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TECHNICAL REPORT

Ship Antiballistic Missile Response:

by

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ABSTRACT

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The 2006 Ship Anti Ballistic Response Total Ship Systems Engineering Team would like to thank our families and friends for their unselfish love and support throughout the SABR project. Without such love and support, the TSSE team would not have successfully completed the mission. We also would like to extend our appreciation to our TSSE advisors Professor Fotis Papoulias, Professor Robert Harney, Professor Bill Solitario, Professor Clifford Whitcomb and Professor Bob Ashton for their assistance and support throughout the TSSE curriculum and design project. A special acknowledgement is due for Professor David Jenn for his invaluable assistance during the Skin of the Ship Radar and RCS evaluation of our design. A special acknowledgement is also due for Professor Joseph Bonometti and Kirk Sorenstom for their technical assistance in designing the molten salt reactor for our design. We would also like to thank Professor Craig Smith for his assistance with lead cooled nuclear reactor technology. Finally we would like to thank American Superconductor, Boeing, General Atomics, Lawrence Livermore National Laboratory, NASA, ONR, NAVSEA, Northrop Grumman, American Superconductor, Massachutes Institute of Technology, and the United States Naval Academy for their assistance in supplying us with invaluable technical information.

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I. INTRODUCTION

The future of the United States Navy requires building ships and systems capable of performing missions to counter many different threats. As such, the ships and systems built will have to exceed the requirements given in order to be successful. At the Naval Postgraduate School students are already being tasked to conduct research into designing ships and systems capable of meeting our Navy's future needs.

A. SEA-9 & TSSE 06 TASKING

In designing these ships and systems, a multi-disciplinary approach is required that combines engineering science, systems engineering, and operational research. Together, teams from the SEA and TSSE curriculums design and develop conceptual Navy systems of the future. For the year 2006, the mission presented to the TSSE and SEA teams involved designing a ship system to counter ballistic missiles in the 2025 to 2030 time frame. The term was more formally adopted as Ship Anti Ballistic Response (SABR) by the SEA-9 team.

B. TASKING AUTHORITY

Under the guidance of the Wayne E Meyer Institute, the SEA-9 group of students developed the problem statement, needs, and scope of the problem to solve. In essence, the faculty from the Wayne E Meyer Institute became the primary stakeholders of the project. Furthermore, senior Navy leadership has established recent policies stating that all engineering duty officers be proficient in systems engineering. "Every EDO will be an excellent systems engineer…", VADM Belisle and RADM Lengerich, NAVSEA, March 2004. And "Beginning with the class entering NPS in July

06, all Engineering Duty Officer students will be required to complete either 8 graduate level courses in Systems Engineering (i.e., a SE concentration) or complete the TSSE curriculum.” RADM Lengerich, NAVSEA, March 2005 [1].

This project satisfies the above requirements for engineering duty officers in the Navy.

C. SEA-9 & TSSE-06 COLLABORATION

Previous design studies at NPS involved SEA and TSSE teams working independently on projects. The SEA team would conduct a detailed Systems Engineering analysis of a system and their results would be forwarded to the TSSE team. The TSSE team would then design a ship-based system to meet the requirements of the system. This year, professors from the Meyer Institute and the TSSE curriculum decided that the two teams should work together as early as possible in hope of achieving: 1. cross-functional education, 2. collaboration and team work between students, and 3. to facilitate an earlier start for designing the ship-based platform. The TSSE team used the opportunity to interact with the SEA team to begin learning the systems engineering process. The goal was to assist the SEA team as much as possible in their systems engineering analysis while at the same time giving the TSSE team a head start at designing their ship-based system.

Both the SEA-9 team and Ship Anti Ballistic Response (SABR) TSSE-06 team worked together on this project beginning in January 06. The timeline for this project can be viewed in figure 1.

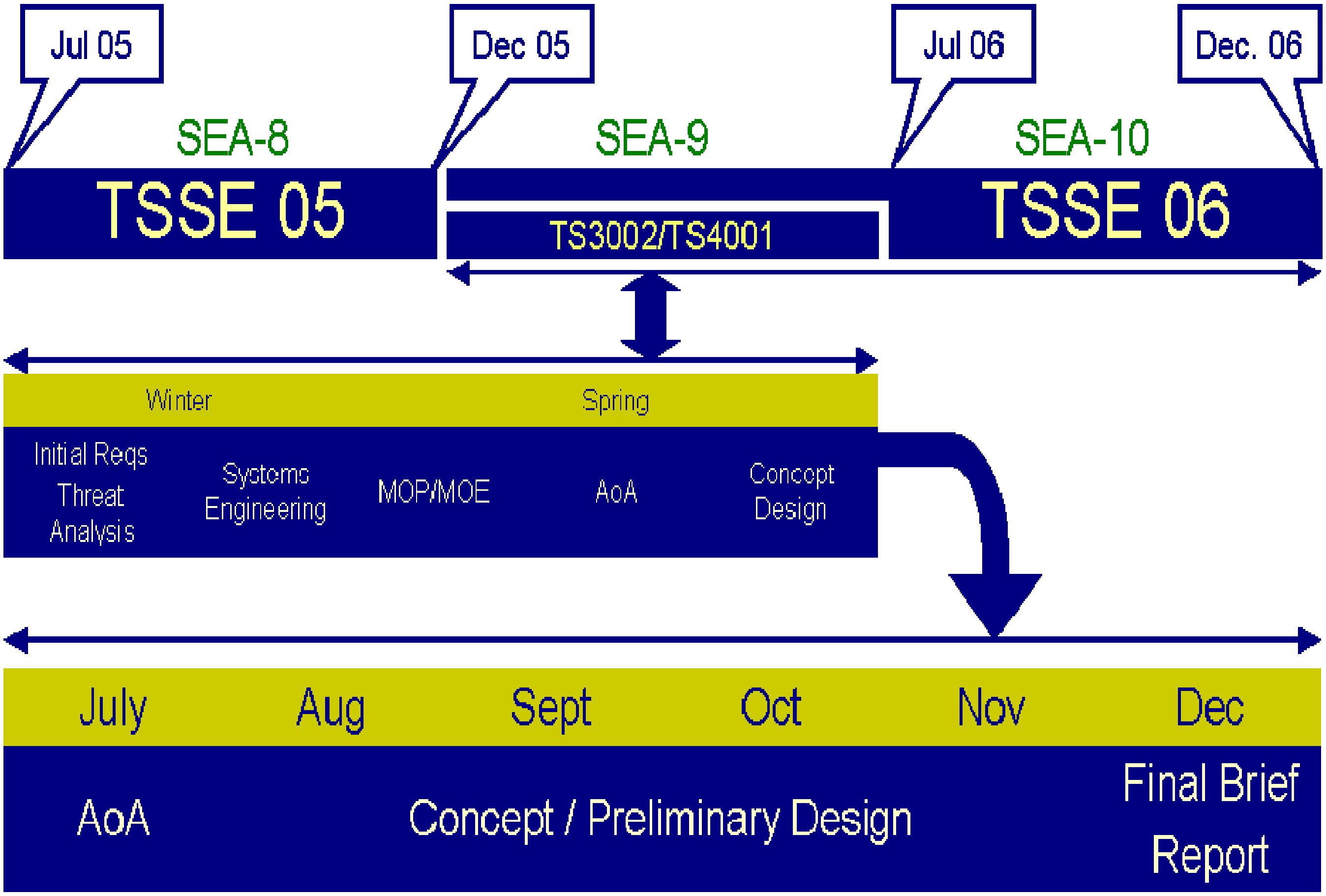

Figure 1. TSSE Timeline

The SEA-9 team's goal was to "Develop and evaluate a conceptualized ship-based BMD system architecture to meet emerging short and medium range ballistic missile threat capability in the 2025 to 2030 timeframe. The system must be able to integrate with prospective coalition BMD architectures and contribute to the whole of layered BMD."[1] [2]

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[1] Qtd in SEA-9_SABR_Thesis_Report, pg 13

The SABR TSSE-06 team was primarily tasked in designing the ship to carry the anti-ballistic missile defense system the SEA-9 team developed. Figure 2 from reference [2] shows the breakdown of the tasking assigned to SEA-9 and SABR TSSE-06.

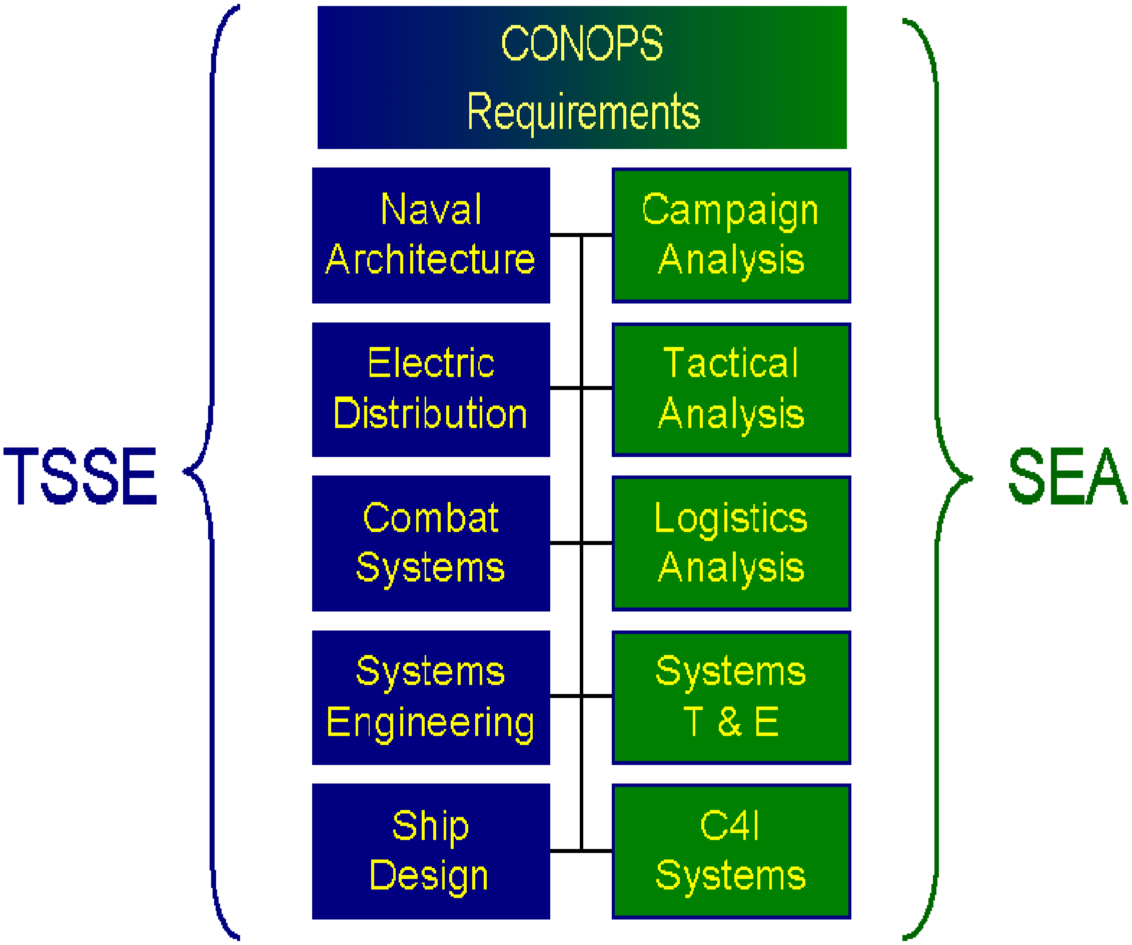


Figure 2. TSSE and SEA objectives

The SABR TSSE-06 team was asked to assist the SEA-9 team from January to June 2006. We assisted the SEA-9 team from January to March 2006 in the requirements analysis of the system. Working independently, the TSSE team developed mission requirements based on the stakeholder's needs. We then developed metrics, specifically measures of effectiveness and measures of performance for each requirement. The data was gathered and presented to SEA-9 whom had independently done their own requirements analysis. Results were compared and some of the TSSE team's results were used by SEA-9. From March to June 2006 the TSSE team paid close attention to the SEA-9 team's design and methodology because we knew we would need to design the ship based on SEA-9's results. We decided to use the results from our requirements analysis to begin our ship design by performing an Analysis of Alternatives study based on the requirements we had received from SEA-9 for the ship design. To ensure we could meet all the needs and requirements of the anti-ballistic missile defense system, we created a contract between SEA-9 and SABR TSSE-06 detailing all the requirements and technical performance measures that were needed. This would allow the SABR TSSE team to begin its ship-based study and design.

D. SABR TSSE-06 DESIGN CONTRACT

An Operational Requirements Document (ORD) was developed and submitted to the stakeholders in order to formalize the system expectations. This contract between the customers and the designers served as a foundation for the initial conceptual design. The preferred system architecture, including threshold and optimal levels of performance, as determined through extensive modeling by SEA-9 were included. Due to the unique situation of the SEA-9 team graduating 6 months prior to the design completion, this document was used as a handoff between SEA-9 and TSSE-BMD. It was important to document the SEA vision and the modeling constraints they used since they would not be available during the ship design process. The contract enables the TSSE group to incorporate the extensive work done by the system engineers into viable ship design without their interaction.

Specifically, the circular of requirements describes the general requirements for a new ballistic missile defense ship and the essential features and functions (but not necessarily the details) of its design. It includes the required operational capabilities (ROC) and the projected operational environment (POE) for the ship system. In addition to being reviewed by the SEA-9 team, it was submitted to both the TSSE and SE faculty coordinators. They reviewed the document and signed off as stakeholders. The contract can be viewed in Appendix III.

E. TSSE-06 DESIGN APPROACH

Our design approach was to follow the systems engineering approach of designing a ship, but would also include some detailed engineering analysis and design pertaining to hull, mechanical, and electrical systems. We adopted the Classical Systems Engineering Process Model outlined below [3]. We used this model as a baseline for designing our ship.

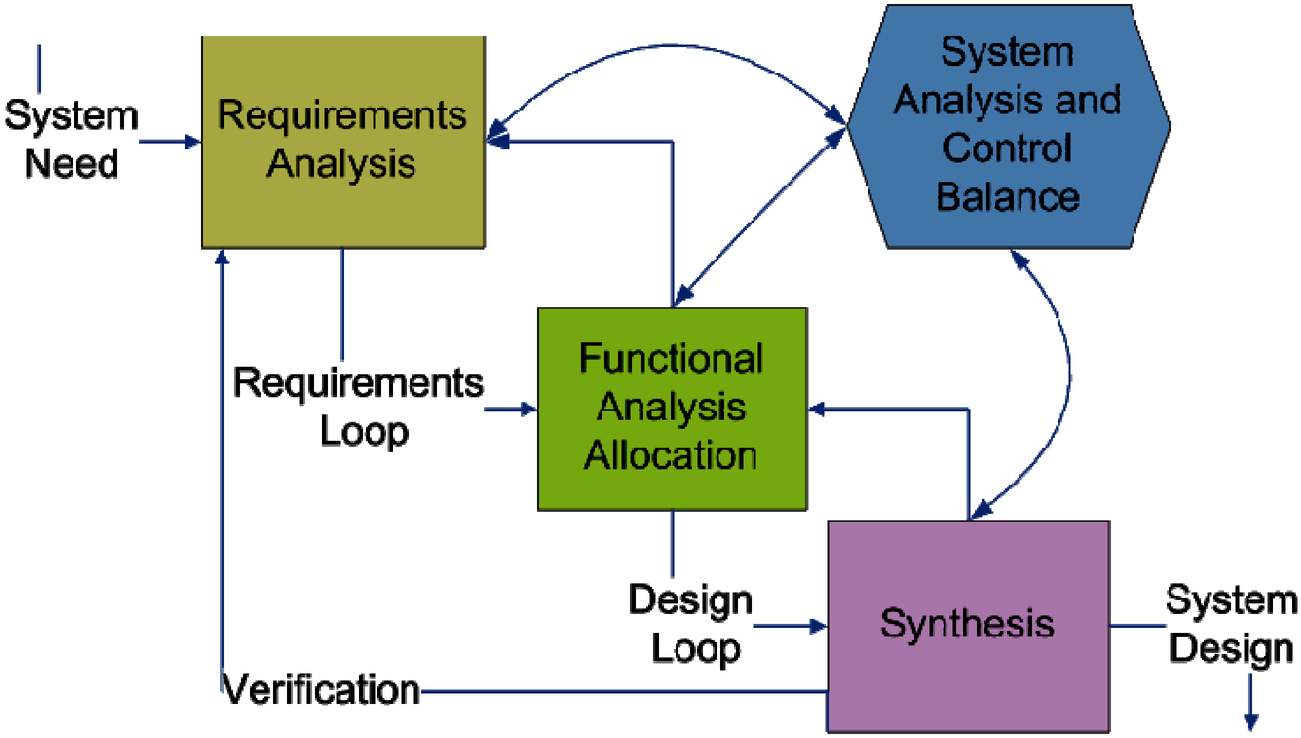
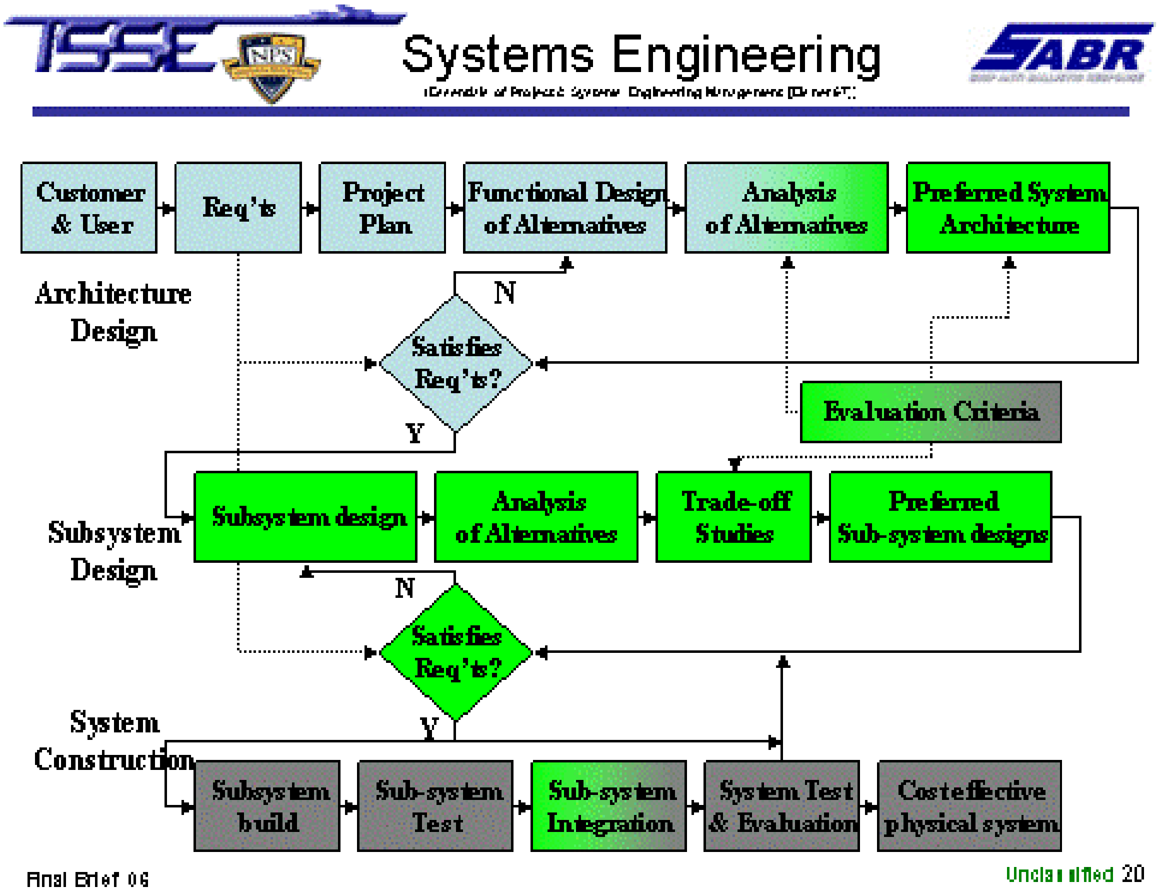


Figure 3. Classical Systems Engineering Model

Having studied this model in detail, the TSSE-06 group decided that we needed to construct a model or block diagram to further illustrate the step by step processes involved in our design approach. We adopted a block diagram from a systems engineering class illustrated below [3].


Systems Engineering

Customer & User
Req'ts
Project Plan
Functional Design of Alternatives
Analysis of Alternatives
Preferred System Architecture

Architecture Design
Satisfies Req'ts?
N
Y
Evaluation Criteria

Subsystem Design
Subsystem design
Analysis of Alternatives
Trade-off Studies
Preferred Sub-system designs
Satisfies Req'ts?
N
Y

System Construction
Subsystem build
Sub-system Test
Sub-system Integration
System Test & Evaluation
Cost effective physical system

Final Brief 06

Unclassified 20

Figure 4. Systems Engineering process

The blue shaded portion illustrates the work we performed in collaboration with the SEA-09 team. The green shaded portion illustrates the work performed solely by the TSSE group in designing the ship and the grey portion indicates functions not performed by the TSSE group but would be performed in a complete design of a ship.

Beginning with our customers' (stakeholders) needs and requirements, we came up with the Project plan where we made decisions on how we would proceed with our project. We decided to begin with an Analysis of Alternatives study to choose our hull form and energy delivery system. Once we could determine the best hull form and energy system to meet the requirements given, we could then move into sub-system design and analysis. In the sub-system design portion, we conducted fairly detailed engineering analysis and design of hull, mechanical, and electrical systems needed to construct our ship. This included further analysis of alternatives and trade off studies of sub-system components. On conclusion of sub-system determination, we proceeded to construct, build, and test our sub-systems using various software tools, such as RHINO, Matlab, Excel, and Navcad to ensure they would work and meet all the requirements stated. More than one iteration of the construct, build, and test cycle was conducted as necessary to improve the overall design of our systems. Once complete, it became necessary to integrate all of our sub-systems to ensure compatibility. Here, we ensured that our various systems such as hull , electrical generation, and combat systems all intertwined to produce the desired end product. Finally, we conducted a final evaluation of our overall system and made corrections or changes as necessary.

F. REFERENCES

[1] Fotis Papoulias. "TS 4001: Lecture Summary 1:Introduction," p 7, 2006.

[2] Systems Engineering and Analysis Cohort 9. "Ship Anti Ballistic Missile Response," p 13, 2006.

[3] William Solitario. "TS 3002: Module 3, SE Process," p 1-10, 2006.

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II. SABR OVERVIEW

A. PROJECT MOTIVATION

Although the cold war has come to an end, there are still hostile nations capable of launching weapons of mass destruction via ballistic missiles. Many states (nations) possess ballistic missiles and these states can and are expected to use these missiles for intimidation and offensive purposes. With this in mind, the U.S and its allies must strategically challenge these states through the use of forward presence and a formidable and active ballistic missile defense (BMD) system.

For nearly thirty years defense against ballistic missiles has been a top priority relating to our nation's national security objectives. In 1981-1989, significant and intense research and funding was allocated as part of the Strategic Defense Initiative (SDI). In 1991, it became even more apparent for the need for ballistic missile defense systems during the Gulf war when Saddam Hussein used SCUD missiles targeted at Israel. At that time, there were no highly developed counter measures and the U.S Army modified its PATRIOT anti-aircraft missile system to counter the SCUD missiles. While the patriot missile system had a fairly high success rate at engaging the scud missiles, the interceptions often resulted only in scattering debris. [1] Since the gulf war, the effort has stepped up in research and development of suitable anti ballistic missile systems and this effort is continuing and will need to continue as the threats become more dangerous.

A proven BMD system acts as a strong deterrence towards aggressors and enables the U.S and its allies to avoid catastrophe from a possible hit by a ballistic missile from any hostile nation.

According to the SEA-9 study on ballistic missile defense, there are three critical factors that have changed in terms of adversarial missile development in comparison to missile development during the cold war days. Specifically from the SEA-9 study, these factor are: [2]

- Current ballistic missile and weapons of mass destruction (WMD) development programs do not follow the same traditional paths set forth by the U.S. and the Soviet Union. Today, these programs do not require high standards, such as missile accuracy, reliability, and safety.
- Nations can now easily obtain technical information regarding development of ballistic missiles and weapons of mass destruction from other nations. It is a fact that foreign nations possess extensive knowledge on building ballistic missiles and WMDs.
- Many nations have the ability to conceal important elements of their ballistic missile and associated WMD programs.

As such, the U.S must continue to develop advanced missile defense systems capable of deterring and countering today’s and tomorrow’s ballistic missiles.

B. CURRENT AND FUTURE BALLISTIC MISSILE THREATS

Although many nations possess ballistic missiles and are possible threats towards western nations and allies, only a few nations are considered as serious and potential threats today and in the future. The most significant threat nation is North Korea with its Taepo Dong missile. As recently as 1998, one of these missiles flew over the Japanese island of Honshu and landed roughly 330 km away from the Japanese port city of Hachinohe after a flight of approximately 1,320 km. [3] Another major concern pertaining to North Korea is the proliferation of missile technology to such nations as Pakistan, Iran, and China. With such proliferation comes the assumption that the aforementioned nations will also develop similar Taepo Dong missiles and will likely use them for political motivation and strategic employment, but for the wrong reasons. [3] The former Soviet Union has also participated in the proliferation of missile technology by supplying missiles to many rogue nations in an attempt to get rid of its stockpiles from the cold war and to bolster its economy. Figure 2 shows a list of the current ballistic missile profiles that are possible threats today.

Although North Korea is considered the biggest threat nation, other nations such as Russia, China and Iran are also on the top of the list. Russia still has about 1000 strategic ballistic missiles with about 4500 warheads. As of today, it is unlikely that Russia will lunch any of these missiles. China is also in possession of many CSS-4 ICBMs with ranges capable of reaching the United States but no present launches are likely. Then there is Iran with its very active missile and Weapons of Mass destruction development programs. They currently possess many short range (150-500 km) ballistic missiles and some medium range

(1300 km) Shahab ballistic missiles capable of reaching Israel. [4]

The future (2020-2025) time frame suggests that Iran may develop long range ballistic missiles by then capable of reaching the United States. With the proliferation of missile technology and the current 2006 timeframe tensions between the United States and Iran concerning its nuclear development program, it is very likely that Iran may remain a threat nation for a long time. It is also likely with China’s ideological beliefs that they will continue to be a possible and formidable threat in the future. North Korea will also be expected to remain a future threat for a long time.

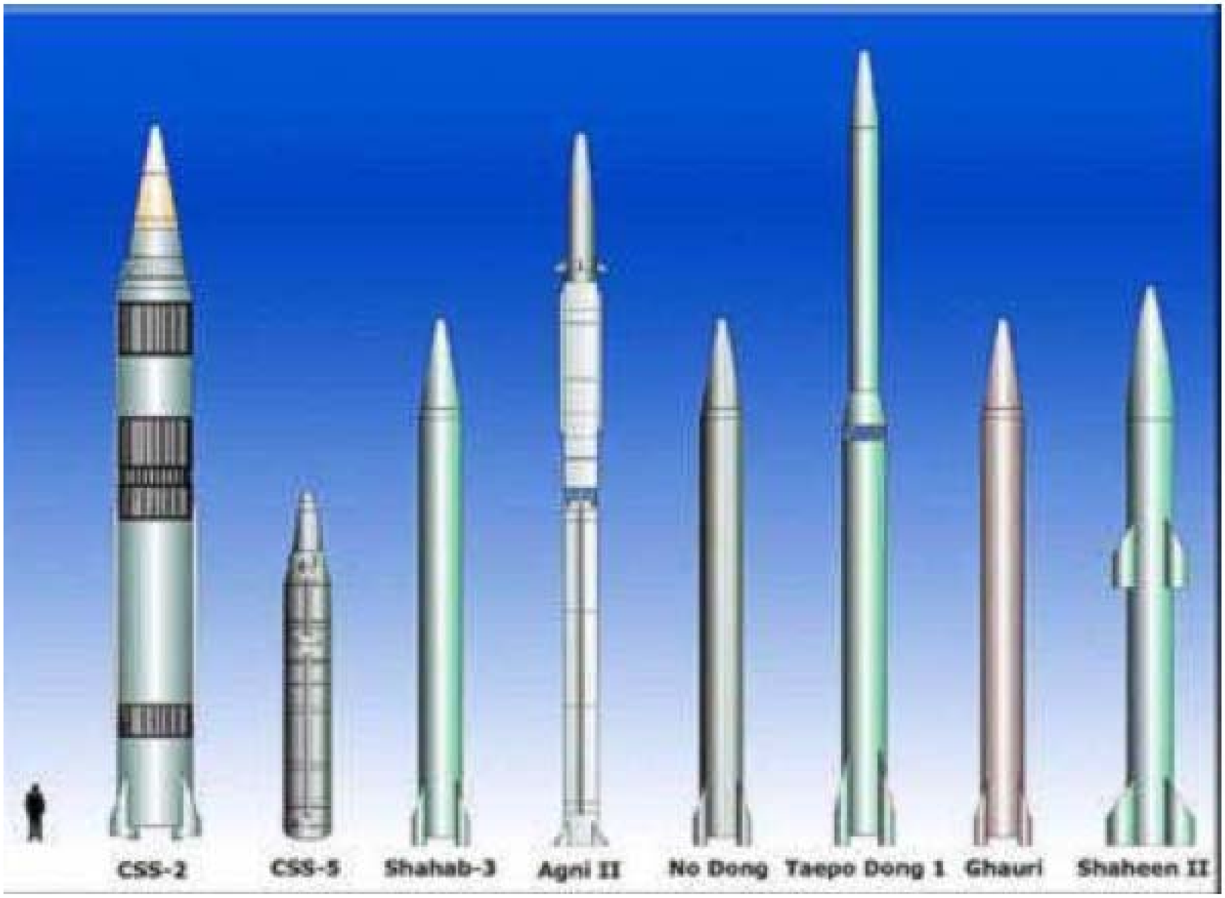

Figure 5. Various threat Ballistic Missile Profiles

C. SEA-9 TASKING & ANALYSIS DEVELOPMENT

The SEA-9 team was tasked to "Use a top-down, system of systems approach to examine future surface combatant operations in terms of their conduct and support of current and emerging sea-based Theater Ballistic Missile Defense (TBMD) missions,"[5]

The SEA-9 team then developed a set of issues concerning current BMD systems. These issues were developed after consulting with sources from the Department of Defense and analyzing current surface combatant systems and BMD systems. The following were identified in SEA-9's technical report: [6]

a. There is no operational sea-based BMD capability

b. There is no integrated network to connect all players in BMD (sea, air, land, and space) for layered defense

c. Current systems in development will not have the technical capability to counter ballistic missiles of the future.

d. Current systems in development will not be able to counter large salvos of ballistic missiles

After identifying these issues, the SEA-9 team proposed developing an effective and suitable BMD system capable of countering ballistic missile threats in the 2025-2030 time frame. They proposed that to solve the current problems relating to ballistic missile defense, the following solutions core attributes must be analyzed: [7]

a. Current and Prospective Threats (principle measure for performance evaluation)

b. Network (data and voice exchange)

c. Sensors

d. Seaframe

e. Interceptor

f. Command and Control (C_2)

The following data was taken from the SEA-9 final report: [8]

1. Current and Prospective threats

This issue addresses the current threats and prospective threat attributes that are applicable in the timeframe of the study (2025 – 2030). Key attributes include:

a. size (mass, dimensions, etc)

b. fuel type

c. number of stages

d. mobile or fixed launch (or both)

e. proliferation

f. number of warheads

g. decoy capability

h. range

i. expected velocities throughout trajectory

j. radar cross section

k. max altitude (range dependent)

2. Network

The network is the means to communicate and exchange data between all participating units in ballistic missile defense. Key attributes of the network include:

a. number of required data feeds

b. cryptological requirements (security)

c. expected size (bytes) of significant BMD information (bandwidth consideration)

d. interoperability with participating BMD units

e. ability to exchange detection, tracking and fire control (FC) data

3. Sensor

Sensors and their networking is a critical issue for ballistic missile defense. If launches and ballistic missiles in flight are not detected, then interception is impossible.

This issue considers the attributes required for the whole of BMD (on and off the ship)

Key attributes for sensors include:

a. capability to detect ballistic missile launches and missiles in flight from space

b. number of required satellites to provide continuous worldwide BMD coverage

c. capability to detect ballistic missile launches and missiles in flight from land based sensors

d. number of required land based sensors to provide BMD coverage in key world “hotspots”

e. sea-based capability to detect ballistic missile launches and ballistic missiles in flight

1. sensor sensitivity

2. sensor power requirements

3. sensor rate of track/update

4. sensor error

5. sensor max and effective ranges

6. sensor altitude

7. sensor interoperability with non-organic detection system

8. sensor compatibility with ship display, weapon control, and C_2 system

4. Seaframe

A suitable means of getting the system components on station is required in order to participate in the integrated ballistic missile defense of a given region. With a “sea-based” ballistic missile defense implementation, the logical response was a ship or seaframe. According to the SEA-9 report, “The term seaframe is generic term used to describe a non-descript, yet non-fixed sea-based vessel capable of mobility, sustainability, and reliability to conduct the given mission at hand (regional ballistic missile defense).”[9] Specific characteristics of the seaframe include:

a. capability to arrive on station at a given time (speed)

b. capability to maintain station for a given period of time (endurance)

c. capability to provide requisite power for all BMD systems

d. capability to provide favorable conditions for BMD system component operation (stability)

e. capability to contain requisite BMD system components (capacity)

5. Interceptor

An interceptor enables a ballistic missile engagement to be completed. The interceptor consists of three key aspects: the launcher, the projectile, and projectile guidance. The key attributes of the interceptor :

a. type (e.g. missile, directed energy weapon (DEW), rail gun, etc)

b. depth of magazine

c. rate of fire (accounts for reliability)

d. power requirements

e. launcher configuration (e.g. vertical, slewed-turret, etc)

f. compatibility with ship weapon control and C_2 system

g. launcher size (includes mass, dimensions, etc)

h. interceptor size (if applicable; includes mass, dimensions, etc)

i. interceptor speed

j. interceptor maximum and effective ranges

k. interceptor ability to receive guidance

l. interceptor maneuverability

m. interceptor kill mechanism (warhead, KKV, energy duration, etc)

6. Command and Control (C_2)

Decision making becomes the final essential element in ballistic missile defense. Whether controlled by computer or an actual commander, C_2 decisions are essential to an effective defense. The requisite attributes for C_2 are:

a. Common Operation Picture (COP) for BMD (covering BMD asset positions and threat activity)

b. Interceptor inventory of all available

c. Network and communication availability

SEA-9 then narrowed the broad scope of ballistic missile defense (BMD) to simply concentrating on two areas of BMD: commit stage and intercept stage. These two stage are anchored with the seaframe as the "hub" of the system.

The following definitions were given by SEA-9 for commit and intercept

"Commit – All actions taken to detect, track, identify, develop a fire control solution, and make a C_2 decision to intercept a ballistic missile. "[10]

"Intercept – All actions that occur from the decision to employ an interceptor until a ballistic missile is destroyed, handed off, or reaches the end of its midcourse phase." [10]

Any aspects of BMD that precede or occur after these areas were the first items to be designated outside the scope of the SEA-9 study.

The SEA-9 team further developed a list of sea based BMD aspects that were applicable to their analysis and another list of aspects that were not applicable to their study due to scope, time constraints, complexity, and faculty input.

The applicable list is as follows: [11]

- [The system is] Part of the overall layered U.S. Integrated Ballistic Missile

Defense System (IBMDS) and coalition BMD effort (the sea-based portion of BMD)

- 2025-2030 timeframe[3]

- Sea-based

- Must counter the perceived SR to IR ballistic missile threats[4]

- Intercept warhead in the boost through midcourse phases[5] (earliest engagement possible)

The non=applicable list is as follows:

- BMs that survive beyond midcourse will not be engaged by the sea-based system[6]

- Post-intercept debris collateral damage and intercept over-flight issues

- Vulnerability of the ship due employment of sensors, FC radar, and employment of interceptor(s) (EW signature)

Ability for ship self-defense while conducting active BMD (will be covered by ship self-defense system)

- Non-physical interceptors (cyber attack, etc)

7. Assumptions

In further developing guidelines for their analysis, the SEA-9 team outlined some important assumptions. Since the focus of the study is for sea-based BMD in the 2025-2030 time frame, a certain level of expected capability must be assumed. The following are key assumptions made by SEA-9: [12]

- Integrated external sensor network is deployed and operational for all Unified Commands[7]

- Collaborative Information Exchange (CIX) exists between all participants in the IBMDS

- BMD System will be installed as part of a ship[8]

- Physical interceptor(s) (i.e. missile, rail gun, DEW, etc.) will be employed if able

- Automated Battle Management System exists on ship and interacts with other participants in regional BMD via CIX

C. CONCEPT OF OPERATIONS

The CONOPS for the deployment of SABR ships was developed by the SEA-9 team. The team used a derivative of existing anti-air warfare (AAW) tactics currently employed by American naval units. The SABR ships will act like longe-range picket vessels with missions designed to detect, track, and intercept a target at the earliest point, as far from friendly forces, or friendly territory, as possible. The SEA-9 team envisions using a deployment construct similar to the one currently used by the Navy’s Strategic deterrent Submarine forces, where a ballistic missile submarine (SSBN) deploys as a single, self sufficient unit with the capability of launching its weapons with little concern about counter attacks. While a ship is not expected to have the same stealth capabilities of the SSBNs, the SABR ships will still have the ability to operate as self sufficient units for up to several months. SABR ships will be able to operate away from the Strike group and Sea Base and will be able to position themselves in optimum locations for detection and possible engagement of ballistic missiles. [13]

The SEA-9 team also proposes a deployment of up to three BMD capable surface assets to a area where potentially hostile ballistic missiles are expected. These three vessels will be linked to each other electronically and also to non-organic sensor systems. These three ships will also be able to establish an effective defense perimeter capable of early detection and engagement of enemy missiles [14]. The process as a whole is best shown in the following illustration as described in the SEA-09 report.

"Based upon modeling and information and provided through Operations Research techniques, a standard Naval Task Unit for an effective BMD force equipped with the Rail Gun interceptor consists principally of three warships. It is assumed that intelligence gathering efforts and the geo-political situation will permit sufficient time (measured in weeks) for decision makers to deploy assets to observation positions in the region of the threat area. These warships are equipped with the conformal hull mounted phased array radar system for organic long range detection. Supplementing this onboard system are non-organic detection and early-warning assets, principally satellites designed to detect missile launches through the use of Electro-Optic (EO) detection equipment. This initial setup is shown below, with the satellite shown in the upper left-hand corner, orbiting over a nation which has threatened ballistic missile launch. The BMD Task Unit ships are stationed at different locations and distances off of the coast." [15]

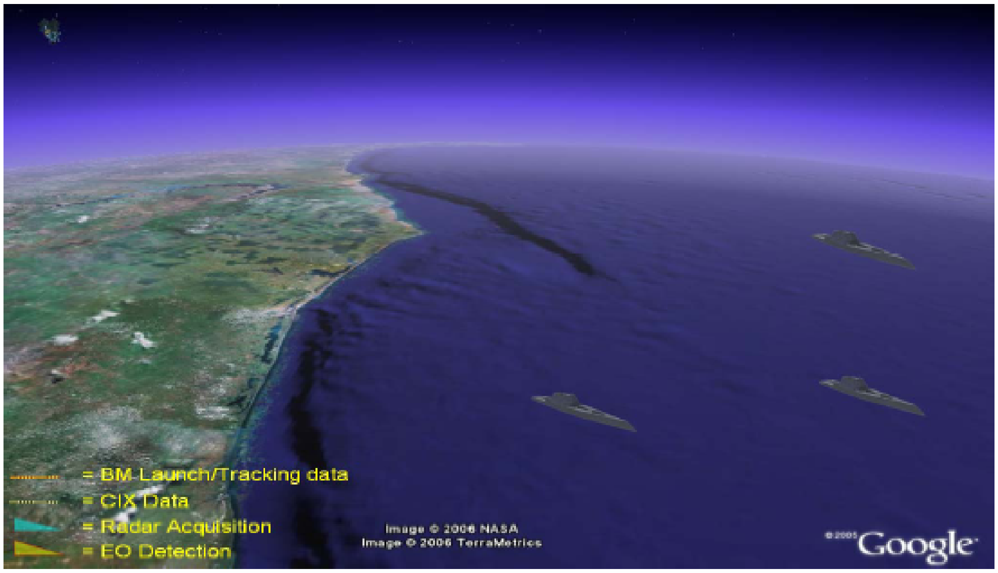

Figure 6. SABR CONOPS

"Should a ballistic missile launch occur, the expected sequence of events is analogous to the standard Air Defense 'Detect-to Engage' sequence. This sequence consists of the following steps[2]:" [15]

a. Detection
b. Entry
c. Tracking
d. Identification
e. Threat evaluation
f. Weapons pairing
g. Engagement
h. Engagement assessment " [15].

"For the application of the proposed SABR system, this process is applicable.

A, B: Detection and Entry: A ballistic missile launch is detected, most likely by nonorganic assets. This detection is entered into the detection network, and queuing information is sent to the 'firing units,' the warships stationed offshore " [15].

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[2] U.S. Naval Academy Air Warfare Training Presentaion, www.usna.edu

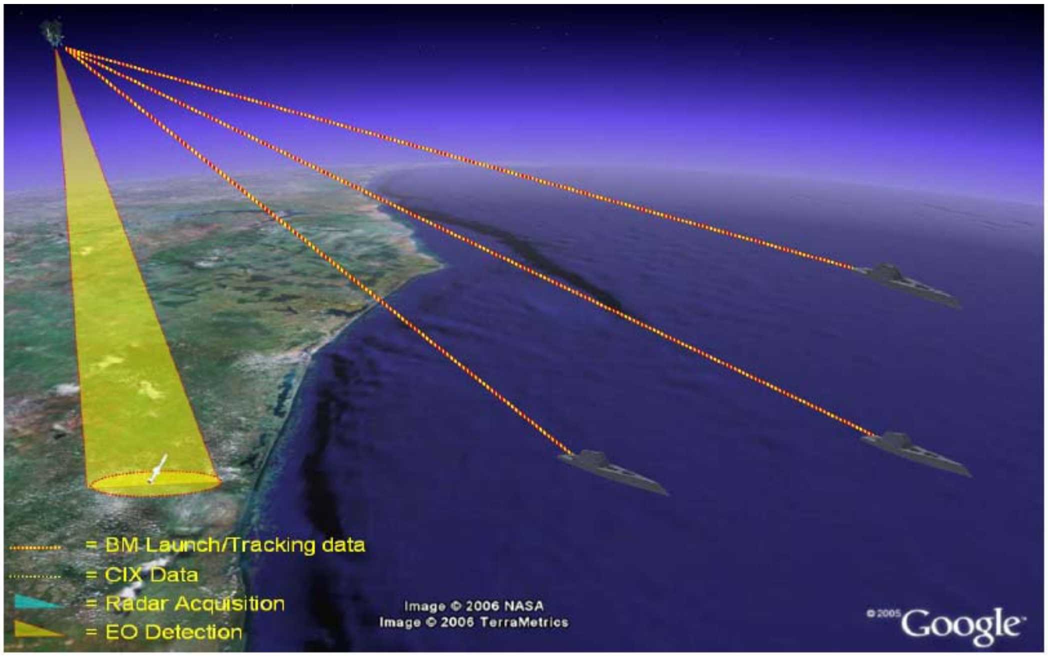

Figure 7. SABR CONOPS

"C, D: Tracking and Identification: The target is detected by the nearest warship, and a fire-control solution is generated. This tracking data is shared with other BMD ships via the previously mentioned Collaborative Information Exchange (CIX). The kinematics of the target are analyzed and a determination is made as to whether or not the target being tracked is classified with high confidence as being a ballistic missile " [15].

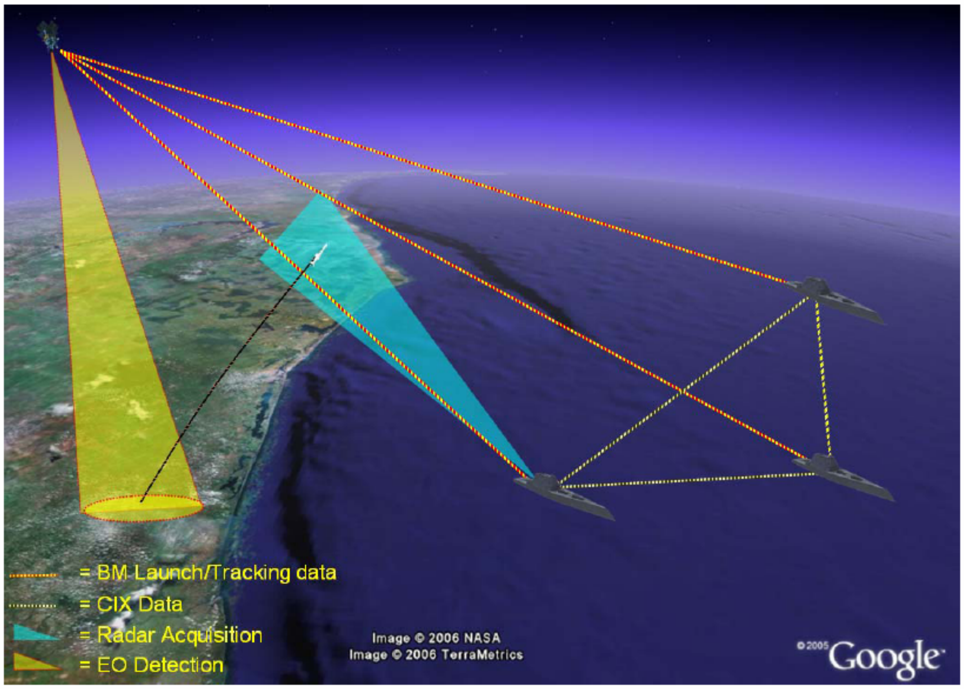

Figure 8. SABR CONOPS

"E, F: Threat Evaluation and Weapons Pairing: As the firing units track the target, it's flight path and threat to potential downrange targets is assessed. Anticipating that the target will be engaged, the best available weapon system and platform are selected. This is based on a system analysis of which platform will have the highest probability of hit and probability of kill" [15].

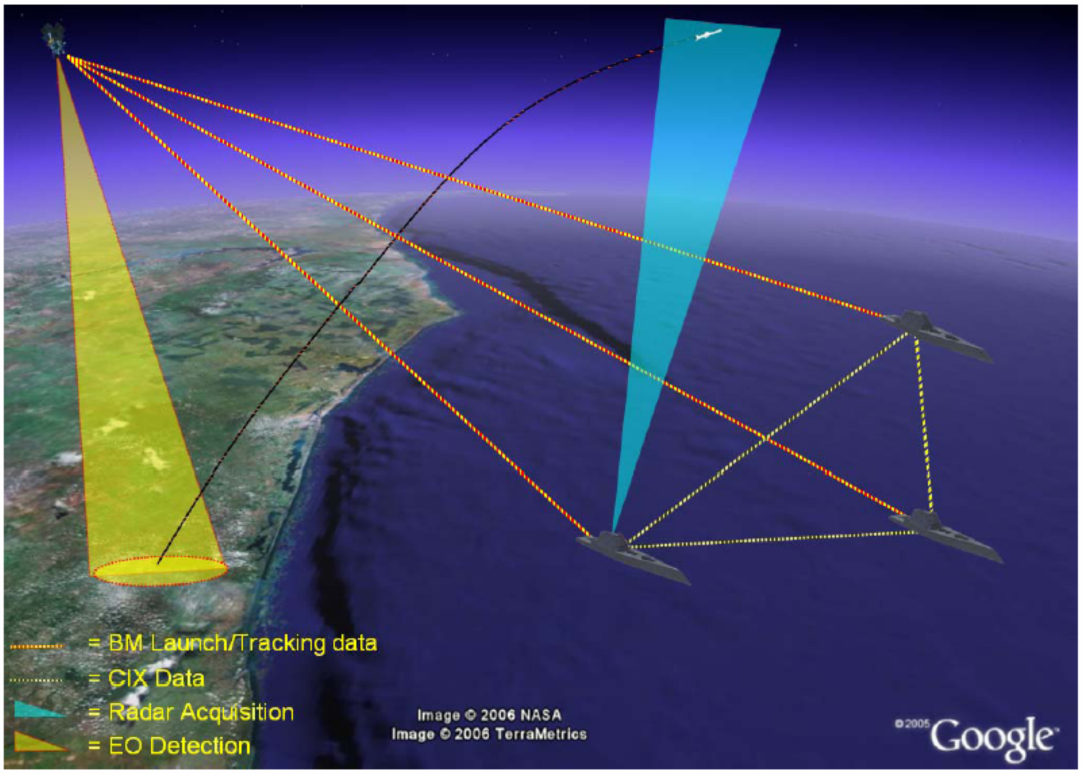

Figure 9. SABR CONOPS

"G, H: Engagement and Engagement Assessment: Having determined that the ballistic missile is a threat that needs to be engaged, the selected ship will open fire with its' railgun. A standard salvo will be four projectile per engagement, per individual target.

One ship equipped with two railguns will be able to have all four projectiles in-flight within 4 seconds (based on SABR project modeling and entering assumptions). Once the anticipated time-of-flight for the railgun projectiles has expired, tracking systems will assess the effectiveness of the engagement, looking for detection of impact and breakup of the target. If no impact is detected, the fire control system will assess the feasibility of a re-engagement, another salvo from the shipboard railgun. If this is possible, another salvo will be fired, and steps G and H are repeated. If another salvo is not physically possible (ie the P (Hit) and P (Kill) are too low), the CIX will ‘hand-off all tracking data to other ballistic missile defense assets, such as those described in section 3.3” [15].

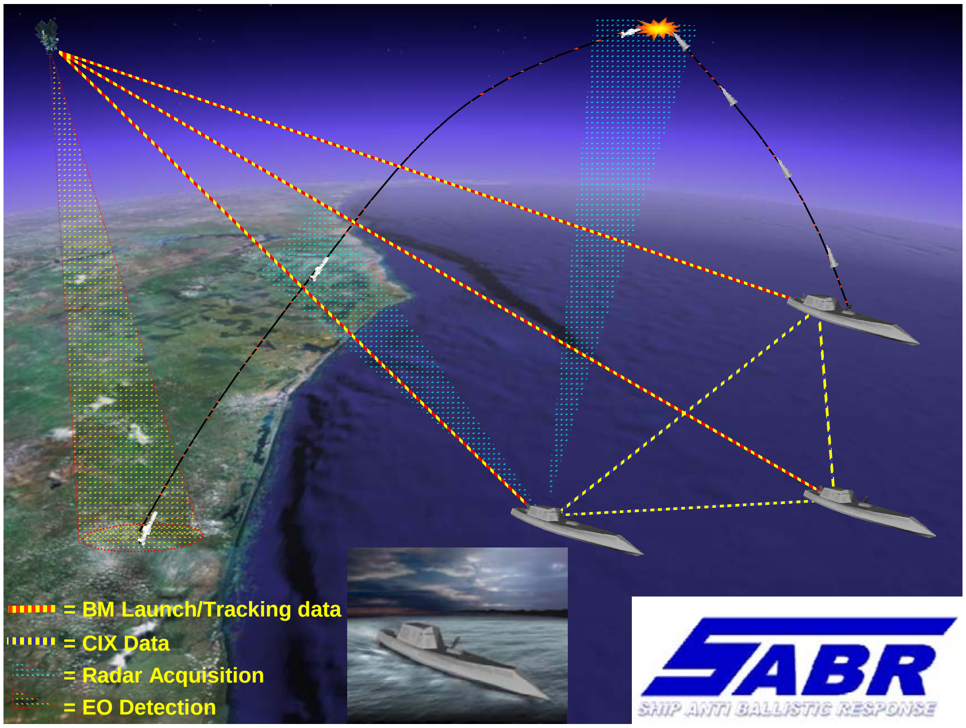

Figure 10. SABR CONOPS

D. REFERENCES

[1] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 29, 2006.

[2] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 11, 2006.

[3] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 26, 2006.

[4] Robert D Walpole, National Intelligence Officer for Strategic and Nuclear Programs. “Statement for the Record to Senate Subcommittee on International Security, Proliferation, and Federal Services on the Ballistic Missile Threat to the United States, ” p 2-5, 9 Feb 2000

[5] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 1, 2006.

[6] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 2, 2006.

[7] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 4, 2006.

[8] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 4-7, 2006.

[9] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 5, 2006.

[10] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 7, 2006.

[11] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 8, 2006.

[12] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 9, 2006.

[13] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 283-284, 2006.

[14] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 284, 2006.

[15] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 57-63, 2006.

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III. TRANSITION FROM SEA-9 TO TSSE-06

A. INTRODUCTION

The SABR TSSE team is required to design a ship capable of meeting the needs and requirements of the SABR system developed by the SEA-09 team. In order to do so, The TSSE team first analyzed the needs and requirements given by the SEA-09 team. Using these needs and requirements, a set of design parameters with threshold and optimal values for the SABR ship were developed. These design parameters are sufficient for designing a ship platform capable of anti ballistic missile defense. These design parameters are included in the Circular of Requirements (contract) used between SEA-09 and TSSE-06 and is included in appendix III. The contract acted as the major component in the hand off from SEA-09 system development to TSSE-06 ship design. This chapter is focused on presenting the needs and requirements given to the TSSE team and the corresponding design parameters used in the SABR ship design. A look at the limitations (risk) of the ship design due to technical considerations is also considered.

B. SHIP ANTI BALLISTIC RESPONSE SYSTEM NEEDS

1. SEA-9 System Needs Definition

The sea-09 team first looked at the tasking directive for the BMD project with the following specific design criteria [1]:

- Create a ship based BMD system architecture.
- Use emerging criteria for short to medium range threats.
- Integrate with coalition partners.

- Contribute to the whole of layered BMD

The SEA-09 team then used the design criteria to develop set of needs, acting mainly as their own stakeholders, due to the lack of well defined stakeholders for their project. They did, however, use faculty members and visiting organization representatives to verify and validate the needs developed to ensure that the need statements actually fit the desires of the institute for their assigned project [1]. The following needs were developed by SEA-09 [1].

- Protect Coalition Partners from Ballistic Missile Threat.
- Operate Independent of Nation State Territorial Boundaries.
- Employ over a wide range of environmental conditions.
- Assimilate into the Integrated Layered BMD system.
- Interoperate with coalition partners.
- Destroy TBMS with a high probability of kill.

2. TSSE-06 System Needs Definition

During the first three months of the project, the SABR team developed their own set of needs for a BMD system and compared the results with those obtained from the SEA-09 team.

The following set of needs were developed by TSSE-06:

- Able to counter potential 2025-2030 short/medium range ballistic missile threat by intercept in boost to midcourse phase.

- System must be ship-based
- System must be able to integrate into the coalition BMD architecture as part of a layered ballistic missile defense
- System must be cost-effective based off probability of kill
- System must be able to achieve a 100% on-station time for a particular area despite weather conditions
- System must not require high personnel costs (low manning)
- These needs developed closely matched those developed by SEA-09.

C. SHIP ANTI BALLISTIC RESPONSE SYSTEM REQUIREMENTS

1. SEA-9 System Requirements Definition

Following SEA-09's needs analysis, a requirements analysis was conducted. The system requirements were meant to describe the "whats" and not the "hows" of the system [1]. SEA-09 originally developed about sixty different requirements for the BMD systems, but after further analysis and iterative procedures, the list was narrowed down to the following set of top level the requirements [1].

- Rapidly deployable Sea Based Platform capable of prolonged operations.
- Stable platform capable of operations in heavy seas.
- Detect and track over the horizon ballistic missile launch and flight path.

- Share real-time sensor, weapon, fire control, and BDA data among coalition forces.

- Prioritize threats and optimally pair assets with highest probability of kill.

- Designate targets with a low probability of kill to other assets.

2. TSSE-06 System Requirements Definition

The TSSE group also performed a requirements analysis based on the six top level needs defined earlier. These requirements were then further broken down into a set of measures of performances and measures of effectiveness to give a set of quantitative and qualitative means for determining how well the ship based system must perform. This requirements analysis can be viewed in Appendix II.

After developing the requirements for a BMD system, the TSSE-06 team compared the results with the requirements stated by the SEA-09 team and a set of design parameters for the SABR BMD(X) ship were developed. These parameters were reviewed by faculty members and determined to be adequate to proceed with the ship design and analysis. The design parameters are stated below:

a. Optimal and Threshold Performance Parameters:

System should combine radar range, interceptor range, ship range and speed, and number of units for an optimal coverage area of 4000 nm (500 threshold).

- The seaframe's endurance, seakeeping ability, magazine capacity, reliability, and logistics support should combine to allow for an optimal time on station (ready to respond) of 6 months (1 month unreplenished is the minimum threshold), in seas up to sea state 6.
- The installed weapons system should have the optimum capability of launching the interceptor

projectile at 10 km/sec, with the minimum threshold velocity of 6 km/sec.

- Automation, high reliability equipment, and low maintenance materials should be employed for an optimal reduction in crew manning of 50% from 2006 standards (25% threshold).
- The ship's maximum speed, sprint endurance and proposed basing locations should allow for rapid deployment in order to be on scene within 3 days of a deployment order (optimally, or in 1 week as a minimum threshold).
- Construction materials, displacement, length, and manning should allow for an optimal lifecycle cost comparable to a LCS-class ship, with the threshold parameter being comparable to a CG-47 class cruiser. Cost estimate per ship: $2.5 billion. Total Annual Operating Cost (assuming 20 engagements): $31.8 million.
- The ship's signature, redundant and dispersed systems, damaged stability and shielding should optimally be maximized for survivability. As a minimum, the ship must meet the US Navy standards for damaged stability and have system redundancy.
- At a minimum the ship must have BMD capabilities. Optimally, it should also be able to defend itself.

It is worth mentioning that these parameters incorporate the requirements given by the SEA-09 as well as the requirements needed to design a ship in the 2025-2030 time-frame capable of performing the mission to the best extent possible.

E. TSSE-06 ASSUMPTIONS

Before proceeding with the detailed analysis and design of the BMD ship for the SABR project, it became important to list and identify a set of assumptions that would aid in providing a feasible design. The TSSE group carefully examined the set of requirements given by the SEA-09 cohort and conducted a preliminary technical analysis to ensure that a design could be produced that would meet or exceed the minimum requirements given. The following is a list of the assumptions:

1. Design Assumptions

(Jesse, please fill in)

F. TSSE-06 LIMITATIONS

Due to the high technical detail of some of the components of a rail gun system and some of the future technological innovations in ship design and construction, there are certain limitations that must be taken into account for this project due to technology that has not yet been proven. Although efforts are well under way to getting many of the technical issues resolved, there is no guarantee that some of the technical issues will ever be resolved. Hence, it became important for the TSSE-06 team to formulate a set of realistic expectations of a future BMD ship with a rail gun system. The following are key technical areas that must be taken into account:

1. Design Limitations

(Jesse,please fill in)

2. Design Risks

While designing the SABR BMD(X) ship, the TSSE-06 team collected and analyzed the technical risks involved in such a complex design. The results can be viewed in chapter VI.

G. REFERENCES

[1] Systems Engineering and Analysis Cohort 9. “Ship Anti Ballistic Missile Response,” p 23-37, 2006.

IV. ANALYSIS OF ALTERNATIVES

A. INTRODUCTION

The main goal of TSSE-06 team consisted of designing a system capable of finding the best possible ship design to meet the stake holder’s needs. The stakeholders in this case included the SEA-9 team and professors from the TSSE and SEA curriculums. An Analysis of Alternatives (AOA) study is necessary to facilitate finding the best design possible. To assist us with our AOA study and research, we developed a simple questionnaire, listing all eight of the stake-holder’s main requirements. The requirements were coverage area, time on station, probability of kill, minimum manning, rapidly deployable, life-cycle cost per unit, muti-mission capability, and survivability.

The purpose of the questionnaire was to allow stakeholders to distinguish relative importance of requirements when compared to each other. We wanted to know which requirements were more important to them. This would allow the TSSE team to formulate weighting factors for each requirement, that would in turn assist us in finding the best possible ship design to meet the mission. Stake-holders were given a total of eight tokens representing values of one, three, and five. Two tokens were worth five, three worth three, and two worth one. A five token ranked highest and a one token ranked lowest in terms of importance. A total of nine questionnaires were completed and the results tallied to calculate the final weighting factors for each requirement. The results from the questionnaires varied. For example, some stakeholders placed higher weights on say probability of kill while others placed a higher weight on coverage area. The final results, however, best represent the overall average weight per requirement. The TSSE team then took these weights and used them in calculations for AOA's on different possible hull forms, types of propulsion, and types of electrical generation power systems. Figure 1 shows the results obtained from the questionnaires.

