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Machinery Research and Development Directorate
Research and Development Report

HIGH TECH SHIP CONCEPT DESIGN

by
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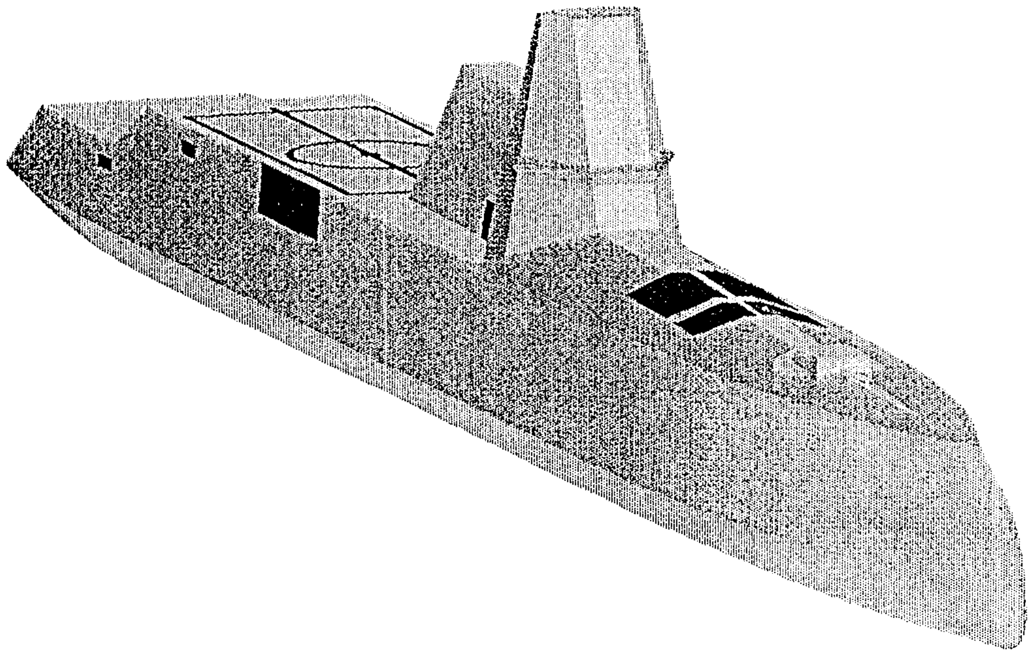
High Tech Ship Concept Design

CRDKNSWC/SSD-CR-94-005



FOREWORD

The work described in this report was performed for the Office of Naval Research (ONR). Technical direction was provided by the Carderock Division of the Naval Surface Warfare Center (CDNSWC). The respective technical points of contact were:

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EXECUTIVE SUMMARY

The High Tech Ship (HTS) project was started in 1992 at CDNSWC, under ONR sponsorship, to develop the design of a futuristic ship. This ship was intended to "showcase" emerging technologies and, in keeping with the current Navy doctrine "From The Sea," it was to be an affordable corvette-sized vessel capable of quick response to crisis situations in remote areas of the world. The overall objective of the study was to provide inputs for the development of a Technology Investment Strategy for Hull, Machinery and Electrical (HM&E) systems, to satisfy the future needs of naval surface combatants, with a focus on:

a. Improvements in affordability by satisfying required force capability with innovative and collective/synergistic application of emerging technologies, and

b. Avoidance of technological surprise by keeping ahead of developing threats with emphasis on improved covertness, operational effectiveness and survivability.

The HTS is a 2100-ton shallow-draft combatant dedicated to littoral surface warfare missions that is expected to face a threat from mainly third-world/developing countries. The HTS is designed to deploy up to 3000 nm in less than four days, monitor the situation for up to ten days without support and deliver destroyer-level fire power. The HTS is not intended to replace larger combatants, but instead to provide a complementary capability at a more reasonable cost by exploiting the following emerging technologies:

- **STEALTH FEATURES** having a low visual profile, low RCS clean top sides with conformal weapons and enclosed/embedded sensors and com system; fuel-cell power plants with a ten-fold reduction in IR signatures from low exhaust flow and temperature, quiet operation with no combustion, few moving parts, and low-noise waterjet propulsors; composite low-magnetic hull and advanced automatic EM frequency management and active signature monitoring and control.

- **REDUCED MANNING** concepts with advanced damage-control, fire-control and maintenance concepts, *including CBR citadel defense, fully-integrated intelligent monitoring and control of ship's systems, automation* and artificial intelligence/neural networks with data link to shore-based resources for administration support and global C^3I.

- **LOW POLLUTION** from non-toxic power plant exhaust, cleaner power plant with few moving parts, reduced waste from reduced crew size and on-board advanced waste management systems.

- **COMBAT HARDNESS** using zonal architecture for power generation offering quick reconfigurability, with advanced distributed auxiliaries, all dc power grid, advanced armor protection, damage tolerant structures, survivable communications and survivable ship's sensors.

- **HIGH FIRE POWER** with thermal-electric gun, terminally guided ordnance-600 rounds with 60 nm range plus six RPVs with hangar and flight deck for OTH targeting/surveillance, eight ASUW-VLS missiles, 16 AAW-VLS missiles, triple torpedo tube, electro-thermal CIWS and multi-purpose weapon systems; real-time 3-D dynamic fire control and high-power electronic countermeasures.

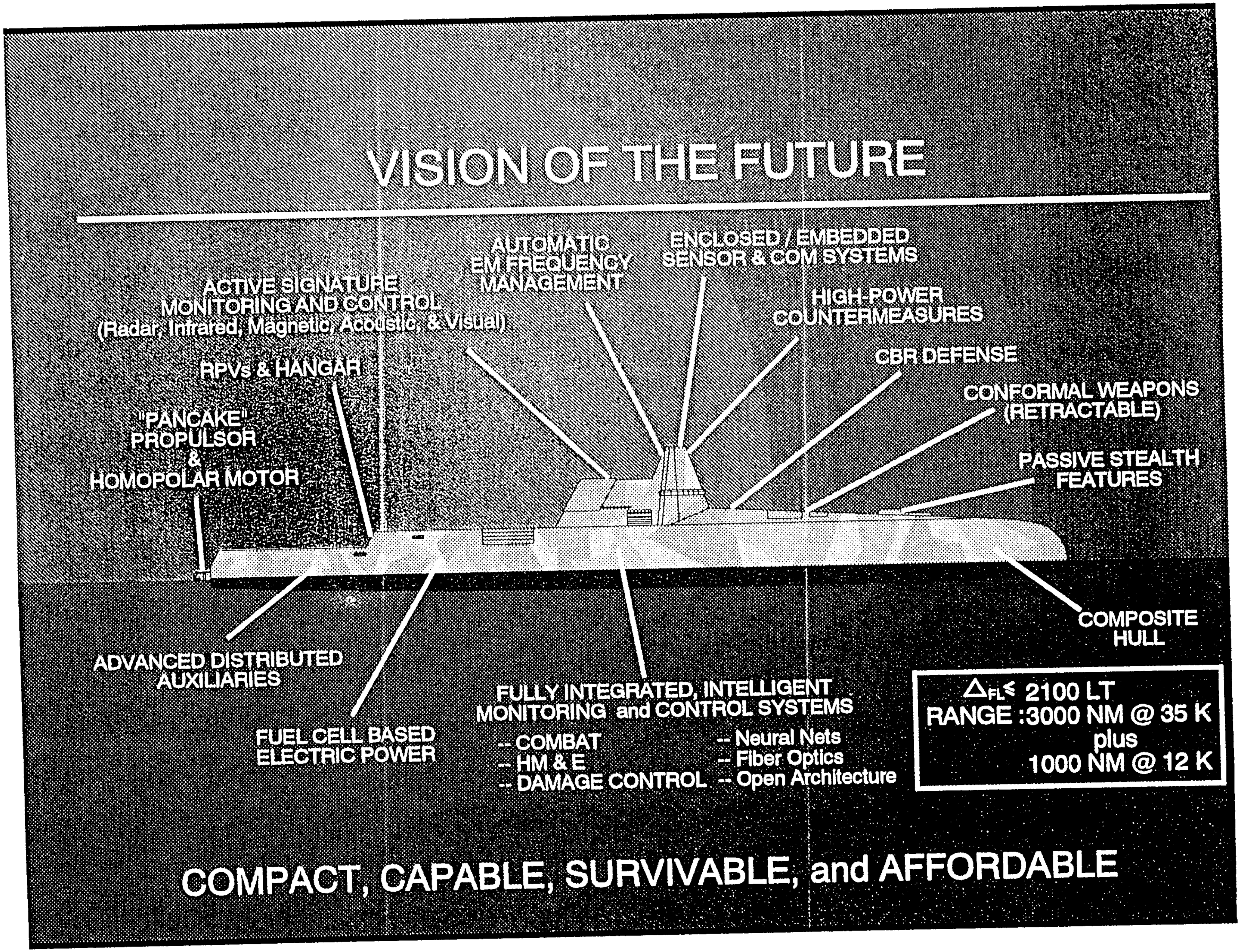
- **ADVANCED PROPULSION** featuring a distributed all fuel-cell electric propulsion/ship-service plant, capable of providing pulse power for electric guns, offering at least a 15% fuel savings with permanent magnetic waterjet propulsors providing shallow draft operation.

- **ADVANCED SEAKEEPING HULLFORM** having high length-to-beam roll stabilized slender form and wave-piercing bow for improved high-speed performance in high sea states.

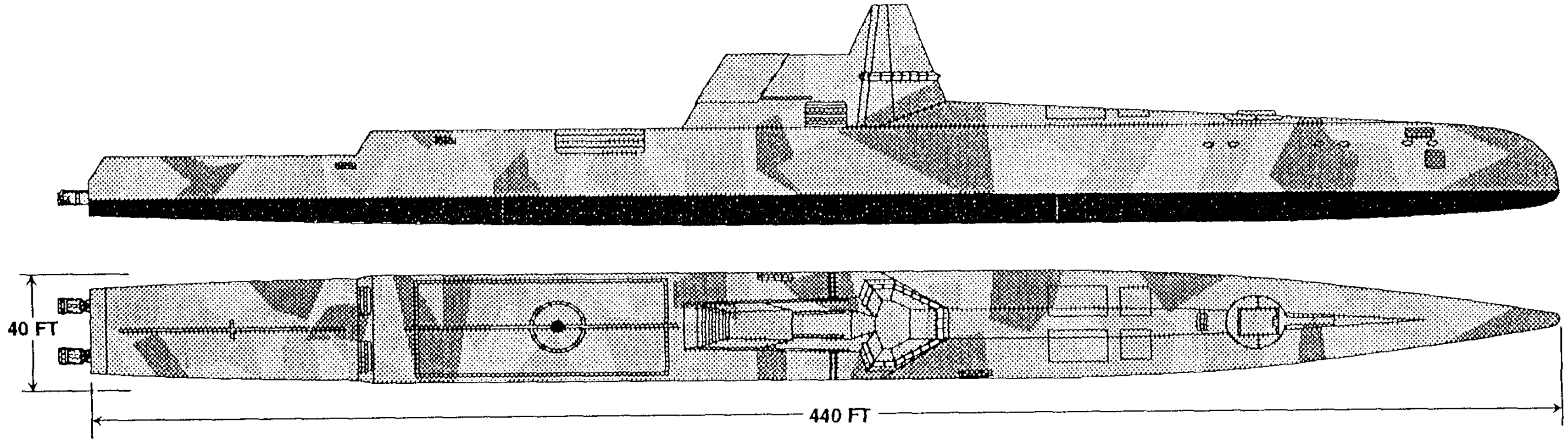
- **MODULAR HULL AND SUPERSTRUCTURE** of advanced lightweight composite construction to provide flexibility for the installation of payloads for multi-mission options, lower fabrication cost and easier maintenance.

- **AFFORDABLE** at one-third the cost of a destroyer, primarily because of its relatively small size and ship's complement.

- **INCREASED AREA OF OPERATION** afforded by shallow draft hull and flush-inlet waterjet propulsion providing enhanced tactical flexibility for operation in coastal waters.


VISION OF THE FUTURE
AUTOMATIC EM FREQUENCY MANAGEMENT
ENCLOSED / EMBEDDED SENSOR & COM SYSTEMS
ACTIVE SIGNATURE MONITORING AND CONTROL (Radar, Infrared, Magnetic, Acoustic, & Visual)
HIGH-POWER COUNTERMEASURES
CBR DEFENSE
RPVs & HANGAR
CONFORMAL WEAPONS (RETRACTABLE)
"PANCAKE" PROPULSOR & HOMOPOLAR MOTOR
PASSIVE STEALTH FEATURES
COMPOSITE HULL
ADVANCED DISTRIBUTED AUXILIARIES
FULLY INTEGRATED, INTELLIGENT MONITORING and CONTROL SYSTEMS
-- COMBAT
-- HM & E
-- DAMAGE CONTROL
-- Neural Nets
-- Fiber Optics
-- Open Architecture
FUEL CELL BASED ELECTRIC POWER
Δ FL ≤ 2100 LT
RANGE :3000 NM @ 35 K
plus
1000 NM @ 12 K
COMPACT, CAPABLE, SURVIVABLE, and AFFORDABLE

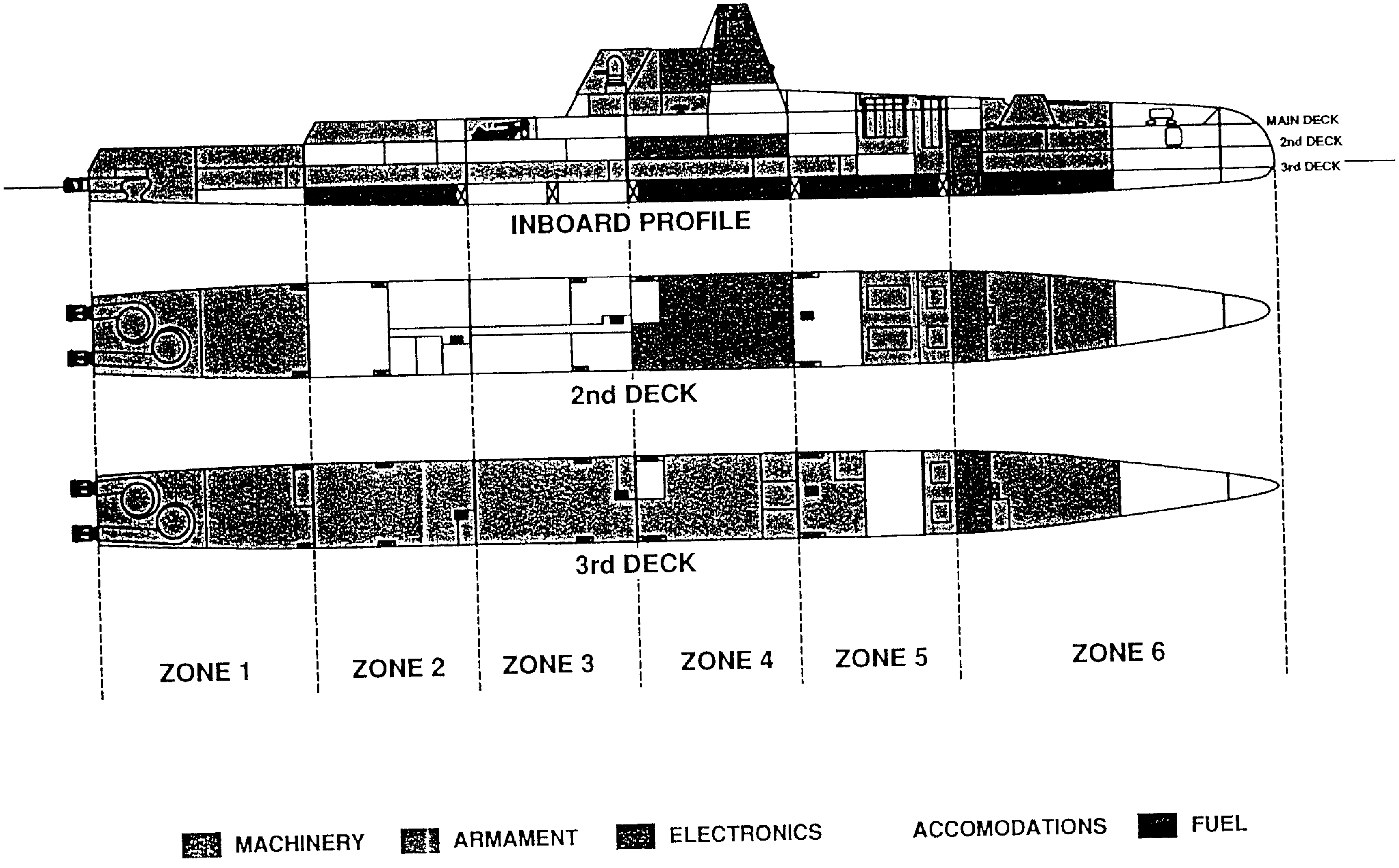
HIGH TECH SHIP



DISPLACEMENT	=	2100 LT
LENGTH OVERALL	=	440 FT
MAXIMUM SPEED	=	40 KTS
RANGE @ 20 KNOTS	=	13000 NM
INSTALLED POWER	=	34 MW
CREW COMPLEMENT	=	30

HIGH TECH SHIP

ARRANGEMENTS



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1.0 INTRODUCTION-BACKGROUND

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b. Avoidance of technological surprise by keeping ahead of developing threats with emphasis on improved covertness, operational effectiveness and survivability.

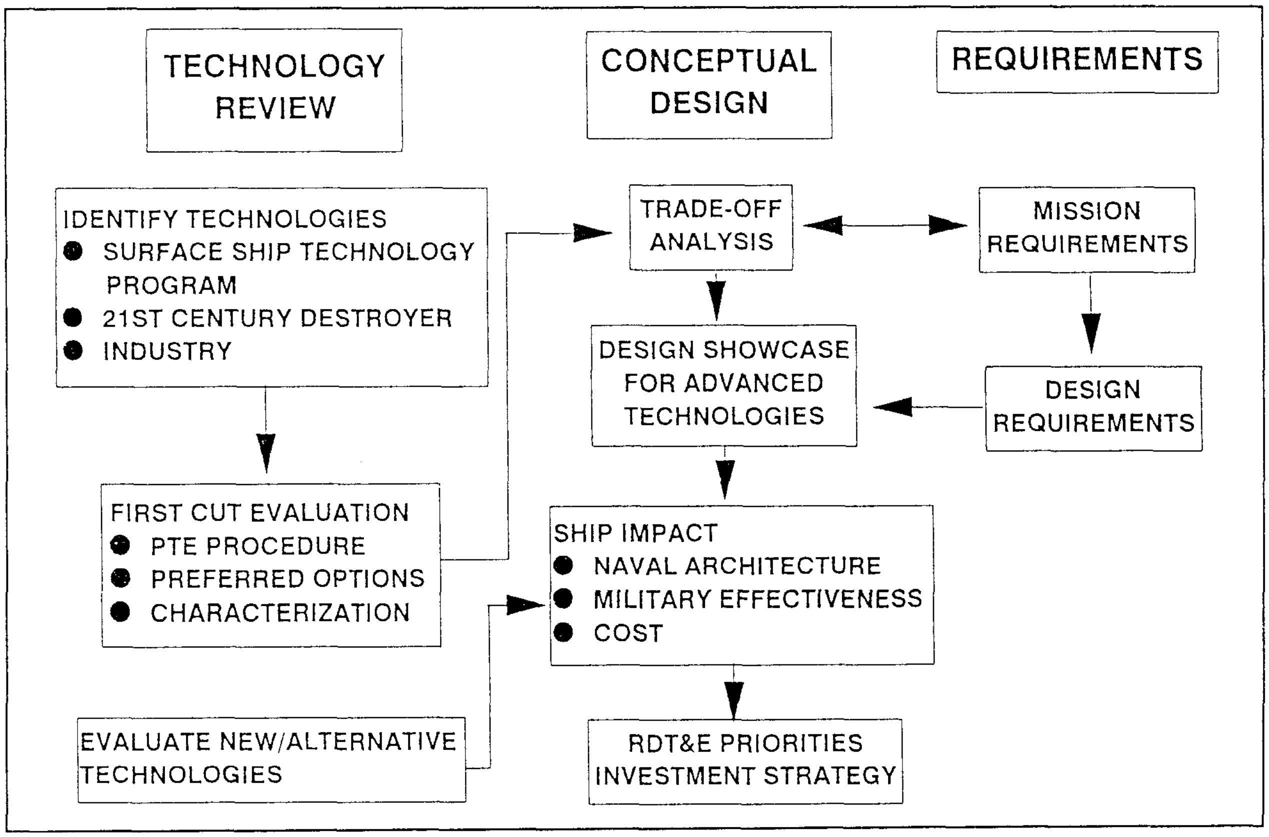

Figure 1-1. HTS Study Plan

The HTS is a small combatant dedicated to surface warfare missions and is expected to face a threat from mainly third-world/developing countries. The HTS is not intended to replace larger combatants, but instead, to provide a complementary capability at a more reasonable cost.

A state-of-the-art conventional corvette, designated the Corvette 2100 Baseline, was designed first to represent a reference for comparison. As such, this conventional ship was designed to meet speed and range requirements that are consistent with the current state-of-the-art and, therefore, less demanding than those specified for the HTS. The Corvette 2100 Baseline, reported in Referenced 1, uses current technology and hardware.

