and the MAS were considered to have a similar ordnance payload as the SEA ARROW aircraft.

Logistics: Logistics was broken down to stores and parts. The stores load out was based on a typical TRIDENT submarine load out of 0.425 tons/man, which is a load out for 90 days. The parts load out was based on a carrying 25 percent of the weight of one aircraft of each type if there was SEA QUIVER support. One hundred percent of the weight of one of each aircraft was utilized if there was no SEA QUIVER support. For the ship's parts load out, 3.5 percent of total expected ships weight was utilized to calculate the parts weight with SEA QUIVER support and 7 percent without SEA QUIVER support. The parts load out is based on a similar parts load out percentage for a 10,000-ton ship.

C. RESULTING HULL SIZES

At the time of this AOA the most promising hull form appeared to be a Pentamaran design (as will be shown in the final concept design the Pentamaran hull form was not ultimately chosen). In order to compare the relative effects on size for the differing payloads, a common Pentamaran was modeled and utilized to compare these effects. The resulting hull parameters are listed in Table 5

	1 Squadron			2 Squadron		
	w/ Sea Arrow	w/JSF	w/Sea Quiver	w/ Sea Arrow	w/JSF	w/Sea Quiver
Length (m)	160	180	163	175	206	186
Beam (m)	18	21	19	22	26	23
Breadth(m)	39	44	40	44	52	47
Draft (m)	7	8	7	8	9	8
Depth (m)	13	16	14	15	18	16
Displacement (T)	10500	15100	11100	13600	22100	14500

Table 5 AOA Ship sizes

The results clearly show the effects on size of the ship by going from carrying the SEA ARROW UCAV's to carrying the JSF aircraft. These however are not equivalent aircraft and bring very different capabilities to the ship. The effect of carrying two squadrons vice one squadron of aircraft also significantly impacts ship size.

D. MEASURES OF EFFECTIVENESS

Due to the fact we are trying to determine the optimal size ship and which size and type of aircraft will be carried the alternatives listed in Table 5need to be compared against a set of Measures of Effectiveness.

The following Measures of Effectiveness where chosen:

Flexibility - Flexibility is defined as how well any given mission is performed. Some criteria we considered in rating flexibility of the different ship options were as follows.

Number of possible missions that can be performed by the platform. The total possible number of missions a platform can perform is based on the ability to perform any randomly chosen mission. This would be related from the versatility table on a weighting scale as follows.

JSF is an option that opens possibilities we thought were the cornerstone of flexibility. Independent of its added abilities for strike missions alone, JSF is a manned aircraft. As such, it allows the opportunity for changing mission targeting based on pilot visual perception of the space. Secondary targets and/or targets of opportunity

become an open option. Additionally, JSF adds air-to-air capability for targets of opportunity along the mission path as necessary. Due to its viewed importance, JSF received the highest relative rating of (0.4).

"Split-ability" refers to the ability to split the forces for several smaller mission areas. It relates to the ability to spread out the forces for multiple tasking. Also it adds to the improvement in survivability, which will certainly be considered later. Then, for this category, ship options were weighted with respect to their overall numbers. "Split-ability" was given a relative rating of (0.3).

SEA QUIVER option. When considering the relative weight SEA QUIVER included options should have, we first must consider the question of what SEA QUIVER ultimately brings to the table. If SEA QUIVER is to be a measured compilation of existing assets, it brings nothing new to the table. There would then be no relative difference between with or without SEA QUIVER. Certainly any ship designed as "with SEA QUIVER" would be designed to max out the capability, stores, etc., as would the one "without". However, if SEA QUIVER is to be some new designed ship with the speed capability of SEA ARCHER, and, for example, one SEA QUIVER operates in conjunction with each pair or four SEA ARCHERs, then it brings a great deal to the table. In short, it brings replenishment on demand. It would most certainly carry stores, fuel, ammunition, possibly manpower, maintenance capabilities etc. As such, it adds to the flexibility of the squadron as a whole. We gave SEA QUIVER a relative rating of (0.2).

A platform's draft is an indication of its ability to go deep into the littorals. Then also, it is a measure of the percentage of battle-space coverage possible. Draft was given a relative rating of (0.1).

Each option was graded within each category (except for the number of missions category) on a scale of high to low (3 to 1) regarding its ability. We multiplied each grade by its respective relative rating percentage. Then for each option, the grades were added to achieve a cumulative grade for the options. The cumulative grade was then applied to the versatility chart which details total number of missions each option is able to perform. It was applied by multiplying the total number of missions the option is

capable of. This produced an overall score for the option. The overall score for each option was normalized to the 3-point scale used for the project as a whole. Appendix A.4 is a complete data analysis.

Versatility - Versatility is defined as a measure of how many different missions could be performed by any option. Twenty-four distinct missions were chosen as a baseline to evaluate each alternative. The set was not exhaustive but was determined to be representative of the entire spectrum of missions expected to be performed by the CROSSBOW force. The mission areas considered were each equally weighted. Each alternative was evaluated on its ability to perform a given mission. If an alternative was determined to be capable of performing a mission a unit value was awarded. The sum of all points, over all missions, defined each alternative's cumulative score. Analysis of the options indicated there was no difference in mission versatility between the forces comprised of one or two squadrons of aircraft. An additional evaluation factor was applied to account for the difference in squadron size. This weighting factor adjusts for the increase in mission versatility afforded by more air platforms. A summary table is included in the appendix.

The primary mission of the SEA ARCHER platform is to support sea based aviation assets. Therefore, the choice of air platform will have the most significant impact on the type of missions capable of being performed by the CROSSBOW force. Logistic support to the SEA ARCHER platform or the aircraft was not used as a criterion for assessment of versatility. The assessment assumes that all solutions would have sufficient provisions for completion of any of the reference missions.

When squadron size was not considered the Sea Arrow alternative proved to be slightly more versatile than the JSF platform. The difference in versatility was based on the ability of the Sea Arrow to perform more missions in the C4ISR, Electronic Warfare (EW), and Information Warfare (IW) areas. The advantage of Sea Arrow over JSF is slightly offset when squadron size is considered. Even when two squadrons were considered, the Sea Arrow platform was considered more versatile. However, the two squadrons of SEA ARROW or JSF aircraft will produce an improvement in overall force versatility.

Lethality - The team defined lethality as a measure of the ability of the CROSSBOW force to inflict damage to another vessel(s) or land target(s) and the extent to which that vessel(s) or land target(s) mission(s) are degraded/ eliminated by the damage inflicted. This MOE evaluates the CROSSBOW force for all six CROSSBOW options. An explanation precedes the table.

To quantitatively evaluate lethality, the total aircraft weapons payload for each CROSSBOW force option was calculated, and the total aircraft weapons payload for each individual ship was calculated. Each option was rated according to the calculated weights. A weighted sum of the force and ship results was used to determine the overall lethality of each option. The primary concern is the lethality of the force, more than the lethality of an individual ship. Therefore, the force lethality rating was weighted by 0.75, and 0.25 was used to weight the ship lethality rating.

All options meet the SEA ARCHER requirements. All platforms perform well. However, JSF provides far more firepower per sortie. Although SEA ARROW appears to have better endurance, JSF offers far more weapon yield than Sea Arrow for both 5 and 7-day missions. It is for this reason that JSF receives a High for the one- and two-squadron configurations and Sea Arrow receives a Medium for the two-squadron configuration and a Low for the one-squadron configuration. Of the 6 options listed, JSF with 1 or 2 squadrons is considered most lethal.

Survivability- Survivability is defined as a measure of how well a vessel could survive in a high threat environment. Survivability can be subdivided into three areas:

- Susceptibility: Probability that an enemy can detect, classify, target, and successfully engage the vessel.
- Vulnerability: The ability to survive and continue to conduct combat operations after being hit.
- Recoverability: The ability to recover and continue to conduct operations after being hit.

Deployability: This assesses the ability of the SEA ARCHER squadron to arrive on station expeditiously and quickly. It will also cover the capability to operate in the littoral environment. The potential of independent operation will also be assessed.

The most critical criterion is the time of arrival, since all the vessels will be designed with similar transit speeds. It will negate all differences between the options. The only mitigating factor would be the potential for independent operation and as such, SEA ARCHER without SEA QUIVER has the highest score, as it can operate without logistical support.

All the above measures were evaluated for the CROSSBOW force level. Throughout the analysis of alternatives, most of the ship characteristics (Combat Systems, hull-form, floodable length and others) remained constant. Only two of the main ship characteristics of the different alternatives were considered to have any significant impact on the measures of effectiveness. These are the displacement and the number of ships. The different alternatives were sorted by size and a relative grade from one to three was given to each one. When it was decided that size was beneficial the number three was given to the largest and vice versa. A weighting factor was assigned to the different abilities to adjust for the increased value of reduced susceptibility, which is the main reason behind the distributed air platform.

Evaluations of Measures of Effectiveness

The evaluation of each of the six alternatives studied was completed and each MOE was given an appropriate weighting factor to account for the relative importance in meeting the SEA ARCHER ORD requirements. Each alternative was then evaluated based on its ability to meet each MOE. An absolute score system of High-3, Medium –2, or Low –1, was utilized to evaluate each alternative against each MOE. The totals were then calculated as a weighted total based on the weighting factors chosen for each MOE. Table 6summarizes the results.

Measure of Effectiveness	Flexibility	Versatility	Lethality	Survivability	Deployability	
Weighting Factor	0.25	0.25	0.25	0.15	0.1	
Options						**Totals**
1 Squadron						
w/Sea Arrow	3	3	1	3	1	2.3
w/JSF	3	2	3	3	1	2.55
w/o Sea Quiver	2	3	1	2	3	2.1
2 Squadron						
w/Sea Arrow	2	2	2	2	1	1.9
w/JSF	2	1	3	2	1	1.9
w/o Sea Quiver	1	2	2	1	3	1.7

Table 6 MOE Matrix Evaluation.

E. RECOMMENDATIONS AND ALTERNATIVE SELECTION

The mission needs statement stated the ship would be required to support only SEA ARROW aircraft. However, upon review of the possible alternatives, A SEA ARCHER with a single squadron of JSF was determined to be the alternative that produced the most effective total system. The design team recommends that further study to evaluate the potential of a composite platform. This platform would be primarily designed to support JSF aircraft. However, SEA ARROW operations would be fully supported. This alternative has the potential to provide an operational mix between platforms with improved system effectiveness.

F. FACULTY DECISION FOR DESIGN

Due to the fact this project was coordinated with two other curricula (Aeronautical Engineering and Systems Engineering Integration) the decision was made to design the ship primarily to operate the newly designed SEA ARROW aircraft. The one squadron SEA ARROW alternative was the next highest scored alternative in terms of Measures of Effectiveness. In addition, the requirement to support the Manuever Air Support Craft was taken away, and the ability to refuel improved SEA LANCE craft was added.

Since the concept of distributed aviation warfare in the littorals has no well-defined operational concepts it was necessary to define a design base operational scenario. In addition to meeting the mission needs and operational requirements for the SEA ARCHER ship (see Chapter II – Requirements Documents), SEA ARCHER is required to show the ability to meet the following design reference mission:

Design Reference Mission

The SEA ARCHER will:

Leave port and transit 4000 nm at a speed of 50 kts. Carry sufficient fuel to re-fuel two improved SEA LANCE ships (SEA LANCE ships as defined by the 2000 SEA LANCE report with twice the payload capacity, and transit speeds of 50 kts) that will act as escorts during the transit. Reach the 4000 nm transit limit with 20% fuel remaining. At the end of the 4000 nm leg of the transit, replenishment of SEA ARCHER and SEA LANCEs will be provided by outside assets. This 4000 nm leg could be repeated one or two additional times.

At the end of the final 4000 nm transit leg, the task force will arrive in the intended operating area. Here it will be capable of operating unsupported for 7 days of combat operations, including two refuelings of each of the two SEA LANCE escorts per SEA ARCHER (4 total SEA LANCE refuelings in a 7 day period).

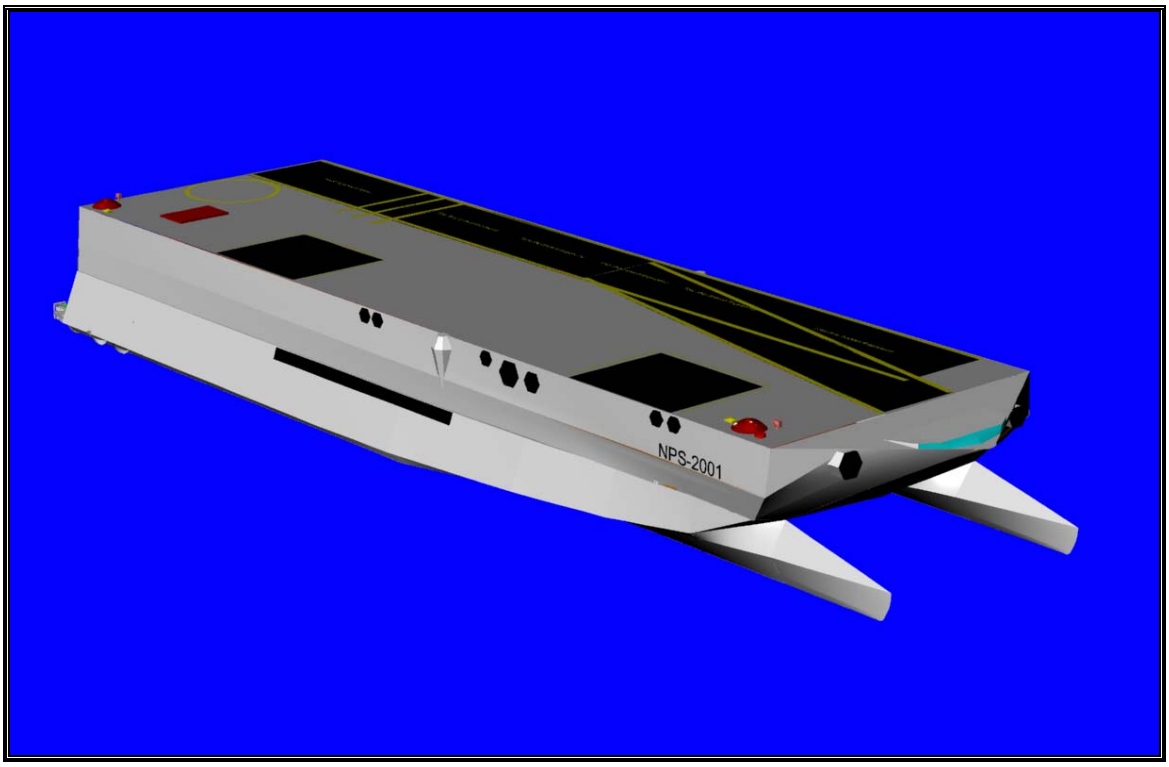
The speed profile will be:

- 2 days at 20 kts
- 1 day at 25 kts
- 3 sprints of 60 kts, each for 2 hours duration.

Remaining time at "loiter speeds" in the 10 to 15 kt range.

At the end of the 7 days in the operating area, SEA ARCHERs and SEA LANCES will be replenished by outside assets or withdrawn. All other capacity/ sustainment capabilities of SEA ARCHER will be as discussed in the SEA ARCHER ORD, under Key Performance Parameters.

IV. CONCEPT DESIGN



A. HULL

1. Hull Design

The SEA ARCHER hull design is based on the patented Harley Surface Effect Ship (SES) design as shown in Figure 2 below. The design combines the advantages of several different hull forms in order to achieve superior performance. The twin hull arrangement provides the stability and low wave-making resistance of catamarans, shallow draft and low hull resistance of an SES, and the above average seakeeping performance of a wave-piercing planing hull. Unlike typical SES ships this design has eliminated the flexible seals that were troublesome and significantly affected performance at higher sea states. Twin pressurized air cavities are used to statically lift approximately 85% of the vessels weight while additional lift at higher speeds is achieved through the planing bow and the airflow across the centerbody. With a larger portion of the ship out of the water the required installed propulsion power is significantly reduced at higher speeds.

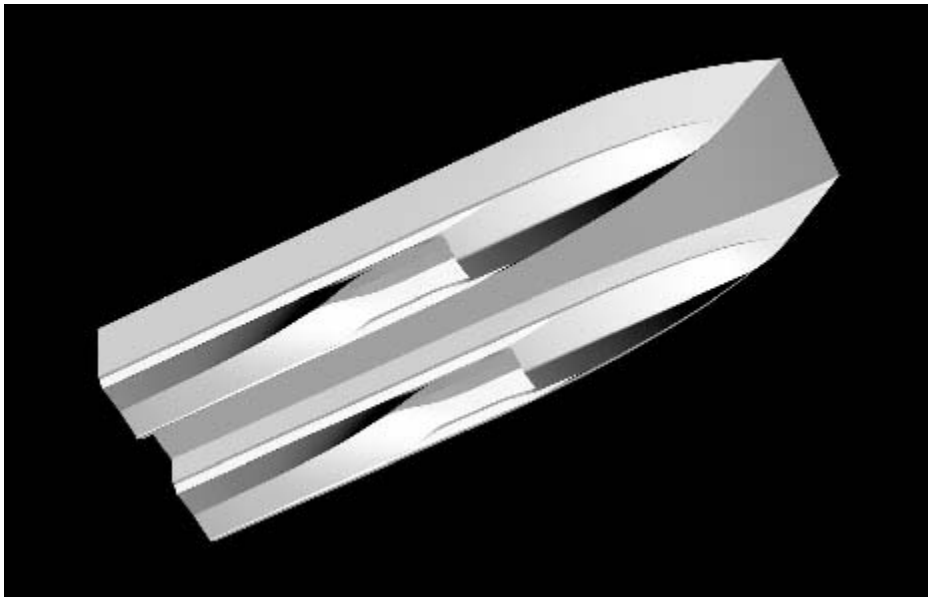


Figure 2 Harley SES Design from Vibtech Website

The SEA ARCHER hull design is shown in Figure 3 below with some modifications to the original Harley SES design. The hull design added a narrow wave-piercing bow to each sidehull and a broad wave-piercing bow to the centerbody section

for better seakeeping performance at higher sea states. The planing shape bow of each sidehull was maintained for dynamic lift. The structural part of the SEA ARCHER design is built of composite materials largely due to the reduced weight and better mechanical properties of these materials.

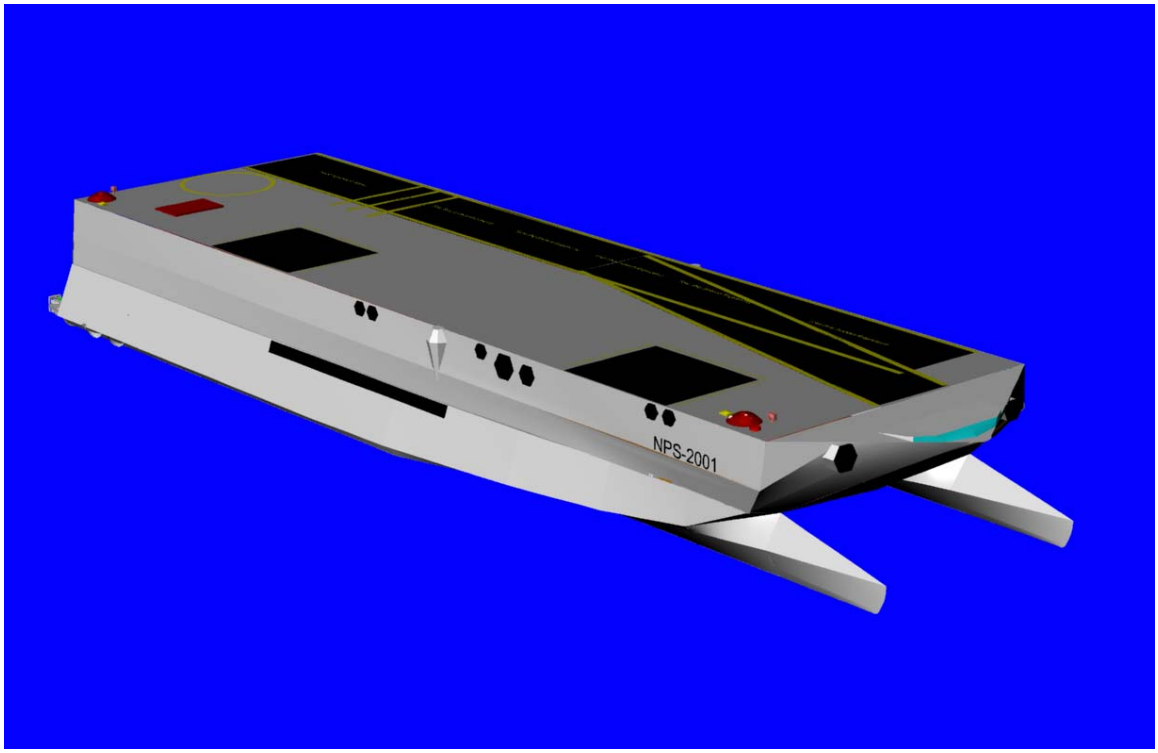


Figure 3 SEA ARCHER Hull Design

Shown in Figure 4is the speed verses power required for SEA ARCHER. The data was determined from model data provided by the Harley's engineering design agency Vibtech. The power curve includes the fan power above approximately 40 knots. The SEA ARCHER would operate primarily in three distinct modes: off-cushion, on-cushion, and partial-cushion. In the off-cushion mode the ship would operate much like existing catamaran designs although there may be increased hull resistance due to the additional wetted surface area in the air cavity. This mode allows for efficient operation at low speeds while operating in congested areas where precise low speed control is required or when patrolling. The SEA ARCHER design should achieve a maximum speed of approximately 50 knots in this configuration. In the on-cushion mode the ship is

designed to have 85% of the ships displacement supported by an air cushion located in each side hull.

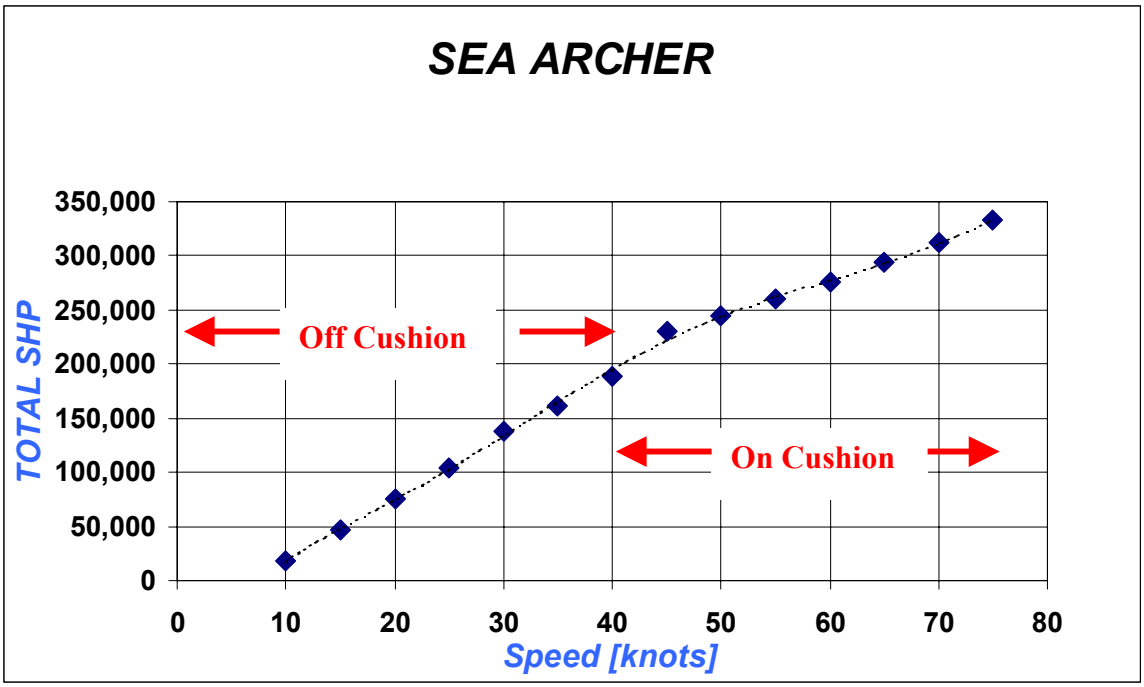


Figure 4 SEA ARCHER Speed verses Power Curve

Supporting most of the ship's weight, the cushion pressure acts as a frictionless planing surface. Without the air cushion the design would require far more propulsion power than the additional fan power required to reach the same speed. After the lift pressure reaches full lift pressure of 32.7 KPa additional airflow will continue to lower resistance. This effect is significant at first and then gradually reduces. The optimum airflow as defined for a SES by Reference [1] is "that [airflow] which the power required to increase flow is greater than the reduction in propulsion power needed to maintain a constant speed." As speed and seastate increase, the optimum flow also increases slowly until the power requirement is from 10 to 15 % of propulsion power at maximum speed. By lifting the ship out of the water the hull resistance is significantly reduced resulting in the objective speed of 60 knots. The on-cushion mode would also be used for littoral operations in shallow areas where the reduced draft would be needed or in high sea state conditions where the cushion may act as a motions-damping system for the ship. The

partial-cushion mode allows the amount of lift to be varied from 0 to 100 % in order to optimize the design performance during each unique operating condition. The ship would operate in the on-cushion or partial-cushion modes during high-speed operations or where the operational need requires it.

The SEA ARCHER design characteristics are shown in Table 7 below. The size of the ship is driven by the amount of payload and fuel required for the 4000 nm and 50 knot desired range and transit speed respectively.

Displacement	13,500	mT
Length	181	m
Beam	59	m
Side-Hull Beam	22	m
Range (50 Knots)	4000	nmi
Draft On/Off Cushion	2/4	m

Table 7 SEA ARCHER Design Characteristics

Consideration was given to the Panama Canal maximum beam constraint of 32.9 meters but this limited the design selection to only slender monohulls and was therefore deemed too restrictive for the desired high-speed requirements. In addition the team examined building size limitations at existing U.S. shipyards and found that if the beam could be maintained less than 52.7 meters at least 8 shipyards would be capable of building this design Reference [2]. However since the design was based completely on the performance data of a single model, deviation from geometric similarity was deemed to bring reduced credibility to the design. The decision was made to maintain geometric similarity with the model and on subsequent design iterations with future model or built data the vessel could be more appropriately dimensioned for shipyard size constraints. With this consideration the SEA ARCHER beam of 59m limits the current number of U.S. shipyard that could construct this size vessel to only three.

2. Lift System

The SEA ARCHER has 56 two-staged centrifugal blowers installed in parallel on 14 fan modules in each sidehull. Each fan module as shown in Figure 5 consists of two

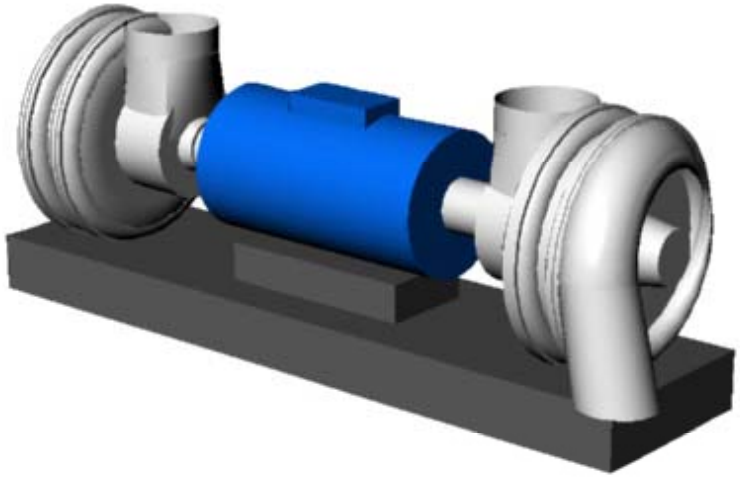


Figure 5 Fan Module General Arrangement

Number of Blowers	2 Continental 60002 Series Centrifugal (Reference [3])
Pressure Rise per Blower	41.4 KPa
Combined Flow Rate	1133 m^3/min
Speed	3550 RPM
Impeller Diameter	915 mm
Inlet/Outlet Diameter	612/511 mm
Weight per Blower	4.8 MT
Number of Motors	1 Reliance Q5808s Series AC Motor (Reference [4])
Power Rating	821 KW (1100 HP)
Weight per Motor	2.676 MT
Total Fan Module Weight	12.3 MT

Table 8 Fan Module Specifications

fans designed to deliver 42 KPa at 1133 m^3/min powered in pairs by a single a 821 KW (1100 HP) AC electrical motor mounted on a common foundation. Table 8lists the specifics of each fan module. The combined flow in both sidehulls is approximately 27,000 m^3/min at 42 KPa. The number of lift fans required is a function of the ship's current displacement and speed. The design allows for an approximately 22% pressure loss due to ducting and header loss and two extra fan modules are provided in each sidehull for redundancy and to permit maintenance. The blowers take suction from the outboard side of each sidehull and discharge directly into the top of each air cavity. The lift system requirements are based in part on SES technology because this part of the design has not matured at this point. The concept has been tested on a small scale but has not been optimized for large ships.

The SEA ARCHER lift system is designed to minimize ship motions by operating as a dynamic system. SES and catamarans usually are equipped with a ride control system that reduces the heave accelerations through the use of trim tabs in the case of catamarans or regulation of the cushion pressure for SESs. The pumping action of waves passing through the air cavity can cause heave motions that result in crew discomfort. The SEA ARCHER design relies on fan inlet guide vanes (ICVs) located on the suction side of each blower to regulate the cushion pressure. Lift fan ICVs regulating at around 5 Hz have been shown to maintain a constant ship attitude and minimize the vertical accelerations on SES type ships. (Reference [1]).

3. Space Upgradeability

The SEA ARCHER design allows for a significantly enhanced upgrade capability with its large open area under the wetdeck. The operations level below the hanger deck and above the wetdeck was designed to have these as modular spaces. Although a few countries can provide mission flexibility through modular change out of some weapon systems this capability has never been fully exploited in the United States. The design allows for entire spaces to be lowered out through the bottom of the wetdeck either waterborne or in drydock.

Each module is a "plug and play" configuration that is easily isolated and quickly tagged out for efficient removal and installation. This offers many advantages over conventional manufacturing, overhaul, damage/repair and mission flexibility. From the Navy standpoint the ship is operationally available more time since the ship's overhaul time is reduced. The ship will not have to be torn apart to gain assess to replacement components nor will the ship have to be present until the space has completed testing and is ready for installation. The reduced manning of this size vessel requires more efficient work practices such as this.

The shipyard would have significantly improved access and could manufacture the modules in a controlled environment where major testing is completed before ship arrival. This would give improved control of shipyard manning and improve overall quality control. The disadvantage of modular construction is the stringent requirement to maintain system design constraints and the additional structural weight requirements for the system. The targeted spaces are those that require frequent upgrades like the CIC and computer systems.

4. Hull Characteristics

The Harley SES is a new design for which there is little actual seakeeping performance data. Many of the attributes of the SEA ARCHER performance and seakeeping characteristics could be inferred by examination of current catamarans and SES designs and where possible the limited working prototype built by Harley Shipbuilding Corporation is used. The twin hull SES catamaran (SECAT) concept ship that conducted model testing during the 1980's also offers some estimate of seakeeping performance.

The volume and area efficiency of this design is similar to other SES and catamaran designs. These designs typically result in significantly improved volume and area efficiencies compared to standard monohulls. This is primarily due to the box-like shaped centerbody section that runs the length of the ship. The box like shape of the superstructure greatly simplifies design and fabrication of a major portion of the hull. This is balanced by increased complexity of the air cavity sidehulls. The wide design

allows more flexibility in payload and weapon systems arrangement and for the SEA ARCHER design a large wide flight and hanger deck provided more flexibility to the design.

The shallow on-cushion draft of two meters will allow the vessel to operate in the shallow littoral areas and enter harbors and rivers where a standard monohull could not. The air cushion will act as a buffer from underwater explosions and results in a significantly reduced portion of the hull being exposed to shock damage. The results would be similar to the response of the US Navy SES experiments conducted on the Bell Aerospace-Textron SES during the 1980's as shown in Figure 6.

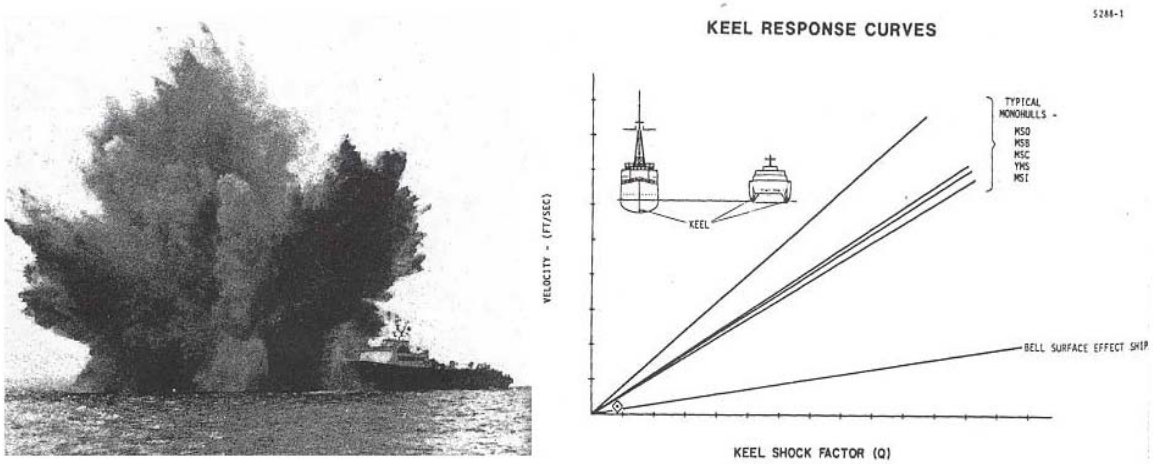


Figure 6 Bell Aerospace-Textron SES Underwater Shock Test and Keel Shock Response from Reference [1].

These experiments showed that the SES type hull experienced 60 to 80% less shock than a typical monohull. From this perspective the additional structure required to prevent shock damage is significantly less than for other full displacement designs. In addition the air cushion is expected to act as sound barrier to prevent acoustic transmission of machinery noise into the water. These attributes will enable the SEA ARCHER to operate with less risk in the littorals where mines are of more concern.

The design should be very maneuverable due to the widely spaced sidehulls and because two of the three propulsion units located on the outboard side of each sidehull are equipped with steering and reversing systems as shown in Figure 7.

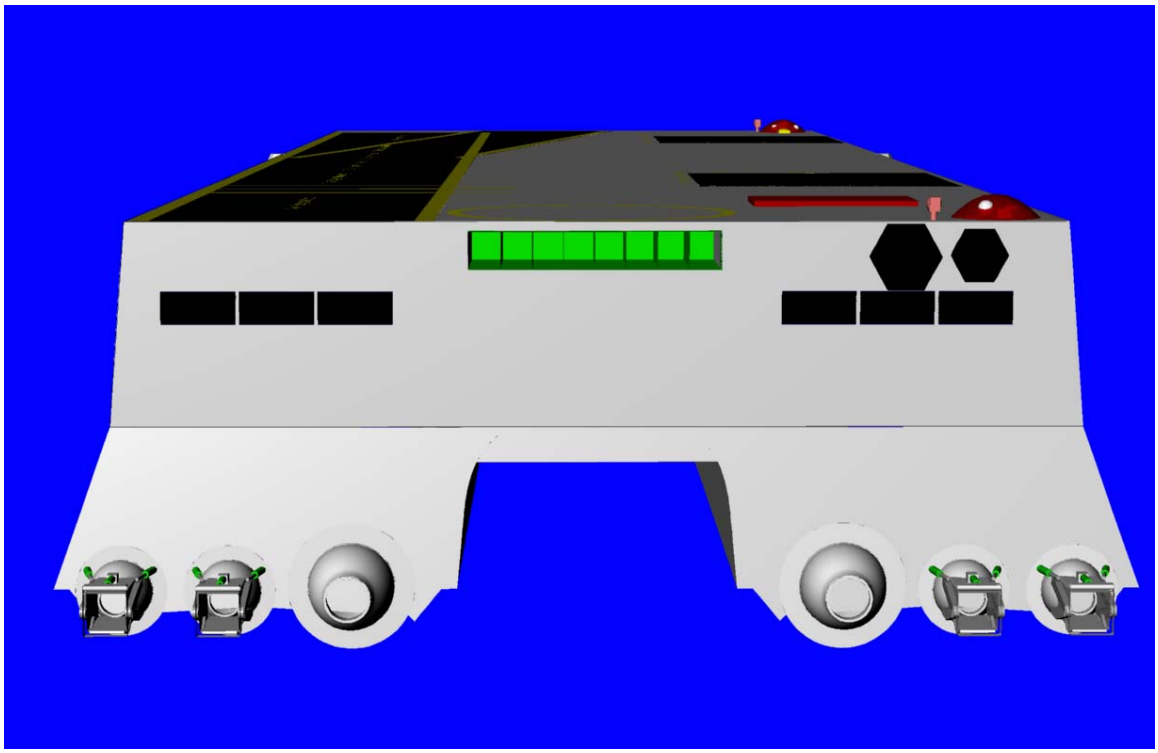


Figure 7 SEA ARCHER Propulsion Unit Locations

This aspect of the design along with the redundancy built into the propulsion systems will allow the SEA ARCHER to not only turn in its own length at slow speeds but also enter port unassisted without tugs. This not only reduces operational cost but also supports the reduced manning concept for the design. Vessels with waterjets and similar steering and reversing systems are shown in Figure 8.

Figure 8 Maneuvering waterjet equipped vessels with Steering and Reversing Systems from Reference [5].

SEA ARCHER should have a reduced wake compared to similar sized monohulls operating at high speeds. This assessment is a qualitative assumption based on the slender experimental US Navy SES XR-5 built during the 1970's. The XR-5 was a high length to beam ratio SES that is shown in Figure 9. This photograph shows the significantly reduced wake of the SES compared to a conventional monohull operating at similar speeds. SEA ARCHER twin hull design could be viewed as two slender SES hulls operating in parallel with a similar reduction in wake. The reduction in radar cross-section from special materials and design could quickly be lost if the wake becomes substantial.

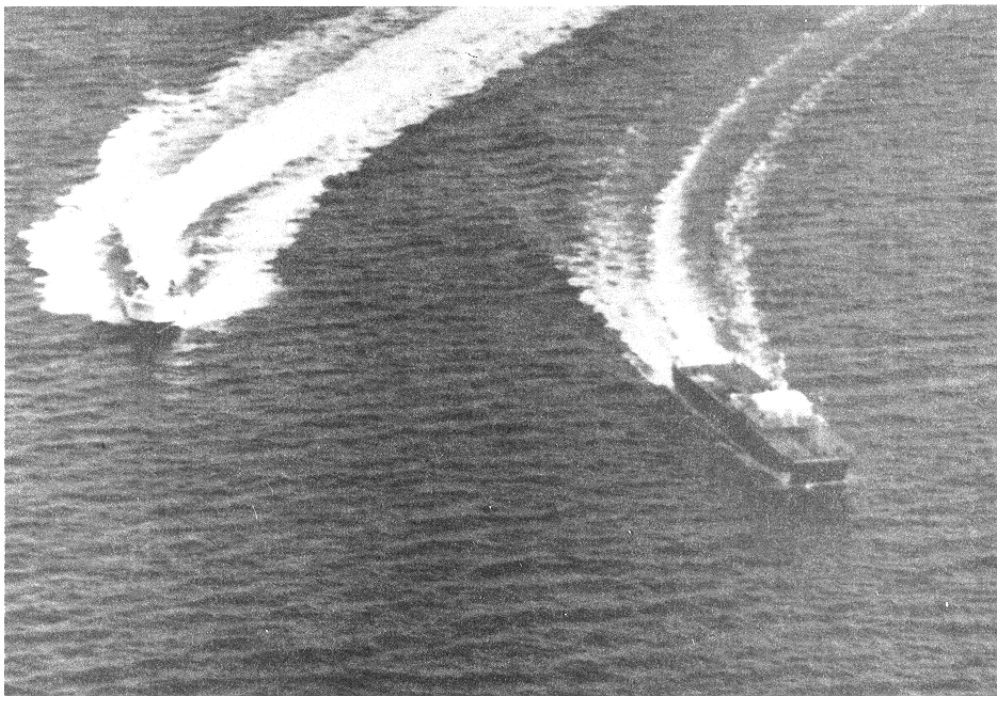


Figure 9 High Length/Beam Ratio SES Wake Comparison to Monohull from Reference [6].

The SEA ARCHER offers advantages in terms of the freeboard height when compared to monohull designs. The ship is designed to normally operate with no exposed passageways or manned operating stations. However during special evolutions such as underway replenishment, manned stations are exposed to the exterior environment. Under these condition when the vessel is operating in the off-cushion mode the available freeboard is similar to a monohull design. However with the ability to vary the draft by 2.1 meters the available freeboard is dramatically improved. This is viewed as particularly advantageous in higher sea states and offers some flexibility when loading and unloading during docking.

The stability advantages currently exhibited by catamarans also applies to the SEA ARCHER design. The stability curves shown in the Appendix demonstrate the stability characteristics of this design. The "SECAT" model testing showed improved roll stiffness and damping because the heave stiffness and damping of each cushion acts on the cushion separation arm. The model data also showed that the center of gravity could be considerably higher than a single cushion SES because of the higher static roll

stability Reference [1]. The design does not require a fuel compensating system since the lift system compensates for any changes in weight. The SEA ARCHER also does not require dead weight ballast because of the wide twin hull separation. These advantages also carry over into the damage stability conditions requiring less counterflooding to maintain acceptable list and roll angles as compared to a monohull. The SEA ARCHER has eight transverse bulkheads of which the forward most is designated the collision bulkhead. The engine room is further divided by a single longitudinal bulkhead for increased survivability. The bulkhead arrangement is shown is Figure 10below.

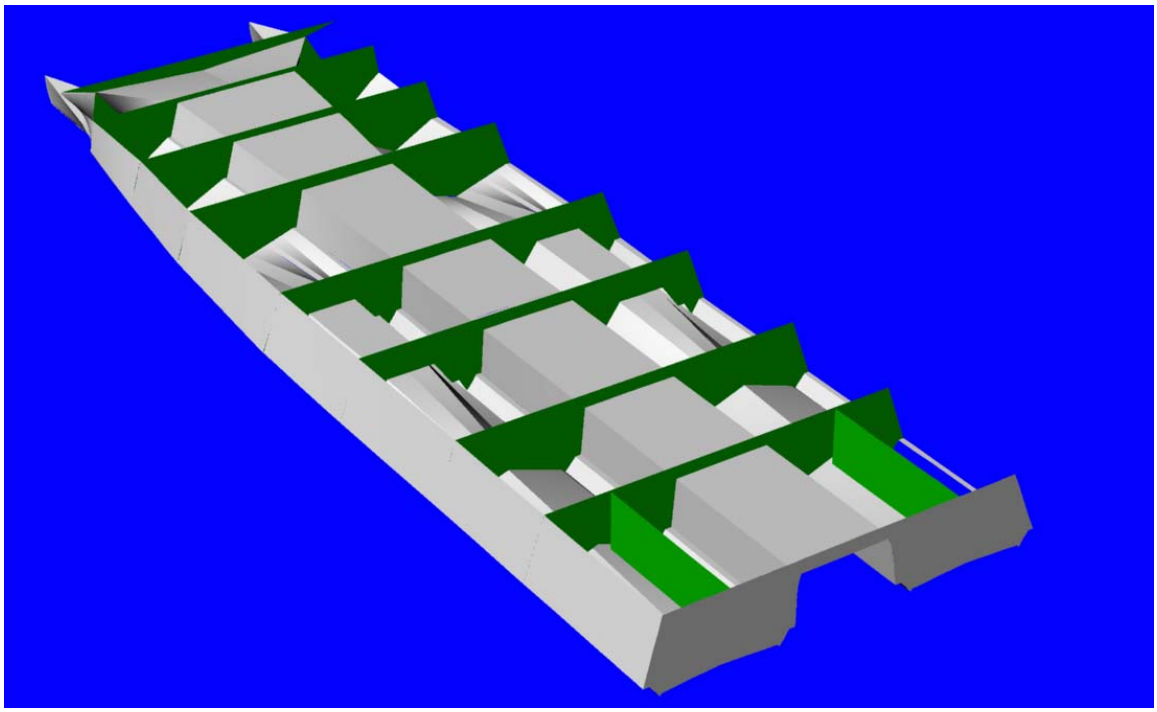


Figure 10 SEA ARCHER Bulkhead Arrangement

The floodable length calculations show that the vessel will float even without bulkheads with over 120 meters of a sidehull's 180 meters flooded centered at the mid-station. The floodable length drops to a minimum value of 40 meters centered at the stern. Depending on the location of hull damage, the lift system may be used to compensate for flooded areas. The twin hull design of SEA ARCHER also has built in redundancy for damage control since most major systems are divided equally between the two hulls and simultaneous damage of both hulls is unlikely because of the wide spacing between the two hulls. The additional longitudinal and transverse structural support

required for this design allows the ship to sustain more damage than a monohull design. The SEA ARCHER like typical catamaran designs should start to experience hull slamming when the significant wave height exceeds the wet deck height. With an off-cushion and on-cushion height of 4.5 and 6.6 meters respectively this would translate to a sea state of 6 to 7. Thus the design should be capable of full power operation up to these values without a significant reduction in speed. The wave-piercing bow similar to the one shown in Figure 11was added to improve the performance at higher sea states. With an active ride control system operating, the vertical accelerations would be significantly lower than a standard monohull.

Figure 11 Typical Wave Piercing Bow from Reference [7]

The SEA ARCHER hull design allows for a reduced radar cross section because of the rectangular sloped sides and lack of compound curves. Additionally, systems requiring exposure to the outside were recessed behind faired enclosures that are opened only when the system is operated. The SECAT model data also showed that an active ride control system operating in each hull could also effectively control roll.

5. Hull Construction

The hull is constructed primarily of carbon fiber because of its high strength to weight ratio and corrosion resistance compared to high strength steels. The use of composite hulls has the potential to reduce the structural material weight by half when compared to steel construction (Reference [8]). Bonded to the carbon fiber is a fiberglass

layer that protects the carbon fiber from ultraviolet light. The outermost layer is a bonded pigment layer for coloring that provides a permanent maintenance-free surface that will serve the life of the ship. This significantly reduces the hull life cycle cost and works with the reduced manning requirements. Certain high impact and critical design areas requiring ballistic protection would also have additional layers of Kevlar for added protection. In some instances the Kevlar may be bolt-on components that could be changed out after damage. Although carbon fiber does not burn and can be made to be self-extinguishing the material will start to break down at 116°C. For those areas that may be susceptible to high temperatures, such as the flight deck, a thermal barrier layer of silicon based polymer is used to protect the carbon fiber. An insulator layer is used to separate the carbon fiber and thermal barrier. The primary disadvantages of carbon fiber are the high material cost and the low impact resistance. The material cost is offset by the smaller ship size resulting from the better material properties and the reduced weight handling requirements during construction.

B. PROPULSION

1. Propulsion

Selection of the propulsion plant was driven by SEA ARCHER's requirement to do 60-knot sprints and the large ship's service electric load requirement. It is anticipated that SEA ARCHER will require ~34MW of continuous ship's service power (with a peak requirement of ~44MW) and up to ~188 MW for propulsion (blowers included in electrical load).

The final propulsion system, in its simplest form, is illustrated in Figure 12 below, with the reasons for its selection discussed in detail in Chapter (V). The Trent 50 (50MW) and Trent 30 (36MW) Gas Turbine Engines (GTEs) manufactured by Rolls-Royce were the prime movers selected for SEA ARCHER. Two 36MW Alstom Induction Propulsion Motors (PMs) were also selected. Kamewa waterjet variants rated at 36MW were selected as propulsors for the Trent 30 GTEs while 50MW waterjets were selected for the Trent 50 GTEs. The converters (Conv in Figure 12) along with the motor/generator sets are discussed in the Electrical section of this report.

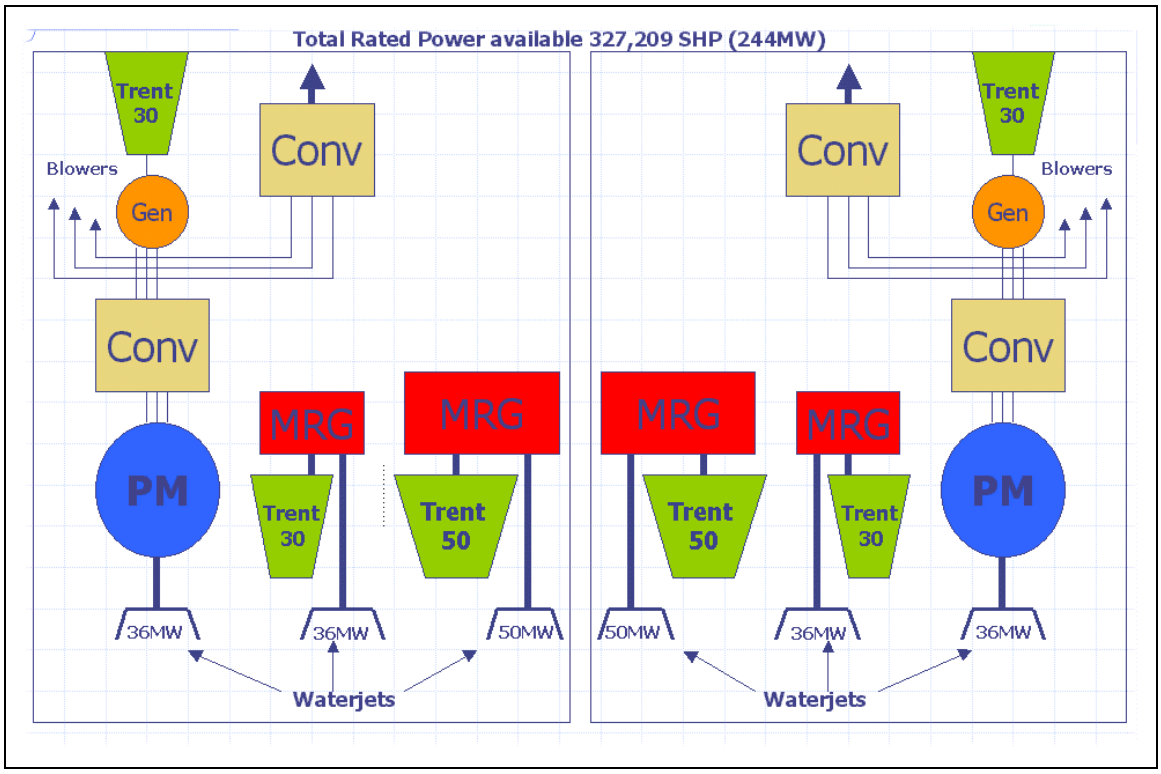


Figure 12 SEA ARCHER Propulsion Plant.

The propulsion box volume requirements are illustrated in Figure 13. Sufficient allotted space was left between prime movers to ensure that maintenance and upkeep could be performed. As indicated in Figure 13, 5242.27m^3 of volume is required for the propulsion plant engine rooms (includes both hulls). Figure 14 illustrates SEA ARCHER's engineroom.

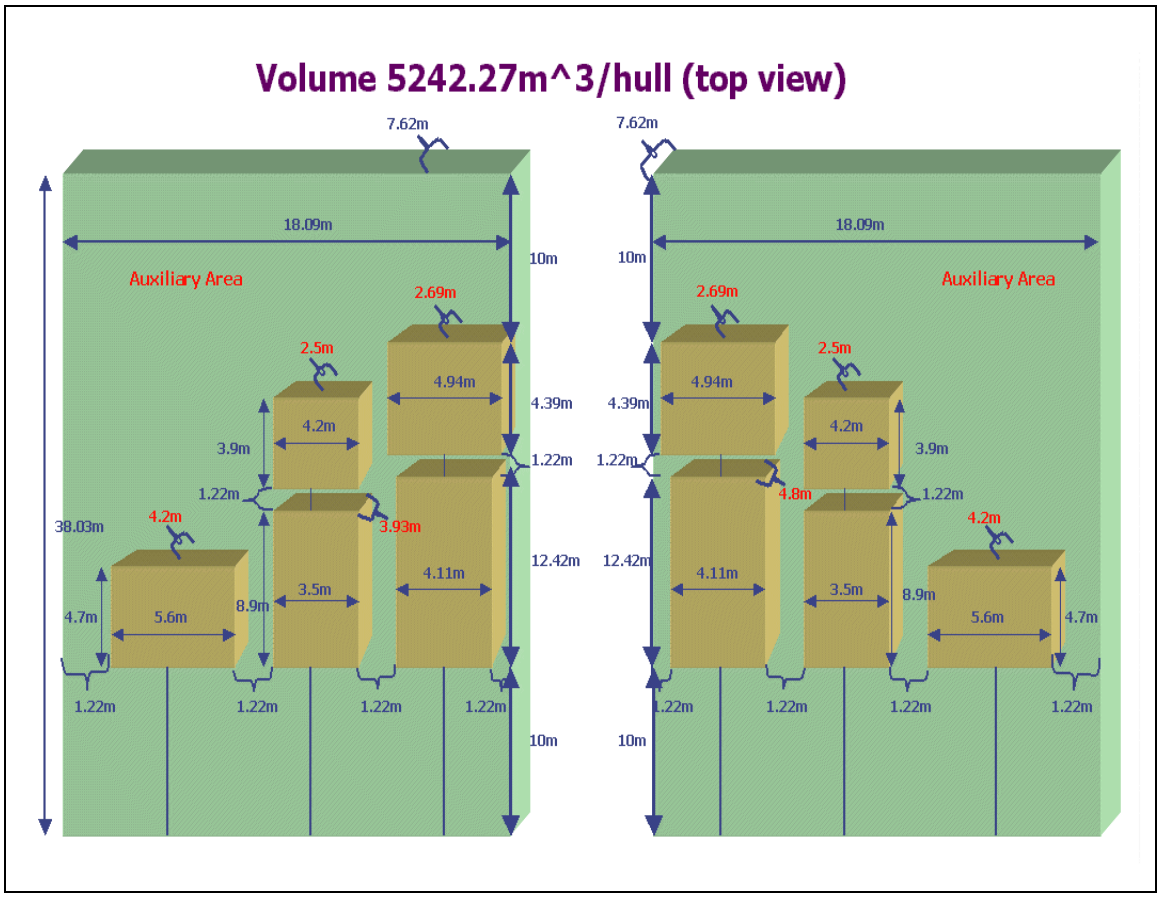


Figure 13 Propulsion Plant Volume Requirements.

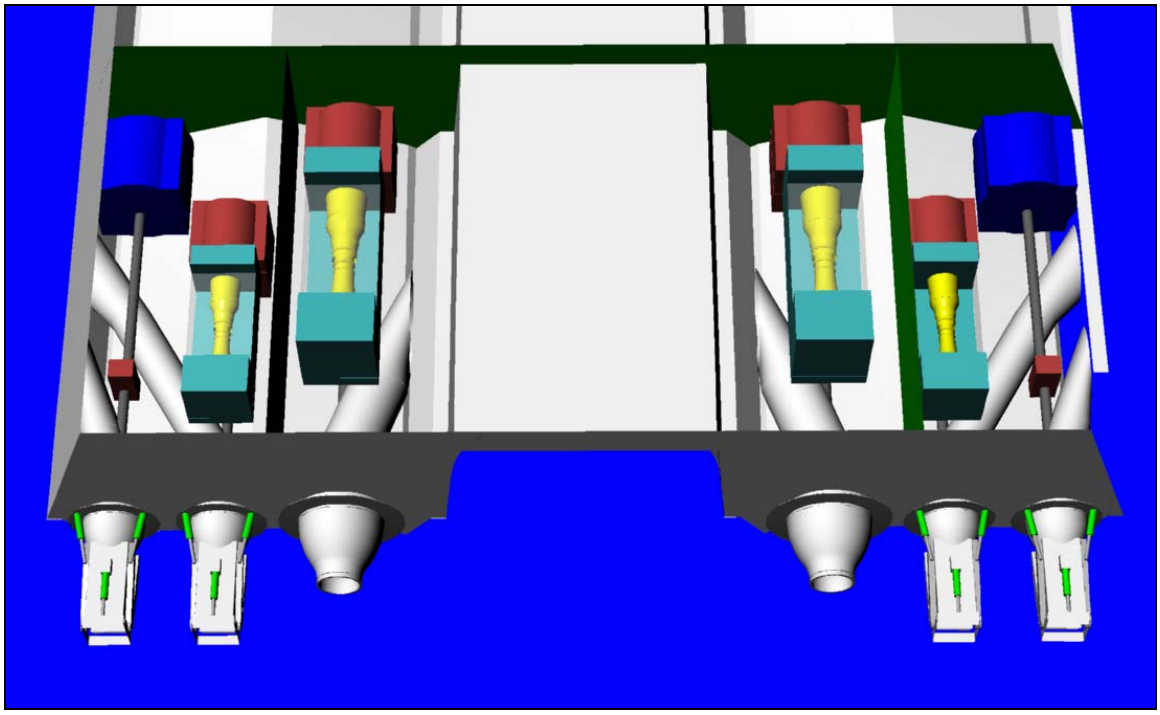


Figure 14 SEA ARCHER's Engineroom.

2. Propulsors

As indicated in Figure 15, Waterjets/Hydro-Air Drives propel SEA ARCHER. Figure 15 illustrates the maneuvering buckets attached to the ends of the Waterjets/Hydro-Air Drives. These buckets steer SEA ARCHER and are attached only to the 36MW units. The 50MW units are for boost only and require no bucket. Chapter (V) details the Waterjet/Hydro-Air Drive parameters and selection process. Cost data was not provided from the manufacturer for the Waterjets/Hydro-Air Drive so the team assumed that costs were based on rated horsepower, similar to the Gas Turbine Engine. A cost of 200 dollars per horsepower was assumed for all propulsors (Gas Turbines are $\approx$ \$225/HP). Figure 16 illustrates the inlet piping for the propulsors while Figure 17 pictures SEA ARCHER's stern view.

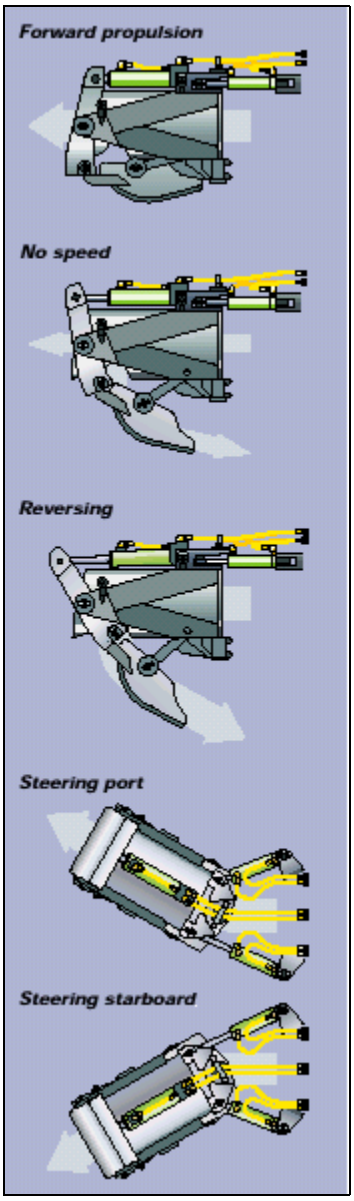


Figure 15 SEA ARCHER Steering (From Ref [9])

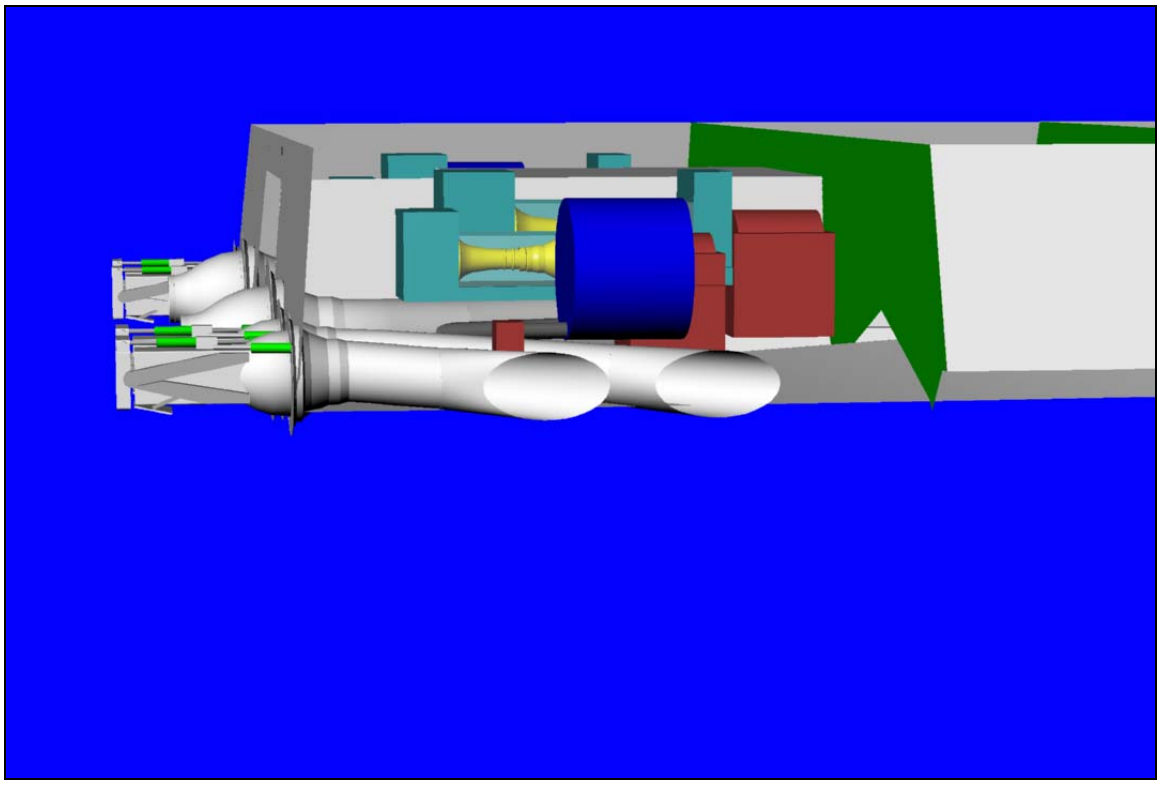


Figure 16 Waterjet/Hydro-Air Drive Inlet Duct.

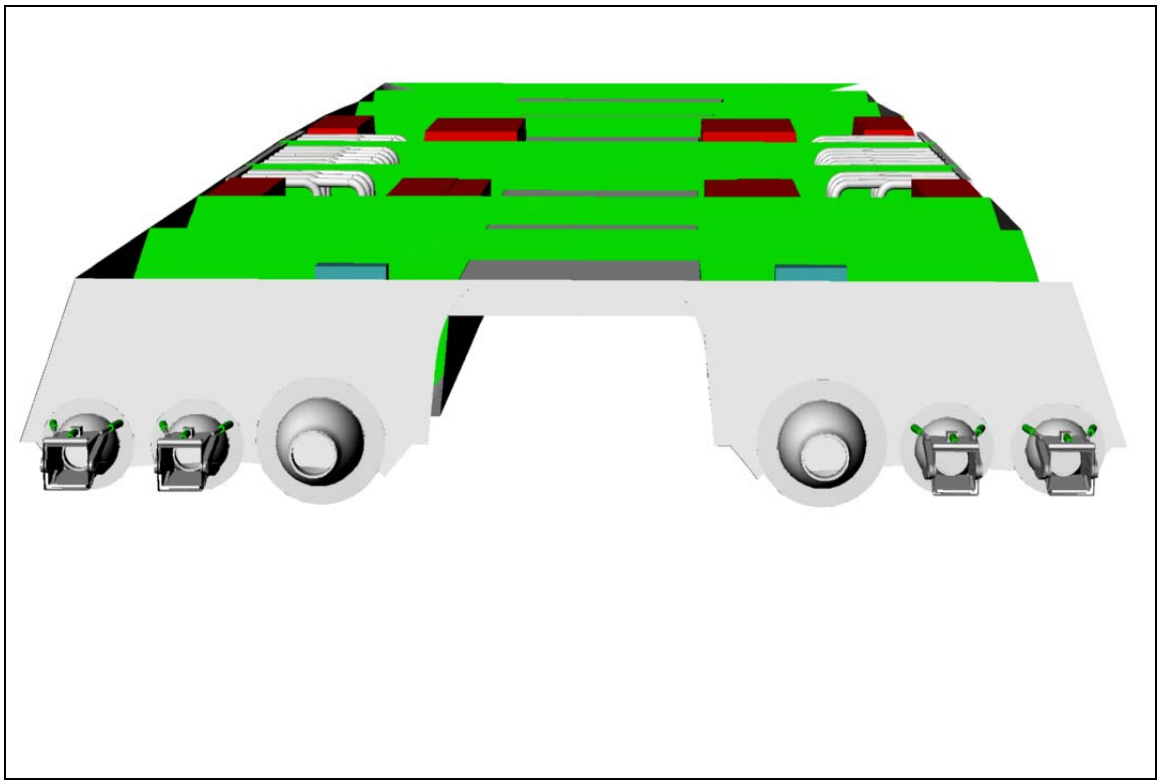


Figure 17 Waterjet/Hydro-Air Drive Stern View.

3. Propulsion Plant Cost And Weight Data

A summary of the final propulsion plant weight and cost estimates are listed in Table 9Detailed data and References are offered in Chapter (V).

Device	# req'd	Weight (mT)	Cost (Millions)
Trent 50	2	76	22
Trent 30	2	52	17
Motor (30 MW)	2	210	8.8
Reduction Gear (36MW)	2	50	11.7
Reduction Gears (50MW)	2	91	20
Waterjets (36MW)	4	464	38.6
Waterjets (50MW)	2	604	26.8
Totals		1547	144.1

Table 9 Propulsion Weight And Cost Data.

4. Fuel Requirements

Fuel requirements were calculated based on the speed profile given in the design reference mission (refer to Table 10). The assumption used for fuel calculations was that SEA ARCHER maintained constant displacement. These are worst-case "static" calculations. Fuel burn will be "dynamic" based on the fact SEA ARCHER will not use seawater compensated fuel systems and therefore will become lighter as fuel is burned. Horsepower requirements attained from model test data for various ship speeds are listed in Table 11 Equation (4-1) below is a sample calculation in determining a fuel requirement at 20 knots for 48 hours (refer to chapter (V) for SFC determination):

$$\frac{0.28\text{lbs}}{\text{SHP}-\text{hr}} \times 68210\text{SHP} \times 48\text{hrs} \times \frac{1\text{mT}}{2205\text{lbs}} \approx 416\text{mT} \quad (4\text{-}1)$$

Equation (4-1) was repeated for the entire speed profile, Table 12 illustrates required fuel burn for the speed profiles given in the design reference mission and highlights the 50-knot case as the most limiting case.

Time	**Event**	**Speed**
0	Leave Port	40/50 kts
End of day 2	Refuel Escorts	(20 kts during refueling ops)
End of day 4	Force Replenished from outside; arrive at op area	40/50 kts
Days 5-11	Ops in op area; Conduct 4 SEA LANCE refuelings	2 days @ 20 kts 1 day @ 25 kts 3 sprints at 60 kts, 2 hours each rest at "loiter speeds" @ 10-15 kts
Day 12	Force Replenished or withdrawn	

Table 10 Speed Profile For SEA ARCHER.

Speed	Horsepower	MW
10	16378	12.2
15	42294	31.5
20	68210	50.8
25	94126	70.2
30	125279	93.4
35	146670	109.4
40	170936	127.5
45	209543	156.3
50	222346	165.8
55	236159	176
60	251037	187

Table 11 Speed Versus Horsepower Requirements.

Speed Profile	Transit Fuel (mT) @ 40kts (threshold)	Transit Fuel (mT) @ 50kts (objective)	Oparea Fuel (mT) @ 15 kt loiter
Fuel burn @ 40kts for 94 hours	2585		
Fuel burn @ 50kts for 94 hours		3198	
Sea Lance Refuel	346	346	692
Refuel @ 20kts for 2 hours	29	29	
Fuel burn @ 20kts for 48 hours			694
Fuel burn @ 25kts for 24 hours			426
Fuel burn @ 60kts for 6 hours			226
Loiter @10 kts for 90 hours			
Loiter @15 kts for 90 hours			1004
Totals Fuel Burn	2960	3573	3042
Total Capacity with 20% remaining	3551	4288	3650

Table 12 Fuel Required at Various Speeds.