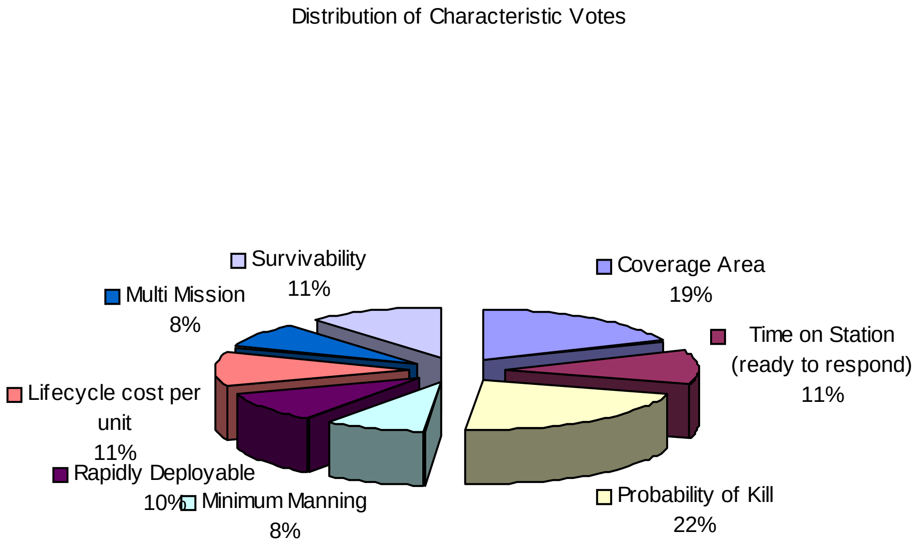


Figure 11. Weight Factors

B. AOA BREAKDOWN

The TSSE-06 team divided the AOA into smaller components, consisting of the following: Hull form AOA, propulsion AOA, Power AOA, Cost Analysis AOA, and Combat Systems AOA. Each component was analyzed by small groups of three to five members of the TSSE team. The groups conducted detailed research and analysis in attempting to find the best possible systems for the SABR ship design. Each AOA used the weighting factors developed from the questionnaires in determining which hull form, propulsion system, etc would best meet the mission of the SABR ship.

C. HULL FORM AOA

1. Overview

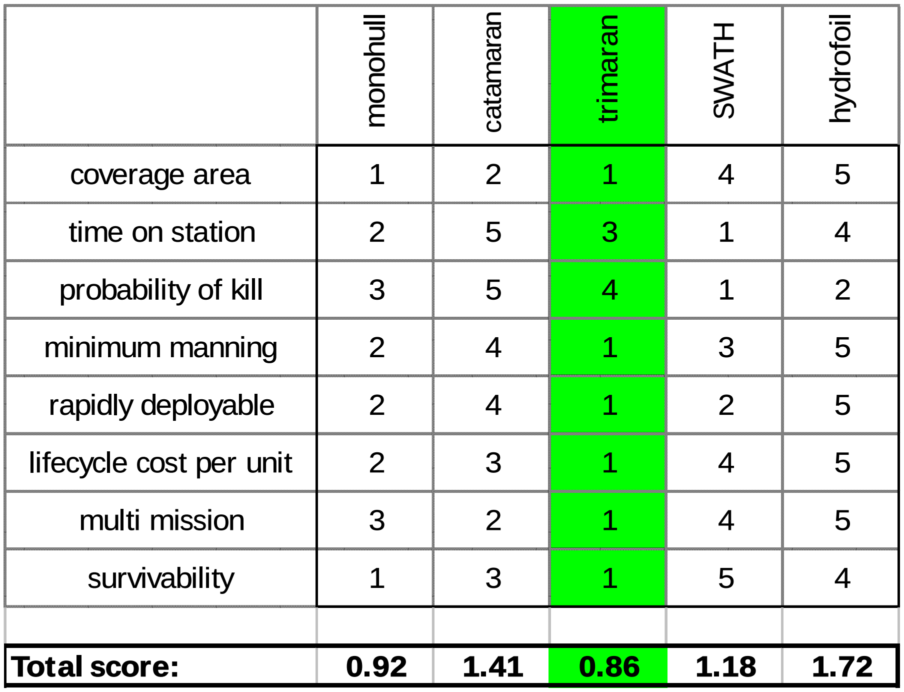
In the development of the hull design, several different hull types were considered and evaluated based on how well they achieved the overall system characteristics, ranked by the stakeholder’s priorities. The data from the questionnaire provided characteristic weightings as well as optimal and threshold characteristic values.

A variety of hull configurations were available for consideration, some of them were just conceptual designs but many have been proven through years of service. In order to determine the optimal hull configuration, five primary hull types were evaluated:

- Monohull
- Catamaran
- Trimaran
- SWATH
- Hydrofoil

The analysis combined the data taken from the Maritime Applied Physics Corporation’s spreadsheet collection (MPAC) with specific performance traits collected from other published sources. This data was then input into the AoA spreadsheet that categorized the traits within the required performance characteristics of the total system. It also included the weighting factors, determined from the stakeholder survey, to prioritize each hull's performance traits accordingly.

From this analysis, the two hull types that broke out as being the best alternatives were the trimaran, followed very closely by the monohull. The remaining three design types scored considerably worse. The trimaran scored the best in the: minimum manning, rapidly deployable, lifecycle cost per unit, and multi-mission categories. The monohull tied with the trimaran as the best design alternative for coverage area and survivability and it finished second in the: time on station, minimum manning, rapidly deployable, and lifecycle cost per unit categories. The greatest hindrance for the trimaran design was the technical feasibility. Due to initial estimates for the displacement being 15,000 tons, it became clear that a trimaran of that scale was not as technically feasible based on past designs. Figure 2 shows a summary of the results from our performance AOA.



	monohull	catamaran	trimaran	SWATH	hydrofoil
coverage area	1	2	1	4	5
time on station	2	5	3	1	4
probability of kill	3	5	4	1	2
minimum manning	2	4	1	3	5
rapidly deployable	2	4	1	2	5
lifecycle cost per unit	2	3	1	4	5
multi mission	3	2	1	4	5
survivability	1	3	1	5	4
Total score:	**0.92**	**1.41**	**0.86**	**1.18**	**1.72**

Figure 12. Hull Performance AOA results

2. Hull Options

Specific characteristics (from the TSSE 2004 design analysis) of the two primary design types considered are:

a. Monohull

The traditional type of hull. There is large experience designing, building and operating monohulls. This type of vessel, due to the amount of available information and experience, is the less risky option. Requires less development effort and, therefore, is one of the cheapest alternatives. Research and development expenses, that will increase the overall cost of the project, are estimated low for this kind of hulls.

Having large hull volume, monohulls offer great flexibility when designing cargo spaces, engine rooms and accommodation. Can be operated with variable deadweight; because of the large water plane area and provide the biggest grow margin for future requirements. Monohulls also provide good enough seakeeping, when sailing in open waters, and enough maneuverability when getting close to shore.

DDX Concept

Figure 13. DDX Concept

When considering normal operational speeds, the monohull becomes the most attractive option. But, on the other hand, when the speed increases, the powering requirement becomes larger and so does fuel consumption.

b. Trimaran

Although several trimarans have been built recently, most information about the class comes from conceptual studies that consider the trimaran hull configuration for cargo, passengers and naval ships.

Figure 14. Triton Research Vessel. [3]

Characteristics can be summarized in two fields:

- Lower Hull Resistance: A slender center hull with large L/B ratio is able to reduce, at least, 20% the hull resistance than the equivalent monohull, especially at high speed. Outrigger hulls increase of overall resistance is clearly compensated by the center hull resistance saving. Smaller power plant is required and fuel saving is important. In this way more cargo can be transported at faster speed than a similar and comparable monohull.

- Better Seakeeping and Stability: Outrigger hulls provide improved large stability and heavy weights can be transported in upper decks without stability degradation. Trimarans are able to operate in higher sea states compared to other hulls. However, side hull separation is not a free variable and has negative effects, requiring more structural weight and may have negative influence on the overall resistance due to wave's interferences.

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[3] Taken from www.globalsecurity.org

3. Summary

Ultimately, in our analysis the trimaran finished with a score of 0.86 and the monohull scored with a nearly identical 0.92 (lowest being better). The next closest-rating design alternative was the SWATH scoring a distant 1.18.

Although the trimaran scored marginally better in our Analysis of Alternatives, we decided to use a standard monohull for the ballistic missile defense ship. This decision was based on stakeholder feedback and the technical challenges of a large-displacement trimaran.

D. PROPULSION AOA

1. Overview

The goal of the power AOA group was to determine the main energy producing plant, not to be concerned with the propulsion of the ship. The Power AOA compared seven different power plants to determine the best plant for the ship. The seven different power plants that were investigated were: Gas Turbine; Diesel; Fuel Cells; Nuclear (high pressure reactor), Nuclear (molten salt), Nuclear (lead cooled), and Conventional Steam.

The seven different power plants were compared to each other using the requirement characteristics as produced in the stakeholder’s survey.

- Time on station
    - Endurance: 1/days between refueling
    - Reliability: repair maintenance hour/ operating hour
    - Logistic support: hour refuel at sea
- Probability of Kill : N/A
- Coverage area

    - Ship speed: EHP @Fn(low)
    - Ship range: KW/ ton of Fuel
    - Basing: power density tons/ 500MW
- Minimum Manning
    - Automation: number of watch standers per ship
    - Training hours per month per person
    - Equipment reliability: repair hours per plant/ operating hour
    - Low maintenance system: PMS hours per plant/ month
- Rapidly Deployable
    - Light off time: hours to light off
    - Basing: political considerations
- Lifecycle cost per unit
    - Fuel cost:$/KW
    - Maintenance cost: $/year
    - Overhaul: $* number of overhauls
    - Manning: personnel * pay/ year
    - Procurement cost: $
- Multi Mission: N/A
- Survivability:
    - Signature: heat signature
    - Signature: vibration noise
    - Redundant systems: number of plants
- Technical Feasibility: based on past designs

After completion of the performance AoA, the final statistics indicated that both Gas Turbines and a molten salt nuclear reactor were the most practical power plants to meet all of the requirements stated. We wanted to find a way to more effectively choose between gas turbines and the molten salt reactor and the TSSE team decided that a cost analysis could be used. The two plant designs were compared using a cost AoA in which the life cycle cost of the plants were compared. There were three time frames (procurement, operational life, and end of life) that the plants were compared against each other. The group created a cost calculator that compared the two plants. The calculator allowed the comparison to vary the cost of fuel as well as procurement cost, and procurement time. The molten Salt reactor was the winner in the cost AOA due mainly to the high cost of fuel, and the assumed continuous rise in fuel costs.

In the end, the molten salt nuclear plant was determined to be the choice for the power plant because of the almost identical result in the performance AoA and the clear winner in the cost AoA. Figure 5 summarizes our AOA performance results

2. Propulsion Options

a. Gas Turbine Engines

Initially the gas turbines that were compared were the LM2500, LM2500+, LM6000, and the MT30. Their size, weight, specific fuel consumption, and electrical output were identified and weighted in a sub-analysis of alternatives. The LM6000 won based on its magnitude of electrical output, 40MW. This would allow 13 generators to supply the base line required power of 500MW. The smaller gas turbines would require a greater number, consuming more volume and a greater number of personnel for maintenance. The main disadvantage of using a gas turbine engine is the fuel consumption with increasing crude oil prices. A spreadsheet was created comparing prospective cost of nuclear power plant vs. a gas turbine plant, the resulting winner for a ship whose life-cycle is greater than thirty years was the nuclear reactor plant.

b. Diesel Engines

In order to be able to analyze the best suitable solution for Power generation, several alternatives have been analyzed. In order to compare these technologies, diesel engines capable of producing 500 Mw of power is needed for Powering the Ship (Main Propulsion System) and for Electrical Power Generation.

We analyzed diesels from CATERPILLAR; MTU; YANMAR; BURMEISTER & WEIN, among others. Because of the consideration for High reliability and Standardization, we narrowed our selection to CATERPILLAR (USA) and MTU (Germany).

Considering the power density for Propulsion we selected a **MTU 20V 1163 TB73L** for Power generation using the **Caterpillar 3608.** From the point of view of standardization, this is not the best solution and we considering changing Propulsion Diesel to **CATERPILLAR 3618**. This decision is consistent with Maintainability and Specific Consumption characteristics.

However, the power requirement of 500 MW means there needs to be more than 60 Diesel engines on board the ship, increasing dramatically the Procurement Cost, Maintainability Cost, Size and Volume to fit the diesels, and manning requirements. For those reasons, the diesel engine did not perform as well on the performance AOA to use it as the best alternative for our design.

c. Fuel cells

Fuel cells were considered during the Analysis of Alternatives selection for electrical generation. A fuel cell offers a means of making usable power efficiently and with low pollution to the environment. The fuel-cell technologies being developed for power plants generate electricity directly from hydrogen in the fuel cell, but may also use the heat and water produced in the cell to power steam turbines and generate even more electricity.

The primary advantages of the fuel cell are its low heat signature, high efficiency, low/no pollution, and very little maintenance. Currently the largest fuel cell only produces 200kW. It would take 2500 very large fuel cells to supply the 500MW electrical requirement of the SABER ship. This is an unreasonable amount.

More importantly, fuel cells require a source of hydrogen to generate their power. Hydrogen is flammable and explosive, which makes it difficult to store and distribute. Due to logistics, a navy ship would likely use diesel fuel to run a separator plant which would produce the hydrogen. This would increase maintenance of the system, decrease the fuel cell's efficiency and continue to pollute the environment, practically negating any of the advantages for using fuel cells. For these reasons, fuel cells were removed from the list of feasible means of electrical generation.

d. Conventional Nuclear Plant

We looked at nuclear plants found on aircraft carriers and on Long Beach class cruisers. The most important advantage of the nuclear plant is its high endurance. It is not needed to refuel repeated times compared to other systems. However, building ships with conventional nuclear plant is more expensive in terms of life cycle costs when compared to building ships with technologies such as gas turbine or diesel engines. When comparing two aircraft carriers, one with nuclear plants, and the other with conventional steam, the life cycle cost of the nuclear carrier was almost twice as high as the non-nuclear carrier. [1] When comparing long beach class nuclear cruisers with Spruance Class cruisers, it was determined that if the Navy continued purchasing nuclear cruisers instead of the spruance cruisers, the life cycle costs would have amounted to an increase of about 40 percent. As such, the Navy decided to save money and purchase the Spruance Class ships. [1]

Other disadvantages of conventional nuclear plants are high manning, personnel training, and maintenance required. Another disadvantage of this system is large power density. Other factors to consider include political problems and safety issues. In the end, the performance AOA on the conventional nuclear plant showed that it was favorable in some categories such as time on station and survivability but unfavorable in many other categories. The major factor affecting this choice for use on our ship was high costs, and hence it was decided that this type of propulsion system is not feasible for the design.

e. Molten Salt Nuclear plant

The Liquid Fluoride salt, Thorium-fuelled nuclear reactor (hereafter referred to as the Molten Salt reactor) was first introduced to the design group in the TS 4001 class in May 2006. The introduction was in the form of two guest lecture sessions given by Dr. Joseph Bonometti, P.E., Ph.D. who is the Naval Postgraduate School NASA Chair. As the propulsion design group was recently involved in an Analysis of Alternatives for power generation type, it was decided by the group to include Molten Salt reactors into the overall analysis.

A basic description of a Molten Salt reactor is a reactor in which the primary working fluid is a molten salt fuel mixture. Typically UF^4 or some derivative thereof, the salt-fuel mixture flows through a graphite core which acts as a moderator. Heat thus generated is passed to a secondary loop, usually consisting of a separate molten salt loop containing thorium for processing through the Thorium – ^{233}U cycle. Molten salt reactors are distinguished by their typically high output temperatures and easier reprocessing capability due to the liquid nature of their fuel[]. Thus, the advantages of the Molten Salt reactor are that Thorium can be utilized as a relatively low-cost nuclear fuel, reprocessing of the fuel occurs consistently so that the waste products have a half-life on the order of 300 years, and the flowing liquid nature of the design allows the implementation of passively safe operation designs. Another important advantage is that this reactor is designed to operate at temperatures in excess of 700°C, thereby allowing the team to couple the thermal output to closed-cycle gas turbines and achieve higher efficiency and less manning than a traditional Naval nuclear reactor coupled to a steam cycle. The primary disadvantage of this type of reactor is the limited previous research conducted, thereby limiting the industrial knowledge base in potential construction. Where this plant succeeded in the original Analysis of Alternatives was in the areas of minimal manning and potentially negligible fuel costs. An in-depth description of the Molten-Salt technology will be provided in the design section. [2]

f. *Lead cooled Nuclear plant*

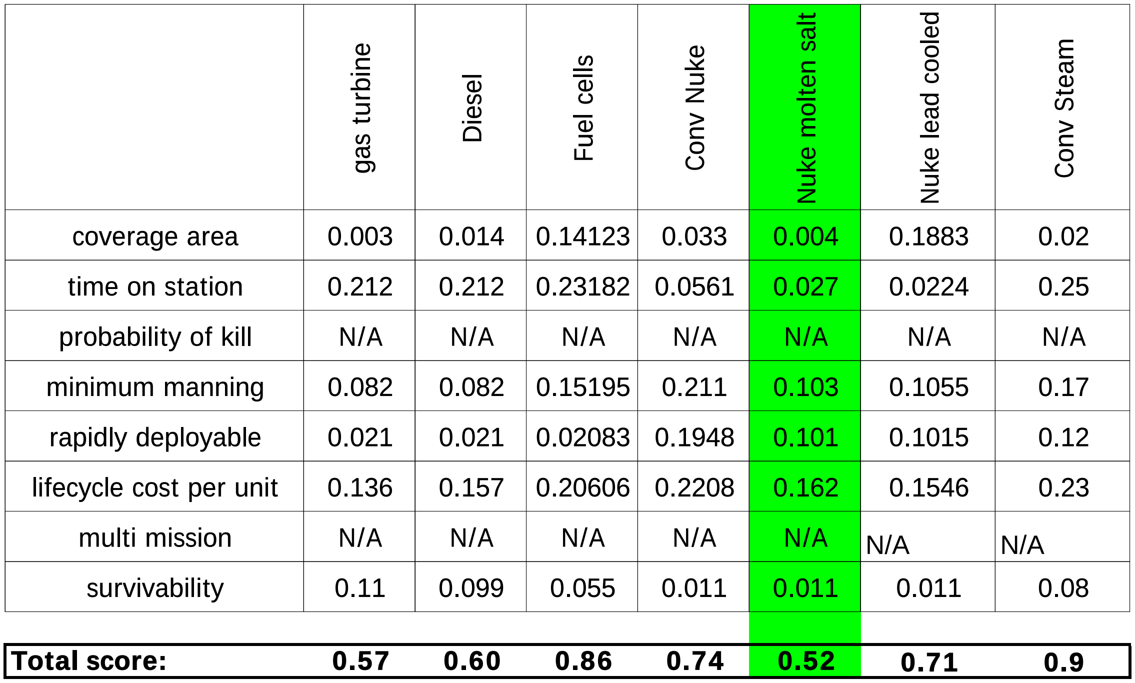
The Lead-cooled Nuclear plant is currently a technology supported by Lawrence Livermore National Laboratory for the 'Generation-IV' nuclear initiative. The nuclear dynamics of the Lead Cooled plant are similar in scope to the High-pressure water reactor, with the use of solid fuel in the core and the exception being the use of Lead instead of water as the primary coolant. Benefits of this type of reactor are the passively safe results of encasing the primary fuel in lead. The disadvantages of this technology is that the Lead coolant does not operate well in temperatures in excess of 500°C, thereby making coupling of this reactor to a Brayton Gas Turbine cycle less efficient, possibly resulting in coupling with a Rankine Steam cycle which would necessitate a higher manning level. Additionally, this reactor will suffer the same fueling concerns as a conventional Naval reactor. This reactor thus did not perform well in the initial Analysis of Alternatives, as it was seen as similar in scope and benefits as the conventional Naval reactor, without the industrial construction and training familiarity that can be leveraged in a traditional reactor. [3]

g. Conventional Steam plant

Steam plants do offer some advantages. They are very efficient at low speeds and the steam can be utilized for auxillary systems. High power is also available for high speeds even though efficiency is low. Steam plants are also very easy to start up, although start up times are rather long and can require a high volume and weight. The major disadvantage for steam plants is low fuel efficiency , therefore requiring much more volume and weight for fuel storage. Manning for a conventional steam plant is also high, and maintenance demands are extensive due to long overhaul periods. Based on design considerations such as reduced manning, the conventional steam plant was determined to be an unsuitable choice for the SABR design.

3. Propulsion AOA Results

Below is a capture of the final values tallied after conducting the AOA. The resulting winner highlighted below was the molten salt reactor, followed closely by gas turbines.



	gas turbine	Diesel	Fuel cells	Conv Nuke	Nuke molten salt	Nuke lead cooled	Conv Steam
coverage area	0.003	0.014	0.14123	0.033	0.004	0.1883	0.02
time on station	0.212	0.212	0.23182	0.0561	0.027	0.0224	0.25
probability of kill	N/A	N/A	N/A	N/A	N/A	N/A	N/A
minimum manning	0.082	0.082	0.15195	0.211	0.103	0.1055	0.17
rapidly deployable	0.021	0.021	0.02083	0.1948	0.101	0.1015	0.12
lifecycle cost per unit	0.136	0.157	0.20606	0.2208	0.162	0.1546	0.23
multi mission	N/A	N/A	N/A	N/A	N/A	N/A	N/A
survivability	0.11	0.099	0.055	0.011	0.011	0.011	0.08
Total score:	**0.57**	**0.60**	**0.86**	**0.74**	**0.52**	**0.71**	**0.9**

Figure 15. Propulsion AOA results

Because of the fact that the scores between gas turbines and molten salt reactor were so close and due to the fact that gas turbines is currently the most popular choice for building and designing modern ships, we felt it necessary to conduct further analysis to make our final decision. We also felt that with the increase of demand for oil in the future, that prices for oil would continue to rise to a point where it may become inconceivable to build ships without consideration of alternate fuel sources. As such, we conducted a cost analysis to determine whether gas turbines or a molten salt reactor would best fit our needs in the future.

4. References

[1] Cost-Effectiveness of Conventionally and Nuclear-Powered Aircraft Carriers, 01 Aug 1998, http://www.globalsecurity.org/military/library/report/gao/nsiad98001/a1.htm [15 May 2006]

[2] "Molten Salt Reactor", Idaho National Laboratory Gen IV Website, 13 July 2005 http://nuclear.inl.gov/gen4/msr.html [01 August 2006]

[3] "Generation IV Nuclear Energy Systems Ten-Year Program Plan – Fiscal Year 2005", Office of Advanced Nuclear Research, DOE Office of Nuclear Energy, Science, and Technology, March 2005. Retrieved from: http://neri.inl.gov/program plans/pdfs/gen iv program plan.pdf [20 OCT 06]

E. COST ANALYSIS OF GAS TURBINES VERSUS MOLTEN SALT

The primary goal of the cost analysis work was to decide between Combustion Gas Turbine or the Molten Salt Reactor as the primary plant for the ship. The primary distinguishing feature between both types of plants is that for Combustion Gas Turbines, there is less installment cost, virtually no end-of-life cost, but a significant variable cost resides in usage, in particular the price of the fuel. For the Molten Salt Reactor, fuel is not a primary cost concern since the 'initial charge' fissile fuel is included in the construction cost and refueling thereafter consists of adding relatively small amounts of Thorium, which is approximately four times as abundant as Uranium. Thorium is produced as a byproduct of certain rare-earth metal production, such as monazite, and is currently disposed of in United States low-level radioactive disposal sites, making the life-cycle fuel cost negligible. [United States Geological Survey product: Thorium, by James B. Hedrick] The price of the Molten Salt Reactor resides in its considerable startup costs, as well as anticipated lifecycle and post-life cost associated with the radioactive waste. It is important to note that waste handling for the products of this reactor should be less costly than conventional nuclear reactors due to the continuous reprocessing and the use of U-233 as the fissile fuel.

In an attempt to provide a first-approximation cost comparison of these two technologies, the decision was made to utilize a spreadsheet representation of lifecycle and detail the assumptions that were made. After this had been completed, the decision was then made to revise the spreadsheet such that all assumptions could be user-variable using toolbars, so that future design teams could potentially use this tool with revised information. This was in line with our open-design methodology in which the design group took pains to ensure that tools developed in the analysis and design process were generic enough to be utilized in other projects if the need arises.

The assumptions that were utilized for our final choice were that both models were normalized in terms of inflation, and that the percent annual rise in fuel costs was that which was above inflation. It was assumed that the lifecycle of both systems was 30 years, with no end-of-life/disposal cost for the Combustion Gas Turbine as whatever cost there might be could possibly be alleviated by secondary sale of parts and equipment. The reactor, on the other hand, incurred a 30-year disposal cost timeline in which 10% of the running cost was maintained to cover the disposal of the waste products at end of life. While this is a simplification of the large number of variable costs associated with dismantling a reactor, it was estimated as significantly higher than the actual dismantling cost, since most of the fuel could be reused due to its liquid form, and the waste products for U-233 have significantly shorter half-lives than other nuclear fuels. The reactor also incurred a significant five-year startup cost to reflect the potential industrial switchover costs. Finally, the in-life running/maintenance costs of the gas turbine was a combination of current naval data and a 3.2% yearly increase in fuel cost. An average daily power production of 17MW was utilized as the assumed Combat Systems, propulsion, and hotel services load. This number was fed back into the specific fuel consumption of the combustion gas turbines, also assuming that the gas turbines powered an energy storage medium for an all-electric ship which would allow them to only operate at maximum efficiency. The molten salt running cost was extrapolated from the original Oak Ridge data, using the funds requested for building and running a 1-GWe plant for 11 years and, calculating for interest, dividing to achieve a yearly cost estimate of $224,363,636. This value, as all other values assumed in the spreadsheet cost analysis, is variable if follow on work arrives at different costs. Once the assumptions were run through the model, the resulting data supported the Molten Salt reactor, primarily due to the lack of susceptibility to world oil prices.

Figure 8 displays the results for a molten salt reactor versus gas turbine based on gas prices for June 2006.

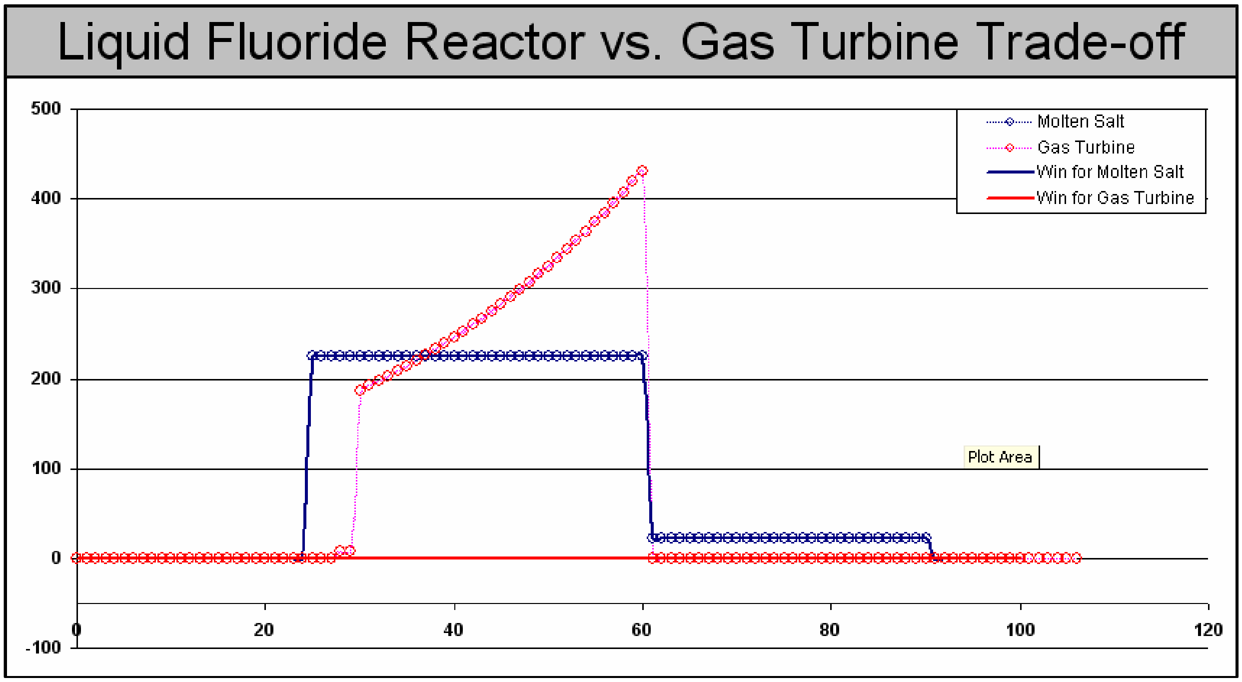


Figure 16. Cost Analysis Trade Off

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V DESIGN PROCESS

A. HULL AND MECHANICAL DESIGN PROCESS

1. Introduction

Ship design is a spiral process in its very nature. This means that some decisions cannot be made without preliminary information, but often that information is related to the current decision. For example, the amount of water a ship displaces directly effects how much propulsive power it must have installed, but the weight of the propulsion engines is a large component of the displacement. Therefore, it is easy to see how many different parts of a ship design are intertwined.

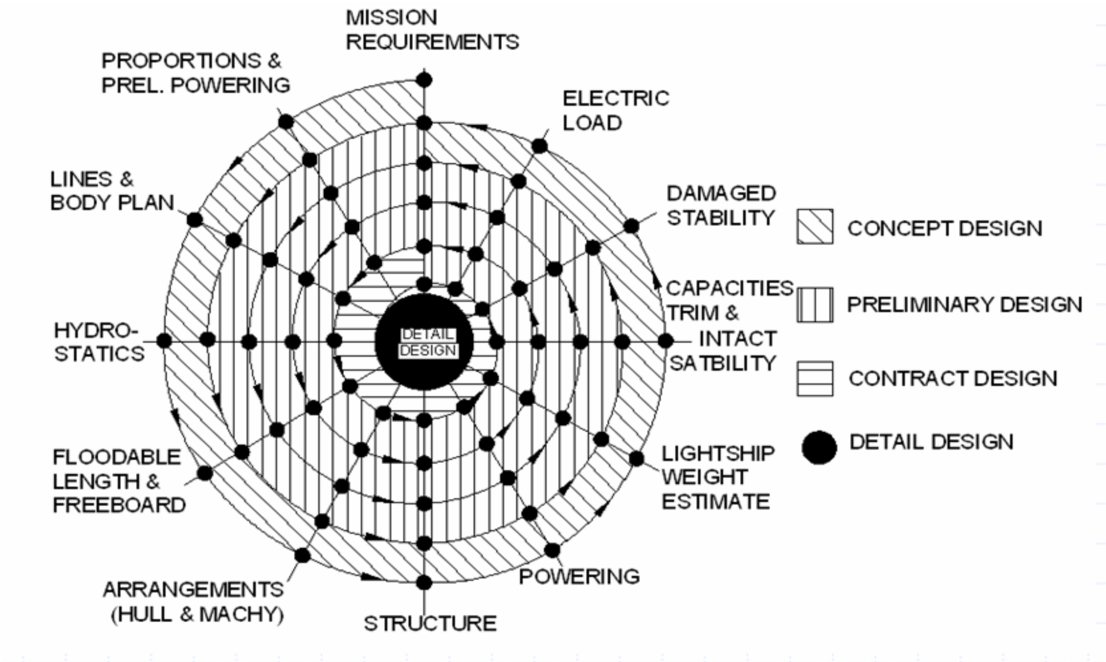
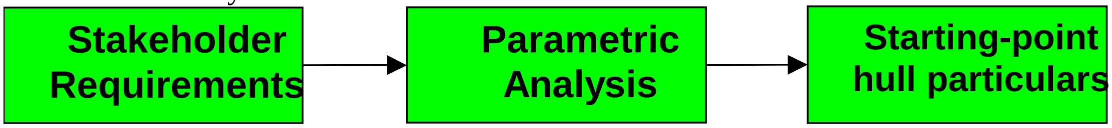


Figure 17. Spiral Design Process

In order to manage these interrelated relationships, the spiral design process is used for ship construction. A starting point must be chosen and several key parameters designated. Once a starting point is defined, these values can be used as an entry point into the loop. Every dependent process is then carried out, and once the first iteration of each step in the process has been done, the original entry values used to begin the process can be refined based on the results of the first iteration. Going back to the displacement example, if an entry value for the displacement is given, the required installed power that is needed to move that displacement can be determined, and therefore a more exact weight estimate based on the exact engines needed can be determined. The weight of the exact engines can then be fed back into the model to refine the original displacement estimate. For the design of a system as complex as a ship, the design spiral governs each step in the process.


Parametric Analysis

Our goal in the design of the Ballistic Missile Defense ship was to make one complete loop around the design spiral. In order to get a starting point to enter into the spiral, a parametric analysis was used to understand what successful design attributes in similar existing ships are. Beginning with customer and shareholder requirements based on the questionnaires discussed earlier, deployment distance and speed, as well as payload were determined. The worst case deployment scenario was seen as Hawaii to the Korean Peninsula and the response time dictated by the customer, determined a maximum speed requirement of 30 knots. The principal characteristics of the rail gun weapons system to be installed were also known at that time, so that weight was used as an initial payload estimate.

The range, speed and payload were fed into the Maritime Applied Physics Corporation (MAPC) spreadsheet program for a monohull. This program uses existing data from actual designs to match requirements to hull parameters. The results from MAPC were the initial length and displacement estimates. In order to further refine these estimates into a successful hull shape the Summers design lanes (fig 18) were utilized along with other design guidelines for optimizing hull shape summarized in table 1 (below).

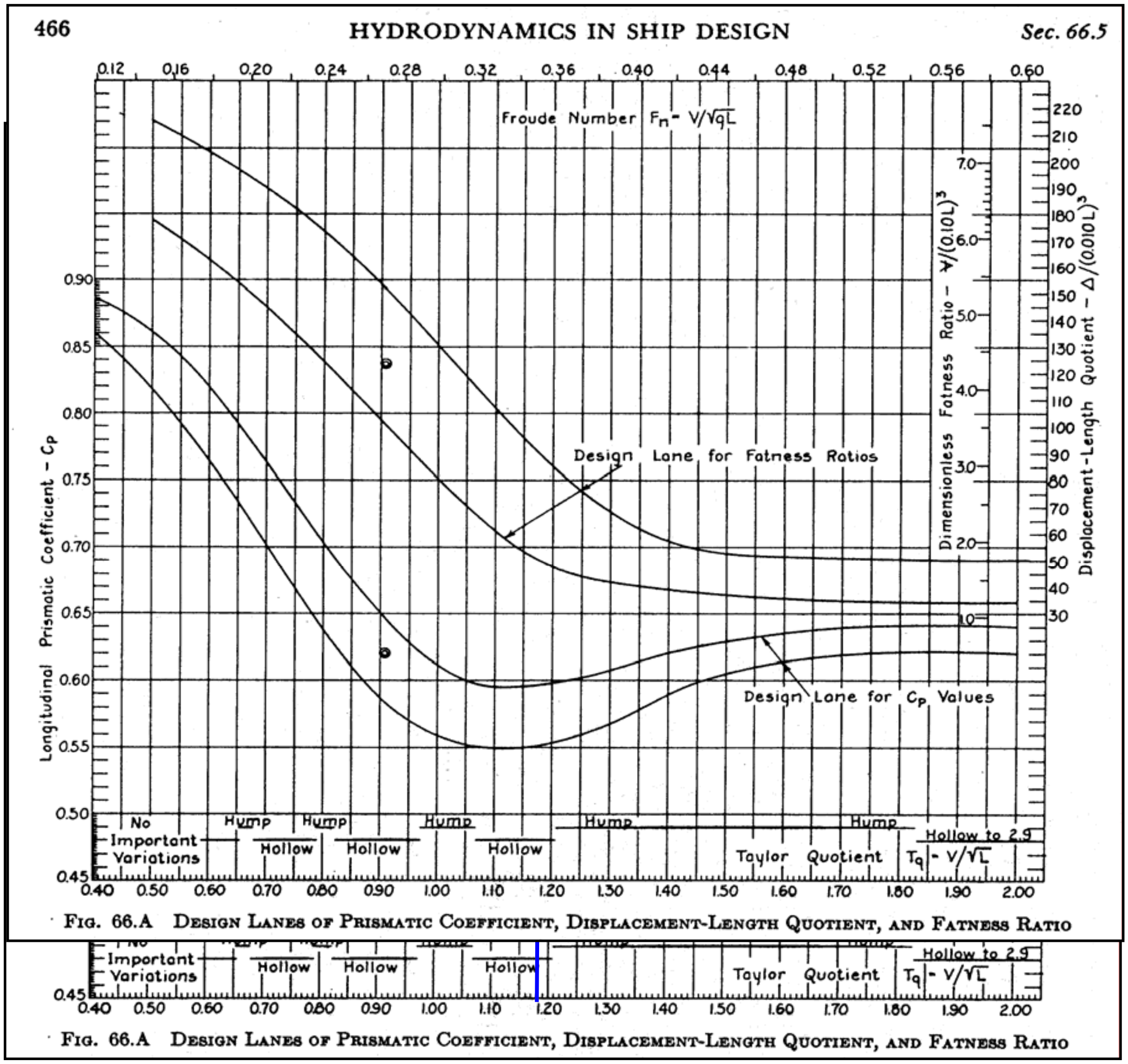

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FIG. 66.A DESIGN LANES OF PRISMATIC COEFFICIENT, DISPLACEMENT-LENGTH QUOTIENT, AND FATNESS RATIO

FIG. 66.A DESIGN LANES OF PRISMATIC COEFFICIENT, DISPLACEMENT-LENGTH QUOTIENT, AND FATNESS RATIO

Figure 18. Summer's Design Lanes, for parametric analysis

Parametric Solutions:	**SABR design:**		**Typical values and design guidelines:**
Volume Displaced	525,000	cuft	
Length (LWL) (initial estimate)	650	ft	
Displacement to Length	55		Combatants usually range from 40 to 100.
Speed-to-Length ratio	1.18		0.4 to 2.0
Froude Number	0.35		Typical combatant: 0.42 (CG) to 0.59 (Fletcher). 0.25-0.27 and 0.37-0.50 should be avoided.
Prismatic Coefficient	0.60		(from Summers chart)
Midship Section Coefficient	0.72		For seakeeping, a max section coefficient close to 0.61 is better. Corvettes are about 0.60, CV's are at 0.99. For powering, the optimum max section coefficient is 0.785 (or p/r4), which again implies a semi-circular cross section.
Beam-to-Draft Ratio	3.0		Optimum beam-to-draft is 2.0 (rarely achieved), which implies a semi-circular midship section and the most efficient surface area for a given volume. Combatants usually range from 2.5 to 3.5.
Block Coefficient	0.43		Typical combatant: CG-47, FFG-7: 0.445; DDG-51: 0.505
Draft	25.0	ft	
Beam	74.9	ft	
Length-to-Beam Ratio	8.7		Higher length-to-beam tends to be better, since it implies lower resistance, but could create stability and arrangement problems. Combatants usually range from 7.0 to 10.0.

Table 1. Summary table of design parameters for a typical combatant and corresponding SABR design values.

2. Generate a Hull Form

Once the shape of the desired hull was determined through the parametric analysis and the incorporation of typical design guidelines, the exact hull shape was created to match those coefficients. The results of the parametric analysis step included length, beam, draft, and multiple coefficients listed in Table 1 above. Rhino three-dimensional drafting software was used create the desired shape as defined by the coefficients. The focus of the effort at this stage was primarily on the underwater hullform (Figure 20). In later developments, the design of the hull above the waterline was optimized based on

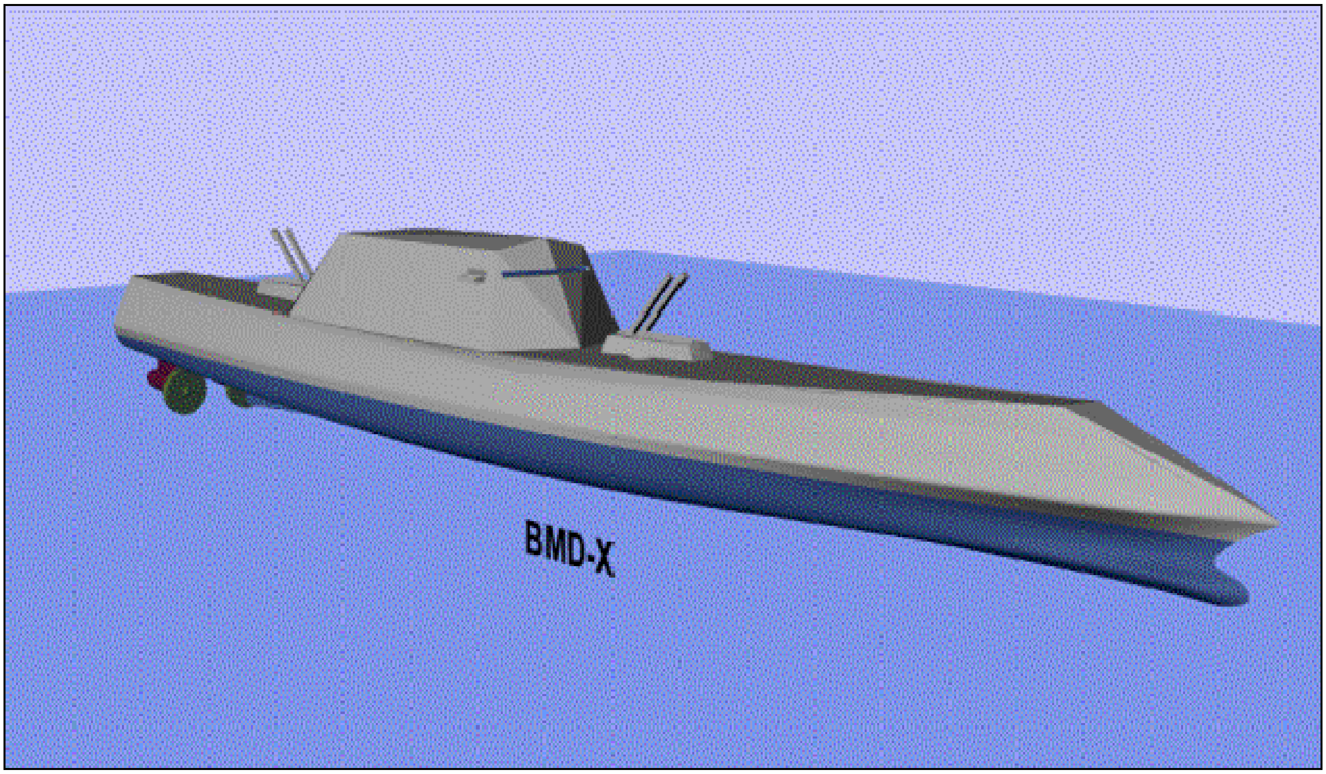


Figure 19. The hullform generated in Rhino, matching the parametrically-determined design criteria

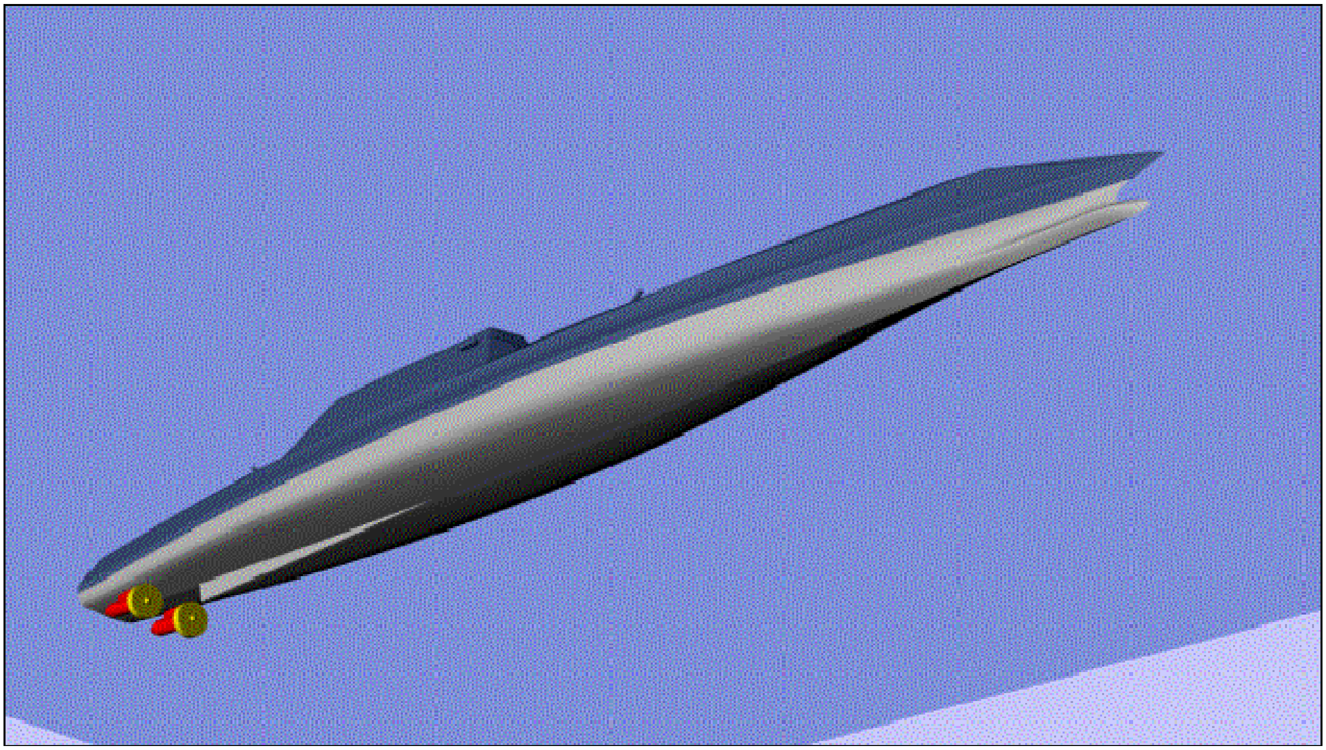


Figure 20. Underwater hull form.

The process of creating the hull in Rhino was an iterative one, beginning with a basic hull shape of the correct length, beam and draft. From that starting form, the shape was manipulated slowly, through trial and error, until the correct form coefficients were achieved. RhinoMarine is an accompanying plug-in that was used to determine the basic hydrosatics. In this way, it was possible for the designers to immediately tell how a change to the shape of the hull affected the hydrostatics.

Table 2 lists the particulars at the completion of the first iteration of hull design in Rhino. These values very closely match the desired values as determined through the parametric analysis described above.

LOA	**645 ft**
LWL	**632 ft**
Beam	**79 ft**
Draft	**24.2 ft**
Displacement	**15260 tons**
Cb	**.437**
Cx	**.721**
Cp	**.606**

Table 2. Hull Design Values for first iteration

3. Determine Resistance

By completing the hull design, several follow-on steps in the design spiral that are dependent on first having an established hull form were able to proceed. One of the most important of those steps was to determine the resistance that that hull would generate going through the water at the designed maximum speed. From the resistance the amount of propulsive powering that needed to be installed could be calculated.

The resistance calculations were performed using three different resistance prediction algorithms: i)Navcad 4.0,ii)Autopower 3.0.5 and the Power Prediction Calculator(PPP) developed by the University of Michigan. To ensure the consistency of the yielding predictions the Holtrop prediction method was chosen ,since it is the only one used in PPP and it can also be selected in the Navcad and Autopower software as well. In addition to this, Holtrop method is designed to provide more accurate results predicting the resistance for monohulls, seeming the most appropriate for the monohull design previously selected.

The resistance predictions are tabulated below in Tables 3-6 and the corresponding ship speeds for a given EHP , in kilowatts and horsepower , are depicted in Figures 21 and 22. The yielding results were averaged in order to calculate the required shaft power.

Autopower				
V(knots)	Fn	Resistance (lb)	Effective power (kw)	EHP(hp)
3	0.036	523.89	36.17	48.23
6	0.071	3855.49	266.21	354.94
9	0.107	12258.09	846.37	1128.49
12	0.142	27723.85	1914.21	2552.28
15	0.178	52567.21	3629.54	4839.38
18	0.213	90095.77	6220.72	8294.29
21	0.249	144793.52	9997.36	13329.81
24	0.284	221489.56	15292.88	20390.51
27	0.32	312422.70	21571.42	28761.89
30	0.355	443045.92	30590.38	40787.17

Table 3. Resistance Predictions using Autopower

PPP				
V(knots)	Fn	Resistance (lb)	Effective power (kw)	EHP(hp)
3	0.036	434.50	30	40
6	0.071	3258.72	225	300
9	0.107	12058.01	827.78	1110.07
12	0.142	27255.35	1871.07	2509.15
15	0.178	51611.10	3543,09	4751,36
18	0.213	88275.01	6060,06	8126,67
21	0.249	141624.96	9722,52	13038,11
24	0.284	215414.88	14788,18	19831,27
27	0.32	304400.94	20897,05	28023,40
30	0.355	434277.80	29813,06	39979,97

Table 4. Resistance predictions using PPP

Navcad				
V(knots)	Fn	Resistance (lb)	Effective power (kw)	EHP(hp)
3	0.036	543.77	37.545	50.06
6	0.071	3918.06	270.525	360.7
9	0.107	12311.10	850.0275	1133.37
12	0.142	27610.44	1906.38	2541.84
15	0.178	52010.07	3591.068	4788.09
18	0.213	88687.13	6123.458	8164.61
21	0.249	142003.95	9804.75	13073
24	0.284	216546.30	14951.57	19935.43
27	0.32	304651.21	21034.83	28046.44
30	0.355	431832.02	29816.11	39754.81

Table 5. Resistance Predictions using Navcad

Average				
V(knots)	Fn	Resistance (lb)	Effective power (kw)	EHP(hp)
3	0.036	500.7559165	34.575	46.1
6	0.071	3677.460207	253.9125	338.55
9	0.107	12209.10271	842.985	1123.98
12	0.142	27529.84403	1900.815	2534.42
15	0.178	52062.75624	3594.705	4792.94
18	0.213	89019.30324	6146.393	8195.19
21	0.249	142807.4406	9860.228	13146.97

24	0.284	217816.8751	15039.3	20052.4
27	0.32	307158.248	21207.93	28277.24
30	0.355	436385.2099	30130.49	40173.98

Table 6. Average Resistance

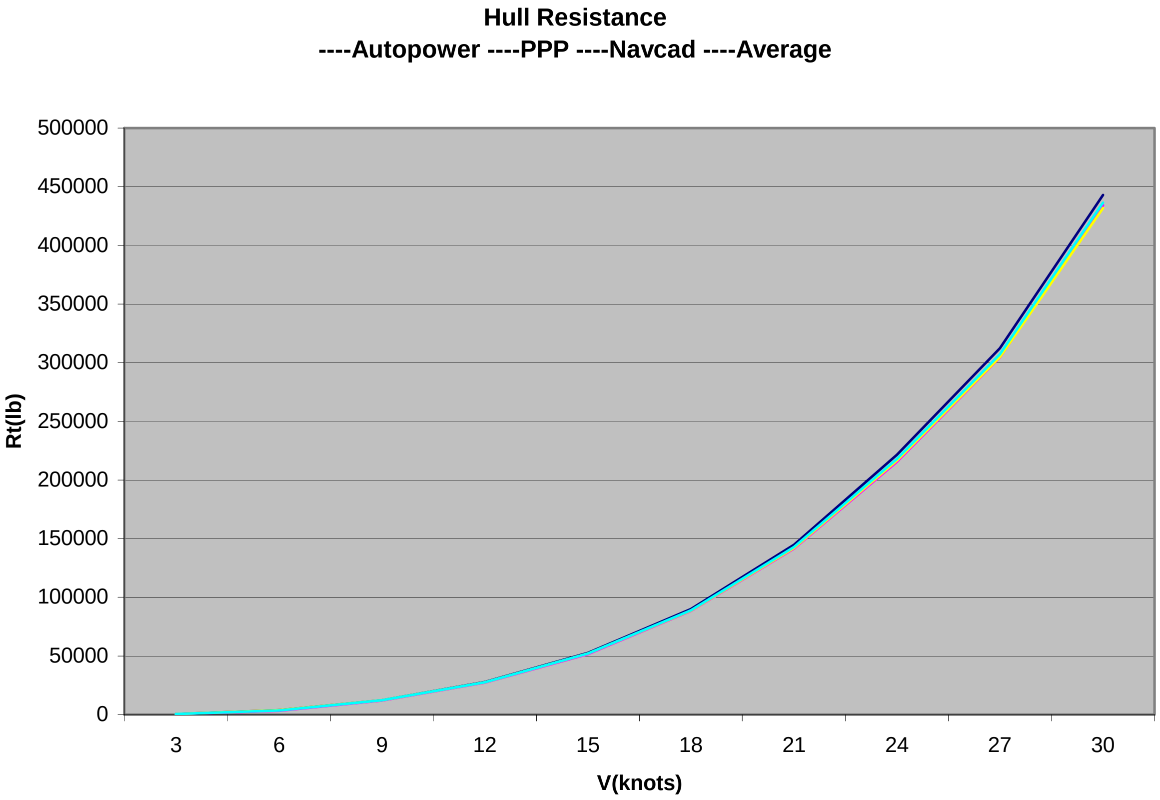


Figure 21. Ship’s Speed VS EHP using kilowatts

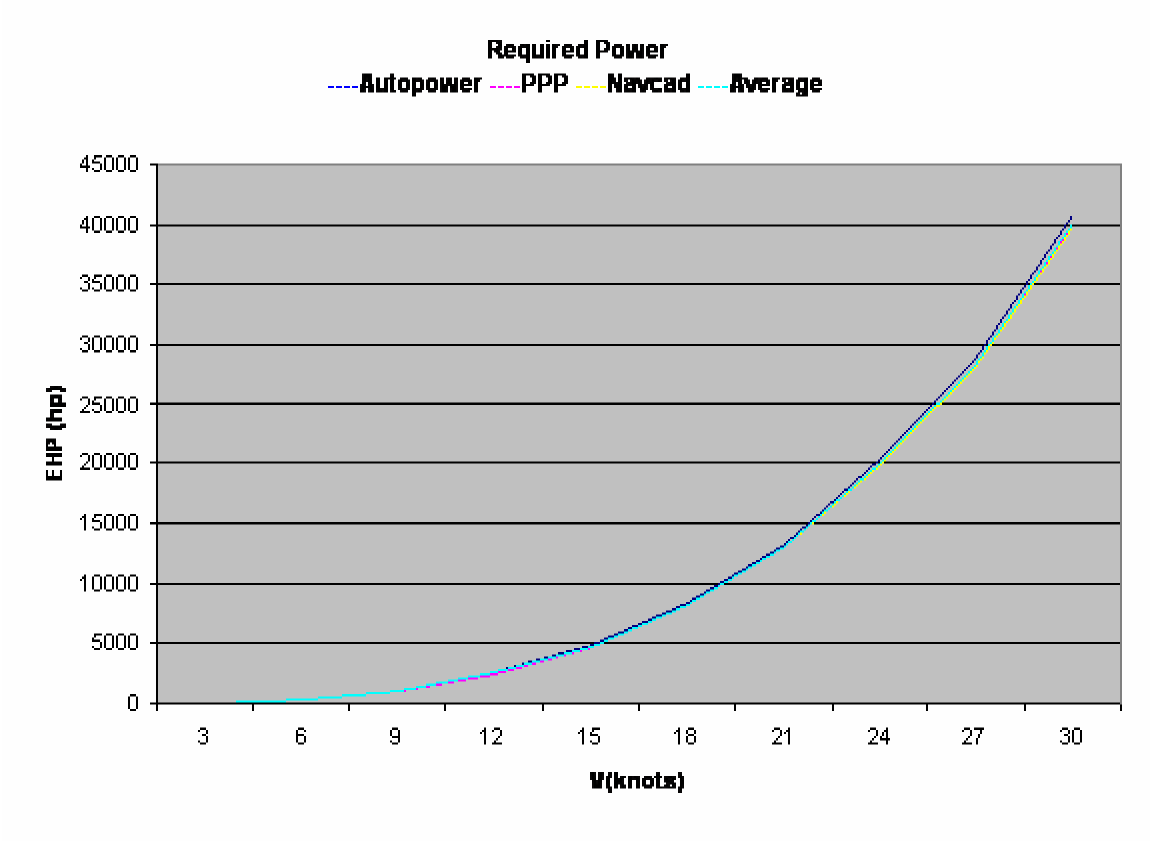


Figure 22. Ship's speed VS EHP using horsepower

Other Hull Calculations were also performed. Autohydro software has been used for Naval Architecture calculations. These calculations are shown in a separate appendix and include:

Hydrostatics

Cross Curves of Stability

Floodable length

Longitudinal Strength

Intact Stability

Damaged Stability

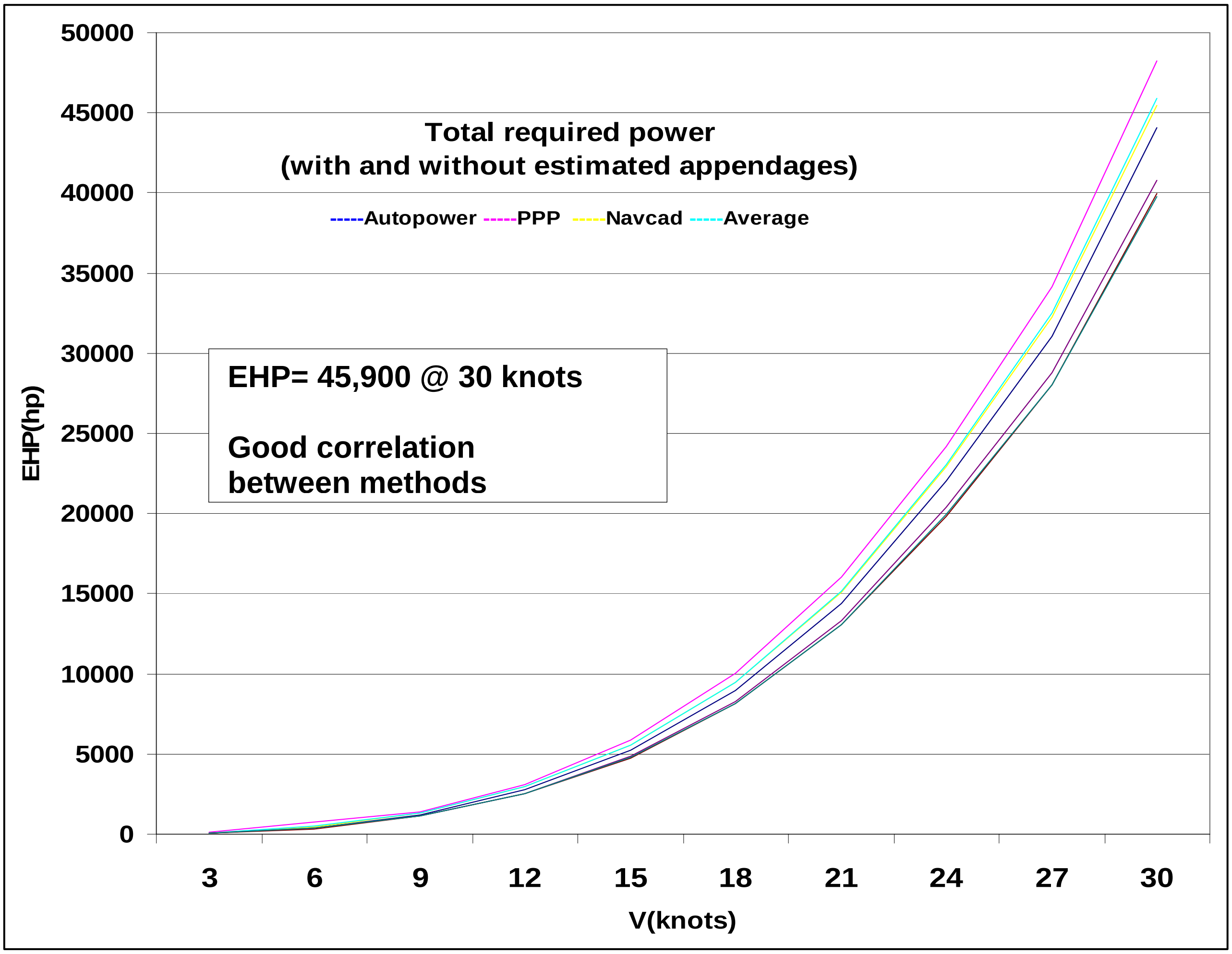


Figure 23. Power Required to propel the ship at various speeds

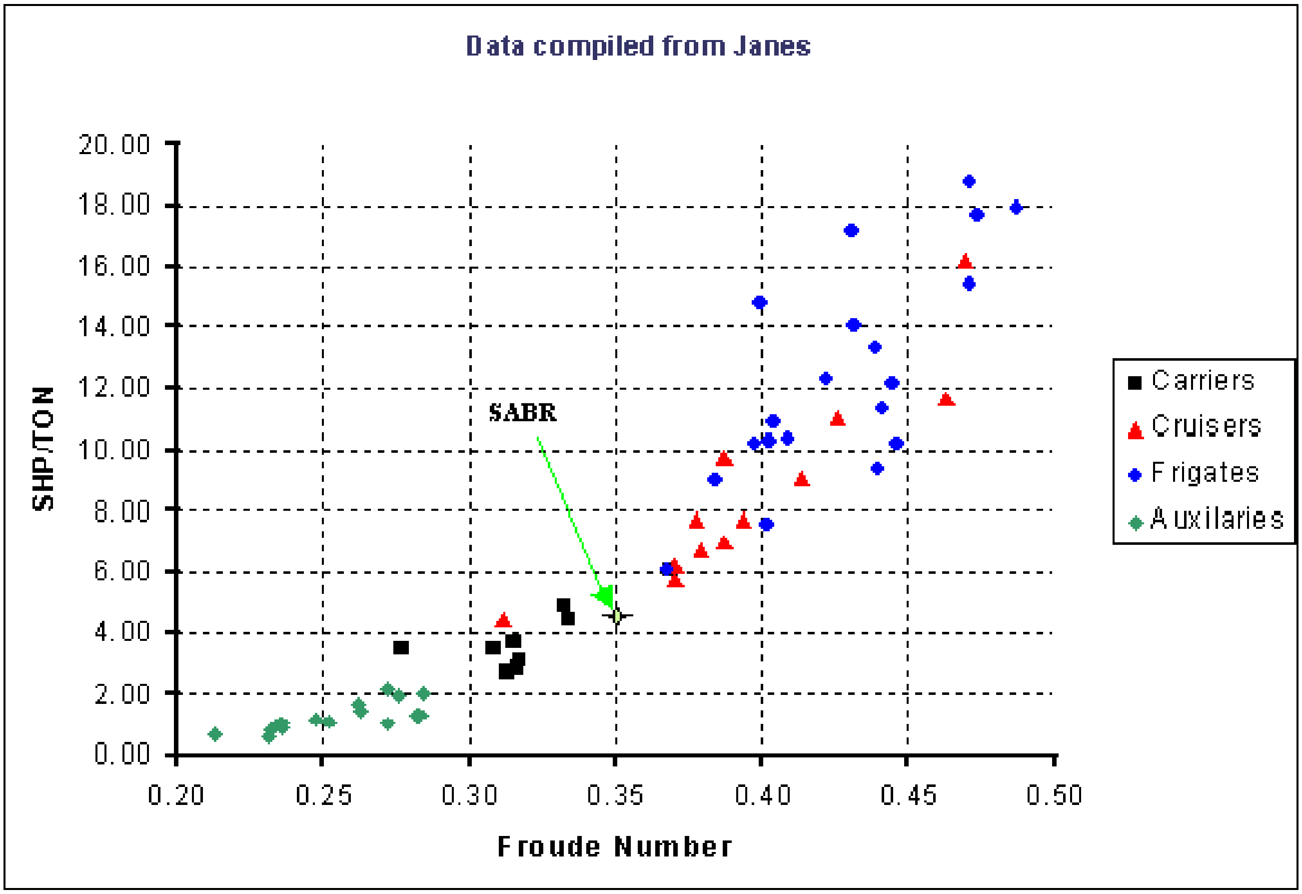


Figure 24. Power requirement validation against other existing combatant designs

4. EHP to SHP

The resistance calculations give the amount of power needed to tow a ship through perfectly smooth water at a given speed. In other words, it is the power to overcome the total ship resistance at that speed. This power, known as effective horsepower (EHP), must then be modified to include the inefficiencies inherent in the appendages, shafting, and propeller in order to determine the actual power that must be installed in the ship. The installed, shaft power (SHP), is that amount which will provide the requisite power to overcome resistance once the inefficiencies are subtracted out.

