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A Combined (USN/USCG) Patrol Corvette (CPCX)

by

C.N. Calvano
CDR M.A. Witt, USN
LT E. Anderson, USN
LT J. Comar, USCG
LT J. Hurley, USCG

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Prepared for: Naval Postgraduate School
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This report was prepared by:

CHARLES N. CALVANO
Associate Professor, Total Ship Systems Engineering
Mechanical Engineering Department

Reviewed by:

TERRY R. MCNELLEY
Chairman and Professor
Mechanical Engineering Department

Released by:

GORDON SCHACHER
Dean of Research (Acting)

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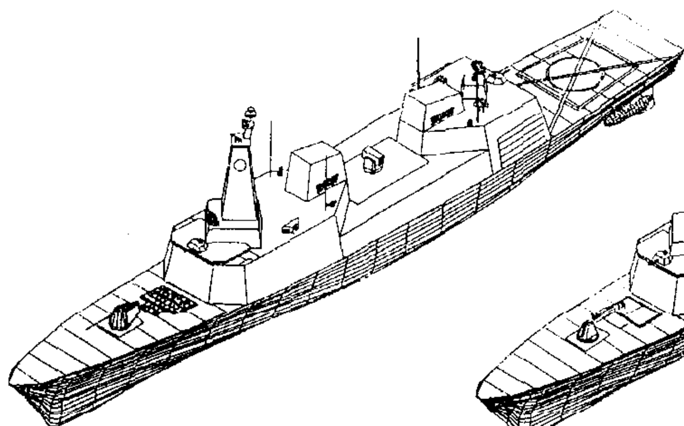

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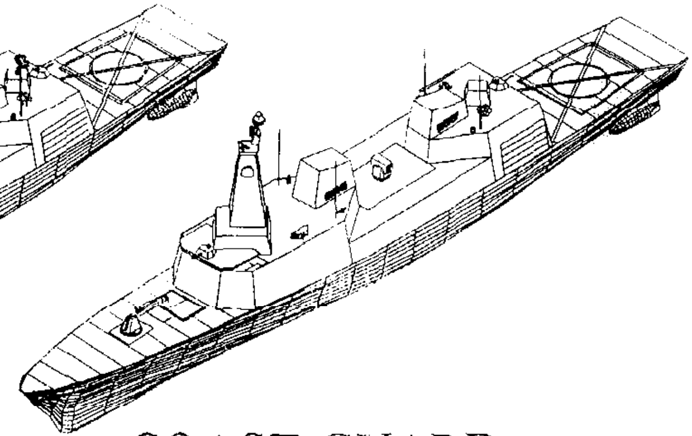


COAST GUARD

Total Ship Systems Engineering

Report Authors
Prof. C. N. Calvano
Commander M. A. Witt, USN
LT Eric Anderson, USN
LT John Comar, USCG
LT Jim Hurley, USCG

May 1996

The Combined Patrol Corvette (CPCX)

This report documents a Total Ship Systems Engineering capstone design project undertaken by students at the Naval Postgraduate School, under the direction of Prof. C. N. Calvano, assisted by CDR M. A. Witt, USN. The design team consisted of: LCDR Jay Renken, USN; LT Eric Anderson, USN; LT Bob Armstrong, USN; LT John Comar, USCG; LT Jim Hurley, USCG; LT Helen Kilty, USCG; LT Thomas Jean, USN and LT Bob Jones, USN. These officer students all contributed to the performance of the design project over a six month period. The present report, however, represents a significant re-work of the team's design project report, hence the listed authorship of Calvano, Witt, Anderson, Comar and Hurley.

Abstract

A Systems Engineering approach to the preliminary design of a combined-usage (USN/USCG) corvette is presented. The design responds to recognition that as lawbreakers become more sophisticated and heavily-armed, the Coast Guard's law enforcement operations become more similar to warfare; and at the same time, the Navy's increasing involvement in Operations Other than War (OOW), such as sanction enforcement and humanitarian operations, is becoming more like traditional law enforcement operations.

The design, responding to this situation, pursues two variants of a single basic ship -- one with a Coast Guard payload and one with a Navy combat payload. Major objectives of the design are (1) cost savings by permitting larger numbers of the ship to be built than either service, alone, would need, with a high degree of commonality between the two variants and (2) provision of the ability to rapidly reconfigure the Coast Guard variant into the Navy variant when there is an expectation of increased combatant ship needs. Mission analysis, payload selection, development of measures of effectiveness and analysis of Naval Architecture features, as well as other design factors, are addressed.

TABLE OF CONTENTS

I. REQUIREMENTS PHASE

A. MISSION NEED STATEMENT/FACULTY GUIDANCE

The following was provided by the faculty as guidance for this Total Ship System Engineering design project.

1. World View

The United States will continue to find itself faced with a threatening world, but one in which the nature of the threat is unpredictable. The following characteristics are expected to mark the world the U.S. must face in the timeframe 2000-2020:

(a) Major, all-out oceanic Naval warfare will remain unlikely.

(b) Regional conflicts among and between "third world" nations will be likely.

(c) International (U.N., NATO) organizations will attempt to maintain world peace and order and U.S. forces will operate under control of such organizations.

(d) Operations other than war (OOW) (trade interdiction, embargo, port closure, humanitarian relief, peacekeeping patrols, etc.) are likely employment for U.S. ships.

(e) Budgets will remain extremely tight; the lack of a clear cut threat to the existence of the United States will make it difficult to obtain defense funding.

(f) Pressures to decrease the size of the federal government and of the armed forces will continue, causing consolidations of roles for the armed forces.

(g) Proliferation of high-technology weapons among nations will continue.

(h) Law enforcement at sea (anti-drug, anti-piracy, etc.) will get more frequent and be conducted against more sophisticated and more heavily-armed criminals.

(i) The "CNN effect" will continue to make it vital to reduce the likelihood and numbers of U.S. (and even enemy) casualties.

2. Background

There has been a lengthy national debate, involving the Congress, the State Department, DOD, other Executive Branch departments and the White House. It has been decided to proceed with a ship design and procurement that has the following characteristics.

(a) There will be two variants of the ship. One will be operated by the Navy for its role in littoral operations and OOW; one will be operated by the Coast Guard in increasingly challenging law enforcement scenarios. It is noted that as the Navy does more OOW, its operations begin to look more like law enforcement; and that as the Coast Guard takes on more sophisticated and richer criminals, its operations will begin to look more like war. Hence a convergence toward a ship which can, at least in part, meet both needs has strong political attractiveness.

(b) As much as possible of the two variants will be kept the same, to reduce costs and ease production. The variants will differ where that is made necessary by their different missions.

(c) Keeping costs down is of great importance because it is intended to buy these ships in large numbers. There is a significant consensus that "small" is desirable.

(d) To keep costs down, and reduce the risk to human life, the crews are to be small as feasible for the ships' size and equipment.

(e) The ships are to use automation and other high technology approaches to make them survivable.

(f) Initial Operational Capability (IOC) is to be 2010.

3. Guidance

The following is general guidance from senior levels in the Navy and Coast Guard.

Navy Variant:

(a) Will be fully deployable and fleet-compatible. The Coast Guard version will be capable of easily being made so.

(b) Will be operating in the presence of AEGIS combatants and, therefore, do not need an area AAW capability.

(c) Must be capable of operating effectively in the littoral environment, with specific capabilities defined by the Operational Requirements Document.

(d) Must be capable of independent as well as battlegroup operations; in the Coast Guard role, the ships will operate in one or two ship groups.

Coast Guard Variant:

(a) Must be capable of detecting, intercepting and, if necessary, defeating well-equipped drug smugglers and pirates who may have the resources to purchase significant militarized equipment. Specific capabilities will be defined in the Operational Requirements Document.

(b) Will be used to interdict illegal immigration and smuggling.

(c) Must perform search and rescue.

Conversion:

(a) It would be desirable to be able, quickly and cheaply, to convert one variant into the other, with a short (less than four weeks) shipyard availability. The design must provide for this conversion as much as is possible.

4. Amplifying Information

The Coast Guard wants a ship whose primary uses will be drug, smuggling, and illegal immigration interdiction (board and search), fisheries protection, search and rescue, escort, navigation, and survey and general maritime police duties. Low maintenance and support costs is a primary concern.

The Navy wants a robust self defense capability, some strike capability and sophisticated air search capabilities. Low observability for special operations and operations in the littoral is considered a necessity. Helicopter capabilities will be essential and multi-mission considerations are expected to govern. The ship will support amphibious operations, perform choke point clearance and function as an alternative mine hunter. Cooperative Engagement Capability and the ability to operate in the rapidly-changing littoral environment are essential. A radar that handles land clutter well without losing low/slow targets is essential.

The applications of new technologies and concepts such as interlinking ship control, administration, combat systems, C^4 I data, training and control systems are desirable. The concept of human casualty avoidance possibly through reduced crew sizes, which in turn require excellent organic training capabilities, is an important feature to be considered for incorporation into the ship system.

B. OPERATIONAL REQUIREMENTS DOCUMENT

1. Description Of Operational Capability

The system is defined as a Combined Patrol Corvette (CPCX) suitable for use by either the Coast Guard or the Navy. The ship will be required to operate in an all weather environments year-round in all oceans of the world, particularly in littoral waters. Transit of ice covered waters is not required. Two variants will be designed and each will be convertible into the other in a shipyard availability.

The Navy variant will provide independent forward presence and operate as an integral part of joint and allied maritime expeditionary warfare operations. CPCX will launch and support precision strike weapons and will provide firepower support for amphibious and other ground forces. The ship will protect itself and friendly forces against air, surface, and subsurface threats. CPCX will perform escort duties of other military and civilian craft. The ship will conduct and support special operation forces worldwide. The ability to conduct blockade operations will be required. The ship will perform board and search operations, choke point clearance, picket and patrol duties and will function as an alternative mine hunter. The ship will maintain sea lines of communication and will protect and enforce the freedom of navigation of US and allied vessels in the navigable waters of the world. Coastal intelligence gathering will be conducted by the ship. Humanitarian assistance in the form of at sea rescues, emergency medical care, sustenance and protection will be provided. CPCX will be capable of both humanitarian evacuations and those resulting from military action. The ship will perform search and rescue (SAR) operations involving people and property.

The Coast Guard variant will primarily conduct SAR and Enforcement of Laws and Treaties operations. Humanitarian assistance in the form of at sea rescues, emergency medical care, sustenance and protection will be provided. The ship will detect, intercept, and defeat drug smugglers and pirates. It will also interdict illegal immigration and smuggling. Fisheries protection, escort, safety of navigation, survey, and general maritime police duties will be carried out by the Coast Guard variant. Coastal intelligence gathering will be conducted by the ship. Port security duties in the form of searching and boarding vessels will be performed. The ship will carry and station small navigational buoys. The ship will assist in the containment of oil spills. The Coast Guard variant will be capable of joining the Naval fleet in joint operations and in time of war.

2. Threat Summary

While traits of projected threats cannot be predicted exactly, reasonable threat estimates can be made by identifying projected threat environments, extrapolating data from current weapon systems, and examining possible technologies for future weapon systems.

Major all-out oceanic warfare will remain unlikely while regional conflicts among and between third world nations will occur. Limited warfare in the littorals requires different resources than currently exist. Operations other than war such as trade interdiction, embargo, port closure, humanitarian relief, and peacekeeping are expected. Proliferation of high technology weapons among nations will continue. Encountering more sophisticated and heavily armed criminals will be commonplace.

Future weapon systems include missile threats that, when compared to today's weapon systems, will be smaller, faster, capable of flying at lower or higher altitudes, will have smaller radar cross sections, and improved targeting and avoidance systems. Gun threats include guided as well as unguided projectiles that will be challenging to detect, engage, and defeat. Threats will also include combined arms attacks intent on eroding ship self-defenses and removing offensive capabilities.

Specific projected threats categorized by threat environments are as follows:

(1) Law Enforcement (Independent operations - ship operating independently in littoral waters):

Small arms	- 20 mm and smaller bullets (armor piercing).
Projected grenades	- 40 mm explosive and chemical.
Mortar	- 80 mm explosive and chemical.
Guns	- 76 mm, 20 km range.
Missiles	- Mach 2.0, -40 dB, 3 km range.

(2) Low Intensity Conflict (Independent and Group operations - ship(s) operating jointly in littoral waters):

Small arms	- 20 mm and smaller bullets (armor piercing).
Projected grenades	- 40 mm explosive and chemical.
Mortar	- 80 mm explosive and chemical.
Guns	- 76 mm, 20 km range.
	- 127 mm, 28 km range.
Missiles	- Various flight profiles
	- Mach 2.0, -40 dB, 3 km range.
	- Mach 3.0, -35 dB, 100 km range.
	- Mach 1.5, -30 dB, 200 km range.

Mines	- Bottom or moored, -25 dB.
Torpedoes	- 100 knots, -30 dB, 7.5 km range.

(3) Major Regional Conflict (Force operations - operating as a junior member of an amphibious or carrier battle group task force in littoral or deep waters).

Guns	- 76 mm, 20 km range.
	- 127 mm (unguided), 30 km range.
	- 127 mm (guided), 30 km range.
ETC guns	- 127 mm (rocket assisted), 110 km range.
Missiles	- Various flight profiles
	- Mach 2.0, -40 dB, 3 km range, dual mode seeker.
	- Mach 3.0, -35 dB, 100 km range.
	- Mach 1.5, -30 dB, 200 km range, dual mode seeker.
	- Mach 4.0, -20 dB, 700 km range.
Mines	- Bottom or moored, -25 dB.
Torpedoes	- 100 knots, -30 dB, 7.5 km range.

3. Shortcomings Of Existing Systems

Current ship designs are inadequate to meet the needs of the Navy and Coast Guard into the 21st century. Existing ship designs such as the Navy's Spruance, Kidd and Perry classes and the Coast Guard's Hamilton, Reliance and Bear class cutters will reach the end of service life before the year 2010. A new surface combatant is necessary to maintain the required surface combatant force level capable of countering the 2010 and beyond threat.

Present ship designs were built for open ocean battle group operations, with strong steady logistic support, and defense in depth. These ships were not designed to operate for extended periods far from the strength and support of the battle group. Our current fleet is being taxed by the need to provide global forward presence in littoral waters with limited numbers of ships.

Present designs employ an inflexible architecture that prevents timely and cost effective updates and reconfigurations. Shortfalls include obsolete computers and software, with the inability to introduce subsystems into an effective total ship system. These shortfalls make current designs vulnerable to threats from advanced aircraft, small fast surface craft, mobile and fixed land-based weapon systems, and submarines.

Current designs have large manning requirements but have inadequate ship self-defense systems to protect the ship and its crew from close in attack. Shortfalls in accuracy, reaction time, target discrimination, and kill assessment create vulnerabilities. Mines and diesel submarines are cheap, viable threats that must be countered. Present ships have no mine avoidance capability and their active and passive sonar systems are designed for open ocean operations. They are vulnerable to attack from mines, torpedoes, and anti-ship missiles making them "*littorally challenged.*"

4. Range Of Capabilities Required

BOTH VARIANTS

CPCX must be able to operate independently in its patrol area. The ship must be fully interoperable with other Naval expeditionary, interagency, joint and allied forces. The ship must maneuver in formation at sustained Naval expeditionary force speeds in excess of 25 knots (kts). The ship will have a minimum range of 8000 nautical miles (nm) at a cruise speed of 14 kts. The ship must be able to perform seamanship, airmanship, and navigation tasks and to prevent and control damage. Underway fueling at sea capability is required as well as the ability to provide fuel to an astern rig. The ship must be able to embark and support armed rotary-wing aircraft, and conduct rotary-wing aircraft operations. The ability to stop, board and disable other vessels is required. CPCX will have a reduced electronic, magnetic, thermal, and acoustic signature to achieve low observability. A sensor suite able to operate in both open ocean and close to land with minimal detection degradation is required. The communications suite must have an integrated database capable of interfacing in a Joint Task Force/Combined Task Force (JTF/CTF) environment to include compatibility with joint systems such as the Global Command and Control System (GCCS) and the Joint Worldwide Intelligence Communications System (JWICS). The ship must have a full suite of radios and antennas to support full connectivity via EHF/SHF/UHF/SATCOM. The ship must be able to support the equipment and personnel of a mine disposal system. Weather deck connections for temporary sewage and sanitation facilities must be provided. In water personnel rescue is required from the ship. The ship will be capable of providing routine health care, first aid assistance, triage, and resuscitation, to include care of evacuees numbering 50% of crew size. Towing capability is needed for seized vessels up to 10,000 LT displacement. Multi-purpose ship's small boats will be readily deployable, have a minimum capacity of 8 people, and be able to perform in waters up to sea state 4. Modularized mission specific items for future updates will be used and will lend toward quick conversion between variants. Minimization of crew size while maintaining capability is essential.

NAVY VARIANT

The ship must destroy or neutralize enemy targets afloat and ashore through the use of coordinated, precision strike weapons. The ship must be capable of performing ship self defense against foreign military enemies and civilian terrorists at sea and in port. The ship must be capable of conducting engagements cooperatively with other ships, submarines, aircraft, space systems, and land systems. The ship must detect and chart underwater mines. The ship must detect, identify, and engage air, surface, and underwater threats. The ship must capable of defending itself against raids comprised of 3 ASCMs arriving within a one minute interval.

COAST GUARD VARIANT

The ship must destroy or neutralize enemy targets afloat and ashore. The ship must be capable of performing ship self defense against foreign military enemies and civilian terrorists at sea and in port. The ship must be capable of conducting engagements with other ships, military and civilian aircraft, and land systems. The ship must detect and chart underwater mines. The ship must detect, identify, and engage air and surface threats. Capability to transport and station small navigational buoys is required. A system for prisoner containment will be provided.

5. Integrated Logistic Support (ILS)

The ultimate goal of the logistic support system will be to develop a "paperless" ship, one that is able to devote 100% of its personnel and equipment to its assigned missions. The CPCX will be designed with a squadron type basing system. This will simplify the logistic support planning and requirements.

Maintenance Planning: The CPCX will incorporate minimum-manning concepts wherever possible. The onboard crews will be expected to perform routine, recurring minor maintenance (less than 3 hours per individual task) and casualty repairs while underway. Shore based Maintenance Augmentation Teams (MAT) will assist the ship's force with non-depot level maintenance and repairs while the CPCX is in port. MATs shall incorporate both contract and government personnel. The maintenance philosophy will consist of the Preventative Maintenance System (PMS) and Condition Based Maintenance System (CBMS). CBMS shall be implemented to the greatest extent possible using the technology available.

Depot level repair: Systems shall be designed for extended cycles between depot level availabilities. A 5 year drydocking cycle with one pierside availability near the halfway point shall be the minimum major maintenance intervals.

Support Equipment: All combat and HM&E systems shall include built-in diagnostic capabilities to reduce troubleshooting man-hours. Artificial intelligence driven trouble-shooting systems are to be included with all combat and HM&E systems. Tools required for onboard maintenance and repair shall be available on CPCX. This shall include a small machine shop for emergency repair (underway) functions. The use of special tools required for maintenance and repair shall be minimized.

Human Systems Integration: The use of minimum-manning requires each crewmember to be trained for multiple skills. Pipeline and/or squadron training facilities shall be utilized to reduce on-the-job training (OJT) requirements for primary skills. This will enable OJT to be utilized for cross-training. Combat systems and HM&E systems (to the greatest extent possible) shall incorporate individual and team training functions without external support.

Computer Resources: Software shall be written using existing languages with code length and storage requirements minimized to the greatest extent possible. Hardware shall consist of militarized Commercial-Off-the-Shelf (COTS) equipment wherever possible, militarized only as required. Components chosen shall be open systems compliant.

Other Logistic Considerations: Provisioning shall be consistent with current Navy/Coast Guard policy at the time of implementation. Home port piers shall be designed to moor at least one half of a six-ship squadron at all times. Adequate office space shall be provided for squadron staff, consistent with the goals of this system, the "paperless ship".

6. *Infrastructure Support and Interoperability*

The CPCX shall be designed as a squadron supported ship. It will be based in large groups (6 or more). The CPCX will depend on its squadron staff for the bulk of its administration, maintenance, planning, contracting, supply, training ,and personnel functions thereby minimizing manning requirements on the ships.

The CPCX shall be designed with standardization (within ship class) as a priority. The ability for a rapid reconfiguration between the Navy and Coast Guard variants is desired. Commonality with existing US and NATO systems to the greatest extent possible is highly desired.

7. Force Structure

The introduction of a corvette sized hull with modular combat systems suitable for mission tailoring for combined Navy and Coast Guard use would require a change in the mindset of ship-counters. These combined service corvettes are not suited to be one for one replacements for ships of the line such as DDG-51 class destroyers and CG-47 class cruisers and will not be expected to fulfill all the missions of an Aegis fleet. CPCX cannot be viewed as one for one replacements for the DD-693 and FFG-7 classes because of differences in the types of missions required in the littoral regions of the world.

Although the CPCX would not be a direct replacement for current combatants, ship class life cycle comparisons provide a basis for the future force structure. In 2005 the DD-963 hull will have completed 30 years of service and will be nearing the retirement phase of the Spruance and Kidd Classes (35 hulls 1200 officers, 11,100 crew). In 2007 the FFG-7 will have completed 30 years of service and will be nearing the retirement phase of the Oliver Hazard Perry Class (51 hulls, 1000 officers, 10,000 crew). In 2013 the CG-47 will have completed 30 years of service and will either be upgraded to extend their life cycle or begin the retirement phase of the Ticonderoga Class (27 hulls, 900 officers, 10,000 crew). In 2011 the DDG-51 will have been in service for 20 years and will still have at least 10 years of service remaining for the Burke Class (28 hulls, 644 officers, 7,840 crew). With the retirement of the non-Aegis ships and the high cost of the Aegis platforms, the CPCX would be ideally suited to perform independent or small group operations in the littorals or support battle group or amphibious group operations.

In view of this information, the integration of the CPCX into the Navy should be in proportion to the number of major combatants in service which would include aircraft carriers, large deck amphibious ships (LHD's, LHA's, and LPD's), cruisers and destroyers. It is estimated that the future major combatant fleet size in 2010 will be approximately 120 hulls. In consideration of the future fleet size, a two one ratio of major combatants to the CPCX is appropriate. This will result in 60 CPCX hulls for Navy use.

The Coast Guard's need for a new ship class is more pressing than the Navy's need. The Coast Guard's ships are older, and therefore will require a significantly higher percentage of maintenance and financial resources. In 1997 the WHEC-715 hull (Hamilton class 378 ft HEC) will have completed 30 years of service (12 hulls 250 officers, 1,870 crew). All twelve hulls were modernized between 1988 and 1992 and the class can be expected to be operational for a 40 year hull life. In 1994 the WMEC-615 hull (Reliance class 210 ft MEC) will have completed 30 years of service (16 hulls 130 officers, 870 crew). All sixteen hulls where modernized between 1989 and 1994 and the class can be expected to be operational for a 40 year hull life. In 2013 the WMEC-901 hull (Bear class 270 ft MEC) will have completed 30 years of service (13 hulls 143 officers, 1365 crew). Service life could easily be extended to 35 years with proper maintenance and planning. In view of the age and time in service of the above classes it is proposed that they be replaced by the CPCX as the new hulls become available. The current Coast Guard force would be replace by 40 CPCX's.

The production strategy for CPCX is to construct two hulls (one Navy variant, one Coast Guard variant) in 2009 for acceptance trials and testing resulting in delivery in 2010. A second hull of each variant will be produced by the same yard or yards the following year to validate production processes prior to commencing full production of the class. It is expected that the production run will last between 10 and 15 years. A total of 100 ships would be built resulting in the construction of 7 to 10 hulls per year. The first five years of production should be 8 units per year divided 5-3 in favor of the Coast Guard. This will help alleviate financial and manning strains on the Coast Guard and will help to keep production costs down in the early part of the production run. After five years the number of hulls constructed will be 25 Coast Guard variants and 15 Navy variants. The second five years of production should continue at 8 units per year in a 6-2 split in favor of the Navy. This will allow continued modernization of the Coast Guard fleet and timely retirement of non-Aegis combatants. After ten years the number of hulls constructed will be 35 Coast Guard variants and 45 Navy variants. The last five years of production will complete the production run with 4 hulls per year and a 3-1 split between Navy and Coast Guard. The total number of hulls constructed will be 40 Coast Guard variants and 60

Navy variants. A replacement for Aegis platforms will probably start production around the year 2020 reducing the funds available for the CPCX program.

8. Schedule Considerations

The ship will be considered fully operational after acceptance trials, and completion of Post-Shakedown Availability (PSA), as well as having all support and maintenance facilities in place and operable.

A projected timeline for design and production processes is as follows:

Present - 2002	Feasibility studies and Preliminary Design
2003	Contract Design
2004	Bid process
2005	Award contract
2006	Detail Design and begin construction
2010	Deliver First ship (testing and PSA complete)
	Every 5 years review and update design
2025	End production
2050	Begin decommissioning

The ships crew and squadron will stand up approximately one year prior to delivery to begin the precommisioning process. All personnel required to attend critical rate schools prior to reporting will complete training pipelines no less than 6 months prior to ship delivery. The remaining period prior to delivery will be used for on the job training, team trainers, and training with mockups or with actual shipboard equipment when possible.

Shore based maintenance and logistics facilities and systems will be in place 6 months to a year prior to ship delivery.

9. *Cost Considerations*

Cost is one of the primary factors concerning the design of this class of ship. The high costs of current combatants preclude their use to satisfy the mission defined for the littoral regions. The CPCX must be a more cost effective system for dealing with littoral warfare. The missions required of this ship will dictate that ship self defense will be of the highest priority. This along with the desire to automate systems while maintaining a robust ship self defense capability will tend to increase the acquisition costs. Reduced manning, however, should lead to lower operational costs and fewer potential personnel casualties. In view of these points it is intended that this ship type will be significantly less expensive than the current Aegis platforms being constructed. The ship price (averaged over the production run) may not exceed $450 Million (Navy variant) or $375 Million (CG variant), 1995 dollars. The displacement may not exceed 4000 LT (either variant).

II. FEASIBILITY STUDY/COMBAT SYSTEM SELECTION

A. INTRODUCTION

The design team was given the task of designing two separate ships, one Navy Variant and one Coast Guard Variant. Each variant must be easily convertible into the other, meet the design constraints in terms of weight and cost, and satisfy the requirements as defined by the Operational Requirements Document (ORD). The team divided into two sub-teams: a U.S. Navy team, and a U.S. Coast Guard team, with each team consisting of both Navy and Coast Guard members. The following chapter outlines the feasibility study which was conducted to measure the suitability of the CPCX design for service in the Navy and Coast Guard.

The first task was to develop "threat scenarios" based on expected future threats. While the traits of future threats cannot be projected exactly, reasonable threat estimates can be determined by identifying projected threat environments, extrapolating data from current weapon systems, and examining possible technologies for future weapon systems. The expected threats were broken down into service specific threat scenarios. A threat level and opportunity analysis was done to assist in prioritizing the emphasis on specific warfare areas for each design. These threat scenarios are included in Appendix (A).

The design constraints, specific design requirements, and projected threat summary provided the bases for the Combat System selection. The following sections provide a detailed analysis of the Combat System selection process including: Combat System elements considered, method of element selection, trade-off studies, option analysis, measures of effectiveness, and final design recommendations.

B. COMBAT SYSTEM REQUIREMENTS

The requirements set forth in the ORD were reduced to reflect requirements which pertained to Combat Systems and separated into three areas; common requirements for both variants, Navy specific requirements, and Coast Guard specific requirements. These Combat Systems requirements are included in Appendix (B).

C. FUNCTIONAL ALLOCATION

A functional allocation table was developed to link each operational requirement to a specific warfare area and functional area. The Combat System requirements listed in Appendix (B) were broken down into functional and warfare areas. Functional areas include: Detection, Control and Engagement. The warfare areas include: Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASuW), Mine Warfare (MIW), Strike Warfare, Amphibious Warfare (AMW), Enforcement of Laws and Treaties (ELT), Search and Rescue (SAR), and Other Than Warfare (OTW). These nine warfare areas are a subset of each functional area which linked each specific requirement in the ORD to a warfare and functional area. Table (1) contains an example of a functional allocation table. Under each warfare area, The functional allocation tables were used as a tool to ensure all requirements are satisfied and each warfare function will be performed by at least one element in the Combat System suite.

D. COMBAT SYSTEM ELEMENTS

The threat scenarios and functional analysis guided the team toward general Combat System areas. Six warfare/Combat System areas were investigated: Guns, ASW sonars, air/surface search sensors, missiles, mine hunting devices, and small boats. These investigations were conducted by two-person "mini"-teams (consisting of one member from each parent team). The mini-teams compiled lists of data on existing systems and systems under development. The lists for some of the sensor and engagement systems are included in Appendix (C). This raw data was examined and used to evaluate the identified systems in terms of performance, ship impact, cost, and convertibility. A detailed system trade-off study was conducted in two areas: sonar and air search radars.

E. TRADE-OFF STUDY: SONAR

Sonar selection for the CPCX was a difficult problem. The Navy obviously needed some sort of active sonar but the Coast Guard did not want a sonar system. The desire to use the same hull for both variants and the difficulties of installing or removing a hull mounted sonar drove the selection toward a smaller hull mounted system or some sort of

Elements	AAW						ASW				ASUW						MIW			STW		AMW			ELT							SAR							OTW						
	Vol Search	ESM	IR	Visual	Organic	Inorganic	Active	Passive	Organic	Inorganic	Surf Search	ESM	IR	Visual	Organic	Inorganic	Ship Board	Organic	Inorganic	Organic	Inorganic	Visual	Organic	Inorganic	Vol. Search	Surf Search	ESM	IR	Visual	Organic	Inorganic	Vol. Search	Surf Search	ESM	IR	Visual	Organic	Inorganic	Vol. Search	Surf Search	ESM	IR	Visual	Organic	Inorganic
Oper. Requirements																																													
A1																																													
A2	X	X	X	X	X		X	X	X		X	X	X	X	X										X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	
A3																																													
A4											X	X	X	X	X										X	X	X	X	X	X															
A5					X				X						X					X			X							X							X							X	
A6					X				X						X					X			X							X							X							X	
A7																																X	X	X	X	X	X		X	X	X	X	X	X	
A8	X	X	X	X	X		X	X	X		X	X	X	X	X		X								X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	
A9																																													
A10																	X	X																											
A11																																													
A12																																													
A13																																													
B1																				X																									
B2																						X	X																						
B3	X	X	X	X	X		X	X	X		X	X	X	X	X																														
B4	X	X	X	X	X		X	X	X		X	X	X	X	X																														
B5	X	X	X	X	X																																								
B6	X	X	X	X	X		X	X	X		X	X	X	X	X																														
B7																	X	X																											

Table 1 - Functional Allocation, Detection, Navy

removable system. With this logic in mind two major options were selected for the active sonar system. The hull mounted SQS-56 and an active towed array system called ATAS.