An advanced-technology, monohull corvette, designated the High Tech Ship (Monohull), was designed to meet the more demanding requirements given in Appendix A. The design of the ship is described in this report. The High Tech Monohull incorporates the most promising emerging HM&E technologies currently under development, including those in the ONT 6.2 Surface Ship Technology Program, as reviewed in Reference 2.

2.0 PRINCIPLES AND RATIONALE FOR THE DESIGN OF THE HIGH TECH SHIP

2.1 Preselected Technologies

A review of the emerging technologies developed, in particular, under the 6.2 Block program was conducted prior to the design effort reported herein. This technology review was documented in Reference 2 and provided a preselection of the most promising technologies to be used in the design of the HIGH TECH SHIP. The selected technologies are listed in Table 2-1.

A hullform selection analysis was also conducted and reported in Reference 3. From this it was concluded that SES and Monohull versions should be pursued further. This report describes the Monohull version. An SES variant is also to be assessed.

2.2 Design Methodology

A common procedure was used to design the HTS and the CORVETTE BASELINE. This procedure was checked against actual conventional designs as was reported in Reference 1 with a correlation usually within 5% of the actual values for the main characteristics such as displacement and power. However, some specific routines and/or corrections were applied to accurately represent the specific technology and design features of the HIGH TECH SHIP. In particular, the following subsystems were modeled for that purpose:

- Fuel Cell Power Plant
- Waterjet Propulsion
- Composite Structures (Hull and Superstructures)
- Homopolar/Superconducting Motors.

Other aspects such as high length-to-beam ratio hullform and reduced manning were investigated parametrically.

A number of emerging technologies were also accounted for by adjusting the standard weights of some subsystems. In particular, it was assumed that the following goals would be met by combining the use of such techniques as automation, artificial intelligence, neural networks, fiber optics, distributed auxiliaries, integrated electric distribution, electronic switches, etc. (see list of technologies retained for the HIGH TECH SHIP - Section 2.1):

- 70% reduction of manning requirements. The HIGH TECH SHIP was assumed to require only 30 crew members versus 100 for the CORVETTE BASELINE

- 20% weight reduction for Electric Power Distribution (SWBS 320 and 330)

- 20% weight reduction for auxiliaries (SWBS 500)

- 20% weight reduction for outfitting (SWBS 600).

Those weight reduction goals were factored into the design of the HIGH TECH SHIP and are considered as "targets" to be achieved by technological innovations such as those listed above.

Table 2-1

List of Selected Technologies

1. **Hullform**

   Slender Hull Monohull
   Surface Effect Ship (SES)

2. **Stealth Techniques**

   Topside Shaping
   Acoustic Signature (Fuel Cells, Waterjets)
   IR Signature (Fuel Cells)
   Magnetic Signature (GRP)
   Noise and Vibration Cancellation

3. **Structure**

   GRP Hull and Superstructure
   Enclosed Mast (Integrated Antennas)

4. **Propulsion Plant**

   Fuel Cell and Electric Drive
   Vertical Axis Motor Propulsor (VAMP)
   Automation (Reduced Manning)

5. **Electric Plant**

   Distributed Fuel Cells
   Zonal DC Electric Distribution (IED)

6. **Command and Surveillance**

   Fiber Optics for Communications and Data Processing
   Integrated Damage Control (Neural Network)

7. **Auxiliaries**

   Distributed Auxiliaries
   Electric Auxiliaries Only
   Water Mist Fire-Fighting

8. **Outfit and Furnishing**

   Advanced Insulation Materials Integrated With GRP Structure
   Molded In Fittings

9. **Armament**

   Remotely Piloted Vehicles (RPVs)
   Electro-Thermal Chemical (ETC) Gun and CIWS

2.3 Parametric Evaluation

The principal characteristics of the HIGH TECH SHIP were set by determining parametrically the optimum dimensions for:

- Waterline Length (LWL)
- Waterline Length-to-Beam Ratio (L/B)
- Beam-to-Draft Ratio (B/T)

These parameters were varied within the following range of values:

- LWL between 120 m and 150 m (390 ft to 490 ft)
- L/B between 10 and 14
- B/T between 2.75 and 4.25.

For a given value of L/B and B/T, the optimum LWL was determined by minimizing the full-load displacement while retaining an acceptable block coefficient and stability characteristics (whenever possible). The influence on full-load displacement of varying L/B and B/T is shown in Figure 2-1.

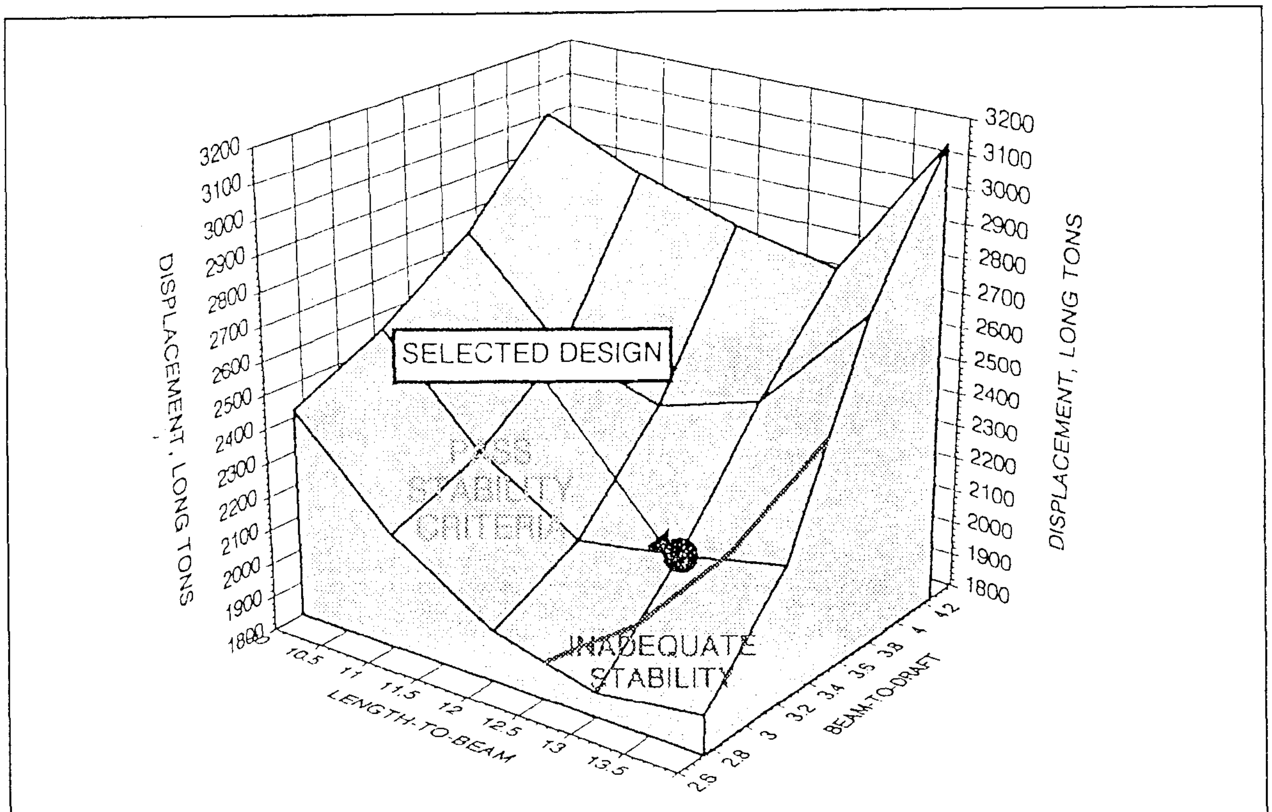

Figure 2-1. Parametric Optimization of the HIGH TECH SHIP

As can be seen, the optimum B/T ratio is found to be 3.25 in order to provide adequate margins for stability. Then along the B/T = 3.25 line, the optimum L/B is found between 12 and 13. An L/B ratio of 13 was selected for the design point.

Finally, the optimum design point was found to be for:

LWL = 134 m (440 ft)
L/B = 13
B/T = 3.25.

3.0 GENERAL DESCRIPTION OF THE HIGH TECH SHIP

3.1 Leading Particulars, General Arrangements

The leading particulars of the HTS are summarized in Table 3-1.

The outboard profile of the HTS is shown in Figure 3-1 while the internal arrangements are shown in Figures 3-2 and 3-3. Compared to a conventional hullform the overall length of the HTS is disproportionate to the displacement (the length is that of a 6000 LT destroyer). This is due to the unusually high length-to-beam ratio which renders comparison with conventional hullforms overall length misleading. The length of the HTS provides, in return, large internal volume, in spite of a relatively narrow beam. This combined with a reduction of volume requirements for advanced machinery (the power/volume density of a fuel cell plant is typically twice that of a conventional plant) as well as for crew accommodation (because of reduced manning) has allowed the hull itself to contain most of the required space, thus leaving an unusually small superstructure. In fact, superstructures are really necessary only in order to provide a high location for sensors (enclosed radars and communications antennas) as well as a pilothouse with a good, all-around visibility. In addition, a conformal CIWS (pulse power weapon) was integrated into the superstructure block. As a result of the virtual elimination of superstructure, the center-of-gravity has been lowered, thus providing adequate stability for such a narrow hullform.

As can be seen in Figure 3-1, all weapons have been made conformal in order to minimize radar signature. All the weapons, as well as some auxiliary systems, such as the Rigid Hull Inflatable Boat (RHIB) and anchors are enclosed in the hull or superstructure and are uncovered only when needed. Although a number of sliding doors and panels will be needed for this purpose, which will cost in weight and installation complexity, those closures are necessary to ensure virtual elimination of any radar traps. All enclosed weapons and auxiliary systems are shown deployed in Figure 3-4. Note that the 5-inch electro-thermal gun (pulse power) was set low in the hull because its firing angle is typically about 45 degrees in order to fire at a long range (60 nm approximately). It is envisioned that, rather than lowering the gun when firing at closer range, the intensity of the pulse may be adjusted to reduce the muzzle velocity while keeping the working angle at 45 degrees. Although the shell would have a reduced muzzle velocity, it would have an improved precision when using smart shells as the shell would be coming down on the target. Alternatively, it is also possible to fire with a given muzzle velocity but at a higher elevation to fire ballistically at a short range. However, the time for the shell to reach its target would increase significantly. The small multi-purpose weapon systems are intended to be used against short range targets (up to the horizon) and, therefore, it is not necessary to fire the 5-inch gun at low angles (such as -15 degrees typically used for conventional guns).

All crew accommodations were regrouped within three central/aft longitudinal sections of the hull in order to provide comfort and compactness for the spaces that most need air-conditioning and service power.

The CIC was set low in the hull for maximum protection. A secondary ship control station is fitted in the CIC, thus allowing the ship to be fully operated, with remote cameras for visibility, in the event of combat damages to the pilothouse.

The ship is fitted with an RPV platform on its after deck while RPVs are stored and maintained in the nearby hangar. In addition, a helicopter landing pad is provided on its upper deck in order to allow refueling and/or resupply operations (but no helicopter hangar is provided).

The RHIB can be put in the water on the side using a telescopic crane.

