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Monterey, California

Technical Report

"SEA LANCE"
LITTORAL WARFARE SMALL COMBATANT SYSTEM
By

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SEA LANCE is designed as the deployment mechanism for the Expeditionary Warfare Grid proposed in the Capabilities of the Navy after Next (CNAN) study being conducted by the Naval Warfare Development Command. The system composed of the SEA LANCE and Expeditionary Grid will be capable of providing the deployability, flexibility, versatility, lethality and survivability necessary within the contested littorals to provide the operational commander with the awareness and access assurance capability lacking in the fleet of the POM.

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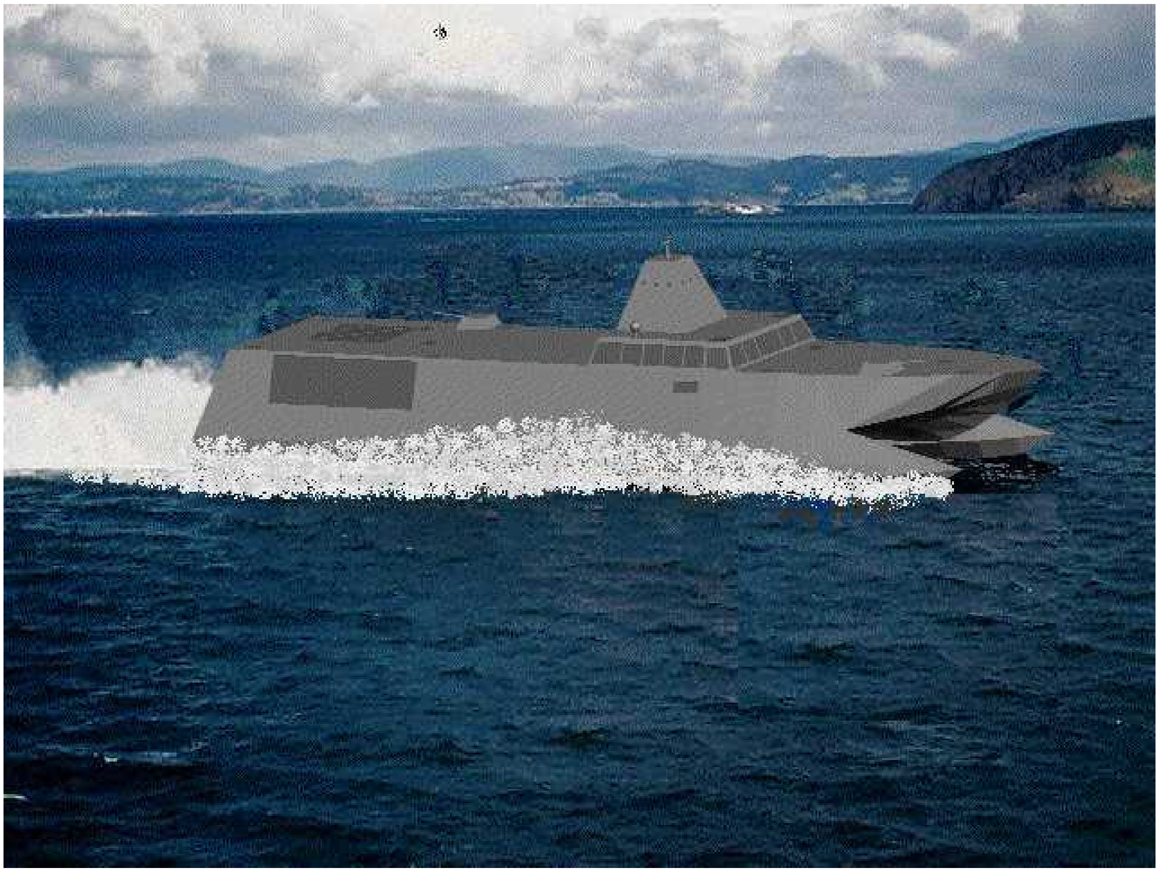


SEA
LANCE

FACULTY COMMENTS AND PROMULGATION STATEMENT

The level of achievement by the Academic Year 2000 TS 4002/4003 “SEA LANCE” Capstone Design Project Student Team was exceptionally high. As reflected in this report, the depth and breadth of the work performed was significant, particularly in the “front end” portion of the process covering the threat assessment, mission need statement, operational analysis, requirements setting etc. phases. Equally significant was the work done at the “back end”, including hydrostatics, structural analysis, and hydrodynamic (motions and loads) calculations. In the ten years since the Total Ship System Engineering (TSSE) Program was initiated at NPS, this project is considered to have produced the highest overall quality product, given the higher “degree of difficulty” of the initial design problem, i.e., the very general level of requirements provided by the project sponsor, the Navy Warfare Development Command (NWDC) and the impact of some of the front-end decisions the students made as they worked through the process.

In fact, the very favorable reception of the project outbriefing by the sponsor and other high-level Navy officials, is testament to the worth of the work. While SEA LANCE was unquestionably an “academic” project performed by graduate engineering students not having formal degrees in naval architecture, their work represents a rationally derived, through the TSSE process, conceptual design for a small, littoral warfare surface combatant incorporating high risk/high payoff technologies from the starting point of a very broadly defined military requirement. There is a real basis for follow-on work to further validate the feasibility of the basic design concept.

As mentioned above, it is important to note that the students on this project had an exceptionally difficult design challenge for two primary reasons. In the early stages of the design they were confronted with a very “fuzzy” open-ended concept of small, high-speed craft contributing to the concept of Network Centric Warfare in a littoral region, in conjunction with a deployed grid of weapons and sensors. Such basic questions as the geometry of the scenario; whether the craft would both deploy and tend the grid elements; whether the craft would cooperate with the “blue water” fleet after its arrival; whether the grid deployment would occur in the face of active opposition, and many others, required resolution and answers. An unusually difficult and lengthy scenario-development phase consumed the first several weeks of the project, becoming an essential foundation for the remainder of the work. This level of operational analysis greatly exceeded that required in any previous TSSE student project.

The second difficult design challenge was due to the fact that their choice of a catamaran hull form as their basic platform architecture meant that they would have to perform manually, in combination with selected specialized computer tools, the fundamental ship system synthesis process and feasibility check normally accomplished through use of the ASSET design program. Available versions of ASSET are limited to monohulls and can only be applied to multi-hull platforms with difficulty, even by skilled users. Further, much of the data for the specific wave-piercing catamaran hull form variant which the students selected is proprietary to the companies constructing such ships, which have primarily been built for the commercial fast ferry market. Although it accordingly proved difficult for the students to obtain the kind of technical information needed even for a conceptual/feasibility-level study, their persistence in dealing directly with the shipbuilders involved at least gave them as much as could be reasonably obtained.

Among the noteworthy novel features of the SEA LANCE concept, are the following:

- “Tractor/Trailer” platform concept.
- Use of Wavepiercing catamaran hull forms for both “tractor” and “trailer” portions.
- Semi-rigid, close-coupled tow system.
- Advanced waterjet propulsion.
- Minimal manning by specially trained crew.
- Telescoping sensor mast.
- Gravity-based deployment system for “Expeditionary Grid” components.
- Use of a common missile for both surface-to-air and surface-to-surface defensive roles.

Given the novelty of some of these features, it should not be surprising that the overall technical feasibility of the SEA LANCE concept as presented in this report will depend on the outcome of follow-on research in associated areas. The students recognized this need in their recommendations for further work. Some of the more critical questions still to be resolved are as follows:

1. Is the whole concept of a close-coupled semi-rigid tow feasible, even if applied to conventional monohull forms? The load calculations and sizing of the tow member presented in the report were based on certain assumptions that warrant further review.

2. Is the wave-piercing catamaran hull form suitable for the "trailer" portion of the vessel? The impacts of the wake and flow behind the "tractor" portion, particularly if it is also a catamaran, on the "trailer" portion are unknown. This problem is compounded both by the close-coupled (20-feet) towing system design and the use of waterjet propulsion.

3. Will the significant improvements in efficiency over a range of speeds claimed for the "Advanced Waterjet-21 (AWJ-21)" concept be borne out in testing? The presumed ability of the AWJ-21 to provide efficient propulsive power at two distinct design points- with the tow at 15 knots and without the tow at 38 knots – is vital to the success of the SEA LANCE concept.

4. Is it possible to achieve a relatively high-speed tow (15 knots) while maintaining adequate directional stability & controllability? This is a concern even for a monohull-based concept, let alone for the catamaran hulls employed in the SEA LANCE approach.

Despite these uncertainties, the SEA LANCE study clearly shows that the general concept of a force of relatively smaller, fast, stealthy surface combatants offers real potential for a cost-effective improvement in our capability to conduct littoral warfare operations, complementing already programmed future assets such as the DD21. Even if the risks associated with the "tractor-trailer" concept prove too high, the basic SEA LANCE combatant design based on an advanced hull form such as a wave-piercing catamaran hull form remains an attractive candidate for further study.

Fortunately, as of this writing, the favorable reception of SEA LANCE by the NWDC sponsor and other high level officials has led to plans to have the SEA LANCE concept formally evaluated by the Naval Sea Systems Command. Coupled with related efforts to pursue some of the technologies incorporated in SEA LANCE, e.g., a proposal for the US Navy to lease an "off-the-shelf" wave-piercing catamaran for evaluation purposes, there is a real

possibility that the SEA LANCE work can lead to development of a new type of warship and associated operational concept for the “Navy-After-Next”.
That possibility alone makes this particular TSSE Capstone Design project a notable success and benchmark against which future projects will be judged.

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The team would like to acknowledge the following individuals or groups that aided us in the design effort.

- The Faculty of the NPS TSSE Program
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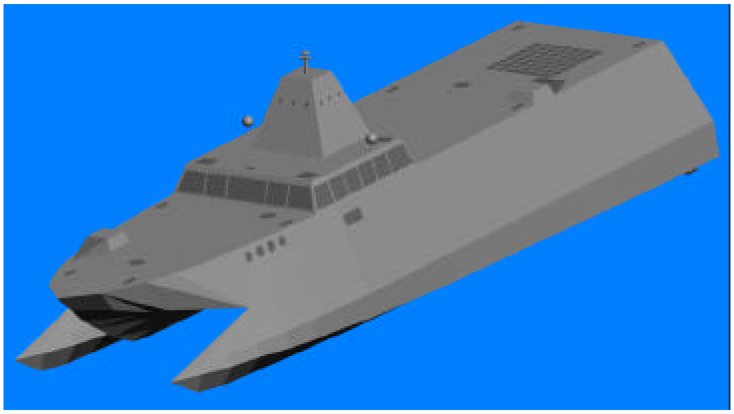
- Mr. Ken Brower, Naval Architecture Consultant
- And all those who aided us in the design who we may have inadvertently omitted.

Chapter I: Executive Summary and Operational Scenario

A. Executive Summary

SEA LANCE is designed as the deployment mechanism for the Expeditionary Warfare Grid proposed in the Capabilities of the Navy after Next (CNAN) study being conducted by the Naval Warfare Development Command. The system composed of the SEA LANCE and Expeditionary Grid will be capable of providing the deployability, flexibility, versatility, lethality and survivability necessary within the contested littorals to provide the operational commander with the awareness and access assurance capability lacking in the fleet of the POM.



Extracts from Operational Requirements Document:

SEA LANCE must be capable of:

- Maximum speed of 38 knots
- Minimum range of 3000 Nm at 13 knots
- Maximum crew size of 20 officers and enlisted
- Maximum of $100 million for the first ship
- Maximum displacement of 1000 LT
- Transit in sea state 6, grid deployment in s.s. 4

The fleet of the POM is not ideally suited to directly operate in the highly complex and hostile littoral environment. Concealment together with the surprise factor, inherent to an adversary operating in its own littorals, will pose high risk to our conventional power projection assets.

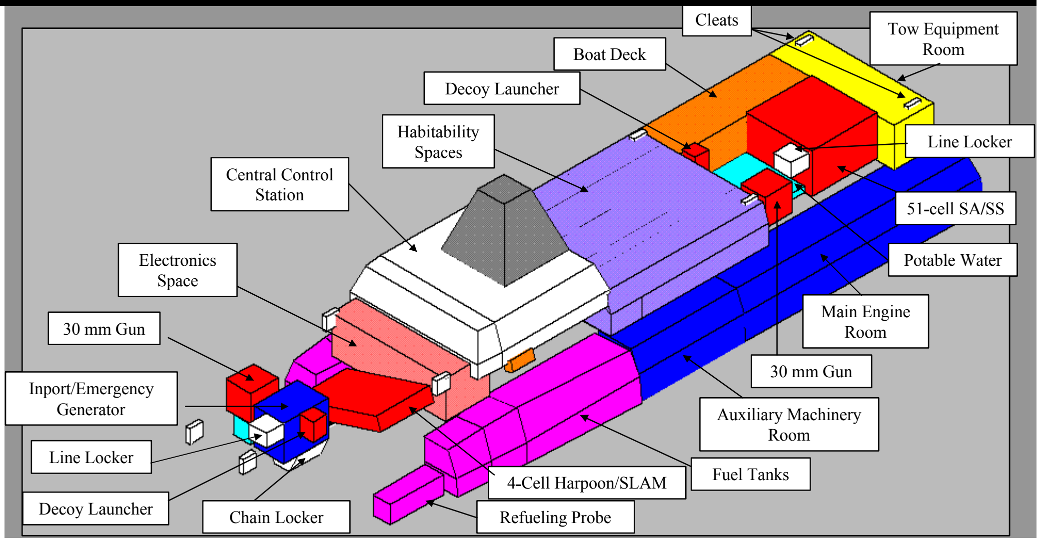
This situation creates the need to develop a capability that will allow gaining, maintaining, sustaining and exploiting access to the littorals, in order to project power into enemy territory.

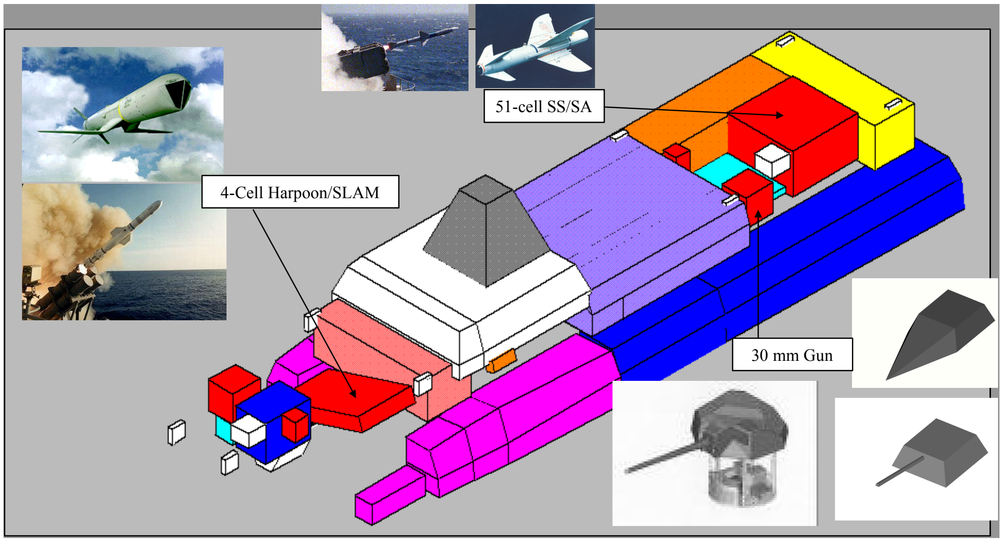
SEA LANCE in conjunction with the Expeditionary Warfare Grid will be capable of performing this vital mission.

Seaborne
Expeditionary
Assets for

Littoral
Access
Necessary in
Contested
Environments

The combatant is a robust fighting platform that provides its 13-person crew with all the support necessary to conduct operations in support of the mission needs statement. From the combined control station to the auxiliary equipment, all components are connected to the Ship's Wide Area Network via a Total Open Systems Architecture (TOSA). Technology advancements like these are key to the success of the austere manning concept.

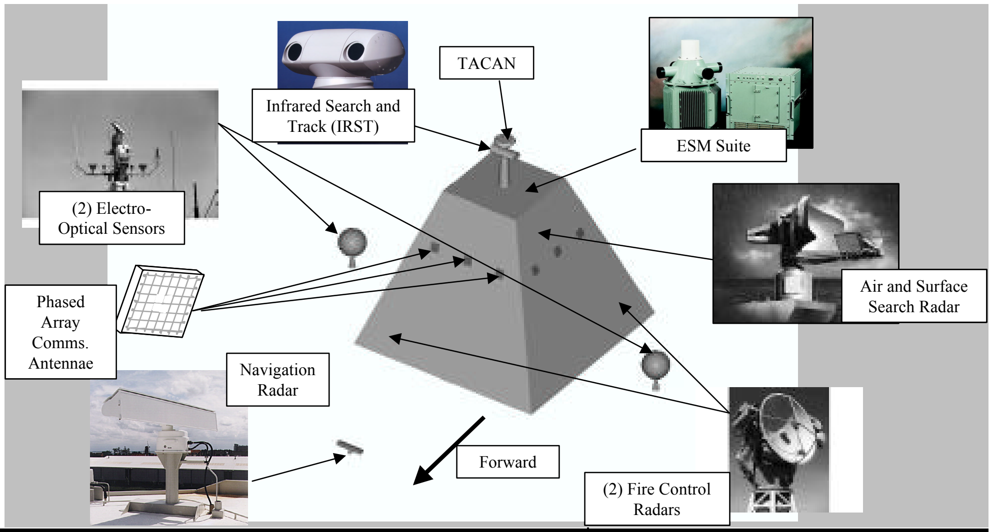




The combat systems suite of the craft is capable of detecting, classifying and engaging aircraft, missiles and small surface combatants.

The combatant has a 4-cell Harpoon/SLAM launcher capable of engaging both surface and land targets. It also has a 51-cell surface-to-surface and surface-to-air missile system that is outfitted with active, semi-active and infrared guided missiles. Additionally, it has (2) 30 mm guns similar to those proposed on the AAAV and LPD-17 class.

The combat systems suite of the combatant is capable of operating in a wide range of environments. The air/surface search radar has a range of 54 Nm while the infrared search and track (IRST) as well as the fire control radar has a range of 20 Nm. The electro-optical suite has a range of 10 Nm and the mine-avoidance sonar has a detection range of approximately 350 yards. Additionally it is equipped with an ESM suite and phased array communications antennas. The entire suite is enhanced by the use of an advanced enclosed mast.



SEA LANCE is pair of vessels composed of a combatant and tow. The tow has relatively the same hull form and naval architecture characteristics as the combatant. It is a semi-fixed close proximity tow of approximately 20 feet. The tow is referred to throughout the literature and presentation as the Grid Deployment Module (GDM). Some characteristics of the two vessels are provided to the right.

Combatant

Full Load Displacement:	450 LT
Light Ship Displacement:	283 LT
Length Overall:	167 feet
Length at Waterline:	146 feet
Draft	8 feet
Beam	10 feet
Block Coefficient (CB)	0.625
Prismatic Coefficient (CP)	0.857
Midship Section Coeff. (Cx)	0.729
Grid Deployment Module (GDM)	
Light Ship Displacement	146 LT
Payload Fraction	67 %

The acquisition costs were estimated at approximately $83.9 million dollars for the first combatant and grid deployment module pair. Assuming a learning curve through the first ten ships, the cost of the 11th and subsequent pairs will be $82.7 million. The first squadron will cost $914 million with follow-on squadrons at $827 million.

The Naval Postgraduate School's Total Ship Systems Engineering Program is composed of:
Faculty: Prof Charles Calvano, Prof Dave Byers, Prof Robert Harney, Prof Fotis Papoulias, and Prof John Ciezki
2000 Students: LT Howard Markle, LT Rick Trevisan, LT Tim Barney, LCDR Garrett Farman, LT Karl Eimers, LT Chris Nash, LT(jg) Ahmet Altekin and LT Ricardo Kompatzki

B. Operational Scenario

The following paragraphs will describe in detail the operational scenario that was utilized to develop the NPS TSSE design. The initial discussion will frame the physical geography of the scenario followed by a description of the geometry, transit, placement of the Expeditionary Warfare Grid, operational considerations, etc. that complete the framework of the overall problem scenario.

The CNAN craft will be forward-based throughout the world to allow a rapid response to the area of interest. These forward bases will provide the necessary logistic support as outlined in the requirements document. The forward base will be located approximately 1000 Nm from the coast of the adversary nation. The CNAN craft will be outfitted at the forward base with the desired Expeditionary Warfare Grid components and will transit with no logistic support other than is carried by its fellow CNAN craft.

The Expeditionary Warfare Grid will be deployed in a “cul-de-sac” region. This region can be a gulf, group of islands or any region that has restricted maneuverability in a littoral environment. Most coastal countries have such regions. They are typically vital in terms of enemy operations and strategy. They are likely focal points of any access denial strategy. The “cul-de-sac” will have a radius of 400 Nm and the adversary nation will encompass the entire area of the cul-de-sac.

The land littoral region will extend approximately 200 Nm inland from the coast of the adversary nation. The sea littoral will be defined as extending 500 Nm from the coastline of the adversary nation and 1000 feet below the surface of the water. The adversary nation will have significant access denial capability within the sea littoral region. This access denial capability will prevent operations of the fleet of the POM. The fleet of the POM could operate within the access denial region, but with unacceptable risk to the units and personnel. The air littoral region will extend to 90,000 ft above the land and sea littoral.

The Notional Adversary that was chosen was Competitor 2 that is described in the "World View" document of Appendix A. This document contains the assumptions the team used for the political climate, training and readiness as well as size and complexity of the adversary.

The CNAN craft will transit from the forward base into the access denial region, deploy the Expeditionary Warfare Grid and transit out to refuel/rearm (if necessary) with POM logistic units. This refueling/rearming will be conducted outside the access denial region at a point approximately 600 Nm from the coast of the adversary nation. Prior to this refuel/rearm the CNAN craft will not have logistic support. The exception to this may be to provide logistic support from one of the other CNAN craft (i.e. a "tanker" variant). The CNAN craft will transit at 15 knots, deploy the Expeditionary Warfare Grid at 15 knots, and conduct engagements at 40 knots.

Figure (1) on the next page is a pictorial of what the preceding paragraphs describes.

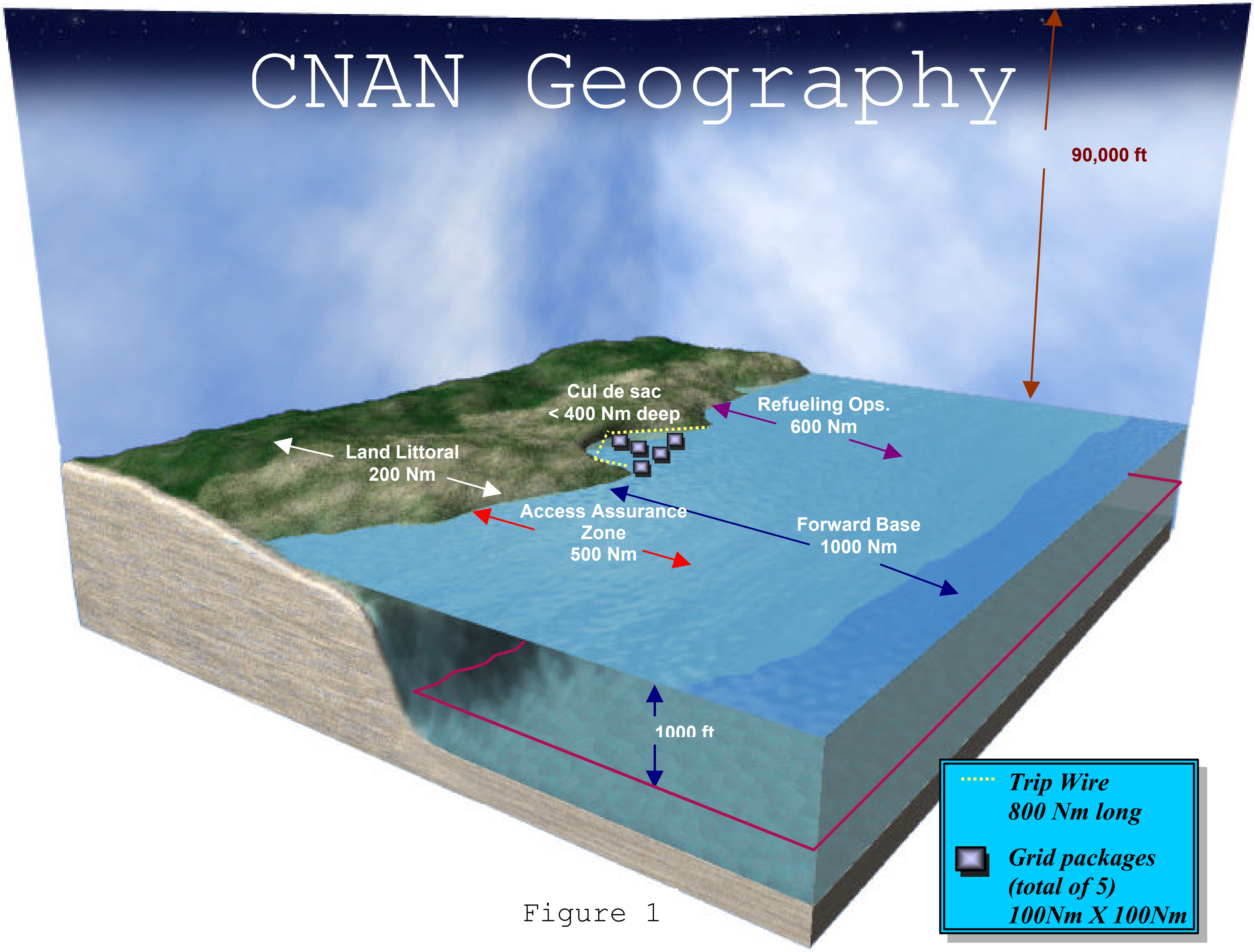

CNAN Geography
90,000 ft
Cul de sac
< 400 Nm deep
Refueling Ops.
600 Nm
Land Littoral
200 Nm
Access Assurance
Zone
500 Nm
Forward Base
1000 Nm
1000 ft
Trip Wire
800 Nm long
Grid packages
(total of 5)
100Nm X 100Nm

Figure 1

The Expeditionary Warfare Grid will consist of a tripwire and 5 grid boxes. The tripwire will be approximately 800 Nm long and be placed in close proximity to the adversary nation's coast. The tripwire will consist of sensors only as depicted in Figure (2). Sensors and their capabilities were assumed to be the same as outlined in the CNAN FDCS Event 3 (CTTAS Game)"tool box" (Appendix A). It will be assumed that the Expeditionary Warfare Grid elements have some limited mobility and that three lines of elements can be deployed by the CNAN craft per pass through the area.

The grid boxes cover an area of 100 Nm by 100 Nm. They will consist of both sensor and weapon packages. Once again the weapons ranges, weights, volumes and capabilities are outlined in the CNAN FDCS[define term] Event 3 (CTTAS [define term]Game)"tool box" (Appendix A). The number of weapons required to effectively attrite the access denial capability of the adversary nation are presented in Table (1). These numbers include the weapons required to defend the craft and the grid as well as diminish the access denial capability. The grid boxes will be deployed within the cul-de-sac. Three of the grid boxes will be deployed along the entrance spaced 100 Nm apart. The remaining two grid boxes will be placed in a line perpendicular to the grid line at the entrance, centered in the cul-de-sac and spaced 100 Nm apart. Figure (3) depicts the geometry of the grid boxes. The total weight and volume required for all the grid and weapons elements is presented in Table (2). The total weight is 6,000 LT with a total volume of 170,000 ft^3.

Weapon Totals

	Carried	Required
AAW:	3,000	3,000
ASUW (Large):	340	400
ASUW (Small):	1,000	1,000
ASW:	160	100
STRIKE (Long):	300	300
STRIKE (Short):	700	700

NOTE: The 60 extra ASW weapons were applied to the ASUW (large) weapons requirement.

Table 1

CNAN Distributed Grid and Craft Payload

	Number Elements	Total Volume (ft^3/element)	Total Weight (Tons/element)
CM Radar Picket	1337	23,610	668
DADS	4160	1,602	208
TAMDA	20	8	1
LFAS	20	480	18
UCAV Small	15	525	4
RSTA	12	4,944	148
IR SAM	2000	53,000	400
Air Mines	800	3,601	200
Tomahawk	300	13,959	570
SubBAT	500	1,200	48
FSAM	500	625	37
SM-3/TBMD	1000	19,360	2,000
NTACM	700	21,889	1,575
TORP BATT	40	12,783	399
HARPOON	340	10,540	432
		168,126 Total ft^3	5,989 Total LT

Table 2

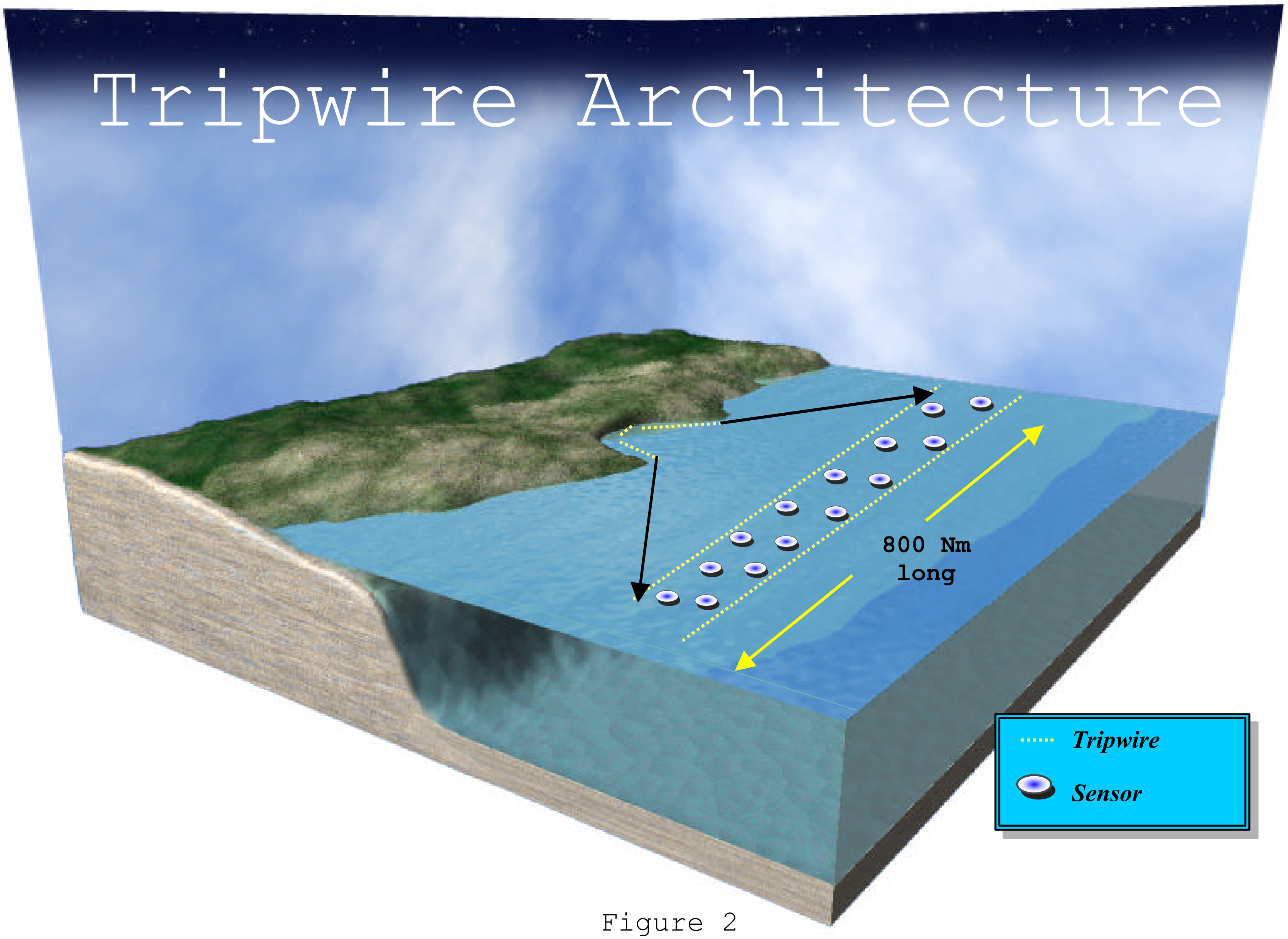


Figure 2

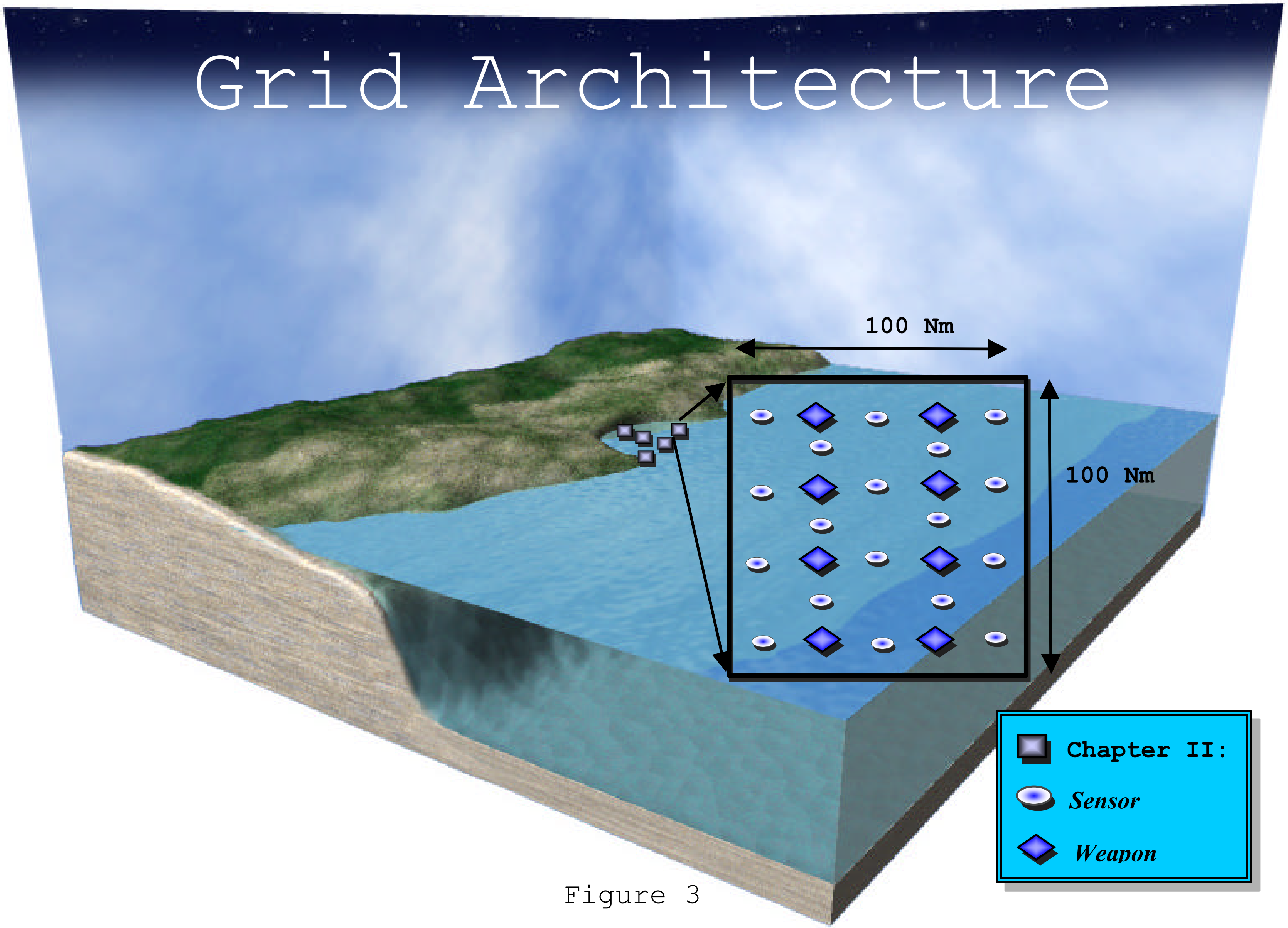


Figure 3

Chapter II: REQUIREMENTS DOCUMENT

A. MISSION NEEDS STATEMENT

After the end of the Cold War, the view of the world has shifted from a global-war scenario to one of regional crisis situations. This fact implies a very important shift in operational orientation for the Navy, because the battlefield has moved from "blue waters" into the "contested littoral environment." Emerging powers are developing massive access denial capabilities to prevent power projection into their territory.

The size of the "contested littoral" environment of threat nations continues to grow. The Navy needs to develop a system that can provide assured access in these closely contested littoral environments. The "Navy After Next" must marry new capabilities with the best capabilities of the fleet of the POM to gain, sustain and exploit that access. It must be an integral part of Network Centric Warfare (NCW) and be capable of joint and combined operations.

An essential key to success in the littoral environment is increased numbers of sensors, weapons, combatants and unmanned vehicles to produce a force structure capable of tipping the scales in our favor. Numbers will matter and the Navy After Next must be affordable and yet be robust enough to provide the support required of our current forces as well as produce the numbers necessary to upset the future littoral force imbalance. The combatant and its payload must be expendable to the extent that it is not viewed as a high value unit, but have a level of survivability capable of allowing the crew time to “eject” when the combatant is no longer capable of sustaining them (much like modern-day aircraft).

The fleet of the POM is not ideally suited to directly operate in the highly complex and hostile littoral environment. Concealment together with the surprise factor, inherent to the enemy operating in its own littorals, will pose undue risk to our conventional power projection assets.

This weakness creates the need to develop a capability that will allow gaining, maintaining, sustaining and exploiting access to the littorals, in order to project power into enemy territory.

B. OPERATIONAL REQUIREMENTS DOCUMENT

1. Description of Operational Capability

In support of the mission needs statement, the Naval Warfare Development Center (NWDC) is conducting a Navy research program, which will explore new “Capabilities for the Navy After Next” (CNAN) that will take advantage of the leading edge technology and information superiority. The Naval Postgraduate School (NPS) Total Ship Systems Engineering (TSSE) Program is supporting the Platform Team of the NWDC CNAN study. The NPS TSSE team will develop a design of a combatant(s) which will distribute the Expeditionary Warfare Grid discussed in the mission needs statement, tend (and be part of) the Expeditionary Warfare Grid once in place and become an integral part of the warfighting capability of the Expeditionary Warfare Grid system in support of the Expeditionary Warfare Grid’s access mission.