Velocity	Resistance	Delivered Power (Pd) per shaft	Shaft Power per Shaft	Shaft Power TOTAL	Open Water Efficiency	RPM
KNs	Lbs	HP	HP	HP		
5	13708	157	162	324	0.716	19.2
10	49587	1093	1127	2254	0.743	37.3
15	105135	3395	3500	7000	0.761	54.9
20	186249	8007	8254	16508	0.762	73.2
25	299834	16313	16818	33636	0.753	92.3
30	443046	29227	30131	60262	0.745	111.6

Table 7. Conversion of EHP to SHP. This shows that a total of 55 MW SHP required for 30 knots

5. Powering and Propulsion

a. Power Transmission Analysis:

In modern ships propulsion systems are so large and heavy that they force the rest of the ship to be constructed around it. The large power density of machines and their specific locations on ships tend to reduce availability of space for other resources, such as for cargo. Shafts can extend for a long part of the ship, compromising the proper utilization of available space, reducing payload and increasing maintenance requirements. Therefore, after considering the Analysis of Alternatives for hull and power generation for the ship, a detailed survey of possible candidates to use for propulsion was completed. In order to increase the payload, especially for the Rail Gun System and Molten Nuclear Plant, it is desired to have a shaft-less system. Many attributes were taken into consideration for the selection, which in order of importance were: technical feasibility, weight and volume, efficiency, reliability, coverage area, life cycle cost, and manning. Since a molten salt Nuclear Plant was chosen as a prime energy source, the Coverage Area attribute had no meaning, so we discarded it from our analysis.

Considering modern technology , three different propulsion options available to accomplish the goals are:

Magneto hydrodynamic Propulsion

Water Jet

Propulsion Pod

1. Magneto Hydrodynamics Propulsion

Magneto hydrodynamics relates to the phenomena of motion of electrically conducting fluids in the presence of an electric and magnetic field. When the current flows through an electrolyte (fluid can conduct electricity) it creates a force, which is perpendicular direction to the applied current and magnetic field (fig 25). That is following that **F=BxI.** In figure 14 can be seen a propulsion device where 4, 5 are the electrodes; 2, 3 are the magnets that produce the magnetic field; and 7 is the electrolyte [1].

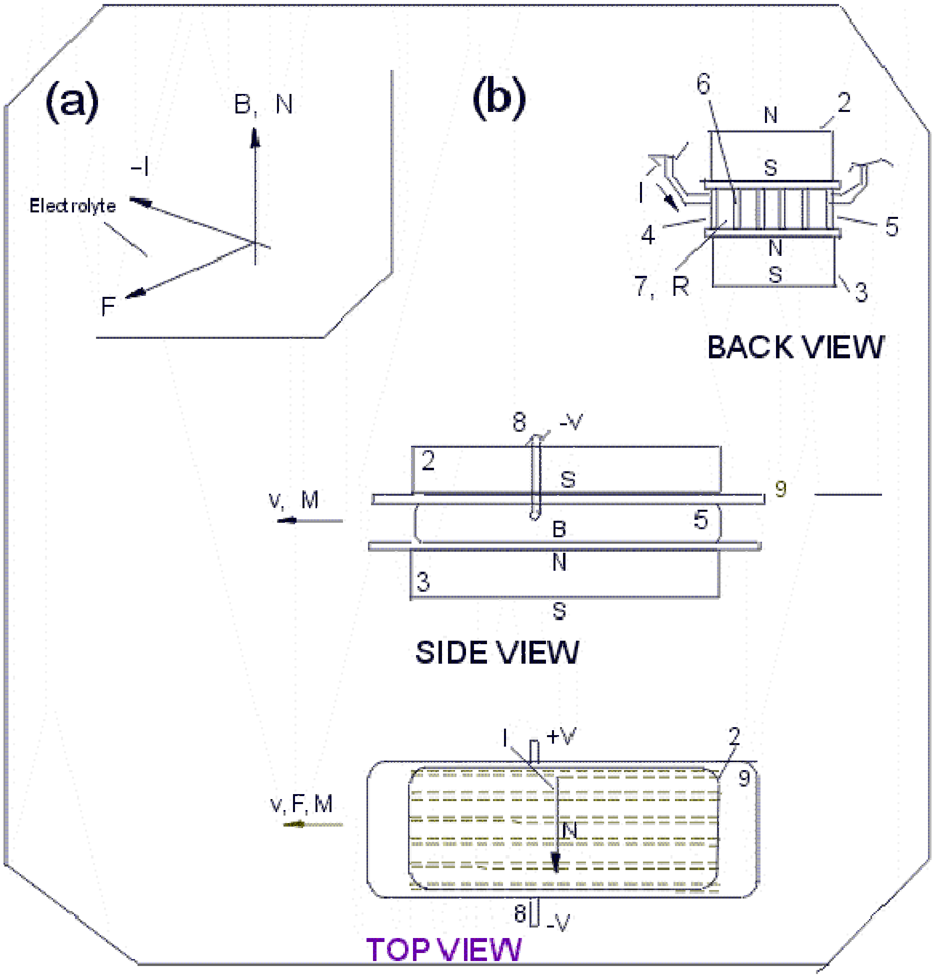


Figure 25. Magneto Hydrodynamic Propulsion

This kind of propulsion has been analyzed and studied in several places around the country. [2]To prove that this kind of propulsion is feasible, MITSUBIHI constructed a boat, which was expected to reach 200 kms/hr, but only reached 15 kms/hr [3]. This test stated that the power conversion is pretty low, meaning that this technology needs more development before being a serious consideration as propulsion option for SABR, and as such was not chosen for our design.

2. Water Jet Propulsion

Water Jet propulsion is a kind of propulsion created by inducting water through inboard pumps and ejecting it aft with an increase of momentum [4]. The force and acceleration experienced by the boat is determined by the mass of water the drive can impel, and the velocity of mass of water on exiting the water jet propulsion system. The water is forced out of a nozzle, which can be rotated giving thrust in all directions.

To power the water jet, it must be connected to an engine that could be an internal or external engine (gas turbine). One disadvantage is that its maximum efficiency is around 25 Kns [6].

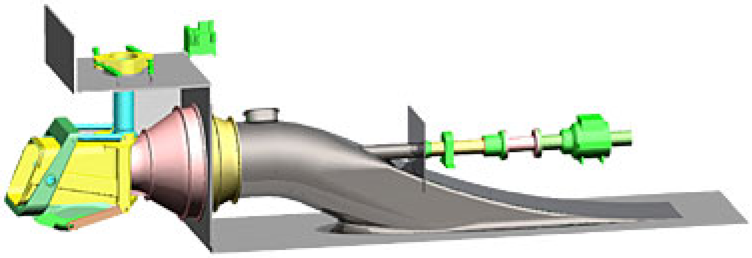


Figure 26. Kamewa VLWJ

It is claimed that this propulsion has several advantages [5]:

I. More safe for divers since less likely to hitting debris in shallow water, or fouling with a loosen ropes.
II. Better Maneuverability, because of vectored thrust, even backwards.
III. Low drag due to no need for steering devices.

Today, it has been operationally proven in a Lifeboat [8] in rescue and towing in a Lake in Finland. For combatant ships, it is used on a Valour Class Meko-200 for the South African Navy [7], which uses a propulsion system based on CODAG-WARP (combined Diesel and Gas- Water Jet and Refined Propeller), capable of propelling a 3500 ton frigate at 27 knots. However, it is not yet suitable for bigger combatants, since the technology feasibility has not been operationally proven, and needs further development. Currently, the U.S Navy and Rolls Royce are working together to develop the AWJ-21, using it in a design case for a 600 foot length ship, 8400 LT hull, which was equipped with four General Electric LM6000 to drive four water jets [9], with a total installed power of 229,320 HP.

Figure 27. Bird Johnson AWJ-21 (Rolls Royce)

3. Propulsion Pod

This propulsion system is a derivation of older "steerable" systems, like the ones used in tugs and small patrol boats. In order to save space, an electric motor was included inside the thruster hub to directly drive the propeller. With that concept, we can eliminate all mechanical items like reduction gears, driving shafts, support bearings, stern tubes and rudders.

Figure 28. View of "MERMAID" concept

The concept invokes several advantages like:

Compact and reduce weight, due the absence of mechanical devices. This reduction in engine's room sizes gives more flexibility to internal layout and increase cargo spaces (payload).

The absence of rudders reduces drag and allows propeller to be fitted further aft. Due to the capability of turning pods in all directions, increase maneuvering characteristics, even astern.

Modularization of propulsion system will change assembly in building process, because they can be installed late in building process, saving costs.

It has been I operation since 1999 in "Queen Mary" and some other big Ferries. [10]

However, podded propulsion has had some issues on some vessels. A couple of Cruise Liners reported suffering leaking through seals and also reported bearing failures, requiring emergency dock periods to fix the systems.

b. Selection Process

For the selection of the most suitable system, a Matrix was used with a scaling system, from 4 for the best to 1 for the worst, considering the given factors:

Technical feasibility: Since both the water jet and podded propulsion are proven systems, both of them get the highest grade. On the other hand, due is pretty low energy conversion and need of further development, the MHD was graded at the lowest.

Weight & Volume: Due to the need to increase payload, mechanical devices like shafts and reduction gears should be eliminated. Due the outer layout of podded systems and regarding the amount of turbines needed for water jet systems [9], the highest grade was awarded to podded propulsion.

Efficiency: Podded and water Jet manufactures claim high efficiencies for their devices. Since there is not enough literature and model which compare these devices, the same grade was given for both. For MHD, the efficiency is reported as low.

Reliability: The first combatant using a water jet a MEKO-200 for the South African Navy, commissioned in February 2006 [7]. On the other hand, podded propulsion was implemented in 1990, since in 1999 there were many reported major failures using it. Since reported failures were properly solved and no new failures reported, the podded propellers were assigned the highest grade.

Coverage Area: Since a molten salt plant reactor was selected as a prime energy source, this requirement was discarded from the matrix.

Life Cycle Cost and Manning: Since the technology has been feasible for a couple of years, there is not proven experience to compare, thus the reason to assign a medium grade for all choices.

Table 8 lists the values allocated to all three choices and the final values tabulated.

item	weight	MHD		Water Jet		Propulsion POD	
Technical Feasibility	0.15	1	0.15	4	0.6	4	0.6
Weight & Volume	0.15	3	0.45	3	0.45	4	0.6
Efficiency	0.15	1	0.15	3	0.45	3	0.45
Reliability	0.15	1	0.15	3	0.45	4	0.6
Coverage Area	0.15	0	0	0	0	0	0
Life Cycle Cost	0.15	2	0.3	2	0.3	2	0.3
Manning	0.1	2	0.2	2	0.2	2	0.2
Total	1	1.4		2.45		**2.75**	

Table 8. Propulsion Trade Off Analysis Results

The clear winner was POD Propulsion. There are some additional advantages that were not included in the decision process. First of all, podded propulsion can incorporate itself into an all electric ship and also standardizes technical training. Furthermore, due to the years of development, podded propulsion is a more mature and operationally proven technology as compared to Water jet.

c. Propeller Selection

Considering that the Podded Propulsion system was selected due to major advantages over other choices, it was then necessary to calculate the best suitable propeller for use. For that purpose, two programs were used: AUTOPOWER and MATLAB CODE. After the Hull resistance was established, AUTOPOWER was used to calculate the necessary Brake Horse Power needed to propel the ship for Nozzle propeller. The program gives the best results considering the limitation for draft. MATLAB CODE was used to calculate the B-Series, using several iteration for blades, diameter and area ratios in order to get the higher open water efficiency and the results compared with results using AUTOPOWER.

In order to be consistent with both methods, the HOLLTROP method was used [11] considering the following factors extracted from AUTOPOWER:

Wake fraction: 0.067

Thrust fraction: 0.073

Hull Efficiency: 0.994

Rotative Efficiency: 0.943

Shaft Efficiency: 0.97

Propulsion Allowance: 20% (ref)

After all iterations the results are:

TYPE	Diameter (ft)	P/D	Area Ratio	Open Water Efficiency	Method
Kd-5-100 ln 33 nozzle	16.79	1.8	1	0.747	AUTOPOWER
Ka-4-70 ln 37 nozzle	11.63	1.498	0.7	0.587	AUTOPOWER
Ka-4-70 ln 19 nozzle	10.52	1.278	0.7	0.610	AUTOPOWER
B-Series 5 blades	17	1.4	1	0.642	MATLAB CODE
B-Series 5 blades	16.5	1.4	1	0.640	MATLAB CODE
B-Series 5 blades	16	1.4	1	0.637	MATLAB CODE
B-Series 5 blades	15.58	1.3	1	0.623	MATLAB CODE
B-Series 5 blades	16	1.3	0.85	0.639	MATLAB CODE
B-Series 5 blades	17	1.4	0.85	0.660	MATLAB CODE
B-Series 4 blades	16	1.4	1	0.621	MATLAB CODE
B-Series 4 blades	16	1.4	0.85	0.647	MATLAB CODE

Table 9. Propeller selection

Considering the higher open water efficiency, Kd-5-100 ln 33 Nozzle propeller was selected. This is Ducted Propeller with decelerating nozzle, 5 blades, area ratio of 1.0, diameter of 16.79 ft, and open water efficiency of 0.747. With that value for efficiency, the BHP total was drawn in a curve; the BHP considering a 20 % allowance; and the necessary Electrical input for an efficiency of 0.994 for a Homopolar Motor. Results can be seen in the curve below.

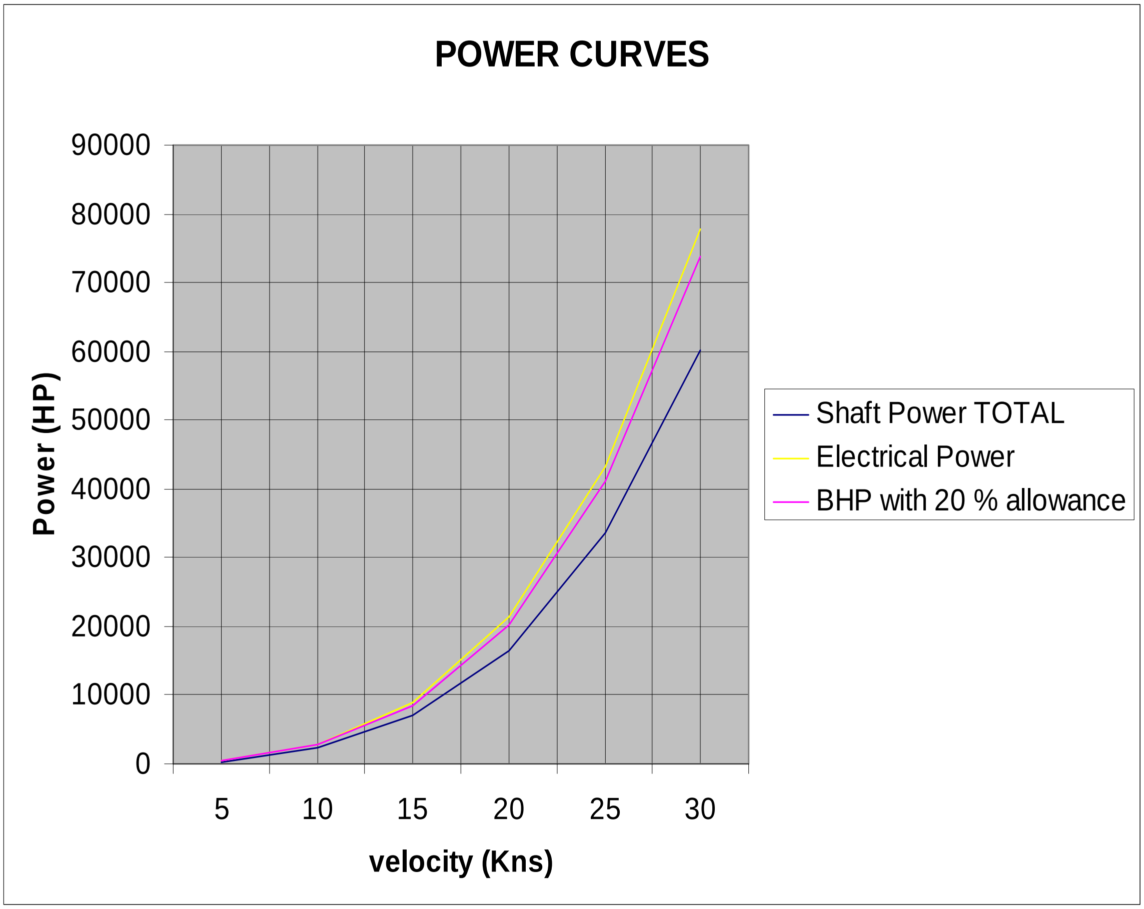


Figure 29. Power Curves

6. Engineroom Design and Weight Placement

Because of the detailed advance work done in conjunction with NASA, all the major components of the ship's power plant were identified early in the design process. The weights, volumes and quantities of the machinery were defined during the initial power plant layout. This knowledge allowed precise placement within the hull, which contributed to a more accurate weights and centers estimate (discussed in detail later).

One of the largest hurdles to overcome was the distribution of power to the railguns. Due to the large magnitude of the currents going to the guns, the need to minimize the distance from the pulse alternators to the guns was a driving factor of the machinery space layout. The helium gas turbines, electrical generator sets, and pulse alternators were placed in that sequence in order to best facilitate power distribution.

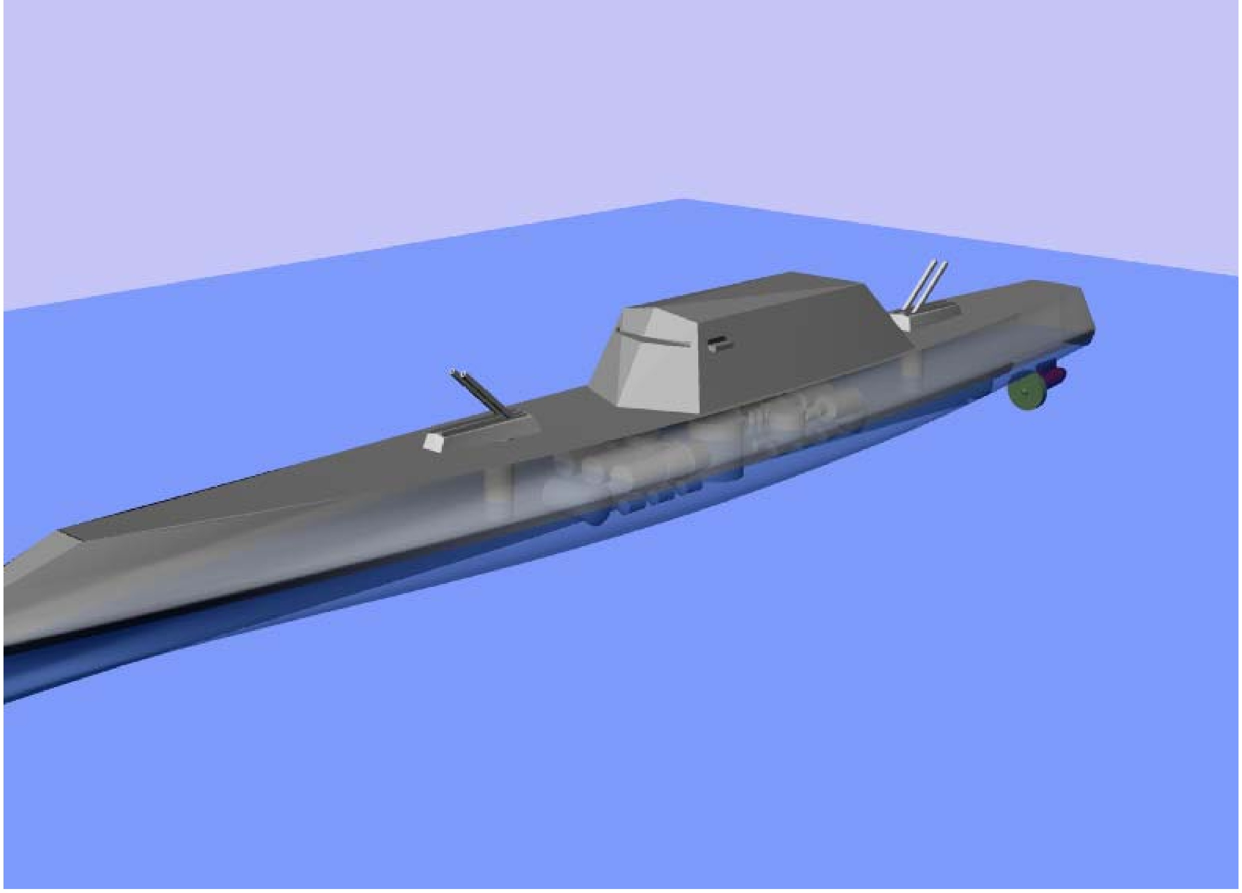


Figure 30. Transparent hull revealing the location and layout of the machinery spaces

There is one central reactor space that provides heat (power) to a forward and an aft engine room. The two engine rooms are mirror images of each other, reflected about the reactor space. The reactor space was located so that its forward bulkhead was on the ship longitudinal center of buoyancy. This was done so that in the event of an catastrophic failure, such as a mk 48 torpedo hit, if the ship was stressed enough to break in half, the most likely breaking point would not be in the reactor space.

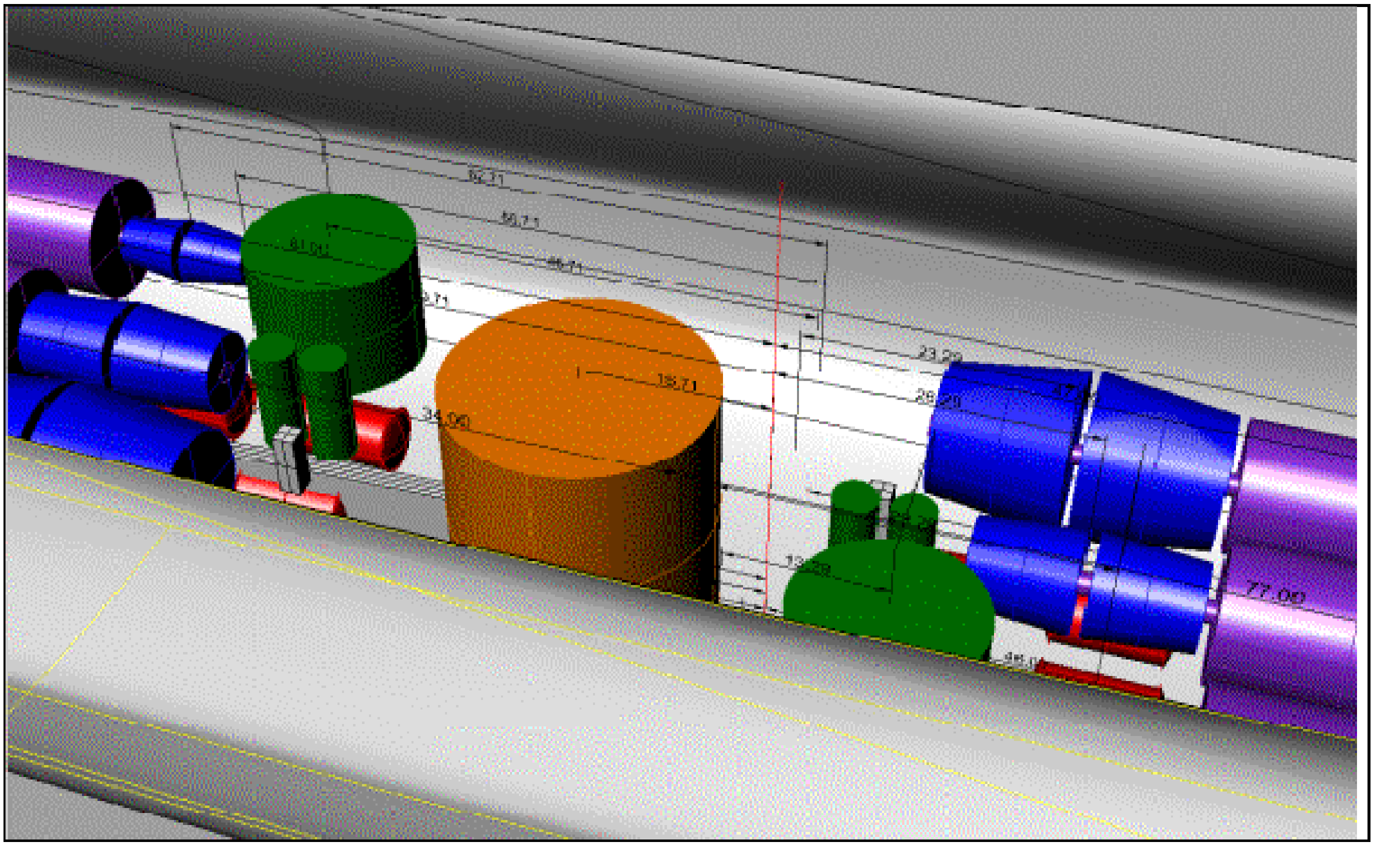


Figure 31. Positioning major machinery for weight estimation

7. Weight Estimation

a. Center of Gravity Estimation

The model developed for the calculation of the longitudinal (LCG), transverse (TCG), and vertical (VCG) centers of gravity utilized the same format for the weight estimation. The components were broken down into the traditional group format and the positions were recorded in an Excel based spreadsheet. The center of gravity estimation was built within the weight estimation model. This allowed the centers calculations that were dependent upon weight to be interlinked with the weight calculations to maximize efficiency. With this set up, if there were any design changes the centers estimation model would update along with the weight estimation.

The list of components was expanded to account for duplicate components. For example, generator was listed six times because, although the generators are all the same weight, they are placed in different positions throughout the ship design. Minor components such as stanchions or lighting fixtures were not specifically placed within the design; therefore the locations for such components were designated as the center of buoyancy, provided by the hullform design.

Once the individual component locations were designated, the center of gravity for each group was calculated by determining the moment contribution for each component. The LCG was calculated by multiplying each components weight by their position relative to the longitudinal center of buoyancy, and dividing by the total weight of the ship. The TCG was calculated by multiplying each components weight by their position relative to the centerline, and dividing by the total weight of the ship. The VCG was calculated by multiplying each components weight by their position relative to the keel, and dividing by the total weight of the ship. This provided an estimate of the individual contribution of each component to the centers of gravity.

To determine the final VCG, TCG, and LCG each component’s contribution was summed within the group. Then the centers of gravity for the groups were summed to produce the centers of gravity for the entire design. The complete set of calculation tables has been included in Appendix V. The results of these calculations are shown below.

GROUP	Center of Gravity		
	Vertical	Transverse	Longitudinal
100	8.50	0.00	2.01
200	1.60	0.00	-3.00
300	1.68	0.00	-0.60
400	0.55	0.01	-0.30
500	0.93	0.00	1.04
600	1.24	0.00	0.00
700	1.30	-0.01	0.55

Center	Reference	Value
VCG	Above Keel	15.80
TCG	From Centerline	0.00
LCG	From Oy	-0.30

Figure 32. Center of Gravity Calculations

b. Weight Estimation

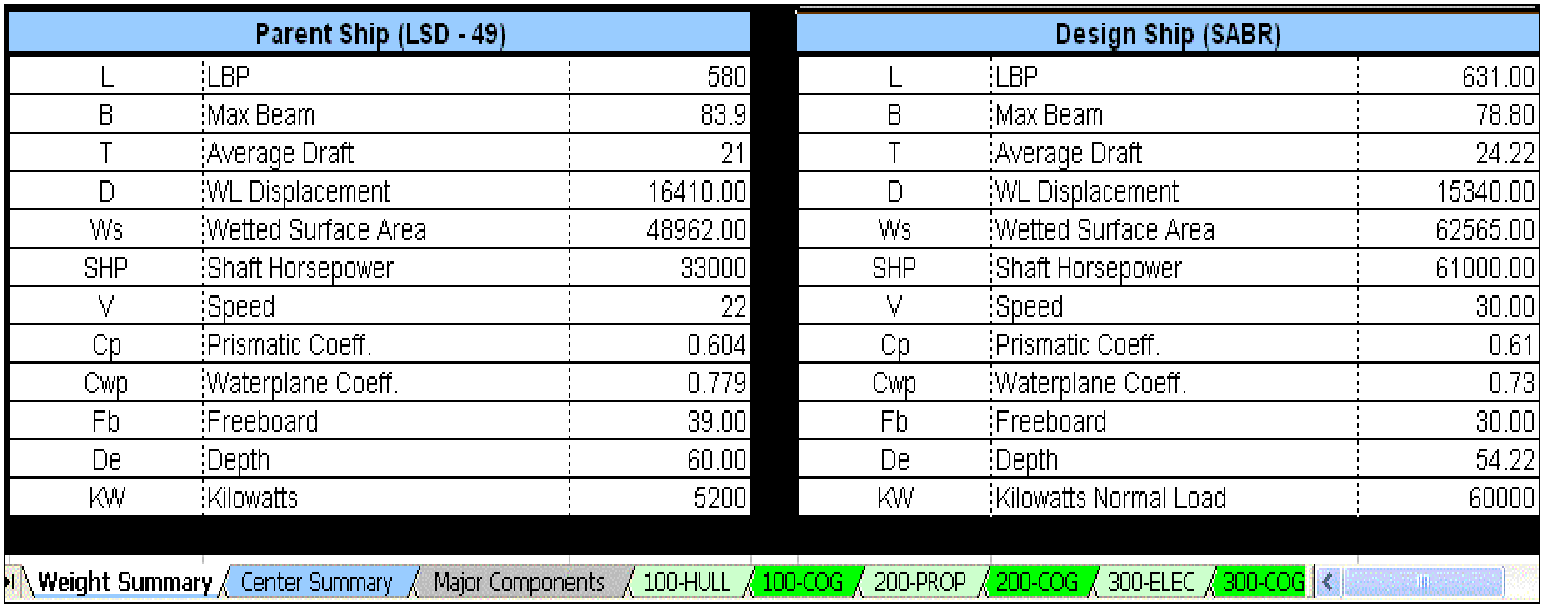
The initial weight estimation for SABR was extrapolated from the output of the MAPC (Maritime Applied Physics Corporation) program which based its calculations on a given set of initial design requirements. This initial calculation provided the characteristics needed for the conceptual design. Following the conceptual design, it was determined that a more precise means of weight estimation had to be utilized.

The necessity for refined ship weight estimation drove the design group to a much more accurate weight estimation model based on the Parent Ship Weight Estimation

Method. The Parent Ship Method uses ratios between conceptual design characteristics and the known characteristics and component weights of a “parent” ship, which is already in production, in order to predict the platform’s design weight with greater accuracy. The detailed individual component weight estimates were broken down into the traditional group format.

100 - Hull Structure
200 - Propulsion
300 - Electric
400 - Command and Surveillance
500 - Auxiliary Systems
600 - Outfit and Furnishings
700 - Armament

The LSD-49 Harpers Ferry Class amphibious ship was adopted as the “parent ship” due to the similarities in displacement, length, beam, draft, and prismatic coefficient relative to the conceptual design. The following design and parent ship characteristics were used to develop various ratios:



Parent Ship (LSD - 49)

L	LBP	580
B	Max Beam	83.9
T	Average Draft	21
D	WL Displacement	16410.00
Ws	Wetted Surface Area	48962.00
SHP	Shaft Horsepower	33000
V	Speed	22
Cp	Prismatic Coeff.	0.604
Cwp	Waterplane Coeff.	0.779
Fb	Freeboard	39.00
De	Depth	60.00
KW	Kilowatts	5200

Design Ship (SABR)

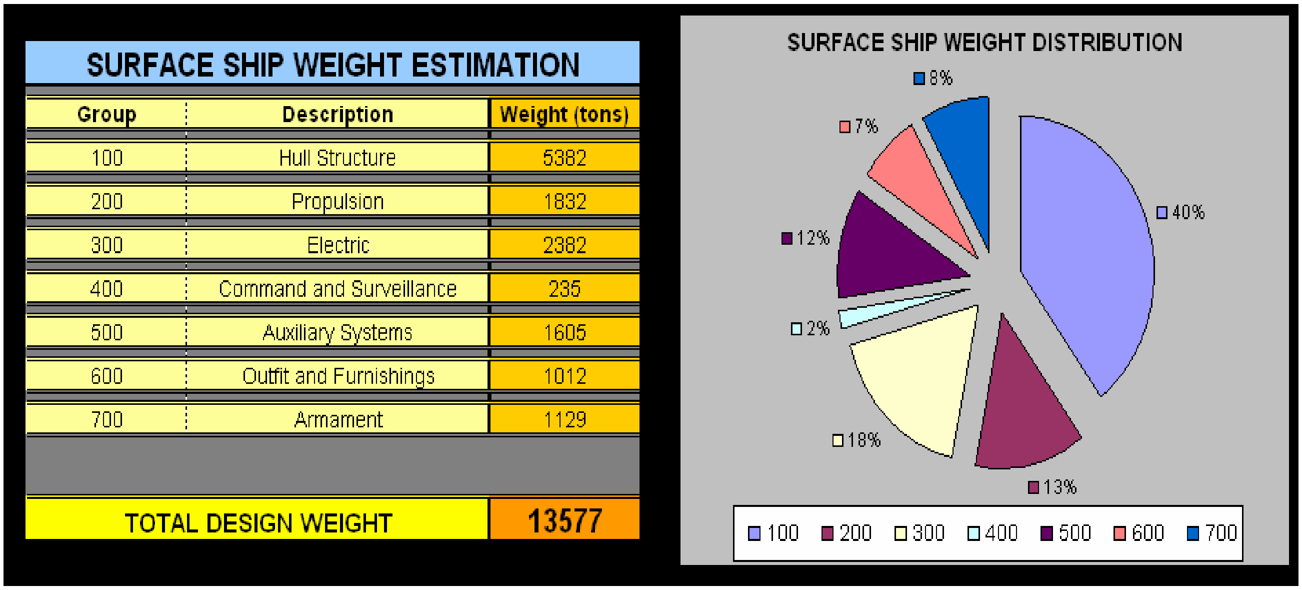
L	LBP	631.00
B	Max Beam	78.80
T	Average Draft	24.22
D	WL Displacement	15340.00
Ws	Wetted Surface Area	62565.00
SHP	Shaft Horsepower	61000.00
V	Speed	30.00
Cp	Prismatic Coeff.	0.61
Cwp	Waterplane Coeff.	0.73
Fb	Freeboard	30.00
De	Depth	54.22
KW	Kilowatts Normal Load	60000

Figure 33.   Parent Ship/ Design Ship weight comparison

The ratios were used in many different calculations to obtain weight estimates of components that would otherwise be extremely difficult to obtain.

All calculations were executed in an Excel based model which slaved each ratio and weight estimation formula to the original characteristic breakdown shown above. This setup was imperative in order to allow for design flexibility while generating the model and greatly increased efficiency when design changes had to be made.

The only differences between the Parent Ship Method and the technique used by the design group were that the SABR weight estimation model included additional ratios and a section for the manual input of major components. Additional ratios were needed specifically for the group 100 components (hull structure). If the group was able to determine a major components weight such as the nuclear core, pulse alternators, gas turbines, propellers, etc, the actual weight of the component was input into the model rather than using the formula outlined by the Parent Ship Method. The manual input of actual component weights increased the accuracy of the weight estimation beyond the completely formula based Parent Ship Method. The results are as follows:



SURFACE SHIP WEIGHT ESTIMATION

Group	Description	Weight (tons)
100	Hull Structure	5382
200	Propulsion	1832
300	Electric	2382
400	Command and Surveillance	235
500	Auxiliary Systems	1605
600	Outfit and Furnishings	1012
700	Armament	1129
	TOTAL DESIGN WEIGHT	13577

Figure 34. SABR ship Weight Estimation

The model was able to refine the weight estimation by almost 2000 tons relative to the initial displacement estimate provided by MAPC. The complete set of calculation tables has been included in Appendix ___.

The development of a more precise weight estimation tool contributed beyond a more accurate design weight. The accuracy of the estimate contributed to higher quality centers calculations which produced higher quality resistance, seakeeping, maneuvering, and damage stability calculations. With the development of this model, additional iterations through the design spiral can be executed with much greater efficiency.

6. Damaged Stability

Once the engine room design was complete, watertight bulkheads could be placed around the equipment and floodable length could be determined. The requirements described in the U.S. Navy Design Data Sheet DDS 079-1 "Stability and Buoyancy of U.S. Naval Surface Ships," (REF 12) were used as the minimum threshold standard for stability. In section 2.5.3.3.4.1.1 it states that the criteria for new designs of combatants that are greater than 300 ft and do not have without side-protective systems, is that they shall be able to withstand, as a minimum, "rapid flooding from a shell opening equal to 0.15 LBP at any point forward or aft." For this design, that means that the ship needs to be able to survive a longitudinal shell opening of about 95 feet in length.

In order to validate this requirement, the locations of the watertight transverse bulkheads were graphed on top of the floodable length curve generated by GHS. Taking into account the different permeability of each space, figure 23 shows that the design meets DDS 079 0.15 LBP requirement and it also can be said that the ship is built to a 3-compartment standard. This means any three contiguous spaces can be completely flooded and the ship will not sink below the margin line. The margin line in this case is defined as 3 inches below the upper surface of the highest continuous watertight deck.

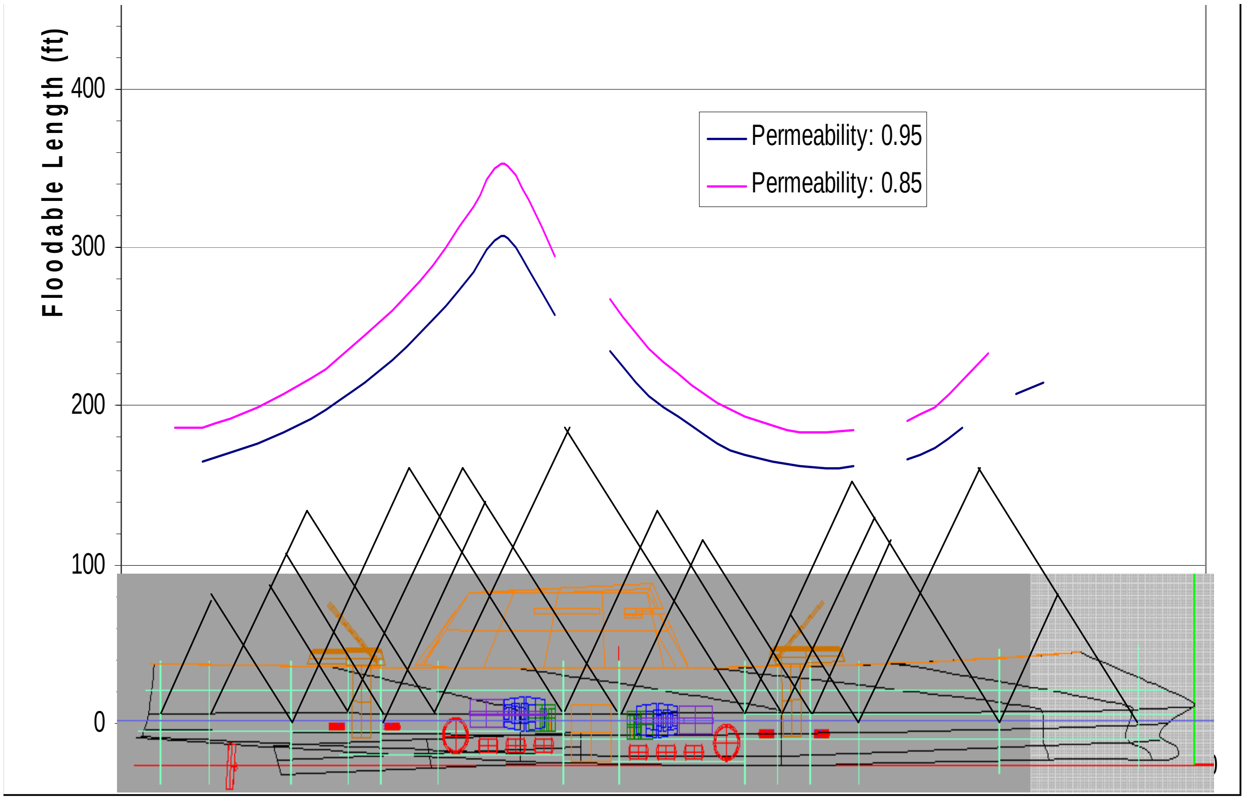
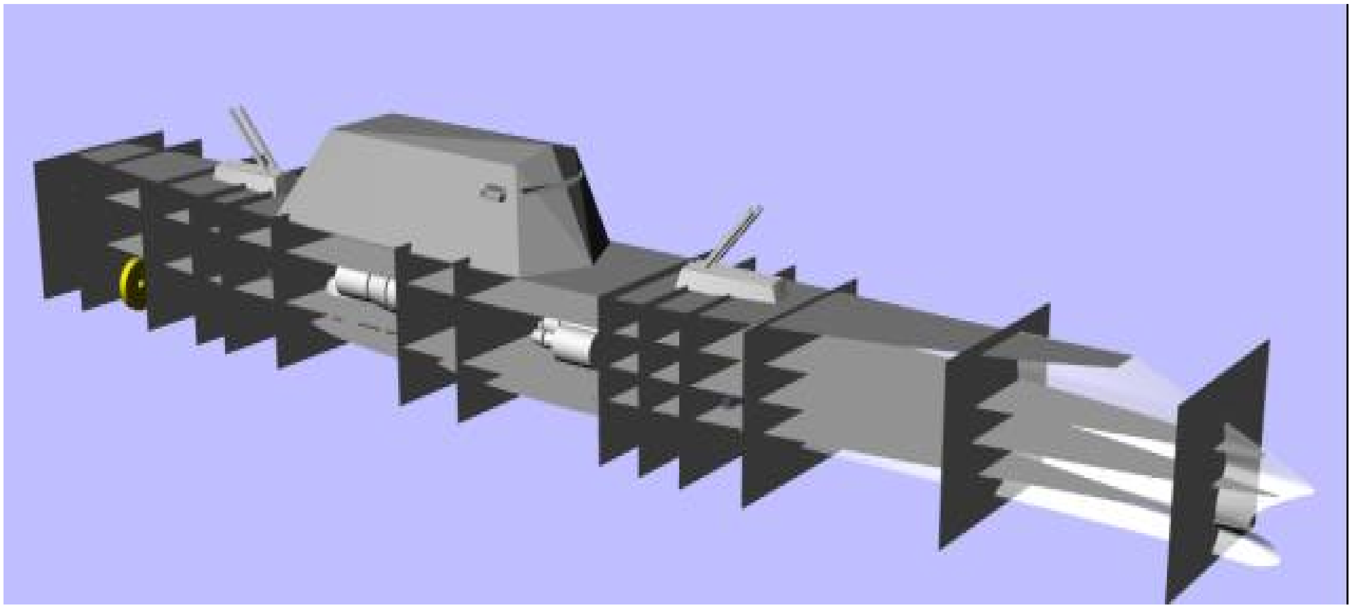


Figure 35. Plot of floodable length with the ship's watertight bulkheads overlayed.

The good floodable length characteristics are a byproduct of the work done in laying out the machinery spaces to minimize power distribution distances. By placing the bulkheads where they were required to separate machinery components, the design also became very resistant to flooding. In other words, there was no additional expense in achieving the higher than required damaged stability characteristics. However, an added benefit can be realized in reduced manning for damage control.



Bulkheads also serve as primary structure surrounding the railgun mounts and separate the mechanical and electrical portions of the railgun system.

7. Intact Stability

Once the weight estimate was complete (the location of the center of gravity defined by the parent ship technique, discussed earlier) the cross curves of stability and the ship's righting arm were computed.

8. Structural Design

Once the initial stages of the hull design are complete, the next necessary step in refining the ship's estimated displacement is to do a preliminary structural design. This design includes choosing the materials to be used in different parts of the ship's structure. These choices are made based primarily on material: loading, strength, weight, and cost. Table 10 summarizes the structural component choices made for the SABR design.

Table 10. Structural Material summary

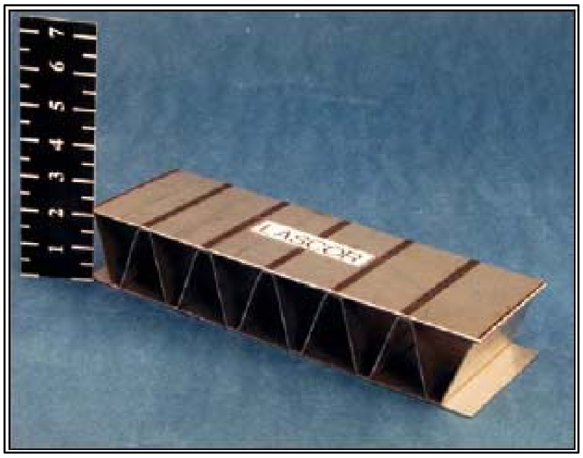
Note: Green shaded blocks below denote advanced (non-standard) materials.

Structure	Structural Element	Design Material	Advantage
Primary	long'l girders, keelsons, transverse frames	steel (HSLA80)	stiffness(reduce deflection, whipping), ease of construction, low cost
Secondary	deckhouse, bulkheads, machinery foundations	Carbon composite	35-50% weight savings, low thermal conductivity, lower life-cycle costs, optimize complex geometries
	decks	laser-welded corrugated core (LASCOR)	20-50% weight savings, increased stiffness, reduced assembly and fit-up costs, thermal and vibration insulation
Tertiary	deckhouse plating	Carbon composite	35-50% weight savings, low thermal conductivity, lower life-cycle costs, integrated antennae structures
	hull plating	Steel (HSLA80)	stiffness (reduce deflection, whipping), ease of construction, low cost

Primary ship structure is made up of elements such as longitudinal girders, keelsons, and transverse frames. These elements undergo the largest loads and must have the highest stiffness characteristics in order to control the hogging and sagging deflections of the hull. These loads may be both static (based on loading or grounding) and dynamic (as encountered during any significant seaway) so the material must have good fatigue characteristics and be able to resist hull girder bending. Because of the length of the SABR design, the structure will undergo large bending moments.

Steel was selected to be the material for the primary hull structure. Its advantages include good stiffness qualities (which will reduce deflection and whipping), ease of construction and relatively low cost. Specifically, high strength low alloy (HSLA) steel was chosen. HSLA steels are a group of low carbon steels that utilize small amounts of alloying elements to attain yield strengths in excess of 275 MPa in the as-rolled or normalized conditions. These steels have better mechanical properties than rolled carbon steels, largely by virtue of grain refining and precipitation hardening. Because the high strength, of HSLA steels can be obtained at lower carbon levels, the weldability of HSLA steels is generally better than that of mild steel. This will further reduce construction costs.

The secondary type of ship structure includes items such as: decks, bulkheads, deckhouse, and machinery foundations. For these areas, more advanced materials have been selected for the SABR design. In the design of these components, a significant weight savings can be realized without sacrificing any strength.



For the interior decks, a sandwich metal structure called LASCOR (laser-welded corrugated core) is used. As described in ref 13, this consists of two thin face sheets of metal joined together by a corrugated core. (See Figure at right) The separation of the face sheets provides high bending stiffness at low weight. Stainless steel LASCOR panels have been used on Navy ships for over a decade to save weight for platforms, hangar doors, and deckhouse enclosures.

There are several advantages of LASCOR over conventional steel:

1. Compared to conventional steel structures, metallic sandwich structures have reduced weight and increased stiffness. They have a weight savings of 20 to 50 percent over conventional steel construction.

2. They result in reduced fabrication and outfitting costs. LASCOR panels are 20 percent cheaper to build and install than steel grillages. They have high dimensional stability that helps reduce assembly and fit-up costs in the shipyard. Outfitting of distrubutive systems and installation of insulation costs are also reduced because of the smooth surfaces resulting from the elimination of most of the stiffeners.

3. The elimination of stiffeners on decks and bulkheads increases the usable volume within the total ship.

For the secondary structure other than the interior decks (deckhouse, bulkheads, and machinery foundations), carbon fiber composite was selected for the construction material. Composites have been used as the primary structure in small vessels for many years. Advances in technology and reductions in cost have made then a good alternative for secondary components as well.

Figure 21 from ref 13 is a summary of the composite

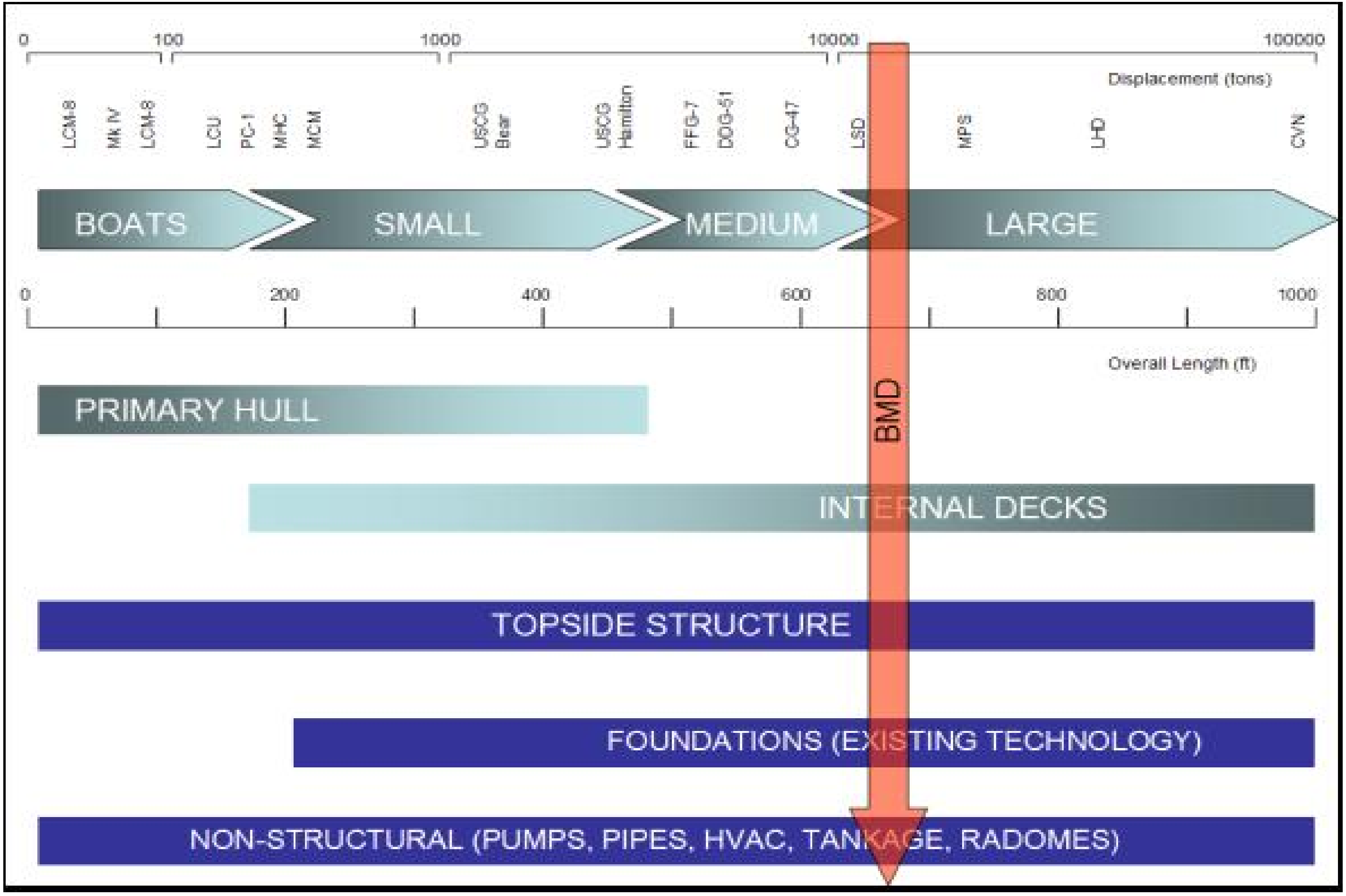


Figure 37. Composite Applications

Composites offer many advantages to standard metallic structures. Below is a summary of the advantages as detailed by NSWCCD in ref 13

1. They are light weight. Weight reductions of 35 to 50 percent, compared to steel, can currently be realized for secondary structures made of E-glass composite laminates. Since secondary structures comprise a significant fraction of the total structural weight, this

translates to a total ship weight savings of about 8 percent of a large vessel (nominally 800 feet long).

2. Composite structural elements have better dimensional stability than steel elements. This is an aid to the fit-up and assembly in the shipyard, and results in lower fabrication costs and better overall dimensional tolerances.

3. They have reduced noise and vibration properties. Composites have inherently better damping and compliance than metallic structures. They also have the potential to be adapted into smart structures, i.e. structures that can monitor and/or adapt their properties in service.

4. Fires are more easily contained in composite structures because of their low thermal conductivity. The cores in composite sandwich panels are good thermal insulators.

5. The designer has increased flexibility to tailor the composite structure to the particular need. Complex geometries can be designed to optimize the strength and stiffness, or to enhance the producibility by minimizing the number or location of joints.

6. Composites have lower life-cycle maintenance costs than steel structures. Fewer inspections, less painting, and fewer repairs are needed over the life of the ship because of the non-corrosion and reduced fatigue damage of composites over metallic structures.

Tables XX through XX, in Appendix X, present the relative weights of panels having equal stiffness and equal strength under both in-plane (axial) and bending loads. Composites are more advantageous than steel or aluminum when compared on an equivalent strength basis rather then on stiffness basis.

9. References

[1] http://www.science.radioelectronics.biz/magnetohydrodynamics/magnetoWaterPropulsion

[2] AIAA 2003-4442 July 2003, "Overview of Electric Propulsion Research in U.S. Academia".

[3] Kissel, Joe, "Magnetohydrodynamics: Motors without moving parts," (2005): 20 Aug. 2006< http://itotd.com/articles/500/magnetohydrodynamic-propulsion>.

[4] Fujisawa, Nobuyuki. "Measurement of Basic Performances for Water jet Propulsion Systems in Water Tunnel"

[5] http:// www.ultradynamics.com/sections/educational

[6] "Water Jet Propulsion Engines," July 2006, available http://www.ship-technology.com/contractors/propulsion/waterjet.html

[7] http://www.naval-technology.com/project printable.asp

[8] http://www.pitkajarvi.net/jetrew.htm

[9] "Marine Design Case Study", by Center for Commercial Deployment of Transportation Technologies (CCDoTT)

[10] "Podded Propulsion: Its future in Marine Transportation", by Dr. Arun Kr. Dev.

[11] Principles of Naval Architecture Vol. II

[12] Design Data Sheet (DDS 079-1), "Stability And Buoyancy Of U.S. Naval Surface Ships." Version 1.21, 16 Oct 03.

[13] "High-Speed Sealift Technology Development Plan ," Carderock Division - Naval Surface Warfare Center, NSWCCD-20-TR-2002/06, May 2002, pg 53-54.

B. **POWER GENERATION**

1. Introduction

2. The SABR Implementation of the Liquid-Fluoride Reactor

The initial estimation of the liquid-fluoride reactor model was developed in August 2006 by the SABR team with the assistance of Dr. Joseph Bonometti, the Michael Smith NASA chair professor with the Space Systems Academic Group at Naval Postgraduate School, and the assistance of Kirk Sorensen from NASA Marshall Space Flight Center. Over the course of several days, the group worked together to come up with design and operation estimations.

As previously discussed, this particular liquid-fluoride reactor is patterned after the work that was conducted at Oak Ridge National Laboratories from 1951 until 1976. This work included the design, construction, and operation of two liquid-fluoride reactors: the Aircraft Reactor Experiment (ARE) and the Molten-Salt Reactor Experiment (MSRE). The SABR Reactor is similar to the MSRE design in the composition of the molten salt. The SABR salt composition is a mixture of enriched lithium fluoride (7LiF) and beryllium fluoride (BeF2), referred to as "FLiBe", used due to the observed superior neutronic and operational performance in extensive study and test at ORNL.

There are several key differences between this particular reactor and other conventional (solid-core) reactors. The first and foremost difference is that the nuclear fuel in the core is a fluid instead of solid, resulting in a number of operational advantages. One ability that a fluid-fuel reactor allows is on-line refueling and reprocessing, since the fuel/salt mixture can be easily used as a transfer medium for the addition of fuel or the removal of waste products. The second ability of the fluid-fuel reactor is the advantage that drain ports can be built which allow rapid flow of the fuel into a non-critical configuration for storage or when damage renders the reactor unsafe to operate. This passively safe option is an advantage confirmed in a paper by recent nuclear experts [1].

There are two salt compositions in the core. The first is the "fuel salt", containing uranium-233 tetrafluoride (UF4) dissolved in "FLiBe" (LiF-BeF2). The second is the "blanket salt", a similar mixture of thorium tetrafluoride (ThF4) dissolved in FLiBe.

The following design details were provided by Kirk Sorensen, author of the "Energy From Thorium" Blog:

"The configuration envisioned for the SABR reactor would introduce fuel salt axially into the reactor vessel, and then the fuel salt would spiral outward toward the periphery of the core in channels similar to those seen in a spiral heat exchanger. In the interstitials of the spiral channels, axially-oriented rods of graphite would serve as a neutronic moderator, and blanket salt would circulate throughout the interstitial region. Within the blanket salt, roughly half of the neutrons produced in fission would be absorbed in the thorium. This would lead to the production of protactinium, which would be isolated and allowed to decay to uranium-233. The uranium-233 would then be introduced into the core salt and thus continuously refuel the core. The simplicity of this fuel cycle is driven by the basic chemical advantages of the fuel and blanket form, namely liquid salts.

The fuel salt Uranium fission would provide heat to the salt which is then exchanged with a coolant salt which consists of "FLiBe" without actinides added, used as a heat transmission medium and a radioactivity isolating agent. This coolant salt would then be used to transfer heat out of the core to heat exchangers for the closed cycle Helium Gas Turbines, discussed in the next section. The utilization of a coolant salt loop prevents the high-pressure helium from the gas turbines from entering the core vessel, and prevents radioactive particles from leaving the core vessel, allowing the core to operate close to atmospheric pressure and preventing unnecessary radiation exposure.

A "loss-of-coolant" accident is a very different event in a liquid-fluoride reactor than in a conventional solid-core reactor. In the event of a LOCA, the reactor's power would shut down naturally from the action of the negative temperature coefficient of reactivity, similar to solid-core reactors. But unlike solid-core reactors, the remaining decay heat generated by fission products could be removed passively by means of draining the core into a different configuration. This passive drain is accomplished by means of a "freeze plug" in the base of the vessel. If all cooling and power fails, then the gas blower that maintains the “freeze” on the plug stops, the plug melts, and the core drains into this passively cooled configuration. There is no parallel for this in a solid-core reactor, which is one of the reasons a multiplicity of emergency core cooling systems are employed to keep cooling water on solid-core fuel elements at all times. This reactor does not require these engineered safeguards, instead using a simple and fail-safe core cooling system.”[2]

The estimated weight of the core is 400 Tons, which is the weight of the exchanger, moderator, core and blanket fuel salts, required pumps and shielding. The estimated size for the core (shielding included) will be approximately 300 m^3. These figures were based off core power densities and sizes that were designed at ORNL in the Molten-Salt Reactor Program. Anticipated improvements in core design may yield even better performance as models are checked and refined.

3. Generators

4. Pulse Alternators

5. Electrical Distribution

C. DAMAGE CONTROL

1. Introduction

The SABR ship is designed for reduced manning. Since our main mission is to counter ballistic missile threats, with limited involvement with emergency relief, naval gun fire support, and other surface ship missions, there is no need for a large crew. With this in mind, however, the ship must have the ability to perform its mission effectively while at the same time controlling and restoring battle damage throughout the ship. To do so, state of the art, proven damage control systems must be in place. One such system currently being tested by and managed by the Naval Research Lab's N Technology Center for Safety and Survivability is the damage control- automated reduced manning, DC-ARM.