5. Engine Changeout

Finally, Figure 18 illustrates an engine change out process. The GTE will traverse the intake system up to the hangar deck. In the hangar, the intake will be removed and the engine brought out onto the hangar deck. If deployed or at sea, the engine can be placed on the aircraft elevator and transported to the flight deck. From the flight deck, the GTE can be flown off to a maintenance facility.

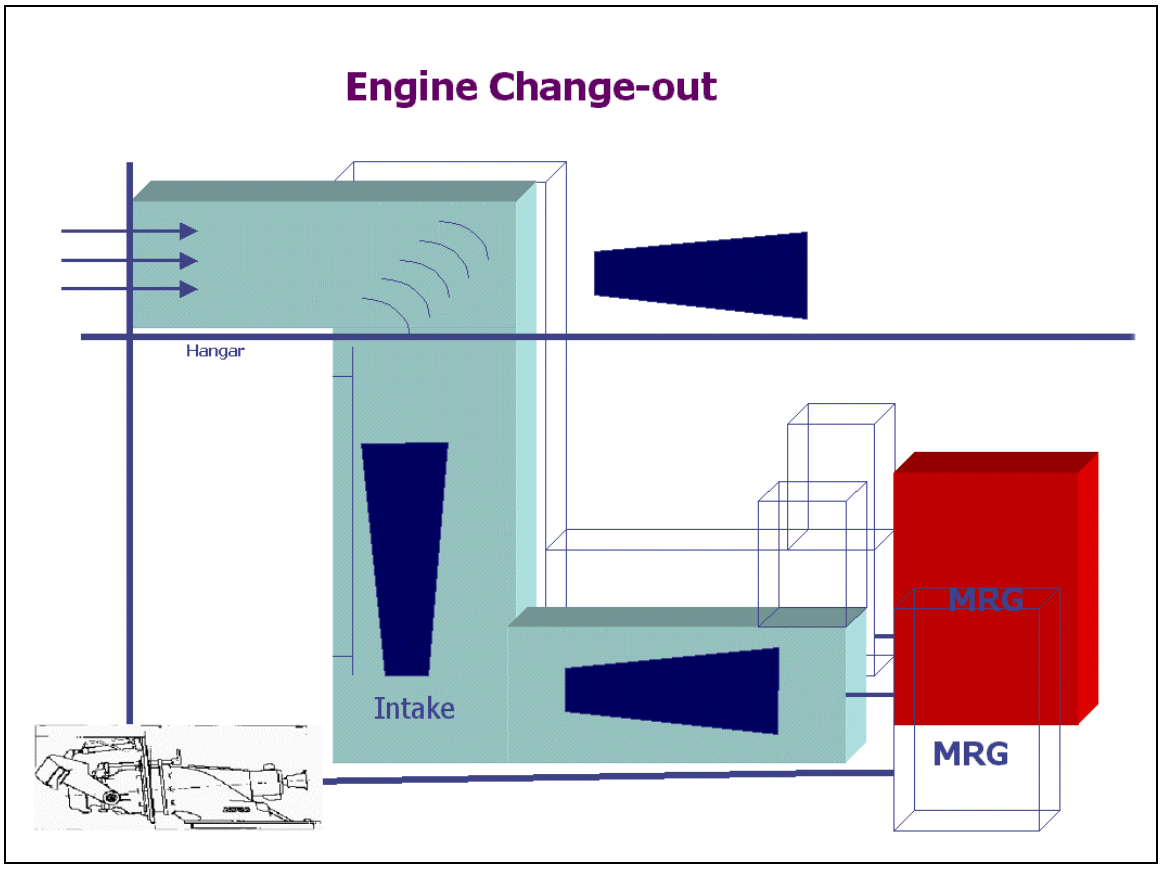


Figure 18 Engine Changeout.

C. ELECTRICAL

The electrical system has been broken down into four subsystems. These subsystems are power loads, power conversion, power distribution, and power generation. The following section describes each category for SEA ARCHER.

1. Power Loads

Based on the requirements from the other components of the SEA ARCHER design, Table 13shows the required power for each major design subsystem, and whether the demand is continuous or intermittent. Baseline continuous operation is defined as the power required to operate SEA ARCHER at 60 knots, without launching aircraft, recovering aircraft, or using the Free Electron Laser (FEL). The total installed electrical power on SEA ARCHER is 83.2 MW.

	Continuous	Intermittent Power (MW)					
	Power (MW)	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Electrical							
None							
Propulsion							
Blowers @ 60 kts	18.7						
Hull							
None							
Combat Systems							
FEL		11			11	11	11
Misc	5						
Aviation							
EMALS			1.13		1.13		1.13
EARS				0.6		0.6	0.6
misc	2						
Auxiliary							
Ship Service	8						
Total	33.7	11	1.13	0.6	12.13	11.6	12.73
Total: Cont + Int	33.7	44.7	34.83	34.3	45.83	45.3	46.43

Table 13 Required Electrical Power

Three intermittent operations have been specified. These include launching aircraft, recovering aircraft, and firing the FEL. Launching and recovery of aircraft are exclusive operations. The intermittent options in Table 13show some possible combinations of the three intermittent operations. It is not anticipated that all three of the

intermittent evolutions will occur at the same time. The FEL, however, can be fired at the same time as launch or recovery.

At 60 knots, 187 MW is required to power the waterjets, and the four dedicated propulsion turbines can provide 172 MW of that power. This leaves only 15 MW that needs to be supplied by the electrical plant to the electric drive propulsion, leaving 68.2 MW available for the non-propulsion drive electrical loads. It can be seen in Table 13that there is enough electrical power at 60 knots to shoot the FEL and conduct launch and recovery simultaneously, though launching and recovery are exclusive operations.

Besides the total power required, each major ship subsystem's power requirements have been qualitatively categorized into "dirty" AC power, "clean" AC power, and DC power. "Clean" AC power is AC power that has a smooth waveform that can be used by sensitive equipment, such as combat system computers or lighting. "Dirty" AC power is AC power that has a choppy waveform that is unsuitable for use in sensitive systems. Rugged equipment, like EMALS and the power conditioner for the FEL, can use and transform the "dirty" AC into a useable form of power. Table 14shows a simple qualitative breakdown of major components.

	AC (dirty) 4160 VAC	AC (clean) 450 VAC	DC 900/860 VDC
Electrical			
Propulsion	Blowers		
Hull			
Combat Systems	FEL	Misc	
Aviation	EMALS EARS Elevators	Misc	
Auxiliary		Lighting Outlets Emer Lights Pumps Fans	Drain Pump

Table 14 Power Types for Major Components

"Dirty" medium voltage AC power is being used because of the high power requirements of some of the aviation and combat system loads. This enables smaller currents than the DC system and thus less cabling. The Total Harmonic Distortion (THD) of the "dirty" AC power needs to be less than 12% to be useful, and this AC power will feed the AC zonal bus as described in the "power distribution" paragraph below. The THD specification will be achieved through passive filtering, the use of multilevel architectures, and potentially active filtering approaches (particularly with the blower drives).

2. Power Distribution

AC and DC power is distributed through the ship via a combined AC and DC zonal distribution system. The zonal system allows the ship to be sectioned into multiple zones that are powered from port and starboard AC and DC bus ties, minimizing the number of electrical penetrations through the watertight bulkheads. The zonal system also allows for modular construction and testing.

SEA ARCHER has been broken down into 21 zones, corresponding to the eighteen watertight compartments and three zones for the hangar bay. Figure 19 shows a notional layout for one zone. Redundancy within a zone is ensured through diode auctioneering of the port and starboard busses. Through diode auctioneering, if the primary 900 VDC power source is lost, the secondary 860 VDC power source will automatically start powering the loads. This power transfer occurs in microseconds, which is much faster than standard mechanical ABT devices which take on the order of milliseconds.

The power conversion modules are described in the "power conversion" paragraph below.

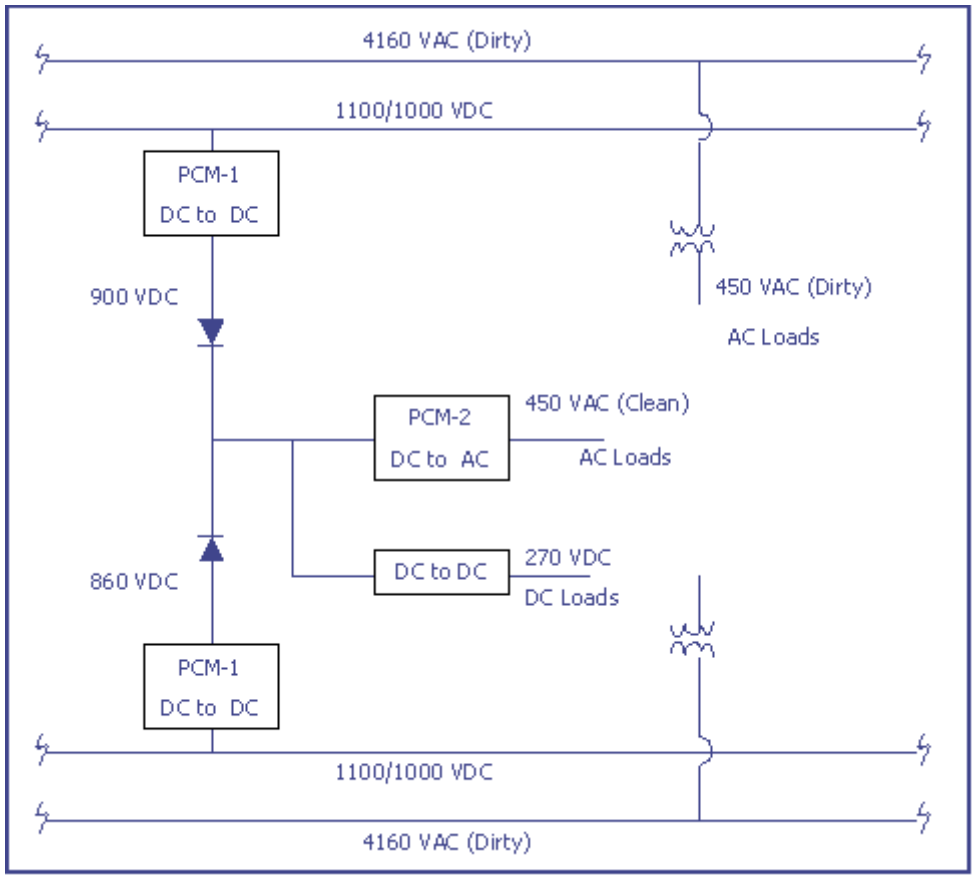


Figure 19 Notional Layout for One Zone

Power to the AC and DC bus ties is derived from two primary gas turbine generators and one emergency/backup gas turbine generator. These generators are described in section 4 below. The emergency/backup generator can be tied to either the port or starboard busses via the appropriate breaker. This allows flexibility in case of an electrical casualty to one of the primary gas turbine generators or bus ties. Figure 20 shows a notional breakdown of the electrical power source plant layout.

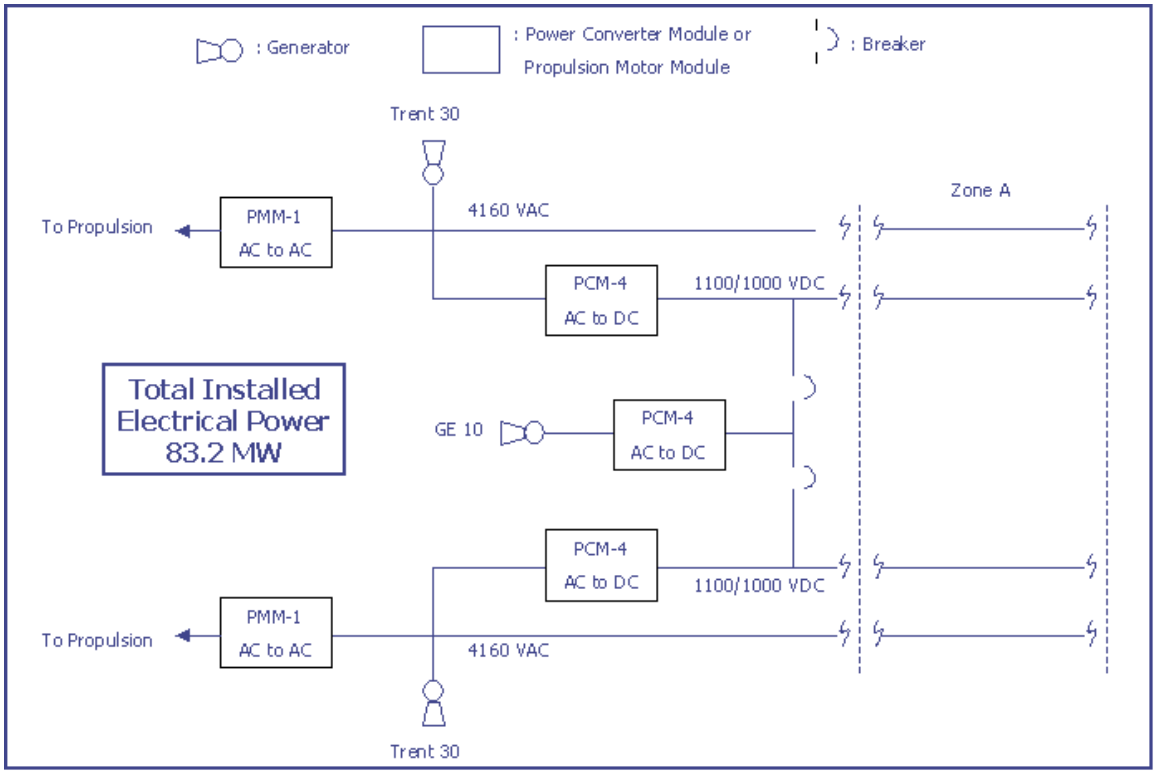


Figure 20 Notional Layout of Electrical Source Components

A notional ship layout is provided in Figure 21 for visualization of a combined AC and DC zonal distribution system.

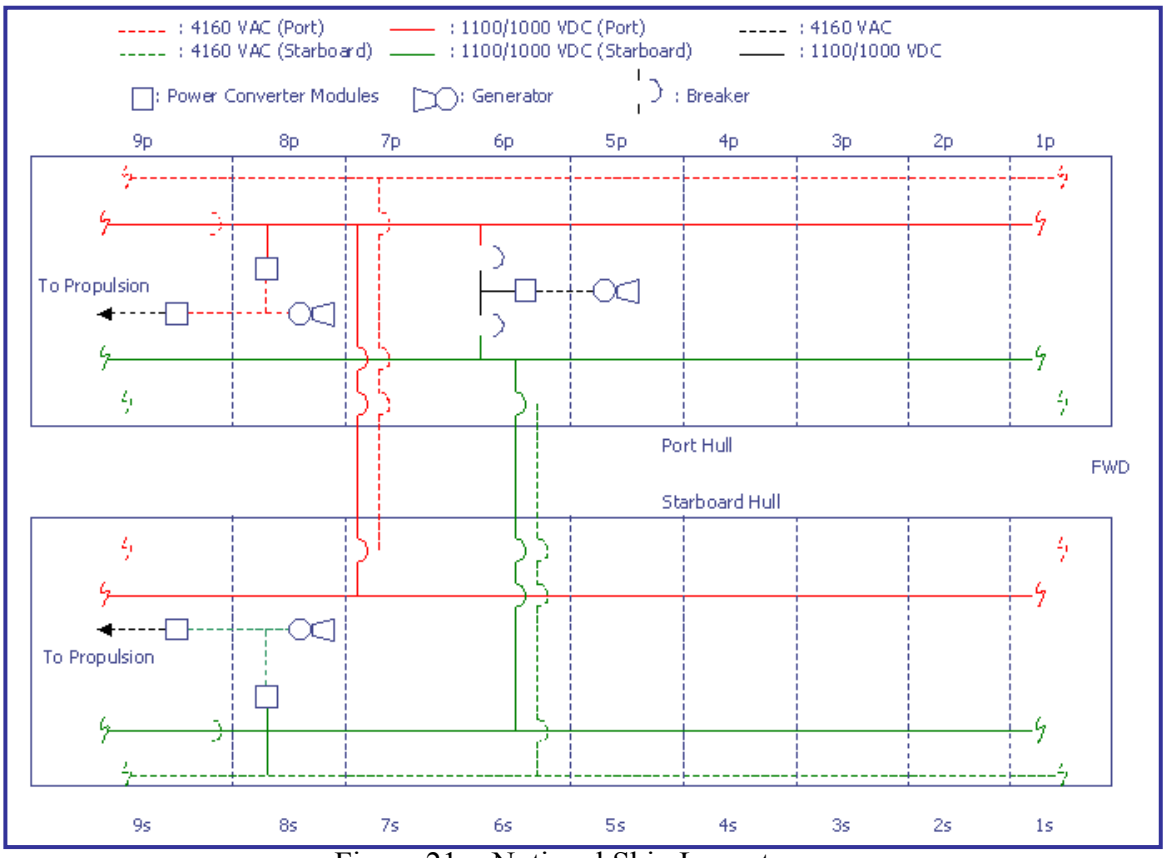


Figure 21 Notional Ship Layout

3. Power Conversion

There are four major power conversion modules used in the electrical distribution system. These are the Power Motor Module (PMM-1) and the Power Conversion Modules (PCM-1, PCM-2, and PCM-4). Their functional characteristics are described below. The range of longitudinal DC bus voltage is constrained from 1000 VDC to 1100 VDC to accommodate existing power device technology while also keeping grounding and converter complexity issues at a minimum. Higher values would be an advantage particularly in reducing the main bus current, thereby reducing the cost and weight of the

conductors. The output of the port and starboard PCM-1 modules in each zone will have slightly different voltages to allow for diode auctioneering. That is, if the primary PCM-1 power flow is disrupted, the diode connected to the alternate PCM-1 becomes forward biased and that unit quickly picks up the load. This occurs in microseconds.

The calculations for the weights and volumes stated in the following paragraphs are contained in Chapter 5.

Power Motor Module (PMM-1): PMM-1 is used to provide AC power to propulsion motors. 4160 VAC, 3-phase, 60 Hz power is supplied to PMM-1, which then converts the power to 0-3700 VAC, 15-phase, 0-15 Hz for propulsion motor operation. The predicted weight for a 30 MW PMM-1 in 2012 is 90 mT, with a volume of 54 m^3. There are two PMM-1s on SEA ARCHER. Each powers one propulsion motor. Only two of the six water jets are powered with electric drive. The two electric drive propulsion motors allow SEA ARCHER to operate the gas turbine generators at optimum efficiency under almost all conditions.

The PMM-1 will consist of 15 conventional H-bridge pulse-width modulation inverters, though some advantages are accrued by developing a multi-level solution. In particular, lower rated devices can be used, dv/dt is minimized, and Total Harmonic Distortion (THD) as seen by the motor can be more readily reduced. Currently, 30 MW multi-level converters would pose additional technical risk since commercial units are only at approximately the 5 MW level.

AC-DC Power Conversion Module (PCM-4): PCM-4 is used to convert "dirty" 4160 VAC to 1100/1000 VDC, which is then fed to the DC bus tie for distribution. There are three PCM-4s on SEA ARCHER rated at 15 MW, one for each gas turbine generator. One PCM-4 weighs approximately 52 mT and has a volume of 50 m^3. These units require a transformer to match the 4160 VAC to the lower 1000 VDC requirement plus multiple 6-pulse rectifiers to minimize the THD of the currents drawn from the generators.

DC-DC Power Conversion Module (PCM-1): PCM-1 is used to convert 1100/1000 VDC to 900/860 VDC for use by DC electrical loads or for conversion to "clean" AC power through PCM-2. Each zone has two PCM-1s rated at 1 MW each to

allow for diode auctioneering between the port and starboard DC busses, to protect the vital loads. One PCM-1 weighs 2.5 mT and has a volume of approximately 4.5 m^3.

DC-AC Power Conversion Module (PCM-2): PCM-2 is used to convert 900/860 VDC to "clean" 450 VAC or variable-voltage and variable-frequency for use by AC electrical loads. Each zone may have one or more PCM-2s to handle the anticipated variety of loads. A 1 MW PCM-2 weighs an estimated 8 mT and has a volume of approximately 12 m^3.

4. Power Generation

Two Trent 30s and a GE 10 power the electrical distribution system. These gas turbine generators provide a maximum power of 83.2 MW. A Trent 30 powers each electrical bus, port and starboard. The GE 10 is capable of powering either bus through the appropriate breaker. A Trent 30 weighs 200 mT and occupies 276 m^3 of volume. The GE 10 weighs 66 mT and occupies 82 m^3 of volume.

Three generators were chosen for flexibility throughout the range of possible uses. Due to their large power output, the Trent 30s are not optimally suited for low power usage, such as inport operations or anchorage. The GE 10 can be more optimally loaded in low power usage conditions. In addition, the GE 10 provides an emergency generator that can power enough electrical loads, in particular the propulsion blowers, to allow the SEA ARCHER to return to port, if a major electrical casualty occurs. Table 15shows a breakdown of possible electrical casualties and their effects on propulsion and the electrical system. A table of propulsion casualties has also been included in Table 16below.

Electrical Generator Failures	Power Available (MW)	Electrical Power Available @ 60 kts	Propulsion Limit (Reduced Electrical)	Propulsion Limit (Full Electrical)
No Casualty	83.2	49.28 MW	60 kts	60 kts
Lose Allison 601	72	38.08 MW	60 kts	60 kts
Lose 1 Trent 30	47.2	13.28 MW	60 kts	55 kts
Lose 1 Trent 30 & Allison 601	36	2.08 MW	55 kts	50 kts
Lose 2 Trent 30	11.2	0 MW	<10 kts	0 kts
Lose 2 Trent 30 & Allison 601	0	0 MW	0 kts	0 kts

Reduced Electrical = 9 MW
Full Electrical = 15 MW

Table 15 Electrical Generator Casualties

As an example of Table 15, if one Trent 30 was shutdown due to a casualty, the available electrical power would 47.2 MW. The ship would be able to go 60 knots, but would only have 13.28 MW available for electrical loads. In a reduced electrical condition, this is enough electrical power. If full electrical power (15 MW) was desired; the ship would have to reduce speed to 55 knots to shift electrical power from the blowers and propulsion to all the electrical loads.

Propulsion Motor Failures	Power Available (MW)	Propulsion Limit (Reduced Electrical)	Propulsion Limit (Full Electrical)
No Casualty	172	60 kts	60 kts
Lose 1 Trent 30	136	60 kts	55 kts
Lose 1 Trent	122	55 kts	50 kts
Lose 2 Trent 30	100	45 kts	40 kts
Lose 1 Trent & 1 Trent 30	86	40 kts	40 kts
Lose 2 Trent	72	40 kts	40 kts
Lose 1 Trent & 2 Trent 30	50	35 kts	30 kts
Lose 2 Trent & 1 Trent 30	36	30 kts	30 kts
Lose 2 Trent & 2 Trent 30	0	20 kts	20 kts

Reduced Electrical = 9 MW
Full Electrical = 15 MW

Table 16 Propulsion Casualties

As an example of Table 16, if two propulsion Trent 30s were to fail, the total propulsion power, excluding the electrical system Trent 30s, would be 100 MW. In a reduced electrical condition, this would still allow the ship to travel at 45 knots. If full electrical power was desired, then the ship would only be able to travel at 40 knots.

5. Weight and Volume Data

Table 17lists all the weight and volume requirements for the electrical distribution system. Year 2012 weights and volumes were calculated using predicted technology developments. The calculations are contained in Chapter 5.

Type	Trent 30	GE 10	PCM-4	PCM-1	PCM-2	PMM-1
Function	Gen	Gen	AC/DC	DC/DC	DC/AC	AC/AC
Weight (mT/unit) Year 2012	199.8	66.3	52.3	2.6	7.8	45.1
Volume (m^3/unit) Year 2012	275.4	81.6	49.7	4.4	11.9	26.8
Number of Units/zone	1	1	1	2	1	1
Number of Zones	2	1	3	21	21	2
Total Weight (mT) Year 2012	399.5	66.3	156.8	107.1	164.2	90.3
Total Volume (m^3) Year 2012	550.8	81.6	149.2	185.6	249.9	53.6

Table 17 Electrical Weights and Volumes

D. AVIATION OPERATIONS

Just as unmanned aviation is making a foothold in the combat aviation world, we foresee that the Navy will also move towards unmanned *support* of aircraft. The high cost of manpower, the increasing concern for quality of life at sea and in port, and the rapid pace of affordable technology growth, point towards a future in which unpleasant, dangerous, manpower-intensive work aboard ships is performed by automated systems. The next step towards that future is the SEA ARCHER. The SEA ARCHER has a fully automated aircraft launch and recovery system. The fully automated flight deck is coordinated with an unmanned hangar deck in which aircraft are moved, refueled and rearmed under computerized automated control. The use of robotic technology, most of which is available now, and a hyper-accurate positioning system will make the unmanned movement of ordnance and aircraft a reality. All aircraft are stored in the hangar bay, reducing topside radar signature.

1. Flight Deck

The flight deck environment is one of the most hazardous in the Navy today. Every year valuable lives are lost in flight deck mishaps. Flight deck operations are also extremely manpower intensive. The distributed aviation concept of CROSSBOW removes the time crunch on the flight deck (and the associated hazards of rushed operations) and opens the window of opportunity for automating launch, recovery, and movement of aircraft.

Figure 22 shows the flight deck arrangement of the SEA ARCHER. The flight deck runs the length of the ship, nearly 183 meters. Forward, angling back to port at an angle of ~5 degrees, is the single, 61 meter electromagnetic aircraft launching system (EMALS) catapult. The angle of the catapult eliminates the need for jet blast deflectors by angling the jet blast away from any aircraft parked along the starboard side. The danger area for a jet engine at military power extends less than 6 meters to either side of the exhaust and 64 meters behind the aircraft [12]. The EMALS has an average power requirement of ~1 MW, delivers a peak power of ~14 MW to the aircraft being launched, and has a 45 second cycle time, more than sufficient to meet the required sortie rates.

The trough for the catapult extends 0.6 meters into the hangar bay, preventing the folding/unfolding of aircraft wings when underneath the catapult.

The need for a single ship to launch large numbers of aircraft is obviated by the distributed aviation concept. This eliminates the need for multiple catapults. Redundancy for aircraft launch is provided by the SEA ARCHER's ability to launch aircraft without a catapult when operating at speeds over 40 knots [13].

The single landing area is also on the port side and is approximately 27 meters wide and runs the length of the ship, parallel to centerline. This simple arrangement prevents simultaneous launch and recovery of aircraft, but given the distributed aviation concept, there is no need for that. Aircraft recovery is through a two-wire electromagnetic aircraft recovery system (EARS). The EARS has an average power demand of less than 1 MW. The need for a 4-wire landing system is eliminated by the increased accuracy of unmanned, computer-controlled landings. The recovery wires are spaced 12 meters apart with #1 wire located 30.5 meters from the stern ramp. The emergency barricade is centered between the two wires. The emergency barricade is provided for inflight emergencies such as flap or tailhook failure.

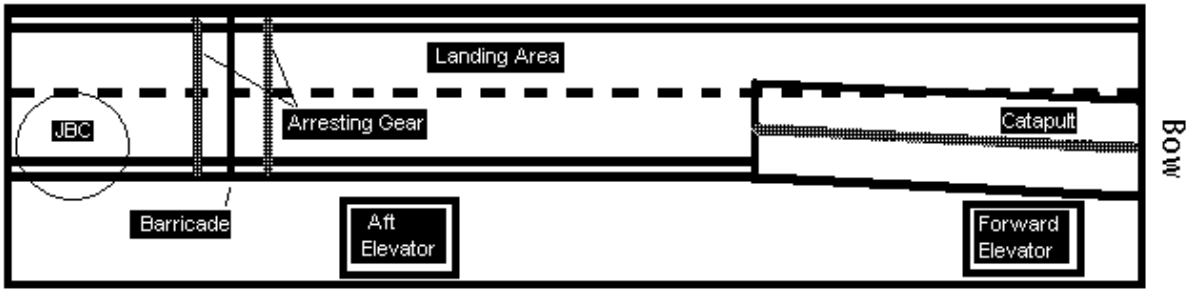


Figure 22 Flight Deck Layout

On the starboard side of the flight deck are two 18-m by 21-m aircraft elevators. The elevators have an installed power of 140 hp and are capable of lifting 13600 kg in under 30 seconds [14]. The elevators' normal position will be down on the hangar deck level. The totally enclosed elevators have a reinforced "garage door" which will close when the elevator departs the flight deck allowing aircraft on the flight deck to traverse unimpeded over the elevator pit. Centered on the flight deck, all the way aft is a Jet Blast

Collector (JBC) which funnels the jet blast of STOVL/VTOL aircraft overboard. The JBC is as envisioned by the May 1998 TSSE design group [15].

Flight Deck Aircraft Movement: Towbots

After the recovered aircraft disengages from the recovery wire, a "towbot" will go to the aircraft, engage the nose gear and control aircraft movement on deck. A scheduling computer will ensure all aircraft/towbot movement is deconflicted, as well as scheduling aircraft for resupply in the hangar and associated movement including elevator runs. The towbot, Figure 23, is a 730-kilogram, computer-controlled, diesel-powered robot. The towbot triangulates its position from an in-deck grid of small electromagnetic beacons. It will also use onboard positioning sensors while engaging the nose gear of the aircraft. An uplink to the aircraft will be provided in the hook-up. The towbot was sized by comparing sizes and requirements of existing "yellow gear" [16] to the requirements imposed upon the towbot by the smaller, lighter, SEA ARROW unmanned combat air vehicle.

Figure 23 Flight Deck Towbot

Once successfully uplinked, the aircraft will receive an engine-shutdown command and weapons safe command from the shipboard computer via the towbot. Engine wind-down occurs while the aircraft is being towed from the landing area. The towbots can also provide tie-down capability by strong electromagnets in the base of the towbot for temporarily securing the aircraft (e.g. while waiting for an elevator). SEA ARCHER will be fitted out with four towbots. Additionally, the ship will have a 1600 kg

firefighting towbot with a 760-liter AFFF tank, a water cannon, and a bulldozer-type blade to push damaged aircraft out of the way or if necessary overboard.

Aircraft Securing: Chainbots

After engaging the recovered aircraft, the towbot will position the aircraft on the elevator for its trip to the hangar bay. Proper lineup on the elevator is critical to interface with the tracked system in the hangar bay. Coming up from the hangar bay with the elevator are two "chainbots," one for each of the main gear. Each 114-kg battery powered, chainbot has a robotic arm and two tie-down chains. Using the same position-sensing grid as the towbots, the chainbots are programmed with the location of all the deck tie-down cloverleafs in the flight deck and hangar bay. The chainbot's robotic arm attaches the tie down chains to the landing gear and, when signaled, attaches the chains to the nearest cloverleafs. After the aircraft is secured on the elevator, the towbot disengages the nosegear and remains on the flight deck to await the next aircraft. When not at Flight Quarters, the towbots are stowed in the hangar bay.

The chainbots stay with the aircraft throughout its stay in the hangar bay. Chainbots automatically recharge themselves by a recharging probe in the tip of the arm. Recharging sockets are located throughout the deck of the hangar bay. The chainbots have electric motors to give them the ability to move under their own power. Once attached to the aircraft, however, the chainbots allow themselves to be towed around by the aircraft's landing gear to conserve battery power. Although attached to the landing gear for parasitic movement, the chainbots will not be load bearing insofar as securing the aircraft. This will allow the chainbots to remain relatively small and lightweight. SEA ARCHER will be equipped with 44 chainbots; one pair for each of the twenty aircraft, plus four spares.

2. Hangar Bay

SEA ARCHER's hangar bay arrangement is depicted in Figure 24. SEA ARCHER has a totally enclosed hangar bay. The aircraft elevators are also totally enclosed and are equipped with spray nozzles for routine washing of aircraft and CBR decontamination. Vertically sliding doors seal the hangar bay from the elevators. Throughout the hangar bay is a tracked system for aircraft movement as shown in Figure

24. The hangar bay uses the pit-stop method of resupply. The plane is refueled from an overhead-refueling rig; a robotic refueling arm in the overhead of each pit stop connects to the refueling port in the top of the aircraft fuselage. Ordnance is uploaded and downloaded from the wings through an automated ordnance handling system that comes up through the deck. The ordnance handling system is discussed later. All pit stops have refueling capability. Pit stop #2 and #3 have ordnance capability while pit stop #1 can only change out avionics packages. The space located directly underneath pit stop #1 contains the equipment used to download intelligence gathered from the avionics payloads.

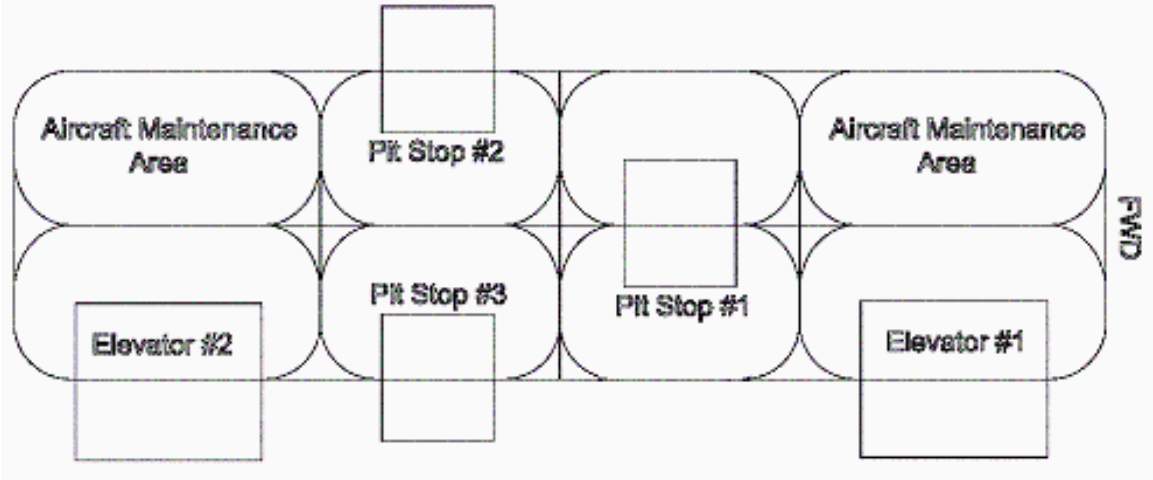


Figure 24 Hangar Bay Layout

Hangar Bay Aircraft Movement: Trackbots

Robots are used to tow the aircraft around the hangar bay track system. These 'trackbots,' pictured in Figure 25, are similar to the towbots used on the flight deck except that they are electrically powered through connections in the track system rather than by a diesel engine. When an elevator arrives in the hangar bay from the flight deck, the trackbot scheduled by the computer will meet it. The trackbot's uplink to the aircraft will provide feedback to the control system computer on aircraft status. The aircraft is taken via the track to the scheduled pit stop where it is either prepared for storage or resupplied for launch.

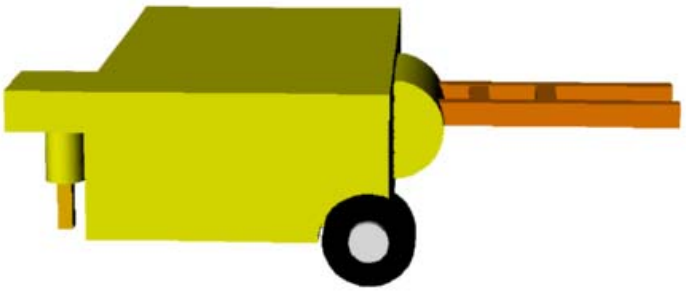


Figure 25 Hangar Bay Trackbot

Pit Stops

As discussed above the aircraft is refueled from overhead while ordnance is simultaneously being loaded from below. Figure 26 shows a diagram of the layout of the ordnance pit stop. Proximity switches in the deck will ensure aircraft alignment in the pit stop. Positioning sensors on the automated weapons loading system will account for slight misalignments as the ordnance is mounted on the aircraft. Separate weapons bays are provided for the helos and UCAV's. The weapons bays are placed such that all attachment points can be loaded simultaneously once the aircraft is in position.

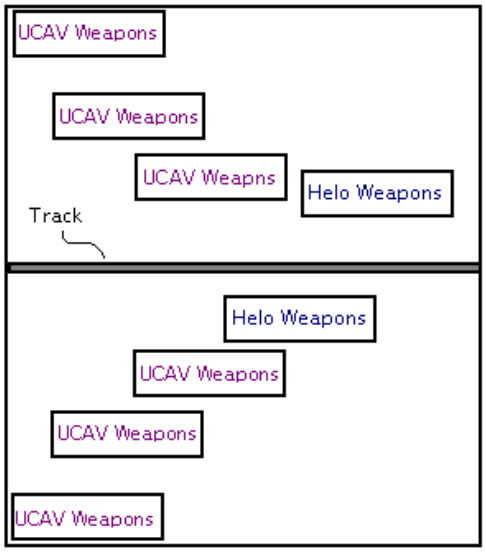


Figure 26 Pit Stop Layout

The weapons bays occupy the top half of the deck directly beneath the pit stop. The remainder of the space below the pit stop weapons bays contains the weapons shuttle. The weapons shuttle transfers ordnance from the magazine to the pit stop

weapons bays. The bays are loaded individually from below by the weapons shuttle on a schedule determined by the scheduling computer. Initially, the weapon holding bay is facing downward. When the shuttle arrives beneath the holding bay, the mechanism telescopes downward to retrieve the weapon. After retrieving the round from below, the mechanism will reposition itself for mounting by rotating 180 degrees, so that the mechanism now faces upward. Once the aircraft is positioned, the mounting mechanism will telescope up from the weapons bay to the attachment point. Using infrared positioning sensors, the mechanism will mount the weapons to the aircraft.

The scheduling computer ensures that the time spent in the pit stop is optimized. For example if the aircraft only needs a small amount of fuel and the time-limiting factor will be the time required to mount the ordnance, the computer will ensure that the weapons are in the bays waiting when the aircraft arrives in the pit stop. However, if the aircraft will require longer to fuel than to transfer and mount the weapons, the computer will consider this when assigning priority to the scheduled tasks.

3. Magazines and Ordnance

The two weapons magazines are located one deck below the hangar bay and inboard of the respective pit stop they supply. The magazines are 12 meters long by 13 meters wide. The weapons are stored in racks that line the forward and aft bulkheads of the magazine. An articulated robotic arm mounted on a track occupies the open area in the center of the magazine. The robotic arm removes the round from its rack canister and places the weapon in the Ammunition Transfer Station (ATS). The ATS serves as an airtight/explosion tight boundary between the magazine and the weapons shuttle. The weapons shuttle accepts the round from the ATS and transports it to the weapons bay via a 2-D translating shuttle. Each component of the computerized ordnance handling system retains positive control of the weapon until the feedback loop confirms the next component has positive control, thus maintaining handling safety. The magazine layout is depicted in Figure 27.

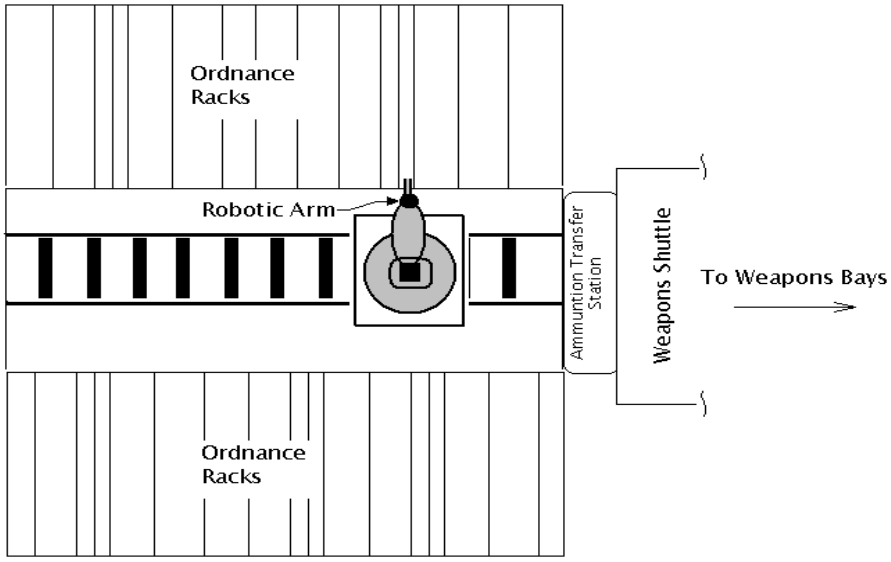


Figure 27 Magazine Layout

Aircraft Missions

For each of the SEA ARROW's possible missions there is a tailored ordnance loadout. For SEA ARROW, the ordnance loadout is constrained to the six attachment points and the 1500-pound payload capacity [13]. For the helo, current SH-60 weapons loadouts were used [17]. The possible *ordnance-expending* UCAV missions are defined as follows:

- Battlefield Interdiction (BI) – Hard targets such as tanks, bunkers
- Close Air Support (CAS) – Light fire in support of ground forces
- Combat Air Patrol (CAP) – Air-to-air patrol and combat
- Suppression of Enemy Air Defenses (SEAD) – Self explanatory
- Maritime Patrol (MarPat) – Air-to-surface patrol and combat
- Multipurpose Mission – Undefined target

Similarly for the helo:

- Maritime Patrol (MarPat) – Air-to-surface patrol and combat
- Anti-Submarine Warfare (USW) – Self-explanatory
- Strike – Air-to-surface attack (similar to BI, but not as limited in scope)

To determine an ordnance loadout, it was necessary to assume what percentage of the given sortie rate was dedicated to each mission type and the percentage of those missions in which ordnance was expended. To size the ordnance loadout, it was assumed SEA ARCHER is operating in a hot war environment at maximum sustained sortie rates. The basic assumption in the percentages is that SEA ARROW will be expending the most ordnance in her designed missions and only a fraction of the ordnance in the missions that she is not designed for. Based in part on the mission profiles described in the SEA ARROW design team's final report [13], the following breakdown was assumed:

UCAV

% of Missions		% of Time Ordnance Expended
25%	Multipurpose Mission	75%
20%	Battlefield Interdiction	100%
20%	SEAD	100%
15%	Close Air Support	100%
10%	Combat Air Patrol	25%
10%	Maritime Patrol	25%

HELO

% of Missions		% of Time Ordnance Expended
37.5%	Maritime Patrol	25%
37.5%	USW	25%
25%	Strike	25%

Aircraft Weapons Payloads

The weapons payload was tailored for each mission type. Only weapons currently in the inventory were used. The only assumption made for the weapons is that by 2012 the AGM-88 HARM missile's weight will be less than 750 pounds, thus allowing SEA ARROW to carry two of them. The AGM-88 currently weighs in at 800 pounds [18]. The tailored weapons loadout for each of the missions is as follows:

Multipurpose Mission	1 AMRAAM
	1 Sidewinder
	1 JDAM
	1 Maverick
	2 Hellfire

Battlefield Interdiction	2 Maverick 2 JDAM
Suppression of Enemy Air Defenses	2 HARM
Close Air Support	1 JSOW 2 Hellfire 1 JDAM
Combat Air Patrol	4 Sidewinder 2 AMRAAM
UCAV Maritime Patrol	1 Maverick 3 JDAM 2 Hellfire
Helo Maritime Patrol	1 Penguin
Helo USW	3 Torpedoes
Helo Strike	4 Hellfire

The magazine racks are optimized for the varying sizes of the weapons. The weapons are onloaded to the ship already finned so that the round requires no maintenance before being loaded onto the aircraft. Table 18 summarizes what types of weapons are carried onboard for the airwing, how many of those weapons are in each magazine and the total carried onboard. Refs [19] through [22] provided details on weights and sizes of the various weapons to assist in sizing the magazine racks and the mission payloads.

Weapon	Port Magazine	Starboard Magazine	Total Onboard
AGM-154 JSOW	14	21	35
AGM-88 HARM	39	39	78
AIM-120 AMRAAM	24	24	48
AGM-119 Penguin	5	5	10
AIM-9 Sidewinder	30	30	60
MK-54 Lightweight Hybrid Torpedo	7	7	14
AGM-65 Maverick	60	60	120
GBU-29 JDAM	80	80	160
AGM-114 Hellfire	81	81	162

Table 18 Airwing Weapons Loadout

4. Cyclic Operations

In typical cyclic operations, the aircraft will all start out in the hangar bay. Operators enter the flight plan into the scheduling computer and the computer will automatically schedule fueling and arming of the aircraft to meet the scheduled launch time. The computer will select aircraft for the missions to ensure equal flight hours on all aircraft (or in accordance with some other criterion). When scheduled, the aircraft will be repositioned to the pit stop, with other aircraft being repositioned as necessary to allow repositioning of the designated aircraft.

After launch preparations are completed the aircraft will be repositioned to the aft aircraft elevator. In similar fashion, all the aircraft scheduled for launch are prepared and repositioned in the hangar bay. In this manner the entire first launch cycle is prepared and stored in the hangar bay. When scheduled, elevator runs begin with the first run taking the first aircraft for launch (and its towbot and chainbots) to the flight deck. The

aircraft is immediately taken to the catapult for launch, leaving the chainbots on the elevator for return to the hangar bay. The engine startup command and weapons arm command occur once the aircraft is topside.

While the first aircraft is respotting to the catapult, the elevator returns to the hangar bay for the next aircraft. This pattern continues until all the aircraft for that air plan event have launched. A typical event would have five aircraft: 2 UCAV's and 3 UAV's. When scheduled, the next event will launch aircraft followed immediately by recovery of the first event's aircraft. This launch/recovery process continues until the end of the cycle, which ends with two successive recoveries with no launches. A sample air plan is shown in Table 19. The normal flow of operations is depicted graphically in the flow chart in Figure 28.

SQUADRON		EVENT 1 0700 0900	EVENT 2 1100	EVENT 3 1300	EVENT 4 1500	
UCAV	A	--A1 2 STK-->	--A1 2 CAP-->	--A1 2 STK-->	--A1 2 STK-->	
UAV	B	--B1 3 RCN->	--B1 3 RCN->	--B1 2 RCN->	--B1 3 RCN->	
HELO	C	---H1 ASW----------®----------®----------1				
LAUNCH:LAND		L1-5 L2-5	R1-2 L3-4	R2-5 L4-5	R3-5 R4-7	

Table 19 Hypothetical Airplan

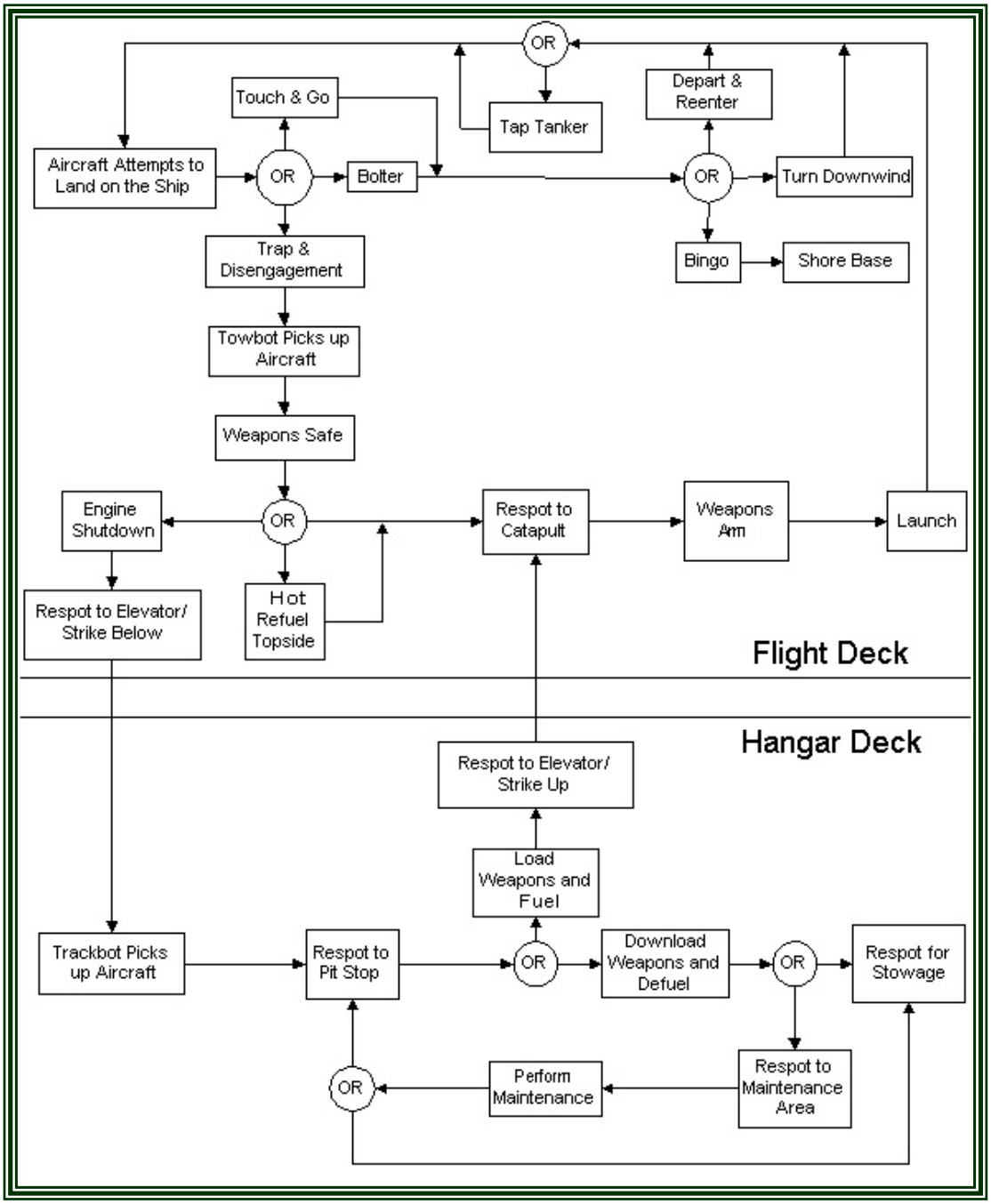


Figure 28 Aircraft Flow from Recovery to Launch

If a surge sortie is required, all eight UCAV's can be positioned on the flight deck for successive launches as pictured in Figure 29. The aircraft not secured by towbots must retain their chainbots plus an extra chainbot for the nose gear until ready to launch.

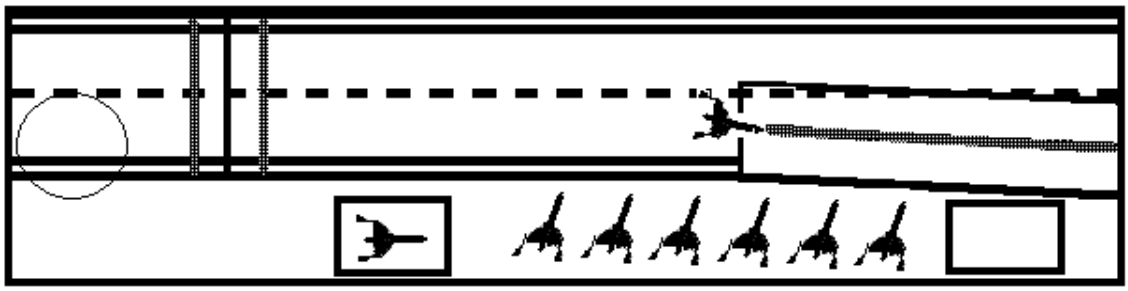


Figure 29 Flight Deck Arrangement for Surge Operations

E. COMBAT SYSTEMS

1. Combat Systems Overview

SEA ARCHER will utilize a layered defense concept for protecting the taskforce and its assets. It will leverage on technology that is being currently developed for the U.S. Navy, while certain systems that will be specific to SEA ARCHER's MNS and ORDs are also being proposed.

	Range	***SEA LANCE II***	***SEA ARCHER***
Outer Layer Defense	200 km		SEA ARROW
Middle-Layer Defense	50 km		
Inner-Layer Defense	30km	Super Sea Sparrow Missile	Super Sea Sparrow Missile / USC Missiles
Point Defense	5 km	RAM	FEL

Table 20 Layered Air Defense for CROSSBOW Taskforce

	Range	***SEA LANCE II***	***SEA ARCHER***
Outer Layer Defense	>200 km		SEA ARROW
Middle-Layer Defense	>50 km	Harpoon / Medium Range Missile	
Inner-Layer Defense	30km	Super Sea Sparrow Missile	Super Sea Sparrow Missile / Unmammned Surface Craft Missiles / Helo Missiles
Point Defense	5 km	Small Caliber Gun System	Free Electron Laser / Small Caliber Gun System

Table 21 Layered Surface Defense for CROSSBOW Taskforce

	Range	***SEA LANCE II***	***SEA ARCHER***
Middle-Layer Defense	>50 km		Helicopters
Inner-Layer Defense	15km	Torpedoes	

Point Defense	5 km		

Table 22 Layered Sub-Surface Defense for CROSSBOW Taskforce

It can be seen that SEA ARCHER will be heavily dependant on the long-range defenses of SEA LANCE II. This ship will be different from the original SEA LANCE [23], in that it will match the speed and endurance of SEA ARCHER. It will also have a larger complement of missiles to provide a higher capability in both self and task force protection, coupled with sensor suites to match the missile and threat environment

SEA ARCHER's combat system will be limited to self-protection for up to 30km. It must be understood that a family of SEA ARCHER vessels will leverage on the advantage of distributed platforms while having the ability to share information seamlessly. This will then effectively increase the coverage of the complete taskforce, enhancing combat effectiveness and finally increasing survivability. Figure 30 provides an overview of the complete SEA ARCHER combat system layout.

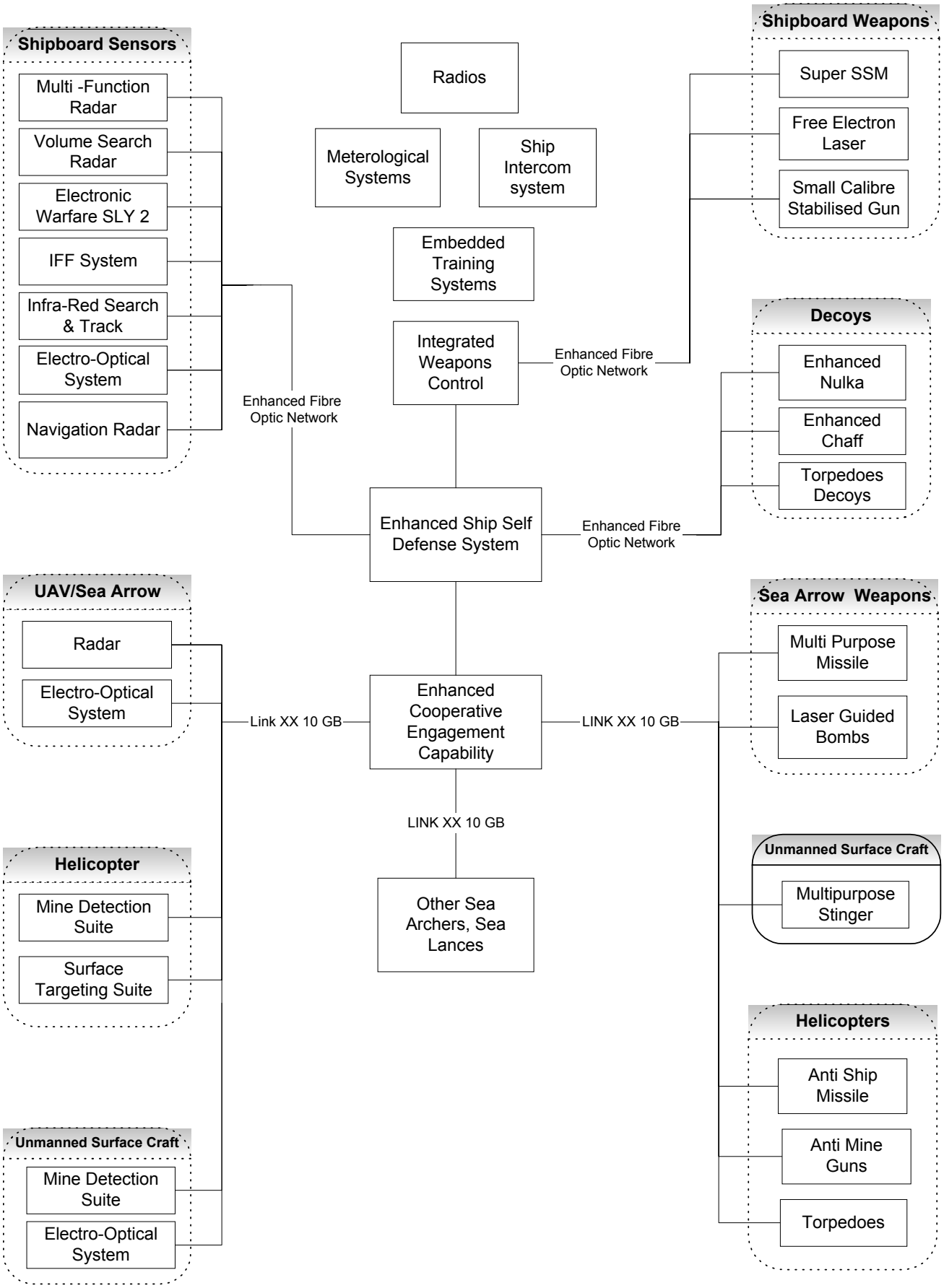


Figure 30 SEA ARCHER Combat System Layout

Command & Control

Enhanced Cooperative Engagement Capability (ECEC) - This is the core backbone of the entire Crossbow taskforce, it is expected that every platform will have this system installed. It will be a generation beyond the CEC that is being introduced into the US Fleet in 2002. ECEC will take the concept of sharing fire control information into the next level. Instead of sharing only air target tracks, ECEC will exchange information in the surface and subsurface environment. Fire control quality data will be exchanged among *all* CROSSBOW assets (including SEA ARROW). This will effectively increase the area coverage and situational awareness of the taskforce. The combat effectiveness of the taskforce is enhanced as one vessel can fire its weapons utilizing information and/or control from another taskforce member. Electronic warfare can also be conducted on a grander scale, as all vessels will then be able to assist each other and provide extra electronic protection. A taskforce commander will also be able to control all assets within his command in a more precise and expeditious manner. The system will utilize Link XX to communicate among all taskforce components and will have sufficient bandwidth to handle the necessary information exchanges. The system will also overcome all time latency issues.

Enhanced Ship Self Defense Capability (ESSDS) – SSDS will be installed on future and current large ships (LPD-17, CVN). It integrates the hardkill and softkill weapons onboard a vessel against air targets. The generation beyond that, hereafter called ESSDS, will also provide an automated self-protection capability but against *all* threats. Encompassing air, surface and subsurface threats it will utilize all the weapon systems and electronic warfare suite to provide enhanced survivability. It will also be integrated with ECEC, and as such provide a superior "umbrella" as all assets are then in a unified system. In a target rich environment, this automated system will be an enclosure barrier in which all unidentified threats will be engaged, with veto capability from the command group. To ensure rapid control of all installed assets, the system will reside on a fiber optic Local Area Network.

Electronic Warfare – Future Electronic Warfare will undertaken by the SLY2 system that is undergoing development. SEA ARCHER will employ this system in conjunction with decoy systems It will integrate the following subsystems

- radar/threat warning
- missile attack and laser illumination warning
- transmission of various jamming

Active decoys for SEA ARCHER will be the Nulka system, which will be fired from standard 5.125 inch tubes (Mk 36 Launchers). Once fired it will hover on the surface and emit signals similar to the SEA ARCHER, thus seducing the incoming Anti-Ship Cruise Missile (ASCM). Passive decoys will include chaff and infra-red emitters. Infra-red emitters are envisaged to be a necessary requirement in the future littoral environment as low cost missiles which utilize heat seeking guidance systems will be employed by the enemy. Since SEA ARCHER will be a low radar cross section ship, decoys like chaff and Nulka will prove to be effective when used in conjunction with jammers. The system installation will include the following –

- Advance Multi-Function Active Apertures (AMFAR) – This is to minimize the number of antennas and maintain a low radar cross section. It will handle both jammers and receivers. Will also be used as communication portals.
- 5.125" Launchers – installed with Small Caliber Gun Systems which can fire either Nulka, Chaff or Infra-Red emitters

AN/SLY-2(V) AIEWS is intended to replace the AN/SLQ-32(V) radar warning and jamming system (see separate entry) aboard US Navy (USN) surface ships during the early part of the 21st century. When fully implemented, AIEWS is intended to incorporate Electronic Support (ES), Electronic Attack (EA), Infra-Red Search and Track (IRST) and IR jamming capabilities that are fully integrated with a host vessel's combat information system. As of early 2001, it is expected that AIEWS applications will take the form of full capability or ES/IRST only systems according to perceived individual platform requirements.

Integrated Weapons Control – All current weapons systems require specific fire control systems to enable the weapons employment. SEA ARCHER will employ a common architecture that integrates all fire control systems for all weapons. This will allow easier cross platform exchanges in an ECEC environment. Within SEA ARCHER, it allows a central system to control weapon fire control solutions and enables a more seamless common console in the Combat Information Center (CIC).

Sensor Suite

Multi-Function Radar (MFR) – this 3 dimensional system will be able to perform air/surface detection and tracking. It will be act as a fire control radar and provide missile control for the SEA ARCHER's missile complement. It will operate in the X-Band and will have a maximum detection range of 76km against ASCM threats. It's placement on SEA ARCHER will allow it to have a radar horizon of 22 km. The system will also be optimized for the littoral environment and provide superior clutter rejection. This system is essentially the SPY 3 radar currently undergoing development.

Volume Search Radar (VSR)– as the MFR will be optimized for target tracking and missile control, it will be necessary for a Volume Search Radar to provide early warning detection. It would be a 3 dimensional radar that would search, detect and track aircraft, missiles and UAVs, while providing target cueing to the MFR. It will operate in the L-band to provide a longer detection range utilizing solid-state, active array radar technology. The system will be placed on the same level as the MFR and as such the surface detection capability will be similar to the MFR but the maximum detection capability will be 250km for aircraft. It would also perform air traffic control requirements for the SEA ARROW, UAVs and helicopters.

Infra-Red Search and Track – The littoral environment will degrade the detection capabilities of all radar systems regardless of type; this is exacerbated by the physical radar horizon that all systems experience. Future ASCMs will be more stealthy and be able to skim even closer to the surface of the ocean. This will severely reduce the reaction time for defending against incoming ASCMs. SEA ARCHER will overcome this shortfall by introducing an IRST system onboard. This passive system will scan the

horizon at 1 Hz rate; even if the threat missile utilizes low RCS material, the missile plume will be detectable. The heat signature of a missile plume is also unique and the system will be able to detect the plume out to the physical horizon. It will only provide a bearing but not range information, nonetheless this will be adequate so that the self-defense systems have proper forewarning and can be brought to bear. The system will operate in the 3 to 5 μm and 8 to 12 μm ranges.

Electro Optical Systems (EOS) – will provide SEA ARCHER with day and night capability. It will have a high resolution TV camera and thermal imager operating in the 3-5 μm range. This system will also be optimized for all naval environments. The EOS will allow the commander to obtain visual identification of all surface and air threats. It can also act as a secondary fire control director for the missile systems by providing bearing and elevation. Range information will be provided by a built-in Laser range finder system.

Navigation Radar - This will be included as part of the sensor suite to allow SEA ARCHER to switch off the high power (and distinctive) radar suites and utilize a simple system for navigation. Coupled with the low RCS nature of the platform, the Navigation radar will enhance the deception capability of the ship by giving it an emission signature comparable to commercial vessels.

Identification Friend-Foe System (IFF) – IFF will allow SEA ARCHER to process the targets obtained from the radar systems and properly identify all tracks on the system. This system will be the standard IFF system that is to be installed on the US warships in 2020.

Offboard Sensors – The embarked components of SEA ARCHER will have sensor suites onboard each platform. SEA ARCHER will be able to obtain this information for target detection and tracking of surface/air threats, thus increasing the detection range of the taskforce.

- SEA ARROW Radars - Each SEA ARROW UCAV will have onboard air to air and air to ground radar capability.

- UAV Reconnaissance Sensors – The UAVs are designed to carry a variety of reconnaissance and surveillance sensors. Information from these sensors will be integrated into a common operational picture.
- Helicopter – onboard mine detection suites are available. Helicopters will utilize LIDAR systems for mine detection and have towed sonars for Anti-submarine warfare.
- Unmanned Surface Craft (USC) – it will be equipped with optical sensors and a low cost infra-red thermal imager for night operations. A low cost IRST will also be used for early warning detection of incoming sea skimming ASCMs.

Shipboard Weapons

Vertical Launch System (VLS) – to provide a 360° coverage a 16 cell vertical launch system (not the current MK 41 VLS) for the missiles will be installed. Each cell will contain 4 missiles to bring the missile complement to 64 missiles. The launcher will be downsized to accommodate the shorter missiles envisioned.

Super Sea Sparrow Missile (SSSM) – This missile will be both air and surface capable with a maximum range of 30 km. It will be essentially a 4^{th} generation of the Sea Sparrow missile with similar airframe, speed and warhead. Though the fragmentation pattern will be similar to current Sparrow warheads it will have dual detonation modes instead. For air targets it will use a proximity fuze with a fragmentation pattern to increase its lethal radius against ASCMs or UAVs/aircrafts. For surface targets the missile can again employ a fragmentation pattern or have a delayed detonation to allow the missile to explode within the target, thus enhancing chances of a kill. It will have an active seeker for terminal guidance, while obtaining initial target information and mid-course correction from the MFR. This will allow SEA ARCHER to engage up to 32 separate targets (if one missile is fired against each target). Terminal guidance can be active radar homing, IR homing, Home-On-Jam or Laser Guided. SSSM will be able to switch automatically if any one of the modes have lost track of the target. For surface engagements beyond the radar horizon, the SSSM will receive approximate

target bearing and range prior to launch; once beyond the radar horizon, it will open the seeker and start target scanning and lock onto the radar cross section/heat signature/jamming signal of the enemy vessel. It is envisaged that the signal processing capabilities of the seeker head will be such that it can discriminate specific portions of the ship and as such will be able to target relevant portions of the ship to ensure highest mission kill. For instance, if the weapon is programmed for a sensor kill, it can target the radar mast or if necessary the bridge or the ASCM launchers. It will also be able to utilize the Laser Designator on the Unmanned Surface Craft to engage the surface vessel.

Speed	Mach 3.6
Range	Max 30 km Min 1.5 km
Length	3.85 m
Diameter	25.4 cm
Warhead	38.7 kg Annular blast fragmentation warhead, Proximity fuzed or delayed detonation
Launch Weight	245 kg

Table 23 Super Sea Sparrow Missile Characteristics

Free Electron Laser System (FEL) – The final layer of defense will be this directed energy weapon. It will engage air and surface targets up to 8 km, this system will be highly effective against missile threats and compliment the SSSM. Firing a 1.5 MW beam of light, it will take up no more than 3 seconds to destroy a missile target. The system will be operated continuously when required. A FEL provides coherent, tunable, high power radiation. Systems can be designed to operate anywhere from millimeter to ultraviolet wavelengths. It is also capable of the high spatial coherence and a near diffraction limited radiation beam characteristic of conventional lasers. The difference from conventional lasers is in using a relativistic electron beam as its lasing medium, as opposed to bound atomic or molecular states, hence the term free-electron. The main advantage of FELs compared to chemical or CO2 lasers is the tunability of the laser beam. This allows users to select the wavelength of light to suit the application. The caveat for this system is that there is still a large amount of developmental work that would still be required and as such would not likely be fielded with the 2020 IOC. Nonetheless, SEA ARCHER has been sized with the necessary footprint and power

requirements to met this future growth weapon. In the interim, the space allocated can be used for Rolling Airframe Missiles to provide the inner-layer defense.