The Expeditionary Warfare Grid system will consist of four parts: a global satellite-based network, logistic support ships (which may or may not be the existing logistics force), a distributed sensor and weapons system, and small combatants that deploy/tend the sensors and weapons.

The Expeditionary Warfare Grid is assumed to be robust, secure, and readily accessible for two-way exchange of information. Antenna requirements will not exceed 40 cm in diameter and need not be aimed at specific satellite coordinates.

The logistics force will be capable of providing any asset needed by the combatants. This will include food, replacement parts, fuel, replacement-distributed components, Fly-Away Teams for extensive preventive/corrective maintenance and all administrative support. The logistic force will provide crew replacements for the combatants during extended operations. The logistic force will not provide berthing or long-term mooring for the combatants or their personnel. The logistic force will not be capable of transporting the combatants. Logistics replenishment will be performed in relatively safe waters and in modest sea states.

The sensors will be connected to the Expeditionary Warfare Grid via some form of modems and will have some limited mobility. The sensors are acoustic arrays, radar array elements, magnetic detectors, ESM sensors, infrared detection arrays, and optical elements. The weapons are also connected to the network and receive their firing authorization via the network. The weapons will include torpedoes, torpedo-based mines, surface-burst fragmentation mines, canister surface-to-air missiles, canister surface-to-surface missiles and strike missiles. The sensors and weapons will be deployed wherever they are tactically needed. This may include blue water, in littoral waters, near the shore or inland.

The combatants will carry the sensors and weapons. Some of the sensor and weapon capability of the Expeditionary Warfare Grid will be organic to the combatants. The combatants will have the capability of exercising local command and control of the sensor and weapons within the Expeditionary Warfare Grid. It is expected that the combatants will be capable of a trans-oceanic crossing when time is not a concern. It is envisioned that the ocean transit will be limited to 1000 Nm or less by use of appropriate forward basing of some kind (i.e. Guam, Naples, Hawaii, Diego Garcia, etc). Forward bases may be subject to attack by the enemy, so the combatants must be capable of rapid sortie. The access denial area is extends approximately 500 Nm from the enemy's coastline. The Expeditionary Warfare Grid will be distributed within a "cul-de-sac" that has a radius of approximately 400 Nm. The combatants will be required to transit 100 Nm outside the access denial area to obtain logistic support.

The Expeditionary Warfare Grid/Combatant System must perform the following:

a. Perform early warning: detect, classify and track contacts

b. Destroy or drive off enemy coastal waterborne commerce

c. The combatant must deploy, monitor, protect and control sensor/weapon Expeditionary Warfare Grid

Some possible Expeditionary Warfare Grid/Combatant System missions include:

a. Protection of anchorages/MODLOCs [define term]

b. Harbor and restricted waters blockade

c. Theater Ballistic Missile Defense (TBMD)

d. Area Mine mapping operations

e. Escort for amphibious and logistic forces

f. Strike warfare

g. Shallow water ASW

Some possible Combatant missions include:

a. Maritime Interdiction Operations (MIO)

b. Non-combatant Evacuation Operations (NEO)

c. SOF insertion/extraction

d. Independent operations (showing the flag)

e. Strategic deception operations

2. Threat Summary

It is difficult to predict exactly what the threat will be, but projecting current weapons systems into the future using technologies that are expected to be available allows us to make realistic threat estimates.

The littoral environments that the CNAN units will encounter closely resemble a cul-de-sac with a radius of approximately 400 Nm. The cul-de-sac may be bordered by the aggressor nation or a combination of the aggressor nation and other nations that may or may not be friendly to the U.S. Most of the operations will be conducted against third world nations, however it is conceivable that some of the missions will be applied to emerging world powers.

The contested littoral environment poses a tough problem in that every fishing vessel or personal water craft can carry a shoulder-launched missile system capable of producing significant damage to one of the combatants or Expeditionary Warfare Grid elements. It is envisioned that the threat weapons will be much smaller, faster and more capable in terms of detection, localization, classification, stealth as well as maneuverability. The aggressor nation will also have significantly more of them because they will be relatively cheap and there will be an ample supply of them from the weapons producing countries of the world. Specifically some of these threats include, but are not limited to:

a. Anti-ship missiles

  i. Shore launched

  ii. Ship launched (small fishing boat to large cruiser)

  iii. Sub-surface launched

  iv. Air launched

b. Gunfire

  i. Major caliber

    1) Shore emplacements
    2) Ships

  ii. Minor caliber from small fishing vessels to corvette size combatants

c. Mortars and grenades

d. Torpedoes

  i. Air launched

  ii. Surface launched

  iii. Sub-surface launched

e. Chemical, Biological and Radiological

f. Special Forces

g. Mines

h. Electromagnetic Pulse (EMP)

3. Shortcomings of Existing Systems

The current fleet and the POM 00 Program Navy are capable of performing the assured access and intelligence gathering mission in the contested littoral environment. However, they have some significant shortcomings:

a. To overcome the access denial capability within the littorals, the present Navy and Navy of the POM must come dangerously close to the coast of the aggressor nation. This presents a problem in the following areas:

  i. **Cost.** Fleet of the POM assets are far too expensive to risk damage while operating in the littoral environment. This expense is both in the cost to procure and operate one of the ships as well as the large loss of life onboard one of our personnel-intensive ships.

  ii. **Stealth.** Even with stealth measures, these ships are too large to enter and operate within these waters undetected. A smaller combatant may be able to operate within the littorals for extended periods of time without being detected, localized and identified.

  iii. **Mind Set.** Other nations and our country view these ships as “high value” units. This is ideal for the purposes of power projection and deterrence, but these ships become prime targets during a conflict. A smaller ship may be viewed by an adversary as annoyance rather than a threat worth expending valuable ammunition on.

b. In the current environment, data collection sensors are forced to standoff at ranges which are so great that they can no longer provide the required information rapidly, timely and with sufficient coverage and volume to provide a commander with information required to support accurate tactical choices. There must be an increased number of sensors available and these sensors must be viewed as expendable enough to be placed in a high-risk environment.

c. The Expeditionary Warfare Grid and combatant system must be capable of providing the deployability, flexibility, versatility, lethality and survivability necessary within the contested littorals to provide the operational commander with the awareness and access assurance capability lacking in today’s fleet and fleet of the POM.

4. Range of Capabilities Required

The proposed Expeditionary Warfare Grid/Combatant System shall provide the following capabilities (note: the System includes the combatant):

a. The system shall be capable of sufficiently weakening the area denial capability of the aggressor to allow an acceptable level of risk to the fleet of the POM in the littorals.

b. The system will have an anti-ship missile defense (ASMD) capability.

c. The system will have an area air defense capability.

d. The system will have an area USW capability.

e. The system will have an area SUW capability.

f. The system will be capable of supporting choke point and harbor blockade operations.

g. The system will be capable of sending and receiving data throughout the Network Centric Warfare Environment.

h. The system will be interoperable with any Joint/Combined Task Force.

i. The system will be capable of operating in mined waters.

j. The system shall be designed to produce a low signature (underwater acoustic, airborne, acoustic, IR, and electromagnetic).

k. The system shall perform precision strike missions against land-based targets.

The Combatant shall provide the following capabilities:

a. The combatant will have a minimum sustained speed (80% of full power) of 30 knots with a goal of 34 knots.

b. The combatant will have a maximum speed of 38 knots with a goal of 40 knots. The combatant displacement will not exceed 1000 LT.

c. The combatant will not exceed 100 million dollars in “first ship” cost (FY 01 dollars).

d. The combatant shall conduct transits in sea state 6, deployment operations as well as fight in sea state 4 and small boat operations in sea state 3.

e. The combatant will be capable of conducting a trans-oceanic crossing with dedicated logistic support.

f. The combatant will have a range of 3000 Nm with a goal of 4000 at a minimum endurance speed of 13 knots with a goal of 15 knots.

g. The total combatant force shall be capable of carrying 6000 LT of Expeditionary Warfare Grid components with a volume of 170,000 ft^3.

h. The combatant will have a point air defense capability.

i. The combatant will have a maximum crew size of 20 officers and enlisted combined with a goal of 13.

j. The combatant will be capable of operating within a CBR environment.

k. The combatants shall be capable of performing Maritime Interdiction Operations (MIO) and support Non-combatant Extraction Operations (NEO).

l. The combatant shall be capable of refueling and replenishing at sea.

m. The combatant shall be capable of receiving stores via vertical replenishment.

n. The combatant shall be capable of providing limited accommodations for special operations teams, maintenance support Fly-Away Teams (FAT) and combatant squadron staff.

o. The combatant will have standard couplings and connections to receive hotel services from the pier.

p. The combatant’s combat systems suite must be capable of operating in the open ocean as well as the littoral environment.

q. The combatant shall be capable of towing a combatant of approximately its size.

r. The combatant will be designed with a 10-year with a goal of a 15-year frontline service life.

s. The combatants control (combat systems, navigation and HM&E) will be located in a single location and be networked as much as possible to support minimum manning.

t. The combatant will utilize advanced technologies in HM&E systems and design materials to minimize the size and weight of the craft while maximizing the payload fraction.

u. The combatant crew accommodations (berthing and messing) will be austere to maximize the utility of the combatant.

v. The combatant will be configured to accept payload modules to perform additional mission capabilities after they have deployed the distributed Expeditionary Warfare Grid components.

w. The combatant will meet all MARPOL requirements.

5. Integrated Logistic Support (ILS)

The combatants that support the Expeditionary Warfare Grid must be minimum manned. The small crew will only be capable of supporting the underway watch requirements. The administrative, maintenance and logistic support must be totally automated onboard the ship or must be provided from the fleet to support this minimum manning concept. The following are some of the key requirements of the ILS:

a. A combatant squadron support staff on another vessel must perform the administrative functions such as evaluations, fitness reports, medical, dental, etc. The combatant will not have the personnel or space to support these administrative tasks.

b. Any reports or messages the ship must generate will be incorporated into the ship’s control workstations in template fashion to facilitate ease of drafting, release and transmission.

c. Fly Away Teams embarked on the carriers, amphibious warfare ships or auxiliaries will perform major preventative and corrective maintenance on the combatant and the Expeditionary Warfare Grid.

d. All normal watch standing duties will be performed from the control consoles located in a central workstation.

e. All monitoring of the combatant’s equipment must be automated and distributed through the combatants Ships Wide Area Network (SWAN) to the combatant’s control consoles.

f. Phased maintenance will performed every 12 months (15 day duration), with a Docking Selective Restricted Availability (DSRA) every 5 years (3-month duration). The homeport support teams that are also members of the Fly Away Teams will perform all of the above.

g. Commercial-Off-The-Shelf (COTS) equipment will be utilized wherever possible to utilize and exploit commercial research and development.

h. Parts support for the combatant as well as the Expeditionary Warfare Grid will be maintained elsewhere.

i. Underway Training will be conducted from computer terminals within the central control station or within the crew berthing compartments.

j. Inport Training will be conducted in a dedicated training facility in the homeport of the combatant.

6. Infrastructure Support

The combatant will require augmentation of its crew while in port. The small crew will be unable to paint and preserve the ship, on-load stores, refuel, pull shore power cables and numerous other labor-intensive tasks. The port facilities will need to be manned with support personnel who are coordinated with these tasks to support the ship's day-to-day routine.

All support material for the ship (charts, publications, technical manuals, etc.) will be produced in electronic media format and stored within the combatant's SWAN to be displayed at the workstations when required.

All systems produced for the combatant/ Expeditionary Warfare Grid system must have an open architecture format with minimum storage requirements and compatibility with all other systems utilized in the combatant/Expeditionary Warfare Grid.

7. Force Structure

The total number of combatants will be approximately 100 ships that will be divided into approximately 10 squadrons. They will be forward deployed through out the world to facilitate rapid response.

8. Schedule Considerations

The System must be deployable within 5 years of authorization and funding with an IOC of no later than 2015. Combatants must be produced at a rate of 10 per year with an FOC of 2025.

9. Cost Considerations

The system must be robust enough to provide awareness and gain access as desired, while keeping the cost of a single combatant to less than 100 million dollars (FY 01 dollars). The combatants must maintain deployability, flexibility, versatility and survivability to meet the challenging requirements of the contested littoral environment.

Chapter III: Analysis of Alternatives

A. Alternative Architectures

There are three main architectures that the NPS TSSE design team considered. The first of these is a medium size combatant with a tow (Option I). The second is all medium size combatants (Option II). The final architecture is a mixture of small and medium sized combatants (Option III). A representative combatant already in production will be presented to provide an idea of the range of capabilities and limitations of the architecture. The representative combatant may or may not look like or have the same capabilities as the TSSE design, but are provided as starting point to estimate size, range, naval architecture parameters, etc. The three architectures will be discussed in more detail in the following paragraphs.

1. Option I

Medium Size Combatant (450 LT) with Tow (450 LT)

In this option the combatant is designed as just that, an extremely capable fighting craft that is designed to be a warship. However, this combatant must be capable of connecting to and towing a “barge” of approximately the same displacement at the desired transit and deployment speeds of 15 knots. The combatant will contain largely self-defense weapons and be capable of defending itself and the Expeditionary Warfare Grid. The vast majority of the Expeditionary Warfare Grid components will be contained on the tow to provide maximum flexibility of the combatant. The tow may also provide some of the fuel required during the transit and deployment phases of the operation. The tow system will be of a semi-fixed design, similar to that depicted in Figure (4). This figure depicts a SLICE/KAIMALINO configuration currently studied by the Office of Naval Research (ONR 362, Advanced Hullforms Program) and Lockheed/Martin Corporation. In higher sea states the tow may be extended to a conventional tow or may be rapidly disengaged to allow the combatant greater maneuverability during an engagement.

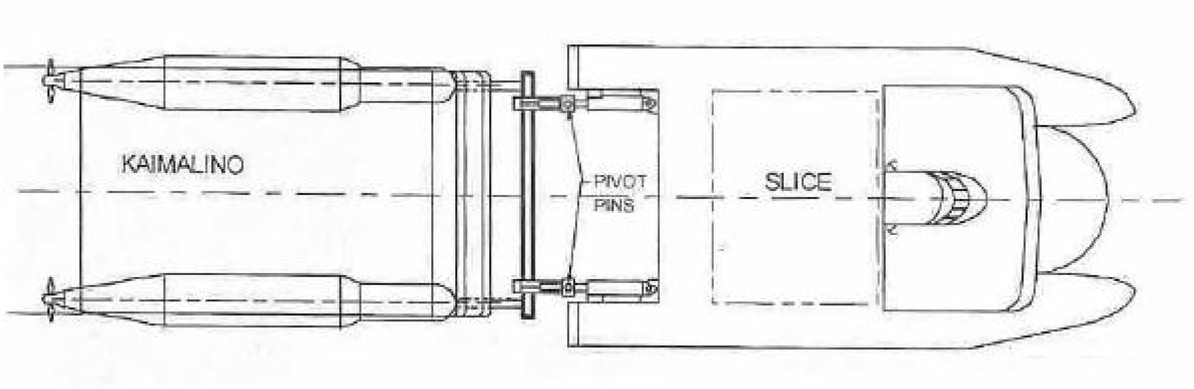


Figure 4

The Swedish “GOTEBORG” class is representative of modern combatants n the 450LT displacement range. Figure (5) is a picture of the GOTEBORG, with characteristics given below:

Figure 5 (Goteborg Class)

Nation:	Sweden
Class:	GOTEBORG
Number in Class:	4
Built by:	Karlskrona Shipyard
Displacement:	420 tons (full load)
Dimensions (ft):	187 x 26 x 6.6
Speed:	30 knots
Range:	1900 Nm at 12 knots
Propulsion:	3 MTU 16V 396 TB4 diesels (8700 hp) KaMeWa 80-S62-6 water jets

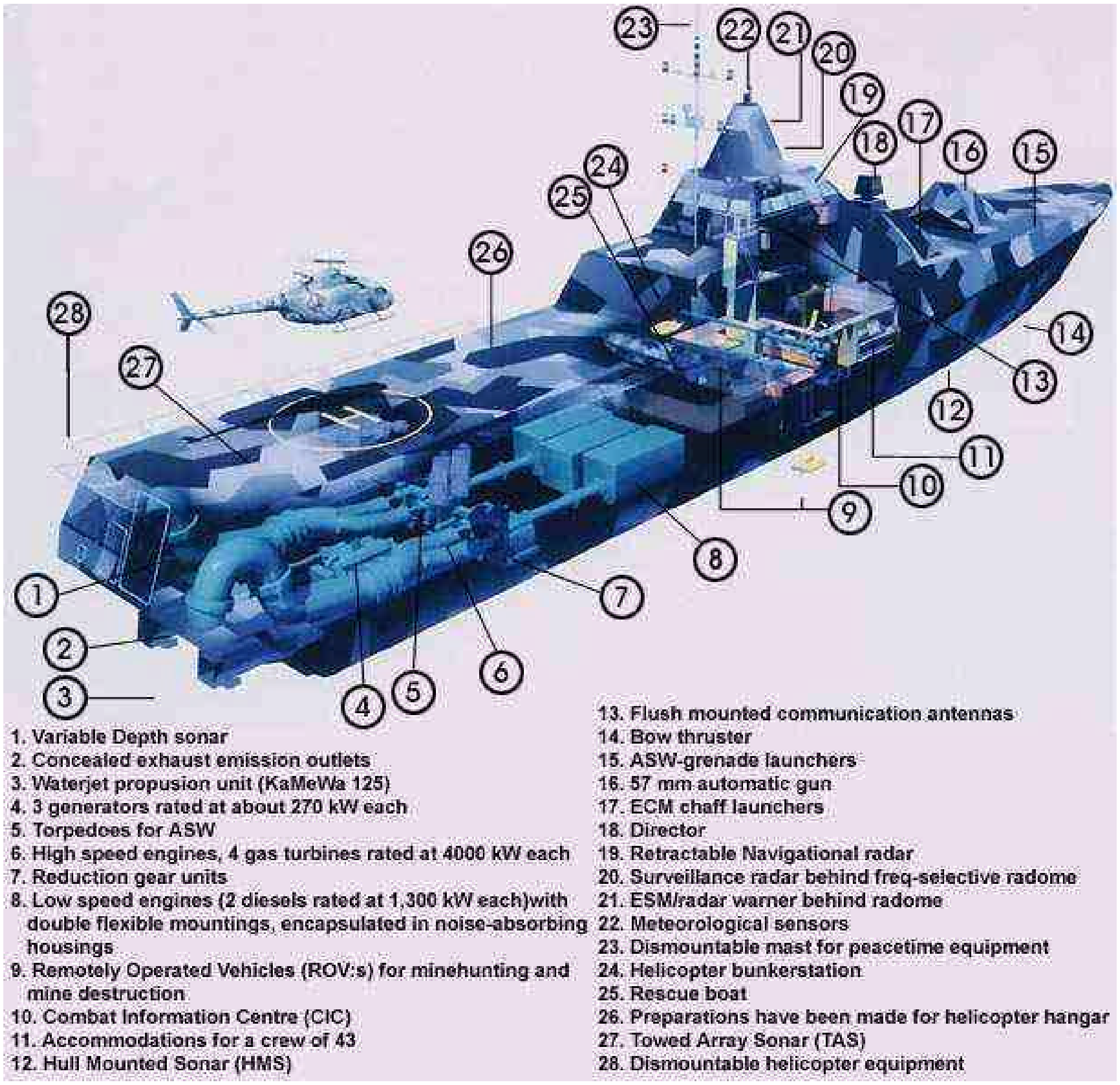
Electrical:	3 285-kVA diesel generators
Weapons:	1 Bofors 57mm
	1 Bofors 40mm
	4 torpedoes
	8 RBS-15 SSM
	A/S Mortars 4 Saab 9-tube launchers
Sensors:	Sea Giraffe (G/H Band) air and surf
	2 Bofors Sea Viking optical directors
	Thomson Sintra VDS
	Simrad hull mounted active sonar
Manning:	7 Officers, 36 enlisted
Construction:	Steel Hull
	Aluminum Superstructure
	Fin stabilizers
Improvements:	Upgrade Sonar (CDS Hydra)
	IRST director
	Passive Towed Array

2. Option II

All Medium Size Combatants (600 LT)

This variant was looked at to assess the cost/benefit of building the entire combatant system using a single hull design versus the alternative of a system with more than one design, such as that in Option I. This combatant would need to carry all the Expeditionary Warfare Grid components. It would either need to have a reduced number of organic weapons or greater numbers of hulls to maintain a higher payload fraction of organic weapons. The combatant would have the flexibility, upon completing deployment of the

Expeditionary Warfare Grid, to transit out of the access denial zone and have weapons modules placed in its now empty grid deployment modules. Figure (6) shows the Swedish VISBY class as an example of the displacement range of the medium size combatant.



1. Variable Depth sonar
2. Concealed exhaust emission outlets
3. Waterjet propusion unit (KaMeWa 125)
4. 3 generators rated at about 270 kW each
5. Torpedoes for ASW
6. High speed engines, 4 gas turbines rated at 4000 kW each
7. Reduction gear units
8. Low speed engines (2 diesels rated at 1,300 kW each)with double flexible mountings, encapsulated in noise-absorbing housings
9. Remotely Operated Vehicles (ROV:s) for minehunting and mine destruction
10. Combat Information Centre (CIC)
11. Accommodations for a crew of 43
12. Hull Mounted Sonar (HMS)
13. Flush mounted communication antennas
14. Bow thruster
15. ASW-grenade launchers
16. 57 mm automatic gun
17. ECM chaff launchers
18. Director
19. Retractable Navigational radar
20. Surveillance radar behind freq-selective radome
21. ESM/radar warner behind radome
22. Meteorological sensors
23. Dismountable mast for peacetime equipment
24. Helicopter bunkerstation
25. Rescue boat
26. Preparations have been made for helicopter hangar
27. Towed Array Sonar (TAS)
28. Dismountable helicopter equipment

Figure 6 (Visby Class)

Nation:	Sweden
Class:	VISBY
Number in Class:	6 planned
Built by:	Karlskrona Shipyard
Displacement:	600 tons (full load)
Dimensions (ft):	236 x 34 x 7.9
Speed:	38 knots (max) 35 (sustained)
Range:	2300 Nm at 15 knots
Propulsion:	4 Allied Signal TF50A gas turb (5370hp)
	2 MTU 16V 2000 N90 diesels (1760 hp)
	KaMeWa 125 SII water jets (21480 shp)
Electrical:	3 270-kVA diesel generators
Weapons:	1 Bofors 57mm
	1 Bofors 40mm
	4 torpedoes (400mm tubes)
	SSM: 8 RBS 15 MKII inertial guidance, active homing, 54Nm
	A/S mortars Saab Alectro 601 127mm
Sensors:	Bow mounted high frequency sonar
	Computing Device Canada(CDC) hydra
	Passive towed array and VDS active
	Ericsson Sea Giraffe 3D(C band)Air/Surf
	Celcius Tech Pilot (I band) Surface
	CEROS 200 MK3 Fire Control (I/J band)
Manning:	6 Officers, 37 enlisted
Construction:	GRP/FRP Hull and superstructure
	Fin stabilizers
Aviation:	Helo capable
	Hangar

3. Option III

Mixture of Small (250 LT) and Medium (800 LT) Size Combatants

This design was thought of as the “fighter” and “freighter” architecture. The small combatant would be designed primarily as a combatant, while the medium combatant would be designed to carry the majority of the grid components. As in the case of the 600-ton combatant of Option II, the larger (800 ton) combatant in this option would have the flexibility upon completing deployment of the Expeditionary Warfare Grid to transit out of the access denial zone to have weapons modules placed in its now empty grid deployment modules. The UM AL MARADIM Class (Figure (7)) is considered representative of the 250 LT “fighter” and the Laksamana LAKSAMANA Class (Figure (8)) representative of the 800 LT “freighter”.

Figure 7 (Um Al Maradim (Combattante I) Class)

NATION:	Kuwait
Class:	Um Al Maradim (Combattante I)
Number in Class:	8 planned
Built by:	CMN, Cherbourg
Displacement:	245 tons (full load)
Dimensions (ft):	138 x 27 x 6.2
Speed:	30 knots
Range:	1300 Nm at 15 knots
Propulsion:	2 MTU 16V 538 TB93 diesels (4000 hp) 2 KaMeWa water jets
Weapons:	1 Giat type M621 20mm 1 Orobreda 40mm SSM: 4 BAe Sea Skua (semiactive)8.1Nm SAM: may be fitted with Simbad twin for Mistral missiles
Sensors:	Thomson-CSF MRR,3D,C-band, air and surf

BAe Seaspray Mk3(I/J band) fire control

Manning: 5 Officers, 24 enlisted

Construction: Steel Hull

Figure 8 (Laksamana (Assad) Class)

NATION: Malaysia

Class: Laksamana (Assad)

Number in Class: 4

Built by: Fincantieri, Breda, Mestre, Marghera

Displacement: 705 tons (full load)

Dimensions (ft): 204 x 30 x 8

Speed: 36 knots (max), 34 knots (sustained)

Range: 1900 Nm at 18 knots

Propulsion: 4 MTU 20V 956 TB92 diesels (5030 hp)
4 propellers

Electrical: 3 diesel generators

Weapons: 1 OTO Melera 76mm/62 Super Rapid
2 Breda 40mm/70 (twin)
6 torpedoes (324 mm)
SSM: 6 OTO Melera/Matra Otomat Tesea

	Mk2 active homing, 98 Nm SAM: 1 Selenia/Elsag Albatros launcher (4 cell/2 reload), Aspide, semi-active homing, 7 Nm
Sensors:	Selenia RAN 12L/X(D/I band)air and surf 2 Selenia RTN 10X(I/J Band)fire control 1 Selenia RTN 20X(I/J Band)fire control STN Atlas Elektronik, 94-41, hull mount
Manning:	52 (combined officer/enlisted)
Construction:	Steel Hull

B. Measures Of Effectiveness

The measures of effectiveness/performance (MOE/MOP) were drawn from the sponsor’s global requirements for the system. In order to determine the requirements that needed to be evaluated within each area, the Team broke down each individual MOE/MOP. These are summarized in Table (1). In the absence of any guidance to the contrary, the Team assigned the same weight to each MOE/MOP and the architectures were ranked in each MOE/MOP based on the requirements in each category. The following are the MOE/MOP utilized:

1. **Flexibility: How well the mission is performed**
2. **Versatility: How many missions can be performed**
3. **Lethality: How much weapon capability**
4. **Survivability: How well can craft survive in high Threat environment**
5. **Deployability: How easy to arrive in theatre**

Table 1: **Measures Of Effectiveness/Performance**	**Flexibility**	**Versatility**	**Lethality**	**Survivability**	**Deployability**
1. Range	X				X
2. Speed	X		X	X	X
3. Grid Deployment Order	X				
4. Payload Capacity	X	X			
5. Sea Keeping	X		X		X
6. Organic Sensor Capacity	X	X	X		
7. Cost	X	X	X	X	X
a. Total Fuel Consumed					
b. Number of personnel at risk					
c. Procurement					
d. Maintenance/Upkeep					
8. Multiple Mission Capability		X			
9. Modularity		X			
10. Craft Organic Weapons		X	X		
11. Weapons Load Out			X		
12. Stealth			X	X	
13. Suceptability	X		X	X	
a. Speed					
b. Stealth					
c. Point Defense					
14. Vulnerability				X	
a. Armor					
b. Redundancy					
c. Egress Capability					
d. Arrangement of Equipment/Spaces					
15. Endurance					X
16. Habitability					X
17. Logistic Support					X

C. Analysis of Alternatives

This section outlines in detail the process and outcome of the analysis conducted on the three alternative architectures evaluated by the NPS TSSE team during the first half of the project. The main focus of the analysis of alternatives phase of the project was to determine the best choice of Option I, II or III and proceed with a detailed analysis of that option during the second half of the project. However, in conjunction with the research on the architectures, the team reviewed some key design factors to further define the character of the chosen option. These design factors were the choice of a hull form, hull material, propulsion plant and mechanism to convert the propulsion plant’s mechanical work into thrust. The MOE/MOP utilized were flexibility, versatility, lethality, survivability and deployability. These MOE/MOP are outlined in more detail in the previous section. As before, each of the MOE/MOP was weighted equally in the analysis.

1. Operations Analysis

In order to estimate and compare the effectiveness of the proposed SEA LANCE designs, it was necessary to formulate a salvo equation (following Prof. Hughes’ work) that could be used on all platforms of interest. This equation was used to develop a spreadsheet that calculates the engagement results of our design options one salvo at a time. The designs are evaluated using various sets of initial conditions in order to compare their relative performance. The following summarizes the formulation of the basic salvo equation and how it is implemented.

To assess the number of platforms that have been destroyed, the number of shots fired must first be determined. This calculation is weapon and platform specific, based on the firing rate (*per salvo*) of each platform multiplied by the number of those platforms remaining at the beginning of that salvo. A weapon failure rate, typically 5-15%, is assumed based on weapon type and platform that slightly reduces the number of weapons available to inflect damage. The ammunition remaining on each platform type is also tracked per salvo and if the platform runs out of ammunition, it no longer contributes to the number of shots fired.

$$\text{Weapons Fired} = \sum_{n=1}^{N} (\text{Platform})_n (\text{Failure Rate})_n (\text{Shots Per Salvo})_n$$

$N \equiv$ Number of platforms with that weapon type

(Weapons Fired Per Platform) $\leq$ (Weapons Remaining Per Platform)

(Equation 1)

The total weapon delivery capability is then divided among the total number of targets that weapon would be used against. The natures of the targets (*i.e. offensive or defensive*) are not weighted any differently for simplicity of calculation and to compensate for target identification ambiguity.

$$\beta = \frac{\text{Offensive Weapons Fired}}{\sum_{n=1}^{T} (\text{Offensive Targets})_n}$$

$$S_d = \frac{\text{Defensive Weapons Fired}}{(\text{Defensive Targets}) + \sum_{n=1}^{T} (\text{Offensive Targets})_n}$$

$T \equiv$ Number of types of platforms that weapon would be used against.

(Equations 2 & 3)

To account for the dual role of most defensive weapons as missile defense and anti-air weapons, both planes and incoming missiles are considered targets. If there are no targets detected, with respect to weapon type, then no weapons are fired during that salvo. If there are ANY targets detected, a full salvo is fired.

The next step is to determine the number of those missiles fired that hit each target. Threat-specific defensive weapons, active, and passive defense characteristics are estimated for each platform type. The number of defensive weapons available for each incoming offensive weapon has been determined (**S_d**). A "Weapon Kill Factor" is calculated by estimating the average number of defensive weapons expended (*i.e. "Shoot, Shoot, Look, Shoot"*) to destroy one offensive weapon before it hits the platform (**S_k**). For our calculations, it is assumed that if there were two defensive weapons fired at an incoming surface-to-surface, or air-to-surface missile, it would be destroyed. All other offensive weapons are immune to this form of defense. The "Weapon Kill Factor" is that fraction of incoming offensive weapons destroyed by defensive weapons and is calculated using the following equation *(Note that it is limited to a 100% kill rate.)*:

$$\boxed{\omega = \frac{S_d}{S_k} = \text{Weapon Kill Factor}}$$

$$0 \le \omega \le 1$$

(Equation 4)

This results in the fraction of incoming offensive weapons not destroyed by defensive weapons equal to:

$$(1 - \omega) = \text{Weapon Leakage}$$

(Equation 5)

Some platforms also have active and/or passive defenses. To take this into account, the fraction of incoming offensive weapons deceived by any combination of these (*i.e. ECM, chaff, decoys,…, etc.*) was calculated as the "Platform Deception Factor." This calculation assumes that the number of shots expected to miss, out of 100 shots fired at the target, is $\mathbf{S_m}$. This was estimated as 30 for our opposition and manipulated as required to meet our mission objectives (*typically 50-75*) for the SEA LANCE combatant. A value of 50 for torpedo decoys was used across the board. Aircraft were assumed to avoid 90 “air mines” out of 100 and this was included in this factor, even though it doesn’t exactly fit the definition. This factor applied to only surface-to-surface missiles, air-to-surface missiles, air mines, and torpedoes. All other weapons were assumed to be immune to this form of defense.

$$\boxed{\varepsilon = \frac{S_m}{100} = \text{PlatformDeceptionFactor}}$$

$$0 \leq \varepsilon \leq 1$$

(Equation 6)

Taking both of these defensive characteristics into account yields the following representation for the fraction of weapons fired that are neither destroyed by defensive fire, nor otherwise deceived. This fraction is defined as:

$$\boxed{\lambda = [(1-\varepsilon)(1-\omega)] = \text{Weapon Hit Factor}}$$

$$0 \leq \lambda \leq 1$$

(Equation 7)

Then, taking the number computed in equation 2, the total number of hits due to that weapon type is expressed as:

$$\beta\lambda = \text{Hits Per Platform}$$

(Equation 8)

To estimate the damage inflected by these hits, the number of hits (weapon specific) required to kill each platform is estimated and defined as **'a'**. If there are ***'n'*** different types of weapons used against a specific target, the fraction of each target destroyed each salvo is:

$$\sum_{t=1}^{n} \frac{\beta_t \lambda_t}{a_t} = \text{Fraction Destroyed} = \xi$$

(Equation 9)

The fraction that survived that salvo is:

$$(1 - \xi) = \text{Survival Fraction}$$

(Equation 10)

For the all of the variations of the SEA LANCE combatant, it was assumed that one hit would result in a mission kill. In this case if the salvo calculations resulted in fractional units remaining, the number was rounded down prior to calculating the next salvo. For larger platforms, requiring multiple hits to kill, fractional units were carried over and considered damaged. Due to the nature of the calculations, the damage had no effect on the delectability of the craft, but did reduce its weapon delivery capability and its sensor contribution.

Assuming **'A'** equivalent platforms, under uniform attack, the total remaining force after each salvo is:

$$A_f = A_o(1-\xi\ )$$

(Equation 11)

Up to this point it is assumed that the opposing force detects all platforms. This assumption has been used in the past to evaluate blue water engagements of large ships. This was not considered "safe" in this application due to the size, possible stealth, and geographic location of the platforms being evaluated. A platform's detectability was based on size and stealth. This however did not account for the ability of the opposition to locate the target platforms. In an attempt to correct for this, estimations of expected sensor characteristics were coupled with the number of platforms and the possibility of non-organic sensors (*referred to generically as intelligence*), to quantify the sensor ability of each side of the engagement.

Assumptions made to estimate how easily a platform can be detected are based on comparisons of its physical size, relative stealth, and the accuracy of expected intelligence that would be available on platforms of that type. For the purposes of these calculations, “intelligence” refers to all non-organic sensor systems, but is used for stationary targets only (*i.e. bases, ballistic missile sites,…, etc.*). **‘X’** is the fractional reduction in the detection range due to a platform’s stealth (*i.e. construction materials, coatings,…, etc.*). Typical values used for an advisory platform range from 5% to 50%. The SEA LANCE combatant values were varied to determine the design value of stealth on mission effectiveness and typically varied between %50 and 75%. **‘T’** is the range a platform of its size would be detected compared to a “Standard Platform” (*i.e. Boeing 747 for an airplane, PERRY (FFG-7) Class for a ship, or LOS ANGELES (SSN 688) Class for a submarine*). **‘I’** is the reliability of intelligence on that specific platform type. Based on those estimations, the likely hood of that platform being detected by a nominal adversary is:

$$\boxed{\delta = (1 - X)T + I = \text{Detectabilty Factor}}$$

$$0 \le \delta \le 1$$

(Equation 12)

Based on a curve fit using existing ship designs, the change in radar cross section is approximately equal to the fractional change in displacement raised to the $^{3}/_{2}$ power. Unfortunately, the detection range scales with the 4th power of cross section. This result is the following equation for **'T'** used for SEA LANCE combatant of various sizes:

$$T = \sqrt[0.375]{\frac{\text{Platform Displacement}}{\text{Standard Displacement}}}$$

$$0 < T \leq 1$$

(Equation 13)

Estimates were made of the opposition characteristics based on the same standard platforms, chosen due to the Team's familiarity with those units. Because both sensor and detection characteristics were normalized to these platforms, changing the "standard" platform would not change the relative performance of any sensor or the detectability of any platform.

In an access assurance situation, the goal is to clear an area for the blue water fleet to "safely" operate. This scenario lends itself to the notion that the SEA LANCE combatant would sweep the area for possible threats and engage the enemy as it encounters them. Likewise, the opposition forces are principally land based and/or littoral; therefore their pattern of operation would be unidirectional as well. In both cases, it is assumed that there would be a "front line" of some shape that would form the principal search area. Sensor characteristics were used assuming that there was this line of engagement. For our scenarios, this distance was assumed to be about 200 NM.

To calculate the cumulative sensor effectiveness for locating a specific platform type, we define the number of a specific platform as **'*B*'** and the length of the line of engagement as **'*L*'**. The range that a platform will detect the standard platform is defined as **'*R*'**. It is acknowledged that most units can detect more than one type of platform, even if the detection is only visual. To account for this, the sensor range is adjusted by a factor **'*D*'**. This factor varies the effective search radius based on the platform of interest. Adjusting for the fact that a single unit can search a linear distance that is twice its sensor range (*search diameter vs. search radius*), and assuming that there are **'*n*'** types of platforms, the "Sensor Factor" is defined as:

$$\boxed{\eta = \sum_{t=1}^{n} \frac{2R_n B_n D_n}{L} = \text{Sensor Factor}}$$

$$0 \leq \eta$$

(Equation 13)

If there are **'*A*'** target platforms, the number of platforms detected is calculated by:

$$\boxed{A_D = A_o \eta \delta \ = \text{Platforms Detected}}$$

$$A_D \leq A_o$$

(Equation 14)

It is assumed that if a platform is detected that both sides are coordinated enough to target it, regardless of the source or quality of the initial detection.