2. Damage Control – Automated Reduced Manning

The DC-ARM program is a multi-tiered effort designed to evaluate and demonstrate incremental reductions in damage-control manning, corresponding to increases in automation and doctrine improvement through scientifically based experimentation. [1]

The technologies associated with DC-ARM include:

a. Water mist for fire suppression and containment.

b. Sensors for fire detection and fire characterization.

c. Firemain distributed controls (Smart Valves) for robust, survivable isolation of firemain ruptures.

d. Smoke ejection systems for clearing smoke

e. Access closure monitoring to improve situation awareness.

f. Video installed in most spaces for compartment monitoring and to reduce investigation work load.

g. Supervisory Control System (SCS) to enable effective situation awareness and overall control of the D.C response.

h. New doctrine developed to integrate with new technologies.

The DC-ARM system begins with sensors placed throughout the ship that monitor everything from smoke and heat levels in a compartment to water levels, feeding that information to computers in D.C. Central so that watchstanders can monitor the status of every compartment on the ship from one central location, with instantaneous input. The sensor input is also re-enforced with video feeds from around the ship; if sensors register damage to a section of the ship, in addition to those compartments lighting up on computerized plotting boards, D.C. Central also gets instant, real-time pictures of the compartments to enhance decision-making. The Supervisory Control System in D.C. Central also give the DCA automated recommendations on how to most effectively deal with the situation, further enhancing the decision making process. [1]

The DC-ARM technology has been tested during demonstrations that included both peacetime fire scenarios and wartime damage scenarios. An anti-ship missile hit was used for the wartime damage scenario and the damage sustained included structural damage, damage to sensors and control systems, major fires, smoke and flooding. Navy sailors actively participated in the damage control scenarios to exercise the DC-ARM systems and reduced manning doctrine in a realistic shipboard damage environment. [1]

The results from the damage control scenarios indicated that the DC-ARM system results in more efficient combating of fires and flooding with reduced manning. More importantly, DC-ARM would enable safer, more cost effective ships to be built, such as the SABR ship. Together with Human System Integration(HSI), the SABR ship of the future will have the ability to conduct its mission effectively and to respond, control, and restore damage throughout the ship very effectively. More detailed information on Human Systems Integration can be found in the Combat Systems Section of this report, Chapter V.

a. Water Mist Fire Suppression System

Water mist technology is based on the use of plain water, discharged at high pressure through special nozzles, resulting in very small droplets, high discharge velocity and good penetration capabilities into fires. The micro-droplets are very efficient in cooling down fires and the fast vaporisation results in oxygen depletion inside fires due to the expansion of the vaporizing water.[2]

As only water is used, the water mist system will not harm personnel located in spaces where activation of the water mist system occurs. One of the main benefits of water mist is the fact that it can be activated the second a fire is detected. Furthermore, there is no need to lose time on evacuating people, shutting off ventilation or closing openings. This immediate activation will keep damage at a minimum. [2]

A water mist system can also be tested at anytime to ensure that it is fully operating. Training to operate the system is easily attainable on board ships. The system has no pressure cylinders to be replenished, so the system is quickly reset after such a test. [2]

A water mist system can be used to protect any space on a ship. One single pump unit can protect living quarters, service spaces, and storage spaces. A single pump can also supply all the machinery spaces. The pump unit can be made shock-proof as well as anti-magnetic, features which are often important on a naval vessel. If redundancy is desired, the system can be fed by two independent pump units. Special units are available to operate without electrical power. [2]

The system has proven its efficiency in more than 30 reported fires, all with a positive outcome. No major damage occurred and the ships could continue their operation more or less without any time lost. In one well documented case, on the world’s at that time largest cruise vessel, an explosive fire caused by a fuel pump failure was extinguished in less than a minute with total damage of only 500 dollars. [2]

Marioff Corporation is the leading supplier and developer of water mist fire suppression systems. They build a HI-FOG high pressure water mist system that is currently the most common water mist system world-wide. More than 700 ships and offshore structures have been equipped with the system. In the very safety conscious segment of passenger cruise vessels, basically every new vessel has been or is being equipped with Marioff’s HI-FOG system. Currently, more than 50 naval vessels are protected by HI-FOG. Marioff’s water mist systems have been tested and proven reliable in more than 30 reported fires. The tests showed that no major damage occurred and the ships could continue their operation more or less without any time lost. In one well documented case on board one of thee world’s largest cruise vessel, an explosive fire caused by a fuel pump failure was extinguished in less than a minute with total damage of only US 500 dollars. [2]

b. Sensors for fire detection and fire characterization

The fire detection system for SABR will provide fast, automated responses by installed systems and also allow for quicker crew response to damage. The following systems will be installed to provide maximum detection capabilities for all types of casualties: smoke detectors, carbon monoxide detectors, fire and flame detectors, a closed circuit television (CCTV) system, heat detectors, smart micro sensors, humidity monitors, and liquid level sensors. Key fire suppression systems can be automatically initiated by preprogrammed system logic. In addition, input to a wireless smart shipboard sensor network will provide continuous updates via webpages and ICAS (Integrated Condition Assessment System). [3]

The ship-wide array of sensors will also provide continuous monitoring of multiple parameters that pose a threat to ship’s integrity and safety of the crew. The detection system and associated wireless network will immediately indicate the precise location of any damage, allowing the ship’s damage control crew to respond quickly. Real time assessment of damage allows the ship’s crew to eliminate the need for investigators to search for and report damage. [3]

Multiple interconnected data networks will be strategically routed throughout the ship with redundancy to increase system survivability. As such, control stations will be located in critical watch station areas, such as the Bridge, CIC, Damage Control Lockers, and Engineering Spaces.

With only one nuclear reactor aboard SABR, much of the damage that would occur during a casualty can be isolated from the rest of the ship as practically as possible. Fire is the most serious threat to the nuclear plant and can be caused by lube oil or explosives that are stored around the ship. To better respond and react to fires, multi-sensor fire detectors will monitor each compartment. Fiber optical or electrostatic smoke detectors, triple wavelength infrared flame, carbon monoxide, CCTV, and high performance optical, or fiber optical heat sensors will detect smoke and fires. These detectors will send information over a wireless network, providing instant real time data to Damage Control Central.

Controlling Shipboard flooding and restoring damage caused by flooding is also very important. As such, there is a need to provide systems capable of detecting and responding to flooding to the maximum extent possible. Therefore, compartments located below the damage control deck will be continuously monitored for flooding by liquid level detectors. Flooding detectors will consist of sensors arrayed from the bilge level to the overhead. The detectors will be located to indicate the presence of liquid at 2 and 6 inches, and at heights corresponding to flooding levels of 10%, 25%, 50%, 75%, and 100%. This information will also aid in the calculation of changes in ship’s stability due to flooding. In addition, all remotely operated valves and compartment accesses will also be monitored for their material condition status. [3]

Although fire and flooding are the most common types of casualties occurring on ships, there is also danger from toxic gases. Sensors will provide instantaneous information to Damage Control stations via the wireless networks. Toxic levels will be known almost immediately, allowing the ship’s crew to know how to isolate adjacent spaces to prevent personnel casualties.

c. Smart Valves

With smart valve technology, sensors in valves can detect sudden changes in flow, and send messages back to Damage Control Central indicating a break and potential flooding. The valves then automatically close or open, isolating the damaged section and rerouting flow so critical systems, such as the firemain system remain fully functional. [1]

d. Smoke ejection system

An improved smoke ejection system (SES) such as the one used on LPD-17 class ships is a viable choice for assisting with clearing smoke in spaces affected by fires. Smoke is a primary concern when trying to put out fires and the importance of clearing smoke quickly can not be understated. As such, using DC-ARM means having a good smoke ejection system on SABR.

e. Access closure monitoring

A number of systems are available to automatically control the opening and closing of accesses. These systems can sense changes in environmental conditions, and respond accordingly while at the same time sending notification to the damage control stations to increase personnel awareness.

f. Video surveillance

A number of digital video surveillance systems will be installed with the ability of displaying real-time data to damage control stations throughout the ship. The benefits of advanced video surveillance systems are numerous to include constant update s of damage, safety to personnel, and recordings of proceedings used for feedback and learning purposes.

g. Supervisory Control System

The SCS is a hierarchical distributed-control system that provides a user interface for displaying D.C. sensor information, pre-hit damage prediction, video, door closure, automated decision aids and automated actuation of D.C. systems. [1] The SCS offers improvements from traditional systems by offering recommendations for making decisions to reduce damage based on information from video, sensors, and detectors. The SCS is beneficial in that you can gather information quickly, review it carefully, and quickly make a decision without the need of human intervention. The whole SCS picture uses the speed of computer processing to gather information and to calculate results, thus greatly improving response time.

h. Doctrine

New doctrine is currently being developed by Office of Naval Research to integrate shipboard damage control procedures with new technologies. The new doctrine will facilitate reduced manning and improved performance.

3. Installed Firefighting Systems

A number of installed firefighting system options are available for SABR. The goal is to choose systems that have low maintenance, are highly automated, and very effective on board a ship such as the SABR model with nuclear material and dangerous explosives on board. The proposed fire suppression systems include: FM-200, carbon dioxide, AFFF, and water mist. Active damage control measures will be required to keep the damage contained and from progressing through out the ship. Fire extinguishing methods include the use of a ship-wide water mist sprinkler system, AFFF flooding, FM 200 system and carbon dioxide flooding. A combinations of the water mist sprinklers, AFFF sprinklers, and CO2 flooding systems will be used to protect machinery spaces and combat systems spaces. All other spaces will be protected by either FM200 systems, AFFF systems, CO2 systems, or a combination of systems. The recommended type of fire suppression systems installed in each type of compartment is shown below in Table 3.

Compartment	FM200	CO2	Water	AFFF
Aux Machinery			X	X
Reactor Room	X		X	X
Magazine Areas			X	X
Elect Equip	X			
xHanger			X	X
xFlight Deck			X	X
CIC		X		
Bridge		X		
Rail Gun			X	X
Berthing			X	
Galley			X	X
Passageways			X	
Paint Lockers		X		
Pump rooms			X	X

AC /		X		X

Table 11. Installed DC Systems

4. Installed Firefighting System Descriptions

The following is a description of the systems that will be installed in the spaces referenced in the previous section.

a. FM-200 Fire Suppression Systems

FM-200 is chemically known as heptafluoropropane, and is a new Halon alternative agent now in use to protect essential applications traditionally protected by Halon 1301. FM-200 has been found to be safe when used around personnel and it also has no ozone depletion properties as its predecessor Halon. Like Halon, the extinguishing agent is typically stored in cylinders or spheres. It is delivered to distribution nozzles through a system piping network. [4]

The FM-200 system operates similar to the Halon system: First, smoke detectors sense the presence of fire in the affected space. Next, the detection and control panel sounds an alarm, shuts down air handlers, disconnects power from the protected equipment, and then releases agent into the protected area. The FM-200 system is very suitable for spaces where a water based fire suppression system is not suitable, such as in CIC, Bridge, and electrical control spaces. [4]

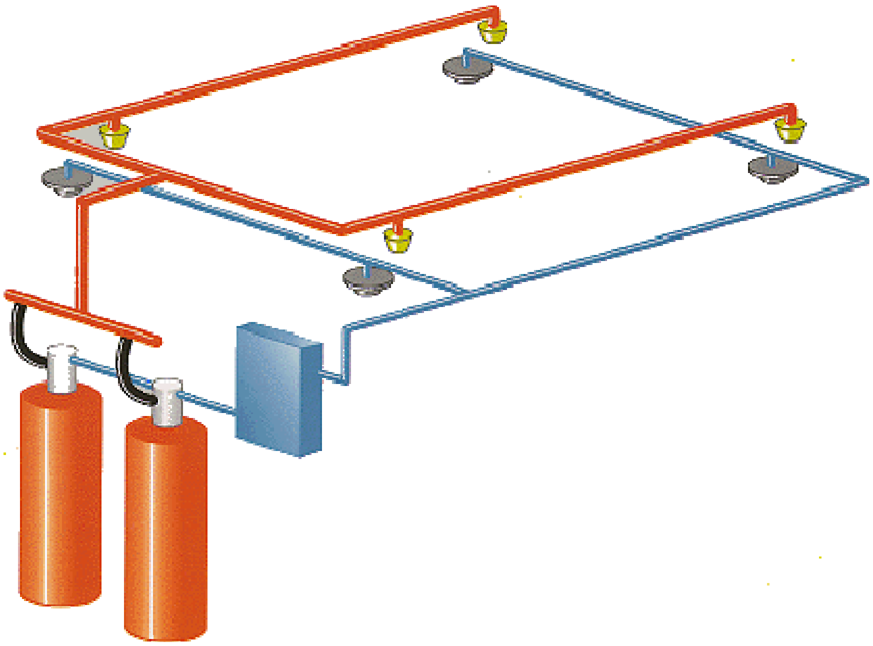


Figure 38. Carbon Dioxide Fire Suppression Systems

Clean agent carbon dioxide systems chosen for SABR will consist of flooding systems, where CO2 is stored in a bank of cylinders and released as needed. Today’s Navy ships are incorporated with these systems in paint lockers, machinery spaces, and magazines, and these systems will be used in a similar manner on board SABR vessel. The main goal of these systems is to suppress or control fires as quickly as possible.

c. Water Mist System

The water mist system was previously described in the DC-ARM section, heading 2. Refer to the DC-ARM section for a detailed description.

d. Aqueous Film Forming Foam (AFFF) Systems

AFFF is still one of the primary agents used on Naval vessels for fire protection. On SABR, AFFF systems will be available for combating fires in almost all spaces where a water based agent is tolerable. AFFF consists of a combination of fluoro-chemical surfactants, hydrocarbon surfactants, and solvents. AFFF works on suppressing 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. [3] AFFF is a very good choice for SABR because it is a low-cost and highly efficient system. Furthermore, automated AFFF flooding systems reduce the need for personnel needed to operate these systems.

5. Chemical, Biological and Radiation (CBR) System

A standard suite of chemical, biological and radiological sensing and protective systems commonly used on today's Naval vessels will be employed in SABR. Table 12 briefly outlines the threats that SABR will likely encounter in the future. It is not likely that ships will encounter a biological attack, and hence the focus of modern and future war ships is the defense against chemical and nuclear attacks , with the nuclear threat being the most lethal and potential threat.

Chemical	Nerve, Blister, Blood, Choking Agents
Biological	Toxin, Bacterial, Viral, Fungal Infection
Nuclear	Blast and Level Radiation

Table 12. Common CBR Threats

a. Chemical Detection Systems

The Improved [Chemical Agent] Point Detection System (IPDS) is a chemical detection system that automatically detects chemical agents through vapors in the atmosphere. The system alerts the crew when chemical agents are detected as being present in the air. It will be externally mounted on the superstructure with control and display units on the bridge and in central damage control stations. [5]

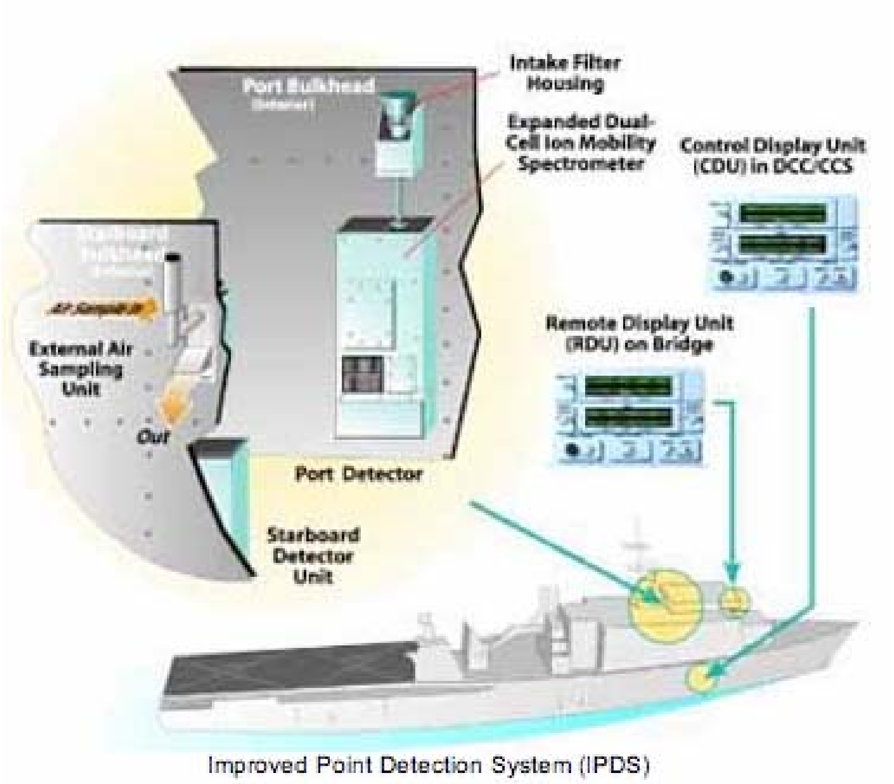


Figure 39. Improved Point Detection System

SABR will also utilize the Chemical Agent Point Detection System (CAPDS). This system is capable of detecting selected chemical agents in vapor form using baffle tube ionization. Samples are collected from the external air, and then the airborne vapor molecules are ionized and collected on a charged plate after eliminating lighter molecules via the baffle structure. When sufficient ion mass is collected, an alarm is sent to the Bridge and the central damage control stations. It will be mounted atop the superstructure as well. [5]

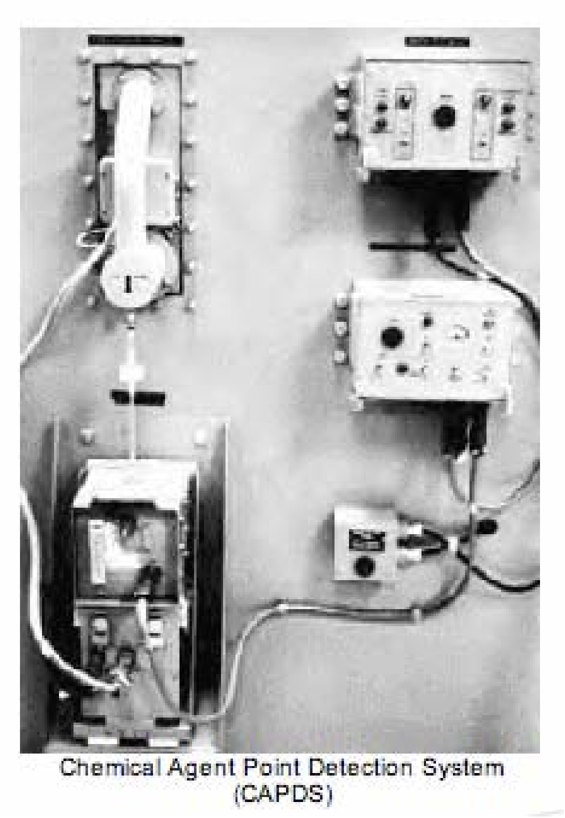


Figure 40. Chemical Agent Point Detection System (CAPDS)

b. Biological Detectors

The Interim Biological Agent Detector (IBAD) is a suitable Biological agent detector capable of detecting, and identifying biological agents, as well as alerting the ship’s crew of the presence of such agents. The IBAD is composed of a particle sizer/counter, particle wet cyclone sampler, and manual identifier. It is likely to be placed in locations above the weather decks with alarms placed on the bridge and in central damage control stations. [5]

Figure 41. Interim Biological Agent Detector (IBAD)

c. Nuclear Detectors

The **SVG2** is a hand-held microprocessor controlled radiation meter, based on state-of-the-art semiconductor technology. It is developed by Bruker Daltonics. And is now commonly known as the Nuclear and Chemical Detection System (NCDS). The SVG2 is equipped with integrated sensors for gamma and neutron radiation detection, an external personal dosimeter and an external alpha-beta-gamma probe. A broad range for gamma-dose rate is covered (10nGy/h-20Gy/h). Newly developed handheld probes complete the modular system of SVG2 equipment. For naval environment a special external gamma-probe can be mounted.

All NCDS components can be connected and controlled by the NC Monitoring Software. Furthermore the instruments can be integrated into a shipboard control and managing system. The NCDS can be used on any type of ship. [6]

Figure 42. SVG2

The **RAID-M 100** is another device made by Bruker Daltomics that is designed as a portable, hand-held device for chemical and radiological detection. It is equipped with a data logging system and provides very low detection limits. The detector is extremely flexible and has been developed for military use, including the Navy. [6]

SABR will also have an installed Ship Countermeasure Wash Down System (CMWDS) to aid in CBR defense. A CMWDS consists of fire-main piping and a series of nozzles that spray salt water onto the weather decks and other surfaces. The film is designed to retard the further accumulation of and facilitate the removal of foreign agents. CMWDS are designed to remove up to 99 % of contaminants.

Figure 43. CMWD System

6. References

[1] "DC-ARM Marks the Wave of future Damage Control," NRL Press Release, 10 March 2002, http://www.nrl.navy.mil/pao/pressRelease [15 Sep 06]

[2] "Marioff HI-FOG Water Mist System," Marioff website, http://www.marioff.com/en/fireprotection/index.htm [25 Sep 06]

[3] TSSE Project Report 2005

[4] "FM-200 (HFC-227) Fire Suppression Systems," Reliable Fire Company web page, 10 October 2006, http://www.reliablefire.com/fm200/fm200.html [30 Sep 06]

[5] TSSE Project Report 2003

[6] "BRUKER DALTONICS – SHIPBOARD NC DETECTION SYSTEMS," naval-technology.com, 2 October 2002, http://www.naval-technology.com/contractors/nbc/bruker/ [10 Oct 06]

D. COMBAT SYSTEM DESIGN

1. Introduction

2. SABR Self Defense Weapon Systems

There are numerous threats for naval combatants operating in international and inland waters. As warships operate closer to the littorals, the threats increase in lethality and number. The first threat is the anti-ship cruise missile (ASCM). ASCM are considered the most lethal due to proliferation and the inability to defend against with the traditional weapon systems due to advances in reduced radar cross section (RCS), supersonic velocities, advanced seeking and guidance systems, and finally terminal maneuvers. Next are mines and torpedoes[4] especially in the littorals and affecting Expeditionary Warfare. The third category can be considered asymmetrical threats; including small boat attacks, low slow flyers, terrorist action, personnel attacks, and a variety of combined tactics and sideways technology[5]. An example of sideways technology would be combining over the horizon radar with ballistic missiles creating a hybrid ASCM that could be launched at targets thousands of miles away from the radar {from reference listed in footnote 2}. In general, tactics that match the strength of the attacker with the weakness of the defender would be a considerable risk to the defended unit. In the case of SABR, this section identifies systems to

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[4] Mine and Torpedoes are in the same category based on the underwater environment in which they deliver their payload.

[5] Paul Bracken, "Sidewise technology: national security and global power implications," Military Review, September-October , pp 64-67

provide point defense while not impeding the primary mission of TBMD.

There is a possibility that the technology for self defense systems employed on the warships of 2030 and beyond have not been invented yet. Some weapons to consider would be of the direct energy type. A combination of radio frequency and laser energy in a layered defense would form a combination of medium and short range defense against a variety of threats potentially in a non-lethal manner. RF weapons would form the longer range layer while lasers would form the short range layer. The all electric ships proposed for the future and for SABR would provide the power to energize such weapons. For the time being, even though considering the gun and missile systems of today is not the ideal approach to project the type of threat defense SABR will employ, it provides a substantial first analysis of the needed capability to fill the areas that are not supported by organic systems.

The starting assumptions for the analysis for hard kill self defense systems for the SABR Ballistic Missile Defense ship are as follows:

I. SABR is a stand off asset, using distance as a defense against threats from the littorals. The weapon and sensor systems for the primary mission of TBMD are such that stand off distances from littorals is projected to be sufficient enough against threats such as small boats attacks, mines, short range ASCM and torpedoes from shallow water diesel submarines.

II. SABR will be considered a high value unit employing escorts such as the Littoral Combat Ship with modules to conduct high value unit defense. Such modules would include capabilities to conduct passive and active surveillance for defense undersea on the surface and in the air at significant ranges. Therefore there is no self defense requirement for an at sea small boat attack

III. There are no crew serve weapons (i.e. .50 caliber, 20mm) on the deck. The drive for minimum manning does not permit the extra manning required for the small possibility of attack. As previously stated, the ship will not be equipped to defend against small boat attacks; those weapons are not effective against air targets. Even if the other two assumptions were invalid, the radiation of SOTS radar would make manning deck guns potentially very dangerous for crew members.

IV. SABR will not have more that four weapon systems for point defense. Some of the reasons for this are; minimizing crew size, lower maintenance, weight considerations, SOTS T/R element density requirements, and minimum RCS considerations.

V. Each weapon system can only prosecute a single threat at a time. Each threat can only be prosecuted by one weapon system at a time

VI. The threat scenario that was used for the analysis: an attack by two subsonic cruise missiles with a simultaneous attack by two supersonic missiles.

VII. The missile firing doctrine is “Shoot-Shoot-Look-Shoot”.

The primary weapon of the SABR is the rail gun, its primary mission is TBMD, secondary is Naval Surface Fire Support and tertiary would be for anti-air and anti-ship warfare to include unit self defense. The rail gun coupled with the SOTR is the most capable system for unit self defense. As stated in the assumptions, the worst case scenario the rail gun and the SOTR would be fully engaged with TBMD and be unavailable for self defense against an attack. This scenario requires a separate weapon system to provide unit defense.

The following is a description of the gun and missile systems that were alternatives that were considered. The Phalanx and Goalkeeper systems are comparable machine gunnery systems while the other systems are comparable missiles systems.

a. Phalanx

A fast-reaction, rapid-fire 20-millimeter gun system that provides US Navy ships with a terminal defense against anti-ship missiles that have penetrated other fleet defenses. Designed to engage anti-ship cruise missiles and fixed-wing aircraft at short range, Phalanx automatically engages functions usually performed by separate, independent systems such as search, detection, threat evaluation, acquisition, track, firing, target destruction, kill assessment and cease fire.

b. Goalkeeper

An autonomous and completely automatic weapon system, developed by the Netherlands for short-range defense of ships against highly maneuverable missiles, aircraft and fast maneuvering surface vessels. The system automatically performs the entire process from surveillance and detection to destruction, including selection of the next priority target. The crucial importance of a last-ditch defense system has been proven on numerous occasions.

c. *NATO Sea Sparrow Missile System:*

A medium-range, rapid-reaction, missile weapon system that provides the capability of destroying hostile aircraft, anti-ship missiles, and airborne and surface missile platforms with surface-to-air missiles. The NSSMS can also be used to detect missile launchings by a surface vessel utilizing the NSSMS surveillance radar capability. Consists of a Guided Missile Fire Control System (GMFCS) Mk 91 and a Guided Missile Launching System (GMLS) Mk 29. The NSSMS employs AIM/RIM-7 Sparrow III series, surface-to-air/surface-to-surface semi-active homing missiles. The RIM-7 version is commonly referred to as SEASPARROW. The missile utilizes the energy reflected from the target and from rear reference RF (transmitted from the director system) for developing missile wing movement orders enabling target intercept.

d. Sea Wolf

A high speed close-range anti-missile with a guidance system of semi-automatic command to line of sight with radar and/or infra-red missile and target tracking. This close in defense system is designed to handle anti-ship missiles in speeds up to Mach 2.

e. RAM

RAM is designed to provide surface ships with an effective self-defense system which will provide an improved capability to engage and defeat incoming (ASCMs). It is a 5 inch missile that utilizes SIDEWINDER technology for the warhead and rocket motor, and the STINGER missile's seeker. Cueing is provided by the ship's ESM suite or radar. The MK-31 RAM Guided Missile Weapon System (GMWS) is defined as the MK-49 Guided Missile Launching System (GMLS) and the MK-44 Guided Missile Round Pack (GMRP).

Table 13 displays quantitative attributes comparing the five different systems. [6]

Table 9 displays quantitative attributes comparing the five different systems.	Shots Prior to Reload	Range Max (m)	Range Min (m)	Detection Range (km)	Firing Rate Shot/min	Cost/unit ($M)
Phalanx	1550	2000	100	10	3000	3.5
Goalkeeper	1190	2000	100	10	4200	7
NATO Sea Sparrow	8	19000	1000	100	30	12[7]

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[6] Taken from professor Harney's LPD Design Exercise, Based on presentation by CAPT Barry Tibbits, USN(Ret) in Surface Ship Combat System Design Integration M.I.T. Summer Course, August 1998

Missile						
Seawolf	4	10000	1500	50	60	10
RAM	21	6500	1000	Various[8]	12	11

Table 13. Weapon System Comparison

f. Conclusion and System Selection

An Excel spread sheet was used to compare the different options of number of each type of weapon system it is attached as an appendix. Some of the results are in the table below. If the threat changes from that of the assumptions; the probability of survival can be recalculated using the Excel spreadsheet. This is a tool that can be used to determine if, and when escort ships should be used in support of the SABR platform.

The utilization of counter measures such as chaff, flares, and EW resources such as the SLQ-32 V (III) will increase the Probability of Survival for the ship. The actual quantitative values for these countermeasures are not available for comparison.

Options	Pk of Threats	Total Cost of Systems
4 Phalanx(1-sm, 2-fm)	3.86	$14M
2 NSSM (2-fm) 2 Phalanx (2-sm)	36.26	$31M
2 NSSM 2 Phalanx	99.99	$31M
3 NSSM 1 Phalanx	99.99	$37.5M
4 NSSM (2-fm, 2 sm)	99.99	$48M
2NSSM (1-fm, 1-sm)	**98.39**	**$24M**
2 Phalanx (1-fm, 1-sm)	3.62	$7M

Figure 44. Weapon System Options

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[7] Cost was determined from a combination of the CAPT Tibbets presentation and the unit cost found on www.fas.org/man/dod-101/sys

[8] RAM can get tracking information from various ship sensors

The NATO Sea Sparrow was a more capable missile system than both the Seawolf and the RAM. The Phalanx offered more rounds on target than the Goalkeeper. The analysis of alternatives compared the benefits of using different combinations of the NSSM and the Phalanx.

The final decision is to employ NSSM dual quad mounts (8 missiles per mount), one mount fore and one aft. This combination is more is costly than the Phalanx system however it has 25 times better P_k and a much farther rang than the Phalanx. Therefore, the most economic system for SABR is to have two NSSM launchers and directors (one fore and one aft) on the ship.

3. Radar Cross Section

a. Introduction

In the military context, the radar and the systems that attempt to "see" the adversary, have continuously been in a costly competition. Military platforms such as aircrafts and warships have transitioned to techniques that reduce RCS to counter radars and conversely more sensitive radars have evolved to detect lower RCS targets [1]. With decreasing fiscal budgets for military spending, RCS reduction raises the question of diminishing returns. Once the specular scatter of radar emitters from a complex surface is reduced, the remaining scattering sources are costly to reduce at a minimal result. Treating these scatters is much more difficult and eventually becomes a question of cost: Is RCS reduction of a few percent worth an additional $2 million [1]?

The characteristics of a low observable target are no longer limited to the RCS of a platform. With network centric warfare and sensor fusion, a platform must minimize its signature in many spectrums to defeat active and passive threats. The DDG-1000 warship that intends to augment the Arleigh Burke class Destroyer, is a prime example of the direction that minimizes all signatures.

According to Richard R. Brooks of California State University Monterey Bay and S. Sitharamar Iyengar of Louisiana State University, "Sensor integration is concerned with the synergistic use of multiple sources of information." Sensor fusion is a major component of sensor integration merging multiple inputs with a common representation. The processing of data from different sensors can provide targeting information. With this in mind, the cost and effectiveness of RCS reduction must be reexamined. To counter warfare in a network centric battle field, a shift is occurring from removing heavy emphasis on reducing RCS and focused more on achieving an optimum balance between a whole host of performance measures where RCS is one among equals [1].

A trend in mitigating the cost and effectiveness of defeating radar systems can be seen in future Electronic Warfare Countermeasure projects. The electronic warfare suites of new US fighter aircraft particularly the Air Force’s F-22 Raptor and planned F-35 Joint Strike Fighter implement systems that cover ECM and intelligence, surveillance and reconnaissance (ISR) systems for the first time in history [2]. Advances in signal processing and electronic miniaturization can be attributed to the new capabilities.

A recent example of cost due to RCS reduction can be found in the design of the F-22. Initial estimates of the impact of changing the F-22's radar signature to US Air Force requirements included an additional \$20-\$25 million and approximately 170 pounds of added weight. The redesign also required removing more than half of the corners of specially designed landing gear and weapon bay doors, reducing access panels by one third, and eliminating more than 80 percent of the drain holes in the aircraft's underside [2].

b. Anti-ship Cruise Missile Problem

The Exocet anti-ship cruise missile is a range of combat-proven air-launched, sea-launched (surface and submarine) and coastal battery missile systems with 3,300 missiles currently sold to 33 customers around the world [6]. The Exocet family includes:

Exocet MM38 (surface-to-surface)

Exocet AM39 (air-to-surface)

Exocet SM39 (submarine-to-surface)

Exocet MM40 Block 1 and Block 2 surface-to-surface or coastal batteries)

Exocet MM40 Block 3 (surface-to-surface and coastal attack)

The Exocet is an inexpensive solution to most nation or non nation states searching for a method of self-defense or specific offensive endeavors against United States ships of interest. Open source information such as the FAS Military Analysis Network provide the estimated range of the Exocet to be 40 nm with seeker turn on at approximately 5 nm.

The assumptions for the problem are as follows: The missile profile is sea skimming and for the use of equation 1.4, we assume that the grazing angle is nearly zero. The missile incorporates an inertial processing unit as guidance prior to seeker activation. At missile activation, an ESD ADAC X-band mono-pulse active radar homer guides the missile to the target. All losses are neglected. The RCS reduction and active ECM will be examined to view the results of the terminal phase of an inbound Exocet. Ship self-defense systems are not considered. The missile parameters are listed in Table 2. The missile’s terminal homing is the only portion of interest for this problem.

By examining all the equations that include RCS of a target, it is possible to determine the effects of RCS reduction for a platform [5].

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{0.1}$$

$$R_{BT} = \sqrt{\frac{P_t G_t G_r \sigma}{P_j G_j 4\pi}} \tag{0.2}$$

$$P_j = \frac{P_j G_j G_r \lambda^2}{(4\pi R)^2} \tag{0.3}$$

Equation 1.1 is the power received from a target scatter via the two-way range equation, equation 1.2, is the radar burn-through equation, and equation 1.3 is the relationship equating the power received from equation 1.1 to the one-way radar range equation.

By Combining RCS reduction and jamming techniques, an increase in platform survivability is gained. If each of the range or power equations that have an RCS term is evaluated for the significance of decreasing RCS, a 50 percent RCS reduction translates to the following [5]:

1. A self-screening or standoff jammer that only needs 50 percent of the power to obtain the same jamming effectiveness

2. The burn-through range becomes 25 percent closer to the radar
3. The radar's detection range is reduced by six and a quarter percent

There are methods of obtaining the RCS such as the Method of Moments, Physical Optics Approximation, and other techniques [1]. There is also commercial software such as Rhinoceros® NURBS modeling for Windows, that allow for a computer aided design of a complicated surface. Once the design is in a usable file format, it can be converted into RCS prediction software. An example of this a MATLAB script is called POFacets [1].

The RCS for three ship types will be discussed. These ships are the CG 47 Ticonderoga Class Guided Missile Cruiser, DDG 51 Arleigh Burke class Destroyer, and the next generation destroyer, DDg-1000. Merrill Skolnik produced an empirical method for determining the RCS of a ship by knowing its displacement. At grazing angles close to zero degrees, the 50th percentile value of the radar cross section can be expressed empirically by equation 1.4.

$$\sigma = 52\sqrt{(f)(D^3)} \qquad (0.4)$$

Sigma is the radar cross section in square meters; f is the emitter frequency in MHz, and D is the displacement in thousands of tons.

$$R_{\max} = \sqrt[4]{\frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 k T_0 F_R B_{Ri} (SNR)}} \qquad (0.5)$$

Equation 1.5 is used to calculate the maximum detection range of the missile seeker.

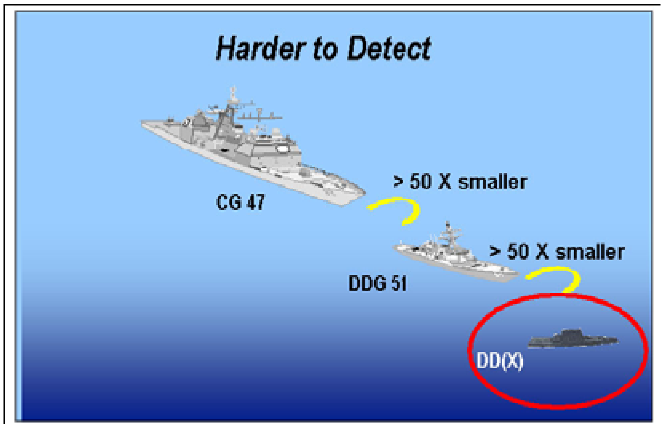

Figure 45. RCS Reduction CG to DD(X) from [4]

From equation 1.4, the CG 47 class cruiser empirical RCS was calculated. The reason the RCS was calculated in this manner was due to the shape of the hull; there are no measures to reduce the RCS. The DDG 51 and DDG-1000 were designed with RCS reduction principles. The DDG 51 was designed with RCS reduction 50 times smaller than the CG 47, and the DDG-1000 initial design is a reduction of 50 times the RCS of the DDG 51 [4]. The RCS values for DDG 51 and DDg-1000 are estimated from [4] and the empirical estimation of the CG 47 class cruiser.

Table 14. Empirical RCS Results

SHIP	Displacement (TONS)	Empirical RCS (m^2)
CG 47	9,600	154,670
DDG 51	8,315	3,093
DDG-1000	1,400	61.86

From the empirical results in Table 1, the reflected power, burn through, and jamming to signal ratio (JSR) power were calculated from the parameters given on the Exocet missile in Table 2. The power received from the ship RCS scatter was plotted in Figure 2 and the JSR was plotted in Figure 3. The burn-through range and missile maximum seeker detection range are shown in Table 12.

Table 15. Missile Seeker Parameters

F_R	5 dB
f	10 GHz
k	1.38×10^{-23} J/K
T_0	290 K
B_{RI}	1 MHz
G_t	30 dB
G_r	30 dB
SNR	20 dB

To calculate the maximum range that the emitter will be able to detect the ship of interest given its seeker parameters and the seeker's ability to "burn through jamming" equations 1.2 and 1.3 are used. (Given that the shipboard jammer power is 100 W and gain of 30dB)

Table 16. Maximum Missile Seeker and Burn Through Range

SHIP	Max Range	Burn-Through Range
CG 47	61.01 km	175.42 m
DDG 51	22.94 km	24.81 m
DDG-1000	8.63 km	3.51 m

Figure 37 demonstrates that the lower the RCS, the lower the reflected power will be from a radiated target. The DDG-1000 reflected power is low enough to be masked in clutter or a small fishing dow intermittently appearing as a target. The DDG 51 is the middle ground between the cruiser and DDG-1000, however in order to maintain a low RCS, the topside surfaces must maintain a low RCS profile. For example, the life lines railing the ship defeat the low observable features of the angled surfaces.

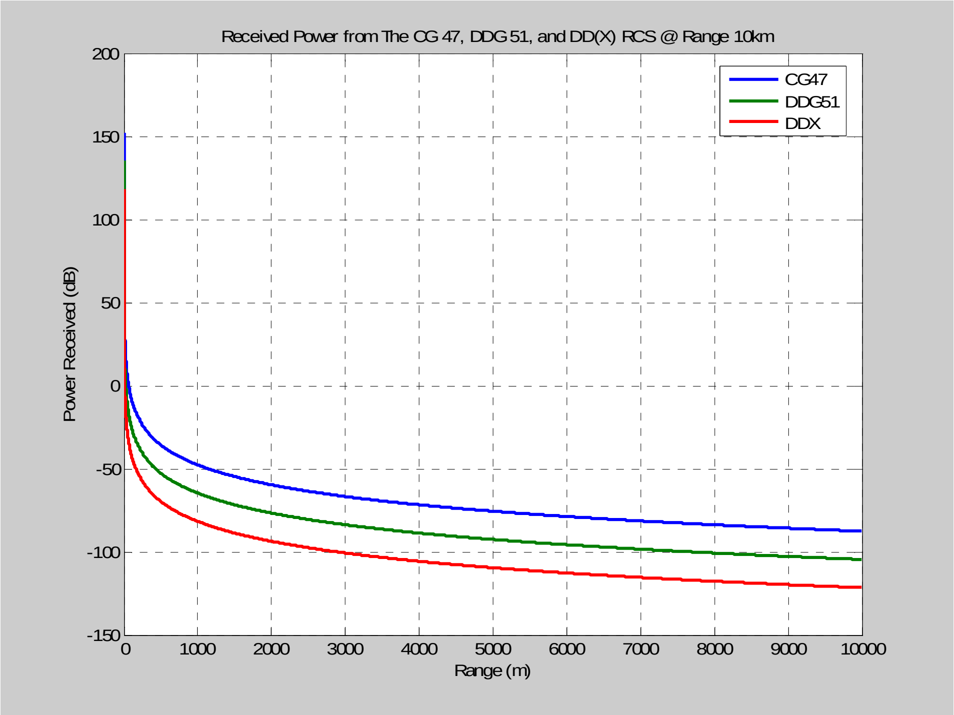

Figure 46. Reflected Power From Ships

Figure 37 demonstrates that the DDG-1000 can scale down jamming output power significantly. The combination of the small reflected power in Figure 3 and the 100 W output power, mask the seeker’s ability to detect a target up until 3 m (from table 13)

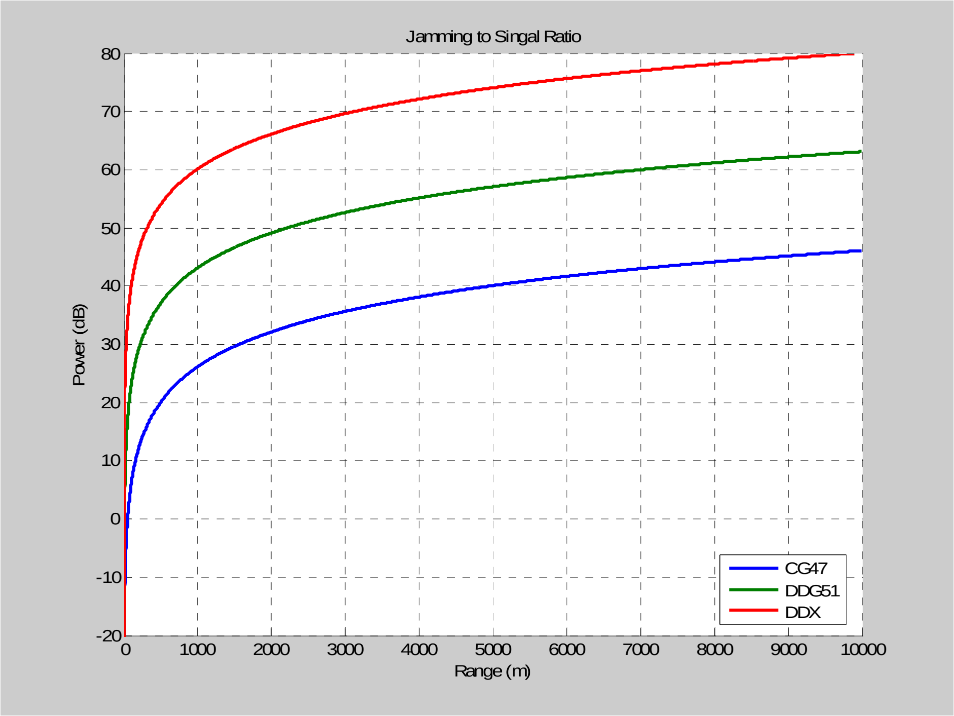

Figure 47. Jamming to Signal Ratio for three Ships

The JSR for all three warships is greater than one for the duration of the terminal phase. Sophisticated missile seekers may detect active ECM and switch to an infrared or other optical sensors for target discernment. Figure 4 demonstrates that the shipboard active ECM at 100 W of output power over powers the reflected power.

c. Conclusion

RCS reduction combined with ECM techniques can provide on overall increased survivability for a platform. The results from the DDG-1000 calculations show that it is nearly invisible to an X-band emitter where the CG47 is more vulnerable. Reducing platform RCS increases the ability to implement ECM for ship self defense.

d. References

[1] D.C. Jenn, "Radar Cross Section," in 2nd ed., vol. 1, Reston, Virginia: American Institute of Aeronautics and Astronautics, 2005, pp. XV.

[2] D.A. Fulghum, "F-22 fix to cost $20-25 million” ***Aviation Week & Space Technology,*** vol. 140, pp. 27, 1994.

[3] G. Goodman Jr, "Confluence of Missions, The electronic warfare and ISR domains begin to overlap," ***C4ISR Journal,*** vol. 4, pp. 18-24, 2005.

[4] Statement of Admiral Vern Clark, U.S. Navy Chief of Naval Operations before the House Armed Services Committee Projection Forces Subcommittee July 19th, 2005

[5] A.C. Kinghorn, S. Haaland and J.V. Chenevey Eds., ***Electronic Warfare and Radar Systems Engineering Handbook,*** Point Mugu, CA: Naval Air Warfare Center Weapons Division Avionics Department Electronic Warfare Division, 1997.

[6] Retreived from: http://www.mbda.net/site/FO/scripts/siteFO_contenu.php?lang=EN&noeu_id=108

e. SABR Radar Cross Section Analysis

The field of Computational Electromagnetics (CEM) uses numerical algorithms to solve electromagnetic problems that have no analytical solution. *lucernhammer* is a collection of software tools for calculating electromagnetic (EM) signatures. Some of the problems that can be addresses include scattering phenomena, antenna and waveguide design, wave propagation, and imaging. The SABR RCS results were calculated using High Frequency (HF) techniques that make assumptions about the behavior of fields, surface currents, and use these assumptions to simplify the scattering equations [1]. *Lucernhammer* MT solves scattering problems in 3D using a combination of Physical Optics (PO), the Physical Theory of Diffraction (PTD), and Shooting and Bouncing Rays (SBR) [2], [3]. Refer to [2] for the techniques mentioned.

Two frequencies were selected to conduct the RCS calculations; The X-band: 10 GHz missile seeker and UHF: 800 MHz long-range search radar. The elevation, ϕ, was held constant at five degrees and the scan was in azimuth, θ, from zero to 180°.

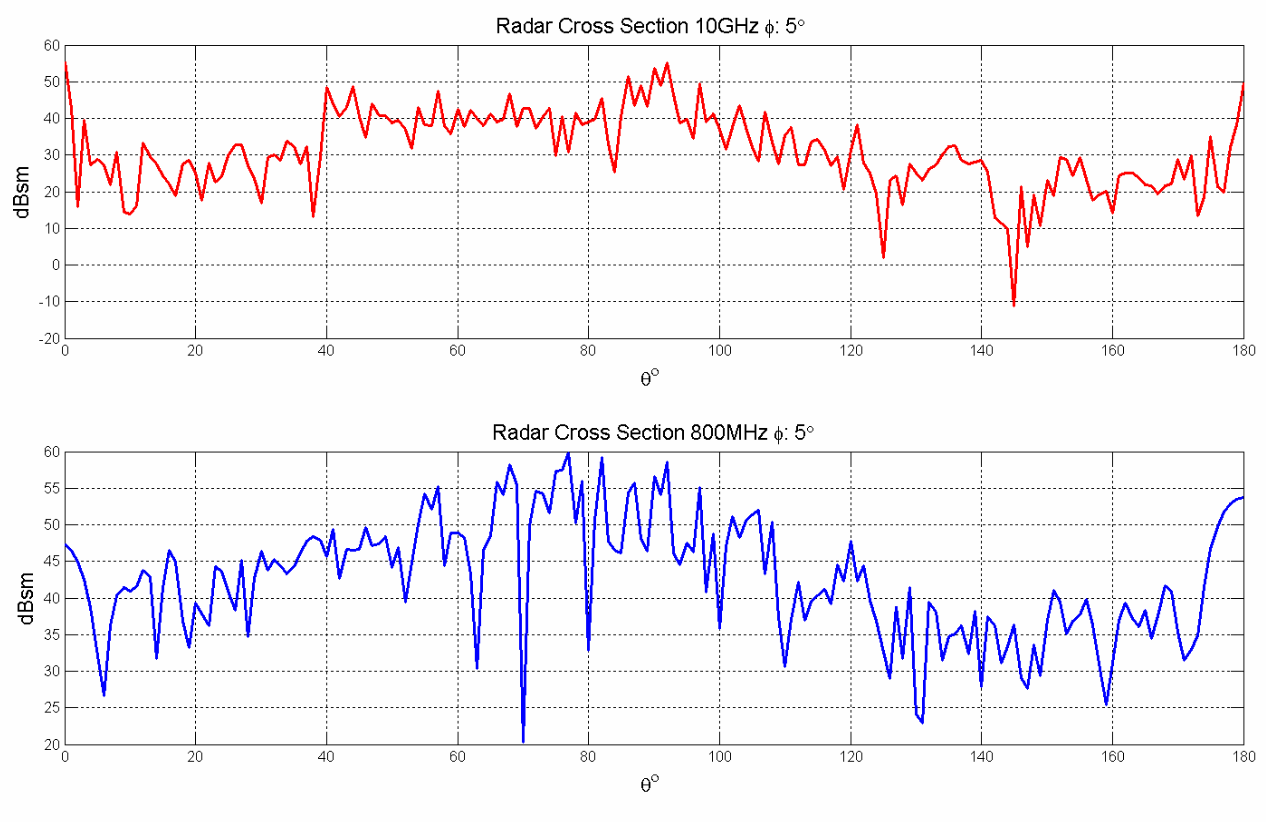

Figure 48. SABR RCS for 10 GHz and 800 MHz

Table 17. SABR RCS Summary

SABR RCS SUMMARY					
Emitter	Maximum	Theta	Minimum	Theta	Average
GHz	dBsm	deg	dBsm	deg	dBsm
10	55.2	92	-11.19	145	31
0.8	59.86	77	20.33	70	42.6

Figure 39 displays the RCS for both frequencies in dBsm versus azimuth at constant elevation. Table 2 summarizes the results by max, min and average RCS in dBsm. From reference [4], the empirical RCS of three ships are shown in Table 15.

Table 15 is a compilation of RCS values from Equation (0.6) where σ is the radar cross section in square meters, f is the emitter frequency in MHz, and D is the displacement in thousands of tons [4]. Equation (0.6) is valid for grazing angles close to zero degrees.

$$\sigma = 52\sqrt{(f)(D^3)} \tag{0.6}$$

Table 18. Empirical RCS

SHIP	**Displacement (TONS)**	**Empirical RCS (m^2)**
CG 47	9,600	154,670
DDG 51	8,3.15	3,093
DD(X)	1,400	61.86
SABR		1,259*

*The average RCS for the X-band emitter from *lucernhammer* calculations

SABR has the second least RCS signature out of the four ships. The significance of this observation can be seen from Figure 40.

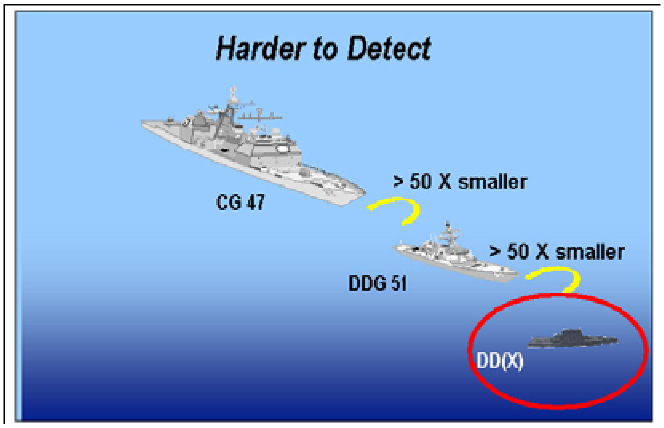

Figure 49. RCS signature

The DDG 51 was designed with RCS reduction 50 times smaller than the CG 47, and the DD(X) initial design is a reduction of 50 times the RCS of the DDG 51 [5]. The RCS values for DDG 51 and DD(X) are estimated from [5] and the empirical estimation of the CG 47 class cruiser.

By examining all the equations that include RCS of a target, it is possible to determine the effects of RCS reduction for a platform [6].

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{\left(4\pi\right)^3 R^4} \tag{0.7}$$

$$R_{BT} = \sqrt{\frac{P_t G_t G_r \sigma}{P_j G_j 4\pi}} \tag{0.8}$$

$$P_j = \frac{P_j G_j G_r \lambda^2}{\left(4\pi R\right)^2} \tag{0.9}$$

$$R_{\max} = \sqrt[4]{\frac{P_t G_t G_r \lambda^2 \sigma}{\left(4\pi\right)^3 k T_0 F_R B_{Ri} \left(SNR\right)}} \tag{0.10}$$

Equation (0.7) is the power received from a target scatter via the two-way range equation, Equation (0.8), is the radar burn-through equation, and Equation (0.9) is the relationship equating the power received from Equation (0.7) to the one-way radar range equation. Equation (0.10) is the maximum range a specific seeker system is capable of detecting a target based on receiver parameters.

By Combining RCS reduction and jamming techniques, an increase in platform survivability is gained. If each of the range or power equations that have an RCS term is evaluated for the significance of decreasing RCS, a 50 percent RCS reduction translates to the following [6]:

- A self-screening or standoff jammer that only needs 50 percent of the power to obtain the same jamming effectiveness
- The burn-through range becomes 25 percent closer to the radar
- The radar's detection range is reduced by six and a quarter percent

The effort to reduce the ship's RCS is aimed primarily at improving survivability against radar homing, anti-ship cruise missiles (ASCM). Stealth in combination of softkill systems has the ability to enhance surface warship defense against the current ASCM threat.

f. References

[1] W. C. Gibson, "User's Manual For *lucernhammer*," pp. 137-166, December. 2005.

[2] D. C. Jenn, ***Radar and Laser Cross Section Engineering.*** ,2nd ed.1801 Alexander Bell Drive, Reston, VA 20191-4344: American Institute of Aeronautics and Astronautics, 2005, pp. 501.

[3] D. C. Jenn, "Computer modeling techniques for array antennas on complex structures," Naval Postgraduate School, Monterey, CA, December, 1997.

[4] M. J. Holguin, "The Combination of Radar Cross Section Reduction and other Electronic Warfare Techniques for Antiship Cruise Missile Defense," 2005.

[5] Statement of Admiral Vern Clark, U.S. Navy Chief of Naval Operations before the House Armed Services Committee Projection Forces Subcommittee July 19th, 2005

[6] Naval Air Systems Command, "Electronic warfare and radar systems engineering handbook," Electronic Warfare Division, 1997.

E. HUMAN SYSTEMS INTEGRATION

1. Introduction

The purpose of SABR is Theater Ballistic Missile Defense implementing revolutionary technology in sensor and weapon employment. The railgun and opportunistic array are an example of two systems that are revolutionary and critical to the mission of TBMD. Determining the personnel required to operate these systems is difficult and an empirical undertaking. During the SABR design, an attempt was made to model the crew manning specifically for the Combat Information Center (CIC). Although significant results were not obtained, much can be learned from merging the systems engineering process and Human Systems Integration (HSI). In this section, discussion is based on the HSI approach, the history of HSI modeling for US Navy, simulation models and tools that have been validated for use by the HSI community, the attempt at manning for SABR, and concluding recommendations for HSI and future TSSE projects

2. HSI Approach

Developing the optimal shipboard manning plan is a critical process for new and old navy warships. The most expensive asset in the US Navy is the personnel that serve ashore and afloat. In recent years, there have been specific programs to establish methods to capitalize on the investment made in each sailor and officer serving in the Navy[9].

Considerable research was conducted to establish what tools were available and what processes to account for

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[9] Human Capitol Strategy June 2004

identifying manning needs. Initial questions were asked at the beginning of the project. These questions were:

How many people are required to support the ship and mission?

What is the trade off between fully manned and sub-manned spaces[10]?

In order to address these questions, an investigation of simulation capabilities in the HSI community was conducted. There are modeling and simulation tools that can assist in determining manning numbers given that sufficient detail is available for model development. Some software packages are for macro-level simulation where others deal with micro-level. Macro-level pertains to the overall function of several units working as a team such as the divisions and departments of a ship. Micro-level pertains to an individual or a small unit such as that of a tank. The key was to develop the right combination of models to determine a detailed enough shipboard system for both Theater Ballistic Missile Defense and Naval Surface Fire Support (NSFS). The rail gun is also a weapon that increases fire support and thus can be considered a secondary mission while conducting TBMD. A comparative assumption was made for the manning analysis in the two mission areas. The Aegis Guided Missile Cruiser is a comparable platform with SABR and specific missions such as Air Defense (AD) and NSFS are assumed to be projected to SABR. Figures (Generic Air Defense Manning CG 47 Class Aegis Cruiser)} and (CG 47 NSFS Generic Manning) are not all inclusive and manning can increase or decrease

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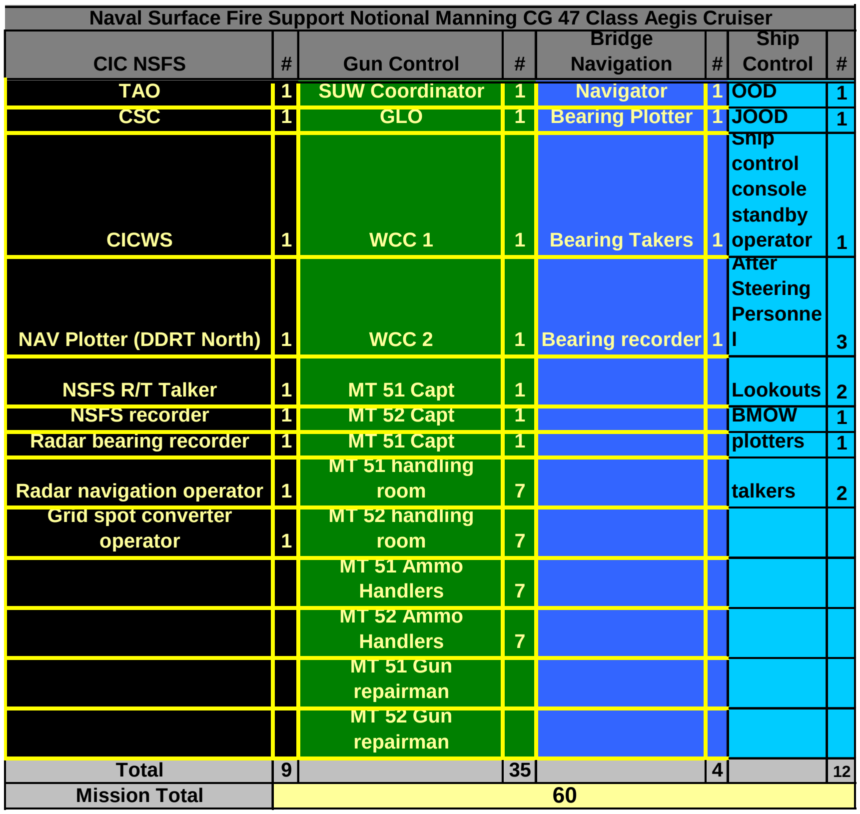
[10] HSI Considerations for the SABR Project TSSE 2006, IMPRINT Seminar NPS,18 Jul 2006

depending on the operations being conducted. For the current Aegis Cruiser, both missions are completely different. NSFS requires one team while AD is another. SABR would combine these missions with technology. That is where the improvements of the rail gun come into play with the replacement of missiles with intelligent projectiles. The manning shown in Figures (Generic Air Defense Manning CG 47 Class Aegis Cruiser) and (CG 47 NSFS Generic Manning) would combine and even decrease the number of participants. For example the AD team could combine the Missile System Supervisor with the Ship AAWC, combine the Identification Supervisor and Red Crown, and Combine the Force TAO with Force AAWC. Further changes would include the combination of the Combat Systems Coordinator and the Radar System Controller.

CG 47 Class Air Defense Manning
Force Tactical Action Officer
Force Anti Air Warfare Coordinator
Ship Anti Air Warfare Coordinator
SHIP Tactical Action Officer
Missile System Supervisor
Red Crown
Electronic Warfare Control Officer
Identification Supervisor
Radar System Controller
Combat System Coordinator

Figure 50. Generic Air Defense Manning CG 47 Class Aegis Cruiser **[1]**

Total notional manning is ten personnel. With combination of functions and tasks it is possible to reduce to six personnel. The NSFS system requires many support personnel that can be replaced with technology. There are numerous combinations that can be analyzed for the best use of people. The remaining portion of the HSI brief will provide some insight on the HSI process.



Naval Surface Fire Support Notional Manning CG 47 Class Aegis Cruiser							
CIC NSFS	#	Gun Control	#	Bridge Navigation	#	Ship Control	#
TAO	1	SUW Coordinator	1	Navigator	1	OOD	1
CSC	1	GLO	1	Bearing Plotter	1	JOOD	1
CICWS	1	WCC 1	1	Bearing Takers	1	Ship control console standby operator	1
NAV Plotter (DDRT North)	1	WCC 2	1	Bearing recorder	1	After Steering Personnel	3
NSFS R/T Talker	1	MT 51 Capt	1			Lookouts	2
NSFS recorder	1	MT 52 Capt	1			BMOW	1
Radar bearing recorder	1	MT 51 Capt	1			plotters	1
Radar navigation operator	1	MT 51 handling room	7			talkers	2
Grid spot converter operator	1	MT 52 handling room	7				
		MT 51 Ammo Handlers	7				
		MT 52 Ammo Handlers	7				
		MT 51 Gun repairman					
		MT 52 Gun repairman					
Total	9		35		4		12
Mission Total	60						

Figure 51. CG 47 NSFS Generic Manning **[2]**

3. Brief History of Human System Integration Tools

There are several software tools that have been developed to demonstrate the simulation of human and system integration (See Appendix XXX). Some of these tools have gone to the wayside, no longer supported. Others have combined with others to provide HSI designers more robust analytical tools. Industry has used modeling and simulation to evaluate manpower needs for several decades and the Department of Defense (DOD) began developing methods for modeling human systems in the 1970's. The Navy began research in the use of modeling for manpower analysis in the 1990's and the majority of advancement came with the tools developed for the program DD-21. The DD-21 and eventually the DD(X)/DDG-1000 program changed the systems engineering process with respect to manpower modeling in the DOD. Manpower became a key performance parameter (KPP), and manpower issues had to be tied to operational consequences. Forecasting manpower requirements accurately, tracking them to system performance requirements, and conducting business on a sound engineering basis was and will be a necessity for future warship designs. Several Navy research and development efforts evolved from the manpower modeling tools of the DD-21 program early timeframe. These efforts are important to note, because they are becoming standards for the future assessment of manning needs for warship designs. These tools combine macro-level, micro-level, operational, and maintenance considerations.