To analyze the active capabilities of the two systems a sample detection scenario was used and range detection predictions were calculated. The target of interest was a submarine with a Target Strength of 15 dB, at a depth of 150 meters in water 2000 meters deep. Assumptions made for the analysis included 50% probability of detection and straight ray path propagation. It was realized that the constant velocity sound propagation is not realistic but this was the best tool available for analysis. Actual propagation paths will be addressed in the discussion of the system selected. Factors considered in the calculation included; spreading losses, reverberation, ambient noise levels, array characteristics, power level, and geometry. The calculation spread sheets are included as Appendix (D) . The Signal Excess for the SQS-56 system is positive to a range of 30,000 meters while the Signal Excess for the ATAS is positive in excess of 40,000 meters.

The ranges from the sonar analysis are not important in themselves, but they do show that the ATAS outperforms the SQS-56. Another factor not considered in the model was self noise. The towed array system would see much less self noise than the hull mounted system which would improve the towed array's performance relative to the hull system. Another major consideration for the selection is the effect of velocity profile on prediction ranges. Because the propagation paths will not be straight, both systems should experience performance degradation. The degradation of the hull mounted system performance should be much greater than that of the towed array system because the hull mounted system operates above the surface layer while the towed system has the capability to be lowered to a depth of 300 meters. Based on this sonar analysis, the ATAS has better performance characteristics.

F. TRADE-OFF STUDY: RADAR

A table of detection ranges for various radars against the incoming threat missiles was created. To analyze radar performance, the characteristics of each radar were entered into known radar equations to compute signal excess versus range plots. From the signal excess plots and the radar cross section (RCS) of each threat missile, the maximum detectable range can be found. The table of detection ranges is located in Appendix (E).

The comparison of radar characteristics shows that a radar such as a SPY-1D with 5 MW of peak power has the longest detection range and can detect an incoming missile at the greatest range. This provides more time for the CPCX to react and defeat the incoming missile threat. A radar such as the SPS-49 has much less power output and shorter range detection capability. Power output is an important characteristic in the detection of a high flying or beam centered (CL) target. The detection of a sea skimming (SS) target is much more difficult than the detection of a high flyer. The sea skimming target is masked by the earth's curvature and its detection range is based primarily on the CPCX's height of radar. A height of 20 meters was used for all radar calculations.

Two radars which stand out in this analysis are the SPY-1D and XPAR or X-band Phased Array Radar. The XPAR is similar in design to a SPY-1D but operates with an X band frequency. The reduced size and weight of the XPAR are more compatible with a small ship design such as the CPCX. In addition, the X-band phased array design operates at a higher frequency and offers improved resolution over the S-band SPY-1D in open ocean and littoral environments.

G. MEASURES OF EFFECTIVENESS (MOE)

Measures of effectiveness were developed for each vital mission area as determined from the ORD. Each MOE provided a relative gauge of the Combat System capability with respect to cost in a specific mission area. A description of each MOE is located below.

The strike MOE equates the parameters used for the number of strike missiles (N_M), range (R), ability to target (P_T), circle error probability (CEP), ship cost (CS) and the number of missiles needed for a kill (N_K). The strike MOE evaluated the CPCX's capability to launch long range strike missiles against land targets. The Coast Guard Variant was not evaluated with this MOE because it was not expected to carry out strike warfare missions.

$$\text{Strike MOE} = \frac{N_M * R * P_T}{CEP * CS * N_K}$$

The air engagement MOE equates the parameters used for defense efficiency (DE), probability of kill given a hit for the ship ($P_{K/H}$), ship cost (CS) and the number of air defense missiles (N_M). The air engagement MOE evaluated the CPCX's capability to defend itself against enemy missiles. Both variants were evaluated with this MOE based on the threat of missile attack.

$$\text{Air Engagement MOE} = \frac{1 - [DE * P_{k/h} * N_M]}{CS}$$

The sub-surface engagement MOE equates the parameters used for number of vertically launched ASROC or VLA (N_A), range of VLA (R_A), number of surface vessel torpedoes (N_S), range of surface vessel torpedoes (R_S), effectiveness of MK 50 torpedo (P_K), and ship cost (CS). The sub-surface engagement MOE evaluated the CPCX's capability to defend itself against an underwater submarine threat. The Coast Guard Variant was not evaluated with this MOE based on little need for ASW detection capability.

$$\text{Sub-surface Engagement MOE} = \frac{[(N_A * R_A) + (N_S * R_S)] * P_K}{CS}$$

The Naval Gun Fire Support (NGFS) MOE equates the parameters used for number of guns (N_G), range of gun fire in kilometers (R_G), weight of each round (W), number of rounds (N_R), circle error probability (CEP), and ship cost (CS). The NGFS MOE evaluated the CPCX's capability to provide gun fire support. There was no requirement for the Coast Guard Variant to have a large caliber gun so the Coast guard Variant was not evaluated with the NGFS MOE.

$$\text{NGFS MOE} = \frac{N_G * R_G * W * N_R}{CEP * CS}$$

The patrol area MOE equates the parameters used for search width in nautical miles (W), velocity in knots (V), search time in hours (T), area of search in square nautical miles (A), and ship cost (CS). The patrol area MOE evaluated the CPCX's capability to effectively search large areas of ocean.

$$\text{Patrol Area MOE} = \frac{1 - \left\{ \left[e^{-(W*V*T/A)} \right]_{ship} + \left[e^{-(W*V*T/A)} \right]_{helo} \right\}}{CS}$$

The convertibility MOE equates the relative difficulty involved in the conversion of each major job. A numerical factor will be assigned to each major conversion job based on its estimated completion time. The scale below shows the weighting factors (RD) with the respective cutoff times:

RD=0.25 - Critical path job with estimated completion time greater than 14 days.
RD=0.50 - Non-critical path job with estimated completion time greater than 14 days.
RD=0.75 - Non-critical path job with estimated completion time greater than 7 but less than 14 days.
RD=1.00 - Non-critical path job with estimated completion less than 7 days.

The product of these conversion factors is the convertibility MOE which was evaluated for both Variants. Each Variant is required to be convertible to the other in a four week period.

$$\text{Convertibility MOE} = RD_1 * RD_2 * RD_3 * \ldots RD_n$$

The ship signature MOE equates the parameters used for ship displacement (LT), estimated stack temperature in degrees Celsius (T), estimated machinery plant noise in decibels (N), and ship cost (CS). The ship signature MOE evaluated the CPCX's susceptibility to acoustic and infrared detection.

$$\text{Ship Signature MOE} = \frac{1}{D*T*N*CS}$$

The boarding MOE equates the parameters used for number of boarding parties (N_P), number of small boats (N_B), Availability of boats (A_B), and ship cost (CS). The boarding MOE evaluated the CPCX's capability to conduct boarding operations.

$$\text{Boarding MOE} = \frac{N_P * N_B * A_B}{CS}$$

Table 2 - Navy Variant Whole Ship Options

	Option 1	Option 2	Option 3
Radar	SPY-1D	XPAR	SPS-49
	SPS-67	SPS-67	SPS-67
	TAS	-	TAS
ASW Sonar	SQR-19	ATAS	SQR-19
	SQS-56	-	-
Mine Sonar	SH-100	SH-100	SUTEC DOUBLE EAGLE
Passive Element	SLQ-32	SLQ-32	SLQ-32
	VIDEO/OPTICAL	VIDEO/OPTICAL	VIDEO/OPTICAL
	IR Mk-46	IR MK-46	IR MK-46
Helicopter	PANTHER	PANTHER	PANTHER
Small Boats	4	2	2
MFCS	MK 99	MK 99	-
Illuminator	SPG-62	SPG-62	-
GFCS	Mk 34 GFCS	Mk 34 GFCS	MK 86 GFCS
GFCS Radar	SPG-60/SPQ-9	SPG-60/SPQ-9	SPG-60/SPQ-9
ASW System	SQQ-89	SQQ-89	SQQ-89
ASW FCS	Mk-309 ASWFC	Mk-309 ASWFC	
Command & Decision	VOICE COMMS	VOICE COMMS	VOICE COMMS
	GPS	GPS	GPS
	TACAN	TACAN	TACAN
	IFF	IFF	IFF
	WCS	WCS	WCS
	ACDS	ACDS	ACDS
	CEC	CEC	CEC
	JMICS	JMICS	JMICS
Air Defense System	ISDS	ISDS	ISDS
Large Gun	155 mm	127 mm	127 mm
Small Gun/Point Defense	(2) CIWS	(2) 40 mm	(2) 40 mm
Launcher	Mk 49 (RAM)	Mk 49 (RAM)	MK49 (RAM)
AA Missile	RAM	RAM	RAM
Launcher	-	-	CANNISTER
Anti Ship Missile	HARPOON	HARPOON	HARPOON
Launcher	VLS	VLS	ABL
Strike Missile	TOMAHAWK	TOMAHAWK	TOMAHAWK
AA Missile	ESS	ESS	-
	SM-2 MR	SM-2 MR	-
ASW rocket	VLA	VLA	-
Torpedo Launcher	SVTT	SVTT	SVTT
	MK 50	MK 50	MK 50
Decoy	SRBOC	SRBOC	SRBOC
	NIXIE	NIXIE	NIXIE
Mine Disposal	EOD TEAM	EOD TEAM	EOD TEAM

Table 3 - Coast Guard Variant Whole Ship Options

	Option 1	Option 2	Option 3
Radar	SPY-1D	XPAR	SPS-49
	SPS-67	SPS-67	SPS-67
	TAS	TAS	-
ASW Sonar	SQS-56	-	-
Mine Sonar	SH-100	SH-100	SUTEC DOUBLE EAGLE
Passive	SLQ-32	SLQ-32	SLQ-32
	VIDEO/OPTICAL	VIDEO/OPTICAL	VIDEO/OPTICAL
	IR Mk-46	IR Mk-46	IR Mk-46
Helicopter	DOLPHIN	DOLPHIN	DOLPHIN
Small Boats	4	4	3
GFCS	MK 92 GFCS	GFCS	GFCS
GFCS Radar	CAS/STIR	GFCS RADAR	GFCS RADAR
ASW System	SQQ-89	-	-
ASW FCS	Mk-309 ASWFC	-	-
Command & Decision	VOICE COMMS	VOICE COMMS	VOICE COMMS
	GPS	GPS	GPS
	TACAN	TACAN	TACAN
	DATA FUSION	DATA FUSION	DATA FUSION
	WCS	WCS	WCS
	ACDS	ACDS	ACDS
	CEC	CEC	CEC
	JMCIS	JMCIS	JMCIS
	IFF	IFF	IFF
Air Defense System	ISDS	ISDS	ISDS
Large Gun	76 MM	-	-
Small Gun/Point Defense	CIWS (1)	(2) 40 mm	(1) 40 mm
Launcher	Mk 49 (RAM)	Mk 49 (RAM)	-
AA Missiles	RAM	RAM	STINGER
Torpedo Launch	SVTT	-	-
Torpedo	MK 50	-	-
Decoy	SRBOC	SRBOC	SRBOC
	NIXIE	NIXIE	NIXIE
Buoy Handling	CRANE and STOWAGE	CRANE and STOWAGE	CRANE and STOWAGE
Mine Disposal	EOD TEAM	EOD TEAM	EOD TEAM

The overall MOE equates the individual MOEs discussed above with an individual weighting factor for the relative importance of that MOE against the other MOEs. The equation below shows the overall Measure of Effectiveness:

$$MOE_{overall} = \sum MOE_i * WF_i$$

H. WHOLE SHIP OPTIONS

The functional allocation requirements and individual system evaluations were used to define three whole Combat System suite options for the CPCX. These whole ship options are shown in Table (2) for the Navy Variant and Table (3) for the Coast Guard Variant. The Combat System elements chosen for each whole ship option were analyzed on the basis of satisfying operational requirements and performing warfare functions in the detect, control, engagement sequence. The functional allocation tables for each whole ship option are contained in Appendix (F). Each whole ship option has varying capabilities and cost, but all options satisfy the requirements in the ORD and defeat the projected threats.

I. ELEMENT VS. ELEMENT INTERFACES

The Combat System suite for each whole ship option was placed in a table to develop the architecture for each suite. Each specific element was linked to other elements in the system by means of either an electrical, data, mechanical, or logical interface. These interfaces show how the whole system will be connected and provide a basis on which to develop the Combat System architecture. The systems chosen drove the Combat Systems architecture or Ring Information Network (RIN). The network is depicted in Figure (1), which shows how the information from outside the loop is used to make decisions inside the loop and then flows back out to be implemented. The Element Interface Tables are included in Appendix (G).

J. ELEMENT VS. SHIP SUPPORT SYSTEM

A table of ship support systems for each Combat System element was developed. The first of three whole ship options was used to generate the table, which is included as

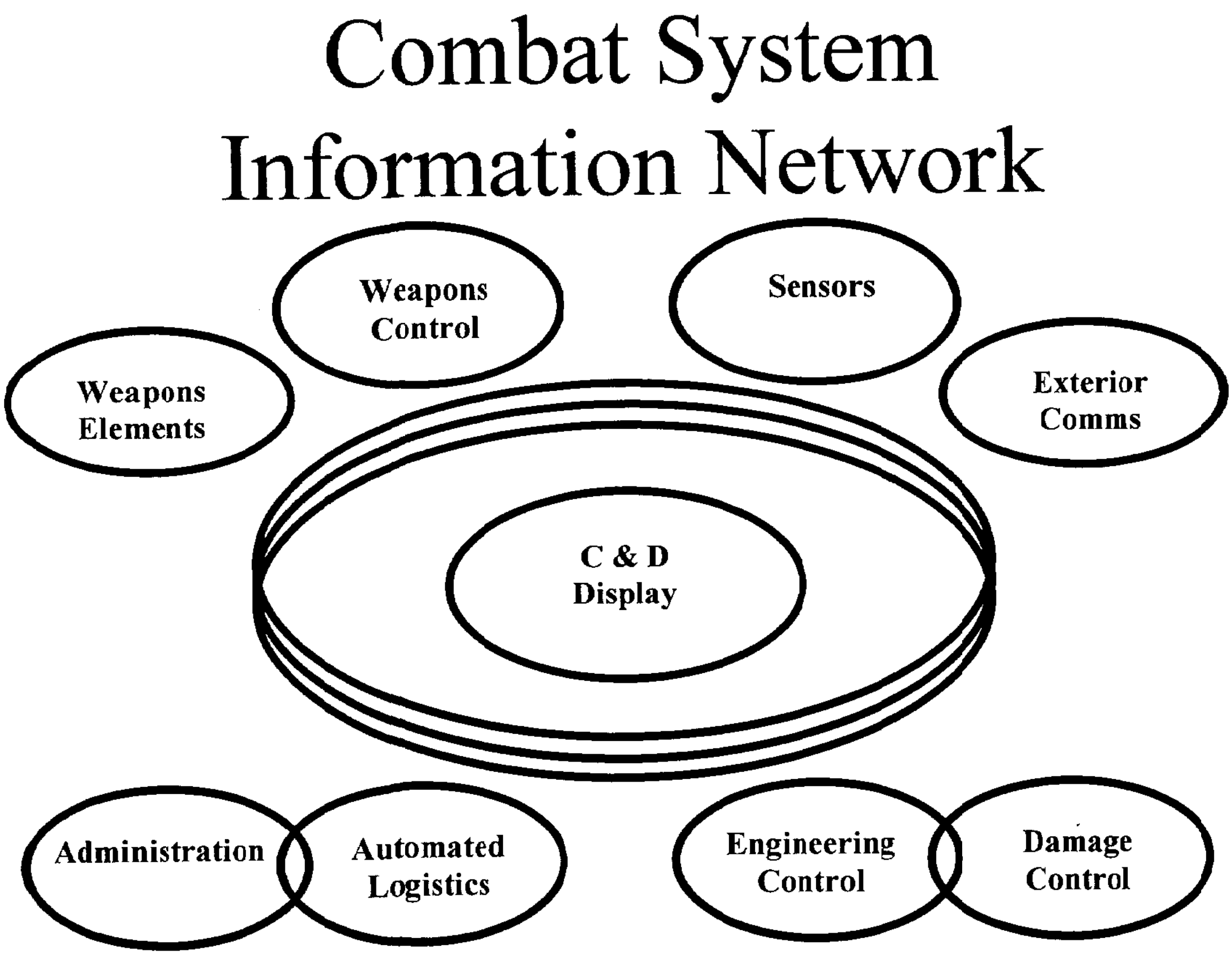


Figure 1. Combat System Architecture - Ring Network

Appendix (H). This ship option had the most equipment and the other options could be characterized as a subset of the first ship. For the most part, the support system interfaces were determined from experience and the TS4000 course notes. Almost all of the elements required electric power. The shipboard electric distribution system is not specified. It could be either AC or DC. The type of electric power is only specified for 400 Hz power. The 400 Hz power is used mainly in topside equipment to reduce the size and weight of motors.

During the preliminary design of a single ship option, the exact requirements for each system will be investigated to determine the capacity required for the individual support systems. The shipboard electric distribution will be finalized and sized to allow for growth and emergency backup capacity.

K. ELECTROMAGNETIC INTERFERENCE (EMI):

To provide a basic gauge of which systems are likely to induce or be subjected to EMI, a table of operating frequencies was developed. This table is included as Appendix (I). The EMI table shows the frequency band where each Combat System element operates. The L and X frequency bands contain most of the Combat Systems elements and are the areas most likely to experience EMI. The X band is shared by the surface search radar, fire control radars and SHF communication frequencies. The L band is shared by the TAS, IFF, TACAN and VHF/UHF communication frequencies.

L. ANALYSIS OF OPTIONS

After researching Combat System suites and choosing three whole ship options, each option was again dissected to come up with the "best" choice. The following tools were used for this process: Warship 21, self-defense engagement scenarios, and MOE analysis.

1. Warship 21 Analysis:

Warship 21 provided initial cost and size data. Each option's payload was entered into Warship 21 along with a standard propulsion and electrical plant that met the ORD requirements of sustained speed and range. The program provided cost data which was used as input for the MOEs. The printouts from Warship 21 are included in Appendix (J).

2. Self-Defense Engagement Scenarios:

Engagement scenarios were completed on each option to determine whether the combat systems payload could meet the prospective threats as defined by the ORD. Defense efficiencies were calculated from the engagement scenarios. Self-defense data is included in Appendix (K). This data includes a sample engagement description, summary table of defense efficiencies, and the individual engagement diagrams.

3. MOE Analysis:

The MOEs described earlier were used to quantify the relationship between each whole ship option. Data collected from individual system characteristics, Warship-21, and self-defense engagements were used with the MOE equations to determine which ship option was most effective in each mission area. Weighting factors were then used to indicate relative importance of each mission area and the overall MOE for each option was calculated. A summary of the MOE tables are contained in Appendix (L). The highest overall MOE was used to select the recommended Combat System payload for each variant.

M. RECOMMENDATION, NAVY

All three whole ship options met or exceeded survivability requirements and are feasible. The balance of requirements and costs led to the conclusion that the "Option Two" vessel was the best solution to the diverse requirements established by joint inter-operability, convertibility, survivability and broad utility as reflected in the MOEs. Option One, which included high-end systems offered increased capability but at a higher cost, which approached the maximum ship cost leaving no margin for unforeseeable costs. Option Three, which included low-end systems appeared to meet all requirements and was rapidly convertible but lacked significant offensive payload. The chosen option offers a formidable weapon payload capable of effective self-defense against sea skimming missiles, strong offensive firepower to strike targets tens of miles away, and rapid conversion to a Coast Guard Variant. The broad spectrum of possible options presented by modular combat systems allows the chosen option to be improved with future combat system upgrades as they become available. Option Two provides the most balanced design between cost and capability for a small naval combatant for the 21st Century.

N. RECOMMENDATION, COAST GUARD

All three whole ship options met or exceeded survivability requirements and are feasible. The balance of requirements and costs led to the conclusion that the "Option Two" vessel was the best solution to the diverse requirements established by joint inter-operability, convertibility, survivability and broad utility as reflected in the MOEs. Option One, which included high-end systems, offered increased capability but at a higher cost which exceeded the maximum ship cost. This option also included a sonar system which is not necessary for the Coast Guard mission but was included to enhance convertibility in the event the Navy chose Option One. Option Three, which included low-end systems, appeared to meet all requirements but was more difficult to convert to an effective Navy variant. The chosen option offers a formidable weapon payload capable of effective self-defense against sea skimming missiles, adequate offensive firepower to conduct Enforcement of Laws and Treaties, and rapid conversion to a Navy Variant. The broad spectrum of possible options presented by modular combat systems allows the chosen option to be improved with future combat system upgrades as they become available. Option Two provides the most balanced design between cost and capability for a Coast Guard Cutter for the 21st Century.

III. COMBAT SYSTEMS JUSTIFICATION

The following is a brief summary and justification of each combat system element included in the design.

A. DETECTION SYSTEMS

1. Air Search Radar: XPAR (1)

The X-band phased array radar (XPAR) incorporates most of the capabilities of a SPY-1D, in a scaled down version. XPAR's higher frequency allows the radar's dimensions and weight to be reduced significantly while it provides long range detection, tracking and over-the-land capability. It is capable of surface search, air search, fire control, and navigation. The non-rotating antenna design promotes stealthy architecture. The XPAR looks to the future as radars continue to get smaller and lighter.

The Navy variant was required to defend against three sea skimming missiles in a period of one minute. This requirement drove the need for a high performance radar that could detect this threat and provide an instantaneous fire control solution to fire weapons in defense. The Coast Guard variant was not faced with this same threat, but the XPAR was included as part of its Combat System suite to minimize conversion issues.

2. Surface Search Radar: SPS-67 (1) & Furuno (1)

The SPS-67 will be employed as the primary surface search radar, with the primary navigation radar, the Furuno, as the backup. Both radars are currently in use on numerous naval craft surface craft and thus do not require any additional research and development or operational testing. The combination of these two radars provides for excellent navigation functions and target resolution in a modern, lightweight package.

3. IR Search: MK 46 Electro-Optical detector (1)

The MK 46 will be used for infrared detection and tracking. IR in combination with the video/optical system provides visual pictures during low light and adverse weather conditions. Additionally, the MK 46 can detect heat plumes of sea skimming missiles over the horizon, enhancing self defense capability.

4. Helicopter: HH-65 Dolphin (1) USCG AS-565 Panther (1) USN

The Dolphin is currently in use by the Coast Guard and many foreign navies. It is lightweight, compact and offers a good balance between long range capability and mission flexibility. The militarized version of the HH-65, Panther, will be utilized with the Navy variant. It is capable of carrying sonobuoys and torpedoes for ASW as well as air-to-surface missiles for surface engagements and over-the-horizon targeting.

5. Identification: Identify Friend or Foe (IFF)

IFF will be used as an identification system to differentiate enemy from friend. In today's and the future's battle situation, IFF will play a key role in preventing fratricide.

6. ESM: SLQ-32(V)3 (2)

The SLQ-32 is the standard system for active/passive electronic support in the U.S. Navy. It provides highly directional electromagnetic detection and jamming capability to enhance survivability characteristics.

7. Sonar: Active Towed Array Sonar (ATAS) (1)

ATAS provides the capability of an active hull mounted sonar with the flexibility and modularity of a tail which can be easily removed to meet conversion requirements. The lack of a required Coast Guard sonar capability along with the inherent limited effectiveness of a hull-mounted sonar, eliminated the hull-mounted sonar from consideration. Other factors such as the extra weight, volume, cost and maintenance associated with a hull mounted sonar contributed to its elimination.

8. Mine Sonar: SH-100 (1)

The hull mounted SH-100 provides mine localization and identification up to 1000 meters. Additionally, it provides bottom mapping and survey capability. The SH-100 is retractable and accessible from within the ship for ease of operation and maintenance. The SH-100 is installed in both the Navy and Coast Guard variants.

B. COMMUNICATIONS

1. External Communications: (Misc.)

The communications suite will consist of the following types of equipment: HF, UHF, VHF, and SATCOM. The ship will have the ability to access any and all strategic or tactical data networks, such as JMCIS or ACDS and CEC networks. Cooperative Engagement Capability (CEC) allows the CPCX to conduct engagements cooperatively with other ships. The goal is real time communication for worldwide connectivity.

2. Internal Communications (Misc.)

The interior communication system will consist of a fiber optic digital multiplexing system for voice and data distribution, with traditional sound powered phones and portable wire-free radios for damage control and emergency backup voice communications.

C. WEAPON CONTROL SYSTEM

1. Missile Fire Control System: MK 99 (1)

The MK 99 MFCS uses the XPAR to control SM-2 anti-aircraft missiles in flight. This system is currently used by all Aegis cruisers and destroyers and will require little research and development to integrate the Mk 99 with the XPAR.

2. Gun Fire Control System: MK 34 (1)

The MK 34 fire control system allows the use of the XPAR as a gun fire control radar. This eliminates the need for additional radars, reducing cost and topside weight.

3. Anti-Submarine Warfare Fire Control System: MK-309 (1)

The ASW fire control system to be used with the ATAS, Vertical Launched ASROC (VLA), and Surface Vessel Torpedo Tubes (SVTT).

D. NAVIGATION SYSTEM

1. Navigation radar: Furuno, GPS, TACAN (1 ea.)

The Furuno radar is a commercial grade, low cost navigation radar. It was chosen over the SPS-64 because it is cheaper and easier to operate. It does, however, introduce an interface problem that needs to be solved. In addition, the Global Positioning System (GPS) will be used for accurate automated navigation. Portable GPS units will be used for small boat navigation. TACAN will be used for helicopter support.

E. ENGAGEMENT/WEAPONS

1. Long Range Intercept Missile: SM-2 MR (12 cells), ESS (4 cells)

After debating the various missile parameters, SM-2 was chosen for long range intercept of air targets. It offers accurate, long range capability and future upgrades and blocks within the standard missiles series will offer even greater capability including Theater Ballistic Missile Defense (TBMD). It is U.S. made and a standard on U.S. Naval combatants. Enhanced Sea Sparrow (ESS) was chosen for intermediate engagements, thereby increasing the number of missiles carried and improving engagement flexibility. Both missiles are fully compatible with the vertical launching system.

2. Short Range Intercept Missile: RAM (21)

The Rolling Airframe Missile (RAM) was chosen as the short range missile for intercept of airborne targets. It offers passive IR and RF guidance and a trainable launcher for short range, high speed intercepts.

3. Anti-Ship Missile: Harpoon (8 cells)

The upgraded version of the Harpoon, featuring IR capability and VLS compatibility, will be used. The Harpoon offers long range anti-ship capability. The innovative feature of the missile is that it will be launched from the Vertical Launching System, thereby eliminating the need for a separate launcher.

4. Land Strike Missile: Tomahawk (9 cells)

The Tomahawk missile provides the capability to destroy or neutralize enemy targets ashore. It was chosen for the strike mission because of its high performance level and integration capability with VLS launcher.

5. Point Defense System: Bofors L70 40mm gun (2)

The 40mm guns serve dual purposes. They will be used for ultra-short range (point defense) airborne target intercept and in a more traditional sense as a self defense weapon against small surface targets. The need for a separate "CIWS" system is eliminated saving weight, space, and cost.

6. Small Caliber Gun: Bofors L70 40mm (2)

As stated above, the 40mm gun serves a dual purpose. The 40mm gun enhances the AAW point defense capability, improves self defense capability, and provides a meaningful weapon against small boats for boarding operations.

7. Large Caliber Gun: 5" -54 MK 45

The 5" gun provides the Navy variant with the capability to provide firepower support for amphibious and other ground forces. It is the standard U.S. large caliber gun for naval combatants and has the capability of accepting barrel and propellant source upgrades for future munitions.

8. Torpedo: MK 50

The MK 50 torpedo will provide the Navy variant with ASW engagement capability. It will be launched from the SVTT MK 32 torpedo tubes or with the Vertical Launch ASROC (VLA) launched from the VLS.

9. Missile Launching System: Vertical Launch System (VLS)

The VLS will hold SM-2, ESS, Tomahawk, Harpoon, and VLA missiles. This launcher configuration eliminates the need for additional launching systems. Topside space is made available and radar cross section is be reduced.

F. COUNTERMEASURES

1. ECM: SRBOC, NIXIE, SLQ-32(V3) (Misc.)

All available countermeasure systems will be used. The anti-missile versions will be launched using the MK 36 Super Rapid Bloom Offboard Countermeasures (SRBOC) Launcher. The SRBOC munitions provide protection against missiles with active and passive radar and infrared homing systems. New countermeasures under development will be incorporated into the system.

IV. PRELIMINARY DESIGN PHASE

A. COMBAT SYSTEMS ARCHITECTURE

1. Design Statement

The CPCX Combat System and supporting elements are designed to meet the requirements delineated in ORD. Specifically, the combat system must:

(a) Provide anti-air self-defense against limited intensity threats;

(b) Provide anti-surface defense against third-world surface naval forces;

(c) Provide anti-submarine defense in deep and shallow water while employed independently;

(d) Provide firepower support for amphibious and other ground forces;

(e) Destroy or neutralize enemy targets afloat and ashore through the use of coordinated, precision strike weapons;

(f) Conduct engagements cooperatively with other ships, submarines, aircraft, space systems, and land systems;

(g) Detect and chart underwater mines;

(h) Defend itself against raids of 3 ASCM's arriving within a one minute interval;

(i) Be capable of joining the Naval Fleet in joint operations and during time of war;

(j) Provide coastal intelligence gathering.