Using this modified value for the initial number of "targets" that the offensive force has to shoot at, the final value for the number of defensive platforms remaining after each salvo is:

$$A_f = A_o - A_D (1 - \xi)$$

(Equation 15)

When the larger platforms were destroyed, all the assets allocated to that platform were destroyed as well. For example, if an air base was destroyed, all the aircraft at that base are destroyed too.

The calculations were integrated into a spreadsheet capable of predicting several possible scenarios for each of the three options. The scenarios considered based on the opponent described in Chapter 1 are outlined below:

a. <u>Opposed Grid Insertion</u>. It is assumed that the SEA LANCE combatants meet with naval resistance at 500 nm and engage them while attempting to transit and deploy the trip wire and grids. The first salvo involves all opposition naval forces, the full land based ASM threat, and 10% of its "merchant" fleet. A three salvo per day model was used and 25% of available aircraft attack each salvo (*when applicable*). By the time of the next engagement, another 10% of the merchant fleet is in range and the opposition aircraft support the attack along with all surviving forces. The third and fourth salvos both add another 30% of the merchant fleet to all remaining forces. By the fifth salvo, the SEA LANCE combatant would be about 480 nm into the area and the remaining 20% of the merchant fleet are now in range. Assuming the worst-case scenario, the SEA LANCE combatant would have to transit another 400 nm into the area before laying the trip wire. This takes them until salvo number nine. Once the trip wire is deployed, it adds sensor capability but no weapons to the SEA LANCE combatant/system. After the grid is deployed, both the sensor and weapon capabilities are increased. The first salvo that makes use of this increased capability is salvo number eleven. It should be noted that both the trip wire and the grid are assumed to be cargo until deployed. As each SEA LANCE combatant/GDM is destroyed, the capability of the trip wire and grid is degraded. After the trip wire and grid are deployed, they are immune to attack and are only degraded by logistics.

b. Semi-Opposed Grid Insertion. In this scenario, the first salvo doesn't take place until after the trip wire is deployed, while the grids are being deployed. The SEA LANCE combatant engages with the added benefit of the trip wire's sensors, but not the weapon capability of the grids. The first salvo involves all opposition naval forces, the full land based ASM threat, and 100% of its "merchant" fleet. The next engagement includes 25% of available aircraft along with all surviving forces. After the second salvo, all grid weapons and sensors are available.

c. Unopposed Grid Insertion. In this scenario, the first salvo doesn't take place until after the trip wire and grids are deployed. The SEA LANCE combatants engage all opposition naval forces, the full land based ASM threat, and 100% of its "merchant" fleet with full capability trip wire and grids. The second salvo includes 25% of available aircraft along with all surviving forces.

The platform characteristics used in the calculations are included in Appendix B.

2. Cost Analysis

In order to compare the alternative architectures on a level playing field, the cost of each option had to be factored into the analysis. In order to do this, the production cost of the Danish FLYVEFISKEN "Standard Flex 300 (STANFLEX 300)" Class variable mission small combatant was used. This vessel was chosen due to its modern design, composite construction, and the availability of cost data. The estimated cost of a STANFLEX 300 , fully equipped for minesweeping, is $61 million per craft[1]. This design has a displacement ofs 450 LT, modular, composite construction, and a CODAG propulsion plant. To adjust for the increased combat systems anticipated on our craft, as compared to a minesweeper, this price will be increased by ~15% to estimate the cost of a 450 LT SEA LANCE Combatant at $70 million.

Historical data on larger classes of ship suggest that doubling the displacement of a craft increases the cost by a factor of $^3/_2$. This weighting factor was used to linearly scale this cost to the different option sizes. In order to estimate the cost of the tow, the estimated price of a craft of that displacement will be multiplied by $^2/_3$. This results in the following cost estimates:

$$\text{800 LT Option} = \frac{800}{960}(1.5)(\$70) = \$87{,}500{,}000 \approx \$88\text{ Million}$$

$$\text{600 LT Option} = \frac{600}{960}(1.5)(\$70) = \$65{,}625{,}000 \approx \$66\text{ Million}$$

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[1] 514 million kroner, CAPT Poul Grooss, Managing Director, Naval Team Denmark

$$\text{400 LT Option} = \frac{400}{960}(1.5)(\$70) = \$43{,}750{,}000 \approx \$44\text{ Million}$$

$$\text{250 LT Option} = \frac{250}{960}(1.5)(\$70) = \$27{,}343{,}750 \approx \$27\text{ Million}$$

$$\text{Tow } = \left(\frac{2}{3}\right)\left(\frac{400}{960}(1.5)(\$70)\right) = \$29{,}166{,}667 \approx \$29\text{ Million}$$

Payload calculations were used to determine the minimum number of each option required to deploy the grid elements. These numbers are based on a total craft payload capacity of 35% with a standard deduction of 5% for combat systems and the remaining 30% split between the calculated fuel required and grid/weapon payload. The tow is assumed to have a 70% payload fraction added to the unit total payload available for fuel and grid elements. Each minimum is defined as the base unit for comparison.

Option I (450 LT with 450 LT Tow):	33 Craft (450 LT) 33 Tow (450 LT) $2.40 Billion
Option II (600 LT):	60 Craft $3.96 Billion
Option III (250 LT and 800 LT):	45 Craft (250 LT) 45 Craft (800 LT) $5.17 Billion

These numbers represent the estimated cost of the craft only. All weapons and grid components are additional. This additional cost is, however, uniform because the bases of the "minimum" numbers represented above are weapon and grid component payload capacity, so it would cost the same to equip any of the options.

A smaller tow was considered, but later rejected due to the desire to maximize hull commonality between the towing craft and the tow. The calculations are included for comparison, but were not used in the operational analysis that follows. If the tow size were reduced to 250 LT, the calculations change as follows:

$$\text{Tow} = \left(\frac{2}{3}\right)\left(\frac{250}{960}(1.5)(\$70)\right) = \$18{,}229{,}167 \approx \$18 \text{ Million}$$

The base unit for cost comparison is increased to 53 pairs in order to have the same total payload capacity.

Option I (450 LT with 250 LT Tow): 53 Craft (450 LT)
53 Tow (250 LT)
$3.29 Billion

A cost-weighted operational analysis can now be done using the most expensive option as a benchmark and adding additional units to the other two options based on the same total expenditure. The units added are combatants only; this adds to the combat effectiveness without the additional expenditure of grid elements. All grid elements are assumed to be carried in the original units for this analysis.

Since Option III sets the "benchmark" maximum system cost of $5.17 Billion this leaves $2.77 Billion for Option I (*with the 450 LT tow*) and $1.21 Billion for Option II. Spending this "extra" money on combatants yields the following results:

Option I (450 LT with 450 LT Tow): $44 Million (per craft)
$2.77 Billion (Extra)= 63
Additional Combatants

Option II (600 LT): $66 Million (per craft)
$1.21 Billion (Extra)

= 18 Additional Combatants

The operational analysis was done using the cost-adjusted number of craft. Option I starts off with 33 pairs of craft escorted by 63 additional combatants. Option II starts off with 78 craft. Option III starts with the original cargo limited number of craft, 90. Option I was clearly superior. The full results of this analysis are included in Appendix B.

NOTE: The ability of the opposition to detect the SEA LANCE craft in this analysis was understated. The factors were later adjusted based on existing ship design radar cross-section data. The comparative analysis is considered valid regardless due to the error being applied consistently across all options. The finial operational analysis done on the design was considerably more stressing and the results are not as optimistic.

3. Flexibility

The team defined flexibility as a measure of how well the option performed the mission. Option I, the 450-ton combatant with equal-sized tow, was at the top of this category. The tow is immensely flexible and modular by the nature of its design. The range lost due to the increased powering requirements when towing the “trailer" can be recouped by providing additional fuel capacity on the tow. Payload capacity is the best for the dollar spent because of the high payload fraction associated with the tow.

Analysis of Option 1 resulted in the fewest number of manned combatants to complete the mission. This would put the fewest number of personnel at risk. The maintenance and upkeep costs should be less than the other options because of the lower complexity of the tow, which is essentially an unpowered (except for emergencies), uninhabited barge. The other options pay the price of increased complexity (propulsion, electrical, habitability, etc.) by having the combatants carry the network components.

Assuming that modularity means that the combatants can be outfitted with weapons/sensor modules following deployment of the network, Option II and III could carry a greater number of organic sensors and weapons than Option I following deployment of the network. This would limit their flexibility during deployment of the network, but increase it following deployment. This would greatly increase the complexity of the Option II and III designs and would provide a number of difficult challenges to overcome. The modular change-out would need to be performed at sea and would require the combatant to return outside the access denial zone to rendezvous with the POM logistic force, change-out and then return to the access denial zone, a round trip of up to 1200 nm.. Although the conversion of the “freighter” to “fighter” capability is attractive, the time and logistics support force required to do so is felt to be an excessively high penalty. The tow can shift to a “fighter” role quicker, simply by releasing the tow, and without the need for logistic support.

Option I does have its challenges as well. The tow must be capable of operating in the sea states outlined in the requirements document. The design will need to account for the vessel interaction issues of the combatant with a fixed tow, solve the material and controls requirements of the fixed tow, produce a platform with the stability to deploy the network and conduct the secondary missions outlined in the requirements document.

4. Versatility

The team defined versatility as a measure of how many different missions could be performed by an option. The team chose Option I as the overall choice in this measure. Option I has the advantage that the towing craft becomes a very capable combatant when it is no longer towing the “trailer”. It is capable of performing secondary missions such as MIO or SOF insertion. The tow could be placed on a sea anchor following the deployment phase. It could then be used as a “lily pad” for helicopter or UAV operations. It would also provide another target of relatively the same size and shape of the combatant for the adversary to consider. It could also be utilized as a platform to house the retrograde and unexpended network components once the overall mission is completed.

The other options could produce variants that would be capable combatants, but would do so at the expense of network carrying capability. All the platforms would be designed with modularity in mind. This could lead to the argument that the larger platform could house more modules of a more diverse nature and therefore be more versatile. This could lead to the choice of the “fighter/freighter” concept of Option II. The towed vessel of Option I would provide as much versatility of payload as the freighter of Option II without the burden of protecting the larger, less capable freighter. Therefore, Option I was the choice for this versatility.

5. Lethality

The team defined lethality as a measure of the ability to inflict damage to the enemy and the extent to which the enemy’s mission capabilities) are degraded/eliminated by the damage inflicted. This MOE/MOP evaluates the combatants, not the entire system. This is the only MOE/MOP that Option I did not come out the winner. Option II faired the best under this definition because of its size and ability to carry a large amount of lethal payload. Assuming modularity is designed into the craft and/or some of the medium-size combatants (800 LT) may be designed as fighters vice freighters, this option would provide a large, mobile organic weapons capability. The 250 LT small combatants would provide a fast, extremely maneuverable platform to transport this option's lethality rapidly around the area of operations.

Option I performed well in this option too. The combatant (450 LT) would provide a large amount of organic weapons capability and could rapidly transit the area of operations when the tow was detached. Conceivably the tow could have weapons modules placed in it, but that would add complexity to both the tow and the modules themselves. Overall, Option II was the best because of its large freighter with the ability to carry a large amount of organic weapons and its small fighter with its stealth and high degree of maneuverability.

6. Survivability

The team defined survivability as a measure of how susceptible an option is to attack, how vulnerable it is to that attack, and how well it recovers from the attack. All of these factors will determine the level of survivability of the individual option. The operations analysis based on cost in the Appendix (page A-53) shows that the Option I beat the other options in all the scenarios when placed on a level playing field. It also shows that the 450 LT combatants with its tow beat all the other combatants in all the scenarios with the exception of the opposed assault. The increased stealth of the 250 LT combatants provides it with less susceptibility and therefore greater survivability in this scenario.

The vulnerability of the combatants should be about equal. They will all be designed with relatively the same degree of redundancy (minimal), armor (none), and egress capability (maximum for crew survival) and with relatively the same equipment/space arrangements. The larger combatants may have a slight advantage in number of minor weapons hits it can absorb, but it is assumed that none of these craft, due to their relatively small size, are capable of surviving a cruise missile or similar sized weapon hit. The tow may provide some deception when it is “anchored” following deployment of the network. It is relatively the same size and shape as the combatant and will provide the adversary another to track to identify. The recoverability of the craft should be relatively the same as well, which is minimal. They will all have the same basic automated damage control and firefighting systems capable of dealing with minor operational casualty or weapons effects but, in the aftermath of any significant weapon hit or fire, they are assumed to be non-recoverable. Accordingly, most survivability design features are dedicated to maximizing the ability of the crew to safely abandon ship. Option I was evaluated as the best overall in this measure.

7. Deployability

The Team defined deployability as a measure of how habitable the option is, how much outside support it requires and how often it requires outside support. If habitability were based on size, the 800 LT craft component of Option III would be best but, since Option III also includes the smallest (250 LT) craft as well, which would be the worst, overall Option III does not do well. The 450 LT craft of Option I and the 600 LT craft of Option II would probably be of comparable design, with the exception that Option II would need space and volume for network components and habitability may be sacrificed to meet mission requirements. Option I has the greatest potential for storing sufficient fuel on the combatant and tow without sacrificing network carrying capacity. The logistic support required to provide the 800 LT craft of Option III with the rearming necessary to transform from a freighter to a fighter would add significantly to the total ownership cost of the option. All of the combatants would probably have relatively the same requirements in terms of parts, maintenance, underway replenishment, etc. Overall, Option I was found to be the best of all the options.

8. Architecture Conclusion

Option I was the winner in 4 of the 5 MOE/MOP. The Team assigned equal weight to each of the 5 MOE/MOP and therefore Option I was the choice of the 3 architectures reviewed. Option III was next best and had some of the same attractive features as Option I, but there were substantial penalties to be paid for meeting the same level of performance as Option I. Option II performed the worst in all but one of the categories. It followed the adage that a ship designed to be a jack of all missions, will be a master of none.

9. Defining The Architecture

The team analyzed the following options to choose the architecture’s hull form, hull material, propulsion plant and mechanism to convert the propulsion plant’s mechanical work into thrust. It should be noted that a more detailed computational analysis is contained in Chapter IV, Technical Evaluation of the report.

a. Monohull versus Wave-Piercing Catamaran

Flexibility, versatility, lethality, survivability, and deployability attributes of the combatant hull form are crucial to the achievement of the mission of the vessel. Analysis of hull stability and seakeeping, hull resistance and powering requirements, payload capacity and other characteristics and capabilities against the above attributes revealed that a Wave-Piercing Catamaran hull form would provide the required characteristics necessary for the combatant to meet all mission requirements.

Seakeeping, maneuverability and operability characteristics are essential for successful mission completion. The combatant is required to perform open ocean transits in Sea State 6, network deployment operations as well as fight in Sea State 4 and small boat operations in Sea State 3. The combatant is also required to perform refueling and replenishing operations at sea. Additionally, the combatant will conduct vertical replenishment operations.

After reviewing seakeeping information for several hull forms and the measures of performance, the Wave-Piercing Catamaran was judged to best meet all fundamental requirements.

In general, a Wave-Piercing Catamaran is a catamaran with long, slender outboard hulls designed to slice through waves. A flared center hull incorporated into the cross-structure provides wave deflection. The above-water potions of the outboard hulls slope sharply forward toward the waterline, allowing the bows to pierce through waves.

b. Wave Piercing Catamaran

The following are generalized seakeeping, maneuverability and operability characteristics for the wave-piercing catamarans.

i. Seakeeping

- Maintain a relatively high percentage of calm water speed in high sea state conditions.
- Ride control systems are able to control relatively high deck-edge accelerations.
- A Shock mounted bridge could further reduce accelerations.

ii. Maneuverability

- Ship’s turn radius is relatively larger at high speeds.
- Relatively good turning ability at slow to medium speeds.

iii. Operability

- Capable of a relatively the same endurance as monohulls
- Requires large amounts of fuel during high-speed long-range transits

c. Monohull

The following are general seakeeping, maneuverability and operability characteristics obtained from “Seakeeping, maneuvering and operability issues of high speed vessels”[reference] for a conventional monohull.

i. Sea Keeping

- Experience substantial speed reduction in heavy seas.
- Speed reduction required to diminish undesirable ship motion, slamming and deck wetness as wave height increases.
- Larger monohulls are less sensitive to rough seas than smaller monohulls.

- Active stabilization systems provide improved sea keeping.

- Wave-piecing monohulls improve sea-keeping performance in rough seas, requiring less speed reduction.

ii. Maneuverability

- Good maneuvering performance at higher speeds.

- Directional stability improves with increasing ship speed.

- Overall maneuverability is significantly affected by size, type and location of steering/propulsions system.

- Poor position-keeping, station-keeping, and low speed maneuvering performance.

iii. Operability

- Rugged, simple and survivable.

- Forty knots appears to be the maximum practical speed.

- High speeds are achieved with a cost.

d. Other Comparisons of Monohull versus Catamaran

The catamaran has a greater payload capacity (weight) than the monohull of the same general characteristics. A catamaran has greater flexibility as far as hull option to improve stealth. Appendix F shows comparisons of resistance, horsepower and fuel consumption rates for catamarans versus monohulls utilizing diesel engines. The catamaran has a greater combat efficiency (high speed >15 knots) than the monohull. However, the monohull has greater transit efficiency (low speed <15 knots) than the catamaran. Since the majority of the operations will be performed at high speed, the catamaran is the choice based on powering requirements. The catamaran provides a large deck area to provide space for combat systems, cargo handling and stowage or aviation operations.

e. Hull Form Conclusion

The characteristics listed above meet or exceed the measures of performance required of the combatant. For a small ship, the wave-piercing catamaran provides superior seakeeping characteristics, improved stealth, greater combat efficiency, greater deck area and greater payload than a monohull.

The tow option was further analyzed to determine if the hull forms should both be catamarans or a combination of catamaran and monohull. There was a slight benefit powering advantage to the catamaran combatant and monohull trailer. The analysis of towability, directional stability and equivalent motions favored the catamaran combatant and catamaran tow variant with relatively the same displacements. This is not to say that the other combinations of tow and trailer could not be produced, but that they would require increased complexity and more than likely greater cost. The commonality between the hull form of the combatant and trailer will likely decrease design, fabrication and production costs. The small advantage in powering that the combination of monohull and catamaran provides does not outweigh the large number of benefits from producing a catamaran/catamaran combination.

f. Hull Material

There were three general classes of materials analyzed for use during the design effort. They were steel, aluminum, some composite (i.e. glass/fiber reinforced plastic GRP/FRP) structure or a combination of them. The team did not want to rule out either aluminum or composites, but made a determination that steel would be used on a limited basis for structural strengthening only. Steel has the advantage of being stronger and less susceptible to damage of fire or weapons. However, it is more costly and produces a lower payload fraction than aluminum or composites. Steels exceed the survivability requirements of the craft and produce undesirable payload fractions and excessive cost. Aluminum and/or composites can be designed to meet the requirements and will be primary construction materials utilized during the design project.

g. Propulsion Plant

The choices for propulsion plant were gas turbine, diesels or a combination of the two. Gas turbines have a small machinery box size relative to a diesel plant of the same horsepower. The large intake and exhaust ducts required for the gas turbine are a significant draw back. A comparison of gas turbine versus diesel fuel consumption rates for Option I are presented in the Chapter IV. The diesel consumes less fuel than the gas turbine for the range of speeds from 5 through 40 knots. This is a critical point given the distances that the combatant must travel. Fuel consumes a large amount of the payload and any extra payload lost to fuel is network payload that cannot be carried. The large intake and exhaust ducts that are required for the gas turbine also take up volume that could be utilized for network components as well. The gas turbine will require a reduction gear for both propellers and water jets. The weight of the gas turbine and its associated reduction gear will exceed the weight of a medium speed diesel that could be directly connected to both the water jet and the propeller. For these reasons the gas turbine was eliminated as a choice for propulsion throughout the range of speeds required. It should be noted that the team recognizes the ongoing advances in gas turbine technology and would reconsider this decision if the weight and specific fuel consumption figures approached those of diesels. Option I will be powered by a plant consisting of entirely diesel engines.

h. Conversion of Mechanical Work into Thrust

The process of converting the work of the diesel engines into thrust becomes even more difficult with the fact that we are towing a vessel for a good portion of the mission. Designing a combatant that can attain a maximum speed of 40 knots without the tow and a speed of at least 15 knots with the tow while maintaining the maximum efficiency throughout the range to conserve fuel is a difficult problem. The optimum propeller to produce the maximum thrust while towing is obviously not the propeller that you would want to push the ship through the water at 40 knots. Even a controllable pitch propeller would have problems achieving the maximum efficiency throughout the range. Another problem of a propeller is that it will normally increase the navigational draft of the combatant. A good alternative that may improve on the above problems is the use of water jets. The water jets could be sized and arranged to provide the maximum thrust at their most efficient speeds. They also are not as draft limiting as propellers.

An analysis of the Advanced Water Jet, 21st Century (AWJ-21) built by Bird-Johnson in conjunction with Rolls Royce, is presented in

Chapter IV. It compares the water jet with a controllable pitch propeller in the areas of maintenance, effect on draft, thrust requirements, etc. The water jet is comparable or outperforms the propeller in all evaluated areas. In conclusion the Team chose water jets as their method of converting the work of the diesels into thrust.

10. Overall Conclusions of the Analysis of Alternatives

The architecture chosen was Option I, which is a 450 LT combatant with a 450 LT vessel with a semi-fixed close proximity tow. The hull form will be a wave-piercing catamaran combatant and wave-piercing catamaran tow. The hull will be made of aluminum, composites or a combination of the two with steel utilized for structural support where necessary. The propulsion plant and electrical generation will be composed of diesel engines and their work will be converted to thrust by water jets.

D. Design Drivers/Enablers

The team determined the design drivers associated with the choice of the architecture, hull form, propulsion plant, requirements, etc. An example of a design driver is the shallow draft requirement that comes from the requirement to operate in littoral waters. This driver is also linked to other drivers, such as the choice of propulsion plant that will produce the endurance and speed requirements. The interaction between drivers is as important as determining the individual drivers as well. The drivers must be analyzed to determine their interaction with other drivers as well as how many of the requirements and capabilities they affect.

Next was the process of determining design enablers to be mapped to the design drivers to enable SEA LANCE to perform the requirements set forth in the requirements document. For instance, water jet propulsion was chosen to provide the shallow draft requirements and the increased efficiencies at high speeds. Finally the driver/enabler pairs and pair interactions were reviewed to ensure that while fulfilling one requirement, a pair did not detract from another requirement. An example of this was the choice of a conventional water jet. While it provided good efficiency at high speeds and enabled a shallower draft by not extending below the hull, its efficiency dropped to unacceptable values at our critical tow and deployment speed of 15 knots. We reviewed the choice of water jets over propellers and looked at other water jet options. The AWJ-21 being developed by Bird-Johnson filled this gap by providing improved efficiency at low speeds and met or exceeded the efficiency of a propeller throughout the operating regions stipulated in the requirements document.

The process continued until the team had satisfactory results for all of the design driver/enabler pairs and had sufficiently met all the requirements and capabilities set forth in the requirements document. The drivers and their associated enablers are depicted in Figure (1) and (2) on the following pages. A complete analysis of the choices with the technical documentation can be found in the technical evaluation section of Chapter IV.

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Evaluating the Drivers and Determining Associated Enablers

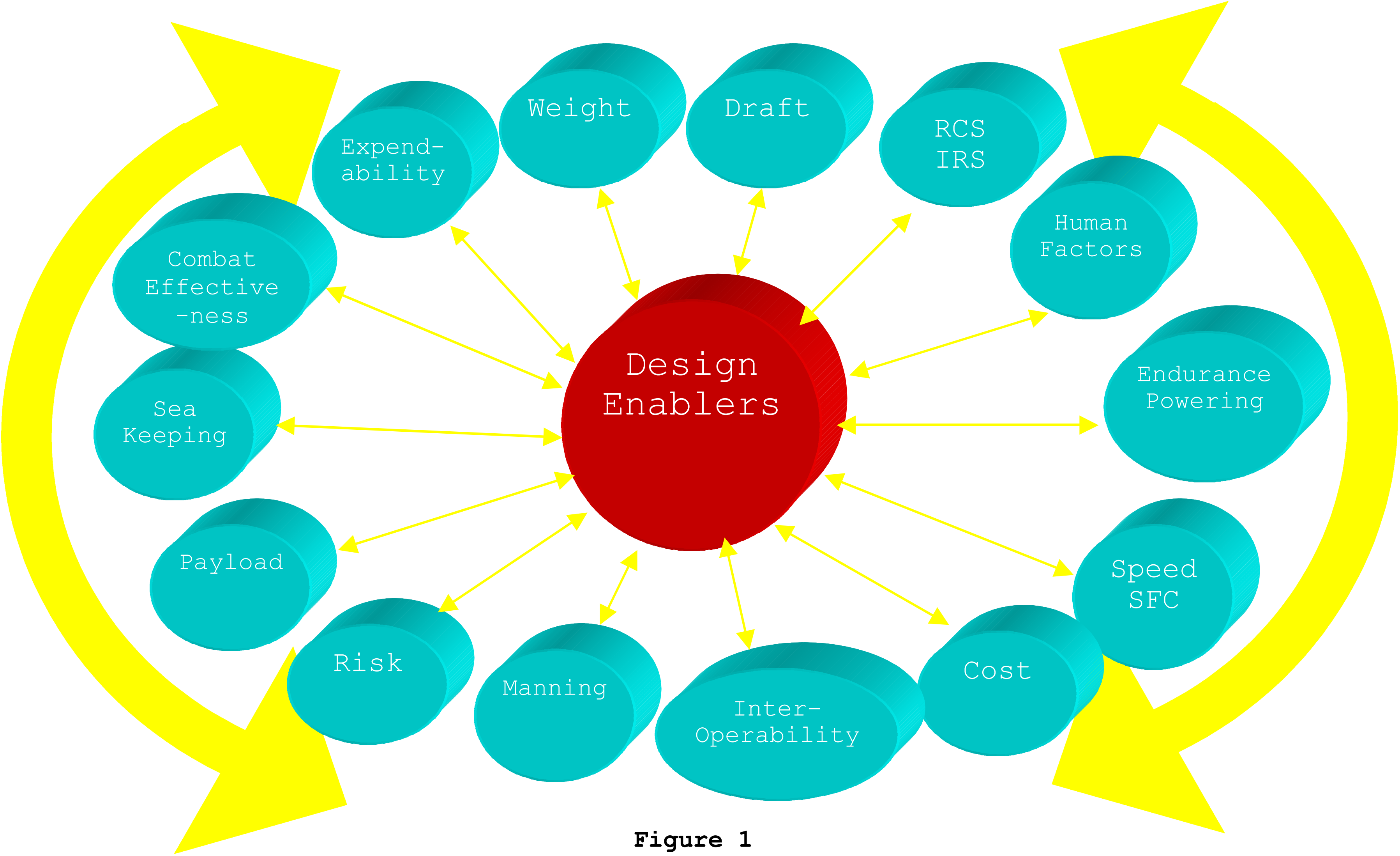


Figure 1

Evaluating the Enablers and Mapping to Associated Drivers

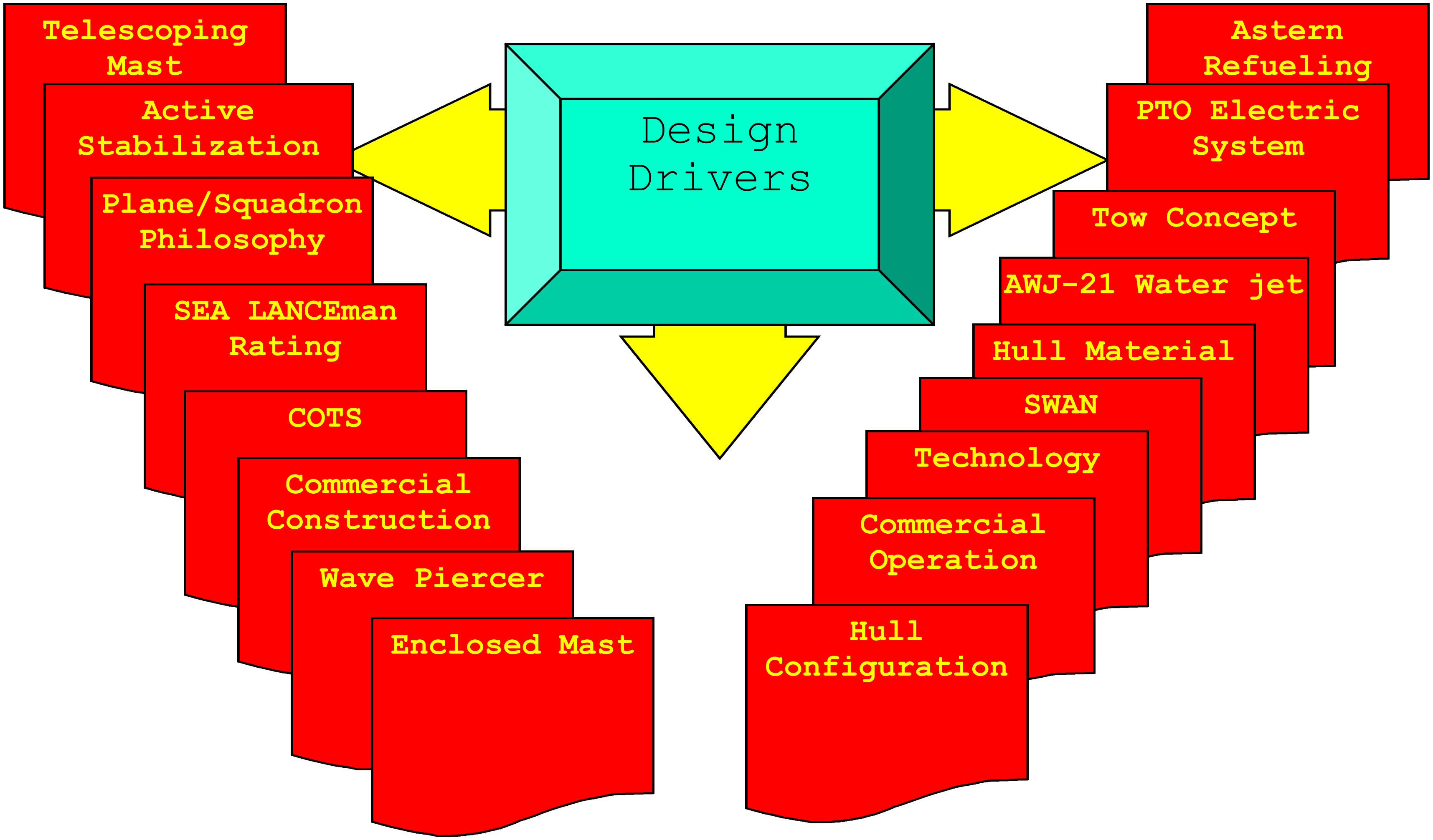


Figure 2

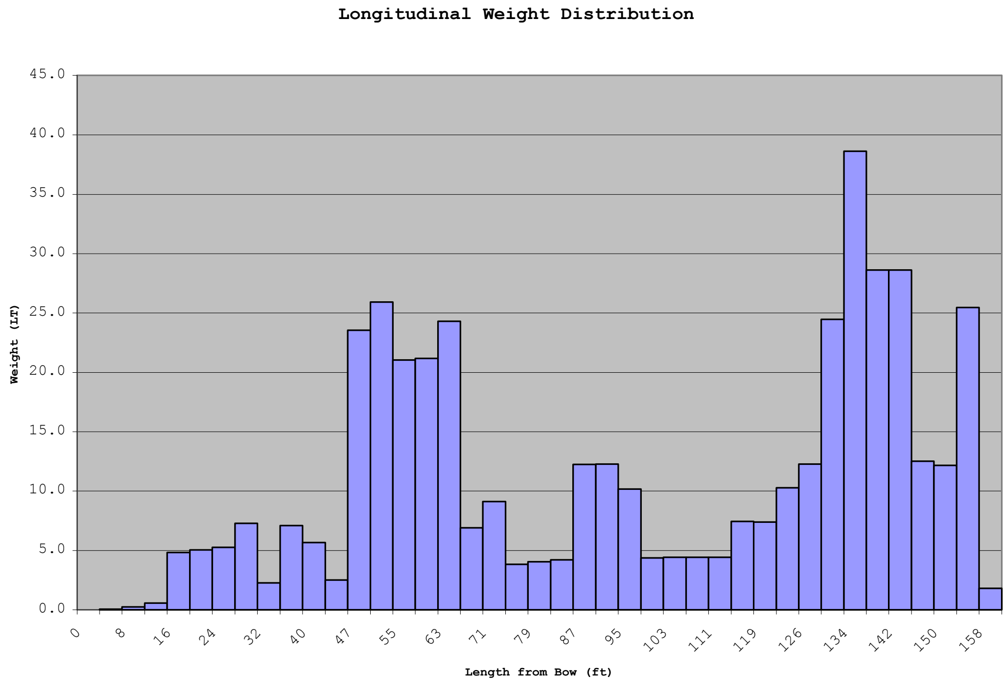
Chapter IV: Technical Evaluation

Weight breakdown structure groups divide the technical evaluation section of the report into sections. The analysis and computations that pertain the total ship are provided in the final section of this chapter. Some examples are the radar cross section analysis and the cost estimation.

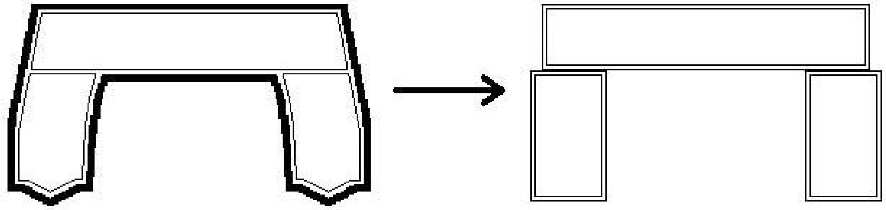
A. Hull and Structure Analysis

1. Structural Analysis

A structural analysis was preformed to determine the structure required to withstand the anticipated loading conditions. Due to the variable nature of the loading on the GDM, the combatant was used to determine the most stressing weight distribution. The weight distribution used is shown below, the data table is included in Appendix C. The GDM hull would have a larger safety margin due to the ability to load both modules and fuel to match the weight and buoyancy distributions.



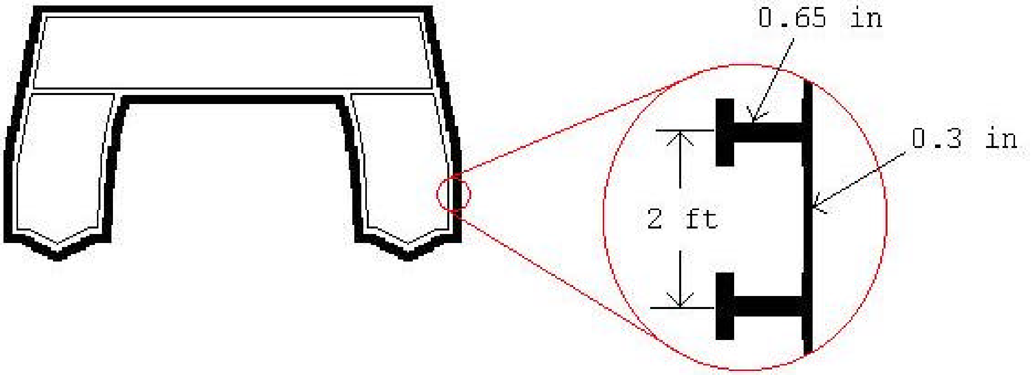
Aluminum (5086-H34) was used as the majority material for construction. This was chosen both for weight savings over steel and to allow for rough pricing estimates using commercial high-speed catamaran designs. All structural analyses were preformed using only a simplified version of the skin of the ship, main deck, and uniformly placed stiffeners. This provides an inherent safety factor, as internal floors and bulkheads will provide some additional structural support.



Simplified Structure

An eight-foot wave was used to determine hogging and sagging shear, moments, and stresses. Any wave higher than that would contact the center section and provide additional buoyancy that would actually reduce the maximum bending moment. The maximum bending moment resulting from this analysis was $5.9\text{x}10^6$ lb-ft in a hogging condition, located 94.8 ft aft of the forward perpendicular.

A thin walled beam model was used to calculate the bending stresses. The wall thickness in the calculation was adjusted by varying the skin thickness, stiffener thickness, and stiffener spacing. The same structure is used for structural decks and hulls. The finial iteration has a skin thickness of 0.3” with 0.65” thick stiffeners spaced 2’ apart on center. The resulting maximum stress for longitudinal bending was 4,700 psi. This gave us a safety margin of 9.3 to yield.



A transverse analysis was done using a sixteen-foot wave with the trough between the hulls. This resulted in a maximum tensile force of $3x10^5$ lbs being exerted on the weather deck. Using only the 0.3” skin, this resulted in a 503 psi stress and a safety margin of 87 to yield. The graphs and analysis results are included in Appendix C.

Using the same model to estimate the weight of aluminum required to construct the basic hull resulted in an estimate of 105 LT of aluminum. This does not include the superstructure, mast, or structural reinforcements required for towing. These weights were estimated using a composite superstructure and mast with minimal steel reinforcements for the telescopic section. This resulted in an additional 5 LT. The tow structure is assumed to be all steel and an additional 15 LT was added to account for that structure. The total weight of the hull structure (Group 100) is then 125 LT, which is reasonable considering a commercial fast ferry, car carrier, of this size would have a hull weight of approximately 128 LT[2].

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[2] Kim Gillis, Manager Military Projects, Austal Ships

2. Hydrostatics

The SEA LANCE hull, a wave-piercing catamaran hull, is an inherently stable hull form.

The hull hydrostatic stability characteristics were analyzed using General Hydrostatics computer software by Creative Systems, Inc. Appendix D contains all related data and plots performed in the analysis.