Small Calibre Gun System – This stabilized gun system will have a caliber of 30mm. Effective range of the system will be between 3 to 5km (depending on threat), it will employ automated target tracking and engagement. Target cueing will be from the ESSDS. It will also have its own automatic tracking optical system. This system will utilize centroid tracking and will be able to predict future target position even when firing the gun. This is necessary as firing 30mm shells on the surface will cause large splashes around the target which will then cause the system to lose track. It will be highly effective against fast moving surface vessels. On each side of the gun system will be 5.125 launchers that fire the decoy systems for SEA ARCHER. Thus it can also be employed as a trainable launcher to enhance the electronic warfare capability when compared to fixed launchers.

Range	Max 5 km
Weight	1 200 kg
Gun	30mm Chain Gun
Ammunition Load	200 rounds

Table 24 Small Caliber Gun System Specifications

OffBoard Weapons

Unmanned Surface Craft (USC) – this will employ a jet ski-like platform with weapons and sensors emplaced and be remotely controlled from SEA ARCHER. The role envisaged for the USC will be

- To ensure a forward presence and maintain a barrier for the SEA ARCHER. By utilizing the USC as a reconnaissance platform, SEA ARCHER has another asset that can ensure more effective situational awareness. It will be armed and can engage both surface and low flying air threats; this will allow SEA ARCHER to engage more threats in case saturation attacks occur.
- To provide early warning for sea skimming missiles. The current radar horizon for sea skimming ASCMs at 5ft is only 23km. Having a platform, such as the

USC, that is beyond the physical horizon will allow SEA ARCHER more reaction time for the shipboard weapons to react to incoming threats.

- Forward mine detection capability. Due to its small size it will not detonate moored or subsurface mines (except floating mines). It will tow a small towed array sonar optimized for mine detection. The size of this towed array sonar will be 80kg in weight and it will be optimized for high speed mine detection.

The USC will have a maximum speed of 70 knots while the optimum cruising speed is 50 knots. The speed will allow it to maintain contact with SEA ARCHER while being able to surge ahead of SEA ARCHER if necessary. Operating range will be 200 nm. The conformal weapons payload will be 210 kg. The USC will be controlled controlled from SEA ARCHER using the Advance Multi-Function Apertures, it will relay its optical video back for feedback and control. These sighting system will have both a standard CCD camera and a thermal imaging senor in a 3 to 5 μm range for night and day operation. A wide field of vision, low cost scanning IR detector will also be installed to provide early warning detection of missile plumes and jet exhaust. The USC will have a high resolution GPS receiver to allow the operator to know its precise location. Coupled with a Laser Range Finder (LRF), it can reveal the exact location of an enemy surface vessel. If necessary, the LRF can act as a laser designator and allow SEA ARCHER to fire the SSSM at 30km and utilize the reflections off the designator to engage the enemy.

Weapons payload will include small IR Stinger type missiles optimized for both surface and air threats. Each USC is envisaged to carry four missiles with a combined weight of 40 kg. These IR missiles will be able to engage targets up to 8km in range and will have a small point detonating fragmentation warhead. For surface engagements, it will not have sufficient capability to sink vessels but will provide degradation of enemy capability. This will allow other missiles from other platforms to further destroy the target if required.

The USC maneuverability ensures that this target will be difficult to engage while the low RCS signature will allow it to be stealthy and prevent its own detection by the enemy. The USC will have a significant amount of autonomous operation capability. It will be capable of performing most mission functions under control of an autopilot. Only

changes in mission or handling of exceptions (such as detection of a threat) wil involve operator interaction. The high degree of autonomous control will allow minimal operational impact on the SEA ARCHER crew size as any personnel within the CIC will be able to control the USC.

The USC can be deployed while SEA ARCHER is traveling at its maximum speed. It will be lowered from between the hulls of the ship onto the surface and then released through the center of the ship. Retrieval will be the reverse process; the USC will enter through the center of SEA ARCHER where it will then lock on a retrieval probe (much like a probe for mid air refueling) and be winched onboard SEA ARCHER. Due to the high speed nature of SEA ARCHER, the wake generated may make retrieval at 60 knots difficult. At this juncture, there has been no modeling done on the wake generated at high speeds so these methods are just proposals for consideration. Another possible retrieval method would be through the helicopters which could winch the USC up and lower the craft onto the deck elevator. The elevator would then lower into the ship and the USC recovered.

Helicopters – these platforms will be able to perform anti-surface, -submarine and -mine warfare. They can be equipped with up to 4 Penguin type missiles for anti-surface warfare or 3 anti-submarine torpedoes. They will also have a RAMICS (Rapid Airborne Mine Clearance System) onboard; this includes a Light Detection and Ranging System (LIDAR) coupled with a 20mm Gatling gun. LIDAR will be able to detect floating and subsurface mines. Once a mine is located, the gun will fire projectiles optimized for traversing the water and will detonate the mine.

Combat Systems General Arrangement Plan

The arrangement of combat systems onboard SEA ARCHER utilizes the design principles that were used throughout the design process. They are ranked according to importance :

Surviability, Automation, Reduced Manning, Upgradeability, Maintainability, Reliability, Manufacturability, COTS, Affordability

The most controversial element was the elimination of the shipboard superstructure and placement of all sensors on the sides of the ship. Initial designs considered a normal island for installation of a sensor suite but survivability was deemed primary, and placement on the sides of the ship provided the following benefits:

- Maintain a low radar cross section when compared to an island design
- Provide graceful degradation in sensor capabilities if SEA ARCHER has been hit, compared to a complete sensor loss if a missile hit the island.

The losses incurred with this design were:

- Increased cost – one extra array for the VSR and MFR were required to ensure a proper 360° sensor coverage. Two extra IRSTs were also required to provide a detection capability for ASCMs.
- Reduced surface detection capability. Lowering the antenna from a proposed 24 to 20m meant a surface detection capability of 18km.

The VSR will be placed at opposing corners of SEA ARCHER, with the MFR beside it to optimize coverage. The small caliber guns will be placed at the 4 corners of the ship to allow a good minimum engagement range and coverage. The VLS will be placed at the aft portion of the ship. Though its placement is not in the direction of flight flow, it will be prudent not to conduct flight operations when firing the SSSM due to the inherent back blast from the rocket plume.

For the C4ISR and EW portals, the AMFAR will be simply aligned along the port and starboard sides of the ship. Due to the size of SEA ARCHER more apertures can be added if needed.

The FEL system was placed port and starboard as the weapons were placed in the optimum position to provide maximum 360° coverage.

Survivability Analysis

At 200km, it has been assumed that the UCAV can engage the threat aircraft that launches the missiles. Furthermore, the UCAV has the probability of killing half of these aircraft and half of any launched missiles, then the total kill probability of the UCAV against targets is:

$P_{K\text{-}UCAV} = 1 - 0.5 \times 0.5 = 0.75$

It is assumed that missile reliability encompasses 3 components - tracking of target, the seeker's ability to guide itself and the fuse detonating properly. For this scenario, the SSSM is assumed to have reliability of 85% and a warhead lethality (given a hit) of 0.70. Therefore Single Shot Kill Probability against an ASCM is

$P_{SSK} = 0.85 \times 0.7 = 0.595$

Since killing an incoming missile is not assured, it may be prudent to fire two SSSMs to ensure a higher kill probability, this will then enable the Standard missiles to have the kill probability against an ASCM of-

$P_{K\text{-}SSSM} = 1-(1- 0.595)^2 = 0.835975$

For an FEL system, the "reliability" will be based on the beam director's ability to track the target and the proper functioning of each individual component. A figure of 85% has been assigned to it, which is similar to the rest of the combat systems. The lethality will be assumed to be 100% (FEL ensures destruction on the ASCM) Therefore the total kill probability of the FEL will be -

$P_{k\text{-}FEL} = 0.85 \times 1.0 = 0.85$

The electronic warfare systems has been given a $P_{k\text{-}EW} = 0.5$ effectiveness against ASCMs.

Therefore the total effectiveness of the layered defense is defined as -

$$P_{KTOTAL} = 1-(1-P_{K-AC})(1-P_{K-SSSM})(1-P_{K-RAM})(1-P_{K-EW}) \quad (2.1)$$

P_{Ktotal}=1- (1-0.75 (1-0.835975)(1-0.85)(1-0.5)

=0.99692

A maximum credible attack would involve 1000 ASCM fired against a SEA ARCHER Taskforce. It is reasonable to assume that at most, 100 missiles would target any one vessel. Assuming 100 incoming ASCMs, the possibility of 1 or more missiles leaking through the defensive layer is

$P_{Leakage} = 1- 0.99692^{100} =$ **0.2654**

Given this value, 6 of the 8 SEA ARCHERS would escape unhit; 2 would be damaged. The squadron would remain a viable fighting force even after a maximum credible attack.

It has been assumed that there will be sufficient number of missiles to engage each ASCM

2. Combat Engagement Flow

The proposed concept for employing the combat systems and sensor suites onboard SEA ARCHER when enemy targets are detected is decribed below.

Air Defense – The target is first detected by either the UAVs, VSR, MFR, IRSTs or SEA ARROWs. If it has been identified by the IFF system as a threat, fire control information (range, bearing and velocity) must then be obtained. If this data is unavailable, more sensors must then be allocated to synergize the location. For instance, UAVs, SEA ARROWs or USCs, may be vectored in to meet the threat. Once the target information is obtained, the ESSDS will propose the most appropriate weapon system to engage the target. The ESSDS will also propose a heading to minimize the RCS of the ship based on target bearing. Once the air target is within the SSSM firing range, missiles will be fired. The number fired will be based on the target characteristics and the number of threats. If the target is not destroyed with the salvo of missiles and is within 5km, the SSDS will designate the FEL weapon to engage the target. During the entire sequence, the system is providing bearing and speed directions to optimize the RCS of the ship. Decoys like chaff, Nulka and IR emitters are fired in proper sequences while jamming the incoming targets. Due to the low RCS of the ship, decoys employed will prove to be more effective. The complete engagement can be fully automated or placed in the operational command of the Tactical Officer with suggestions from the ESSDS. If the entire taskforce is being attacked, each platform will ensure that the self defense mechanisms are optimized force-wide and prevent systems from conflicting with each other.

Surface Engagements – Similar to air defense sequence, surface targets are detected by either, the MFR, VSR, IRST, UAVs, USCs. If it has been identified as a threat, fire control information must be obtained from the target. Once obtained, the

ESSDS will allocate the most appropriate weapon system to engage the threat. Long range engagement (>30km) may be possible if the helicopters or Sea Arrows are in the vicinity. Air to surface missiles and Penguin type missiles may be fired to destroy the target. USCs will be able to engage the threat if it is within the firing range of the Stinger missiles of the USC. If the target enters the lethal range of the SSSM, the ESSDS will decide if the target has high enough priority to utilize the SSSM to engage. If the enemy target is beyond the radar horizon of the MFR, the ESSDS will obtain target information from the other sensors or USC and fire the SSSM in the direction of the bearing. As mentioned earlier, terminal engagement is provided by active homing, IR homing, HOJ and laser designation from USC.

For targets from 0 to 8km, the SSDS will be able to employ the FEL weapon system to destroy the target also. At 5km and below, the SCGS will be made available to engage the surface threats. SSDS will select the firing gun based on optimum firing position and range.

Subsurface warfare Submarine warfare will be conducted by either the SEA LANCE or the helicopters. If a torpedo is fired against SEA ARCHER, the SSDS will employ sound generators to seduce the incoming torpedo.

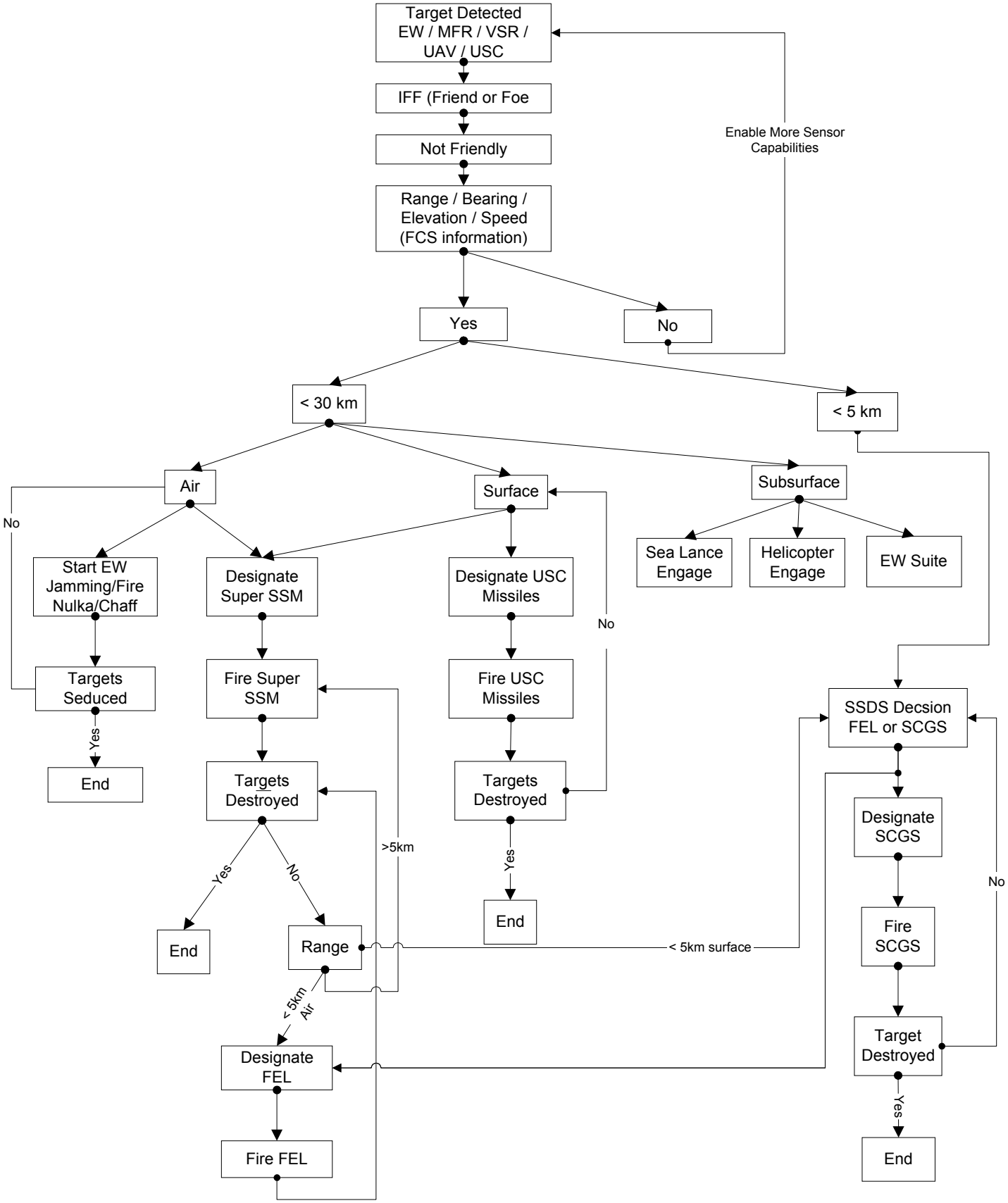


Figure 31 Ship Self Defense Sequence

3. C4ISR

The strength and payoffs of CROSSBOW as a distributed sea based air asset can only be realized if the C^4ISR demands can be adequately met by means of a robust and resilient communications backbone architecture that provides interconnecting links amongst all these distributed assets within the theater of operations. The CROSSBOW communications architecture is defined as an Airborne Communications Node (ACN), which is essentially a network hub operating in the sky, that can circumvent most Line-of-Sight (LOS) related problems and bandwidth congestion problems associated with MILSATCOM usage. The detailed analysis of this requirement is outlined in MAJ Foo Khee Loon's Report[1]. The other key aspect of the entire CROSSBOW communication system is the shipboard communications systems. This paper seeks to provide an overview of the key considerations for the communications systems that we need for CROSSBOW ships.

Key Considerations

In determining the communications system specifications that are essential for CROSSBOW operations, the CVNX/CVN communications requirements are used as the baseline requirements for initial bandwidth and bit rate estimation. It is recognized that the overall requirement for CROSSBOW would be smaller due to the lower user terminals and information needs.

CROSSBOW Communications Suite

Similar to the CVNX/CVN basic infrastructure, CROSSBOW will require a substantially different C^4ISR capability to operate in a complex and changed information environment. CROSSBOW will operate with information gathered from military, government, commercial, and coalition sources. This will create Multi-level Security (MLS) challenges regarding the source, content and reliability of the information. Information transfer sources will also become more diverse.

[1] Requirement Analysis for An Airborne Communications Node (ACN), Specialized Supporting Study by MAJ Foo Khee Loon. NPS (2001).

Information will be transferred via voice, video, and data formats over military and commercial RF channels, Internet, LANs and WANS. The transmission media frequency spectrum that CROSSBOW will use ranges from acoustic frequencies for ASW through the traditional communications bands (HF, VHF, UHF, SHF, and EHF) and the higher commercial satellite bands (Ka, Ku, and V). In addition, there are other high bandwidth imagery and data files transfers that are required for Intelligence, Surveillance, Reconnaissance and Targeting (ISRT) operations. Voice communications will be emphasized less, while data transfer will assume a much greater importance because of the increased operational tempo and rate of information exchange. Data especially imagery and file transfer, requires larger bandwidths. This means that higher frequency will be required to carry the larger bandwidths.

Communications Architecture - Functional Groupings

The architecture can be broadly organized into five functional groupings:

- **Shipboard Operations**

  Onboard ship control, navigational function and other shipboard operations will be highly automated onboard CROSSBOW. One of the key elements in information transfer is the Ship Automated Communications Control System (SACCS). This system provides an advanced ship radio communications network and circuit management tool. This system provides automated, reliable and robust circuit connectivity and HF, VHF, UHF, SHF radio network monitoring and reconfiguration.

- **CIC Operations**

  Global Command and Control System (GCCS) will provide the common operational picture (COP) to CROSSBOW for theater-level battle space situational awareness. In addition, the Global Broadcast Service (GBS) will be the service that provides intelligence, warning, common operational picture, target information, ATO dissemination, weather, imagery, maps, database updates, and other tactical and administrative information.

- **Intelligence, Surveillance and Reconnaissance (ISR)**

  Integrated Broadcast Service (IBS) will provide current air, ground, surface, and subsurface information on threats, indications of enemy intentions, and resolution of Identification Friend and Foe (IFF).

- **Fire Control and Coordination**

  Cooperative Engagement Capability (CEC) provides for a real-time capability to extend the CROSSBOW horizon by combining, on a pulse-by-pulse basis, data from many sources to enable earlier detection and tracking of air contacts.

- **Logistics Support Functions**

  Central to all combat mission, CROSSBOW will need to cater for coordination of logistics replenishment, supplies, personnel affairs, medical needs, maintenance and repairs onboard CROSSBOW forces and other support bases.

Bandwidth Requirement:

The overall bandwidth demand for CROSSBOW will be estimated based on the envisaged requirement of the CVNX. This is summarized in Table 1 as follows:

Transmission Medium	**Bandwidth Requirement**	**Data rate Requirement**	**Purpose**
VHF band	32 kHz	9.6 kbps	Tactical voice communications
UHF band	48 kHz	2.4 kbps 4.8 kbps	IXS, CUDIXS, NAVMACS TACINTEL
SHF band	128-1024 MHz	9.6 kbps 19.2 kbps 64 kbps 128 kbps 384 kbps	GCCS SIRRNET NIPRNET Voice and VTC JWICS

Ku band	15.15–15.35 GHz (Uplink) 14.4-14.83 GHz (Downlink)	200 kbps – 45 Mbps	UCAV control through TCDL
Ka/Ku band	1.55 MHz–24 MHz	6-24 Mbps	GBS Video
Commercial band	1.55 MHz	9.6 kbps 56 kbps 128 kbps 352 kbps 772 kbps	WWMCCS Medical STU III and VTC STU III Imagery

Table 25 Estimated Bandwidth Requirement

Tactical Data Links

Naval tactical command and control is primarily conducted over voice and three data networks; the Joint Planning Network (JPN) that is used for planning, strategic awareness, and command of forces; the Joint Data Network (JDN) used for tactical control of forces and weapons employment; and the Joint Composite Tracking Network (JCTN) that is used for the computer-to-computer tracking of fast moving (air and missile) contacts. Each of these networks is designed to provide a level of situational awareness through the tracking of aircraft, ships, land units, and other objects of interest. The situational awareness picture in the JPN uses overlays to provide commander's intentions and planning in graphical format. The JPN is the primary net the commander uses to transmit intentions and plans.

4. UAV Control & Communications

A key attribute of the proposed CROSSBOW Force is the ability to deploy Unmanned Air Vehicles (UAV) for Surveillances, Air-to-Air Strike and Air-to-Ground Strike. The fundamental command and control functional requirement of UAVs consists of an uplink and downlink channel. The uplink channel must be able to send command and control instructions for the maneuver of the UAVs telling them where to go, what to see or track and whether to fire its ammunition. The downlink channel must be able to

provide the operator with the data gathered by the UAVs, be it image of the EO/IR, SAR sensor or its location, altitude, direction or target track data. Based on the developmental trends, the uplink data rate requirement is expected to be less than or at worse equals the existing 200 kbps rate used by Predator or Global Hawk. The downlink data rate is expected to follow the MPEG 2 compression/transmission standard dictated by the Motion Imagery Standards Profile (MISP) in Joint Technical Architecture (JTA) 4.0. MPEG 2 requires a transmission bandwidth of 6-8 Mbps for full color motion image at 30 frames/second. It can be reduced to about 1.5 to 2 Mbps for gray scale motion image.

The functional requirement identified will require three physical components. A Ground Control Station (GCS) on board Sea Archers that will allow the Commander to command and control the UAVs, a Communication Link that can handle the required data rate and a Transceiver unit for both the Ship and the UAV. Operationally, each Sea Archer will be able to control at least 8 UAVs simultaneously. Control of the UAVs willl be interchangeable among the Sea Archers when required. Information downlink from the UAVs will be accessible to all surface combatants within CROSSBOW and be able to hand over UAV control to land-based GCS for ground support missions.

The command, control and communication of the UAVs carried by the CROSSBOW Forces will fall within the Navy's C4ISR vision of Joint and Naval Warfare laid out in the Navy " Copernicus Concept…Forward". Two of these developments is to integrate UAV operations with the Services joint C4ISR infrastructure, they are the Tactical Control System (TCS) and Tactical Common Data Link (TCDL).

A proposed system architecture using TCS and TCDL for CROSSBOW UAV command and control communication is shown below.

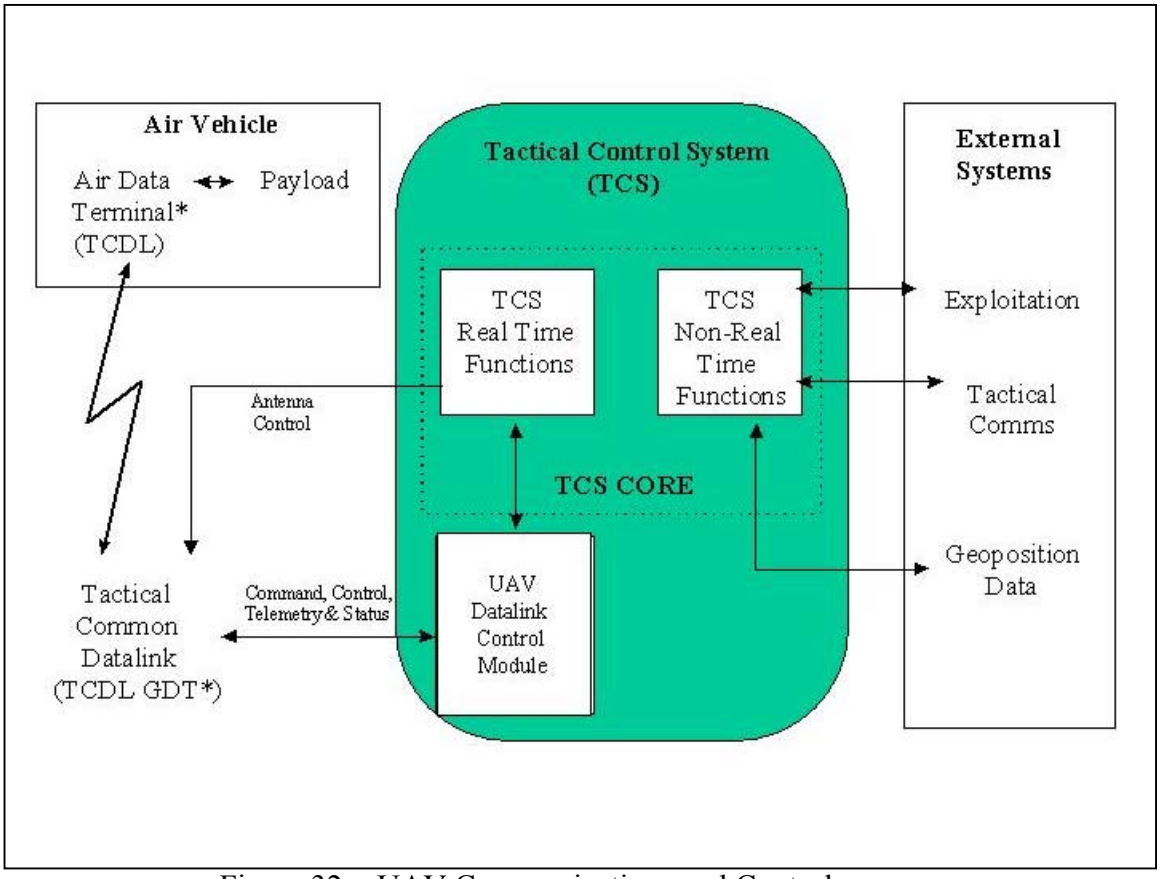


Figure 32 UAV Communications and Control

The number of platforms that the TCDL is able to accommodate will depend on the communication scheme and required data rate. Although the proposed communication scheme is able to accommodate up to 60 UCAVs and 20 ISR UAVs uplink at 200Kbps, 60 UCAVs downlink of 2 Mbps and 20 ISR UAVs downlink of 10.71 Mbps, it must be known that TCDL has to serve other platforms that could exist within the theater operation, like the Hawklink. Hence, the possibility of saturation must be taken seriously. Tactically, UCAVs should be grouped as a single task force wherever possible and cut down on channel requirement.

The communication and control of the UAVs/SEA ARROWs will be through the Multi-Function Apertures that are dispersed across the hull of the ship.

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F. DAMAGE CONTROL

An Automated Damage Control System (ADCS) will assist in SEA ARCHER achieving the requirement for reduced manning. Considering that a large number of personnel is assigned to damage control organizations onboard ships of today, a significant reduction will be permitted by ADCS.

The damage control system, including the chemical, biological and radiation warfare system is described below.

1. Detectors

The available and proposed fire detection systems, smoke detectors, carbon monoxide detectors, fire and flame detectors, CCTV system, heat detectors, smart micro sensors, humidity detectors, and liquid level detectors are analyzed for the best selection for SEA ARCHER.

A ship-wide array of sensors allows continuous monitoring compartment by compartment. Pinpoint detection will indicate the exact location of the damage. Progressive damage or changes in damage will be updated or reported in real time. Controlling actions can be directed to the exact area where required. The speed of the response will be greatly increased by eliminating the need to search for the damage within present detection zones.

Multi-sensor fire detectors will monitor each compartment. Fiber optical, or ionization, or electrostatic smoke detectors, triple wavelength infrared flame, carbon monoxide, closed circuit television, and high performance optical, or fiber optical heat sensors will detect smoke and fires. Monitoring of a fire's progression from the first smoke, through the initiation of the flame, until ultimately the detector is physically damaged, is accomplished, with this detector array. Various alarm thresholds can depict different conditions from the same sensor. Safety of Life at Sea (SOLAS) guidelines were used in determining the type of fire and smoke detectors required in each space.

Compartments located below the damage control deck will also be monitored for flooding by liquid level detectors. Flooding detectors consist of multiple sensors located from bilge level to overhead. Stability information can be calculated by the use of seven

detectors per compartment. The detectors are located to indicate the presence of liquid, at 2 and 6 inches, and monitor flooding at 10%, 25%, 50%, 75%, and 100% of the compartment height.

Important parameters about ship status will be monitored as well. All the remote operated valves and compartment accesses will be monitored for exact material condition present.

Paint lockers and pump rooms will be monitored for explosive gases and lack of oxygen. Sewage spaces will be monitored for hydrogen sulfide gas. Air conditioning and refrigeration rooms will be monitored for refrigerants and low oxygen levels. Other appropriate monitoring will be conducted in spaces subjected to localized hazards.

Immediate notification to control stations will prevent unaware watch standers from entering the compartments.

The type of detectors installed in each type of compartment is shown in Table 26

Compartment	**3IR**	**CCTV**	**HPO**	**FO**	**Smart**	**Humidity**	**Liquid Level**
Machinery spaces	X	X	X	--	X	--	X
Engine enclosures	X	--	X	--	X	--	--
Magazine areas	--	--	--	X	X	X	X
Electronics equipment rooms	X	--	--	X	X	X	--
Hangar	X	X	--	--	X	--	--
Flight deck	--	X	--	--	--	--	--
CIC	X	--	--	X	X	--	--
Bridge	--	--	X	--	X	--	--
Accommodations	--	--	X	--	X	--	--
Kitchens&Galley	--	--	X	--	X	--	--
Offices	--	--	X	--	X	--	--
Passageways	--	--	--	--	X	--	--
Paint lockers	--	--	--	--	X	--	--
Pump rooms	--	--	--	--	X	X	X
A/C&Refrigeration rooms	--	--	--	--	X	X	--

Table 26 Installation of the Detectors Onboard

2. Data Network, Processing Centers, and Evaluation Tools

All sensors will be connected to a data network allowing the various processing centers to access the information. The processing centers in turn pass the information to the control centers for display and decision-making. Multiple interconnected data networks are strategically routed throughout the ship. The redundant networks enhance the survivability of the system. All data networks will carry the same information, providing backup in the event of loss of a network. Each single network is capable of handling the entire system requirements. The recommended data network would be a Thin Ethernet based upon the report "Ethernet Options for the EX-USS Shadwell" by David Tate and Dr. Frederick Williams of the Naval Research Lab. [30]

Multiple distributed processing centers are located throughout the ship, with one center per zone. Each processing center is a hardened PC capable of independently supporting the system. Processing centers send information to the control centers, pass the information to evaluation tools, or initiate action based upon the sensor alarms.

3. Control Station Display and Interface

Control stations will be located at the main watch stations including the Bridge, CIC, Damage Control Lockers, and Engineering Control Center. All control stations will have full control and display capabilities. However, they do not have processing capability and therefore loss of a control station does not affect the system. Watch standers will be able to monitor the alarms and sequence of events that follow. Colorful graphical displays will provide easy-to-understand plots of the damage. This representation allows the control station operators to make faster, better-informed decisions in relation to their areas of control. The watch stander will be able to analyze where in the related compartment the fire is by looking at the display and determining which detector in the compartment alarms. Damage control plotting would be automatically performed from the known sensor information. Actions performed by damage control personnel could be added manually to the display at any control station. On scene personnel would have wireless hand held input/output into the ADCS.

Control stations can allow the system to act automatically or in a manual mode. In the automatic mode all preprogrammed events will be carried out without crewmember

involvement. In manual mode, the system will prompt a watch stander with the suggested action but will wait for the approval before carrying out the action.

4. Isolation System

The first reaction to any reported damage will be to isolate the damaged compartment to control or limit the spread of the damage. Remote closure of main personnel accesses will be controlled through the use of hydraulically and pneumatically operated watertight doors and hatches. Remote watertight actuators and fan settings will control ventilation. By concentrating on these main closures, damage is restricted to the smallest area possible. The ventilation closures may be kept open to facilitate certain procedures. The various arrangements will allow compartment de-smoking or the establishment of a buffer zone.

The automatic watertight doors and hatches will be located on the damage control deck and below. The watertight closures are located primarily for control of flooding. Automatic watertight hatches will prevent the vertical rise of damage, while; hydraulic doors will prevent horizontal damage progression. These automatic closures can be controlled remotely by the ADCS, allowing material condition to be set remotely and quickly. The watertight doors can, in emergency, be forced shut even in flooding situations. Required secondary escape scuttles will be still be available for egress. The scuttles are normally closed, but will be monitored to assess closure. Personnel will be responsible for these closures. The electric power will be rerouted around the fire boundary.

5. Reactive System

The available and proposed fire suppression systems, FM-200, FE-13, NAFS-III, inert gas, carbon dioxide, AFFF, and water mist are considered the best selection for SEA ARCHER.

Active damage control measures will be required to keep the damage contained and from progressing. Fire extinguishing methods include the use of a ship-wide water mist sprinkler system, AFFF flooding, FM 200 system and carbon dioxide flooding.

Independent extinguishing agents, such as carbon dioxide flooding for the paint locker and FM 200 for the electronics equipment compartments will protect specialized spaces. Water mist sprinklers will protect machinery spaces. Combinations of the water mist sprinklers and AFFF sprinklers will be used to combat fuel fires in the machinery spaces and the hangar bay.

The type of fire suppression systems installed in each type of compartment is shown in Table 27

Compartment	**FM 200**	**CO_2**	**Water Mist**	**AFFF**
Machinery spaces	--	--	X	X
Engine enclosures	--	X	--	--
Magazine areas	--	--	--	--
Electronics equipment rooms	X	--	--	--
Hangar	--	--	X	X
Flight deck	--	--	--	X
CIC	X	--	--	--
Bridge	X	--	--	--
Accommodations	X	--	--	--
Kitchens&Galley	X	--	--	--
Offices	X	--	--	--
Passageways	X	--	--	--
Paint lockers	--	X	--	--
Pump rooms	--	X	--	--
A/C&Refrigeration rooms	--	X	--	--

Table 27 Installation of the Fire Suppression Systems Onboard

There will be a safety area on the flight deck where burning aircraft will be extinguished by AFFF system installed on the deck. This burning aircraft will be pushed to that safe area by a Towboat, which is capable of both pushing and extinguishing with a portable AFFF system.

6. Chemical, Biological and Radiation (CBR) System

SEA ARCHER will be capable of performing launching and recovering of the aircraft for all types of CBR contaminated environments.

Long-range detection systems for chemical, biological and radioactive agents will be installed on SEA ARCHER. Also, portable chemical and biological mass spectrometers, joint chemical agent detectors, radiac equipment, and CBR protective clothes will be available at each damage control locker, and hangar bay.

A collective protection system will protect the manned areas against CBR warfare in SEA ARCHER. All aircraft will be decontaminated in the elevators, which are a part of the collective protection system, after recovery. In case of emergency, one elevator will be adequate to operate and decontaminate the contaminated aircraft, although for redundancy purposes two of the elevators will have the capability.

7. Personal Locator Device (PLD)

The ship's crew will be issued a PLD. The PLD is a kind of electronic bracelet, transmitting the identity of the crew. Receivers around the ship will detect the signals from the PLDs, and a data network will be connected to the damage control data network.

There will be three modes of operation of PLD: (1) personal location, (2) personal paging, and (3) emergency notification. From the damage control displays, the location of each person will be monitored. Emergency notification mode will be used by the crewmember him/herself, if he/she is in an emergency situation, to notify the watch stander.[31]

8. Damage Control Party Organization

As a consequence of ADCS, the number of the personnel in a damage control party is reduced to fourteen personnel consisting of one unit locker leader (repair party leader), one scene leader, two investigators, two nozzle men, four hose men, and four boundary men (repair men).

Also, a thirteen men flight deck damage control party, formed by the aircrew, will be ready for the manned flights and for both manned and unmanned flights against a probable damage on the flight deck. This damage control party consists of one unit locker

leader (repair party leader), one scene leader, two nozzle men, four hose men, two rescue men (protection clothed), two divers, and one medic.

9. Damage Control Elements and Scenarios

The habitability deck is chosen as the damage control deck. The ship is divided into three damage control zones. One damage control party is assigned for each damage control zone. Three damage control lockers are placed on the damage control deck.

Fire and smoke boundary settings take two forms: (1) material condition, (2) manned boundaries.

Material condition settings is such that all watertight as well as non-watertight boundaries that require setting as a result of material conditions Y or Z should be fully mechanized such that no personnel are required to open or shut them. The ability to open or shut these closures will be performed by remote control via the damage control displays.

In the event of damage, manned boundaries will be provided in the compartments surrounding the primary damaged area in order to contain the damage to a box, in case of the failure of the ADCS.

The hangar bay will have two fire-resistant curtains. These curtains will be in two parts, each rolled to the tumblehomes of the hangar bay. The bottoms of the curtains will slide on wire tracks.

A probable peacetime fire-fighting scenario is thought to be as follows. The nearest detector to the fire will detect the smoke of the fire. Immediately, the watch stander will be warned by the alarm. He/she can detect where the fire is in that compartment by the location of the detector. The personal locator device network will inform if there is a person in that compartment or nearby. As he/she will be able to see the composition of the combustion products, it will also be possible to determine the fire class. Automated fire suppression, rerouting the electrical power and ventilation, closing or opening the appropriate hatches will be done at the same time via the remote controls. During all of these, the damage control party will be getting ready to take over the fire

fighting. If the detectors in that compartment are damaged, or not working properly, the detectors around that compartment will inform the watch stander that something unusual is happening. Eventually the damage control party will engage the fire.

Another scenario is envisioned for wartime, missile hit situation. The sensors detect the missile, and can determine where it is going to hit. If there are any personnel in or around that compartment, he/she will be warned by both the personal locator assistant and the interior communication system. The automated fire suppression system in the target compartment(s) to be hit will be activated. At the same time, rerouting the electrical power and ventilation, closing or opening the appropriate hatches will be done via the remote controls. As this is a wartime scenario, the damage control parties are already ready for action.

In both scenarios, the electronic devices, on the valuable electrical equipments, will inform about the status of that equipment in the compartment.

10. Crew Egression

Five on each side of the ship, a total of ten, throw over board life rafts with twenty-five personnel capacity, will be installed. The total capacity of the life rafts is 250, being ten percent more than the crew size. They will be evenly distributed and will be inside a shield to reduce their contribution to radar cross section.

Figure 33 A Typical Life Raft for Sea Archer

G. AUXILIARIES

The goal of auxiliary systems selection was to improve reliability and maintainability of fluid, electrical, and mechanical systems, support reduced manning, and reduce ship magnetic signature and vulnerability to mines.

Magnetic Sensors

As an innovation to SEA ARCHER, a magnetic sensor will be placed on an electrical equipment to detect the power consumption to provide information if there is any other failure or whether the equipment is damaged or not.

A network will provide all the information from these magnetic sensors to the damage control and engineering department displays.

Variable Speed Pumps

Another innovation will be variable speed pumps, to reduce the weight, maintenance, and power and to increase efficiency, which allows the use of those pumps at different speeds.

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H. HABITABILITY

1. Accommodations

SEA ARCHER incorporates the latest quality of life standards including the sit-up berth, with the flexibility to accommodate mixed gender as a part of the crew and aviation personnel.

Individual staterooms for the commanding officer, executive officer, and one flag officer on board will be available, with integrated shower and toilet.

Officer staterooms can accommodate two officers. A typical arrangement of an officer stateroom is shown at Figure 34. Three officer toilet and shower compartments, each with three toilets and three showers, will be installed.

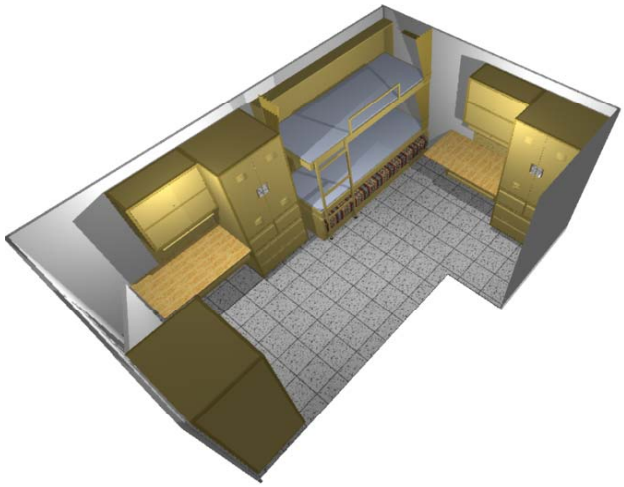

Figure 34 Typical Officer Stateroom Arrangement

A typical CPO stateroom can accommodate six CPOs, which is shown in Figure 35. Three CPO toilet and shower compartments, each containing for three toilets and three showers, will be provided.

The sit-up berth will be used in SEA ARCHER for the ability to sit upright in the bank, and shown in Figure 36. This provides forty percent more stowage space than a classical bank; a writing/reading surface, electrical outlet, shelf for small items and personal fan units are provided. Three sit-up berths in each of the eight enlisted compartments can accommodate a total seventy-two.

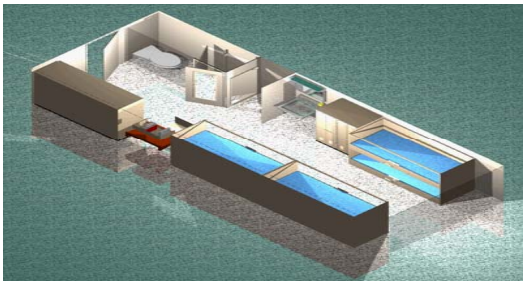

Figure 35 Typical CPO Stateroom Arrangement

Figure 36 Sit-up Berth

Accommodation arrangement including personnel, area and volume is shown in Table 28

Rating	Number of	Per stateroom	# stateroom	Area m^2	Total Area m^2	Volume m^3
CO	1	1	1	15	15	45
XO	1	1	1	10	10	30
Flag Officer	1	1	1	15	15	45
Officer	32	2	16	8	128	384
CPO	30	6	5	15	75	225
Enlisted	72	9	8	12	96	288
Maintenance	9	9	1	12	12	36
Transients	45	15	3	15	45	135
Officer Toilets	3	--	--	6	18	54
CPO Toilets	3	--	--	6	18	54
Officer Showers	3	--	--	6	18	54
CPO Showers	3	--	--	6	18	54
Enlisted&Transient Toilets&Showers	4	--	--	6	24	72
TOTAL	**211**	**--**	**--**	**--**	**408**	**1224**

Table 28 Accommodation Arrangement

Available spaces for other habitability compartments intended for recreation of the personnel are shown in Table 29.

Compartment	Area m^2	Volume m^3
Officers' Wardroom	90	270
CPO Mess	60	180
Enlisted Mess	70	210
Galley	60	180
Gym	30	90
Others (Offices, Work Shops)	200	600
TOTAL	**510**	**1530**

Table 29 Habitability Compartments Other Than Accommodations

2. Food Services

The decision was made to have cook and chill technology, which is an innovation in LPD-17, for food preparation at the initial phase of the cruise or deployment, for

reduced manning. All the food will be prepared in one galley, and the food storages will be near the galley for reduced manning again. On the rest of the cruise, frozen food will be maintained to reduce manning and also the need for storage. Also, biodegradable meal containers will be used for reduced trash onboard.

3. Other Services for Reduced Manning

Shipboard Wide Area Network (SWAN) will be installed onboard the ship. All staterooms will have computers available for the inhabitants. The time for the daily scheduled briefs will be reduced by sending e-mails daily, or when needed.

Utilities like laundry, and ship's store will be self-service to the crew. Coin operated vendoring machines will be available.

The material for the deck will be selected, as mentioned in chapter IV, part A, such that it will demand less waxing. Also, the paints will be long endurance paints, and as the surfaces are not metallic, less paint will be needed.

I. TOTAL SHIP SYSTEM

Figure 37 illustrates the complex nature of ship design. The ship integration and engineering aspect of the SEA ARCHER design involved bringing the individual pieces and subsystems of the ship together to ensure a synergistic relationship among the components. The ship systems are integrated and function to compliment the various missions that must be performed. The integration processes began with developing an understanding of how the ship would function with in the CROSSBOW force and how each mission the ship performs influences specific system requirements. Once the basic system requirements were understood the methods required to effectively construct, maintained, upgraded, and operated SEA ARCHER were determined. Specific areas of consideration included:

1. Ship construction and methodology
2. Operational Supportability to include
    a. Manning,
    b. Logistics and Resupply
    c. Maintenance Support
3. Modularity and Upgradeability
4. Survivability

Each of these areas is addressed below.

To facilitate implementation of the SEA ARCHER concept a ship design philosophy was employed to manage competing priorities. The design philosophy was not intended to substitute or replace sound engineering judgment but instead assist in focusing the integration process to ensure that any differences between competing mission needs were settled in favor of meeting the top level objective of the SEA ARCHER design and the CROSSBOW force. The design philosophy with their relative priority is listed in Table 30

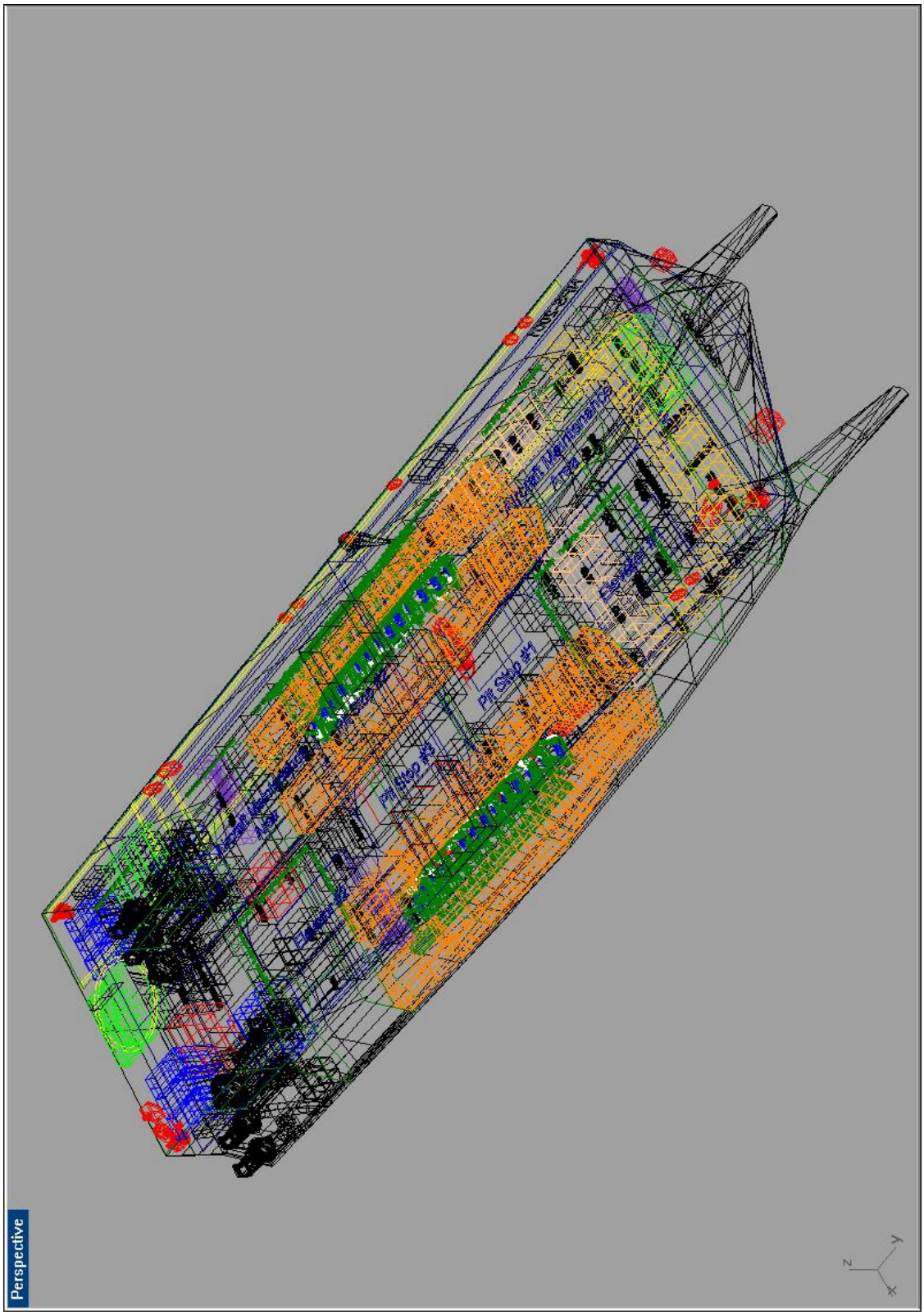

Figure 37 Wireframe View of SEA ARCHER

SHIP DESIGN PHILOSOPHY PRIORITY SET	
SURVIVABILITY	HIGH
AUTOMATION	HIGH
REDUCED MANNING	HIGH
UPGRADEABILITY	MEDIUM
MAINTAINABILITY	MEDIUM
RELIABILITY	MEDIUM
MANUFACTURABILITY	LOW
COMMERCIAL OFF THE SHELF TECHNOLOGY	LOW

Table 30 Ship Design Philosophy Priorities

1. Construction and Methodology

The large beam of SEA ARCHER requires a large dock facility for construction and outfitting. To expedite ship construction a modular building method will be employed. The ship will be built in functional groups and segments that will facilitate local outfitting and testing. The internal bulkhead separation of the ship allows efficient module development for the engineering plant. The engine-room gas turbine layout and cushion air inlet fan duct arrangement are split between both side hulls and are easily segmented into building/construction zones. The AC and DC zonal electrical power distribution system also facilitate this design approach. Each zone built will include standard interface connections for power, ship monitoring system (SWAN), and any other support service required to ensure interoperability with each adjoining zone.

The modular construction zones will be determined based on best practices of commercial industry. Zones will be designed to allow a variety of commercial shipbuilders to participate in construction.

2. Operations Support

The SEA ARCHER interior and exterior designs were developed to maximum operational flexibility while keeping with the priorities of the design principles. The basic profile of the ship was governed by the need to conduct unmanned aerial vehicle flight operations. Figure 38and Figure 39are exterior profile views of the hull. The large flat deck area is the essential component here. Similarly the integrated flight and hangar decks required a large interior volume, which controls the basic profile for the ship.

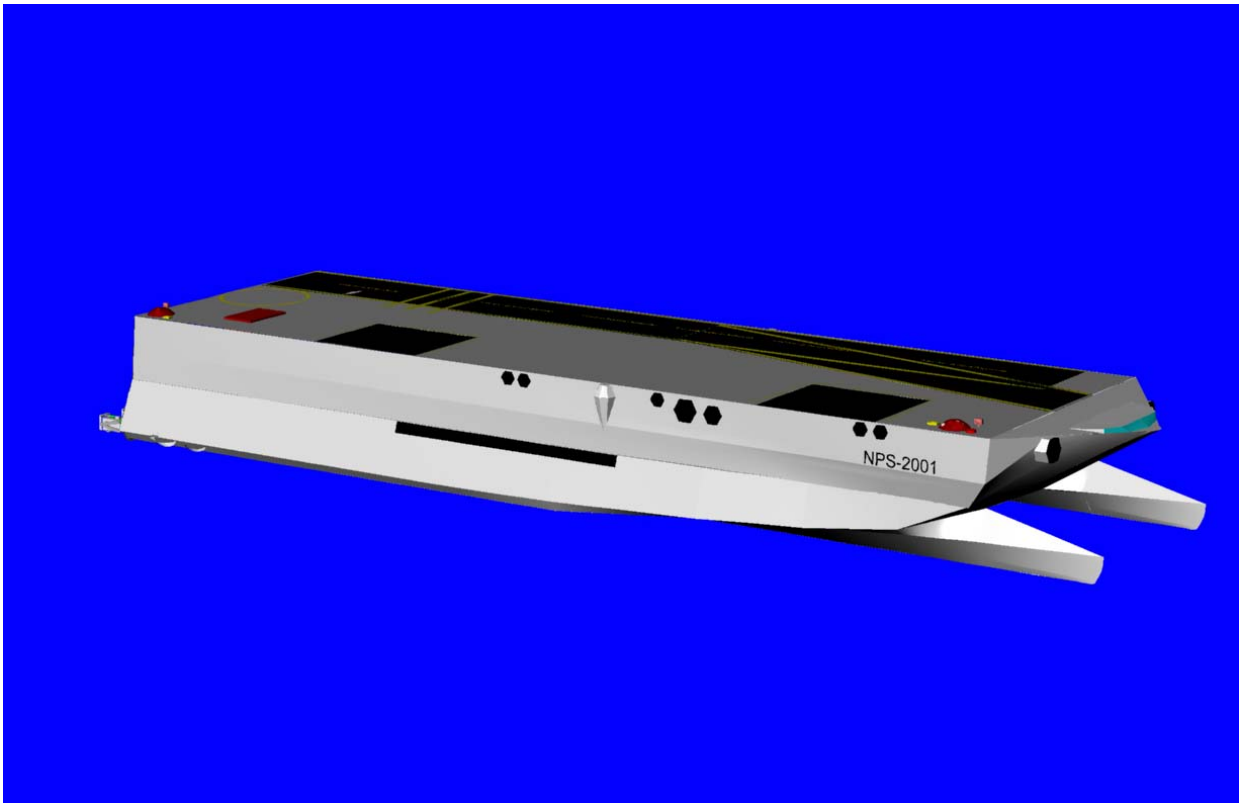

Figure 38 Hull Exterior Profile

The most prominent feature of the ship is the lack of a single integrated mast or superstructure. The mast structure was eliminated through the use of multiple planar arrays, which are discussed in the combat systems section of this report. Additional special communications requirements are supplemented by the use of small dome arrays located in the flight deck region on the starboard side of the bow and stern. The dispersal of the command, control, sensing and communications assets contributes to the reliability and survivability of the ship by preventing a single point of failure.

The lack of a superstructure is a unique feature of the SEA ARCHER design. This feature necessitates performing the ship control, piloting and navigation functions in a different manner. The design includes a bridge/pilothouse located at the bow just forward of the hangar deck and below the flight line. The ship propulsion controls and navigation functions are fully automated and may be performed by two people. Additionally, all functions can be performed either from the bridge/pilothouse or the integrated ships operations center. A closed circuit camera system will be employed to support lookout functions, and to maintain a virtual presence in areas of obstructed visibility.

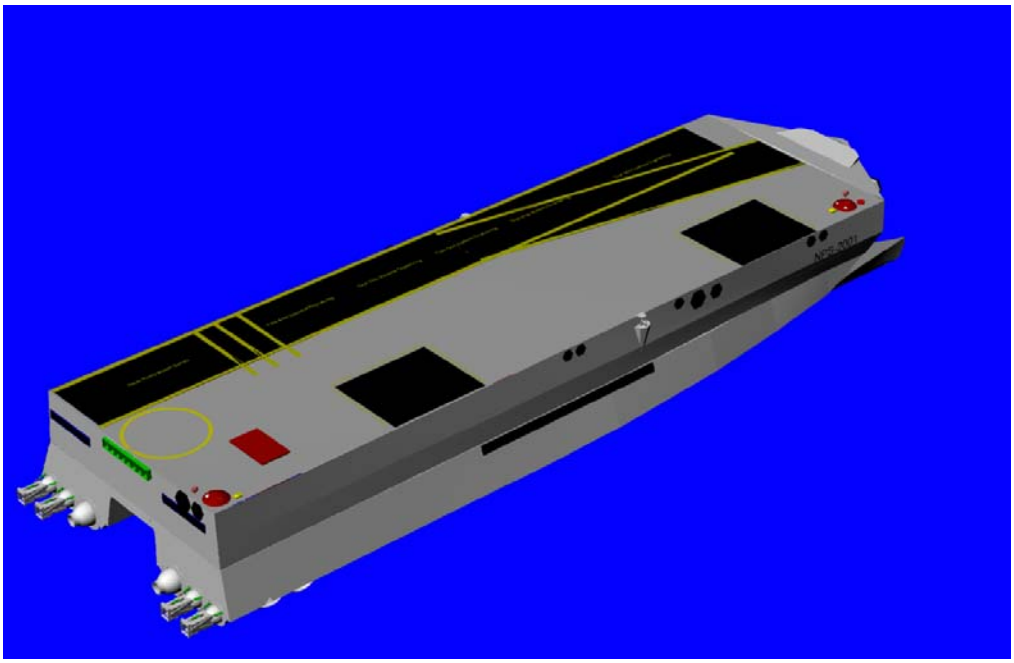

Figure 39 Hull Profile Aft View

3. Arrangements

The SEA ARCHER design incorporates a single deck, which runs the length of the ship, to support mission operations and habitability functions. Similar mission functions are grouped in close proximity to facilitate work flow and operations. Figure 40through Figure 42 show the internal arrangements of SEA ARCHER. Some of the special features in the arrangement plan include:

a. The co-location of ship and aircraft operations spaces. This was done to provide an efficient support for the ships primary mission. The space is located centerline between the side hulls.

b. One galley to support all meal preparation functions. The officer, chief petty officer and enlisted dining facilities are collocated to allow easy meal service. Additionally, all dry food and refrigerated storerooms are located within close proximity to support meal preparations. Storerooms are located along the sides of the hull in areas under the hangar deck that will support ease of restocking.

c. Extensive repair and auxiliary machinery spaces are provided to support onboard maintenance.

d. Multiple damage control spaces, each capable of managing all of the ships damage control resources.

e. Multiple ship control stations. SEA ARCHER may be piloted from either the Ships Combat Operations Center or bridge.

f. Dispersal of vital resources, such as electrical generation, to improve reliability in cases of battle damage.

g. Integrated support for modular replacement of ship systems. The primary combat systems and ship operations stations are located on modular frame construction grid built into the centerline area of the ship. This facilitates rapid and easy reconfiguration and upgrade.

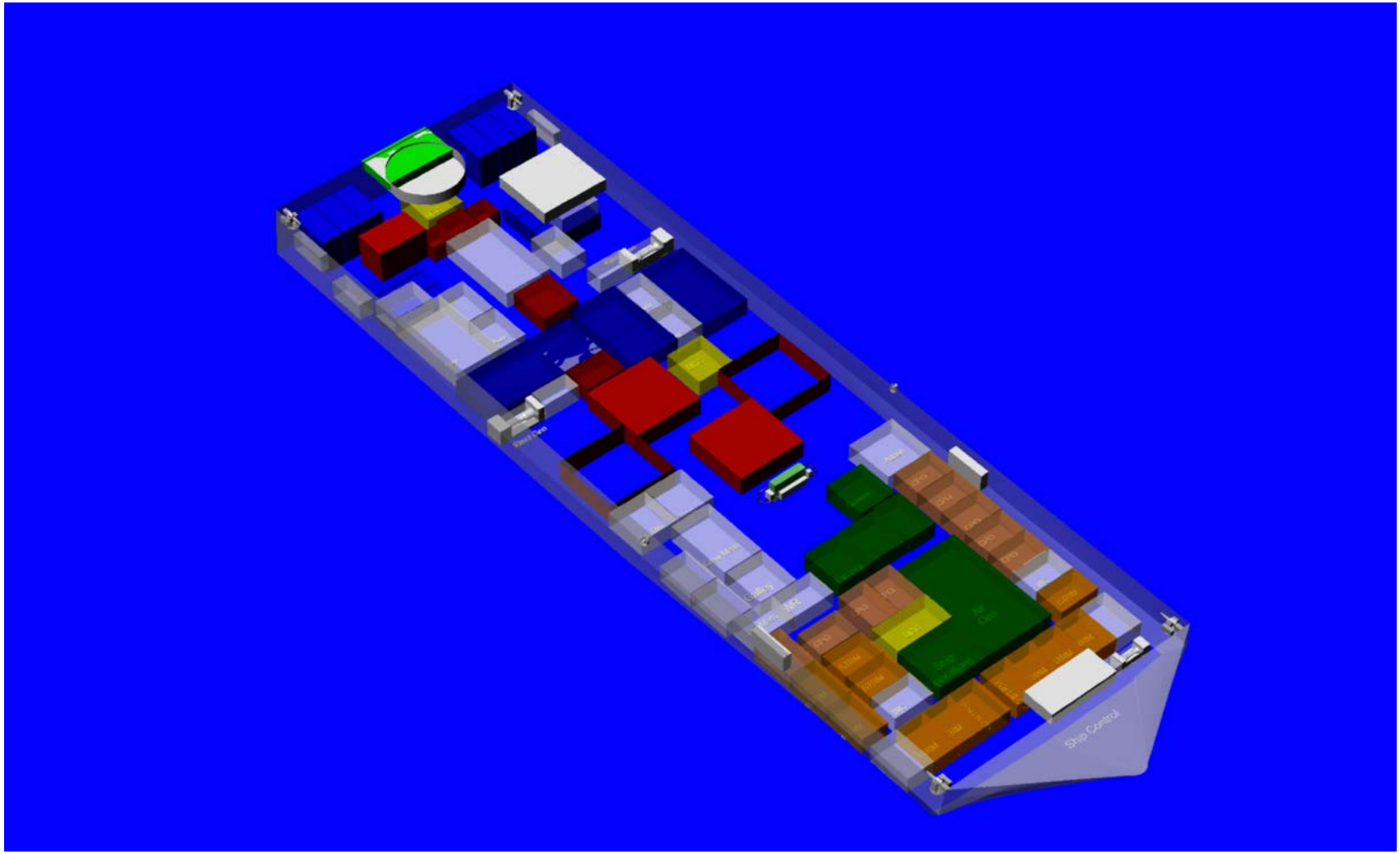

Figure 40 Internal Arrangements

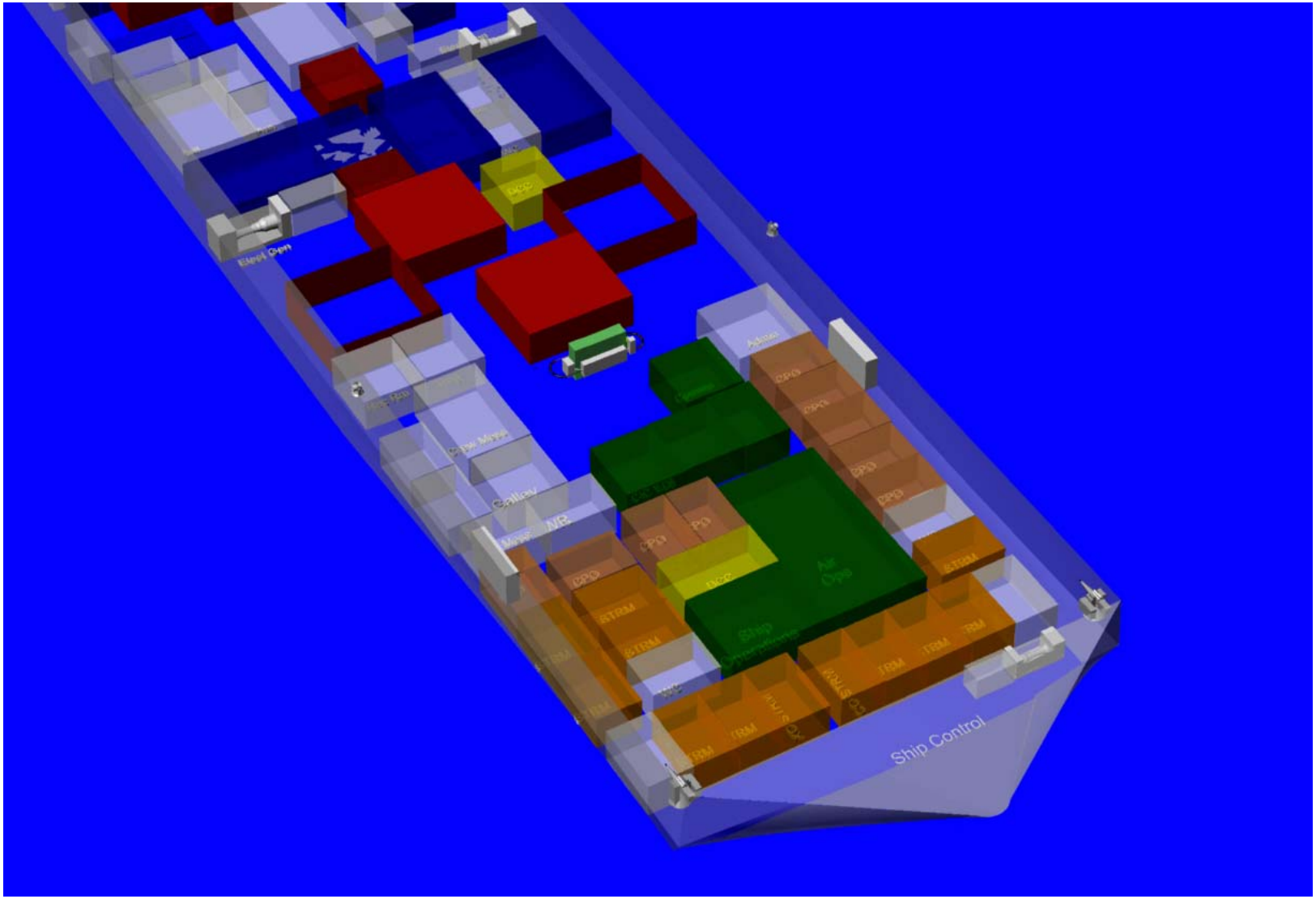

Figure 41 Internal Arrangements - Forward

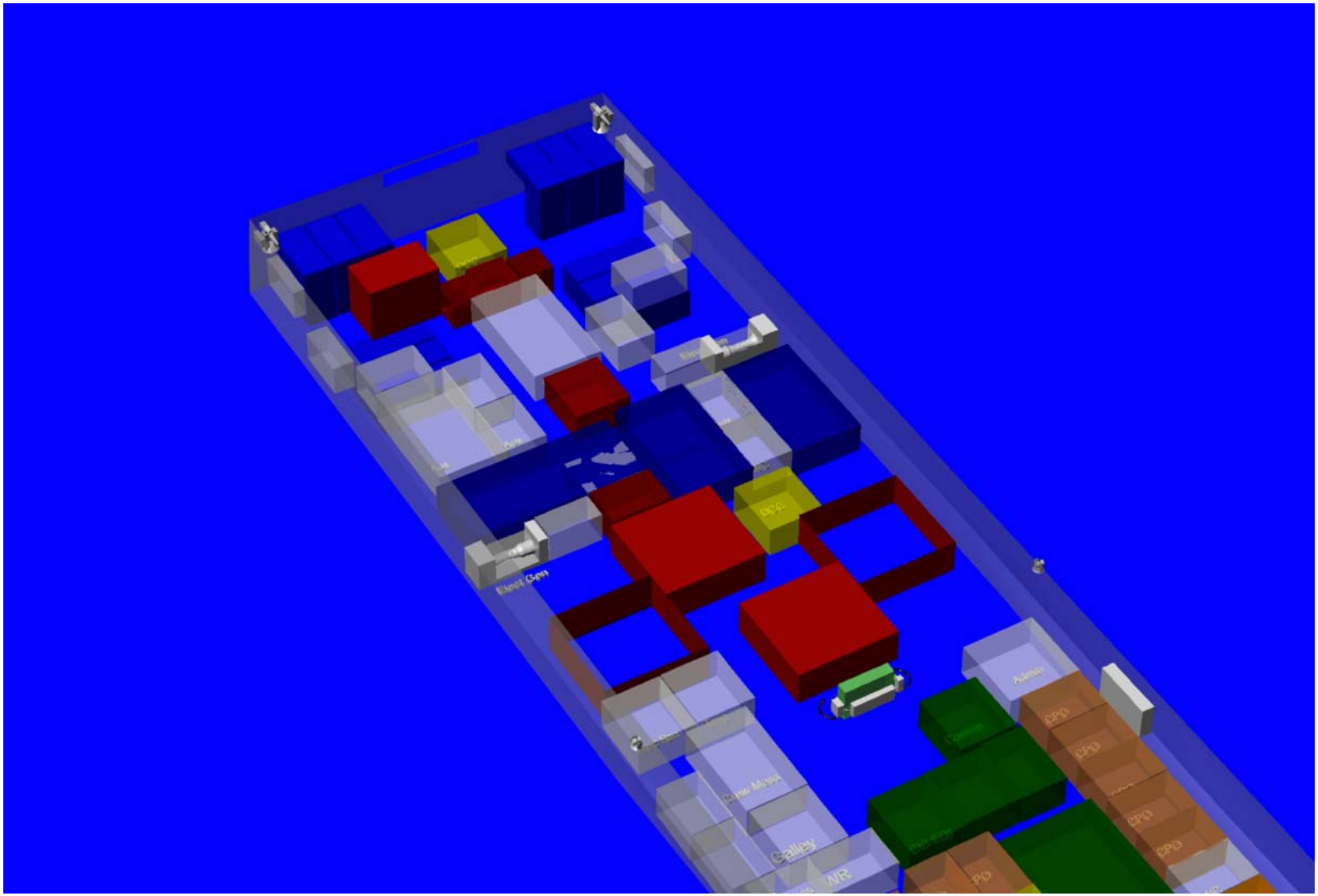

Figure 42 Internal Arrangements - Aft

4. Manning

The manning requirement for SEA ARCHER is 75 for ship's company, 53 for Air Wing. The shipboard total is 128 personnel. SEA ARCHER is manned with 27 officers, 27 Chief Petty Officers, and 74 enlisted. Fifty additional temporary berths are provided for evacuees or for "tiger team" personnel as necessary.