2. Top Level Design Goals

Based on the above requirements, the top level combat system design goals are:

(a) self-defense;

(b) discriminate targets minimize unwanted damage;

(c) fight hurt--minimize damage by effective assessment and rapid restoration;

(d) continuous high readiness for extended periods;

(e) self-sufficient, capable of independent or small group operations;

(f) reduced manning;

(g) built in automatic reconfigurability of ship's based on evolving threat scenario/condition;

(h) built in fault identification with rapid repair capability; and

(i) combat system automation with preset options for layered self-defense.

3. Combat System Description and Capability

Figure 2 depicts the functional arrangements of the CPCX combat system. General design attributes include:

(a) Primary connectivity between elements is provided by a multi-channel, multi-redundant fiber optic ring bus. Envisioned is a series of five functionally redundant data buses geographically separated within the ship to decrease vulnerability. Each system has multiple channel capacity and each channel has the capability to carry multiplexed data. Determination of data types and flow that allow use of multiplexing vice dedicated channels must be determined during detailed combat system design. The application of the Fiber Optic Data Multiplexing System (FODMS) and Fiber Optic Interior Voice Communications System (FOIVCS) improves capability and enhances survivability while reducing ship acquisition cost, primarily via the associated weight and volume savings.

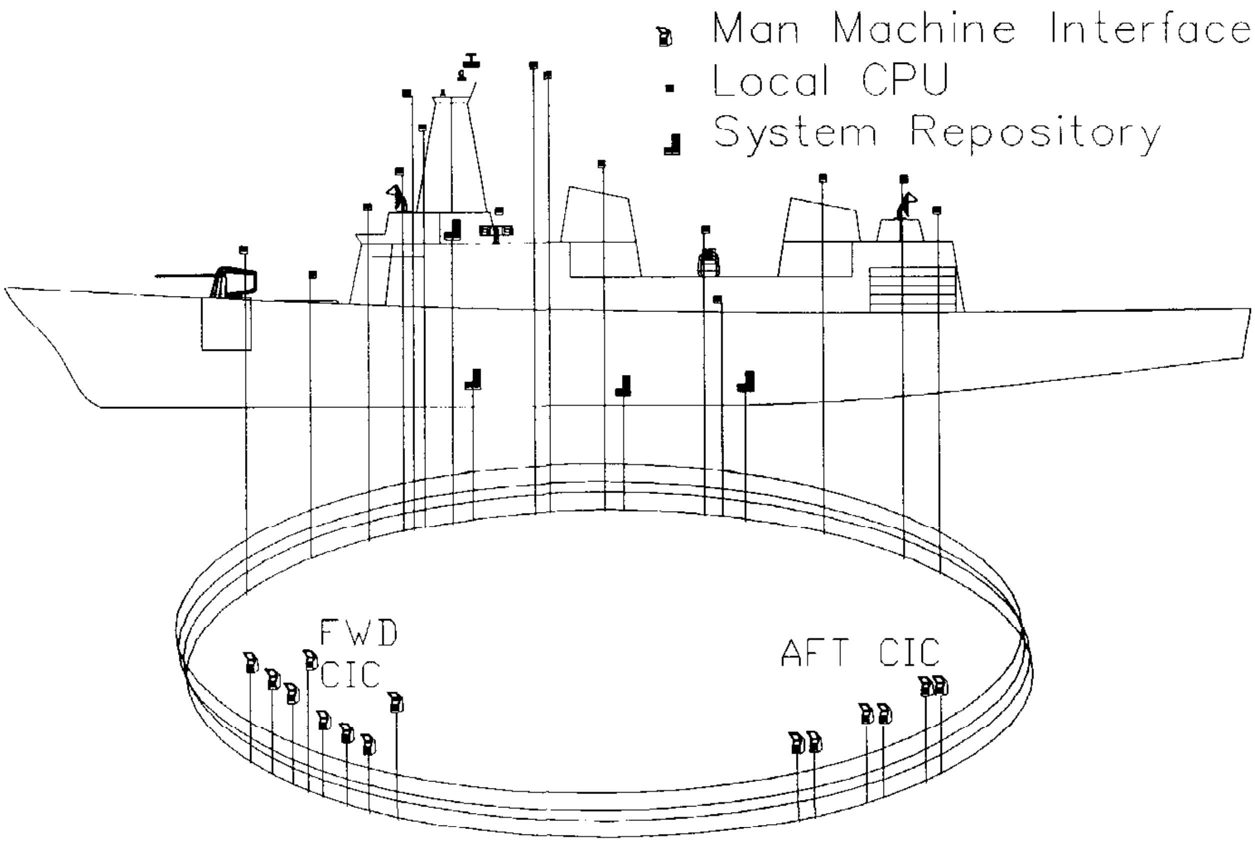


Figure 2 Ring Information Network Distribution

(b) The processing capabilities for all shipwide systems are distributed throughout the ship instead of being located in one central location. There will be no "central computer" in the traditional sense . The computer processing power required by all combat systems is distributed among the individual elements and linked by the fiber optic ring bus. This distributed processing capability provides redundant computational capacity and eliminates processing bottlenecks. The system will contain the following types of hardware:

(1) System Repository Units. These units perform the system control functions and provide the system software storage capability. There are four of these units distributed throughout the ship. This ensures that the system will have a control station in the event of a casualty to the system or battle damage.

(2) Multipurpose Man Machine Interface (MMI) Consoles. These represent generic, programmable operator interface consoles that provide the man/machine interface for the combat system elements or administrative data elements. These consoles are militarized versions of modern, commercial workstations. They allow the operator to access all information on the data bus and perform the watch station functions as required by the watch organization or administrative duty. Each MMI unit will contain processor hardware.

(3). Local element processing units. Each Combat System element will have a local processor unit designed to function primarily as the processor for that element. The system control station will have the capability to access the local processor to perform other system functions as necessary.

(c) The system is design to integrate not only the combat system elements, but also other functions vital to the ship's mission. Engineering and Damage Control stations will be included to automatically provide up to date equipment status to the decision makers. Automated logistics functions will be performed to reduce equipment downtime and all administrative functions will be maintained electronically to eliminate paper.

(d) Two manned Combat Information Center (CIC) spaces are provided. CIC #1 is the primary control space and is supported by CIC #2. Although the spaces are designed to function as a single control unit, equipment functional redundancy is provided between the two spaces to allow a single space to function individually if necessary. The processing equipment, display panels and number of control operator stations are almost identical. The two CIC's are located in separate enclaves to improve survivability. The elements in the spaces utilize all available sensors and external information data stream to provide the necessary information to create a complete tactical picture.. The tactical picture created must be complete and coherent enough to provide necessary reaction time for ship defense. The major functions performed by the combat system elements are:

(1) Detection. These elements determine contact detection and develop basic track data on contacts. The elements exports the track data to the ring bus for distribution and use by other combat system elements. This function is performed by sensor equipment including, but not limited to AN/SPS-67 radar, X Band Phased Array radar, ATAS, AN/SLQ-32, Helicopter sensor suite, and all other passive or active elements.

(2) Control. These elements perform all control functions to go from contact detection to contact engagement. Track data from various detection elements on and off the ship is correlated and integrated into central track files. Track correlation contact parameters are initially fed into the ring bus. The next control functions are threat assessment as friendly, neutral, or enemy. The system then coordinates engagement decisions and sets the engagement priorities. Additionally, it coordinates own ship operations with the operations of other ships or aircraft in the task force. The system is capable of fully automated ship self-defense operation. The level of automation employed is determined by the Commanding Officer based on the tactical situation. Weapons selection and engagement coordination is also performed by these elements. The system maintains an inventory of available ordnance and carries out the engagement planning

needed for weapons release. The system coordinates the use of individual weapon elements to prevent interference between own ship weapons and damage to friendly forces. Following engagement battle damage assessment is also performed.

(3) Engagement. These elements deliver ordnance on target at the direction of the control elements. The necessary data for engagement is relayed by the ring bus. These elements are the guns, missile launchers, active countermeasures, torpedoes and all other similar systems.

(e) The power interface module provides the interface management function between the ship's engineering plant electric plant control module and the combat systems with regards to load shed command and coordination. The primary backup system is an uninterruptable power supply (UPS) which provides short term power backup. If there is continued loss of electrical generation capacity due to casualty, the electric plant control module sends a load shed command to the combat system, essentially conveying available generating and bus configuration. The interface module communicates with the control element to determine combat system needs commensurate with tactical situation. With a balance between power requirements (demand) versus generating capacity, the power system interface module transmits shut down commands to appropriate combat system elements and also communicates electric plant reconfiguration requests to the electric plant control module.

(f) Readiness assessment, fault detection and localization. The survivability management and readiness assessment (SM/RA) module works in conjunction with the various combat system element's built-in test and evaluation (BITE) capabilities to provide an integrated system readiness assessment. All the combat system elements must have this BITE capability. An additional BITE feature is the requirement that all combat system elements provide automated troubleshooting capability. This enhances fault localization and subsequent repair to place equipment fully operational in as short a time as practical. The readiness assessment sub-module provides the commanding officer (CO) and tactical action officer (TAO) with a real-time comprehensive assessment of the ship's ability to continue fighting. Additionally, it enables the combat information center officer of the watch (CICO) and engineering officer of the watch (EOOW) to better coordinate efforts to maintain/recover mission readiness prioritized to current mission needs. The readiness data includes current status of mission capabilities, times to failure and times to recovery. Readiness data is obtained from all systems including auxiliaries that supply the individual combat systems.

(g) Survivability and reconfigurability. System survivability is enhanced by a number of design features, including:

(1) dual Control element functionality geographically separated in CIC #1 and CIC #2;

(2) multiple, distributed processing capabilities;

(3) multiple redundant connectivity between all combat system elements;

(4) graceful degradation of overall system capability due to power loss through the uninterruptable power supply and smart load shed management. With the available redundant/alternate functional capabilities, system reconfiguration is practical to optimize combat system employment during casualty conditions.

(h) Embedded training. The integrated combat system includes an embedded training module to allow realistic threat scenario engagement exercises. These training scenarios will exercise the control elements and watchstanders. Essentially, this entails the capability to run pre-programmed engagement scenarios by injection of track and other necessary data directly onto the data bus.

(i) Embedded support service management. Primary support services for the combat system are electrical, chilled water, sea water, ambient space cooling and high pressure air. With the zonal scheme, each zone has fully self-contained capability with the exception of electrical power generation. Status of these systems is maintained by Damage Control Central (DCC) and the engineering plant status module. Support service configuration is coordinated with required combat system capability as determined by the tactical situation during casualty situations. Maximum capability will be maintained consistent with available capacity remaining during casualties. With input to/from the survivability management system, certain automatic damage control actions can be accomplished before a weapons hit occurs.

(j) Automated Communications Suite. To enhance manning reduction and increase external communications, the external communications suite is automated. This automation allows incorporation of the external communications function as an integral part of the integrated combat systems suite. Features such as automated electronic message routing with dispersed remote terminals streamline message dissemination. Automated external connectivity allows integration of the ship in a task force/battle group scenario. Export of sensor data and import of weapon command functions to extend the integrated fighting power of the task force/battle group. Import of real time data from outer sources provides a coherent, integrated picture of the battle space. With continuously updated information, the ship could support or be supported by other ships, engaging targets its own sensors cannot detect.

B. HULL, MECHANICAL AND ELECTRICAL (HM&E) ARCHITECTURE

The CPCX HM&E architecture was developed using Advanced Surface Ship Evaluation Tool (ASSET). ASSET can be used to construct a model of a entirely new ship, or a modification of an existing ship. ASSET uses historical data and empirical formulas to model the ship's geometry, its powerplant, weight, performance, cost, manning, etc. It is used as a preliminary design tool to determine whether or not a proposed design is feasible. ASSET is a powerful tool, but has it's limitations. The biggest limitation appears to be that it can not model what has never been tried before, either for a new hull design or a non-traditional use of a existing system.

1. Ship's Power Generation and Distribution System

A variety of engineering configurations were evaluated using ASSET. The combination of endurance and displacement requirements demanded a low volume, low weight, high efficiency power plant. The CODAG/Integrated Electric Propulsion offered the lightest vessel that met our requirements for speed, endurance and payload. The Additional benefits of the electric drive ship are numerous, including:

- More flexible power generation arrangements
- More freedom in plant arrangements
- Propulsion arrangement is not limited by shaft alignment
- Propulsion prime movers and generators can be smaller and more numerous
- Power can be generated in the most convent and/or efficient wave form
- More adaptable to future growth:
    - Directed energy weapons
    - ETC Gun Technology
    - Design conversion to fuel cells
- Better fuel economy

- Capability of operation at the most economic engine combination at any given speed
- Active Ship silencing capability
- Allows the power to the main engines to be adjusted to counteract cyclic load imbalances in order to reduce propulsion generated vibration

HULL, MECHANICAL AND ELECTRICAL (HM&E) ARCHITECTURE

1. Ship's Power Generation and Distribution System CPCX uses an integrated Combined Diesel and Gas Turbine (CODAG) Power Off Main Bus (POMB) propulsion/ships service power plant. The power plant architecture consists of the following functional areas: power generation, power distribution, power conversion and conditioning, power storage, system loads, system control and information.

(a) Power Generation

There are four power generation sets,: two LM-1600 ICR gas turbines, each driving a 15 MW generator, and two Alco 12V270 diesels, each driving a 3000 KW generator. The power output is multiphase AC that is immediately rectified to DC for distribution on the DC Zonal Electric Distribution System (DC ZED).

(b) DC Zonal Electric Distribution System.

The power distribution system consists of port and starboard main busses feeding distribution zones as shown in Figure 3. The main lines aft of No. 1 ER are sized to provide full propulsion power on via either main bus. Portions of the main bus that are not expected to carry propulsion loads are sized to carry a full combat load.

(c) CS power supplies

The use of the DC ZED system allows multiple source paths without complex paralleling and switching systems. The power supply to the CS takes advantage of this ability by providing disbursed supplies from each of the main generators and

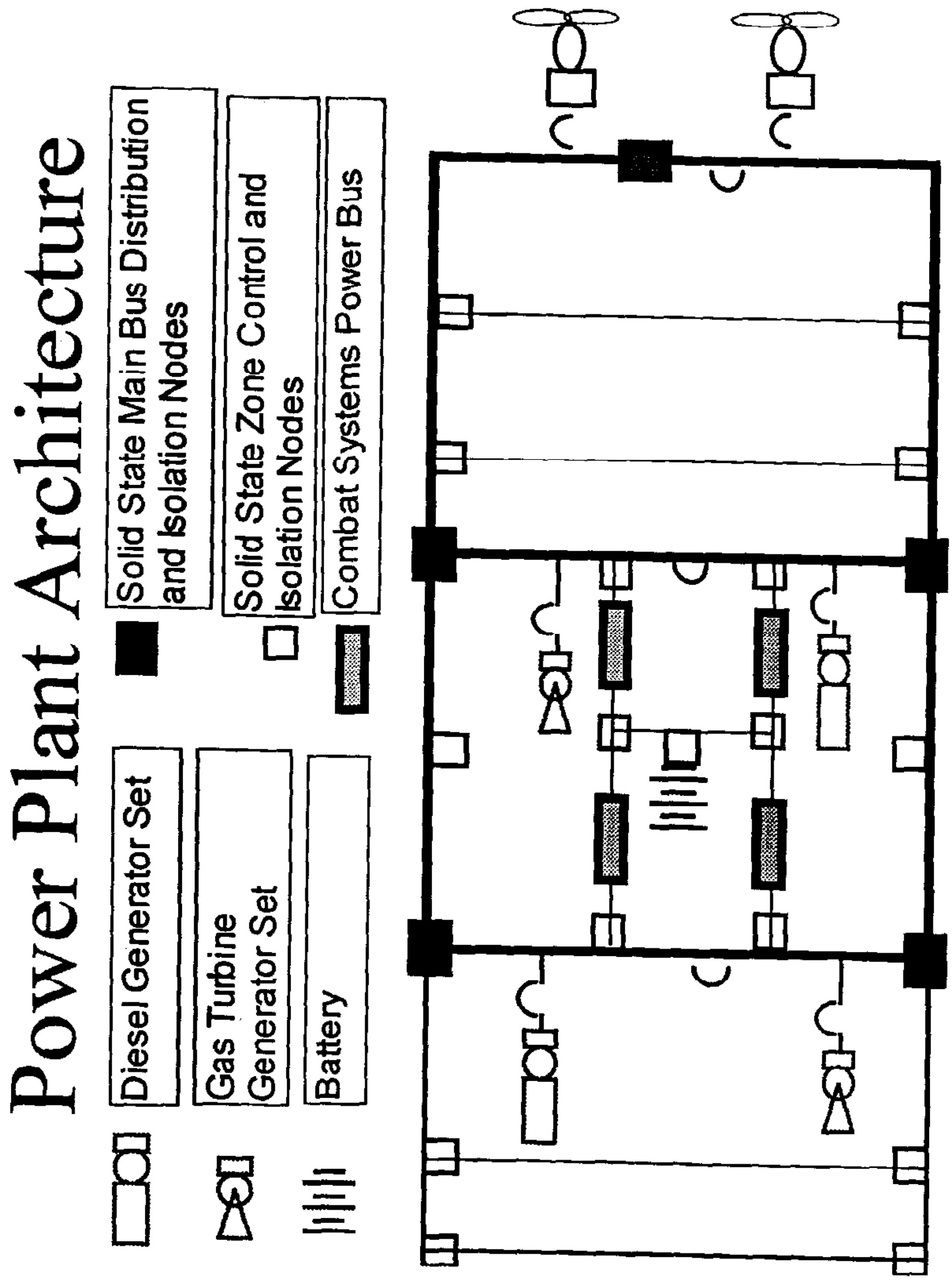


Figure 3 Electrical Distribution System

directly from the battery as shown in Figure 3. The four Combat System power buses (CSPB) are electrically the closest to the generators and the battery, Isolation and switching nodes can protect the CSPB's from abnormalities on the rest of the distribution system. The solid state controllers and isolation and switching nodes can present the combat system with an "infinite" bus as long as there is sufficient power available.

(d) Battery backup

To maximize survivability and system flexibility, a 30 ton battery was installed to provide emergency power in the event that all main generators go off line. The primary advantage of this, is that the battery is static and thus not as susceptible to shock as the generators. It will provide bus inertia and stability during shock events and continuing power when the generators trip off line on impact. A secondary but no less desirable benefit of the battery is the ability to cruise using the most efficient power plant alignment. Figure 4 shows the power generation requirements vs. speed for CPCX. It is important to note that most speeds can be attained using one gas turbine or two diesels engines operating at a moderate to heavy loaded. The battery allows operating turbines at their most efficient loading without compromising combat readiness of the ship during cruising and patrol/loitering operations. The ability to provide uninterrupted power during casualty loss of generators is also beneficial during Restricted Maneuvering conditions wherein the ship would still be able to maintain bare steerage propulsion and rudder control. The battery would also help reduce the run time on the ships engines, since only those engines required to provide power need be running. Standby engines can be started when necessary and can be allowed to pre-lube and soft start rather than emergency start at the lose of the on-line units (tactical situation permitting)

(e) Control and Monitoring

The power distribution system is overlaid with fiber optic control and monitoring network. This network connects the solid state controllers of the ships equipment to the control stations and monitoring computers. The solid state controllers effectively isolate the individual loads from the main bus and allow more accurate

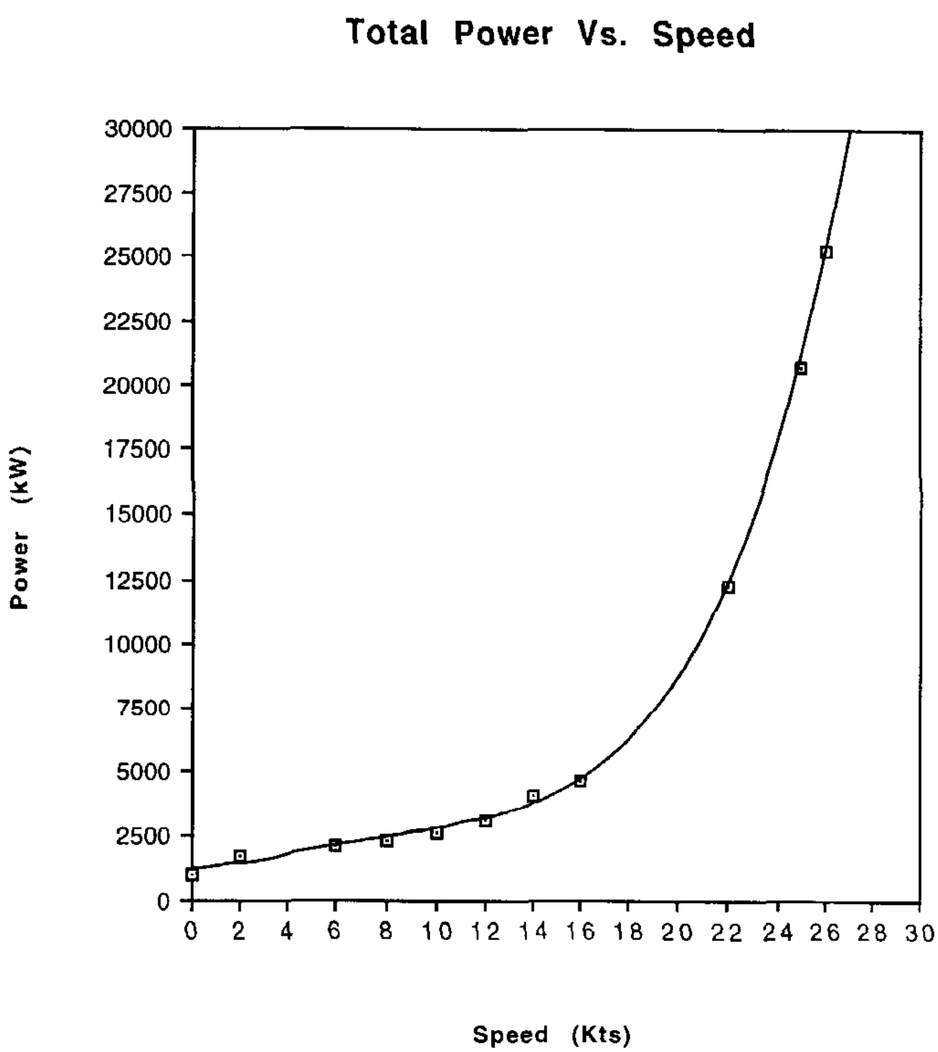


Figure 4 Power Curves

monitoring of cyclic load fluctuations of the individual loads. Central monitoring and control of the ships equipment allows more accurate failure analysis, faster fault detection and isolation, and smarter, more effective load shedding and load restoration. Automatic central control and monitoring greatly enhances the ability to implement condition based maintenance and significantly improves trend analysis and reduces the need for paper equipment logs.

2. *Hull, Mechanical and Electrical Arrangements*

(a) Machinery Spaces

The CPCX incorporates two main machinery spaces, Engine Room 1 (ER1) and Engine Room 2 (ER2). Each engine contains two power generation sets (gensets), one gas turbine and one diesel. The gas turbine gensets consist of General Electric LM1600 RGT, producing 15,902 Bhp, which is connected to a 14.94 MW AC generator. The diesel gensets consist of a Alco 12V270 producing 4000 Bhp, driving a 3,000 kW AC Generator. The AC power produced by the generators is rectified to DC for propulsion power and ship's service distribution throughout the ship. Both engine rooms are completely independent of each other with respect to support equipment.

Below is a listing of the major machinery components found in the engine rooms.

EQUIPMENT	NUMBER INSTALLED (per Engine Room)
Gas turbine genset module	1
Diesel genset	1
Lube oil service and purification system	1
Fuel oil service and purification system	1
High pressure air compressor	1
Low pressure air compressor (ship's service)	1
Power Conversion Modules	As required

Power Distribution Modules	As required
Machinery Control Equipment (local)	As required
Jacket water system (Diesel cooling)	1
Salt water cooling system (Diesel and generators)	1
Fire Suppression and Extinguishing System	1
Bilge Eductor	1
Machinery Room Ventilation System	1
Anti-roll fin system (in ER2 only)	1
Auxiliary Boilers (electric powered)	1

(b) Auxiliary Machinery Spaces

The CPCX incorporates 3 Auxiliary Machinery Spaces (AMS1,2 & 3), all on the fourth deck. AMS1 is located just aft of the VLS compartment, and includes access to the mine detection sonar trunk. Major equipments found in AMS1 include a vacuum type sewage collection, holding and transfer system that serves the forward end of the ship. A fire pump, air conditioning plant, fuel oil distribution manifold.

AMS2 is located between ER1 and ER2 and contains the reverse osmosis/potable water system, fire pump and air conditioning plant for the middle of the ship.

AMS3 is located aft of ER2. Its major equipment is the oily water separation system, and the third fire pump.

(c) Miscellaneous Engineering Spaces

The Miscellaneous Engineering Spaces include the Pod Machinery Room, After-Steering, stern launch area and the assorted shops (Machine, Electrical, Filter, and Damage Control).

The Pod Support Room will contain the Power Conditioning Modules (PCMs) for the motors in the pods. After steering will contain the steering gear and associated equipment, while the stern launch area will contain ATAS or boats and NIXIE equipment, as well as handling equipment.

It is in the stern launch area where the most noticeable HM&E difference between the Navy and Coast Guard version exists. For the Coast Guard variant, this is the location of the Aft Boat Launch and Retrieval System. It consists of a pivoting, semi-buoyant, V-shaped ramp, which is lowered (drawbridge style) into the wake to allow for Rigid Hull Inflatable launch and recovery. The ramp is a steel framework, with rubber rollers along the sides of the V, much like a recreational boat trailer. The Navy variant will also have a similar system for launching and handling ATAS.

(d) Fuel Capacities

All diesel fuel tankage is distributed on the 3rd and 4th (inner bottom) decks of the CPCX Navy version. The Coast Guard version retains all of the Navy tanks and adds 7 more at the bottom of the VLS well and below it. The total diesel fuel tankage for the Navy Version is 143,976 gal. (466.6 ltons) and 183,160 gal. (593.6 ltons) for the Coast Guard version. The additional weight of the Coast Guard tankage, is offset by the removal of the VLS and the 5" gun and its ammunition. Both versions also carry 23,578 gal. (71.3 ltons) of JP-5 aviation fuel. The JP-5 tank is also located in the inner bottom, forward of ER2. The tank characteristic tables and graphs are shown in Appendix (M).

(e) Firemain System

The Firemain system for the CPCX is a hybrid of the traditional Navy (wet) and Coast Guard (dry) systems. It consists of 3 pumps (one in each Auxiliary Machinery Space), on a ring, that is segregatable into 3 independent loops. The firemain system will be used only for fire-fighting capability, vice as a fire and flushing/cooling system. Auxiliary cooling water for major systems will be provided via Auxiliary Saltwater (ASW) cooling pumps. This feature is intended to reduce maintenance on cooling systems, by providing cooling water at much lower pressures (30-60 psi vice 115-150 psi).

The key feature of the firemain system, are the hydro-pneumatic accumulator (HPA) tanks (3 each). The accumulator tanks will pressurize the entire main, each capable of provide 1 minute of firefighting water to two 95 gpm nozzles. This is sufficient time for the firepump(s) to start up and supply the system. The normal operating mode for the firepumps will be in a standby (off) status. The pumps will be activated via pressure switches on the accumulator tanks. A simple line diagram of the system is shown in Figure 4.

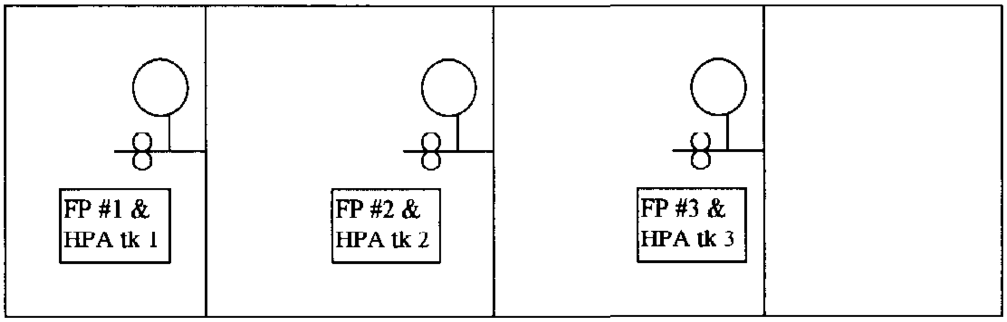


Figure 5 Firemain Line Diagram

The HPA tanks are charged off the ship's service low pressure air system. This system is designed to reduce the overall maintenance requirements for the pumps. While it can be expected that maintenance will increase on the starting circuits, the reduced maintenance on the pumps, and piping systems will more than offset the slight increase in electrical maintenance.

(f) Miscellaneous Engineering Features

Several key features of the CPCX in addition to those discussed above, include: Collective Protection System (CPS), federated compartments, vacuum sewage system, reverse osmosis distillation plant, combat system holdup battery, and automated machinery control system.

C. ARRANGEMENTS

1. Navy Variant

The detailed arrangement drawings for the Navy variant are included in Insert Pages (1) through (6). The drawings start on the 02 level and work down through the ship.