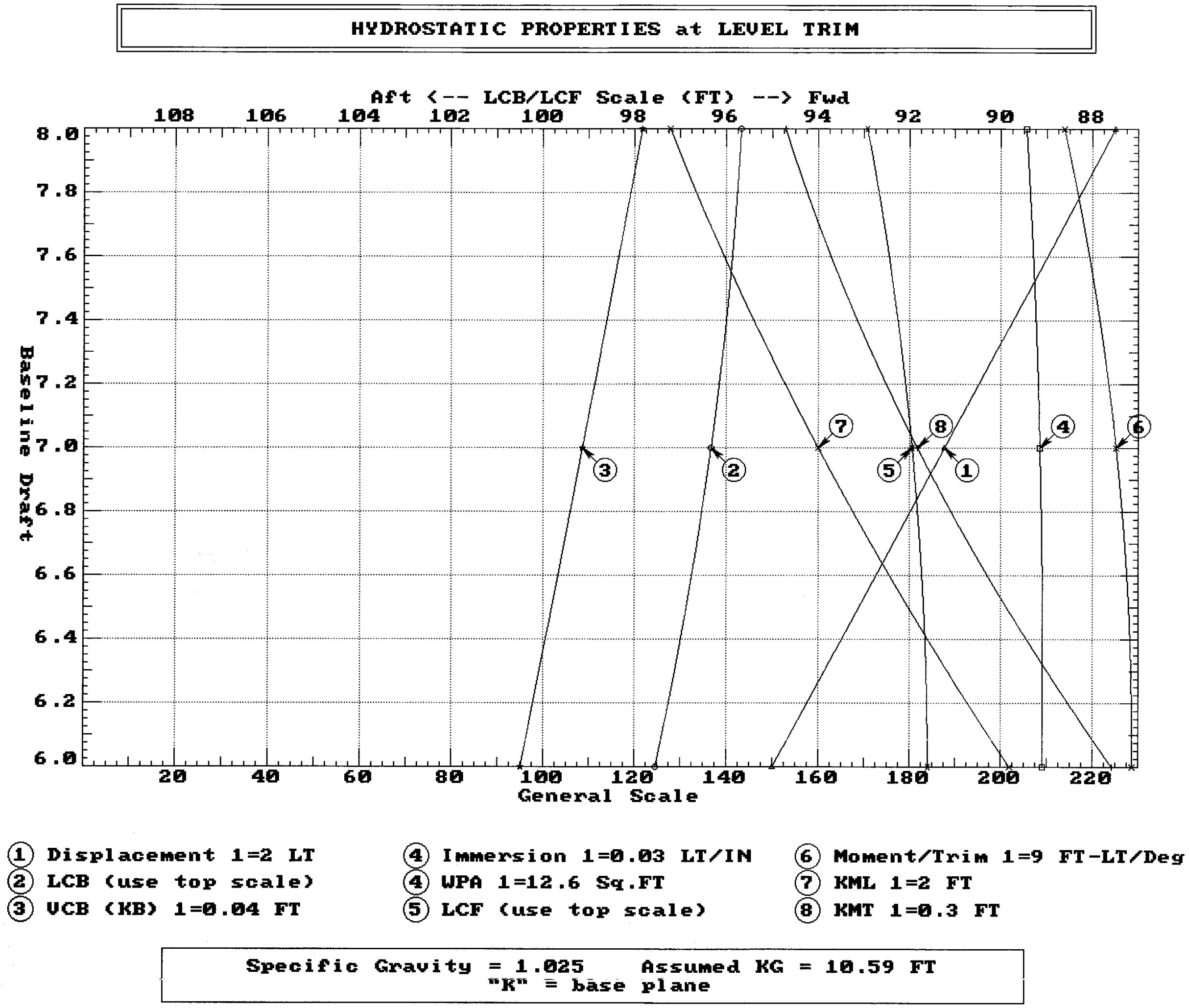
HYDROSTATIC PROPERTIES at LEVEL TRIM
Aft <-- LCB/LCF Scale (FT) --> Fwd
108
106
104
102
100
98
96
94
92
90
88
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
Baseline Draft
20
40
60
80
100
120
140
160
180
200
220
General Scale
① Displacement 1=2 LT
② LCB (use top scale)
③ VCB (KB) 1=0.04 FT
④ Immersion 1=0.03 LT/IN
④ WPA 1=12.6 Sq.FT
⑤ LCF (use top scale)
⑥ Moment/Trim 1=9 FT-LT/Deg
⑦ KML 1=2 FT
⑧ KMT 1=0.3 FT
Specific Gravity = 1.025 Assumed KG = 10.59 FT
"K" = base plane

Figure 1.

Figures 2 and 3 are plots of the hull cross curves for 5-20 degrees of heel and 10-60 degrees of heel respectively.

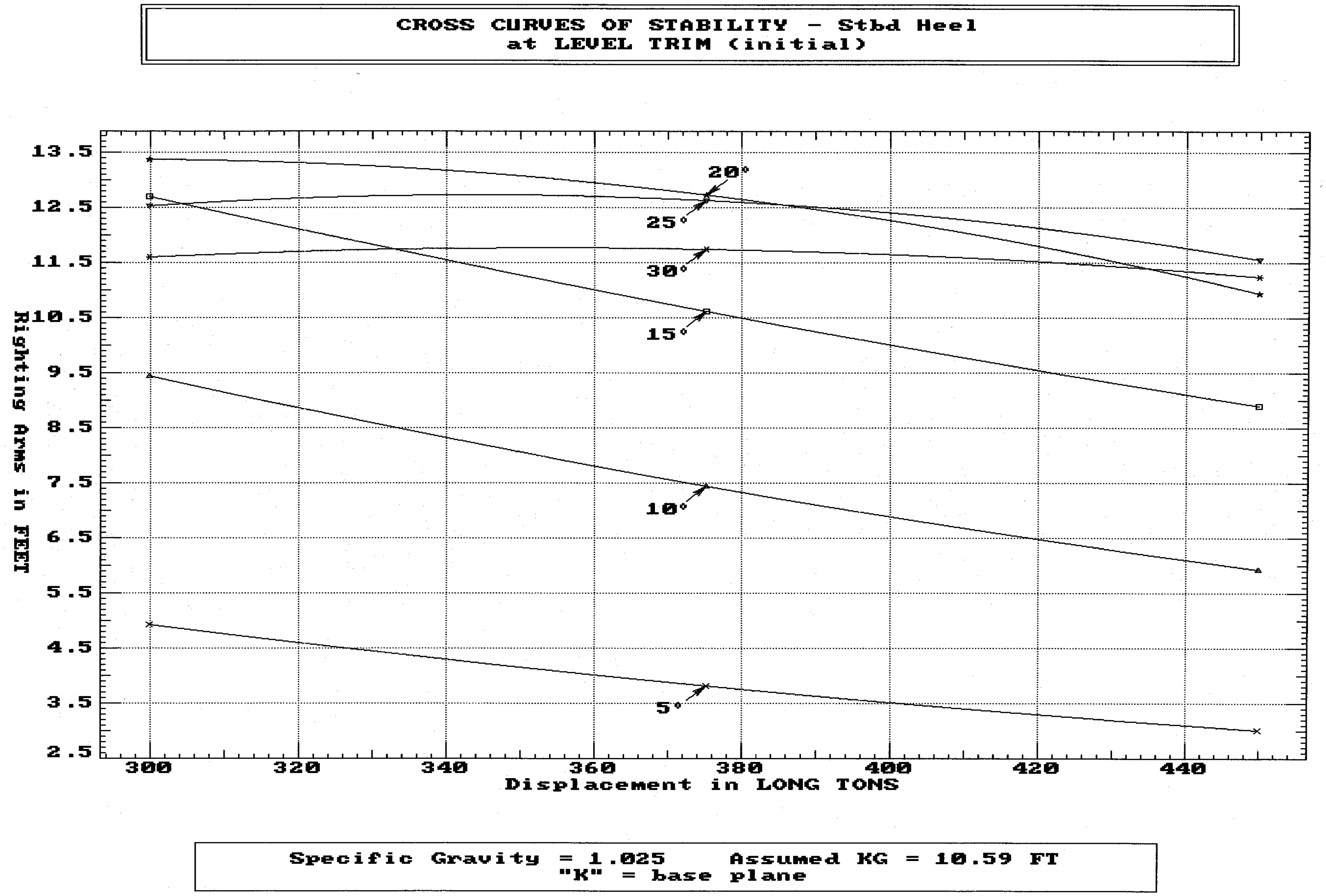

Figure 2.

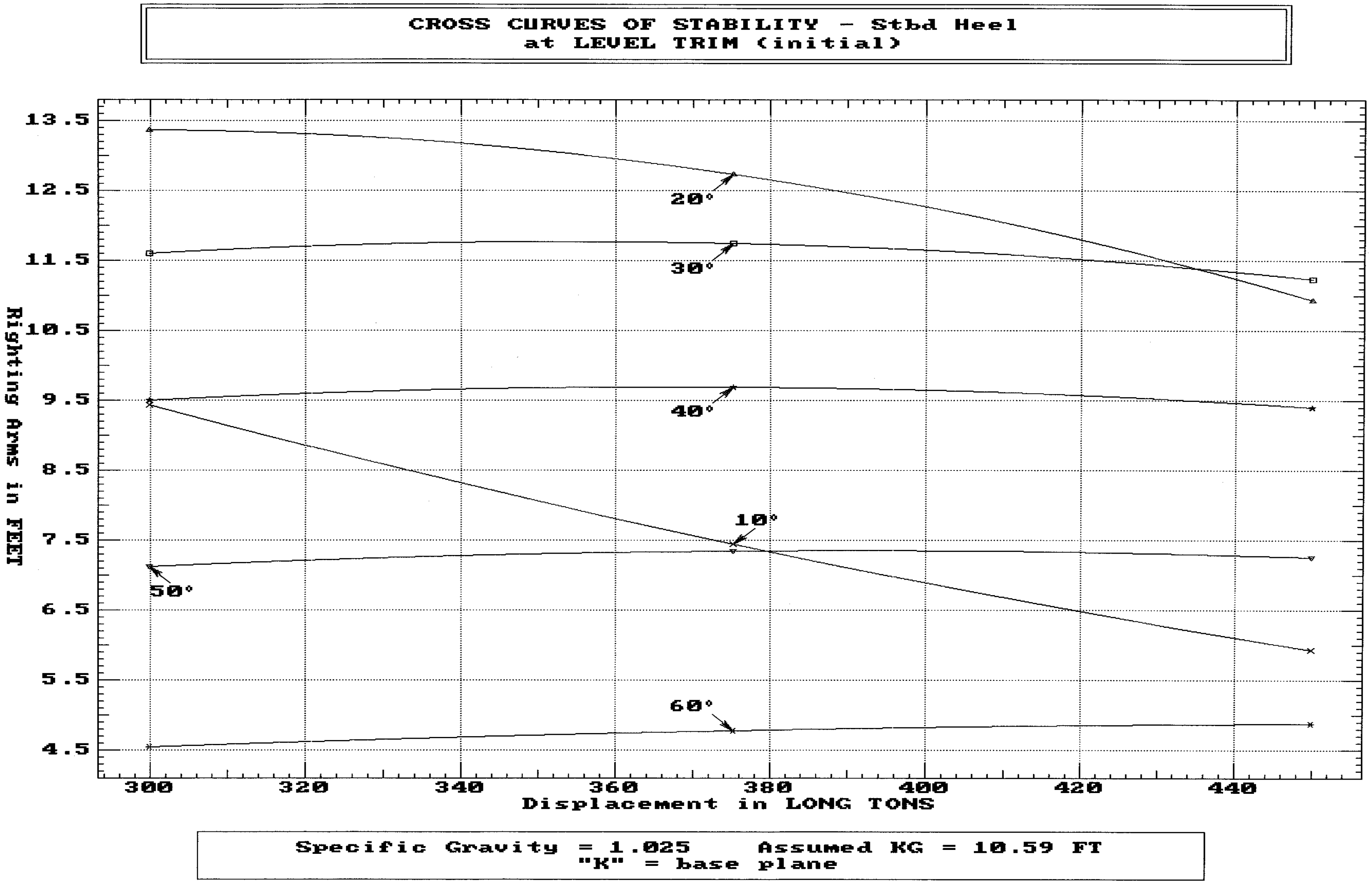
CROSS CURVES OF STABILITY - Stbd Heel
at LEVEL TRIM (initial)
Righting Arms in FEET
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
20°
30°
40°
10°
50°
60°
300
320
340
360
380
400
420
440
Displacement in LONG TONS
Specific Gravity = 1.025 Assumed KG = 10.59 FT
"K" = base plane

Figure 3.

Figures 4 show the floodable length of the ship. This plot assumes that both hulls are flooded simultaneously. Additional analysis of floodable length is required for flooding a single hull.

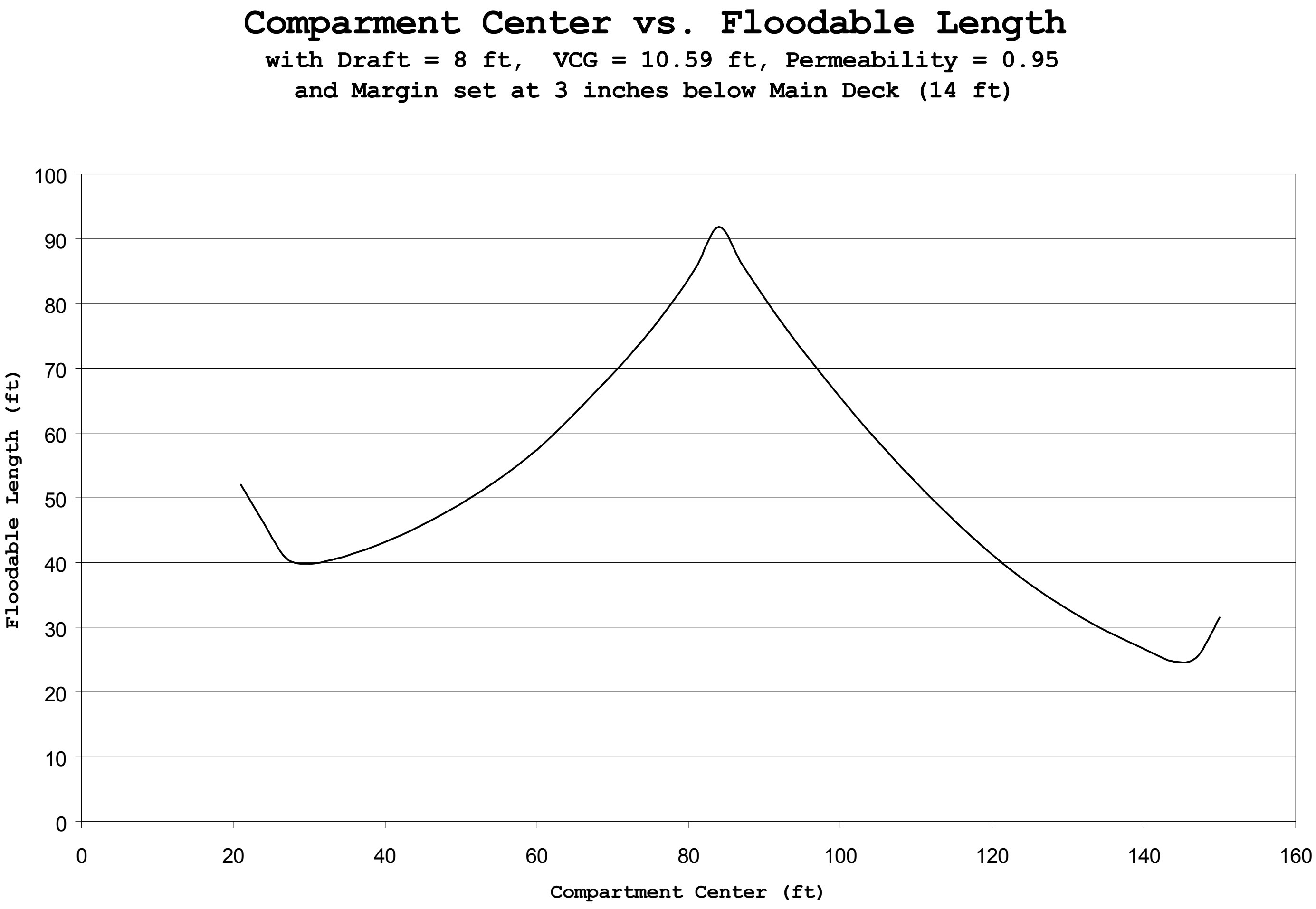

Figure 4.

3. Ship Motions Analysis

Ship Motions were calculated using primarily two sources. The first of these sources was the motions chapters of The Principles of Naval Architecture[3]. These computations where used to check the results produced by the Ship Motions Program, SHIPMO[4]. SHIPMO is a FORTRAN 77 based program that utilizes strip theory to compute motions in 6-degrees of freedom. The program will compute the motion responses, shear and bending moments to regular waves and long or short-crested seas in infinite or finite water depth. The motion, velocities, acceleration and relative motions at any point on the vessel could be calculated. Motions were analyzed at the bow, stern and at the mid point of the bridge in the horizontal plane. All points were at the weather deck in the vertical plane.

The viscous damping of the hull forms, the effects of the wave-piercer and the ride stabilization system were not taken into account due to the complexity of the modeling. Accelerations were found to be high as expected without the effects of these stability features. Accelerations as high as 1.2 g’s were computed. Ride stability features were added to the design in space, weight and volume to lower the accelerations to those of commercial wave-piercing catamarans of similar design. These commercial designs produce accelerations in the range of .2 to .4 g’s with a maximum of .8 g’s through the use of fin stabilizers and trim tabs.

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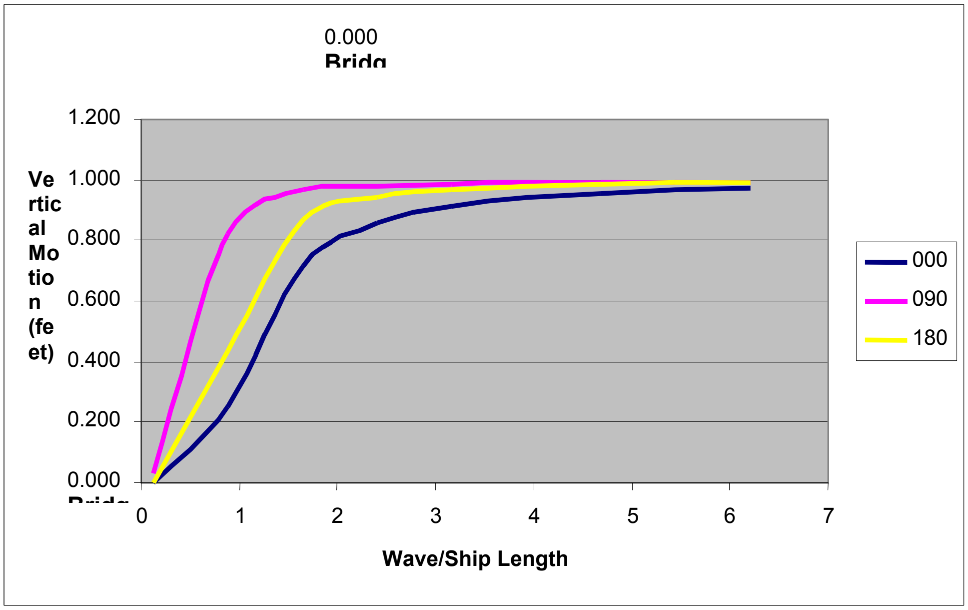
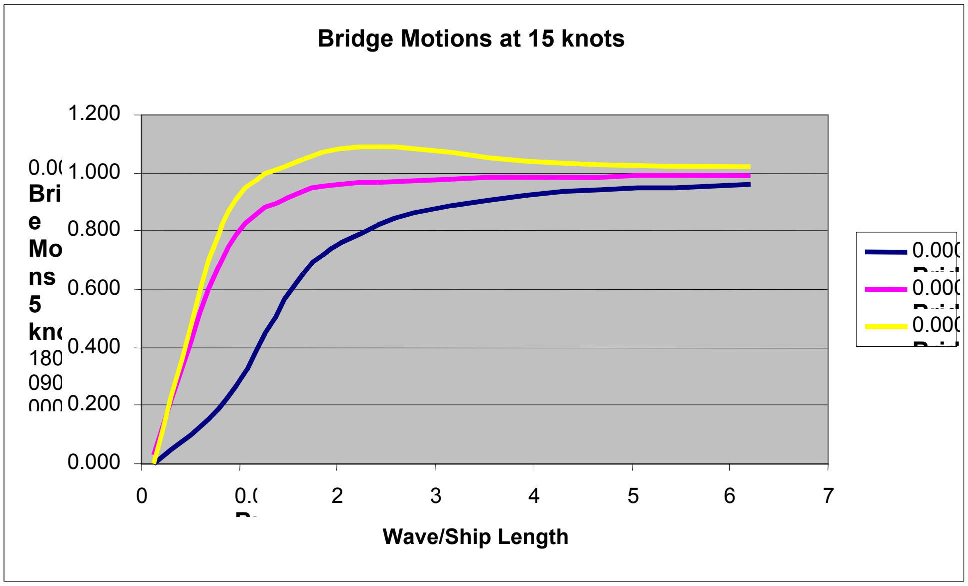
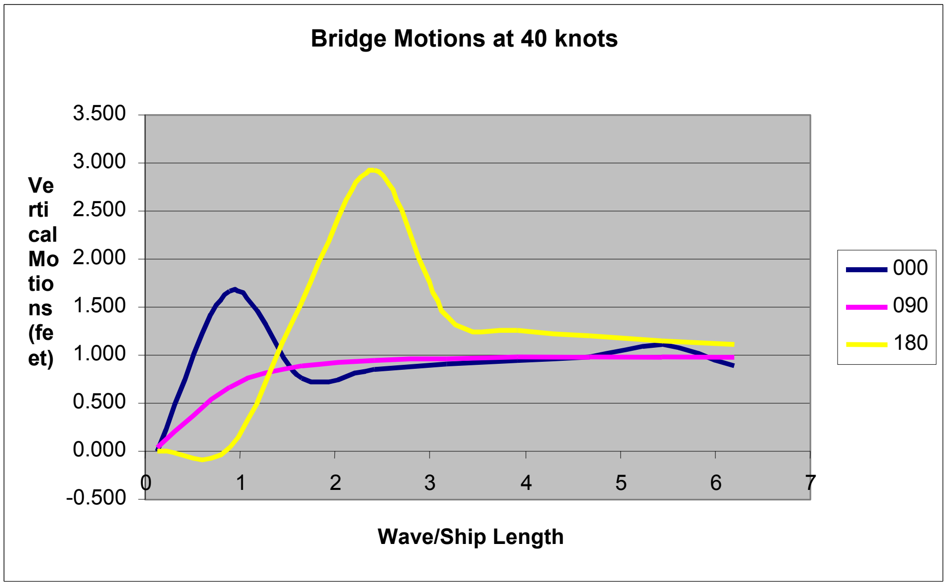
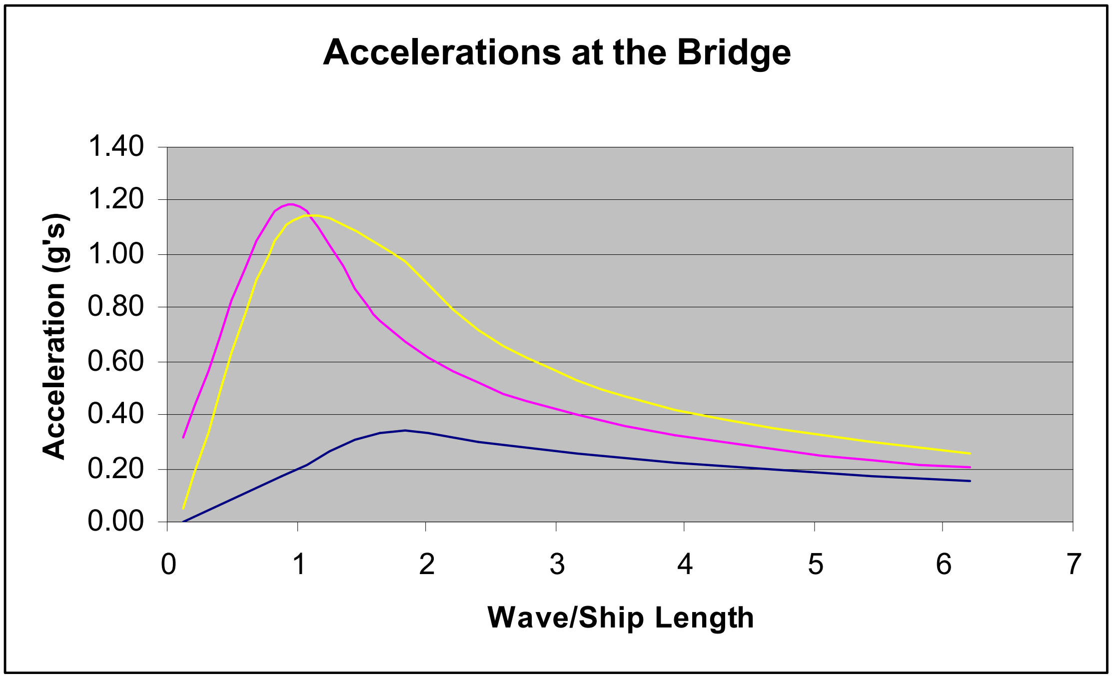
[3] Principles of Naval Architecture, Volume III, Society of Naval Architects and Marine Engineers, 1989
[4] Robert F. Beck, Armin W. Troesch SHIPMO, Ship Motions Program, 1989

Some graphs of representative motions and accelerations are in the following pages. A complete set of data for the bridge is contained in Appendix E.






Bridge Motions at 40 knots
Vertical Motions (feet)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
0
1
2
3
4
5
6
7
Wave/Ship Length
000
090
180


Accelerations at the Bridge
Acceleration (g's)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
7
Wave/Ship Length

B. Propulsion

1. Hull Resistance

Resistance is very important in deciding on the right hull form, because it directly affects the size, power and fuel consumption of the engines put on the ships. The two main hull form types considered to enable the ships to attain higher speeds are the improved monohull and advanced catamaran hulls. Recent designs of fast ferry craft show the superiority of the catamaran over the monohull in these high (35-40 knot) speed regimes.

There is enough data for monohulls to make accurate resistance calculations, but data for high speed catamarans is lacking in the open literature. This is due to the fact that the dominant part of catamaran resistance is wave-making resistance and it is calculated by modeling utilizing prototypes and is made for specific, real designs, data for which is generally proprietary. Therefore, for initial comparisons, monohull data was used to estimate catamaran resistance by dividing the displacement between the two separate hulls of catamaran for the same length of monohull, then applying corrective factors for relative ship length and hull spacing. In other words, the resistance of a catamaran is mainly affected by the wetted surface ratio ($S_w/V^{2/3}$), the slenderness ratio ($L/V^{1/3}$) and the hull spacing (S/L).

Previous studies on specific designs show that catamaran has poor resistance performance at low speeds

(Fr<0.35). On the other hand with the right configuration of wetted surface ratio, slenderness ratio and hull spacing at high speeds, the catamaran has better performance, up to 45% less resistance than monohull for the same displacement.

The Fast Patrol Craft design team of MIT mentioned in their report that they had the same difficulties and they had generated curves for the catamaran hull by using ACC prototypes and paper designs, while they were making their own design. Examination of the resistance comparisons for monohulls and catamarans from the curves of the MIT design team verified the previous studies on this area. The catamaran shows a poor resistance performance at low speeds but at high speeds (above 15 knots) it decreases the resistance up to 50% percent.

Because the GDM has the same hull form as the Combatant, the resistance of the GDM was assumed the same as Combatant's resistance and the total resistance for both Combatant and GDM is assumed as the twice of Combatant's resistance. The Resistance/Weight vs. Fn curve that was created by the MIT design team for catamaran hulls can be seen in Figure (1).

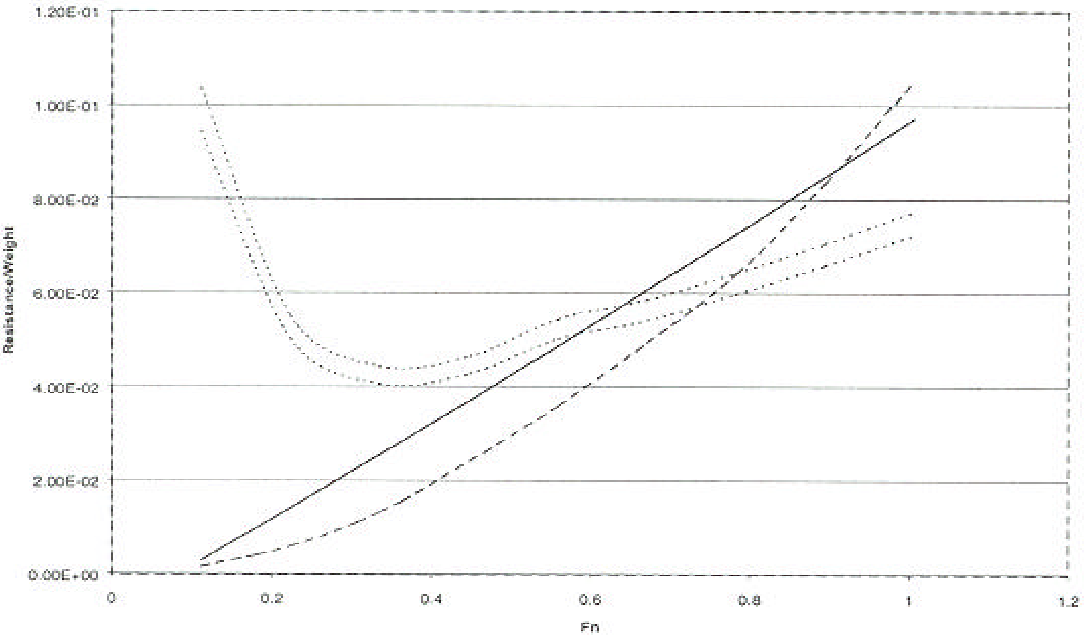


Figure 1. Resistance/Weight vs. Fn

References:

- The Royal Institution of Naval Architects (1978), Symposium on small fast warships and security vessels.
- SNAME, Principles of Naval Architecture (1989)
- Massachusetts Institute of Technology (MIT), Fast Patrol Craft Design Report (2000)

2. Power Requirements

The nature of the mission determines the required power for SEA LANCE. The missions that require towing the GDM will demand more power than missions that do not require the GDM for the same speed. Because of this, the power requirements up to 15 knots, which is the grid deploying speed, are defined for both Combatant and GDM. Power requirements for speeds higher than 15 knots are defined only for the Combatant. For the safety, service life and fuel consumption, it is assumed that the maximum power that the prime movers serve will be 75% of the full power and each prime mover will operate at 80% of the maximum rated rpm. Under these conditions the required power for 15 knots with GDM is 6135 HP and 13816 HP for 40 knots without the GDM. The analysis of power requirements for various speeds shows that in the emergency conditions both Combatant and GDM can reach the speed of 23knots without exceeding 13816 HP. Speed vs. SHP curves for the cases with GDM and without GDM can be seen on Figure (2).

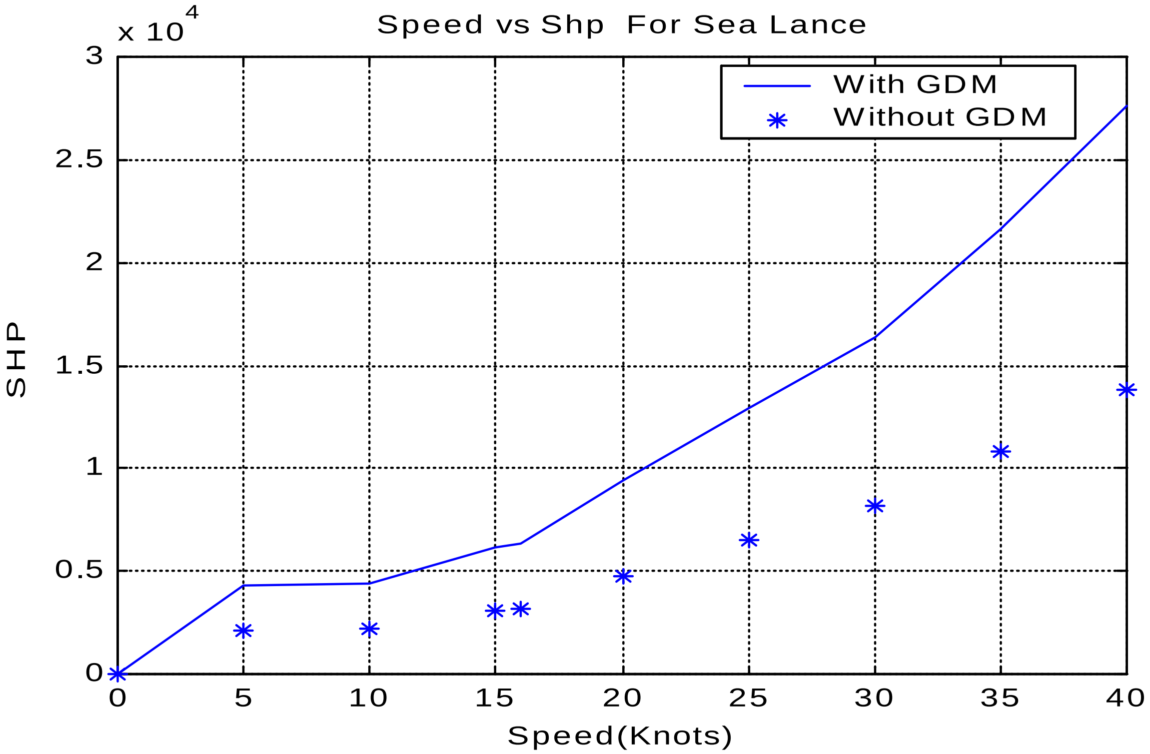


Figure 2. Speed vs. SHP

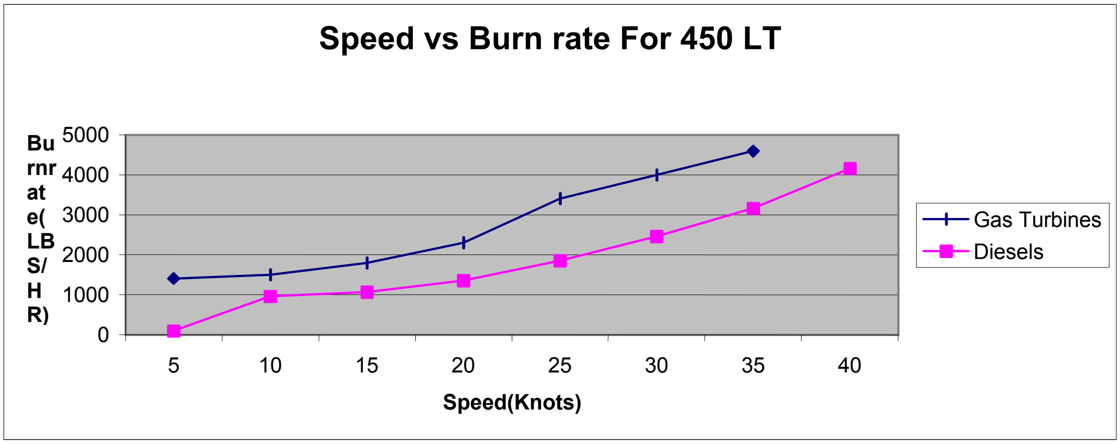
3. Diesel vs. Gas Turbine Analysis

Diesels where compared to gas turbines in the areas of specific fuel consumption, weight impact on interior volume of the ship and maintenance requirements. The marine diesels utilized in the comparison were from MTU diesel and the gas turbines were of the LM class produced by General Electric. Manufacturer data sheets where utilized for the computations.

Fuel consumption was calculated based on the hull resistances and horsepower requirements previously calculated. Figure (1) shows the results of the computations. It is clear throughout the operating range that the MTU diesels studied have a lower SFC than the gas turbines studied for the operating range.

FUEL BURNRATES FOR 450 TON'S CATAMARAN

Gas Turbine				Diesel			
Disp		450 LT		**Disp**		450 LT	
L		282 ft		**L**		282 ft	
Vol		8750 ft3		**Vol**		8750 ft3	
Engine No		2 LM500		**Engine No**		3 MTU12V595TE70	
Hp/Eng		5340		**Hp/Eng**		3621	
				Eng. Rpm		80%	
W/Eng				**W/Eng**		9.6	
Speed	EHP	**70%PrEf.**	**FBR(LBS/HR)/2ENG**	**Speed**	**EHP**	**70%PrEf.**	**FBR(Lbs/Hr)/3Eng**
5	151	215		5	151	215	90
10	1745	2477	1400	10	1745	2477	966
15	1941	2756	1500	15	1941	2756	1061
20	2533	3597	1800	20	2533	3597	1349
25	3579	5082	2300	25	3579	5082	1850
30	4708	6685	3400	30	4708	6685	2460
35	5974	8484	4000	35	5974	8484	3156
40	7158	10164.68	4600	40	7158	10165	4168



The team realizes that there are efforts to improve the thermodynamic efficiency and therefore SFC for gas turbines. If the advancements such as ICR gas turbines or others produce results comparable to the diesels, this decision would need to be reviewed.

Gas turbines had further drawbacks for this design. The volume that would be necessary for the intake and the exhaust ducting would require volume that could be needed for grid elements or fuel tankage. The gas turbines would also require the use of a reduction gear to connect to the propellers or water jets. The diesels could be direct drive and even with their heavier weight to horsepower ratio, they still added less weight to the propulsion plant.

The weight and volume limitations for each hull of catamaran demand the use of 4 medium-size diesel engines instead of two large ones.

If 4 engines are put on the ship, the best configuration is CODAD with 2 engines on each side of the ship (15 knots with tow and up to 25 knots without tow); one engine on each side can be operated. For higher speeds all of the engines will be in operation.

For the speed of 15 knots with GDM attached, the required power is 6135 HP which means that each one of low speed engines has to have at least the maximum power of 4100HP(with 75% service factor). For the speed of 40 knots without tow, required power is 13816 HP and this means that each one of high-speed engines has to have a maximum power of at least 4610 HP (with 75% service factor). The difference between these 2 numbers is just 510 HP and for the fuel consumption, weight and size, and cost considerations this does not create a significant reason to use 2 different types of engine on the combatant. If 4 of the same type of engine are used on board, this will provide numerous advantages for the combatant (i.e. Less spare parts on board for the same maintenance program). Therefore, it is reasonable to have one type of engine, which serves the ship. The MTU Model 16V 595 TE 70 was utilized. This engine has a maximum power of 4828 Hp and this gives the opportunity of using 2 engines up to 25 knots. After tow is released and for the speeds higher than 25 knots, 4 engines should be used.