Manning levels were determined primarily based on General Quarters requirements for watch stations and fire fighting parties. To achieve manpower reduction, we began with an assessment of watchstations and determined an appropriate set for SEA ARCHER. We assumed the personnel required for SEA ARCHER would be more highly skilled on average than personnel on a typical navy ship today. A significantly higher number of the personnel would be required to carry on multiple tasks and be able to think on their feet. As such, our manpower profile is more "top heavy" than traditionally observed on U.S. navy combatants. Table 31 and Table 32 reflects the watchteam profiles and manpower assignment considered for SEA ARCHER. A breakdown of how manhours are apportioned is included in chapter V.

To achieve these manpower requirements, each piece of equipment placed onboard the ship must be given careful consideration of its workforce impact. There is no way to achieve these manpower requirements given the standard set of navy equipment in use today. Even some of the simplest pieces of equipment in use today are manpower intensive and must be re-designed with reduced manning at the forefront of consideration.

The CV(X) manpower study presented CVN 76 manning and some assumptions on how much manning could reasonably be reduced for CV(X) [32]. The study detailed weekly manpower estimates for CVN 76 totaling 245,000 manhours for 3,246 billets not including airwing requirements. Assuming technology and automation advances take reduce manpower requirements by 90 percent as in manufacturing plant conversions, then the CVN shipboard manpower requirement of 245,000 manhours per week could be presumed reduced to 24,500 manhours per week for SEA ARCHER. The design assumes that manpower reductions due to technology advances and automation can be applied linearly across all manhours.

With SEA ARCHER, given 75 personnel and presumed 12 hour workdays, the ship achieves 6300 manhours maximum. Tiger teams of 50 personnel for maintenance could be arranged to arrive once a month and work for a period of 7 days. At 12 hours a day of labor, that would bring an additional 4200 manhours per month or equivalent of 1050 manhours per week. This would have to be traded off with the logistics required to support the movement of the tiger teams for one round trip each month and their lodging onboard ship for the week.

With the tiger teams accounted, we amass approximately 7350 manhours per week. Our goal was 24,500 manhours in the best-case scenario. The difference of 17,150 manhours must be accounted for by a reduction in major maintenance requirements and re-categorizing some of what is considered today, routine ships force maintenance, to intermediate or depot level maintenance. To achieve the manning specified, manhour requirements for ships force would need to be reduced by 97 percent over a current CVN.

SEA ARCHER's manning was determined to be 128. However, further research would need to be conducted in order to refine and validate the number of shipboard personnel required to operate and maintain the ship. To achieve our manning objectives, we required that non-essential functions currently performed by shipboard personnel such as program overhead and collateral assignments be shifted to shore support facilities. Some of the assumptions, for automation, may not come to fruition due the fact that automated equipment itself requires some maintenance. Additional maintenance personnel have been included to account for automation, however further research would be needed to refine and validate the number.

SHIP Operations									
	Bridge		Ops		Engineer		Service		
Watch	OOD	1	TAO	1	EOOW	1	Galley (WC)	1	
	JOOD/Driver	0	CICWO	0	Mn Plant Rover	2	Galley	2	
	NAV	1	Air Control	0	Aux Sys Rover	2			
	BMOW	0	Air	1	Eng Plant Ctr	1			
	F L/O	0	Surf/Guns	1					
	A L/O	1	Subsurf	0					
			EW	1					
			Mine CM	0					
			Deck Ops	1					
Support	CO	1	Intel/OPS su	1	Aux/DC Sys	2	SUPP	1	
	XO	1	ET/EW	1	Electrical	2	SUPP	2	
			Comms	1	ET/IT	2	ADMIN	2	
							Laundry/FS Su	1	
					GSM	3	Med	1	
	helm	0							
			Deck						
Watch Section		3		5		6		3	17
Watch Total		9		15		18		9	
Maint/Support		2		3		9		7	
Maint/Support Total	1 Section	2	2 Section	6	1 Section	9	1 Section	7	Ship
									Sub-total
Sub Total		11		21		27		16	75

Table 31 Ships Manning Matrix

AIR Operations										
		Ops		Maintenance		Logisitics		Helo		
		FLT DK CTRL	1							
		HGR DK CTRL	1							
		A/C Handler	2							
		FLT OPS	5							
Air Boss	1	Ops O	1	Maint O	1	SUPP O	0	Pilots	5	
Air XO	0	Ops CPO	1	Maint CPO	1	Supp CPO	1	Air Crew	3	
Admin	1	OPS Support	1	Air Mech	2	Supp Clerk	1	Maint	10	
				Air ET	2	AV QA	1			
	0		9		0		0		0	9
	0	2 Section	18	2 Section	0	2 Section	0		0	Air Sub-total
	2		3		6		3		18	
1 Section	2	2 Section	6	1 Section	6	1 Section	3		18	
	2		24		6		3		18	53

Table 32 Aviation Manning Matrix

5. Logistics and Maintenance

The operational requirements document for the CROSSBOW system stated the minimum sustainment capability for SEA ARCHER. The SEA ARCHER design includes provisions as listed in Table 33

Provisions Capacity	
Dry Food Stores	90 days
Ship Ordnance	30 Days
Aviation Ordnance	7 Days
Fuel	4500 mT

Table 33 Provisions Capacity

Provisions for refueling at sea are incorporated in the SEA ARCHER design. Four refueling at sea stations, two port and two starboard, are provided. Each station is capable of transferring fuel to or from the ship. The stations are located on the hangar deck level aft of the aircraft maintenance area and aft of the aircraft elevators. The forward stations are located in the frame bay/hull deck support area and are positioned to prevent interference with aircraft operations within the hangar bay.

Dry stores and ammunition will be provided by vertical replenishment methods. To support the minimal manning requirements of the SEA ARCHER platform, all stores and supplies are provided in palletized or containerized form. Modern commercial practice for warehouse management and inventory control, which include barcode and automated scanner technology, will be employed. This will allow automation of supply provision procurement and management. Storerooms are located with in the ship to support direct restocking from areas on the hangar deck.

Minimum manning for this ship required a new maintenance approach. The SEA ARCHER platform draws upon commercial maritime experience in determining the type of maintenance required and the mix of personnel required to perform the maintenance.

The ships basic manning includes personnel, whose full time duties, and primary function is to maintain the ship. Maintenance man-hour reductions will be essential to achieve the manning reductions for SEA ARCHER. To support this, system reliability and supportability will be included from initial component selection.

Ships force personnel will be expected to perform operational level maintenance only. This capability will be limited to functional unit fault isolation and swap out repair. Although the ship has significant repair capability included on the hangar deck and operations deck level, the requirement for major maintenance to be performed by ships force has been eliminated. "Tiger teams" of 50 personnel, which will come aboard at least every 30 days. They will provide any maintenance beyond the operational level. These additional support personnel will be provided from the carrier battle group, a shore based intermediate maintenance activity, or a dedicated support vessel such as the notional SEA QUIVER in the CROSSBOW concept. Sufficient berthing and habitability provisions have been include for these personnel in the SEA ARCHER design.

6. Modularity/Upgradeability

Modularity and the ability to rapidly upgrade and reconfigure the SEA ARCHER system have been design into the platform. Modularity begins with the hull construction, where the hull section will be built in integrated modules. This modular concept is extended to provide a means to upgrade and improve the ship over its operational lifetime. Centerline sections along the ship, in between the side hulls, are provided with modular power, data and auxiliary service interfaces. These interfaces are built in a standard configuration to allow rapid replacement of operations compartment systems. This will allow development and testing of new complete systems prior to insertion in the ship.

Significant use has been made of commercial off the shelf technology and open systems architecture. Commercial "best practices" and industry standards are employed whenever possible to allow systems to capitalize on new technology as they emerge.

The large internal volume of the ship provides significant growth potential for other mission and ship systems.

7. Survivability

The SEA ARCHER design team assigned survivability as the highest priority. To support this objective some survivability features built into the ship include:

a. Reduced radar cross-section. The ship employs signature suppression and geometric based radar cross-section reduction techniques.

b. Infrared signature suppression methods. Hot discharge gases from the ships 7 gas turbine engines are discharged in between the side hulls and cooled with sea spray. This reduction in hot gas temperature also provides the added advantage of reducing hot gas impingement on the composite hull.

c. Redundant and fully functional ship systems. Specifically the damage control stations and the ship control stations.

d. Combat survivability is enhanced by locating vital spaces between the side hulls and away for the exterior of the ship.

e. Distributed communications, sensors, and command and control capabilities. This is accomplished by removing the single point of failure of a mast structure.

f. High damage stability of the hull form

g. Propulsive plant reliability and redundancy.

The SEA ARCHER design allows the graceful degradation of ships capabilities through survivability and system redundancy. The systems integration has attempted to prevent a single point failure from causing a "mission kill" in any area. Every major functional system has been designed with at least one contingency mode of operation.

8. Cost Estimation

In estimating SEA ARCHER's acquisition cost, we produced a weight scaled model similar to that employed in the S-CVX study [33]. The resulting model incorporates the non-traditional weight fractions, the high cost for materials not commonly associated with large ship construction, and the cost for highly specialized equipment required to meet SEA ARCHER's mission. Cost estimates for SEA ARCHER's specialized equipment included in the cost model are summarized in Chapter V.

The lead ship cost for SEA ARCHER is estimated at $1.41 billion and its accompanying airwing cost is $388.4 million. When equivalent weight only cost models for current warships designs are utilized, SEA ARCHER's cost is $1 billion. In our opinion, the weight only cost estimate is low based on the specialized materials and non-standard weight fractions inherent to the SEA ARCHER design. Cost was driven by several factors including hull material selection, combat systems, command and control systems and automation. For this iteration of our design cost minimization was given the lowest priority to allow maximum exploration of potential new technologies.

SEA ARCHER contains some innovations precluding a simple comparison to current ships whose primary mission is aviation operations. First, in an effort to reduce manning, automation was included in the design wherever feasible. A significant effort was given to automation of the aircraft handling, weapons handling and damage control functions of the ship. These are traditionally manpower intensive operations. Automation cost includes the hardware necessary such as robotic arms, conveyers, elevators and the software needed to orchestrate the operation. In our cost estimate, the cost of such software was estimated to be 75 percent as much as the cost of the hardware. In reality, that number can vary. For simple systems, generally the hardware is significantly more expensive than the software operating it. For example, a robotic arm serving one particular function in the auto industry may cost $250,000 and have a control program which cost the owner $50,000 in Intellectual Property (IP) services provided by programmers. However, for more complex systems, i.e. those requiring complex decision matrices such as in our automated Damage Control System, the number can

easily be twice and three times the cost of the hardware. The SEA ARCHER system is intended to have a lot of autonomous functions. With respect to overall automation costs, our estimate takes the conservative lower middle ground based on the idea that once such software is developed, its use can be replicated such that the impact on a single ship would average to the lower end.

SEA ARCHER's combat system and weapons suite were compared to that employed in Arleigh Burke class ships. As seen in the weapons/sensors section of this report, some of SEA ARCHER's sensor and weapons systems include high-end equipment including a volume search radar, multi-function radar, electronic warfate suite, infra-red search and track, electro-optical system, chain gun/chaff launcher, free-electron laser, and a 16 cell vertical launch system with quad missile bays among others. Though these systems do not give our ship the same capability as a Burke in terms of mission profile, they do carry the same relative cost for the capability required. The combat systems and weapon suite also have secondary cost impacts on the SEA ARCHER system. The sensing and free-electron laser systems require a significant amount of electricity. This energy demand forced a requirement of more power generation and hence higher electric plant cost.

The single biggest cost-driving factor in our design was speed. Speed drove a number of design elements from hull selection to propulsion system. The high-speed objective required a non-conventional hull form and material selection that resulted in the added cost of carbon fiber for weight reduction. Our cost estimate includes $100 million addition for carbon fiber construction. Although some commercial industry sources suggest this was twice the current cost, we assess the military unique requirement, to include an armor plating (Kevlar), and a thermal boundary layer, as major cost additions. The carbon fiber material costs are potentially as expensive as $10 per pound. This yields a total raw material cost of just over $62 million. The blowers required for the air cavity added to the ship's weight, and electrical burden. Overall, the hull brought direct costs of its form and material as well as the cost of required blowers. Selection of a high technology engine and propulsor combination brought an estimated $140 million for material alone, based on manufacturers cost data.

The true cost of speed was not fully studied in our design process. However, there are some observations worth noting. First, as mentioned previously, speed drove hull form selection, propulsion, additional equipment, and indirectly electrical plant selection among others. The consolidation of such modifications compared to a weight scaled version of cost presented by the S-CVX study suggests that $400 million was added to the ship design to meet speed requirements. That is roughly estimated based on the additional cost presented by the hull form, propulsion system, air cushion blowers, and a scaled amount for the electric plant and fuel.

Though a complete life-cycle cost assessment was not conducted as part of this design process, we would speculate that in a squadron's entire life, all the automation systems could be fully replaced roughly 7 times before reaching the manning cost of a CVN(X). In that sense, over the life of the ship, the automation equipment more than compensates its added cost.

Although SEA ARCHER squadrons are not intended as a direct replacement for CVN(X) and do not provide the same firepower or power projection, the mission types are relatively comparable and provide a viable alternative to consider for cost analysis and comparison. SEA ARCHER squadron, air assets can easily be apportioned to meet the needs of a given situation. With CVN(X), these assets are an all or nothing provision. With CVN(X), if a smaller crisis should break out, a decision must be made whether it is significant enough to commit the assets of CVN(X) entirely and whether the such risk is worthwhile. The same argument is presented in terms of force level survivability. The loss of a CVN(X) results in the loss of its entire air assets whereas with a SEA ARCHER squadron, the loss of one SEA ARCHER removes only $1/8^{th}$ of its air assets. Thus, there is less assumed risk in sending the necessary level of force to meet a given situation.

V. ANALYSIS AND TRADE STUDIES

A. HULL

1. Hull Type Selection

Hull-Type Candidates

The SEA ARCHER Mission Needs Statement and Operational Scenarios illustrate the requirements for high-speed transport in the littorals, with above the average seakeeping abilities. The very high maximum speed requirement of 60 knots by itself it was a major challenge since there are no existing ships of a considerable size that reach more than 40 or 45 knots. This fact along with the non-existence of a tool that could provide, with some level of accuracy, power requirements from first principles required the design team to base the calculations on geometric and dynamic similarity while extrapolating existing data. This is known to be a high-risk approach but it was considered to be the only option for the amount of time that the design team had available.

The design team considered as candidates all the hull forms for which a reasonable amount of engineering data was available. A basic characterization of the hull form candidates based on their means of support can be seen in Figure 43

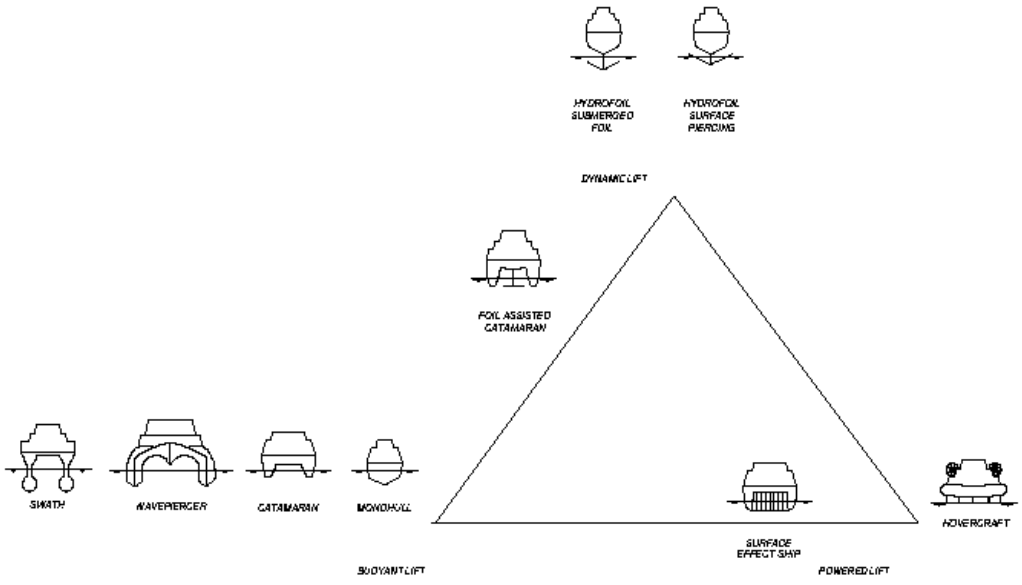

Figure 43 Hull Form Candidates Characterization Based on Means of Support

Given the data that were available in the naval engineering and maritime community the design team soon realized that some hull forms could not be considered because of the very high power requirement. A generic power versus speed curve for the basic hull forms can be seen in Figure 44.

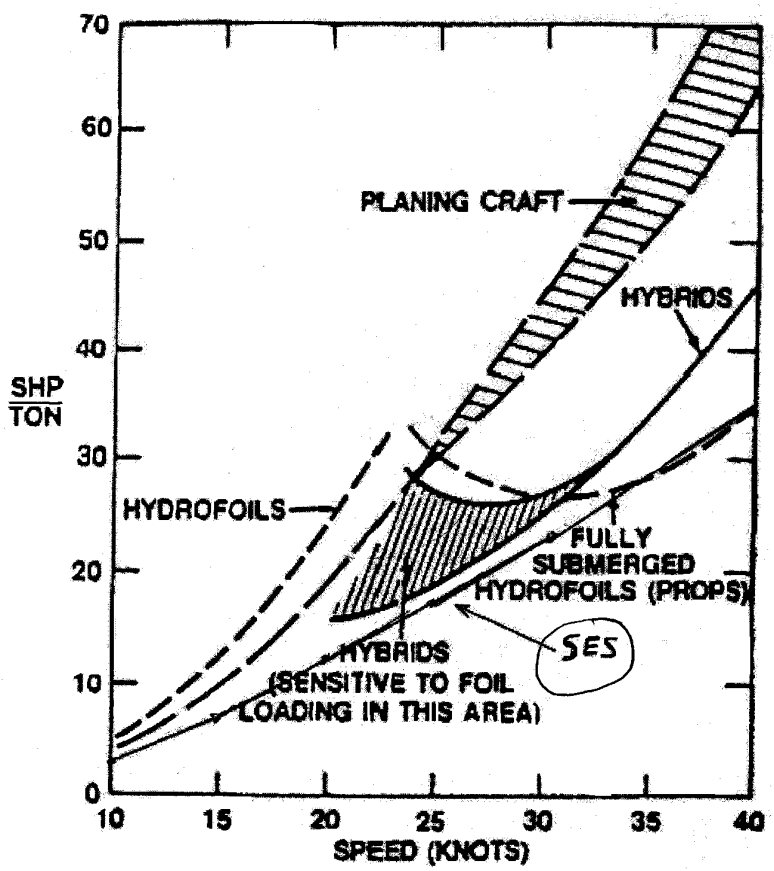

Figure 44 Generic Power versus Speed Curve

For this reason Monohulls and Planing Monohulls (although some supporters of the Planing Craft will argue) were not considered to be viable options since the demand in power was found to be extremely high for the SEA ARCHER speed. SLICE and SWATH (small water plane area hulls) were considered for their very good seakeeping characteristics but they were ruled out by the design team because of their poor ability to operate in the littorals as a consequence of their relatively deep draft. Hydrofoils were considered for their low resistance characteristics at high speeds but the design team soon ruled them out because of their very low efficiency when

operating in the mid-speed range. The SES (Surface Effect Ships) were considered for their low overall resistance but there was a concern because of the decay in their seakeeping performance in moderate sea state as can be seen in Figure 45.

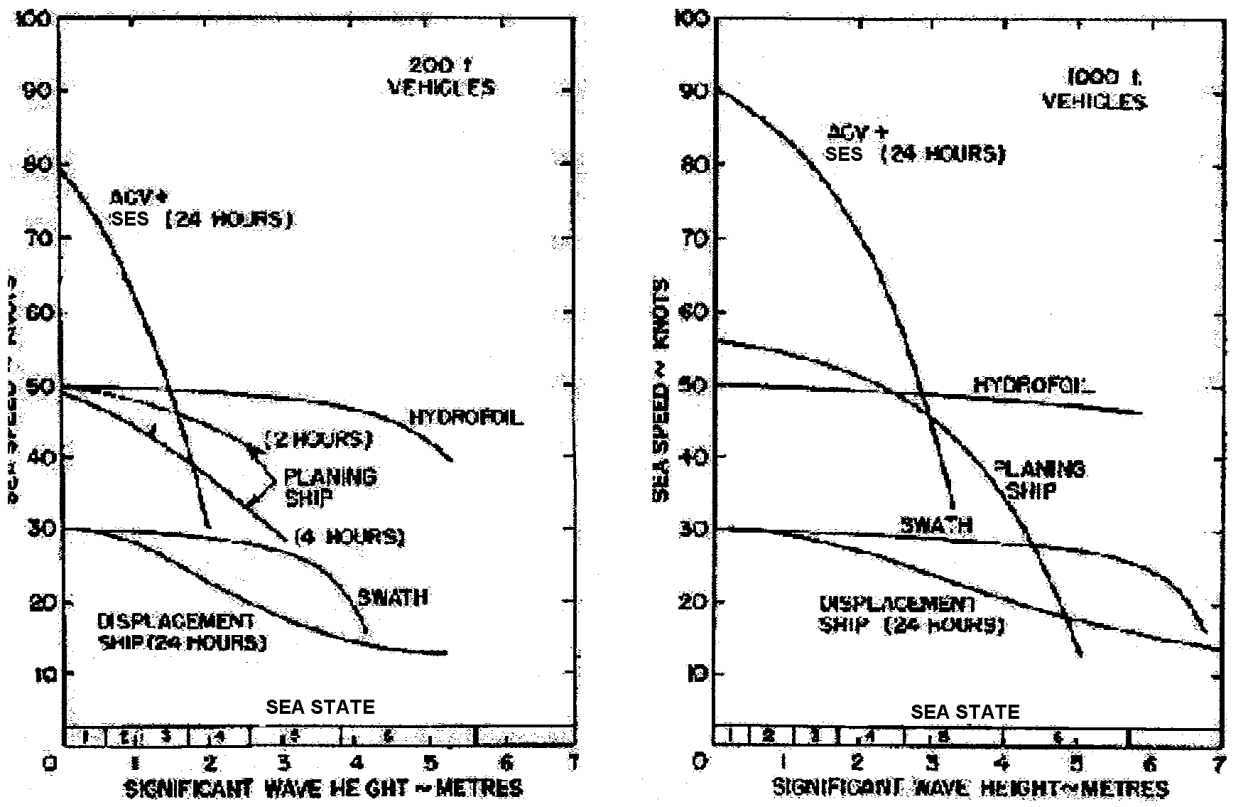

Figure 45 Speed Degradation with Sea State for Various Hullforms.

Promising candidates for the SEA ARCHER hull were considered to be the Wave Piercing Catamarans and the Trimarans. For the former a lot of existing data were available and ships are operating successfully at speeds between 40 and 45 knots. INCAT from Australia kindly provided the design team with additional data as well as with some design concepts of larger and faster vessels. Recently, the U.S. Navy contracted for tests for seaway performance and power requirements with an INCAT design vessel. From those tests and the data collected a power curve for Wave Piercing Catamarans was created. For the Trimaran on the other hand not a lot of data were available for high-speed vessels. Recently the Royal British Navy has shown interest in building future ships with Trimaran hulls. A test ship was built and is still in testing. Data was

collected from different existing Trimarans and concept designs to create a power curve for Trimarans.

Another candidate considered was the Pentamaran, designed by Nigel Gee and Associates Ltd. This hull-type consists of a very slender monohull with four struts on the sides, two forward and two aft. The very slender hull has a high length to beam ratio that makes the vessel operate in high speeds with low resistance.

The candidates that were chosen to be considered for further analysis were the Wave Piercing Catamaran, Trimaran, SES and the Pentamaran.

Further Narrowing of the Possible Candidates - AOA

As next step in the selection of SEA ARCHER hull form the resistance of each candidate was found for different speeds. Data were collected from existing ships and designed concepts. Where model test data were available the resistance was calculated based on standard model theory. The calculations and the data were then compared and validated. Finally, power curves were created for comparison. In the power curves, the volumetric Froude number was used as the basis for comparison since the design team considered it to permit comparison among different kinds of multihulls.

The main tool used in this phase of the hull selection was a series of spreadsheets created by the Maritime Applied Physics Corporation from Maryland. This tool was created for the Massachusetts Institute of Technology (MIT) as a “first cut” tool for different hullforms evaluation. This tool was intended for relatively small vessels with speeds up to 40 knots. This tool allows the comparison of Hydrofoils, HYSESs, SWATHs, SESs, Planing Monohulls, Catamarans, and Trimarans. The design team found the tool useful but there were a lot of limitations because of SEA ARCHER’s high speed and considerable payload requirements. To overcome this difficulty the design team modified the spreadsheets so that reasonable results could be generated. Validation of the results was made against existing and concept designs with very good level of accuracy (less than 10% error).

In the AOA phase of the design, sensitivity studies were conducted so that further narrowing down of the possible candidates could be made. The design team was able to relate

ship size to payload, range and speed. Graphs were created by keeping constant either the speed or the range, using all the hullform candidates. From those graphs the design team determined the best possible candidate between the Wave Piercing Catamarans, Trimaran, SES and Pentamarans. A sample of these graphs can be seen in Figure 46. In this figure the speed and range were kept constant (50 knots and 4500 nm) while the payload was varied. It can easily be seen that the Pentamaran gives the least displacement. Similarly the rest of the graphs created show the same result. From the above, the design team considered the Pentamaran as the best candidate at that stage.

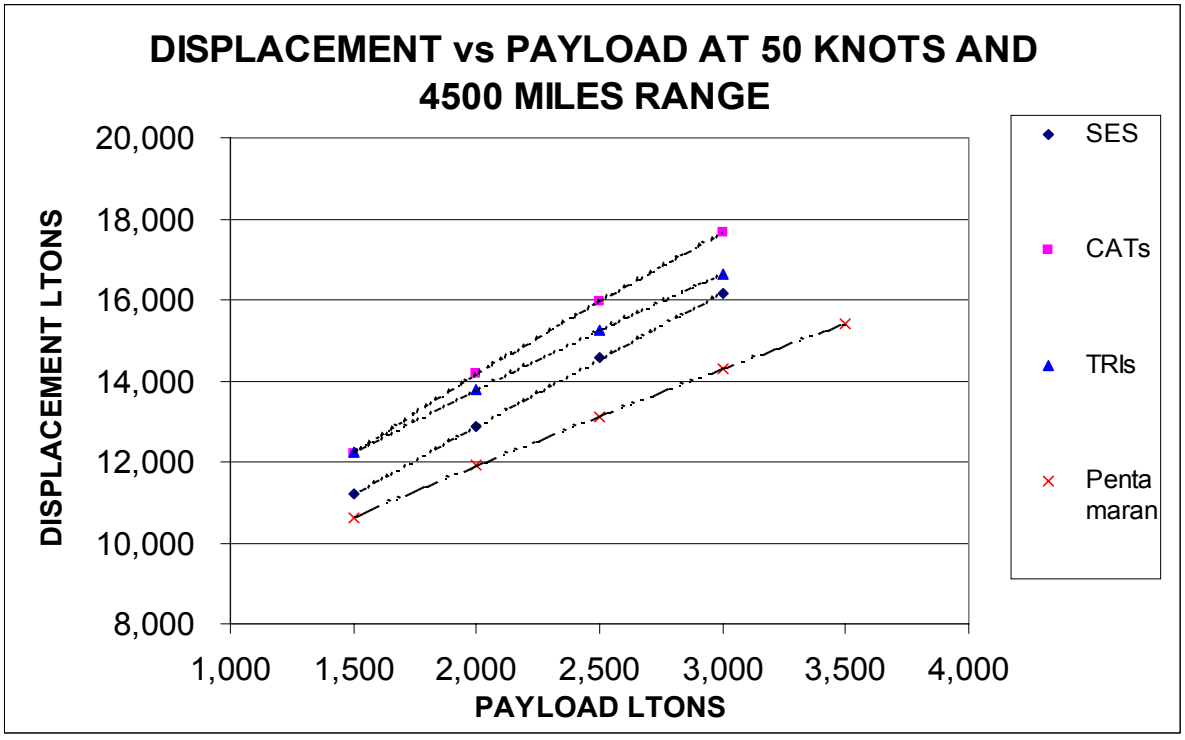

Figure 46 Displacement vs. Payload Graph Comparing SES, Catamaran, Trimaran and Pentamaran.

Payload Considerations

Before any additional progress could be made, the design team had to concentrate on finding SEA ARCHER's payload. The team decision on the payload was based on the ORD and the additional Operational Scenarios that were given at the beginning of the second design

quarter. In the Analysis of Alternatives phase the design team defined the payload as can be seen in Table 34 (only the one squadron version is shown here).

Sea Archer AOA Study Results

	1 Sqd w/Sea Arrow	1 Sqd w/JSF	1 Sqd w/o Sea Quiver
Sea Archer Payload			
Airwing			
Sea Arrow (LT)	30		30.4
JSF (LT)		85.7	
UAV's (LT)	16	15.6	15.6
MAS (LT)	0	0.0	0.0
Helicopters (LT)	21	20.5	20.5
Airwing Ordnance (LT)	169	1180.0	156.1
Airwing Fuel (LT)	653	1527.5	652.5
Aircraft Landing and Recovery (LT)	227		
Automatic Aircraft Handling	15		
Ship's Weapons Systems (LT)	379	378.6	378.6
Added Electic Load	600		
Logistics			
Stores (LT)	0	0.0	0.0
Airwing Parts (LT)	5	6.5	19.4
Ship Parts (LT)	350	350.0	700.0
TOTAL	**2464**	**3565**	**1973**

Table 34 AOA Payload Summary

The six different alternatives were given by the faculty requirements setters and were not a product of a design process by the team. As can be seen from Figure 46 in all the three different alternatives the Pentamaran gave the least displacement. In Table 35 the size of the SEA ARCHER Pentamaran hull can be seen for the six different alternatives under consideration. The spreadsheet outputs of the calculation tool used for the AOA can be found in Appendix A.

Operational Scenarios given after the Analysis of Alternatives changed the payload requirements considerably. The requirement for transit was decoupled from the maximum speed and there was the additional requirement for SEA LANCE refueling. Because of the way that our

tool understands payload and range we had to define as payload, despite the traditional Navy definition, additional weights such as fuel for SEA LANCE, additional engine weight to achieve 60 knots in addition to the 50 knot range speed, and the requirement for 20% remaining fuel.

	1 Squadron			2 Squadron		
	w/Sea Arrow	w/JSF	w/o Sea Quiver	w/Sea Arrow	w/JSF	w/o Sea Quiver
Hull Type	Pentamaran			Pentamaran		
Length (m)	160	180	163	175	206	186
Beam (m)	18	21	19	22	26	23
Breadth (m)	39	44	40	44	52	47
Draft (m)	7	8	7	8	9	8
Depth (m)	13	16	14	15	18	16
Displacement (T)	**10500**	**15100**	**11100**	**13600**	**22100**	**14500**

Table 35 AOA Hull Dimensions Results

New SEA LANCE Concept

The team, after reviewing the SEA LANCE refueling requirement, as described in the Operational Scenarios, decided that it was going to be a major driver for the SEA ARCHER size and cost. So after discussion with the faculty a new notional SEA LANCE Concept was created based on the same hull form as the SEA ARCHER. The team had to calculate a ship with the same speed requirements as the SEA ARCHER but with the payload of the SEA LANCE and with a range of 2000 nm. After a quick design procedure the new characteristics of the SEA LANCE were created and can be seen Table 36.

Speed (knots)	50
Displacement (MT)	1030
Range (nm)	2000
Fuel (MT)	197

Table 36 New SEA LANCE Concept Characteristics

The new payload requirements for SEA ARCHER can be seen Table 37. Two different missions were considered, the *transit* and the *operations*, both of them with the new SEA LANCE fuel requirement. Also a 10% margin would be included in the final calculations for design and growth.

	MISSION 1: TRANSIT	***MISSION 2: OPERATIONS***
Sea Lance Refueling (MT)	315	631
Remaining Fuel (20%) (MT)	419	419
Additional Weight for 60 knots (MT)	57	35
Fuel Required for 7 days operations (MT)		1537
***Total Additional Payload** (MT)*	**793**	**521**
Fuel Required for the 50 Knot Transit (MT)		2099
Initial Payload (MT)	2558	2558
***TOTAL (no margin)** (MT)*	**3351**	**3081**

Table 37 Final Payload for SEA ARCHER Design.

Final Hull Selection and Calculations

At the end of the AOA phase new data for two similar hullforms, were found by the design team, which caused the team to consider them as very promising candidates. A Harley SES hull-type, which is based on technology patented by Vibtech, Inc. of Rhode Island, became a candidate. The hull is a Wave Piercing Catamaran; however it differs from a catamaran in that there are air cavities built into the underside of each sidehull. Blower pressurized air is supplied to the cavities to form an air cushion, similar to a surface effect ship, which supports about 80% of the vessel weight. As in the SES case this results in a decrease in draft and a reduction of the wetted area resistance. There is another air-cushion catamaran hull-type, similar to the Harley SES with some modifications in the sidehull shape that was designed by Air Ride Craft Inc. of Miami Florida and referred to as Air Cushioned Catamaran (ACC). The performance of this vessel is similar to Harley SES and since more structural information was accessible for the Harley SES it was chosen over the ACC.

Initially the ACC was considered and was compared with the Pentamaran, which was the preferred choice after the AOA. Similarly with the sensitivity study contacted in the AOA phase, graphs were created to show the size of the vessel as we increased the payload and kept everything else constant. Two of these graphs created can be seen in Figure 47 and in Figure 48. In those figures the range and the speed were kept constant while the payload was increasing.

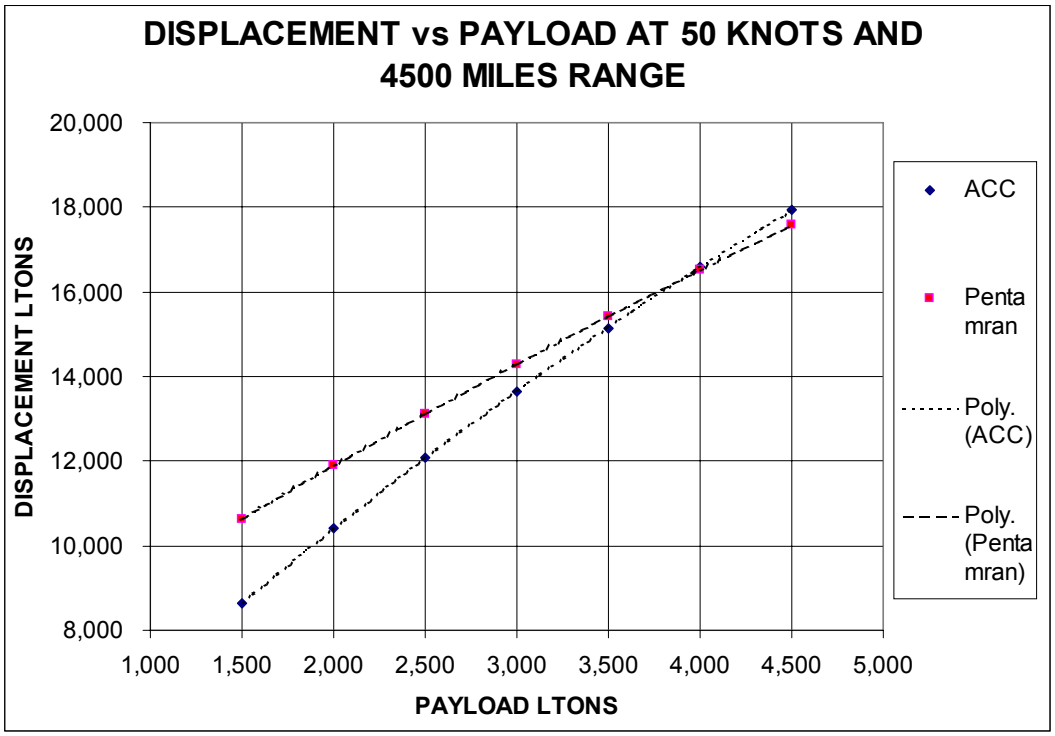

Figure 47 Graph Displaying the Displacement Crossover Point Between Pentamaran and ACC

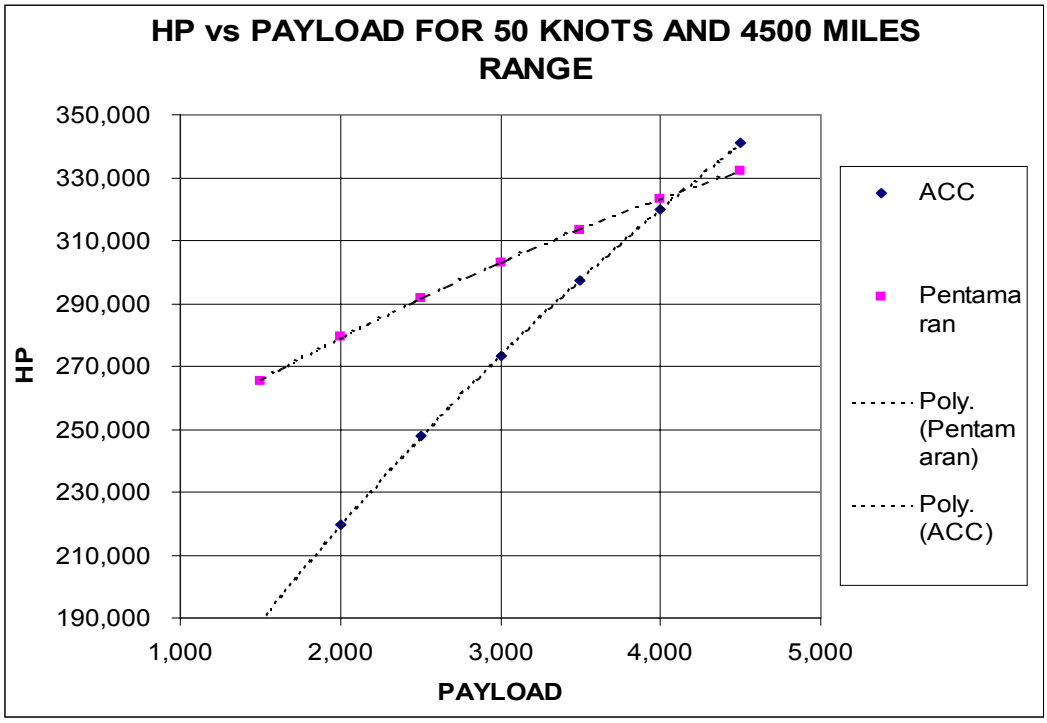

Figure 48 Graph Displaying the Required Horsepower Crossover Point Between Pentamaran and ACC

Both the payload and the power required show the same trend. Clearly there is a crossover point where the one hullform is preferred over the other. In our case the preferred choice is the ACC. Another reason that caused the design team to choose the ACC instead of the Pentamaran is that the power curve created for the Pentamaran was based on only one existing ship whose speed is only 30 knots. The extrapolation procedure here is very weak and does not create any confidence. As previously mentioned the design team chose to proceed with the Harley SES design since considerably more resistance data, structural information and model descriptions were found.

As mentioned above, the Harley SES is essentially a combination of a Wave Piercing Catamaran and a skirt-less SES. A vessel with this type of hull can have two major operating modes *off cushion* and *on cushion.* In the off cushion mode the vessel should have similar resistance characteristics as the Wave Piercing Catamaran. In the on cushion mode the vessel should have the resistance characteristics provided by the model testing data from Vibtech Inc.

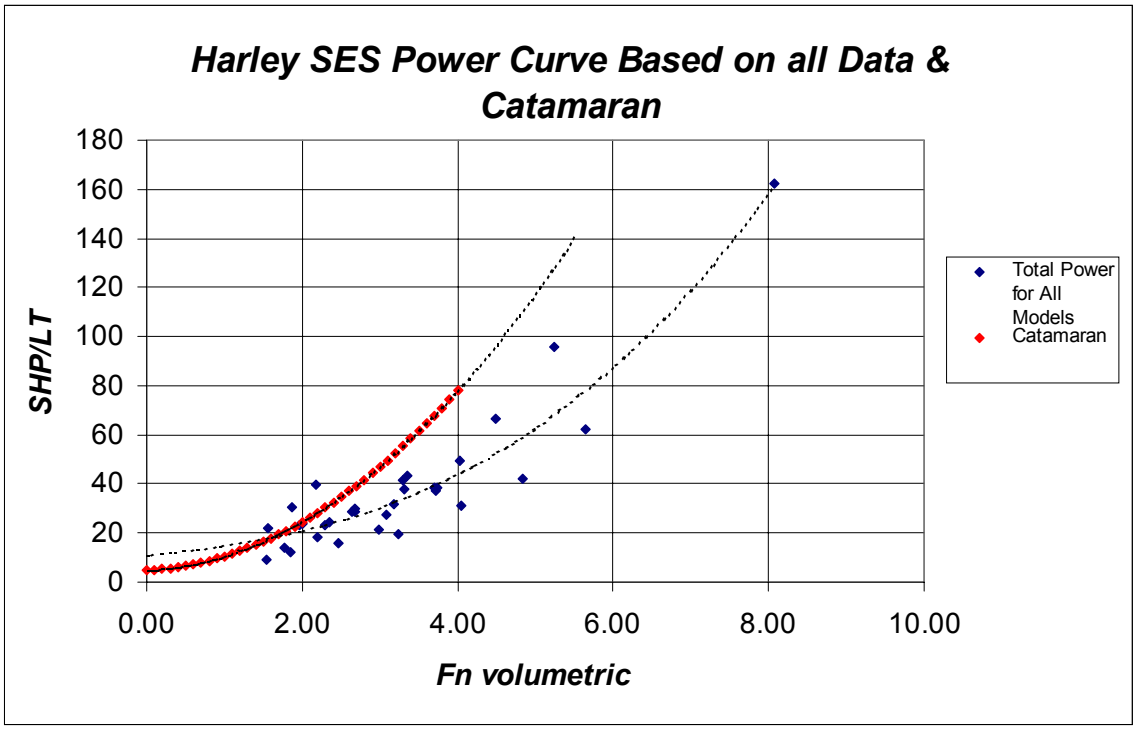

Figure 49 Power Curve for Harley SES Based on All the Data Compared to Catamaran

In Figure 49 two curve fits were created. One from the data selected for the Harley SES and one for the Catamaran. Since a single power curve for the SEA ARCHER for the whole range of speeds was needed, the design team decided to create a power curve having three different regions. One was for high speeds (above 1.5 Froude number) where the Harley SES concept is very efficient and should operate fully on-cushion. The 1.5 Froude number corresponds to 45 knots speed for a 13,000 LT ship. This 45 knot crossover point can be found from the intersection of the Catamaran and the Harley SES curves. The next mode should be partial cushion operation where the vessel begins to resemble a Catamaran and the power requirement is similar to the Wave Piercing Catamaran (quadratic fit). The last one is completely off-cushion where the vessel operates in low speeds (below 25 knots or below 0.8 Froude number); the resistance for that speed range can be found easily from first principles as the frictional resistance plus the catamaran wave resistance and resembles a linear fit of the Harley SES data. The final power curve is given in Chapter IV.

After a final modification and optimization for the Harley SES hullform the analytical tool was used to finally size the SEA ARCHER. The final dimensions were calculated based on weight inputs from all the different sub teams. To finally size SEA ARCHER we used

geometric similarity and a concept design from Vibtech Inc. The final dimensions of SEA ARCHER are given in Chapter IV.

2. Hydrostatic Calculations

For calculating the hydrostatic values and performance of SEA ARCHER the hull must be drawn. The design team used Rhino 3D to make the initial drawings and to create the necessary geometry files. For the hull - only section we used a scaled model of a concept design created by Vibtech Inc. At this point it should be mentioned that although the design team realized that the very large beam of the ship would create problems with the construction and the support of the ship in the United States the same length to beam ratio was used so that the model theory for the power requirements would be valid.

From the hydrostatic analysis results the SEA ARCHER is found to be a very stable platform with high values of reserve buoyancy. This is something expected since this is a general advantage of the multihull vessels. The floodable length was also calculated and the results show the increased survivability features of SEA ARCHER. The body plan of the SEA ARCHER's hull can be seen in Figure 50 while isometric views of the hull can be seen in Figure 51 and Figure 52.

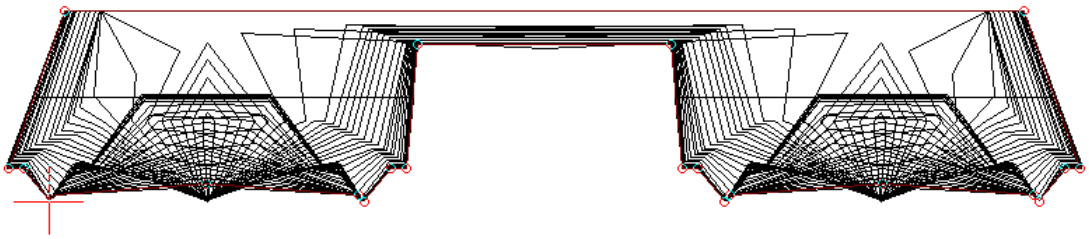

Figure 50 SEA ARCHER's Hull Body Plan View

For the hydrostatic calculations we used Auto-Hydro. The results from the Auto–Hydro calculations can be seen in Appendix B. It has to be mentioned that the marine software community only recently has started to incorporate multihulls in their programs and that is obvious in the case of the SEA ARCHER. The design team had to change considerably the geometry files so that the software could understand the shape of the hull by introducing pseudohulls.

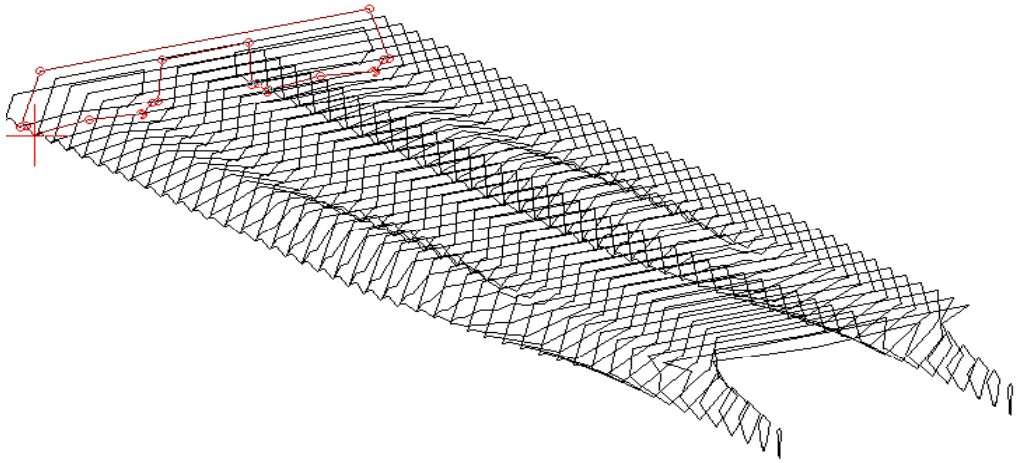

Figure 51 SEA ARCHER's Hull Top Isometric View

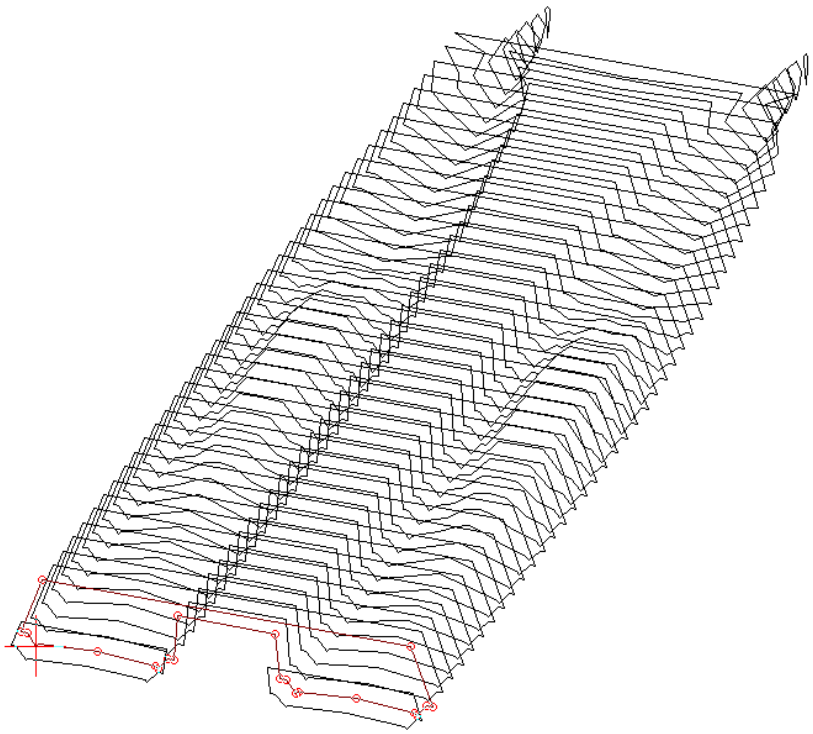

Figure 52 SEA ARCHER's Hull Bottom Isometric View

B. PROPULSION

1. Main Engine Analysis and Trade Studies

The propulsion study began by focusing on the requirements set out in the Mission Needs Statement (MNS) and the Operational Requirements Document (ORD). Based on these two documents, propulsion studies focused on the following areas: SEA ARCHER speed of 60 knots, Commercial Off the Shelf Technology (COTS), reduced manning, lower cost, reduced maintenance, high reliability, acoustically quiet, and the technology proven by the year 2012.

All marine capable propulsion systems were investigated. These included Diesel and Gas Turbine engines, Nuclear propulsion, and Fuel Cells, with key parameters identified and compared. The parameters investigated included Specific Fuel Consumptions (SFCs), power to weight ratios, and propulsion weight. The results are as follows:

Nuclear Propulsion: Nuclear propulsion was found not to be a viable option for the following reasons: manning and cost. Nuclear propulsion requires more people in the engineering department. Secondly, nuclear power plants total ownership costs are higher than conventional plants. Since both of the previous disadvantages are contrary to the basic design principle of low cost and manning, nuclear power was dropped from consideration

Fuel Cells: Fuel cells were found not to be a viable option for SEA ARCHER propulsion. Current fuel cell technology can only achieve output power levels at or near 0.12MW for Marine applications, falling well short of the anticipated required output power (150MW-350MW). Experts in the field were consulted and stated that by the year 2012, Fuel Cell technology will not be mature enough for the power levels required to propel SEA ARCHER to 60 knots.

Diesel Engines: Diesel engines were thoroughly investigated for possible feasibility. Knowing the powering requirement could approach 350MW, all Marine capable medium speed Diesel engines were studied. Diesels have the major advantage of

low Specific Fuel Consumption (SFC) but suffer because these engines have the potential of becoming manpower intensive and are extremely heavy. It was found that the largest Marine capable Diesel Engine available was rated at 35MW ($\approx$47,000 BHP). This engine weighs nearly 347mT (mT=metric tons) and would require a minimum of 10 engines (3474mT and $\approx 5000m^3$ of internal volume) to propel the ship to 60 knots. Based on the volume and weight required for the Diesel engine, it was found not to be feasible for SEA ARCHER. Figure 53 illustrates the Power to Weight Ratio for the Diesel and Gas Turbine engine.

Gas Turbines: Present production and anticipated Marine capable Gas Turbine engines were investigated. The advantages of Gas Turbine engines are as follows: Gas Turbine installations are relatively simple/modular in design and are lightweight ranging from (0.68kg/Hp to 1.81kg/Hp). They possess good high power fuel efficiency and are capable of rapid start up (times of less than 10 seconds are feasible), typical engines require reduced shipboard maintenance and produce less hull noise than equivalent power Diesel installations. Units are currently available at 50MW ($\approx$67,000SHP) and are estimated to reach 90MW ($\approx$121,000SHP) within the near future. Gas Turbines have a power footprint of 1650HP/m^2 to 3100 HP/m^2 (in the area of interest) as compared to 415HP/m^2 to 450HP/m^2 for Diesels and approximately 10 HP/m^2 for Fuel Cells. The disadvantages of the Gas Turbine engines include: unit cost of a Gas Turbine generator system is relatively high, increasing ship procurement cost. Marine Gas Turbines are susceptible to damage beyond ship force capability to repair. Large volumes of air are required to produce acceptable power levels. This results in increasing intakes and uptake volume within the ship. Gas Turbines produce a large infrared signature, which must be reduced by appropriate exhaust and stack design, Infra-red (IR) suppression systems add to the cost and weight of the ship, and the Gas Turbine has a higher SFC than the Diesel engine.

After weighing the advantages and disadvantages for each potential propulsion systems, the Gas Turbine engine was found to be the most feasible option for SEA ARCHER. It is estimated that approximately 6-8 Rolls-Royce Trent Gas Turbine engines could provide the required power up to 350MW with a volume of ($\approx 1500m^3$ -$2000m^3$) and a weight of ($\approx$160mT - 210mT of engines). The LM2500+ was also investigated

due to its lower weight and volume constraints (≈ 6mT/engine at 37m^3/engine). Figure 53 illustrates the power to weight advantage of the Gas Turbine engine over the Diesel engine. Figure 54 illustrates that as the power level increases, the SFC of the Gas turbine approaches that of the Diesel.

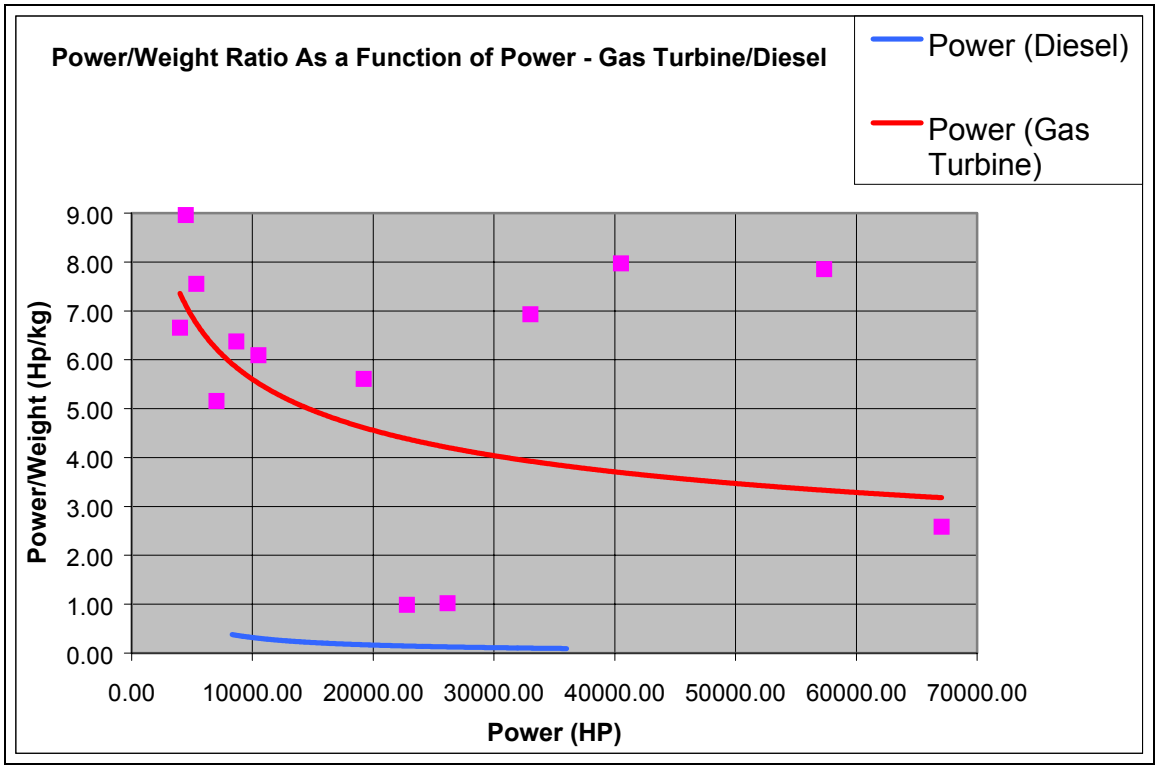

Figure 53 Power to Weight Ratio Comparison.

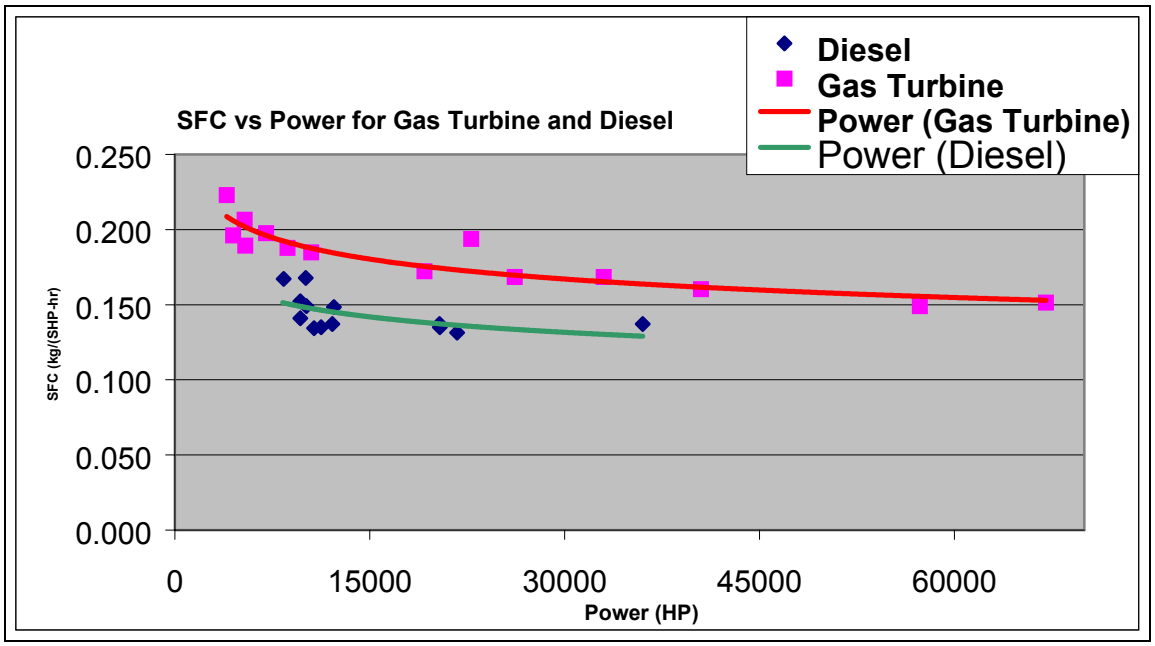

Figure 54 SFC Comparison.

Based on the above analysis, a gas turbine engine was selected to be the prime mover for SEA ARCHER. It was also mentioned that the Trent Gas Turbine, manufactured by Rolls-Royce, and the LM2500+, manufactured by General Electric, were the top candidates for the design. What follows is a brief discussion on several Gas Turbines that were considered and ultimately which Gas Turbine(s) was selected for the design. The driving factors used to select the final Gas Turbine were: ships speed, total fuel consumption, engine weight, engine volume, and engine cost. It should be mentioned that power for the blowers, required for dynamic lift of the ship was considered an electrical load and was not part of the propulsion power requirement.

LM2500 (25.06 MW, 33,600 SHP)

Data for this engine was obtained from General Electric's website [34]. This engine has a proven track record that dates back to the early 1960's. The LM2500 is currently in use on US Navy ships and other naval ships throughout the world. The disadvantage of this engine is low horsepower and high Specific Fuel Consumption (SFC) 0.373lb/(SHP-hr) or 0.226kg/(KW-hr) as compared to others. For this design, more than eight LM2500 engines would be required for propulsion only (to achieve 60 knots). Based on this fact, the LM2500 was dropped from consideration. Cost data for

General Electric Engines is available in Reference [35]. The LM2500 is pictured in Figure 55 below.

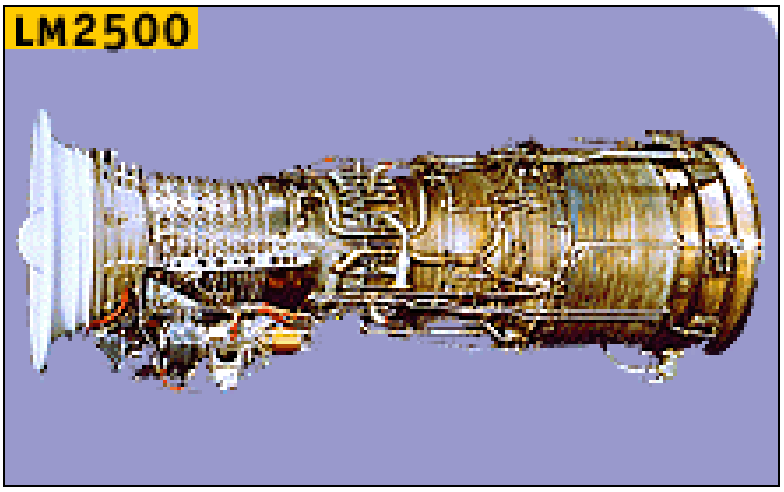

Figure 55 LM2500 GTE (From Ref [34]).

WR-21-ICR (25.24MW, 33847 SHP)

The WR-21-ICR (InterCooler Recuperator) incorporates revolutionary advancements in Gas Turbine technology. By using compressor intercooling, exhaust energy recover, and airflow management this Gas Turbine can achieve greater than 14% reduction in specific fuel consumption as compared to the simple cycle Gas Turbine and greatly reduces the ship Infrared signature (IR). The efficiency of the WR-21 can lead to 25% annual fuel savings depending on the ship's mission. The disadvantage of the WR-21 is weight [36]. The intercoolers and recuperators would add excessive weight (in terms of this design) to SEA ARCHER. The engine weighs nearly 50mT and would require eight WR-21 Gas Turbine engines to achieve 60 knots. Based on engine weight and volume requirements, the WR-21 was dropped from consideration. The WR-21 is illustrated in Figure 56 from Reference [37].

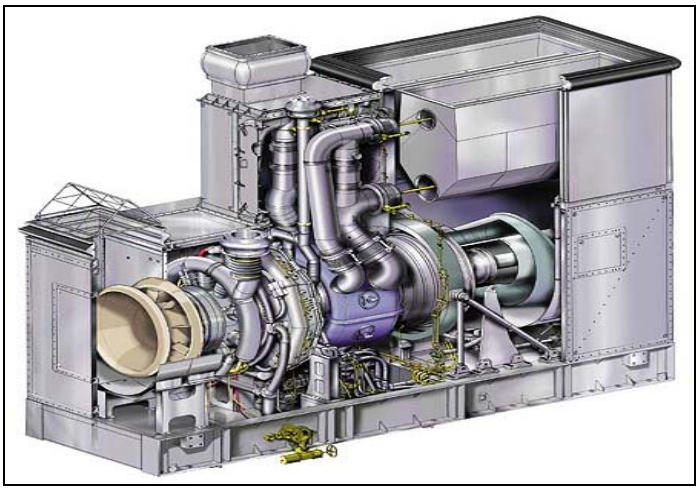

Figure 56 WR21 GTE (From Ref [37])

LM6000 (42.75MW-44MW, 57330 SHP-59000 SHP)

According to Reference [38], the LM6000 is the most fuel-efficient, simple-cycle Gas Turbine in the world with an SFC at 0.200 kg/(KW-hr). The LM6000 has a higher thermal efficiency and lower exhaust gas temperature as compared to other General Electric engines. The LM6000 requires 202m^3 of volume and weighs 55mT (including Gas Turbine, inlet, vents, exhaust, Gas Turbine Enclosure, Gas Turbine Base, Auxiliary Skids, and Shock mounts). This engine is well suited for high-speed ferries and cargo ships. The LM6000 has a high power to weight ratio (7.85HP/kg). The disadvantage of employing the LM6000 for SEA ARCHER is engine water-cooling. The LM 6000 is a water-cooled engine requiring excessive weight and volume requirements not suitable for this design. If used as the only prime mover, 5-LM6000 GTEs and 5 reduction gears would be required to propel SEA ARCHER to 60 knots. The LM6000 GTE is illustrated in Figure 57.

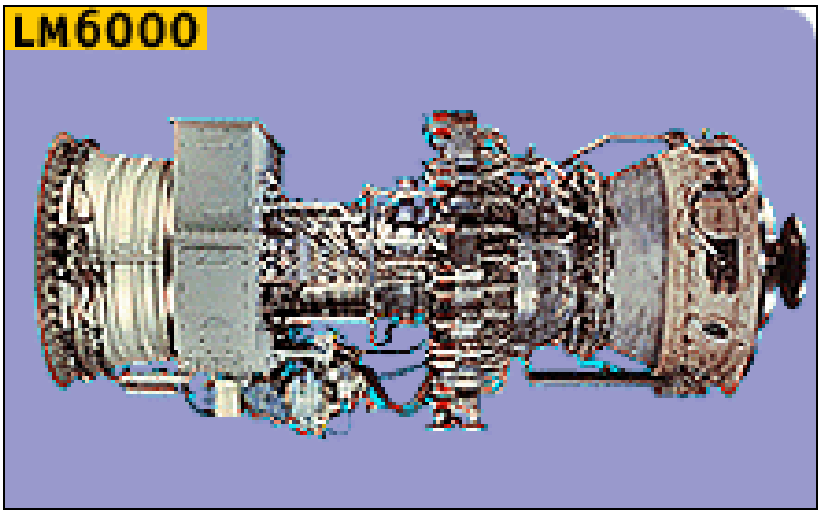

Figure 57 LM6000 GTE (From Ref [34]).

TRENT (50MW, 67051 SHP)

The Rolls-Royce Trent Gas Turbine is an aero-derivative Gas Turbine Engine that delivers 50MW at a thermal efficiency of 42%, comparable to the LM6000. The Trent Gas Turbine also possesses an attractive SFC at 0.205kg/(KW-hr) [39]. Of all the engines considered (with the exception of the WR-21), the Trent has the lowest exhaust temperature at 445°C. The lower exhaust temperature provides SEA ARCHER with a lower IR signature. The main disadvantages of this engine are its weight and volume characteristics. Each Trent requires 248m^3 of space and each engine weights nearly 12mT while the enclosure weighs 26mT. However, this weight is lower than the LM6000. SEA ARCHER requires, at a minimum, 4-Trent Gas Turbines Engines (at full rated power) to achieve 60 knots. Four Gas Turbines would require 4 Main Reduction Gears and 4-waterjets/Hydro-Air Drives further increasing the volume and weight requirements. The Trent GTE is illustrated in Figure 58.

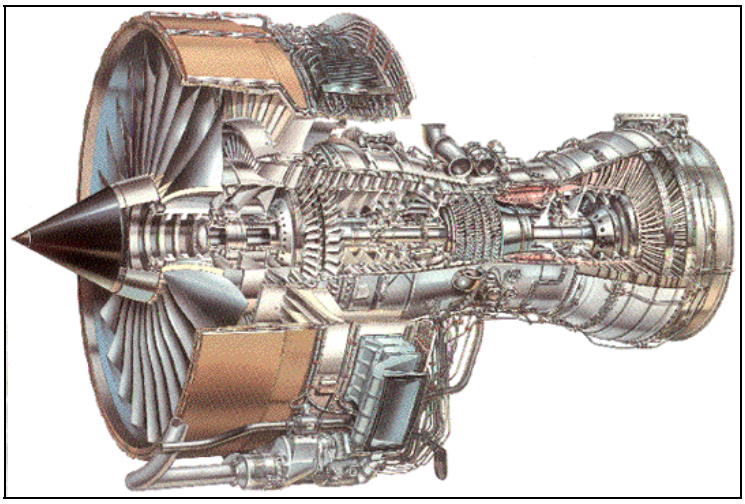

Figure 58 Trent 50 GTE (From Ref [40]).