Table 3-1

Leading Particulars of the HTS

```
PROJECT NAME:  HIGH TECH SHIP

      LEADING PARTICULARS

 DISPLACEMENT                      2126.  MT       2093.  LT
 OVERALL LENGTH                  143.38  M        470.4  FT
 FLOTATION LENGTH                134.00  M        439.6  FT
 FLOTATION BEAM                   10.31  M         33.8  FT
 HULL DRAFT                        3.17  M         10.4  FT

      PROPULSION PLANT
 ELECTRIC PROPULSION PLANT:
   ELECTRIC MOTORS TYPE :              SUPERCONDUCTING HOMOPOLAR (DC) MOTORS
   ELECTRIC MOTORS POWER :             2. x  15447. KW
   PROPULSION ELECTRIC POWER           2. x  15289. KW
 (INTEGRATED ELECTRIC PROPULSION PLANT)
 PROPULSORS:
  WATERJETS
   NUMBER OF PROPULSION SHAFT          2.
   WATERJET DIAMETER                 178. CM           5.83 FT
   PROPULSOR SHAFT RPM               281.

      ELECTRIC PLANT
  FUEL CELLS ELECTRIC POWER PLANT:
   TOTAL ELECTRIC POWER GENERATION                         33103. KW
   NUMBER OF GENERATORS (INCLUDING STAND-BY)        34.
   GENERATORS POWER RATING                         974. KW

      OTHER SUBSYSTEMS
RUDDER ROLL STABILIZATION
 NUMBER OF CREW          30.
 HELICOPTER LANDING PLATFORM
 NUMBER OF EMBARKED HELICOPTERS:       0.

      MILITARY PAYLOAD
 MISSION ELECTRONICS (SWBS400) :  44.20 LT   (INPUT)
 MISSION ARMAMENT (SWBS700)    :  68.17 LT   (INPUT)
 MISSION EXPANDABLES (F20)     :  37.37 LT   (INPUT)
 TOTAL PAYLOAD                 :                149.74 LT

      PERFORMANCE
 DESIGN SPEED           38.00 KTS  (AT FULL LOAD)
 MAX OPERATING SPEED    40.00 KTS  (AT HALF LOAD)
 MAX SUSTAINED SPEED    37.97 KTS  (AT HALF LOAD)
 REQUIRED RANGE         4001. NM
    COMPRISES:                         3001. NM AT 40.00 KTS
                                          0. NM AT 20.00 KTS
                                       1000. NM AT 15.00 KTS

 ENDURANCE                30. DAYS
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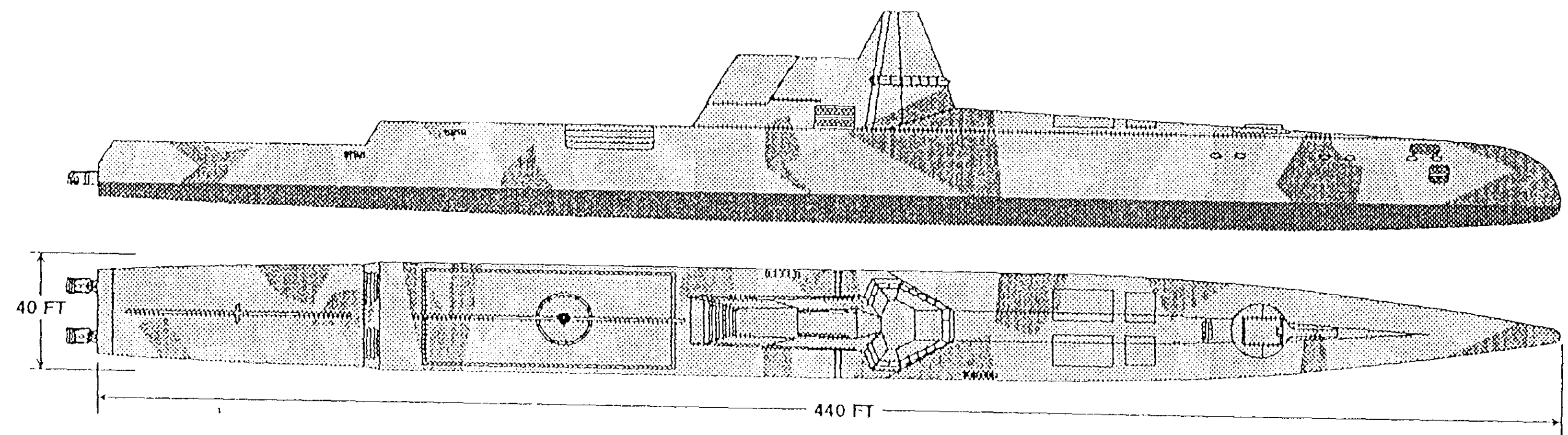

Figure 3-1. Outboard Profile

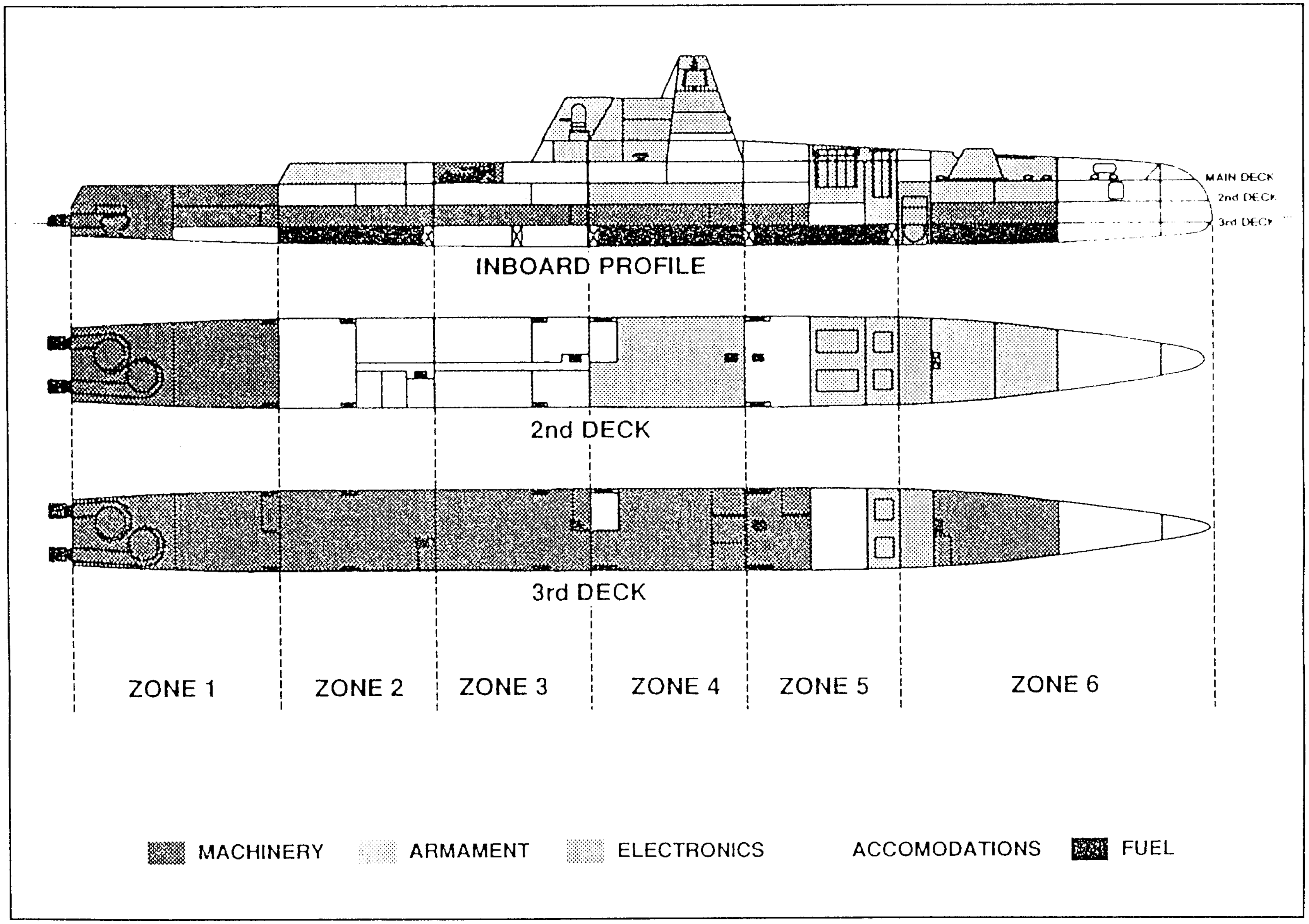

Figure 3-2. Internal Arrangements

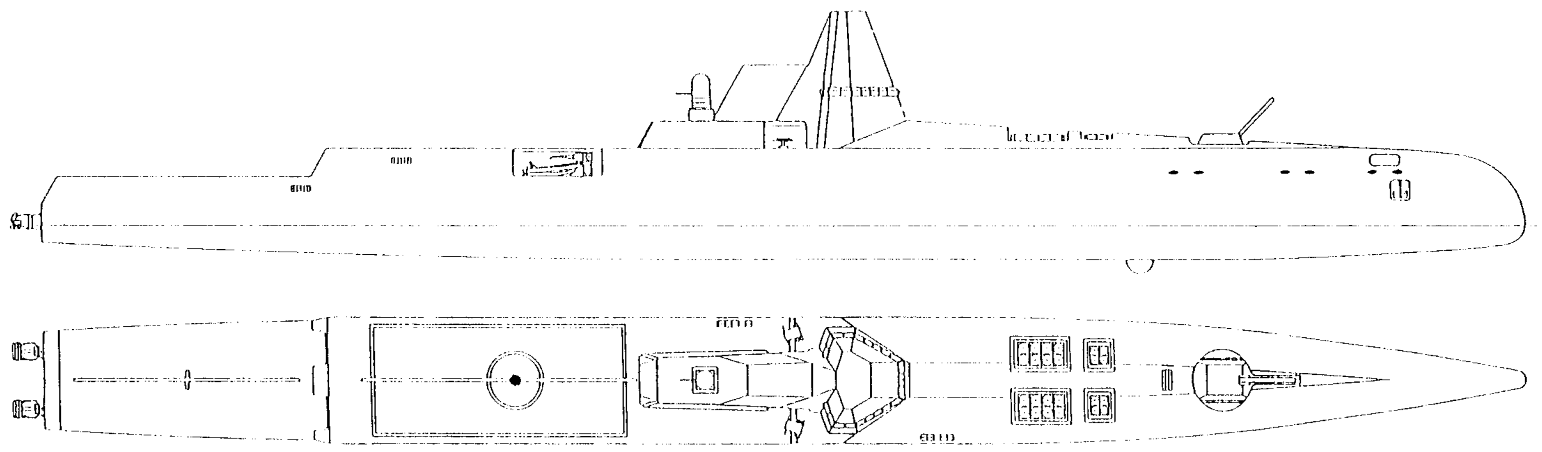

Figure 3-3. Conformal Weapons and Auxiliary Systems

Note that the accommodation spaces were separated from the forward weapons space by a safety void. The most significant deviation from conventional ship design is that there is no machinery space perse. Instead of the machinery being distributed vertically and transversely for a finite length, it is distributed longitudinally and transversely for a finite height.

Fuel cells for propulsion as well as for ship service power were distributed throughout the ship for increased survivability. Each fuel cell group can accommodate the needs of the section they are shelter by as well as being capable of transferring the required amount of power either aft to the propulsion motors or forward to the pulse-power weapons.

All fuel cells in one section are supported by an overhead system for air, exhaust, fuel system and cooling systems. Local outboard exhaust, just above the waterline is used. Flush water inlets are fitted for each section. A design inspired by the need for low drag as achieved by airplane-type inlets is used to minimize ship resistance.

3.2 Hullform

Although the details of the hull lines were not worked out for this preliminary study, the basic principles were established as follows:

- A high length-to-beam ratio was selected in order to provide minimum resistance at speeds up to 40 knots. Due to the great length of the hull, this can be achieved for a Froude Number of 0.57 for which no or very limited planing effect may be expected. This, in turn, will allow a relatively small resistance without requiring extra power to transit a hump speed. The length-to-beam ratio of 13 was selected as a result of a parametric analysis (see Section 2.3). It proved to be in the order of what is commonly being used for catamaran sidehulls and currently being explored for high-speed commercial monohulls.

- A typical midship cross-section was assumed with a CX coefficient of 0.8. A round bilge hullform was assumed, but some consideration should be given to a limited hard chine hullform which could provide extra stability, especially roll stability. Outwardly inclined sidewalls are used which provide improved stability reserve, extra deck space and reduced radar signature (at least when roll motions are small). In case a round bilge hullform is retained, bilge keels would be used to dampen roll motions while active roll stabilization would be provided using special control of the waterjet steering system, similar to rudder-roll stabilization. Due to the large net forces available with a waterjet, it is anticipated that more effective results would be obtained than with rudder-roll stabilization.

- A flat transom was fitted in order to allow an above water level waterjet exhaust, which is more efficient than underwater exhaust for the jet. However, the on-going development of the vertical axis motor propulsor may revise this assumption. An underwater exhaust may be preferred in order to reduce wake signature. In that case, it is envisioned that the transom will need to be redesigned to adapt to the design configuration adopted for a vertical axis motor propulsor.

- A wave-piercing bow was fitted in order to allow smooth passage through heavy seas. Note that the high length of the hullform will provide extraordinary pitch stiffness to the HTS. However, in order to avoid severe slamming as well as excessive surge motions in head seas, a slim, wave-piercing bow is preferred to a more traditional flared bow. Significant deck wetness may be expected as a result of this bow shape, however, the conformal nature of the weapons as well as the concept of operation will accommodate such a drawback. It should be expected that no personnel nor vulnerable equipment will be exposed to the weather on the forward deck. The pilothouse itself is located almost amidship (approximately 180 ft from the bow), thus it is believed that reasonable protection against severe deck wetness will be provided.

3.3 Power Plant

3.3.1 Power Generation

A fuel-cell plant has been assumed for the HTS. A fuel cell is an electric cell that converts the chemical energy of a fuel directly into electrical energy. The process is somewhat analogous to a battery that is constantly being replenished. The efficiency of this conversion can be made greater than that obtainable by thermal power conversion.

A fuel cell, in its most basic form, consists of an anode, cathode and electrolyte. Chemical reactions that are involved are not limited to, but almost always include the combination of oxygen (considered to be the oxidant) and hydrogen (considered to be the fuel). Air is typically used for the oxidant in most fuel cells. A host of various fuel types can be used so long as hydrogen is abundant in them (i.e., hydrocarbons found in fossil fuels). In some fuel cell units, reformation of the fuel is required to be performed before it can enter the cell. In this process, elements in the fuel molecules are recombined into hydrogen and other gases.

A proton exchange membrane (PEM) fuel cell is shown in Figure 3-4. Typically, the anode of a fuel cell is in contact with the incoming fuel and the cathode is in contact with the incoming air. The fuel and oxidant are physically separated by an electrolyte which can exist in solid, semi-solid, of liquid forms. It is required that the electrolyte prevent the conduction of electrons between the electrodes. When a circuit containing resistance is completed between the electrodes, hydrogen ions form at the meeting point of the fuel, anode and electrode. The resulting free electrons start flowing to the cathode, thus creating the mechanism for power generation. The chemical reactions that take place for the described acid electrolyte are as follows:

Anode $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Overall $2H_2 + O_2 \rightarrow 2H_2O$

The fuel cell plant contains all of the necessary machinery required for the plant to produce power, such as a fuel reformer, filters, pumps, etc. A fuel cell schematic is shown in Figure 3-5. The only required connections are for fuel, an oxygen source (air), cooling water, and unless pure hydrogen and pure oxygen are used, exhaust.

A variety of fuel cells are being developed commercially that will have various performance and suitability levels for ship power. The principal type of fuel cells that can be envisioned are:

- Proton Exchange Membrane (PEM)
- Phosphoric Acid (PA)
- Molten Carbonate (MC)
- Solid Oxide (SO).

For this preliminary study, data generated from the CDNSWC, Code 27, PEM fuel cell model were used. PEM fuel cells were chosen because of their high power density and their low exhaust temperature (approximately 200 degrees Fahrenheit). However, Solid Oxide Fuel Cell (SOFC) show very promising characteristics regarding their power density and their fuel efficiency. However, they also operate typically at high temperature (1600 degrees Fahrenheit) and are less developed. SOFC and PEMFC are believed to be the best candidates for the HTS. A final selection between those two types should be made based on which characteristics, fuel efficiency or low operating temperature, is most desirable. Weight volume and specific fuel consumption data for PEM fuel cells are shown plotted in Figures 3-6 through 3-8 as a function of power plant size. The specific fuel consumption is also shown as a function of percentage loading in Figure 3-9.

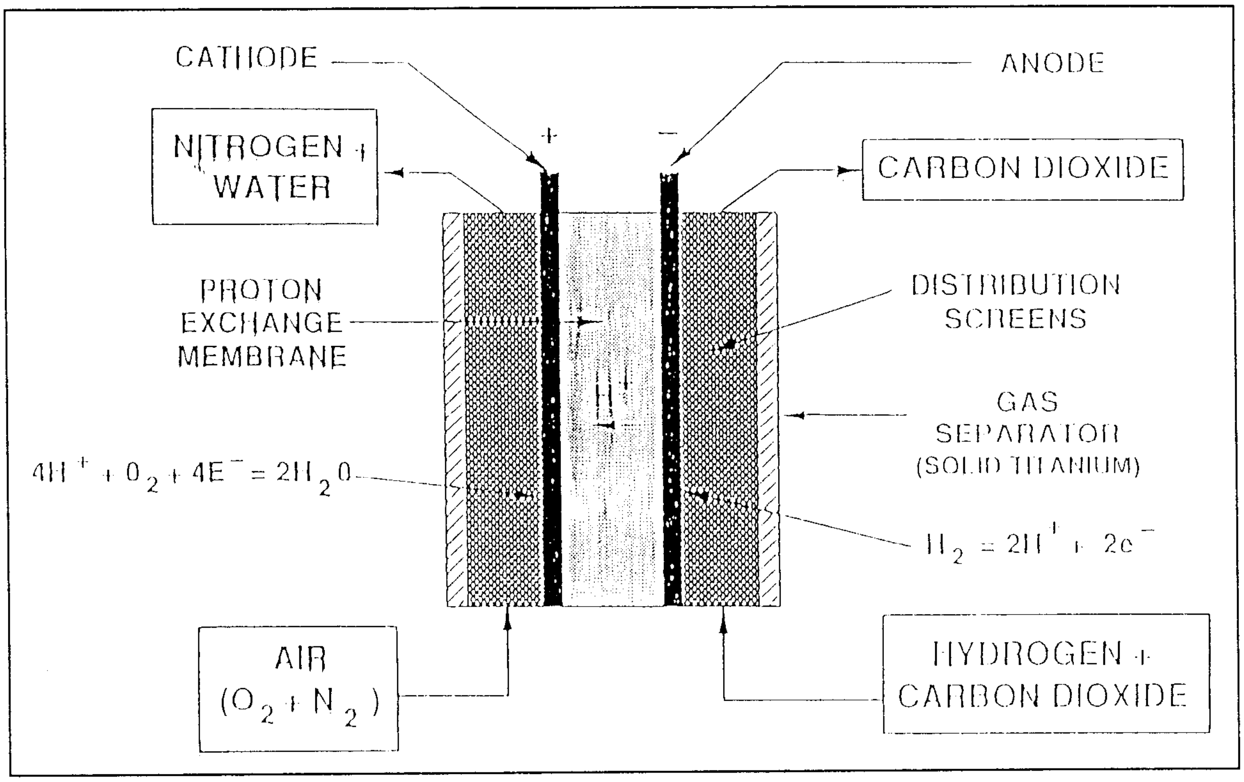

Figure 3-4. Cross-Section of a Proton Exchange Membrane Cell

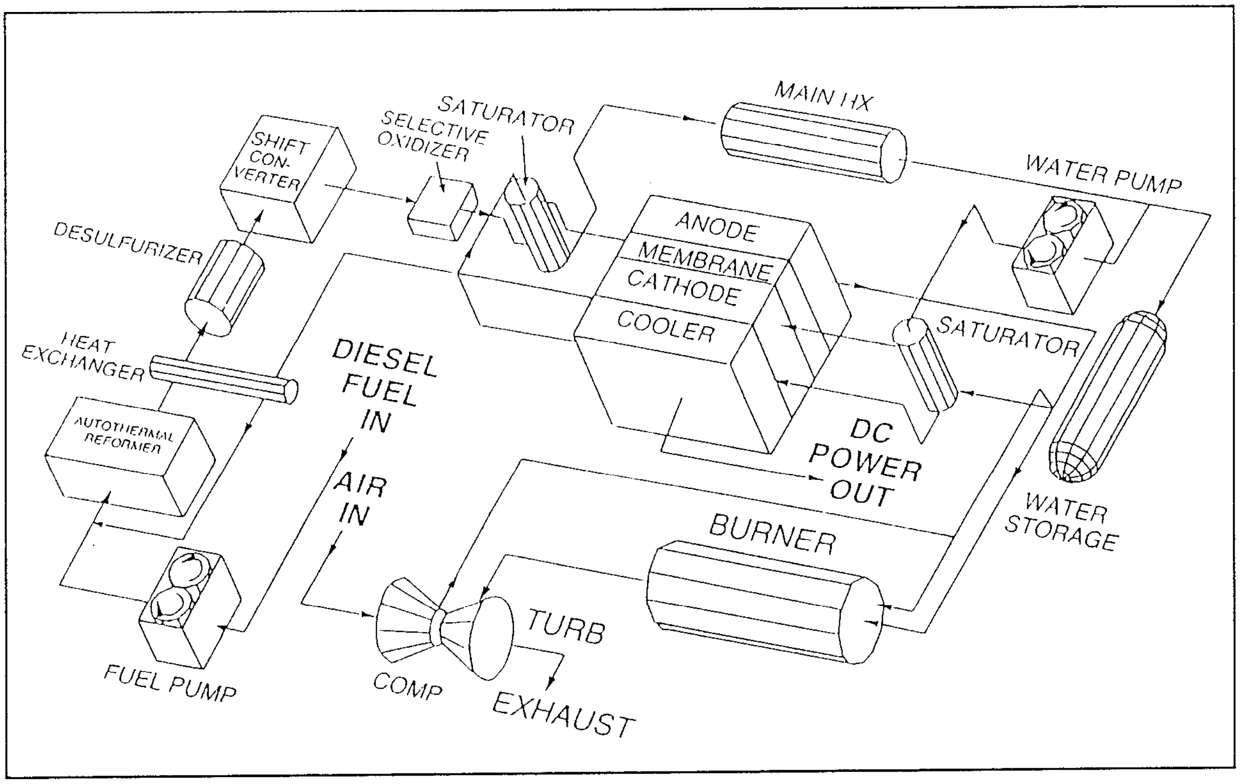

Figure 3-5. Proton Exchange Membrane Fuel Cell Power System

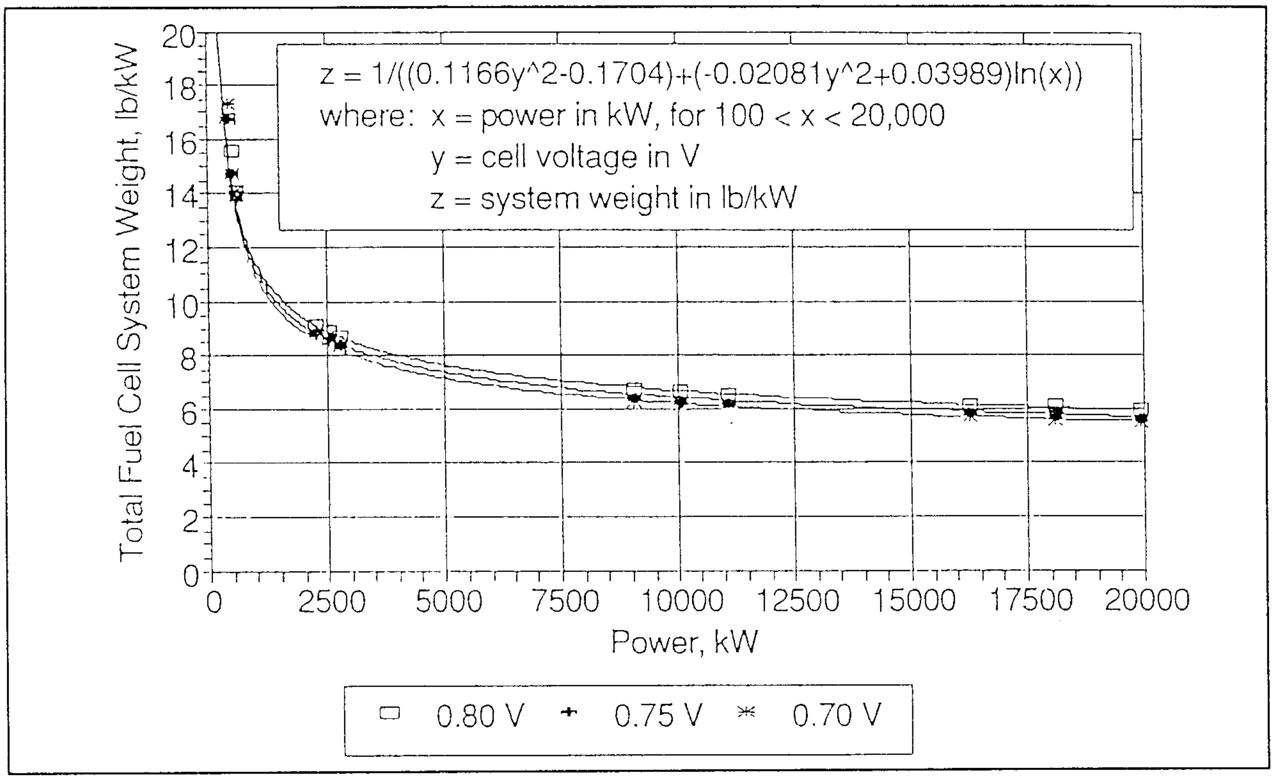

Figure 3-6. PEM Fuel Cell Parameters - Total System Weight Versus Power

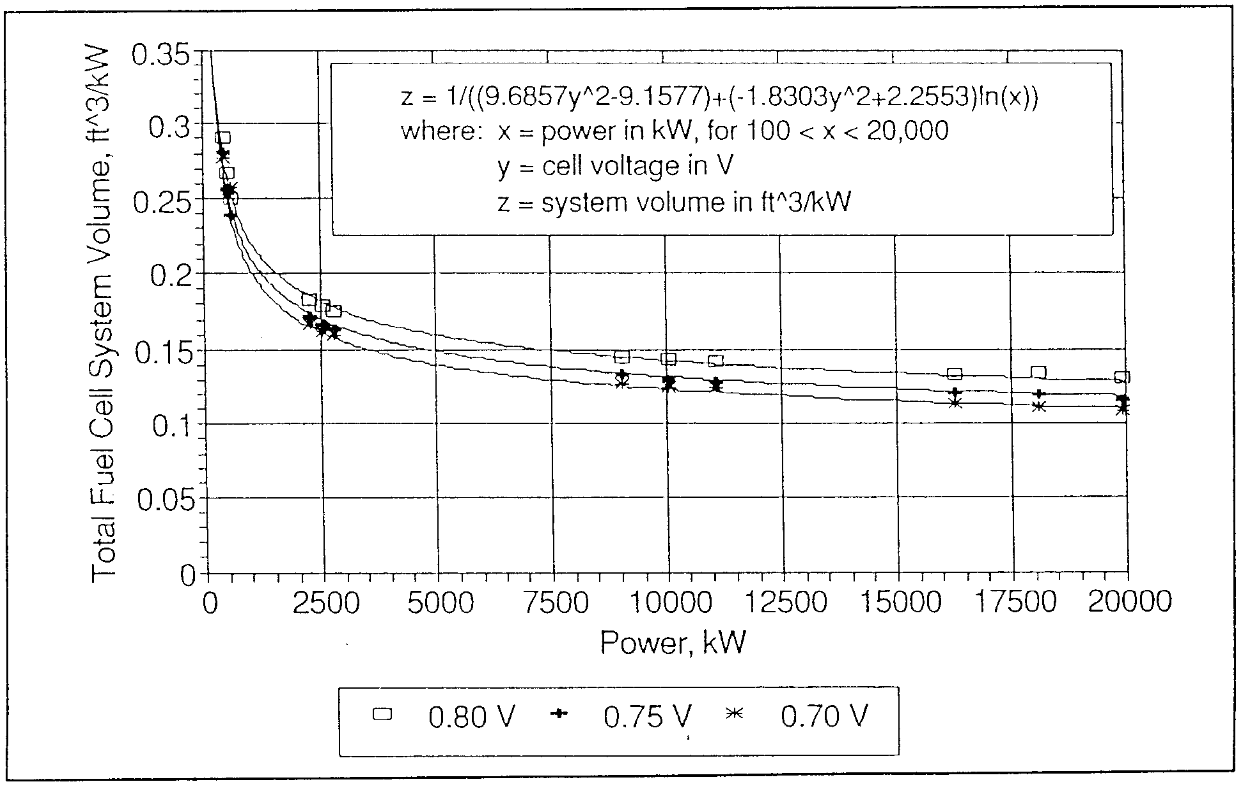

Figure 3-7. PEM Fuel Cell Parameters - Total System Volume Versus Power

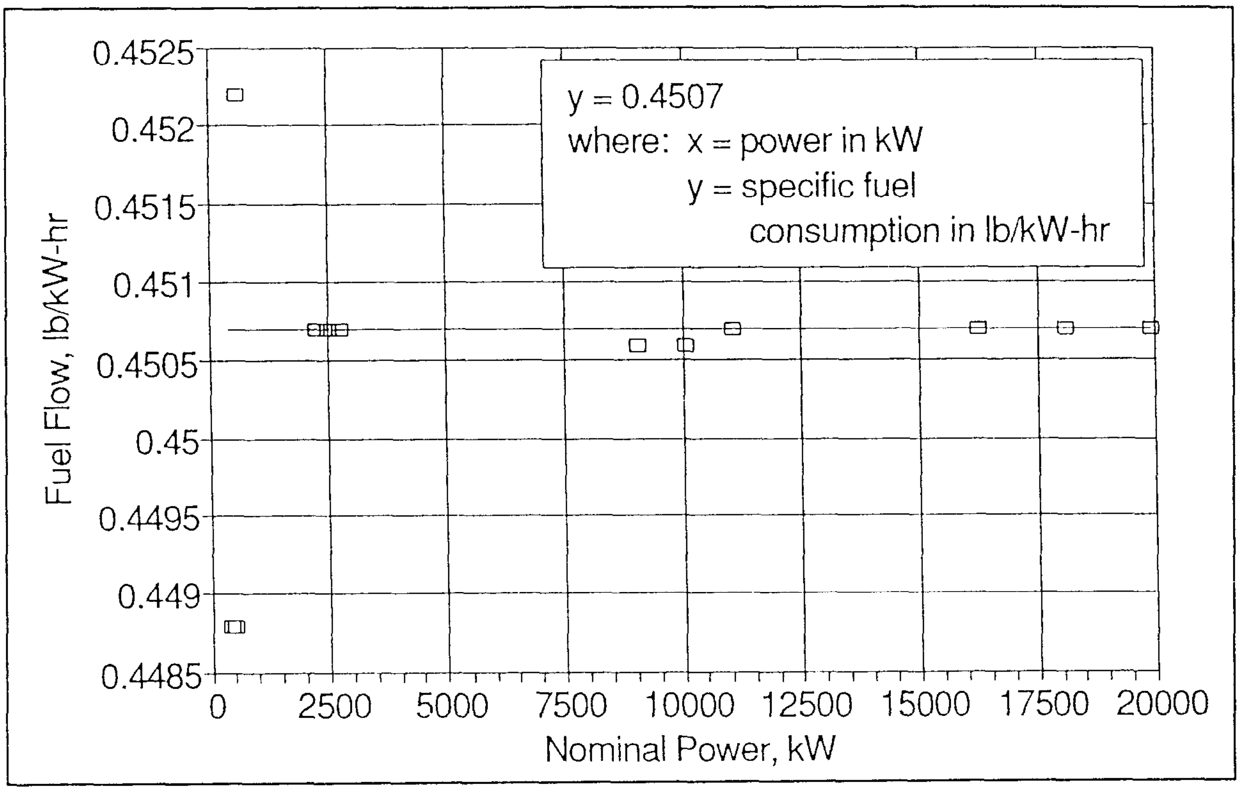

Figure 3-8. PEM Fuel Cell Parameters - Fuel Flow Versus Power

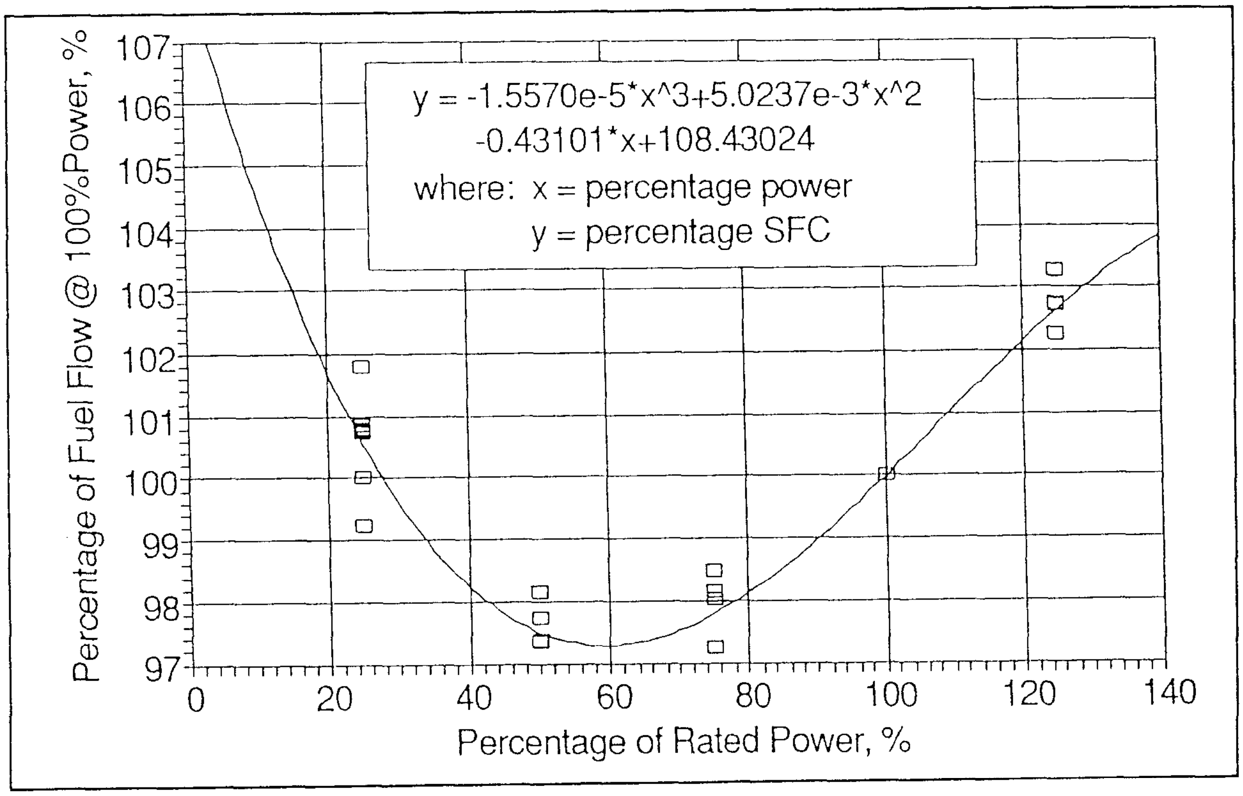

Figure 3-9. PEM Fuel Cell Parameters - Fuel Flow Versus % Power at 0.75 V

Note that fuel cells have been shown to be capable of achieving an efficiency in excess of 60%, when a bottoming cycle is used, and are theoretically capable of efficiencies as high as 80%, when running on pure hydrogen and oxygen, which would far exceed what may be expected from any carnot cycle machine (gas turbines, diesel engines, etc.) even in their most efficient configuration (with high operating temperature/pressure, heat recuperation systems, etc.). Currently, diesel engine efficiencies are typically around 40% while gas turbine efficiencies are around 35%. Although the PEM fuel cell data shown in Figures 3-7 to 3-10 are only 41% efficient, they are state-of-the-art and could be manufactured today. It was assumed, however, that for a relatively long term objective, such as that of the HIGH TECH SHIP, efficiencies of 55% should be attainable by Solid Oxide Planar fuel cells while retaining weight and volume density comparable or lower to that shown in Figures 3-7 and 3-8. The design was therefore conducted with a fuel cell that would have, as an objective, the characteristics shown in Table 3-2.

Table 3-2

Fuel Cell Plant Characteristics for HIGH TECH SHIP