- Insert (1) : 02 Level -- Equipment placed here includes the 40mm multipurpose guns, Signal Shack, SRBOC locker, SPG-62 Equipment room, and mounts for various antennas.
- Insert (2) : 01 Level -- Major spaces include the Bridge, CO's Cabin, Chart Room, RAM Launcher and various equipment rooms. The location of the CO's cabin provides immediate access to the Bridge.
- Insert (3) : 1st Deck (Main) -- Key features include the 5" Gun, VLS Missile Modules (on Foc'sle), Officer Staterooms, Operations Office, Wardroom, Ship's Office, Helicopter Hangar, Aviation Repair Shop, Boat Rooms, Torpedo Rooms and Flight Deck. The Flight Deck is sized to launch/recover all current US/NATO inventory rotary wing aircraft with the exception of the CH-53. The Helicopter Hangar is composed of two major components, a fixed portion and telescoping portion, which will enable the stowage of the selected airframe, the AS-565 Panther.
- Insert (4) : 2nd Deck -- The 2nd Deck is characterized by two main outboard passageways, port and starboard, which run nearly the length of the ship. In addition to simplifying access, these passageways provide a protective buffer zone for small arms fire and shrapnel from close aboard misses. Major spaces forward include the Bos'n Locker, Forward Windlass Room, 5" Gun Control Room (immediately below gun), VLS compartment, Weapons Control Room for VLS, Repair Locker #2, Supply and Log Offices, and the Casualty Control Station (CCS), which is located between the two engine rooms. Immediately forward of amidships lies the Mess Deck, CPO Mess, Galley, Scullery, and Recycling (Trash) spaces. The AFFF station for the foward Engineroom is outboard of the Recycling Space. Aft of amidships is the secondary Combat Information Center, CIC #2. Repair Locker 5 (Machinery Repair) is situated between the two engine

rooms. The aft portion of the second deck contains CPO and crew berthing, Sick Bay, Fitness Room, Collective Protection System (CPS) airlocks and various storerooms. Furthest aft lies After Steering, which contains ATAS, NIXIE, and the steering gear.

- Insert (5) : 3rd Deck -- The forward portion of the 3rd Deck contains mostly unmanned spaces (Chain Locker, Upper 5" Magazine, VLS, and a storeroom). Amidships lies the majority of the respective technician shops and storerooms (machine, filters, electrical, tool room), the combat system holdup batteries (UPS) and laundry. The after end of the 3rd deck contains fuel tanks, storerooms, and the Pod Machinery Room.
- Insert (6) : 4th Deck -- The 4th Deck is the information and propulsion center of the CPCX. It houses the main warfighting, communication, and mobility stations onboard. The forward 3 compartments of the 4th deck contains the same spaces as the 3rd Deck (Chain Locker, Lower 5" Magazine, and VLS). Aft of the VLS is the SH-100 Mine Sonar Trunk, and Auxiliary Machinery Space #1. The primary Combat Information Center, CIC #1 is located just forward of Engine Room #1. This location provides two watertight bulkheads and one deck seperation between primary and secondary CICs. The space between the enginerooms is occuppied by Auxiliary Machinery Space #2, Refrigerated and Dry Stores, and Radio. Aft of Engineroom #2 is Auxiliary Machinery Space #3. Below the 4th deck are the majority of the CPCX fuel tanks, JP-5 and potable water tanks.

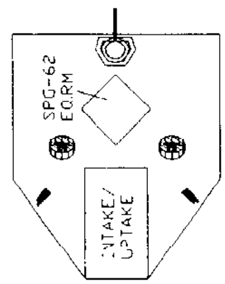
2. Coast Guard Variant

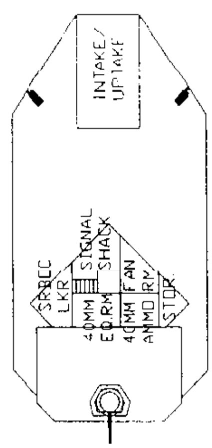
The detailed arrangement drawings for the Coast Guard variant are included in Insert Pages (7) through (12). The drawings start on the 02 level and work down through the ship. The only differences between Navy and Coast Guard layouts will be discussed below.

- Insert (7) : 02 Level -- Similar.
- Insert (8) : 01 Level -- Similar
- Insert (9) : 1st (Main) Deck -- On the foc'sle, the 5" Gun and VLS have been replaced by a hydraulic crane and storage well, respectively. The Torpedo Rooms have been converted into Prisoner Containment Rooms as well.

- Insert (10) : 2nd Deck -- The gun hydraulics in the space known as the Gun Control Room on the Navy version will remain to power the crane. The remainder of the space will be used for storage of an environmental containment skirt. The space once occuppied by the VLS is now dedicated to large item storage, such as bouys. The ATAS/NIXIE Room aft has been converted into a Rigid Hull Inflatable (RHI) Launch and Recovery Room, with an integral ramp through the transom.
- Insert (11) : 3rd Deck -- The Upper 5" Magazine has been converted into a storage room for an environmental containment skirt. Removable fuel tanks have been installed in the VLS space.
- Insert (12) : 4th Deck -- The Lower 5" Magazine has been converted into a storage room for an environmental containment skirt. Removable fuel tanks have been installed in the VLS space.

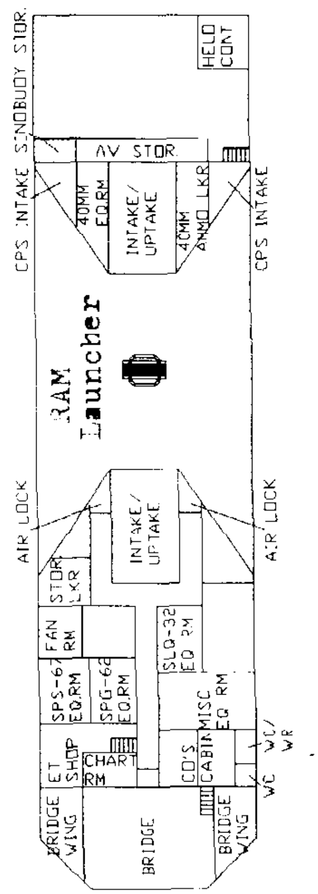
02 LEVEL





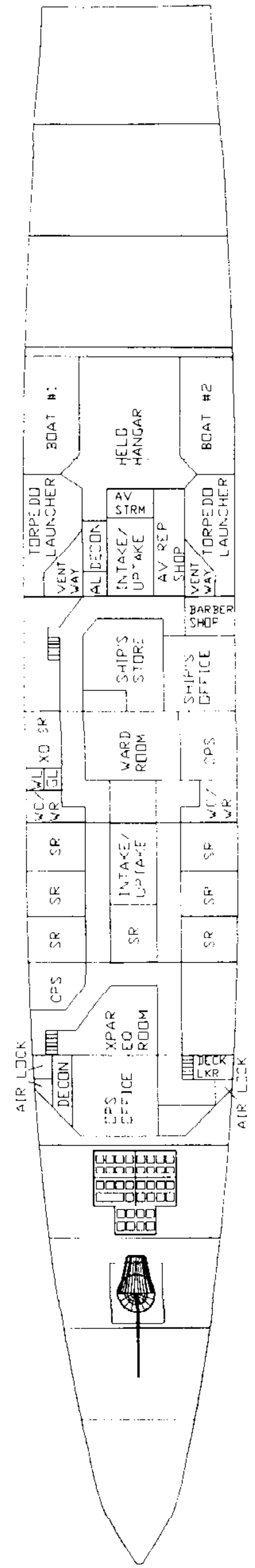
Insert 1
Navy Layout

01 LEVEL



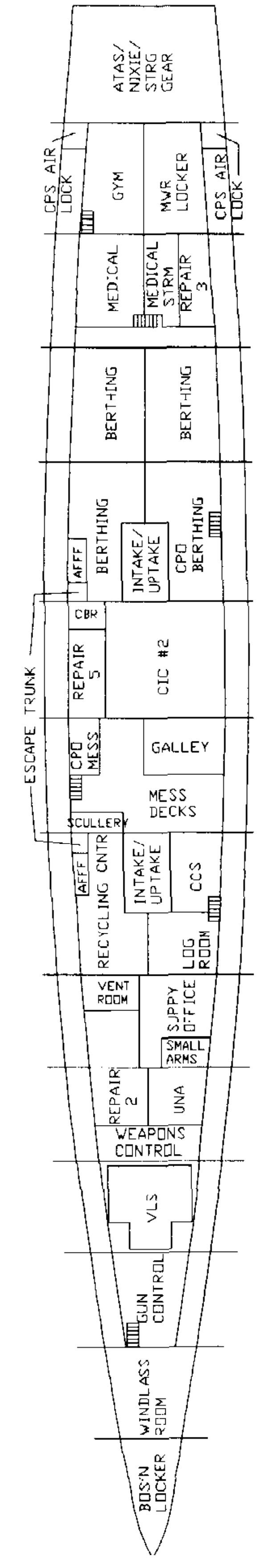
Insert 2
Navy Layout

1ST DECK



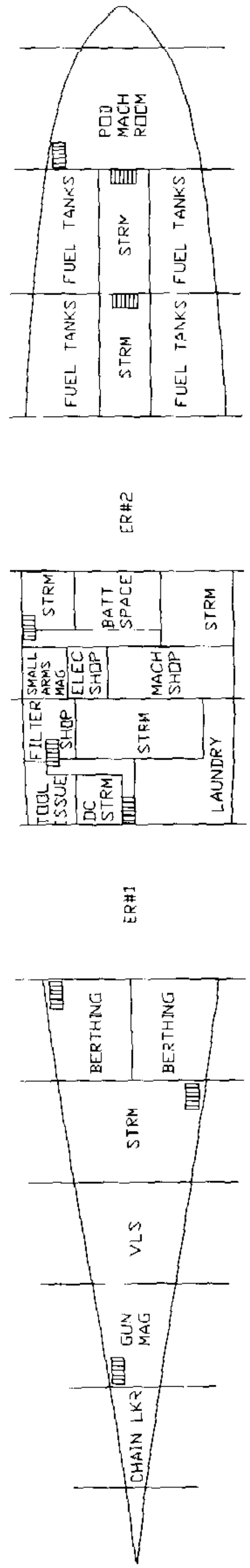
Insert 3
Navy Layout

2ND DECK



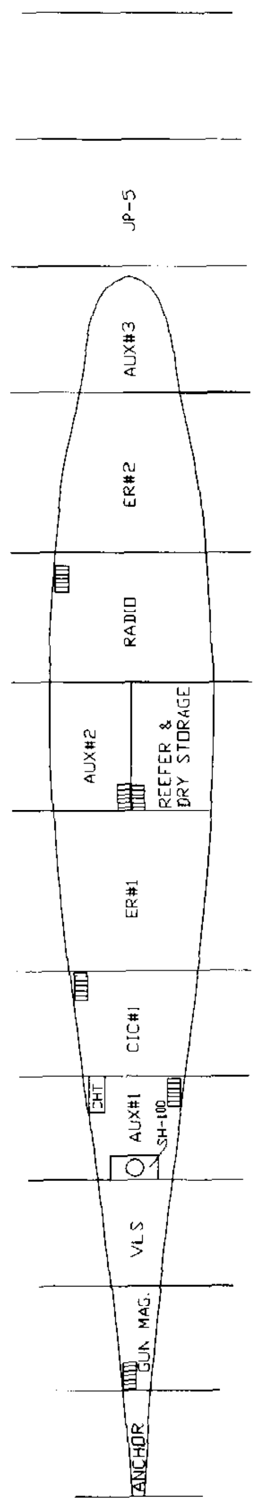
Insert 4
Navy Layout

3RD DECK



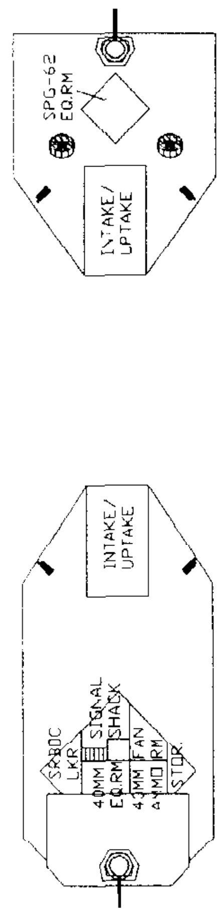
Insert 5
Navy Layout

4TH DECK



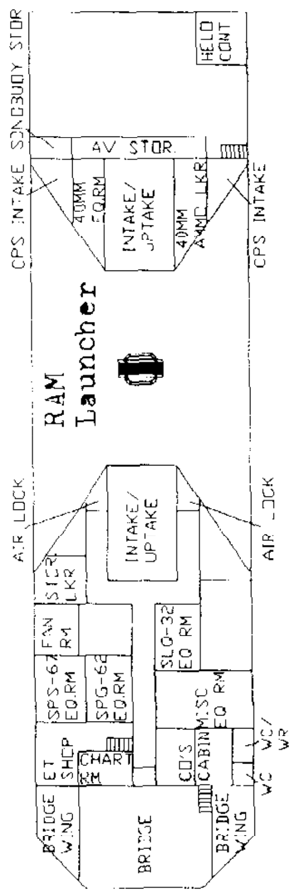
Insert 6
Navy Layout

02 LEVEL

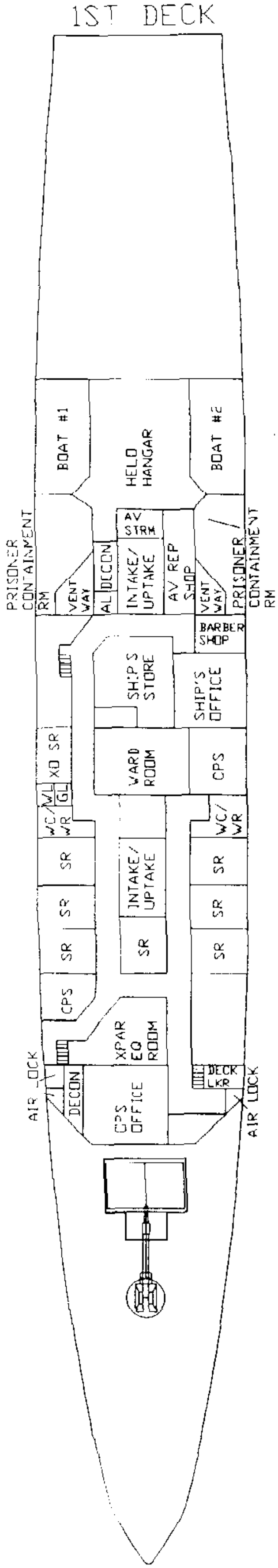


Insert 7
Coast Guard Layout

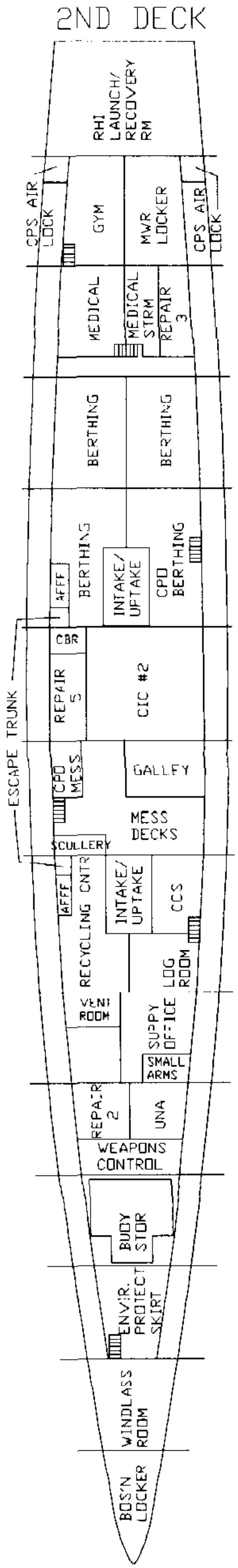
01 LEVEL



Insert 8
Coast Guard Layout

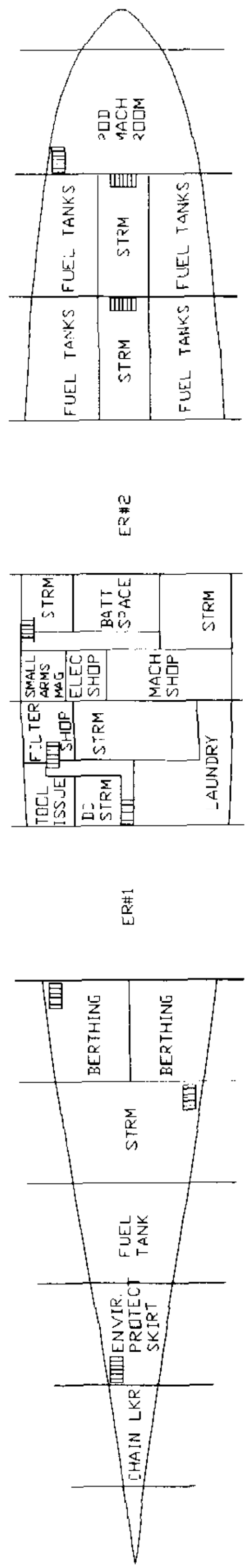


Insert 9
Coast Guard Layout



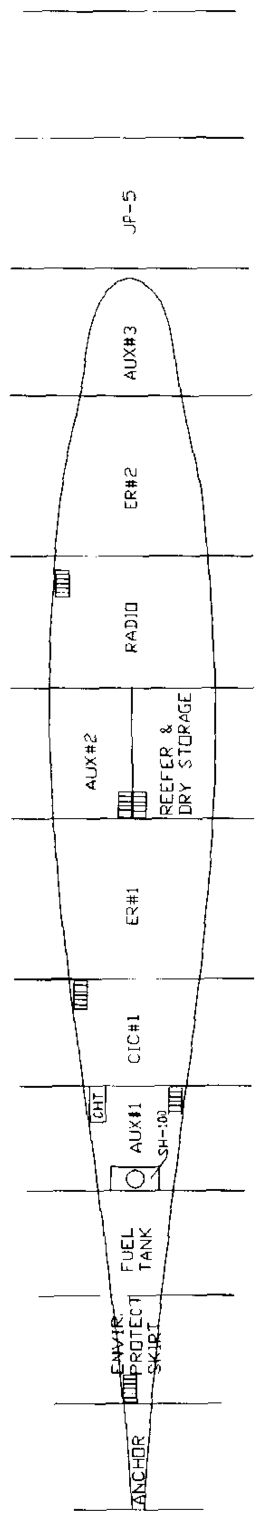
Insert 10
Coast Guard Layout

3RD DECK



Insert 11
Coast Guard Layout

4TH DECK



Insert 12
Coast Guard Layout

D. NAVAL ARCHITECTURE

The initial naval architecture calculations were done using ASSET, and the results are provided in Appendix (N) (ASSET printed reports) and Appendix (O) (ASSET Drawings). The offsets from the hull form were imported into "General Hydrostatics" (GHS), and analyzed. The naval architecture figures and calculations provided include: lines drawing, curves of form, cross curves of stability, floodable length, static stability, weight distribution, and bending moments. The computer models run through GHS were based on a full load displacement of approximately 4000 tons. This is a slight difference from the ASSET predictions of 3980 tons displacement. This displacement difference can be attributed to several factors: Appendages (pods, propellers, rudders, fins, bilge keels, skeg) were not modeled on GHS, but their respective weights were (due to complexity and time-constraints). Actual tankage vs. required tankages were also different. For example, ASSET did not include any lube oil storage capacity while the GHS model accounts for 9.62 ltons. The actual modeling of the tankage has several inherent inaccuracies as well. The tank size, location and permeability inputs for GHS were all estimated. Further iterations of the design would refine the geometry, most likely resulting in smaller tanks.

The most significant discrepancy with the hull geometry is the full load trim. It is at 3.5 ft forward. This is most likely due to the weight distribution (combat payload and fuel tankage) in the forward half of CPCX. Possible remedies include a redesign of the bow section to make it fuller, ballast aft, rearrangement of fuel tanks, and rearrangement of combat payload (VLS and main gun). The following charts and graphs were plotted from and computed by GHS and included in Appendix (P).

1. Body Plan and Isometric View

The Body plan and Isometric view are shown in Figure 6.

2. *General Hydrostatics*

The General Hydrostatic curves are shown in Figure 7.

3. *Curves of Form*

The curves of form are shown in Figure 8.

4. *Cross Curves of Stability*

The Cross Curves of Stability are shown in Figure 9. It provides a display of the ship's righting arm for various angles of heel, over a range of displacements. The curves displayed need to be corrected for the assumed KG, which in the figure shown is 0.0 ft.

5. *Floodable Length*

The floodable length curve is used to determine the allowable compartment lengths which will ensure that the margin line is not submerged, should the compartments spanning the defined factor of subdivision become flooded. As described in Design Data Sheet (DDS) 079-1, *Stability and Buoyancy of Naval Surface Ships*, the factor of subdivision for combatants is 15% of LBP, with a margin line of three inches below the bulkhead deck (main deck). The factor of subdivision for the CPCX is 57 feet. The standard values of permeability given in Principles of Naval Architecture, Vol. I (p. 190) are:

Cargo and Stores	0.6
Accommodations and voids	0.95
Machinery Spaces	0.85

GHS was used to calculate Floodable Length based on hull form, and the results were used to verify the bulkhead placement generated by ASSET. A worst case and best case scenario were used for the permeability value for the CPCX hull form. Worst case assumed a permeability of 0.95 for the entire ship, best case assumed a permeability of 0.70. The results are shown in Figure 10. CPCX meets the worst case foldable length criteria, except at the stern. There is one three bulkhead group that is 57 feet apart and another that is 57.5 feet apart. This necessitates further analysis into the actual placement and expected permeability's, which is recommended for future iterations of the design.

6. *Static Stability Curve at Design Load Condition*

The CPCX static stability curve is shown in Figure 11. The CPCX reaches a maximum righting arm of 5.140 ft at 46.1° of heel.

7. *Hull Load Distribution Curve*

The hull load distribution curve is shown as part of the bending moment curves described below.

8. *Bending Moment Curve (sagging)*

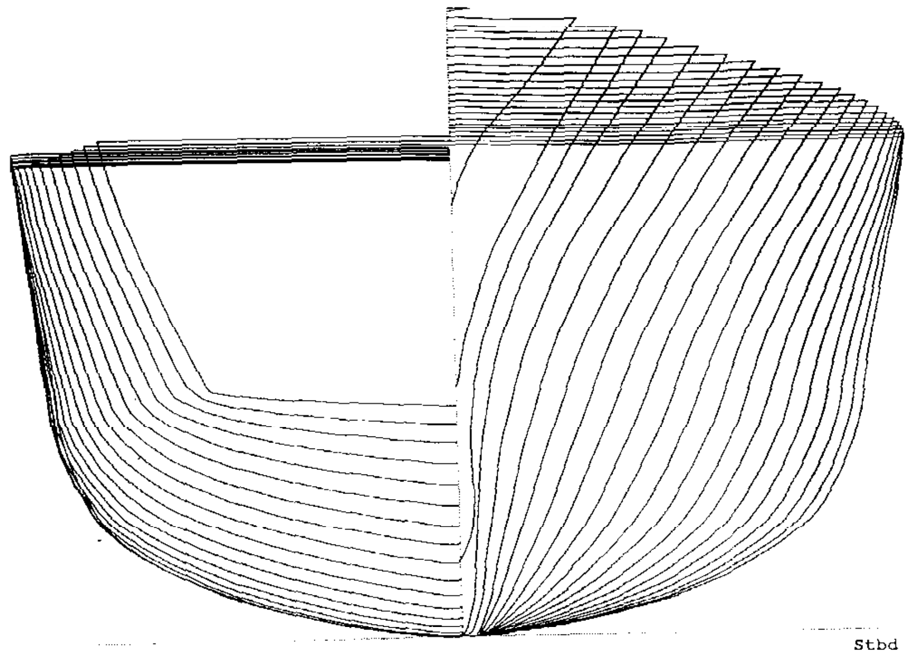
The Bending Moment curve (sagging) is shown in Figure 12. CPCX has a maximum bending (sagging) moment of 62,961 LT-ft at 191 ft aft of the forward perpendicular.

9. *Bending Moment Curve (hogging)*

The Bending Moment curve (hogging) is shown in Figure 13. CPCX has a maximum bending (hogging) moment of 57,893 LT-ft at 195 ft aft of the forward perpendicular.

10. Midship Section Structural Design

The Midship Section Structural Design developed by ASSET is shown in Figure 14.