LM2500+ (30.2MW, 40500 SHP)

The last General Electric engine considered in this design was the LM2500+. The SFC for the LM2500+ is 0.215kg/(KW-hr) [41]. The LM2500+ entire module with engine weighs approximately 40mT (scaled from other GE engines and enclosure data) and occupies 67m^3 of enclosure volume (does not include intakes and uptakes), far less than the Trent or the LM6000. The LM2500+ is a direct descendant of the LM2500. The performance of the LM2500+ represents a 25% increase in power output compared to the LM2500. SEA ARCHER would require 7-LM2500+ to propel the ship to 60 knots. Extra engines can have the advantage of providing a multitude of engine arrangements at different speeds where the propulsion plant can be optimized based on the mission profile. Also, with 7-engines, maintenance can be accomplished more easily than a ship with only 4 or even 6 engines. The LM2500+ has the disadvantage of a higher SFC as compared to the Trent, LM6000, and as will be seen, the Trent 30. However, assuming Main Reduction Gears can reach 60MW and maintain the current weight (2001 weight) of 57mT, up to 8-LM2500+ engines will fit into SEA ARCHER. The LM2500+ is illustrated in Figure 59.

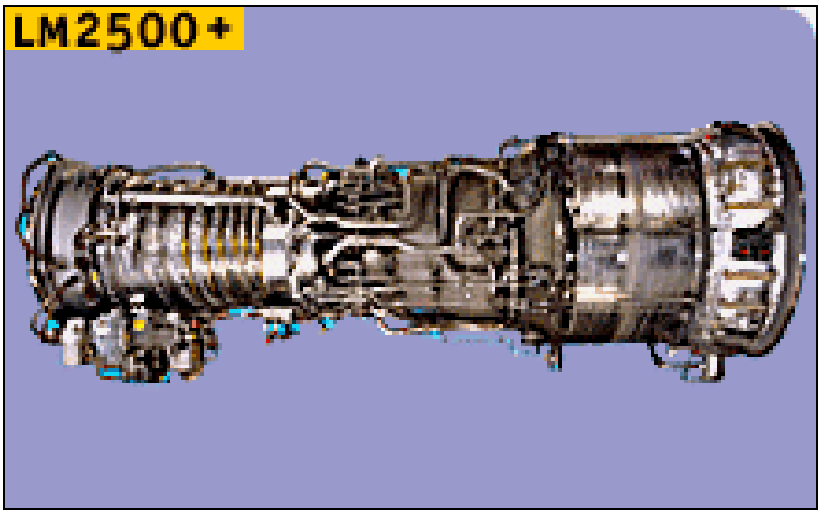

Figure 59 LM2500+ GTE (From Ref [34]).

Trent 30 (30-36MW, 40231-48277 SHP)

The last engine considered was the Trent 30 GTE by Rolls-Royce. The engine is advertised with a power rating up to 36MW (48277 SHP). The total package, including enclosure and auxiliaries occupies a volume of 134m^3 and weighs 26,000kg (26mT) [42]. The marine Trent 30 is compact and lightweight and possesses an SFC of 0.2068kg/(KW-hr). The Trent 30 has the best power to weight ratio in its class. This Gas Turbine is available in mechanical and electrical generator sets (similar to GE generator sets). The engine can be changed out within 12 hours. The Trent 30 is acoustically enclosed and self-contained, meeting all military specifications. Trent 30 is nuclear, biological, and chemical warfare designed. This engine is highly reliable and readily available. Another key feature of the Trent 30 is its ability to rapidly load-shed should waterjet aeration occur. The Trent 30 is pictured in Figure 60.

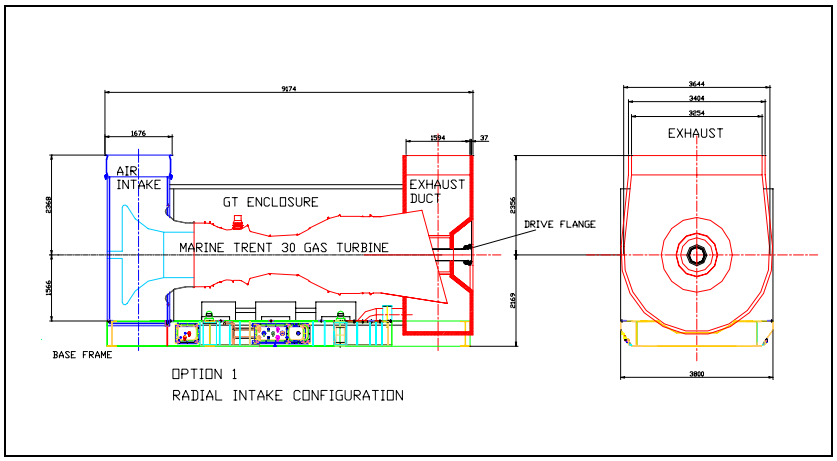

Figure 60 Trent 30 GTE (From Ref [43]).

To determine the correct prime mover for SEA ARCHER, all requirements were taken into account. The ship was found to require nearly 188MW (252,000 SHP) to achieve 60 knots. Also, 34MW (≈46,000 HP) is the anticipated requirement for continuous ship's service electric load. As required by the design reference mission, the ship will only be required to be at 60 knots 3.5% (6hours/168hours) of the time in a 7-day period while in the operational area. With this in mind, the ship will have excessive power available that is not being utilized. To harness this extra power, a hybrid mechanical/electrical drive system was proposed. Engine selection was based on the advantages and disadvantages as discussed above, volume and weight constraints, technology maturity dates, specific fuel consumption, power to weight ratios, main reduction gearing, and finally, available propulsors.

The technology cut off date for SEA ARCHER is 2012. Advances in Gas Turbine and propulsion motor technologies are occurring rapidly. It is assumed that advances in reduction gear and Waterjet/Hydro-Air Drive technologies (to be discussed later) will continue to advance, with decreasing weight and increased power levels. For this design, Waterjets/Hydro-Air Drives are assumed to reach 50 MW and have rotational speeds of 400rpm (as projected) by 2012. Main Reduction Gears will require a smaller reduction ratio (9:1 vice 21.4:1 for today); this will lead to significant weight reduction in gearing (40mT vice 45.55mT (currently) [44] for 50 MW units and 25mT for 36MW units). Propulsion motor weight will continue to decrease from 140mT (currently) at 36

MW to 100mT at 36MW. As waterjet rpm increase, motor rpm will increase, thus driving motor size down.

A major consideration for a high-speed ship like SEA ARCHER is fuel consumption. Recently, studies have been conducted concerning where Specific Fuel Consumption (SFC) for Navy ships is projected to be in 10-15 years. It is anticipated that advances in high temperature materials will continue to improve and drive SFC down to 0.26lb/(SHP-hr) or 158kg/(MW-hr) [45]. Figure 61and Figure 62from reference [45] illustrate SFC projection. Using the SFC projection data, an SFC of 0.28lb/(SHP-hr) or 170.2kg/(MW-hr) was utilized in this design.

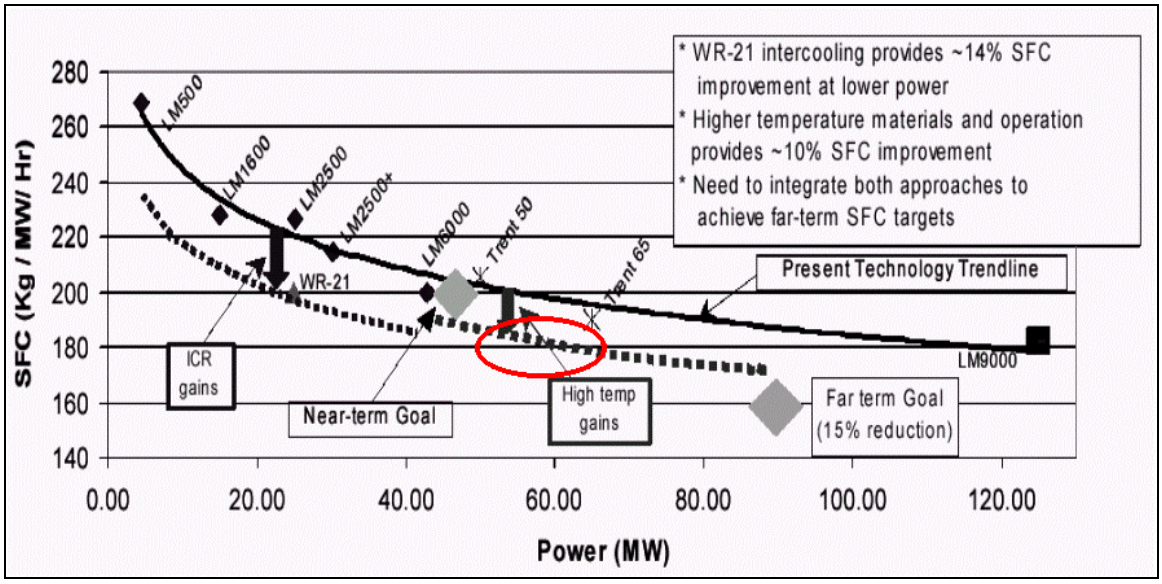

Figure 61 SFC Performance Predictions (From Ref.[45]).

Key Parameters	Near-Term	Far-Term	Defense Range (near-term)
Power (hp)	70,000	125,000	80,000
SFC(lb/hp-hr)	0.33	0.26	0.33
lb/hp	1.0	1.0	1.0
ft^3/hp *	0.1	0.1	<0.1
Fuels	Distillate/Natural Gas	Distillate/Natural Gas	Distillate/Natural Gas
Emissions	meets standards	meets standards	meets standards
MTBO (hr)	12,500 – 25,000	12,500–25,000	1,000-2,000

* engine only

Figure 62 Far Term SFC Predictions (From Ref [45]).

Main Engine Selection. Each of the engines investigated had certain advantages and disadvantages. The driving factors for engine selection were which set of engine types and arrangements would meet the required horsepower for both propulsion and electrical, provide a low SFC, and furthermore, fit inside the ship within the allotted volume and weight constraints. Several iterations where performed on different engine arrangements (including mixing engine types), it was decided that 2-Trent 50 and 2-Trent 30 Gas Turbine engines would be used for strictly propulsion while 2-Trent 30 motor/generator sets would be used for both propulsion and electrical needs (see propulsion Appendix for different engine arrangement configurations considered). This arrangement buys enormous flexibility by allowing several plant configurations based on mission requirements. At low speeds, only certain engines will be on line, while at high speeds the big Trent 50's can be brought online to provide boost for op-area repositioning. It was determined that the Trent engines are technologically further along in SFC improvement as compared to similar engines in their respective classes.

2. Propulsion Motors

The following Propulsion Motors from Reference [46] were considered for this design. Since the Trent 30 provides nearly 36 MW of rated power, a 36 MW induction motor was selected for the hybrid electric drive portion of the power plant. Although only 35 MW versions are listed in the table, it is anticipated that a 36 MW motor can be

built and that substantial weight improvements can be made in the next 11 years both by motor rpm increase and material improvement factors. The 140mT motor was selected and by 2012 is projected to weigh 100mT at speeds near 400rpm.

Power (MW)	Speed (rpm)	Phase No	Overall Length (mm)	Overall Height (mm)	Overall Width (mm)	Weight (Tonne)
35	100	21	6500	5080	5300	230
35	100	2 x 15	12100	3750	4250	260
35	100	2 x 15	9680	3750	4250	240
35	135	21	5700	5080	5300	175
35	170	15	4710	4210	5600	140
38	110	21	6500	5080	5300	230
40	130	21	5990	4270	5000	200
44	125	21	6500	5080	5300	235

Table 38 Induction Propulsion Motors (From ref [46]).

3. Propulsors

The following propulsors were considered to propel SEA ARCHER: propellers, PODS, Waterjets and Hydro-Air drives.

Propellers are only efficient up to approximately 35 knots; at speeds greater than this, serious cavitation results. Furthermore, a controllable reversible pitch propeller requires substantial navigational draft and hydraulic systems. Since SEA ARCHER will be required to reposition at 60 knots, propellers were dropped from consideration.

POD propulsors were also considered. The disadvantages with PODs in a SEA ARCHER design are added drag resistance and increased navigational draft at lower speeds. Both of these disadvantages caused PODs to be dropped from consideration.

Waterjets/Hydro-Air Drive technology can deliver the power required by SEA ARCHER. At present Kamewa and Rolls-Royce are building 50MW Waterjets for

Fastship Atlantic. The disadvantage of the Waterjet is entrained water weight. As stated in Reference [47], 50MW Waterjets with water in the duct can weigh as much as 470mT (fitted with steering and reversing gears). SEA ARCHER would require 2-50MW Waterjets and 4-36MW Waterjets. Even with a 15% technology improvement factor applied, these jets are too heavy. Another potential risk with a pure waterjet design is aeration. SEA ARCHER will operate on cushion a large percentage of the time; hence, air can be trapped in the inlet duct causing the waterjet to shut down. This is an obvious disadvantage. A 50 MW waterjet is illustrated in Figure 63

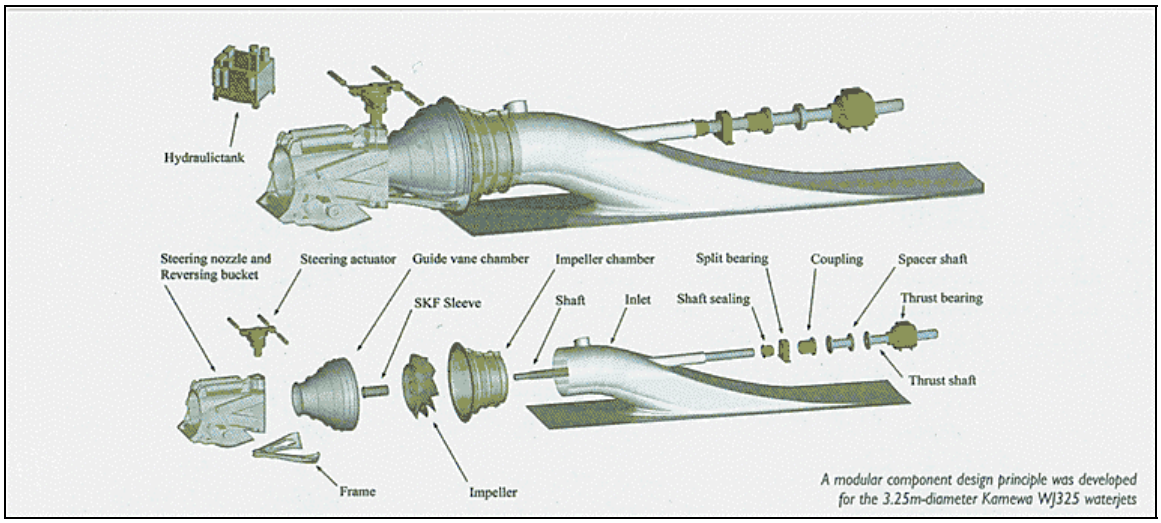

Figure 63 Kamewa 50MW Waterjet (From Ref [48]).

A new technology called Hydro-Air Drive reduces the water weight substantially because the inlet duct is only half-full of water (when on cushion) by design. Hydro-Air Drives combine the principles of Waterjets and surface-piercing propellers. According to Reference [48], the Hydro-Air Drive features a flush inlet and a close-fitting protective duct that encloses its rotor like a waterjet. The rotor operates only half-submerged at cruising and high speeds, however, similar to a surface propeller, it can be fully submerged at low speeds to double mass flow and increase thrust. This design promises significant benefits in performance and efficiency, along with reduced costs. Furthermore, while offering all the advantages of conventional waterjets, Hydro-Air Drives claim to offer the following benefits: 1) significantly better efficiencies at high and low speeds, 2) improved low speed thrust, 3) no cavitation damage, 4) full reverse

thrust on the shaft, and 5) less susceptibility to damage or failure from debris ingestion. Reference [48] further states that improved Hydro-Air Drive efficiency at high speeds results from less inlet water not having to lifted as high, and the reduced wetted area friction compared with inlet water flowing into a traditional fully submerged waterjet rotor. This translates to higher inlet pressure recoveries and therefore higher efficiency; refer to Figure 64 The disadvantage of the Hydro-Air Drive is that it uses a gearbox to reverse and a rudder to steer. The rudder will add drag to the ship as well as increase navigational draft at slow speeds. In order to take the weight and efficiency advantage of the Hydro-Air Drive, this designed used a combined Hydro-Air and Waterjet technology. The design uses Hydro-Air Drive with the Waterjet steering and reversing bucket for maneuvering. Figure 65 illustrates the Hydro-Air Drive concept.

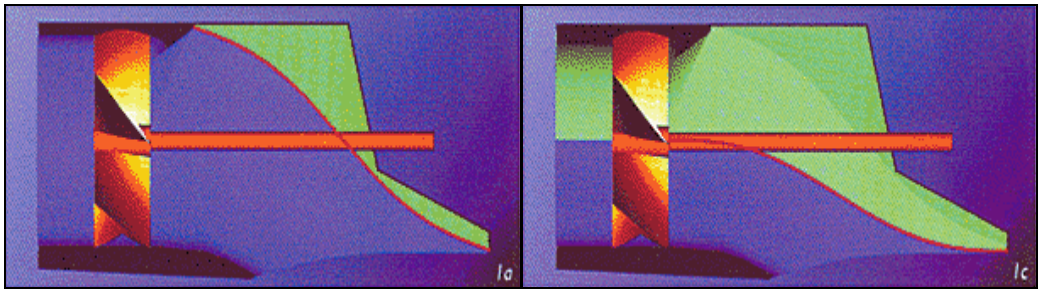

Figure 64 Hydro-Air Half Submerged (from Ref [48]).

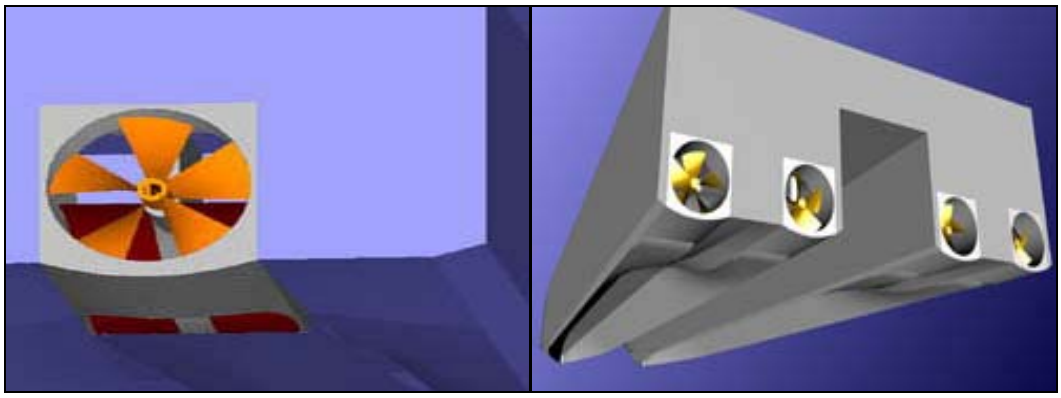

Figure 65 Typical Hydro-Air Drive Install (from Ref[48]).

To take advantage of the 15% technology improvement factor and the decreased water weight attributed to Hydro-Air Drive, all Kamewa Waterjet data was plotted to determine the most accurate weight of an anticipated 36 MW and 50 MW Hydro-Air drive unit [49]. Figure 66is a plot of all Kamewa waterjet data.

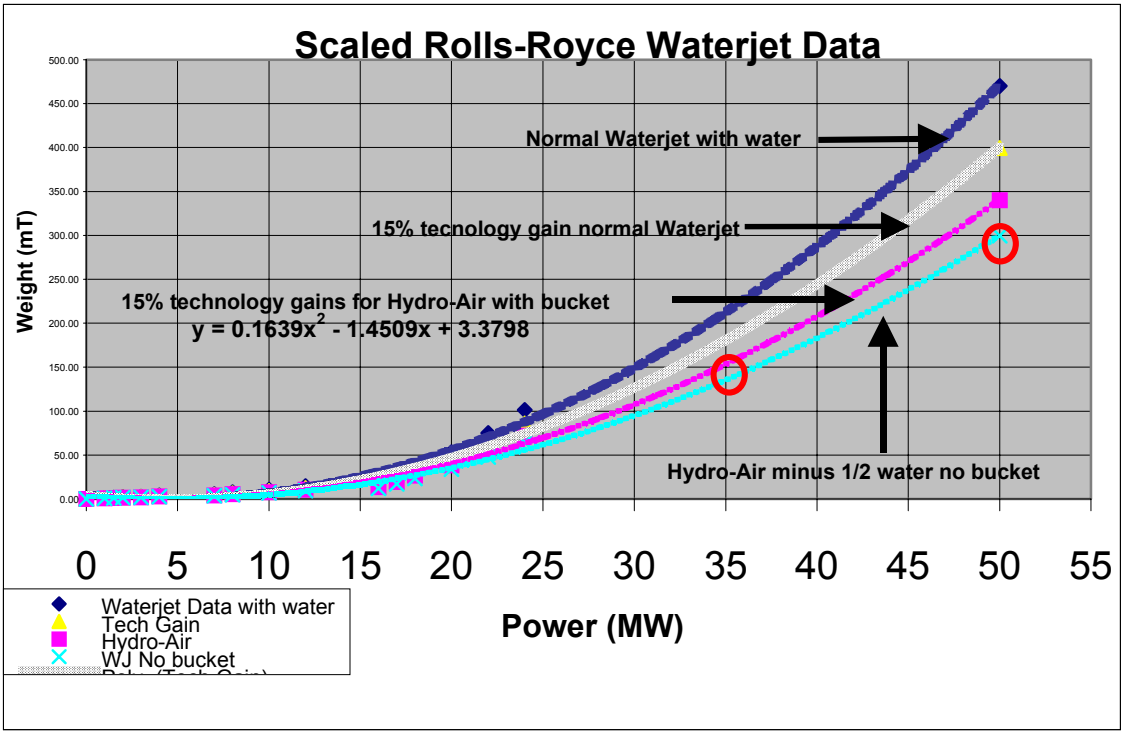

Figure 66 Scaled Waterjet/Hydro-Air drive Data (data from Ref [49]).

The figure illustrates 4 plots. The top dashed curve represents present day waterjet weight data including water entrained inside the waterjet. The solid curve below the top curve represents a 15% technology improvement on current day waterjets. The third curve from the top is the same as the second curve from the top except that 0.5 of the water was removed from the waterjet duct to take advantage of the Hydro-Air technology. The bottom dashed curve represents the yellow curve with 0.5 of the water removed and no reversing or steering components. The 50 MW waterjets/Hydro-Air Drives will only be used for boost and require no reversing or steering gear. Only the 36MW waterjets/Hydro-Air Drive units will be equipped with steering and reversing buckets. The red circles represent the power and weights utilized in this design.

4. Main Reduction Gears

Main Reduction Gear (MRG) selection was based on prime mover selection. Since the Trent 50 and Trent 30 GTEs were selected for this design, both a 36MW and 50MW MRG is required for SEA ARCHER. General Electric, NAVSEA, Philadelphia

Gear, and Rolls-Royce were all consulted to determine MRG requirements for SEA ARCHER. As stated in Reference [42], Philadelphia Gear has designed a 67,000SHP MRG for Fastship Atlantic (which will use the Trent 50 for propulsion). They estimate this MRG to weigh 45.55mT. Taking known reduction gear weight for several US Navy plants, a 36 MW reduction gear weight was determined based on linear scaling (this was verified by Rolls-Royce). The 36MW MRG weighs 25mT.

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C. ELECTRICAL

The electrical system has been broken down into four subsystems. These subsystems are power loads, power conversion, power distribution, and power generation. The following section describes each category for SEA ARCHER. Based on these studies and the electrical load requirements, the optimum system can be designed.

1. Power Loads

The power loads were mainly based on the needs of the other systems in the SEA ARCHER design, and for the most part did not require trade-off studies. With propulsion, however, the question arose of whether to keep the propulsion engines separate from the electrical systems, or to design an Integrated Electric Drive system (IED) that uses electrical power to drive the propulsion motors. Three options were available. They were to keep the electrical and propulsion systems independent, to use a complete IED system, or to use a hybrid-IED system, where some of the propulsion engines are electric drive and some of the propulsion engines remain independent. The following paragraphs briefly explain the systems and their advantages and disadvantages.

Conventional Power System: By designing two independent systems for propulsion and electrical power, the complexity of each design is minimized. This is only an advantage in the design phase. With two independent systems, the power generators and prime movers are routinely not optimized and operate during many operating modes with high inefficiencies. This adds extra weight and cost to the ship for the amount of useful power being generated. Though this has been the standard method of designing ships, current technology allows for designing a more optimum propulsion and electrical system.

Integrated Electric Drive (IED): Integrated Electric Drive is a step towards increasing the efficiency of the propulsion and electrical systems. By using an electric propulsion motor many advantages are gained. The primary design advantages of an IED system are flexibility in locating prime movers and vertical integration of propulsion equipment. In addition, the IED system decouples the prime mover speed from the propeller speed, allowing the prime mover to operate at a higher Specific Fuel

Consumption (SFC). By optimizing the prime mover location, the intake and exhaust volumes can potentially be minimized. In addition, the need for a long shaft is eliminated.

By using common prime movers, an IED system can also reduce the potential manning size and reduce overall cost through elimination of components. From a power aspect, using the same prime movers allow the prime movers to be operated at optimum conditions for the needed propulsion and electrical loads. This reduces the amount of fuel consumed, which generates additional cost savings.

The disadvantage of an IED system is that a large generator, power converter, and motor are inserted between the prime mover and shaft, vice a reduction gear. The weight and volume of this equipment demands careful consideration.

Hybrid-IED: A hybrid version of IED, where only some of the engines are electric drive, possesses advantages and disadvantages compared to either the conventional or IED systems. The mechanical drive propulsion motors will still operate inefficiently at low speeds, but overall weight and cost gains will be realized. This is because ships do not operate at high speeds for extended periods of time so traditional propulsion turbines waste fuel when not operating at the most efficient speeds. Electric drive propulsion motors can be modulated to operate at different speeds while keeping the electrical generator prime mover at a constant speed. At low propulsion speeds, the excess power can be used to power ship service loads without the use of extra electrical generators. As ship propulsion is increased extra electrical generators can be brought on-line to supplement the propulsion power requirements.

Summary

Based on the extremely high power requirements needed to operate at 60 knots, a true Integrated Electric Drive is not practical. The cost, weight and volume of the combination of motor, converter module and generator for multiple propulsion drives preclude using a total IPS system. However, by using electric drive on two of the propulsion motors, increased efficiency can be achieved in the electric plant. Therefore, SEA ARCHER will have a hybrid Integrated Electric Drive.

2. Power Distribution

Four types of distribution systems were investigated in determining the optimum electrical arrangement. These were the traditional radial, AC Zonal, DC Zonal, and modified AC/DC Zonal distribution.

Radial Distribution: One of the key advantages of the radial distribution system is that it has been fully developed and has been in use in Navy ships for years. The technology is well understood and the components are readily available commercially. The drawbacks, however, are significant. Because of the radial nature of the design, the distribution system typically has multiple switchboard panels, scores of power transformers and many switchboard feeder cables. All these components add much weight and numerous watertight compartment penetrations, which adversely affect hull design and damage control.

AC Zonal Distribution: AC Zonal distribution allows the ship to be electrically segmented into multiple smaller sections. Each section then has a couple of main bus lines that feed power to that particular zone, and the zones are connected together by their bus lines. By designing the zones to coincide with watertight compartments, damage control is improved by minimizing electrical penetrations through the watertight bulkheads. In addition, many feeder cables and transformers can be eliminated reducing the overall ship weight.

Zonal distribution also benefits construction because of its modular nature. Each zone can be built and tested independently. This simplifies installation and should reduce building costs.

DC Zonal Distribution: DC zonal distribution possesses the same advantages as an AC zonal distribution, but the bus lines carry DC power, vice AC power. With DC zonal distribution added advantages are realized. A primary advantage is that fault detection is simpler and faster, and can be isolated to a zone immediately. In conjunction with fault detection, DC power uses diode auctioneering to maintain power to vital loads. Diode auctioneering is superior to automatic bus transfer (ABT) switches

because power source is transferred in microseconds vice milliseconds or tenths of second as is common with ABTs.

A second advantage is that the generator frequency is decoupled from the load frequency requirements. This allows the generator to operate at its optimum speed for the load condition and still allow the loads to have constant frequency power.

Current drawbacks to a DC zonal distribution are issues with converter EMI compatibility and system stability. In addition, other drawbacks include research and design costs and power density optimization. These issues are being addressed at the Land Based Engineering Site (LBES) in Philadelphia, PA, and it is expected that by 2012 these issues will be largely resolved.

AC/DC Zonal Distribution: Because of the extremely high power requirement on SEA ARCHER coupled with the fact that some loads are non-sensitive and can tolerate millisecond-level casualty responses vice microsecond response times, a modified AC/DC zonal distribution was studied. This distribution system would have an AC and DC power bus on both the port and starboard busses. By using an AC bus, the high power AC loads, like the propulsion blowers, could be tied closer to the source output. This would eliminate the need to convert the AC power to a high power DC and then reconvert the power back to high power AC for use, which would aide in minimizing the size of the converters and inverters needed. The majority of loads, AC and DC, could still be powered by the DC bus line through smaller converters and inverters.

Because of the two types of power sources, the number of electrical penetrations in the watertight bulkheads will double, thereby reducing the overall integrity of the watertight compartment as compared to a DC only zonal distribution.

Summary

It became apparent after investigation that a zonal architecture offers many advantages over the traditional radial architecture. The technology exists to implement zonal distribution and the converter controls are understood. Ideally, a DC zonal distribution system provides the greatest survivability advantage. However, the number

of loads that have large AC power requirements and the need to minimize weight made it necessary to consider an AC zonal power line as well. Therefore, the optimum electrical distribution for SEA ARCHER to employ is an AC/DC zonal distribution.

3. Power Conversion

Based on the total power requirements of the power loads, section 1 above, it is assumed that notionally only 1 MW will need to be provided to each zone, including lifetime growth allowances. Further design iterations would refine how much power each zone would really need. Some might need more and some might need less, but notionally it is 1 MW. Therefore the DC-DC and DC-AC power converter modules need only be able to supply a maximum of 1 MW of power. Based on this maximum power load Table 39 and Table 40 show the current power converter module weights and volumes and the predicted year 2012 characteristics.

The practical size of the power converter modules is limited by the admissible bus voltage and magnified by cabling requirements. Despite the advancement of technology in solid-state electronics, the cables must be of specific size to carry the electrical current.

Type	Trent 30	GE 10	PCM-4	PCM-1	PCM-2	PMM-1
Function	Gen	Gen	AC/DC	DC/DC	DC/AC	AC/AC
Power (MW)	36	11.2	2	0.5	0.25	20
Scaled Power (MW)	36	11.2	15	1	1	30
Scaling Function	Linear	Linear	Linear	Linear	Linear	Linear
Scaling Factor	1	1	7.5	2	4	1.5
Unpackaged Weight (mT)					0.23	
Weight (mT)	235	78	8.2	1.5	2.3	35.4
Scaled Weight (mT/unit) Current Year	235	78	61.5	3	9.2	53.1
Technology Function	Linear	Linear	Linear	Linear	Linear	Linear
Technology Factor Year 2012	0.85	0.85	0.85	0.85	0.85	0.85
Scaled Weight (mT/unit) Year 2012	199.75	66.30	52.28	2.55	7.82	45.14
Number of Units/zone	1	1	1	2	1	1
Number of Zones	2	1	3	21	21	2
Total Weight (mT) Year 2012	399.50	66.30	156.83	107.10	164.22	90.27

Table 39 Gas Turbine and Power Conversion Module Weights

Type	Trent 30	GE 10	PCM-4	PCM-1	PCM-2	PMM-1
Function	Gen	Gen	AC/DC	DC/DC	DC/AC	AC/AC
Power (MW)	36	11.2	2	0.5	0.25	20
Scaled Power (MW)	36	11.2	15	1	1	30
Scaling Function	Linear	Linear	Linear	Linear	Linear	Linear
Scaling Factor	1	1	7.5	2	4	1.5
Unpackaged Volume (m^3)					0.35	
Volume (m^3)	324	96	7.8	2.6	3.5	21
Scaled Volume (m^3/unit) Current Year	324	96	58.5	5.2	14	31.5
Technology Function	Linear	Linear	Linear	Linear	Linear	Linear
Technology Factor Year 2012	0.85	0.85	0.85	0.85	0.85	0.85
Scaled Volume (m^3/unit) Year 2012	275.40	81.60	49.73	4.42	11.90	26.78
Number of Units/zone	1	1	1	2	1	1
Number of Zones	2	1	3	21	21	2
Total Volume (m^3) Year 2012	550.80	81.60	149.18	185.64	249.90	53.55

Table 40 Gas Turbine and Power Conversion Module Volumes

4. Power Generation

In determining the optimum electrical generation system, diesel and gas turbine engines were both investigated. Detailed comparisons of their advantages and disadvantages are contained in the Main Engine Analysis and Trade Studies reported earlier.

Both the diesel and gas turbine generators are capable of providing the required electrical needs. However, the excessive weight and manpower of the diesel system, along with the fuel compatibility with the propulsion gas turbines, make the gas turbine generators the practical choice.

Table 41 shows the major gas turbine generators investigated and their characteristics. Based on the required electric drive propulsion and electrical load requirements and the need for a small generator for emergency and light load conditions, two Trent 30s and a GE 10 were chosen as the electrical generators to provide a total of 83.2 MW.

Engine Type	Output Power (MW)	Weight (kg)	Length (m)	Width (m)	Height (m)	Volume (m^3)
GE 2	2	23000	5.5	2.3	3.75	47.4375
GE 5	5.5	57833	9.8	2.5	2.9	71.05
GE 10	11.2	77814	12.8	2.5	3	96
LM1600	13.7	177500	20.7	4.2	4.4	382.536
LM2000	17.6	61818	23.6	5.47	7	903.644
LM2500	22.8	183705	20.7	4.2	4.4	382.536
LM2500 STIG	28.278	185973	20.7	4.2	4.4	382.536
LM2500+	28.6	204117	21.6	4.2	3.6	326.592
LM6000	43.4	259863	17.2	4.1	4.4	310.288
LM6000 SPRINT	47.3	215910	17.2	4.1	4.4	310.288
Trent 30	36	234499				324.288

Table 41 Available Gas Turbine Generators

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D. AVIATION OPERATIONS

The driving factor in designing the flight deck, hangar deck, and ordnance handling system was reduced manning. Current carrier operations are *extremely* manpower-intensive, which translates to high cost of ownership. Automating as many functions as possible was a top priority in designing the aviation systems. The caveat to these automated systems is that they must be high-reliability and low maintenance to truly achieve manning reductions. Other specific requirements set forth by the Operational Requirements Document include:

- Flight deck design should focus on automation.
- High-speed launch and recovery operations should take place from an unmanned flight deck.
- SEA ARCHER should have the ability to act as a "lily pad" (recover, fuel & launch) for AV-8s, VTOL JSFs, and helicopters under 30,000 pounds maximum gross weight.
- SEA ARCHER should have responsibility for control of unmanned vehicles within its air wing.
- SEA ARCHER should be capable of sustained combat operations of three days (threshold) and seven days (objective) without resupply.
- A SEA ARCHER battle group should be capable of ninety days of self-sustained peacetime operations.

1. Aircraft Stowage and Service

The first step in determining what the SEA ARCHER's flight deck would look like was figuring out where the aircraft would be stowed and serviced. To decide where the stowage and service functions would be located, the sortie rate was analyzed, with the result being that CROSSBOW's distributed aviation concept eliminates the requirement for a single ship to launch large numbers of aircraft in a short amount of time. The small airwing size allows almost 45 minutes to turn around an aircraft, a virtual eternity in carrier operations. The net result is that options with the advantage of reduced manning are preferred over options that reduce turn-around time.

To reduce manning, it is necessary to automate the refueling and rearming process. The two automation schemes considered were assembly line type and pit stop

type. The assembly line method would require a large amount of volume and would likely not reduce manning a great deal since a lot moving parts generally means more maintenance. The advantage would be that it could turn around aircraft at a high rate, but as already discussed, this is not of great advantage in the distributed aviation concept.

For the other half of the picture, where the service is performed at, the choices were: all aircraft topside, all aircraft inside the skin of the ship, or something in between. If all servicing were performed on the flight deck, the aircraft turn-around rate would be faster than if the servicing were performed in the hangar bay. However, the high ship speeds involved would require an island to shelter the systems from the wind, and would generate a higher radar cross-section (RCS). Moving all the functions to the hangar deck reduces RCS, wind, and corrosion concerns, but slows down the aircraft turn-around and requires an efficient means of moving the aircraft between the flight deck and the hangar deck. The hangar bay must then be large enough to accommodate the automated servicing stations, maintenance areas, and stowage. Since the aircraft turn-around time doesn't drive the sortie rate, only the hangar bay's size was a concern. The initial analysis of alternatives by the hull team indicated that the ship would be weight-limited not volume-limited, so concerns about the size of the hangar bay were considered to be secondary. The configuration decided upon was pit stop type servicing performed in the hangar bay and no aircraft stowed topside.

2. Aircraft Launch and Recovery

The next step in the design was to choose a launch and recovery method. Designing the layout of SEA ARCHER's launch and recovery system was vastly simplified by not having any aircraft parked topside. The first task was to determine if a catapult was necessary and, if so, what type. The SEA ARROW was designed to take off unassisted with 40 knots wind over deck [52], making the no-catapult option a possibility. Eliminating the catapult has numerous advantages including decreased manning, decreased ship's power requirement, decreased volume, decreased weight, decreased cost, decreased structural requirement and stresses on aircraft, and no catapult reset time. The disadvantages of not having a catapult include loss of ability to launch aircraft if dead in the water, decreased range of aircraft, and the need for more sea room due to higher ship speeds. Having a catapult on the other hand, allows the ship to launch

aircraft even while at anchor and if the process can be automated, reduced manning can still be achieved.

The dominating constraint in this decision was determined to be the tight sea-space encountered in the littorals. Having to make frequent high-speed runs is extremely complicated, especially in the littorals where traffic and water depth are always an issue. For this reason it was decided that SEA ARCHER would have a catapult. However, since the aircraft can launch unassisted with 40 knots of wind over the deck and since the ship is capable of speeds greater than that, it was decided to have only a single catapult, with the back-up launching method being the unassisted launch.

Five options were considered for the type of catapult to be used: steam, hydraulic, stored energy rotary drive (SERD), internal combustion catapult powerplant (ICCP), and electromagnetic aircraft launching system (EMALS). Hydraulic catapults and SERD were discarded due to insufficient energy output and prohibitive manning and maintenance requirements. Figure 67 shows the energies capable of being developed by the different catapult systems [53]. The horizontal line shows the energy required to launch a SEA ARROW with zero wind over deck. Though steam launch is a proven method, it is prohibitive for ships with gas turbine propulsion and has the same prohibitive manning and maintenance requirements. ICCP is viable with gas turbine propulsion, but still has prohibitive manning and maintenance requirements. The remaining method, EMALS, was chosen because it had the most to offer with its high power density, reliability, closed-loop control, plus positive impacts on weight, manning, volume, and maintenance.

For aircraft recovery, the current wire-recovery system can be improved by replacing the hydraulics system with the same linear motor technology used in the EMALS. The Navy has designated this the electromagnetic aircraft recovery system (EARS) [54]. The advantages of EARS include high power density, reliability, closed-loop control, reduced weight, reduced manning, reduced volume, and reduced maintenance.

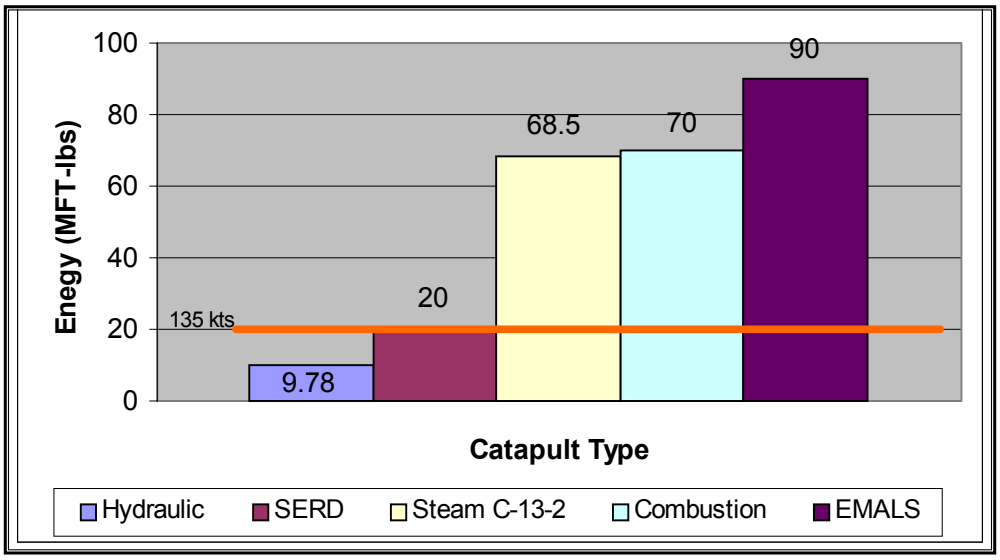

Figure 67 Available Catapult Energies

3. Aircraft Movement

Another manpower-intensive aspect of flight operations at sea, is the delicate ballet of aircraft movement. The distributed aviation concept, by reducing the number of aircraft carried by a single ship, vastly simplifies this complex operation and opens the door for automated aircraft movement. The high wind speed encountered during high-speed ship operations also drives the design towards an unmanned flight deck. With this in mind, the options considered for aircraft movement were: unassisted movement (autonomous aircraft movement), use existing yellow gear, use a rail or tracked method, use robots, or some combination of these options.

When considering the different options it became apparent that to make the system simpler, it was advantageous to combine a robotic and a tracked system. The final iteration of the concept resulted in an aircraft movement system that uses diesel-powered robots on the flight deck and electrical-powered robots guided by a track in the hangar bay. Having the tracked system in the hangar bay reduces the complexity of aircraft movement down to a level manageable by a scheduling computer. The computer can simply forecast aircraft arrangement and necessary movements to relocate any aircraft.

4. Ordnance Handling

The ordnance handling system was changed numerous times throughout the design of the ship. As the design evolved, different systems became more appropriate. Several features were common to all the designs, however. To eliminate the manning necessary to prepare weapons, it was decided that SEA ARCHER would only carry all-up rounds that were finned and in all other manners completely ready for launch. This would then require a special magazine designed to hold finned missiles and bombs. Additionally, the manpower required to move the weapons would be eliminated by completely automating the movement from the rack in the magazine to mounting the weapon on the aircraft.

Two different options were considered for removing the weapons from their storage racks in the magazine: a two-dimensional, translating "retriever," and an articulated robotic arm mounted on a track. To understand the retriever design, picture a honeycomb viewed from the end. A weapon is stored in each cell of the honeycomb. The retriever would move over the face of this honeycomb to the appropriate cell, remove the weapon, and deliver it to the conveyor for transport to the pit stop. The robotic arm idea was similar, except instead of being attached to the face of the storage racks, the robot rides back and forth on a track in the deck as in Figure 68.

Ultimately, the robotic arm system was chosen over the retriever system. Two factors helped make this determination. First, robotic arm technology is already available and in use in industry today, thus reducing risk and cost. Second, structural requirements of storage racks that could support the retriever were, to a first approximation, adding weight and volume to the ship that were unnecessary given the availability of the robotic arm design. Given that the initial analysis of alternatives indicated the design was weight-limited it was decided that the robotic arm design better fit the overall ship system.

The initial ordnance handling system design used conveyor technology to move the weapons through the ship between the magazine (assumed to be deep in the hull) and the hangar bay. As the hull design evolved from a pentamaran to a surface-effect catamaran, the volume available low in the ship decreased pushing the magazines higher

and higher up in the ship. Eventually the magazines ended up in the deck beneath the hangar bay, eliminating the need for a conveyor system. The final design of the ordnance handling system needed only a shuttle to the weapons a short distance from the magazine to the pit stop.

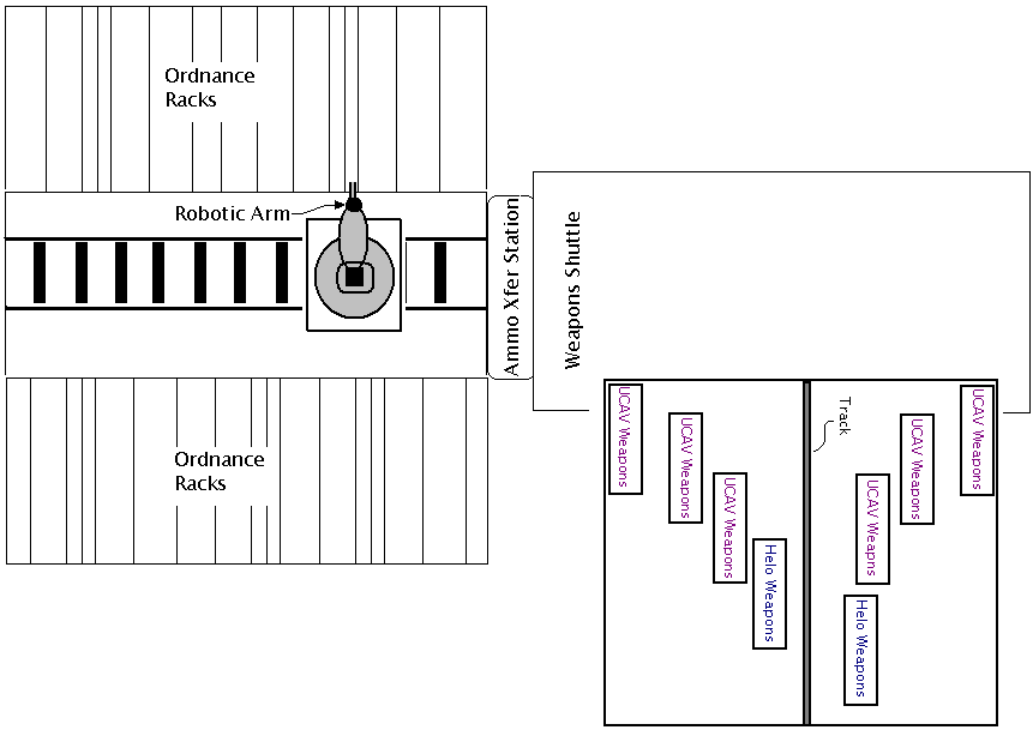

Figure 68 Ordnance Handling System

5. Sizing/Scaling of Systems and Equipment

Having obtained a conceptual design for each of the aviation services, it was then necessary to determine the size, weight, volume, power requirements, etc. of the equipment involved. When possible, existing systems and their parameters were used and scaled appropriately for our application. However, for many of the systems, it was necessary to quantify several of the unknowns in the design, so assumptions were made as necessary. For example, in order to size the magazines, it was necessary to determine how much ordnance would be carried onboard to meet the requirements set forth in the Mission Needs Statement and the Operational Requirements Document. But to quantify the amount of ordnance needed to meet those requirements, it was necessary to make

assumptions about what type of ordnance would be used and an expenditure rate of that ordnance.

Robot Sizing

The towbots were scaled off the SD-2 tow tractor currently used in the fleet today [56]. The SD-2 tractor has the capability to actually lift the nose gear of the aircraft off the ground in case the aircraft is damaged. This capability was traded off to make the towbot smaller and lighter. The assumption was made if the SD-2 didn't have to lift the aircraft it would be half the size it is. Given that the SD-2 can tow up to a 70,000-pound aircraft, and the towbot need only tow up to a 20,000-pound aircraft, a two-sevenths scaling factor was used. Thus, the towbot weight was given by dividing the SD-2 weight by two and then multiplying by the two-sevenths scaling factor, yielding a final weight of 730 kilograms. The trackbots were sized by assuming that if the diesel engine on the towbot were replaced by a track-connector the robot would be ~270 kilograms lighter, giving the trackbot a weight of 460 kilograms. The flight deck firefighting robot was sized by taking a towbot and adding a 760-liter AFFF tank (780 kg), a bulldozer type blade (100kg), and a water cannon (10 kg) for a total weight of 1620 kg. Given their application, the chainbots were assumed to be 115 kilograms.

EMALS, EARS and Elevators

The EMALS was sized using data provided by the Naval Air Warfare Center (NAWC) Aircraft Division Lakehurst. NAWC Lakehurst provided up-to-date estimates of weight, volume, and power requirements for the EMALS system to be installed in CVNX-1. To scale SEA ARCHER's EMALS from the CVNX-1 EMALS, the kinetic energies imparted to the aircraft by the launchers were compared. Using KE = $\frac{1}{2}mv^2$, and inserting the SEA ARROW's design weight and launch speed [52], for m and v, the energy required by the SEA ARCHER EMALS was calculated to be 16 million Joules (16 MJ). Adding a 25% margin for future aircraft growth, the SEA ARCHER EMALS design launch energy was 20 MJ. NAWC Lakehurst gave 122 MJ as the launch energy of CVNX-1 [56], with a stored-energy-to-launch-energy efficiency of 40%. This requires that the EMALS Energy Storage Device (ESD) in SEA ARCHER must store 50 MJ of energy in the 45 second cycle time giving an average power of ~1 megawatt (1

MW) and deliver that energy in a two-second launch for a peak power output of ~10 MW.

For weight and volume estimates, the NAWC Lakehurst team discouraged our original estimate of scaling our EMALS linearly from CVNX-1 EMALS based on power. They suggested that rather than using an uncertain scaling relation, we should just use the sizes of a similar conceptual design they had done for an EMALS system to launch UAVs off replenishment ships. That EMALS design had a shorter length and thus a greater acceleration but had similar power requirements to SEA ARCHER's EMALS. Using the size and weight from that 76 metric ton design, the SEA ARCHER's weight/volume breakdown is given in Table 42.

Component	Volume (m^3)	Weight (kg)
Launch Motor	34	38,000
Power Conditioning Inverter	18	11,400
Power Conditioning Rectifier	7	7,600
Energy Storage Device	23	19,000
Total	82	76,000

Table 42 Weights and Volumes of EMALS Components

The EARS was sized by first calculating the energy dissipated in recovering a SEA ARROW using the landing speed given in Reference [52]. The result was that recovering an aircraft uses just under half the energy of launching an aircraft. Given this, the EARS system was sized as being approximately half the size and weight of the EMALS system: 38 metric tons, ~0.5 megawatts average power load, and 41 m^3 in volume.

The aircraft elevators' power requirements were determined using information provided by Jered Industries, Inc., manufacturer of CVN deck-edge aircraft elevators [57]. The size of the elevator was driven by the desire to keep personnel off the flight deck. This meant preparing the helo for launch (i.e. unfolding pylon and rotors) in the hangar bay. Therefore, the elevator must be able to accommodate an unfolded SH-60 helo. Using the size elevator necessary to meet this requirement and the load weight the elevator would be required to handle, the data provided by Jered Industries was used to

determine the installed power requirements of SEA ARCHER's aircraft elevators: 250 HP (186 kilowatts).

Reconnaissance UAV

The only requirements specified for SEA ARCHER's UAV were that it perform a reconnaissance mission and that it weigh approximately 5000 pounds. Given no other data a parametric study of all existing UAVs was done to determine the size, weight, and payload of SEA ARCHER's UAV. An internet search on UAVs produced an extensive database maintained by NASA's Wallops Flight Facility [58]. Using the data provided in this database, graphs of range, payload, and wingspan vs. weight were generated. A linear relationship was assumed in all cases and the parameters for a 5000-pound UAV were read directly off the graphs. The results were a 5000-pound UAV with a range of 1200 nm, a payload of 500 pounds and a wingspan of 43 feet.

Ordnance Payload and Magazine Sizing

The magazine sizing has previously been discussed. The only additional information worth noting is that the level of detail of magazine sizing went as far as determining the type, numbers and location of weapons in each magazine. This was necessary to determine the size of the magazine since the ordnance racks are specially designed to hold each weapon. To make sure it was possible to evenly balance the weapons loadout, the number of racks holding each type of weapon was determined. The breakdown of the magazine loadout is given in Table 43.

	Port Magazine			Starboard Magazine		
Weapon	# of racks	# in each rack	Total # in magazine	# of racks	# in each rack	Total # in magazine
JSOW	2	7	14	3	7	21
HARM	13	3	39	13	3	39
AMRAAM	4	6	24	4	6	24
Penguin	1	5	5	1	5	5
Sidewinder	6	5	30	6	5	30
Mk 54 Torpedo	1	7	7	1	7	7
Maverick	12	5	60	12	5	60
JDAM	10	8	80	10	8	80
Hellfire	9	9	81	9	9	81

Table 43 Magazine Loadout

E. COMBAT SYSTEMS

1. Radars

Volume Search Radar

The U.S. Navy released a Radar Roadmap in 1999 to call for a greater commonality of radars across ship classes The VSR selected for SEA ARCHER was the same radar as that proposed for the DD21 program, CVNX and possibly the upgrade radar for LPD-17.

Current research does not provide a size requirement for such a radar, requiring certain assumptions to be made. It was assumed that an early detection of a supersonic aircraft is critical to allow the SEA ARROW to engage the target and prevent it from releasing its missiles. Furthermore, it is assumed that the ASCM has a range of 120 km and it takes 6.5 minutes for a SEA ARROW to scramble from SEA ARCHER and fly to 100km and fire its missiles to engage the enemy aircraft. Then a supersonic aircraft must be detected at –

Maximum Detection Range = Speed of enemy aircraft (Mach 1)× 6 minutes + 120 km

= (343 × 6.5 × 60)/1000 + 120

= 253 km

Assume - Aircraft radar cross section = 5 m^2,

Radar Frequency = 2 GHz (L band radars are between 1-2 GHz)

Probability of Detection, $P_D = 0.9$

Probability of False Detection, $P_{fa} = 0.01\%$

$S_{min} = 1 \times 10^{-12}$

Peak Power = 63 dB = 2 MW assumed

Since,

$$\text{Maximum Detection Range} = \sqrt[4]{\frac{P_p G \sigma A}{(4\pi)^2 S_{min}}} \qquad (1.1)$$

Therefore the size of the antenna will be 3.5 m by 3.5 m large.

This figure is only a rough estimation of the VSR and is not comprehensive. It provides a rough installation guide for the platform and is not purported to be the actual system.

Multi Function Radar

Similar to the VSR rationale, the Multi-Function Radar (SPY 3) program initially slated for the DD21 program, was selected as the radar of choice for SEA ARCHER. The MFR is to be also installed on the CVX, with studies into the feasibility for retrofitting it on LPD-17. Thus it would be prudent that a future sea combatant utilize common sensor systems and obtain better costs savings and easier integration across all platforms (for instance when CEC is implemented). Sizing was obtained from NAVSEA and is shown in Figure 69The system was designed for 3 planar arrays with 2200 elements on each array, since it was decided to place all the arrays at the side of the ship, the number of arrays had to increase to ensure proper 360° coverage. Consequently, the weight of the arrays was increased from 7700 kg to 12000kg. This weight increase considered that extra equipment that would be required to facilitate the operation of the radar compared to locating all the sensors in one location. The number of equipment enclosures had to be increased to provide for the heat exchangers and auxiliary power, while the size of each equipment enclosure was reduced as it had only to maintain two planar arrays instead of three.

Since the specifications of the system are classified and are still being developed a rough order of magnitude calculation was performed to ascertain the approximate detection range of the system.

Assume - ASCM radar cross section = 0.05 m^2,

Radar Frequency = 10 GHz (X band radars are between 8-12 GHz)

Probability of Detection, $P_D = 0.9$

Probability of False Detection, $P_{fa} = 0.01\%$

$S_{min} = 1 \times 10^{-12}$

$$\text{Antenna Gain } G = \frac{4\pi A_e}{\lambda^2} \qquad \left(\text{where } A_e = \text{ Area of Array } \& \ \lambda = \frac{c}{f}\right)$$

$$= \frac{4\pi \times 1.59 \times 0.96}{\left(\frac{3\times 10^8}{10\text{GHz}}\right)^2}$$

$$= 21321.52$$

$$= 10\log(21321.52)$$

$$= 43.29 \text{ dB}$$

Peak Power = 66 dB = 3.981 MW (from SPY 1 data)

$$\text{Maximum Detection Range} = \sqrt[4]{\frac{P_p G \sigma A}{(4\pi)^2 S_{min}}}$$

$$= 71.5 \text{ km}$$

Since, the missile range for the Super SSM is only 30km, this range for weapon control is sufficient. The extra range will allow for target tracking.

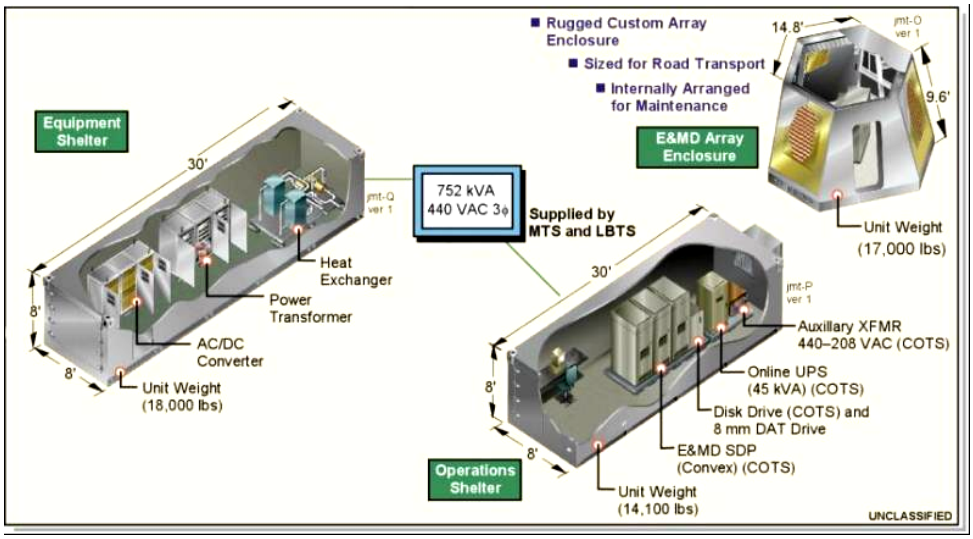

Figure 69 Size and Weight for SPY 3

Radar Coverage

It can be assumed that the MFR and VSR have a maximum azimuth spread of 120º; with four planar arrays for each of the radar systems, this would provide the adequate 360 ° coverage required for situational awareness. Nonetheless, blind zones still occur, as shown in Figure 70 this zone has the maximum distance of 120 m from the

ship centerline. This minimum range is deemed acceptable and is less than a ship's length. The problem associated with this spread is that maximum detection range at the extremities is reduced to almost half the calculated detection ranges. This can be overcome by increasing the power output of the beam. More detailed analysis with trade off studies would have to be made to optimize the solution for this class. It would require a comprehensive threat document and detailed mission requirements, and is beyond the scope of this study.

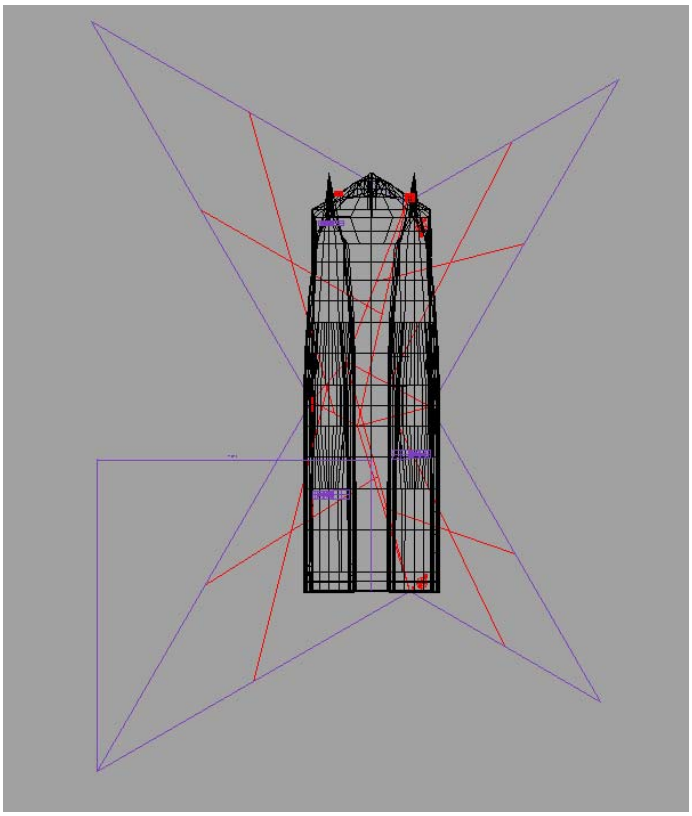

Figure 70 SEA ARCHER Radar Blind Zones

2. Vertical Launch System

A deliberate decision was made to install a vertical launch system rather than trainable launcher system. It was based on the following reasons

- Most Optimum coverage – if trainable launchers (like Mk 21) were to be employed, it would require installations either port/starboard or fore/aft to provide 360° firing angles. The number of missiles that can engage a threat will also be dictated by the number of missiles facing the specific direction. If a saturation

attack occurs in one specific direction, it will quickly overwhelm the number of available missiles. VLS will not have directional issues with regard to missile firing; it will be able to engage threats in any direction

- Lower RCS - VLS will be flush with the deck and thus does not affect the overall RCS of the ship. A trainable launcher will either have to have RAM material or be shaped to reduce the RCS. If this option was not viable and the system was to be enclosed within the ship, the firing angles of the launcher would be reduced the minimum firing range.

Nonetheless, there were impacts on utilizing the VLS compared to trainable launchers. The main issue was the reduced firing range of the SSSM; vertically launched missiles have inherently longer minimum engagement ranges, as the missile has to vector itself towards the target. The vectoring has to take place within a finite distance, whereas trainable launchers do not experience this minimum turning range. This risk was deemed acceptable as SSSM was a long range weapon system and short range targets will be taken up by the FEL system or SCGS.

Increased costs are another factor when comparing VLS against trainable launchers. Historically, trainable launchers are cheaper than VLS but the design principles laid out dictate that survivability have precedence over cost.

Finally, installation of VLS will be more difficult as it requires larger installation volumes. The SEA ARCHER hull design has the necessary volume and the installation can meet the allocated combat spaces. Moreover, if it is decided that the missile payload should be increased to meet more enemy targets, SEA ARCHER will have adequate space and weight to increase the number of launchers.

Super Sea Sparrow Missile

The system was selected as the optimum solution for SEA ARCHER as long-range missile engagement will be handled by SEA LANCE II and SEA ARROWs. The sizing of the vertical launchers was based on the Sparrow missile and was not sized for Standard Missiles or Tomahawk missiles like a Mk 41 Vertical Launch System.

To optimize space and meet threat scenarios, the SSSM had to have dual modes of engagement. Future surface threats are envisaged to be heavily sensor dependant i.e. weapons cannot be fired without fire control systems or radars. Thus it will not be necessary for a target to sink to remove its effectiveness from the combat scenario. The SSSM warhead (40.5 kg) will be sufficient for a mission kill, as compared to a Harpoon warhead at 220 kg.

The system has to be active homing rather than semi-active homing to counter saturation attacks. Semi-active homing would require terminal guidance from the MFR system, which will prevent it from engaging more targets when compared to active homing. The impact of this is the cost of the missile will increase but this is deemed necessary for the SEA ARCHER's requirements.

The missile payload will allow it to engage a total of 32 separate targets simultaneously. As in all weapon systems, there will never be a perfect kill probability. For an ASCM engagement, if a "Shoot-Shoot-Look" strategy is employed, a total of 16 targets per SEA ARCHER can be destroyed by the SSSM.

3. Free Electron Laser Weapon System

The following choices were analyzed for the inner-layer defense for SEA ARCHER –

- Phalanx Type Close In Weapon System
- Railgun concept
- Rolling Airframe Missile
- Directed Energy Weapon – Free Electron Laser

The problem associated with Phalanx is the extremely short engagement range, typically at 1000m. At these distances, even if the incoming missile has been hit by the 20 mm rounds from Phalanx, the danger still exists that the missile has sufficient inertia and remaining components to damage the ship. This has been recognized and as a result,

all current and future USN ships will be upgraded to fire the RAM system to extend the engagement range.

A railgun concept utilizes electromagnetic rails to launch projectiles with a muzzle velocity of 4 km/s. The extremely high muzzle velocity will ensure a higher hit probability against incoming ASCMs as target prediction errors within the fire control system will be minimized. Target kill will also be enhanced as the terminal velocity will high enough to ensure target destruction. In spite of these benefits it will still be a weapon that will not have long range capability against incoming ASCMs; target engagement range will still be close range and approximated at around 3 to 4 km. At these ranges, ASCM can still perform maneuvering profiles to throw off the fire control prediction and mislead the weapon system.

Therefore, two possible alternatives were narrowed down to consider the possible implementation of an inner layer defense- RAM and FEL system.

The table below provides an overview between the current point defense systems in the USN inventory and the FEL system

	FEL	RAM
Range	5 km	9.6 km
Number of Targets	2 sec per target	10
Cost per engagement	$2.24	$0.732M Assume 2 missiles per engagement
Unit Cost	$55 M	Launcher =$7.924 M Missiles = $7.686 M Total = $15.61 M

Table 44 Comparison of Inner Layer Defense Systems (from [23] & [25])

The range of RAM is based on the rocket's motor capability and not the actual performance range. This will be tied closely with performance capability of the detection, acquisition and tracking of the incoming ASCM with respect to the ship radar system and the RAM seeker head.

The 10 targets that RAM can engage is an estimation using the Mk 49 21 cell Launcher, where two RAM missiles will be fired against each incoming subsonic ASCM.

The two missiles fired are to ensure high kill probabilities and to counter any possible missile failures. The number of engageable targets will decrease if the incoming ASCM is supersonic as more missiles may have to be fired to ensure a kill. This figure is only a rough estimate based on 3 seconds of firing at 4500rpm per target. The number of targets for FEL will be based on the method of implementing the power supply to the system. If it is linked directly to the shipboard supply, then the number of targets will only be limited by the available power. If storage devices are used (like flywheel or capacitors), it will be dependant on the power density of the device.

The cost of engagement is linked to the number of possible targets engaged. As the estimated cost of one RAM missile is $0.366M [25], two missiles will cost $0.732M. FEL cost is linked to the amount of fuel consumed to generate the requisite power for 1 engagement. The $0.45 was obtained using the specific fuel consumption of an LM2500+ Gas turbine engine that can generate the requisite power for this application. If 1MW of laser power hitting the target for 2 seconds is necessary for killing the target and it is further assumed that the FEL system has 10% efficiency in converting the power supplied to laser power. It will require 10MW for 2 seconds from the LM2500+. This translates to 20 MJ, the turbines may only be 20% efficient. The final energy required would then be 100MJ, since the specific fuel consumption for LM2500+ is 235 g/kwh, consequently 6.5 kg or 2.15 gallons of F76 fuel is consumed. Given that the cost of F76 fuel is $1.05 per gallon, the cost of 1 engagement is only $2.25.

The $55M for FEL is an estimate, and though the unit cost is higher than RAM or Phalanx, the total operating cost has yet to be factored into the total life cycle cost. The FEL will not require replenishment or a stockpile of missiles and projectiles but only be dependant on shipboard power supply. Thus the high capital cost will be offset by the reduced operating costs.