The objective of Manpower Modeling is to provide quantitative metrics in a controlled simulation to support system engineering and manning optimization. The tenets of optimized manning are simple: to maximize crew performance and reduce workload. This translates into identifying the best suited operator to perform the work related tasks and by insertion of the right technology. There is an important note to make when optimizing a ship crew: reduced workload does not equate to a direct elimination of billets. Shipboard billets are related to the Ship Manning Doctrine conditional watches, collateral duties, and policy requirements. Furthermore optimizing a unit at the micro level may not optimize mission completion results at the macro-level. This is apparent for shipboard considerations. If one examines the life of a crew member, there are many responsibilities per person. For example, Figure (crewman) demonstrates that one sailor may be responsible for own unit support, maintenance, administration, damage control, and watch standing and if replaced for one function, the other tasks may not get redistributed.

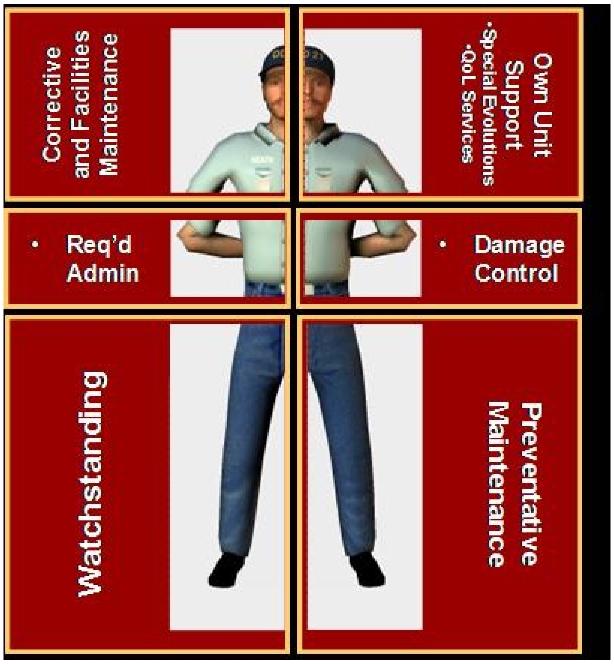


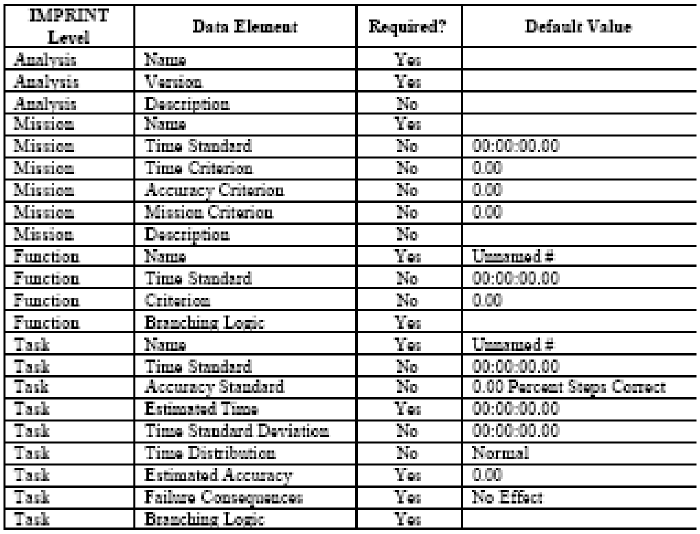
Figure 52. Many Responsibilities of a crew member [4]

4. HSI Tools

During the research phase of the HSI implementation, many software packages were investigated. They include Improved Performance Research Integration Tool (IMPRINT), Watchstander Model (WSM), Total Crew Model, and SMART Build 3. The software engine behind these models is called Micro Saint (Sharp). Micro Saint is a general purpose, discrete-event simulation software tool. In order to understand the models, the "language" of Micro Saint must be understood. The two tools that were considered for the SABR project were IMPRINT and TCM. An account of how these two software tools were incorporated will precede the conclusion of this section.

5. IMPRINT

IMPRINT is a stochastic task-network modeling tool designed to help assess the interaction of a unit member and system performance from concept and design through field testing and system improvements [3]. The most beneficial aspect of IMPRINT is that it assists design team members concerned with manning to evaluate operator and crew mental workload while testing alternate system-crew function allocations [3]. Figure (IMPRINT input matrix after [3]) lists the all the data input options for IMPRINT models



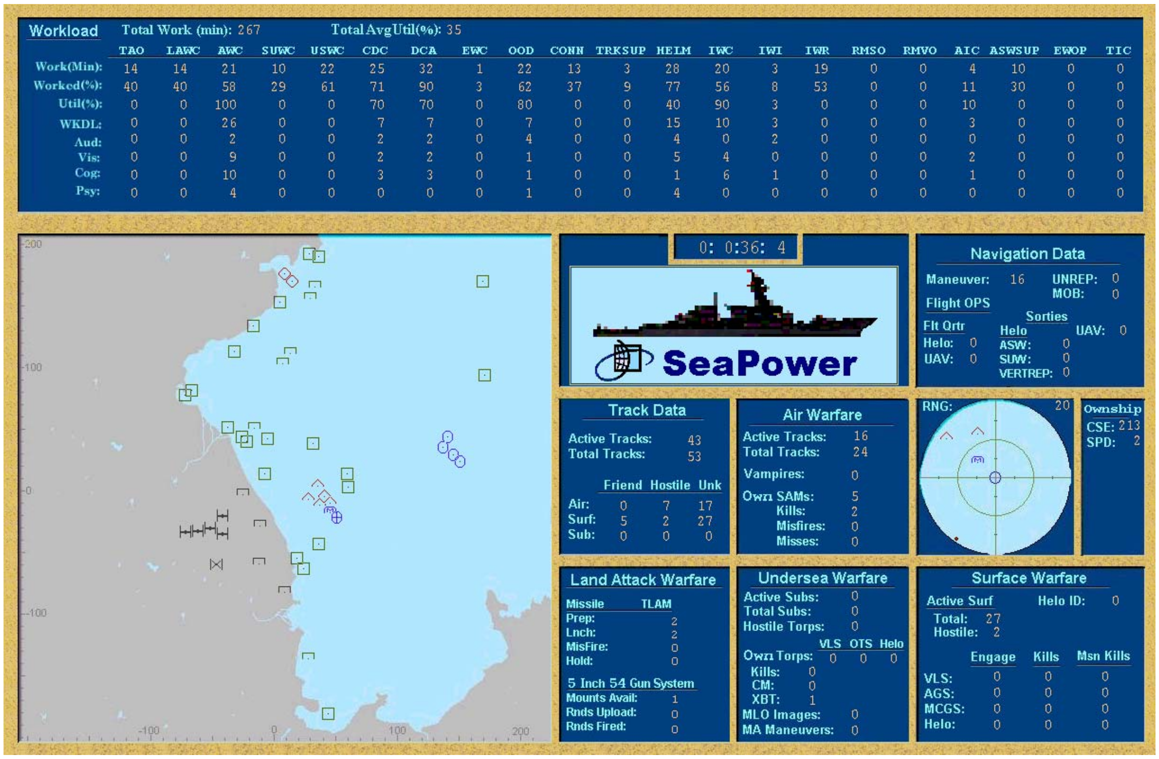
IMPRINT Level	Data Element	Required?	Default Value
Analysis	Name	Yes	
Analysis	Version	Yes	
Analysis	Description	No	
Mission	Name	Yes	
Mission	Time Standard	No	00:00:00.00
Mission	Time Criterion	No	0.00
Mission	Accuracy Criterion	No	0.00
Mission	Mission Criterion	No	0.00
Mission	Description	No	
Function	Name	Yes	Unnamed #
Function	Time Standard	No	00:00:00.00
Function	Criterion	No	0.00
Function	Branching Logic	Yes	
Task	Name	Yes	Unnamed #
Task	Time Standard	No	00:00:00.00
Task	Accuracy Standard	No	0.00 Percent Steps Correct
Task	Estimated Time	Yes	00:00:00.00
Task	Time Standard Deviation	No	00:00:00.00
Task	Time Distribution	No	Normal
Task	Estimated Accuracy	Yes	0.00
Task	Failure Consequences	Yes	No Effect
Task	Branching Logic	Yes	

Figure 53. IMPRINT input matrix after [3]

The downside of the software is that it is designed primarily for the Army units and in all cases of using IMPRINT, a user would have to select similar functions of an Army unit and caveat the model for a shipboard sailor function.

6. Watchstander Model

The WSM was developed from the Office of Naval Research Manning Affordability Initiative and is considered a micro level model. It takes time slices every second of an introduced scenario. Simultaneous mission execution is conducted based on the scenario designed [4]. Like IMPRINT, team definition and workload calculations are conducted. The primary focus of this model is human capabilities. The process for implementing WSM is also similar to IMPRINT. Initially a task analysis of each team member is conducted. Task flows are then determined and then each team member/sailor is allocated to a task. Automation may also be introduced. The scenario is activated and the results can be analyzed. Figure (WatchStander Tracking Data) shows the data tracked per watchstation as a scenario unfolds in any of the typical warfare areas.



Workload

Total Work (min): 267

Total AvgUtil(%): 35

	TAO	LAWC	AWC	SUWC	USWC	CDC	DCA	EWC	OOD	CONN
Work(Min):	14	14	21	10	22	25	32	1	22	13
Worked(%):	40	40	58	29	61	71	90	3	62	37
Util(%):	0	0	100	0	0	70	70	0	80	0
WKDL:	0	0	26	0	0	7	7	0	7	0
Aud:	0	0	2	0	0	2	2	0	4	0
Vis:	0	0	9	0	0	2	2	0	1	0
Cog:	0	0	10	0	0	3	3	0	1	0
Psy:	0	0	4	0	0	0	0	0	1	0

	TRKSUP	HELM	IWC	IWI	IWR	RMSO	RMVO	AIC	ASWSUP	EWOP	TIC
Work(Min):	3	28	20	3	19	0	0	4	10	0	0
Worked(%):	9	77	56	8	53	0	0	11	30	0	0
Util(%):	0	40	90	3	0	0	0	10	0	0	0
WKDL:	0	15	10	3	0	0	0	3	0	0	0
Aud:	0	4	0	2	0	0	0	0	0	0	0
Vis:	0	5	4	0	0	0	0	2	0	0	0
Cog:	0	1	6	1	0	0	0	1	0	0	0
Psy:	0	4	0	0	0	0	0	0	0	0	0

0: 0:36: 4

Navigation Data

Maneuver: 16
UNREP: 0
MOB: 0

Flight OPS

Flt Qrtr
Helo: 0
UAV: 0

Sorties
Helo
ASW: 0
SUW: 0
VERTREP: 0
UAV: 0

Track Data

Active Tracks: 43
Total Tracks: 53

	Friend	Hostile	Unk
Air:	0	7	17
Surf:	5	2	27
Sub:	0	0	0

Air Warfare

Active Tracks: 16
Total Tracks: 24
Vampires: 0
Own SAMs: 5
Kills: 2
Misfires: 0
Misses: 0

Ownship
CSE: 213
SPD: 2

Land Attack Warfare

Missile TLAM
Prep: 2
Lnch: 2
MisFire: 0
Hold: 0

5 Inch 54 Gun System
Mounts Avail: 1
Rnds Upload: 0
Rnds Fired: 0

Undersea Warfare

Active Subs: 0
Total Subs: 0
Hostile Torps: 0

	VLS	OTS	Helo
Own Torps:	0	0	0

Kills: 0
CM: 0
XBT: 1
MLO Images: 0
MA Maneuvers: 0

Surface Warfare

Active Surf
Total: 27
Hostile: 2
Helo ID: 0

	Engage	Kills	Msn Kills
VLS:	0	0	0
AGS:	0	0	0
MCGS:	0	0	0
Helo:	0	0	0

Figure 54. Watchstander Model Data **[4]**

7. Total Crew Model

TCM simulates underway manning requirements for naval combatants from a macro-level perspective to determine the adequacy of a proposed crew complement. The TCM consists of a series of non-networked tasks that represent high-level task type performed by the crew. These include both work and non work tasks and cover the entire twenty-four hour period for each crewmember, each day through the duration of the scenario. Crew assignments and mission scenario events are updated in the TCM every fifteen minutes. Typical scenarios are fourteen to twenty-eight days in length in order to capture the cumulative effects of fatigue. The simulation considers the combined effects of crew size, skill sets, work schedules, evolution task assignments, watch standing requirements, and operational scenario [5].

Simulation results are used to evaluate whether the assigned crew complement can successfully accomplish all underway operations and do so within acceptable time constraints and crew fatigue levels. Adjustments may be made to the manning hypotheses with the goal of optimizing the crew size and schedules. Subsequent iterations may be used to support recommendations for billet reductions or schedule modifications intended to improve crew performance over the course of the scenarios [5]. Figure (Total Crew Model Simulation Data of interest) demonstrates some of the data available for analysis from TCM

MISSION DATA

Steaming: Condition III
EMCON: C
Completed Evolutions: 260
Delayed Evolutions: 83
Failed Evolutions: 24

SYSTEM DATA

Avail. Helos: 0
Avail. UAVs: 1
Avail. Boats: 1

CREW DATA

Ships Crew: 112
Casualties: 2
Exhausted: 9
Tired: 41
Rested: 60
Peak Fatigue: 9.3
Min. Fatigue: 1.3
Avg. Fatigue: 4.2
Avg. Sleep: 7.1
Avg. Work Wk: 80.5

	Pending	Active	Failure
Man Overboard			
DC Emergency		8	
Medical Emergency		4	
Engineering Casualty		1	
SAR		2	
Emergency Drill	5	8	3
Non-Emergency Drill	9	21	5
Navigation Detail		9	
Low Visibity Detail		6	
Anchor / Moor	1	1	

	Pending	Active	Failure
RAS / FAS		4	
Boat Ops	18	26	7
Boarding	8	14	3
Flight Quarters	26	69	16
Helo Ops	11	33	5
UAV Ops	15	26	11
AIC	1	9	5
Maintenance	16	65	21
Ship Drill	7	17	5
Meeting	37	56	13

Billet #:	Peak Fatigue	Average Fatigue	Current Fatigue
101	10.3	5.6	9.3
102	8.3	4.0	5.8
103	9.5	8.7	8.8
104	5.6	3.7	5.3
105	8.7	2.6	8.5
106	4.3	1.1	1.3
107	5.8	2.6	2.3
108	8.2	5.0	5.3
109	5.9	2.8	4.8
110	8.1	3.4	2.3
111	5.2	3.3	3.8
112	5.3	2.7	2.8
113	8.3	5.0	1.9
114	8.8	2.1	8.3
115	8.3	5.5	4.3
116	4.2	2.3	3.8
117	12.3	8.8	8.3
118	5.8	5.1	3.7
119	10.5	3.4	8.3
120	4.5	3.6	2.3
121	3.8	2.9	3.0
122	6.6	2.3	1.8

Figure 55. Total Crew Model Simulation Data of interest **[4]**

The analysis metrics for TCM are ship’s schedule, mission accomplishment, and crew activity data.

8. SMART B3

The SMART B3 Model is based on equipment usage and provides detailed maintenance and skill set data. The process includes defining system parameters that are specific to equipment, compartments and maintenance actions. A scenario is developed within a Gantt chart feature. Functions and task analysis are incorporated into the Gant chart and task flows are assigned to each team member. The analysis metrics include skill usage over time, crew requirement, operational and directed man-hour requirements, personnel conflicts, crew composition and cost data. This model addresses the best crew composition for a new system by skills, size and cost.

9. HSI Tool summary

To summarize, IMPRINT is a dynamic, stochastic discrete event network modeling tool designed to help assess the interaction of soldier and system performance throughout the system lifecycle--from concept and design through field testing and system upgrades. WSM is a micro-level design tool that conducts detailed workload analysis for watchstanders, and provides empirical data on low level task and performance. TCM is a macro-level design tool that conducts high level workload and crew activity analysis for the entire ship’s crew. It considers fatigue and crew resiliency. It identifies manpower resource drivers and provides empirical data identifying the relationships between manpower, scenarios, and performance. SMART B3 focuses on mixing the jobs that the crew does to optimize different aspects of ship manning. It includes sophisticated maintenance modeling capability.

10. HSI and SABR

Research was conducted in search of an approach for manning identification. This research included discussions with HSI experts from NAVSEA, NAVAIR, JHU-APL, SPAWAR, and OPNAV N-173E2, modeling and simulation seminars from Army Research Laboratory, literature searches, and multiple phone conferences with program managers at companies such as Alion Science & Technology and SkillsNet. In hindsight, the proper process for conducting this research would have been as follows:

Using a micro-level simulation model in IMPRINT, create and simulate models for each unit on the ship. The watch stations would be broken down into members, functions, tasks, and mission requirements following the format of Figure (**input matrix after** [3]. The outcome would provide a trade space to compare current manning and projected manning given a change in personnel at the unit level. The change in personnel would be similar to the discussion of combining members of the AD team at the beginning of the section. Once the optimized watch units were obtained, TCM would be used to observe the macro-level changes between a baseline simulation and the experimental simulation. The output results were discussed in the TCM overview.

11. Recommendations

Determining manning requirements for a ship design is a complex task. A study of this magnitude qualifies as a thesis topic for the HSI curriculum students. A partnership with the HSI Department at the Naval Postgraduate School may be an option to satisfy a thesis project for the HSI student, and at the same time, obtain results that make the TSSE Ship Design Project more complete with traceable results.

12. References

[1] S. H. Calfee and N. C. Rowe, "Multi-Agent Simulation of Human Behavior in Naval Air Defense," *2005,*

[2] Anonymous "Navy tactical reference publication aegis CG class tactical publication (U)," Tech. Rep. NTRP 3-20.6.02, 2006.

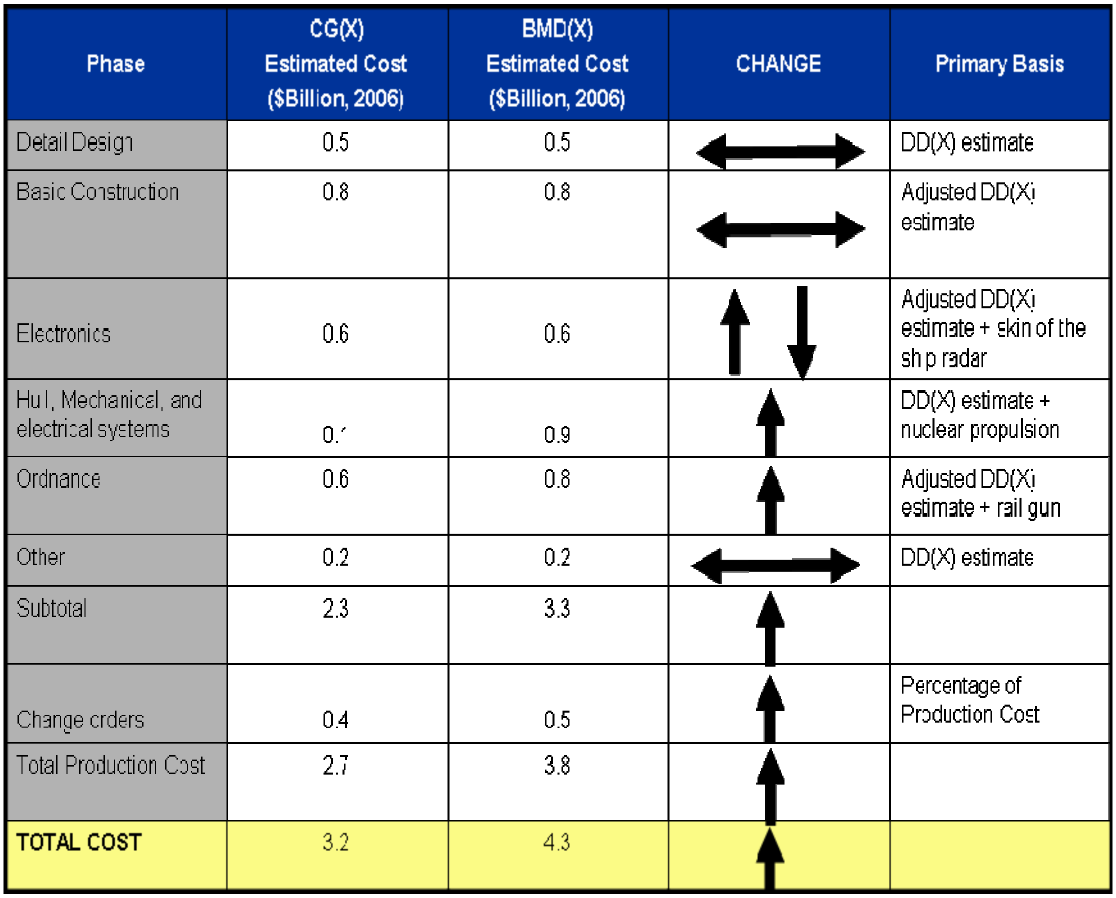
[3] D. K. Mitchelle, C. L. Samms and M. M. Glumm, "Improved performance research integration tool (IMPRINT) model analyses in support of the situational understanding as an enabler forUnit of action maneuver team soldiers science and technology objective (STO) in support of future combat systems (FCS)," ARL, Aberdeen Proving Ground, MD 21005-5425, Tech. Rep. ARL-TR-3405, 2004.

[4] B. Sargent, "Modeling Tools to Support Navy Manpower Requirements Analysis," September 2. 2002.

[5] J. Miller and J. French. Estimating the conditions of stress during operational conditions. Presented at *Proceedings of the 2005 Winter Simulation Conference*. Available: http://delivery.acm.org/10.1145/1170000/1162931/p1275-french.pdf?key1=1162931&key2=5781820611&coll=GUIDE&dl=&CFID=929869&CFTOKEN=65085745

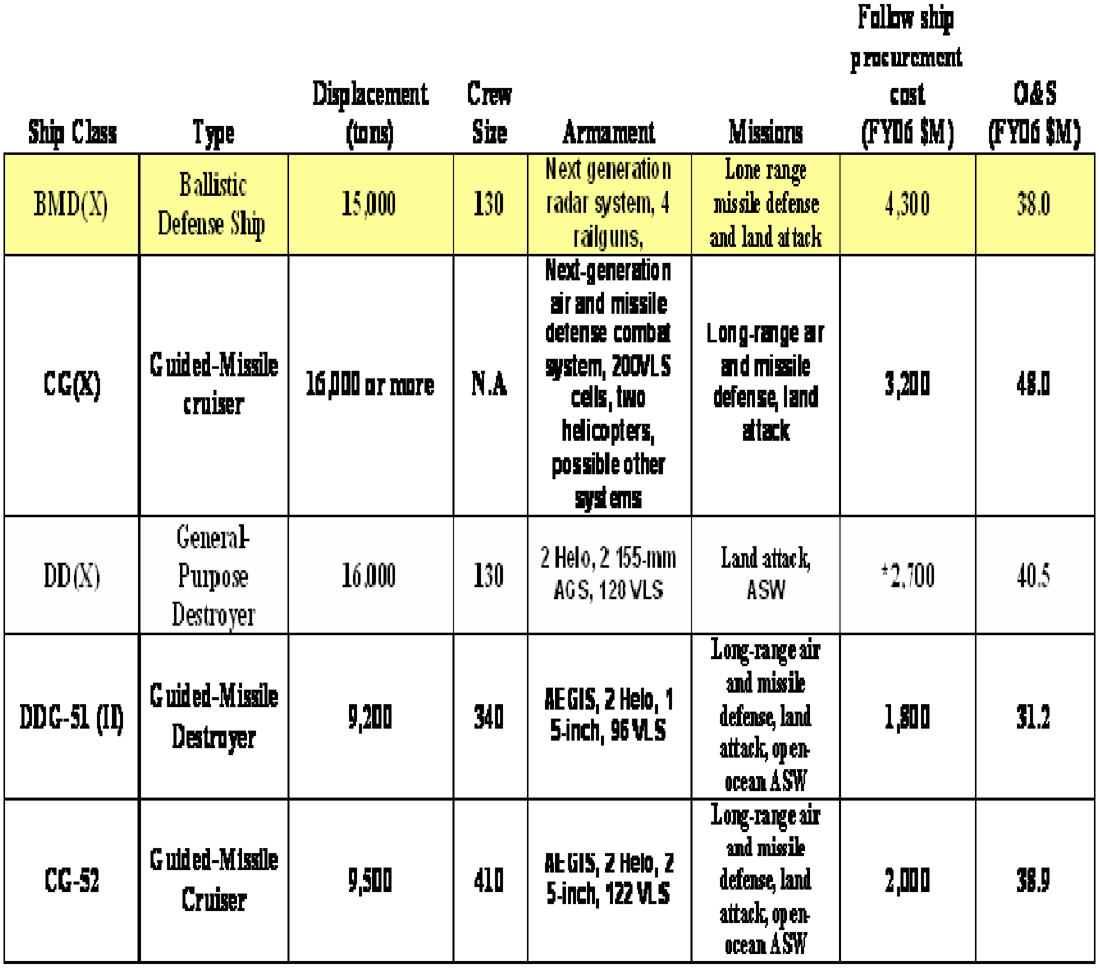
E. COST ANALYSIS

The cost prediction was based on similar costs of DD(X) and CG(X). The cost prediction of this project becomes difficult due to projecting cost of new developing technology far into the future. Figure 50 shows a cost prediction of the BMD(X) based on the DD(X) estimated cost. The two driving force for cost of the BMD(X) are the nuclear propulsion and rail gun. The BMD(X) has an average cost of 4.3billion dollars but, the cost should decrease as the technology becomes more developed in the future. The costs for the propulsion and rail gun are estimated costs since the technology has not fully developed. The BMD(X) does have an lower operating cost than the CG(X) and DD(X) due to the reduce missions that are carried onboard.



Phase	CG(X) Estimated Cost ($Billion, 2006)	BMD(X) Estimated Cost ($Billion, 2006)	CHANGE	Primary Basis
Detail Design	0.5	0.5	↔	DD(X) estimate
Basic Construction	0.8	0.8	↔	Adjusted DD(X) estimate
Electronics	0.6	0.6	↑ ↓	Adjusted DD(X) estimate + skin of the ship radar
Hull, Mechanical, and electrical systems	0.1	0.9	↑	DD(X) estimate + nuclear propulsion
Ordnance	0.6	0.8	↑	Adjusted DD(X) estimate + rail gun
Other	0.2	0.2	↔	DD(X) estimate
Subtotal	2.3	3.3	↑	
Change orders	0.4	0.5	↑	Percentage of Production Cost
Total Production Cost	2.7	3.8	↑	
TOTAL COST	3.2	4.3	↑	

Table 19. Cost comparison of the BMD(X)



Ship Class	Type	Displacement (tons)	Crew Size	Armament	Missions	Follow ship procurement cost (FY06 $M)	O&S (FY06 $M)
BMD(X)	Ballistic Defense Ship	15,000	130	Next generation radar system, 4 railguns,	Lone range missile defense and land attack	4,300	38.0
CG(X)	Guided-Missile cruiser	16,000 or more	N.A	Next-generation air and missile defense combat system, 200VLS cells, two helicopters, possible other systems	Long-range air and missile defense, land attack	3,200	48.0
DD(X)	General-Purpose Destroyer	16,000	130	2 Helo, 2 155-mm AGS, 120 VLS	Land attack, ASW	*2,700	40.5
DDG-51 (II)	Guided-Missile Destroyer	9,200	340	AEGIS, 2 Helo, 1 5-inch, 96 VLS	Long-range air and missile defense, land attack, open-ocean ASW	1,800	31.2
CG-52	Guided-Missile Cruiser	9,500	410	AEGIS, 2 Helo, 2 5-inch, 122 VLS	Long-range air and missile defense, land attack, open-ocean ASW	2,000	38.9

Table 20. Operating and Support cost of the BMD(X)

VI. DESIGN EVALUATION

The extensive design above meet the requirements set by SEA-6 and the TSSE Faculty. In addition, it produced a robust multi-mission capable self-sustaining vessel that:

- Can augment the MPF(F) by accommodating the embarked troops and cargo from the FLS and/or CONUS to the Sea Base
- Transit 2640nm @34kts fully loaded with 15% fuel remaining
- And has defensive and offensive combat capabilities

The extensive capabilities of this HSAC lead the team to name it the "Joint ACCESS" for it allows joint forces to quickly and forcefully access areas of the world from a distant Sea Base, which no current vessel can do. Specifically, the Joint ACCESS delivers a joint force's amphibious combat cargo while providing expeditionary support. These capabilities are built into the ship's name as Figure 86 demonstrates.

Figure 56. Joint ACCESS Name and Ship Seal

A. PRIMARY MISSION EVALUATION

The Joint ACCESS satisfies the high speed assault connector requirements as shown in Table 18.

Table 21. Design Requirement Satisfaction

Top Level Requirements	**Joint ACCESS Capability**
Carry two BLTs (~8000LT of Cargo).	A system of twelve ships can transport 9600LT of cargo.
Transport the two BLTs 200nm in one 10 hour period	Each ship can make the 200nm trip at 43kts fully loaded in less than 8 hours and can offload in 2 hours.
Interface with the Sea Base and the beach.	RO-RO capable stern gate and a flight deck with elevator allow for cargo exchange at the Sea Base. 35m floating bow ramp allows for cargo loading/unloading at the beach.
Support amphibious operations ashore in addition to payload delivery.	Flexible combat systems suite provides defensive and offensive capabilities.
Conduct independent operations.	Self-sustaining for up to 10 days and can transit 3380nm @20kts
Conduct secondary missions.	Flight deck, flight deck elevator, helicopter hangar and large flexible cargo areas allow multi-mission capabilities.

In addition to satisfying the above requirements, the Jint ACCESS can effectively augment the MPF(F) ships during seabasing operations. The Joint ACCESS has the facilities to embark 260 troops and their gear and transport them from the forward logistics site or CONUS to the Sea Base. Thus the system of 12 Joint ACCESS vessels can arrive at the Sea Base ready to deploy the two BLTs ashore. This ability not only reduces the number of cargo transfers required at the Sea Base, but also greatly decreases the time needed for employment.

B. SECONDARY MISSIONS

In addition to the capabilities inherent in the Joint ACCESS, it integrates well with supporting forces. Multiple support missions can be conducted. These include but are not limited to:

1. Special Operations Support

The Joint ACCESS will provide mobility for the support and sustainment of SOF in support of the Global War on Terrorism and other traditional SOF missions. While operating in low-threat environments, the Joint ACCESS will embark SOF elements, along with mobility assets and unmanned vehicles to interdict terrorists, weapons of mass destruction, and other high-value targets.

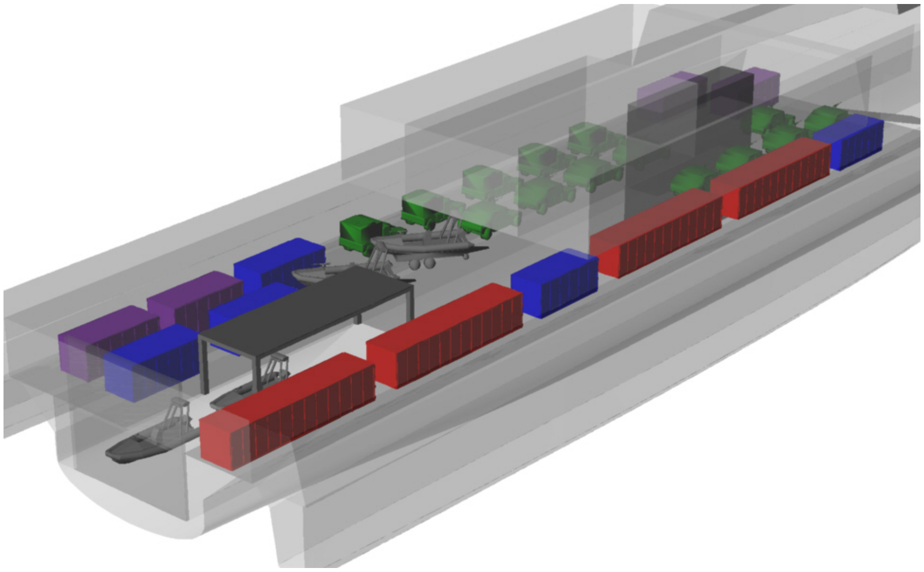


Figure 57. Example Special Operations Support Loadout

2. Embassy and High Asset Reinforcement

As a potential crisis develops, the Joint ACCESS will rapidly deploy a security force, with embarked rotary-wing assets, to reinforce a threatened embassy or high asset without reliance on host nation basing or over flight rights.

3. Humanitarian Assistance/Disaster Relief

The Joint ACCESS' high-speed, its capability to operate in austere, degraded and minor port environments, its interface with the beach, as well as its ability to carry multi-mission Conex boxes, make it ideally suited for supporting HA/DR missions. Because infrastructure at the crisis site is often destroyed or severely degraded, the capability of the Joint ACCESS to deliver supplies to the shore absent port services, tugs, or other infrastructure, allows the JFC to deliver initial forces and relief supplies.

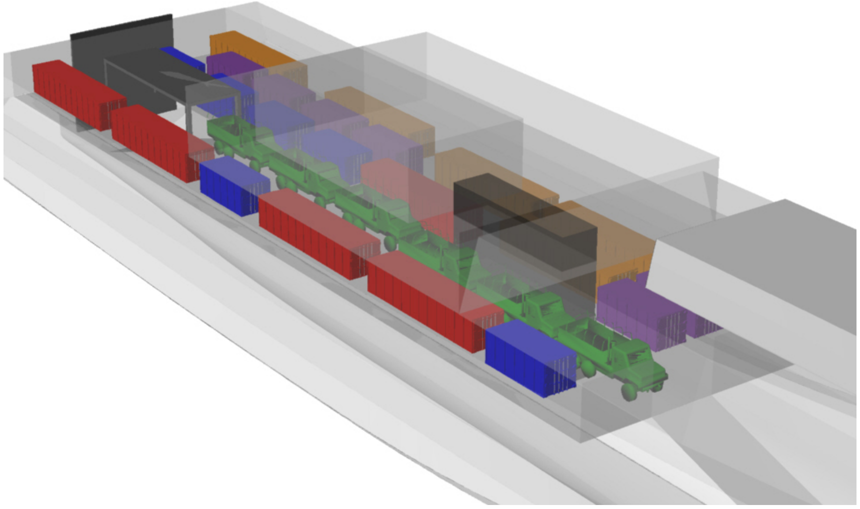


Figure 58. Example Humanitarian and Evacuation Operations Loadout

4. Theater Security Cooperation

With the growing importance of theater engagement activities as a critical element of the Global War on

Terrorism, the Joint ACCESS will provide a platform well suited for executing these engagement missions. As naval forces shift to a surge response posture, forward based Joint ACCESS’ will fill the void left by the decrease in the availability of other platforms to conduct engagement activities throughout the world. The access provided by the Joint ACCESS is especially important in the conduct of port visits and combined training in less developed countries that lack developed infrastructure.

5. Maritime Interdiction

The modularity of the Joint ACCESS’ and their ability to operate independently in the littoral environment will enable them to be rapidly configured to conduct these supporting operations.

C. RISK ASSESSMENT

C. CONCLUSIONS

The 2004 TSSE design team acknowledges that it was unable to perform a thorough analysis on all the technical issues that exist with every ship design. However, the team believes that to achieve the HSAC mission, displacement craft such as the Joint ACCESS need to be researched and implemented.

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APPENDIX I 2006 TSSE PROJECT GUIDANCE

TSSE Total Ship Systems Engineering

June, 2006

TS4002
2006 Capstone Design Project

Ship AntiBallistic Missile Response

1. **TASK.** Your TSSE capstone design project is to examine the concepts associated with ballistic missile defense. From this examination you will produce a design for a ship to enable effective response to ballistic missile threats in the theater of operations. The purpose of your design is to produce a SABR ship that can meet all the requirements specified by SEA-9 to counter anti ballistic missiles in a littoral environment.

2. **OBJECTIVES.** The objectives for this project include:

A. Applying to this project all you have learned in all your previous education.
B. Performing the analysis necessary to define the concept of employment needed to meet a broadly-defined need.
C. Learning first-hand the ship-impact of requirements, cost and performance tradeoffs within technical and acquisition constraints.
D. Increasing your familiarity with the process of evaluating a military need and determining how best to meet it.
E. Obtaining experience in the process of translating broad military requirements to mission-based ship requirements and to specific design tasks resulting from those requirements.
F. Practicing technical teamwork in an interdisciplinary design effort where the quality of the product is greatly affected by team dynamics.

G. Internalizing the systems approach to a Naval ship as a single engineering system satisfying mission requirements.
H. Exploring innovative ideas which may prove useful to those working on similar projects, both inside and outside NPS.

3. **TEAM.** After an initial kickoff period in which the faculty will exert some leadership, you will function as a team in all aspects of this project. As is the case in all team efforts of this nature, you will need to have a leader and you will have to assign the lead on various subtasks to individual team members. However, to be successful (both as a design team and in the academic sense) it will be necessary for you to coordinate your efforts closely. The faculty will expect all team members to be familiar with the major design decisions made by the team, and the reasons therefore. We will expect each team member to be cognizant of the results and major features of subtasks performed by other team members as well, of course, as being fully familiar with the subtasks he had the lead on. *You may expect to be quizzed on such matters.*

4. **BACKGROUND.** All background information and documents are located in the \\kiska\tsse\2004\Background\Reading folder. Your first task is to familiarize yourselves with those documents.

5. **APPROACH.**

A. Phase I-a (Jan). You are the "analysis team". Your first task is to understand the concepts associated with seabasing and expeditionary warfare. Review and understand the requirements from the SEA team. The goal is to determine a set of requirements for the Ship Anti Ballistic Response (BMD(X)) ship. This will require you to consider such things as: threat analysis; existing combat systems capabilities of the Sea Base; and required combat systems capabilities. Furthermore, your ship must be flexible so that it can assist in all aspects of expeditionary warfare including littoral combat and logistic support. Pay particular emphasis on the use of unmanned systems. As you develop your concept of operations, consider the role of the ship in non-expeditionary warfare scenarios. You must also establish desired interfaces with transfer assets (e.g. helos, boats, LCACs, etc.); survivability levels needed; etc.

B. Phase I-b (August). By the end of July you should have developed an initial concept of operations and have acquired desired payload requirements from the SEA team. You should also have a general idea of the desired combat system capabilities based on your threat analysis. You will then start exploring concepts for meeting the basic requirements. By the end of this phase you will have reconciled in more detail the requirements for the basic ship and for its possible variants. Ensure that your overall measure of effectiveness is computable and the SEA team agrees with your choice. Perform an analysis of alternatives to evaluate the optimum basic characteristics (including payload, speed, rough size) of your ship. The faculty members will verify (or change) your intended approach to the basic design and its variants.

C. Phase I-c (September). Refine the operational concept and conclude your analysis of alternatives. Identify a basic hull type and its rough dimensions and geometry.

D. Phase III (September/October/November). During phase III you will perform a more complete design of the basic concept and variants resulting from Phase II. You will prepare a design report suitable for publication as part of an NPS technical report and you will make a formal presentation of your design to members of the NPS community and invited visitors. At or before the beginning of Phase III you will receive from the faculty a list of required "deliverables" which must be included in your report or presentation or both. Past TSSE reports will provide you of a glimpse of what is expected;

however, this list is always subject to change in light of the unique requirements and expectations of each design effort. Your design report will become part of the overall SEI report of the integrated campus project. Do not underestimate the time needed for final report write-up and formatting and preparation of the presentation; this will occupy you most of the month of December. Project presentation usually occurs around December 7th.

6. **FACULTY ROLE.** This is to be YOUR design. Do not feel that you are competing with previous teams or designs. Normally, the faculty will avoid having undue influence. The design will NOT give preference to faculty ideas at the expense of the team's ideas merely because of their faculty source. On the other hand, the faculty will participate in discussions and try to assist you in reaching conclusions, consensus and feasible solutions. In general, we will act like "coaches", though to some degree we will also be team members. We will, of course, act to avoid letting you call for the impossible or unreasonable. After Phase I, the faculty will play two roles – members and coaches of the design team, as discussed above, but we will also, when the occasion calls for it, become the "seniors" of the design team, acting as the decision makers to consider changes to requirements if the design team should propose them. Of course, our main objective is to maximize the utility of the project as a learning experience and we will always retain the right to change the rules as we think it necessary to achieve that objective. The faculty will contribute to the process and will author some sections of the final report. If we deem your report to be of sufficient quality, we will publish it as an NPS technical report, showing all of us as the authors.

7. **ADMINISTRATIVE.** Some administrative items:

A. The six scheduled hours each week are considered mandatory class hours and you will be expected to be present for all of them. We will occasionally use the scheduled time for lectures or presentations by visitors or the faculty. We do not consider the scheduled six hours per week to be sufficient for you to accomplish the necessary tasks to produce a quality design. As in any other course, you are expected to devote between 1 and 2 additional hours for every scheduled hour on the project. You should largely try to use the scheduled hours for coordination and group work and do much of your individual effort outside scheduled times.

B. We will use both the assigned classroom and the Bullard workspace. The latter will be shared by other students, so please be courteous.

C. You will be expected to do library and other research; to make phone calls and contacts and request information from individuals outside NPS. Doing this is always a part of this kind of project in the "real world". The faculty can be of assistance in finding individuals and organizations who can help. (While others will generally be glad to send information, answer questions, etc., don't expect your request to go immediately to the top of their priority list – so timeliness in such efforts is extremely important.)

8. **GRADES.** As is the case with other courses, the faculty must assign you a grade for this project. Frankly, we are strongly of the opinion that it is the team output that is most important and are inclined to give the project a grade and assign the same grade to all the team members. We fully recognize that individuals contribute to different degrees; that some work harder than others; that some facilitate progress while others may actually hinder it. But, as is true in life, the result is what counts and if the result is good, all associated with it bask in the glow – and vice versa. (And learning to cope with the differing contribution levels of team members is one of the "real life" experiences we expect you to reap from this project.) We are inclined to continue to give a single grade for the project to all participants. However, we wish to be able

to have greater insight into the individual contributions you are making and may, from time to time, request that you provide a summary of your personal, recent activities.

9. **AND, FINALLY**. As in any real design effort, this project is open-ended. There is no pre-existing “right” answer. Numerous designs could “work”. We could spend a significant fraction of a career on this project, carrying it to increasing levels of completeness and sophistication. However, this is an academic exercise and we are limited by outside time constraints. Our expectation is that you will work hard, strive for creativity and innovation, work cooperatively, honor commitments to team members and produce work which you are honestly proud of. If you do that, we’ll take care of the rest.

APPENDIX II REQUIREMENTS ANALYSIS

1. Able to counter potential 2025-2030 short/medium range ballistic missile threat by intercept in boost to midcourse phase.

- 1.1. Early Detection
  - 1.1.1. Instantaneous notification of launch
  - 1.1.1.1 System must detect launch quickly within launch basket
    - 1.1.1.1.1 System must detect target within ___ secs from launch
    - 1.1.1.1.2 System must detect target within ___ miles from launch
  - 1.1.2. Receive tracking/cueing data
    - 1.1.2.1 System must have a highly reliable tracking capability
      - 1.1.2.1.1 System must be able to maintain track 99 % time. (under normal environmental conditions)
  - 1.1.3. IFF prior to engagement
    - 1.1.3.1 System must have highly reliable IFF capability
      - 1.1.3.1.1 System must be able to identify threat as Foe with 99% probability.
  - 1.1.4. Low false alarm rate
    - 1.1.4.1. System must have highly reliable detection capability
      - 1.1.4.1.1 P(d) = 99% and P(fa) = 1 %

- 1.2. Efficiently execute fully automated detect to engage sequence
  - 1.2.1. Develop or receive a fire control solution
    - 1.2.1.1 Develop or receive a fire control solution rapidly within boost phase of target.
      - 1.2.1.1.1 Develop or receive a fire control solution within ____ secs from launch.
  - 1.2.2. Make decision or receive decision to shoot
    - 1.2.2.1 Make decisions in either auto or manual mode based on highly reliable data
      - 1.2.2.1.1 Decision criteria based on highest probability of kill of available BMD system
  - 1.2.3. Fire "interceptor" to destroy target
    - 1.2.3.1 interceptor must neutralize target effectively
      - 1.2.3.1.1 interceptor must neutralize target with 80 % prob of kill.
  - 1.2.4. Push button response
    - 1.2.4.1 launch of interceptor must be accomplished by fully automated integration of system components.
      - 1.2.4.1.1 When system placed in ready status, a single point of activation must be available.
  - 1.2.5. Scalable automation
    - 1.2.5.1 System must have ability to switch from auto to manual mode
      - 1.2.5.1.1 System must have 0 % prob of launch without human interaction when in manual mode.
      - 1.2.5.1.2 System must have 100 % prob of launch when in auto mode.
  - 1.2.6. Weapon must have terminal guidance capability
    - 1.2.6.1 System must have active/passive sensors to track threat prior to interception.
      - 1.2.6.1.1 Weapon system must be able to track target at a range that ensures a probability of kill of 80 % or greater.

- 1.2.6.2 Weapon must have sensors capable of tracking multiple types of ballistic missiles.
  - 1.2.6.2.1 Weapon must be capable of tracking 100 % of ballistic missile profiles.

1.3. Effective BDA capability
- 1.3.1. Evaluate and reengage, if necessary
  - 1.3.1.1 System must have highly reliable BDA algorithm
    - 1.3.1.1.1 System must make BDA assessment correctly 95 % of the time.

1.4. Large coverage area
- 1.4.1. Long weapons range.
  - 1.4.1.1 System must provide coverage of threats up to end of midcourse phase.
    - 1.4.1.1.1 Weapons range = 300 nm.
- 1.4.2. USV/UAV capability to increase coverage area
  - 1.4.2.1 System must have highly effective integration with USV/UAV units.
    - 1.4.2.1.1 System integration with 80 % of coalition USV/UAV units must be attainable.
  - 1.4.2.2 System must have capability of launching and recovering USV/UAV units.
    - 1.4.2.2.1 System must launch USV/UAV units within ten minutes of notification.
    - 1.4.2.2.2 System must launch USV/UAV units in sea state 6.
- 1.4.3. Operate close enough to launch site to intercept in boost/midcourse, IVO potentially hostile coast
  - 1.4.3.1 System must operate safely close to launch coastline
    - 1.4.3.1.1 System must maintain operations safely within 12 nm from launch coastline.
- 1.4.4. Large number of simultaneous engagements
  - 1.4.4.1 System must be able to handle multiple ballistic missile threats simultaneously
    - 1.4.4.1.1 Magazine capacity based on type of weapon
    - 1.4.4.1.2 Intercept rate of ten/minute
  - 1.4.4.2. System must have highly efficient Counter-countermeasure capability
    - 1.4.4.2.1 If threat uses counter measures, system must be able to differentiate between threat and counter measures with 95 % degree of accuracy.

2. System must be ship-based

2.1. Self sufficient
- 2.1.1. Power generation
  - 2.1.1.1 Ship must be able to conduct high speed operations to get on station (within launch basket)
  - 2.1.1.1. Speed requirements 20 kts
    - 2.1.1.2. Fuel efficiency/range 1500 nm
- 2.1.3. Self guiding, navigating
  - 2.1.3.1 Ship must have fully-automated navigation and guiding systems
  - 2.1.3.1.1 Automated systems must be 95 % reliable

2.2. Ship must have long endurance time
- 2.2.1 Ship must be able to remain on station for long periods of time

2.2.1.1 Ship must have endurance time of 30 days

2.3. Stealth capabilities

2.3.1. EMCON capable

2.4.1.1 System should suffer minimal degradation in performance under EMCON conditions.

2.4.1.1.1 System must be able to detect & engage threats 95 % of the time under EMCON

2.4. Ship size must be able to meet system requirements

2.5.1 Ship must be large enough to generate electrical power to support combat system requirements applicable to BMD system.

2.5.1.1 Ship must be able to provide power requirements to the weapon system 100 % of the time.

3. System must be able to integrate into the coalition BMD architecture as part of a layered ballistic missile defense

3.1. First layer of defense

3.1.1 System must act as primary method of combating ballistic missile threats.

3.1.1.1 System acts as first layer of defense 100 % of the time.

3.2. Open architecture

3.2.1 System must have ability to allow for upgradeability by different sources.

3.2.1.1 System must utilize at least 75 % of materials under an open architecture.

3.3. Common communications network

3.3.1. Large amount of bandwidth

3.3.1.1 System must have communications bandwidth to keep track of and engage multiple targets simultaneously.

3.3.1.1.1 System must be able to use 90 % available bandwidth.

3.3.1.2 System must have communications bandwidth to communicate with all other coalition BMD assets to facilitate destruction of all BMD threats.

3.3.1.2.1 System must be able to use 90 % available bandwidth.

3.3.2. Redundancy

3.3.2.1 Communication system must be redundant to provide high reliability of detecting, tracking, and engaging BMD threats.

3.3.2.1.1 Two or more coalition assets must be able to share information to effectively destroy BMD threats.

3.4. Reliable handoff to follow on layers of defense

3.4.1 System must have fully automatable capability to hand off engagements to follow on layers of defense.

3.4.1.1 Next layer of defense must receive hand off automatically 100 % time if system fails to destroy BMD threats within its limitations.

3.4.2 System must be able to hand off engagements to follow on layers efficiently and expeditiously.

3.4.2.1 Next layer of defense must receive hand off 100 % time if system fails to destroy BMD threats within its limitations.

4. System must be cost-effective based off probability of kill

4.1. 80 % Probability of kill per weapon

4.1.1. Firing doctrine vs. cost effectiveness

4.1.1.1 The system must use a firing doctrine that maximizes PK, while limiting the number of weapons delivered.

4.1.1.1.1 Maximum PK must require no more than three weapons delivered.

4.2. Cost per shot should be minimized.

4.2.1 Cost per shot = ______________________

4.3. System must be minimal size or employed as a component of a larger system

4.3.1. Multi-mission capable platform

4.3.1.1 Platform must be capable of utilizing weapon for non-BMD missions.

4.3.1.1.1. System should be usable against enemy targets

4.4. Maximize COTS usage/modularity

4.4.1 COTS usage will reduce system's cost.

4.4.1.1. COTS should provide the majority of the parts of the system.

4.4.1.1.1 A minimum of 75% of system's parts should be COTS.

5. System must be able to achieve a 100% on-station time for a particular area despite weather conditions

5.1 Operations in any sea state

5.1.1 System endurance in any sea state

5.1.1.1 System must be able to operate safely and efficiently in many sea states.

5.1.1.1.1 System operation up to sea state 6

5.2 Cover entire coast line

5.2.1 Multiple network units

5.2.1.1 Multiple platforms should be employed to ensure entire threat area is covered by BMD system.

5.2.1.1.1 Number of platforms determined by size of coverage area where coverage area/platform = 200 nm radius.

5.2.1.2 USV/UAV/UUV units will be utilized to increase coverage area in an expeditious manner.

5.2.1.2.1 Capable of launch within 10 minutes notice

5.2.1.2.2 All units centrally controlled

5.2.2 Centrally controlled network system

5.2.2.2 System will be operated and controlled from a central control station capable of transferring control to secondary station if needed.

5.2.2.1.1 Redundant and 100% reliable comms to a Central Control station.

5.2.2.1.2 Each system platform capable of assuming control of system

5.3 Self diagnoses capabilities

5.3.1 System must have capability of running self diagnostic test for evaluation of system components and requirements.

5.3.1.1 Entire weapon system capable of running self diagnostic program once a day

5.3.1.2 Capable of sending self diagnoses report to IMA daily.

5.4. Logistic Support

5.4.1 Multiple logistics facilities

5.4.1.1 Logistics facilities available in forward areas to provide logistics support for entire system.

5.4.1.1.1 Logistics facilities capable of weapon storage to maintain 200 interceptors minimum.

6. System must not require high personnel costs (low manning)

6.1. Highly automated

6.1.1. Integrated watch-stations

6.1.1.1 System must be developed as a highly automated system, requiring few personnel to operate and maintain while still performing its mission at a highly reliable rate.

6.1.1.1.1 System should have no more than 10 personnel to operate and to maintain.

6.1.2. Automated damage control system

6.1.2.1 System must have a fully automated damage control system capable of withstanding significant damage for a sustained period of time while allowing system to still perform its mission effectively.

6.1.2.1.1 Automated damage control system must be fully operational 100 % of the time.

6.1.2.1.2 If system suffers damage, damage control system should enable system to continue to perform its mission at about 50 % capacity.

6.2. Low maintenance

6.2.1. System reliability cost vs. manning

6.2.1.1 System must operate and sustain operations for long periods of time with little or no maintenance

6.2.1.1.1 System must operate for up to 30 days without any major maintenance, only preventive and minor corrective maintenance.

6.2.2. Sea water or air based cooling

6.2.2.1 System must have either an air or a sea-based cooling system to permit sustained operations at sea.

6.2.2.1.1 Air or sea water cooling system must provide 100 % of cooling to all system components.

6.2.2.2 Air or sea-based cooling system composed of next generation alloys(Ti), highly resistive to corrosion.

6.2.2.2.1 Corrosion resistant for life-span of system.

6.2.3. Resistance to corrosion

6.2.3.1 System must be highly resistive to corrosion to permit sustained operations at sea without the need for corrective maintenance.

6.2.3.1.1 System components must resist corrosion for up to 12 months at a minimum.

6.3. Reduce training requirements – shore based facilities

6.3.1. Onboard

6.3.1.1Training required to operate and maintain system must incorporate efforts from both shore based & onboard training facilities.

6.3.1.1.1 Shore based training should be performed on a continued basis while systems are being used.

6.3.1.1.2 Onboard training should be performed at a maximum of 6 hours a week.

6.3.2. Coalition

6.3.2.1 Coalition assets must take part in shore based and onboard training of system, to include having fully qualified personnel capable of operating system at all times.

6.3.2.1.1 Coalition assets should train on a continued basis while systems are being used.

6.3.2.1.1 Coalition assets must have personnel capable of manning and operating systems 100 % of the time.

APPENDIX III DESIGN CONTRACT

Ship Anti-Ballistic Response (SABR)
Circular of Requirements

Stakeholder Signatures:

*TSSE Course Coordinator:*___________________________________

*SEA-9 Course Coordinator:*__________________________________

*TSSE Group Leader:*____

*SEA-9 Group Leader:*_______________________________________

Ship Anti-Ballistic Response (SABR)
Operational Requirements Document (ORD)

1. Introduction

This circular of requirements describes the general requirements for a new ballistic missile defense ship and the essential features and functions (but not necessarily the details) of its design. This vessel will be an essential element of a ballistic missile defense (BMD) system of systems which will include surface, air, sensor and C4I platforms and systems.

The purpose of this circular of requirements is to formalize the stakeholder system expectations in order to serve as a foundation for initial conceptual design. The preferred system architecture, including threshold and optimal levels of performance, as determined through extensive modeling by SEA-9 are included. This document will be used as a handoff between SEA-9 and TSSE-BMD; incorporating the most effective system architecture into viable ship design.

2. Background

Problem statement: To develop and evaluate a conceptualized ship-based BMD system architecture to meet emerging short and medium range ballistic missile threat capability in the 2025-2030 time frame. The system must be able to integrate with prospective coalition BMD architectures and contribute to the whole of layered BMD.

3. Required Operational Capabilities (ROC):

Requirements:

- Rapidly deployable Sea Based Platform capable of prolonged operations.
- Stable platform capable of operations in heavy seas.
- Detect and track over the horizon ballistic missile launch and flight path.
- Share real-time sensor, weapon, fire control, and BDA data among coalition forces.
- Prioritize threats and optimally pair assets with highest probability of kill.
- Designate targets with a low probability of kill to other assets.

Optimal and Threshold Performance Parameters:

- System should combine radar range, interceptor range, ship range and speed, and number of units for an optimal coverage area of 4000 nm (500 threshold).
- The seaframe's endurance, seakeeping ability, magazine capacity, reliability, and logistics support should combine to allow for an optimal

time on station (ready to respond) of 6 months (1 month unreplenished is the minimum threshold), in seas up to sea state 6.
- The installed weapons system should have the optimum capability of launching the interceptor projectile at 10 km/sec, with the minimum threshold velocity of 6 km/sec.
- Automation, high reliability equipment, and low maintenance materials should be employed for an optimal reduction in crew manning of 50% from 2006 standards (25% threshold).
- The ship's maximum speed, sprint endurance and proposed basing locations should allow for rapid deployment in order to be on scene within 3 days of a deployment order (optimally, or in 1 week as a minimum threshold).
- Construction materials, displacement, length, and manning should allow for an optimal lifecycle cost comparable to a LCS-class ship, with the threshold parameter being comparable to a CG-47 class cruiser. Cost estimate per ship: $2.5 billion. Total Annual Operating Cost (assuming 20 engagements): $31.8 million.
- The ship's signature, redundant and dispersed systems, damaged stability and shielding should optimally be maximized for survivability. As a minimum, the ship must meet the US Navy standards for damaged stability and have system redundancy.
- At a minimum the ship must have BMD capabilities. Optimally, it should also be able to defend itself.

4. Design Guidelines

Projected Operating Environment (POE):

All equipment and machinery shall be capable of continuous operation and the ship designed to meet all performance requirements throughout the following ambient conditions:

- Seawater temperatures from a high of 30 °C to a low of minus 2 °C
- Air temperatures from a high of 35 °C to a low of minus 25 °C, with relative humidity ranging from 20% to 100%

- Permanent trim down by the bow or stern as much as 5° from the normal horizontal plane.
- Permanent list of to 15° to either side of the vertical.
- Pitching 10° up or down from the normal horizontal plane.
- Rolling up to 30° to either side of the vertical.

Level of Threat Anticipated:

- Highly proliferated ballistic missile easily acquired with the right amount of money.
- Short range to medium range (<3500 km)
- Exo-atmospheric capable
- Mobile launch capable
- Deployed decoys throughout trajectory
- Two-stage solid propellant (est. 140 s burn time)
- 10-15 minute launch preparation
- Can hit targets with a CEP of 3.5 km
- Can target land and sea targets

General Performance Requirements:

Maximum Speed: 30 knots or greater in calm seas at full load with 80% of installed power.

Patrolling Speed: 5 knots or greater in calm seas at full load.

Maneuvering Speed: 2 knots or less in clam water.

Endurance: 30 days at patrolling speed (unreplenished) with 'burnt-out" levels (10% of usable volume) of fuel, water, and stores still onboard.

Stability: The design shall meet the intact and damaged stability criteria for ocean-going ships based on US Navy DDS 079-1. The intact beam wind criteria shall be 100 knots.

Seakeeping: the ship shall meet the following seakeeping requirements at a speed of 12 knots in sea state 5:

Motion	Limit	Location
Roll	8° *	Center of Gravity
Pitch	3° *	Center of Gravity
Vertical Acceleration	0.4 g*	Bridge
Lateral Acceleration	0.2 g*	Bridge
Slams	20/hr	station 3
Deck Wetness	30/hr	station 0

*Note: Significant (average of the 1/3 highest) value.

Personnel: Crewing should be minimized while maintaining a sufficient number of officer and crew to carry out mission in a safe manner for the duration of patrol.

Structure: The design shall comply with commercial standards such as ABS.

Propulsion: Use any foresee ably probable technology and subsystems while emphasizing automation and reliability. Engines must be capable of using a logistically supportable fuel.

Electric Plant: Install at least two SSGs with enough capacity to support 130% of the power requirements determined by electrical load analysis. If an Integrated Power System (IPS) is used to support propulsion needs, the 25% propulsion power margin may not be used for electrical load or margin. All sensitive electronic gear will have back-up uninterruptible power supply (UPS). Install one emergency generator.

Navigation: Equipment shall include but not be limited to two gyro compasses, two alidades, one magnetic compass, navigation radar, weather fax, global positioning system, electronic and manual plotting capabilities, electronic display and information system (ECDIS), and remote cameras to see astern if 360° vision is not possible from the bridge. Automation and technology should be used where applicable.

Voice Communications: Civilian and military, clear and secure HF/VHF/UHF/SHF radios, satellite.

Data Links: Link 16, CIX: command and control network between coalition forces, Internet.

C2 Capability: Automated Battle Management System (AMBS)

- Two planning functions
  - Plan pre-positioning of ships in group: where each ship should be to guarantee best chances to defend assuming specific scenarios.
  - Plan fire allocation to targets: how many interceptors at which time from which ship should engage each of the targets
- Optimize fire allocation
  - Dynamic programming algorithm for real-time allocation of interceptor to targets in imperfect detection and decoys environment.
  - Based on:
    - Sensors performance
    - Decoy-BM discrimination capability
    - Interceptor capabilities and stocks
- Commercial-off-the-shelf (COTS) components

Surface and Air Search Radar: Conformable skin of the ship radar (SOTSR) assisted by integrated multi-function phased array (MFPA) giving an effective detection range of 2000 NM.