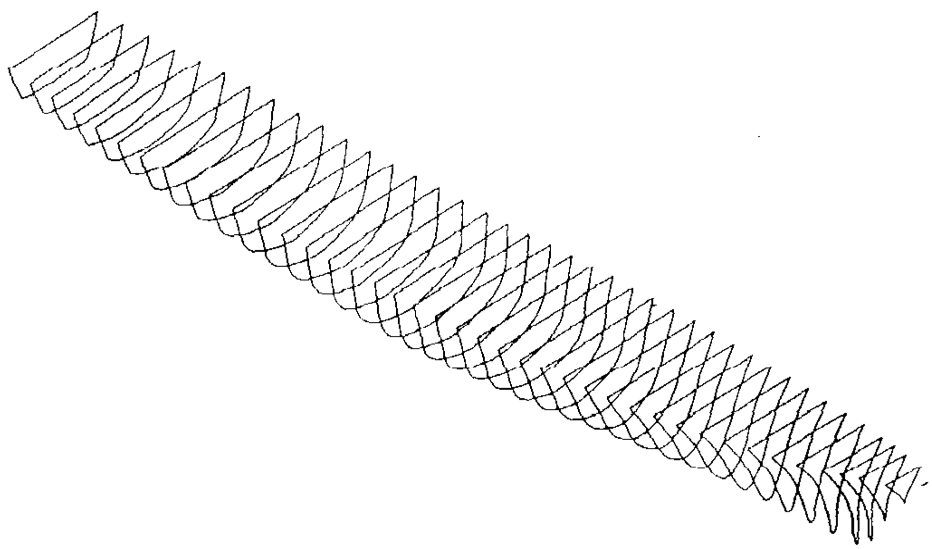


Figure 6 Body plan and Isometric View

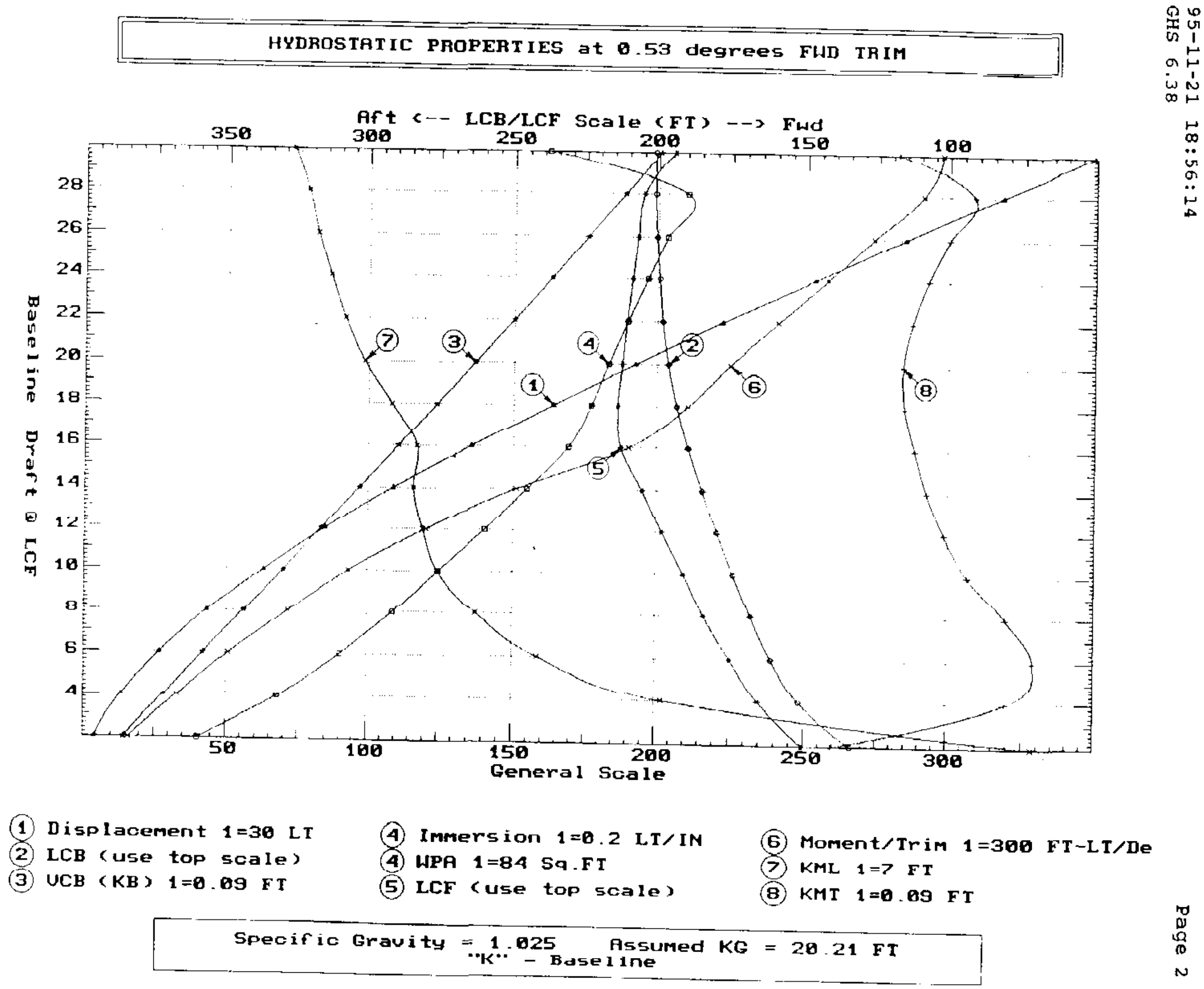


Figure 7 Hydrostatic Curves

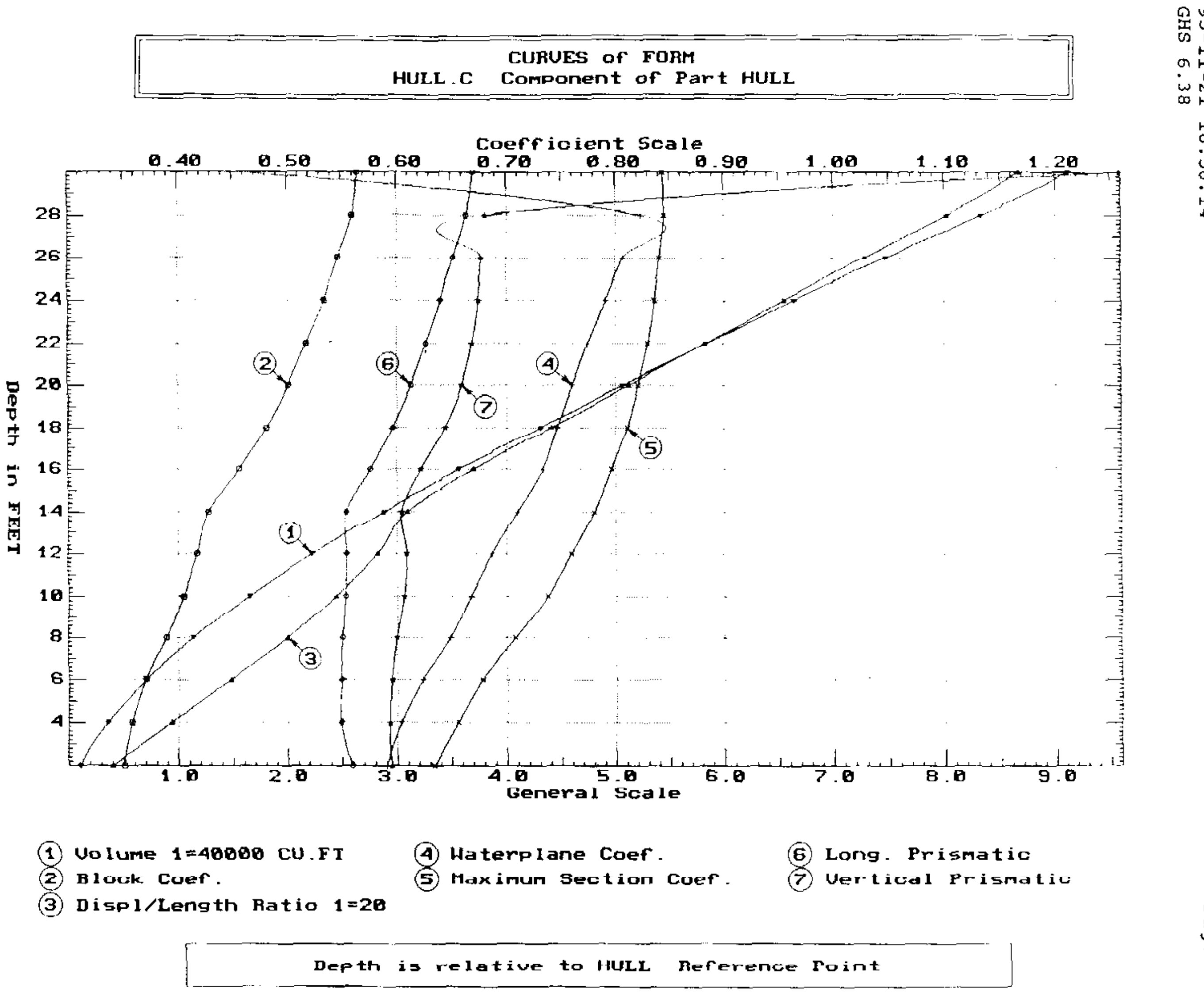


Figure 8 Curves of Form

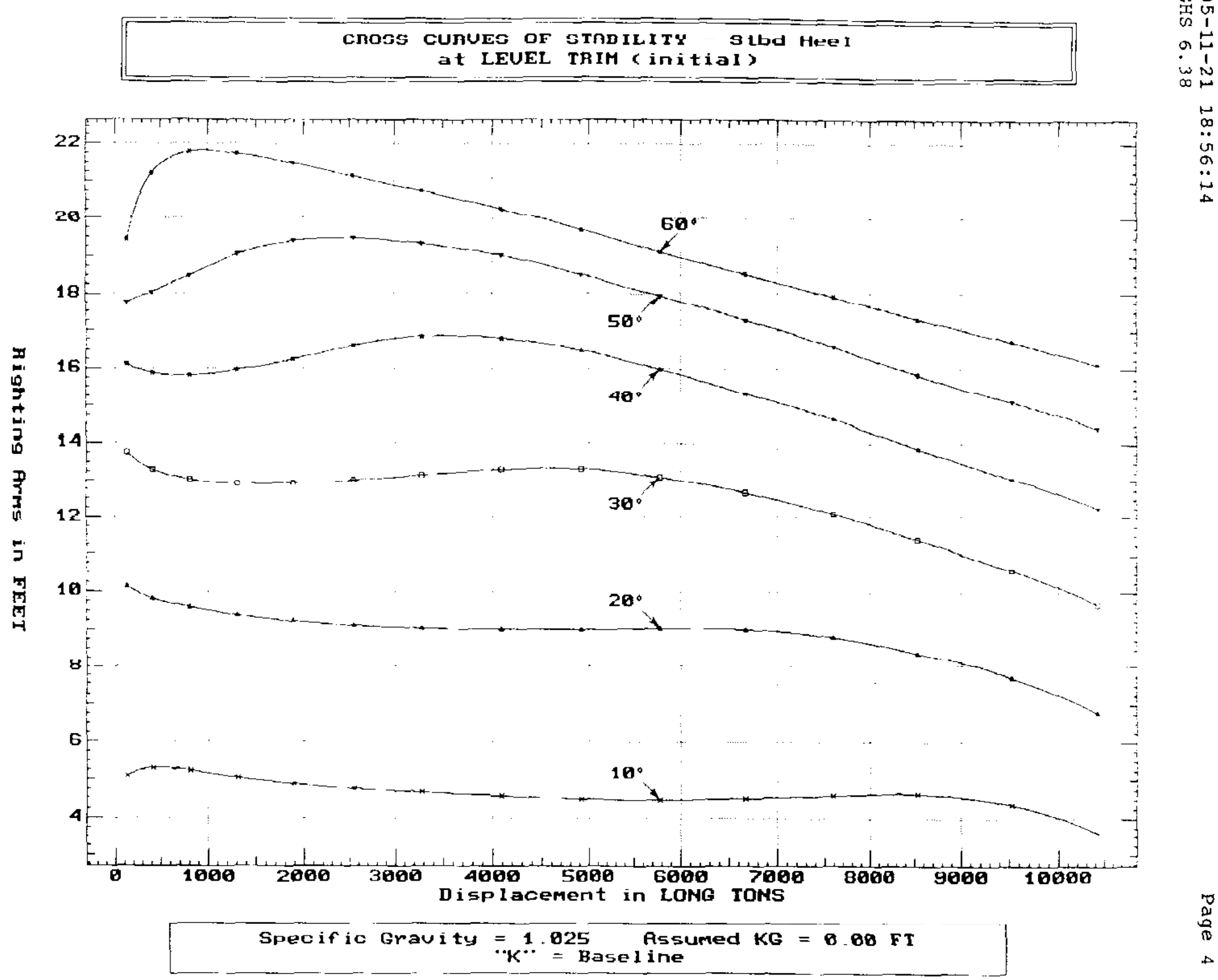


Figure 9 Cross Curves of Stability

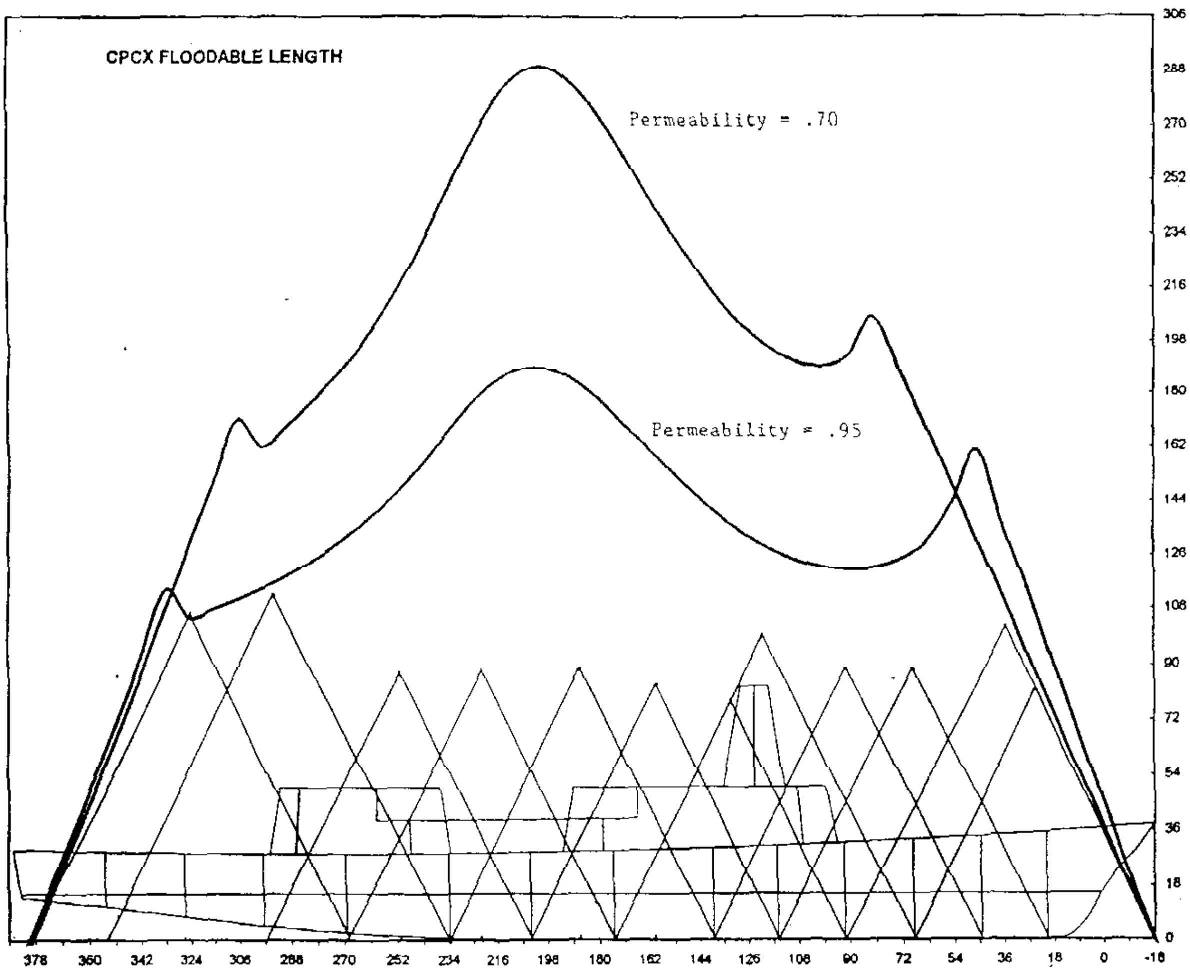


Figure 10 Floodable Length

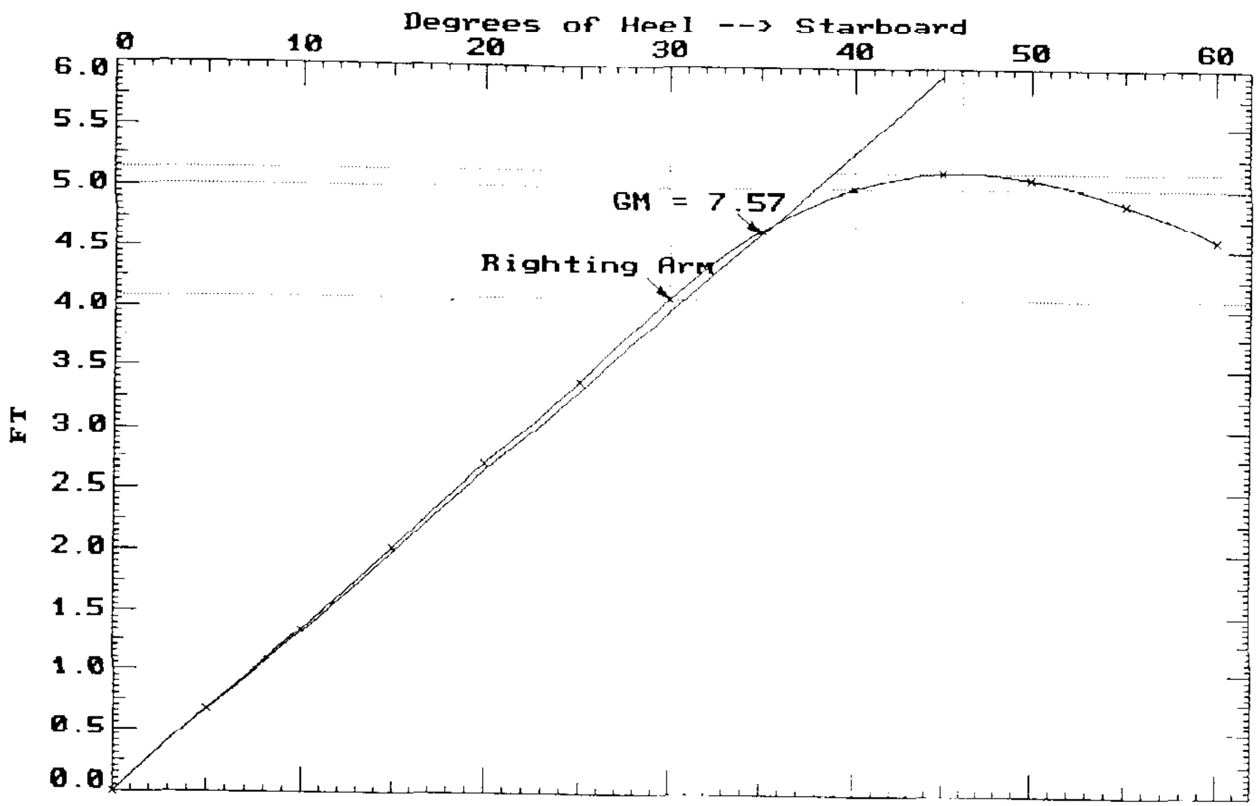


Figure 11 Static Stability Curve

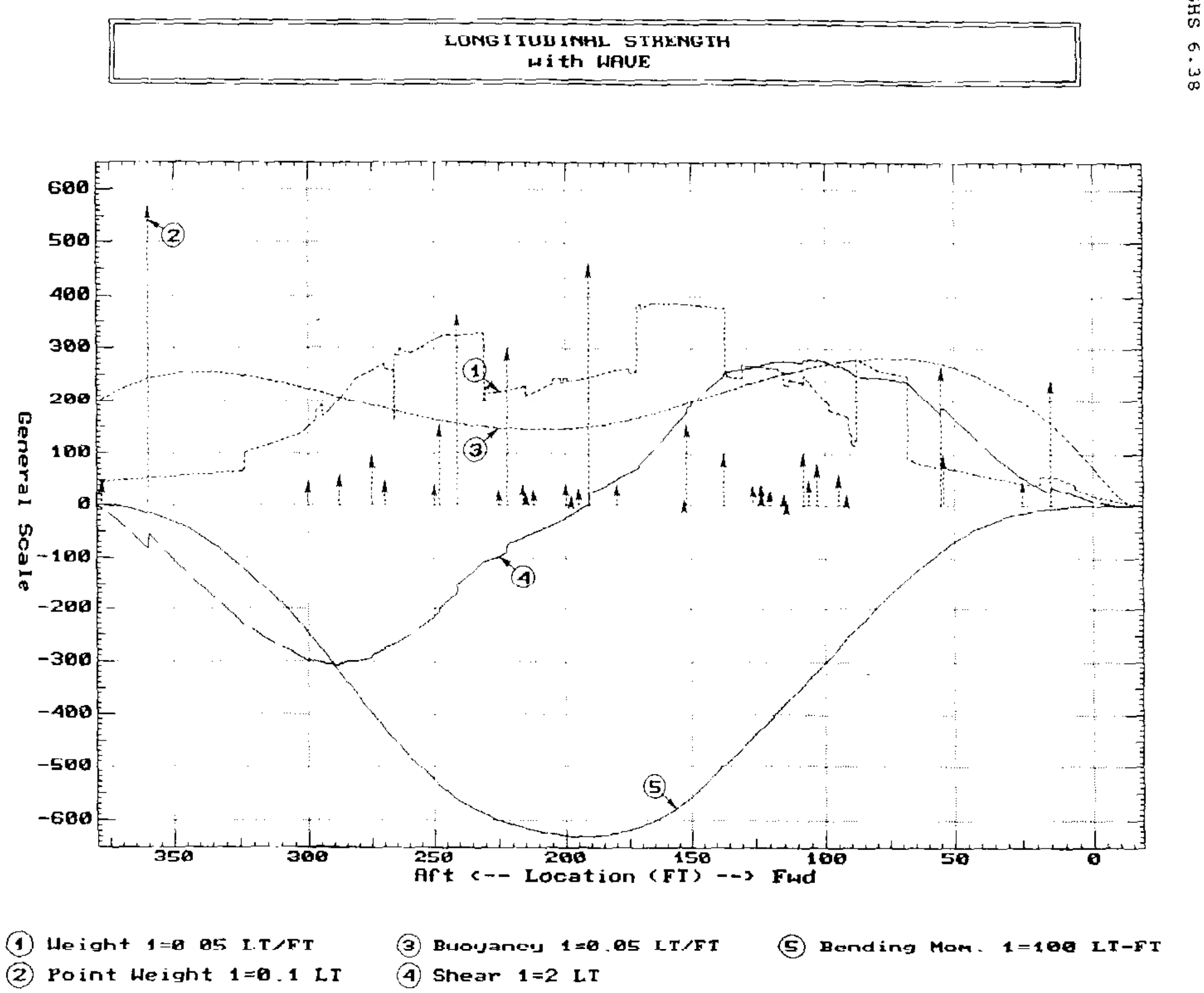


Figure 12 Bending Moment Curve (Sagging)

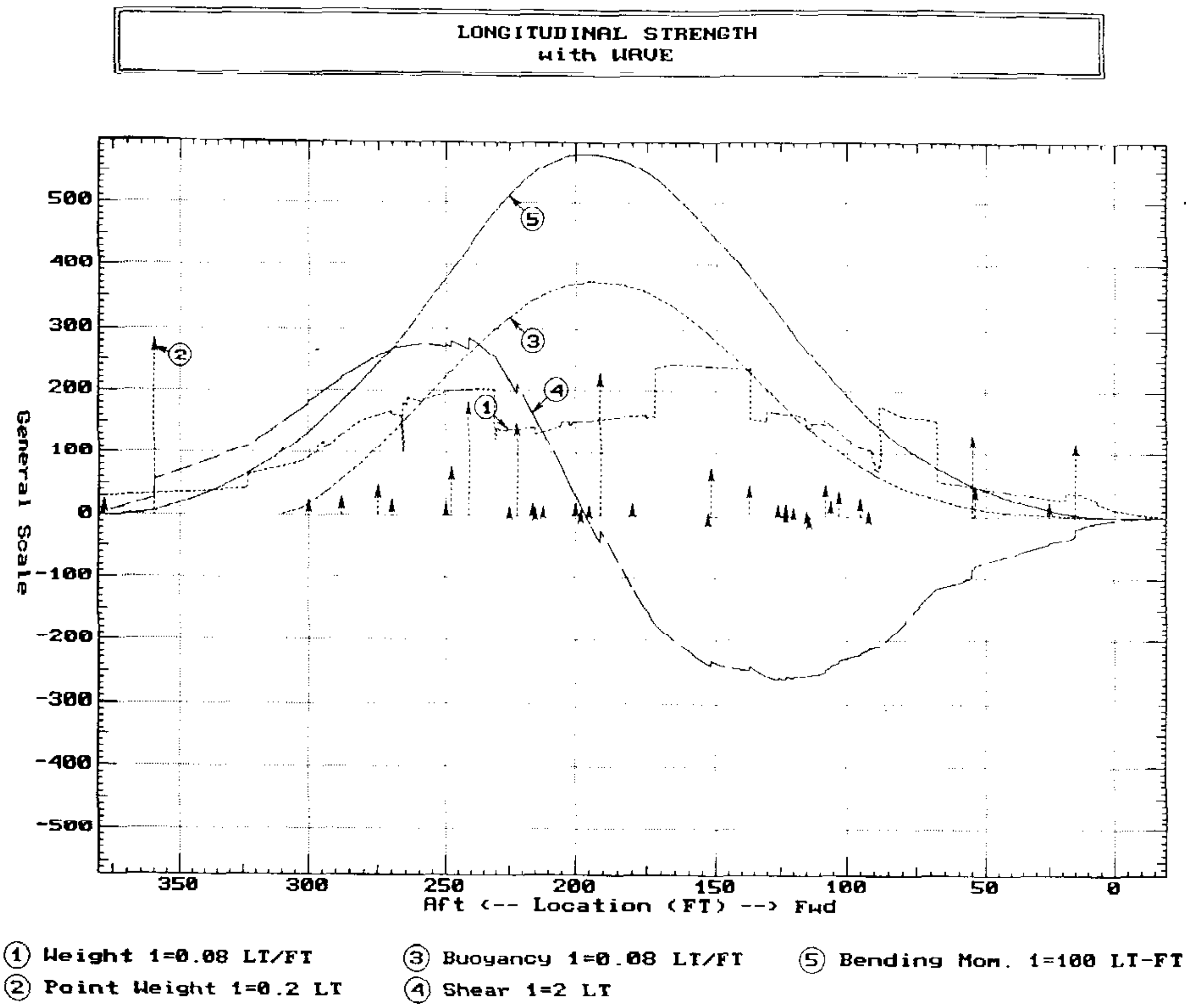


Figure 13 Bending Moment Curve (Hogging)

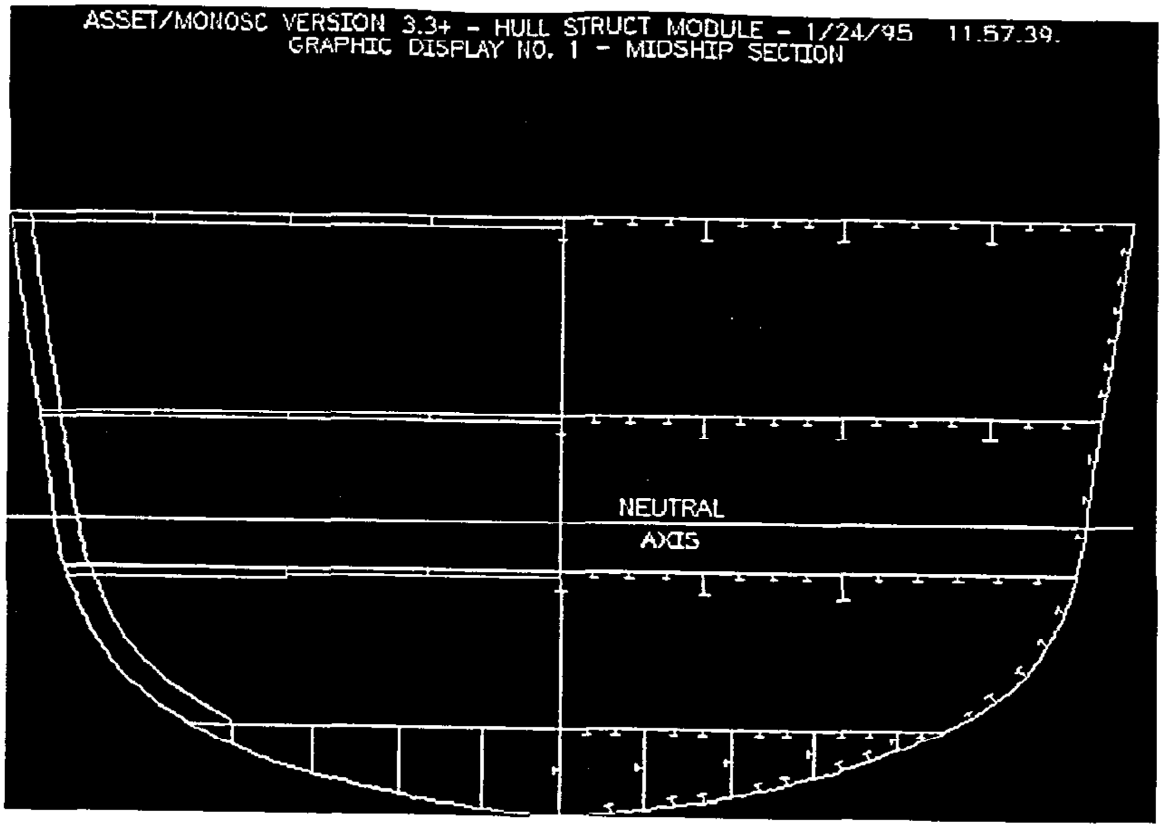


Figure 14 Midship Section

E. DETAILED DRAWINGS

Detailed space arrangements are included for the following spaces as Insert pages (13 through (15).

Combat Information Center 1

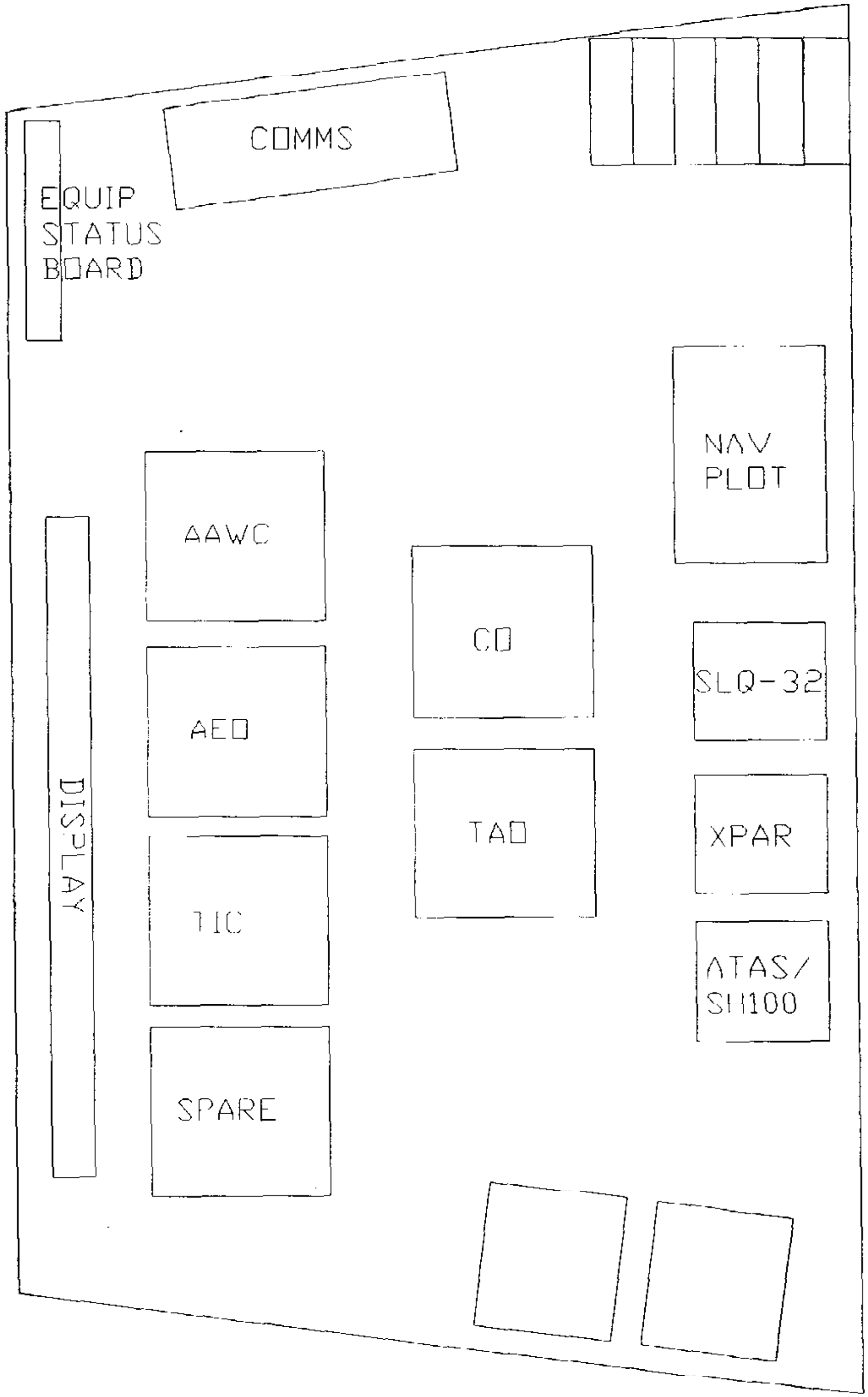
Combat Information Center 2

Pilothouse

Various topside views of the Navy variant are included as Insert pages (16) through (23).

Various topside views of the Coast Guard Variant are included as Insert pages (24) through (30).