FEL Advantages

A FEL weapon employed to provide inner-layer defense would enhance ship survivability when compared to the RAM system. This system will have a proposed

effective range of 5000 meters and it will employ laser power to defeat a missile by structurally destroying sections of the target. The advantages will be -

- Almost zero time of flight – A light beam will only take 16.7 microseconds to reach 5000 meters. In contrast, RAM will typically require 7.3 seconds to traverse the same range. Thus, a FEL system will sidestep all the problems associated with target position prediction and ASCM maneuvers.
- True Line of Sight Weapon – The FEL system will require a beam director to channel the light to the target; essentially this will be high performance Electro Optical (EO) system. This optical system will be providing the tracking function against any targets. Thus, when the system has a proper lock onto an ASCM, the FEL weapon will be firing at the same point as the tracking system. The other benefit is to allow the operator to ascertain whether the target has been effectively destroyed.
- No extra supply requirements – Currently, RAM has 21 missiles in a launcher and a certain number stored for replenishment. Similarly, Phalanx has 1470 ready-to-use rounds, with extra rounds stored for spares. The FEL weapon will utilize shipboard power supply for its engagement and will be limited only to the amount of power available. It will not require extra supplies to support engagements, as replenishment will not be required.
- Quick reaction and reengagement time – In littoral warfare, a possibility exists that the enemy will be able to remain undetected until he is able to fire missiles at close ranges. This cuts down the reaction time of all combat systems to engage the threat. The negligible time of flight for the beam will allow target destruction at further ranges than RAM. The FEL system only requires an approximate dwell time of 2 seconds for a target kill. This coupled with the almost zero time of flight, will allow for quick reengagement of other targets.

- Low utilization cost – As mentioned, the cost of the light beam is coupled with the utilization of shipboard power supplies. The initial cost of acquiring the complete system will be inherently more than that of a missile system. However, the total life cycle cost may be lower than a missile system as the replenishment, training utilization, and the necessity for stock piling missiles is avoided.

Time Engagement Analysis

Another important methodology to establish the effectiveness of a weapon system is to analyze the time engagement scenario against targets; this will assess the reaction time of the system, the number of targets it can engage and the range of interception. In any engagement analysis, the following sequence with respect to the target has to occur -

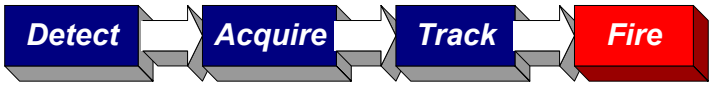

Figure 71 Combat Engagement Sequence

The sensor system has to first be able to detect the target, subsequently an acquisition process has to follow. This phase also differentiates whether the target is an enemy or friendly force. If it has been assessed to be a foe, the sensor suite would track the target, and require the system to predict target motion and calculate fire control solutions before firing a weapon against it. This chain of events occurs both in radar and optical systems. To have an estimation of the maximum possible detection range using a radar system against a sea skimming ASCM, the following equation is used -[26]

$$H = \sqrt{0.672}\left(R - 1.22\sqrt{h}\right)^2 \qquad (3.1)$$

where H is target height in feet, h antenna height in feet, R is the radar range in nautical miles.

This equation is plotted with a target at different heights, while varying the antenna heights. It can be seen from the plots that target height plays a critical role in the radar horizon, if a target is moved from 5 feet to sea level, the maximum radar horizon is reduced by 5km –

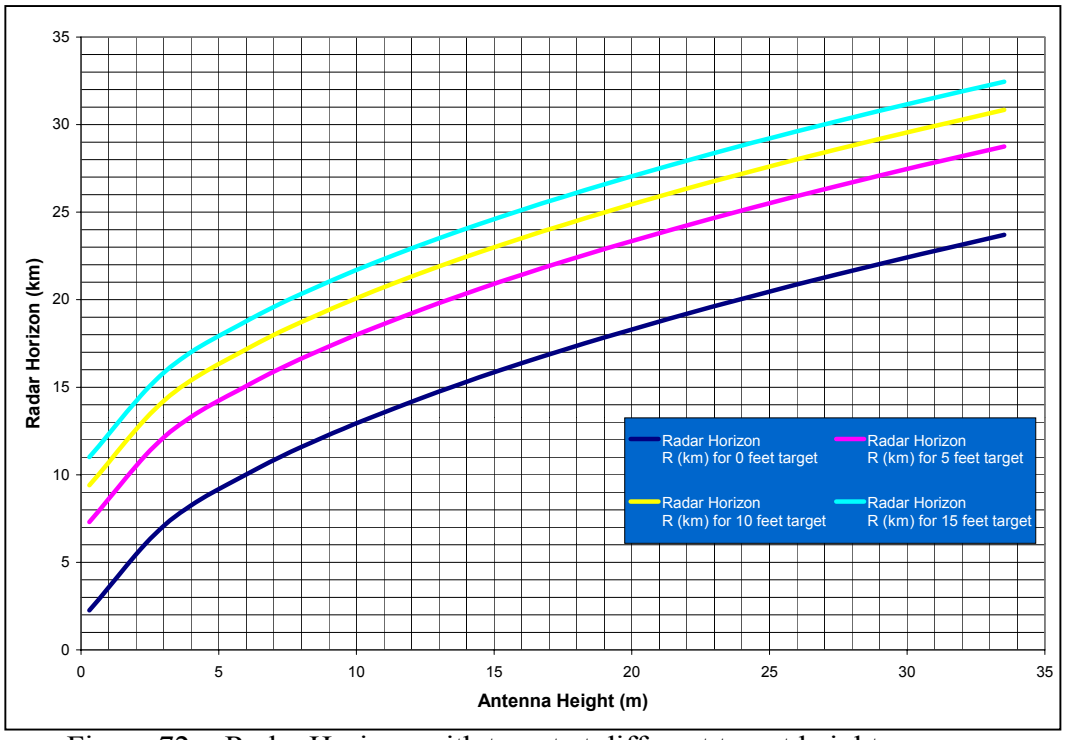

Figure 72 Radar Horizon with target at different target heights

Assuming a radar is placed on SEA ARCHER at a height of 20m above sea level, the estimated radar range will only be about 23 km for a 5 feet target height. This range is the maximum physical distance in which the radars can reach the ASCM. It does not consider the signal to noise ratio capability of the radar system or the sea clutter noise created by flying near the surface or even the radar cross section of the target. Any of this will severely affect the performance of the detection range. To have a sense of scale, a typical RCS of ships range from 3,000 sq m to 1,000,000 sq m while missiles are only 0.5 sq m. It can then be inferred that the detection range for a stealthy sea skimming missile may be even lower than expected. Due to the sensitivity of this information, detection ranges for various targets are always classified. Therefore, the detection ranges are educated guesses.

To proceed with the analysis, the following assumptions are made -

Speed of ASCM	Mach 2 (686 m/s)
Speed of RAM	Mach 2 (686 m/s)
Detection range of ASCM	10 km
Time between 2 RAM launches	3 seconds
Time to detect ASCM	1 second

Time to acquire ASCM	1 second
Time to track ASCM	1 second
Time to Launch RAM	1 second
Total	4 seconds

Table 45 Table of ASCM assumptions

The detection range of 10km is an estimated distance based on the size of the target and sea skimming profile the ASCM will perform. As for the time between launches being 3 seconds, this was obtained from a video of RAM firings against ASCM[27]. Time lag exists between 2 RAM missiles because firing simultaneously will cause the rocket blast to affect each other. Currently, the time between each launch has to be long enough so that the plume from the first missile does not affect the IR seeker of the second missile. Based on the assumptions, a time engagement sequence was performed below

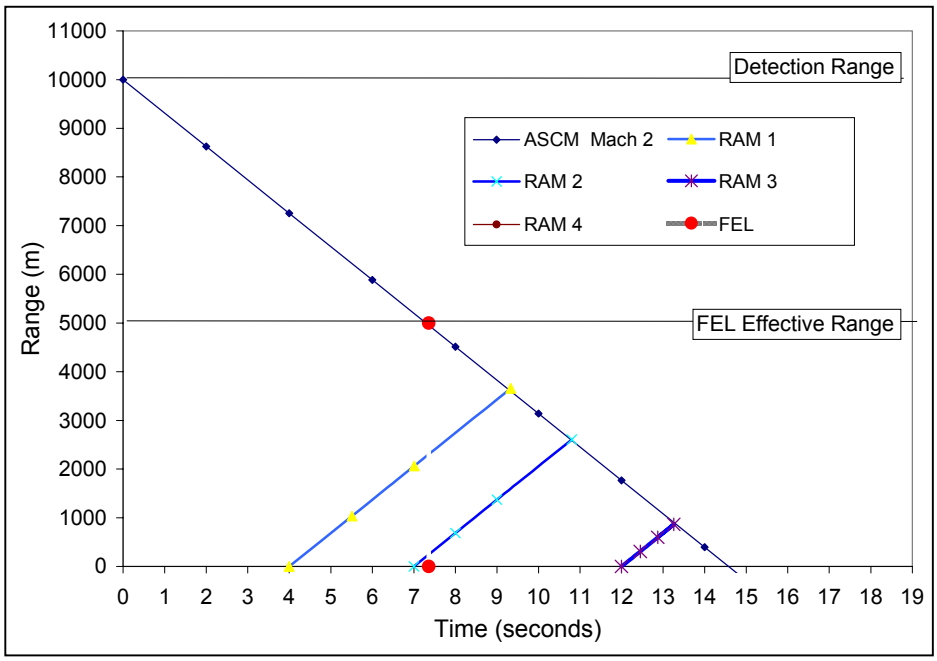

Figure 73 Time Engagement Analysis for Mach 2 ASCM

It can be seen from the figure above that the FEL can intercept the ASCM at 5000m, with more than 7 seconds available to track the incoming target. With a two second dwell time, the ASCM will be destroyed by 3628m. If the "Shoot-Shoot-Look" strategy is employed, the first RAM is launched at 4 seconds and intercepts the ASCM at 3656m. If the target is not destroyed, the second interception range will be at 2606 m. A third

possible intercept occurs at 800m given a one second “look” before launching the third RAM.

Another scenario would be to increase the speed of the ASCM to Mach 3 and the rest of the parameters remain the same. The FEL can fire when the ASCM reaches 5km as there will be 5 seconds for the system to detect, acquire and track. The RAM will fire again at 4 seconds and intercept the missile at 2440m. The second missile intercepts 1255 m. There will be no time left for a third launch of RAM if the previous 2 missiles failed to destroy the target as the Mach 3 ASCM will have hit the ship.

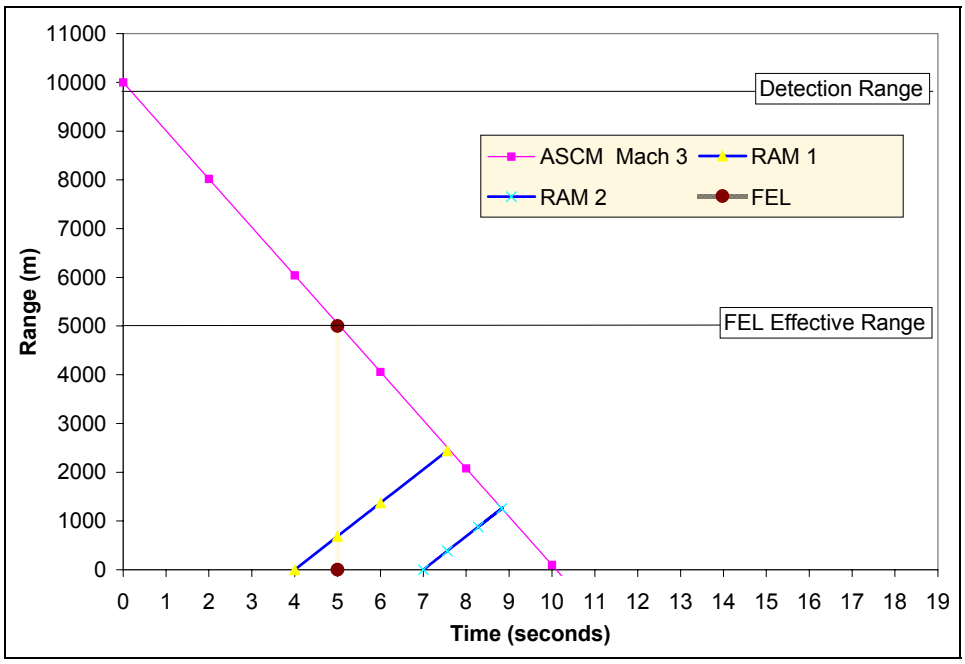

Figure 74 Time Engagement with Mach 3 ASCM

It can be observed in both engagements that FEL will allow the target to be destroyed at longer ranges than RAM. The lethality of the FEL will also ensure that there will be no requirement for reengagement of the target. For a Mach 3 ASCM engagement, the danger is that if the RAM missiles do not destroy the target within two shots, the ASCM will be able hit the ship.

Another inference is the importance of detection range of the ASCM. If it is reduced further, the reaction time of the combat system must be shortened further. When a missile is used to counter the ASCM, there may not be adequate time for the missile to reach the target as it will take a significant time of flight compared to a beam of light.

In littoral warfare, this can weaken missile defense as enemy missiles have the possibility of being fired at close ranges in the congested waters. This significantly reduces the reaction time for all weapon systems. In these scenarios, the FEL will be able to achieve greater success.

Target Lethality

A quick way; to estimate of the amount of energy required to destroy a missile is to assume that a 3 cm penetration with a 10 cm radius spot size would be sufficient for destruction. If it is further supposed that the material is made of aluminium and the melting of the aluminum is assumed to be the kill mechanism, then the energy required would be :

$$\text{Melting Energy} = \rho V \left[C(T_m - T_o) + \Delta H_m \right] \qquad (3.2)$$

where

		Aluminium Properties
ρ	Mass Density	2.7 g/cm^3
V	Volume of material	942.5 cm^3
C	Specific Heat Capacity	896 J/kg-K
T_m	Melting Temperature	933 K
T_o	Ambient Temperature	300 K
ΔH_m	Latent Heat of Fusion	4×10^5 J/kg

Table 46 Properties of Aluminum

Using the material properties of aluminium listed above, the energy required is 2.461 MJ. If the time for engagement is fixed at two seconds, the irradiation would then be 2.461/2 = 1.23 MW of beam power.

These destruction mechanisms have not considered thermal conductivity, target reflectance and the impulse effects on the target due to rapid temperature changes.

The effectiveness of the damage mechanism is also dependant on the beam, pulse duration, wavelength, the material and the finish of the target surface. The absorption for each material varies for different wavelengths. For instance, the absorption of a ruby laser light at 694 nanometres is 11 % for aluminium, 35 % for light coloured painted metals and 20% for white paint. Whereas, the corresponding numbers for a CO_2 laser (at 10,600 nanometres) are 1.9%, 95% and 90%. For many materials, the surface is blackened quickly so that light is absorbed more readily than indicated by the low power absorption.

FEL System Configuration

An FEL installed onboard a vessel would have to consider system power requirements, weight, sizing and radiation hazards. To optimize all concerns, it appears desirable to use an energy recovery concept in the FEL. This will ensure a higher wall-plug efficiency reducing the required input power. Electron beam bends will also have to be employed rather than straight configurations to enable a more compact shipboard installation. Concept studies have shown that straight configurations for the electron beam would require a length of 26 m, while bends would reduce the length to about 12 m. This is especially important in shipboard installations as it will minimize the number of bulkheads the FEL system has to traverse.

The proposed architecture is shown in Figure 76Electron beams are initially injected into the linear accelerator with 7 MeV energy. A superconducting RF (SRF) linear accelerator (LINAC) then increases the electron beam energy to 100 MeV along its 6.7 m path. The electron beam is then turned by a series of bending magnets to be injected into the wiggler. The wiggler will have an energy extraction efficiency of approximately 2% and produce a laser beam of 1.5MW. A second set of bending magnets will take the residual electron beam from the wiggler and transport it back to the accelerator where it enters out of phase with respect to the accelerating fields. As a result, the energy from the decelerating electrons is then transferred back into the RF fields, which in turn are used to accelerate subsequent electron pulses. The decelerated electrons retain about

7MeV of residual energy which is transferred to the beam dump for dissipation. The optical cavity, where the light beam is amplified, is 12 m in length.

The light beam from the optical cavity will be guided through a series of mirrors to either one or both of the two beam directors. Adaptive optics will also be used for these mirrors to handle beam fluctuations from ship vibration and motion.

This configuration dramatically reduces the radiation from the beam dump as the residual energy will only be at 7MeV. If a energy recovery is not used, the electron energy leaving the wiggler would be at 100 MeV, making it difficult to prevent the materials in the beam from generating neutron radiation. Shielding for neutron radiation is much more extensive.

The complete system will be installed at the center of the ship to minimize the effects of hull flexure on the beam transport system as shown in Figure 75.

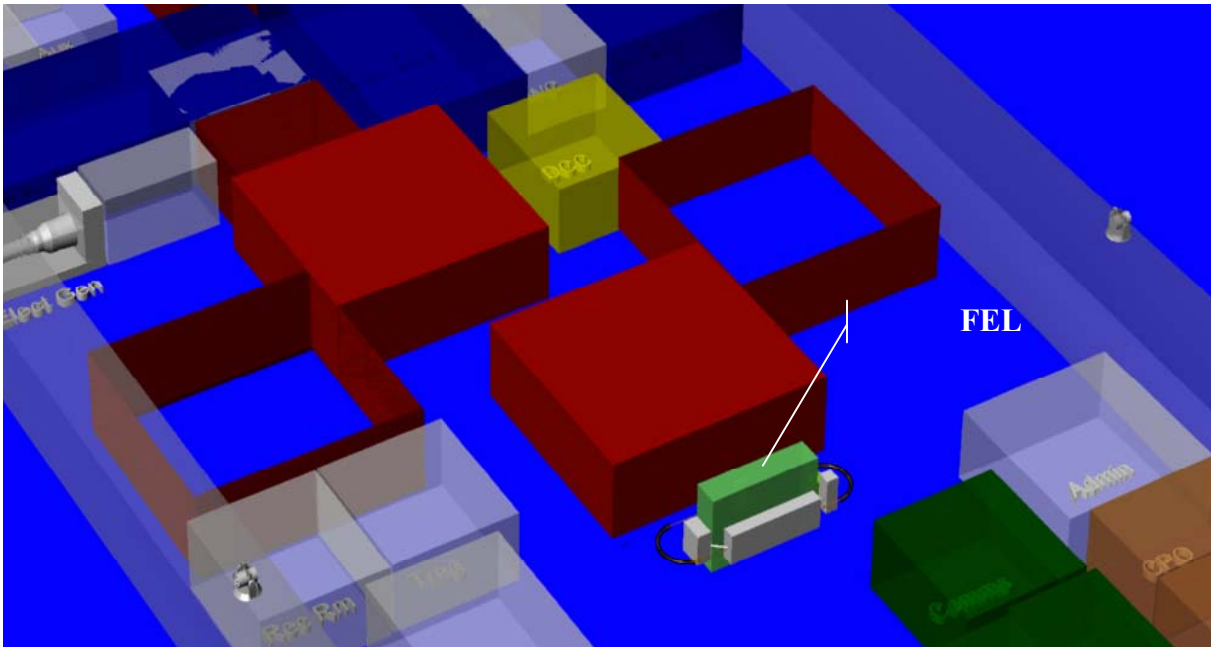

Figure 75 FEL System Location

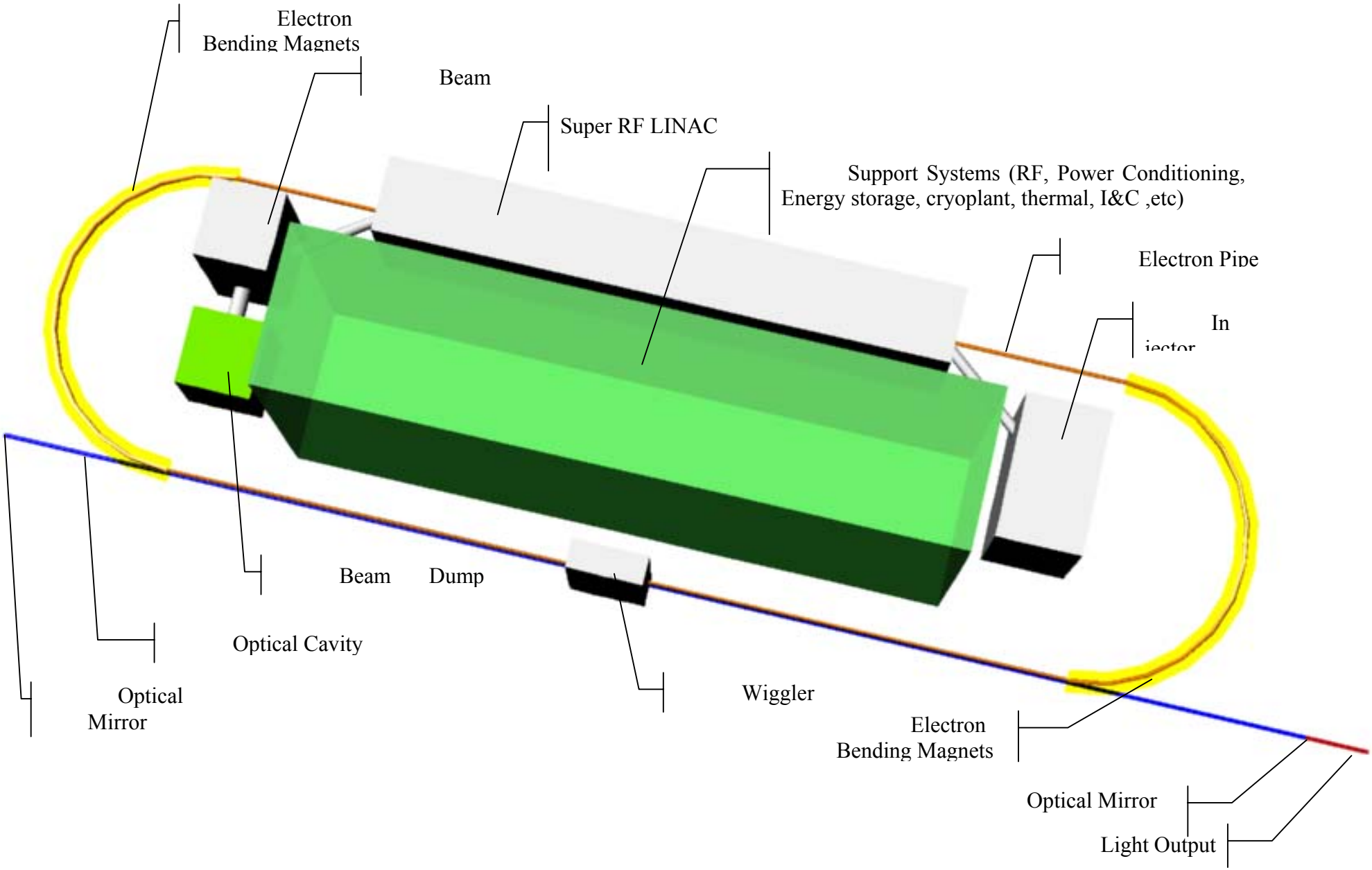

Figure 76 FEL System Architecture

Beam Director - This 2-axis system will direct the 1.5 MW beam output. The exit mirror radius will be around 0.3 m, which is larger than the calculated exit mirror radius of 0.13m that provides a 0.1m size spot radius on the target. This increase is reserved for a tracker system that uses the outer annulus of the exit mirror. An aperture-sharing element in the high power beam path ensures that it would be possible to track the target visually even when firing the beam laser. Such technology is already employed in the MIRACL program and by the SEALITE Beam Director. High power density mirrors will employ adaptive optics to minimize turbulence effects.

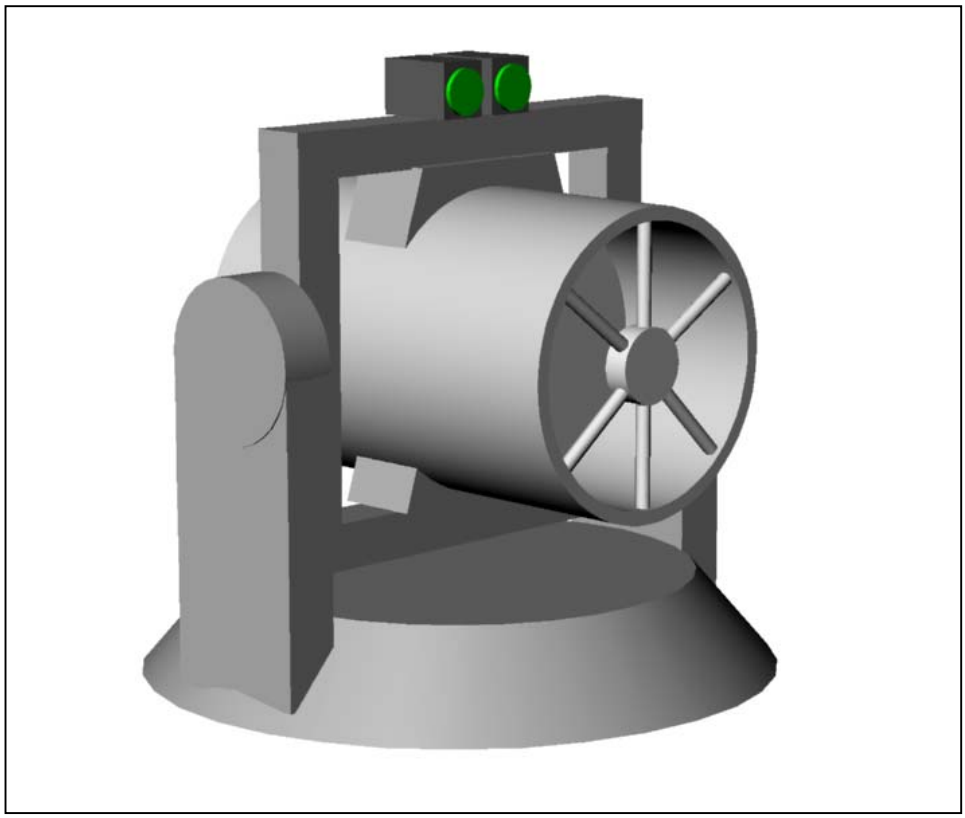

Figure 77 Beam Director for Sea Archer

The beam director will also have a separate independent infra-red camera operating in the 3 to 5 μm on top of the beam director. This will provide target detection and cueing for the beam director itself. It allows the beam director to maintain multiple target track profiles while the director is firing at a specific target.

The beam director will require a high slew rate to engage crossing targets. If a Mach 2 crossing target at 500m is envisaged, it translates to a slew rate of 82 degrees/s. This will not be a difficult requirement to fulfil as gun systems in fleet today can perform slew rates up to 140 degrees/s.

A major requirement for the targeting of the system will be the tracking accuracy of the beam director. There must be minimal dispersion errors in tracking as the beam would then be misdirected. For engaging missile targets up to 5000m, the dispersion error has to be less than 0.06 mrad, assuming a typical missile diameter of 0.3 m, to ensure that the beam is held on the target. Though it is more stringent than current naval tracking systems (for example, optical systems and fire control radars), the tracking system has been proved viable by the SEALITE Beam director and the Army's Tactical High Energy Laser System. The difference would be the pitch and roll of the ship.

A typical engagement sequence for the FEL system would begin with the initial detection of incoming threats from the sensor suites onboard SEA ARCHER. This encompasses the Multi-Function Radar, Volume Search Radar, Infra-Red Search and Track and Electronic Warfare systems. Once the target has been identified and classified as a threat, the combat system will cue the appropriate beam director to the proper elevation and bearing. The wide FOV of the camera on the beam director will perform quick scan and acquire and track the target. This allows the system to have sufficient resolution for the beam director to track the target. Furthermore, the outer annular exit mirror can perform visual confirmation of proper target tracking. Firing can then be automated or commanded by the operator once the target has reached the firing range. This entire sequence of cueing from the sensors to tracking of the beam director should be performed in 2 seconds or less.

Multiple tracks should be maintained by the wide FOV infrared camera to ensure that a target file with the proper resolution is maintained by the FEL system. That is the reason why the camera has independent movement from the beam director itself. Subsequently the FEL can quickly engage another target when the first target has been destroyed.

The locations of the beam directors are at the port and starboard sides of SEA ARCHER. This will be the most advantageous position as the hull flexure for a ship will be the lowest at the centre of the ship. Also, a beam transport system through the length of a ship would be unnecessary as the FEL system is co-located at the centre of the ship. The beam director itself has been placed on a pedestal that provides a 180° firing arc. When the system is on standby, an automatic cover would protect it. Firing sequences can commence when the covers is recessed into the ship as shown in .

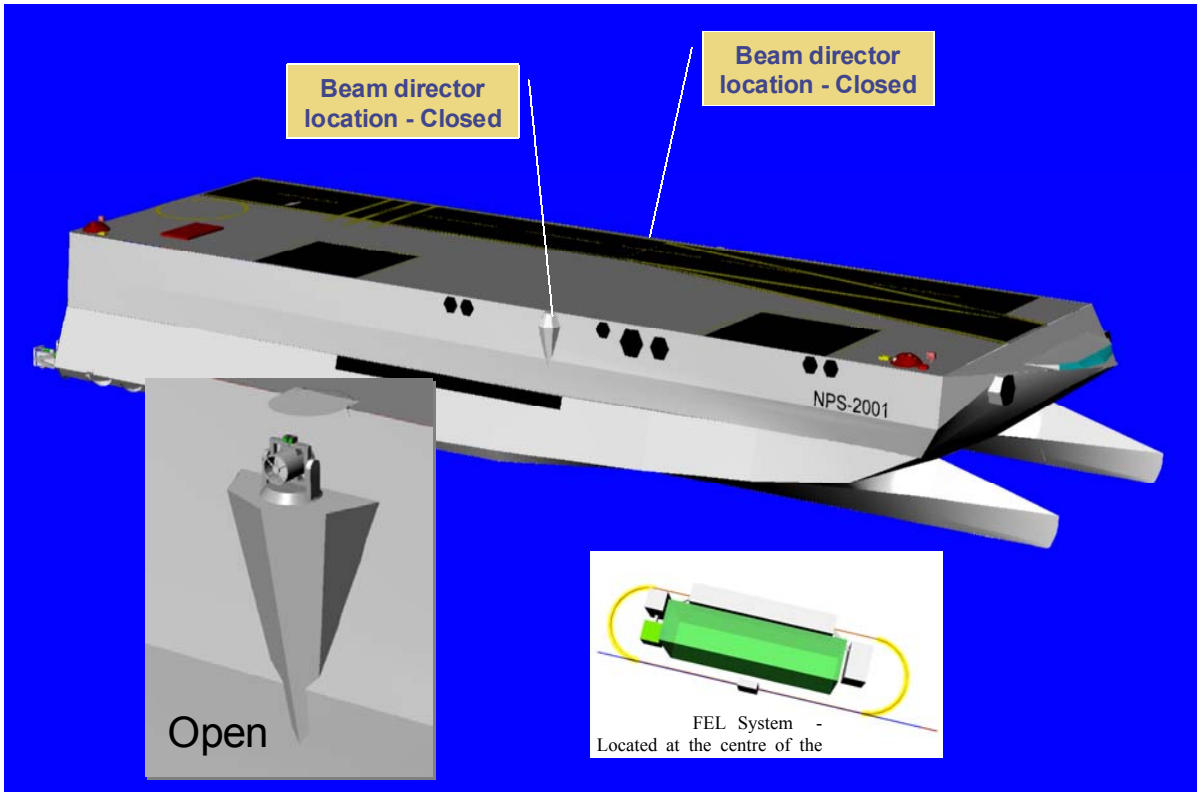

Figure 78 Beam Director Location

Prime Power Generation

It has been frequently mentioned that the amount of power required for an FEL system to effectively engage missile targets require is approximately 10 MW.

The Sea Archer prime power design did not implement an IPS design but rather a hybrid version. The reason was due to the extremely high power requirements to drive the ship to 60 knots. Dedicated turbine generators were necessary to provide the propulsion for the water jet engines. Other generators were required for the blowers to inject air into the air cavities it operated as a Surface Effect Ship (SES) at high speeds.

Nonetheless, the power requirements for combat system was initially sized based on a 1.5 MW FEL weapon drawing 10 MW of power with 1 MW of extra power supporting the cooling systems and other ancillary devices. It was decided that the requirements for direct power generation for the FEL in the Sea Archer was not the optimum solution as the increase in power draw from 1 MW for a standby mode to 10 MW almost instantly would affect the other shipboard systems. Therefore, storage devices were deemed a more attractive solution for this design.

Energy Storage devices - Energy storage devices like flywheels and capacitors provide an alternative method to power the FEL system. To ascertain the *TOTAL* energy required for the FEL weapon system, it may be prudent to assume that such a weapon system should at least handle the same number or even more targets than a RAM system. As mentioned, the number of targets that a single RAM system can engage is supposedly 10. A standard platform installation usually has two RAM systems, the total number of targets that can be engaged before reloading is then 20. To destroy a missile target the 1.5 MW beam would need 2 to 3 seconds of irradiation. Since, the efficiency of the system has been assumed at 10%, the total energy required for 20 targets is then 400 to 600 MJ.

Modern flywheels have energy densities of 36 MJ/m^3 and 47 kJ/kg, this translates to approximately 11 m^3 in volume and weighing 8500 kg. As mentioned previously, the advantage of flywheels over direct power generation is that the power is made available instantly and would not affect other ship loads when the FEL system is operating.

Charging the flywheels would be performed by any shipboard power supply. In the case of Sea Archer, the shipboard generators would produce a total of 82.2 MW. Of this amount 4 to 8 MW may be drawn to charge the FEL system. This takes 50 to 100 seconds to have a complete charge of the flywheels. The system would then be ready to fire another set of 20 targets or 60 seconds, if necessary. This is extremely noteworthy as a missile system will not be able to fire at such a short notice once all missiles are expended. It would take a substantial amount of time to reload the missiles before it is operable.

Capacitors offer another avenue for storage of power, similar to the flywheels and it can also be instantly discharged when required. The estimated power density of modern capacitors place is 39 MJ/m^3 and 30 kJ/kg, which provides an installation of 10 m^3 and 13,300 kg for the capacitor banks. The advantage of capacitors over flywheels is that they afford a combat system graceful degradation in effectiveness. The number of capacitor banks required would be numerically more substantial than the number of flywheels desired; if a failure occurs on single flywheel it would reduce the amount of power available significantly. Conversely, failures of a few capacitors would only reduce the overall available power by a lower percentage. The disadvantage of capacitors would be the added complexity of maintaining more components with an increased weight. The design philosophy of Sea Archer gives survivability prime importance; capacitors would allow for graceful degradation when components fail and thus ensure higher survivability as the FEL system can still function, albeit at a lower output. Hence, the choice of for energy storage would be capacitor banks even though the weight is 60 % heavier. The prime power layout is shown in Figure 79.

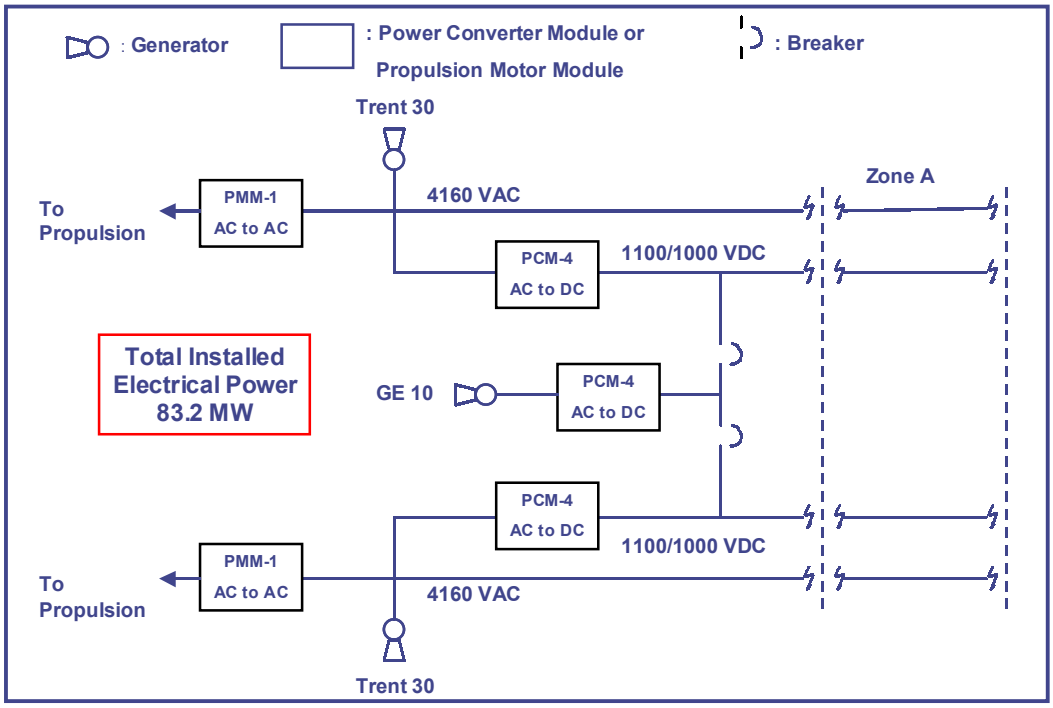

Figure 79 SEA ARCHER Prime Power Layout

As mentioned previously, there are a total of 3 turbine generators, with the two Trent 30s producing 36 MW each, while the GE 10 producing 11.2 MW. This combined power will be used to generate the necessary power for Sea Archer. Power will be distributed at 1100 VDC; if necessary, rectifiers will convert the power output for use with the FEL system.

Shipboard Requirements

The beam and light transport systems would also require some form of control to alleviate problems associated with vibration and hull flexure. This can be performed by adaptive optics or utilising active control mechanisms to counter flexure. The placement of the FEL system in SEA ARCHER was selected to minimise the effects of hull flexure.

Developmental Issues

The FEL system architecture proposed is still conceptual and no system has yet to be built for shipboard applications. Most of the systems are either currently too large or too low powered to be deployed directly. Certain areas that need to be improved into include,

- High average power injectors – it has been demonstrated that 5mA CW injectors are feasible. Though it may seem a far cry from the required 0.75A, there is a great need within the mainstream physics community for light sources with requirements similar to the FEL weapon parameters. With this parallel developmental need, any work to achieve it would benefit the FEL system. Moreover, Boeing has demonstrated a 1A injector 10 years ago but the system would is too huge for shipboard implementation.
- High peak power density optical elements – present proposals for FEL oscillator design have power densities 3 to 4 times higher than those experienced in the chemical high energy laser systems. Current optical element technology has demonstrated the handling capacity for half the required power density. Consequently, more development is still required. However, one aspect that has

not been analysed is the impact of high peak, non-continuous FEL power loading on optical surfaces and coatings.

- SRF and room-temperature acceleration – room-temperature acceleration was not chosen, as a significant amount of RF power loss is experienced because of resistive losses in the acceleration walls. These accelerators have undergone space

Problems Associated

No perfect weapon system has yet to be designed and an FEL weapon system also suffers from a myriad of problems. The most glaring issue with FEL weapon system would be the effect of the atmospheric conditions on its operation. It has been shown that selection of wavelengths and other measures can be used to alleviate the effects but once heavy rain occurs the effectiveness of the weapon system is drastically reduced. Figure 80 shows a plot of energy required against rainfall. It illustrates the necessary energy required to vaporize a column of water with a radius of 0.2 m by 5000m long, replicating a beam of light that engages a target. Therefore, the energy is the requisite amount necessary to vaporize the water before the beam can engage the target. It shows an exorbitant amount required.

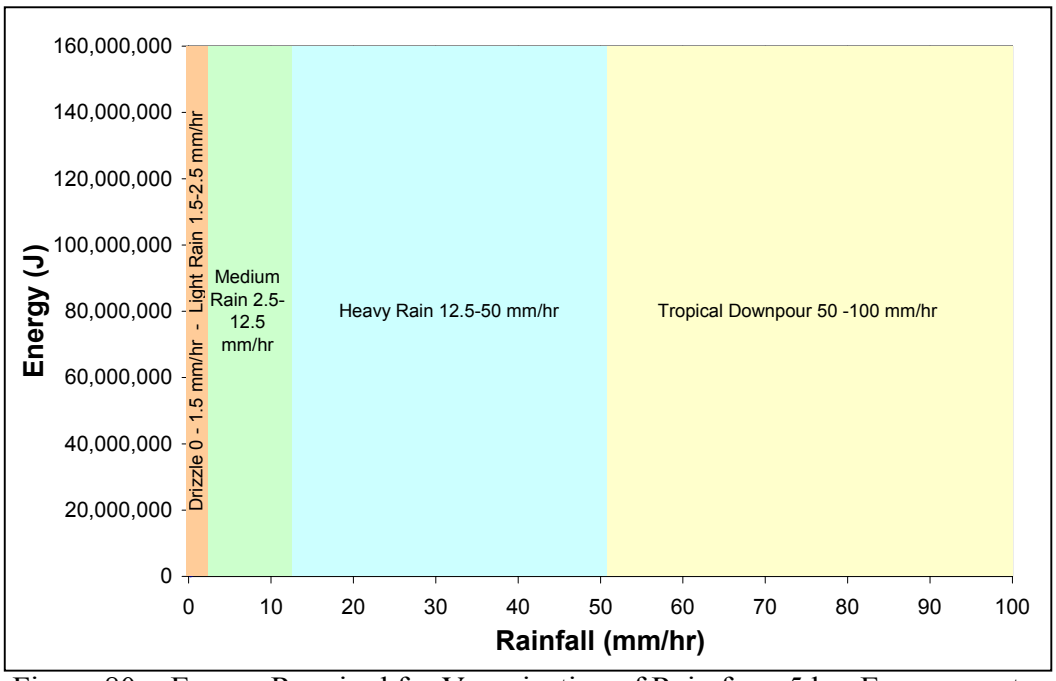

Figure 80 Energy Required for Vaporization of Rain for a 5 km Engagement

Countermeasures by the ASCM may also be employed to counter the effects of the irradiation, though no system can really deflect the amount of energy directed at it. It would lengthen the required engagement time and thus reduce the effectiveness of the weapon

4. Small Calibre Gun System

To engage surface threats in the littoral region, gun systems were studied that provided the most cost effective solution. To maintain low manning requirements and high hit probabilities against surface targets, the system proposed has to be unmanned and stabilised. Stabilization is necessary as the pitch and roll from the sea state will make targeting an enemy difficult. Unmanned operations will allow SEA ARCHER to maintain a low manning crew as the SCGS can then be operated from any console within the CIC. Charge Coupled Devices with thermal imagers in the 3-5 μm will ensure both day and night operations. Target prediction software will be included in the system to ensure high hit probability.

Gun choices were based on the following:

- Gas operated cannons like the Mauser Mk30 or Oerlikon KCB

- Electrically operated chain guns like the Bushmaster cannons.
- 40mm Automatic Grenade Launchers

Gas operated cannons operate at higher rates of fire (600 to 800 rounds per minute) compared to Bushmaster cannons at 400 rounds per minute. But Mean Rounds Between Failures (MRBF) for Bushmaster cannons are much higher than gas operated guns, and they also allow for automatic recocking when rounds are jammed in the receiver. Gas operated cannons require manual recocking for jammed rounds.

Accuracy for the Bushmaster is also better than gas operated cannons. Reported dispersion rates were single shot dispersion at 0.2 mrad compared to 0.45mrad for gas operated cannons. For surface engagements, a high rate of fire is not necessary when compared to air engagements as the target is moving slower and target prediction errors are not as critical. Therefore, a Bushmaster cannon was selected as the appropriate gun.

The calibre of the gun was initially selected at 30mm as it afforded the best possible maximum range at 5km. A 25mm cannon only be able to engage targets up to 4km. 35mm cannons can be selected at a later juncture if the range increase is required, as the sizing of the system will allow this upgrade. The types of the 30mm rounds to be used can range from High Explosive (HE), to Armour Piercing Fin Stabilized Discarding Sabot (APFDS) to High Explosive Incendiary (HEI). Each type of round is optimised for different types of target.

Forty mm Grenade rounds were not selected as the range of this round would only be around 2000m, it also exhibits bad dispersion characteristics. Though the fragmentation pattern will allow it to be an area weapon. It was deemed that a longer range engagement with greater accuracy is essential for increased barrier while allowing the possibility to engage more targets.

Medium calibre guns like the Otobreda 76mm Super Rapid Gun or the Bofors 57mm Mk 3 were not considered as a possible solution as the size of the weapon precluded their selection. Phalanx CIWS was also not a viable solution as the engagement range of the surface targets was around 2000m.

The 200 ready to fire rounds will ensure that the system can engage 10 to 15 targets. If this is deemed insufficient at a later date, increasing the ammunition load out will be easily implemented.

The number of the SCGS selected was to obtain 360^{o} coverage of the SEA ARCHER platform. The minimum engagement range is dictated by minimum depression angle of the SCGS. It was decided that the minimum range for this system should be 50m. This implied that the depression angle has to be 68 °.The traversing speed of the gun will be at least 140°/s, as this will translate to a crossing target at 50m travelling at 180 knots, sufficient for surface and air targets. This will also be beneficial for quick reengagement.

It must be noted that the SCGS cannot be viewed as a CIWS as the rate of fire, lack of dedicated fire control radar and ammunition load out prevents it from fulfilling this role. Nonetheless it can engage slow moving UAVs as their profile permits this.

Figure 81 provides an overview of the Small Calibre Gun Systems that were analysed for SEA ARCHER. It can be seen that this type of gun system is around 1000 kg and could bw either gas operated or chain-driven guns. All offer similar characteristics in terms of weight and sizing. The only difference would be the addition of the rocket launchers for the chaff and Nulka decoys.

Name		Contractor	Type of Gun used*	Control System**	R.O.F. rds/min	Types of Rounds	Range km	Traver Speed °/s	Eleva Speed °/s	Traver Accer°/s²	Eleva Accer°/s²	Mount Wt Ton	Holding capacity rds	Operational Status	Remarks
	Typhoon	Rafael	Mainly uses M242 Bushmaster Gun but undergoing studies to use other types for example GAU 8, 30mm Bushmaster	Slave Mode - slaved to external electro-optical surveillance system or FCR. Stabilisation Mode - cannon stabilised in traverse and elevation. Target acquired through sight mounted beside gun Servo Mode - used for servicing Manual Mode - emergency mode	400/ 600/ 800	TP, HEI, HEI-SD, API, APFDS	3 to 4	51	51	68	68	0.78	150	Operational	can be used with other 20 mm, 25mm and 30 mm guns
 SIGMA MODEL	MSI 25/30 mm Gun Mountings	MSI Defence Systems Ltd	25 mm M242 Bushmaster 1 or 30 mm Bushmaster II or Mauser Mk 30F or 30 mm Oerlikon KCB	Local Control (LOCSIG) - joystick control by operator using optical and electro-optical sighting system, possible to use ship sensors for target indication Remote Control (REMSIG) - by External FCS but onmount operator is retained Autonomous Control (AUTSIG) - similar to REMSIG but with remote control from dedicated below deck console Stabilised Integrated Gun Missile Array (SIGMA) - gun/ missile defence allows layered air defence. may use REMSIG or AUTOSIG control	400/ 600/ 800	TP, HEI, HEI-SD, API, APFDS	3 to 4	55	55	100	100	1.36	160	70 mountings ordered by UK and Malaysian navies	
 WITH BK 27	Mauser MN 27/30 GS	Mauser	BK 27 or MK 30F	**Remote Control** operation via TV camera, in-built Fire Control Computer and control handle. **Remote Control** via Naval Combat System (AIS etc). **Remote control** via partial NCS and FCS.	1700 / 800	TP, HEI, HEI-SD, API, APFSDS	2.7 / 4	55	55	100	100	<900	120	Recently completed development. German Navy has ordered 88 MN27 mounts	Intended to replace all the 20 mm and 40 mm guns onboard German vessesl; 2600 BK 27 guns produced since 78, this gun is actually an aircraft gun onboard Tonardo, Alpha, Eurofighter 2000 and contender for JSF.
	Single 30 Compact Naval Mounting	Otobreda	25 mm M242 Bushmaster 1 or 30 mm Bushmaster II or Mauser Mk 30F or 30 mm Oerlikon KCB	**Remote Control** hrough FCS or Integrated TV LOS stabilised system.	400/ 600/ 800	TP, HEI, HEI-SD, API, APFDS	3 to 4	140	80	250	250	1.58	160	40 mountings have been produced of which 75% are single and 25 % Twin	Buffer batteries for autonomous operation in case of power failure;Dual ammunition feed system;Twin version available-A1(2000 rd below deck), A2 (2000 rd above deck),B1(1100 rd below deck),B2 (1100 rd above deck), C(2 x 250 rd on turret platform)

Name		Contractor	Type of Gun used*	Control System**	R.O.F. rds/min	Types of Rounds	Range km	Traver Speed °/s	Eleva Speed °/s	Traver Acce°/s²	Eleva Acce°/s²	Mount Wt Ton	Holding capacity rds	Operational Status	Remarks
	Valkyrie	SEI	25 mm M242 Bushmaster 1 or 30 mm Bushmaster II or Mauser Mk 30F or 30 mm Oerlikon KCB	Remote control using electro-optical package (based on combination of camera, FLIR, laser range finder and laser designator fitted above gun). Posses automatic target tracking	400/ 600/ 800	TP, HEI, HEI-SD, API, APFDS	3 to 4	80	80			1.95		None sold yet	Newer version of the EMERLEC 30; Has autonomous power; Several versions available - basic mount features earlier guns, ano open crew compartment and a lead computing optical sight, provision for alternative remote control. Based on MSI design
	MILLENNIUM MDG-35	Oerlikon Contraves & Royal Ordnance	Oerlikon 35/1000 mm	Remote	1050-1440	AHEAD, APDS-T	5	120	60			2.66		Under development	Only gun mount that uses AHEAD. Currently have not sold any mounts but is a contender for Horizon.

* All mounts, except Millennium & Mauser MN 27, can employ different types of cannons i.e. Electric or gas operated. Therefore ROF will be either 400 (for Busmaster II) , 600 for Oerlikon KCB or 800 for Mauser Mk

** All mounts utilise similar concepts in control. They can be controlled by an in-built Fire Control System (either man-operated or automatic) or an external Fire Control System/Combat System

*** Holding capacity will be based on calibre of round. This column uses 25mm as a benchmark

Note :		
Weight of Mauser Mk 30 F	151	kg
Weight of Bk 27	100	kg
Weight of Bushmaster I 25mr	115	kg
Weight of Bushmaster II 30m	147	kg
Weight of Oerlikon KCB	156	kg

Figure 81 Overview of Small Calibre Gun Systems

5. Radar Crossection

It can be assumed that the highest radar cross section of SEA ARCHER would be a reflection off the broadside. This RCS can be obtained from the RCS equation of a flat plate shown below-

$$\sigma = \frac{4\pi A^2 \rho \cos^2\theta}{\lambda^2}\left[\frac{\sin\left(2ka\sin\theta\cos\phi\right)}{2ka\sin\theta\cos\phi}\right]^2\left[\frac{\sin\left(2kb\sin\theta\sin\phi\right)}{2kb\sin\theta\sin\phi}\right]^2 \tag{5.1}$$

where $2a$ = Length of SEA ARCHER

$2b$ = Height of SEA ARCHER

θ = Angle of wrt to z axis

ϕ = Angle wrt to a- axis & projection on *ab* plane

At the broadside, $\phi = 90°$ and the above equation is reduced to

$$\sigma = \frac{4\pi A^2 \rho \cos^2\theta}{\lambda^2}\left[\frac{\sin\left(2kb\sin\theta\right)}{2kb\sin\theta}\right]^2$$

Different values of RCS based of varying θ were then calculated and shown in Figure 82

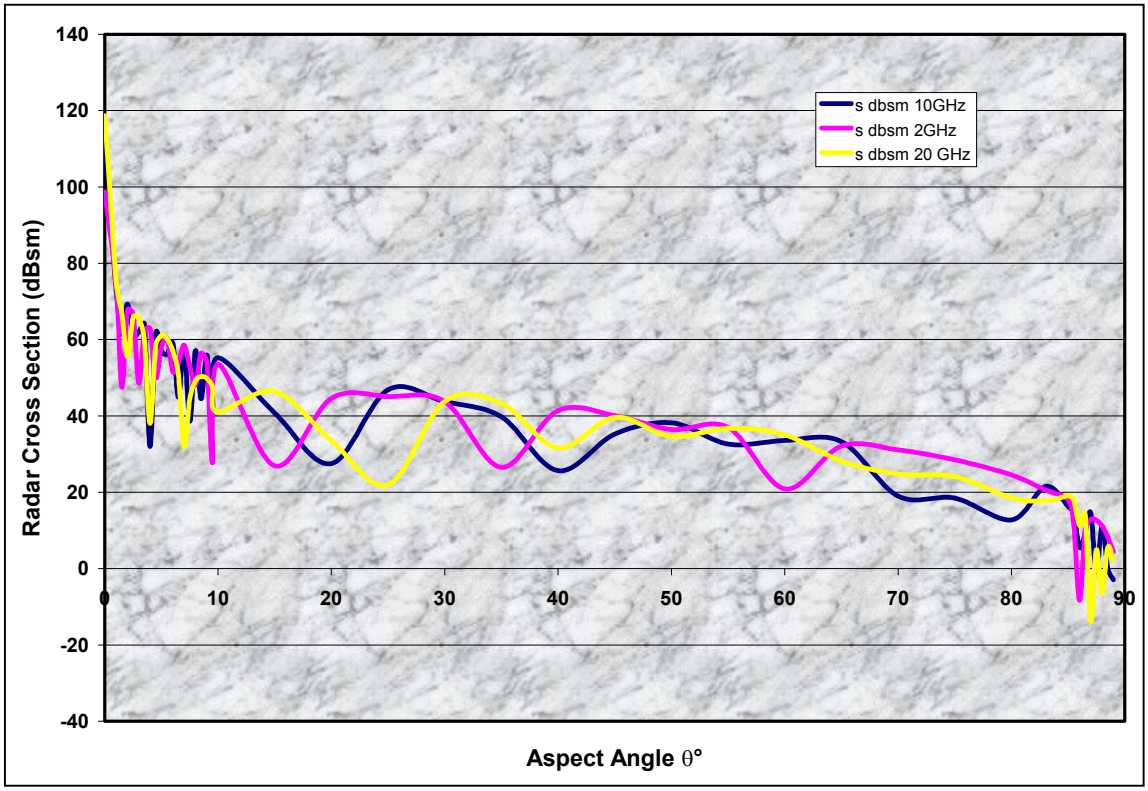

Figure 82 Radar Cross Section against Aspect Angle θ

The angle of slope for SEA ARCHER has been designed at 5°. The RCS for different surface based radars are-

	10 GHz (X Band Radar) Fire Control Radar		2 GHz (L-Band Radar) Search Radar		20 GHz (Ku Band) Missile Seeker Radar	
Angle θ	σ m^2	σ dbsm	σ m^2	σ dbsm	σ m^2	σ dbsm
5°	507660	57	652115	58	1282269	61

Table 47 Radar Cross Section of SEA ARCHER for Surface Based Radar

To obtain the RCS when an air based radar system is searching for SEA ARCHER, it has been assumed that the aircraft is at 40 000ft and at 200 nm. The worst case scenario for RCS would be a broadside detection, where the radar would reflect off the top and side of SEA ARCHER . This translates into an aspect angle of 88° for the top (with a top deck

area of 10679 m^2) and 3° for the side of SEA ARCHER. The combined RCS would then be

	10 GHz (X Band Radar) Fire Control Radar		2 GHz (L-Band Radar) Search Radar		20 GHz (Ku Band) Missile Seeker Radar	
angle θ	σ m^2	σ dbsm	σ m^2	σdbsm	σ m^2	σ dbsm
3°	2.83		54.42		0.43	-3.68
88°	92.08		1672.07		0.00	-44.78
Total	94.91	19.77	1726.49	32.37	0.43	-3.68

Table 48 Radar Cross Section of SEA ARCHER for Air Based Radar

It can be ascertained that the RCS magnitude drops dramatically for air based radar systems. This is due mainly to the flat sloping sides of the SEA ARCHER design and the lack of an island structure, which greatly reduces the detection of the SEA ARCHER from air assets. Other ship architectures which employed a mast structure and antennas protruding from the vessel would have substantially larger RCS. Surface based RCS is found to be around 61 dBsm, which is comparable to a Navy auxiliary vessel. This is acceptable as surface based radars are limited by the physical horizon, at around 30 km.

6. Electro Optical Sensors

Electro Optical Systems selection was a simple choice based on utilizing developed technology. The system selected would be the generation of imaging systems available during the 2020 period. It would be necessary to operate in the 3-5 μm and 8-12 μm to maintain effectiveness in the littoral region. Both bands have their own strengths and weaknesses, so a dual band system would cover all gaps in performance. A Laser rangefinder will also be necessary to provide a 3 dimensional data for the target. Figure 83 shows the current imaging system installed on current warships, the system proposed will be similar but will be required to be low RCS.

Figure 83 Thermal Imaging Sighting System (TISS) (from [23])

7. IRST

Similar to the EOS, the IRST will use conventional equipment available within 2012. The threat of stealthy, sea-skimming missiles makes this detection system a requirement for this vessel. Figure 84shows a dual band system that is currently available. The requirement for SEA ARCHER would be that this system has either to be low RCS or be enclosed within the ship structure.

Figure 84 Notional IRST system (from [23])

8. Mine Detection

The initial design process included a mine detection suite for SEA ARCHER. Noise limited sonar calculations were done at various frequencies to find the optimum frequency for short range mine detection. This sonar system would operate in the 40 kHz and had an aperture of approximately 2m. Figure 85 provides the result of the calculation.

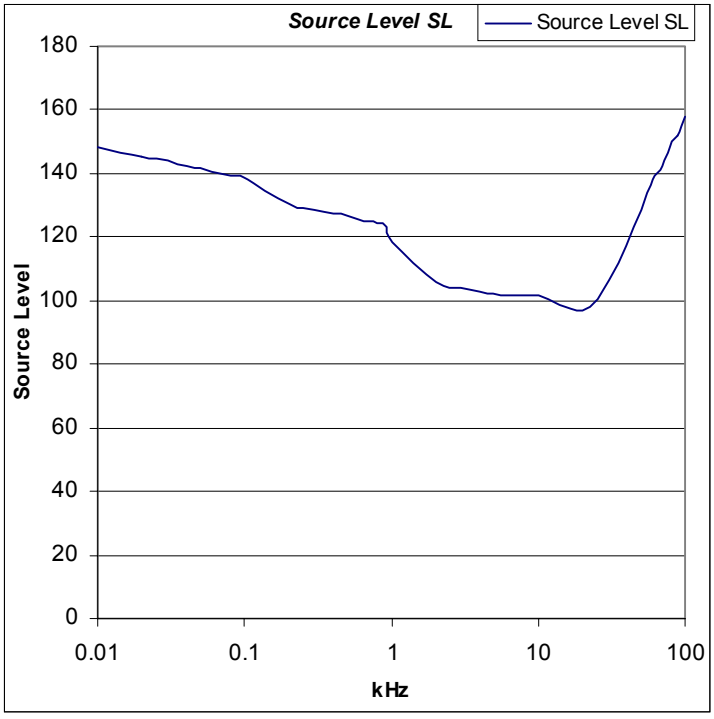

Figure 85 Source Level Calculation

It was later decided during the design process to remove the mine detection suite for the following reasons

a. Hull Design – the final hull design required that the draft of the ship would be at 2.1 m when it was operating in the surface effect mode. This would then be too low for placement of a mine detection sonar. If a smaller aperture was to be used, the effective range or power had to be increased. The wave piercing design of the hull required that the forward portion of the hull be sharp; this would preclude a rounded sonar dome or shaping to suit the mine detection suite and thus affect the hull design.

b. Self Noise Generation – the operating speed of SEA ARCHER would entail large amounts of self noise; this would reduce the effectiveness of a mine detection sonar. The calculations could not consider this effect as no data existed for surface effect ship noise generation at such a velocity. A frequency could possibly be selected to minimize the effects of self noise but the number of variables would make this selection difficult as considerations would have to be given to noise generated by the flow of 60 knots over the dome, blower noise generation and air interaction between the SES cavities.

c. Operational Scenario – it was concluded that the SEA LANCE/helicopters/USCs would be able to handle the mine detection requirements. This would be more appropriate for the SEA ARCHER as long range mine detection can then be performed by other assets and allow it ample reaction time to perform necessary maneuvers. The short range detection of the initial mine detection suite would only allow it to stop or perform evasive maneuvers to counter the threat.

9. Mine Clearance

The concept of mine clearance is to utilize the current developmental concept of Rapid Airborne Mine Clearance System (RAMICS). A Light Detection Ranging (LIDAR) system located on the helicopter will use a laser beam to scan the water for shallow and floating mines. Once located a stabilized gun pod mounted on the helicopter will fire 20mm caliber rounds optimized for traversing the water with sufficient terminal velocity for mine detonation.

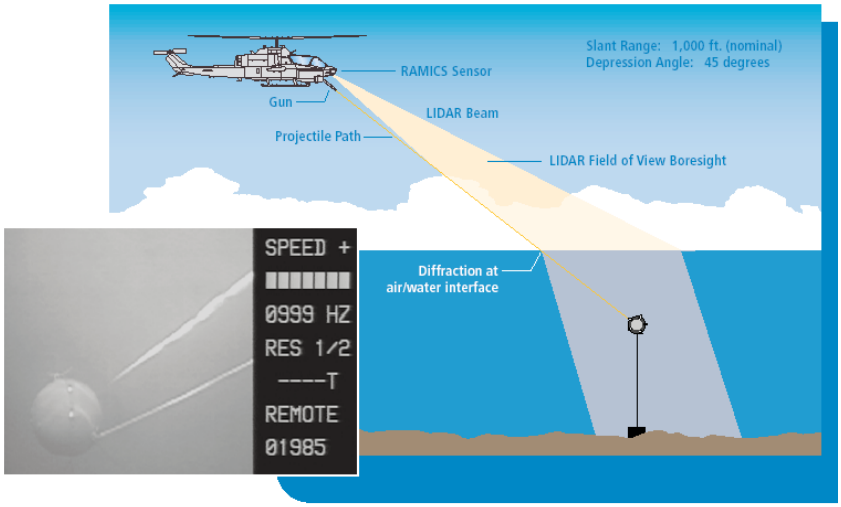

Figure 86 RAMICS Concept

Weight Estimates

Appendix D provides the detailed breakdown of the combat systems with their proposed locations.

F. DAMAGE CONTROL

The damage control system, including the CBR system, is described in Chapter IV under Damage Control section.

The selection of the detectors and the fire suppression systems, and organizing the damage control parties is discussed in this section.

1. Detectors

The available and proposed fire detection systems are analyzed for the best selection for SEA ARCHER.

Smoke Detectors

Photoelectric smoke sensors operate by projecting a beam of light across a sensing chamber. A photosensitive receiver detects changes in the projected light pattern caused by smoke particles within the chamber. These detectors provide good response to smoke with larger particles. However, they are subject to false alarms from other airborne particulates.[68]

Optical detectors (including fiber optics) are based upon the photoelectric principle, except the beam is not confined to a sensing chamber and may be projected across open areas. These detectors can monitor areas up to 25 meters across, and areas subjected to high airflow rates.

An ionization detector uses an extremely small quantity of radioactive material to make the air in the detector chamber conduct electricity. Smoke from a fire interferes with the electrical current and triggers the alarm. Smaller particles are detectable, as compared to the photoelectric sensor, providing higher sensitivity in critical compartments. These detectors can also be prone to false alarms from airborne particulate matter.

Electrostatic detectors operate by detecting naturally charged particles across a set of electrodes. The principle of operation is the same as the ionization detectors without the need for a radiation source, as with an ionization detector. These detectors are not as sensitive as ionization detectors and do not alarm with "nuisance"

smoke, such as burnt toast. These detectors generally require smoke from a developed fire to trigger an alarm.

Carbon Monoxide Detectors

Irrespective of how intelligent a smoke detector is it still needs the smoke to be introduced to the detector before it can be sensed and an alarm decision made. It is difficult if the protected area is large and open or the seat of the fire is in a hidden area such as a linen locker or adjacent unprotected room. [69]

In a slow smoldering fire situation, typical of those started by discarded cigarette ends in soft furnishings or smoldering sawdust and other organic materials, smoke may not be given off for many minutes, even several hours in certain situations, after ignition. During this time the insidious carbon monoxide gas can build up to a level sufficiently high so that, on awakening, sleeping persons are too disoriented to evacuate the area. When smoke is given off and has reached the detector it can frequently be too late to stop the rapid spread of the fire.

It is also well known that smoke escaping into corridors can cool and fall to the floor thus making them impassable by the time the smoke reaches the detectors at the ceiling and generates an alarm condition. Smoke can also be prevented from reaching the detectors by barriers of hot air building towards the ceiling.

CO fire detectors react well to smoldering pyrolysis fire (wood), and glowing smoldering fire (cotton), but open plastic fires (polyurethane), and liquid fires (n-heptane) do not produce sufficient CO gas to trigger an alarm.

CO fire detectors are particularly well suited to accommodation areas where there is a risk of slow smoldering fires causing death through the build up of CO, limiting occupants' ability to evacuate.

Fire/Flame Detectors

Infrared and ultraviolet detectors operate on the ability to distinguish respective radiation wavelengths that are only given off during a fire. These optical sensors are capable of monitoring large open areas by a single sensor. Infrared sensors can be subject to false alarms by such things as electrical arcs, whereas ultraviolet sensors

are subject to false alarms by such things as arc-welding, electrical arcs, x-rays and lighting. Certain infrared sensors can also be used to monitor temperatures by annualizing the returned radiation spectrum.

UV flame detectors are very sensitive to arc-welding, electrical arcs, x-rays and lighting. Although it is possible to eliminate false alarms from lighting and electrical arcs by the inclusion of time delay processing the elimination of false alarms from arc welding and x-rays is much more difficult to achieve. The detectors' sensitivity to these false alarm sources can be a significant problem. There are external influences, whose presence can have a detrimental effect on the ability of the detector to see flame radiation. The main inhibitors of UV propagation are oil mists or films, heavy smoke or hydrocarbon vapor and water films. These phenomenon are present in machinery spaces and on offshore platforms and can significantly reduce the intensity of the UV signal if present in the flame detection path.

The shortcoming of UV detectors for offshore and machinery space applications has resulted in operators preferring the Triple Wavelength Infra Red Flame Detectors.

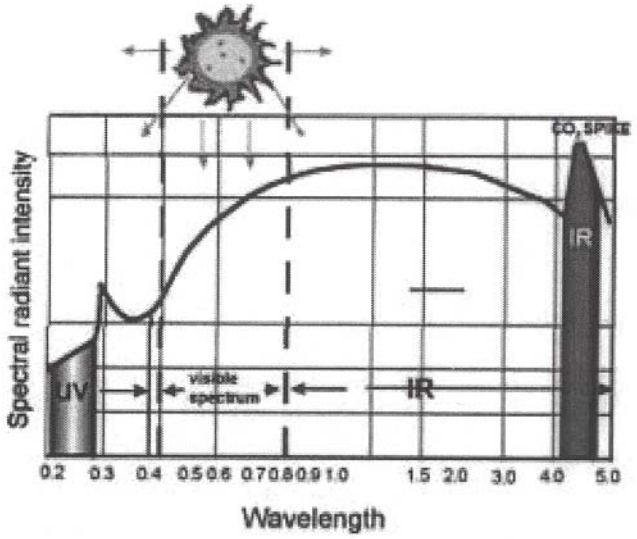

Figure 87 Typical Hydrocarbon Fire Spectrum

The use of Triple Wavelength Infra-Red Detection principles has overcome the main shortcoming of Infra Red Flame Detectors, namely response to solar radiation and black body radiation.

Closed Circuit Smoke and Flame Detection System

The system uses standard CCTV Cameras. The system functions by comparing one frame with the next, so that any change can be evaluated. Compound Obscuration evaluates the total attenuation of light from the camera to the furthest point in the field of view. The algorithm is able to de-couple smoke quantity from smoke density i.e. large clouds of thin smoke can be identified as well as small areas of dense smoke.