Unit Plant Power = 975 kW approximately Unit Plant Weight* = 8750 lb (approximately 9 lb/kW) Unit Plant Volume * = 210 cu ft (approximately 0.2 cu ft/kW) Specific Fuel Consumption = 0.338 lb/kW.hr Efficiency = 55% Voltage** = 0.75 V per cell
*Includes fuel cell stacks and support systems such as pumps, air blowers, heat exchangers, fuel reformers, etc.
**Reference 4.

3.3.2 Power Distribution

There are 34 fuel cell plants distributed throughout the length of the ship on the lower deck. Each plant has approximately a one MW capacity (see Table 3-2), providing approximately 32 MW for propulsion and two MW for auxiliaries. When the electro-thermal-chemical (ETC) gun or the close-in weapons system (CIWS) is needed, the required amount of power is redirected from the propulsion to the appropriate set of capacitors.

The fuel cell plants are distributed throughout the ship in order to increase ship survivability. Thus, if one zone is damaged, the power contained in that zone might be lost, but as long as one of the two buses remains intact (see below), the ship will still have a large percentage of power available. Since most of the power is for propulsion, however, the distribution of cells is slightly biased toward the after zones to minimize the weight of the distribution system. The fuel cell distribution plan is shown in Figure 3-10. Thus, six cells are located in zones four and five, and four in each of zones six and seven.

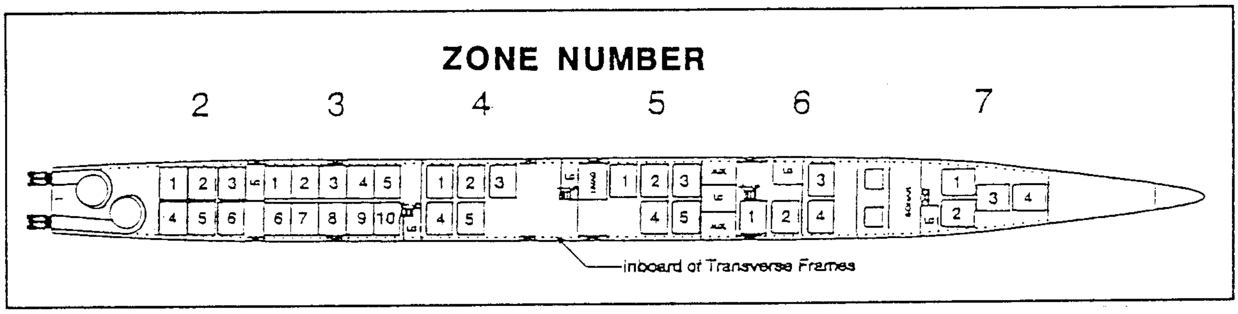

Figure 3-10. Fuel Cell Distribution

The power produced in each of the individual fuel cell plants is fed into a common bus system. The system consists of two identical buses, one port and one starboard, each of which can carry up to 32 MW of power to the propulsors or 3.5 MW to the capacitors of the ETC gun. The buses are connected by a cross-over near the after bulkhead in each zone. Local electric loads are fed from the fuel cells in their respective zones. The electrical schematic is shown in Figure 3-11.

Typical shipboard direct current (DC) voltage installations are in the 500 to 800 volt range, with a recommended upper limit of 1000 volts. However, higher-powered installations benefit from higher voltages and have been used, such as for the very high powered ice breaker "Lenin," which used 1200 volts (Reference 8). Thus, 1200 volts was chosen as the voltage, but further benefits could be obtained through a higher voltage, may be up to 1500 volts.

An electric bus concept is shown in Figure 3-12. The bus consists of two aluminum conductors held apart by ceramic (or other non-conducting material) spacers at intervals along the length and contained in a rectangular, fiber reinforced sandwich tube. Although aluminum has slightly higher resistance than copper, the significantly lower density results in a substantial weight savings (about 50%). Note that this concept was chosen to demonstrate the feasibility within a reasonable development timeframe. However, more futuristic concepts such as a refrigerated superconducting bus may be envisioned given the long term objective of the HIGH TECH SHIP. It is believed that refrigeration would be needed at only a few locations along the bus since the natural thermal conductivity of the material would keep other parts of the bus refrigerated if properly insulated. The feasibility of superconducting cables aboard ship is pending the development of "high" temperature superconduction, i.e., superconduction at the temperature of liquid nitrogen rather than liquid helium. Any progress made toward even higher temperature superconduction would greatly benefit the HTS.

The sizing calculations for the aluminum bus are given in Table 3-3. Figure 3-13 shows the length of and power carried in each segment of the bus. Note that each bus is designed to carry the total power of 34 MW with a total allowable voltage drop of one-half of one percent. The "real dimension" is the required size of the square rounded up to the nearest one-eighth inch. The longitudinal center of gravity (LCG) is measured in feet forward of the transom. Table 3-4 shows the calculation for the actual voltage drop under normal conditions when each bus carries half of the power.

Aluminum has three potential disadvantages as a conductor. The first is that it readily oxidizes, and aluminum oxide is an insulator. This problem is solved by preparing the aluminum properly and coating it during installation. The second problem is that aluminum cold flows (creeps), which is solved using special (spring-loaded) fasteners. Finally, thermal expansion might be a problem but can be solved using U-type expansion joints.

An alternative to the bus system described above is to use stock busways. "Three phase, four wire" busways contain four internal conductors and are currently available for amperages up to 4000 amps for alternating current (AC) with aluminum busbars. Since only two conductors are needed for DC, the conductors can be used in two groups of two connected in parallel, effectively doubling its ampacity. Thus, a 4000 amp busway will actually carry 8000 amps DC. This is a continuous rating, which can be exceeded somewhat depending on the duration of use and the allowable temperature rise. Three of these assemblies connected together should easily carry the required 28,000 amps. (Note that these busways are rated for 600 volts AC, but should be able to handle 1200 volts DC. Also, custom busways are available, but at greater cost. However, either stock or custom busways would probably result in a higher total weight. One potential problem identified for the main bus is the need for flexible joints since this bus will need to deform with the hull. The hull being made of composite, the enclosure shown in Figure 3-12 may actually be integrated as a frame to the structure, however, it will still be necessary to ensure that hull deformation will not strain the conductor itself.

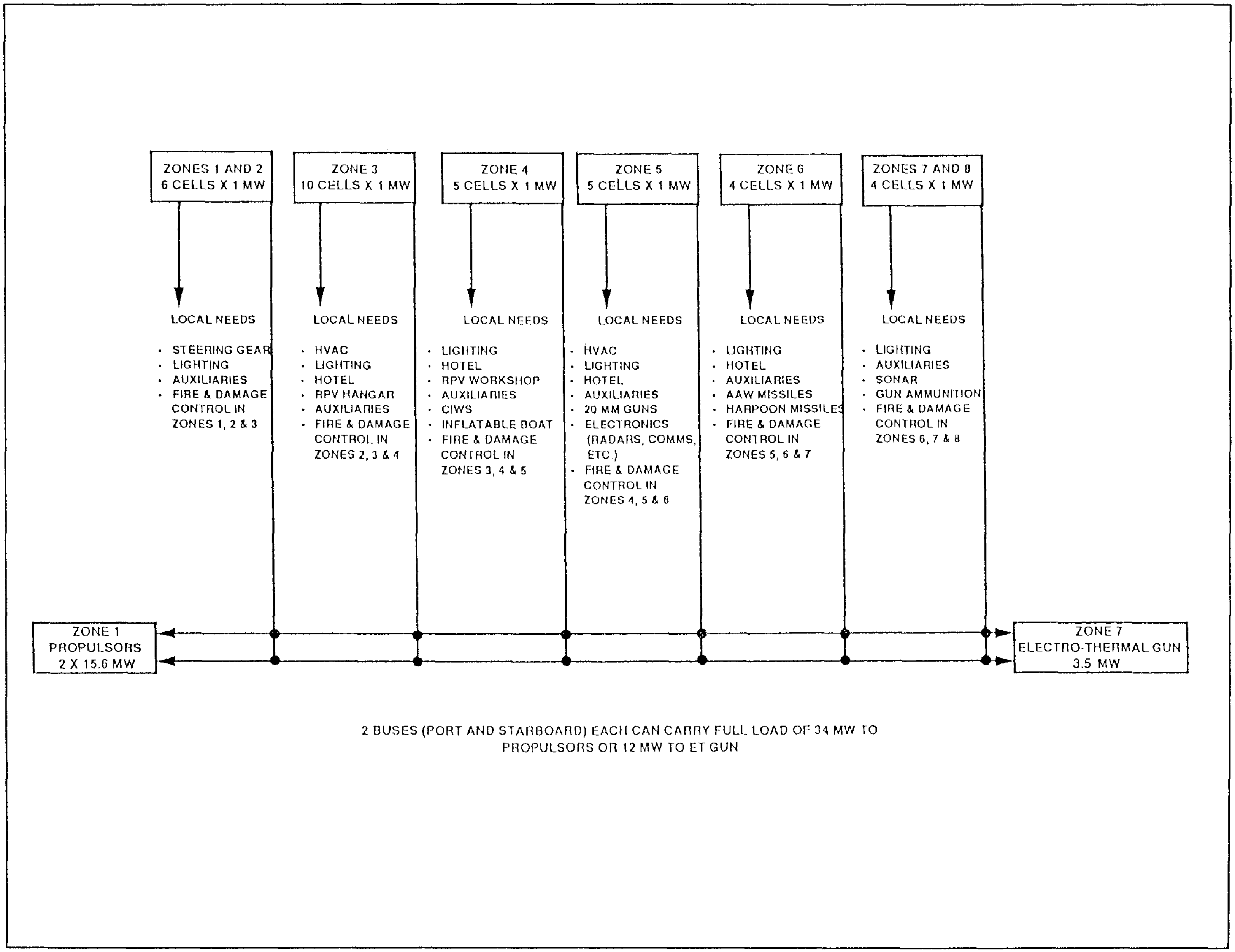

Figure 3-11. Electrical Schematic

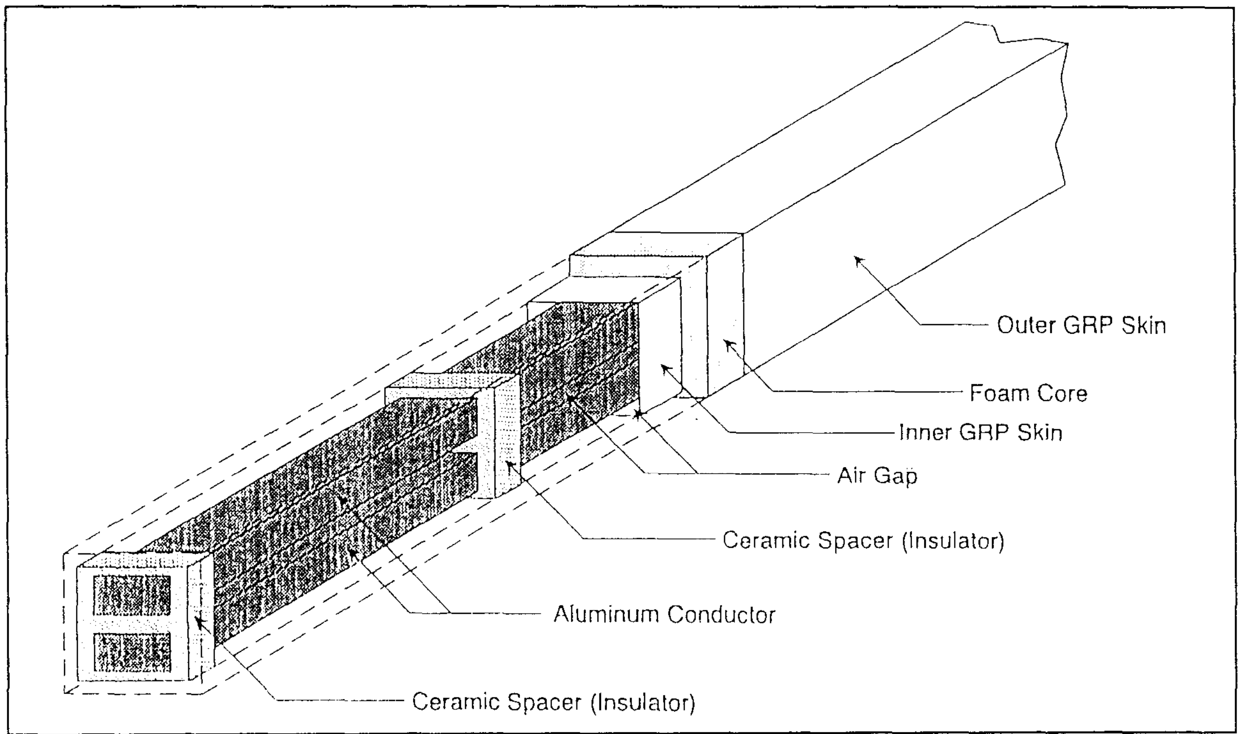

Figure 3-12. Electric Bus Diagram

Table 3-3

Aluminum Bus Sizing Calculations

Material = Aluminum
Voltage, V = 1200 V
Allowable Voltage Drop, E = 0.5 *% Total*
= 6 V Total
Resistivity, rho = 17.01 ohm-cmil/ft
Length, L = 324.0 ft
Density, d = 165 lb/ft^3

Item		Power	Current	Length	Allow. Volt. Drop	Area			Dim. of Square	Real Dimen.	Volume	Weight	LCG	Moment
Symbol		P	i	l	e	A			s	s	vol	W	LCG	M
Units		MW	A	ft	V	cmil	in^2	ft^2	in	in	ft^3	lb	ft	lb-ft
Relation			P/V		E*(l/L)	*rho*l*i/e*	*conver.*	*conver.*	A^0.5		s^2*l	vol*d		W*LCG
Section	1	34	28333.3	4	0.074	2.603E+07	20.44	0.1419	4.52	4.625	1.188	196.08	40	7843
	2	28	23333.3	40	0.741	2.143E+07	16.83	0.1169	4.10	4.125	9.453	1559.77	62	96705
	3	18	15000.0	60	1.111	1.378E+07	10.82	0.0751	3.29	3.375	9.492	1566.21	112	175416
	4	13	10833.3	60	1.111	9.951E+06	7.82	0.0543	2.80	2.875	6.888	1136.52	172	195482
	5	12	10000.0	60	1.111	9.185E+06	7.21	0.0501	2.69	2.75	6.302	1039.84	232	241244
	6	12	10000.0	72	1.333	9.185E+06	7.21	0.0501	2.69	2.75	7.563	1247.81	298	371848
	7	12	10000.0	16	0.296	9.185E+06	7.21	0.0501	2.69	2.75	1.681	277.29	342	94834
Cross Connect	1	34	28333.3	12	0.222	2.603E+07	20.44	0.1419	4.52	4.625	3.565	588.24	38	22353
	2	34	28333.3	12	0.222	2.603E+07	20.44	0.1419	4.52	4.625	3.565	588.24	42	24706
	3	28	23333.3	12	0.222	2.143E+07	16.83	0.1169	4.10	4.125	2.836	467.93	82	38370
	4	18	15000.0	12	0.222	1.378E+07	10.82	0.0751	3.29	3.375	1.898	313.24	142	44480
	5	13	10833.3	12	0.222	9.951E+06	7.82	0.0543	2.80	2.875	1.378	227.30	202	45916
	6	12	10000.0	12	0.222	9.185E+06	7.21	0.0501	2.69	2.75	1.260	207.97	262	54488
	7	12	10000.0	12	0.222	9.185E+06	7.21	0.0501	2.69	2.75	1.260	207.97	334	69462
TOTALS				312							58.33	9624	154.1	1483147

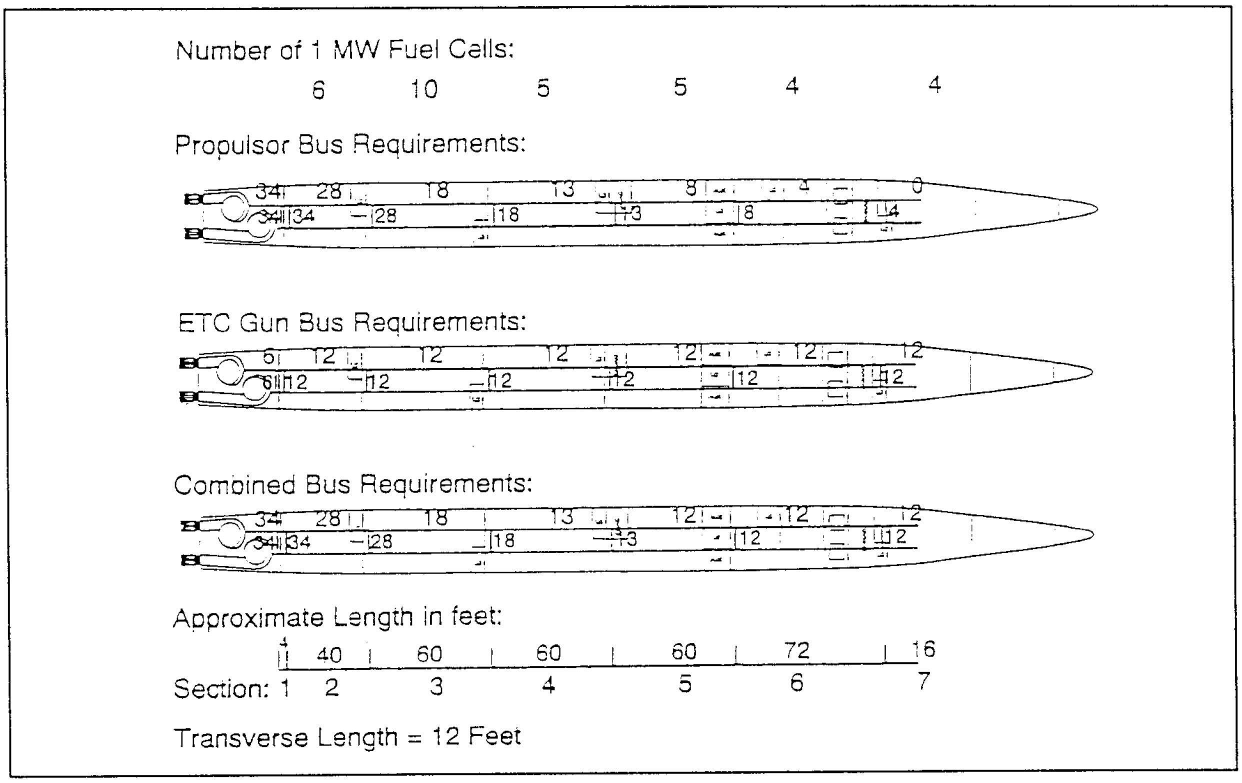

Figure 3-13. Electric Bus System Schematic

Table 3-4

Voltage Drop Performance

Material = Aluminum
Voltage, V = 1200 V
Allowable Voltage Drop, E = 0.5 % Total
= 6 V Total
Resistivity, rho = 17.01 ohm-cmil/ft
Length, L = 324.0 ft
Density, d = 165 lb/ft^3

Item		Power	Current	Length	Length of Side	Area		Resistance	Actual Volt. Drop
Symbol		P	i	l	s	A		r	e
Units		MW	A	ft	in	in^2	cmil	ohm	V
Relation			P/V	given	previous	s^2	conver.	rho*l/A	i*r
Section	1	17	14166.7	4	4.625	21.39	2.724E+07	2.498E-06	0.035
	2	14	11666.7	40	4.125	17.02	2.166E+07	3.141E-05	0.366
	3	9	7500.0	60	3.375	11.39	1.450E+07	7.037E-05	0.528
	4	6.5	5416.7	60	2.875	8.27	1.052E+07	9.698E-05	0.525
	5	4	3333.3	60	2.750	7.56	9.629E+06	1.060E-04	0.353
	6	2	1666.7	72	2.750	7.56	9.629E+06	1.272E-04	0.212
	7	0	0.0	16	2.750	7.56	9.629E+06	2.827E-05	0.000
Cross Connect	1	0	0.0	12	4.625	21.39	2.724E+07	7.495E-06	0.000
	2	3	2500.0	12	4.625	21.39	2.724E+07	7.495E-06	0.019
	3	5	4166.7	12	4.125	17.02	2.166E+07	9.422E-06	0.039
	4	2.5	2083.3	12	3.375	11.39	1.450E+07	1.407E-05	0.029
	5	2.5	2083.3	12	2.875	8.27	1.052E+07	1.940E-05	0.040
	6	2	1666.7	12	2.750	7.56	9.629E+06	2.120E-05	0.035
	7	2	1666.7	12	2.750	7.56	9.629E+06	2.120E-05	0.035
TOTALS				312	23.25				2.219

3.3.3 Ship Service Power

The requirements for the integrated ship service and propulsion power are summarized in Table 3-5.

Table 3-5

Power Requirements

PROPULSION PLANT		
ELECTRIC PROPULSION PLANT:		
ELECTRIC MOTORS TYPE :	SUPERCONDUCTING HOMOPOLAR (DC) MOTORS	
ELECTRIC MOTORS POWER :	2. x 15447. KW	
PROPULSION ELECTRIC POWER	2. x 15289. KW	
(INTEGRATED ELECTRIC PROPULSION PLANT)		
PROPULSORS:		
WATERJETS		
NUMBER OF PROPULSION SHAFT	2.	
WATERJET DIAMETER	178. CM	5.83 FT
PROPULSOR SHAFT RPM	281.	
ELECTRIC PLANT		
FUEL CELLS ELECTRIC POWER PLANT:		
TOTAL ELECTRIC POWER GENERATION		33103. KW
INTEGRATED PROPULSION ELECTRIC PWR	30578. KW	
MAXIMUM SHIP SERVICE ELECTRIC PWR	1077. KW	
ELECTRIC PLANT DESIGN MARGIN PWR	215. KW	
ELECTRIC PLANT SERVICE LIFE MARGIN PWR	258. KW	
STAND-BY GENERATOR PWR	974. KW	
NUMBER OF GENERATORS (INCLUDING STAND-BY)	34.	
GENERATORS POWER RATING	974. KW	
ANCHOR LOAD	1041. KW	
SHORE LOAD	843. KW	
CRUISE LOAD	1077. KW	
VITAL LOAD	1055. KW	
EMERGENCY LOAD	1039. KW	
MAXIMUM LOAD	1077. KW	
AVERAGE LOAD	539. KW	

A distributed power plant was chosen in order to provide the best survivability to the HIGH TECH SHIP. Although the chances of complete power loss with a conventional arrangement fall dramatically as soon as more than one propulsion plant compartment is fitted, the speed loss, in case one propulsion compartment is damaged, is considerable. With a distributed power arrangement, such as that shown in Figure 3-10, it would take several hits by adverse missiles to significantly reduce the propulsion power available.

The principle of a twin distribution bus was also incorporated to ensure more than one distribution route in order to avoid damaged areas. Note that with transversal connection bars, it would be possible to ensure quasi continuity of the distribution bus in all cases.

The ship service and propulsion power requirements per zone were analyzed and are shown in detail in Tables 3-6 and 3-7 for summer cruise and battle conditions, respectively. Note that when the pulse power weapons are used, a reduction of propulsion power is considered in order to minimize total power installed. When used in rapid fire, the pulse power weapons will need up to 12 MW power (35% of the total power), but for short cycles only, thus having a reduced impact on the average speed achieved by the ship. When used in continuous duty a 5-inch gun (firing at a rate of 20 shots per minute) consumes only 4 MW power (12% of the total power) which should have only a small impact on the speed (2 kt drop approximately) achievable by the HIGH TECH SHIP.