CIC #1



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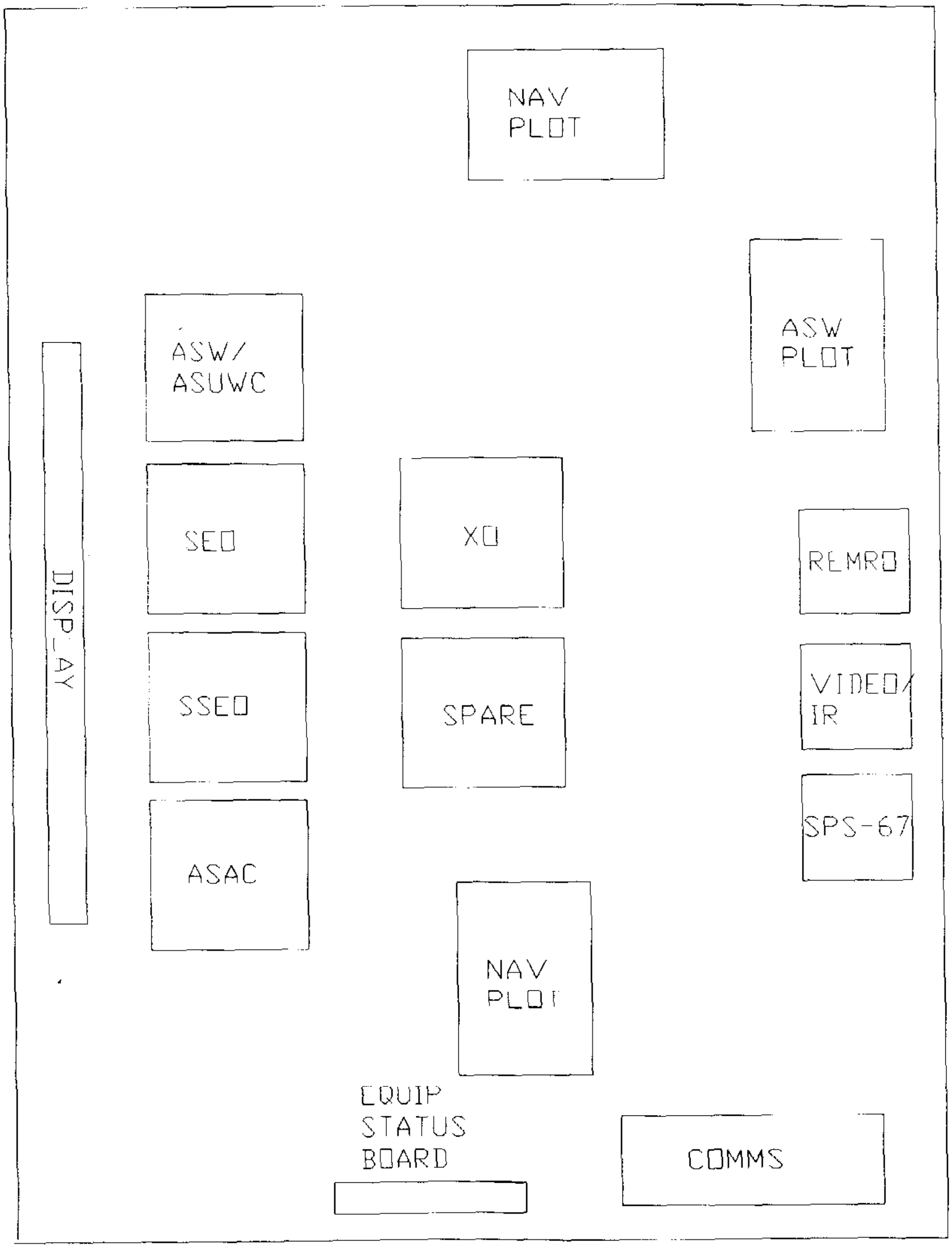
CIC #2



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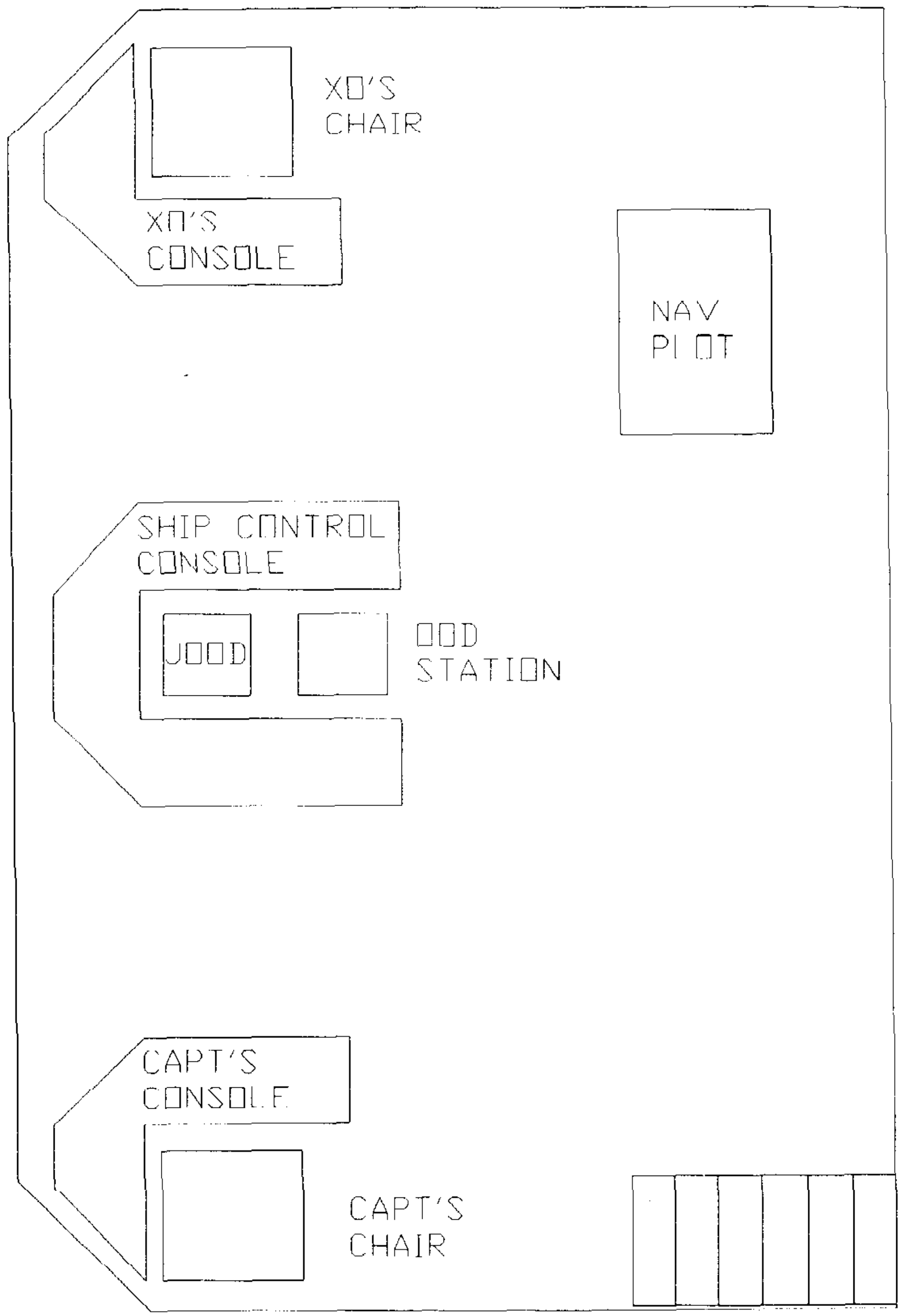
BRIDGE



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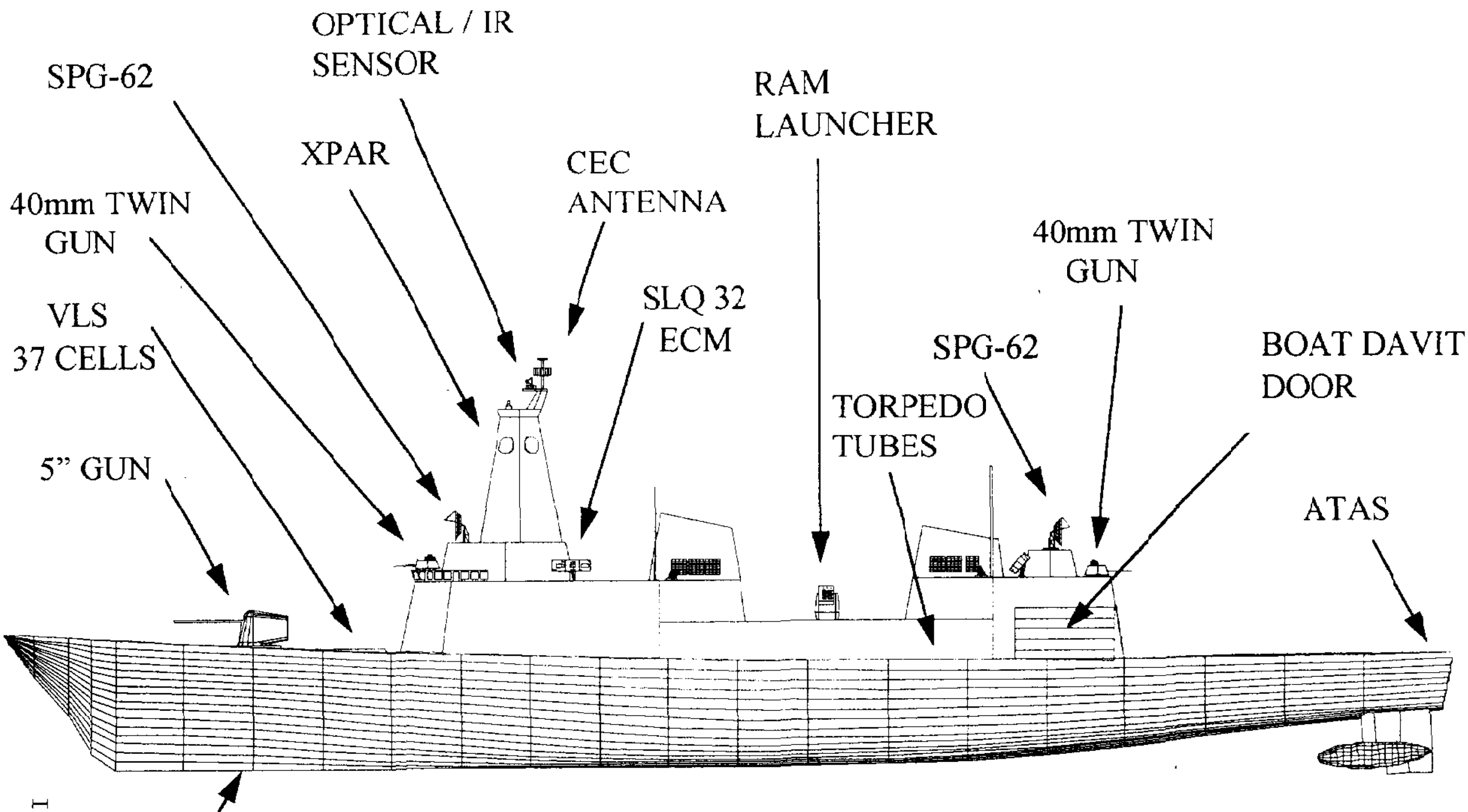
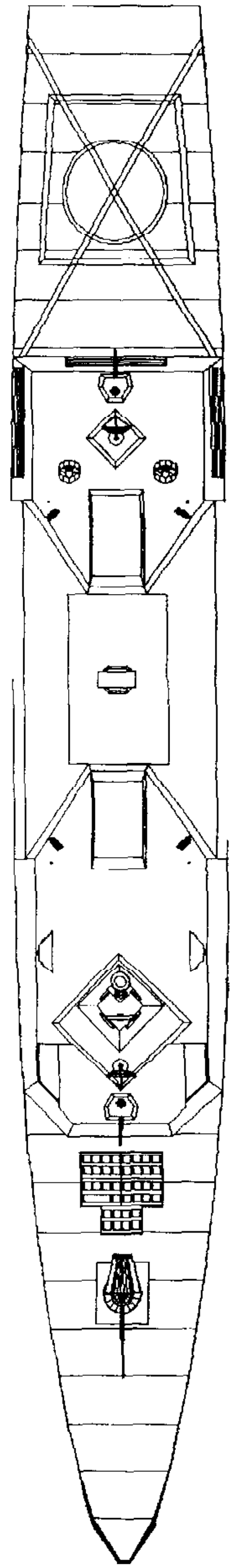


NAVY PAYLOAD



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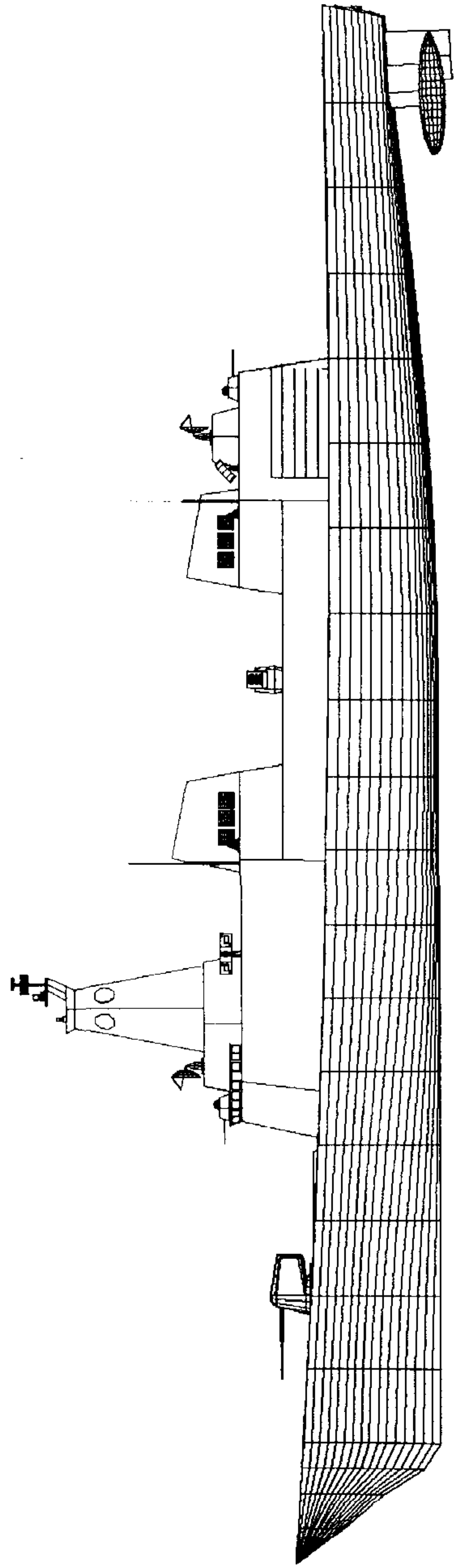

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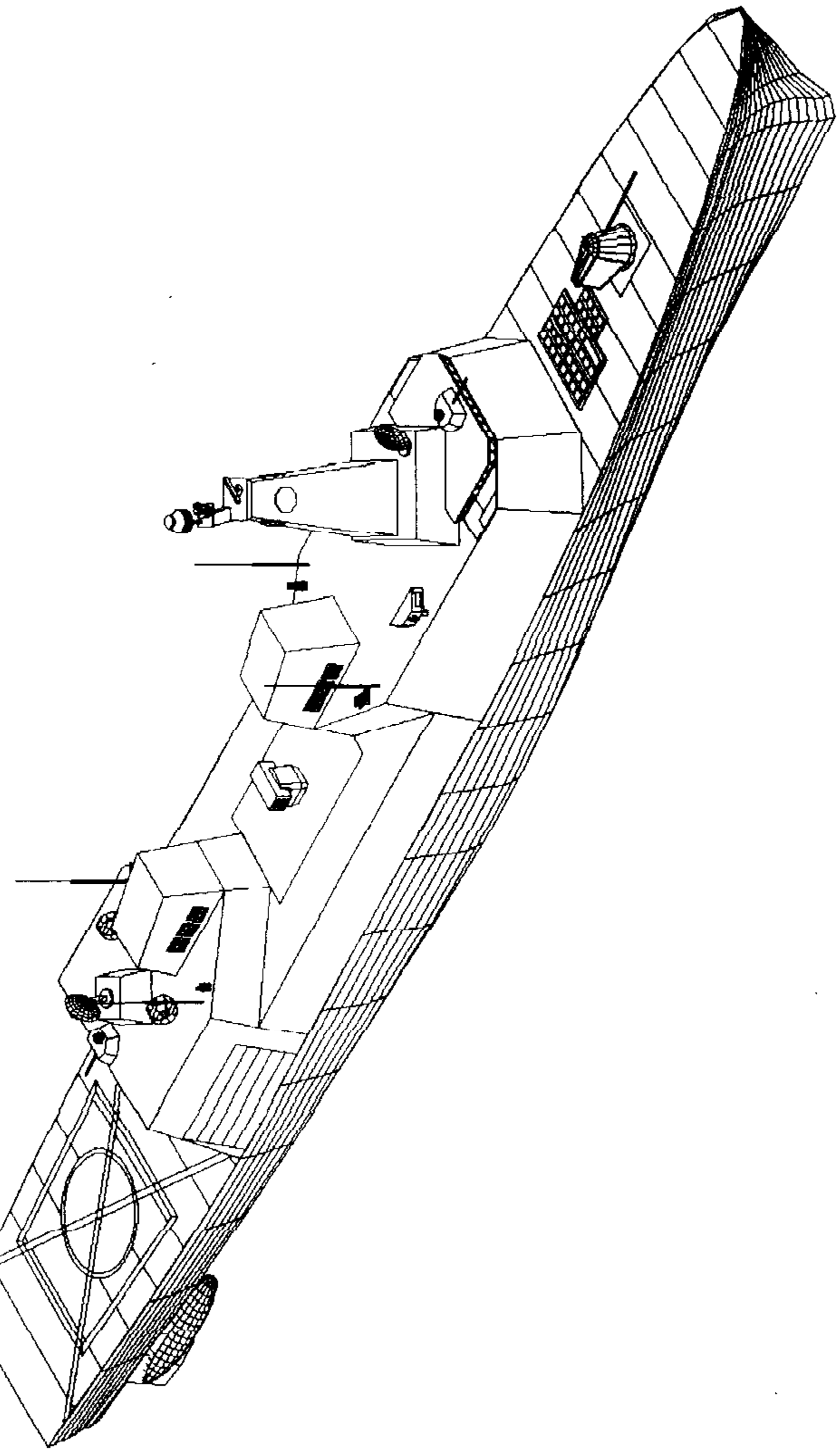

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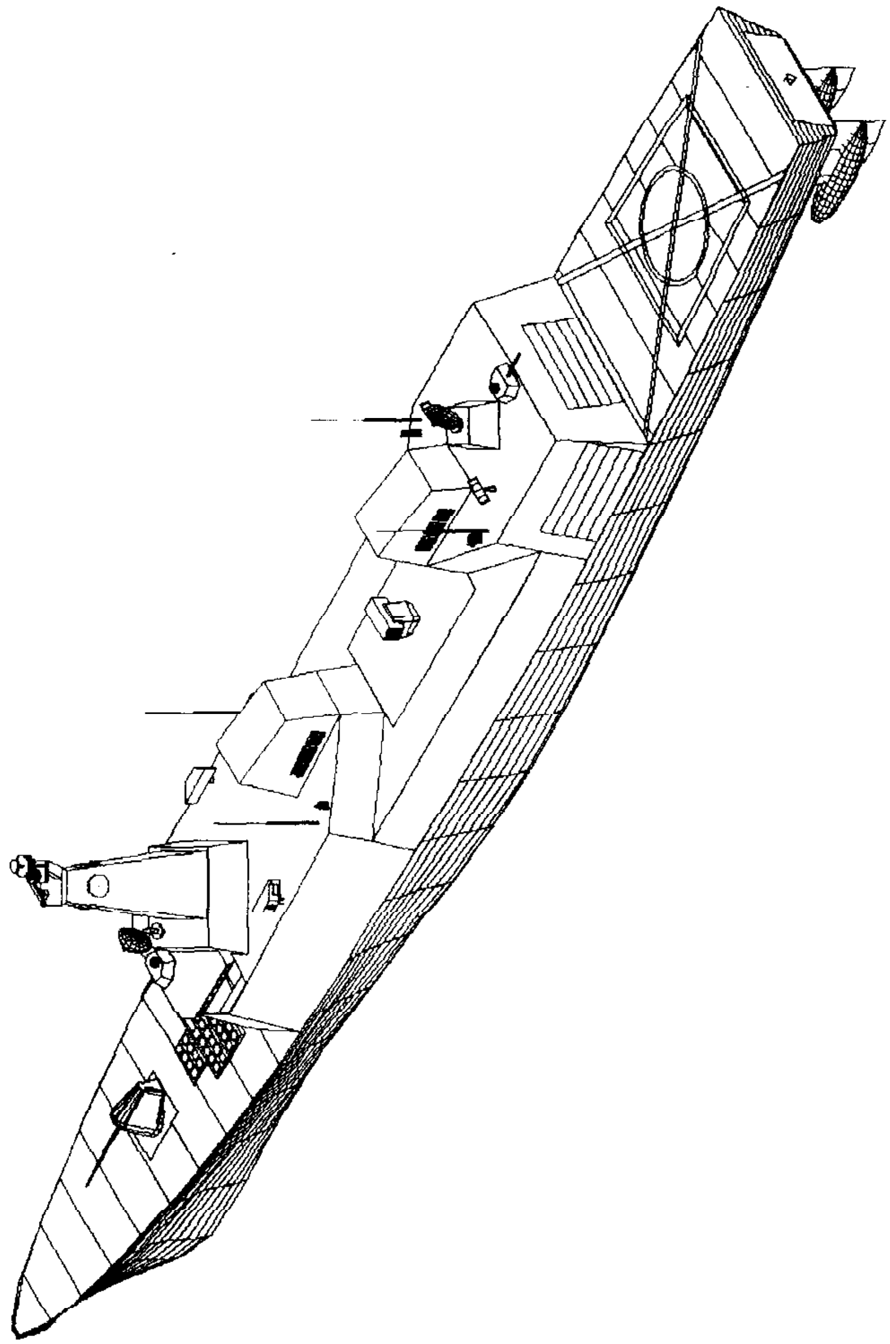

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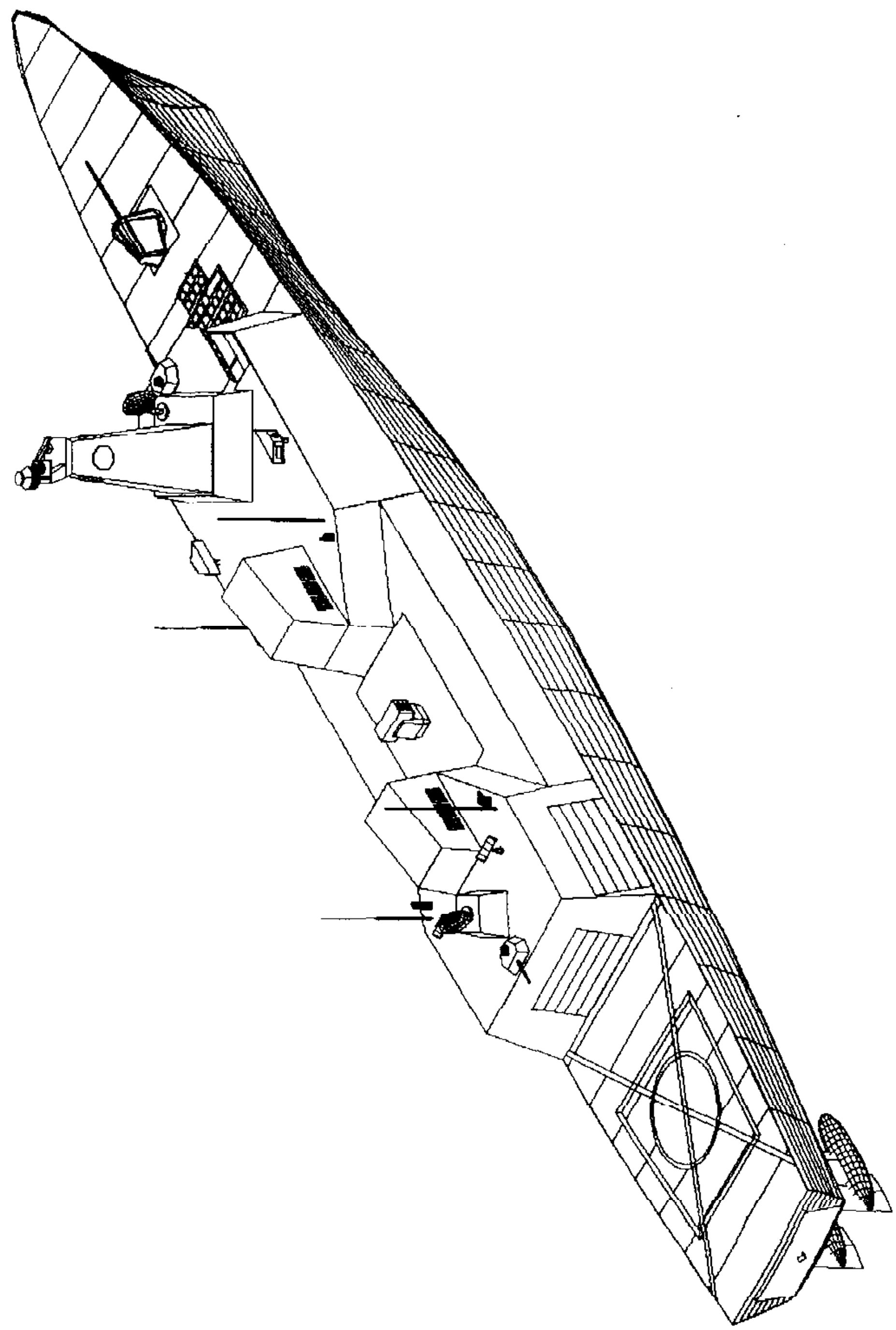

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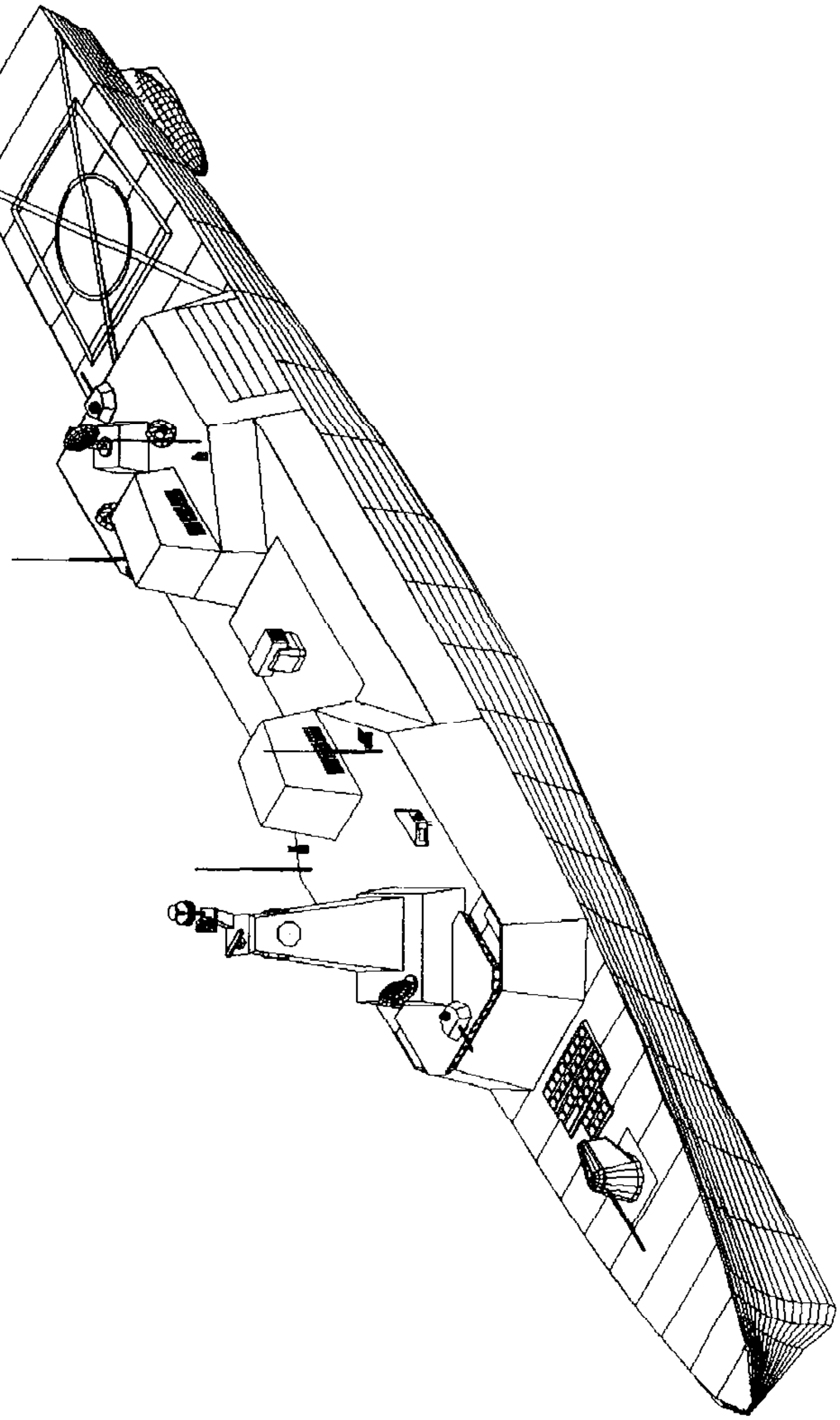