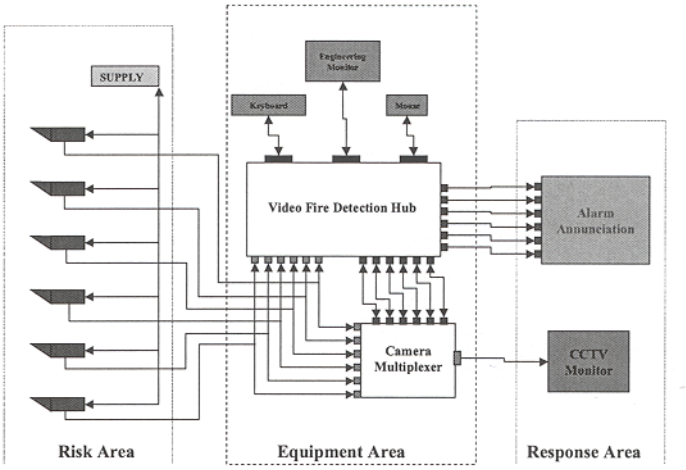

Figure 88 Schematic Video Smoke and Flame

The system can also be used to detect visible oil mist, high-pressure oil leakage from pipes, and steam leaks the moment they occur.

Heat Detectors

Heat detectors come in different types including spot detectors and line detectors. Spot detectors sense temperature at a specific location. Line detectors consist of a cable run where temperatures can be detected at a point along the cable, within a certain distance, typically 1.5 meters. Heat detectors work on five basic principles as follows in the paragraphs below.

Fixed temperature sensors alarm when temperature reaches a fixed point. Fixed temperature heat detectors are suited to alarm in the presence of slowly rising temperatures. Fixed temperature heat detectors are suited for installation where high heat output fires are expected or in areas where ambient conditions will not allow use of other detection methods,

Rate-of-rise sensors alarm when rate of temperature increase exceeds a predetermined value. It is common practice to have fixed rate sensors in combination with rate-of-rise sensors, providing good all round heat protection.

Thermoelectric effect sensors detect a change in electric resistance in response to an increase in temperature. These sensors are typically "hot wire" anemometers used for sensing temperature changes in fluid flows, including ventilation ducts.

Fiber optical heat detection is possible by use of monitoring the scattering of light down the fiber optic, which is proportional to the temperature sensed along the cable. The signals are immune to electromagnetic interference thereby ensuring integrity of readings from electrically noisy areas, for example around power cables and transformers. The system can continue to operate in the event of a fiber break by exploiting the signal processing techniques. The system can reconstitute the temperature profile of the entire fiber length regardless of the position of the break. Depending on the nature of the break a few measurement points in the immediate vicinity of the break may be lost. In the case of multiple breaks, the length accessible to the system will continue to be measured. The optical fiber temperature sensing system has wide ranging applications especially where small changes in temperature need to be detected, like pipe leakages, overheating of sensitive equipment, and magazine areas.

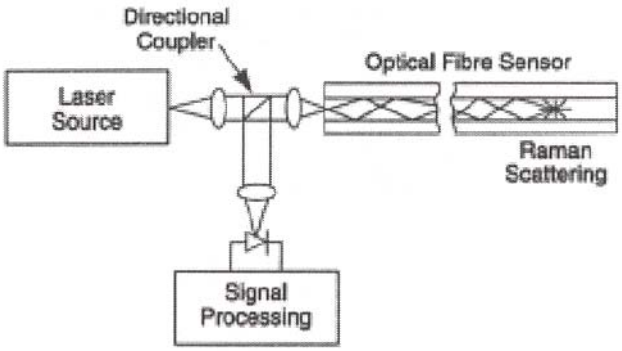

Figure 89 Principle of Fiber Optical Detector

The High Performance Optical Detector has sensitivity to both hot, fast, "Clean" burning fires (domain of the ion-chamber detector) and cold, slow smoldering fires (domain of the optical detector). [69] The High Performance Optical Detector senses the flaming fires that generate a significant rise in air temperature together with a small increase in visible smoke. To sense this temperature rise, two thermistors are arranged in a similar fashion to that found in a standard rate-of-rise heat detector. One thermistor is mounted so as to be exposed to the air while the second is shielded inside the detector's body. If the temperature rises slowly then the thermistor temperature will be approximately equal and no adjustment to optical sensitivity occurs. If however the air temperature changes very rapidly, the exposed thermistor will heat more quickly than the reference thermistor (heat shielded by the detector body) and a temperature difference will be established. The electrical circuit senses that the exposed thermistor is hotter than the reference thermistor and reduces the alarm threshold of the optical sensor accordingly. If there is smoke present at a level above the reduced threshold then an alarm will be raised. Otherwise the detector will remain in its enhanced sensitivity state, without giving an alarm until the temperature stabilizes. The High Performance Optical offers a significant performance improvement over standard optical detectors, with a much more uniform performance, across open cellulosic fires (wood), and liquid fires (n-heptane).

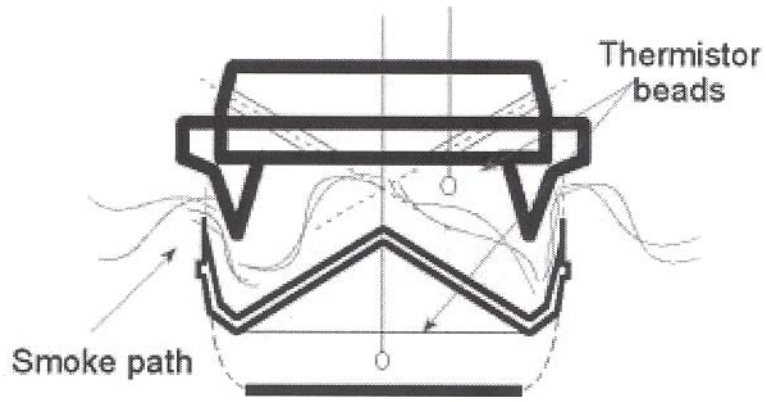

Figure 90 High Performance Optical Detector

The use of this detector that contains no radio-active material, together with its systems design flexibility, now offers the ship operator a cost effective, stable, false-alarm-free alternative to the ion- chamber detector.

Smart Microsensors

A smart microsensor is a miniature voltammetric/electrocatalytic (V/EC) microsensor made of ceramic-metallic (cermet) materials that identifies many different gases by their electrical signatures. [70]

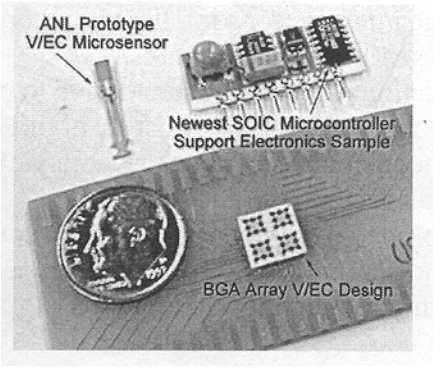

Figure 91 Smart Microsensor

The microsensor's intelligent pattern recognition system can be trained to recognize a wide variety of gases and gas mixtures. The microsensor is inexpensive to produce (< 25 cents per microsensor), and is proving rugged enough to survive in hostile,

high-temperature environments. The microsensor can be remotely cleaned and does not require electrolyte replenishment or replacement. Compared with conventional sensors, power requirements are low (milliwatts). The neural network signature processing is scalable and can be implemented on equipment from a microcontroller up to a larger PC.

Humidity Detectors

Humidity sensor contains a capacitive element that changes value in response to the relative humidity in the air. An integrated circuit timer translates this capacitance into a digital frequency.

Liquid Level Detectors

Typical flooding detectors are open/closed 'dry' contact type switches operating by a float mechanism. A number of these sensors can be mounted at various heights within a tank or compartment to determine the liquid level. These switches are either on or off, and the level of desired accuracy dictates the number of sensors.

"Wet" type contact switches use the fluid level to complete an electrical circuit and provide the alarm. These sensors are not as desirable as the dry contact switches.

Continuous reading tank level sensors are available and operate by a detecting a resistance float sensor along a shaft, providing readings accurate to within one-half inch. These sensors typically monitor normal tank levels. These continuous level sensors can also monitor for excessive liquid loss indicating a damage situation, or provide unmanned filling operations.

The open/closed contact switches can also be utilized for detecting actuator and access status. Fiber optical sensors have also been developed to provide this detection.

Conclusions

Other than fire detection, compartments will also be monitored for humidity and temperature, to calculate heat stress. Paint lockers and pump rooms will be monitored for explosive gases and lack of oxygen. Sewage spaces will be monitored for hydrogen sulfide gas. Air conditioning and refrigeration rooms will be monitored for

refrigerants and low oxygen levels. Other appropriate monitoring will be conducted in spaces subjected to localized hazards.

Monitoring confined areas subject to toxic gas or oxygen deficiency will prevent unwanted exposures of the crew to these hazards. Immediate notification to control stations will prevent unaware watch standers from entering the compartments.

2. Reactive System

The available and proposed fire suppression systems are analyzed for the best selection for SEA ARCHER.

FM-200 Fire Suppression Systems

FM-200, heptafluoropropane, is one of the new halon alternative agents now in use to protect essential applications traditionally protected by Halon 1301. This agent has many similar characteristics to Halon 1301 and is safe in normally occupied areas. FM-200 systems are available in spheres or cylinders. [71]

Inergen Fire Suppression Systems

Inergen is another new alternative agent replacing traditional Halon 1301. Inergen is a high-pressure agent and is stored in cylinders similar to Carbon Dioxide. This agent is comprised of three naturally occurring gases nitrogen, argon and carbon dioxide. The system is laid out with a central bank of cylinders manifolded together and the agent is dispersed through a pressure reducer and a piping system. Critical areas that require non-water based extinguishing agent that is electrically nonconductive, safe for use in human occupied facilities, and not damage sensitive electronic equipment.

The strategy of fire extinguishment employed by an Inergen system is like no other modern suppression system in use today. An Inergen system lowers the oxygen content of the protected area to a point sufficient to sustain human life, but insufficient to support combustion.

Carbon Dioxide Fire Suppression Systems

Clean agent carbon dioxide systems, have been an industry standard for many decades and are still the preferred agent in many applications. There are several common local application systems, which are utilized to extinguish fires in dip tanks, quench tanks and industrial operations where spilled fuel is a possibility. Local

application systems are also popular in the marine market, especially in engine compartments.

FE-13 Fire Suppression Systems

FE-13, trifluromethane, is the safest of the three most commonly used clean agents (FE-13, FM-200 and Inergen). Systems are typically designed at 16-21% concentrations but FE-13 has no exposure restrictions until concentrations reach 30% or higher. The ability to design at higher than required concentrations makes FE-13 an ideal agent for occupied areas where very rapid extinguishments is desired. [72]

Two other characteristics make this a unique agent that should be seriously considered for our clean agent requirements. First, nozzles can be located at heights of up to 25 feet as compared to only 12 feet for FM-200 systems. Second, due to its low boiling point, FE-13 can be used in temperatures as low as 40° F.

As with other clean agents, FE-13 can be used in any area with high valued electronics such as computer facilities, battery rooms and telecommunications facilities. It also has many industrial applications including unheated storage areas.

NAFS-III

NAFS-III consists of HCFC mixed by 82 %HCF22, 9.5%HCFC124, 4.75% HCFC123. It is able to extinguish fires in the B and C rating classes and electrical goods. HCFC exists in gas form after spraying and extinguishing. There is no liquid or solid residue, no remaining trace, and therefore no stain resultes. This type of fire suppression is good for oil stores, paint lockers, flammable chemical stores and electronics equipment compartments.

Water Mist System

Water mist systems extinguish fires primarily by removing heat from the materials involved in the combustion process. Water is applied to the fire in very fine droplets, which appear to the observer as a dense fog. The ratio of droplet surface area to water volume is large and conversion to steam occurs very efficiently. The latent heat of vaporization, which is a physical phenomenon associated with the change of state of water to a gas (steam), removes heat from the fire and the steam produced also helps to smother the fire by displacing oxygen in the vicinity of the fire. [73]

Water mist systems are also safer for people and the environment. These systems only use potable or natural seawater, with no adverse side effects. Lower flow rates equate to less cleanup than traditional water sprinkler systems. Tests have shown that properly designed water mist systems can effectively extinguish a wide variety of exposed and shielded Class B hydrocarbon pool, spray, and cascading pool fires.

A general reluctance to provide water extinguishing for class "C" fires exists because of fears of conductivity.

The Navy sponsored a program at the Applied Physics Laboratory/Johns Hopkins University (APL/JHU) to evaluate the effects of water mist on energized electrical equipment. Equipment selected for testing consisted of 3 phase-450 VAC motors, motor controllers and switchboards that were representative of equipment to be installed in the machinery spaces of LPD-17. The objective was to determine potential for equipment damage and to identify personnel electric shock hazards resulting from the discharge of mist onto energized equipment. Results showed that the conductivity of salt-free potable water is very low. Shock hazards could only exist after a sustained mist flow of sufficient duration to cause plating out or pooling of water on equipment surfaces. There was essentially no current leakage for motors or motor controllers. Shock hazard with switchboards is negligible within the first 15 minutes if the boards are clean and properly grounded. The summary conclusion relative to LPD-17 is the probability of creating a shock hazard is low and that watch standers in the space would not have to evacuate prior to mist activation even if all equipment is energized.

Water mist systems have been successfully tested on telecommunications switchgear equipment, consisting primarily of vertically mounted circuit boards.

The results of a multi-year water mist research and development program by the Naval Research Laboratory, Chesapeake Beach Detachment says that large fires are easier to extinguish than small fires, due mainly to the displacement of oxygen by the expansion of the water mist to steam, obstructed fires become more difficult to extinguish with increased water droplet horizontal travel distance, well-ventilated fires are difficult, but not impossible, for water mist and water mist performs superior to gases in well-ventilated scenarios. Deep-seated Class A fires are difficult to totally extinguish, though

surface flaming is suppressed, and mist enhances room tenability by cooling and smoke scrubbing.

The system effectively extinguishes flammable liquid pool fires as well as spray fires, which could ignite from a ruptured hose or pipe in a process using flammable liquids. Water mist applications include, but are not limited to, engine and generator set enclosures, machinery spaces with incidental storage of flammable liquids, oil pumps, gear boxes, and drive shafts.

Aqueous Film Forming Foam (AFFF) Systems

Aqueous Film Forming Foams (AFFF) is based on combinations of fluoro-chemical surfactants, hydrocarbon surfactants, and solvents. These agents require a very low energy input to produce high quality foam. AFFF agents suppress fire by separating the fuel from the air (oxygen). Depending on the type of foam system, this is done in several ways: Foam blankets the fuel surface smothering the fire, the fuel is cooled by the water content of the foam, or the foam blanket suppresses the release of flammable vapors that can mix with the air.

They can be applied through a wide variety of foam delivery systems. This versatility makes AFFF an obvious choice for handling of flammable liquids.

Conclusions

Active damage control measures will be required to keep the damage contained and from progressing. Fire extinguishing methods include the use of a ship wide water mist sprinkler system, AFFF flooding, FM 200 system and carbon dioxide flooding.

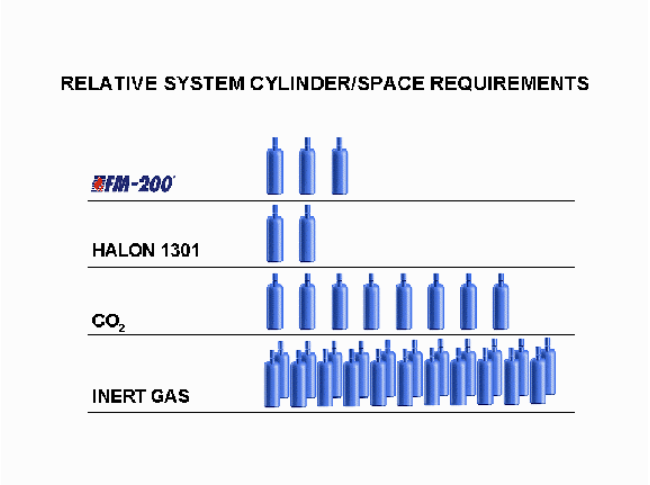

Figure 92 Relative System Cylinder/Space Requirements (from [71])

FM 200 is selected. Because, it requires less space and costs less than inert gas technology, FE 13, and NAFS-III. Although carbon dioxide fire suppression systems are cheaper than the FM 200, carbon dioxide is toxic to human life.

Gas	**Inst**	**RM**/cu.m	**Refill**	**RM/ cu**.m
CO2	18,000	100. 8	1,100	6.2
FE13	45,000	252. 0	14,000	78.4
Water Mist	70,000	392. 1	11,000	6.2
Inergen	60,000	336. 1	10,000	56.0
FM200	50,000	280. 1	19,000	106.4
NAFS- III	38,000	212. 9	14,500	81.2

Table 49 Comparison of Fire Suppression Systems (from [74])

Independent extinguishing agents, such as carbon dioxide flooding for the paint lockers, pump rooms, air conditioning and refrigeration rooms, and engine enclosures, which are all unmanned, and FM 200 for the electronics equipment compartments, CIC, bridge, accommodations, kitchens and galley, and passage ways,

which are manned, will protect specialized spaces. Water mist sprinklers will protect machinery spaces. A combination of the water mist sprinklers and AFFF sprinklers will be used to combat fuel fires, which are possible in the machinery spaces and the hangar bay.

3. Damage Control Party Organization

As the first detection and reaction to any fire or damage will be performed by ADCS, the number of personnel assigned to in a classical damage control party organization is reduced. With the use of electronic hand held devices, the communication and plotter man is no longer needed. Also, the fire and smoke detection network allows us to decrease the number of boundary personnel.

G. TOTAL SHIP SYSTEMS

Levels of Maintenance Concept
1 Routine Minimized to accommodate min manning
2 Tiger Teams Monthly (Possibly 50 personnel, 12 hr days, 7 days out of the month rotational = 4200mhrs / month)
3 Requires less "routine maint" or more of it moved to SRA periods

				#	Hrs	Days/Wk.	Manhrs	Weekly Manhours	
Operational	Watch Stations	Ship Ops		17	24	7	408	2856	
	Daily OPS Brief			20	0.5	7	10	70	
Spec Evs	Unrep	Ship Control		2	4	2	8	16	Helm lookout
	(2 x 4hrs.)	Safety		2	4	2	8	16	rig & eng space
		Riggers		5	4	2	20	40	
		Line Handlers		3	4	2	12	24	
		stowage		1	4	2	4	8	
	GQ	DC parties		42	2	2	84	168	
		Bridge		4	2	2	8	16	Helm, BM, JOOD, L/O
		Combat Sys.		4	2	2	8	16	CIC Consoles
		ENG		3	2	2	6	12	
		Trons		5	2	2	10	20	
	WEPS loading	ciws/gun	reload	4	3	1	12	12	
		ram	reload	4	6	1	24	24	
		chaff	reload	3	2	1	6	6	
Command	CO/XO			2	16	7	32	224	
	Chaplain/RPO			1	1	7	1	7	
Non	Clean/Sweep			70	0.25	6	17.5	105	
Transferable	Prop. Maint.			6	6	6	36	216	Off Watch Personnel
(Non-Watch)	Elex Maint			6	6	6	36	216	RQD some Maint too…
(Routine)	AUX/DC Maint			5	6	6	30	180	
(and minor Repair)									

Table 50 Manhors Summary

Network Maint	3	6	6	18	108	
Automation Maint	3	8	6	24	144	
Weps maint	2	4	6	8	48	
Deck Gear Maint	1	2	6	2	12	
Small Boat Maint	1	1	6	1	6	
Intel/Ops	2	12	7	24	168	
Comms	2	12	7	24	168	
ET/EW	2	12	7	24	168	
Collaterals	20	1	2	20	40	Legal, MWR, Wardroom, CMS, etc.
SUPP	1	8	7	8	56	
SUPP	2	8	7	16	112	
ADMIN	2	8	7	16	112	
Laundry/FS Supp	1	8	7	8	56	
Med	2	12	7	24	168	
Traning	75	1.5	6	112.5	675	
Summations					6293.0	
Ship's Company Proposed				75		
Manhours Per Day (per person)					12.0	
Manhours Per week (per person)					83.9	
manhours in 7 day week (12hour day)					84	
manhours in 7 day week (8hour day)					56	
hours in week					168	

Table 51 Manhours Summary (Continued)

Sea Archer Specialized Equipment used for ship cost estimate

Costs are reflected back to 1991 at 3% inflation rate to align with CER's in given model.
Later, total is reflected to 2001 with same inflation rate.

	Costs in 2001	Costs in 1991	What to add	
Engines/WaterJets	$140,000,000	$104,173,148	$104,173,148	Propulsion
Electric Plant	$60,000,000	$44,645,635	$21,045,635	Electric
Composite Hull Form	$150,000,000	$111,614,087		
Air Cushion	$50,000,000	$37,204,696	$148,818,783	Hull/Air Cushion
MultiFunction Radar	$80,000,000	$59,527,513		
MultiFunction RF system (EW suite)	$30,000,000	$22,322,817		
Volume Search Radar	$30,000,000	$22,322,817	$102,173,148	Radar
Free Electron Laser	$55,000,000	$40,925,165		
Other Weps/Sensor Systems	$5,000,000	$3,720,470		(IRST,EOS,Chain Gun)
2 Unmanned Surface Vessels	$900,000	$669,685	$45,315,319	FEL, Surf, Other Weps/Sensors
Ship Missile Launcher	$40,000,000	$29,763,757	$29,763,757	VLS 16 CELL (Quad Missile) launcl
EMALS	$40,000,000	$29,763,757	$29,763,757	EMALS
Automated DC systs.	$35,000,000	$26,043,287		
DC Automation IP (.75*gear)	$26,250,000	$19,532,465	$45,575,752	Automation (Hab/DC)
Automated Flight Deck/Hanger	$45,000,000	$33,484,226		
Automated Weapons Handling	$35,000,000	$26,043,287		
A/C Automation IP (.75*gear)	$60,000,000	$44,645,635	$104,173,148	Automation Aviation
Network Centric CMD/CONT.	$10,000,000	$7,440,939	$7,440,939	Network Centric
SUMS	$882,150,000	$663,843,386	$638,243,386	

Table 52 SEA ARCHER Specialized Equipment

TSSE Sea Archer Cost Estimate

Sea Archer Ref. Tot 13800

Archer Wt. Ratio	Description	Archer (Scaled) (LT)	Other	Archer MAT CER	Archer MATERIAL COSTS	Archer Labor CER	S-CVX Labor Hours
0.0308	SHELL + SUPPORTS	425.3		1181	$502,314	251	106758
0.0407	HULL STRUCTURE BULKHEADS	561.8		1181	$663,459	251	141006
0.0417	HULL DECKS	574.8		1181	$678,831	316	181635
0.0058	HULL PLATFORMS/FLATS	80.2		1181	$94,665	316	25329
0.0145	DECK HOUSE STRUCTURE	200.8		1028	$206,383	316	63441
0.0513	SPECIAL STRUCTURES	708.0		1632	$1,155,508	251	177716
0.0002	MASTS,KINGPOSTS,SERV PLAT.	2.9		6183	$17,632	164	468
0.0072	FOUNDATIONS	98.7		1028	$101,464	359	35434
0.0078	SPECIAL PURPOSE SYSTEMS	107.6	1000000	4758	$107,597,658	404	43469
0.2000	Hull Sum	2760.0			$111,017,914		775255
0.0000	ENERGY SYS	0.0		0	$0	0	0
0.0000	ENERGY GEN. SYSTEM	0.0		0	$0	0	0
0.0597	PROPULSION UNITS	824.5	500000	144	$72,000,000	209	172316
0.0115	XMISSION+PROP. SYST's.	158.9	560000	63	$35,280,000	162	25745
0.0011	SHAFTING	14.7		20003	$294,023	0	0
0.0301	SUPPORT SYSTEMS	415.5		288	$119,659	412	171179
0.0044	PROP SUP SYS -FUELS,LUBES	61.0		36916	$2,251,546	271	16529
0.0031	SPECIAL PURPOSE SYSTEMS	43.4		288	$12,507	0	0
0.1100	Propulsion Sum	1518.0			$109,957,736		385769
0.0202	ELECTRIC PWR GENERATION	279.4	200000	650	$55,883,802	209	58399
0.0780	POWER DIST. SYSTEM	1077.0		57000	$61,391,345	1294	1393691
0.0189	LIGHTING SYSTEM	260.7		5450	$1,420,839	1329	346476
0.0096	POWER GEN SUPPT. SYSTEM	133.0		13750	$1,828,678	1329	176750
0.0032	SPECIAL PURPOSE SYSTEMS	43.8	480000	788	$21,043,500	471	20649
0.1300	Electrical Sum	1794.0			$141,568,165		1995965
0.0024	COMMAND+CONTROL SYS	33.8	380000	150000	$12,830,743	235	7935
0.0016	NAVIGATION SYS	21.4		150000	$3,210,168	235	5029
0.0045	INTERIOR COMMS	62.0		150000	$9,295,337	235	14563
0.0037	EXTERIOR COMMS	51.1		150000	$7,671,632	235	12019
0.0064	SURF SURV SYS (RADARS)	88.7	1150000	150000	$101,985,535	235	20841
0.0000	UNDERWATER SURV. SYSTS.	0.0		150000	$0	235	0
0.0032	COUNTERMEASURES	44.8		150000	$6,725,712	235	10537
0.0021	FIRE CONTROL SYS	28.4		150000	$4,252,915	235	6663
0.0011	SPECIAL PURPOSE SYS	14.8	3000000	150000	$44,540,155	235	3489
0.0250	CMD/CONT Sum	345.0			$190,512,198		81075
0.0101	CLIMATE CONTROL	139.2		32868	$4,574,447	494	68753
0.0062	SEA WATER SYSTEMS	85.1		50705	$4,312,529	679	57750
0.0013	FRESH WATER SYSTEMS	17.3		34033	$588,336	529	9145
0.0151	FUELS/LUBES, HANDL/STORE	207.8		42125	$8,752,491	271	56307
0.0019	AIR, GAS+MISC FLUID SYSTEM	25.8		70265	$1,812,091	647	16686
0.0000	SHIP CONTL SYS	0.0		14025	$0	353	0
0.0051	UNREP SYSTEMS	69.8		8035	$560,756	176	12283
0.0233	MECH. HANDLING SYST'S.	321.4	322000	16853	$103,490,619	259	83242
0.0072	SPECIAL PURPOSE SYSTEMS	99.7	302000	1888	$30,119,319	282	28125
0.0700	Auxiliary Sum	966.0			$154,210,589		332290

Table 53 SEA ARCHER Cost Estimate

0.0005	SHIP FITTINGS	6.6		55033	$364,157	882	5836
0.0040	HULL COMPARTMENTATION	54.7		11160	$610,509	741	40536
0.0112	PRESERVATIVES+COVERINGS	154.6		10789	$1,668,226	494	76384
0.0033	LIVING SPACES	44.9		29677	$1,332,492	1235	55451
0.0011	SERVICE SPACES	15.5		26174	$405,907	135	2094
0.0030	WORKING SPACES	41.7		27376	$1,141,897	292	12180
0.0068	STOWAGE SPACES	93.6		86901	$8,131,970	12	1123
0.0002	SPECIAL PURPOSE SYSTEMS	2.4	19300000	35511	$45,511,005	235	554
0.0300	Hab Sum	414.0			$59,166,163		194158
		Next 4 Entries are materials needed to support given system vice actual expendable					
0.0001	MISSILES+ROCKETS	1.0		100000	$99,275	235	233
0.0000	SMALL ARMS+PYROTECHNICS	0.3		100000	$32,854	235	77
0.0042	AIRCRAFT RELATED WEAPONS	58.1		100000	$5,811,541	235	13657
0.0007	SPECIAL PURPOSE SYSTEMS	9.6	3100000	100000	$29,646,217	235	2247
0.0050	Weps Sum	69.0			$35,589,887		16215
0.5700	MATERIAL / LABOR SUMS	7866	1991 Material Cost		$802,022,652		3780728
			FY01 Material Cost		$647,097,811		
	(3% inflation rate)		**Total 2001 Material Cost**		**$855,303,843**		
0.0097	SHIPS FORCE	134.2					
0.0523	MISSION RELATED EXPENDABLES	721.7					
0.0220	STORES	303.2					
0.3100	LIQUIDS, PETROLEUM BASED	4278.0					
0.0212	LIQUIDS, NON-PETROLEUM BASED	292.7					
0.0148	FUTURE GROWTH MARGIN	204.2					
0.4300	Total Payload weight:	5934.0			**Payload Cost**		
1.0000	Check Sums	13800.0			**$2,967,000**		
Ship assembly and support labor = .478*Labor			1807188				
Integration and Engineering Labor = .186*Labor			703215				
Program Management Labor = .194*Labor			733461		**(4th ship) Labor cost**		
Combined Labor Total Hours @ Labor rate:		$35	7024592		**$245,860,720**		

	Hours	Labor Cost	Multi-Hull Adj .30*Labor	unit cost with basic Shipyard Overhead	With Multi-Hull Labor Overhead
Total 2001 1st Ship Labor	7783481	272421851	81726555	$1,370,186,717.51	$1,451,913,272.76
Total 2001 2nd Ship Labor	7394307	258800758	77640227	$1,353,637,090.07	$1,431,277,317.56
Total 2001 3rd Ship Labor	7175739	251150871	75345261	$1,344,342,477.21	$1,419,687,738.56
Total 2001 4th Ship Labor	7024592	245860720	73758216	$1,337,914,944.01	$1,411,673,160.12
Total 2001 5th Ship Labor	6909549	241834219	72550266	$1,333,022,744.76	$1,405,573,010.45
Total 2001 6th Ship Labor	6816952	238593328	71577998	$1,329,085,061.79	$1,400,663,060.07
Total 2001 7th Ship Labor	6739631	235887101	70766130	$1,325,796,996.35	$1,396,563,126.62
Total 2001 8th Ship Labor	6673362	233567684	70070305	$1,322,978,905.24	$1,393,049,210.55

SEA ARCHER Cost Estimate (Cont)

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VI. CONCLUSIONS

The Total Ship Systems Engineering team has completed the first iteration of the design spiral and shown that numerous advanced concepts are practical. The SEA ARCHER design is by no means complete. This report has shown the results of the first iteration in the design process of SEA ARCHER. The design is able to meet the demanding speed and range requirements that were set out in the Operational Requirements Document. This by no means though is a finished design. It is recognized that further studies and design could be done to better meet the requirement including a recommendation to further study the effects that speed and range requirement had on both the size and cost of the ship.

When this first iteration was completed, it was realized the ship had been over designed in both volume and power. This was a result of our focus on ensuring we were able to meet the demanding speed and range requirements. Further iteration on this design would aide in refining the ships characteristics, especially in the area of volume utilization and powering requirements for the ship, with an expected overall smaller ship with less installed horsepower and at a lower cost.

This design utilizes many new technologies, many of which would require continued research and development to complete the design. The following is a discussion of some of the further research and next iteration recommendations from the SEA ARCHER design team:

Hull Design: The Harley SES hull form is a new design that has the potential for high-speed naval applications and provides several key advantages over other hull forms in the littoral environment. The team feels that aggressive research with this hull form will determine the design space and demonstrate the usefulness of this design.

Specifically more detailed model testing should be performed to evaluate slow speed performance. Model testing should also be performed to determine how variations in the air cushion geometry affect overall performance. This would allow needed

flexibility in shipyard construction size restrictions and determine the optimal design ratios for this hull form.

The lift system requires 10 to 15% of the propulsion power therefore optimization of this system is critical to the overall design. Further research to optimize the lift system should be conducted both from a sizing issue and from a ride control aspect. The center body shape can contribute lift at higher speeds and research to determine the optimal design shape should be conducted. The use of ram intakes may also reduce blower power requirements at higher speeds and should be investigated.

An important difference for the Harley SES design is the cushion pressure is 4 to 5 times higher than a standard SES. The higher pressure requires a structurally stronger hull and the use of larger and more powerful fans to deliver both high pressure and flow. The design team feels that research into large capacity blowers for shipboard applications is critical to this design's future use.

The SEA ARCHER design benefited from the use of lightweight high strength composite materials and although research supports this application more is still needed. Although composite material use has accelerated in the aircraft industry large scale ship construction with composite materials is still not possible. Continued research should support not only developing material but also large scale production issues.

The first iteration design of SEA ARCHER shows the vessel is overpowered. Allowing for the continuous electrical load of 15 MW results in a total propulsion power available of 306,000 SHP, corresponding to a maximum speed of approximately 68 knots on the speed/power curve. Further iteration with a focus on more refined powering requirements would result in a smaller vessel and should be the next step in the design process.

Propulsion: Based on the design philosophy of ship reduced manning, the gas turbine engine is the correct prime mover for SEA ARCHER. However, research must continue in the areas of material improvement and weight reduction for propulsion motors and propulsors. Motors are still extremely heavy. If they are to be a viable propulsion alternative for future naval ships, weight must be reduced. Hydro-Air Drive is

still in its technological beginnings. Larger units must be built and proven in order for SEA ARCHER to take full advantage of this technology. On the next iteration a better match of required horsepower to installed horsepower could be done as more information about the HARLEY SES is found.

Electrical: In order to improve the electrical system design, a couple of areas need to be researched further: the power converter modules and the cabling. As of yet, there are no power converter modules designed for the power output needed on SEA ARCHER. The SEA ARCHER design uses scaled versions of developed lower power converter modules, but research is currently being conducted at the Land Based Engineering Site (LBES) in Philadelphia, PA. With more research, the size, weight and cost of each module can be refined.

In addition, the large power requirement of SEA ARCHER necessitates large currents with the 4160 V power source of this design. The large currents require large amounts of cabling to carry the current. Lower currents are desirable for safety reasons, as well as, to minimize the cabling size needed for distribution. In order to provide lower current, the next iteration of SEA ARCHER would look at emerging technologies into high voltage power distribution. The emerging trend is to use 13,800 V power lines, vice the 4160 V power lines, which would reduce the current by roughly three times. Issues of safety, handling, and naval qualified circuit breakers for 13.8 kV must be addressed.

The distribution of power between the AC and DC systems should be refined further to improve the balance between survivability and the weight and cost of cabling, converters and switch gear. Along these lines, since there are only a few major "dirty" AC power loads, the next iteration would look at removing the AC zonal busses, and using specific AC lines to power these loads. This should eliminate a lot of bus cable weight in zones that do not have the large AC loads.

Lastly, the Total Harmonic Distortion issues imposed on the AC distribution system by the various power converter loads needs to be further investigated. The investigation needs to focus on assessing the passive and active filtering requirements and considering designs specific to improving power quality.

Aviation Operations: The critical part of the design of the aviation systems onboard SEA ARCHER is the use of automation and robotics to replace people. It is a significant risk that the technologies will be developed to a degree sufficient for shipboard application in a combat environment in the given time frame. From a total systems engineering perspective, the hangar bay design was developed more as a separate entity than as a part of the total system. The rest of the design was forced to mold itself around the hangar deck whereas, ideally, it should have been as flexible as any other part of the design. This was an unfortunate consequence of the time constraint of the project, and as such the hangar bay design might not be the optimum for the total ship design. On the next iteration in the design a more integrated approach to design of the hangar bay and hangar bay functions could be done.

Combat Systems: A more in-depth analysis into the benefits of a non-mast/island design versus a conventional mast (albeit low RCS) would be necessary to ensure the best design alternative was chosen. For the first iteration look at combat systems the concern for survivability of the ship was given a high priority (with cost being much lower). Evaluation of the effectiveness of the ships defensive capabilities and the cost to maintain this level of survivability would need to be traded off in the next iteration of combat systems design.

Damage Control: The reliability of the Automated Damage Control Systems should be reviewed. A particular focus on the expected reliability of the detectors would need to be conducted to better understand the overall reliability of the system.

Further analysis needs to be conducted to determine what else can be done by an automated damage control system, before a missile hit, to increase the survivability of the ship.

The size of the damage control parties should also be analyzed to increase the reliability of the damage control system and the survivability of SEA ARCHER. While thought was given to the differing damage control requirements in a highly automated and enclosed hangar bay, further research and design could be done. In particular the number, locations and the material of the fire resistant smoke curtains should be reviewed.

Auxiliaries: A cost analysis should be performed for the recommended magnetic sensors. Depending on the cost, the equipment that would benefit from use of magnetic sensor can be determined. Also, the maintenance of these devices should be reviewed.

Further research into the use of variable speed pumps and the savings projected could also be done to truly understand their impact throughout the life of the ship.

Habitability: Analysis on the benefits of workload reduction practices, like the self-service utilities, should be performed to understand the benefit in cost and man-hours saved by providing these innovations as well as the added cost to bringing these to the design.

Total Ship: The SEA ARCHER design represents one potential solution for the littorals. Follow on work is required to refine the automated systems and man/machine interfaces required to operate this complex warship with a minimal manning concept. The logistic and maintenance support structure will require further analysis to ensure supportability for the ships life cycle.

The ship design philosophy focused on innovation and advanced concepts in order to explore the entire range of possible solutions for the Navy. The next iteration of the design needs to reorder the design philosophy to interject some practical constraints imposed by limited fiscal resources. These constraints should not limit the basic goals of innovation but help refine the realm of possible solutions to meet the mission needs in the littorals.

The SEA ARCHER design resulted from the concept of Total Ship Systems Engineering. By using this concept from the start, a well balanced design resulted in which no one system was optimized, but as a whole, the ship is capable to meeting its demanding requirements.

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APPENDIX A

TYPICAL RESULTS OF THE ANALYTICAL TOOL DURING THE ANALYSIS OF ALTERNATIVES PHASE

1 Squadron Option with Sea Arrow

Modified at NPS for the TSSE "SEA ARCHER" Project
by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	1,900	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.2	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	1,900	1,200	1,900	1,900	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	13,343	7,508	12,590	10,118	8,508
Installed Power [3,6,7]	HP	209,682	239,172	366,357	342,000	318,709	291,384	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	6 LM 2500+	6 LM 6000	6 LM 2500	6 LM 2500	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	3,488	2,406	3,195	2,969	1,844
Length	feet	478	380	646	430	549	522	330
Beam	feet	121	110	121	86	175	64	146
Hullborne Draft	feet	65.7	53.2	26.7	31.9	25.0	22.6	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	7.5	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 600,200,000	$ 543,000,000	$ 584,800,000	$ 542,800,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	21.5	12.4	22.6	20.8	12.1

Notes

1 Results with speeds below 15 knots are not reliable
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 10 equal-sized Gas Turbines
6 Limited to 670,500 HP = 10 Trent Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

1 Squadron Option with JSF

Modified at NPS for the TSSE "SEA ARCHER" Project
by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	3,850	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.1	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	3,850	1,200	3,850	3,850	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	19,640	7,508	18,892	15,003	8,508
Installed Power [3,6,7]	HP	209,682	239,172	487,020	342,000	432,504	365,411	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	6 LM 5000	6 LM 6000	6 LM 5000	6 LM 2500+	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	4,560	2,406	4,251	3,711	1,844
Length	feet	478	380	735	430	628	596	330
Beam	feet	121	110	138	86	201	73	146
Hullborne Draft	feet	65.7	53.2	30.4	31.9	28.6	25.8	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	8.5	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 666,900,000	$ 543,000,000	$ 649,900,000	$ 580,200,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	23.8	12.4	25.0	24.5	12.1

Notes

1 Results with speeds below 15 knots are not reliable
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 10 equal-sized Gas Turbines
6 Limited to 670,500 HP = 10 Trent Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

1 Squadron Option w/o Sea Quiver

Modified at NPS for the TSSE "SEA ARCHER" Project by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	2,271	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.2	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	2,271	1,200	2,271	2,271	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	14,656	7,508	13,906	11,117	8,508
Installed Power [3,6,7]	HP	209,682	239,172	392,383	342,000	343,349	307,664	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	6 LM 5000	6 LM 6000	6 LM 2500+	6 LM 2500	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	3,725	2,406	3,428	3,134	1,844
Length	feet	478	380	666	430	567	539	330
Beam	feet	121	110	125	86	181	66	146
Hullborne Draft	feet	65.7	53.2	27.5	31.9	25.8	23.3	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	7.7	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 614,300,000	$ 543,000,000	$ 598,600,000	$ 550,700,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	22.0	12.4	23.2	21.6	12.1

Notes

1 Results with speeds below 15 knots are not reliable
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 10 equal-sized Gas Turbines
6 Limited to 670,500 HP = 10 Trent Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

2 Squadron Option w Sea Arrow

Modified at NPS for the TSSE "SEA ARCHER" Project by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	3,220	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.2	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	3,220	1,200	3,220	3,220	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	17,748	7,508	17,000	13,511	8,508
Installed Power [3,6,7]	HP	209,682	239,172	451,777	342,000	399,377	344,165	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	6 LM 5000	6 LM 6000	6 LM 5000	6 LM 2500+	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	4,254	2,406	3,950	3,500	1,844
Length	feet	478	380	710	430	606	575	330
Beam	feet	121	110	133	86	194	71	146
Hullborne Draft	feet	65.7	53.2	29.4	31.9	27.6	24.9	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	8.2	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 647,100,000	$ 543,000,000	$ 630,600,000	$ 569,100,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	23.1	12.4	24.4	23.5	12.1

Notes

1 Results with speeds below 15 knots are not reliable
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3 Red indicates limit has been reached
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5 Assumes 10 equal-sized Gas Turbines
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7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

2 Squadron Option with JSF

Modified at NPS for the TSSE "SEA ARCHER" Project by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	7,143	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.1	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	7,143	1,200	7,143	7,143	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	28,222	7,508	27,473	21,988	8,508
Installed Power [3,6,7]	HP	209,682	239,172	639,316	342,000	574,802	453,946	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	> 2 GT's	6 LM 6000	> 2 GT's	6 LM 5000	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	5,815	2,406	5,482	4,561	1,844
Length	feet	478	380	829	430	711	677	330
Beam	feet	121	110	155	86	227	83	146
Hullborne Draft	feet	65.7	53.2	34.3	31.9	32.4	29.3	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	9.6	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 755,000,000	$ 543,000,000	$ 735,800,000	$ 629,900,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	26.0	12.4	27.4	29.0	12.1

Notes

1 Results with speeds below 15 knots are not reliable
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 10 equal-sized Gas Turbines
6 Limited to 670,500 HP = 10 Trent Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

2 Squadron Option w/o Sea Quiver

Modified at NPS for the TSSE "SEA ARCHER" Project by LT A. DALAKOS HN

Initial Input Ranking			
1	Desired Speed in Waves	60	knots
2	Desired Payload	3,620	long tons
3	Desired Range	4,000	nautical miles
	Sea State	1	wave height at top of SS1 = 0.3 feet
	Maximum Displacement	30,000	long tons

Results				SES		Catamaran	Pentamaran	
Calm Water Speed [3,12]	knots	60.0	60.0	60.0	60.1	60.0	60.1	60.0
Speed in Waves [1,3,4,9,10,11]	knots	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Payload Weight [2,3,4,9]	long tons	1,200	1,200	3,620	1,200	3,620	3,620	1,200
Range at Speed in Waves [4,7,9]	nautical miles	4,000	4,000	4,000	2,404	4,000	4,000	1,994
Displacement [3,7]	long tons	7,871	8,424	18,962	7,508	18,214	14,466	8,508
Installed Power [3,6,7]	HP	209,682	239,172	474,472	342,000	420,719	357,881	342,000
Engines [5]	# Type	6 LM 2500+	6 LM 5000	6 LM 5000	6 LM 6000	6 LM 5000	6 LM 2500+	6 LM 6000
Fuel Carried On Board [3,7,8]	long tons	2,082	2,651	4,451	2,406	4,144	3,636	1,844
Length	feet	478	380	726	430	620	588	330
Beam	feet	121	110	136	86	198	72	146
Hullborne Draft	feet	65.7	53.2	30.0	31.9	28.2	25.5	30.3
Foilborne / Cushionborne Draft	feet	26.6	28.2	8.4	N/A	N/A	N/A	N/A
Rough Order of Magnitude Cost		$ 528,900,000	$ 531,300,000	$ 659,800,000	$ 543,000,000	$ 643,000,000	$ 576,200,000	$ 572,100,000
Lift to Drag Ratio		23.8	19.4	23.5	12.4	24.8	24.2	12.1

Notes

1 Results with speeds below 15 knots are not reliable
2 Cannot drop below 10% of desired
3 Red indicates limit has been reached
4 Green indicates desired quantity has been reached
5 Assumes 10 equal-sized Gas Turbines
6 Limited to 670,500 HP = 10 Trent Gas Turbines
7 Purple indicates limit is exceeded
8 Limited to Minimum of 10 long tons
9 Yellow-Orange indicates desired quantity has not been reached
10 SWATH vessels exhibit superior seakeeping at near zero speed compared to other hull forms
11 Cannot drop below 30% of desired
12 Limited to 80 knots, SES limited to 100 knots

APPENDIX B

HYDROSTATICS

Hull Data (with appendages)

Baseline Draft: 4.059 at Origin
Trim: 0.04 deg.
Heel: 0.01 deg.

DIMENSIONS
Length Overall: 181.000 m LWL: 181.000 m Beam: 58.800 m BWL: 57.278 m
Volume: 13067.060 m^3 Displacement: 13393.800 MT

COEFFICIENTS
Prismatic: 0.513 Block: 0.297 Midship: 0.579 Waterplane: 0.523

RATIOS
Length/Beam: 3.078 Displacement/length: 62.949 Beam/Depth: 14.220
MT/ cm Immersion: 55.584

AREAS
Waterplane: 5422.832 m^2 Wetted Surface: 7986.630 m^2
Under Water Lateral Plane: 713.657 m^2 Above Water Lateral Plane: 1165.874 m^2

CENTROIDS (Meters)
Buoyancy: LCB = 17.904 aft TCB =0.001 stbd VCB = 2.655
Flotation: LCF = 11.660 aft
Under Water LP: 4.645 fwd of Origin, 1.985 below waterline.
Above Water LP: 4.189 fwd of Origin, 3.221 above waterline.

Note: Coefficients calculated based on waterline length at given draft

Cross Curves of Stability

Righting Arms(heel) for VCG = 9.31

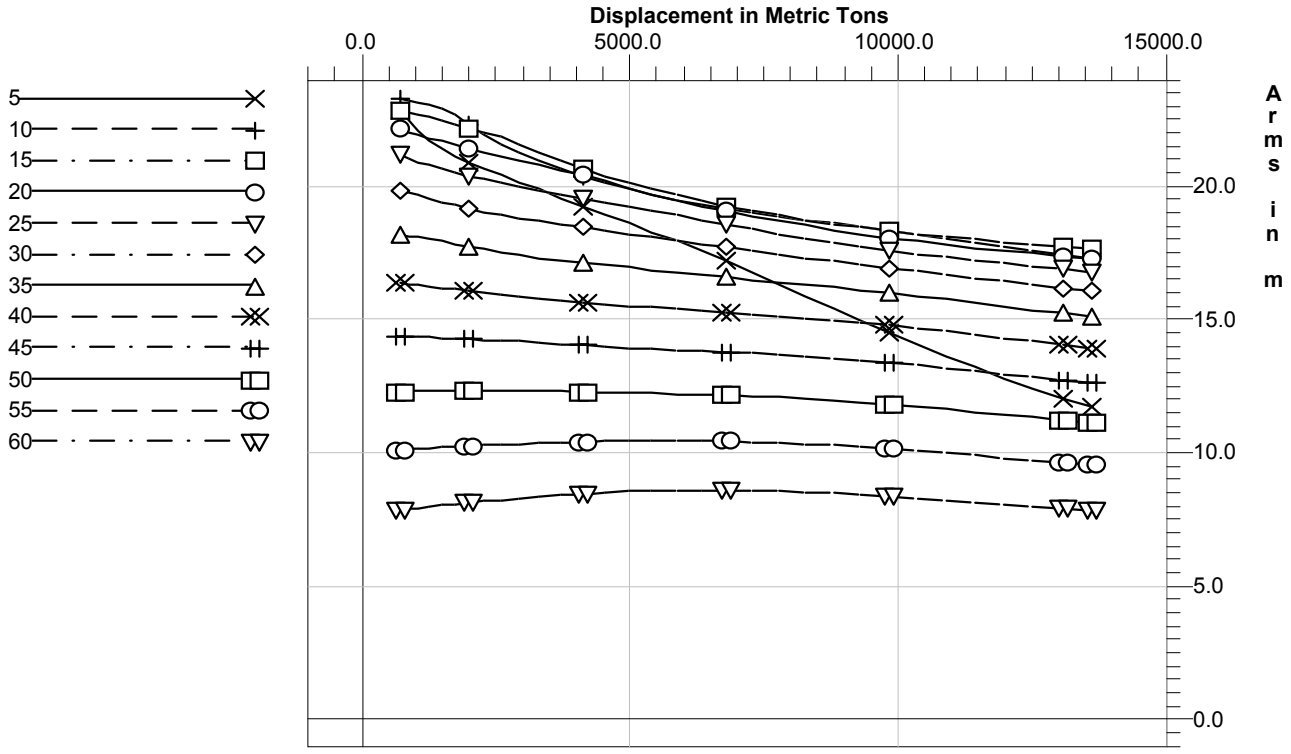
Trim 0.04 deg. at heel = 0 (RA Trim = 0)

Displ (MT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s
675.902	22.911s	23.303s	22.881s	22.172s	21.231s	19.894s
845.591	22.521s	23.273s	22.825s	22.074s	21.091s	19.805s
1034.023	22.131s	23.207s	22.739s	21.963s	20.950s	19.704s
1241.039	21.777s	23.105s	22.633s	21.847s	20.816s	19.585s
1467.126	21.455s	22.953s	22.513s	21.723s	20.686s	19.445s
1713.186	21.167s	22.702s	22.385s	21.590s	20.555s	19.314s
1979.309	20.905s	22.345s	22.233s	21.454s	20.424s	19.186s
2264.686	20.664s	21.977s	22.062s	21.320s	20.294s	19.066s
2570.839	20.435s	21.629s	21.868s	21.175s	20.168s	18.948s
2917.814	20.194s	21.287s	21.629s	21.012s	20.034s	18.832s
3291.426	19.913s	20.966s	21.321s	20.834s	19.896s	18.714s
3684.708	19.607s	20.673s	21.000s	20.644s	19.751s	18.599s
4093.971	19.290s	20.405s	20.698s	20.441s	19.602s	18.483s
4516.920	18.971s	20.156s	20.419s	20.217s	19.451s	18.366s
4952.547	18.653s	19.927s	20.159s	19.973s	19.292s	18.247s
5398.826	18.321s	19.710s	19.919s	19.737s	19.126s	18.126s
5855.431	17.972s	19.508s	19.696s	19.510s	18.957s	18.003s
6321.385	17.611s	19.326s	19.486s	19.298s	18.777s	17.878s
6795.800	17.237s	19.163s	19.291s	19.098s	18.594s	17.749s
7278.998	16.817s	19.015s	19.107s	18.909s	18.418s	17.620s
7769.772	16.372s	18.879s	18.933s	18.728s	18.248s	17.488s
8267.707	15.913s	18.755s	18.772s	18.558s	18.087s	17.352s
8773.214	15.451s	18.633s	18.623s	18.399s	17.933s	17.218s
9287.779	14.987s	18.509s	18.486s	18.249s	17.784s	17.087s
9809.242	14.528s	18.375s	18.361s	18.107s	17.640s	16.959s
10337.060	14.083s	18.233s	18.245s	17.973s	17.505s	16.833s
10869.330	13.656s	18.085s	18.138s	17.847s	17.378s	16.708s
11406.720	13.244s	17.933s	18.040s	17.731s	17.258s	16.582s
11948.760	12.849s	17.777s	17.948s	17.623s	17.143s	16.456s
12494.910	12.468s	17.616s	17.864s	17.523s	17.034s	16.330s
13045.520	12.100s	17.450s	17.785s	17.428s	16.928s	16.207s
13600.500	11.745s	17.281s	17.711s	17.341s	16.823s	16.084s
675.902	18.234s	16.390s	14.411s	12.318s	10.133s	7.875s
845.591	18.177s	16.358s	14.401s	12.328s	10.159s	7.916s
1034.023	18.111s	16.317s	14.383s	12.333s	10.186s	7.962s
1241.039	18.045s	16.272s	14.361s	12.333s	10.210s	8.010s
1467.126	17.968s	16.225s	14.338s	12.333s	10.232s	8.056s
1713.186	17.878s	16.176s	14.315s	12.334s	10.257s	8.103s
1979.309	17.770s	16.123s	14.291s	12.336s	10.282s	8.152s
2264.686	17.659s	16.065s	14.265s	12.337s	10.308s	8.203s
2570.839	17.552s	16.000s	14.237s	12.338s	10.336s	8.255s
2917.814	17.449s	15.917s	14.203s	12.337s	10.365s	8.311s
3291.426	17.350s	15.834s	14.164s	12.334s	10.393s	8.370s
3684.708	17.254s	15.756s	14.118s	12.327s	10.420s	8.426s
4093.971	17.162s	15.682s	14.067s	12.318s	10.443s	8.481s
4516.920	17.072s	15.613s	14.018s	12.303s	10.464s	8.534s
4952.547	16.982s	15.548s	13.974s	12.285s	10.483s	8.583s
5398.826	16.893s	15.484s	13.933s	12.266s	10.497s	8.620s
5855.431	16.802s	15.421s	13.895s	12.250s	10.503s	8.641s
6321.385	16.711s	15.359s	13.858s	12.233s	10.494s	8.647s

Displ (MT)	35.000s	40.000s	45.000s	50.000s	55.000s	60.000s
6795.800	16.618s	15.295s	13.819s	12.207s	10.474s	8.639s
7278.998	16.526s	15.231s	13.773s	12.170s	10.444s	8.620s
7769.772	16.433s	15.162s	13.717s	12.122s	10.404s	8.589s
8267.707	16.338s	15.088s	13.652s	12.065s	10.356s	8.552s
8773.214	16.240s	15.004s	13.577s	11.999s	10.300s	8.508s
9287.779	16.136s	14.912s	13.494s	11.925s	10.237s	8.458s
9809.242	16.024s	14.813s	13.403s	11.844s	10.167s	8.400s
10337.060	15.904s	14.706s	13.307s	11.758s	10.092s	8.336s
10869.330	15.781s	14.594s	13.205s	11.667s	10.013s	8.269s
11406.720	15.653s	14.474s	13.098s	11.571s	9.928s	8.197s
11948.760	15.524s	14.349s	12.985s	11.471s	9.841s	8.120s
12494.910	15.393s	14.222s	12.869s	11.367s	9.750s	8.039s
13045.520	15.259s	14.094s	12.750s	11.261s	9.655s	7.954s
13600.500	15.122s	13.964s	12.627s	11.150s	9.556s	7.868s

Water Specific Gravity = 1.025.

Cross Curves



Hydrostatic Properties

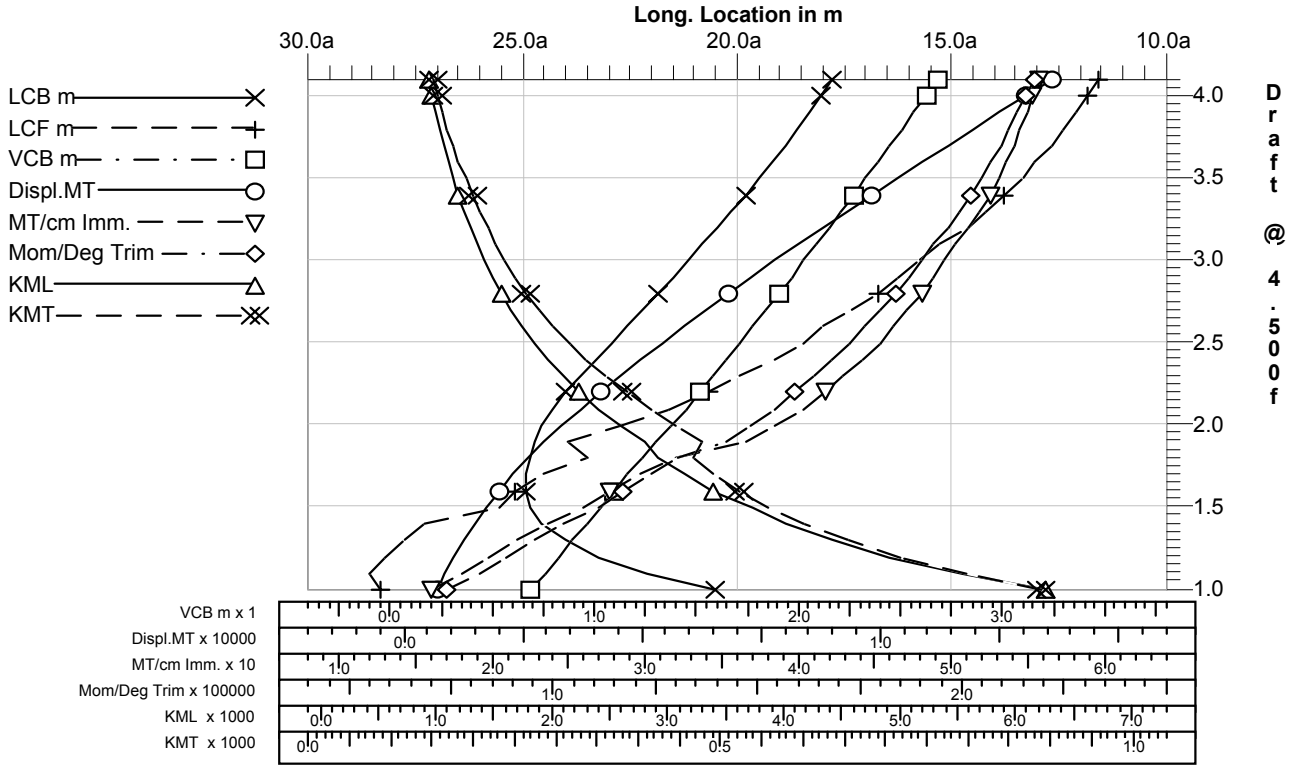
Draft is from Baseline.

Trim: 0.04 deg., No heel, VCG = 9.312

Draft at 4.500f (m)	Displ (MT)	LCB (m)	VCB (m)	LCF (m)	TPcm (MT/cm)	MTcm (MT-m /deg)	KML (m)	KMT (m)
1.000	675.902	20.530a	0.686	28.325a	15.97	73594.80	6,247.261	888.139
1.100	845.591	22.119a	0.755	28.592a	17.96	81553.83	5,534.693	796.093
1.200	1034.023	23.268a	0.823	28.255a	19.74	88280.91	4,900.505	717.664
1.300	1241.039	24.047a	0.891	27.796a	21.61	95264.53	4,406.998	653.050
1.400	1467.126	24.573a	0.958	27.302a	23.54	102368.80	4,006.721	599.706
1.500	1713.186	24.863a	1.026	25.574a	25.88	110924.60	3,718.693	557.352
1.600	1979.309	24.956a	1.094	25.233a	27.54	116815.80	3,390.476	521.495
1.700	2264.686	24.949a	1.161	24.536a	29.58	123509.60	3,133.743	490.716
1.800	2570.839	24.841a	1.229	23.499a	31.85	130296.90	2,912.918	466.368
1.900	2917.814	24.754a	1.301	23.983a	36.49	141879.50	2,795.052	475.093
2.000	3291.426	24.600a	1.372	22.765a	38.45	148069.40	2,586.580	443.000
2.100	3684.708	24.345a	1.442	21.590a	40.31	153711.10	2,399.216	414.322
2.200	4093.971	24.029a	1.511	20.700a	41.70	158746.50	2,230.768	385.053
2.300	4516.920	23.683a	1.578	19.985a	42.89	163448.20	2,082.392	357.716
2.400	4952.547	23.321a	1.645	19.163a	44.18	168120.10	1,954.087	335.441
2.500	5398.826	22.954a	1.710	18.496a	45.23	172200.30	1,836.625	314.721
2.600	5855.431	22.587a	1.774	17.995a	46.09	175862.60	1,729.963	294.930
2.700	6321.385	22.225a	1.837	17.371a	47.06	179746.20	1,638.329	278.509
2.800	6795.800	21.868a	1.900	16.739a	47.97	183509.10	1,556.330	263.695
2.900	7278.998	21.513a	1.962	16.295a	48.67	186644.10	1,478.310	249.232
3.000	7769.772	21.166a	2.023	15.735a	49.49	190156.90	1,411.422	237.058
3.100	8267.707	20.826a	2.084	15.279a	50.15	192979.90	1,346.540	225.219
3.200	8773.214	20.491a	2.144	14.633a	51.09	196602.90	1,293.148	215.899
3.300	9287.779	20.155a	2.205	14.209a	51.82	199296.50	1,238.635	206.338
3.400	9809.242	19.827a	2.265	13.810a	52.42	201754.30	1,187.639	197.187
3.500	10337.060	19.505a	2.325	13.355a	53.02	204662.70	1,143.592	189.068
3.600	10869.330	19.198a	2.384	13.090a	53.44	206661.40	1,098.580	180.855
3.700	11406.720	18.899a	2.443	12.652a	54.01	209570.70	1,061.875	174.050
3.800	11948.760	18.611a	2.502	12.435a	54.39	211280.00	1,022.323	166.998
3.900	12494.910	18.334a	2.560	12.131a	54.85	213511.20	988.274	160.684
4.000	13045.520	18.067a	2.618	11.880a	55.27	215440.90	955.430	154.932
4.100	13600.500	17.809a	2.676	11.596a	55.70	217583.80	925.849	149.486

Water Specific Gravity = 1.025.

Hydrostatic Properties at Trim = 0.04f, Heel = 0.00

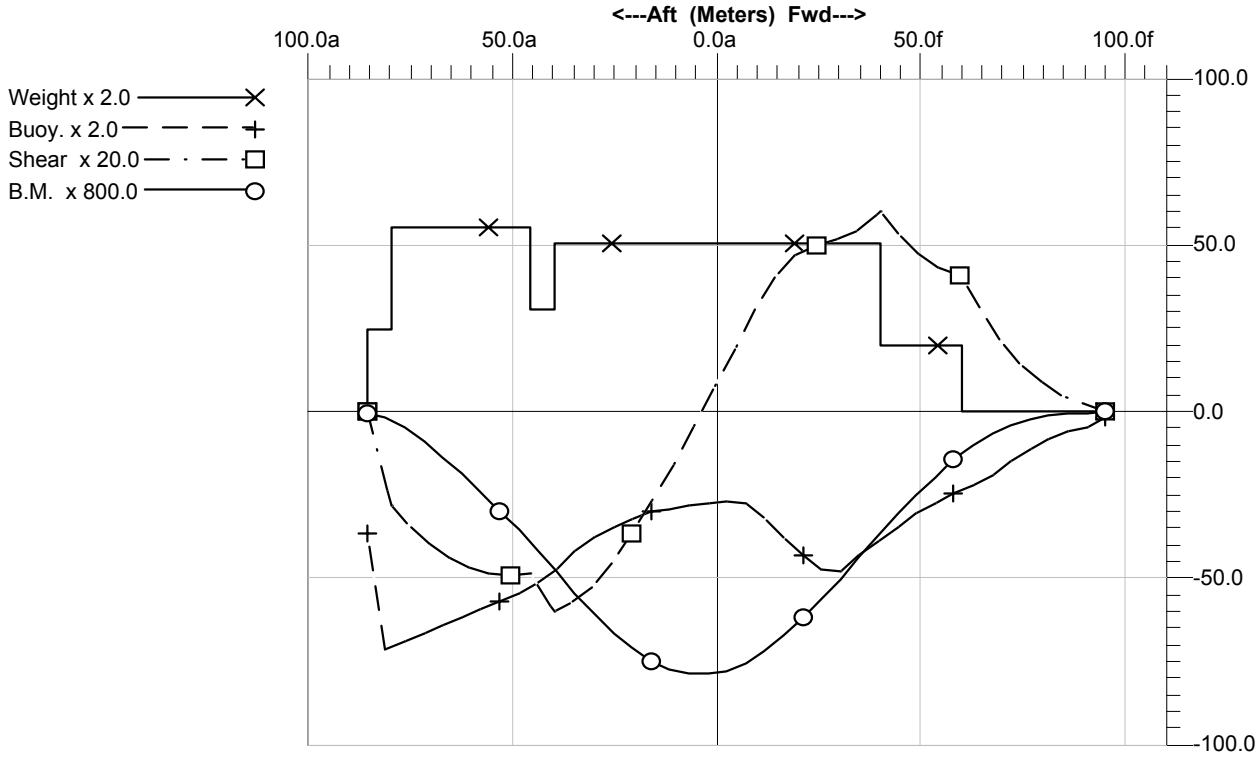


Longitudinal Strength (0.01 deg.)