Due to the complete integration of the ship service and propulsion power and to the distributed power plant concept, each section of the ship will have much more power than it power for ship service needs only, even when design and service-life margins are added to the power needs shown in Tables 3-5 and 3-6. Thus, it appears that this power plant will be very flexible throughout its lifetime to accept reconfigurations and changes of the ship service power requirements. Significant increase of those needs can even be envisioned (beyond the design and service-life margins of 20% each) at the expense of a speed loss (only when maximum ship service power is required). However, it would take a dramatic power requirement increase in order to have a significant impact on speed (an increase of four times the current power needs would result only in a 2 kt speed loss).

Since fuel cells naturally provide DC power and also due to the fact that the propulsion motors require DC power, a DC power distribution system is required for the HIGH TECH SHIP.

As a result, auxiliary systems such as pumps, fans and mechanical systems need to be specified for use with DC motors. A significant change of suppliers and logistic stocks will be required as a consequence, but it is believed that it will be beneficial in all respects (lighter weight, higher reliability, etc.)

There are however systems, especially electronic sensors that require AC power. For those systems, local transformers will be installed as needed.

3.3.4 Propulsion

The propulsion of the HIGH TECH SHIP is provided by two vertical axis motor propulsors (VAMP) with performance equivalent or greater than mixed-flow type of waterjet as defined in Table 3-8.

The concept of the vertical axis propulsor is illustrated in Figure 3-14. The perceived advantages of this configuration over conventional (mixed-flow type) waterjets are:

- Better efficiency across a large range of speeds (towards low speed)
- Reduced size/weight
- Flexibility of electric drive
- Lower wake signature (if exhaust is underwater).

However, in the absence of specific data concerning those objectives, the performance calculations, as well as weight estimates, for the HIGH TECH SHIP were made assuming a mixed-flow type of waterjet.

Therefore, it is clear that the HTS design was conservative. If the VAMP achieves the desired result, the HTS performance may be only improved and if it does not, the HTS feasibility is still guaranteed.

Table 3-6

Summer Cruise Power Needs

	Power per Unit (kW)	Source	Quant.	Number per Compartment 2	3	4	5	6	7	Power per Compartment (kW) 2	3	4	5	6	7	Total Power (kW)
Shaftless Motor	15600	given	2	0.4	0.6	0.3	0.3	0.2	0.2	6240	9360	4680	4680	3120	3120	31200
Steering Gear	200	est	2	0.4						80	0	0	0	0	0	80
Fuel Oil Service Pump	20	typ	2		0				1	0	0	0	0	0	20	20
Fuel Oil Transfer Pump	10	DDG51	2		0				1	0	0	0	0	0	10	10
Fuel Oil Purifiers	20	DDG51	2			0			1	0	0	0	0	0	20	20
Fuel Oil Purifier Heaters	100	DDG51	2			0			1	0	0	0	0	0	100	100
Fire, Bilge, & Ballast Pump	10	est	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Water Service Pump	20	typ	12	1	1	1	1	1	1	20	20	20	20	20	20	120
Fresh Water Circ. Pump	7.5	est	3		1	0	0			0	7.5	0	0	0	0	7.5
FW Transfer Pump	5	est	3		1	0	0			0	5	0	0	0	0	5
FW Circulating Pump (Hot/Cold)	0.5	est	6		1	1	1			0	0.5	0.5	0.5	0	0	1.5
HVAC System	100	DDG2/51	3		1	1	1			0	100	100	100	0	0	300
Lighting	75	DDG2/51	1	0.1	0.2	0.15	0.2	0.15	0.2	7.5	15	11.25	15	11.25	15	75
Distilling Plant	15	DDG51	3		1	1	0			0	15	15	0	0	0	30
Sewage Treatment Plant	25	typ	2			1	0			0	0	25	0	0	0	25
FW Storage Heater	20	DDG51	3		1	0	0			0	20	0	0	0	0	20
Hotel	50	DDG2/51	1		0.3	0.3	0.3	0.1		0	15	15	15	5	0	50
RPV Workshop	50	DDG51	1			0.25				0	0	12.5	0	0	0	12.5
JPS Pumps	4	DDG51	4			1				0	0	4	0	0	0	4
ELECTRONICS																
Navigation Radar	25	typ	1				1			0	0	0	25	0	0	25
FAST Radar (C-band)	1000	data	1				0.01			0	0	0	10	0	0	10
CIC Electronic Equipment	100	est	1				0.5			0	0	0	50	0	0	50
Ship Control Equipment	50	est	1				1			0	0	0	50	0	0	50
Navigation Equipment	50	est	1				1			0	0	0	50	0	0	50
Interior Communication	10	est	1				1			0	0	0	10	0	0	10
Transceivers (MF,HF,VHF,UHF)	0.05	est	9				9			0	0	0	0.45	0	0	0.45
Satellite Communications	1	typ	1				1			0	0	0	1	0	0	1
AAW Missiles	100	DDG51	1					0		0	0	0	0	0	0	0
Harpoon Missiles	50	DDG51	1					0		0	0	0	0	0	0	0
LTV Crossbow	150	DDG51	2				0			0	0	0	0	0	0	0
Torpedoes Mk46	10	DDG51	1			0				0	0	0	0	0	0	0
Anchor Windlass	25	typ	2						0	0	0	0	0	0	0	0
Mooring Winches	25	typ	2	0					0	0	0	0	0	0	0	0
Capstans	20	typ	4	0					0	0	0	0	0	0	0	0
Winches/Cranes	10	typ	3			0				0	0	0	0	0	0	0
Doors & Hatches	5	est	13	0	0	0	0	0	0	0	0	0	0	0	0	0
ELECTRONICS																
Sonar	36	data	1						0	0	0	0	0	0	0	0
Jammers	10	est	2				0			0	0	0	0	0	0	0
Radar Detectors	10	est	2				0			0	0	0	0	0	0	0
MK36-6 Rocket Launcher	25	guess	2				0			0	0	0	0	0	0	0
Degaussing System	25	DDG2	1				0			0	0	0	0	0	0	0
Secure Communications (IFF)	1	est	1				0			0	0	0	0	0	0	0
Total Power per Comp. in kW										6347.5	9558.0	4883.3	5027.0	3156.3	3305.0	32276.9
Average Auxiliary Power per Comp. in kW										107.5	198.0	203.3	347.0	36.3	185.0	1077.0

Total Connected Power = 32.277 MW
Total Auxiliary Power = 1.077 MW

Table 3-7

Battle Condition - Power Needs

	Power per Unit (kW)	Source	Quant.	Number per Compartment 2	3	4	5	6	7	Power per Compartment (kW) 2	3	4	5	6	7	Total Power (kW)
Shaftless Motor	15600	given	2	0.4	0.6	0.3	0.3	0.2	0.2	6240	9360	4680	4680	3120	3120	31200
Steering Gear	200	est	2	0.4						80	0	0	0	0	0	80
Fuel Oil Service Pump	20	typ	2		0				1	0	0	0	0	0	20	20
Fuel Oil Transfer Pump	10	DDG51	2		0				1	0	0	0	0	0	10	10
Fuel Oil Purifiers	20	DDG51	2			0			1	0	0	0	0	0	20	20
Fuel Oil Purifier Heaters	100	DDG51	2			0			1	0	0	0	0	0	100	100
Fire, Bilge, & Ballast Pump	10	est	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Water Service Pump	20	typ	12	1	1	1	1	1	1	20	20	20	20	20	20	120
Fresh Water Circ. Pump	7.5	est	3		1	0	0			0	7.5	0	0	0	0	7.5
FW Transfer Pump	5	est	3		1	0	0			0	5	0	0	0	0	5
FW Circulating Pump (Hot/Cold)	0.5	est	6		1	1	1			0	0.5	0.5	0.5	0	0	1.5
HVAC System	100	DDG2/51	3		0.2	0.2	0.2			0	20	20	20	0	0	60
Lighting	75	DDG2/51	1	0.05	0.1	0.07	0.1	0.07	0.1	3.75	7.5	5.625	7.5	5.625	7.5	37.5
Distilling Plant	15	DDG51	3		0	0	0			0	0	0	0	0	0	0
Sewage Treatment Plant	25	typ	2			0	0			0	0	0	0	0	0	0
FW Storage Heater	20	DDG51	3		0.5	0	0			0	10	0	0	0	0	10
Hotel	50	DDG2/51	1		0.15	0.15	0.15	0.05		0	7.5	7.5	7.5	2.5	0	25
RPV Workshop	50	DDG51	1			0.5				0	0	25	0	0	0	25
JP5 Pumps	4	DDG51	4			2				0	0	8	0	0	0	8
ELECTRONICS																
Navigation Radar	25	typ	1				1			0	0	0	25	0	0	25
FAST Radar (C-band)	1000	data	1				0.01			0	0	0	10	0	0	10
CIC Electronic Equipment	100	est	1				0.5			0	0	0	50	0	0	50
Ship Control Equipment	50	est	1				1			0	0	0	50	0	0	50
Navigation Equipment	50	est	1				1			0	0	0	50	0	0	50
Interior Communication	10	est	1				1			0	0	0	10	0	0	10
Transceivers (MF,HF,VHF,UHF)	0.05	est	9				9			0	0	0	0.45	0	0	0.45
Satellite Communications	1	typ	1				1			0	0	0	1	0	0	1
AAW Missiles	100	DDG51	1					1		0	0	0	0	100	0	100
Harpoon Missiles	50	DDG51	1					1		0	0	0	0	50	0	50
LTV Crossbow	150	DDG51	2				2			0	0	0	300	0	0	300
Torpedoes Mk46	10	DDG51	1			1				0	0	10	0	0	0	10
Anchor Windlass	25	typ	2						0	0	0	0	0	0	0	0
Mooring Winches	25	typ	2	0					0	0	0	0	0	0	0	0
Capstans	20	typ	4	0					0	0	0	0	0	0	0	0
Winches/Cranes	10	typ	3			0				0	0	0	0	0	0	0
Doors & Hatches	6	est	13	0	0	0	0	0	0	0	0	0	0	0	0	0
ELECTRONICS																
Sonar	36	data	1						1	0	0	0	0	0	36	36
Jammers	10	est	2				2			0	0	0	20	0	0	20
Radar Detectors	10	est	2				2			0	0	0	20	0	0	20
MK36-6 Rocket Launcher	25	guess	2				2			0	0	0	50	0	0	50
Degaussing System	25	DDG2	1				1			0	0	0	25	0	0	25
Secure Communications (IFF)	1	est	1				1			0	0	0	1	0	0	1
Total Power per Comp. in kW										6343.8	9438.0	4776.6	5348.0	3298.1	3333.5	32537.9
Total Auxiliary Power per Comp. in kW										103.8	78.0	91.6	460.0	103.1	195.5	1032.0

Total Power = 32.538 MW
Auxiliaries = 1.338 MW

Table 3-8

Waterjet Performance Characteristics

Thrust/Speed	109,000 lb/38 kts
Efficiency	66.6%
Weight of Jet Unit (With Reverse/Steering Gear)	58,700 lb
Weight of Water Entrained	50,700 lb
Mixed-Flow Waterjet Type Inlet Diameter	180 cm (5.9 ft)
Mixed-Flow Waterjet Type RPM	280 rpm

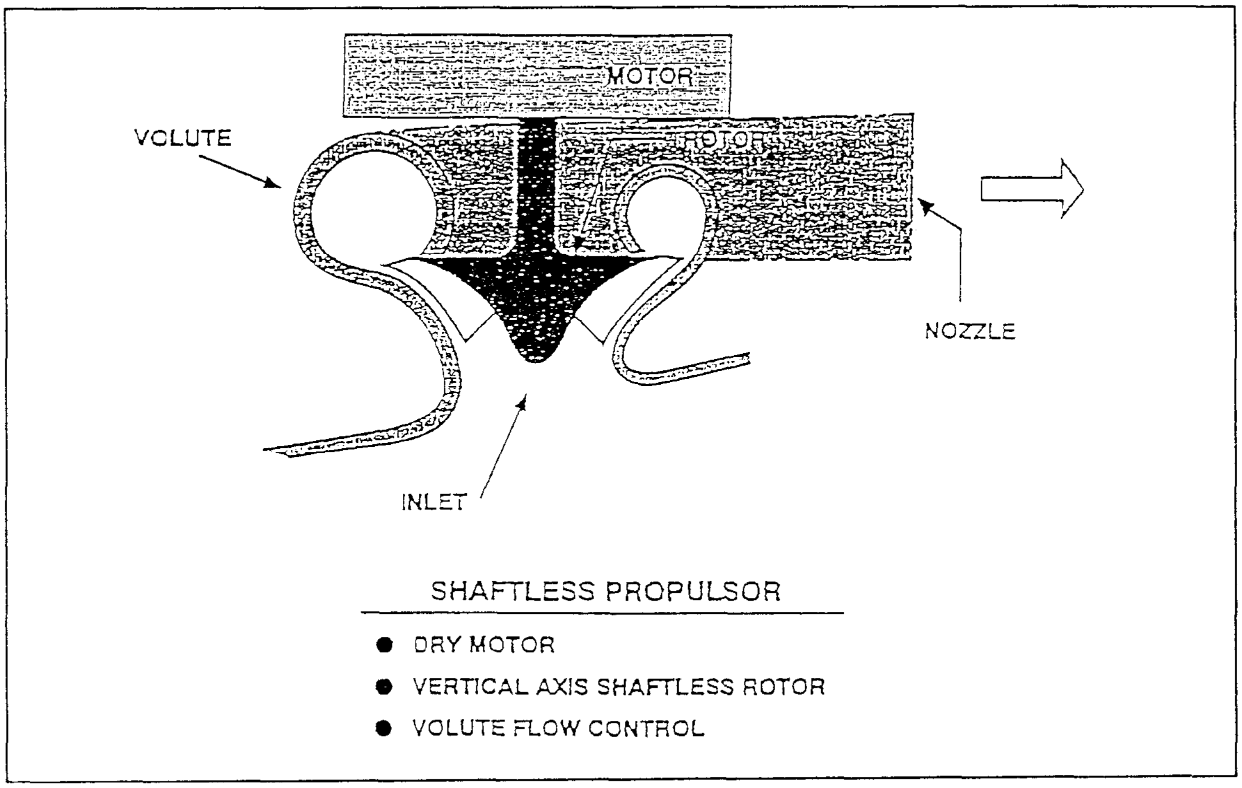

Figure 3-14. Vertical Axis Motor Propulsor (VAMP) Concept

A homopolar motor was chosen to drive each propulsor because of the high potential offered by this emerging technology. For homopolar motors to take full advantage of their characteristics, they need to be associated with other technologies also under development:

- Superconductive Motor
- Contra-Rotating Motor.

The former allows the homopolar motor to have a reduced size and weight while increasing, at the same time the efficiency up to 98 to 99%. The latter allows further reduction of the motor size and weight as well as of its foundations since the two contra-rotating stage tends to cancel the torque reaction forces on the foundations. This configuration is illustrated by Figure 3-15. While superconductive motor technology progresses towards "high" temperature (allowing nitrogen cooling rather than helium cooling) it was deemed likely that this technology would be available for use with motors of the HIGH TECH SHIP.

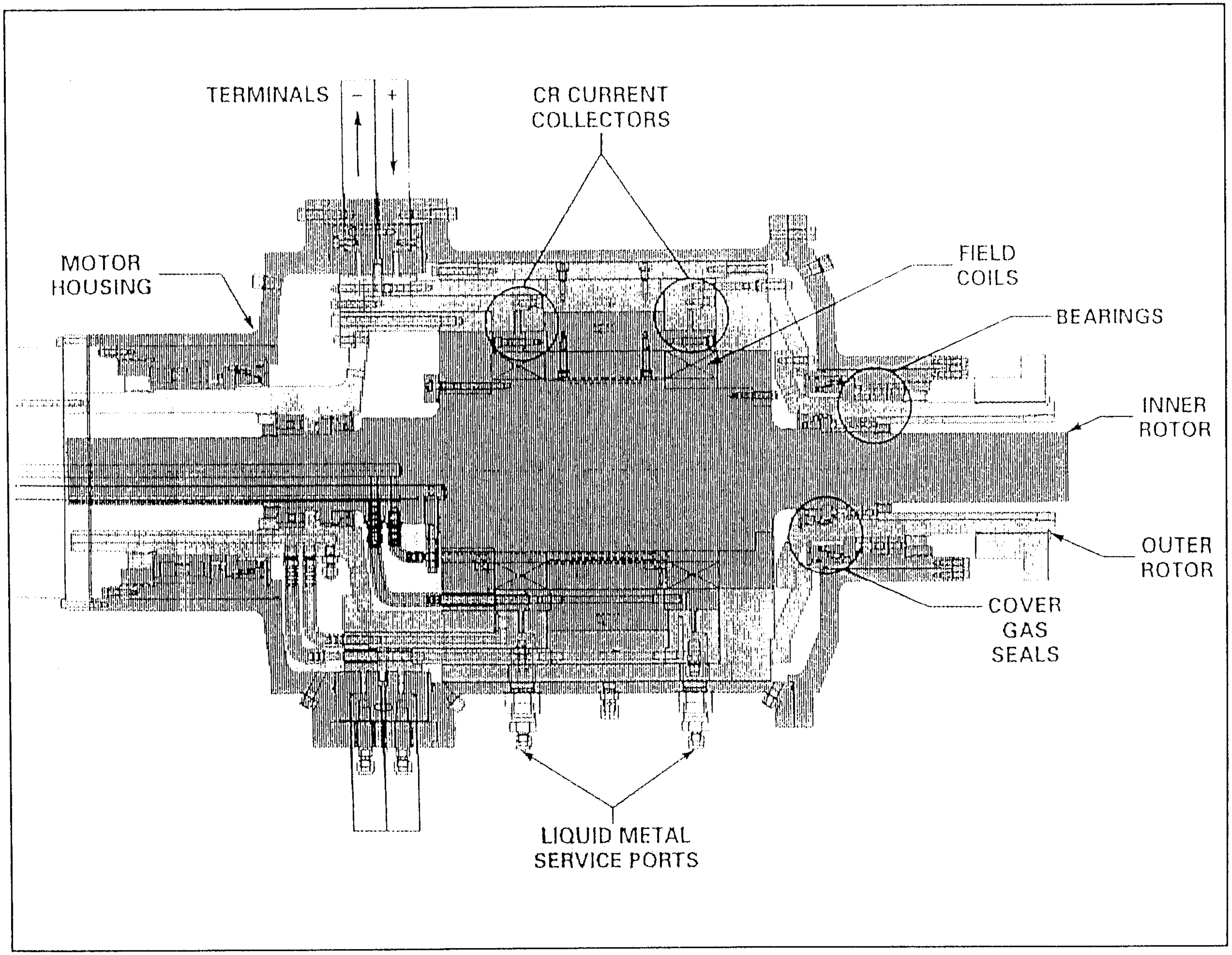

Figure 3-15. Homopolar Motor

The contra-rotating feature, however, would require specific design of the propulsor to incorporate two contra-rotating stages. Another arrangement using a homopolar-contra-rotating motor "wrapped" around a conventional, horizontal axis, twin stage waterjet may be preferred in this case. This type of arrangement has already been used (with one stage) for submarine seawater pumps and may therefore be pursued as an alternative propulsion arrangement for the HIGH TECH SHIP.

Although homopolar motors were chosen for the HIGH TECH SHIP, it was found that permanent magnet motors may also be used. The latter may, in fact, be more readily available for that application depending on the desired timeframe. However, it is believed that homopolar/superconductive/contra-rotating motors would eventually offer the most compact, lightweight and efficient propulsion for the HIGH TECH SHIP in the long run.

3.4 Structure Design

Composite materials were selected for the superstructure as well as for the hull of the HIGH TECH SHIP. It is believed that a significant reduction of structural weight may be achieved using composite materials, even without using exotic, high-strength materials. This, in turn, would greatly reduce the overall ship size and weight required for a given military payload and, therefore, reduce significantly total fleet cost. It is estimated that weight reductions in the order of 30 to 40% are achievable with composite structures over steel structures.

The lack of large scale production experience does not allow, at this time, an accurate projection of the cost of producing a large composite structure. It is believed, however, that once industrialization is accomplished, the production cost for large composite structures should be competitive compared to steel structure. In particular, it is anticipated that labor cost will be significantly less than that required for a metallic structure. Since labor cost is the most important part of the cost of a ship's structure, this is likely to offset some of the extra cost for material and tooling, especially molds. Note that tooling cost for metallic structure is not negligible. The cost of automatic cutting and welding machines represent a large investment that should be accounted for when comparing fabrication cost of composite and metallic structures. Areas of research that are expected to bring composite structure costs down include the development of reusable molds and tools and of automatic prefabrication techniques.