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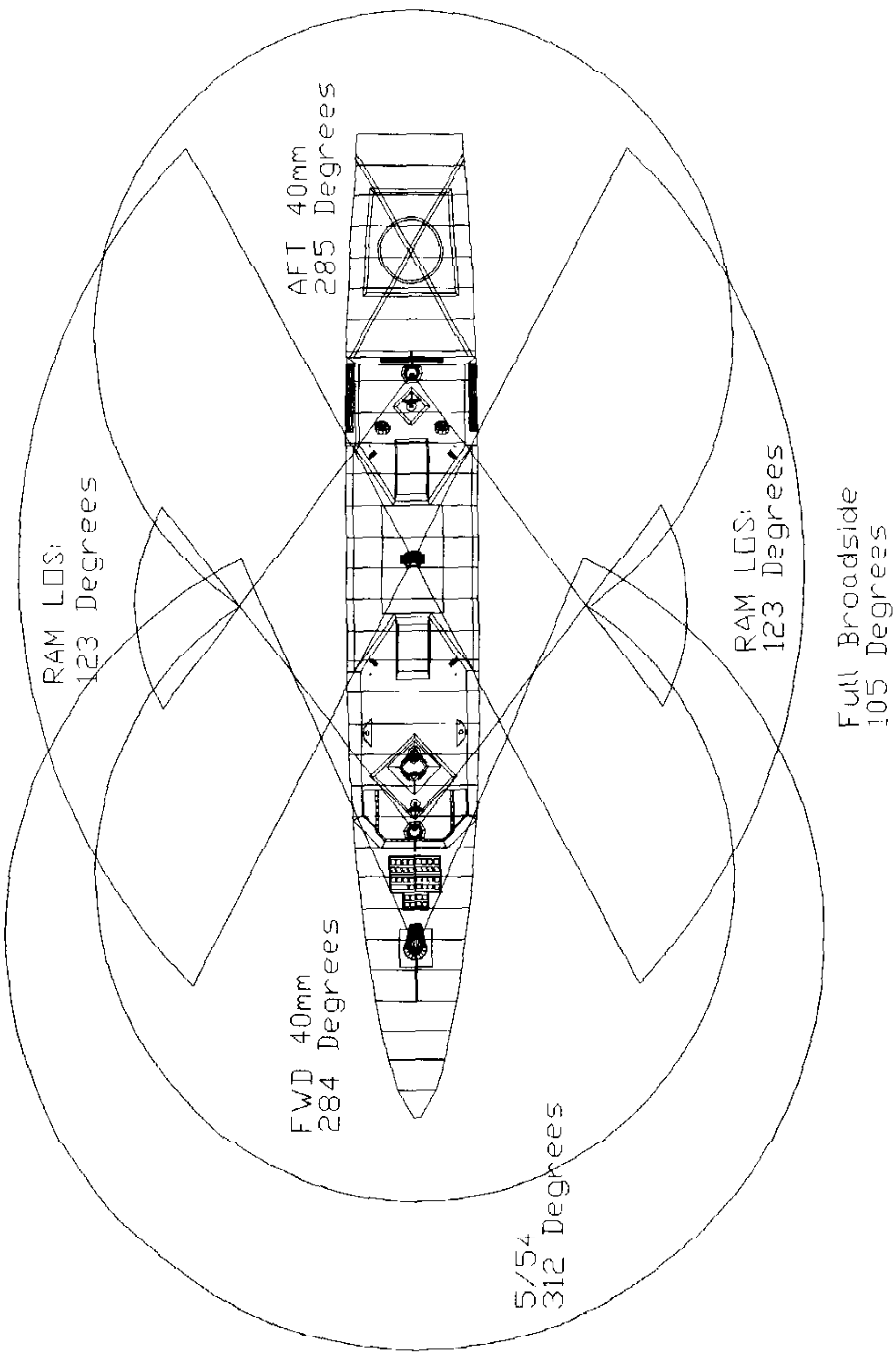
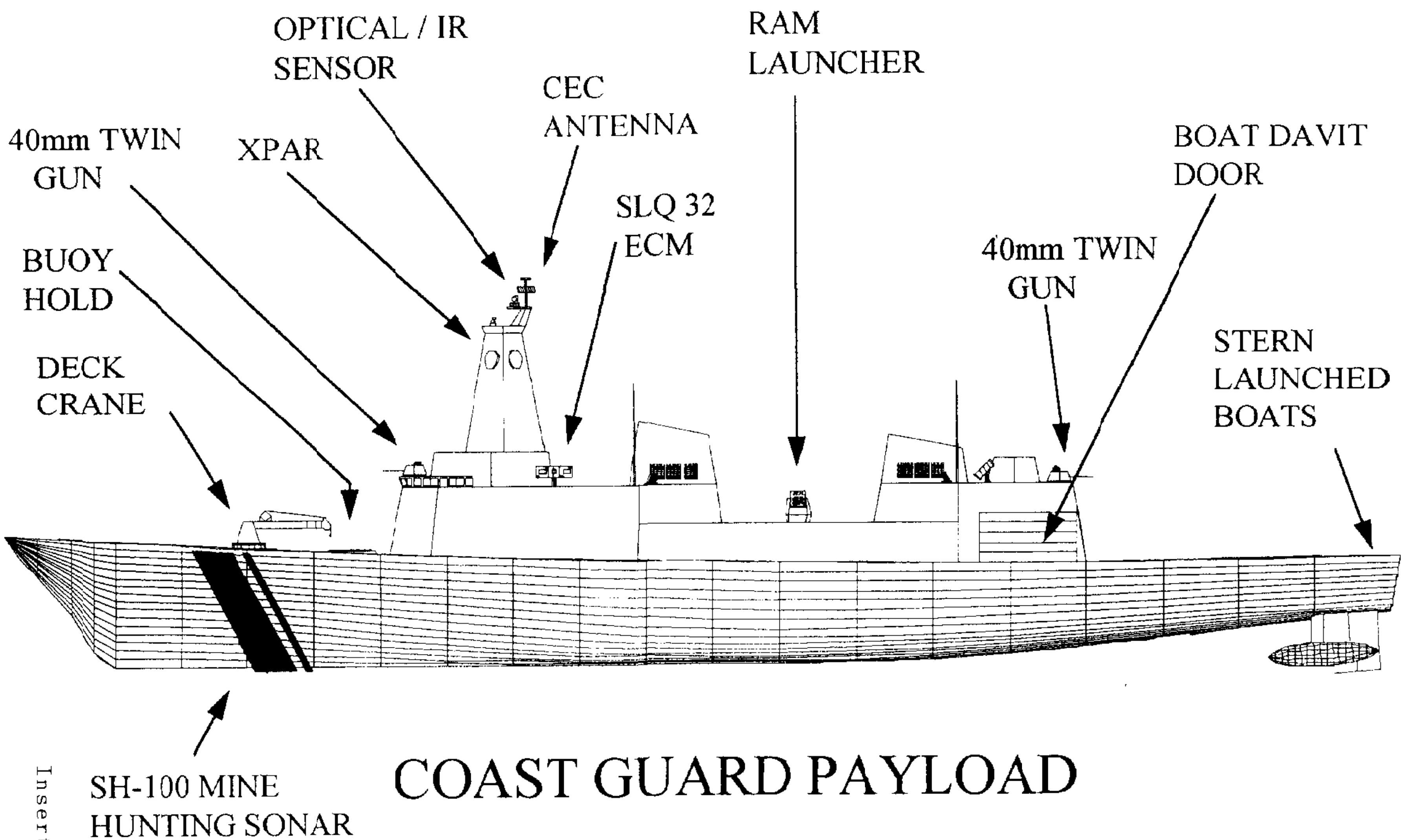
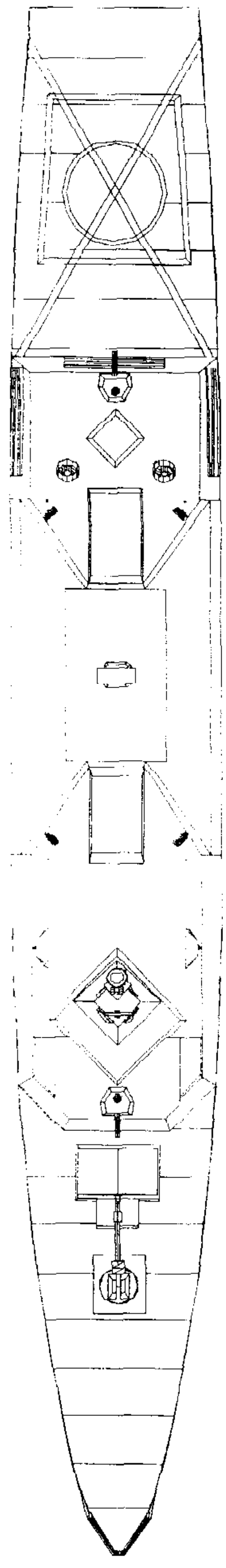
Weapons Coverage Arcs





COAST GUARD PAYLOAD



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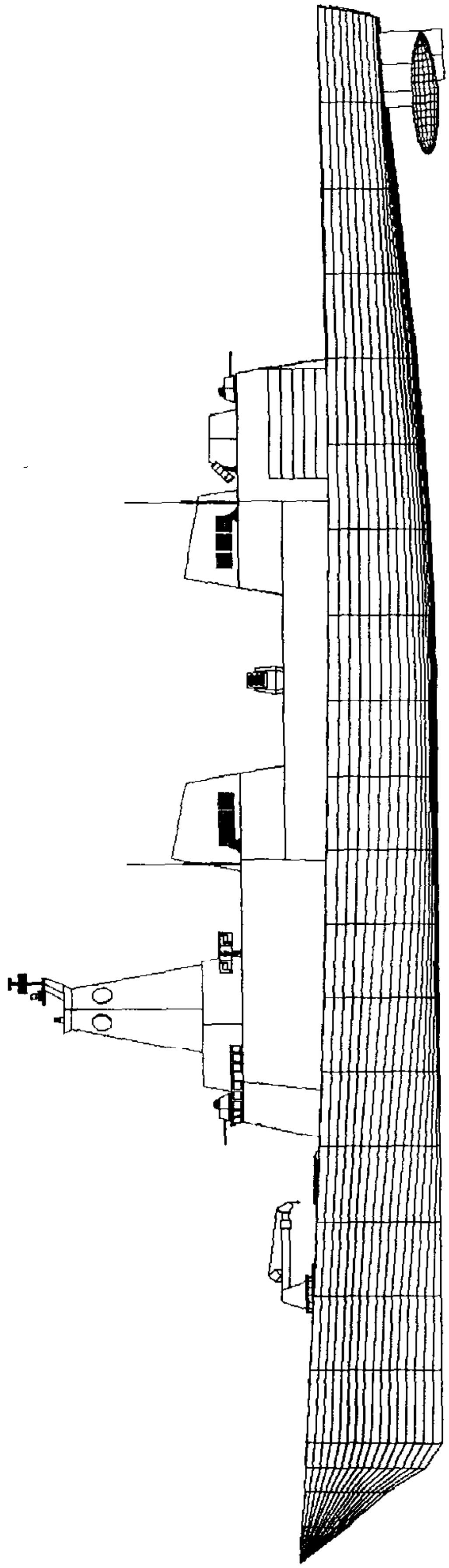

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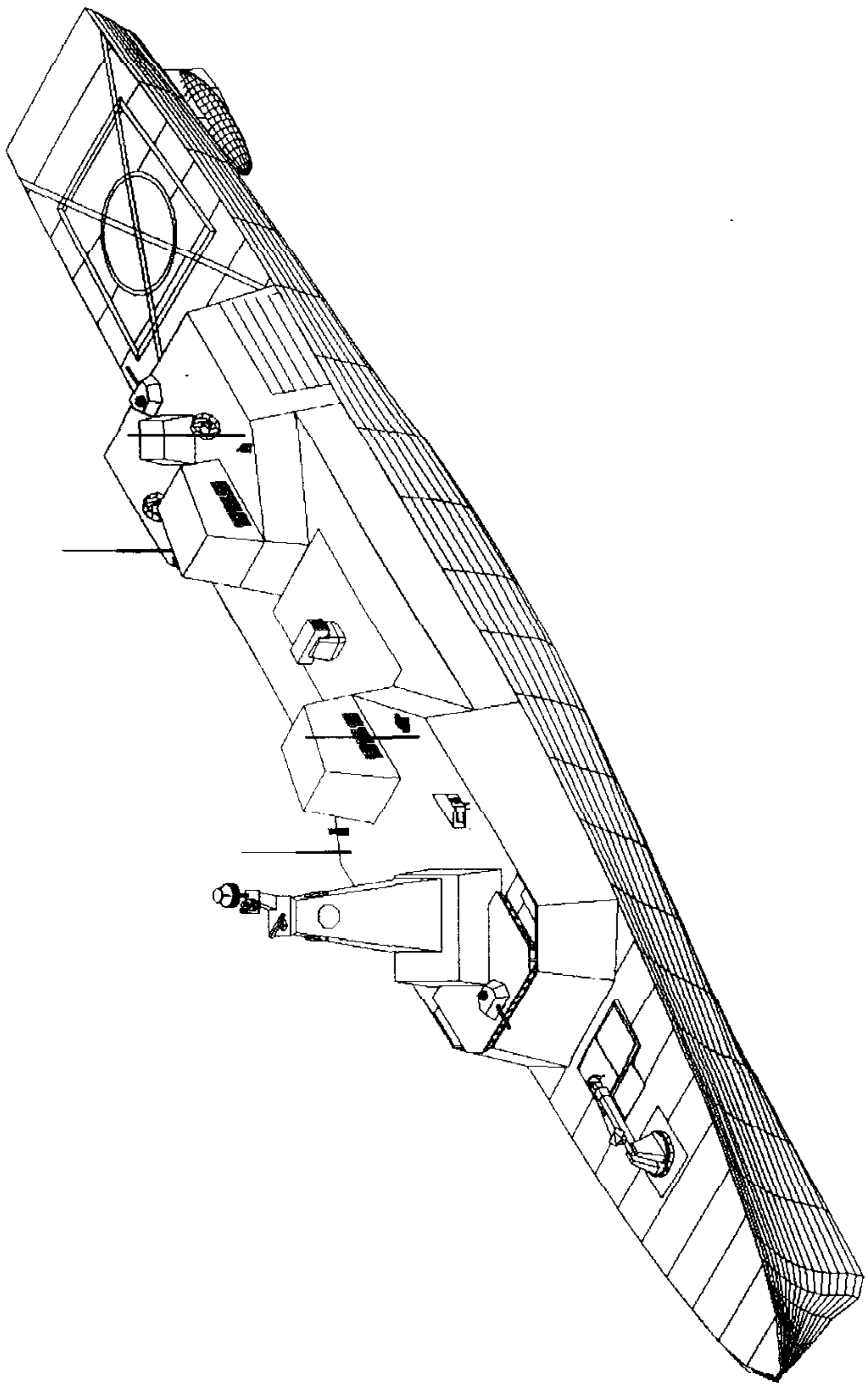

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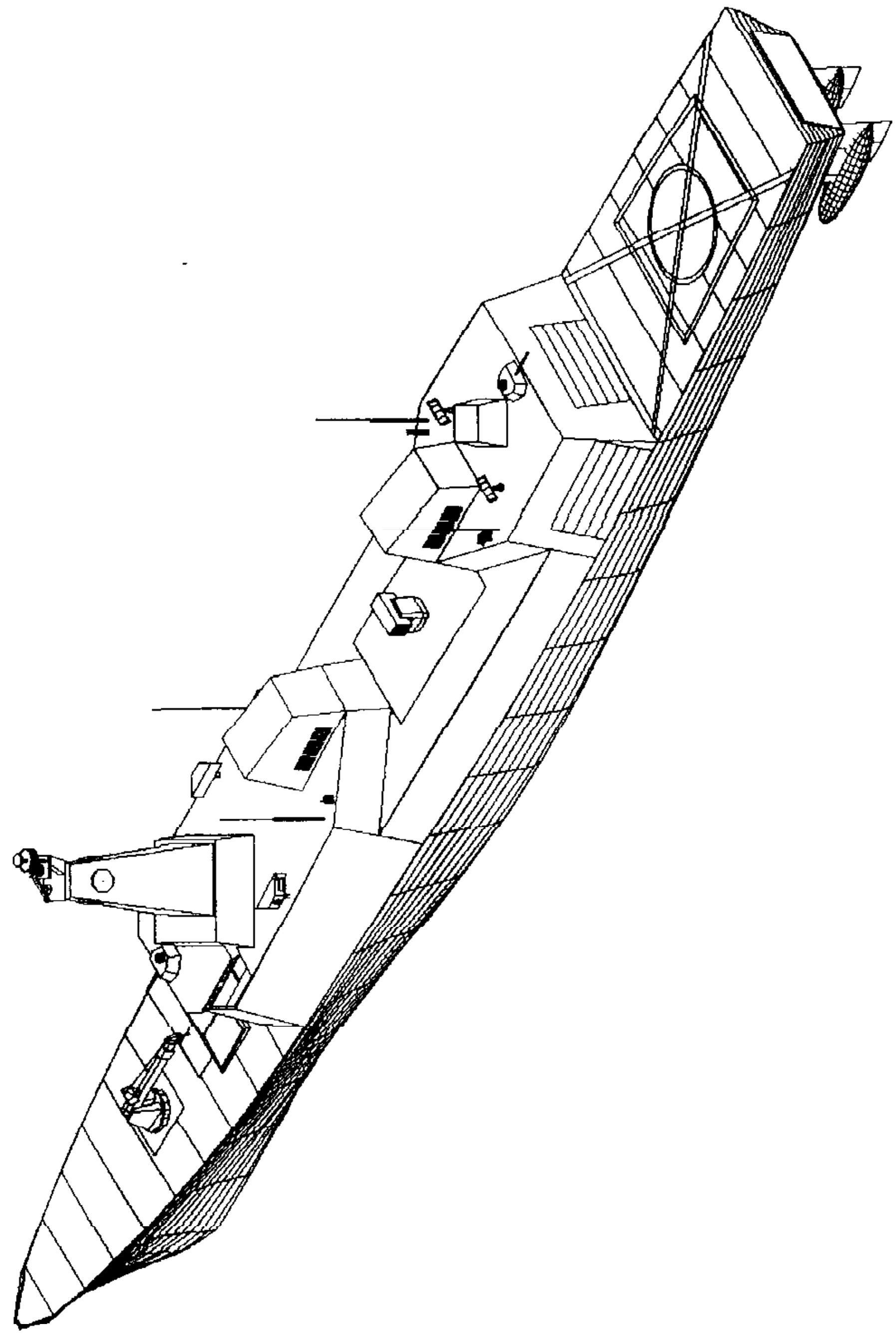

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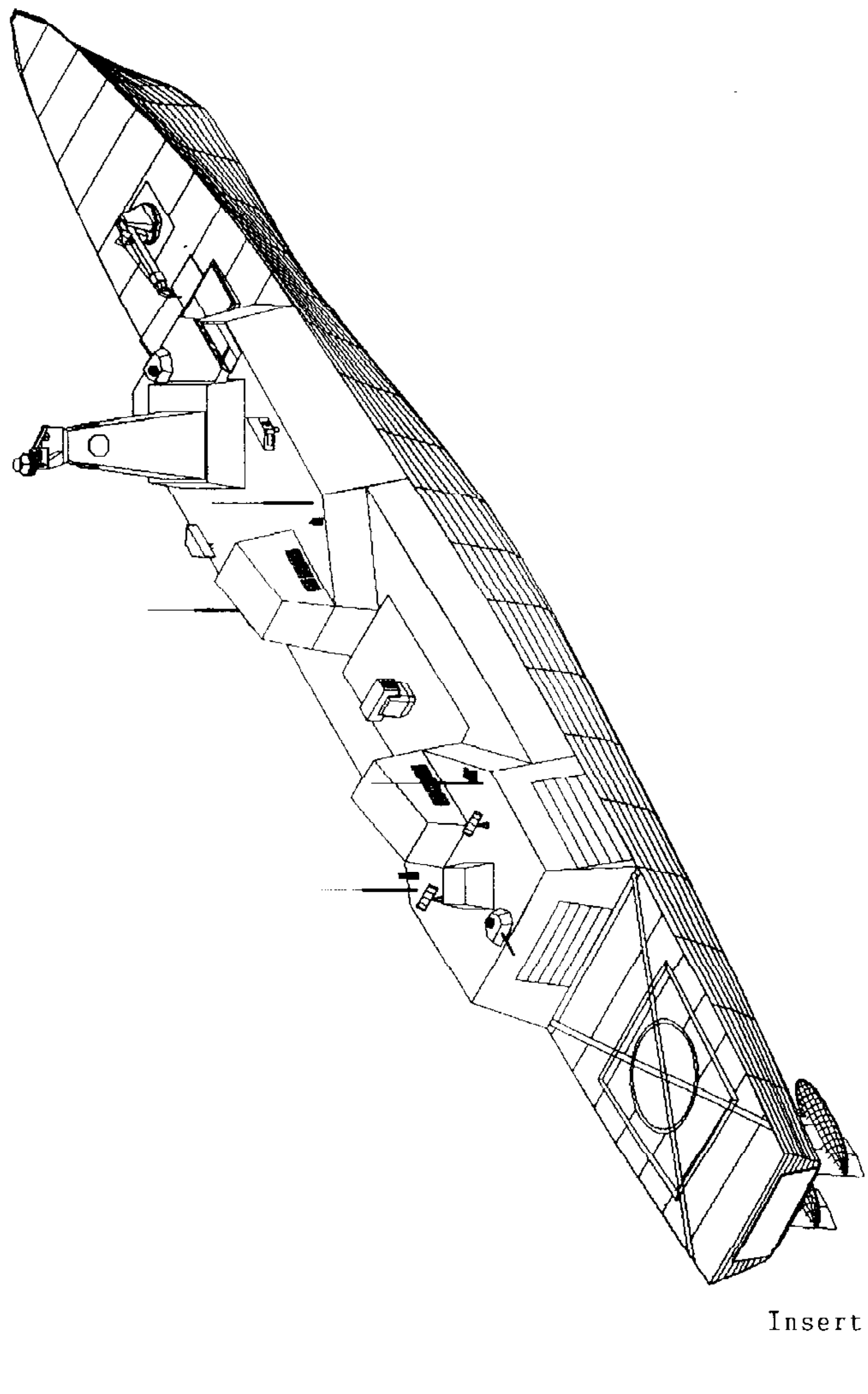

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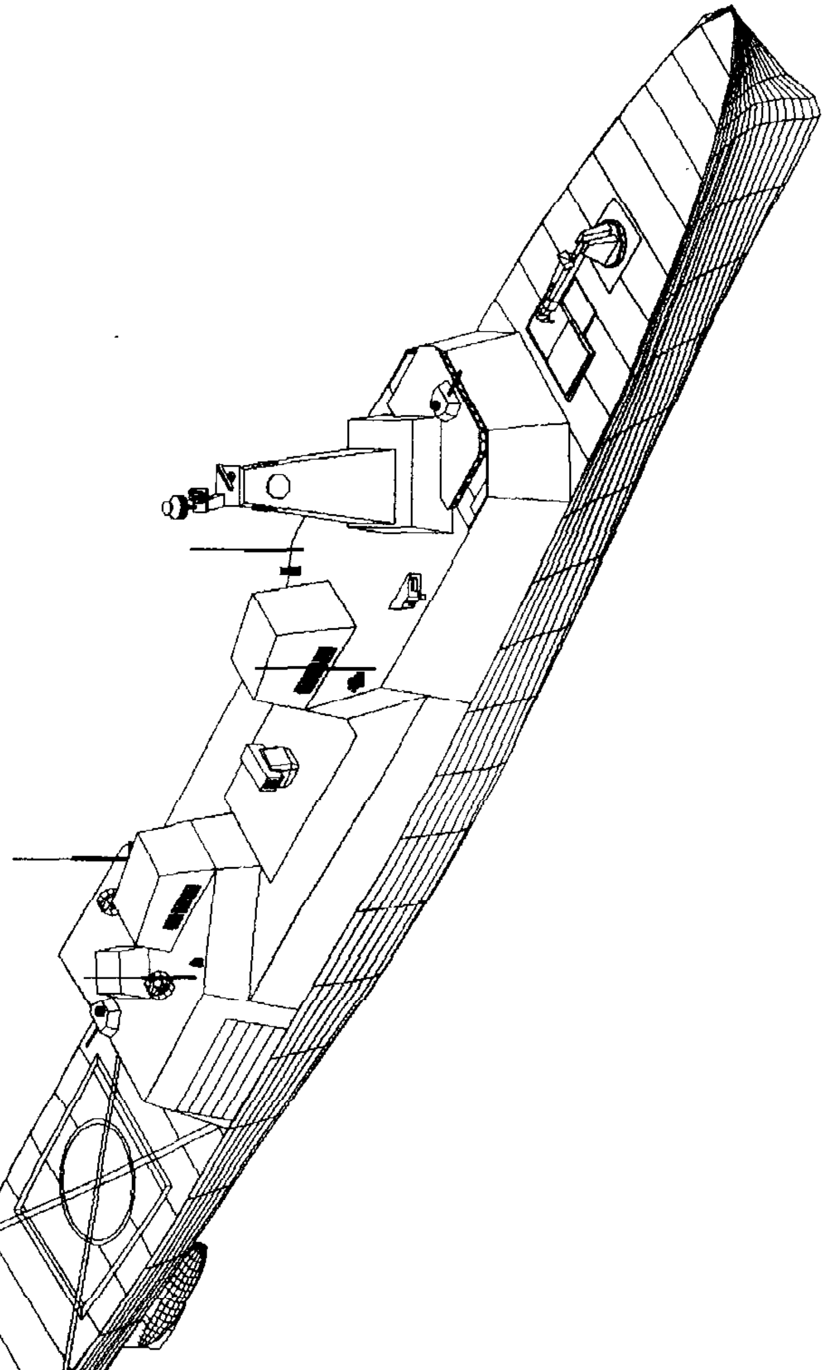

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F. MANNING AND BATTLE ORGANIZATION

1. MANNING

With the requirement of a significant reduction in crew compared to current standards, each position was critically analyzed. Our manning figures were driven by watchstation requirements during General Quarters Condition 1. Two points contributed to our reduction of crew; Service, pay, and health records will be maintained ashore, and major preventative maintenance will be accomplished by shore facilities. Based on our own shipboard experience and our level of automation, these numbers were developed. The manning levels and ratings are included as Tables 1 and 2. Additionally Figures (15) and (16) show the departmental organizational charts for the Navy and Coast Guard. Although this is not a formal manning document, it is an attempt to determine the number of personnel required to man the ship

Navy Variant

DEPARTMENT	OFFICERS	CPO'S	ENLISTED	TOTAL
SHIP SUPPORT	CO, XO, SUPPO (3)	HMC, MSC (2)	MS (3), SH(2) SK(2), YN/PN (8)	13
COMBAT SYSTEMS	CSO,OPS,EMO, WEPS (4)	BMC, ETC, FCC, GMC, OSC, RMC,STC (7)	BM (8), ET (4), EW (3), FC (4), GM (4), OS (8), QM (2), RM (4), SM, ST (2), TM, (41)	52
ENGINEERING	CHENG, MPA, DCA, A&E (4)	EMC, ENC, GSC, HTC/DCC (4)	EM (6), EN (7), GS (7), HT/DC (4), MM (2) (26)	34
AIR DETACHMENT	PILOTS (4)	ATC (1)	AIR CREW AIR TECHS (6)	11
AVAILABLE MANNING	15	14	81	110

Table 1

Coast Guard Variant

DEPARTMENT	OFFICERS	CPO'S	ENLISTED	TOTAL
SHIP SUPPORT	CO, XO, SUPPO (3)	HSC, SKC, SSC (3)	SS (5), SK(2), YN/PN (8)	14
COMBAT SYSTEMS	CSO,CICO, WEPS (3)	ETC, FTC, RMC, RDC (4)	ET (5), FT (2), GM (4), RD (8), RM (5) (24)	31
OPERATIONS	OPS 1ST LT (2)	BMC, QMC (2)	BM (14), QM (3) (17)	21
ENGINEERING	EO, MPA, DCA, A&E (4)	EMC, MKC (2), DCC (4)	EM (6), MK (16), DC (4) (26)	34
AIR DETACHMENT	PILOTS (2)	(0)	AIR CREW AIR TECHS (4)	6
AVAILABLE MANNING	14	13	79	106