HVAC: Provide for air conditioning the following spaces: pilot house, navigation, interior communications, radio room, berthing, messing, sanitary, galley, workshops, and offices. Other spaces will have ventilation only.

Anchor System: Capable of holding the ship in a 100 knot wind and 5 knot current in a water depth of 200 feet.

Firefighting: Suitable firefighting systems shall be installed to address A, B, C, or D fire* in accessible areas. The firemain should be able to provide 100 gallons/minute through two nozzles that are at the end of a 100 foot fire hose (1.5 inch diameter), leading from the highest fire station on the vessel. The engine room must have an AFFF and Halon system at a minimum.

*Note: Fire class definitions can be found in the NFPA publications or NSTM 555.

Habitability Requirements: Officer Berthing and CPO Berthing shall consist of 2 person rooms. Crew Berthing shall allow for segregated berthing compartments for a male/female crew ratio of 4:1. Extra berths shall be provided for AVDETS, or other specialized teams. The following space allocation is considered a minimum threshold:

Space	Sq.ft/Person
Captain berthing	150
Executive Officer berthing	125
Officer berthing	70
Officer messing/lounge	20
Officer sanitary	15
CPO berthing	40
CPO messing	20
CPO sanitary	10
Crew berthing	25
Crew messing	3
Crew sanitary	5
Administrative	1
Food prep/handling	3
Laundry	1

Personal Effects Weight Allowances:

Officers	400 lbs/person
CPOs	350 lbs/person
Crew	250 lbs/person

Armament:

Optimum ballistic missile interceptor:

- Rail Gun (2 mounts)
- Max effective range: 4400 km (to apex)
- Firing rate: 16-20 rounds/min/mount
- Magazine size: Minimum of 600 interceptors per mount
- Interceptor detail: 2 kg, 10 km/sec muzzle velocity

Threshold ballistic missile interceptor:

- Rail Gun (1 mount)
- Max effective range: 2400 km (to apex)
- Firing rate: 5-10 rounds/min/mount
- Magazine size: Minimum of 600 interceptors per mount
- Interceptor detail: 2 kg, 6 km/sec muzzle velocity

The differences between optimum and threshold interceptors reflect the gap between the costumer’s desires and the realities of physics and hypersonic-flow properties. Every effort will be made to meet the optimum requirement levels. However, if that level of technology does not prove to be feasible, the design will include a less capable (threshold-level) railgun system, or an equally capable missile interceptor system.

Force protection: (4) twin 50 Caliber machine gun mounts
Self defense: appropriate close in weapons system (CIWS)

Signature: An effort should be made to reduce the radar cross-section, acoustic, visual and thermal signatures of the vessel without greatly reducing mission capability or efficiency.

Stores Requirements: Stowage shall be provided for consumable stores as required by the vessel’s endurance of 30 days (unreplenished) based upon the following standards:

General Stores	0.118 cuft/person/day	1.94 lbs/person/day
Dry Provisions	0.134 cuft/person/day	3.2 lbs/person/day
Chilled Provisions	0.081 cuft/person/day	1.65 lbs/person/day
Frozen Provisions	0.041 cuft/person/day	1.11 lbs/person/day
Potable Water Storage	15,000 gallons	
Aviation Fuel Storage	20,000 gallons	

Service Life Allowances: A weight margin of 5% and a KG margin of 0.50 feet shall be added to the full load displacement and KG for future growth considerations.

APPENDIX IV ANALYSIS OF ALTERNATIVE DATA

A. SABR REQUIREMENTS QUESTIONAIRE

B. ANALYTICAL HIERARCHY PROCESS WEIGHT CALCULATIONS

SABR Requirements Questionnaire

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INSTRUCTIONS FOR STAKEHOLDERS:

1) Rank the system characteristics in order of the importance to the design. Choose from the following ranking v 3, 3, 3, 1, 1, 1). Five being the assigned to the most important traits and ones to the least important. In other w two characteristics will be ranked 5, three moderately important characteristics will be ranked 3, and the least imp will be ranked 1.

2) In each category, choose an optimum and a threshold parameter. If the listed values do not satisfactorily qua requirement, write in the values required. For example, for the coverage area group, if it would be nice for the sy cover 3000 nm of coastline, but it absolutely must be able to cover 800 nm, the answer would be: optimal=3000 threshold=800nm.

Design requirements	**Rank** (5,3,1)	**System Characteristics**	(Op/Th)	**Optimal / Threshold Parameters**
number of units ship speed ship range radar range interceptor range		coverage area		4000+ nm (Entire Chinese coastline) 1000-4000 nm (entire North Korean coastline) 500-1000 nm (specific launch areas identified) <500 nm (known launch site)
endurance seakeeping ability magazine capacity reliability logistics support		time on station (ready to respond)		6+ months (replenished) 1-6 months (replenished) 1 month (unreplenished) 1 week-1 month (unreplenished) < 1 week
simultaneous engagements Pd		probability of kill		.99 (last resort system) .50 (first in layered defense)
automation equipment reliability low maintenance material		minimum manning		< 5% of 2006 manning standard 5-25% 25-50% 50-75% >75%
max speed sprint range basing (pre-deploy)		rapidly deployable		On scene in 12 hours 24 hours 48 hours one week two weeks
construction material manning		lifecycle cost per unit		Comparable to CV CG LCS
manning additional weapons systems		multi mission		Multi-mission BMD + SUW BMD plus self defense BMD only
signature redundant systems floodable length DC capabilities		survivability		stealth / redundant systems / countermeasure redundant systems / countermeasures shall meet minimum US Navy criteria for stabil

Characteristics	Coverage Area	Time on station (ready to respond)	Pk	Minimum manning	Rapidly deployable	lifecycle cost per unit	Multi mission	survivability
Priority	18.83	11.04	21.43	8.44	9.74	11.04	8.44	11.04

Characteristics	Coverage Area	Time on station (ready to respond)	Pk	Minimum manning	Rapidly deployable	lifecycle cost per unit	Multi mission	survivability
Coverage Area	1.000	1.706	0.879	2.231	1.933	1.706	2.231	1.706
Time on station (ready to respond)	0.586	1.000	0.515	1.308	1.133	1.000	1.308	1.000
Pk	1.138	1.941	1.000	2.538	2.200	1.941	2.538	1.941
Minimum manning	0.448	0.765	0.394	1.000	0.867	0.765	1.000	0.765
Rapidly deployable	0.517	0.882	0.455	1.154	1.000	0.882	1.154	0.882
lifecycle cost per unit	0.586	1.000	0.515	1.308	1.133	1.000	1.308	1.000
Multi mission	0.448	0.765	0.394	1.000	0.867	0.765	1.000	0.765
survivability	0.586	1.000	0.515	1.308	1.133	1.000	1.308	1.000
Sum	5.3	9.1	4.7	11.8	10.3	9.1	11.8	9.1

AHP	Coverage Area	Time on station (ready to respond)	Pk	Minimum manning	Rapidly deployable	lifecycle cost per unit	Multi mission	survivability	Average
Coverage Area	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188
Time on station (ready to respond)	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
Pk	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214
Minimum manning	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
Rapidly deployable	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
lifecycle cost per unit	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
Multi mission	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
survivability	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
Sum	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

C. COST MODEL

APPENDIX V HULL DESIGN DATA

A. PROPORTIONING AND PRELIMINARY POWERING

B. LINES AND BODY PLAN

C. HYDROSTATICS

The final design and ship geometrical and hydrostatic characteristics were achieved after following an iterative process and are tabulated in Table 20.

Overall Length	648.43	ft
LWL	615.892	ft
Displacement (Δ)	11233.910 LT	LT
Displacement (Δ)	12580.96	tons
Max Draft (T)	16.5	ft
Draft (T) at FP	14.8	ft
Draft (T) at AP	5.5	ft
Beam (B)	78.4	ft
BWL	77.705	ft
Volume	393265.300	ft^3
Length/Beam (L/B)	7.86	
Beam/Draft (B/T)	4.713	
Displacement/length (Δ/L)	48.086	LT/ft
Displacement/length (Δ/L)	59.265	Tons/ft
TPI	90.676	tons/inch
LTPI	80.961	LT/inch
MTI	347057.4	LT-ft/deg
LCB (aft)	345.783a	ft
LCF (aft)	367.053a	ft
VCB	10.44	ft
Waterplane Area	34,010.26	ft^2
Wetted Area	43,644.880	ft^2
Cp	0.58	
Cb	0.495	
Cm	0.853	
Cw	0.711	
KG	15.9	ft

KB	10.248	ft
KMt	42.359	ft
KML	1,840.323	ft
BMt	32.111	ft
BMl	1831.075	ft
GMt	26.459	ft
GML	1824.423	ft
Trim	0.07	(° aft)
Heel	0.00	(°)

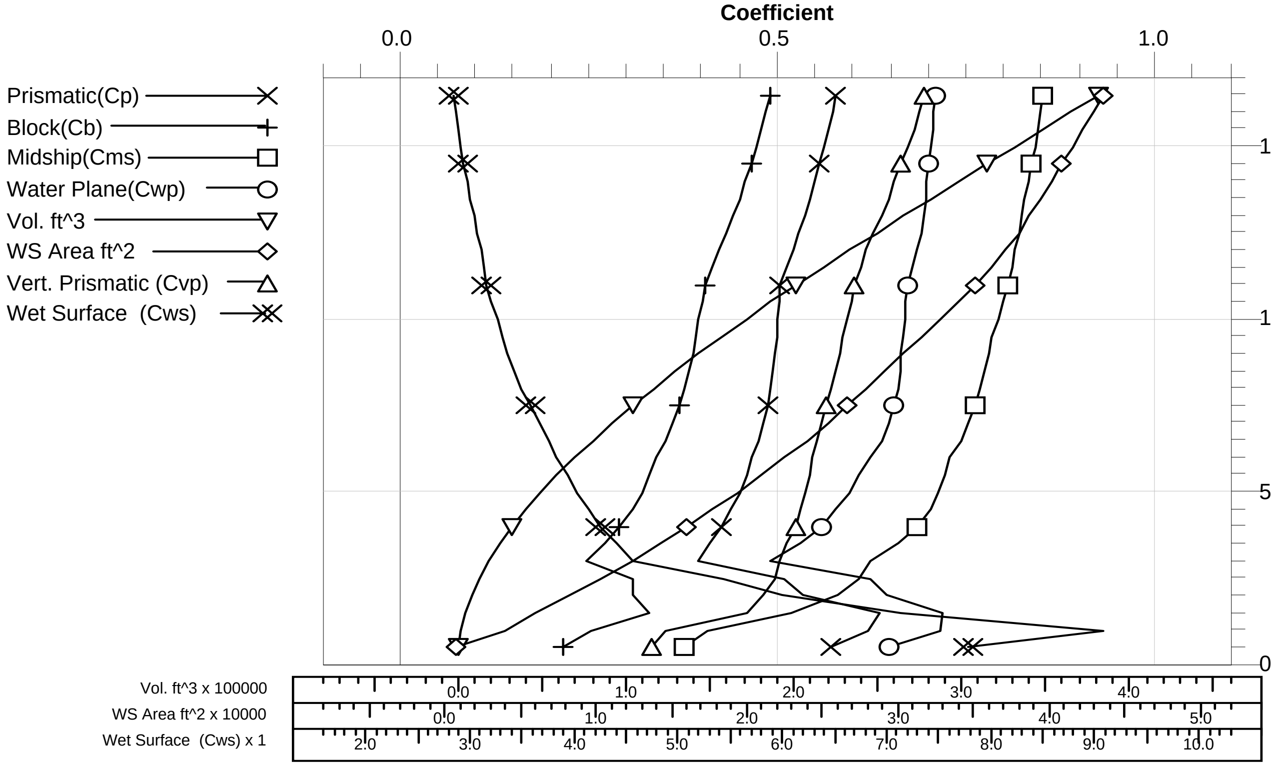
Table 22. ship geometrical and hydrostatic characteristics

Hull Form Coefficients (with appendages)

Baseline Draft: 16.487 at Origin
Trim: aft 0.06 deg.
Heel: stbd 0.00 deg.

Draft	Volume	Coefficients						WS Area
ft	ft^3	Cp	Cb	Cms	Cwp	Cvp	Cws	ft^2
0.223	75.46	0.568	0.212	0.373	0.629	0.337	7.628	686.83
0.713	1,093.10	0.611	0.254	0.415	0.719	0.353	9.072	3,835.57
1.209	3,575.30	0.632	0.329	0.520	0.718	0.458	7.112	5,969.50
1.710	7,071.18	0.533	0.308	0.578	0.643	0.479	5.983	8,213.27
2.207	11,636.76	0.510	0.308	0.603	0.621	0.495	5.409	10,258.56
2.706	17,213.06	0.398	0.247	0.620	0.492	0.501	4.562	12,360.25
3.205	23,784.95	0.412	0.271	0.658	0.530	0.511	4.405	14,256.90
3.703	31,194.00	0.426	0.291	0.683	0.557	0.523	4.244	15,962.41
4.201	39,375.21	0.439	0.307	0.700	0.578	0.531	4.123	17,660.13
4.698	48,303.14	0.449	0.320	0.711	0.596	0.536	4.021	19,320.73
5.195	57,976.49	0.459	0.330	0.719	0.608	0.542	3.916	20,869.34
5.691	68,348.56	0.467	0.339	0.726	0.623	0.544	3.828	22,412.05
6.188	79,395.02	0.474	0.351	0.740	0.637	0.551	3.741	23,873.46
6.684	91,022.45	0.481	0.361	0.751	0.647	0.558	3.659	25,272.82
7.180	103,206.9	0.486	0.370	0.760	0.654	0.565	3.566	26,507.66
7.675	115,856.5	0.490	0.376	0.767	0.659	0.571	3.491	27,782.65
8.170	128,995.9	0.494	0.382	0.773	0.662	0.577	3.424	29,044.46
8.666	142,597.8	0.497	0.387	0.778	0.663	0.583	3.355	30,225.20
9.161	156,612.3	0.499	0.390	0.782	0.665	0.587	3.301	31,464.81
9.656	171,071.2	0.500	0.395	0.790	0.667	0.592	3.250	32,687.04
10.152	185,919.2	0.502	0.400	0.797	0.669	0.598	3.200	33,855.25
10.647	201,096.6	0.502	0.404	0.803	0.671	0.602	3.155	35,031.84
11.144	216,654.4	0.510	0.412	0.809	0.677	0.609	3.126	36,107.89
11.641	232,508.8	0.519	0.422	0.814	0.685	0.616	3.098	37,073.97
12.140	248,587.5	0.527	0.431	0.819	0.689	0.626	3.062	37,891.75
12.640	264,830.2	0.535	0.440	0.823	0.692	0.635	3.026	38,649.70
13.139	281,204.3	0.542	0.448	0.826	0.694	0.645	2.992	39,379.86
13.639	297,699.6	0.549	0.456	0.830	0.697	0.654	2.961	40,093.49
14.139	314,283.4	0.555	0.463	0.835	0.700	0.662	2.932	40,792.32
14.639	330,954.5	0.561	0.471	0.840	0.702	0.671	2.906	41,484.25
15.139	347,709.3	0.566	0.478	0.844	0.704	0.678	2.881	42,161.52
15.640	364,548.8	0.571	0.484	0.847	0.707	0.685	2.860	42,851.74
16.140	381,481.7	0.576	0.490	0.851	0.709	0.692	2.841	43,541.49
16.487	393265.30	0.58	0.495	0.853	0.711	0.698	2.823	43,644.88

Curves of Form (with appendages)



Hydrostatic Properties

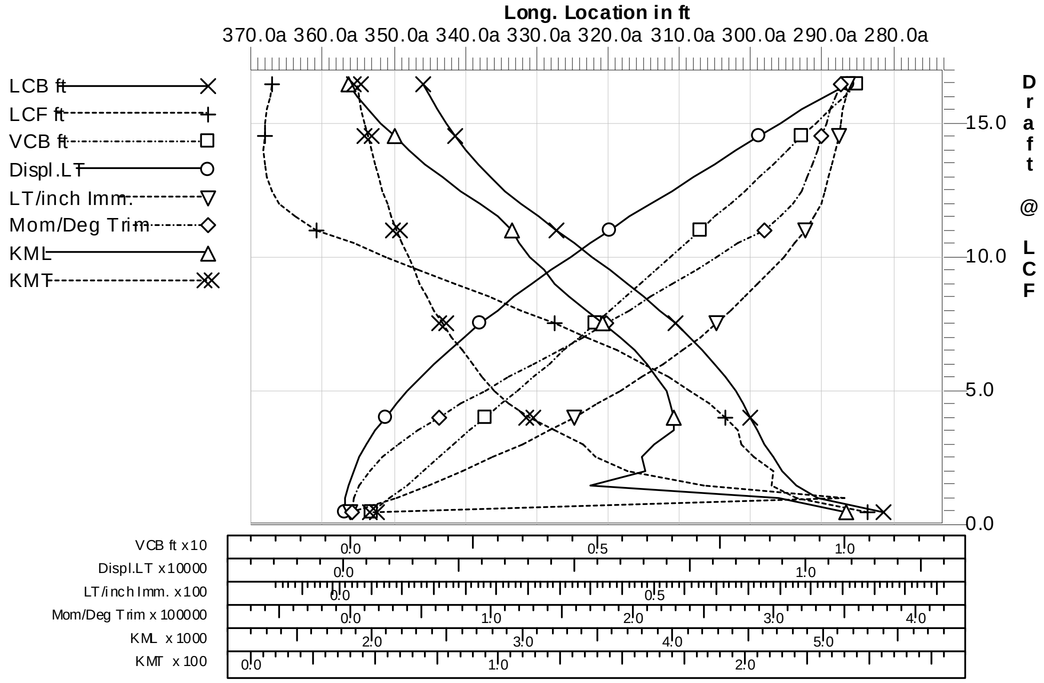
Draft is from Baseline.
Trim: aft 0.06 deg., No heel, VCG = 15.90

LCF Draft (ft)	Displ (LT)	LCB (ft)	VCB (ft)	LCF (ft)
0.5	2.177	280.492a	0.416	282.283a
1.0	31.198	289.901a	0.790	292.911a
1.5	102.110	293.160a	1.125	296.714a
2.0	201.997	294.950a	1.444	296.196a
2.5	332.401	296.143a	1.766	299.006a
3.0	491.589	297.414a	2.089	300.428a
3.5	679.427	298.409a	2.413	301.166a
4.0	891.089	299.372a	2.733	302.753a
4.5	1124.794	300.376a	3.050	305.170a
5.0	1379.836	301.543a	3.366	308.058a
5.5	1656.179	302.913a	3.682	310.973a
6.0	1952.492	304.457a	3.997	314.862a
6.5	2268.043	306.144a	4.311	318.343a
7.0	2600.192	307.985a	4.623	322.529a
7.5	2948.254	310.026a	4.934	327.025a
8.0	3309.600	312.159a	5.242	331.933a
8.5	3684.962	314.407a	5.549	336.366a
9.0	4073.514	316.773a	5.855	341.135a
9.5	4473.860	319.186a	6.159	346.255a
10.0	4886.878	321.676a	6.463	350.753a
10.5	5311.004	324.220a	6.766	355.400a
11.0	5744.576	326.755a	7.067	360.361a
11.5	6188.956	329.285a	7.368	363.651a
12.0	6641.796	331.722a	7.667	365.997a
12.5	7101.088	333.983a	7.964	367.161a
13.0	7564.827	336.038a	8.257	367.770a
13.5	8032.681	337.897a	8.548	368.119a
14.0	8503.864	339.576a	8.837	368.278a
14.5	8977.873	341.091a	9.123	368.244a
15.0	9454.318	342.455a	9.407	368.054a
15.5	9933.053	343.682a	9.689	367.754a
16.0	10414.140	344.787a	9.969	367.429a
16.5	11223.910	345.783a	10.248	367.053a

Water Specific Gravity = 1.025.

LCF Draft (ft)	TPI (LT/inch)	MTI (LT-ft /deg)	KML (ft)	KMT (ft)
0.5	1.593	183.810	4,852.252	50.121
1.0	8.953	2544.567	4,688.533	238.145
1.5	14.070	6089.167	3,432.205	182.612
2.0	19.304	13452.560	3,831.177	151.172
2.5	24.103	21938.750	3,796.990	138.701
3.0	29.011	33337.640	3,900.975	133.299
3.5	33.349	47500.990	4,021.128	121.957
4.0	37.200	62166.420	4,012.606	111.709
4.5	40.902	77954.820	3,986.326	103.551
5.0	44.535	94968.640	3,958.838	97.439
5.5	47.939	111603.800	3,876.355	92.707
6.0	51.450	130285.700	3,838.636	89.194
6.5	54.378	147096.300	3,731.399	85.011
7.0	57.123	164369.600	3,637.348	80.827
7.5	59.585	180014.200	3,513.802	76.990
8.0	61.991	195994.700	3,408.513	73.660
8.5	64.170	210697.000	3,291.497	70.662
9.0	66.310	225988.100	3,194.098	67.975
9.5	68.467	242450.600	3,120.497	65.615
10.0	70.320	256851.300	3,026.923	63.264
10.5	72.094	272567.900	2,955.997	60.834
11.0	73.894	290522.800	2,913.147	58.531
11.5	75.219	302691.500	2,817.755	56.413
12.0	76.312	312294.900	2,709.552	54.503
12.5	77.093	318591.900	2,586.126	52.667
13.0	77.729	323290.000	2,464.139	50.986
13.5	78.281	327071.900	2,348.511	49.459
14.0	78.770	330401.000	2,241.688	48.051
14.5	79.178	333443.700	2,143.583	46.686
15.0	79.552	336446.100	2,054.548	45.427
15.5	79.933	339824.500	1,975.774	44.296
16.0	80.317	343457.300	1,905.216	43.277
16.5	80.961	347057.400	1,840.323	42.359

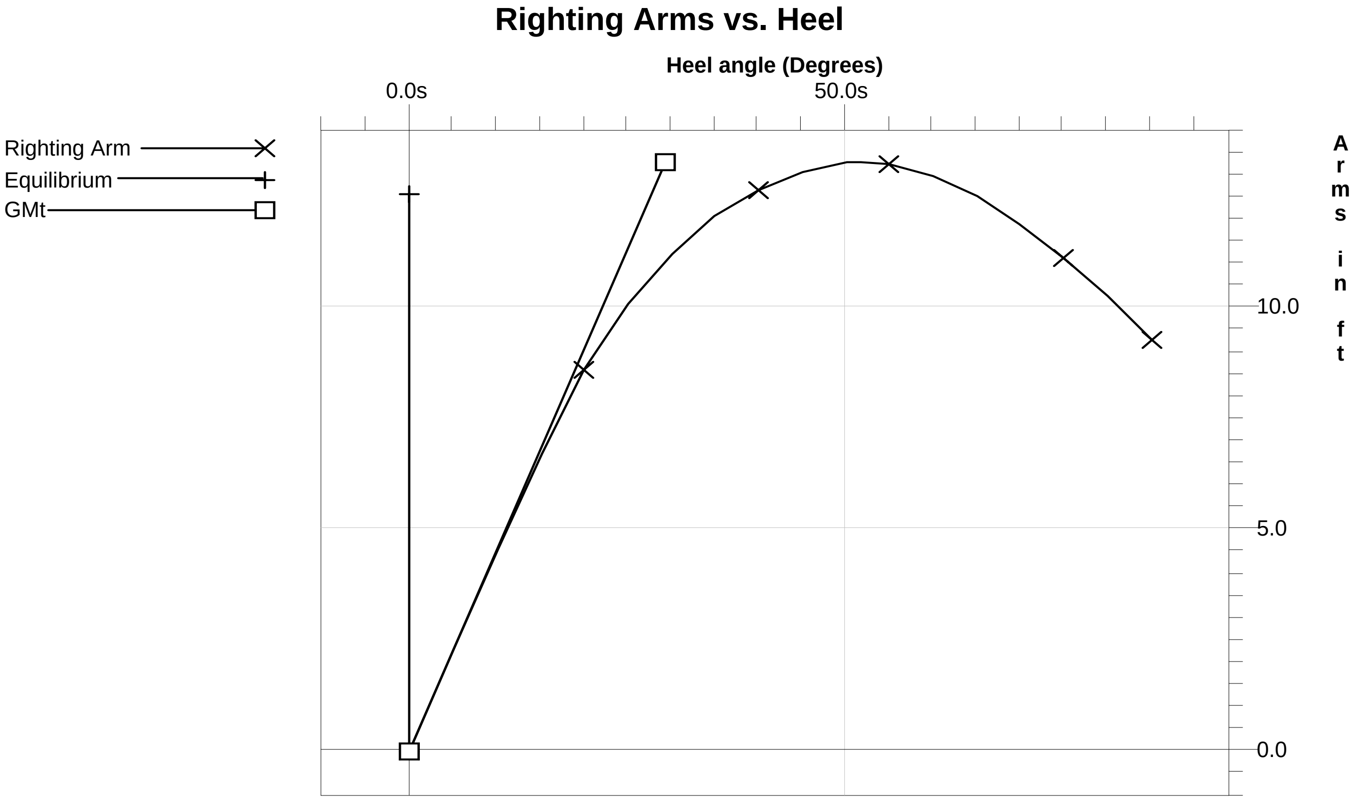
Hydrostatic Properties at Trim = 0.07a, Heel = 0.00



Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Righting Arm (ft)
0.0s	0.06a	16.49	0.00
5.0s	0.06a	16.40	2.27
10.0s	0.06a	16.12	4.54
15.0s	0.05a	15.71	6.72
20.0s	0.03a	15.18	8.59
25.0s	0.02f	14.53	10.09
30.0s	0.08f	13.75	11.22
35.0s	0.15f	12.81	12.04
40.0s	0.24f	11.71	12.63
45.0s	0.32f	10.40	13.06*
50.0s	0.41f	8.93	13.27*
51.64s	0.43f	8.42	13.28*
55.0s	0.49f	7.36	13.23*
60.0s	0.57f	5.69	12.97*
65.0s	0.64f	3.95	12.51*
70.0s	0.71f	2.16	11.90*
75.0s	0.77f	0.31	11.14*
80.0s	0.82f	-1.64	10.25*
85.0s	0.85f	-3.67	9.26*

* Main Deck below sea level



Cross Curves of Stability

Righting Arms(heel) for VCG = 15.90
Trim aft 0.07 deg. at heel = 0 (RA Trim = 0)

Displ (LT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s	35.000s	40.000s
2.177	14.777s	15.960s	20.777s	20.333s	19.263s	18.940s	18.750s	17.440s
31.198	12.664s	17.444s	19.214s	20.114s	20.089s	19.416s	18.427s	17.317s
102.110	11.464s	16.640s	18.681s	19.462s	19.555s	19.176s	18.344s	17.216s
201	10.	15.	18.	18.	19.	18.	18.	17.

.997	658s	702s	002s	865s	039s	767s	066s	079s
332.401	9.806s	14.837s	17.243s	18.255s	18.549s	18.341s	17.741s	16.886s
491.589	8.998s	14.057s	16.521s	17.686s	18.035s	17.902s	17.408s	16.648s
679.427	8.287s	13.329s	15.836s	17.086s	17.533s	17.475s	17.076s	16.438s
891.089	7.710s	12.667s	15.212s	16.498s	17.046s	17.081s	16.774s	16.230s
1124.794	7.211s	12.051s	14.635s	15.963s	16.570s	16.700s	16.490s	16.044s
1379.836	6.766s	11.470s	14.100s	15.476s	16.137s	16.338s	16.219s	15.868s
1656.179	6.360s	10.921s	13.601s	15.028s	15.743s	16.007s	15.966s	15.702s
1952.492	5.987s	10.415s	13.124s	14.607s	15.381s	15.709s	15.737s	15.540s
2268.043	5.655s	9.946s	12.660s	14.207s	15.045s	15.437s	15.530s	15.380s
2600.192	5.358s	9.510s	12.213s	13.827s	14.730s	15.189s	15.342s	15.223s
2948.254	5.090s	9.106s	11.790s	13.466s	14.437s	14.961s	15.165s	15.075s
3309.600	4.834s	8.723s	11.393s	13.120s	14.158s	14.747s	14.993s	14.931s
3684.962	4.596s	8.362s	11.021s	12.786s	13.891s	14.541s	14.821s	14.793s
4073.514	4.372s	8.021s	10.670s	12.465s	13.634s	14.338s	14.651s	14.658s
4473.860	4.158s	7.701s	10.336s	12.159s	13.385s	14.133s	14.482s	14.523s
4886.878	3.961s	7.400s	10.016s	11.866s	13.143s	13.929s	14.311s	14.388s
5311.004	3.777s	7.115s	9.709s	11.586s	12.904s	13.723s	14.142s	14.254s
5744.576	3.606s	6.845s	9.414s	11.318s	12.668s	13.518s	13.970s	14.119s
6188.956	3.444s	6.585s	9.129s	11.057s	12.433s	13.312s	13.799s	13.983s
6641.796	3.289s	6.334s	8.854s	10.804s	12.198s	13.106s	13.626s	13.847s
7101.088	3.142s	6.092s	8.589s	10.555s	11.964s	12.899s	13.452s	13.709s
7564.827	3.002s	5.862s	8.334s	10.308s	11.731s	12.691s	13.277s	13.571s
803	2.8	5.6	8.0	10.	11.	12.	13.	13.

2.681	70s	44s	88s	064s	500s	483s	102s	433s
8503.864	2.749s	5.438s	7.852s	9.824s	11.272s	12.277s	12.928s	13.296s
8977.873	2.638s	5.245s	7.625s	9.587s	11.047s	12.073s	12.755s	13.160s
9454.318	2.537s	5.064s	7.406s	9.354s	10.825s	11.872s	12.584s	13.026s
9933.053	2.445s	4.895s	7.195s	9.126s	10.606s	11.674s	12.415s	12.895s
10414.14	2.361s	4.737s	6.992s	8.903s	10.390s	11.480s	12.249s	12.766s
10897.58	2.284s	4.590s	6.797s	8.686s	10.177s	11.288s	12.087s	12.641s
11383.03	2.214s	4.455s	6.609s	8.474s	9.968s	11.100s	11.927s	12.523s
11871.20	2.150s	4.330s	6.429s	8.267s	9.762s	10.915s	11.771s	12.410s
12361.84	2.091s	4.214s	6.257s	8.066s	9.561s	10.733s	11.617s	12.302s

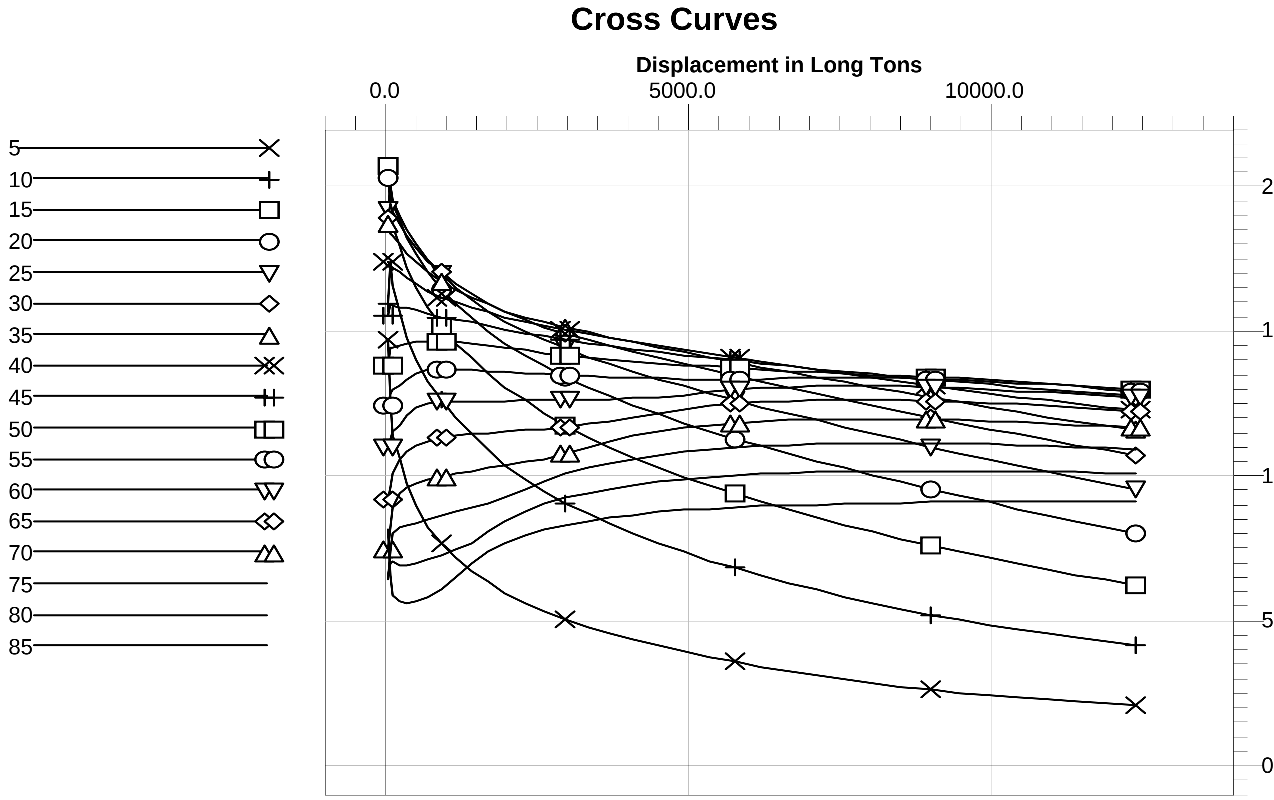
Displ (LT)	45.000s	50.000s	55.000s	60.000s	65.000s
2.177	15.601s	13.819s	12.461s	11.041s	9.218s
31.198	15.986s	14.484s	12.878s	11.266s	9.607s
102.110	15.910s	14.502s	13.030s	11.542s	10.145s
201.997	15.875s	14.556s	13.167s	11.803s	10.570s
332.401	15.825s	14.627s	13.352s	12.101s	10.894s
491.589	15.756s	14.688s	13.547s	12.374s	11.109s
679.427	15.621s	14.709s	13.689s	12.525s	11.233s
891.089	15.522s	14.698s	13.729s	12.588s	11.354s
1124.794	15.429s	14.665s	13.714s	12.618s	11.422s
1379.836	15.338s	14.605s	13.687s	12.631s	11.482s
1656.179	15.228s	14.534s	13.658s	12.631s	11.525s
1952.492	15.106s	14.455s	13.620s	12.637s	11.563s
226	14.	14.	13.	12.	11.

8.043	981s	372s	582s	645s	613s
2600.192	14.860s	14.289s	13.541s	12.652s	11.666s
2948.254	14.745s	14.211s	13.509s	12.662s	11.733s
3309.600	14.634s	14.138s	13.474s	12.679s	11.813s
3684.962	14.527s	14.068s	13.445s	12.702s	11.925s
4073.514	14.425s	14.001s	13.423s	12.732s	12.068s
4473.860	14.324s	13.936s	13.405s	12.778s	12.208s
4886.878	14.225s	13.876s	13.392s	12.848s	12.331s
5311.004	14.128s	13.819s	13.382s	12.931s	12.435s
5744.576	14.031s	13.765s	13.382s	13.007s	12.518s
6188.956	13.935s	13.713s	13.398s	13.068s	12.585s
6641.796	13.838s	13.662s	13.418s	13.114s	12.632s
7101.088	13.742s	13.613s	13.432s	13.141s	12.660s
7564.827	13.647s	13.570s	13.439s	13.152s	12.672s
8032.681	13.550s	13.536s	13.436s	13.149s	12.671s
8503.864	13.454s	13.502s	13.422s	13.136s	12.658s
8977.873	13.362s	13.463s	13.395s	13.111s	12.635s
9454.318	13.278s	13.420s	13.359s	13.078s	12.603s
9933.053	13.199s	13.369s	13.313s	13.036s	12.563s
10414.14	13.122s	13.310s	13.259s	12.986s	12.518s
10897.58	13.043s	13.243s	13.197s	12.929s	12.468s
11383.03	12.963s	13.170s	13.129s	12.866s	12.413s
11871.20	12.880s	13.090s	13.054s	12.796s	12.352s
123	12.	13.	12.	12.	12.

61.84	792s	005s	972s	722s	287s

Displ (LT)	70.000s	75.000s	80.000s	85.000s
2.177	7.476s	6.462s	6.623s	8.175s
31.198	8.224s	7.406s	6.995s	6.612s
102.110	8.937s	8.014s	7.073s	5.918s
201.997	9.417s	8.242s	6.973s	5.691s
332.401	9.648s	8.325s	6.951s	5.616s
491.589	9.771s	8.406s	7.030s	5.680s
679.427	9.900s	8.525s	7.147s	5.823s
891.089	10.016s	8.645s	7.291s	6.099s
1124.794	10.126s	8.776s	7.462s	6.558s
1379.836	10.218s	8.916s	7.702s	7.023s
1656.179	10.311s	9.072s	8.089s	7.411s
1952.492	10.403s	9.262s	8.467s	7.730s
2268.043	10.508s	9.550s	8.784s	7.985s
2600.192	10.635s	9.838s	9.053s	8.189s
2948.254	10.835s	10.087s	9.272s	8.358s
3309.600	11.049s	10.300s	9.450s	8.493s
3684.962	11.247s	10.479s	9.599s	8.606s
4073.514	11.415s	10.628s	9.722s	8.701s
4473.860	11.559s	10.757s	9.825s	8.780s
4886.878	11.679s	10.865s	9.911s	8.845s
5311.004	11.778s	10.952s	9.982s	8.898s
574	11.	11.	10.	8.9

4.576	859s	021s	042s	43s
6188.956	11.920s	11.076s	10.091s	8.981s
6641.796	11.963s	11.119s	10.128s	9.013s
7101.088	11.990s	11.149s	10.155s	9.041s
7564.827	12.002s	11.166s	10.173s	9.067s
8032.681	12.003s	11.171s	10.185s	9.089s
8503.864	11.995s	11.168s	10.192s	9.108s
8977.873	11.978s	11.158s	10.196s	9.125s
9454.318	11.954s	11.144s	10.195s	9.140s
9933.053	11.923s	11.124s	10.191s	9.152s
10414.14	11.887s	11.100s	10.184s	9.162s
10897.58	11.845s	11.072s	10.173s	9.168s
11383.03	11.798s	11.040s	10.158s	9.172s
11871.20	11.747s	11.005s	10.140s	9.172s
12361.84	11.693s	10.966s	10.118s	9.168s



D. FLOODABLE LENGTH

E. ARRANGEMENTS

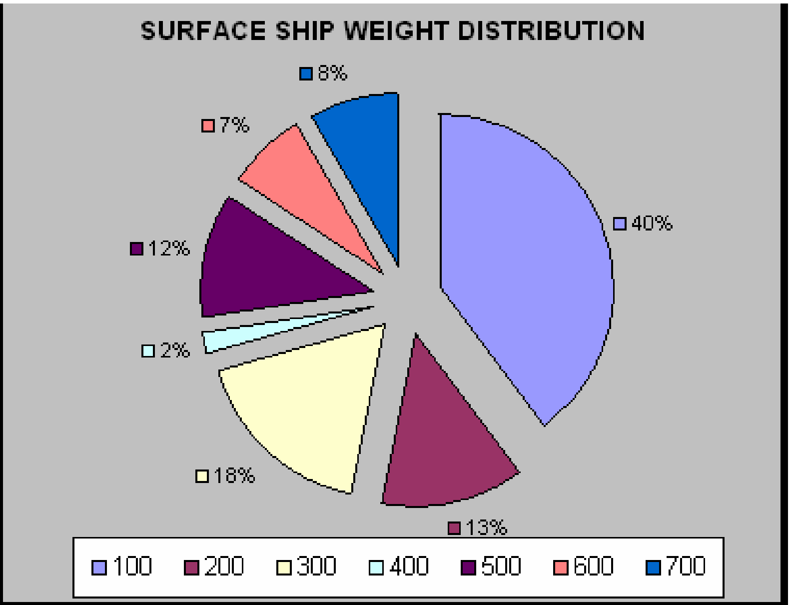
F. STRUCTURE

G. POWERING AND PROPULSION

H. WEIGHTS

SURFACE SHIP WEIGHT ESTIMATION

Group	Description	Weight (tons)
100	Hull Structure	5382
200	Propulsion	1832
300	Electric	2382
400	Command and Surveillance	235
500	Auxiliary Systems	1605
600	Outfit and Furnishings	1012
700	Armament	1129
	TOTAL DESIGN WEIGHT	**13577**


SURFACE SHIP WEIGHT DISTRIBUTION

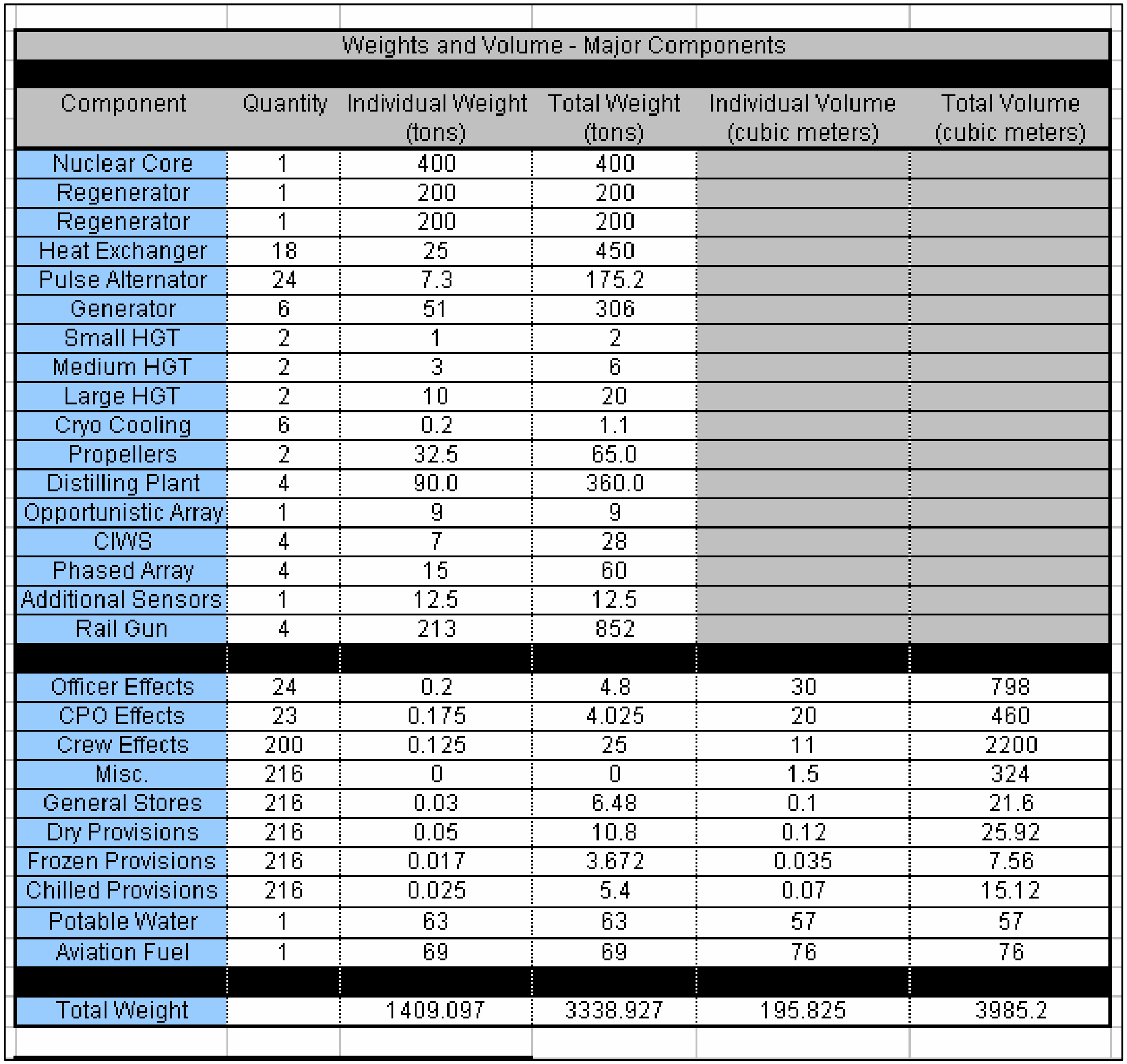
Parent Ship (LSD - 49)

L	LBP	580
B	Max Beam	83.9
T	Average Draft	21
D	WL Displacement	16410.00
Ws	Wetted Surface Area	48962.00
SHP	Shaft Horsepower	33000
V	Speed	22
Cp	Prismatic Coeff.	0.604
Cwp	Waterplane Coeff.	0.779
Fb	Freeboard	39.00
De	Depth	60.00
KW	Kilowatts	5200

Design Ship (SABR)

L	LBP	631.00
B	Max Beam	78.80
T	Average Draft	24.22
D	WL Displacement	15340.00
Ws	Wetted Surface Area	62565.00
SHP	Shaft Horsepower	61000.00
V	Speed	30.00
Cp	Prismatic Coeff.	0.61
Cwp	Waterplane Coeff.	0.73
Fb	Freeboard	30.00
De	Depth	54.22
KW	Kilowatts Normal Load	60000

Major Components

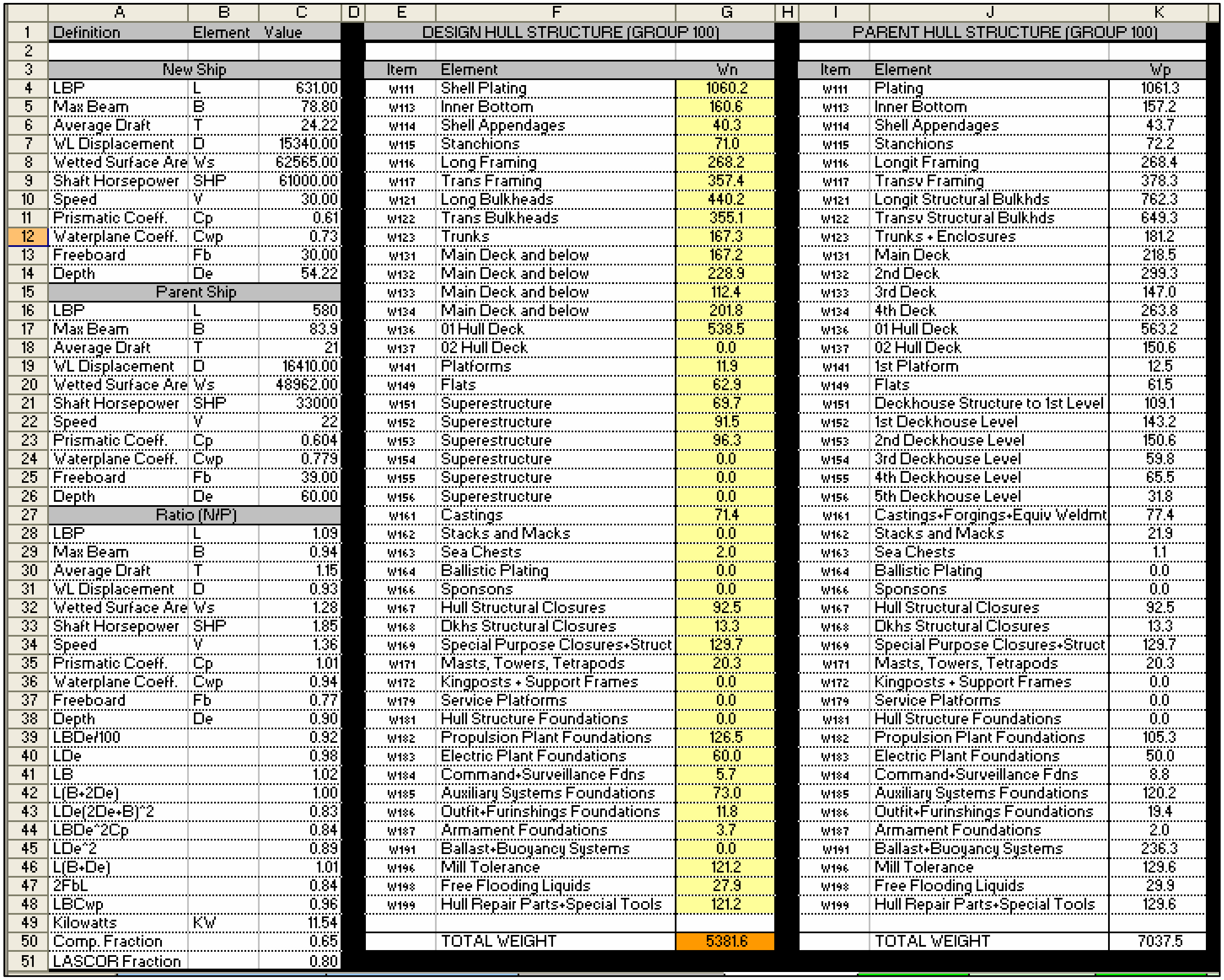


Weights and Volume - Major Components					
Component	Quantity	Individual Weight (tons)	Total Weight (tons)	Individual Volume (cubic meters)	Total Volume (cubic meters)
Nuclear Core	1	400	400		
Regenerator	1	200	200		
Regenerator	1	200	200		
Heat Exchanger	18	25	450		
Pulse Alternator	24	7.3	175.2		
Generator	6	51	306		
Small HGT	2	1	2		
Medium HGT	2	3	6		
Large HGT	2	10	20		
Cryo Cooling	6	0.2	1.1		
Propellers	2	32.5	65.0		
Distilling Plant	4	90.0	360.0		
Opportunistic Array	1	9	9		
CIWS	4	7	28		
Phased Array	4	15	60		
Additional Sensors	1	12.5	12.5		
Rail Gun	4	213	852		
Officer Effects	24	0.2	4.8	30	798
CPO Effects	23	0.175	4.025	20	460
Crew Effects	200	0.125	25	11	2200
Misc.	216	0	0	1.5	324
General Stores	216	0.03	6.48	0.1	21.6
Dry Provisions	216	0.05	10.8	0.12	25.92
Frozen Provisions	216	0.017	3.672	0.035	7.56
Chilled Provisions	216	0.025	5.4	0.07	15.12
Potable Water	1	63	63	57	57
Aviation Fuel	1	69	69	76	76
Total Weight		1409.097	3338.927	195.825	3985.2

Group 100 - Hull Structure

Yellow = Formula Calculation

Blue = Actual Component Weight

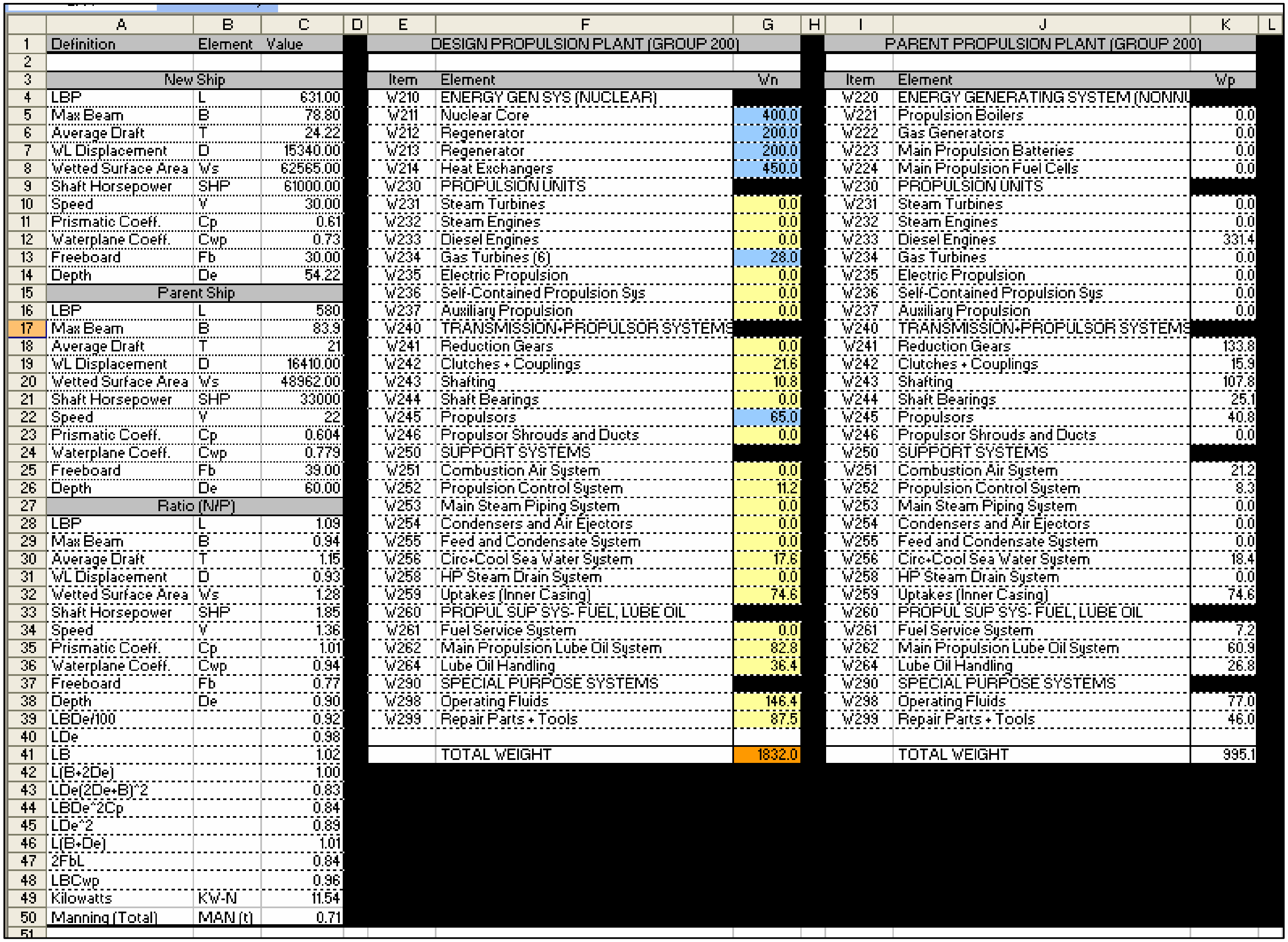


	A	B	C	D	E	F	G	H	I	J	K
1	Definition	Element	Value		DESIGN HULL STRUCTURE (GROUP 100)				PARENT HULL STRUCTURE (GROUP 100)		
2											
3	New Ship				Item	Element	Wn		Item	Element	Wp
4	LBP	L	631.00		W111	Shell Plating	1060.2		W111	Plating	1061.3
5	Max Beam	B	78.80		W113	Inner Bottom	160.6		W113	Inner Bottom	157.2
6	Average Draft	T	24.22		W114	Shell Appendages	40.3		W114	Shell Appendages	43.7
7	WL Displacement	D	15340.00		W115	Stanchions	71.0		W115	Stanchions	72.2
8	Wetted Surface Are	Ws	62565.00		W116	Long Framing	268.2		W116	Longit Framing	268.4
9	Shaft Horsepower	SHP	61000.00		W117	Trans Framing	357.4		W117	Transv Framing	378.3
10	Speed	V	30.00		W121	Long Bulkheads	440.2		W121	Longit Structural Bulkhds	762.3
11	Prismatic Coeff.	Cp	0.61		W122	Trans Bulkheads	355.1		W122	Transv Structural Bulkhds	649.3
12	Waterplane Coeff.	Cwp	0.73		W123	Trunks	167.3		W123	Trunks + Enclosures	181.2
13	Freeboard	Fb	30.00		W131	Main Deck and below	167.2		W131	Main Deck	218.5
14	Depth	De	54.22		W132	Main Deck and below	228.9		W132	2nd Deck	299.3
15	Parent Ship				W133	Main Deck and below	112.4		W133	3rd Deck	147.0
16	LBP	L	580		W134	Main Deck and below	201.8		W134	4th Deck	263.8
17	Max Beam	B	83.9		W136	01 Hull Deck	538.5		W136	01 Hull Deck	563.2
18	Average Draft	T	21		W137	02 Hull Deck	0.0		W137	02 Hull Deck	150.6
19	WL Displacement	D	16410.00		W141	Platforms	11.9		W141	1st Platform	12.5
20	Wetted Surface Are	Ws	48962.00		W149	Flats	62.9		W149	Flats	61.5
21	Shaft Horsepower	SHP	33000		W151	Superestructure	69.7		W151	Deckhouse Structure to 1st Level	109.1
22	Speed	V	22		W152	Superestructure	91.5		W152	1st Deckhouse Level	143.2
23	Prismatic Coeff.	Cp	0.604		W153	Superestructure	96.3		W153	2nd Deckhouse Level	150.6
24	Waterplane Coeff.	Cwp	0.779		W154	Superestructure	0.0		W154	3rd Deckhouse Level	59.8
25	Freeboard	Fb	39.00		W155	Superestructure	0.0		W155	4th Deckhouse Level	65.5
26	Depth	De	60.00		W156	Superestructure	0.0		W156	5th Deckhouse Level	31.8
27	Ratio (N/P)				W161	Castings	71.4		W161	Castings+Forgings+Equiv Weldmt	77.4
28	LBP	L	1.09		W162	Stacks and Macks	0.0		W162	Stacks and Macks	21.9
29	Max Beam	B	0.94		W163	Sea Chests	2.0		W163	Sea Chests	1.1
30	Average Draft	T	1.15		W164	Ballistic Plating	0.0		W164	Ballistic Plating	0.0
31	WL Displacement	D	0.93		W166	Sponsons	0.0		W166	Sponsons	0.0
32	Wetted Surface Are	Ws	1.28		W167	Hull Structural Closures	92.5		W167	Hull Structural Closures	92.5
33	Shaft Horsepower	SHP	1.85		W168	Dkhs Structural Closures	13.3		W168	Dkhs Structural Closures	13.3
34	Speed	V	1.36		W169	Special Purpose Closures+Struct	129.7		W169	Special Purpose Closures+Struct	129.7
35	Prismatic Coeff.	Cp	1.01		W171	Masts, Towers, Tetrapods	20.3		W171	Masts, Towers, Tetrapods	20.3
36	Waterplane Coeff.	Cwp	0.94		W172	Kingposts + Support Frames	0.0		W172	Kingposts + Support Frames	0.0
37	Freeboard	Fb	0.77		W179	Service Platforms	0.0		W179	Service Platforms	0.0
38	Depth	De	0.90		W181	Hull Structure Foundations	0.0		W181	Hull Structure Foundations	0.0
39	LBDe/100		0.92		W182	Propulsion Plant Foundations	126.5		W182	Propulsion Plant Foundations	105.3
40	LDe		0.98		W183	Electric Plant Foundations	60.0		W183	Electric Plant Foundations	50.0
41	LB		1.02		W184	Command+Surveillance Fdns	5.7		W184	Command+Surveillance Fdns	8.8
42	L(B+2De)		1.00		W185	Auxiliary Systems Foundations	73.0		W185	Auxiliary Systems Foundations	120.2
43	LDe(2De+B)^2		0.83		W186	Outfit+Furinshings Foundations	11.8		W186	Outfit+Furinshings Foundations	19.4
44	LBDe^2Cp		0.84		W187	Armament Foundations	3.7		W187	Armament Foundations	2.0
45	LDe^2		0.89		W191	Ballast+Buoyancy Systems	0.0		W191	Ballast+Buoyancy Systems	236.3
46	L(B+De)		1.01		W196	Mill Tolerance	121.2		W196	Mill Tolerance	129.6
47	2FbL		0.84		W198	Free Flooding Liquids	27.9		W198	Free Flooding Liquids	29.9
48	LBCwp		0.96		W199	Hull Repair Parts+Special Tools	121.2		W199	Hull Repair Parts+Special Tools	129.6
49	Kilowatts	KW	11.54								
50	Comp. Fraction		0.65			TOTAL WEIGHT	5381.6			TOTAL WEIGHT	7037.5
51	LASCOR Fraction		0.80								