Several types of composite structure concepts can be envisioned for the construction of the HIGH TECH SHIP. The first choice to be made is between a single skin or a sandwich structure.

Sandwich structures are known to provide cheaper, stronger, and more lightweight structures but have often been rejected for large marine structures (such as Navy ships) due to the lack of resistance to local concentrated loads (shock) that could result in delamination or breaking of the thin and relatively weak skins. As a result of such local failure, it has been anticipated that water would likely flow through the skins and eventually create severe and profound structural damage.

While this may be arguable for relatively small boats that would use typical skin thicknesses of less than one-quarter inch, the skin thickness required for a ship of the size of the HIGH TECH SHIP would rather be one-half to one inch, and would therefore have enough strength on their own to withstand high local loads and to provide an effective barrier against water migration. In effect, the skin thickness for the HIGH TECH SHIP would be comparable to that of the single skin of a mine countermeasure vessel. Therefore, the sandwich construction was retained for the HIGH TECH SHIP. Details of the structural calculations are given below.

The process began by modifying an existing BLA structure calculation program. The major modifications involved adapting the program to use a different stiffener shape and making changes to the program structure to allow for easier future modifications and additions to the program.

The program requires the following items as input: panel size, frame spacing, stiffener sizes, loads, material properties, and lay-up schedules for the plating and stiffeners. The program then calculates stresses, deflections, weights, quantities and costs for the panel.

The stiffener section used is shown in Figure 3-16, and consists of a rectangular hat-stiffener with core height, h, core width, w, constant thickness, t_{core}, bottom flanges of length six times the thickness each, and tapered ends of length three times the thickness each. A subroutine is used to calculate the stiffener area, neutral axis, and moment of inertia about its own neutral axis. The current plating configuration uses sandwich construction with skins of equal thickness, t_{skin}, and an effective width equal to the stiffener width plus 18 times an effective skin thickness, t_{eff}, or $w + 18t_{eff}$. A second subroutine is then used to calculate the overall area, neutral axis, and moment of inertia of the stiffener combined with the cored plating.

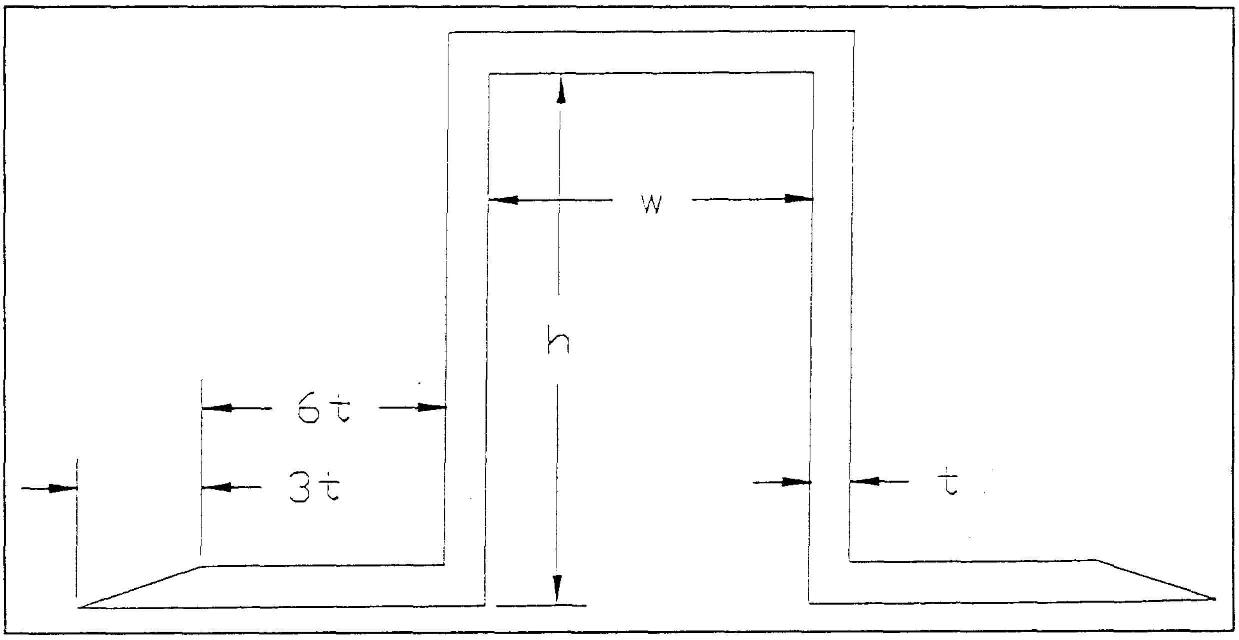

Figure 3-16. Stiffener Geometry

By separating the stiffener and plating calculations into separate subroutines, it is easy to add to the program different geometries of both stiffener and plating and to combine them as required by calling the appropriate subroutine. Other stiffener geometries include trapezoidal hat-stiffeners, variable thickness stiffeners (i.e., thicker "flange" than "web"), reinforced stiffener, or a combination. Other plating geometries include single skin, sandwich construction with non-equal skin thicknesses, or a different value of effective width.

Note that the program used was written to check the calculations performed by a European company on a USCG project. Therefore, there is not one single source for the equations used. Some of the equations came from Det Norske Veritas, others from U.S. Navy Design Data Sheets, etc. No effort was made to update the equations to a more standard source. Thus, the equations may need to be updated at some future time. Finally, note that this program was written in metric units and was kept identical in that regard.

The ship dimensions and shape were determined prior to the structural analysis. However, only midship section scantlings were sized. Scantlings were sized to panel pressure loads and checked against longitudinal bending strength requirements. Little attention was paid at this early stage of design, to foundations and other mounts, deck openings, ship ends, etc. Calculations were made for: the main deck, the sideshell, the bottom, the interior decks, the bulkhead, the deck girders, and for the center vertical keel (CVK). The loads to which each element was designed are shown in Figure 3-17.

The material properties used are present day state-of-the-art properties and were obtained from several sources (References 1 through 3). The fiber used was S-glass because of its slightly better strength per weight ratio over E-glass. However, stiffer materials such as carbon fibers or kevlar may be used on a case-by-case basis for local strengthening. Glass fiber was preferred in general for its low cost. Using high strength materials would result in thinner skins which would not be acceptable for the reasons suggested earlier.

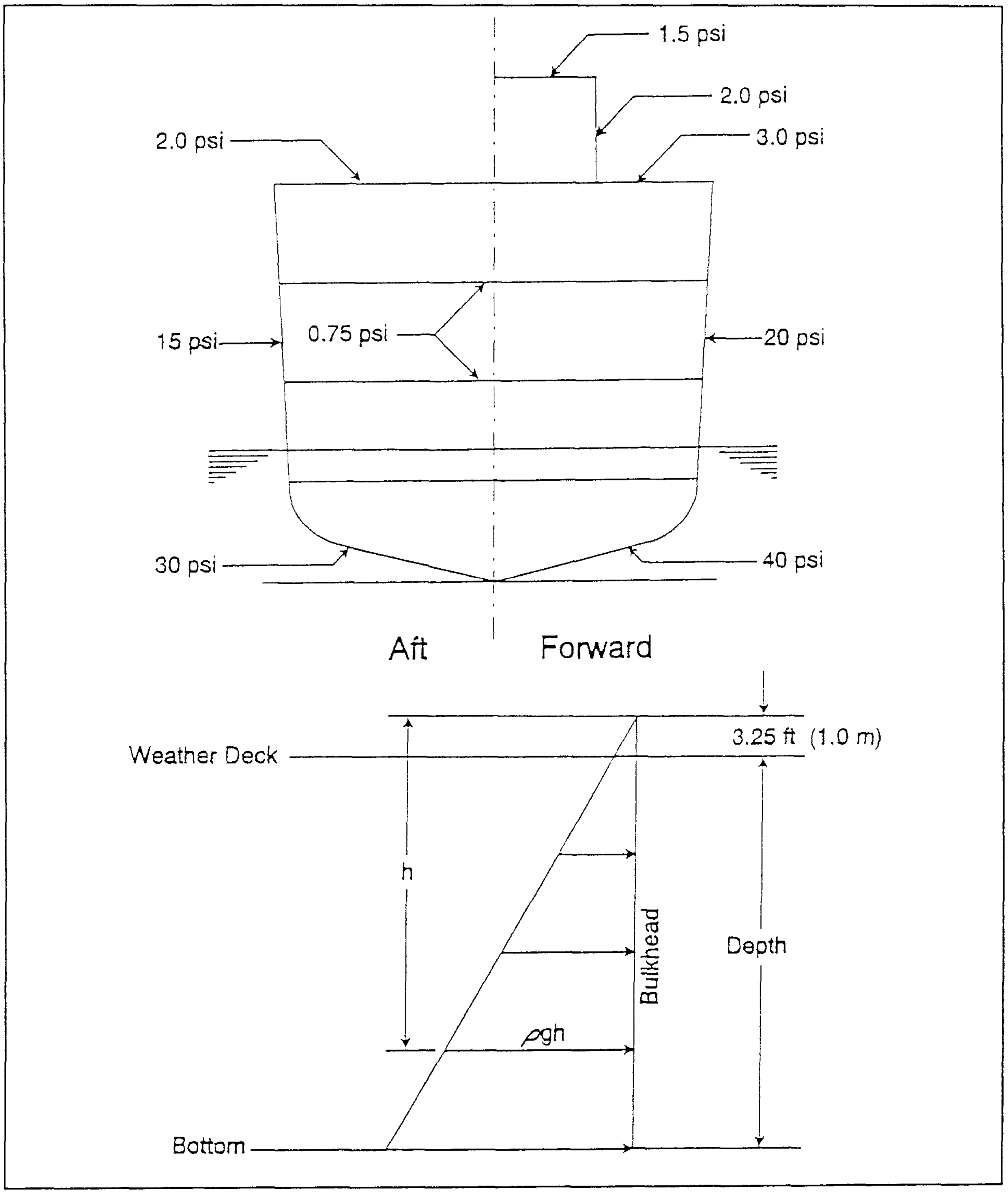

Figure 3-17. HIGH TECH SHIP Design Loads

Epoxy resin was chosen over either polyester or vinyl ester resins, mainly due to better elongation performance. Whichever resin is used, elongation performance is improved by post-curing at elevated temperatures. This process would obviously increase production cost, but would allow for a much stronger construction by allowing the fibers (the stronger component) to carry the maximum possible portion of the loads. Furthermore, the resins would require fire retardance through the use of additives. The plating layup is a loose weave roving or fabric which allows for greater strength by letting the fibers lie flat and straight with less crimps and bends. The disadvantage of loose weave is that layup is more difficult since the fibers are not held in place as rigidly and care must be taken so as not to disturb their lay during handling. Stiffener construction is of unidirectional fiber. Both plating and stiffeners will require pre-impregnated and/or vacuum bag construction to obtain high fiber-to-resin ratios.

The plating core material used is honeycomb although low density foams associated with Z-fibers (process developed by Foster-Miller) may also be considered. Honeycomb was chosen for its higher strength per weight even though it has some disadvantages. One of the more important problems of moisture collecting in the cells of the honeycomb might be solved by filling the cells with a very low density closed-cell foam. Note that the material properties used are only representative (i.e., they fall within the range of availability) of honeycomb, and do not apply to a specific type or size. The core material used for the stiffeners is a low density foam.

There are many methods of increasing the strength per weight of FRP structure, several of which might be applied to the HIGH TECH SHIP. The first is the use of "exotic" materials, such as Kevlar and carbon fiber. Next, by using glass with strands composed of more, smaller diameter, filaments rather than fewer, larger diameter, filaments, the surface area for a given strand size is increased, thus increasing the strength of the resin to fiber bond. The use of a peel ply, a non-impregnated layer of glass placed over the wet lamina that when removed pulls stalagmite-like arms perpendicular to the lamina which will protrude into the next lamina, will increase the interlaminer shear strength. Another way to increase the interlaminer shear is through a patented process that implants fibers in the Z-direction during curing. This process combined with a foam core for the plating may make the foam core strong enough to make it a better alternative than the honeycomb core. All of the above procedures have the disadvantage of increased production cost.

Full-scale material testing would have to be accomplished prior to construction to ensure that the material properties specified can be achieved. Such testing should include yield strength determination as well as fatigue strength and should also include comprehensive fire resistance testing of various panels and combinations of fire retardant resins.

The midship scantlings were determined using the BLA program and are shown in Figure 3-18.

The adequacy of the scantlings was checked as well as the overall ship deflection resulting from them. The results are shown in Figure 3-19 where it can be seen that under normal loads, the ship would deform about 2 inches. This is about six times higher than with a conventional (steel) hull as can be seen in Table 3-9 where various material were compared. This may become an issue since it will have a measurable effect on the precision of weapons and sensors. However, the use of embedded strain gages connected to a neural network may allow to provide real-time corrections for hull deformation under the action of waves, thus alleviating the problem.

Finally, it should be noted that while the largest composite ship structures built to date do not exceed 200 ft in length (versus 440 ft for the HIGH TECH SHIP), their structure weight is of the order of 300 to 400 LT versus 700 LT for the HIGH TECH SHIP. Thus, the "leap" is not as great as it may seem to be.

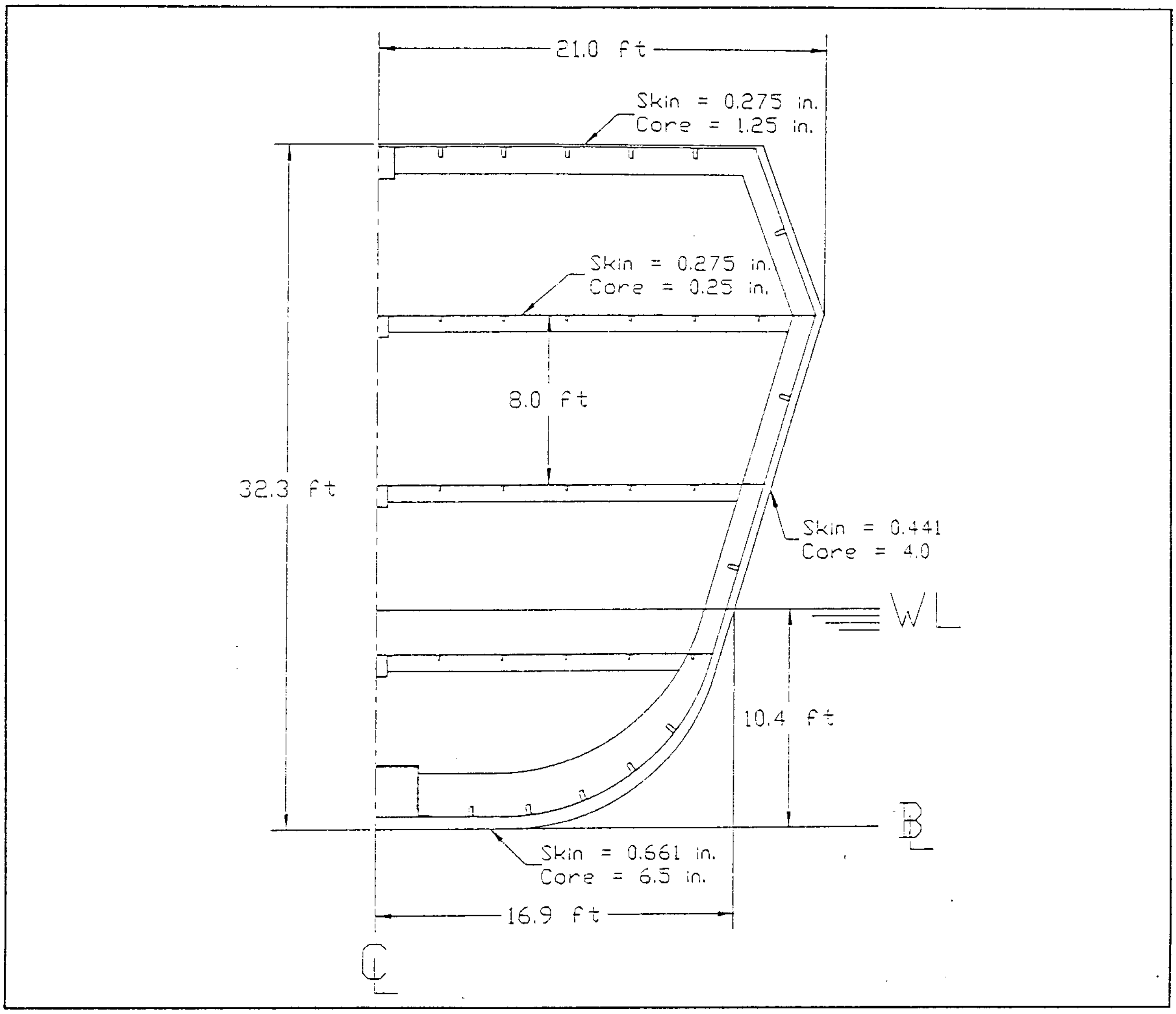

Figure 3-18. Midship Section

3.5 Subsystems

Several subsystems are required for the fuel cell plants to operate, including those for fuel, air, exhaust, and cooling water. Intake air will be obtained form the ambient air in the compartment. No special ducting is required. However, the ventilation system must be sized to include this load. When compared to diesel engine installations, however, the air flow for a given power is reduced. The gaseous exhaust is ducted locally to a common manifold and then discharged overboard due to the low temperature of fuel cells and the absence of polluting and/or soiling elements. It is believed that outboard exhaust is appropriate and will minimize the space required for the exhaust system. The absence of moving parts and of combustion also allows straight exhaust without silencers which greatly contributes to the total space occupied by the exhaust systems of conventional machinery. The feasibility of underwater exhaust and/or of wet exhaust, should also be examined since it would further reduce the infrared signature. It would, however, create a back-pressure in the fuel cell exhaust system that may not be suitable for the optimum performance of the fuel cell. The purpose of discharging the exhaust in small increments (by zone) at several locations is to reduce the thermal signature of the ship.

Seawater for cooling and fire-fighting is pumped into a local seawater main, from which the fuel cells can draw as required, i.e., the main is pressurized so that flow is controlled with valves at the fuel cells.

Therefore, each of the six zones has its own sea chest. The sea chest will be flush and designed so as to minimize appendage drag. The fuel system functions in a similar manner as the seawater system. All systems are interconnected to allow for operation of an adjacent zone in case of damage or failure, but each can operate independent of all other zones as well.