Table 2

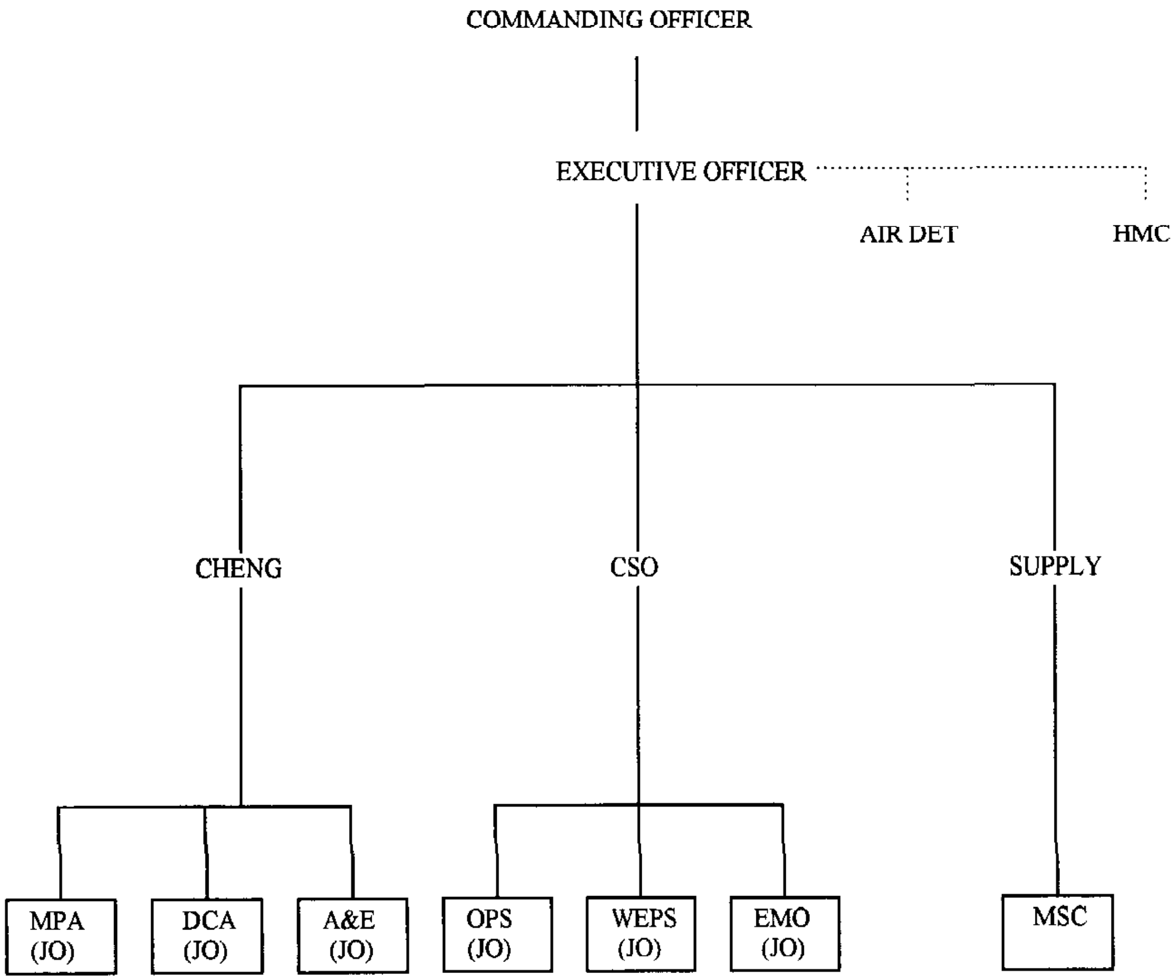


Figure 15 DEPARTMENTAL ORGANIZATION - NAVY

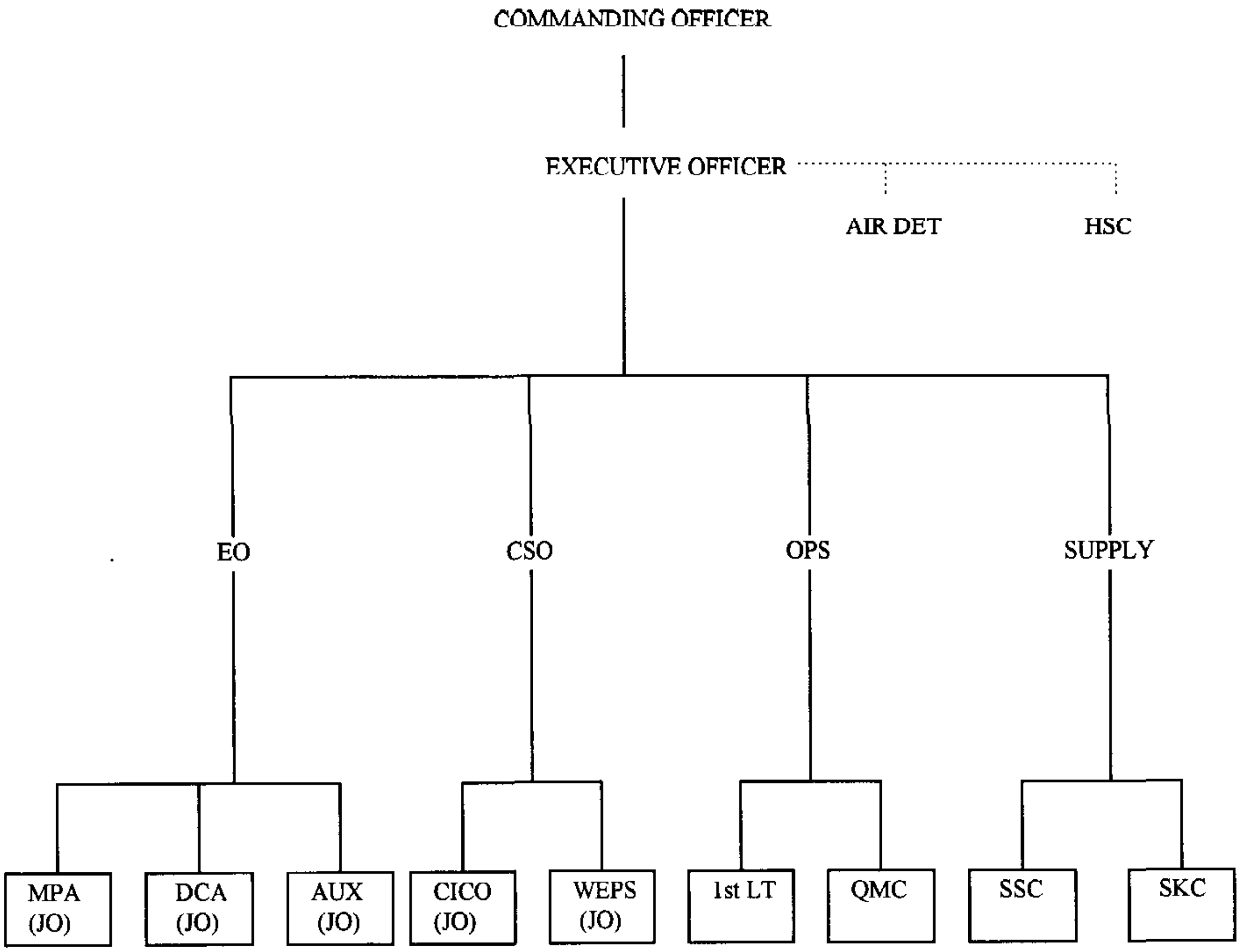


Figure 16 DEPARTMENTAL ORGANIZATION - COAST GUARD

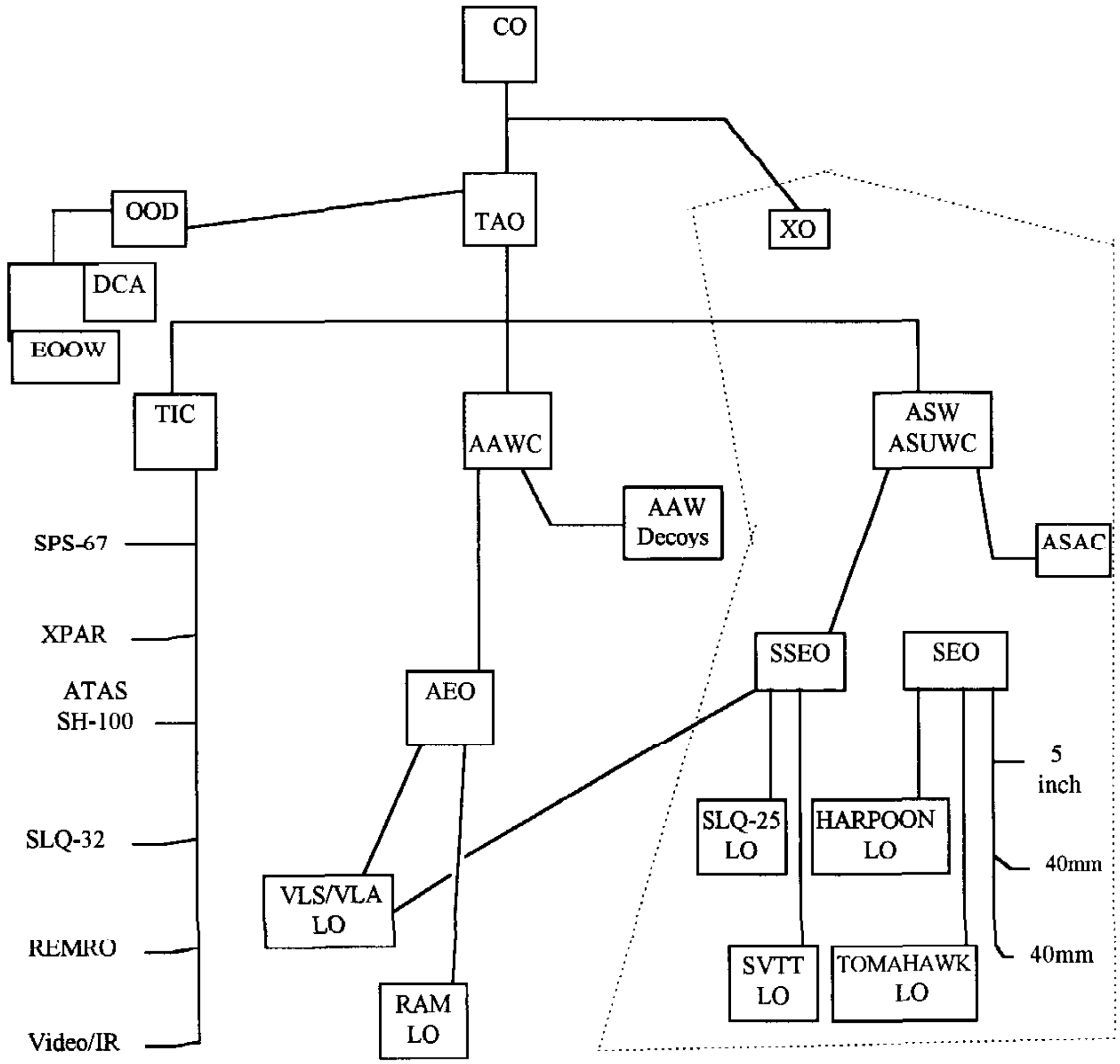
2. BATTLE ORGANIZATION

The manning requirements for the ship drive many design parameters, especially in the Combat System area. Manning is primarily driven by watchstation requirements during battle conditions, and to a lesser extent by normal ship operations. The CPCX's Condition I and Condition III Battle Organizations are given in Figures 17 and 18 and 19 and 20 respectively. The connectivity of the watch organization is for supervisory functions only, and has nothing to do with the flow of information to each watch station. Since each watch station will be connected to the data multiplexed ring bus, all watch stations will have access to any desired information. The watch stations that require consoles will be established with either one of two different types:

(a) a multi-purpose console (MMI) capable of performing any watch station function.

(b) or a watch station specific console used only for local equipment control and specific functions.

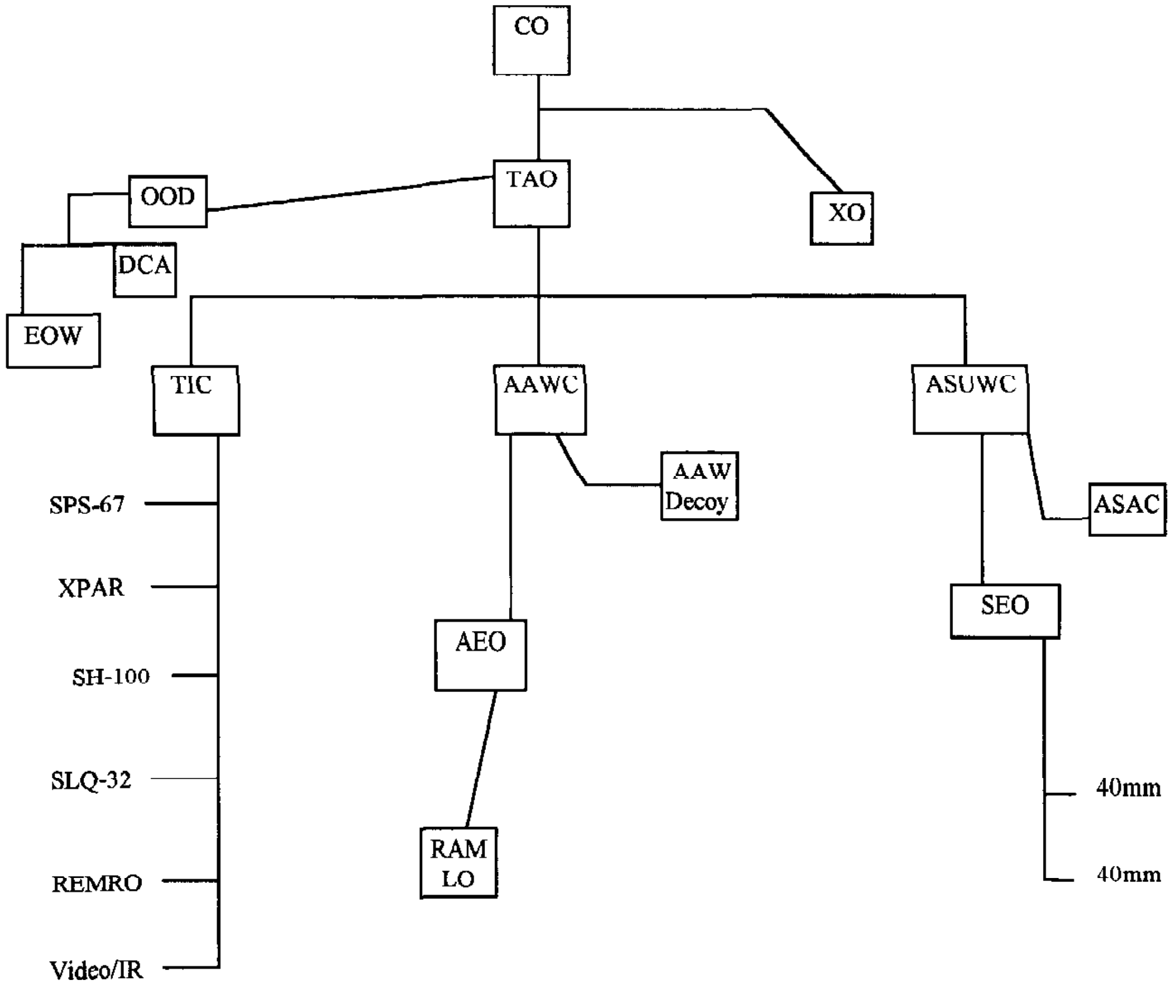
The capability of the combat system watch team during Condition III is that it can fight the ship in a short duration , limited capacity until the ship can man Condition I watch stations. The CPCX's manning will allow, with the exception of radio, all watch stations to be stood in a three section, 4 hours on/8 hours off, watch rotation. This will allow ample time for the off watch sections to conduct training, maintenance and housekeeping.



LEGEND

AAWC	**ANTI-AIR WARFARE COORDINATOR**
ASAC	**ANTI-SUBMARINE AIRCRAFT CONTROLLER**
ASUWC	**ANTI-SURFACE WARFARE COORDINATOR**
ASWC	**ANTI-SUBMARINE WARFARE COORDINATOR**
AEO	**AIR ENGAGEMENT OFFICER**
CO	**COMMANDING OFFICER**
DCA	**DAMAGE CONTROL ASSISTANT**
EOOW	**ENGINEERING OFFICER THE WATCH**
OOD	**OFFICER OF THE DECK**
LO	**LOCAL OPERATOR**
SEO	**SURFACE ENGAGEMENT OFFICER**
SSEO	**SUB-SURFACE ENGAGEMENT OFFICER**
TAO	**TACTICAL ACTION OFFICER**
TIC	**TRACK INFORMATION OFFICER**
XO	**EXECUTIVE OFFICER**
----	**CIC 2 (ALTERNATE CIC)**

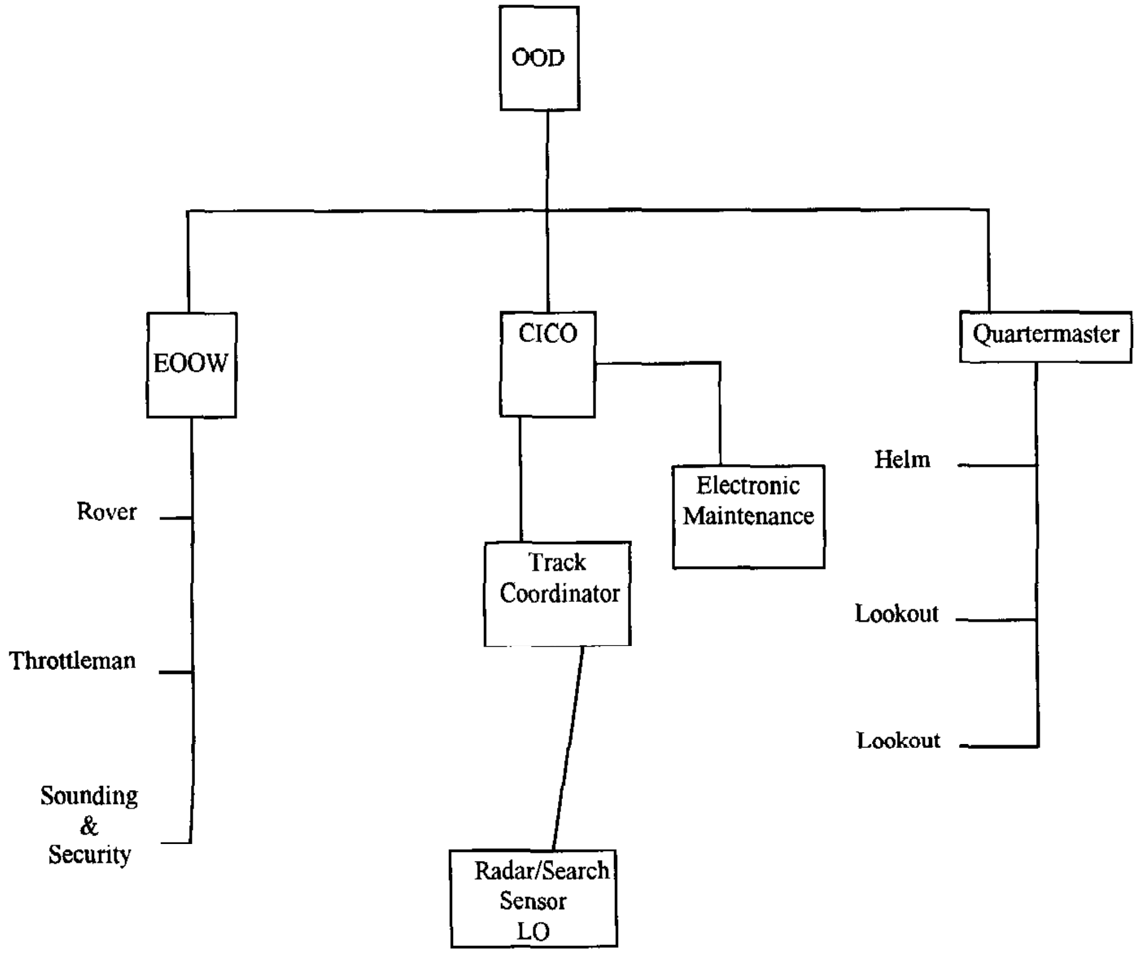
Figure 17 CONDITION I BATTLE ORGANIZATION - NAVY



LEGEND

AAWC	**ANTI-AIR WARFARE COORDINATOR**
ASAC	**ANTI-SUBMARINE AIRCRAFT CONTROLLER**
ASUWC	**ANTI-SURFACE WARFARE COORDINATOR**
AEO	**AIR ENGAGEMENT OFFICER**
DCA	**DAMAGE CONTROL ASSISTANT**
EOW	**ENGINEER OF THE WATCH**
CO	**COMMANDING OFFICER**
LO	**LOCAL OPERATOR**
OOD	**OFFICER OF THE DECK**
SEO	**SURFACE ENGAGEMENT OFFICER**
TAO	**TACTICAL ACTION OFFICER**
TIC	**TRACK INFORMATION OFFICER**
XO	**EXECUTIVE OFFICER**

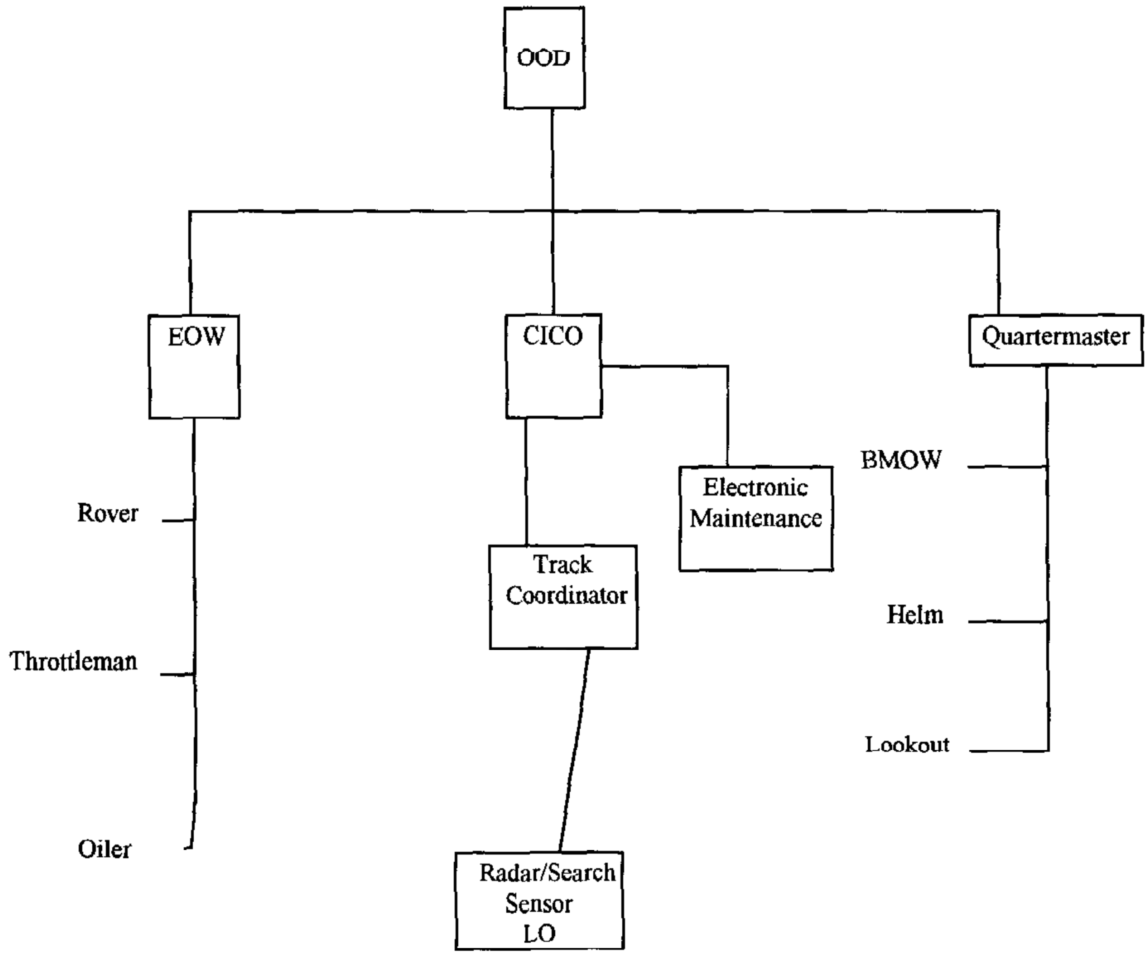
Figure 18 CONDITION I BATTLE ORGANIZATION - COAST GUARD



LEGEND

CICO	COMBAT INFORMATION CENTER OFFICER
EOOW	ENGINEERING OFFICER OF THE WATCH
OOD	OFFICER OF THE DECK

Figure 19 CONDITION III BATTLE ORGANIZATION - NAVY



LEGEND

CICO	**COMBAT INFORMATION CENTER OFFICER**
EOOW	**ENGINEER OF THE WATCH**
OOD	**OFFICER OF THE DECK**
BMOW	**BOATSWAIN MATE OF THE WATCH**

Figure 20 CONDITION III BATTLE ORGANIZATION - COAST GUARD

G. CONVERSION

The ORD dictated the requirement of two ship variants form one hull, one operated by the Navy, the other by the Coast Guard. As much as possible the variants were kept the same to reduce costs and to ease production. The variants differ where it was necessary by due to their different missions. The Navy variant requires a robust self defense capability, some strike capability, and sophisticated air search capabilities. The Coast Guard variant will be used in drug, smuggling, and illegal immigration interdiction, fisheries protection, SAR, escort, and general maritime police duties. In addition, different maximum costs were set for each variant, the Coast Guard variant's being $375 million and the Navy variant's being $450 million. Conversion must take place in under four weeks. Because of these mission differences, the following conversions are required for the Navy variant to become the Coast Guard variant and vice versa.

1. <u>Remove:</u> VLS <u>Install:</u> fuel storage, buoy storage area with sinkers and chain and environmental clean- up gear.

The VLS will be constructed as one unit that can be removed all at once. All missiles will be removed from the ship and then the VLS unit will be lifted out and removed. Associated fire control illuminators will be removed from topside. In its place will be fuel storage tank twelve feet from the keel. A buoy storage room will be on top of the fuel tank. An overboard drainage system will be installed. Flush with the main deck will be a watertight 12'X 12' hatch.

2. <u>Remove:</u> 5" gun <u>Install:</u> buoy crane

Ammunition will be removed from the gun magazine. The ammunition elevator will be removed. A watertight door will be installed at the frame 66' aft of the forward perpendicular. An environmental containment skirt will be stored in the former magazine and will be assessable by this door. The gun will be removed on the main deck and in its place a crane to lift buoys and the skirt will be installed.

3. Remove: ATAS Install: 2 RHI small boats

The ATAS will be removed from the "well deck". Associated equipment in the well deck will be removed. CIC will remain unaffected. Two RHI small boats will be placed in the well deck. Rails are already in place.

4. Remove: Torpedo tubes Install: Prisoner containment room

Remove torpedoes. Remove "bolt on" torpedo tubes and electrical cabling. Patch opening for torpedoes. Install one commode, shower for prisoner head. Fresh water piping will be pre-staged. Install four sets of bunks, three high.

V. DESIGN EVALUATION

A. SURVIVABILITY FEATURES:

The CPCX's survivability characteristics received significant emphasis to support its independent operating nature. Signature reduction was accomplished in three areas by incorporating; radar cross section (RCS) reduction features, infrared (IR) reduction features, and acoustic reduction features. In addition, redundant systems and control spaces further enhance survivability.

The hull, superstructure, and mast consist of flat surfaces, angled at 10 degrees with respect to vertical. All topside equipment such as small boats, deck fittings, torpedo tubes, and miscellaneous gear have been located within the superstructure. These measures will significantly eliminate corner reflectors and reduce the RCS of the CPCX. Further enhancements include the glass reinforced plastic mast and Radar Absorbing Material (RAM) applied to all superstructure and mast surfaces to reduce the reflection of electromagnetic energy.

Infrared cross section reduction methods consist of IR insulation, regenerative gas turbine engines and stack eductors to reduce prime move exhaust temperature.

Acoustic reduction methods include; double sound isolators on the diesel prime movers, acoustic modules on the gas turbine engines, prairie and masker air systems to mask hull noise, and active ship silencing.

The propulsion system was divided among two main engineering spaces located on the 3rd deck. Each engine room contains one diesel and one gas turbine engine to provide main propulsion and electrical power through an electric drive configuration. This propulsion system combined with the DC zonal electrical distribution effectively eliminated all single point failures or "Choke Points" in the engineering system. With a loss of one engine room, the maximum attainable speed is 23kts. In addition, an uninterruptable power supply (UPS) battery is directly connected to the four combat system vital buses. In the event of generator casualties, a seamless transition from primary to alternate power occurs.

Two physically separate CIC's act as a single entity. For the Navy variant, both CIC's are manned during General Quarters. If #1 CIC is lost , the other, although not having as many consoles, is capable of effectively fighting the ship. For the Coast Guard variant, only one CIC is manned during General Quarters. CIC #2 is capable of fighting the ship if CIC #1 is lost and enough personnel are available to main the alternate space.

Finally, the CPCX's information is distributed through several fiber optic paths in a ring information network. This fiber optic ring allows processing capability to be spread throughout the ship while maintaining a rapid flow of information to all users.

The only single point of failure is the mast which contains the XPAR, surface search radar, forward missile illuminator, IR detectors, and CEC antenna. A casualty to the mast would eliminate navigation and combat systems capability entirely.

B. FURTHER STUDY

This design is the result of one iteration of the design spiral. Areas that require further attention in subsequent iterations include; the single mast, Coast Guard cost, weight management, cost analysis, and a comparison of CPCX with similar ships.

The air search and surface search radars, as well as other vital equipment, are located on a single mast. Placing a second mast on the ship should be investigated. Alternate locations for topside and other systems would also need to be analyzed.

The Coast Guard is buying high cost sensors for ease of convertibility. Modularized detection elements would eliminate this problem. With the indications provided by future technological areas, this concept is possible.

The CPCX is at the upper limits of its service life weight margin. Critical analysis needs to be completed in this area by compiling more accurate weights and by reevaluating system placement.

Cost data was obtained from the ASSET model. This Cost was calculated using weight based empirical formulas. Future study would require accurate costs provided by manufactures, particularly for new technology systems.

Finally, an effectiveness analysis should be conducted on the CPCX and then compared to other ships with similar size, mission, and payload. This analysis would clearly show which ship is "better".

C. DESIGN AS A LEARNING TOOL

The value of this design process as a learning tool was in the use of systems engineering principles to design one of the ultimate engineering systems - a multi-mission capable ship. The learning and adoption of a systems engineering approach can be divided into two broad areas. The first area includes the technical or "textbook" aspects of implementing a structured design process that leads to a finished product, in this case a ship design completed through the preliminary design phase. The second area relates to the teamwork or "human" aspects of working on a relatively long term, large scale project as a member of an eight person team. Each of these areas had its related challenges and demands.

The process of transforming operational requirements into a preliminary design demonstrated the multitude of trade-off, optimizations, analysis methods, and engineering judgments that are required for a large system design. The design process using a system engineering approach shed new light on just how integrated ship systems need to be if they are to operate at an optimal level. Progressing from the definition of a need for a new system through to the preliminary design phase with high level of concern for how the various subsystems will integrate to form a whole system is a concept applicable to not just ships or military craft, but any system having two or more components.

The importance of the teamwork aspect to the design process was manifested early. The realization came that in order for any of our ship systems to be integrated, our efforts as a team had to be integrated as well. Everything from previous experience tours to individual schedules and work habits came into play in completing each aspect of the design. The personal experiences, strengths, and interests of each team member had to be considered so that contributions by each team member could be optimized and the common goal of a successful preliminary ship design could be achieved.

D. CONCLUSION

The CPCX is a multi-mission capable ship that satisfies Navy and Coast Guard needs for a replacement vessel in the year 2010. It is suited for use in littoral as well as blue waters. The incorporated concept of convertibility allows for a rapid response to ever changing threat environments.

The CPCX meets all requirements as dictated by the ORD. In a successful adherence to our design philosophy, we were able to meet or better the constraints of maximum cost, minimum range, and maximum displacement. In addition, the RCS features previously discussed contribute to the ship's high survivability. The maximum mission effectiveness was achieved by choosing the ship option with the highest measure of effectiveness. A significant reduction in manning was achieved by reviewing current crew positions as well as by incorporating features that implement automation into the design. Our logistics plan along with a menu-driven maintenance system provide the ship with little required maintenance other than basic preventive and essential corrective maintenance. Finally, the quality of life aspect of the crew was important for a minimally manned crew. To improve habitability, crew service spaces were concentrated around the messdecks, the per person space allotment was increased, and recreation spaces were included.

With the items in further study addressed, the design should provide Navy and Coast Guard policy makers a low cost, easily maintainable, minimum manned ship in 2010.

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