Group 200 - Propulsion Plant

Yellow = Formula Calculation

Blue = Actual Component Weight

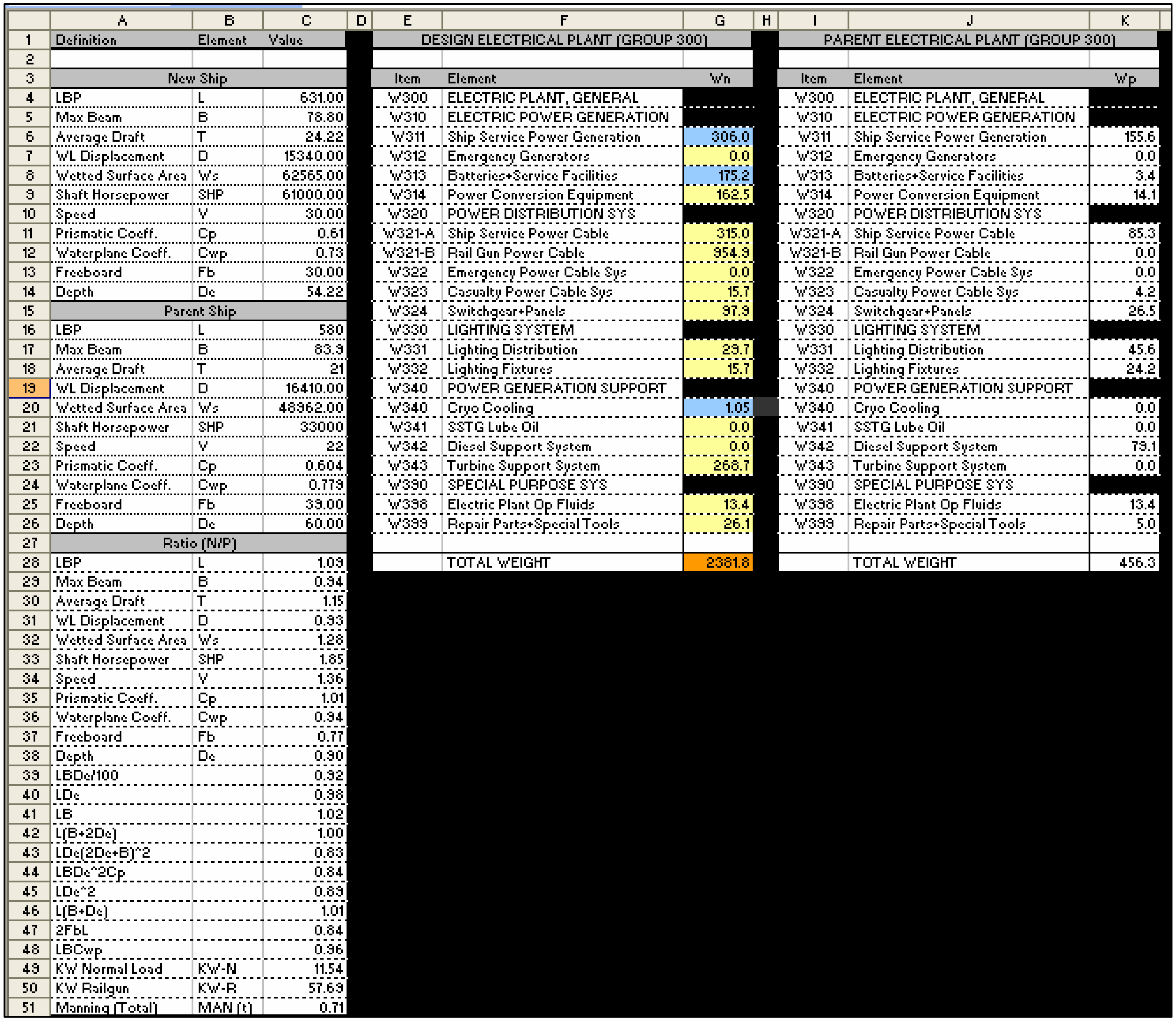


	A	B	C	D	E	F	G	H	I	J	K	L
1	Definition	Element	Value		DESIGN PROPULSION PLANT (GROUP 200)				PARENT PROPULSION PLANT (GROUP 200)			
2												
3	New Ship				Item	Element	Wn		Item	Element	Wp	
4	LBP	L	631.00		W210	ENERGY GEN SYS (NUCLEAR)			W220	ENERGY GENERATING SYSTEM (NONNU		
5	Max Beam	B	78.80		W211	Nuclear Core	400.0		W221	Propulsion Boilers	0.0	
6	Average Draft	T	24.22		W212	Regenerator	200.0		W222	Gas Generators	0.0	
7	WL Displacement	D	15340.00		W213	Regenerator	200.0		W223	Main Propulsion Batteries	0.0	
8	Wetted Surface Area	Ws	62565.00		W214	Heat Exchangers	450.0		W224	Main Propulsion Fuel Cells	0.0	
9	Shaft Horsepower	SHP	61000.00		W230	PROPULSION UNITS			W230	PROPULSION UNITS		
10	Speed	V	30.00		W231	Steam Turbines	0.0		W231	Steam Turbines	0.0	
11	Prismatic Coeff.	Cp	0.61		W232	Steam Engines	0.0		W232	Steam Engines	0.0	
12	Waterplane Coeff.	Cwp	0.73		W233	Diesel Engines	0.0		W233	Diesel Engines	331.4	
13	Freeboard	Fb	30.00		W234	Gas Turbines (6)	28.0		W234	Gas Turbines	0.0	
14	Depth	De	54.22		W235	Electric Propulsion	0.0		W235	Electric Propulsion	0.0	
15	Parent Ship				W236	Self-Contained Propulsion Sys	0.0		W236	Self-Contained Propulsion Sys	0.0	
16	LBP	L	580		W237	Auxiliary Propulsion	0.0		W237	Auxiliary Propulsion	0.0	
17	Max Beam	B	83.9		W240	TRANSMISSION+PROPULSOR SYSTEMS			W240	TRANSMISSION+PROPULSOR SYSTEMS		
18	Average Draft	T	21		W241	Reduction Gears	0.0		W241	Reduction Gears	133.8	
19	WL Displacement	D	16410.00		W242	Clutches + Couplings	21.6		W242	Clutches + Couplings	15.9	
20	Wetted Surface Area	Ws	48962.00		W243	Shafting	10.8		W243	Shafting	107.8	
21	Shaft Horsepower	SHP	33000		W244	Shaft Bearings	0.0		W244	Shaft Bearings	25.1	
22	Speed	V	22		W245	Propulsors	65.0		W245	Propulsors	40.8	
23	Prismatic Coeff.	Cp	0.604		W246	Propulsor Shrouds and Ducts	0.0		W246	Propulsor Shrouds and Ducts	0.0	
24	Waterplane Coeff.	Cwp	0.779		W250	SUPPORT SYSTEMS			W250	SUPPORT SYSTEMS		
25	Freeboard	Fb	39.00		W251	Combustion Air System	0.0		W251	Combustion Air System	21.2	
26	Depth	De	60.00		W252	Propulsion Control System	11.2		W252	Propulsion Control System	8.3	
27	Ratio (N/P)				W253	Main Steam Piping System	0.0		W253	Main Steam Piping System	0.0	
28	LBP	L	1.09		W254	Condensers and Air Ejectors	0.0		W254	Condensers and Air Ejectors	0.0	
29	Max Beam	B	0.94		W255	Feed and Condensate System	0.0		W255	Feed and Condensate System	0.0	
30	Average Draft	T	1.15		W256	Circ+Cool Sea Water System	17.6		W256	Circ+Cool Sea Water System	18.4	
31	WL Displacement	D	0.93		W258	HP Steam Drain System	0.0		W258	HP Steam Drain System	0.0	
32	Wetted Surface Area	Ws	1.28		W259	Uptakes (Inner Casing)	74.6		W259	Uptakes (Inner Casing)	74.6	
33	Shaft Horsepower	SHP	1.85		W260	PROPUL SUP SYS- FUEL, LUBE OIL			W260	PROPUL SUP SYS- FUEL, LUBE OIL		
34	Speed	V	1.36		W261	Fuel Service System	0.0		W261	Fuel Service System	7.2	
35	Prismatic Coeff.	Cp	1.01		W262	Main Propulsion Lube Oil System	82.8		W262	Main Propulsion Lube Oil System	60.9	
36	Waterplane Coeff.	Cwp	0.94		W264	Lube Oil Handling	36.4		W264	Lube Oil Handling	26.8	
37	Freeboard	Fb	0.77		W290	SPECIAL PURPOSE SYSTEMS			W290	SPECIAL PURPOSE SYSTEMS		
38	Depth	De	0.90		W298	Operating Fluids	146.4		W298	Operating Fluids	77.0	
39	LBDe/100		0.92		W299	Repair Parts + Tools	87.5		W299	Repair Parts + Tools	46.0	
40	LDe		0.98									
41	LB		1.02			TOTAL WEIGHT	1832.0			TOTAL WEIGHT	995.1	
42	L(B+2De)		1.00									
43	LDe(2De+B)^2		0.83									
44	LBDe^2Cp		0.84									
45	LDe^2		0.89									
46	L(B+De)		1.01									
47	2FbL		0.84									
48	LBCwp		0.96									
49	Kilowatts	KW-N	11.54									
50	Manning (Total)	MAN (t)	0.71									
51												

Group 300 - Electrical Plant

Yellow = Formula Calculation

Blue = Actual Component Weight

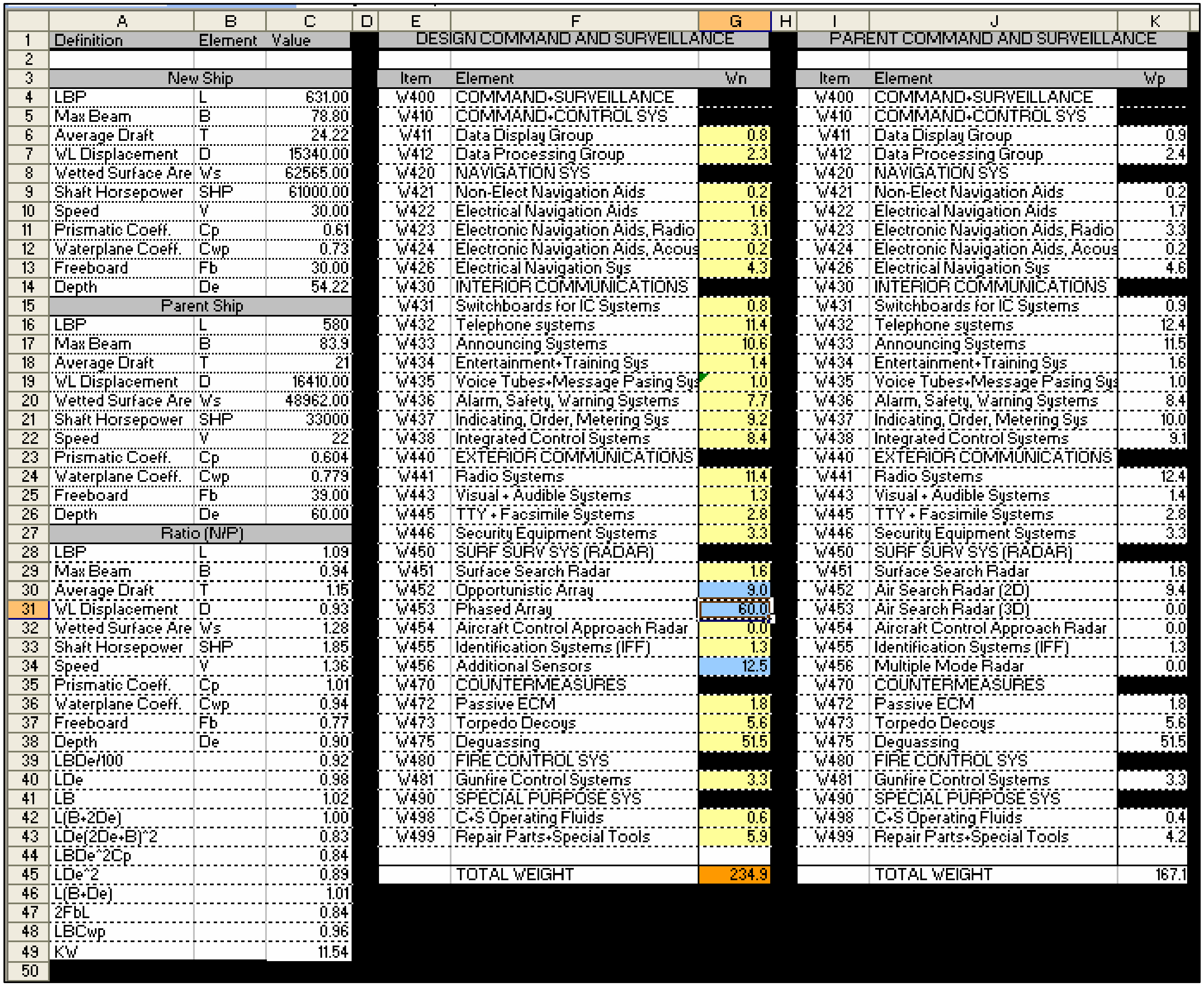


	A	B	C	D	E	F	G	H	I	J	K
1	Definition	Element	Value		DESIGN ELECTRICAL PLANT (GROUP 300)				PARENT ELECTRICAL PLANT (GROUP 300)		
2											
3	New Ship				Item	Element	Wn		Item	Element	Wp
4	LBP	L	631.00		W300	ELECTRIC PLANT, GENERAL			W300	ELECTRIC PLANT, GENERAL	
5	Max Beam	B	78.80		W310	ELECTRIC POWER GENERATION			W310	ELECTRIC POWER GENERATION	
6	Average Draft	T	24.22		W311	Ship Service Power Generation	306.0		W311	Ship Service Power Generation	155.6
7	WL Displacement	D	15340.00		W312	Emergency Generators	0.0		W312	Emergency Generators	0.0
8	Wetted Surface Area	Ws	62565.00		W313	Batteries+Service Facilities	175.2		W313	Batteries+Service Facilities	3.4
9	Shaft Horsepower	SHP	61000.00		W314	Power Conversion Equipment	162.5		W314	Power Conversion Equipment	14.1
10	Speed	V	30.00		W320	POWER DISTRIBUTION SYS			W320	POWER DISTRIBUTION SYS	
11	Prismatic Coeff.	Cp	0.61		W321-A	Ship Service Power Cable	315.0		W321-A	Ship Service Power Cable	85.3
12	Waterplane Coeff.	Cwp	0.73		W321-B	Rail Gun Power Cable	954.9		W321-B	Rail Gun Power Cable	0.0
13	Freeboard	Fb	30.00		W322	Emergency Power Cable Sys	0.0		W322	Emergency Power Cable Sys	0.0
14	Depth	Dc	54.22		W323	Casualty Power Cable Sys	15.7		W323	Casualty Power Cable Sys	4.2
15	Parent Ship				W324	Switchgear+Panels	97.9		W324	Switchgear+Panels	26.5
16	LBP	L	580		W330	LIGHTING SYSTEM			W330	LIGHTING SYSTEM	
17	Max Beam	B	83.9		W331	Lighting Distribution	29.7		W331	Lighting Distribution	45.6
18	Average Draft	T	21		W332	Lighting Fixtures	15.7		W332	Lighting Fixtures	24.2
19	WL Displacement	D	16410.00		W340	POWER GENERATION SUPPORT			W340	POWER GENERATION SUPPORT	
20	Wetted Surface Area	Ws	48962.00		W340	Cryo Cooling	1.05		W340	Cryo Cooling	0.0
21	Shaft Horsepower	SHP	33000		W341	SSTG Lube Oil	0.0		W341	SSTG Lube Oil	0.0
22	Speed	V	22		W342	Diesel Support System	0.0		W342	Diesel Support System	79.1
23	Prismatic Coeff.	Cp	0.604		W343	Turbine Support System	268.7		W343	Turbine Support System	0.0
24	Waterplane Coeff.	Cwp	0.779		W390	SPECIAL PURPOSE SYS			W390	SPECIAL PURPOSE SYS	
25	Freeboard	Fb	39.00		W398	Electric Plant Op Fluids	13.4		W398	Electric Plant Op Fluids	13.4
26	Depth	Dc	60.00		W399	Repair Parts+Special Tools	26.1		W399	Repair Parts+Special Tools	5.0
27	Ratio (N/P)										
28	LBP	L	1.09			TOTAL WEIGHT	2381.8			TOTAL WEIGHT	456.3
29	Max Beam	B	0.94								
30	Average Draft	T	1.15								
31	WL Displacement	D	0.93								
32	Wetted Surface Area	Ws	1.28								
33	Shaft Horsepower	SHP	1.85								
34	Speed	V	1.36								
35	Prismatic Coeff.	Cp	1.01								
36	Waterplane Coeff.	Cwp	0.94								
37	Freeboard	Fb	0.77								
38	Depth	Dc	0.90								
39	LBDc/100		0.92								
40	LDc		0.98								
41	LB		1.02								
42	L(B+2Dc)		1.00								
43	LDc(2Dc+B)^2		0.83								
44	LBDc^2Cp		0.84								
45	LDc^2		0.89								
46	L(B+Dc)		1.01								
47	2FbL		0.84								
48	LBCwp		0.96								
49	KW Normal Load	KW-N	11.54								
50	KW Railgun	KW-R	57.69								
51	Manning (Total)	MAN (t)	0.71								

Group 400 - Command and Surveillance

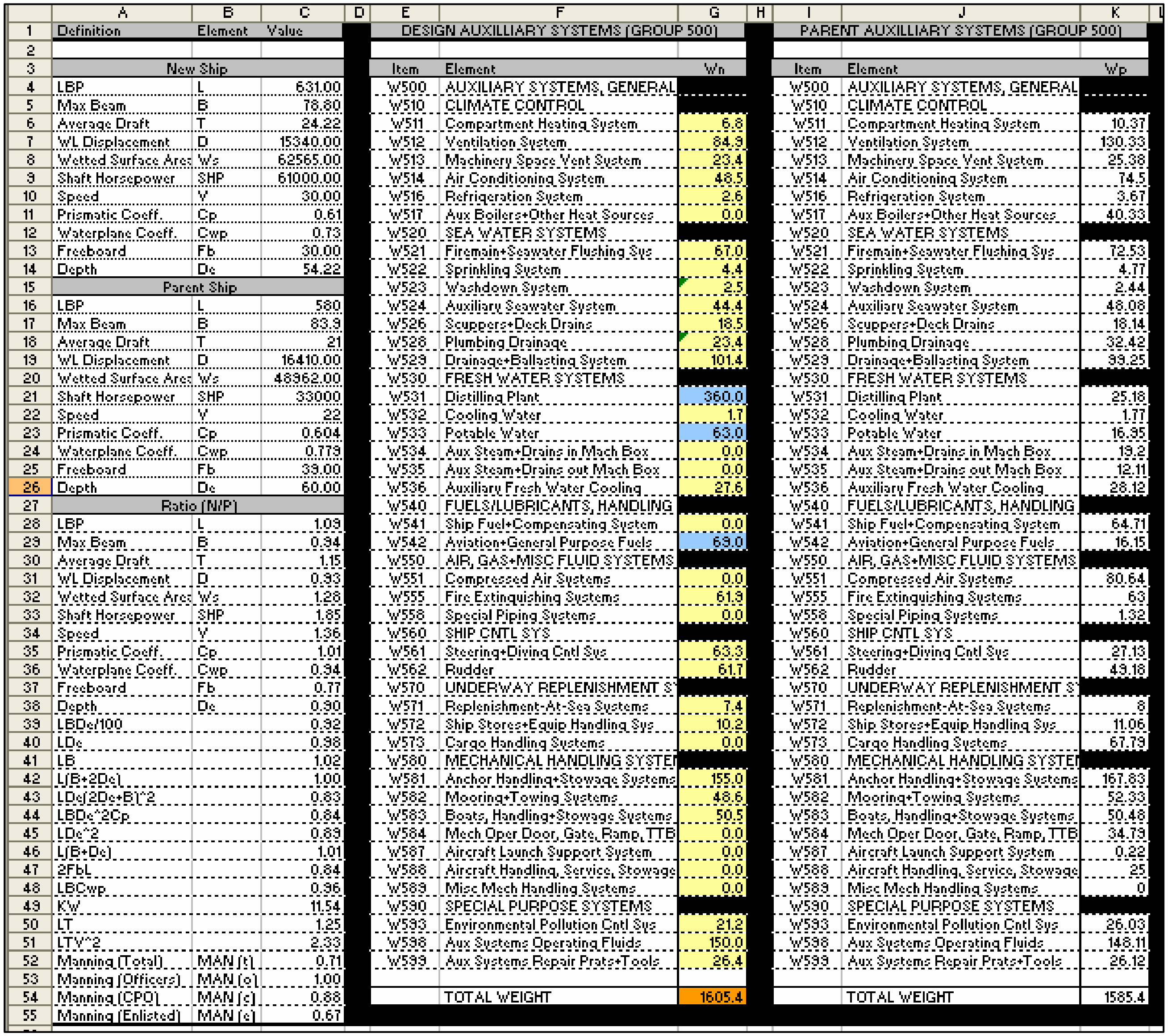
Yellow = Formula Calculation

Blue = Actual Component Weight



	A	B	C	D	E	F	G	H	I	J	K
1	Definition	Element	Value		DESIGN COMMAND AND SURVEILLANCE				PARENT COMMAND AND SURVEILLANCE		
2											
3	New Ship				Item	Element	Wn		Item	Element	Wp
4	LBP	L	631.00		W400	COMMAND+SURVEILLANCE			W400	COMMAND+SURVEILLANCE	
5	Max Beam	B	78.80		W410	COMMAND+CONTROL SYS			W410	COMMAND+CONTROL SYS	
6	Average Draft	T	24.22		W411	Data Display Group	0.8		W411	Data Display Group	0.9
7	WL Displacement	D	15340.00		W412	Data Processing Group	2.3		W412	Data Processing Group	2.4
8	Wetted Surface Are	Ws	62565.00		W420	NAVIGATION SYS			W420	NAVIGATION SYS	
9	Shaft Horsepower	SHP	61000.00		W421	Non-Elect Navigation Aids	0.2		W421	Non-Elect Navigation Aids	0.2
10	Speed	V	30.00		W422	Electrical Navigation Aids	1.6		W422	Electrical Navigation Aids	1.7
11	Prismatic Coeff.	Cp	0.61		W423	Electronic Navigation Aids, Radio	3.1		W423	Electronic Navigation Aids, Radio	3.3
12	Waterplane Coeff.	Cwp	0.73		W424	Electronic Navigation Aids, Acous	0.2		W424	Electronic Navigation Aids, Acous	0.2
13	Freeboard	Fb	30.00		W426	Electrical Navigation Sys	4.3		W426	Electrical Navigation Sys	4.6
14	Depth	De	54.22		W430	INTERIOR COMMUNICATIONS			W430	INTERIOR COMMUNICATIONS	
15	Parent Ship				W431	Switchboards for IC Systems	0.8		W431	Switchboards for IC Systems	0.9
16	LBP	L	580		W432	Telephone systems	11.4		W432	Telephone systems	12.4
17	Max Beam	B	83.9		W433	Announcing Systems	10.6		W433	Announcing Systems	11.5
18	Average Draft	T	21		W434	Entertainment+Training Sys	1.4		W434	Entertainment+Training Sys	1.6
19	WL Displacement	D	16410.00		W435	Voice Tubes+Message Pasing Sys	1.0		W435	Voice Tubes+Message Pasing Sys	1.0
20	Wetted Surface Are	Ws	48962.00		W436	Alarm, Safety, Warning Systems	7.7		W436	Alarm, Safety, Warning Systems	8.4
21	Shaft Horsepower	SHP	33000		W437	Indicating, Order, Metering Sys	9.2		W437	Indicating, Order, Metering Sys	10.0
22	Speed	V	22		W438	Integrated Control Systems	8.4		W438	Integrated Control Systems	9.1
23	Prismatic Coeff.	Cp	0.604		W440	EXTERIOR COMMUNICATIONS			W440	EXTERIOR COMMUNICATIONS	
24	Waterplane Coeff.	Cwp	0.779		W441	Radio Systems	11.4		W441	Radio Systems	12.4
25	Freeboard	Fb	39.00		W443	Visual + Audible Systems	1.3		W443	Visual + Audible Systems	1.4
26	Depth	De	60.00		W445	TTY + Facsimile Systems	2.8		W445	TTY + Facsimile Systems	2.8
27	Ratio (N/P)				W446	Security Equipment Systems	3.3		W446	Security Equipment Systems	3.3
28	LBP	L	1.09		W450	SURF SURV SYS (RADAR)			W450	SURF SURV SYS (RADAR)	
29	Max Beam	B	0.94		W451	Surface Search Radar	1.6		W451	Surface Search Radar	1.6
30	Average Draft	T	1.15		W452	Opportunistic Array	9.0		W452	Air Search Radar (2D)	9.4
31	WL Displacement	D	0.93		W453	Phased Array	60.0		W453	Air Search Radar (3D)	0.0
32	Wetted Surface Are	Ws	1.28		W454	Aircraft Control Approach Radar	0.0		W454	Aircraft Control Approach Radar	0.0
33	Shaft Horsepower	SHP	1.85		W455	Identification Systems (IFF)	1.3		W455	Identification Systems (IFF)	1.3
34	Speed	V	1.36		W456	Additional Sensors	12.5		W456	Multiple Mode Radar	0.0
35	Prismatic Coeff.	Cp	1.01		W470	COUNTERMEASURES			W470	COUNTERMEASURES	
36	Waterplane Coeff.	Cwp	0.94		W472	Passive ECM	1.8		W472	Passive ECM	1.8
37	Freeboard	Fb	0.77		W473	Torpedo Decoys	5.6		W473	Torpedo Decoys	5.6
38	Depth	De	0.90		W475	Deguassing	51.5		W475	Deguassing	51.5
39	LBDe/100		0.92		W480	FIRE CONTROL SYS			W480	FIRE CONTROL SYS	
40	LDe		0.98		W481	Gunfire Control Systems	3.3		W481	Gunfire Control Systems	3.3
41	LB		1.02		W490	SPECIAL PURPOSE SYS			W490	SPECIAL PURPOSE SYS	
42	L(B+2De)		1.00		W498	C+S Operating Fluids	0.6		W498	C+S Operating Fluids	0.4
43	LDe(2De+B)^2		0.83		W499	Repair Parts+Special Tools	5.9		W499	Repair Parts+Special Tools	4.2
44	LBDe^2Cp		0.84								
45	LDe^2		0.89			TOTAL WEIGHT	234.9			TOTAL WEIGHT	167.1
46	L(B+De)		1.01								
47	2FbL		0.84								
48	LBCwp		0.96								
49	KW		11.54								
50											

Group 500 - Auxiliary Systems
Yellow = Formula Calculation
Blue = Actual Component Weight

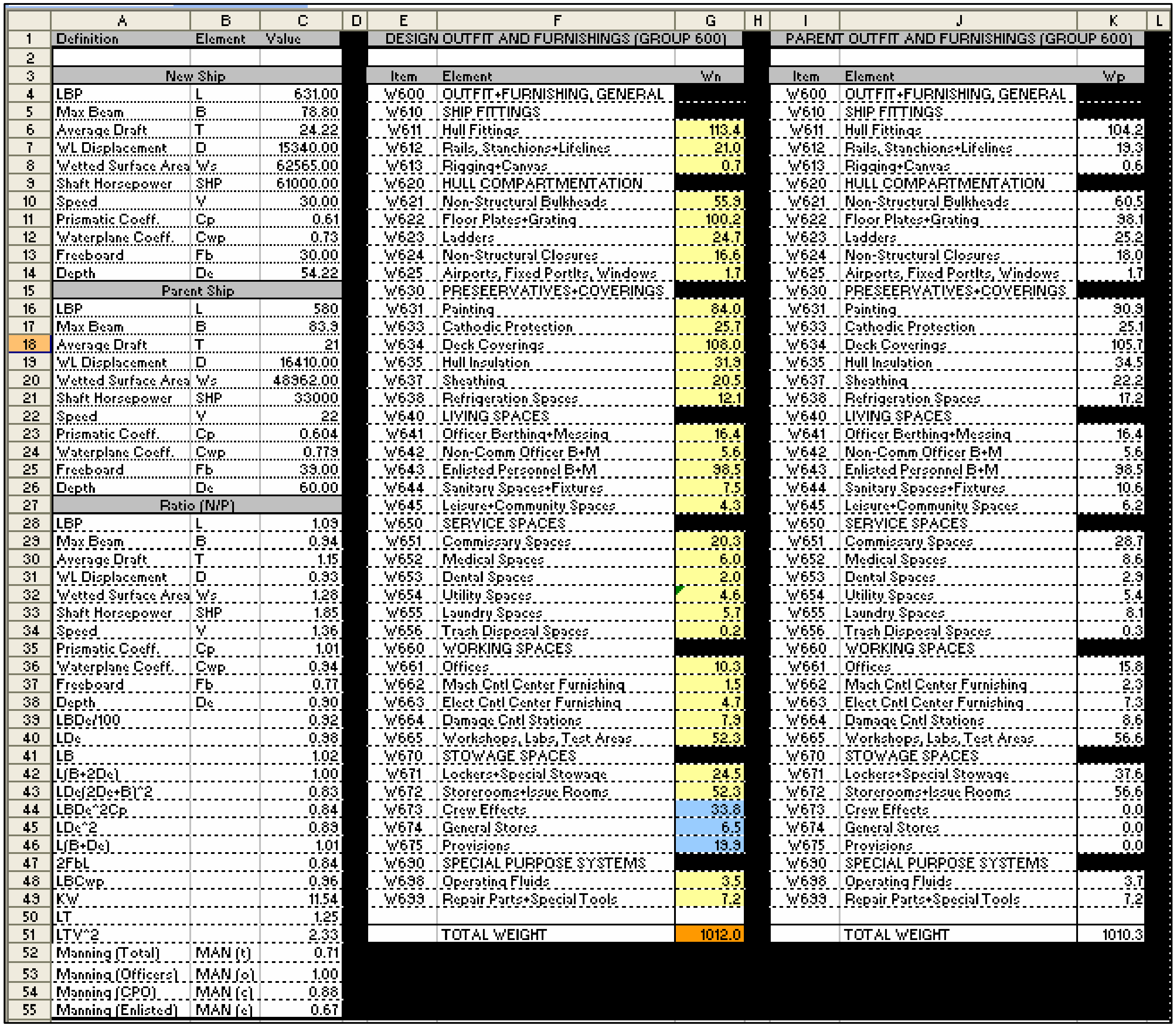


	A	B	C	D	E	F	G	H	I	J	K
1	Definition	Element	Value		DESIGN AUXILLIARY SYSTEMS (GROUP 500)				PARENT AUXILLIARY SYSTEMS (GROUP 500)		
2											
3	New Ship				Item	Element	Wn		Item	Element	Wp
4	LBP	L	631.00		W500	AUXILIARY SYSTEMS, GENERAL			W500	AUXILIARY SYSTEMS, GENERAL	
5	Max Beam	B	78.80		W510	CLIMATE CONTROL			W510	CLIMATE CONTROL	
6	Average Draft	T	24.22		W511	Compartment Heating System	6.8		W511	Compartment Heating System	10.37
7	WL Displacement	D	15340.00		W512	Ventilation System	84.9		W512	Ventilation System	130.33
8	Wetted Surface Are	Ws	62565.00		W513	Machinery Space Vent System	23.4		W513	Machinery Space Vent System	25.38
9	Shaft Horsepower	SHP	61000.00		W514	Air Conditioning System	48.5		W514	Air Conditioning System	74.5
10	Speed	V	30.00		W516	Refrigeration System	2.6		W516	Refrigeration System	3.67
11	Prismatic Coeff.	Cp	0.61		W517	Aux Boilers+Other Heat Sources	0.0		W517	Aux Boilers+Other Heat Sources	40.33
12	Waterplane Coeff.	Cwp	0.73		W520	SEA WATER SYSTEMS			W520	SEA WATER SYSTEMS	
13	Freeboard	Fb	30.00		W521	Firemain+Seawater Flushing Sys	67.0		W521	Firemain+Seawater Flushing Sys	72.53
14	Depth	Dc	54.22		W522	Sprinkling System	4.4		W522	Sprinkling System	4.77
15	Parent Ship				W523	Washdown System	2.5		W523	Washdown System	2.44
16	LBP	L	580		W524	Auxiliary Seawater System	44.4		W524	Auxiliary Seawater System	48.08
17	Max Beam	B	83.9		W526	Scuppers+Deck Drains	18.5		W526	Scuppers+Deck Drains	18.14
18	Average Draft	T	21		W528	Plumbing Drainage	23.4		W528	Plumbing Drainage	32.42
19	WL Displacement	D	16410.00		W529	Drainage+Ballasting System	101.4		W529	Drainage+Ballasting System	39.25
20	Wetted Surface Are	Ws	48962.00		W530	FRESH WATER SYSTEMS			W530	FRESH WATER SYSTEMS	
21	Shaft Horsepower	SHP	33000		W531	Distilling Plant	360.0		W531	Distilling Plant	25.18
22	Speed	V	22		W532	Cooling Water	1.7		W532	Cooling Water	1.77
23	Prismatic Coeff.	Cp	0.604		W533	Potable Water	63.0		W533	Potable Water	16.95
24	Waterplane Coeff.	Cwp	0.779		W534	Aux Steam+Drains in Mach Box	0.0		W534	Aux Steam+Drains in Mach Box	19.2
25	Freeboard	Fb	39.00		W535	Aux Steam+Drains out Mach Box	0.0		W535	Aux Steam+Drains out Mach Box	12.11
26	Depth	Dc	60.00		W536	Auxiliary Fresh Water Cooling	27.6		W536	Auxiliary Fresh Water Cooling	28.12
27	Ratio (N/P)				W540	FUELS/LUBRICANTS, HANDLING			W540	FUELS/LUBRICANTS, HANDLING	
28	LBP	L	1.09		W541	Ship Fuel+Compensating System	0.0		W541	Ship Fuel+Compensating System	64.71
29	Max Beam	B	0.94		W542	Aviation+General Purpose Fuels	69.0		W542	Aviation+General Purpose Fuels	16.15
30	Average Draft	T	1.15		W550	AIR, GAS+MISC FLUID SYSTEMS			W550	AIR, GAS+MISC FLUID SYSTEMS	
31	WL Displacement	D	0.93		W551	Compressed Air Systems	0.0		W551	Compressed Air Systems	80.64
32	Wetted Surface Are	Ws	1.28		W555	Fire Extinguishing Systems	61.9		W555	Fire Extinguishing Systems	63
33	Shaft Horsepower	SHP	1.85		W558	Special Piping Systems	0.0		W558	Special Piping Systems	1.32
34	Speed	V	1.36		W560	SHIP CNTL SYS			W560	SHIP CNTL SYS	
35	Prismatic Coeff.	Cp	1.01		W561	Steering+Diving Cntl Sys	63.3		W561	Steering+Diving Cntl Sys	27.13
36	Waterplane Coeff.	Cwp	0.94		W562	Rudder	61.7		W562	Rudder	49.18
37	Freeboard	Fb	0.77		W570	UNDERWAY REPLENISHMENT S			W570	UNDERWAY REPLENISHMENT S	
38	Depth	Dc	0.90		W571	Replenishment-At-Sea Systems	7.4		W571	Replenishment-At-Sea Systems	8
39	LBDc/100		0.92		W572	Ship Stores+Equip Handling Sys	10.2		W572	Ship Stores+Equip Handling Sys	11.06
40	LDc		0.98		W573	Cargo Handling Systems	0.0		W573	Cargo Handling Systems	67.79
41	LB		1.02		W580	MECHANICAL HANDLING SYSTE			W580	MECHANICAL HANDLING SYSTE	
42	L(B+2Dc)		1.00		W581	Anchor Handling+Stowage Systems	155.0		W581	Anchor Handling+Stowage Systems	167.83
43	LDc(2Dc+B)^2		0.83		W582	Mooring+Towing Systems	48.6		W582	Mooring+Towing Systems	52.33
44	LBDc^2Cp		0.84		W583	Boats, Handling+Stowage Systems	50.5		W583	Boats, Handling+Stowage Systems	50.48
45	LDc^2		0.89		W584	Mech Oper Door, Gate, Ramp, TTB	0.0		W584	Mech Oper Door, Gate, Ramp, TTB	34.79
46	L(B+Dc)		1.01		W587	Aircraft Launch Support System	0.0		W587	Aircraft Launch Support System	0.22
47	2FbL		0.84		W588	Aircraft Handling, Service, Stowage	0.0		W588	Aircraft Handling, Service, Stowage	25
48	LBCwp		0.96		W589	Misc Mech Handling Systems	0.0		W589	Misc Mech Handling Systems	0
49	KW		11.54		W590	SPECIAL PURPOSE SYSTEMS			W590	SPECIAL PURPOSE SYSTEMS	
50	LT		1.25		W593	Environmental Pollution Cntl Sys	21.2		W593	Environmental Pollution Cntl Sys	26.03
51	LTV^2		2.33		W598	Aux Systems Operating Fluids	150.0		W598	Aux Systems Operating Fluids	148.11
52	Manning (Total)	MAN (t)	0.71		W599	Aux Systems Repair Prats+Tools	26.4		W599	Aux Systems Repair Prats+Tools	26.12
53	Manning (Officers)	MAN (o)	1.00								
54	Manning (CPO)	MAN (c)	0.88			TOTAL WEIGHT	1605.4			TOTAL WEIGHT	1585.4
55	Manning (Enlisted)	MAN (e)	0.67								

Group 600 – Outfit and Furnishings

Yellow = Formula Calculation

Blue = Actual Component Weight

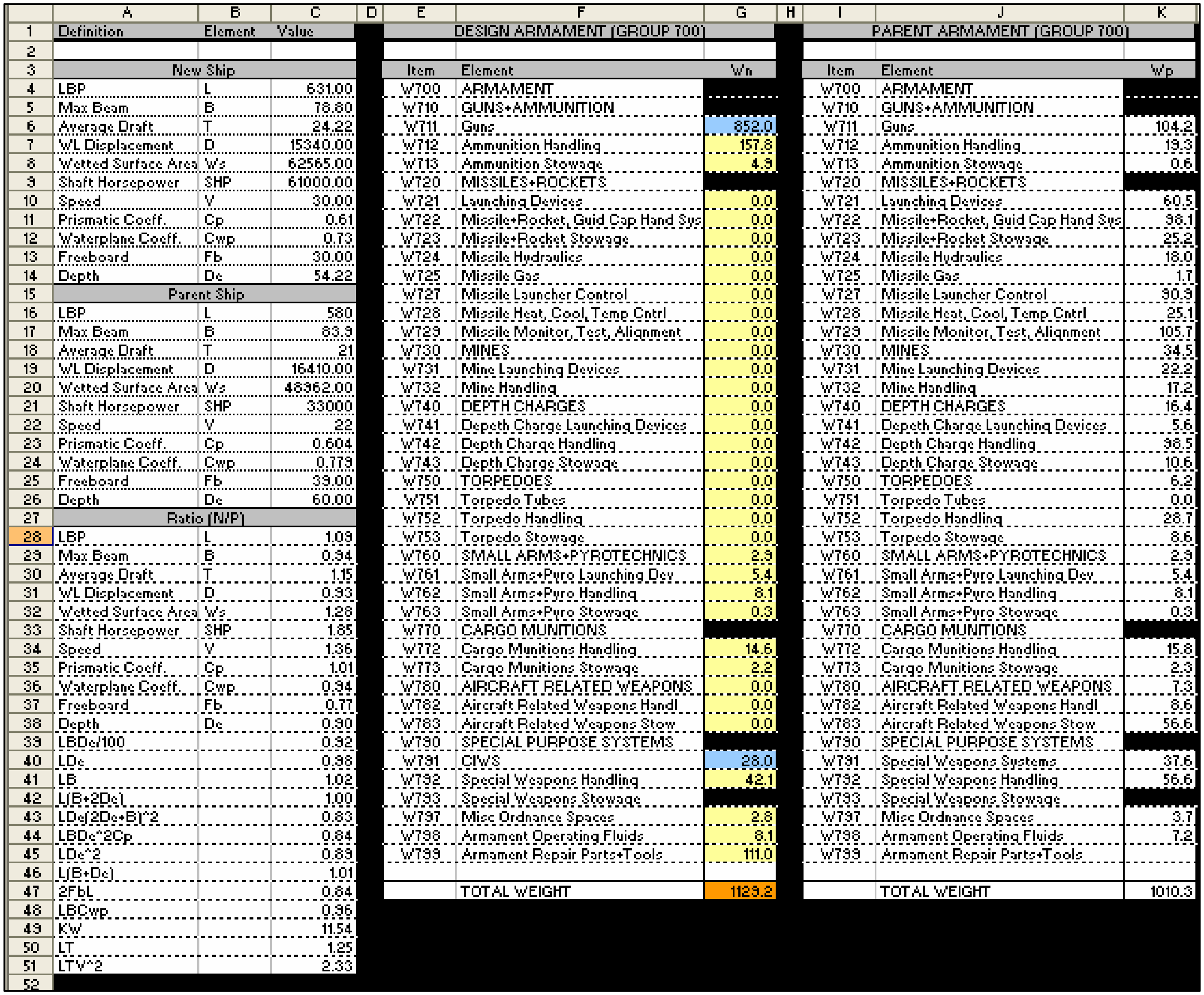


	A	B	C	D	E	F	G	H	I	J	K	L
1	Definition	Element	Value		DESIGN OUTFIT AND FURNISHINGS (GROUP 600)				PARENT OUTFIT AND FURNISHINGS (GROUP 600)			
2												
3	New Ship				Item	Element	Wn		Item	Element	Wp	
4	LBP	L	631.00		W600	OUTFIT+FURNISHING, GENERAL			W600	OUTFIT+FURNISHING, GENERAL		
5	Max Beam	B	78.80		W610	SHIP FITTINGS			W610	SHIP FITTINGS		
6	Average Draft	T	24.22		W611	Hull Fittings	113.4		W611	Hull Fittings	104.2	
7	WL Displacement	D	15340.00		W612	Rails, Stanchions+Lifelines	21.0		W612	Rails, Stanchions+Lifelines	19.3	
8	Wetted Surface Area	Ws	62565.00		W613	Rigging+Canvas	0.7		W613	Rigging+Canvas	0.6	
9	Shaft Horsepower	SHP	61000.00		W620	HULL COMPARTMENTATION			W620	HULL COMPARTMENTATION		
10	Speed	V	30.00		W621	Non-Structural Bulkheads	55.9		W621	Non-Structural Bulkheads	60.5	
11	Prismatic Coeff.	Cp	0.61		W622	Floor Plates+Grating	100.2		W622	Floor Plates+Grating	98.1	
12	Waterplane Coeff.	Cwp	0.73		W623	Ladders	24.7		W623	Ladders	25.2	
13	Freeboard	Fb	30.00		W624	Non-Structural Closures	16.6		W624	Non-Structural Closures	18.0	
14	Depth	Dc	54.22		W625	Airports, Fixed Portlts, Windows	1.7		W625	Airports, Fixed Portlts, Windows	1.7	
15	Parent Ship				W630	PRESEERVATIVES+COVERINGS			W630	PRESEERVATIVES+COVERINGS		
16	LBP	L	580		W631	Painting	84.0		W631	Painting	90.9	
17	Max Beam	B	83.9		W633	Cathodic Protection	25.7		W633	Cathodic Protection	25.1	
18	Average Draft	T	21		W634	Deck Coverings	108.0		W634	Deck Coverings	105.7	
19	WL Displacement	D	16410.00		W635	Hull Insulation	31.9		W635	Hull Insulation	34.5	
20	Wetted Surface Area	Ws	48962.00		W637	Sheathing	20.5		W637	Sheathing	22.2	
21	Shaft Horsepower	SHP	33000		W638	Refrigeration Spaces	12.1		W638	Refrigeration Spaces	17.2	
22	Speed	V	22		W640	LIVING SPACES			W640	LIVING SPACES		
23	Prismatic Coeff.	Cp	0.604		W641	Officer Berthing+Messing	16.4		W641	Officer Berthing+Messing	16.4	
24	Waterplane Coeff.	Cwp	0.779		W642	Non-Comm Officer B+M	5.6		W642	Non-Comm Officer B+M	5.6	
25	Freeboard	Fb	39.00		W643	Enlisted Personnel B+M	98.5		W643	Enlisted Personnel B+M	98.5	
26	Depth	Dc	60.00		W644	Sanitary Spaces+Fixtures	7.5		W644	Sanitary Spaces+Fixtures	10.6	
27	Ratio (N/P)				W645	Leisure+Community Spaces	4.3		W645	Leisure+Community Spaces	6.2	
28	LBP	L	1.09		W650	SERVICE SPACES			W650	SERVICE SPACES		
29	Max Beam	B	0.94		W651	Commissary Spaces	20.3		W651	Commissary Spaces	28.7	
30	Average Draft	T	1.15		W652	Medical Spaces	6.0		W652	Medical Spaces	8.6	
31	WL Displacement	D	0.93		W653	Dental Spaces	2.0		W653	Dental Spaces	2.9	
32	Wetted Surface Area	Ws	1.28		W654	Utility Spaces	4.6		W654	Utility Spaces	5.4	
33	Shaft Horsepower	SHP	1.85		W655	Laundry Spaces	5.7		W655	Laundry Spaces	8.1	
34	Speed	V	1.36		W656	Trash Disposal Spaces	0.2		W656	Trash Disposal Spaces	0.3	
35	Prismatic Coeff.	Cp	1.01		W660	WORKING SPACES			W660	WORKING SPACES		
36	Waterplane Coeff.	Cwp	0.94		W661	Offices	10.3		W661	Offices	15.8	
37	Freeboard	Fb	0.77		W662	Mach Cntl Center Furnishing	1.5		W662	Mach Cntl Center Furnishing	2.3	
38	Depth	Dc	0.90		W663	Elect Cntl Center Furnishing	4.7		W663	Elect Cntl Center Furnishing	7.3	
39	LBDc/100		0.92		W664	Damage Cntl Stations	7.9		W664	Damage Cntl Stations	8.6	
40	LDc		0.98		W665	Workshops, Labs, Test Areas	52.3		W665	Workshops, Labs, Test Areas	56.6	
41	LB		1.02		W670	STOWAGE SPACES			W670	STOWAGE SPACES		
42	L(B+2Dc)		1.00		W671	Lockers+Special Stowage	24.5		W671	Lockers+Special Stowage	37.6	
43	LDc(2Dc+B)^2		0.83		W672	Storerooms+Issue Rooms	52.3		W672	Storerooms+Issue Rooms	56.6	
44	LBDc^2Cp		0.84		W673	Crew Effects	33.8		W673	Crew Effects	0.0	
45	LDc^2		0.89		W674	General Stores	6.5		W674	General Stores	0.0	
46	L(B+Dc)		1.01		W675	Provisions	19.9		W675	Provisions	0.0	
47	2FbL		0.84		W690	SPECIAL PURPOSE SYSTEMS			W690	SPECIAL PURPOSE SYSTEMS		
48	LBCwp		0.96		W698	Operating Fluids	3.5		W698	Operating Fluids	3.7	
49	KW		11.54		W699	Repair Parts+Special Tools	7.2		W699	Repair Parts+Special Tools	7.2	
50	LT		1.25									
51	LTV^2		2.33			TOTAL WEIGHT	1012.0			TOTAL WEIGHT	1010.3	
52	Manning (Total)	MAN (t)	0.71									
53	Manning (Officers)	MAN (o)	1.00									
54	Manning (CPO)	MAN (c)	0.88									
55	Manning (Enlisted)	MAN (e)	0.67									

Group 700 - Armament

Yellow = Formula Calculation

Blue = Actual Component Weight



	A	B	C	D	E	F	G	H	I	J	K
1	Definition	Element	Value		DESIGN ARMAMENT (GROUP 700)				PARENT ARMAMENT (GROUP 700)		
2											
3	New Ship				Item	Element	Wn		Item	Element	Wp
4	LBP	L	631.00		W700	ARMAMENT			W700	ARMAMENT	
5	Max Beam	B	78.80		W710	GUNS+AMMUNITION			W710	GUNS+AMMUNITION	
6	Average Draft	T	24.22		W711	Guns	852.0		W711	Guns	104.2
7	WL Displacement	D	15340.00		W712	Ammunition Handling	157.8		W712	Ammunition Handling	19.3
8	Wetted Surface Area	Ws	62565.00		W713	Ammunition Stowage	4.9		W713	Ammunition Stowage	0.6
9	Shaft Horsepower	SHP	61000.00		W720	MISSILES+ROCKETS			W720	MISSILES+ROCKETS	
10	Speed	V	30.00		W721	Launching Devices	0.0		W721	Launching Devices	60.5
11	Prismatic Coeff.	Cp	0.61		W722	Missile+Rocket, Guid Cap Hand Sys	0.0		W722	Missile+Rocket, Guid Cap Hand Sys	38.1
12	Waterplane Coeff.	Cwp	0.73		W723	Missile+Rocket Stowage	0.0		W723	Missile+Rocket Stowage	25.2
13	Freeboard	Fb	30.00		W724	Missile Hydraulics	0.0		W724	Missile Hydraulics	18.0
14	Depth	Dc	54.22		W725	Missile Gas	0.0		W725	Missile Gas	1.7
15	Parent Ship				W727	Missile Launcher Control	0.0		W727	Missile Launcher Control	30.9
16	LBP	L	580		W728	Missile Heat, Cool, Temp Cntrl	0.0		W728	Missile Heat, Cool, Temp Cntrl	25.1
17	Max Beam	B	83.9		W729	Missile Monitor, Test, Alignment	0.0		W729	Missile Monitor, Test, Alignment	105.7
18	Average Draft	T	21		W730	MINES	0.0		W730	MINES	34.5
19	WL Displacement	D	16410.00		W731	Mine Launching Devices	0.0		W731	Mine Launching Devices	22.2
20	Wetted Surface Area	Ws	48362.00		W732	Mine Handling	0.0		W732	Mine Handling	17.2
21	Shaft Horsepower	SHP	33000		W740	DEPTH CHARGES	0.0		W740	DEPTH CHARGES	16.4
22	Speed	V	22		W741	Depeth Charge Launching Devices	0.0		W741	Depeth Charge Launching Devices	5.6
23	Prismatic Coeff.	Cp	0.604		W742	Depth Charge Handling	0.0		W742	Depth Charge Handling	38.5
24	Waterplane Coeff.	Cwp	0.779		W743	Depth Charge Stowage	0.0		W743	Depth Charge Stowage	10.6
25	Freeboard	Fb	39.00		W750	TORPEDOES	0.0		W750	TORPEDOES	6.2
26	Depth	Dc	60.00		W751	Torpedo Tubes	0.0		W751	Torpedo Tubes	0.0
27	Ratio (N/P)				W752	Torpedo Handling	0.0		W752	Torpedo Handling	28.7
28	LBP	L	1.09		W753	Torpedo Stowage	0.0		W753	Torpedo Stowage	8.6
29	Max Beam	B	0.94		W760	SMALL ARMS+PYROTECHNICS	2.9		W760	SMALL ARMS+PYROTECHNICS	2.9
30	Average Draft	T	1.15		W761	Small Arms+Pyro Launching Dev	5.4		W761	Small Arms+Pyro Launching Dev	5.4
31	WL Displacement	D	0.93		W762	Small Arms+Pyro Handling	8.1		W762	Small Arms+Pyro Handling	8.1
32	Wetted Surface Area	Ws	1.28		W763	Small Arms+Pyro Stowage	0.3		W763	Small Arms+Pyro Stowage	0.3
33	Shaft Horsepower	SHP	1.85		W770	CARGO MUNITIONS			W770	CARGO MUNITIONS	
34	Speed	V	1.36		W772	Cargo Munitions Handling	14.6		W772	Cargo Munitions Handling	15.8
35	Prismatic Coeff.	Cp	1.01		W773	Cargo Munitions Stowage	2.2		W773	Cargo Munitions Stowage	2.3
36	Waterplane Coeff.	Cwp	0.94		W780	AIRCRAFT RELATED WEAPONS	0.0		W780	AIRCRAFT RELATED WEAPONS	7.3
37	Freeboard	Fb	0.77		W782	Aircraft Related Weapons Handl	0.0		W782	Aircraft Related Weapons Handl	8.6
38	Depth	Dc	0.90		W783	Aircraft Related Weapons Stow	0.0		W783	Aircraft Related Weapons Stow	56.6
39	LBDc/100		0.92		W790	SPECIAL PURPOSE SYSTEMS			W790	SPECIAL PURPOSE SYSTEMS	
40	LDc		0.98		W791	CIWS	28.0		W791	Special Weapons Systems	37.6
41	LB		1.02		W792	Special Weapons Handling	42.1		W792	Special Weapons Handling	56.6
42	L(B+2Dc)		1.00		W793	Special Weapons Stowage			W793	Special Weapons Stowage	
43	LDc(2Dc+B)^2		0.83		W797	Misc Ordnance Spaces	2.8		W797	Misc Ordnance Spaces	3.7
44	LBDc^2Cp		0.84		W798	Armament Operating Fluids	8.1		W798	Armament Operating Fluids	7.2
45	LDc^2		0.89		W799	Armament Repair Parts+Tools	111.0		W799	Armament Repair Parts+Tools	
46	L(B+Dc)		1.01								
47	2FbL		0.84			TOTAL WEIGHT	1123.2			TOTAL WEIGHT	1010.3
48	LBCwp		0.96								
49	KW		11.54								
50	LT		1.25								
51	LTV^2		2.33								
52											

I. CENTER OF GRAVITY

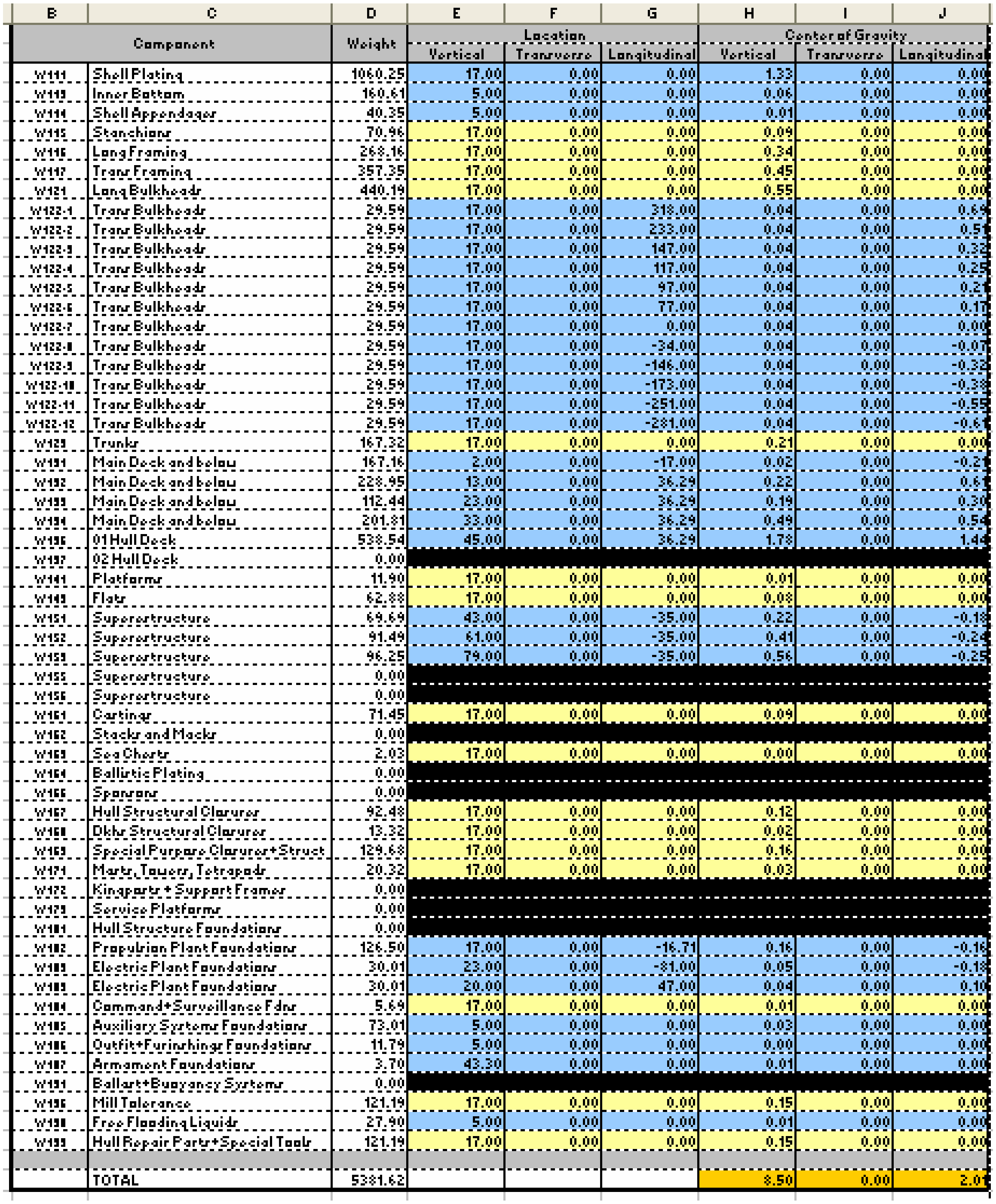
GROUP	Center of Gravity		
	Vertical	Transverse	Longitudinal
100	8.50	0.00	2.01
200	1.60	0.00	-3.00
300	1.68	0.00	-0.60
400	0.55	0.01	-0.30
500	0.93	0.00	1.04
600	1.24	0.00	0.00
700	1.30	-0.01	0.55
TOTAL	15.80	0.00	-0.30

	Vertical	Transverse	Longitudinal
Center of Bouyancy	17	0	0

Center	Reference	Value
VCG	Above Keel	15.80
TCG	From Centerline	0.00
LCG	From Oy	-0.30

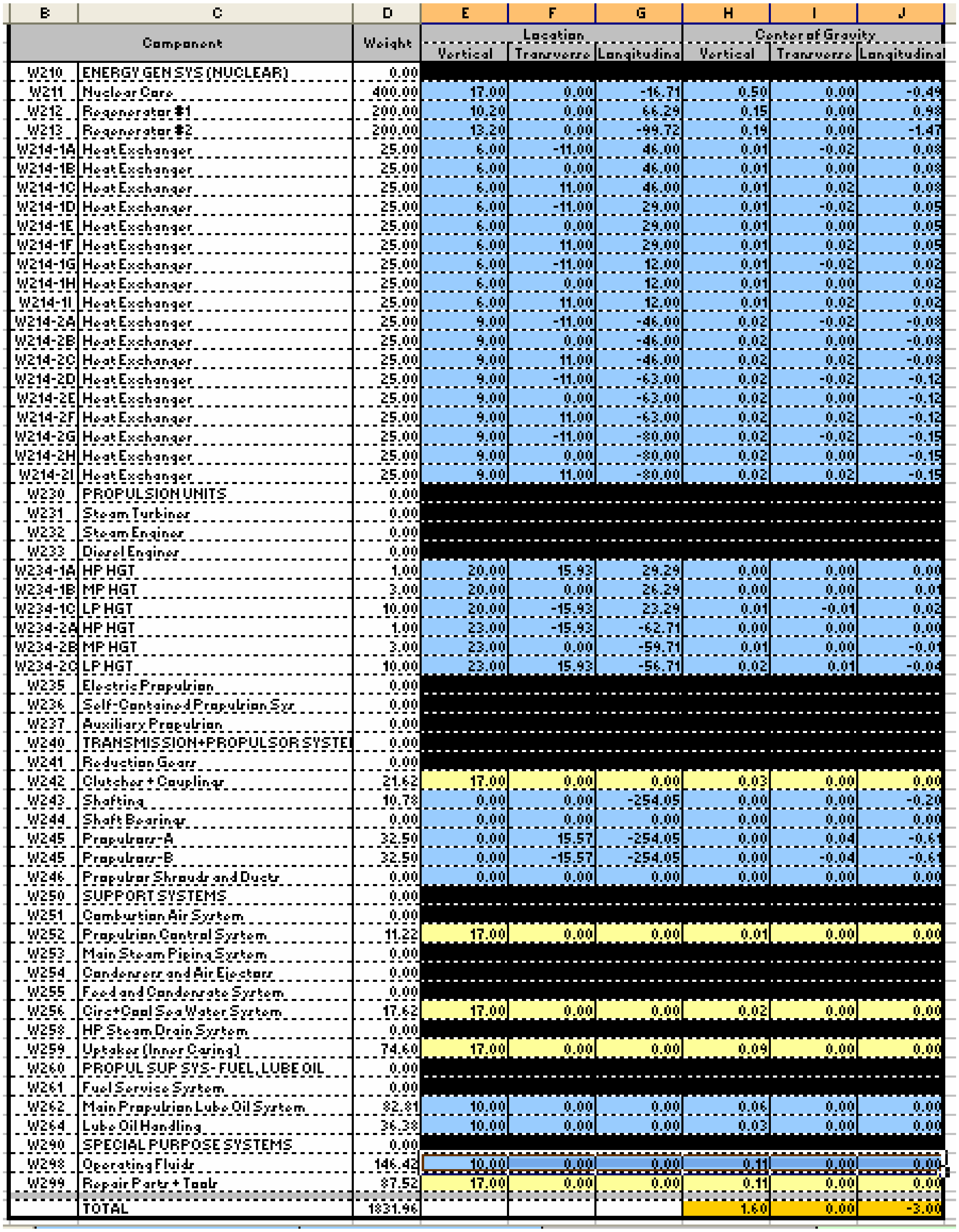
Group 100 - Hull Structure

Yellow = Center of Buoyancy
Blue = Actual Component Position



B	C	D	E	F	G	H	I	J
Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W111	Shell Plating	1060.25	17.00	0.00	0.00	1.33	0.00	0.00
W113	Inner Bottom	160.61	5.00	0.00	0.00	0.06	0.00	0.00
W114	Shell Appendages	40.35	5.00	0.00	0.00	0.01	0.00	0.00
W115	Stanchions	70.96	17.00	0.00	0.00	0.09	0.00	0.00
W116	Long Framing	268.16	17.00	0.00	0.00	0.34	0.00	0.00
W117	Trans Framing	357.35	17.00	0.00	0.00	0.45	0.00	0.00
W121	Long Bulkheads	440.19	17.00	0.00	0.00	0.55	0.00	0.00
W122-1	Trans Bulkheads	29.59	17.00	0.00	318.00	0.04	0.00	0.69
W122-2	Trans Bulkheads	29.59	17.00	0.00	233.00	0.04	0.00	0.51
W122-3	Trans Bulkheads	29.59	17.00	0.00	147.00	0.04	0.00	0.32
W122-4	Trans Bulkheads	29.59	17.00	0.00	117.00	0.04	0.00	0.25
W122-5	Trans Bulkheads	29.59	17.00	0.00	97.00	0.04	0.00	0.21
W122-6	Trans Bulkheads	29.59	17.00	0.00	77.00	0.04	0.00	0.17
W122-7	Trans Bulkheads	29.59	17.00	0.00	0.00	0.04	0.00	0.00
W122-8	Trans Bulkheads	29.59	17.00	0.00	-34.00	0.04	0.00	-0.07
W122-9	Trans Bulkheads	29.59	17.00	0.00	-146.00	0.04	0.00	-0.32
W122-10	Trans Bulkheads	29.59	17.00	0.00	-173.00	0.04	0.00	-0.38
W122-11	Trans Bulkheads	29.59	17.00	0.00	-251.00	0.04	0.00	-0.55
W122-12	Trans Bulkheads	29.59	17.00	0.00	-281.00	0.04	0.00	-0.61
W123	Trunks	167.32	17.00	0.00	0.00	0.21	0.00	0.00
W131	Main Deck and below	167.16	2.00	0.00	-17.00	0.02	0.00	-0.21
W132	Main Deck and below	228.95	13.00	0.00	36.29	0.22	0.00	0.61
W133	Main Deck and below	112.44	23.00	0.00	36.29	0.19	0.00	0.30
W134	Main Deck and below	201.81	33.00	0.00	36.29	0.49	0.00	0.54
W136	01 Hull Deck	538.54	45.00	0.00	36.29	1.78	0.00	1.44
W137	02 Hull Deck	0.00						
W141	Platforms	11.90	17.00	0.00	0.00	0.01	0.00	0.00
W143	Flats	62.88	17.00	0.00	0.00	0.08	0.00	0.00
W151	Superstructure	69.69	43.00	0.00	-35.00	0.22	0.00	-0.18
W152	Superstructure	91.49	61.00	0.00	-35.00	0.41	0.00	-0.24
W153	Superstructure	96.25	79.00	0.00	-35.00	0.56	0.00	-0.25
W155	Superstructure	0.00						
W156	Superstructure	0.00						
W161	Castings	71.45	17.00	0.00	0.00	0.09	0.00	0.00
W162	Stacks and Masts	0.00						
W163	Sea Chests	2.03	17.00	0.00	0.00	0.00	0.00	0.00
W164	Ballistic Plating	0.00						
W165	Sponsons	0.00						
W167	Hull Structural Closures	92.48	17.00	0.00	0.00	0.12	0.00	0.00
W168	Dkhs Structural Closures	13.32	17.00	0.00	0.00	0.02	0.00	0.00
W169	Special Purpose Closures+Struct	129.68	17.00	0.00	0.00	0.16	0.00	0.00
W171	Masts, Towers, Tetrapods	20.32	17.00	0.00	0.00	0.03	0.00	0.00
W172	Kingposts + Support Frames	0.00						
W173	Service Platforms	0.00						
W181	Hull Structure Foundations	0.00						
W182	Propulsion Plant Foundations	126.50	17.00	0.00	-16.71	0.16	0.00	-0.16
W183	Electric Plant Foundations	30.01	23.00	0.00	-81.00	0.05	0.00	-0.18
W183	Electric Plant Foundations	30.01	20.00	0.00	47.00	0.04	0.00	0.10
W184	Command+Surveillance Fdns	5.69	17.00	0.00	0.00	0.01	0.00	0.00
W185	Auxiliary Systems Foundations	73.01	5.00	0.00	0.00	0.03	0.00	0.00
W186	Outfit+Furnishings Foundations	11.79	5.00	0.00	0.00	0.00	0.00	0.00
W187	Armament Foundations	3.70	43.30	0.00	0.00	0.01	0.00	0.00
W191	Ballast+Buoyancy Systems	0.00						
W196	Mill Tolerance	121.19	17.00	0.00	0.00	0.15	0.00	0.00
W198	Free Flooding Liquids	27.90	5.00	0.00	0.00	0.01	0.00	0.00
W199	Hull Repair Parts+Special Tools	121.19	17.00	0.00	0.00	0.15	0.00	0.00
	TOTAL	5381.62				8.50	0.00	2.01