4. Specific Fuel Consumption Analysis

The required power for various speeds determines the fuel burn rates for these various speeds. Relatively high power requirements up to the 15 knots with GDM produces the high fuel burn rates. After GDM is released the fuel burn rates drop significantly. The speed versus fuel burn rate curve for 70% propulsive efficiency can be seen in Figure (3).

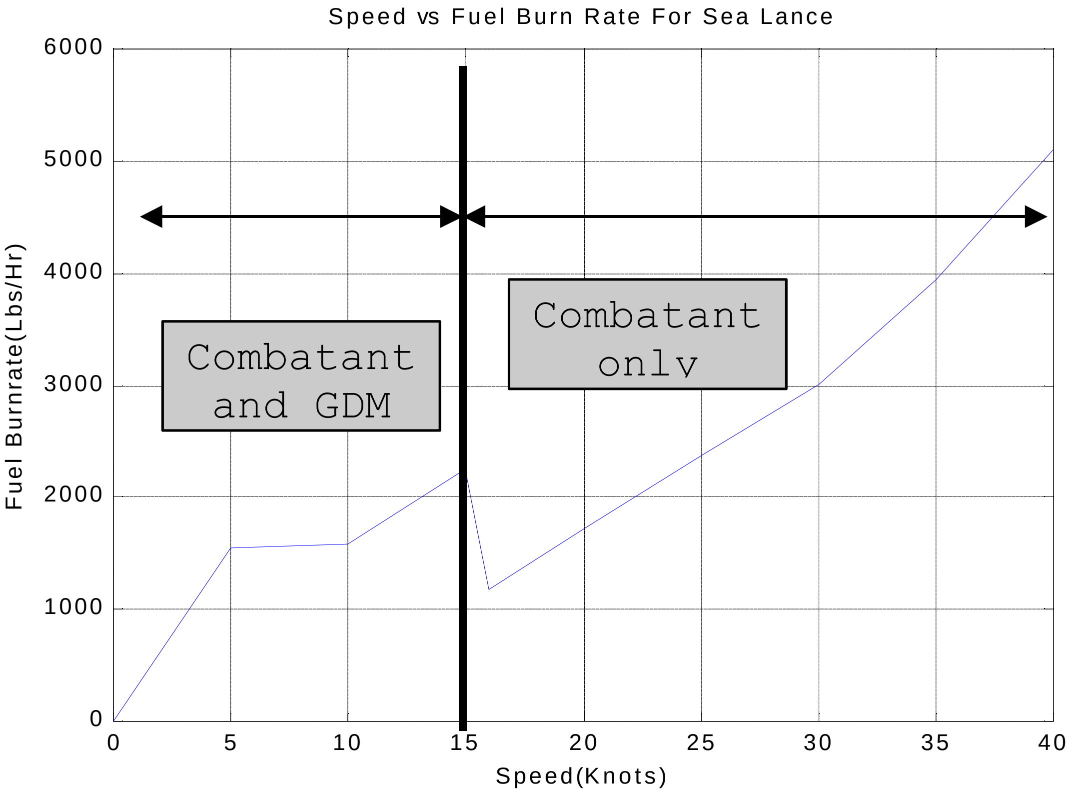


Figure 3. Speed vs. Fuel Burn rate

For the fuel burn rate calculations typical diesel burn rate curves are used. In the case of 70% propulsion efficiency is not possible, the power requirement and fuel burn rate calculations are performed for 62%, 65%, 68% and 70% propulsive efficiencies. These calculations showed that the difference between fuel burn rates for both the speed of 15 knots with GDM and 40knots without GDM is not more than 10%.

The resistance, power requirements and fuel burn rate calculations for different values of propulsive efficiencies and the data for MTU Model 16V 595 TE 70 can be seen in Appendix F.

5. Conventional Versus Electric Drive

The option of transferring engine power to the propulsion mechanism via electric drive was considered. Future naval combatants are expected to use an Integrated Power System, which includes electric drive. Electric drive benefits large gas turbine ships allowing them to burn less fuel, to increase redundancy and survivability, and to relocate prime movers to any location.[5]

Using our diesel engines at our "design point" speeds of 15 and 40 knots and giving the electric drive the most advantageous assumptions, we found that electric drive will be slightly more fuel efficient than conventional drive at 15 knots. Appendix F contains this analysis; when conventional drive is given a best-case assumption, it outperforms electric drive. The electric drive enjoys an average 4-5% specific fuel consumption bonus over conventional drive since the engines are free to spin at their optimal speed. Despite this possible 5% fuel efficiency bonus, the electric drive cannot overcome its inherent and constant 7% transmission efficiency loss[6] when compared to conventional drive.

Further analysis makes electric drive even less desirable. Electric drive's other benefits, survivability and design arrangement flexibility, do not assist our design. Survivability of each SEA

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[5] TS3000 Electrical Power Engineering, Naval Post Graduate School, Professor John Ciezki, p. 3-15,16

[6] Ibid. p. 4-6

LANCE Combatant is not a design priority. Also, the ability to move the prime movers anywhere in the ship is not of real benefit to SEA LANCE: the engines are well-positioned in the hulls where conventional drive requires them to be. Electric drive also carries the liabilities of being costlier, having higher technological risk, and being heavier due to extra components (electric motors, large generators, high power distribution equipment, etc.). Cost and weight are two key parameters that we desire to minimize.

One counter-argument to the above discussion is worth considering. Since the Navy appears to be adopting electric drive for DD-21 and other naval ships, perhaps the Navy should, from a Fleet-wide perspective, consider using electric drive in the SEA LANCE Combatant. Simply put, it will be less expensive for the Navy to make mistakes and build corporate knowledge in electric drive with low-cost SEA LANCE Combatants rather than large combatants. Regardless of this consideration, we have followed the analysis, which clearly favors the choice of conventional drive.

6. Propulsion Mechanism

We have chosen the Bird-Johnson Company's Advanced Waterjet Propulsor Application (AWJ21™) technology. The AWJ21™ is a podded waterjet that hangs beneath the aft-body of the hull as shown in Figure 1. The SEA LANCE Combatant will be equipped with four AWJ21™s (two per hull); each directly driven by a diesel prime mover.

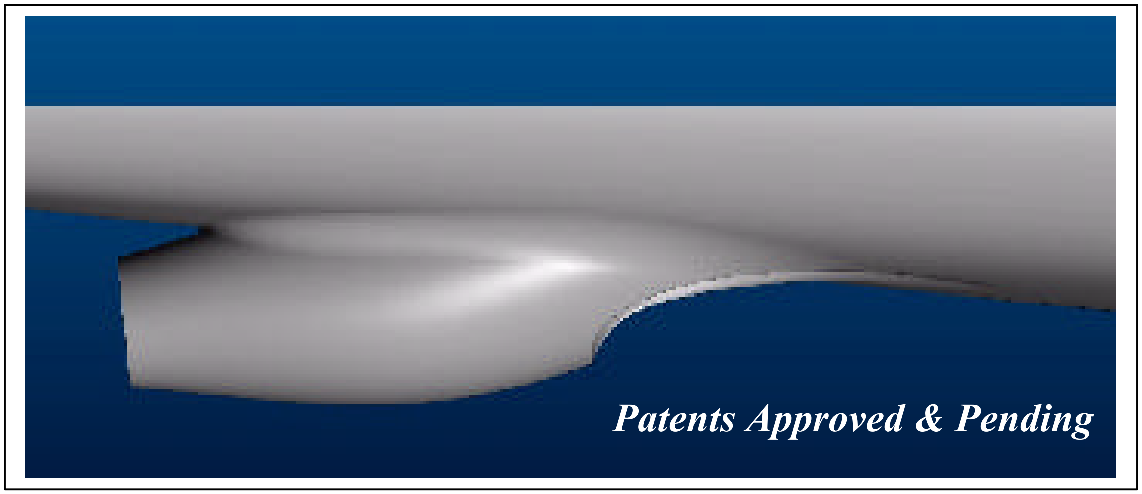

Figure 1

The AWJ21™ adapts efficient, advanced mixed-flow commercial waterjet technology to high performance surface ships, incorporating a novel underwater discharge configuration.[7] Finishing in 1999, Bird-Johnson was sponsored by MARITECH to conduct research and development of an advanced, high power waterjet design. The result is the AWJ21™, which is more efficient than controllable pitch propeller, quieter than propellers, and typically will not increase

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[7] Appendix K Bird-Johnson Brief slide 6

navigational draft (see Figure 2).[8] Additionally, the AWJ21™ promises to be more maneuverable and will not require reversing the engines in order to drive backwards.

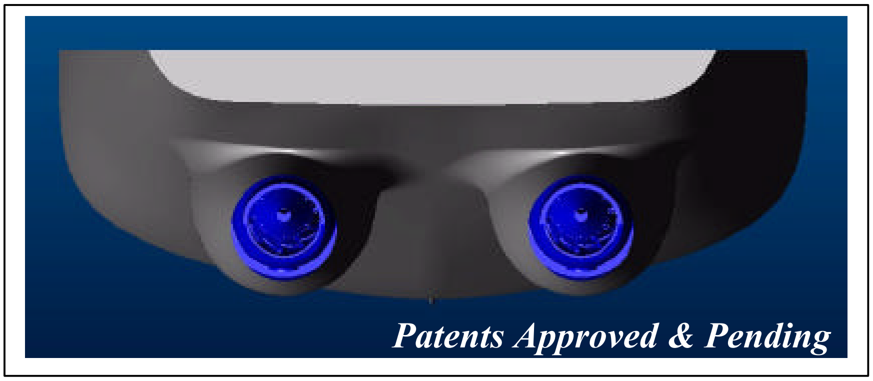

Figure 2

Using data provided by the Bird-Johnson Company, we have estimated the size and expected RPM of AWJ21™ for our application. Although we did not have specifications on appropriately sized jets, we have plotted the size and RPMs versus horsepower of the examples provided.

Figure 3 shows that the SEA LANCE AWJ21™ should operate between 900 and 1800 maximum RPM. The standard MTU 16V 4800HP engines (that served as our typical engine) spin at 1300 RPM. Hence, we conclude that the engines will likely be able to direct drive the AWJ21™ without a reduction gear. Figure 4 shows that an appropriate diameter of AWJ21™ is between 0.4 and 0.8 meters (1.3 and 2.6 feet). The aft-body of the SEA LANCE hull sweeps up 2.0 feet leading us to

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[8] Ibid. slide 10

conclude that AWJ21™ will fit beneath the hull with little or no impact to navigational draft.

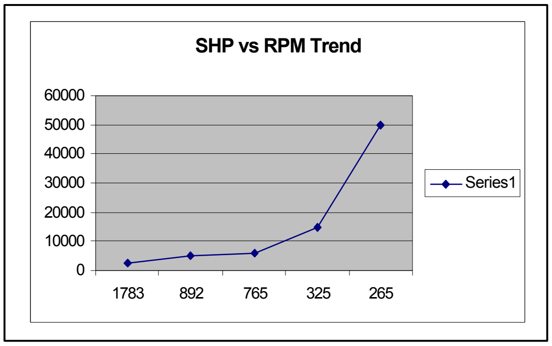

Figure 3

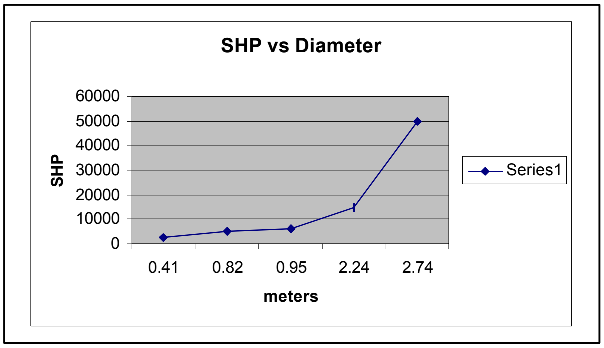

Figure 4

We did examine propellers as an alternative. Using a propeller optimization program[9], we estimated that the SEA LANCE Combatant would require an approximately 8 ft. diameter propeller. This exactly matches our navigational draft of 8 ft. However, since the wave-piercing catamaran is a planing hull form, propellers would have to be placed lower to ensure submersion even at high speed. A reasonable expectation finds the propellers increasing our navigational draft by 2 feet or more. In addition, propellers would require reduction gear regardless of the engine type chosen. Since weight is a primary concern for a catamaran hull, we wish to avoid reduction gear.

A conventional waterjet would also avoid the problems of increased draft and need to provide reduction gear. However, the propulsive efficiency of conventional waterjets is unacceptably low for our

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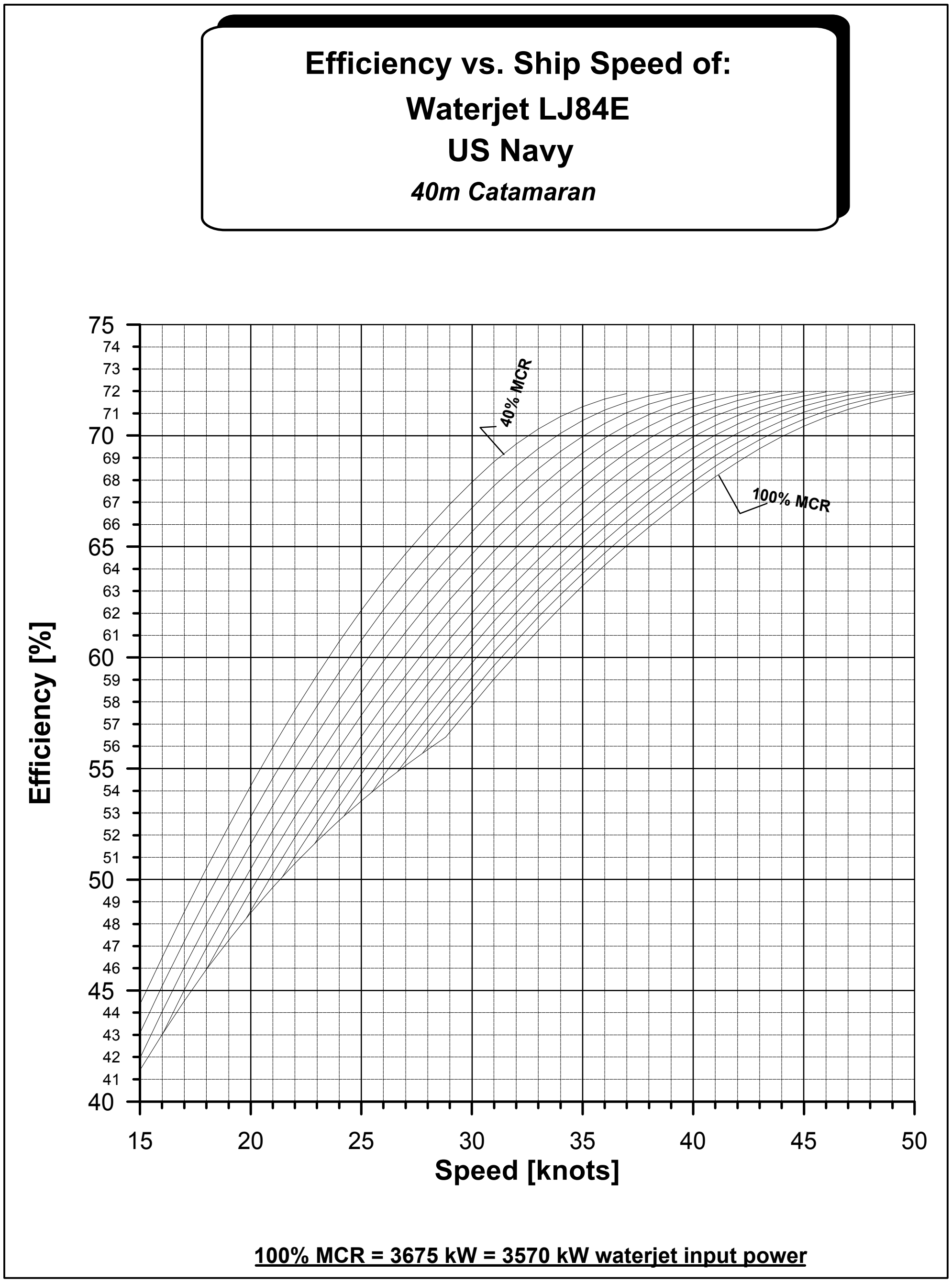
[9] http://web1.nps.navy.mil/~fapapoul/propopt_input.html/

design speed of 15 knots. As can be seen by this waterjet efficiency chart (Figure 5) provided by Lips Propulsion, waterjet efficiency drops to about 45%. This is significantly lower than the 60+% of propellers and would require increasing the Combatant’s fuel load by 25 to 33 percent.



C. Electrical Generation

We propose three design cornerstones for the electric power system. These cornerstones reflect the desire to require the least possible maintenance by the crew and to minimize costs.

1. TOSA

In order to minimize costs, we propose incorporating the Total Ship Open System Architecture philosophy. TOSA involves using open standards for interfaces, services, and supporting formats that enable properly engineered elements to be used across a wide range of platforms with minimal changes. The goal of this philosophy is to allow any given piece of equipment to be easily replaced by a different design with improved technology without requiring changes to the system's support services, control functions, or structure. Ultimately, all U.S. Naval vessels will share these standards allowing commonality of equipment at a universal scale. TOSA is the product of a team sponsored by the Affordability Through Commonality Program (PMS 512) of PEO Surface Strike.[10]

In accordance with the TOSA team's recommendations, the SEA LANCE Combatant can be designed in functional element zones as seen in Figure

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[10] Vasilakos, Devries, Tompkins, "Total Ship Open Systems Architecture" *Naval Engineers Journal,* July 2000, p. 59.

(1). These zones contain physical groupings of equipment such as engineering, C4I, and weapons systems. Each zone's equipment shares functions allowing intelligent design of interfaces to and from each zone. The functional element zone applies to equipment that is confined to single spaces. Some systems, notably the shipboard LAN, are inherently open and so do not require the function element design approach. Using TOSA design philosophy, as shown in Figure 2 for chill water and electric power, a control center space can be updated with modern equipment. This is demonstrated in Figure 3 where consoles and screens are successively replaced by upgraded replacements. Although the SEA LANCE Combatant's planned a 10-year frontline service life will preclude several replacements in a single vessel, the design philosophy will still benefit the SEA LANCE program by minimizing the need to redesign the future Combatants produced years later with new equipment.

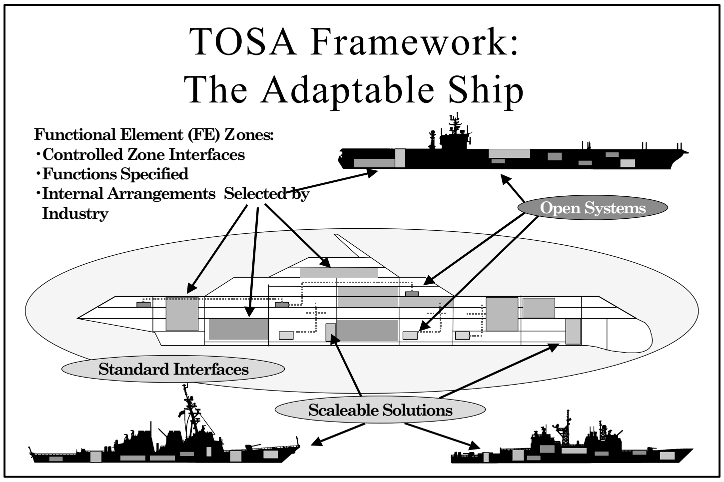

Figure 1

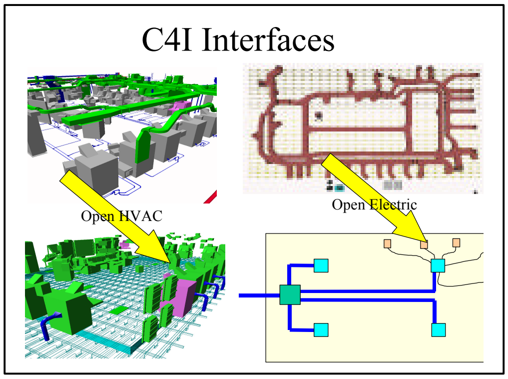

Figure 2

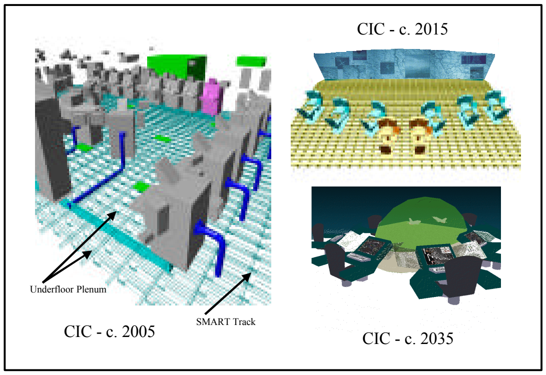

Figure 3

The TOSA team has developed, and continues to develop, reference models for various ship functions and systems. A detailed SEA LANCE design can use these models to ensure affordability is incorporated everywhere possible. A reference model will define the "Atomic Level" below which, industry suppliers control the design process.[11] The government controls the design process above the Atomic Level. This further facilitates commonality amongst different ship classes reducing overall fleet cost.

Including the TOSA design philosophy in SEA LANCE will allow for easier insertion of new technologies at a lower cost. TOSA will allow the SEA LANCE greater flexibility and adaptability while reducing requirements to redesign. It also helps the insertion of commercial products and promoting commonality in all Navy ships.[12]

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[11] Ibid., p. 60

[12] Ibid., p. 76

2. PTO Power Generation

In order to minimize maintenance and weight, we propose using power take-off gear to generate electric power. We have estimated our total electric load by examining our expected power loads and comparing with other small combatant designs. We estimate the following:

Primary Power Consumers

1.	Combat systems	89 kVA
2.	Engine Room (Port & Starboard)	40 kVA
3.	HVAC	20 kVA
4.	Tow dampening system	15 kVA
5.	Damage Control gear	15 kVA
6.	Tow	10 kVA
7.	Communication gear	10 kVA
8.	CBR system	10 kVA
9.	Fresh water system	8 kVA
10.	Galley	4 kVA
11.	GDM Distribution System (intermittent use)	110 kVA

This estimation sums to 220 kVA without the GDM Distribution System active and 330 kVA otherwise. For comparison, we note that the Norwegian Skjold class (260 LT) generates 228 kW[13] and the Swedish Visby class (600 LT) generates about 450 kW[14]. This confirms our estimate to be reasonable.

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[13] http://home.c2i.net/knmskjold/english/index.html
[14] http://www.naval-technology.com/projects/visby/specs.html

To minimize size, we have chosen to design our PTO equipment to be capable of producing 330 kVA at 100% capacity. This results in requiring both PTOs online running at 75% capacity during normal (non-Grid deploying) operations.

This scheme allows some flexibility in load shedding or emergency situations. The emergency generator set is rated at 150 kVA permitting the SEA LANCE Combatant to operate without degradation even with one PTO completely offline. The ship will continue to function with only vital loads with both PTOs offline and operating solely from the emergency generator. Since the GDM is designed to receive power from the Combatant and since the GDM has an identical emergency/inport generator set, the SEA LANCE with GDM attached may have yet another option for alternate power. If the Combatant has its emergency generator online and has the GDM generator power available, the Combatant will be able to operate at full capacity (without the grid deployment system online). The following table describes the Combatant (without GDM) power configurations.

Operational Condition	**PTOs online**	**Emergency/Inport Generator online**
Normal	2	0
Casualty	1	1
Emergency	0	1

The weight saved is the primary advantage of PTO. A generator set capable of producing 180 kVA of power weighs about 3500 lbs.[15]. The lightest possible generator at 180 kVA could weigh as little as 122 lbs. for permanent magnet and easily under 250 lbs. for other generator types[16]. It is difficult to estimate the PTO gear weight, but this should easily weight less than one thousand lbs.

We have decided to use a field wound synchronous machine generator. Although a permanent magnet generator would be lighter, the field wound generator offers important advantages without much greater weight. The permanent magnet option suffers disadvantage since the PTO will provide a variable input speed. This causes variable levels of voltage in the power produced, and variable voltage is difficult to manage. A field wound generator may be controlled to produce a steady voltage, which simplifies the rest of the power generation process.

A step-up gearbox may be required in the PTO gear in order to smooth out the power frequency produced by the generator. However, if the generator is an 8-pole machine with an expected input of 300-1300 rpm (approximately the expected operating range of our 4800 HP diesel prime movers), the field wound machine may be able to direct drive from the engines. The power frequency produced by a synchronous machine is:

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[15] http://www.armstrongpower.com/b143-cum.pdf

[16] TS3000 Electrical Power Engineering, Naval Post Graduate School, Professor John Ciezki, p. 4-7

F_e = RPM x poles / 120

Given the above inputs, these produces power frequencies between 20 and 86 Hz, which may be an acceptable range depending on the generator. The generator operates most efficiently at its designed frequency (often 60 Hz), but it can accept a range based on its design. This issue is worth further research since eliminating a step-up gear will save cost and weight.

The field wound option also best supports the DC zonal distribution system (discussed in the next section) by providing constant voltage power to a rectifier. If an AC distribution system were chosen, the lighter permanent magnet generator ought to be the superior choice. The permanent magnet generator would be followed by a cycloconverter that converts variable voltage/variable frequency power to constant voltage/constant frequency power for distribution. The cycloconverter is a mature technology; its main drawback is the requirement for complex control mechanism.

3. DC Zonal Distribution

In order to minimize costs and maintenance, we propose using a DC zonal distribution system (DCZEDS). DCZEDS offers the advantages of solid state, low maintenance components and by means of technologies already being developed for the DD-21 power distribution system. A notional DCZEDS appears in Figure 4.

AC power generated by the field wound synchronous machine is fed to a phase-controlled rectifier. The rectifier converts the AC power to DC power and distributes it on a main power bus. The rectifier will have 6 phases to allow maintenance and repair while energized. Two sets of three phases will equally share the electric load. The SEA LANCE will have a port and starboard main power bus. The ship is divided into zones (four zones in the notional figure separated by dashed lines) each of which draws power from the port and starboard main buses through a DC converter referred to as a Ship’s Service Converter Module (SSCM). The SSCM can provide power directly to equipment requiring DC power, or it provides the power to a DC to AC inverter referred to as a Ship’s Service Inverter Module (SSIM). The SSIM services equipment requiring AC power. The SSCMs and SSIMs are being developed for the DD-21 power distribution system. SEA LANCE could use modules identical except scaled down for our lower power requirements. The port and starboard buses can cross connect in the forward hull if one PTO goes offline. There they can be connected to the emergency/inport generator for inport, at anchor, and in casualty mode operations.

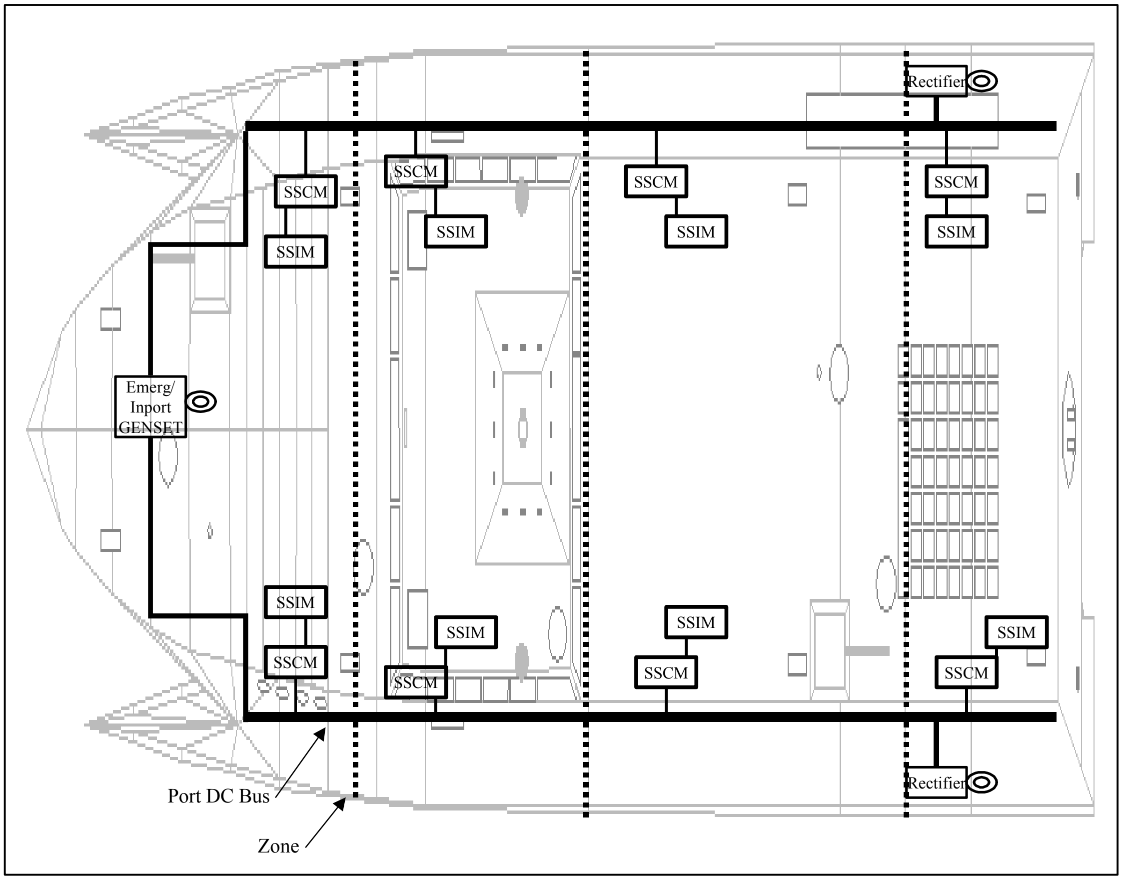

Figure 4

DCZEDS appears to be naturally appropriate for the SEA LANCE design. DC power will be better suited for PTO power generation since it effectively deals with the challenge of variable frequency input power. The port and starboard power generation and the physical shape of the hull support a zonal architecture with port and starboard power buses. The DD-21 program desires DCZEDS for survivability (and other benefits). SEA LANCE does not require such survivability but enjoys the DCZEDS characteristics of reduced weight (few cables and distribution equipment) and reduced manufacturing cost (much less cable pulling after ship sections are connected).

Another issue in survivability and reliability is battery backup of vital equipment. Battery backup, or Uninterruptable Power Supply (UPS), is desirable for critical systems such as control, communications, and (possibly) propulsion. Considering the power levels required, UPS for minimum electronic equipment should be inexpensive in weight and cost. However, the power requirements to keep the prime movers and AWJ21^{TM} operating without ship’s power are expected to be high. Once those requirements are defined, an analysis of weight and cost of large UPS systems should be performed.

D. Combat Systems, Weapons and C4ISR

1. Combat Systems and Weapons

a. Overview

The organic sensors and weapons chosen for SEA LANCE are in accordance with the Operational Requirements Document (ORD). From the analysis of the ORD, the need for sensors and weapons can be summarized by the following functions:

i. Offensive:

- Engage surface targets (surface action)

ii. Defensive:

- Engage surface targets (point defense)
- Engage air targets (point defense)
- Avoid mines

The sensors and weapons that perform the air and surface engagement functions must be able to detect, track, identify/classify and destroy/neutralize targets. Mine avoidance only requires detecting, in order to maneuver accordingly.

The objective of this analysis is to provide notional systems for the first iteration of the conceptual design. These theoretical systems will provide an initial estimation of weight, volume, power consumption, and cost, so that feasibility of the proposed platform can be assessed. The systems described in the following paragraphs have been conceptualized from existing systems in the market today. It is reasonable to assume that due to trends in technology, systems will in general, get smaller, lighter, more efficient, more reliable, and more effective.

b. Weapons

The organic weapons that SEA LANCE will carry are the following:

i. 4 medium range SSM.

ii. 51 short-range dual purpose SAM/SSM.

iii. 2 30mm mounts with 1200 rounds each.

The medium range SSM will give SEA LANCE the capability of engaging in surface actions. Data is based on the existing Harpoon missile.

Both air and surface point defense are allocated in two complementary layered systems. The first layer is given by a dual purpose SAM/SSM. This dual-purpose system has been conceptualized by linear regression data analysis from existing SAM and SSM missiles. The data is shown in Appendix G. The missile system has been conceived as a dual-purpose system in order to provide flexibility while saving space, weight, and manning requirements. It also provides logistic advantages regarding maintenance and parts. If different missiles were to be used for SAM and SSM, more equipment would be needed, resulting in a larger payload fraction. Also, fewer missiles would be available for each function. With a dual-purpose missile, any available missiles will always be usable against air or surface targets, enhancing the ability of SEA LANCE to retain capabilities with less need to reload.

The second point defense layer is given by 2 30 mm gun mounts based on the Mk 46 to be installed in LPD 17. The guns provide a cheaper alternative to destroy/neutralize targets at shorter range when the use of a missile is not justified. It also provides defense at distances below the minimum firing range for the dual-purpose missile, improving survivability. Even though the gun is not designed as a Close in Weapon System, it provides some degree of protection against incoming missiles that penetrate the SAM layer.

General characteristics of the weapons are listed in tables 1 through 3.

Although decoy systems are not weapons, their description has been included in this section. The decoy system for SEA LANCE is based on a Rafael/Manor Israeli system. It is designed to provide a layered defense against radar emitters and IR sensors. The first layer is a long-range, tactical confusion chaff rocket to be used against search radars in their detection phase. The second layer is a medium-range, distraction chaff rocket that is designed to protect against anti-ship missiles before target lock-on. The third layer is a seduction chaff rocket that protects the ship against active missiles that have achieved lock-on. The system also incorporates a rocket powered IR decoy that has both seduction and distraction roles.

TABLE 1

Length with booster	5.23 m
Length without booster	4.4 m
Diameter	0.34 m
Wing Span	0.83 m
Weight with booster	784.7 Kg
Weight without booster	621.4 Kg
Maximum Speed	M 0.85
Range	130 nm
Warhead	221.6 Kg
Guidance	Active radar, GPS

Medium Range SSM specifications

TABLE 2

Length	2.4 m
Diameter	0.25 m
Wing Span	0.9 m
Weight	381 Kg
Maximum Speed	M 2.0
Range	15 nm
Warhead	70 Kg
Guidance	Active, semi-active, IR

Short Range SAM/SSM specifications

TABLE 3

Height	1.8 m
Width	1.7 m
Length	1.9 m
Barrel	2.0 m
Swing Radius	2.9 m
Weight unloaded	1360 Kg
Weight loaded (1200 rds)	2320 Kg
Firing Rate	200 rds/min
Accuracy (Probability of hit of 3 round burst against small boat)	0.4 at 4000m

30 mm Gun specifications

c. Sensors

SEA LANCE is conceived to operate within the capabilities of the grid. Network Centric assets will link situation awareness gathered by the grid to SEA LANCE platforms. Consequently, the main “sensor” for SEA LANCE will be the link with the network, providing detection, tracking, and identification/classification.

In the grid deployment phase, situation awareness will be limited; therefore, the platform must have its own capability to detect, track and identify/classify. Even when deployed, combatants may have to operate in areas of limited grid coverage.

In order to allow for the above, SEA LANCE will carry the following sensors:

i. 1 air/surface search and missile detection radar.

ii. 2 Fire control radar.

iii. 1 Infrared Search and Track (IRST).

iv. 2 Electro-Optic Suites.

v. 1 Electronic Support Measures (ESM) Suite.

vi. 1 Mine avoidance sonar.

vii. 1 Navigation radar.

The chosen sensors give SEA LANCE enough capabilities and redundancy in key functions, to conduct limited operations without the grid. They also make the combatant another sensor of the grid itself. Table 4 summarizes the primary (1) and secondary (2) functions that can be performed with each sensor.

TABLE 4

Sensor/Function	**Detect**	**Track**	**Classify**	**Identify**
Search Radar	1	1	2	
Fire Control Radar	1	1	2	
IRST	1	1	2	
EO Suite	1	1	1	1
Navigation Radar	1	2	2	
ESM	1	2	1	
Mine Avoidance sonar	1	2	1	1

Primary and secondary functions of each sensor

d. Sensor Description[17]

i. Air/Surface Search and missile detection radar:

The search radar is based on the Elta EL/M-2228S system. It is a fully coherent 2-4 GHz pulse-Doppler radar. It is a multimode system in that it provides medium range surface detection, low to medium height air detection, and sea

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[17] www.janesonline.com

skimming missile automatic threat alert with very low false alarm rate. The radar is instrumented to a range of 54 nm.

The antenna is of the cosec square type and it scans mechanically at 12 or 24 RPM. The radar has built in track-while-scan capabilities of up to 100 targets.

ii. Fire Control Radar:

The fire control radar is based on the Elta EL/M-2221 system. It is a 27-40 GHz monopulse radar that provides automatic gun fire control against air and surface targets. Also, the radar provides tracking and guidance for the dual-purpose short range SAM/SSM. The radar is instrumented to 20 nm.

The antenna is mechanical and of the Cassegrain type, and is constructed of lightweight composite materials.

iii. IRST (Infra Red Search and Track):

The IRST is based on the Signaal SIRIUS system. It is a long-range dual-band (3-5 and 8-12 μm) surveillance and tracking system, which gives passive capabilities against sea skimming missiles. SIRIUS provides automatic threat alerts to the weapon systems minimizing reaction times. Stealth has been incorporated to the sensor head that scans at 60 RPM. Detection ranges vary with weather conditions and target height, but 20 nm could be expected given enough horizon.

iv. EO Suite:

The Electro-Optical Suite is based on the Elop Multisensor Stabilized Integrated System (MSIS). It includes an IR imager in the 8-12 μm band, television camera, and a 1.064 μm laser range finder (LRF) and designator. The sensor provides detection, tracking, and recognition of targets in day and night operations. The system also provides fire control for the 30-mm guns and can slave the fire control antennae for missile guidance in case tracking by them fails. Detection ranges vary, but 10 nm could be expected.

v. Navigation radar:

The navigation radar is based on the Signal Scout system. It is a low probability of intercept radar working in the 8-10 GHz band. The radar uses frequency modulated continuous wave techniques and very low transmitter power, making it very hard to detect by enemy ESM. It is a very lightweight system and is instrumented to 25 nm. The transceiver is integrated into the antenna, which rotates at 24 RPM.

vi. Electronic Support Measures (ESM) Suite:

ESM is based on the British Aerospace Australia PRISM III system. It provides detection, direction finding, classification, and analysis of radar emissions in the 2-18 GHz range. The system is very lightweight and well suited for small combatant applications. The system is capable of detecting continuous wave, conventional pulse, frequency agile, frequency hopping, PRF agile, PW agile, and pulse compression radars. It is mainly intended to complement the passive capability of automatic missile threat alert.

vii. Mine avoidance sonar:

The mine avoidance sonar is based on the Thomson Marconi Sea Scout system. It is a lightweight sonar working at 250 KHz, designed to detect and classify objects up to distances of 300 m. The sonar has a 20° fixed azimuth coverage, which can be scanned giving an overall coverage of 80°. The azimuth resolution is 0.6°. The vertical field of view is 10° selectable within the total vertical range of +10°to -45°.

e. Weight and Volume Summary

One of the main goals of the sensor and weapons assessment was to provide realistic weight, volume, power consumption, and cost estimates for the first iteration of the design spiral. Table 5 summarizes the data. The numbers correspond to totals; for example, the numbers for the fire control radar include both units.