Location (m)	Weight (MT)	Buoyancy (MT/m)	Shear (MT)	Bending (MT-m)
95.000f	0.000	2.927	0.00	0
84.000f	0.000	12.984	103.61	-494
79.000f	0.000	19.196	184.06	-1198
74.000f	0.000	24.435	293.14	-2378
69.000f	0.000	34.891	441.45	-4191
64.000f	0.000	41.954	633.56	-6862
60.000f	0.000	46.323	810.12	-9742
60.000f	40.000			
59.000f	40.000	47.415	816.99	-10555
54.000f	40.000	53.442	869.13	-14756
49.000f	40.000	60.461	953.89	-19297
44.000f	40.000	68.771	1076.97	-24355
40.000f	40.000	76.047	1206.60	-28911
40.000f	101.601			
39.000f	101.601	77.866	1181.95	-30105
34.000f	101.601	87.320	1086.92	-35755
29.000f	101.601	97.113	1039.99	-41050
24.000f	101.601	92.873	1006.96	-46175
19.000f	101.601	82.876	938.33	-51057
14.000f	101.601	69.778	811.96	-55458
9.000f	101.601	55.951	618.28	-59060
4.000f	101.601	53.574	384.08	-61569
1.000a	101.601	53.519	143.82	-62887
6.000a	101.601	55.538	-91.54	-63012
11.000a	101.601	57.562	-316.79	-61985
16.000a	101.601	59.586	-531.92	-59857
21.000a	101.601	64.045	-730.85	-56689
26.000a	101.601	69.819	-904.19	-52587
31.000a	101.601	76.506	-1046.38	-47695
36.000a	101.601	85.770	-1148.69	-42186
40.000a	101.601	94.783	-1193.99	-37487
40.000a	61.600			
41.000a	61.600	97.035	-1159.69	-36310
46.000a	61.600	105.609	-961.07	-30988
46.000a	111.601			
51.000a	111.601	110.786	-978.08	-26128
56.000a	111.601	116.010	-969.09	-21247
61.000a	111.601	121.268	-933.90	-16477
66.000a	111.601	126.568	-872.31	-11948
71.000a	111.601	131.907	-784.12	-7794
76.000a	111.601	137.273	-669.18	-4148
80.000a	111.601	141.305	-558.43	-1686
80.000a	50.000			
81.000a	50.000	142.313	-466.62	-1173
86.000a	50.000	144.337	0.00	0
86.000a	0.000			

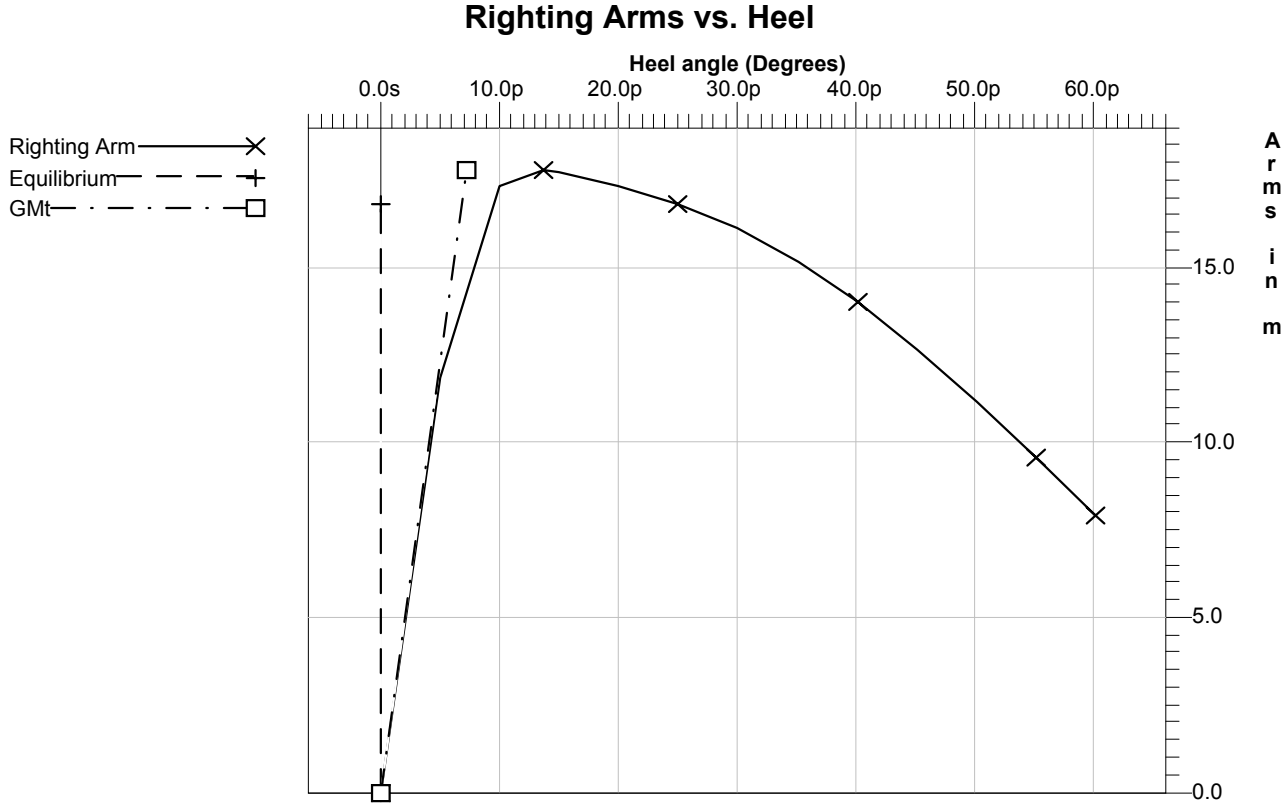
Max. Shear	1206.60 MT	at	40.000f	
Max. Bending Moment	-63012 MT-m	at	6.000a	(Sagging)

Longitudinal Strength



Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)
0.01p	0.04f	4.059	0.000
5.01p	0.07a	3.912	11.859
10.01p	0.37a	2.997	17.344
13.56p	0.50a	1.934	17.809
15.01p	0.52a	1.471	17.731
20.01p	0.56a	-0.148	17.368
25.01p	0.63a	-1.770	16.858
30.01p	0.74a	-3.370	16.127
35.01p	0.88a	-4.933	15.172
40.01p	1.04a	-6.454	14.014
45.01p	1.21a	-7.936	12.675
50.01p	1.37a	-9.359	11.194
55.01p	1.51a	-10.715	9.596
60.01p	1.62a	-11.986	7.902



Floodable Length Calculation

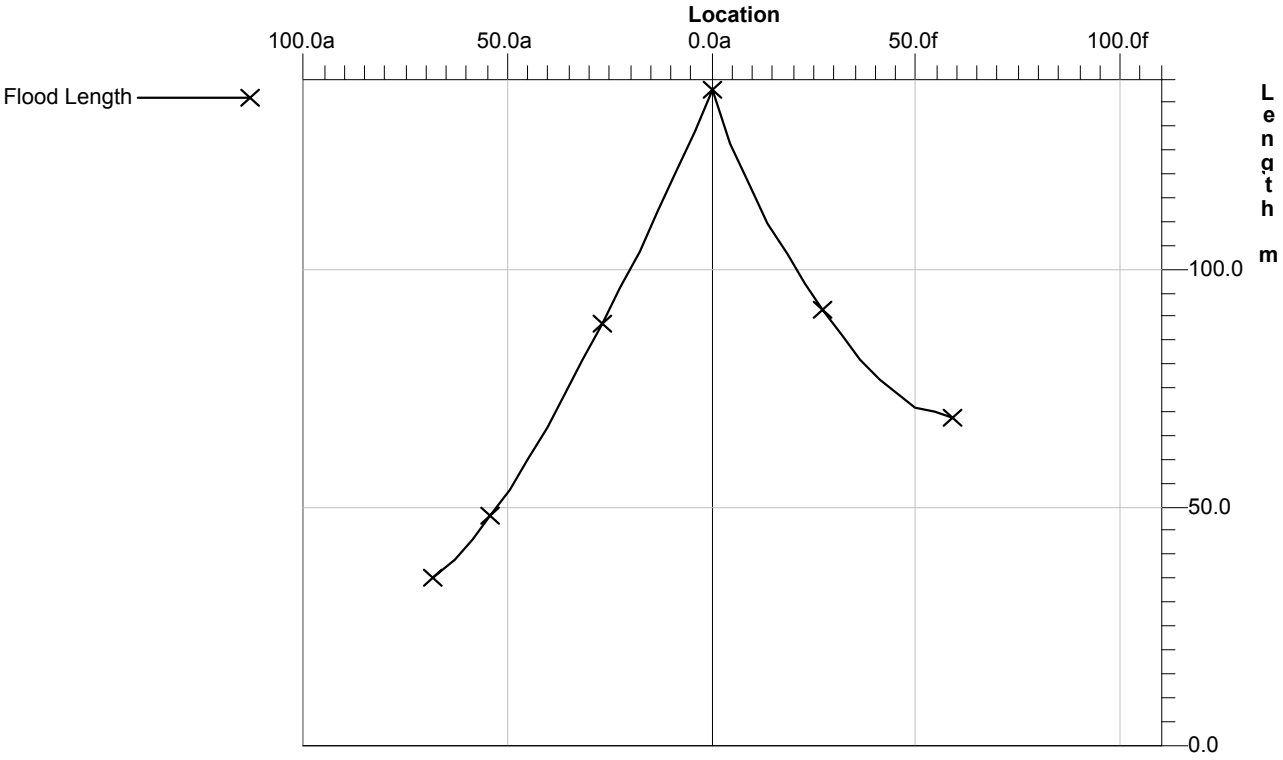
Displacement: 13668.97MT Water Specific Gravity: 1.025 Draft: 4.10 m

L: 18.474a T: 0.000 V: 3.500 m

Required GM: 0.50 m Uniform Permeability: **0.95**

Center (m)	Length (m)	Trim (deg)	GM (m)
58.800f	69.06	2.539f	56.62
54.275f	70.03	2.486f	55.62
49.750f	71.05	2.406f	54.50
40.700f	76.92	2.321f	48.51
36.175f	81.09	2.258f	45.31
31.650f	86.08	2.190f	41.73
27.125f	91.45	2.110f	37.99
22.600f	97.29	2.009f	33.95
18.075f	103.37	1.872f	29.70
13.550f	109.88	1.674f	25.23
9.025f	117.64	1.383f	20.20
4.500f	126.55	0.891f	14.73
0.025a	137.99	0.000	8.64
4.550a	129.10	0.394a	11.37
9.075a	120.40	0.851a	14.69
13.600a	112.05	1.248a	18.13
18.125a	103.95	1.595a	21.90
22.650a	96.24	1.923a	25.77
27.175a	88.72	2.186a	29.88
31.700a	81.27	2.390a	33.78
36.225a	73.81	2.533a	37.61
40.750a	66.74	2.665a	41.16
45.275a	59.97	2.781a	44.60
49.800a	53.76	2.896a	48.08
54.325a	48.19	3.005a	51.24
58.850a	43.32	3.130a	53.46
63.375a	39.01	3.239a	56.03
68.431a	35.14	3.456a	55.41

Floodable Lengths



Floodable Length Calculation

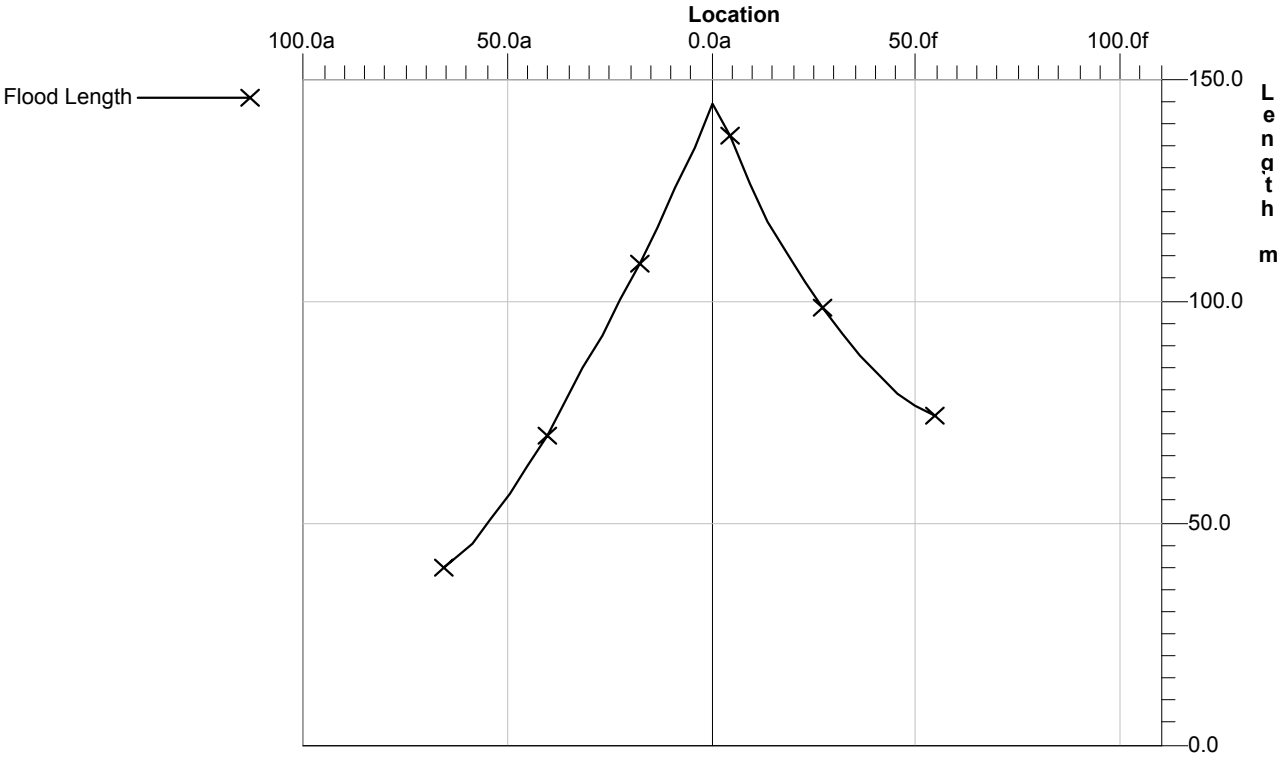
Displacement: 13668.97MT Water Specific Gravity: 1.025 Draft: 4.10 m

L: 18.474a T: 0.000 V: 3.500 m

Required GM: 0.50 m Uniform Permeability: **0.9**

Center (m)	Length (m)	Trim (deg)	GM (m)
54.275f	74.52	2.476f	53.36
49.750f	76.54	2.427f	51.43
45.225f	79.42	2.378f	48.61
36.175f	87.75	2.257f	42.32
31.650f	92.93	2.192f	38.72
27.125f	98.61	2.112f	34.87
22.600f	104.46	2.004f	30.91
18.075f	110.63	1.854f	26.82
13.550f	117.98	1.646f	22.08
9.025f	126.41	1.328f	17.10
4.500f	137.50	0.725f	11.15
0.025a	144.50	0.120a	7.55
4.550a	134.90	0.523a	10.39
9.075a	125.68	0.945a	13.66
13.600a	116.85	1.311a	17.18
18.125a	108.40	1.643a	20.86
22.650a	100.36	1.958a	24.68
27.175a	92.52	2.213a	28.83
31.700a	84.93	2.414a	32.72
36.225a	77.30	2.562a	36.53
40.750a	69.97	2.684a	40.18
45.275a	63.00	2.805a	43.54
49.800a	56.54	2.908a	47.15
54.325a	50.75	3.019a	50.27
58.850a	45.59	3.123a	52.79
65.850a	40.30	3.292a	55.20

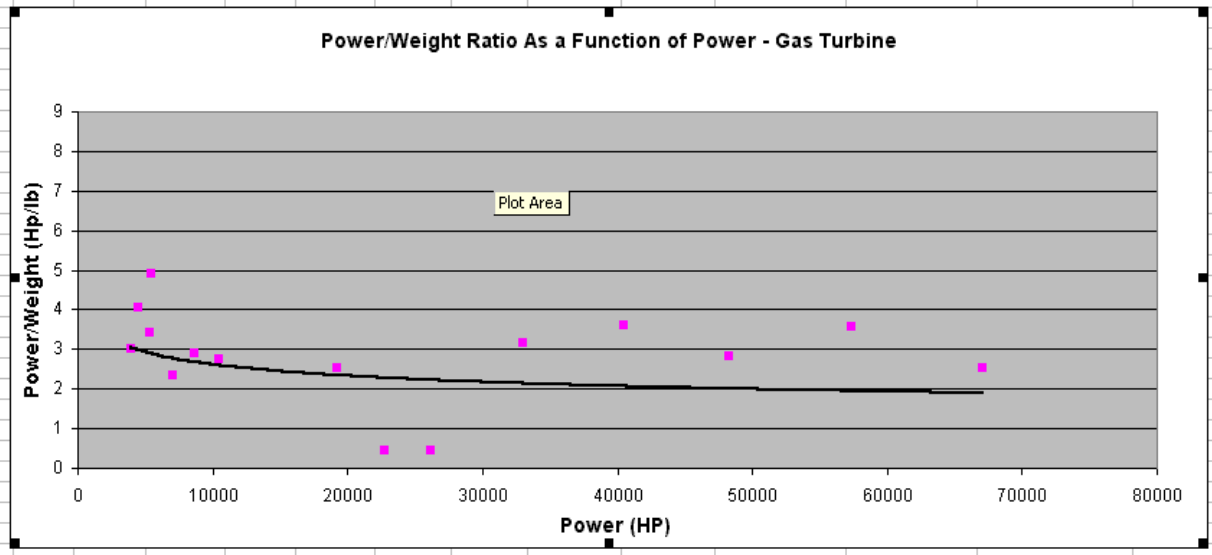
Floodable Lengths



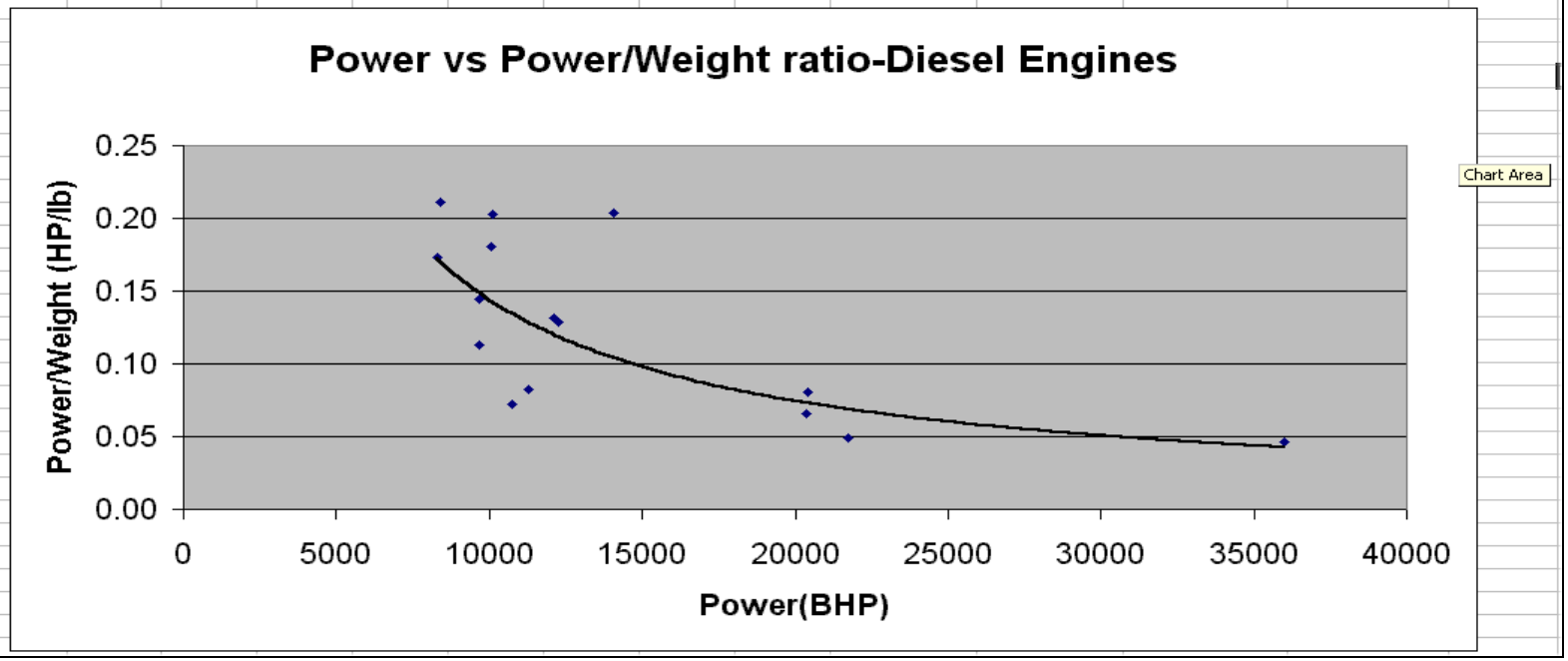
APPENDIX C

PROPULSION

Company	Power (KW)	Power (MW)	Power (HP)	Engine Weight (kg)	Weight (lb)	Weight (LT)	Weight (mT)	Footprint (m^2)	Footprint (ft^2)	Power/Weight (HP/lb)	Power/Weight (HP/kg)	Power/Footprint (HP/ft^2)	Power/Footprint (HP/ft^2)	SFC lb/(SHP-hr)	SFC kg/(KW-hr)
Rolls-Royce Trent 50	50000	50.00	67050.00	12000	26460.00	11.81	12.0	40.06	431.05	2.53	5.59	1673.74	155.55	0.334	0.203
Rolls-Royce Trent 30	36000	36.00	48276.00	7700	16978.50	7.58	7.7		0.00	2.84	6.27	#DIV/0!		0.326	0.198
GE LM6000	42752	42.75	57330.43	7302	16100.91	7.19	7.3	18.51	199.17	3.56	7.85	3097.27	287.85	0.329	0.200
GE LM2500+	30201	30.20	40499.54	5079	11199.20	5.00	5.1	14.96	160.97	3.62	7.97	2707.19	251.60	0.353	0.215
GE LM2500	24609	24.61	33000.67	4762	10500.21	4.69	4.8	14.31	153.98	3.14	6.93	2306.13	214.32	0.372	0.226
Rolls-Royce Spey	19500	19.50	26149.50	25633	56520.77	25.23	25.6	17.14	184.43	0.46	1.02	1525.64	141.79	0.372	0.226
ABB GT35	17000	17.00	22797.00	23000	50715.00	22.64	23.0	37.95	408.34	0.45	0.99	600.71	55.83	0.427	0.260
GE LM1600	14318	14.32	19200.44	3424	7549.92	3.37	3.4	9.06	97.49	2.54	5.61	2119.25	196.96	0.380	0.231
Rolls-Royce 501-KF11	7830	7.83	10500.03	1723	3799.22	1.70	1.7	3.13	33.68	2.76	6.09	3354.64	311.77	0.408	0.248
Rolls-Royce 501-KF9	6469	6.47	8674.93	1361	3001.01	1.34	1.4	2.42	26.04	2.89	6.37	3584.68	333.15	0.414	0.252
Rolls-Royce 501-KF7	5235	5.24	7020.14	1361	3001.01	1.34	1.4	4.31	46.38	2.34	5.16	1628.80	151.38	0.436	0.265
Pratt & Whitney ST40 Dry	4039	4.04	5416.30	500	1102.50	0.49	0.5	1.1	11.84	4.91	10.83	4923.91	457.61	0.418	0.254
Allied Signal TF50A	4000	4.00	5364.00	710	1565.55	0.70	0.7	1.27	13.67	3.43	7.55	4223.62	392.53	0.455	0.277
Prat & Whitney ST30	3341	3.34	4480.28	500	1102.50	0.49	0.5	1.1	11.84	4.06	8.96	4072.98	378.53	0.432	0.263
Allied Signal TF40	2983	2.98	4000.20	601	1325.21	0.59	0.6	1.27	13.67	3.02	6.66	3149.77	292.73	0.492	0.299



Company	Power (KW)	Power (MW)	Power (HP)	Weight (kg)	Weight (lb)	Weight (LT)	Footprint (m^2)	Footprint (ft^2)	Power/Weight (HP/lb)	Power/Weight (HP/kg)	Power/Footprint (HP/m^2)	Power/Footprint (HP/ft^2)	SFC lb/(BHP-hr)
Pielstick 20PC4.2B	26500	26.50	36000	349206	770000	342.22	78.52	844.88	0.05	0.10	458.48	42.61	0.3026
MaK M43	16200	16.20	21715	199546	440000	195.56	52.32	562.96	0.05	0.11	415.04	38.57	0.2895
Man 20V40/50	15000	15.00	20400	115193	254000	112.89	47.35	509.49	0.08	0.18	430.83	40.04	0.2977
Pielstick 20PC2.6B	15000	15.00	20380	139683	308000	136.89	40.64	437.29	0.07	0.15	501.48	46.61	0.3026
Allen 5020	10500	10.50	14074	31293	69000	30.67	30.59	329.15	0.20	0.45	460.08	42.76	
mtu 20V 8000 M90	9000	9.00	12240	42992	94798	42.13	16.29	175.28	0.13	0.28	751.38	69.83	0.3273
Pielstick 20PA6B STC	8910	8.91	12110	41905	92400	41.07	21.01	226.07	0.13	0.29	576.39	53.57	0.3026
Wartsila 18V32	8280	8.28	11260	61678	136000	60.44	28.89	310.86	0.08	0.18	389.75	36.22	0.2977
MaK VM32C	8000	8.00	10723	67120	148000	65.78	24.04	258.67	0.07	0.16	446.05	41.45	0.2961
Ruston 20RK270	7550	7.55	10125	22676	50000	22.22	11.57	124.49	0.20	0.45	875.11	81.33	0.3289
mtu 20V 1163 TB93	7400	7.40	10065	25305	55798	24.80	10.06	108.25	0.18	0.40	1000.50	92.98	0.3701
caterpillar 3618	7200	7.20	9651	38855	85676	38.08	10.87	116.96	0.11	0.25	887.86	82.51	0.3355
wartsila 18V26X	7200	7.20	9651	30385	67000	29.78	17.55	188.84	0.14	0.32	549.91	51.11	0.3109
mtu 20V 956 TB92	6250	6.25	8378	18027	39749	17.67	7.83	84.25	0.21	0.46	1069.99	99.44	0.3684
Niigata 18V26FX	6200	6.20	8310	21801	48071	21.36	13.63	146.66	0.17	0.38	609.68	56.66	



Gas Turbine Engine Parameters

Manufacturer	Engine	Reference	Power	Power	SFC	RPM	Engine Dimensions			Volume	Volume	Cost in	Weight	Weight
Company	Nomenclature	*web address etc.*	*(SHP)*	*(MW)*	*lb/shp-hr*	*Power Turbine*	*L (ft)*	*W (ft)*	*H (ft)*	*(ft^3)*	*(m^3)*	*Millions*	*lbs*	*LT*
Rolls-Royce	**Trent**	**www2.rolls-royce.com**	**67051**	**50.00**	**0.333**	**3600**	**40.73**	**13.50**	**15.93**	**8759.19**	**248.03**	**15.07**	**57330**	**25.59**
General Electric	LM6000	www.geae.com	57330	42.75	0.329	3600	16.00	7.00	7.00	**784.00**	**22.20**	12.10	16000	7.14
General Electric	**LM2500+**	**www.geae.com**	**40500**	**30.20**	**0.354**	**3600**	**22.00**	**8.69**	**6.70**	**1281.59**	**36.29**	**10.30**	**11545**	**5.15**
Alstom Power	GT10C	www.dieselpub.com	39205	29.24	0.394	6500				**0.00**	**0.00**	10.10		0.00
Rolls-Royce	WR-21	www.dieselpub.com/TSSE Binder	33850	25.24	0.3373	3600	26.25	8.67	15.83	**3602.08**	**102.00**	7.1 (1994)	111450	49.75
Alstom Power	GT10B	www.dieselpub.com	33841	25.24	0.394	7700				**0.00**	**0.00**	10.10		0.00
General Electric	LM2500	www.geae.com	33600	25.06	0.373	3600	21.40	15.67	6.70	**2246.29**	**63.61**	9.50	10300	4.60
MAN Turbomaschinen AG GHH Borsig	FT8 MarinePac	www.dieselpub.com	33593	25.05		3000				**0.00**	**0.00**	11.00		0.00
Northrop Grumman	WR-21	www.gas-turbines.com	26400	19.69	0.36	3600	26.25	8.67	15.83	**3602.08**	**102.00**		120000	53.57
Rolls-Royce	Spey	www2.rolls-royce.com	26149	19.50	0.371	5500	24.58	7.50	11.13	**2051.17**	**58.08**	11.00	57568	25.70
Alstom Power	GT35C	www.dieselpub.com	22797	17.00	0.427	3300				**0.00**	**0.00**	8.00	50715	22.64
General Electric	LM1600	www.geae.com	20000	14.91	0.373	7000	13.84		6.67	**0.00**	**0.00**	6.90	8200	3.66
Vericor Power Systems	TF 100	www.vericor.com	10905	8.13		1070	5.33	2.75	3.25	**47.67**	**1.35**		1565	0.70
Rolls-Royce	601-KF11	www.dieselpub.com	10507	7.84	0.407	11500				**0.00**	**0.00**		3800	1.70
Vericor Power Systems	TF80	www.vericor.com	8958	6.68		1030	4.67	2.92	3.67	**49.91**	**1.41**		1325	0.59
Rolls-Royce	601-KF9	www.dieselpub.com	8671	6.47	0.414	11500				**0.00**	**0.00**		3001	1.34
Rolls-Royce	501-KF7	www.dieselpub.com	7012	5.23	0.437	13820				**0.00**	**0.00**		3001	1.34
General Electric	LM500	www.geae.com	6000	4.47	0.443	7000	9.70		3.00	**0.00**	**0.00**	1.90	1990	0.89
General Electric	Allison 571KF (6000 series)	TSSE room File Cabinet	6000	4.47	0.408	1800	15.77	5.69	7.72	**692.16**	**19.60**		15000	6.70
Vericor Power Systems	TF50	www.vericor.com	5599	4.18	0.455	16000	4.58	2.92	3.42	**45.67**	**1.29**		1565	0.70
Pratt & Whitney	ST40	www.dieselpub.com	5416	4.04	0.418	14875	5.58	2.17	3.17	**38.31**	**1.08**		1157	0.52
Rolls-Royce	501-KF5	www.dieselpub.com	5225	3.90	0.503	13820	9.59		4.44	**0.00**	**0.00**		2500	1.12
General Electric	Allison 570KF (5000 series)	TSSE room File Cabinet	5100	3.80	0.467	1800	15.77	5.69	7.72	**692.16**	**19.60**		15000	6.70
Vericor Power Systems	TF40E	www.vericor.com	4598	3.43	0.491	15400	4.33	2.92	3.42	**43.18**	**1.22**		1325	0.59
Pratt & Whitney	ST30	www.dieselpub.com	4479	3.34	0.432	14875	5.41	2.17	3.17	**37.12**	**1.05**		1100	0.49
Pratt & Whitney	ST18A	www.dieselpub.com	2630	1.96		18900	5.02	2.17	2.66	**28.89**	**0.82**		772	0.34
Opra Optimal Radial Turbine B.V.	OP16S2A	www.dieselpub.com	2347	1.75		1800				**0.00**	**0.00**			0.00
Opra Optimal Radial Turbine B.V.	OP16R2A	www.dieselpub.com	2186	1.63		1800				**0.00**	**0.00**			0.00
Pratt & Whitney	ST6L-90	www.dieselpub.com	1576	1.18		30000	4.38	1.58	1.83	**12.70**	**0.36**		305	0.14
Turbomeca	Makila Ti	www.turbomeca.com	1515	1.13	0.559	7000				**0.00**	**0.00**			0.00
Pratt & Whitney	ST6L-812	www.dieselpub.com	984	0.73		30000	1.58	1.45	4.22	**9.68**	**0.27**		300	0.13
Pratt & Whitney	ST6L-794	www.dieselpub.com	810	0.60		33000	4.42	1.75	1.75	**13.53**	**0.38**		230	0.10
Pratt & Whitney	ST6L-721	www.dieselpub.com	681	0.51		33000	4.42	1.75	1.75	**13.53**	**0.38**		230	0.10
Rolls-Royce	EURODYN	www.dieselpub.com	0			13000				**0.00**	**0.00**			0.00
	(Possible Alternatives)													
	(No Longer in production)													
	(Data not currently available)													

WATERJETS POSSIBILITIES WORKSHEET

	Manufacturer	Nomenclature	Reference	Power	Power	RPM	Dimensions if Known		Cost in	Weight (with water)	Weight	Weight
	Company	Model	*web address etc.*	*(MW)*	*(HP)*		*Length (ft)*	*diameter(ft)*	*Millions*	*kg*	*lbs*	*LT*
**	Kamewa	S-series	www.kamewagroup.com	250.00	335255							
	Kamewa	S-series	www.kamewagroup.com	50.00	67051							
	Kamewa	200SII	Kawmema Group	24.00	32185		40.01	10.83		101210	223168.1	99.63
	Kamewa	180SII	Kawmema Group	22.00	29502		36.02	9.74		74910	165176.6	73.74
	Niigata	J1500R	www.niigata-power.com	12.00	16092	480	37.73	8.20				
***	MJP		www.mjp.se	10.00	13410							
	Niigata	J1250R	www.niigata-power.com	8.90	11935	600	24.28	6.56				
	Niigata	J1100R	www.niigata-power.com	6.70	8985	600	20.01	6.22				
	Niigata	J950R	www.niigata-power.com	4.60	6169	750	13.78	5.38				
	Niigata	J850R	www.niigata-power.com	3.70	4962	845	10.83	4.79				
	Hamilton Jets	HM	www.hamiltonjet.com	2.98	4000			2.66				
	Niigata	J750R	www.niigata-power.com	2.80	3755	950	6.89	4.23				
	Niigata	J650R	www.niigata-power.com	2.10	2816	1100	5.25	3.67				
	Kamewa	FF-series (24-55)	www.kamewagroup.com	1.50	2012							
	Niigata	J550R	www.niigata-power.com	1.50	2012	1290	3.87	3.08				
	AWJ	21	www.marinelog.com	1.50	2012							
	Hamilton Jets	HM	www.hamiltonjet.com	0.67	900			1.38				
*	Kamewa	A-series (40-46)	www.kamewagroup.com	0.50	671							
	MJP		www.mjp.se	0.50	671							

*	good from 0.5-2.8MW
**	indicates in progress
***	supports ranges between 0.5-10MW
	(DATA NOT CURRENTLY AVAILABLE)
1mm=	3.28E-03 ft

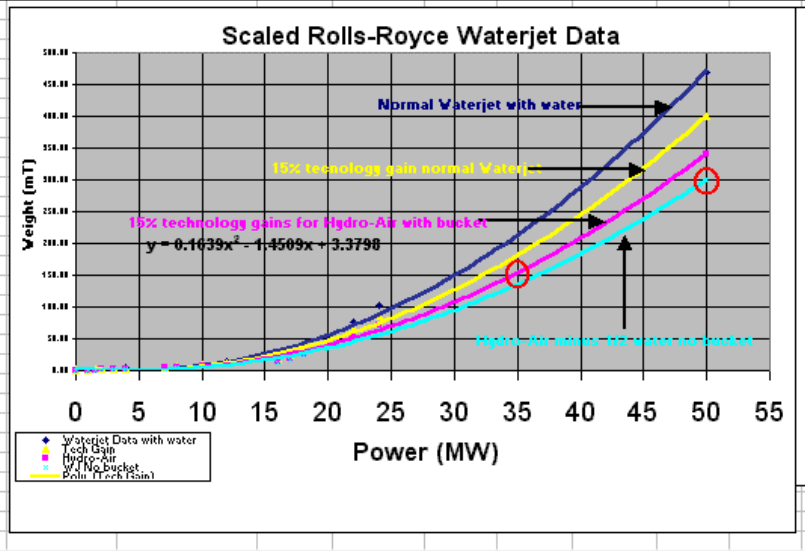
PROPELLERS POSSIBILITIES WORKSHEET

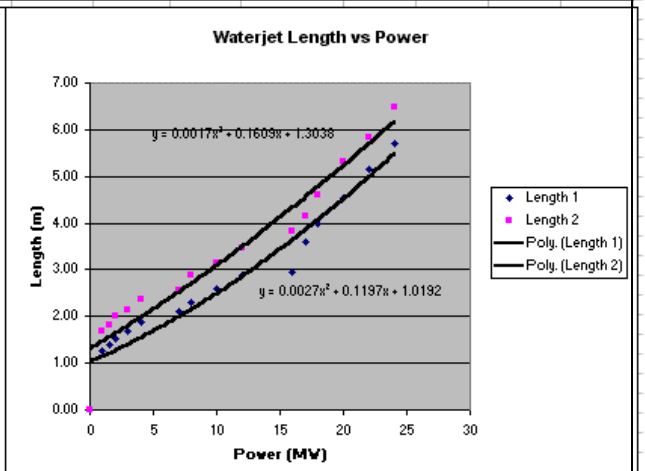
Manufacturer	Nomenclature	Reference	Hp.-Pump Power	Hp.-Pump Power	Input Power	Input Power	DIA	DIA	RPM	Dimensions if Known			Cost in	Weight	Weight
Company		*web address etc.*	*(HP)*	*(kW)*	*(HP)*	*(MW)*	*(ft)*	*(mm)*		*Length (ft)*	*Width (ft)*	*Height (ft)*	*Millions*	*lbs*	*LT*
SCHOTTEL	**Rudderpropeller**	http://www.schottel.de													
	SRP 12					0.04	1.64	500	2300						0.07
	SRP60					0.10	2.30	700	2500						0.54
	SRP110					0.20	2.79	850	2350						0.88
	SRP200					0.31	3.61	1100	1800/2100						2.10
	SRP330					0.47	4.59	1400	1800						3.30
	SRP550					0.75	5.58	1700	1000/1500/1800						7.50
	SRP1010					1.04	6.89	2100	750/1000/1200/1800						15.00
	SRP1212					1.38	7.55	2300	750/1000/1200/1800						17.00
	SRP1515					1.75	8.53	2600	750/1000/1600						28.00
	SRP2020					2.15	9.19	2800	750/1000						37.00
	SRP3030					2.85	11.48	3500	750/1000						56.00
	SRP4500					4.00	14.76	4500	750/900						65.00
	Twin-propeller														
	STP 110					0.20	2.79	850	2350						1.10
	STP200					0.31	3.28	1000	1800/2100						2.60
	STP330					0.47	4.27	1300	1800						4.00
	STP550					0.75	5.25	1600	1000/1500/1800						9.00
	STP1010					1.04	6.56	2000	750/1000/1200/1800						18.00
	STP1212					1.38	7.22	2200	750/1000/1200/1800						20.40
	STP1515					1.75	8.20	2500	750/1000/1600						33.00
	STP2020					2.15	8.53	2600	750/1000						44.00
	STP3030					2.85	10.83	3300	750/1000						67.00
	Controllable-Pitch														
	SCP0334x		1475.124045	1.1	603.4598364	0.45	3.94	1200	550						
	SCP0364X		1743.328416	1.3	670.5109293	0.50	4.10	1250	500						
	SCP0384X		2011.532788	1.5	804.6131152	0.60	4.59	1400	460						
	SCP0424X		2413.839346	1.8	938.7153011	0.70	4.92	1500	420						
	SCP0464X		2682.043717	2	1139.86858	0.85	5.41	1650	390						
	SCP0504X		3352.554647	2.5	1341.021859	1.00	5.91	1800	360						
	SCP0554X		4693.576505	3.5	1609.22623	1.20	6.56	2000	330						
	SCP0604X		5364.087435	4	1877.430602	1.40	7.22	2200	300						
	SCP0654X		6705.109293	5	2279.73716	1.70	7.87	2400	280						
	SCP0714X		8046.131152	6	2682.043717	2.00	8.53	2600	250						
	SCP0774X		10057.66394	7.5	3218.452461	2.40	9.19	2800	230						
	SCP0844X		10728.17487	8	3754.861204	2.80	10.83	3300	215						
	SCP0914X		14751.24045	11	4693.576505	3.50	11.81	3600	200						
	SCP1004X		18774.30602	14	5364.087435	4.00	12.47	3800	180						
	SCP1094X		24138.39346	18	7107.415851	5.30	13.45	4100	170						
	SCP1194X		29502.48089	22	7509.722408	5.60	14.76	4500	150						
	SCP1294X		34866.56833	26	8448.43771	6.30	15.75	4800	140						
	SCP1414X		46935.76505	35	9789.459568	7.30	17.06	5200	130						
	SCP1544X		59004.96178	44	13410.21859	10.00	18.04	5500	130						
	SCP1684X		73756.20223	55	18774.30602	14.00	19.69	6000	130						
	SCP1834X		93871.53011	70	22797.3716	17.00	21.33	6500	120						
	SCP2004X		120691.9673	90	30843.50275	23.00	23.62	7200	110						

Waterjet Data

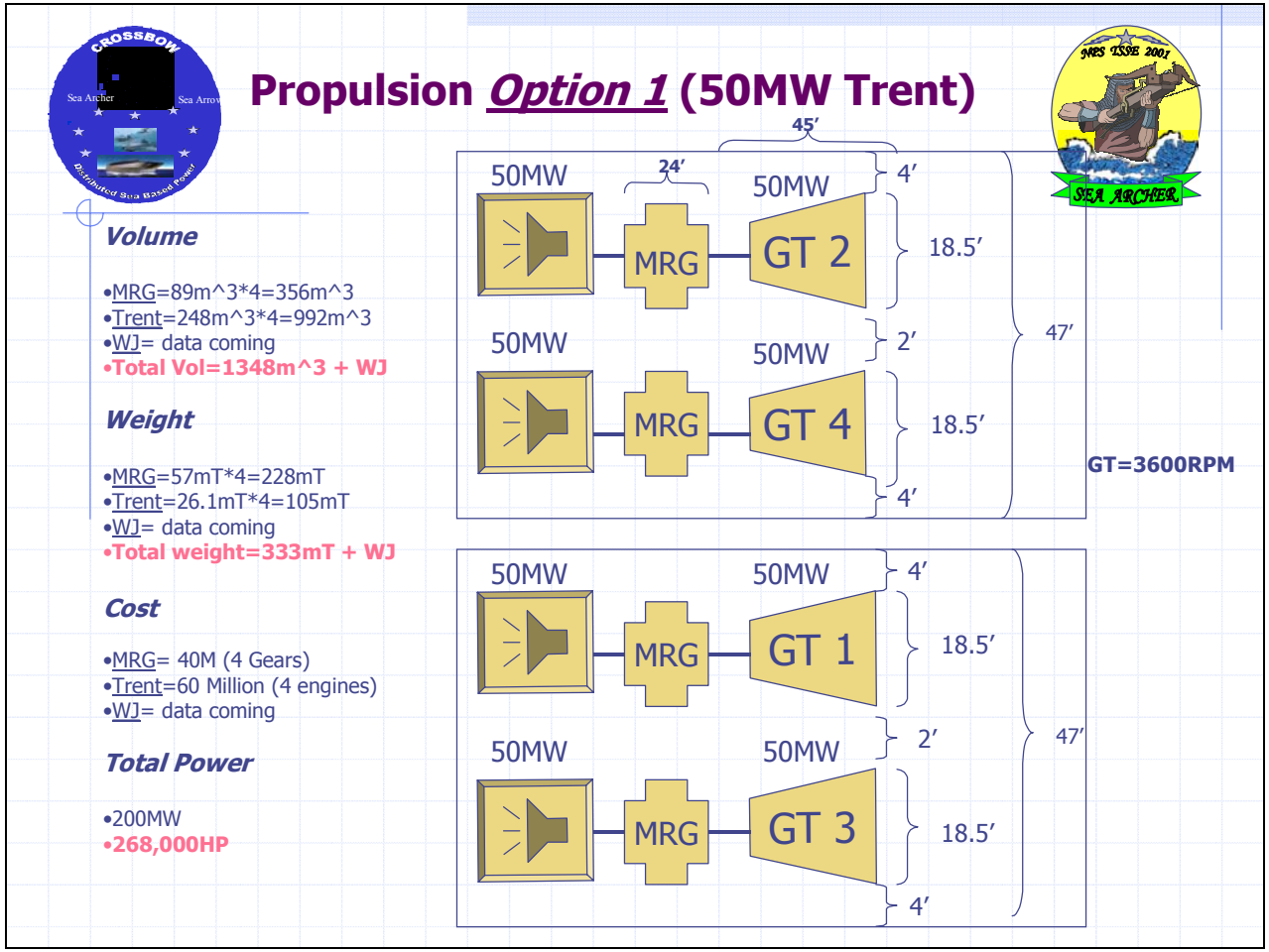
Power MW	L1 (m)	L2 (m)	Diameter (m)	S (kg)	B(kg)	W(kg)	S (lb)	B(lb)	W(lb)	S+B+W (lb)	S+B+W (mT)	15% gain on WJ (mT)	S+B+0.5 W (mT)	15% Gain on Hydro_Air (mT)	Hydro air S+0.5W (mT)	Boost only no steering reversing
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	1.28	1.68	0.79	530.00	370.00	270.00	1168.65	815.85	595.35	2579.85	1.17	0.99	1.04	0.88	0.65	0.75
1.5	1.41	1.81	0.85	650.00	460.00	380.00	1433.25	1014.30	837.90	3285.45	1.49	1.27	1.30	1.11	0.83	0.95
2	1.52	2.02	0.95	880.00	660.00	510.00	1940.40	1455.30	1124.55	4520.25	2.05	1.74	1.80	1.53	1.12	1.31
3	1.68	2.13	1.03	1160.00	820.00	710.00	2557.80	1808.10	1565.55	5931.45	2.69	2.29	2.34	1.98	1.49	1.71
4	1.88	2.38	1.12	1790.00	1210.00	1020.00	3946.95	2668.05	2249.10	8864.10	4.02	3.42	3.51	2.98	2.26	2.56
7	2.11	2.57	1.28	2420.00	1620.00	1450.00	5336.10	3572.10	3197.25	12105.45	5.49	4.67	4.77	4.05	3.10	3.50
8	2.31	2.90	1.45	3230.00	2320.00	2080.00	7122.15	5115.60	4586.40	16824.15	7.63	6.49	6.59	5.60	4.20	4.86
10	2.59	3.14	1.66	4530.00	3130.00	2940.00	9988.65	6901.65	6482.70	23373.00	10.60	9.01	9.13	7.76	5.91	6.76
12	2.88	3.46	1.71	6380.00	4150.00	4050.00	14067.90	9150.75	8930.25	32148.90	14.58	12.39	12.56	10.67	8.27	9.29
16	2.94	3.84	1.92	7650.00	5270.00	5700.00	16868.25	11620.35	12568.50	41057.10	18.62	15.83	15.77	13.40	10.34	11.87
17	3.60	4.14	2.14	11360.00	7510.00	7910.00	25048.80	16559.55	17441.55	59049.90	26.78	22.76	22.83	19.40	15.08	17.07
18	3.99	4.59	2.22	15210.00	10450.00	11130.00	33538.05	23042.25	24541.65	81121.95	36.79	31.27	31.23	26.54	20.45	23.45
20	4.54	5.30	2.64	22870.00	13630.00	16790.00	50428.35	30054.15	37021.95	117504.45	53.29	45.30	44.90	38.16	30.78	33.97
22	5.15	5.83	2.97	30880.00	20570.00	23660.00	68090.40	45356.85	52170.30	165617.55	75.11	63.84	63.28	53.79	42.04	47.88
24	5.72	6.48	3.30	41220.00	27520.00	32470.00	90890.10	60681.60	71596.35	223168.05	101.21	86.03	84.98	72.23	56.56	64.52
50									308700.00	1036350.00	470.00	399.50	400.00	340.00		299.63

lote: S = Total dry weight
= weight of booster unit
= Weight of water in inlet duct
& L2 are water jet section lengths
ering and reversing gear is 25% of weight





PROPULSION LAYOUT OPTIONS EXPLORED



Propulsion *Option 2* (LM 2500+)

Volume

- MRG=89m^3*4=356m^3
- LM2500+=36m^3*8=291m^3
- WJ= data coming
- **Total Vol=647m^3 + WJ**

Weight

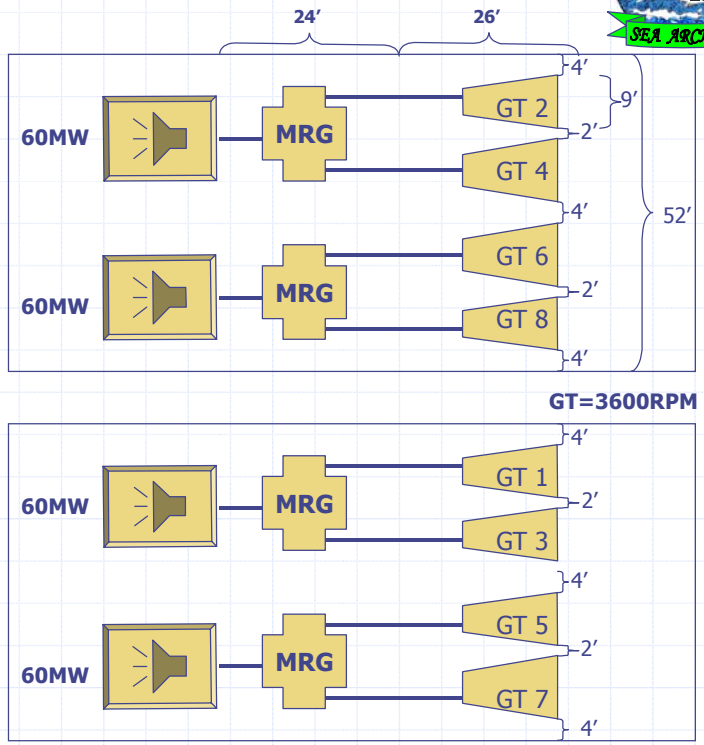
- MRG=57mT*4=228mT
- LM2500+=5.3mT*8=43mT
- WJ= data coming
- **Total weight=271mT + WJ**

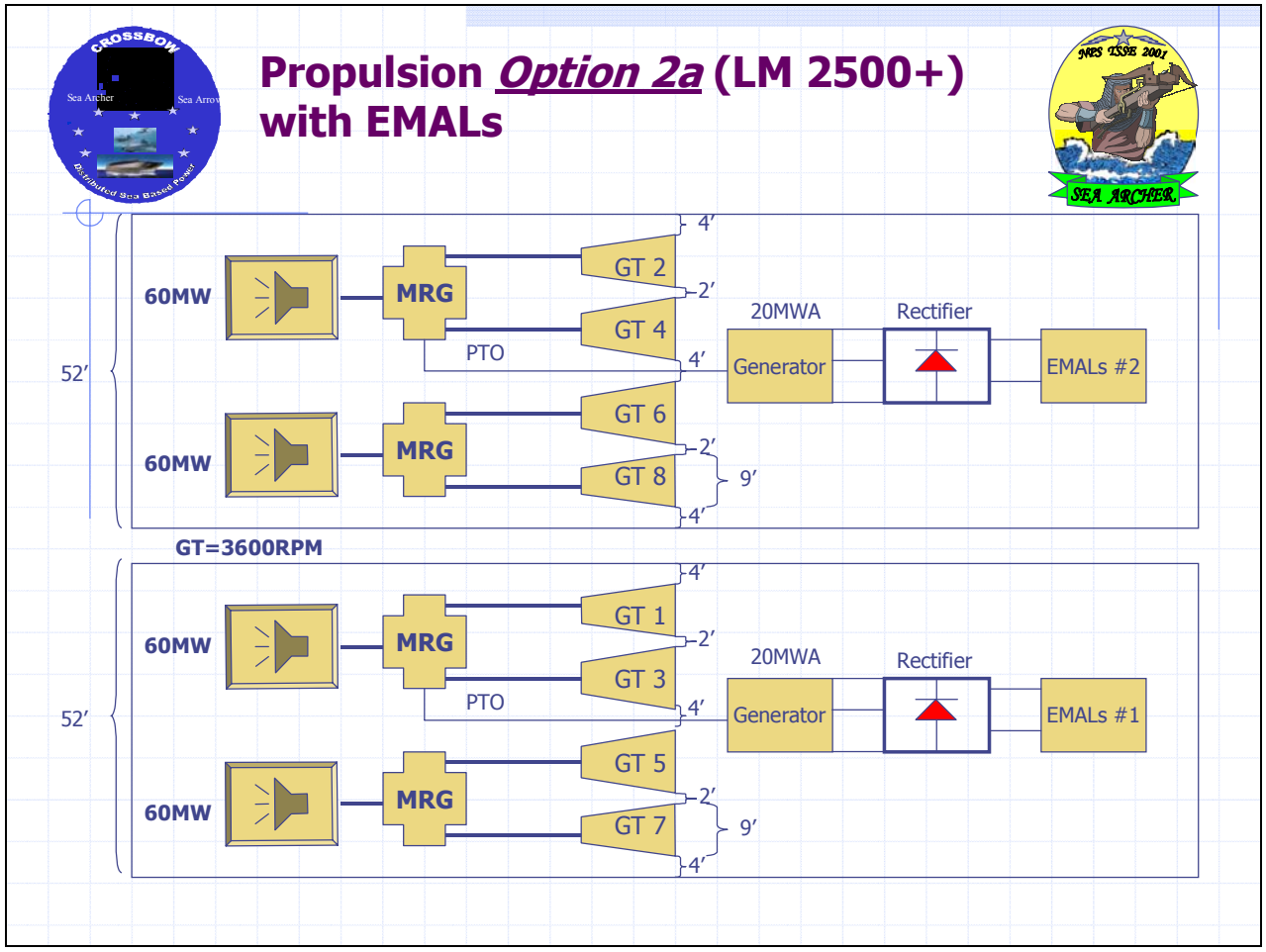
Cost

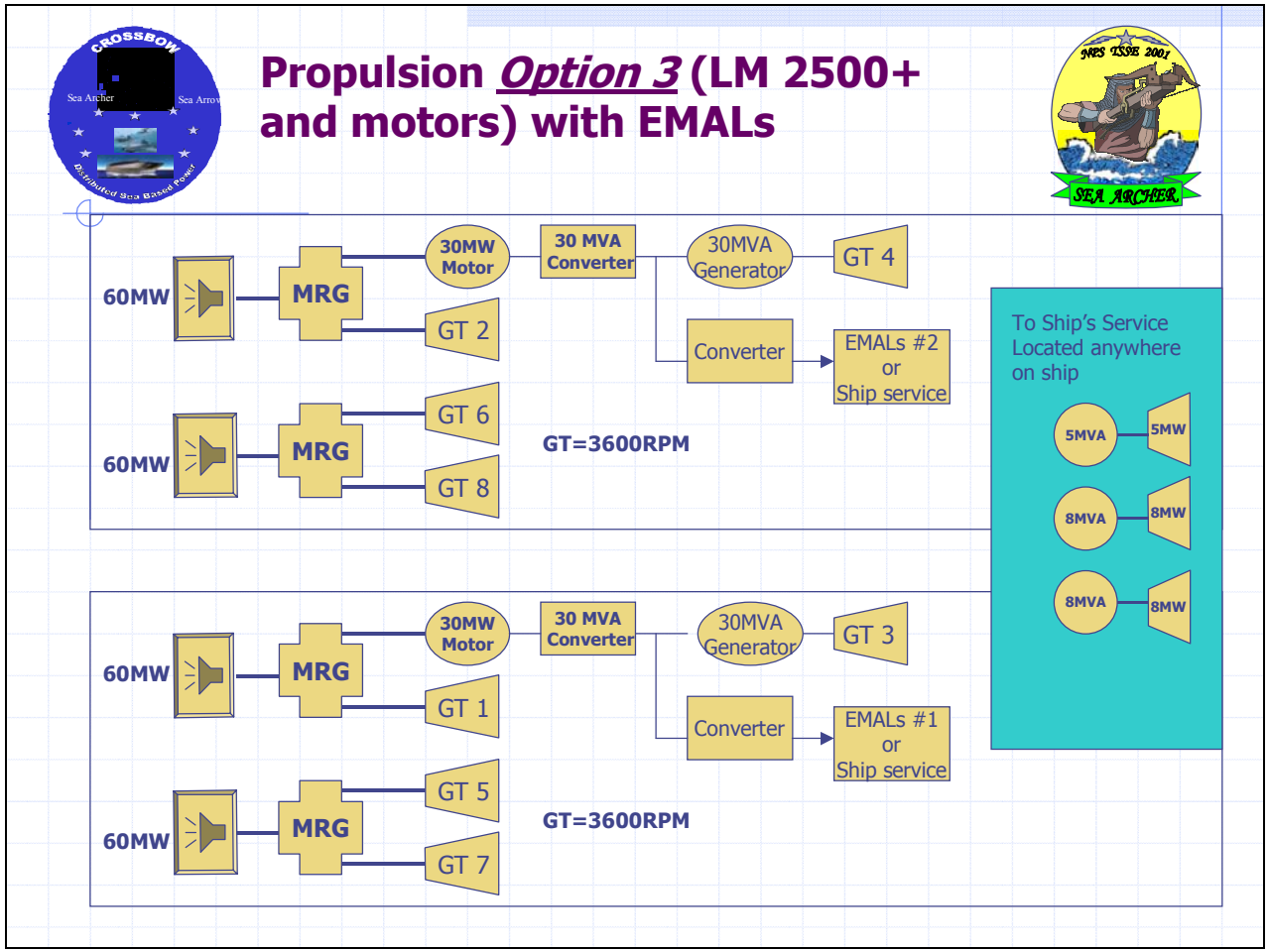
- MRG= 40M (4 Gears)
- LM2500+=81 Million (8 engines)
- WJ= data coming

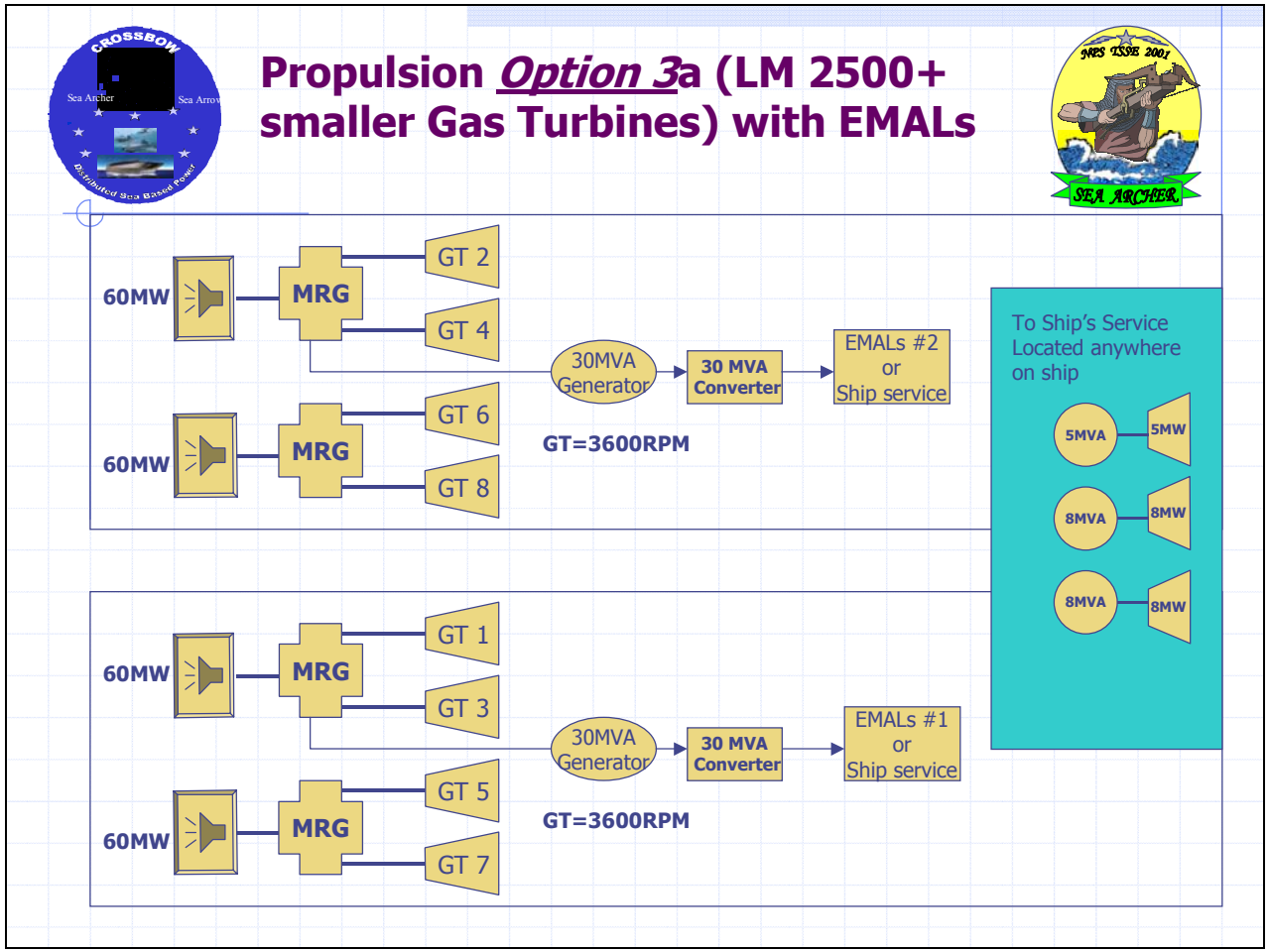
Total Power

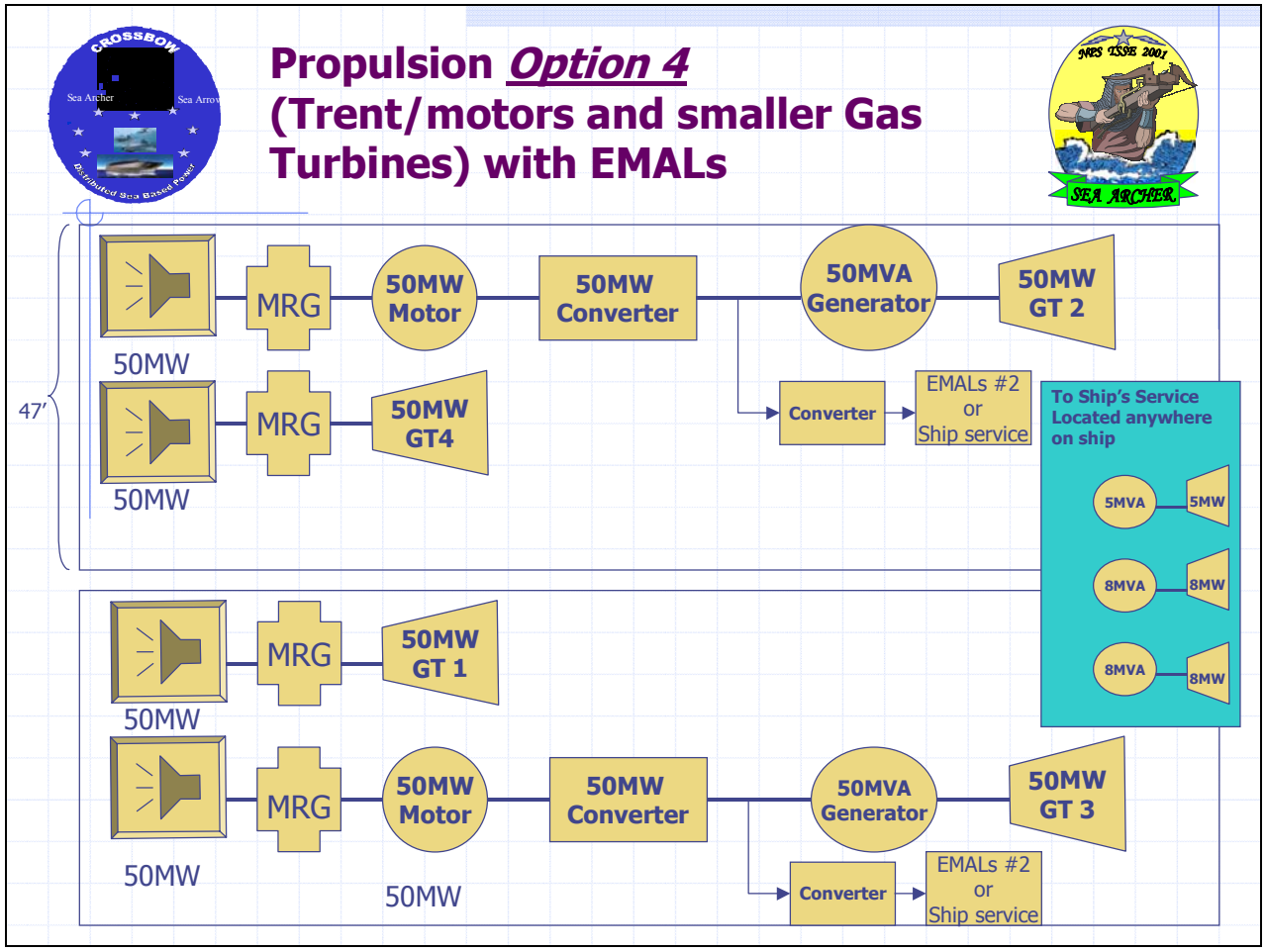
- 240MW
- **321,845HP**




Propulsion Option 2a (LM 2500+) with EMALs
CROSSBOW
Sea Archer
Sea Arrow
Distributed Sea Based Power
INES ISSE 2001
SEA ARCHER
60MW
MRG
GT 2
GT 4
PTO
4′
2′
4′
20MWA
Generator
Rectifier
EMALs #2
52′
60MW
MRG
GT 6
GT 8
2′
9′
4′
GT=3600RPM
60MW
MRG
GT 1
GT 3
PTO
4′
2′
4′
20MWA
Generator
Rectifier
EMALs #1
52′
60MW
MRG
GT 5
GT 7
2′
9′
4′


Propulsion Option 3 (LM 2500+ and motors) with EMALs
60MW
MRG
30MW Motor
30 MVA Converter
30MVA Generator
GT 4
GT 2
Converter
EMALs #2 or Ship service
60MW
MRG
GT 6
GT 8
GT=3600RPM
To Ship's Service Located anywhere on ship
5MVA
5MW
8MVA
8MW
8MVA
8MW
60MW
MRG
30MW Motor
30 MVA Converter
30MVA Generator
GT 3
GT 1
Converter
EMALs #1 or Ship service
60MW
MRG
GT 5
GT 7
GT=3600RPM


Propulsion Option 3a (LM 2500+ smaller Gas Turbines) with EMALs
CROSSBOW
Sea Archer
Sea Arrow
Distributed Sea Based Power
INES ISSE 2001
SEA ARCHER
60MW
MRG
GT 2
GT 4
60MW
MRG
GT 6
GT 8
30MVA Generator
30 MVA Converter
EMALs #2 or Ship service
GT=3600RPM
To Ship's Service Located anywhere on ship
5MVA
5MW
8MVA
8MW
8MVA
8MW
60MW
MRG
GT 1
GT 3
60MW
MRG
GT 5
GT 7
30MVA Generator
30 MVA Converter
EMALs #1 or Ship service
GT=3600RPM


Propulsion Option 4
(Trent/motors and smaller Gas Turbines) with EMALs
CROSSBOW
Sea Archer
Sea Arrow
Distributed Sea Based Power
NES ISSE 2001
SEA ARCHER
47'
50MW
MRG
50MW Motor
50MW Converter
50MVA Generator
50MW GT 2
50MW
MRG
50MW GT4
50MW
Converter
EMALs #2 or Ship service
To Ship's Service Located anywhere on ship
5MVA
5MW
8MVA
8MW
8MVA
8MW
MRG
50MW GT 1
50MW
MRG
50MW Motor
50MW Converter
50MVA Generator
50MW GT 3
50MW
50MW
Converter
EMALs #2 or Ship service

APPENDIX D

COMBAT SYSTEMS PAYLOAD

Combat Systems Payload

Note : Most of the weights were obtained from LPD 17. Some of the weights were adjusted to fit our unique combat systems

S/N	Items	Qty	Weight (kg)	Power	Location
1	**Advanced Combat Direction system**				
	Console	10	324		CIC
	Equipment Rack	12	545		CIC
	Command Table	1	907		CIC
	Signal data Convertor	4	40.8		CIC
2	**Ship Self Defence Equipment**				
	Workstation	2	227.2		CIC
	LAU cabinet	4	158.8		CIC
	Multiple LAU cabinet	3	317.5		CIC
3	**Amphibious Command Group**				
	Workstation	1	249.5		CIC
	Shipboard Master Station	1	227.2		CIC
	Anciliary Equipment	1	100		CIC
4	**Digital Commuication Terminal**	1	25		CIC
5	**Command & Control Processor**	1	227		CIC
6	**JTIDS Antennas**				
	Receive/Transmit Antenna	1	45		Super Structure
7	**TACAN Set**				
	Transponder Group	1	464		Radio
	Shipboard TACAN Antenna	1	50		Super Structure
8	**Navigation Sensor Interface**				
	Display and Control	1	408		Bridge
	Antenna (GPS)	1	9		Super Structure
9	**Helicopter Operations Surveillance System**	1	280.5		Top side

10	**Radio Communications Systems**	1	38314		Radio Room
11	**Exterior Communication Gear**				
	Antenna VHF	3	3.6		Super Structure
	Antenna TADIX B TRE	4	5.9		Super Structure
	Antenna UHF (AS 1735C)	6	12.7		Super Structure
	Antenna UHF (AS 3226A)	5	5.4		Super Structure
	Antenna EHF	2	238.1		Super Structure
	Antenna UHF (PCM 112A)	4	0.9		Super Structure
	Antenna INMARSAT	1	544		Super Structure
	Antenna UHF (AS 4163)	1	68		Super Structure
	Antenna UHF (AS 3018B)	2	104.8		Super Structure
	Antenna 35 ft single whip	2	44.5		Super Structure
	Antenna 14 ft single whip	2	45.4		Super Structure
	Antenna 18 ft twin whip	1	104.3		Super Structure
	Antenna LW fan	1	124.7		Super Structure
	Antenna SHF	2	362.9		Super Structure
12	**Chemical Warfare Directional Detector**				
	Sensor Unit	2	42.6		Top side
13	**Multi Function Radar**	1	33000		Super Structure
14	**Air Search Radar (VSR)**	1	44000		Super Structure
15	Navigation Radar (SPS - 64)	1	59	25	Super Structure
16	**IFF System**				
	Antenna Group	1	380		Super Structure
	Supporting Equipement	1	430		Equipment Room
17	**Thermal Imaging Equipment**				
	EOS Unit	1	155.3		Super Structure
	Console	1	360		CIC

18	**CEC Equipment**				
	Active Aperature antenna	2	124.7		Super Structure
	Data Processing terminal	1	682.2		Equipment Room
	Battery Back Up unit	1	137		Super Structure
	Antenna Environement Control Unit	2	305.7		Super Structure
	Supporting Equipment	1	174.4		Equipment Room
19	**Electronic Warfare**				
	Antenna Receiver unit	2	45.8		Super Structure
	Countermeasure Equipt Enclosure	1	1451.5		Super Structure
	Console	1	249.5		CIC
	Supporting Equipment	1	1425		Equipment Room
20	**Torpedo Countermeasure SLQ 25 (Nixie)**				
	Console	1	386.5		CIC
	Winch	1	1905.1		Top side
	cable	1	544.3		Top side
21	**Decoy Launching Mk 53 (Nulka Capable)**				
	5.125 Launcher	6	404.6		Top side
	Service Locker	6	283.9		Top side
22	**Naval Tactical Command Support System**	1	624.1		CIC
23	**Battle Tactical Training System**	1	528		CIC
24	**Aircraft Landing System**	1	468		Top side
25	**Unmanned Surface Vessel**	4	2000		Inside

Mk 41 Tactical Launcher				
8 cell Module	2	34480	30	top side
Combined Data Processing unit	1	1067	22	Equipment
Small Calibre Gun Systems				
Gun Mounts	4	1500	13	Top side
Free Electron Laser Weapon				
Beam generator/Cooling units/etc	1	22000	1000000	Inside
Beam Director	2	300		Top Side
IRST	1	450		Top Side

Total Weight **255071** excludes MFR!

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