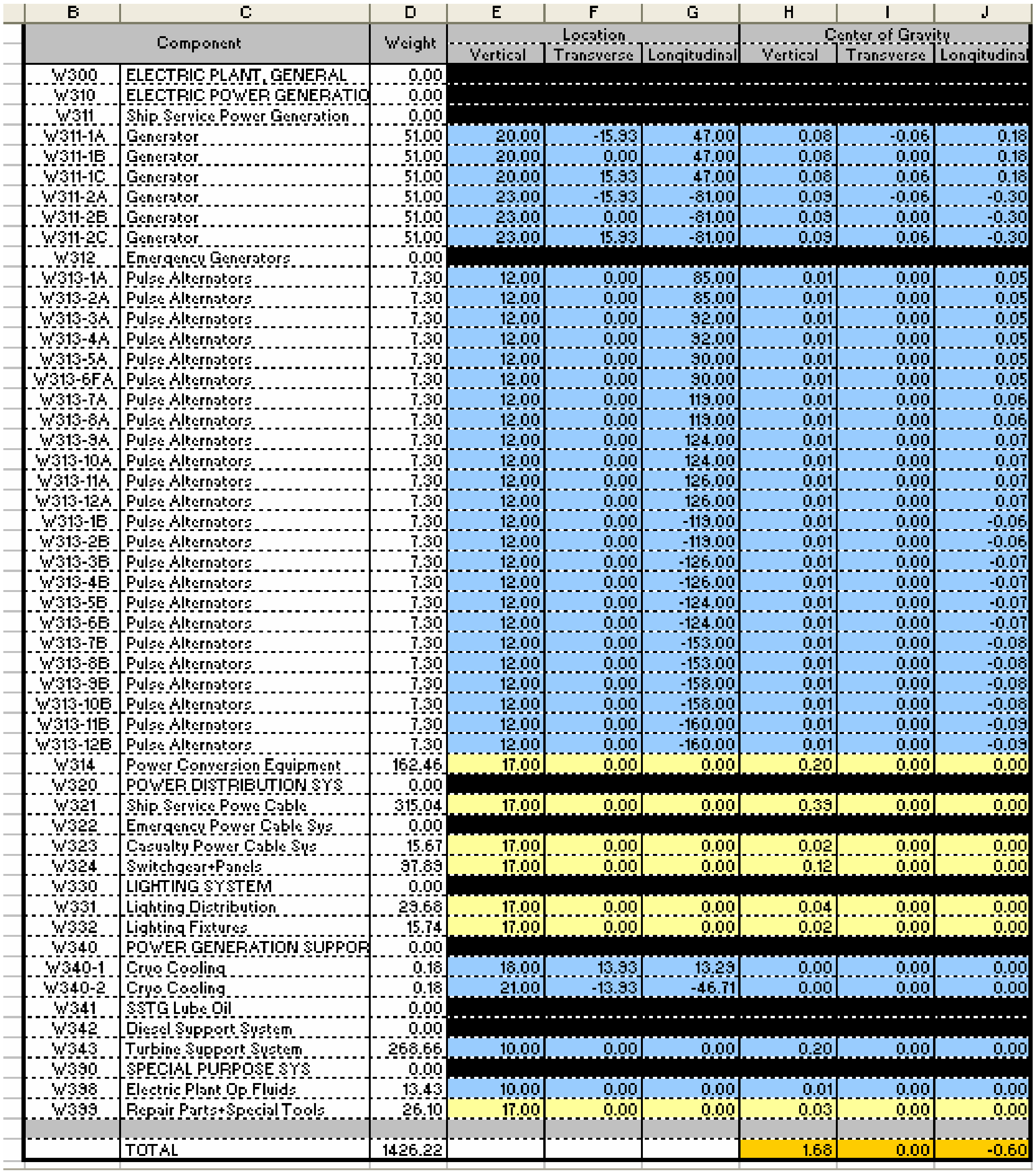
Yellow = Center of Buoyancy
Blue = Actual Component Position



B	C	D	E	F	G	H	I	J
Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudina	Vertical	Transverse	Longitudinal
W210	ENERGY GEN SYS (NUCLEAR)	0.00						
W211	Nuclear Core	400.00	17.00	0.00	-16.71	0.50	0.00	-0.49
W212	Regenerator #1	200.00	10.20	0.00	66.29	0.15	0.00	0.98
W213	Regenerator #2	200.00	13.20	0.00	-99.72	0.19	0.00	-1.47
W214-1A	Heat Exchanger	25.00	6.00	-11.00	46.00	0.01	-0.02	0.08
W214-1B	Heat Exchanger	25.00	6.00	0.00	46.00	0.01	0.00	0.08
W214-1C	Heat Exchanger	25.00	6.00	11.00	46.00	0.01	0.02	0.08
W214-1D	Heat Exchanger	25.00	6.00	-11.00	29.00	0.01	-0.02	0.05
W214-1E	Heat Exchanger	25.00	6.00	0.00	29.00	0.01	0.00	0.05
W214-1F	Heat Exchanger	25.00	6.00	11.00	29.00	0.01	0.02	0.05
W214-1G	Heat Exchanger	25.00	6.00	-11.00	12.00	0.01	-0.02	0.02
W214-1H	Heat Exchanger	25.00	6.00	0.00	12.00	0.01	0.00	0.02
W214-1I	Heat Exchanger	25.00	6.00	11.00	12.00	0.01	0.02	0.02
W214-2A	Heat Exchanger	25.00	9.00	-11.00	-46.00	0.02	-0.02	-0.08
W214-2B	Heat Exchanger	25.00	9.00	0.00	-46.00	0.02	0.00	-0.08
W214-2C	Heat Exchanger	25.00	9.00	11.00	-46.00	0.02	0.02	-0.08
W214-2D	Heat Exchanger	25.00	9.00	-11.00	-63.00	0.02	-0.02	-0.12
W214-2E	Heat Exchanger	25.00	9.00	0.00	-63.00	0.02	0.00	-0.12
W214-2F	Heat Exchanger	25.00	9.00	11.00	-63.00	0.02	0.02	-0.12
W214-2G	Heat Exchanger	25.00	9.00	-11.00	-80.00	0.02	-0.02	-0.15
W214-2H	Heat Exchanger	25.00	9.00	0.00	-80.00	0.02	0.00	-0.15
W214-2I	Heat Exchanger	25.00	9.00	11.00	-80.00	0.02	0.02	-0.15
W230	PROPULSION UNITS	0.00						
W231	Steam Turbines	0.00						
W232	Steam Engines	0.00						
W233	Diesel Engines	0.00						
W234-1A	HP HGT	1.00	20.00	15.93	29.29	0.00	0.00	0.00
W234-1B	MP HGT	3.00	20.00	0.00	26.29	0.00	0.00	0.01
W234-1C	LP HGT	10.00	20.00	-15.93	23.29	0.01	-0.01	0.02
W234-2A	HP HGT	1.00	23.00	-15.93	-62.71	0.00	0.00	0.00
W234-2B	MP HGT	3.00	23.00	0.00	-59.71	0.01	0.00	-0.01
W234-2C	LP HGT	10.00	23.00	15.93	-56.71	0.02	0.01	-0.04
W235	Electric Propulsion	0.00						
W236	Self-Contained Propulsion Sys	0.00						
W237	Auxiliary Propulsion	0.00						
W240	TRANSMISSION+PROPULSOR SYSTE	0.00						
W241	Reduction Gears	0.00						
W242	Clutches + Couplings	21.62	17.00	0.00	0.00	0.03	0.00	0.00
W243	Shafting	10.78	0.00	0.00	-254.05	0.00	0.00	-0.20
W244	Shaft Bearings	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W245	Propulsors-A	32.50	0.00	15.57	-254.05	0.00	0.04	-0.61
W245	Propulsors-B	32.50	0.00	-15.57	-254.05	0.00	-0.04	-0.61
W246	Propulsor Shrouds and Ducts	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W250	SUPPORT SYSTEMS	0.00						
W251	Combustion Air System	0.00						
W252	Propulsion Control System	11.22	17.00	0.00	0.00	0.01	0.00	0.00
W253	Main Steam Piping System	0.00						
W254	Condensers and Air Ejectors	0.00						
W255	Feed and Condensate System	0.00						
W256	Circ+Cool Sea Water System	17.62	17.00	0.00	0.00	0.02	0.00	0.00
W258	HP Steam Drain System	0.00						
W259	Uptakes (Inner Casing)	74.60	17.00	0.00	0.00	0.09	0.00	0.00
W260	PROPUL SUP SYS- FUEL, LUBE OIL	0.00						
W261	Fuel Service System	0.00						
W262	Main Propulsion Lube Oil System	82.81	10.00	0.00	0.00	0.06	0.00	0.00
W264	Lube Oil Handling	36.38	10.00	0.00	0.00	0.03	0.00	0.00
W290	SPECIAL PURPOSE SYSTEMS	0.00						
W298	Operating Fluids	146.42	10.00	0.00	0.00	0.11	0.00	0.00
W299	Repair Parts + Tools	87.52	17.00	0.00	0.00	0.11	0.00	0.00
	TOTAL	1831.96				1.60	0.00	-3.00

Group 300 - Electrical Plant

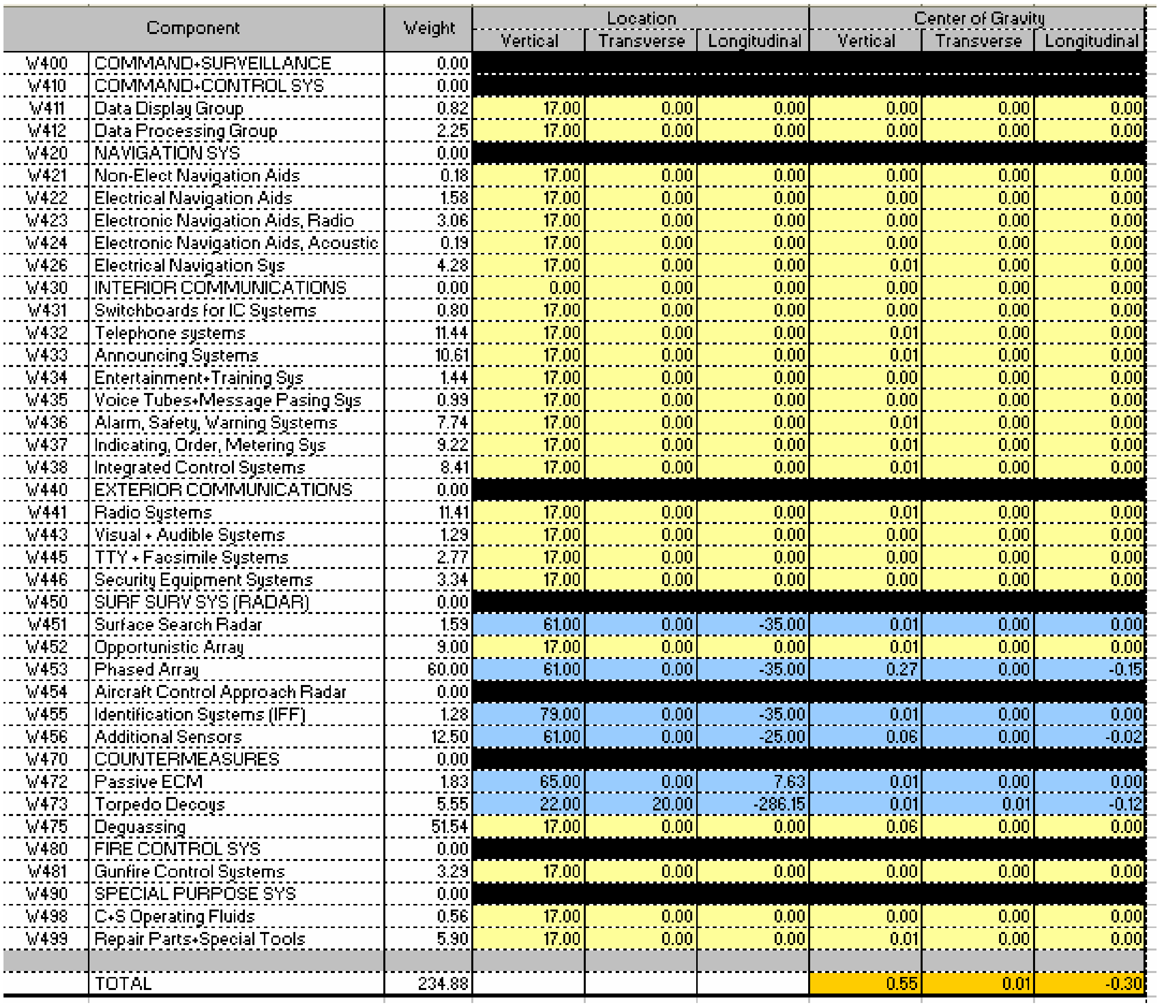
Yellow = Center of Buoyancy
Blue = Actual Component Position



B	C	D	E	F	G	H	I	J
Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W300	ELECTRIC PLANT, GENERAL	0.00						
W310	ELECTRIC POWER GENERATIO	0.00						
W311	Ship Service Power Generation	0.00						
W311-1A	Generator	51.00	20.00	-15.93	47.00	0.08	-0.06	0.18
W311-1B	Generator	51.00	20.00	0.00	47.00	0.08	0.00	0.18
W311-1C	Generator	51.00	20.00	15.93	47.00	0.08	0.06	0.18
W311-2A	Generator	51.00	23.00	-15.93	-81.00	0.09	-0.06	-0.30
W311-2B	Generator	51.00	23.00	0.00	-81.00	0.09	0.00	-0.30
W311-2C	Generator	51.00	23.00	15.93	-81.00	0.09	0.06	-0.30
W312	Emergency Generators	0.00						
W313-1A	Pulse Alternators	7.30	12.00	0.00	85.00	0.01	0.00	0.05
W313-2A	Pulse Alternators	7.30	12.00	0.00	85.00	0.01	0.00	0.05
W313-3A	Pulse Alternators	7.30	12.00	0.00	92.00	0.01	0.00	0.05
W313-4A	Pulse Alternators	7.30	12.00	0.00	92.00	0.01	0.00	0.05
W313-5A	Pulse Alternators	7.30	12.00	0.00	90.00	0.01	0.00	0.05
W313-6FA	Pulse Alternators	7.30	12.00	0.00	90.00	0.01	0.00	0.05
W313-7A	Pulse Alternators	7.30	12.00	0.00	119.00	0.01	0.00	0.06
W313-8A	Pulse Alternators	7.30	12.00	0.00	119.00	0.01	0.00	0.06
W313-9A	Pulse Alternators	7.30	12.00	0.00	124.00	0.01	0.00	0.07
W313-10A	Pulse Alternators	7.30	12.00	0.00	124.00	0.01	0.00	0.07
W313-11A	Pulse Alternators	7.30	12.00	0.00	126.00	0.01	0.00	0.07
W313-12A	Pulse Alternators	7.30	12.00	0.00	126.00	0.01	0.00	0.07
W313-1B	Pulse Alternators	7.30	12.00	0.00	-119.00	0.01	0.00	-0.06
W313-2B	Pulse Alternators	7.30	12.00	0.00	-119.00	0.01	0.00	-0.06
W313-3B	Pulse Alternators	7.30	12.00	0.00	-126.00	0.01	0.00	-0.07
W313-4B	Pulse Alternators	7.30	12.00	0.00	-126.00	0.01	0.00	-0.07
W313-5B	Pulse Alternators	7.30	12.00	0.00	-124.00	0.01	0.00	-0.07
W313-6B	Pulse Alternators	7.30	12.00	0.00	-124.00	0.01	0.00	-0.07
W313-7B	Pulse Alternators	7.30	12.00	0.00	-153.00	0.01	0.00	-0.08
W313-8B	Pulse Alternators	7.30	12.00	0.00	-153.00	0.01	0.00	-0.08
W313-9B	Pulse Alternators	7.30	12.00	0.00	-158.00	0.01	0.00	-0.08
W313-10B	Pulse Alternators	7.30	12.00	0.00	-158.00	0.01	0.00	-0.08
W313-11B	Pulse Alternators	7.30	12.00	0.00	-160.00	0.01	0.00	-0.09
W313-12B	Pulse Alternators	7.30	12.00	0.00	-160.00	0.01	0.00	-0.09
W314	Power Conversion Equipment	162.46	17.00	0.00	0.00	0.20	0.00	0.00
W320	POWER DISTRIBUTION SYS	0.00						
W321	Ship Service Powe Cable	315.04	17.00	0.00	0.00	0.39	0.00	0.00
W322	Emergency Power Cable Sys	0.00						
W323	Casualty Power Cable Sys	15.67	17.00	0.00	0.00	0.02	0.00	0.00
W324	Switchgear+Panels	97.89	17.00	0.00	0.00	0.12	0.00	0.00
W330	LIGHTING SYSTEM	0.00						
W331	Lighting Distribution	29.68	17.00	0.00	0.00	0.04	0.00	0.00
W332	Lighting Fixtures	15.74	17.00	0.00	0.00	0.02	0.00	0.00
W340	POWER GENERATION SUPPOR	0.00						
W340-1	Cryo Cooling	0.18	18.00	13.93	13.29	0.00	0.00	0.00
W340-2	Cryo Cooling	0.18	21.00	-13.93	-46.71	0.00	0.00	0.00
W341	SSTG Lube Oil	0.00						
W342	Diesel Support System	0.00						
W343	Turbine Support System	268.66	10.00	0.00	0.00	0.20	0.00	0.00
W390	SPECIAL PURPOSE SYS	0.00						
W398	Electric Plant Op Fluids	13.43	10.00	0.00	0.00	0.01	0.00	0.00
W399	Repair Parts+Special Tools	26.10	17.00	0.00	0.00	0.03	0.00	0.00
	TOTAL	1426.22				1.68	0.00	-0.60

Group 400 - Command and Surveillance

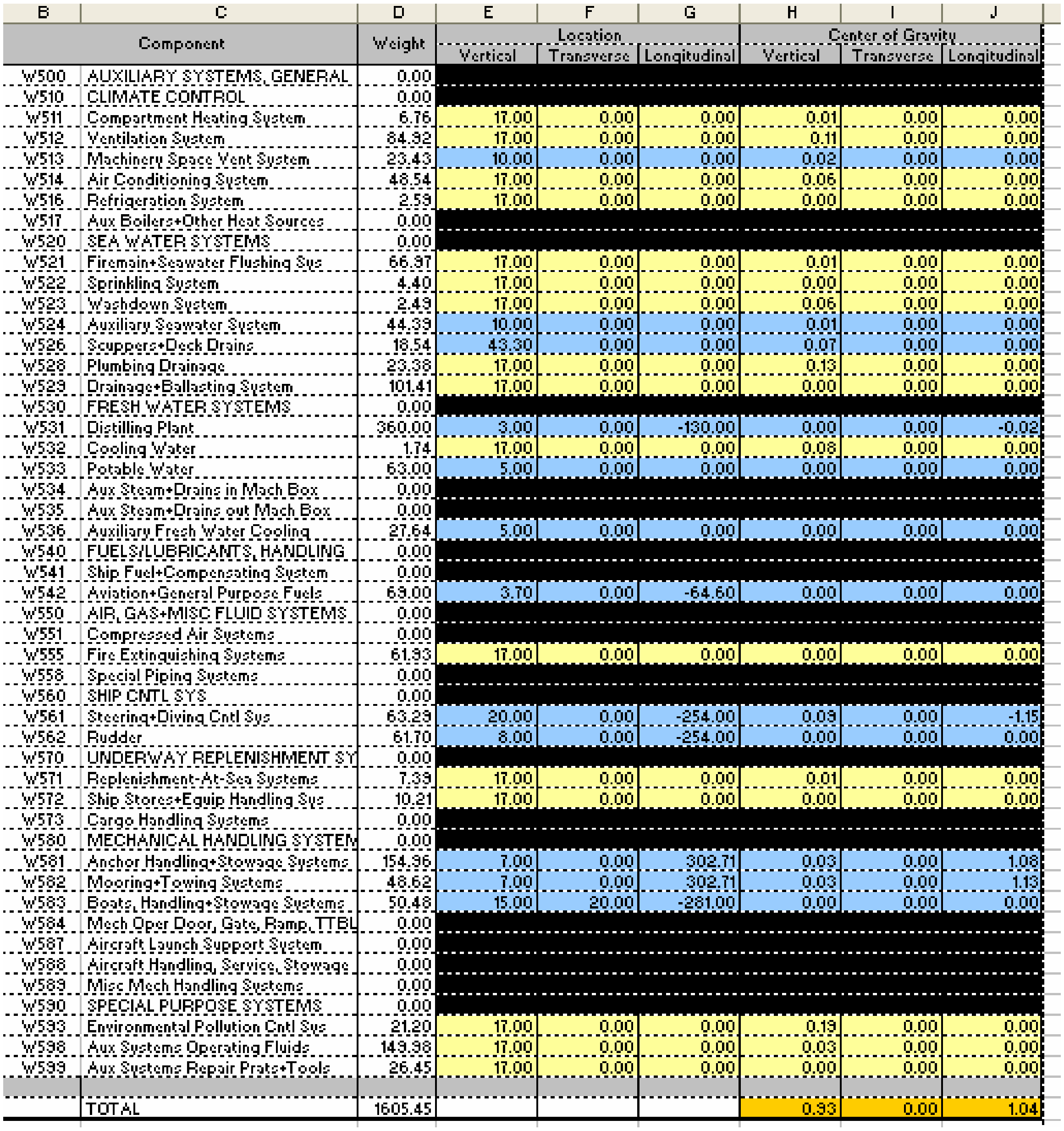
Yellow = Center of Buoyancy
Blue = Actual Component Position



Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W400	COMMAND+SURVEILLANCE	0.00						
W410	COMMAND+CONTROL SYS	0.00						
W411	Data Display Group	0.82	17.00	0.00	0.00	0.00	0.00	0.00
W412	Data Processing Group	2.25	17.00	0.00	0.00	0.00	0.00	0.00
W420	NAVIGATION SYS	0.00						
W421	Non-Elect Navigation Aids	0.18	17.00	0.00	0.00	0.00	0.00	0.00
W422	Electrical Navigation Aids	1.58	17.00	0.00	0.00	0.00	0.00	0.00
W423	Electronic Navigation Aids, Radio	3.06	17.00	0.00	0.00	0.00	0.00	0.00
W424	Electronic Navigation Aids, Acoustic	0.19	17.00	0.00	0.00	0.00	0.00	0.00
W426	Electrical Navigation Sys	4.28	17.00	0.00	0.00	0.01	0.00	0.00
W430	INTERIOR COMMUNICATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W431	Switchboards for IC Systems	0.80	17.00	0.00	0.00	0.00	0.00	0.00
W432	Telephone systems	11.44	17.00	0.00	0.00	0.01	0.00	0.00
W433	Announcing Systems	10.61	17.00	0.00	0.00	0.01	0.00	0.00
W434	Entertainment+Training Sys	1.44	17.00	0.00	0.00	0.00	0.00	0.00
W435	Voice Tubes+Message Pasing Sys	0.99	17.00	0.00	0.00	0.00	0.00	0.00
W436	Alarm, Safety, Warning Systems	7.74	17.00	0.00	0.00	0.01	0.00	0.00
W437	Indicating, Order, Metering Sys	9.22	17.00	0.00	0.00	0.01	0.00	0.00
W438	Integrated Control Systems	8.41	17.00	0.00	0.00	0.01	0.00	0.00
W440	EXTERIOR COMMUNICATIONS	0.00						
W441	Radio Systems	11.41	17.00	0.00	0.00	0.01	0.00	0.00
W443	Visual + Audible Systems	1.29	17.00	0.00	0.00	0.00	0.00	0.00
W445	TTY + Facsimile Systems	2.77	17.00	0.00	0.00	0.00	0.00	0.00
W446	Security Equipment Systems	3.34	17.00	0.00	0.00	0.00	0.00	0.00
W450	SURF SURV SYS (RADAR)	0.00						
W451	Surface Search Radar	1.59	61.00	0.00	-35.00	0.01	0.00	0.00
W452	Opportunistic Array	9.00	17.00	0.00	0.00	0.01	0.00	0.00
W453	Phased Array	60.00	61.00	0.00	-35.00	0.27	0.00	-0.15
W454	Aircraft Control Approach Radar	0.00						
W455	Identification Systems (IFF)	1.28	79.00	0.00	-35.00	0.01	0.00	0.00
W456	Additional Sensors	12.50	61.00	0.00	-25.00	0.06	0.00	-0.02
W470	COUNTERMEASURES	0.00						
W472	Passive ECM	1.83	65.00	0.00	7.63	0.01	0.00	0.00
W473	Torpedo Decoys	5.55	22.00	20.00	-286.15	0.01	0.01	-0.12
W475	Deguassing	51.54	17.00	0.00	0.00	0.06	0.00	0.00
W480	FIRE CONTROL SYS	0.00						
W481	Gunfire Control Systems	3.29	17.00	0.00	0.00	0.00	0.00	0.00
W490	SPECIAL PURPOSE SYS	0.00						
W498	C+S Operating Fluids	0.56	17.00	0.00	0.00	0.00	0.00	0.00
W499	Repair Parts+Special Tools	5.90	17.00	0.00	0.00	0.01	0.00	0.00
	TOTAL	234.88				0.55	0.01	-0.30

Group 500 - Auxiliary Systems

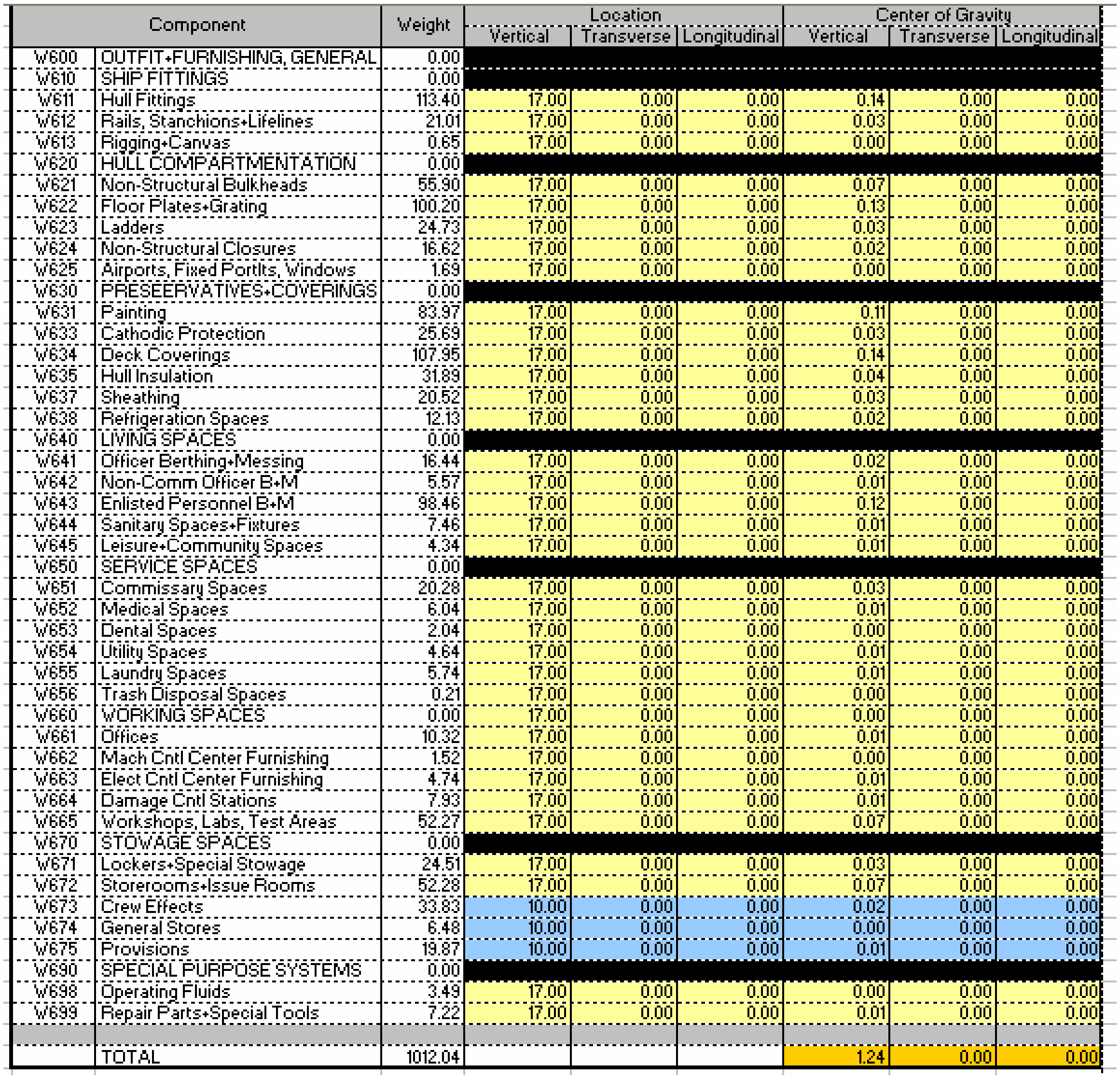
Yellow = Center of Buoyancy
Blue = Actual Component Position



B	C	D	E	F	G	H	I	J
Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W500	AUXILIARY SYSTEMS, GENERAL	0.00						
W510	CLIMATE CONTROL	0.00						
W511	Compartment Heating System	6.76	17.00	0.00	0.00	0.01	0.00	0.00
W512	Ventilation System	84.92	17.00	0.00	0.00	0.11	0.00	0.00
W513	Machinery Space Vent System	23.43	10.00	0.00	0.00	0.02	0.00	0.00
W514	Air Conditioning System	48.54	17.00	0.00	0.00	0.06	0.00	0.00
W516	Refrigeration System	2.59	17.00	0.00	0.00	0.00	0.00	0.00
W517	Aux Boilers+Other Heat Sources	0.00						
W520	SEA WATER SYSTEMS	0.00						
W521	Firemain+Seawater Flushing Sys	66.97	17.00	0.00	0.00	0.01	0.00	0.00
W522	Sprinkling System	4.40	17.00	0.00	0.00	0.00	0.00	0.00
W523	Washdown System	2.49	17.00	0.00	0.00	0.06	0.00	0.00
W524	Auxiliary Seawater System	44.39	10.00	0.00	0.00	0.01	0.00	0.00
W526	Scuppers+Deck Drains	18.54	43.30	0.00	0.00	0.07	0.00	0.00
W528	Plumbing Drainage	23.38	17.00	0.00	0.00	0.13	0.00	0.00
W529	Drainage+Ballasting System	101.41	17.00	0.00	0.00	0.00	0.00	0.00
W530	FRESH WATER SYSTEMS	0.00						
W531	Distilling Plant	360.00	3.00	0.00	-130.00	0.00	0.00	-0.02
W532	Cooling Water	1.74	17.00	0.00	0.00	0.08	0.00	0.00
W533	Potable Water	63.00	5.00	0.00	0.00	0.00	0.00	0.00
W534	Aux Steam+Drains in Mach Box	0.00						
W535	Aux Steam+Drains out Mach Box	0.00						
W536	Auxiliary Fresh Water Cooling	27.64	5.00	0.00	0.00	0.00	0.00	0.00
W540	FUELS/LUBRICANTS, HANDLING	0.00						
W541	Ship Fuel+Compensating System	0.00						
W542	Aviation+General Purpose Fuels	69.00	3.70	0.00	-64.60	0.00	0.00	0.00
W550	AIR, GAS+MISC FLUID SYSTEMS	0.00						
W551	Compressed Air Systems	0.00						
W555	Fire Extinguishing Systems	61.93	17.00	0.00	0.00	0.00	0.00	0.00
W558	Special Piping Systems	0.00						
W560	SHIP CNTL SYS	0.00						
W561	Steering+Diving Cntl Sys	63.29	20.00	0.00	-254.00	0.09	0.00	-1.15
W562	Rudder	61.70	8.00	0.00	-254.00	0.00	0.00	0.00
W570	UNDERWAY REPLENISHMENT SY	0.00						
W571	Replenishment-At-Sea Systems	7.39	17.00	0.00	0.00	0.01	0.00	0.00
W572	Ship Stores+Equip Handling Sys	10.21	17.00	0.00	0.00	0.00	0.00	0.00
W573	Cargo Handling Systems	0.00						
W580	MECHANICAL HANDLING SYSTEM	0.00						
W581	Anchor Handling+Stowage Systems	154.96	7.00	0.00	302.71	0.03	0.00	1.08
W582	Mooring+Towing Systems	48.62	7.00	0.00	302.71	0.03	0.00	1.13
W583	Boats, Handling+Stowage Systems	50.48	15.00	20.00	-281.00	0.00	0.00	0.00
W584	Mech Oper Door, Gate, Ramp, TTBL	0.00						
W587	Aircraft Launch Support System	0.00						
W588	Aircraft Handling, Service, Stowage	0.00						
W589	Misc Mech Handling Systems	0.00						
W590	SPECIAL PURPOSE SYSTEMS	0.00						
W593	Environmental Pollution Cntl Sys	21.20	17.00	0.00	0.00	0.19	0.00	0.00
W598	Aux Systems Operating Fluids	149.98	17.00	0.00	0.00	0.03	0.00	0.00
W599	Aux Systems Repair Prats+Tools	26.45	17.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	1605.45				0.93	0.00	1.04

Group 600 - Outfit and Furnishings

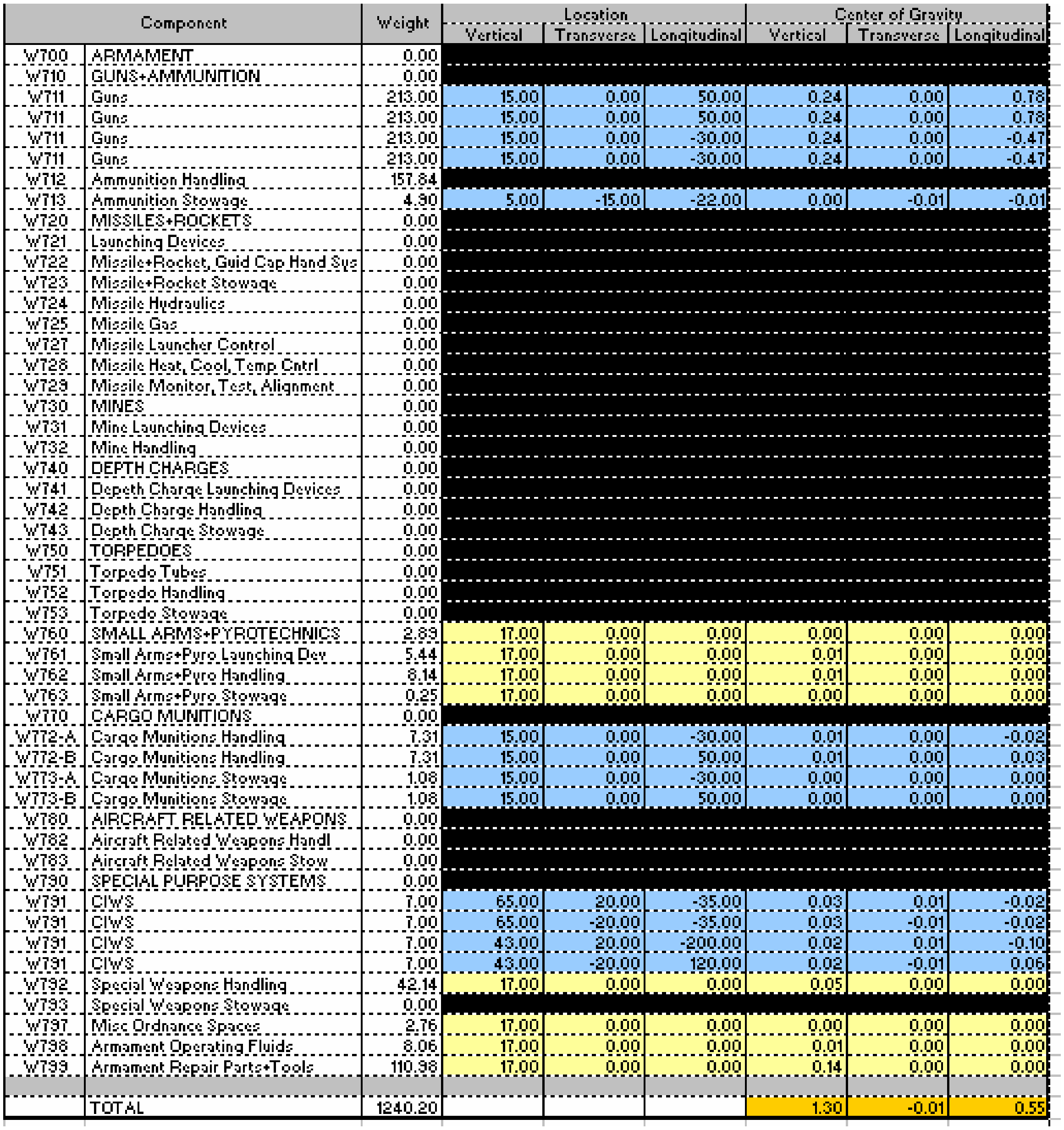
Yellow = Center of Buoyancy
Blue = Actual Component Position



Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W600	OUTFIT+FURNISHING, GENERAL	0.00						
W610	SHIP FITTINGS	0.00						
W611	Hull Fittings	113.40	17.00	0.00	0.00	0.14	0.00	0.00
W612	Rails, Stanchions+Lifelines	21.01	17.00	0.00	0.00	0.03	0.00	0.00
W613	Rigging+Canvas	0.65	17.00	0.00	0.00	0.00	0.00	0.00
W620	HULL COMPARTMENTATION	0.00						
W621	Non-Structural Bulkheads	55.90	17.00	0.00	0.00	0.07	0.00	0.00
W622	Floor Plates+Grating	100.20	17.00	0.00	0.00	0.13	0.00	0.00
W623	Ladders	24.73	17.00	0.00	0.00	0.03	0.00	0.00
W624	Non-Structural Closures	16.62	17.00	0.00	0.00	0.02	0.00	0.00
W625	Airports, Fixed Portlts, Windows	1.69	17.00	0.00	0.00	0.00	0.00	0.00
W630	PRESEERVATIVES+COVERINGS	0.00						
W631	Painting	83.97	17.00	0.00	0.00	0.11	0.00	0.00
W633	Cathodic Protection	25.69	17.00	0.00	0.00	0.03	0.00	0.00
W634	Deck Coverings	107.95	17.00	0.00	0.00	0.14	0.00	0.00
W635	Hull Insulation	31.89	17.00	0.00	0.00	0.04	0.00	0.00
W637	Sheathing	20.52	17.00	0.00	0.00	0.03	0.00	0.00
W638	Refrigeration Spaces	12.13	17.00	0.00	0.00	0.02	0.00	0.00
W640	LIVING SPACES	0.00						
W641	Officer Berthing+Messing	16.44	17.00	0.00	0.00	0.02	0.00	0.00
W642	Non-Comm Officer B+M	5.57	17.00	0.00	0.00	0.01	0.00	0.00
W643	Enlisted Personnel B+M	98.46	17.00	0.00	0.00	0.12	0.00	0.00
W644	Sanitary Spaces+Fixtures	7.46	17.00	0.00	0.00	0.01	0.00	0.00
W645	Leisure+Community Spaces	4.34	17.00	0.00	0.00	0.01	0.00	0.00
W650	SERVICE SPACES	0.00						
W651	Commissary Spaces	20.28	17.00	0.00	0.00	0.03	0.00	0.00
W652	Medical Spaces	6.04	17.00	0.00	0.00	0.01	0.00	0.00
W653	Dental Spaces	2.04	17.00	0.00	0.00	0.00	0.00	0.00
W654	Utility Spaces	4.64	17.00	0.00	0.00	0.01	0.00	0.00
W655	Laundry Spaces	5.74	17.00	0.00	0.00	0.01	0.00	0.00
W656	Trash Disposal Spaces	0.21	17.00	0.00	0.00	0.00	0.00	0.00
W660	WORKING SPACES	0.00	17.00	0.00	0.00	0.00	0.00	0.00
W661	Offices	10.32	17.00	0.00	0.00	0.01	0.00	0.00
W662	Mach Cntl Center Furnishing	1.52	17.00	0.00	0.00	0.00	0.00	0.00
W663	Elect Cntl Center Furnishing	4.74	17.00	0.00	0.00	0.01	0.00	0.00
W664	Damage Cntl Stations	7.93	17.00	0.00	0.00	0.01	0.00	0.00
W665	Workshops, Labs, Test Areas	52.27	17.00	0.00	0.00	0.07	0.00	0.00
W670	STOWAGE SPACES	0.00						
W671	Lockers+Special Stowage	24.51	17.00	0.00	0.00	0.03	0.00	0.00
W672	Storerooms+Issue Rooms	52.28	17.00	0.00	0.00	0.07	0.00	0.00
W673	Crew Effects	33.83	10.00	0.00	0.00	0.02	0.00	0.00
W674	General Stores	6.48	10.00	0.00	0.00	0.00	0.00	0.00
W675	Provisions	19.87	10.00	0.00	0.00	0.01	0.00	0.00
W690	SPECIAL PURPOSE SYSTEMS	0.00						
W698	Operating Fluids	3.49	17.00	0.00	0.00	0.00	0.00	0.00
W699	Repair Parts+Special Tools	7.22	17.00	0.00	0.00	0.01	0.00	0.00
	TOTAL	1012.04				1.24	0.00	0.00

Group 700 - Armament

Yellow = Center of Buoyancy
Blue = Actual Component Position



Component		Weight	Location			Center of Gravity		
			Vertical	Transverse	Longitudinal	Vertical	Transverse	Longitudinal
W700	ARMAMENT	0.00						
W710	GUNS+AMMUNITION	0.00						
W711	Guns	213.00	15.00	0.00	50.00	0.24	0.00	0.78
W711	Guns	213.00	15.00	0.00	50.00	0.24	0.00	0.78
W711	Guns	213.00	15.00	0.00	-30.00	0.24	0.00	-0.47
W711	Guns	213.00	15.00	0.00	-30.00	0.24	0.00	-0.47
W712	Ammunition Handling	157.84						
W713	Ammunition Stowage	4.90	5.00	-15.00	-22.00	0.00	-0.01	-0.01
W720	MISSILES+ROCKETS	0.00						
W721	Launching Devices	0.00						
W722	Missile+Rocket, Guid Cap Hand Sys	0.00						
W723	Missile+Rocket Stowage	0.00						
W724	Missile Hydraulics	0.00						
W725	Missile Gas	0.00						
W727	Missile Launcher Control	0.00						
W728	Missile Heat, Cool, Temp Cntrl	0.00						
W729	Missile Monitor, Test, Alignment	0.00						
W730	MINES	0.00						
W731	Mine Launching Devices	0.00						
W732	Mine Handling	0.00						
W740	DEPTH CHARGES	0.00						
W741	Depeth Charge Launching Devices	0.00						
W742	Depth Charge Handling	0.00						
W743	Depth Charge Stowage	0.00						
W750	TORPEDOES	0.00						
W751	Torpedo Tubes	0.00						
W752	Torpedo Handling	0.00						
W753	Torpedo Stowage	0.00						
W760	SMALL ARMS+PYROTECHNICS	2.89	17.00	0.00	0.00	0.00	0.00	0.00
W761	Small Arms+Pyro Launching Dev	5.44	17.00	0.00	0.00	0.01	0.00	0.00
W762	Small Arms+Pyro Handling	8.14	17.00	0.00	0.00	0.01	0.00	0.00
W763	Small Arms+Pyro Stowage	0.25	17.00	0.00	0.00	0.00	0.00	0.00
W770	CARGO MUNITIONS	0.00						
W772-A	Cargo Munitions Handling	7.31	15.00	0.00	-30.00	0.01	0.00	-0.02
W772-B	Cargo Munitions Handling	7.31	15.00	0.00	50.00	0.01	0.00	0.03
W773-A	Cargo Munitions Stowage	1.08	15.00	0.00	-30.00	0.00	0.00	0.00
W773-B	Cargo Munitions Stowage	1.08	15.00	0.00	50.00	0.00	0.00	0.00
W780	AIRCRAFT RELATED WEAPONS	0.00						
W782	Aircraft Related Weapons Handl	0.00						
W783	Aircraft Related Weapons Stow	0.00						
W790	SPECIAL PURPOSE SYSTEMS	0.00						
W791	CIWS	7.00	65.00	20.00	-35.00	0.03	0.01	-0.02
W791	CIWS	7.00	65.00	-20.00	-35.00	0.03	-0.01	-0.02
W791	CIWS	7.00	43.00	20.00	-200.00	0.02	0.01	-0.10
W791	CIWS	7.00	43.00	-20.00	120.00	0.02	-0.01	0.06
W792	Special Weapons Handling	42.14	17.00	0.00	0.00	0.05	0.00	0.00
W793	Special Weapons Stowage	0.00						
W797	Misc Ordnance Spaces	2.76	17.00	0.00	0.00	0.00	0.00	0.00
W798	Armament Operating Fluids	8.06	17.00	0.00	0.00	0.01	0.00	0.00
W799	Armament Repair Parts+Tools	110.98	17.00	0.00	0.00	0.14	0.00	0.00
	TOTAL	1240.20				1.30	-0.01	0.55

J. DAMAGE STABILITY

B. SIX SHIP CARGO DISTRIBUTION

C. CARGO VERTICAL CENTER OF GRAVITY CALCULATIONS

APPENDIX 6 COMBAT SYSTEMS DATA

A. HIS TOOLS SUMMARY

Tool	HSI Domain	Brief Description	Owner	POC Name	POC Phone	POC Email	Price	Used on Project(s):
3DSSPP	ESH	Material handling strength model	U Michigan	Mr. Doug Hockstad	734/615-4004	dhocksta@umich.edu	$1,195	
ACTA	Training	Cognitive skills analysis for instructional design	Klein Associates	Ms. Erica Rall	937/873-8166 x 117	erica@decisionmaking.com	$90	NPRDC sponsorship, EW training req.
ACT-R	HFE	Cognition modeling	Carnegie Mellon U	Dr. Christian Lebiere	412/268-2787	clebiere@maad.com	Free	Navy-learning, memory models, Army-error, SA models , Air Forece-learning models
ADIVA	HFE	Digital image-and-data capture and analysis	Monterey Technologies	Mr. Bob Chamberlain	831/648-0190	bchamberlain@montereytechnologies.com	$10,000	Naval Air Test Center; auto crash tests
ADVISOR	Training	Training delivery optimizer	BNH Expert Software	Mr. J Bahlis	800/747-4010	bahlis@bnhexpertsoft.com	$295	Navy schools Norfolk, VA Beach, and San Diego; JSF
AIM	Training	Training materials management	NAVAIR Orlando	Mr. Alan Litz	407/381-8607	litzad@navair.navy.mil	Free	Aegis, SQQ89, FASO, NAMTRA
Airbag	ESH	Mathematical Ear Model	ARL/HRED	Dr. Richard Price	410/278-5976		POC	
AIS-MANPRINT	MPT	Resource estimation for info systems	ARL/HRED	Ms. Andrea Krausman	410/278-5814	ahynes@arl.army.mil	POC	
ALPHA Sim	HFE	Workload, throughput, & failure analyses modeling	Alpha Tech Inc.	Mr. Brad Rigby	781/273-3388 x272	alpha.sim@alphatech.com	$1,995	ASW, MSS & C2PM for Dahlgren
AMCOS	Manpower	Manpower cost models	CEAC	Mr. Joseph Gamble	703/614-5876	http://www.ceac.army.mil/	POC	All major Army acquisitions
ANAM	HFE	Individual cognitive health assessment	NAVCOMTELSTA	Ms. Kathy Winter	850/452-7674	winterk@spawar.navy.mil	Free	Navy Experimental Diving Unit; USS Constellation during *Operation Iraqi Freedom*
ASSESS	HFE	Human-system role analysis	Carlow	Dr. Tom Malone	571/434-9222	tbmalone@carlow.com	POC	No Navy projects
ATB	Survivability	Model body dynamics during crashes, ejection	AFRL	Dr. Joseph Pellettiere	937/255-1150	joseph.pellettiere@wpafb.af.mil	POC	Aircraft, automotive
ATB3I	Survivability	Model body dynamics during crashes, ejection	Veridian	Ms. Annette Rizer	937/255-7486	Annette.Rizer@wpafb.af.mil	$2,095	Navy: biodynamic response to underwater explosions
ATEAMS	Training	Objective Based Training Management	PEO IWS 1E	Bruce Acton	619/222-2245	bacton@novonics.com	POC	In evaluation by PEO IWS 1E
BFTT	Training	Battle force team training simulator	PEO IWS 1E	Cmdr. Datko	202/781-1214	datkolc@navsea.navy.mil	POC	In use by the Navy
C3TRACE	HFE	Command & control HPM	MA&D, ARL-HRED	Ms. Beth Plott	303/442-6947	bplott@maad.com	Free	Army: Unit of Action
CAM	ESH	Material system hazard cost estimation	AMEDD	Mr. W. Michael McDevitt	410/671-2925	w.michael.mcdevitt@apg.amedd.army.mil	POC	Medical hazards
CART	MPT	HPM integrated with weapon system models	AFRL HECI	Mr. David Hoagland	937/656-7013	david.hoagland@wpafb.af.mil	Free	Joint Strike Fighter
CASA	MPT	LCC for ops, support, training	LOGSA	Nicholas Giordano	256/955-0808	nicholas.giordano@logsa.redstone.army.mil	Free	Aegis, DD-21, LPD-17
CASHE-PVS	HFE	Human perception & performance	AFRL	Mr. Don Monk	937/255-8814	don.monk@he.wpafb.af.mil	$395	
CCAB	HFE	Cognitive test battery	NAVCOMTELSTA	Ms. Kathy Winter	850-452-7674	winterk@spawar.navy.mil	POC	
CM	Personnel	Officer KSA and role/resposnbility mapping and management	NSWC	Mr. John Valaitis	540/653-0831	valaitixja@nswc.navy.mil	POC	Navy Department Head analysis
COMPUTERMAN	Survivability	Penetrating injury model	ARL	Mr. David Neades	410/278-6335		POC	Live Fire Test of crew casualty prediction; Body armor analysis
CTT	HFE	Psychomotor skill assessment	NAWC-CTL	W. Pat Gatewood	301/342-0009	pat@setd-ctl.nawcad.navy.mil	POC	
DAVID	HFE	Digital image anthropometric data capture	NAMRL	Mr. Jack Saxton	850/452-2557	jsaxton@namrl.navy.mil	POC	
Delmia-Human	HFE	3D human simulation	Delmia	Mr. Bob Brown	248/267-9696	info@delmia.com	POC	DD(X), DDG51, LPD17, naval architects
EDCAS	MPT	LCC for ops, support, training	TFD Services, Inc.	Sylvia Smith	770/419-1262	Sylvia.Smith@tfdg.com	$17,726	P-3, AAAV
EEPP	HFE	Metabolic energy expenditure model	U Michigan	Mr. Doug Hockstad	734/615-4004	dhocksta@umich.edu	$595	
ENVISION-ERGO	ESH	Ergonomic analysis	Delmia	Mr. Bob Brown	248/267-9696	info@delmia.com	POC	DD(X), DDG51, LPD17, naval architects
EPIC	HFE	Human performance modeling	U Michigan	Dr. Dave Kieras	734/763-6739	kieras@eecs.umich.edu	POC	contact POC
ERGO-INTEL-MMH	ESH	Manual material handling ergonomic evlaution	NexGen Ergonomics	Mr. David Pinchefsky	514/685-8593	pinchefsky@nexgenergo.com	$1,395	
ERGO-INTEL-UEA	ESH	Upper extremity ergonomic evlaution	NexGen Ergonomics	Mr. David Pinchefsky	514/685-8593	pinchefsky@nexgenergo.com	$1,295	
ErgoMaster	ESH	Ergonomics tool suite	NexGen Ergonomics	Mr. David Pinchefsky	514/685-8593	pinchefsky@nexgenergo.com	$6,995	
ERGOWEB-JET	ESH	Ergonomics tool suite	Ergo Web, Inc.	Mr. Lee Barney	435/654-4284	lbarney@ergoweb.com	POC	
FAST	HFE	Fatigue prediction	AFRL/HED, SAIC	Dr. Steven R. Hursh	410/538-2901	hurshs@saic.com	POC	In validation with the AF and FRA
FREDYN	Survivability	Ship hull dynamics model	DREA	Dr. Kevin McTaggart	902/426-3100 x 325	kevin.mctaggart@drdc-rddc.gc.ca	Free	DDX
FWTCI	HFE	Experimental measurement of operator skill, effort, or workload	NAWC-CTL	Dr. Richard S. Dunn	301/342-9245	dunnrs@navair.navy.mil	POC	Used in several studies at NAWC-CTL
GEBOD	HFE	Anthropometric data generation	AFRL	Dr. Joseph Pellettiere	937/255-1150	joseph.pellettiere@wpafb.af.mil	POC	
HAWK	HFE	Data collection tool kit for human performance models	MA&D	Ms. Anna Fowles-Winckler	303/442-6947	awinkler@maad.com	POC	
HSIAC Anthro	HFE	Anthropometric data sets	HSIAC	HSIAC Program Office	937/255-4842	http://iac.dtic.mil/hsiac/Anthro_Sets.htm	Free	
iGEN	HFE	Cognitive modeling	Chi Systems, Inc.	Dr. Wayne Zachary	215/542-1400	wayne_zachary@chiinc.com	$17,995	
IMAGE	HSI	Ship functional requirements	Carlow	Dr. Tom Malone	571/434-9222	tbmalone@carlow.com	POC	JCC(X), DD(X), IEP
IMPACT	Manpower	Manpower workload analysis for ships	Carlow	Dr. Tom Malone	703/444-4666	tbmalone@carlow.com	POC	
IMPRINT	HSI	Human system performance	MA&D, ARL	Ms. Sue Archer	303/442-6947	sarcher@maad.com	Free	Fox NBC, Joint Base Station, Crusader, Air Warrior
INDI	HSI	COTS item suitability	Carlow	Dr. Tom Malone	571/434-9222	tbmalone@carlow.com	POC	no Navy projects
INJURY	Survivability	Blast survival model	AMEDD	Maj. Carl Hover	301/619-7301	carl.hover@det.amedd.army.mil	Free	Under review by AMEDD
IPME	HSI	Human-system performance modeling	MA&D	Ms. Anna Fowles-Winckler	303/442-6947	awinkler@maad.com	$15,750	SC21, DRDC-Toronto

B. RCS CALCULATIONS AT 800 MHZ

Frequency GHz	El Degrees	Az Degrees	VV	HV	VH	HH
0.8	5	0	47.41	2.88	-1.26	47.68
0.8	5	1	46.54	0.48	-2.61	46.68
0.8	5	2	44.95	2.18	2.46	45.09
0.8	5	3	42.53	-0.33	2.1	42.62
0.8	5	4	38.74	-1.44	1.75	38.46
0.8	5	5	32.1	2.95	3.15	30.83
0.8	5	6	26.66	9.49	8.09	27.52
0.8	5	7	36.27	10.31	10.01	36.55
0.8	5	8	40.29	12.65	12.38	40.6
0.8	5	9	41.43	13.78	13.74	41.82
0.8	5	10	40.93	13.71	13.67	41.02
0.8	5	11	41.51	14.62	14.39	41.76
0.8	5	12	43.73	13.09	12.91	43.8
0.8	5	13	42.95	13.17	12.74	42.78
0.8	5	14	31.76	11.66	11.37	30.14
0.8	5	15	41.41	10.62	10.28	41.49
0.8	5	16	46.47	10.61	10.23	46.58
0.8	5	17	44.91	12.05	12	45.12
0.8	5	18	36.83	13.81	13.97	37.55
0.8	5	19	33.25	15.2	15.12	33.98
0.8	5	20	39.3	14.98	14.94	39.97
0.8	5	21	37.88	12.79	12.62	38.76
0.8	5	22	36.22	12.61	12.79	34.98
0.8	5	23	44.26	12.73	12.75	44.24
0.8	5	24	43.66	12.53	12.16	44.47
0.8	5	25	40.94	10.41	9.92	42.2
0.8	5	26	38.37	9.57	8.82	36.56
0.8	5	27	45.12	12.62	12.08	44.5
0.8	5	28	34.71	12.95	13.13	33.85
0.8	5	29	42.68	14.71	14.48	42.02
0.8	5	30	46.36	13.9	13.8	45.79
0.8	5	31	43.82	13.83	13.65	44
0.8	5	32	45.23	12.1	11.94	45.58
0.8	5	33	44.39	13.14	13.22	44.15
0.8	5	34	43.24	9.76	9.63	43.16
0.8	5	35	44.33	5.92	5.84	44.51
0.8	5	36	46.12	8.64	8.42	46.01
0.8	5	37	47.82	6.27	5.93	47.9
0.8	5	38	48.37	4.63	4.73	48.46
0.8	5	39	47.85	7.19	6.74	47.74
0.8	5	40	45.69	9.31	9.34	45.82
0.8	5	41	49.32	-3.2	-2.61	49.28
0.8	5	42	42.72	13.25	13.28	42.72
0.8	5	43	46.65	9.75	9.84	46.73
0.8	5	44	46.5	15.63	15.59	46.42
0.8	5	45	46.62	4	3.34	46.74
0.8	5	46	49.64	4.17	3.94	49.59
0.8	5	47	47.18	12.41	12.34	47.29
0.8	5	48	47.41	13.56	13.41	47.37
0.8	5	49	48.43	14.18	14.21	48.38
0.8	5	50	44.18	4.85	5.22	44.11
0.8	5	51	46.94	3.02	3	46.83
0.8	5	52	39.39	11.78	11.77	38.79
0.8	5	53	44.93	-5.89	-4.5	45.06
0.8	5	54	49.97	13.42	12.96	50.05
0.8	5	55	54.28	1.79	3.04	54.23
0.8	5	56	52.13	11.13	10.48	52.18
0.8	5	57	55.18	11.47	11.14	55.08
0.8	5	58	44.43	15.36	15.46	44.38
0.8	5	59	48.89	11.73	11.36	48.96
0.8	5	60	48.92	8.41	8.5	49.01
0.8	5	61	48.21	11.64	11.38	48.13
0.8	5	62	43.26	11.04	11.07	43.11
0.8	5	63	30.41	11.09	10.89	30.08
0.8	5	64	46.56	19.16	18.89	46.04
0.8	5	65	48.49	11.13	10.82	48.65
0.8	5	66	55.86	18.87	18.68	55.73
0.8	5	67	54.04	-2.23	-3.46	54.13
0.8	5	68	58.19	20.47	20.46	57.99
0.8	5	69	55.49	5.79	6.06	55.49
0.8	5	70	20.33	21.29	21.4	28.76
0.8	5	71	49.87	17.85	17.8	49.72
0.8	5	72	54.61	19.48	19.7	54.59