TABLE 5

Sensor	Weight Kg	Volume m^3	Area m^2	Power KVA	Cost M$
Search radar	737.00	4.45	4.25	8.00	3
Fire Control radar	2840.00	7.56	1.94	44.00	12
IRST	1010.00	1.01	0.81	8.00	5
EO suite	200.00	0.81	0.61	4.00	5
ESM	67.00	0.59	0.70	0.50	1
Mine avoidance sonar	300.00	0.63	0.50	4.00	1
Navigation radar	80.00	0.48	0.82	0.70	0.5
Sensor Total	5234.00	15.53	9.64	69.20	27.5
Weapon/ECM					
Medium range SSM	5100.00	154.01	55.80	1.00	2.88
Short range SAM/SSM	43234.00	100.00	25.00	5.00	15.3
Decoy Launchers	1600.00	1.00	2.00	2.00	1.5
30 mm gun	4640.00	5.81	3.23	12.00	2.44
Weapon Total	54574.00	260.82	86.03	20.00	22.12
Overall Total	59808.00	276.35	95.67	89.20	49.62
	(58.86 LT)	(9931.19 ft^3)	(1041.85 ft^2)		

f. Sensor and Weapon Location

Weapons will be located as shown in Figure (1). The medium-range SSM launchers will be forward inside the hull and pointed athwartships towards the port side. The 4 missiles are pointed in the same direction because of space limitations in the starboard side. Even though Harpoon missiles can turn 180°, their range is considerably decreased, but this issue is overcome by the high maneuverability of the craft, which allows it to turn very fast and point closer to the desired direction.

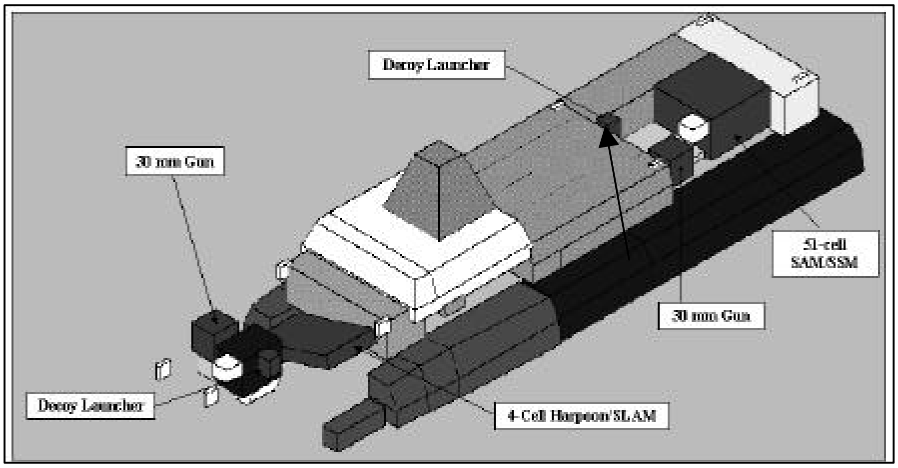

Figure 1. Weapons location

Short-range missiles are installed in a vertical launcher close to the stern, giving the system 360°

coverage. Both the medium range and short-range missiles exhaust plume is discharged between the hulls.

The 30-mm mounts have been installed off centerline to improve their vertical field of view. This will allow repelling small boats that come close to the ship. The arcs of fire, fields of view, and minimum ranges for the guns are shown in Appendix G.

Sensors are located in a partly telescopic, enclosed mast shown in Figure 2. At the top of telescopic part of the mast, the IRST is installed. With the mast fully extended, the IRST will be at 48 feet above the waterline. This height gives the IRST a 20-km horizon against a sea skimmer flying at 3 meters above the water. Right below the pedestal of the IRST, the ESM antenna is installed. The search radar is also inside the telescopic part of the mast about 6 feet below the IRST. The horizon of the search radar against the sea skimmer is approximately 21 km with the mast fully extended.

In the base of the mast (the fixed enclosed portion) the fire control antennae are installed, one forward and the other aft. This location for the antennae provides good overlapping towards the beam and gives the system as a whole 360° coverage. The Electro-Optic suites are installed outside the enclosed mast also providing 360° coverage. The transducer of the mine avoidance sonar is installed forward in the starboard hull.

Sensors and weapons coverage is summarized in Table 6, and sensor coverage diagrams are shown in Appendix G.

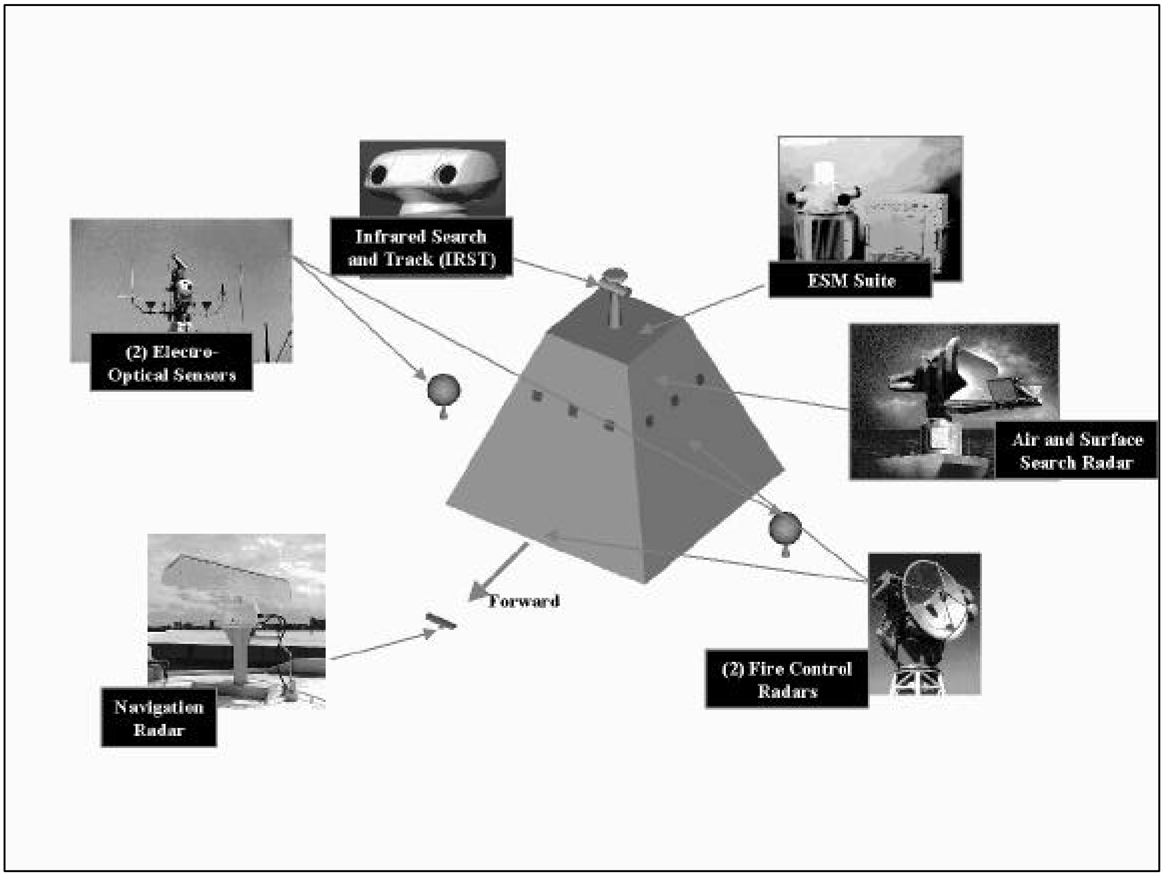

Figure 2. Sensor location

TABLE 6

Sensor/Weapon	**Range**	**Azimuth Coverage**
Air/Surface/Missile detect	54 nm	000-360
Fire Control (fore)	20 nm	195-165
Fire Control (aft)	20 nm	015-345
IRST	20 nm	0-360
EO Suite (starboard)	10 nm	322-217
EO Suite (port)	10 nm	143-038
ESM	-----	000-360
Navigation Radar	25 nm	212-148
Mine Avoidance Sonar	>300 m	320-040
Medium Range SSM	67 nm	000-360
Dual Purpose SAM/SSM	15 nm	000-360
30 mm Gun (fore)	2 nm	223-164
30 mm Gun (aft)	2 nm	039-351

g. Sensor and Weapons Integration

Sensors and weapons are integrated through the onboard digital network. They will comply with the entire plug and play open system features incorporated in the fast Ethernet LAN.

h. SAM Assessment

The most stressing scenario for SEA LANCE is during grid deployment. Situation awareness will be limited; hence detection will probably have to rely on SEA LANCE’s own sensors.

In order to assess the performance of the SAM against anti-ship missiles, a simulation was conducted. A four subsonic (300 m/s) missile salvo was chosen as the threat, flying at 3 m above the surface. The missiles were incoming one after the other separated by 600 m. SEA LANCE’s search radar horizon is 21,713 m, while the illuminator horizon is 18,652 m. The SAM maximum range is 15,318 m. The system is capable of launching SAM every 2 seconds, and good guidance is achieved after 5 seconds in flight. The simulation only considered the use of one illuminator. It was determined that the system can fire 3 SAM per incoming missile in a shoot-shoot-shoot configuration, with the given detection ranges, speed and timing. Table 7 summarizes at what distance from SEA LANCE (meters) each missile would be intercepted.

Table 7

SAM/Threat	Missile 1	Missile 2	Missile 3	Missile 4
SAM 1	14820			
SAM 2	14405			
SAM 3	14000			
SAM 4		9665		
SAM 5		9245		
SAM 6		8825		
SAM 7			6065	
SAM 8			5675	
SAM 9			5255	
SAM 10				3605
SAM 11				3215
SAM 12				2795

Given the reliability R of the SAM, it is possible to determine the probability of killing the whole salvo. This probability is given by

$$P_K = \left(1 - (1 - R)^3\right)^4$$

Table 8 shows the probability of kill for different reliabilities.

TABLE 8

R	Pk
0.5	0.586182
0.55	0.682365
0.6	0.767544
0.65	0.839218
0.7	0.896296
0.75	0.938950
0.8	0.968382
0.85	0.986568
0.9	0.996006
0.95	0.999500
0.96	0.999744
0.97	0.999892
0.98	0.999968
0.99	0.999996

2. C4ISR

The SEA LANCE Combatant is primarily a network centric warfare ship. Its primary mission entails supporting and utilizing the networked SEA LANCE Grid. The Combatant's C4I suite will reflect this focus along with the constraint of a limited crew.

The SEA LANCE Combatant will be equipped with two external data networks. Its primary network will be what the SEA LANCE Grid employs. This network has not been defined (SPAWAR San Diego uses the term "Teamnet"). The TSSE group used a notional network created by each grid component utilizing acoustic modems to communicate with specialized grid components ("RF gateways") that collect acoustic data, process it, and transmit it via a high speed RF link to satellite or AUV. The aerial component transmits the Teamnet to the Combatants and other Teamnet equipped units. The real Teamnet may be drastically different; however, we expect and planned for communicating with the network via a RF link. To support this RF link, SEA LANCE is equipped with antenna to communicate with satellite and by line-of-sight in high frequencies (expected K band) for high data rates.

Since SEA LANCE Combatants are expected to perform other missions than Grid employment, they will be equipped with Link 16/TADIL J. TADIL J is widely used by U.S. Forces and will allow interoperability with a wide variety of units. The need to equip SEA LANCE with another data link besides Teamnet is a point of concern. It reflects the Navy’s problem of “stovepipe” data nets that cannot be inter-networked. Ideally, Teamnet should be a starting point for creating Navy-wide interconnectivity. Rather than being another specialized data network available only to Teamnet equipped ships and shore stations, Teamnet should be the beginning of an integrated, cross-platform, Internet-Protocol-based network.

The Navy’s worldwide mission requires a worldwide radio Wide Area Network. This requires a satellite infrastructure with the traits common to a robust inter-network. Router-to-router interconnect is one such trait; it means to be able to connect any arbitrary set of Internet Protocol routers together. Each ship’s communications center needs a router along with each satellite and ground station. To ensure all systems and local networks can utilize the radio WAN, they must connect to their router via a standard LAN protocol such as Ethernet. This virtually eliminates integration problems between networks.

Another trait desired is the ability of routers to multicast (i.e. deliver data to multiple destinations simultaneously). Multicasting is supported by “shared-use media protocol” which is another key characteristic of our desired network. This protocol governs the RF communications format and abolishes the typical procedure of dividing up satellite bandwidth equally among users. Division of the bandwidth is an inherently inefficient (though some think it “fair” sharing) method of multiplexing several users on the same communications channel. Additionally, the routers themselves need to use the Simple Network Management Protocol (SNMP)[18] that uses a get/set/trap algorithm for efficient data flow and management of networking services.

These issues are well beyond the scope of any single program; but SEA LANCE/Teamnet is especially sensitive to this Navy-wide problem.

SEA LANCE will also communicate with satellite and LOS connections other than its data links. For the sake of simplicity of design and of use by SEA LANCE's reduced crew, we propose a simple communications suite. SEA LANCE will be able to communicate LOS via VHF and UHF and to communicate via satellite on standard EHF/MILSTAR[19]. The SEA LANCE will also be able to receive the Global Broadcast Service (GBS)[20]. While not robust, these communication channels along, with the two data links, should allow SEA LANCE to perform all assigned missions while being simple enough for the minimally manned crew.

A promising technology to assist high-speed RF links for SEA LANCE is the active phased antenna[21]. This antenna electronically steers radio signal toward the intended receiver. This allows less power to achieve greater range and bandwidth. Additionally, the communication transmission is less likely to be

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[18] http://www.faqs.org/faqs/snmp-faq/part1/

[19] http://www.losangeles.af.mil/SMC/MC/Milstar/

[20] http://www.laafb.af.mil/SMC/MC/GBS/

[21] SPAWAR Systems Center-San Diego C4ISR Innovation Cell, Art Chagnon

intercepted or even detected. Current technology makes this feasible for high frequency applications (above 1 GHz). Lower frequency communications, UHF and VHF, may eventually be able to use active phased array technology, but current lower frequency antenna technology (omni-directional) may have to be used. We have equipped the SEA LANCE Combatant with one large, high capacity array that lays horizontally topside behind the superstructure for satellite communications. For LOS and data link, SEA LANCE has three smaller antenna arrays mounted on each of the mast’s four sides. If other (non-array) antennas are required, they can be located on top of the non-extending mast.

For interior communications and networking for the SEA LANCE Combatant we propose a fast Ethernet LAN arranged in a mesh topology. Ethernet is an extremely compatible protocol that can be used by virtually any system. Due to this flexibility, all systems will be required to use Ethernet if they are installed on SEA LANCE. A mesh topology creates super redundancy in the network to ensure the crew will never need to maintain or repair it while underway. A notional topology is seen in Figure 1.

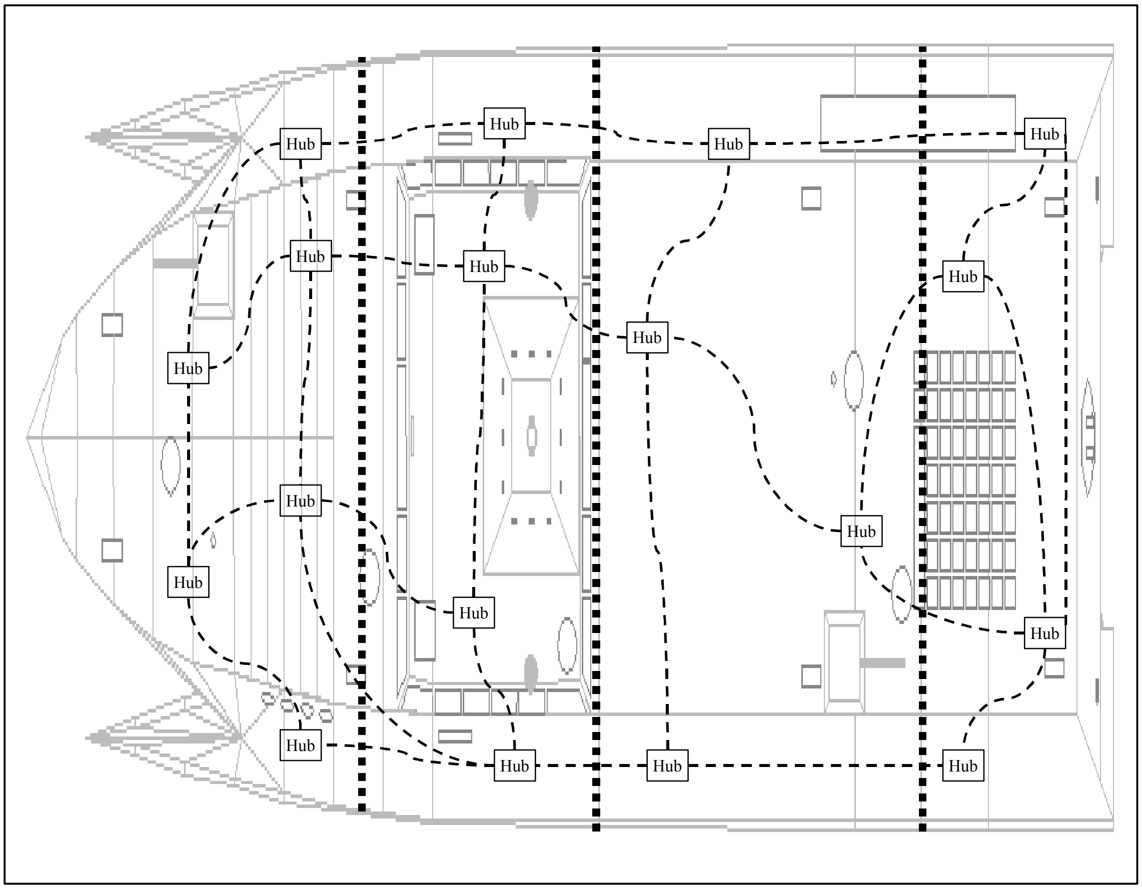

Figure 1

A design philosophy for SEA LANCE systems is functional separation. This entails breaking system functional components and separating them from direct communications and requiring them to communicate to each other via the Ethernet LAN. For example, a RADAR system has a transmit/receive component, a data reduction function, and a decision-making component (deciding what to track, where to transmit the next RADAR pulse, etc.). Normally, these components/functions are consolidated into a single physical system that allows direct communications between them. This is efficient in operation but difficult in repair and upgrading. An entire system might need to be completely replaced to improve one small part. If these components/functions are separated and connected to the LAN, they can easily be removed and replaced individually.

Another aspect to the SEA LANCE LAN will be total integration of all ship's systems. We propose a robust level of automation and control to facilitate the small crew to operate the ship. The crew through the digital data network will interface all engineering, combat systems, operational and administrative systems. This requires software engineering to enable a reasonably trained person to operate a SEA LANCE Combatant.

To interface the ship's system, we propose a single type of multi-function console. The SEA LANCE multi-function console will require multiple touch-scan screens for presenting information. The Raytheon Corporation has developed the Enhanced Command Console (ECC)[22] that approaches the level of control and utility required by SEA LANCE. Raytheon has proposed similar technology for use on DD-21, but Raytheon was not at liberty to discuss this technology due to the upcoming contract decisions at the time of this writing.

Each console is capable of accessing all information available and controlling all ship systems. Each console can assume a mode (Command, Tactical, Operational, Engineering) that will limit

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[22] Raytheon Enhanced Command Console Brief, Helmut Tramposch

the type of automatic alerts and prompts to the watchstander. The OOD console may have special controls (levers, stick, and/or wheel) to allow ship control by tactile sense. Voice communications will be accomplished through a light headset, which connects to the console. The multi-function consoles are located only in the SEA LANCE’s Control Center. All watchstanding will occur in the SEA LANCE Control Center. A notional Control Center is presented in Figure 2.

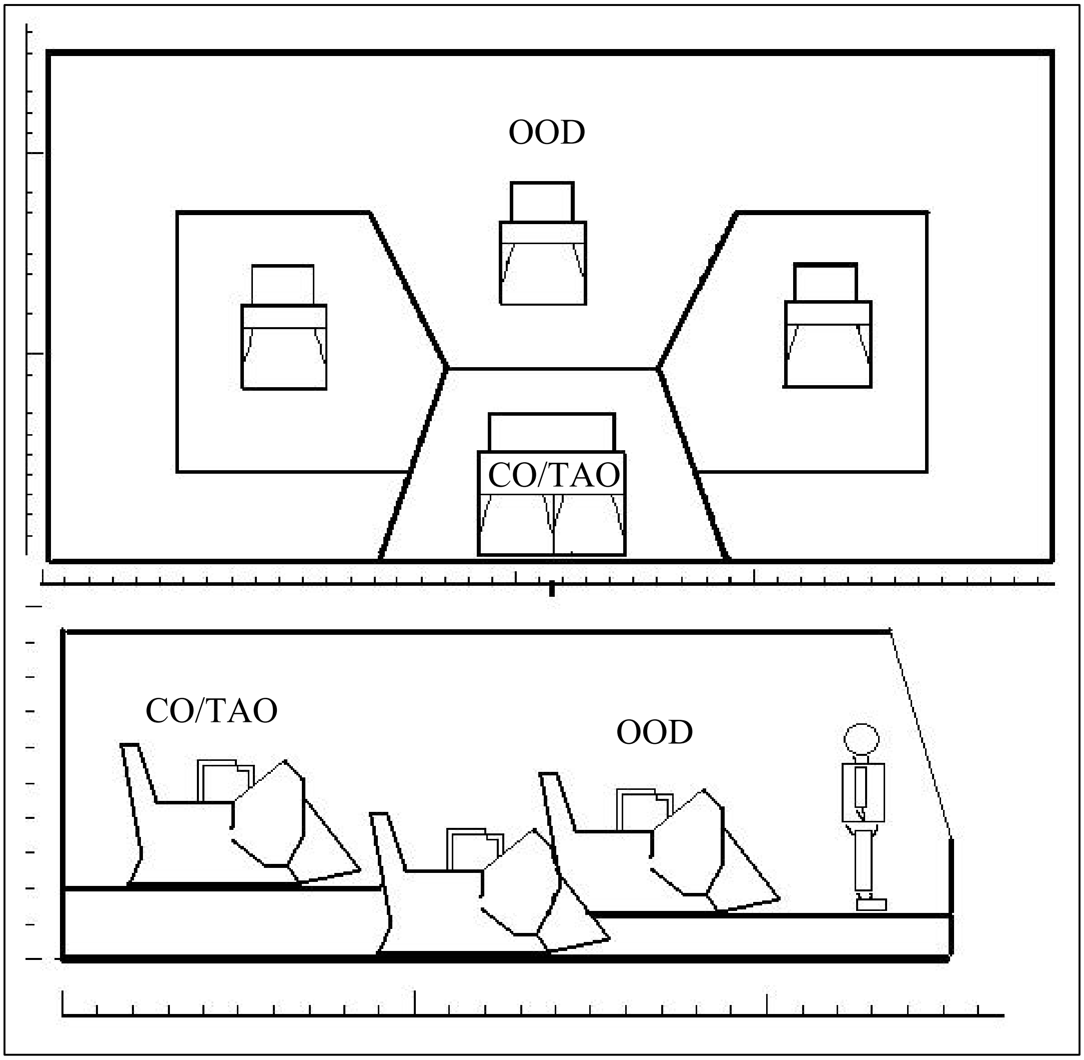

Figure 2

The Control Center has four multi-function consoles to support various manning requirements. An Officer of the Deck or "Ship's Navigation and Safety" watchstander could use the forward most console. If a tactical environment requires it, a TAO watchstander can use the aft most console (raised for a commanding view). In a stressing tactical environment, or whenever the situation calls for a specialized watchstander, either of the remaining consoles can be manned as required. The TAO console is actually two consoles in one; it is designed to allow the CO ready access to a console whenever needed.

Since each SEA LANCE Combatant is required to be able to support a squadron commander and his or her staff, the extra consoles can be dedicated to allowing the squadron staff access to consoles.

One other type of control interface will be available on the SEA LANCE. Each engine room will have an Engineering control station to allow maintenance actions and casualty engineering control. A notional example is provided in Figure 3.

Figure 3

E. Auxiliary and Special Purpose Systems

1. Tow Analysis

The semi-rigid towing system developed for the SEA LANCE project posed unique design challenges. The tow design philosophy is: Develop an integrated towing system based on elementary principles of naval architecture, solid mechanics, and dynamics while minimizing risks within the framework of the SEA LANCE concept of operations.

The risks inherent to the semi-rigid towing system are formidable. First, there are significant historical and traditional prejudices against a warship that doubles as a tugboat. Existing towing rigs are dangerous and hamper the progress of battle groups. For the SEA LANCE to achieve the requirements presented in chapter II, a radical tow-rig had to be developed. Such a radical design is risky because it has to be technically feasible, must meet the ORD requirements, and must do so in a cost-effective manner. The operational guidelines included close-proximity tow operations into sea state 4, with extended towing operations to sea state 6. Close-proximity towing operations utilizing a trailer concept have not been validated, so there was an enormous amount of risk in not only the tow-rig, but in the environmental conditions in which it operates.

The design process utilized in the tow-analysis was the traditional systems engineering model, wherein a divergence to collect data was followed by a convergence to a possible solution. First, a search of historical documentation on towing systems and the integrated tow in particular was performed. Very little research has been done with respect to an integrated tow. Existing data on such systems was limited to concept drawings and strip theory analysis[23]. Next, a conceptual architecture was developed that framed the problem and sources of stress. Mechanical limitations such as shear and axial yield stress, as well as Euler buckling were considered in the sizing of the tow-system components. These mechanical limitations were married with the geometric limitations inherent to a close proximity tow, and a design spiral performed between the two to arrive upon a proposed close-proximity tow architecture.

Although little documentation on integrated tow systems was available, an appreciable amount of background data was assembled to accomplish the architectural analysis. Concept drawings of SWATH hull integrated tow system proposals were available from Lockheed-Martin, and were redesigned to accommodate wave-piercing catamaran geometry and simplify mating. Hull form resistance data gathered as described in chapter (IV.A) was utilized to evaluate forces on the towbar. Seaway modeling software SHIPMO[24] was linked with MATLAB™ files[25] to measure the forces on the towbar due to sea state. Winch characteristics and costs were provided from commercial manufacturer specifications[26]. Mechanical properties and analytic relationships for

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[23] Prof. Fotis Papoulias, Lockheed-Martin SLICE design project.

[24] Robert F. Beck, Armin W. Troesch, SHIPMO ship motions program, 1989

[25] Prof. Fotis Papoulias, strip theory modeling M-files.

[26] Wintech, International, Inc., www.wintech.com

stress analysis were gathered from *Mechanics of Material*[27]*s*, utilizing handling equipment standard safety factors.

Standard rigid body motion is limited to six degrees of freedom as shown in an illustration of the concept architecture provided as figure (H.1). Forces on the towing mechanism arise as a result of constraining theses degrees of freedom between the combatant and GDM. The most severe motions in a seaway are expected to be in the form of roll, pitch and yaw. To minimize handling equipment size these severe motions are unconstrained between the combatant and GDM. Yaw is constrained at the bow of the GDM only by "moment cables" that prevent GDM jackknifing. Surge is constrained by the towbar, while sway is limited by the directional stability of the catamaran and installation of constant tension winches at outer corners of GDM bow. Heave forces are minimized by hinges that provide for pitch at both the GDM bow and combatant stern, as well as by lengthening of the towbar. Roll is decoupled between the GDM and combatant by a "roll bearing" at the stern of the combatant that also provides a thrust bearing for surge forces on the combatant (fig H.2), (fig H.3).

Geometric separation of the combatant and GDM was necessary for several reasons. First, the bar must be long enough to provide clearance in the sea states outlined in Chapter II. Shipway motions modeled using

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[27] Bedford, Liechti, Prentice Hall, 2000.

strip theory at design operating speed yielded 30° as the largest expected pitch angle. Using this maximum angle, towbar length was iterated to ensure physical clearance between the combatant and GDM. AUTOCAD™ drawings were used extensively in this analysis. The requirement to keep the hull lines similar for cost purposes resulted in a longer towbar than would have been necessary if the GDM bow lines were altered. A similar iteration was performed to determine the maximum turn (yaw) angle. The maximum allowed yaw by geometry is 85°, but yaw is limited to smaller angles due to excessive forces on moment cables. The towbar is a box beam with 12" side length to house fuel and power umbilical. The thickness of the shell is determined from stress analysis.

As mentioned earlier, forces on the tow are due to the constraint of degrees of freedom between the combatant and GDM. The assumed forces include: forces from seaway, impulse force to stop in one ship length, hydrodynamic resistance, and bending moments due to maneuver. Each of these forces and moments results in a stress on the tow system. Three structural limitations are considered. Euler buckling, tensile yield stress, and shear yield stress. A brief description of the engineering method used to find the limiting stresses follow. A spreadsheet analysis was performed in each case and is included as fig. (H.4).

a. Seaway forces are derived from strip theory for a given towbar length. The primary force of concern for a catamaran is the vertical force applied to the towbar both in compression and tension.

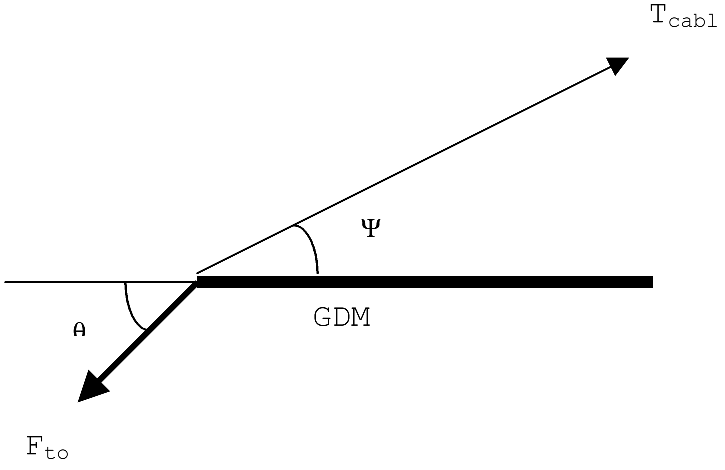
$$F_{bar} = F_{vert}\sin(30^{o}) = 111{,}957lbf \;::::\; F_{vert} = 224{,}000lbf$$

b. Impulse force to stop in one ship length is derived from stopping 450 LT GDM from 15kts in 167ft with hydrodynamic forces neglected. This force is a compressive force to be used in buckling calculations only.

$$F\partial t = M\partial v \;::::::::\rightarrow\; F_{stop} = 62{,}309lbf$$

c. The maximum towing resistance is at 5 kts per chapter IV, determined from hydrodynamic resistance curves is F_{tow}=108,000lbf.

d. The bending moment is derived from the aerial view free body diagram below, where θ=yaw, F_{tow} is described above, and T_{cable} is the tension in the moment cables.



Using the forces described in (1-4) above, a stress analysis was performed for each limiting case (euler buckling, yield stress, shear yield stress) to determine the thickness of the box beam. Based on all considerations, the box beam should be 2/3" thick. Because the box beam side length was chosen as 12 inches, the moment of inertia is relatively large and the beam relatively stiff. This leads to the surprising conclusion that the thickness of the box beam is determined by yield stress, rather than buckling, even though the compressive and tensile stresses are of the same order of magnitude and the beam is fairly long and slender. The solution is outlined below, with iterative calculations performed in figure (H.4).

$$F_{comp}(safetyfactor) = \frac{\pi^2 EI}{Le^2}$$

Esteel=29,000 psi

Le = L = 20ft

Safety factor = 5

a. Solve the buckling equation for box beam thickness using the maximum compression force,

$$F_{bar} = F_{vert}\sin(30^o) = 111{,}957lbf$$

$$I = \frac{1}{12}(s_o{}^4 - s_i{}^4)$$

Thickness = 1/5"

b. Now look again at the free body diagram on the previous page. Two towing mechanisms must be sized based on the maximum hydrodynamic force. As the yaw angle increases greater than ψ, the compressive stress in the towbar increases. Also, for angles less than ψ, the tension in the towbar rises until Ftowbar = Ftow = 108,000lbf. However, the maximum tension in the towbar arises from the vertical force due to seakeeping, Ftowbar = 111,957lbf. This is the force that dictates the box beam thickness via the following yield stress equations:

$$F(safetyfactor) = \sigma_y A$$
$$\sigma_y = 36{,}000 psi$$

Thickness = 2/3"

c. The tension in the moment cables is determined using the same systems of equations used to find the forces in the towbar from the free body diagram above. The wire ropes were chosen as 1 ¾" diameter. From *Mark's Mechanical Engineering Handbook*[28], these ropes have a 114-ton yield. As a result of this limitation, the yaw is operationally limited to 44 degrees.

A look at the tow system, fig (H.2) shows three hinge pins that are sized based on shear stress, with the maximum forces calculated above and factors of

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[28] Mark's Handbook , McGraw-Hill, 1979

safety used throughout. The required pin diameter is calculated on fig (H.4) as shown below:

$$\tau_y = 0.5\sigma_y$$
$$F(safetyfactor) = 2\tau_y A$$

Pin diameter = 4 ½"

Separation and maneuvering geometry were closely linked with towbar forces. A spiral between varying towbar length for maneuvering reasons and varying towbar thickness for stress reasons dictated the final sizing of the towbar and cables. A summary of the integrated tow system parameters follows:

Towbar length	20 ft	Hinge pin diameter	4 ½ "
Towbar thickness	2/3 "	Maximum pitch angle	30°
Moment cable diameter	1 ¾ "	Maximum yaw angle	44°
Constant tension cable diameter	1 ¼ "	Towbar side length	12 "

The integrated close proximity tow is designed for operation in environmental conditions up to sea state 4. Initial hitching is done in port, and the rig consists of the solid towbar and integrated moment cables, as well as two constant tension winches mounted on the forward corners of the GDM. These lines pass to cleats in similar location on the stern of the combatant. The constant tension winches are 10 Hp electric winches with 100 feet of cable installed. Each constant tension winch has a stall load of 33,000 lbf. In the event that sea conditions increase above sea state 4, control signals are sent to the winches that slack them and allow for detaching the lines and placing on hooks on the front end of the towbar. Next, the towbar-retaining pin is released from its claw-like holding clamps on the tow bearing. A wire connected to the pin pays out 1 ¾ " cable from a winch mounted in the towing space behind the tow bearing. The winch line is paid out to 100 yards by the winch for extended tow operations. The line pays out through a hole cut through the center of the tow bearing. When conditions improve, the combatant slows and the winch hauls in the tow. Because the extended towline is connected to the head of the towbar, the towbar is pulled back into its "hitching position" by the towline. Guide rails on the tow bearing and the 20° slope of the combatant stern ensure positive hitching. Once the GDM is "hitched", the constant tension lines are retrieved and engaged to their towing cleats.

2. Grid Deployment Module (GDM) and Deployment

The GDM was designed to provide maximum flexibility in both payload and mission. The GDM is capable of operations without the combatant. It has a generator that is rate at 150 KVA. This will be sufficient to operate the communications and electronics suite contained onboard the vessel. It was outfitted with phased array communications antennas along both sides of the hull to communicate with the combatant as well as to simulate emitters for a deception mission. The decoy launchers can serve in the deception mission, by significantly increasing the radar cross section of the GDM.

The hulls on both sides were designed as tank groups to maximize the logistic utility of the craft in the event that it was needed to provide tankage to other CNAN units or to some other asset operating in the region. The large deck area and good stability of the platform make it a good choice for a “lily pad” or staging point for SOF units, UAV’s, VSTOL UAV’s, etc. The payload modules were arranged over the center hull form to provide maximum flexibility of payload and ease of deployment. It is envisioned that small boats, fuel bladders, stores, SOF units, UUV, USV and numerous other packages could be deployed through the large center hull.

Designing the mechanism for grid deployment depends on the units being deployed. The design group was given a list of grid components which can be found in appendix a. From the list, the surface to air missile, the largest of all the components with a length of 21 feet, was selected to size the largest module. The smaller grid components also had to be considered to ensure they would fit into the smaller modules. This limited the length of the module. The GDM was also considered in deciding module size. The grid units were to be dropped down between the hulls to take advantage of the hulls masking grid deployment in a covert operation. This limited the width and height of the module.

Two different size modules were chosen to keep the design simple. The large or full module measures 22 feet long, 18 feet wide and 9 feet high. The small or half module measures 11 feet long, 18 feet wide and 9 feet high. The arrangement of the modules in the GDM can be seen in figure (1) as the large shaded areas on the main deck of the GDM. The larger areas are capable of carrying one full or two half modules, the small area can only carry one small module. Altogether, the GDM may carry nine half modules or any combination up to one half and four full modules.

To minimize the complexity, gravity is fully utilized in the design. Vertical rails are mounted on the fore and aft bulkheads of the module. The rails are adjusted to port or starboard to accommodate the varying size grid units. The larger grid units that extend the entire length of the module have guides affixed to the ends of their canisters. When loaded into the module, the guide slides on the rail and an electro-mechanical locking device holds it in place. Upon deployment, doors on the bottom of the module open, the electro-mechanical locking device releases and the grid unit slides down the rails into the water. Smaller grid units will be loaded into a receptacle that extends the full length of the module and mounts on the rail. Upon deployment, the grid unit will be released from the receptacle and dropped into the water. The receptacle will be reutilized once back at a reloading facility.