```
       HULL STRUCTURE
HULL MATERIAL: COMPOSITE (SANDWICH)
SUPERSTRUCTURE MATERIAL: COMPOSITE (SANDWICH)


 DISPL.*LENGTH/BENDING MOMENT :             21.36
 BENDING MOMENT :                 144. MNm      106. Mlbft

 TRANSVERSAL FRAME SPACING :     2272. mm        89. in
 LONGITUDINAL FRAME SPACING :     909. mm        36. in

 REQUIRED BOTTOM SKIN THICKNESS :20.81 mm       .819 in
 MINIMUM SKIN THICKNESS :         4.45 mm       .175 in

 BOTTOM SKIN THICKNESS :         20.81 mm       .819 in
 BOTTOM CORE THICKNESS :        104.03 mm      4.096 in
 MAIN DECK SKIN THICKNESS :       8.14 mm       .320 in
 MAIN DECK CORE THICKNESS :      40.70 mm      1.602 in
 HULL SIDES SKIN THICKNESS :     14.71 mm       .579 in
 HULL SIDES CORE THICKNESS :     73.56 mm      2.896 in
 HULL DECKS SKIN THICKNESS :      4.45 mm       .175 in
 HULL DECKS CORE THICKNESS :     22.23 mm       .875 in
 BULKHEAD SKIN THICKNESS :       14.12 mm       .556 in
 BULKHEAD CORE THICKNESS :       70.62 mm      2.780 in