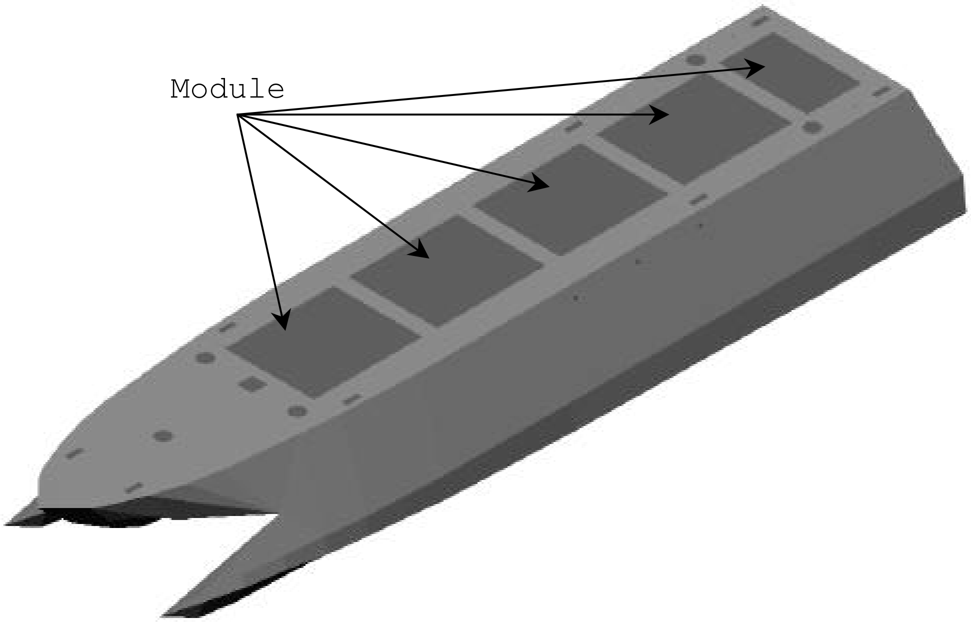

Figure 1

No rearranging after the SEA LANCE was deployed was allowed in the design due to the fact that volume was not a concern. The GDM's as a whole can carry all the necessary grid units for the mission but an individual GDM is weight limited to 190 long tons of payload and could not carry all of its modules fully loaded. Each GDM's grid units are well dispersed throughout the modules so whichever grid unit was needed may be deployed at any time. A typical half module loading is displayed in figure (2).

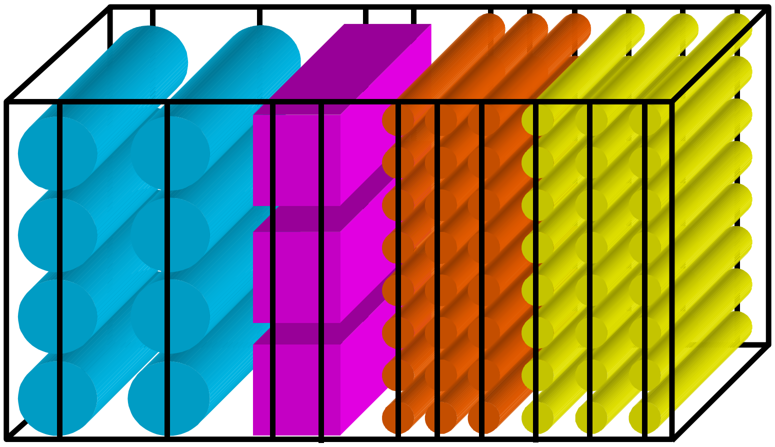

Figure 2

The breakdown of the grid elements is located in Table (1). The table lists the item, its size, which module type it will be carried in, quantity and weight of a module fully loaded with that item. Some grid elements have notional dimensions compared to today's components due to advancements in technology effecting component size. In all likely hood, the modules will be loaded out with numerous grid units per module and will be well below the 144 long ton equivalent of two fully loaded NTACM half modules.

Item	Individual Size	Module Type	Units per module	Weight of full module
CM Pickett	1' x 20'	Full	128	64
Tomahawk	2' x 20'	Full	32	60.8
SM3	2' x 21'	Full	32	64
Torpedo	4' x 4' x 20'	Full	8	80
RSTA	4' x 5' x 20'	Full	6	73.8
Harpoon	2' x 10'	Half	32	40.6
NTACM	2' x 10'	Half	32	72
FSAM	.5' x 10'	Half	288	21
LFAS	2' x 10'	Half	32	32
DADS	.4' x 3'	Half	864	43.2
TAMDA	.4' x 3'	Half	864	43.2
Air mines	1' x 1.5' x 3'	Half	240	60

Table 2

The modules themselves were only designed for deploying the grid components. Many other functions of the module were discussed amongst the design group and numerous outside contacts. One such suggestion is to load out the GDM with vertically launched GPS or laser-guided munitions. It could be towed close into the coast in support of NSFS during an amphibious landing. Many other suggestions were talked about and the module could be designed for just about anything as long as it could fit into the GDM. The main issue was to deliver the grid components and the GDM with the above-described modules accomplish the task.

3. Miscellaneous Auxiliaries

a. Damage Control

SEA LANCE is not expected to recover from significant damage such as an anti-ship missile hit; however, it must have an adequate Damage Control System to maximize the chances of crew survival and prevent loss of the ship due to a shipboard casualty. Therefore, SEA LANCE requires a highly automated, reflexive, low-impact, austere yet effective Damage Control System to handle casualties.

SEA LANCE will have the following Damage Control Systems or capabilities:

i. Multi-function consoles integrated with the Ship Wide Area Network (SWAN) that control the Damage Control System

ii. Firemain System

iii. AFFF Bilge Sprinkling System

iv. FM-200 Space Flooding System

v. Magazine Sprinkling System

vi. Chemical, Biological, and Radiological (CBR) Protection

vii. Main Drainage System

Analysis of damage control systems selected is contained in Appendix I.

Only the crew complex, mess deck, and Control Center will be manned underway. All engineering spaces will normally be unmanned. All damage control functions will be controllable from the multi-function consoles located in the Control Center space and at other multi-function consoles on the ship. The Damage Control System can be manipulated by manual, remote and automated methods and will be fully integrated with advanced sensors, fire suppression systems and that Ship Wide Area Network (SWAN). Standard automated damage control response actions based on specific sensor indications for different scenarios will be programmed into the system. This capability makes damage control more efficient, allows the crewmember to perform other duties and does not expose the crewmember to adverse risk. The Office of Naval Research is presently developing conceptual architectures, integrated sensors, smart component technologies and control algorithms to support automatic damage control operations.[29]

SEA LANCE will have a simple, reflexive distributed firemain system with smart technology that will serve the following purposes:

viii. Provide firefighting water to fire plugs.

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[29] http://www.chemistry.nrl.navy.mil/dcarm/

ix. Provide seawater for magazine sprinkling system.

x. Provide seawater to AFFF bilge sprinkling system.

xi. Provide seawater cooling for auxiliary systems.

xii. Provide seawater for eductor system.

In the event of a major fuel oil leak, AFFF is an ideal substance to cover the fire hazard. A single AFFF station integrated with the Damage Control System will provide services for the following spaces:

xiii. Port and Starboard Main Engine Room Bilge Sprinkling System.

xiv. Port and Starboard Auxiliary Machinery Space Bilge Sprinkling System.

xv. Auxiliary Diesel Generator Room.

xvi. Vertical Replenishment Flight Deck Sprinkling System.

As a replacement for Halon 1301, primary and reserve FM-200 Fire protection systems fully integrated with the Damage Control system will be installed in the following spaces:

xvii. Port and Starboard Main Engine Room

xviii. Port and Starboard Auxiliary Machinery Space

xix. Auxiliary Diesel Generator Room.

In the event of significant combat damage to a magazine, the magazine sprinkling system will extinguish the fire or temporarily control the fire to allow the crew time to abandon ship. If a magazine fire occurs in port, the magazine sprinkling system will extinguish the fire or temporarily control the fire to allow a shore based fire team time to extinguish the fire and save the ship.

SEA LANCE will be capable of operating within a Chemical, Biological, and Radiological (CBR) environment. As discussed earlier, only the crew complex, mess deck, Computer/Electronics Room and Control Center will be manned underway. A Collective Protection System (CPS) will protect these areas.[30] The CPS provides pressurized, filtered air to a full-time CBR protected zone. The CPS is an integral part of the heating, ventilation and air conditioning system. This zone enables the ship to operate in a CBR contaminated environment. While in the CPS zone, the crew is not required to don protective clothing. The CPS is currently being installed on LPD-17. Figure 1 is a depiction of the Collective Protection System.

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[30] http://www.chembiodef.navy.mil/c_a_index.htm

To assist in contamination avoidance, the SEA LANCE will employ the Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD).[31] JSLSCAD is a small, fully automatic, passive infrared, standoff chemical agent detector that is capable of mobile, real-time detection. JSLSCAD detects and provides chemical identification of nerve and blister chemical agent clouds up to five kilometers away. Figure 2 is a depiction of the Joint Service Lightweight Standoff Chemical Agent Detector.

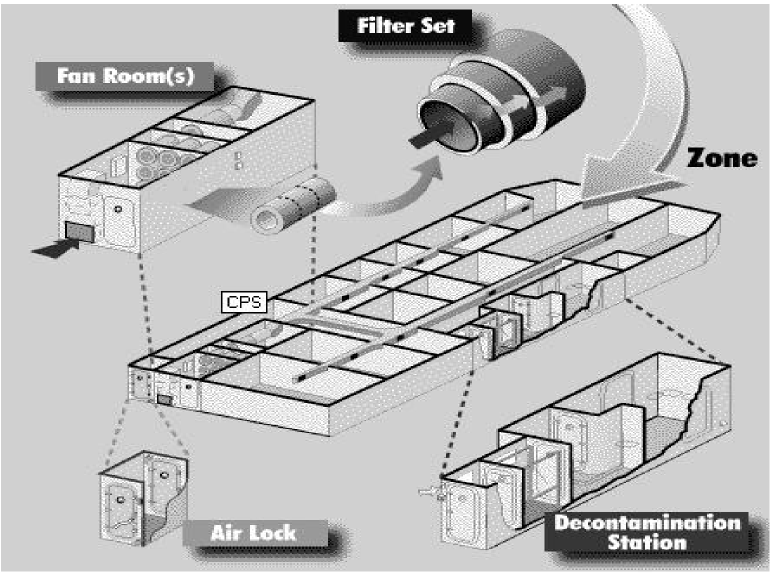

Figure 1. Collective Protection System (CPS).

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[31] http://www.chembiodef.navy.mil/c_a_index.htm

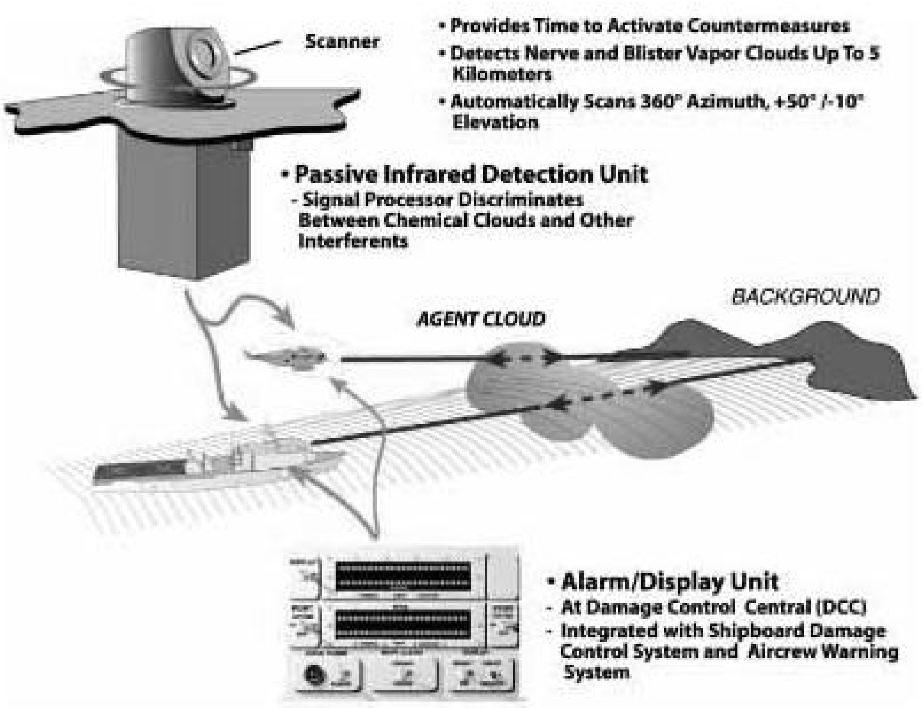

Figure 2. The Joint Service Lightweight Standoff Chemical Agent Detector.

Additionally the SEA LANCE will be equipped with the Improved Point Detection System (IPIDS).[32] IPDS is an Ion Mobility Spectroscopy detection system that detects nerve and blister agent vapors at low concentrations. Figure 3 is a depiction of the Improved Point Detection System.

The Collective Protection System along with the Joint Service Lightweight Standoff Chemical Agent Detector and Improved Point Detection System will be integrated with the Ship Wide Area Network and will be controlled through multi-function consoles.

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[32] http://www.chembiodef.navy.mil/c_a_index.htm

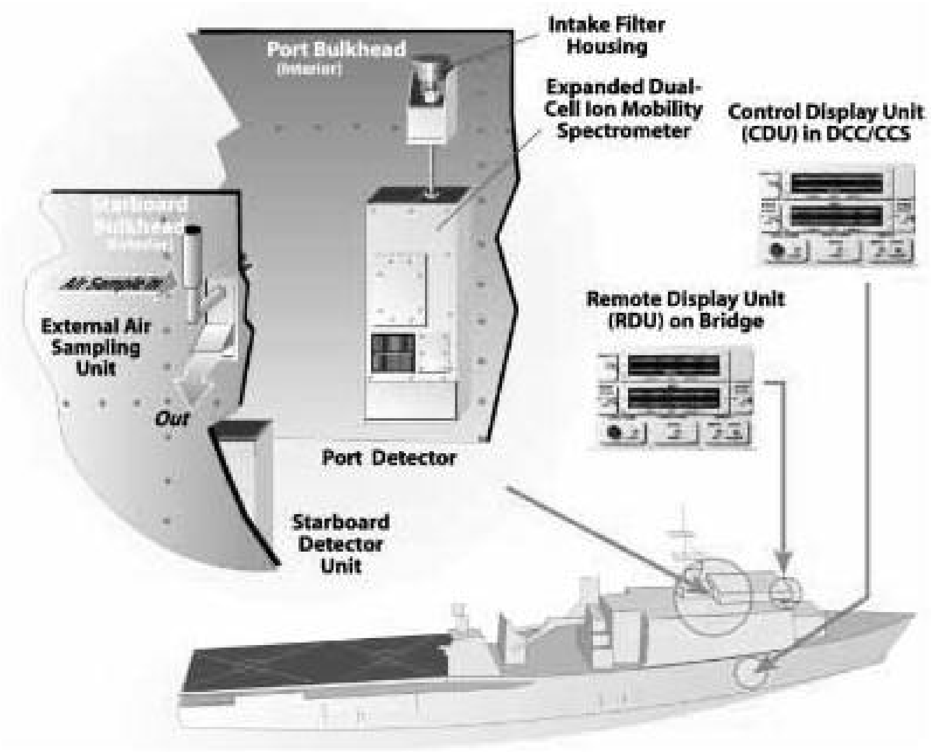

Figure 3. Improved Point Detection System (IPIDS).

b. SEA LANCE Crew Egress

SEA LANCE is not expected to recover from an anti-ship missile hit; therefore, crew egress and survival is critical design issue.

Several crew egress concepts were explored in this study. The basic concepts are listed below:

i. A collective escape “pod” containing all crewmembers at their watch stations that is “ejected” overboard.

ii. Individual escape “pod” for each crewmember that is “ejected” overboard.

iii. A free fall lifeboat that is dropped overboard.

iv. A Rigid Hull Inflatable Boat (RHIB) that is lowered over the side.

v. The present life raft used by the U. S. Navy.

Of these concepts, SEA LANCE will employ two methods of egress, a RHIB and rubber life rafts. The RHIB will be the primary method of egress with two 25-person life rafts as backup options. The RHIB was selected as the primary method of egress because it has the capacity to carry the entire crew and it has the mobility to reach safety expeditiously. In the event that the RHIB sustains battle damage or the crew is unable to reach the boat deck, two 25-person life rafts located port and starboard of the Control Center will be used. Analysis of each of the concepts is contained in Appendix I.

c. Environmental Compliance

SEA LANCE is required to meet or exceed all anticipated International Convention for the Prevention of Pollution from Ships (MARPOL) and Uniform National Discharge Standards (UNDS), in other words, zero discharge of shipboard wastes. This requirement is extremely challenging for a small combatant.

Table 1 shows the current waste generation rate in pounds per person day for a surface ship and submarine.[33]

	Surface Ship	Submarine
Paper	1.1	0.3
Metal	0.5	0.2
Glass	0.1	0
Plastic	0.2	0.1
Food	1.2	
Black Water	25-125	
Grey Water	210	
Laundry	40	

Table 1. Current waste generation rate lb/person/day.

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[33] Committee on Shipboard Pollution Control, “Shipboard Pollution Control U.S. Navy compliance with MARPOL Annex V” National Academy Press, 1996

Three general waste streams were addressed in the SEA LANCE conceptual design:

i. Solid waste (Paper, plastic, glass and metal)

ii. Non-oily liquid waste (Grey and black water)

iii. Oily waste

Analysis of shipboard waste management technologies is contained in Appendix I.

All solid waste will be retained onboard for off-load to a shore facility or MSC ship during replenishment. As seen in Table 1, solid waste generation is very limited on a submarine. The same solid waste management techniques such as minimization of the on load of paper and plastic products onboard through Waste Reduction Afloat Protects the Sea (WRAPS) and Plastics removal in Marine Environment (PRIME) programs must be employed on SEA LANCE. Solid waste generation in the Galley will be further reduced through the use of pre-prepared or Advanced Foods.[34] Unused food will be pulped in a garbage disposal and discharged to the Greywater/Blackwater Treatment System. Metal waste products will be minimal and retained onboard for disposal ashore or to an MSC ship. The crew will operate in a near paperless work environment. A small trash compactor will be

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[34] LOGICON, NAVSUP "Advance Foods Study Onboard USS McFaul", Naval Supply Systems Command, 1999.

installed onboard to compact solid wastes such as paper and plastic products for short-term storage in a sanitary storeroom and future off-load in port or to an MSC ship during replenishment. This method of solid waste management negates the need for a plastic waste processor, metal/glass shredder and pulper.

In order to meet the zero discharge requirements, all greywater and blackwater will be treated by a combined greywater/blackwater treatment system that uses biotreatment in conjunction with microfiltration to treat the liquid waste. The effluent will meet the following standards:

iv. Total Suspended Solids (TSS) <100 mg/ml

v. Fecal Coliform (FC) < 200/100 ml

vi. Biochemical Oxygen Demand (BOD) < 50 mg/l

Appendix I contains a detailed description of the treatment system.

SEA LANCE will process oily waste with a Combined Oily Waste Membrane System. The Navy Integrate Membrane System (NIMS) will produce an effluent less than 15-PPM oil. All bilge water will be processed through the oily waste system. Appendix I contains a description of the Navy Integrated Membrane System.

F. Habitability and Human Factors

1. Habitability

All crew needs are met with the SEA LANCE habitability space. The accommodations on the ship are adequate but comfortable.

The SEA LANCE normal crew size is 13 personnel. The ship's berthing space can berth a maximum of 21 personnel. Berthing arrangements were design for a mixed gender crew with a maximum of six berth designated for minority gender. Figure 1 depicts the deck plan for the habitability space. The habitability space is within the Chemical, Biological and Radiological (CBR) Collective Protection System (CPS).

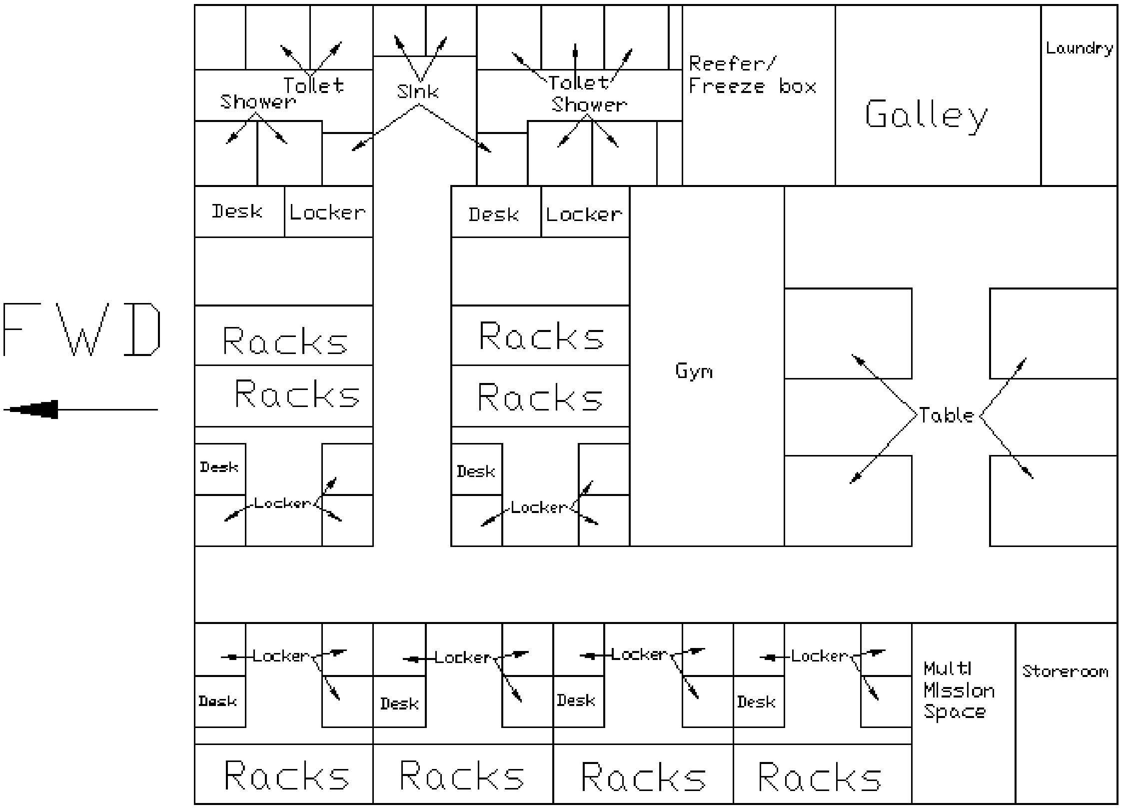

Figure 1

The dimensions of each stateroom are 7 ft x 7 ft x 8 ft. There are six 3-person enlisted staterooms, one 2-person officer stateroom and a stateroom for the Commanding Officer. Each stateroom is accessed through a sliding door to maximize useful space. The enlisted staterooms have one 3-person lightweight modular berth, three standup lockers and one desk. The 2-person officer stateroom has a 2-person modular berth one desk and large partitioned standup locker. The Commanding Officer's stateroom has a single berth, desk and standup locker.

There is a male and female head located on the starboard side of the ship. The male head has three toilets, two showers and one sink. The female head has two toilets, two showers and one sink. Note that in the event that there are more women than men on board, the heads can be swapped. All toilets are low flow fresh flush toilets service by a Vacuum Collection Transfer and Holding (VCHT) system. There is also a common wash area with two sinks located at the entrance of the male and female head. These facilities exceed General Specification requirements which require one shower for every 10 officers and one toilet for every 8 officers.[35] Dimensions for toilets, sinks and showers are located in Table 1.

	Length (in)	Width (in)
Toilet	30	30
Sink	24	24
Shower	30	30

Table 1.

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[35] Naval Sea Systems Command, "General Specifications for Ships of the United States Navy", Naval Sea Systems Command, 1985.

The crew will prepare their own meals in the galley. The galley will be equipped with a Hatchable Combination Convection Oven-Steamer and a microwave oven. All food will be pre-prepared or will include the new Advanced Foods being developed by the Naval Supply Command.[36] The galley will also have a deep sink, a durable dishwasher, and a small beverage bar. All excess food will be disposed of through a garbage disposal and sent to the Greywater/Blackwater Treatment System for processing. Next to the Galley is the refrigerator and freeze box. A dry goods storeroom is located on the starboard side of the mess deck. The mess deck will have four 4-person tables and will also act as a crew lounge.

In addition to cooking their own meals, the crew will also clean their own laundry in the laundry room. The laundry room will contain a durable commercial stackable washer and dryer set.

Since the crew does not normally have access to the weather deck while underway, there is a small gym next to the mess deck for the crew to exercise in.

The SEA LANCE is expected to embarked special teams, such as a SEAL unit, therefore a secure multi-mission space is available for temporary storage of classified material and equipment.

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[36] LOGICON, NAVSUP "Advance Foods Study Onboard USS McFaul", Naval Supply Systems Command, 1999.

Other factors that affected the layout of the habitability space include:

a. Ambient noise mitigation. Berthing is located forward on the ship to minimize noise from the propulsion engines. Additionally, the crew is closer to their watchstations.

b. The galley and mess decks are located aft on the ship close the vertical replenishment deck to shorten the distance that stores must be moved during strike down.

c. All spaces that require water are located on the starboard side to assist the drainage to the Greywater/Blackwater Treatment System located in the starboard hull. The reverse osmosis unit is located in the port hull and freshwater is sent to the starboard side of the ship.

d. Berthing was arranged in staterooms to ensure flexibility in the crew gender makeup.

2. Crew

The SEA LANCE crew will be specially trained to operate the SEA LANCE Combatant. In order to manage the problem of ship upkeep, operating the Combatant is all the crew will be asked to do. We propose an “aircraft paradigm” for SEA LANCE Combatants where the crew operates the vessel while underway, but in port the SEA LANCE shore team maintains the ship just as the maintenance team does for aircraft.

The SEA LANCE will require a new rate that we have dubbed “SeaLanceman.” Every SeaLanceman stands watches and performs duties of Normal and Special Ops and becomes expert in their specialty. SeaLanceman should be a special branch applied for by junior enlisted of other rates in a manner similar to SEALs. The source rate of each applicant can determine his or her SeaLanceman specialty. SeaLancemen will specialize in operations, engineering, or combat systems. These skills are desired so that the crew will be capable of a high level of “first aid” response and repair while underway.

Since SEA LANCEs are organized in squadrons, each squadron will have a staff composed of a CO, Operations Officer, Supply Officer, Repair Officer, and a senior enlisted advisor. A Squadron Master Chief SeaLanceman is selected from senior Sealancemen. Senior Sealancemen not selected for Squadron duty will become members of the SEA LANCE system support force or other duties within the Navy.

We envision a 13-member crew as follows.

Commanding Officer

Division Officers

Combat Systems Officer
Operations Officer

Operations (and Engineering)

1 QuarterMaster/Signalman
2 Diesel Mechanics
1 Electrician
1 Auxiliary Technician

Combat Systems

2 Electronics Technicians
3 Weaponeers

The breakout of the individual “ratings” indicates the specialized advanced “C” schools or NEC’s that will be required on each of the SEA LANCE’s. Not every “SEA LANCEman” will be required to hold each NEC or attend every “C” school. The CO will be a lieutenant or lieutenant commander. His Division Leaders will be second tour line officers or warrant/Limited Duty Officers. The other ten will be SeaLancemen specialists.

The unique nature of this vessel calls for an examination of tradition officer and enlisted personnel. The officer to enlisted ratio might need to be inverted with more officers than enlisted. Does the traditional structure make sense given the intense level of responsibility on even junior members of a SEA LANCE crew? These decisions are beyond the scope of the TSSE project but will have to be answered if the SEA LANCE concept is developed further.

We conducted an analysis of possible watchstation duties that our 13-person crew using four consoles might fulfill.

Watchstation duties

4 Person team (crew of 13)

Combat/Battle stations

TAO	Engagement decisions Communications
AAW	Air picture
ASUW	Surf/sub-surf picture
OOD	Ship Navigation/Safety

Grid deployment

TAO	Engagement decisions Communications Surf/sub-surf picture
AAW	Air picture
OOD	Ship Navigation/Safety Grid Field management/verification
GDS	Grid Deployment Supervisor

Peacetime Steaming

OOD	Ship Navigation/Safety
AAW	Air/Surf/Sub picture Communications

The TSSE team also examined the feasibility of the 13-person crew performing normal and special operations.

Normal Ops

UnRep

TAO	Engagement decisions Communications Air picture Surf/sub-surf picture
ENG	Plant management/Pump monitoring
OOD	Ship Navigation/Safety
Rig Team	Rig Captain and 3 members

VertRep

TAO	Engagement decisions Communications Air picture/Surf/sub-surf picture
OOD	Ship Navigation/Safety

Flight Control Officer	Flight safety/Helo control
Stores Handlers	Team Captain & 5 members

<u>GDM Connection</u>

TAO	Engagement decisions Communications Air picture Surf/sub-surf picture
OOD	Ship Navigation/Safety
ENG	Supervise connection team
Connection Team	5 members to effect connection

(GDM disconnection is an automatic process initiated and controlled from the bridge.)

Navigation Detail

OOD	Ship control
NAV	Navigation/Safety
Bearing Takers	

Mooring/Anchoring Detail

OOD	Ship control
NAV	Navigation/Safety
Line/ Anchor Handling	7 member team

Special Ops

a. Protection of anchorages/MODLOCs

No special requirements.

b. Harbor and restricted waters blockade

No special requirements.

c. Theater Ballistic Missile Defense (TBMD)

TBMD planner (if required) uses extra console

d. Area Mine mapping operations

Mine Mapper (if required) uses extra console

e. Escort for amphibious and logistic forces

No special requirements.

f. Strike warfare

Strike planner (if required) uses extra console

g. Shallow water ASW

No special requirements.

h. Maritime Interdiction Operations (MIO)

Boarding Party Team Leader (a Division Officer)

i. Boarding Party Team (5 junior SeaLancemen)

Sniper Team (Spotter & Shooter)

j. Non-combatant Evacuation Operations (NEO)

4 person Welcome Party

k. (Expect to house non-coms in GDM people module. Welcome Party supervises all non-coms 100% of the time)

l. SOF insertion/extraction

4 person Boat Launch crew

(Expect SEALs primarily to launch boat. SEA LANCE personnel to assist as required. SEALs and vessel housed either in/on GDM or on aft center hull.)

m. Independent operations (showing the flag)

No special requirements.

n. Strategic deception operations

6 member crew (if required) to launch/manage decoys

Considering all the operations that a SEA LANCE crew might be required to perform, the TSSE team believes that a 13-person crew can meet the requirements.

3. Technology Advancements/Automation

The SEA LANCE Combatant will make maximum use of automation to alleviate the stress applied to the crew. Some areas of possible automation were explored:

	Area	Agent
a.	Processing MSG traffic	auto
b.	Navigation	auto
c.	Monitoring/Control Own ship	auto
d.	Electronic Warfare	auto
e.	Strike planning	auto/off ship
f.	Damage Control	auto & manual
g.	Comms circuit set-up	auto
h.	Line handling	manual
i.	GDM hook up	manual
j.	GDM disconnect	auto
k.	Hotel service connect/disconnect	manual
l.	Onload stores	manual/off ship
m.	Refueling	manual
n.	Cleaning Interior/Exterior	off ship
o.	Laundry	manual
p.	Mail	off ship
q.	Admin	off ship
r.	Maintenance	off ship
s.	Training	auto
t.	Grid component deployment	auto
u.	Grid component tending	manual
v.	Module swap out	manual/off ship
w.	Mechanical/Electric repair (First Aid)	manual
x.	Mech/Elec repair (minor-major)	off ship
y.	Food prep	manual(pre-made)

z.	Ammo handling	manual/off ship
aa.	Detect, track targets	auto
bb.	Classify, engage targets	auto & manual
cc.	MIO boarding	manual
dd.	NEO Op	manual
ee.	SOF Insertion	manual
ff.	CBR protection/recovery	auto & manual

Other methods of reducing crew tasks can be employed. All underway inspect and test requirements for equipment can be automated and facilitated by the Ship LAN. Failed parts can be automatically ordered from shore when detected as failed or indicating immanent failure. Appropriate initiatives from the "Smart Ship" program should be incorporated such as reduced pilothouse manning, automated Division Officer's notebook, and core-flex watchbill to allow for manning reduction[37]. The DD-21 program is expected to use new concepts and technologies to facilitate reducing the crew of a 10,000+ LT ship to just 95 people. Due to the stage of contract competition in the DD-21 program, information on enabling crew reduction was unavailable for this report. If further development of the SEA LANCE design continues, we can expect DD-21 information to be releasable by mid 2001.

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[37] Smartship Program Information Brief

G. Total Ship Evaluations

1. Cost Analysis

The weight and cost estimations included in Appendix J are based on existing designs that were scaled based on full load displacement and then adjusted based on mission, hull form, material, and technological variations. The payload fractions for the combatant and GDM are 35% (*11% without fuel*) and 67% respectively. If the 450-ton displacement goal was considered as a hard limit, these required payload fractions would only permit design weight margins of 6.5% for both the combatant and the GDM, which is significantly below the desired 10-15% margin for a new design. For purposes of this design study, these smaller design margins were accepted, partially due to extensive use of commercial of the shelf technology (COTS) equipments for which weights are accurately known and partially due to the limited resources available to further refine our weight estimates in the time allowed. However, the alternative of increasing the weight margin to the 10-15% level reflective of the risk inherent in a new design concept such as SEA LANCE would add between 16 and 38 tons to the total displacement, or raising it to between 466 and 488 tons. This higher displacement value is considered an appropriate starting point for subsequent design iterations.

The hull weights and cost were validated using estimates of car carrying fast ferry designs[38]. A commercial hull of this size would cost approximately $3.8 million. If you remove the special structures required for

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[38] Mr. Kim Gillis, Manager Military Projects, Austal Ships

items such as the telescoping mast and missile blast abetment, the Group 100 cost of our design is approximately $4.5 million for the first combatant and $3.6 million for the first GDM. The total price of $6.5 million for the fast ferry is only 10% of the total cost of our design for obvious reasons. Full weight/cost breakdowns are included in Appendix J.

The weights and costs of the propulsion, electrical, combat, weapon, and C4I systems were modified as based on information outlined in Chapter IV. The final cost of our design was verified against that of the FLYVEFISKEN CLASS (Standard Flex 300) as outlined in Chapter 3. The final price of $64.7 million for the first combatant and $19.1 million for the first GDM were accepted as reasonable and the total cost per pair was under $100 million as required in Chapter 2.

The learning curve used to predict the cost of future units was applied only to the labor due to the extensive use of COTS technology and a largely commercial platform design. The curve was set slightly higher than normal (95%) due the relative inexperience of our shipyards with respect to this hull form. There is also expected savings due to the essentially identical hull forms used for the combatant and GDM.

NSWC Carderock conducted scale model construction tests whose results were published in 1997[39]. These results suggest that not only is a composite hull of this size

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[39] PROFESSIONAL BOAT BUILDER, Aug/Sep 1997, “Competing Composites”, by Paul Lazarus

feasible, but that it could be cost-competitive and result in a weight savings of 30% over an aluminum hull. An attempt was made to estimate the equivalent composite weight of our aluminum structure. The volume of material used was a 6″ shell around the outer hull of our design. Based on this volume and the density derived from the Carderock data, it was found that the equivalent composite structure would weigh more. This calculation also showed an order of magnitude increase in the safety factor. These factors combined affirmed the requirement to do completely separate structural analysis of a composite design.

In order to estimate the possible impact of using a composite hull form, the cost data was used from the Carderock study[40] and the 30% fractional weight savings was applied without supporting structural analysis. Applying the fractional savings to only the base aluminum hull described above and still included the steel reinforcements for towing and the additional weight of superstructure and mast, you reduce the light ship weight by 30 LT. If all other design factors were held constant, that would allow for a margin of over 20% on the combatant and 34% on the GDM. Composite construction also increases the payload fraction of the combatant to 37% (*11% without fuel*) on the combatant and 72% on the GDM. A modified weight/cost breakdown for a composite SEA LANCE pair and the supporting cost data are included in Appendix J.

It should also be noted that the choice of composites could lead to substantial savings in the maintenance and

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[40] Loc Nguyen, NSWC Carderock Division, Code 6551

repair cost associated with SEA LANCE. For example, the FLYVEFISKEN CLASS (Standard Flex 300) has saved the Danish Navy 80% in maintenance costs compared to a similar steel hull design.[41]

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[41] CAPT Poul Grooss, Managing Director, Naval Team Denmark

2. Radar Cross Section Analysis

For this first iteration in the design, three features have been incorporated for radar cross section (RCS) reduction: general shaping, enclosed mast technology, and a telescoping mast.

Hull and superstructure design was driven by optimization against mono-static radar. The geometry was kept simple, maintaining parallelism between different sections in order to concentrate the electromagnetic energy in well-defined directions. No dihedrals or trihedrals are used in the structure, and cavity inlets and outlets have been placed between the catamaran hulls. 20° sloping of the sides is used throughout the hull and superstructure design.

The enclosed mast also follows the 20° sloping guideline. Different portions of the mast are transparent depending on the frequency of the sensor working behind it; hence the influence of the mast in overall RCS varies also due to this factor. The upper part of the mast is telescopic. When SEA LANCE operates within the grid, and does not need more height of eye, the upper part can be brought down, reducing the RCS.

The AUTOCAD model of the ships hull was fed into an RCS prediction code called Xtract. Professor David Jenn from the Naval Postgraduate School ECE department ran the simulation and provided the data, which is shown in the Appendix J.

The RCS estimation was done at three frequencies of interest: 30 MHz, 3 GHz, and 9 GHz. All visible surfaces were modeled as conductor planes.

The 30 MHz estimation is to account for over the horizon radar. At this frequency, the wavelength is 10 m, which is contained in the length and height of the ship only a few times. As expected, the stealth features incorporated are of no good, because the ship is in the resonant scattering region.

The 3 GHz estimation is to account for search radars that work in the E-F (2-4 GHz) band. The 9 GHz prediction is to account for search, fire control, and missile seeker radars that work in the I (8-10 Ghz) band. Although at these two frequencies the RCS is very similar in shape, numbers are better at 9 GHz.

In order to assess the RCS performance of SEA LANCE, predicted values are compared with reference data[42], shown in Figure 1.

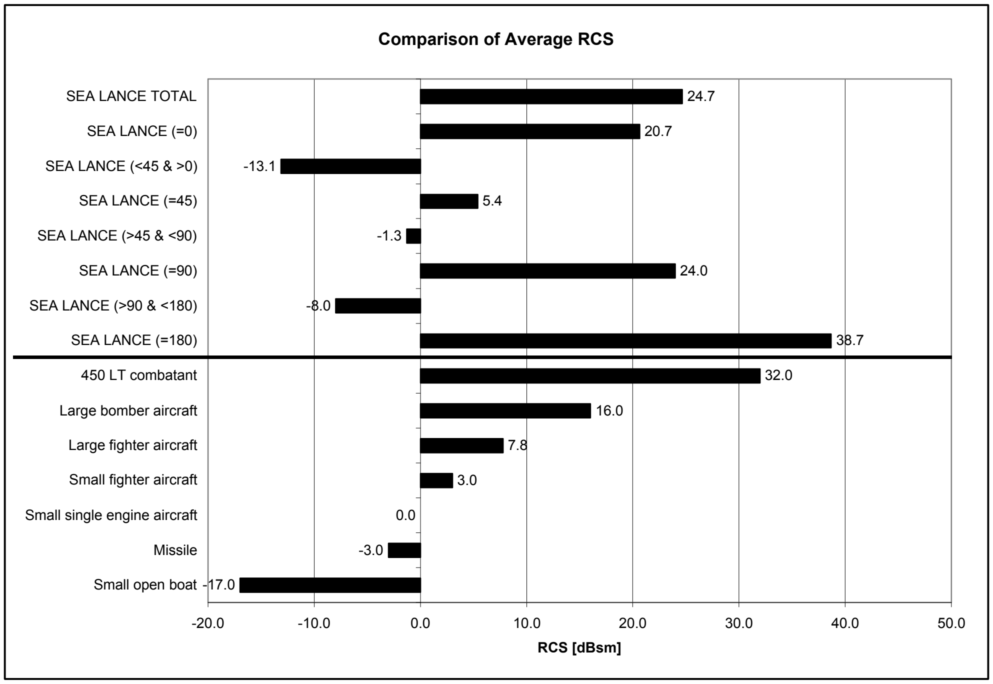

Figure 1. RCS Comparison

The total average RCS of SEA LANCE is 24.7 dBsm, while the median is –14.6 dBsm. From the power regression shown in the Appendix, it was estimated that a 450 LT regular combatant would have an average RCS of 32.0 dBsm; hence in average, SEA LANCE performs better by 7.3 dB. Analyzing

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[42] Introduction to Radar Systems-Merrill I. Skolnik.

the data by sectors, it can be seen that the bow and beam present averages in the order of the total average. The forward quarter has been divided in three sectors for analysis. Between 0° and 45° relative bearing, the average RCS is −13.1 dBsm, making it comparable to a small open boat. At 45° relative bearing, the RCS average is 5.4 dBsm, equivalent to a large fighter aircraft. Between 45° and 90° the average is −1.3 dBsm, comparable to a missile. The entire aft quarter, between 90° and 180° relative bearing, has an average RCS of −8.0 dBsm. The largest RCS average is 38.7 dBsm, and is obtained when SEA LANCE is viewed from the rear.

Another comparison is shown in Table 1. An equivalent displacement has been obtained from the RCS regression for the SEA LANCE values in the different directions. It can be seen, that except for the stern view, the RCS is always equivalent to a much smaller vessel.

TABLE 1

RCS	**Equivalent Displacement [LT]**
Total Average	146.55
Median	0.32
0	78.32
>0 & <45	0.40

45	7.24
>45 & <90	2.55
90	132.01
>90 & <180	0.90
180	1307.00

Due to time considerations, RCS estimation for the GDM and combatant-GDM pair was not conducted. As a reference, the 9 GHz RCS prediction for the port side of SEA LANCE took approximately 107 hours. It can be inferred that the GDM will perform better than the combatant, because it doesn’t have a superstructure or guns. For the pair, it is expected that the RCS will increase in every direction except the bow and stern directions.

The next iteration in the design spiral for the RCS should include more shaping to the superstructure and mast. Energy should be taken away from the bow and stern and concentrated, ideally, in the forward and back quarters (relative bearing angles 45° and 135°). In addition, radar-absorbing material should be incorporated to cover the edges.

3. Total Ship System

SEA LANCE is a compact formidable warship that has been designed for maximum flexibility while providing as much comfort as possible for its highly trained 13-person crew. The operations of the entire ship are controlled from the central control station located on the bridge. There are numerous reasons to centrally locate the crew. The crew berthing spaces are located close to their work environment. This provides them quick access to their battle and watchstations. It also limits the amount of space that must be protected in a CBR environment. Centrally locating all the berthing compartments within the habitability spaces allows the team to produce an environment that was austere in terms of physical space footprint, but afford the crew some things that normally would not be present on a small combatant. The gym and galley area are fairly good size and give the crew ample space to relax and unwind. The habitability space is also designed to accommodate ship riders. These could be Fly Away Teams (FATs) to affect repairs to SEA LANCE or the expeditionary warfare grid as well as SEAL teams or an intelligence detachment. The multi-mission space that is located in the habitability space could be utilized for any special equipment or compartmentalization that is required. Figure (1) and Figure (2) demonstrate orientation of the combatants spaces, while Figure (3) shows the layout of the habitability compartments.

The ship is designed to withstand only moderate damage from an enemy weapon. The ship is designed to afford the crew the maximum opportunity to get off the ship in the event that it sustains heavy damage from an enemy attack. The 2 life rafts located port and starboard in the central control station can accommodate 25 people. The RHIB that is located just aft of the habitability spaces on the starboard side can be accessed directly from the berthing passage way. It can accommodate all 21 personnel that could be assigned. One of these modes of departure should be available to afford the crew an option to abandon ship when necessary. The locations of the egress equipment can be seen in Figures (1) and (2).

The combatant is designed with a robust combat systems suite to ensure that it could protect the grid once deployed and would provide protection for the craft while it is operating independent of the battle group and grid. It has (4) Harpoon/SLAM tubes along the port side, (2) 30 mm guns located fore and aft, and a 51-cell vertical RF/IR guided missile launcher aft. The combatant could also perform such missions as: maritime interdiction operations (MIO), non-combatant evacuation operations (NEO), escort for the carrier or amphibious readiness group (ARG) units. It is ideally suited for combat against the wide range of small surface combatants that the international navies possess. The sensors suite of the combatant is capable of operating in a wide range of environments. The air/surface search radar has a range of 54 Nm while the infrared search and track (IRST) as well as the fire control radar has a range of 20 Nm. The electro-optical suite has a range of 10 Nm and the mine-avoidance sonar has a detection range of approximately 350 yards. Additionally it is equipped with an ESM suite and phased array communications antennas. The entire suite is enhanced by the use of an advanced enclosed mast. For increased RCS reduction the mast can be retracted to produce a height of eye of only 35 feet. This position would be utilized when operating in conjunction with the grid or when in a higher state of emissions control. The mast can be extended 13 feet to produce a height of eye of 48 feet to increase the IRST detection range to 20 Nm. The mast also has 9 phased array antennas (3 per face) located around the mast to support the wide array of communications requirements and large amount of data transfer that the SEA LANCE will require when operating in the Network-Centric environment. Figures (5) and (6) depict the location and rough physical characteristics of the weapons and sensors.

The Grid Deployment Module (GDM) is designed for maximum utility while operating both with the combatant and on its own. It will receive power and electronic information from the combatant through the umbilical that is contained in the center of the tow bar. It will provide fuel for the combatant through the same umbilical during long transits while the tow is attached. It is equipped with a 150 KVA generator to provide power in the event that it is unable to receive power from the combatant or to provide power for the multitude of missions it is capable of performing when it is separated from the combatant. It is also equipped with a communications/electronics suite and phased array communications antennas along the port and starboard hulls. This would allow the GDM to serve as a launching pad for SOF forces or possible a lily pad for VSTOL UAV’s. It would also allow the emitters and decoy launchers to be operated remotely to provide a deception capability. The GDM’s modules are located over the large center hull region. This will provide maximum flexibility of deployment as well as a wide range of things that can be deployed. The grid elements could be deployed from the modules as well as boats, fuel bladders and logistic containers for SOF units and the marine expeditionary force. The large tank groups located in the outer two hulls could hold large quantities of fuel to provide auxiliary support to units operating the area. The GDM is a very flexible platform with numerous mission possibilities. The general arrangements of the GDM are shown in Figure (4)

The combatant and GDM SEA LANCE system is an extremely viable option for performing the Expeditionary Warfare Grid deployment mission. Both the combatant and GDM have been designed to perform countless missions while connected as well as while operating independently. Detailed descriptions and technical evaluations of the combatant, GDM and their individual components are contained throughout the report.

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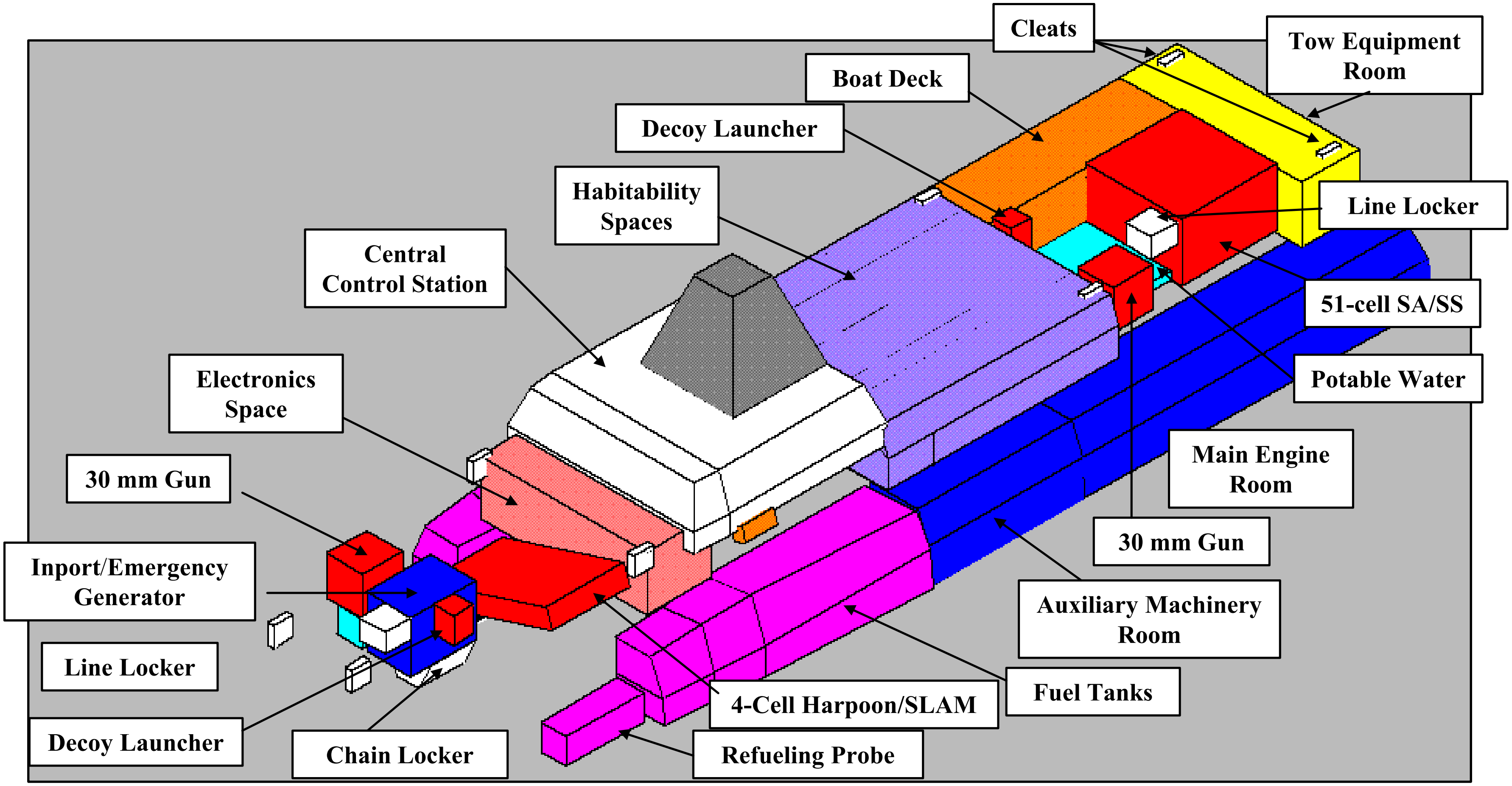
Cleats
Tow Equipment Room
Boat Deck
Decoy Launcher
Habitability Spaces
Central Control Station
Line Locker
51-cell SA/SS
Potable Water
Electronics Space
Main Engine Room
30 mm Gun
30 mm Gun
Inport/Emergency Generator
Auxiliary Machinery Room
Line Locker
Fuel Tanks
4-Cell Harpoon/SLAM
Decoy Launcher
Chain Locker
Refueling Probe

Figure 1

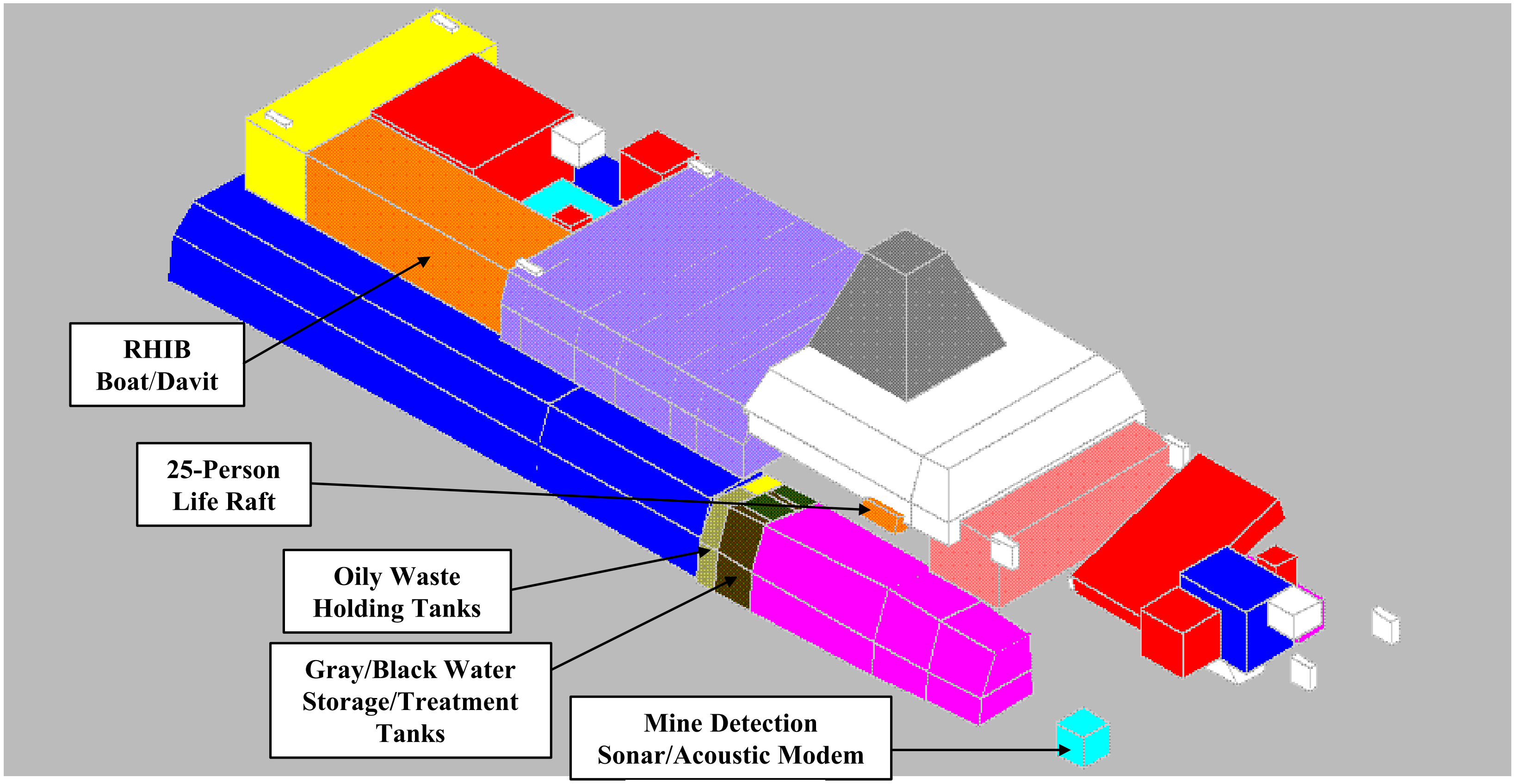
RHIB
Boat/Davit
25-Person
Life Raft
Oily Waste
Holding Tanks
Gray/Black Water
Storage/Treatment
Tanks
Mine Detection
Sonar/Acoustic Modem

Figure 2

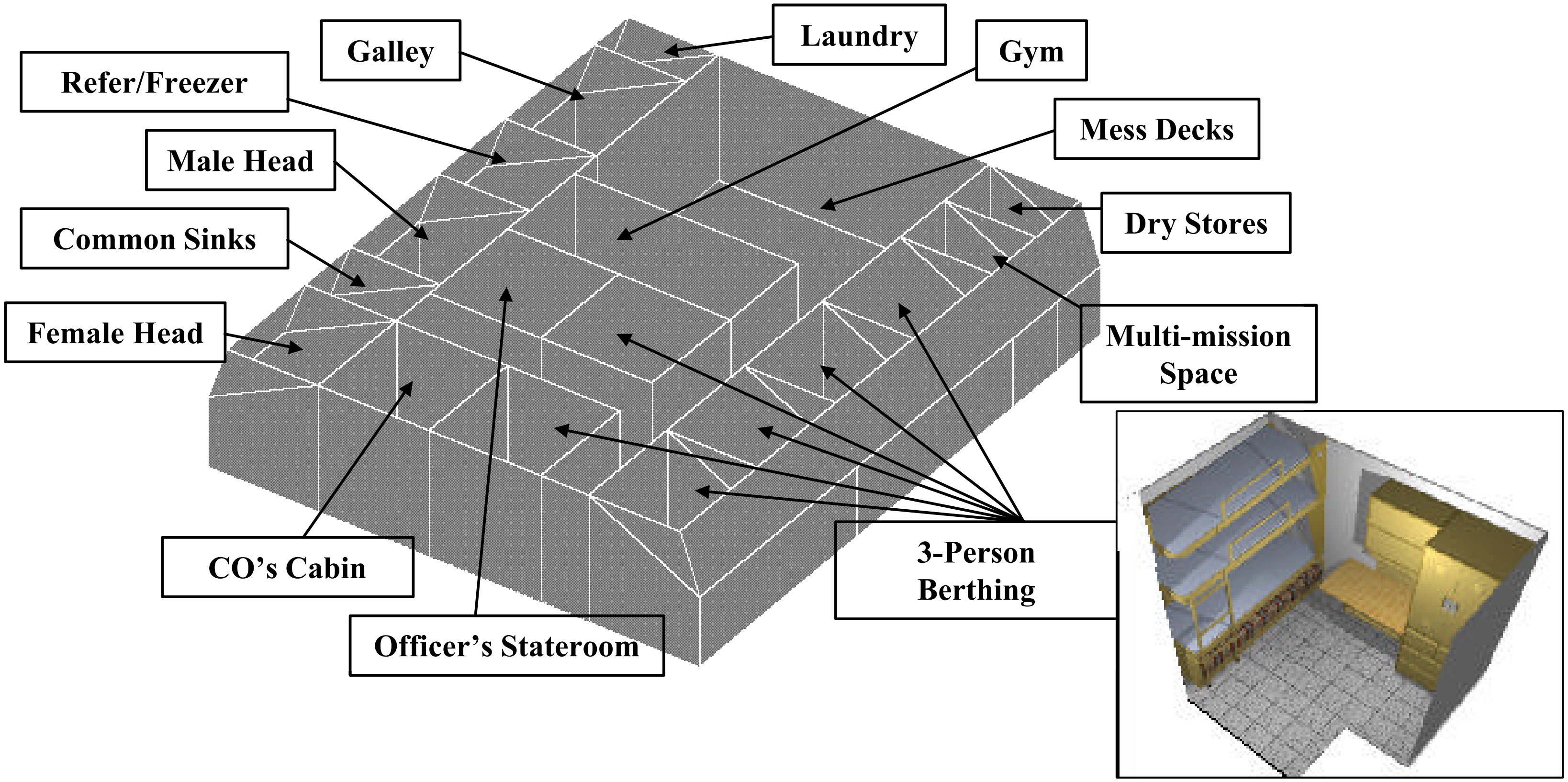
Galley
Laundry
Gym
Refer/Freezer
Mess Decks
Male Head
Dry Stores
Common Sinks
Female Head
Multi-mission Space
CO's Cabin
3-Person Berthing
Officer's Stateroom

Figure 3

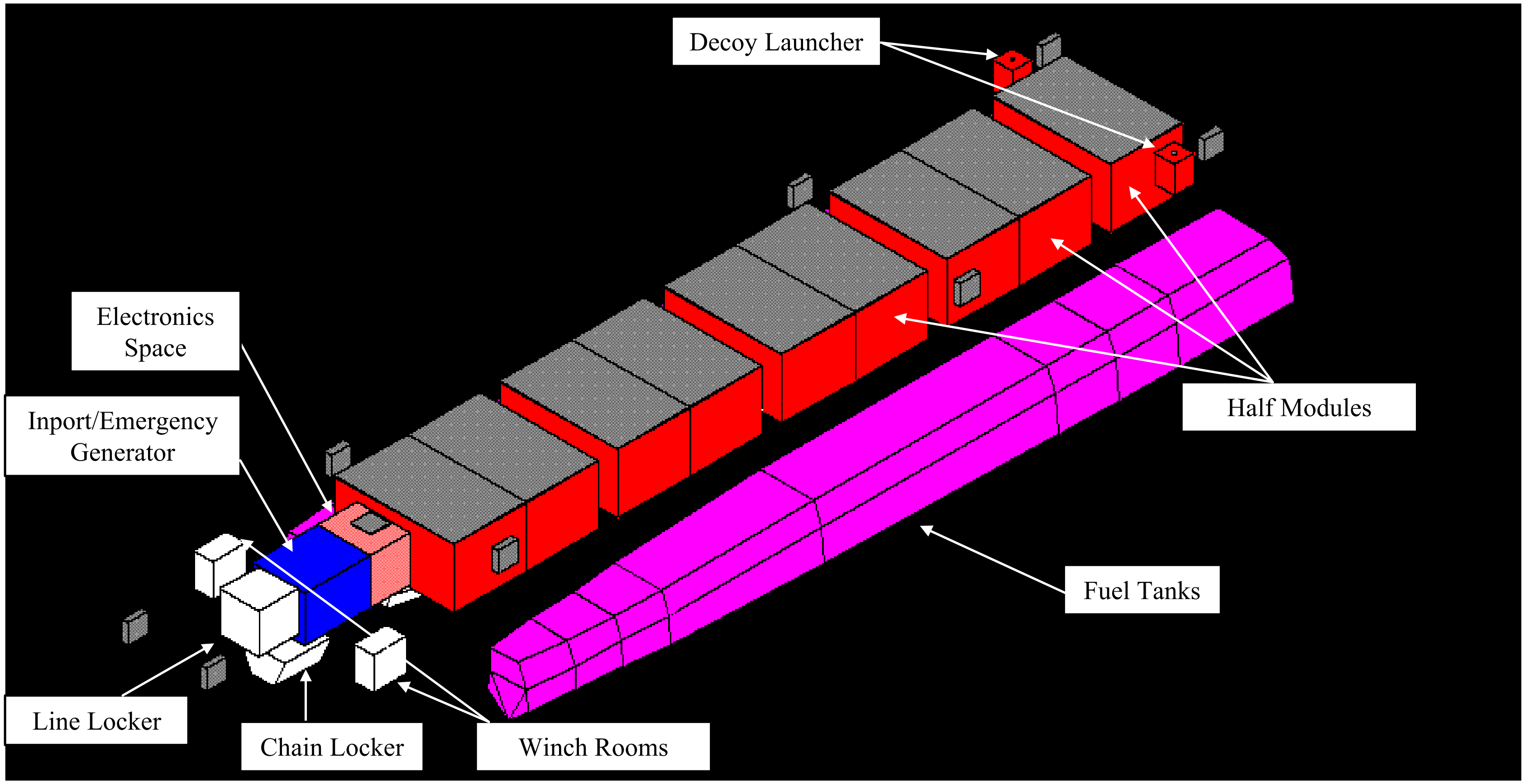
Decoy Launcher
Electronics Space
Inport/Emergency Generator
Half Modules
Fuel Tanks
Line Locker
Chain Locker
Winch Rooms

Figure 4

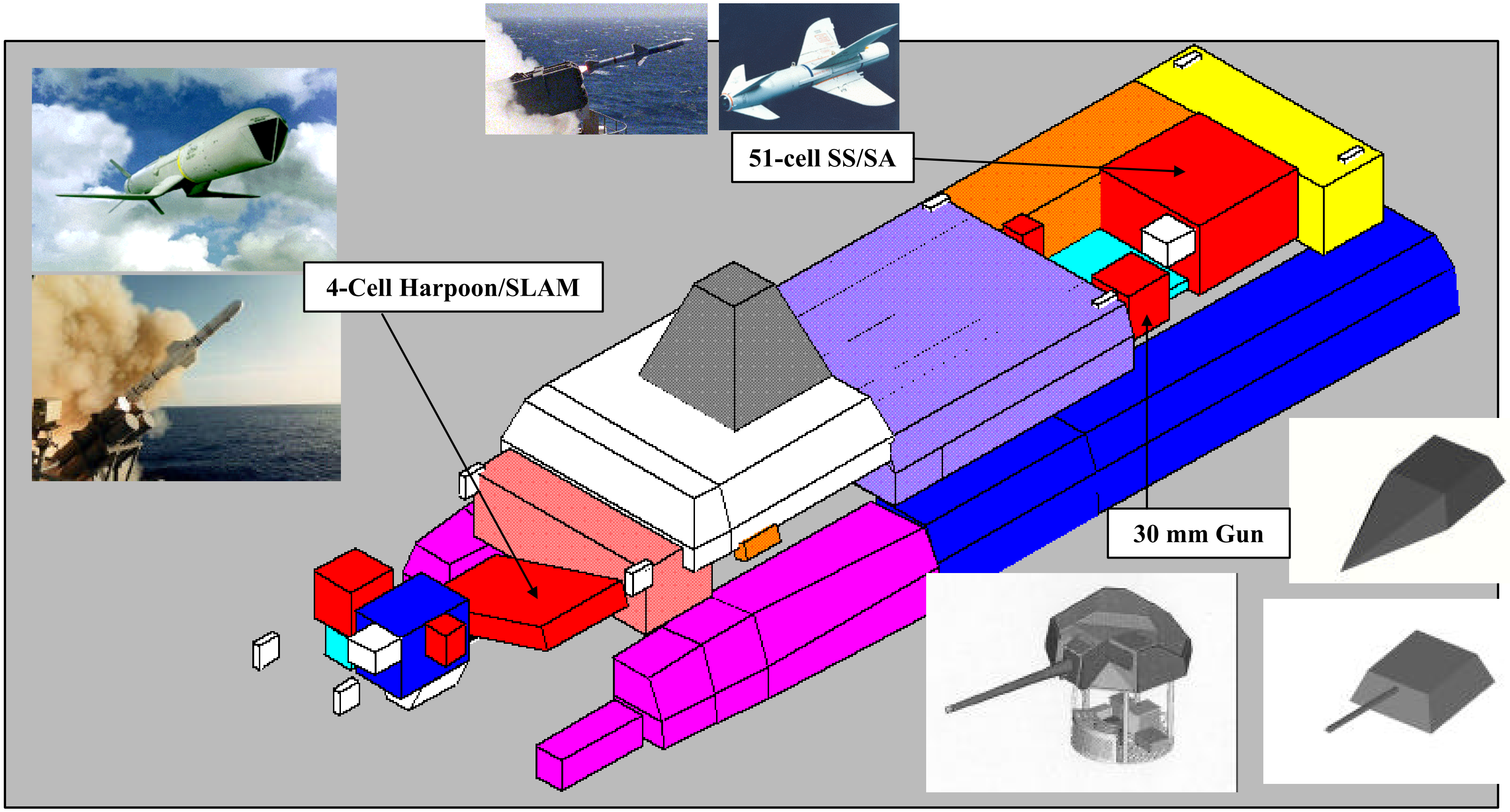

Figure 5

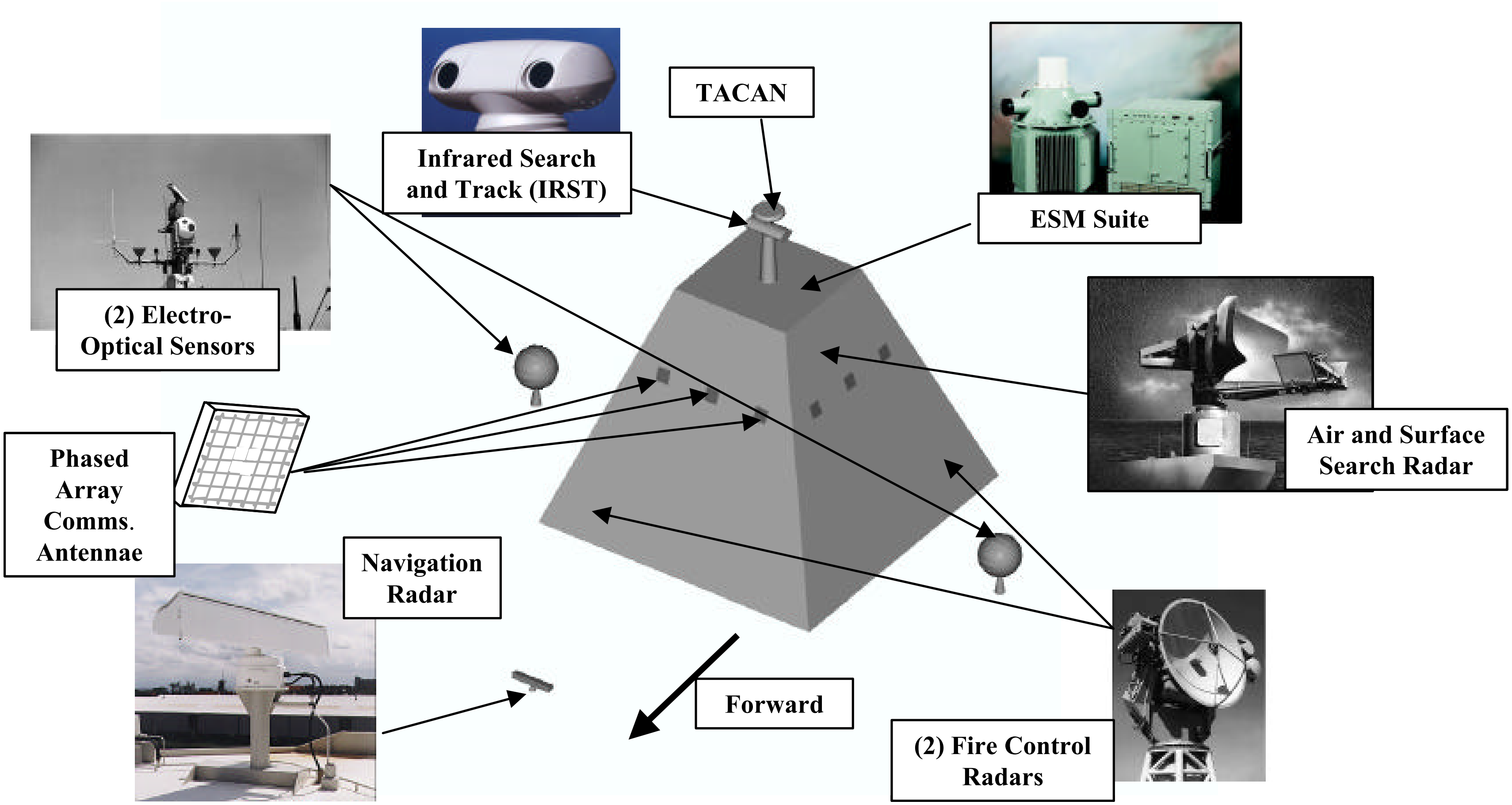
TACAN
Infrared Search and Track (IRST)
ESM Suite
(2) Electro-Optical Sensors
Air and Surface Search Radar
Phased Array Comms. Antennae
Navigation Radar
Forward
(2) Fire Control Radars

Figure 6

Chapter V: Conclusions

A. Requirements Review

SEA LANCE is a robust system of vessels that will ensure the deployability, flexibility, versatility, lethality and survivability necessary within the contested littorals to provide the operational commander with the awareness and access assurance capability lacking in the fleet of the POM. SEA LANCE in conjunction with the Expeditionary Warfare Grid will allow gaining, maintaining, sustaining and exploiting access to the littorals, in order to project power into enemy territory.

SEA LANCE embodies the capabilities discussed in the Mission Needs Statement (MNS). The design meets or exceeds all of the requirements set forth in Operational Requirements Document (ORD). The relatively low cost, flexible and stable hull form as well as the high degree of combatant capability makes SEA LANCE a very effective choice for deployment of the Expeditionary Warfare Grid. The combatant is capable of operations in the contested littoral environment against a wide range of threats without posing undue risk to the power projection assets of the fleet of the POM. The GDM has the flexibility to accept a multitude of diverse payloads. This increases the versatility of SEA LANCE far beyond those outlined in the requirements documents.

B. Assessment of Systems Engineering Design Process Experience and "Lessons Learned"

The design team was faced with the challenge of defining the Mission Needs Statement (MNS) and drafting the Operational Requirements Document (ORD). To accomplish this task the team had to define an operational scenario and determine how the ship they would ultimately design would fit into the overall Expeditionary Warfare Grid System. The Expeditionary Warfare Grid is in the developmental stages of design. Many areas of the grid are just conceptual in nature. The team utilized the Expeditionary Warfare Grid as it was outlined in the Capabilities of the Navy after Next (CNAN) study being conducted by the Naval Warfare Development Command (NWDC). The team attempted to adhere to a strict systems engineering approach to this effort and for the most part succeeded. The team was ready to begin designing the ship at multiple points throughout the first quarter, but adhered to the guiding principles of systems engineering to build the foundation for the second quarter effort. The team dedicated the vast majority of the first quarter design effort to defining what the ship needed to do, what the grid would do, how the ship and grid would interact and what impact they would have on one another. The first quarter ended with the team choosing an architecture of the three that were reviewed and defining some of the basic properties of the ship.

The second quarter began with the team still diverging and wondering whether it would converge on a solution. The team was also faced with a compressed schedule of an 11-week quarter and a deadline to give the presentation in a mere 2 months. Time allocation and planning were lacking in the second quarter design effort. The team was rapidly putting out the individual fires that sprang up throughout the design. Some modifications were necessary to a few systems after they were incorporated into the larger SEA LANCE system. The overall system survived these small trials and tribulations, but the design effort would have been smoother if systems engineering had been followed in its purest sense. The team completed the second quarter design effort with what they believe was the optimum design for the problem that was presented. It was a difficult problem, but all members of the team provided their required inputs and produced a complete design capable of operating within the overall Expeditionary Warfare Grid system.

Some other lessons learned were the need to establish professional contacts early. These professional contacts were invaluable to the design effort. Some contacts were discovered too late within the design effort to incorporate in the design. Networking of the Navy's design infrastructure (including NPS) is essential to providing cost-effective, thorough solutions to the Navy's challenges. The team could have benefited from some of the expertise in other departments within NPS. The operations analysis, software engineering, manning, etc could have been reviewed by some of their associated curriculums.

Some design tools were needed to more rapidly and accurately define some of the areas. NAVSEA is currently developing a cost evaluation tool for ship design. The Advanced Surface Ship Evaluation Tool (ASSET) modules that exist for multi-hull ships need to be converted and incorporated into the current ASSET program. A functional flow diagram construction program would be of benefit. Many of the programs are in FORTRAN format, which produce output that is difficult to analyze and incorporate into a design report. The efforts to convert these programs to PC based environments should be continued and funded.

Overall, the team learned a great deal from the design effort and thoroughly enjoyed being part of the process. The tools, experiences, and professional contacts gained in the capstone design project will prove to be invaluable to our careers and our productivity at future commands.

C. Areas for Future Research

Some areas of the design warrant further analysis to validate the overall system. Some specific areas of interest are:

- A Study of Human Factors: The many factors that are involved in the training and accessions pipeline as well as those that involve the complexity of the tasks required onboard the ship need further exploration.
- The Expeditionary Warfare Grid needs more definition of capability, function and physical appearance.
- The backbone of the Total Ship Open Systems Architecture, Network-Centric Warfare connectivity and “Team Net” networks needs further exploration and definition of shipboard requirements.
- A software engineering study of what is needed to tie all the systems together onboard SEA LANCE’s SWAN needs to be conducted.

- Modeling and Tow Tank experiments need to be conducted on close-proximity semi-fixed tows to further validate its use.
- Resistance data needs to be developed and distributed for catamaran hull forms.
- The numerous automation and technology advances being developed by the various commands are essential to the minimum-manning concept. Some are purely conceptual in nature and need further funding and study.
- The preliminary radar cross-section study was performed on an unclassified level. A classified, detailed RCS analysis and optimization needs to be performed.
- An analysis of the effects of the addition of ride stability systems needs to be completed to ensure they produce the desired affects on deck edge accelerations and stability.
- Composite structures should be incorporated to a greater degree within the design to produce a more desirable balance between payload fraction, design margin and other naval architecture attributes.