 MIDSHIP SECTION INERTIA :       22.90 m^4     2653. ft^4
 MIDSHIP DECK/BOTM STRESS :        31. MPa     4485. psi
 MIDSHIP DEFLECTION :            54.80 mm      2.157 in
```

Figure 3-19. Results of Subsystems

Table 3-9

Hull Strength Comparison

Hull & Sup Material	Steel	Aluminum	GRP (Single Skin)	GRP (Sandwich)
Overall Length (m) Design Speed (kts)	134 38	134 38	134 38	134 38
Ship Displacement (LT) Hull Weight (LT)	2100 1092	2100 830	2100 738	2100 678
Nominal Stress (Midship)* (psi) Nominal Deflection (Midship)* (in.) Ratio of Deflection to Steel Hull	10,650 0.339 1.00	4825 0.451 1.34	 2.321 6.89	4175 2.008 5.96
*Under Normal Loads				

Both the 5-inch electric gun and the CIWS are pulse powered weapons. ETC technology is based on the application of a high voltage, high current pulse to a specially designed cartridge case. This pulse is applied to an ignition substance which changes phase into a hot plasma which facilitates the burning of the secondary fuel, the propellant. Thus, storage and handling of the ammunition is much safer, since combustion of the propellant is dependent on an electrically induced plasma. Furthermore, the potential to regulate the burn rate by controlling the shape and intensity of the electrical pulse allows more efficient acceleration profiles resulting in higher muzzle kinetic energies with lower peak pressures in the barrel. Propulsion power is temporarily diverted from the propulsors to the appropriate pulse forming network (PFN) for the necessary amount of time, on the order of a few seconds. Once charged, the PFN discharges the power to the gun in the required shape and time, on the order of a few milliseconds.

Fiber optics are used for communications and data processing. This allows for more reliable communication was well as eliminating electromagnetic interferences. It may also be envisioned to build a network of fiber optics embedded in the structure itself in order to collect information from sensors throughout the ship for damage control purposes.

Six remotely piloted vehicles (RPVs) for over-the-horizon targeting (OTHT) and support equipment are carried by the HIGH TECH SHIP. The RPVs are of the long endurance (>4 hours), low speed (<250 kts) type and carry video, radar and secure communication links as payload, with no deliverable payload. The RPV landing platform is at the stern on the ship. Forward of the landing platform is the hangar, and adjacent to that is a workshop. Above the RPV hangar is a helicopter landing pad. A fuel system is present to supply both the RPVs and helicopters with JP-5.

The principal auxiliary systems will incorporate the following specific features:

- Due to the low manning requirements of the HIGH TECH SHIP, the volume of accommodation spaces that need to be air-conditioned is greatly reduced. However, the large amount of electronics found throughout the ship will offset, somewhat, this advantage by requiring improved ventilation if not air conditioning.

- Note that ventilation of machinery spaces is expected to be of smaller magnitude than for conventional machinery due to the low volume of air required by fuel cells compared to combustion engines and gas turbines and also due to the low operating temperatures resulting in low radiated heat.

- The firemain is kept pressurized by electrically driven pumps. All auxiliaries are to be electrically driven (DC power) in order to allow the elimination of costly, heavy and relatively fragile hydraulic overhead systems.

- Fresh water is generated by the fuel cells and may be used for sanitary and drinking water. Since the amount of water produced would depend on power as well as other operating parameters, this would be a complimentary production. A reverse osmosis system would still be required and/or a storage capability.

- Fuel tanks are present locally in each section in order to make those sections self-sufficient. However, fuel transfer from one section to the next is necessary to provide flexibility of use of the fuel cell plant as well as ballasting capability.

- No compressed air system is needed in the absence of diesel and gas turbine engines.

- Fire-fighting requirements of machinery rooms may be reduced since the operating temperature of fuel cells are lower than that of combustion and gas turbine engines. Providing that the temperature of all exposed parts is low enough, it is possible that ignition of spilled fuel oil will be prevented in case of rupture of a fuel line which is likely to be the worse case scenario. Although the operating temperature is not yet finalized, the prospects of avoiding the need for halon (or equivalent) in the fire-fighting system is envisioned for the HIGH TECH SHIP.

- Steering, reversing and roll stabilization are provided by the waterjet steering and reversing gear. It is envisioned to use the steering nozzle rotating around a horizontal axis as a more efficient mean of controlling roll motion by orienting the waterjet up and down as required.

Manning requirements of the HIGH TECH SHIP have been anticipated to be drastically reduced compared to today's conventional Navy ships. The reasons for reducing the crew size are obvious. A great number of systems such as air conditioning, utilities, accommodations, etc. are driven by the crew size, thus a reduction of the manning requirement has a significant impact on the ship weight and cost.

The goal was set to a reduction by more than two-thirds from current levels. A 2100-LT ship is currently manned, typically by 100+ crew members. The HIGH TECH SHIP is to be manned by 30 crew members. Given the length of the HIGH TECH SHIP, this reduction may seem even more drastic (the HIGH TECH SHIP has the length of a destroyer typically manned by 250 to 300 crew members). However, it is believed that length should not be looked at for comparisons because of the specific geometry of the HIGH TECH SHIP.

The means used to reduce manning are multiple. First, and above all, a high level of automation of the ship auxiliaries, damage control system and machinery control systems is to be incorporated into the HIGH TECH SHIP. Distributed auxiliaries and distributed service power allow each section of the ship to be controlled locally by computer stations. A centralized station is also needed in order to provide global management of the ship's systems, especially for damage control operations. All communications, both between personnel and between computers, are made through optic fiber networks.

Neural networks are to be used to control the ship systems and provide rapid diagnostic as well as reconfiguration of the vital system in case of combat damage.

Embedded sensors throughout the ship detect and feed the information to the damage control system such as presence of water, smoke, fire or structural failure in any given location without delay.

Fire-fighting requirements are expected to be reduced by the use of fuel cells. Machinery spaces will not need to be manned except for the local control stations.

It is similarly envisioned to integrate all weapons and sensors into a comprehensive combat system neural network that will allow control of the ship's combat system by a reduced number of crew members.

The HIGH TECH SHIP is expected to resemble, in many respects, a combat aircraft where only the essential information is conveyed to the pilot in order for him to concentrate on his task while a number of subsystems are self-managed.

3.6 Manning Requirements

The intention of this project was to determine what effect reducing the manning would have on a corvette-sized combatant, and not to determine how such a manning reduction is to occur. It seems desirable, however, to show that the manning proposed is not unreasonable and to give some suggestions as to how it might be accomplished. The purpose of this section is to outline a possible functional manning breakdown for the HTS.

The current HTS design calls for a crew of 30. Figure 3-20 shows ship complement size as a function of displacement for modern surface combatants. For the purposes of this graph, a surface combatant was loosely defined as a vessel over 100 long tons that had at least two types of weapon systems, including guns, torpedoes, missiles, mortars, and depth charges. As can be seen from Figure 3-20, the High Tech

Ship, which is in the range of 1500 to 2100 LT, would normally have a complement of 90 to 110. the CORVETTE 2100 BASELINE (Reference 2) was designed with a complement of 100. Thus, the HTS project aims at approximately a 70% reduction in manning.

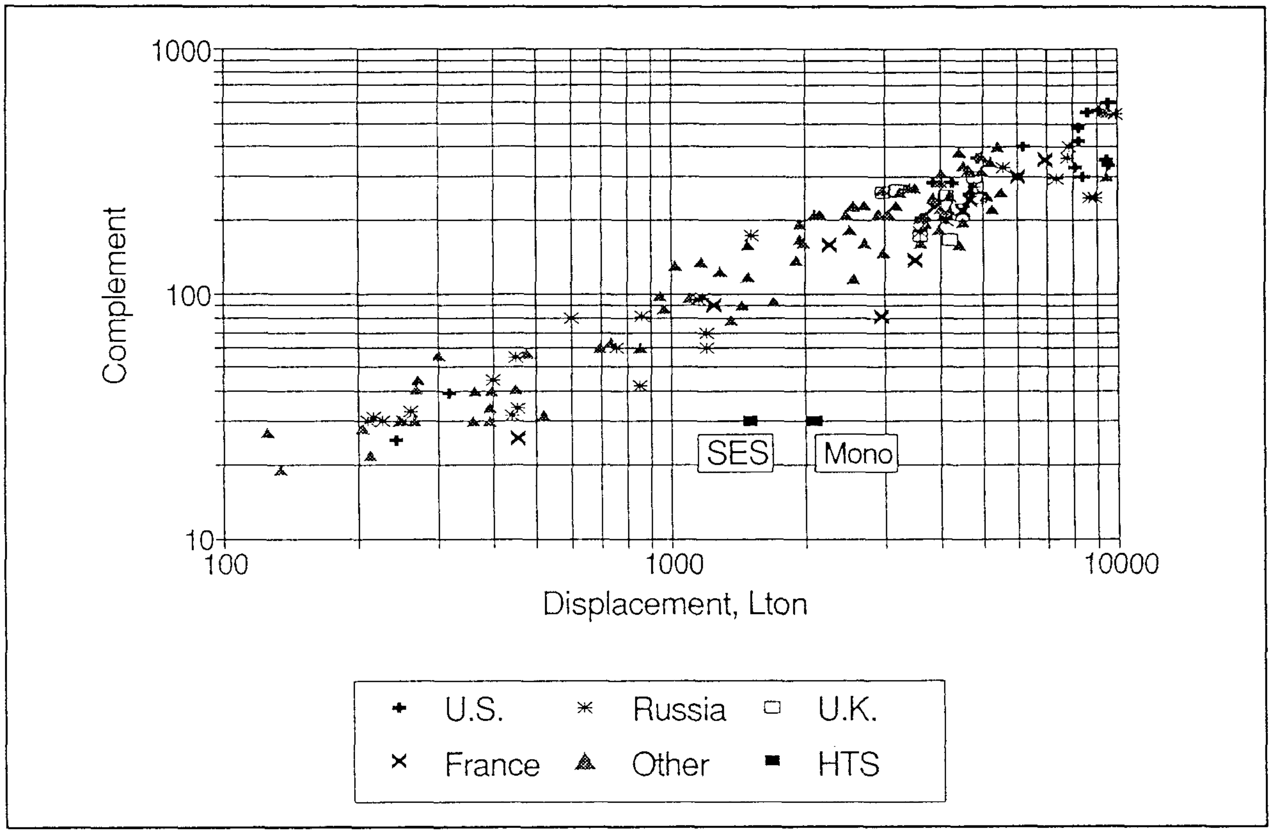

Figure 3-20. Complement Versus Displacement

The first obstacle to achieving reduced manning is to overcome the conventional wisdom belief that more is better. Typically, the larger the ship and the more personnel aboard, the more important the ship is considered to be.

The *second major obstacle is that everyone on board will have to "get their hands dirty,"* so to speak. This may even include the Commanding Officer, who may have to do a task such as standing watch on the bridge.

Automation

The greatest potential for reduction in required manning is through the use of automation. Care must be taken so that the automation devices used are not self-defeating in that the simple labor they replace is not offset by demands for more maintenance.

The fundamental ingredient in the brain of the HTS is artificial neural networks (ANN). The human brain is a powerful pattern recognition processor, both visual and oral, whose basic processing element is the neuron. Synapses are the weighted interconnections between neurons that permit learning and communication between the neurons. Artificial neural network technology attempts to mathematically and/or electrically model neurons and synapses and the interconnect these models in architectures suitable for signal processing tasks.

ANN processors have three unique characteristics. The first characteristic is that they are non-linear processors. The second property is that they are trained, not programmed, to accomplish processing tasks in a manner analogous to the way the human brain learns. Learning is accomplished by modifying the synaptic weights of each artificial neuron until the final desired system response is achieved. The ANN architecture can be configured so that the processor can learn from experience and thus perform its task better each time. The final quality is that they are massively parallel processors, which permits simultaneous processing of large amounts of imaging sensor information in real-time.

ANN technology is particularly suited to pattern recognition, speech recognition, machine vision, robotics, and optimization signal processing tasks. For the HTS, applications include sonar target discrimination, automatic target recognition, autopiloting, and damage control.

Maintenance

A large share of shipboard labor tends to go into maintaining the equipment in proper working order. There are many ways in which this requirement can be reduced: by installing components of greater reliability, by installing redundant components, preventive maintenance, making maintenance easier, and by reducing wear and tear on equipment in the form of vibration, temperature extremes, etc. A combination of these techniques are envisioned for reducing the on-mission maintenance demand for the HTS.

For example, take the power production. The HTS will have approximately 34 identical 1 MW fuel cells to produce both propulsion and ship's service power. A typical machinery arrangement might have two or four high-powered propulsion engines (for the two-shafted ship) plus several ship's service generators. The standardization of components (pumps, motors, etc. to support each plant) achieved with the many, small fuel cells will be beneficial. Fewer spare parts are required and familiarity leads to faster repairs. Also, the components are smaller and easier to handle than if the plant consisted of fewer, larger power producers. And finally, if for some reason one or two of the fuel cells do become inoperable, the ship still has 97% or 94% of full power available, respectively.

Navigation, Control and Communication

The proposed functional manning breakdown of the 30-man crew is as follows. The vessel will have one commanding officer and one executive officer. The operations crew will consist of three officers, three chief petty officers (CPOs), and three enlisted. Their jobs would include basic vessel control, navigation, and communications. The engineering department consist of one officer, two CPOs, and three enlisted. The engineering department's main task is to keep the machinery operating. The combat system crew contains one officer, two CPOs, and six enlisted. The combat system crew will be responsible for manning the CIC, firing and maintaining the weapon systems, and maintaining the RPVs. The support crew ill consist of one CPO and three enlisted. Their tasks would include supplies, messing, and general maintenance.

A typical watch would consist of the following:

Operations:	1 Officer, 1 CPO, 1 Enlisted
Engineering:	1 Officer or CPO, 1 Enlisted
Combat Systems:	1 Officer or CPO, 2 Enlisted.

Each watch would serve one four-hour shift and then have two shifts off. The support crew would each work a more normal eight-hour day and rotate between messing and maintenance tasks.

When the ship is in a combat situation, a second watch and/or the support crew would be on standby. This standby watch would be used to help load weapons, fight fires, etc., when necessary, but probably not as continuous duty. Of course, if the third watch was required, it would be called upon as well, such as if ship survival was at stake.

3.7 Environmental Considerations

The HIGH TECH SHIP has inherently environmental "friendly" features that result from the technologies used in its design. They include the following in particular:

- Low emission engines - Fuel cells are non-pollutant power generation plants. They reject no toxic nor ozone sensitive gases. The main byproduct of the fuel cell is water. In addition, the low exhaust temperature and noise are also less likely to perturbate aquatic life as well as other wildlife or, in coastal areas, human life.

- On-line systems for real-time monitoring of ship discharge is fitted on the HIGH TECH SHIP.

- Low pressure, low temperature catalytic thermal destruction of liquid waste streams will be used.

- The absence of mechanical, moving parts inherent to fuel cells will eliminate most of the lubrication needs, thus leading to virtual elimination of air polluted bilge water to be discharged overboard.

- Short lived bilge detergent will be used to reduce the impact on the environment of their discharge overboard.

- Non-plastic substitute packaging for food and/or plastic packaging with controlled degradation in seawater will be used.

- Non-polluting hull-coating will be used on the HIGH TECH SHIP.

- Absence of VOC paints due to the use of composites for hull and superstructure.

- Non-ozone depleting materials will be used for:

  - Substitutes to Halon for fire-fighting agents
  - Solvents for critical cleaning applications
  - Substitutes for CFC refrigerants.

- Non-fouling coatings for CHT tanks and sewage piping will be used.

- Non-invasive sensors for scale building in sewage piping will be used.

- Waterless shower, laundry and dishwasher technologies will be used.

- Shipboard sewage treatment technology will be used.

- Real-time sensors for PCB surface contamination will be used.

- Real-time on-site cleaning/encapsulation of PCB contaminated surfaces will be used.

3.8 Combat System

Although little information was available yet regarding the pulse power weapons, it was assumed that the 5-inch electro-thermal gun and the 60 mm CIWS would be of equivalent weight and space as their conventional counterparts, the 5-inch MK45 gun and the Phalanx CIWS, respectively. Figure 3-21 shows a comparison of the 60 mm ET CIWS and the Phalanx.

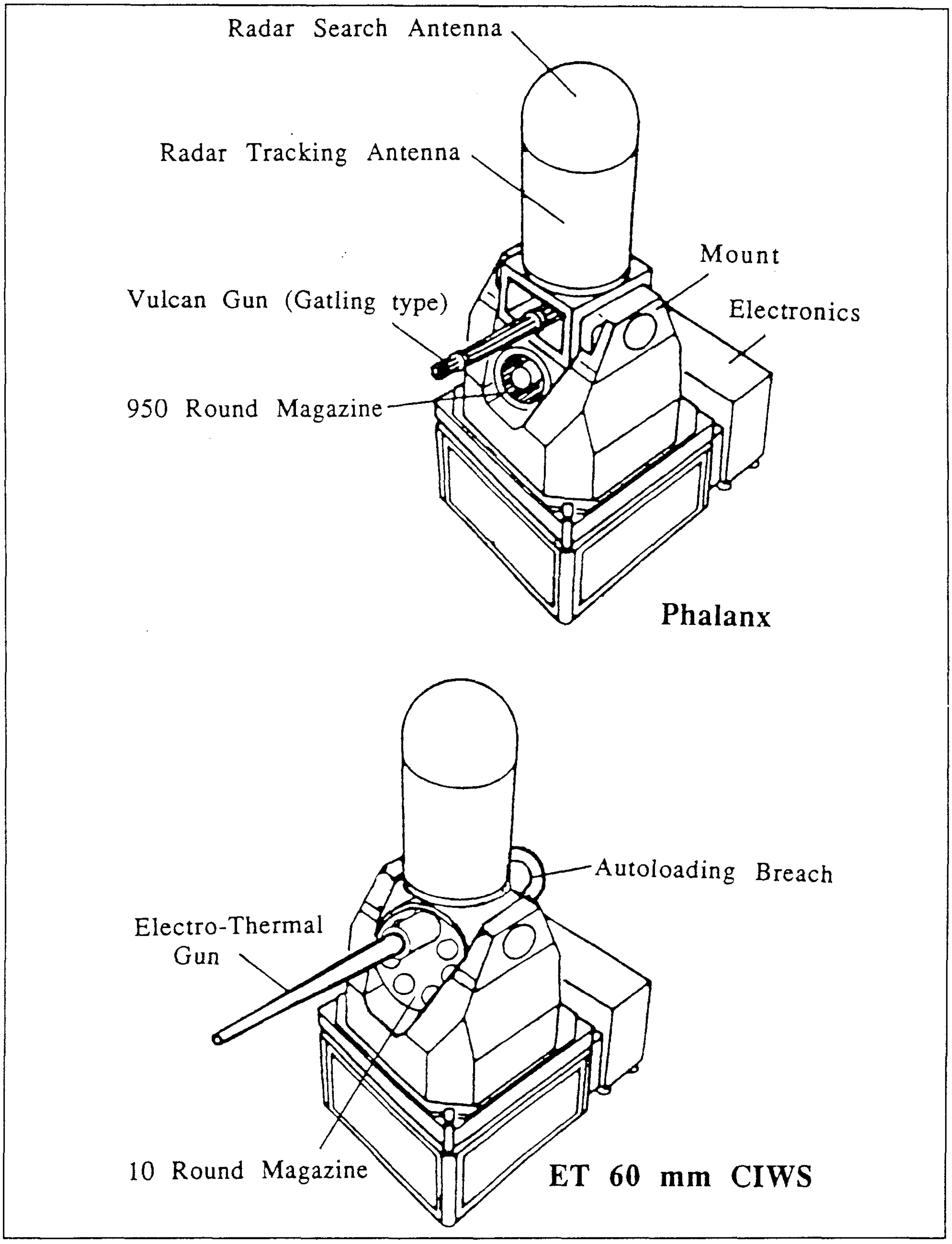

Figure 3-21. Phalanx and ET 60 mm CIWS

Similarly, conventional state-of-the-art radar and sonar systems are assumed, but they are intended to be replaced by high performance future sensors as will be available in the required timeframe for the development of the HIGH TECH SHIP.

A typical weapons suite that fits the design requirements of the Appendix A payload description is shown in Table 3-10.

Table 3-10

Weapons Suite

MISSION : HIGH TECH SHIP
Year :1993.

PAYLOAD DETAILS

	brand & type	weight (LT)	cost ($M)
GUNS	: 1 X 127mm OTO melara (or Mk45)	39.09	25.234
	594 X Ammunition rounds	12.28	.216
	2 X 20mm Oerlikon (single)	1.16	.541
	1800 X Ammunition rounds	1.45	.026
ASUW MISSILES	: 2 X 4 HARPOON (US)	8.03	11.193
AAW MISSILES	: 8 X 2 SEA SPARROW (US)	18.13	7.502
CIWS GUNS	: 1 X PHALANX (US)	5.95	6.111
TORPEDOES	: 3 X tubes	3.81	.387
	3 X MK46 (US)	.76	.633
MISCELLANEOUS	: Small Arms	1.07	.063
ELECTRONIC COUNTERMEAS.	:		
	2 X jammers	.30	.610
	2 X radar detectors	.20	.407
	2 X MK36-6 rockets launcher (US)	3.07	.471
	Degaussing system	4.20	3.780
RADARS	:		
	CASTOR II-C (Fr)	1.59	.358
	FAST (US)	5.16	.317
SONARS	:		
	SQS 56 (DE 1160C) (US)	5.71	1.294
OTHER ELECTRONICS	: Electronic equipment (CIC)	7.50	6.750
	Ship control equipment	5.88	2.938
	Navigation equipment	2.61	1.306
	Interior communications	4.57	2.285
COMMUNICATIONS	:		
	2 X MF transceivers	.06	.100
	2 X HF transceivers	.20	.240
	3 X VHF transceivers	.09	.150
	2 X UHF transceivers	.08	.130
	Satellite communications	5.00	5.000
	Secure communications (IFF)	.05	.100
AIRCRAFT	: 6 X PIONEER (Isr)	1.15	1.959
	Aircraft handling	.27	.028
	Aircraft fuel	3.12	.001
MISCELLANEOUS PAYLOAD	:		
	Cargo	5.50	.051
	Small boats	2.20	.061
EMBARKED PERSONELS	:		
	6 X aircraft personels	.51	
	8 X troops	.35	

TOTAL PAYLOAD

		weight (LT)	cost ($M)
TOTAL PAYLOAD	:	152.71	80.647

The payload weight is shown broken down by SWBS Groups in Table 3-11. These weights were used as inputs to the design procedure. It is recognized that the actual weights will need to be refined as more information becomes available concerning the weapons and sensors.

Table 3-11

Payload Weights

MISSION : HIGH TECH SHIP

Year : 1993.

PAYLOAD SUMMARY

FIXED PAYLOAD

		weight (LT)	cost ($M)
SWBS 500			
swbs540	Aviation fuel system :	.16	
swbs570	Cargo handling system :	.50	
swbs580	Aircraft & boats handling:	2.32	
swbs500	PAYLOAD AUXILARY SYSTEMS :	2.97	.139
SWBS 400			
swbs410	C & C systems :	5.88	
swbs420	Navigation systems :	2.61	
swbs430	Interior Communications :	4.57	
swbs440	Exterior Communications :	5.48	
swbs450	Radars (air/surface) :	6.75	
swbs460	Sonars (ASW) :	5.71	
swbs470	Countermeasures :	5.70	
swbs480	Fire control systems :	7.50	
swbs490	Special purpose systems :	.00	
swbs400	MISSION ELECTRONICS :	44.20	26.415
SWBS 700			
swbs710	Guns :	45.72	
swbs720	Missiles launchers :	17.24	
swbs730-	Mine laying system :	.00	
swbs740	Depth charges launcher :	.00	
swbs750	Torpedo tubes :	3.81	
swbs760	small arms :	1.41	
swbs770	cargo munitions handling :	.00	
swbs780	aircraft weapons handling:	.00	
swbs790	special purpose system :	.00	
swbs700	ARMAMENT :	68.17	35.216
FIXED PAYLOAD	:	115.34	61.770

VARIABLE PAYLOAD

		weight (LT)	cost ($M)
swbsf15	Embarked troops :	.95	
swbsf16	Aircraft personels :	.51	
swbsf21	Ship ammunitions :	26.64	
swbsf22	Aircraft ammunitions :	.00	
swbsf23	Aircrafts :	1.15	
swbsf42	Aircraft fuel :	3.12	
swbsf60	Cargo :	5.00	
swbs F	LOADS :	37.37	18.877

TOTAL PAYLOAD

	weight (LT)	cost ($M)
TOTAL PAYLOAD :	152.71	80.647

Details concerning the Pulse Forming Network (PFN) were found in References 5, 6 and 7. In particular, the PFN characteristics of Table 3-12 were used in the HIGH TECH SHIP design.

Table 3-12

PFN Data for Combined 5-Inch Gun and CIWS

Component	Weight (lb)	Volume (cu ft)
2 x Inverters	840	14
2 x Transformers	11,025	60
2 x Rectifiers	2,750	49
6 x Cable	15,515	42
8 x CIWS PFN	1,890	170
1 x 5-Inch PFN	2,940	28
Auxiliaries for PFN	1,450	60
Total	36,410	423

Note that the voltage required to form the pulse is 15 kV (about ten times what is available), thus converters are required, which were incorporated as part of the weight and volume listed in Table 3-12. The power requirements have been considerably reduced from early predictions of 12 MW for the 5-inch gun (see Reference 6) down to only 3.5 MW (Reference 7). Thus, the impact on ship performance when firing the gun is neglectible.

The centerpiece of the HIGH TECH SHIP weapons system is its 5-inch ET gun which will allow firing of "smart" shells at distances of 60 nm in its over-the-horizon anti-ship or shore bombardment role. Over-the-horizon targeting information is to be obtained through RPVs. Six RPVs were fitted on the HIGH TECH SHIP in order to ensure at least two are on-station at any time when needed (the others being either refueled, on their way or in maintenance). The ET gun will provide, therefore, the equivalent of anti-ship missiles such as harpoon missiles, but in greater quantity (600 shells, for example) for a much smaller volume/weight and without the inconvenience of very flammable propellants that are part of the missiles.

Harpoon missiles in vertical launch tubes were also fitted on the HIGH TECH SHIP only as a "back-up" system in case of unavailability of the ET gun. However, it may be envisioned to replace them by less capable, less expensive missiles.

The ET 5-inch gun may be used also for small targets such as patrol boats since the shell cost is very little compared to the cost of a harpoon missile.

In close range fire, it is envisioned that firing range may be controlled electronically by controlling the pulse power thus allowing the gun to be kept at the same firing angle, whichever role it is used for.

3.9 Weight Breakdown and Volume Summary

A summary weight breakdown is shown in Table 3-13. Note that the fuel cell weight was accounted for in the electric plant since propulsion and ship service power are integrated together. The combat system weight was based on conventional weapons as was described in Section 3.7.

The detailed weights for the various SWBS Groups 100, 200, 300, 500, 600 and loads are detailed in Tables 3-14 through 3-19, respectively.

The volume and space breakdown summary are shown in Table 3-20.

Table 3-13

Summary Weight Breakdown

SHIP WEIGHTS SUMMARY (IN LT)

SWBS100 WEIGHT	:	674.
SWBS200 WEIGHT	:	192.
SWBS300 WEIGHT	:	209.
SWBS400 WEIGHT	:	44.
SWBS500 WEIGHT	:	128.
SWBS600 WEIGHT	:	112.
SWBS700 WEIGHT	:	68.
DESIGN MARGIN	:	143.
LIGHTSHIP WEIGHT	:	1571.
FUEL WEIGHT	:	460.
LOADS WEIGHT	:	62.
FULL LOAD WEIGHT	:	2093.
SERVICE MARGIN	:	209.
MAX LIFETIME WEIGHT	:	2302.

Table 3-14

Detailed Weight for SWBS Group 100

DETAILED WEIGHT BREAKDOWN (IN LT)

SWBS100 BREAKDOWN:

SWBS 111 (SHELL STR.)	228.72		
SWBS 114 (APPENDAGES)	1.77		
SWBS 110 (HULL STRUCT)		269.52	
SWBS 120 (BULKHEADS)		73.07	
SWBS 131 (MAIN DECK)	45.94		
SWBS 132 (SECND DECK)	4.91		
SWBS 130 (HULL DECKS)		50.85	
SWBS 140 (PLATF.&FLTS)		152.64	
SWBS 150 (DECKHOUSE)		2.44	
SWBS 160 (SPEC. STR.)		64.69	
SWBS 170 (MASTS)		1.82	
SWBS 182 (GR2 FOUND.)	4.57		
SWBS 183 (GR3 FOUND.)	13.82		
SWBS 184 (GR4 FOUND.)	1.30		
SWBS 185 (GR5 FOUND.)	6.32		
SWBS 186 (GR6 FOUND.)	1.54		
SWBS 187 (GR7 FOUND.)	.99		
SWBS 180 (FOUNDATIONS)		28.54	
SWBS 191 (SOLID BALST)	.00		
SWBS 190 (SPEC. PURP.)		30.80	
SWBS 100 (TOTAL)			674.36

Table 3-15

Detailed Weight for SWBS Group 200

DETAILED WEIGHT BREAKDOWN (IN LT)

SWBS200 BREAKDOWN:

SWBS 224	(FUEL CELLS)	.00		
SWBS 220	(ENERGY GEN.)		.00	
SWBS 233	(DIESELS)	.00		
SWBS 234	(GAS TURB.)	.00		
SWBS 235	(ELEC.PROP.)*	63.31		
SWBS 230	(PROP.UNITS)		63.31	
SWBS 241	(RED. GEARS)	.00		
SWBS 243	(PROP. SHAFT)	27.94		
SWBS 245	(PROPELLERS)	.00		
SWBS 247	(WATERJETS)	52.44		
SWBS 240	(PROPULSORS)		80.38	
SWBS 250	(SUPRT SYS.)		.00	
SWBS 260	(FUEL SYS.)		.00	
SWBS 298	(WATER ENTR.)	45.32		
SWBS 299	(TOOLS&PARTS)	3.19		
SWBS 290	(SPEC. PURP.)		48.51	
SWBS 200	(TOTAL)			192.20

*ELECTRIC PROPULSION GENERATORS WEIGHT	.00
ELECTRIC PROPULSION POWER TRANSMISSION WEIGHT	10.92
ELECTRIC PROPULSION MOTORS WEIGHT	52.39

Table 3-16

Detailed Weight for SWBS Group 300

DETAILED WEIGHT BREAKDOWN (IN LT)

SWBS300 BREAKDOWN:

SWBS 310	(GENERATORS)		132.65	
SWBS 321	(PWR CABLES)	6.62		
SWBS 323	(CASLTY CABL)	1.16		
SWBS 324	(SWITCHG.&PL)	11.76		
SWBS 320	(DISTRIBUT.)		19.54	
SWBS 331	(LIGHT. SYST)	4.01		
SWBS 332	(LIGHT. FIXT)	3.01		
SWBS 330	(LIGHTING)		7.03	
SWBS 340	(SUPPT SYS.)		27.12	
SWBS 390	(TOOLS&PARTS)		22.95	
SWBS 300	(TOTAL)			209.29

Table 3-17

Detailed Weight for SWBS Group 500

DETAILED WEIGHT BREAKDOWN (IN LT)

SWBS500 BREAKDOWN:

SWBS 510 (CLIMAT CTRL)		16.06	
SWBS 521 (FIRE MAIN)	24.66		
SWBS 520 (SEA WATER)		37.76	
SWBS 530 (FRESH WATER)		4.72	
SWBS 540 (FUEL & LUBE)		15.99	
SWBS 551 (COMP. AIR)	.00		
SWBS 555 (HALON SYST.)	6.85		
SWBS 550 (AIR,GAS,MISC)		6.85	
SWBS 561 (STEERING)	7.19		
SWBS 562 (RUDDERS)	.00		
SWBS 565 (FINS STAB.)	.00		
SWBS 560 (SHIP CTRL)		7.19	
SWBS 570 (REPLENISH.)		7.03	
SWBS 581+582 (MOORING)	15.06		
SWBS 583 (BOATS)	2.30		
SWBS 586+588 (AICRFT)	2.00		
SWBS 580 (HANDLING)		19.36	
SWBS 590 (SPEC.PURP.)		12.88	
SWBS 500 (TOTAL)			127.84

Table 3-18

Detailed Weight for SWBS Group 600

DETAILED WEIGHT BREAKDOWN (IN LT)

SWBS600 BREAKDOWN:

SWBS 510 (FITTINGS)		4.33	
SWBS 621 (BULKHEADS)	12.14		
SWBS 622 (FLOORS)	19.20		
SWBS 623 (LADDERS)	6.27		
SWBS 624 (CLOSURES)	4.61		
SWBS 625 (PORTS)	.41		
SWBS 620 (COMPARTMENT)		42.62	
SWBS 631 (PAINT)	6.48		
SWBS 633 (CATHOD.PROT)	.20		
SWBS 634 (DECK COVRNG)	14.64		
SWBS 635 (INSULATION)	8.21		
SWBS 636+637 (DAMPING)	2.78		
SWBS 638 (REFRIG.)	.46		
SWBS 630 (PRES.& COV.)		32.78	
SWBS 640 (LIVING SPA.)		2.69	
SWBS 650 (SERVNG SPA.)		6.50	
SWBS 660 (WORKNG SPA.)		10.30	
SWBS 670 (STOWGE SPA.)		11.46	
SWBS 690 (SPEC.PURP.)		1.14	
SWBS 600 (TOTAL)			111.83

Table 3-19

Detailed Weight for Loads

DETAILED WEIGHT BREAKDOWN (IN LT)

LOADS BREAKDOWN:

F10 (SHIPS FORCE)		3.01	
F20 (MISSION EXPAND.)		37.37	
F30 (STORES)		4.30	
F41 (DIESEL FUEL)	460.06		
F42 (JP-5 FUEL)	2.50		
F46 (LUBE OIL)	4.83		
F40 (PETROL LIQUIDS)		467.39	
F50 (OTHER LIQUIDS)		10.25	
F00 (TOTAL LOADS)			522.31

Table 3-20

Volume Summary

BELOW DECK VOLUME	9489. M^3	335113. FT^3
(TANKAGE VOLUME	653. M^3	23061. FT^3)
SUPERSTRUCTURE VOLUME	122. M^3	4308. FT^3
TOTAL VOLUME	9611. M^3	339421. FT^3

SPACE BREAKDOWN

MILITARY MISSION	325. M^2	3494. FT^2
LIFE SUPPORT	154. M^2	1653. FT^2
SHIP SUPPORT	853. M^2	9181. FT^2
MACHINERY	1193. M^2	12838. FT^2
PASSAGES	266. M^2	2859. FT^2
UNASSIGNED	802. M^2	8630. FT^2
TOTAL AREA	3591. M^2	38655. FT^2

COMPARTMENTATION:

NUMBER OF WATERTIGHT BULKHEADS:	12.
NUMBER OF DECKS	3.297 (4.000)
NUMBER OF SS DECKS	.072 (.000)

3.10 Performance

The performance requirements were set as part of the design requirements of Appendix A.

The drag calculations are shown in Table 3-21 for the full-load displacement. Note that the data base used to calculate the drag was derived primarily from more conventional hullforms (length-to-beam ratio less than 10.0). However, some data from catamaran sidehulls with length-to-beam ratios of 11 to 13 were also used in generating the drag predictions. It is believed, however, that model tests should be conducted to provide adequate performance predictions including, in particular, seakeeping predictions.

Table 3-21

Drag Calculations

PROJECT :HIGH TECH SHIP

speed (kts)	froude #	Fric. drg (lb)	Resid. drg (lb)	Appen. drg (lb)	drg margin (lb)	Tot drg (lb)	drg-to-wt ratio	EHP (hp)
0.	.000	0.	0.	0.	0.	0.	.00000	0.
1.	.014	112.	6.	47.	13.	178.	.00004	1.
2.	.028	412.	26.	138.	46.	622.	.00013	4.
3.	.043	885.	63.	260.	97.	1304.	.00028	12.
4.	.057	1522.	119.	408.	164.	2212.	.00047	27.
5.	.071	2320.	197.	578.	248.	3342.	.00071	51.
6.	.085	3275.	300.	768.	347.	4690.	.00100	86.
7.	.099	4384.	431.	977.	463.	6255.	.00133	134.
8.	.114	5646.	592.	1203.	595.	8037.	.00171	197.
9.	.128	7058.	787.	1446.	743.	10034.	.00214	277.
10.	.142	8619.	1017.	1705.	907.	12248.	.00261	376.
11.	.156	10327.	1286.	1979.	1087.	14679.	.00313	496.
12.	.170	12181.	1597.	2267.	1284.	17329.	.00370	638.
13.	.185	14181.	1951.	2569.	1496.	20197.	.00431	806.
14.	.199	16325.	2488.	2884.	1736.	23432.	.00500	1007.
15.	.213	18611.	3535.	3212.	2029.	27387.	.00584	1261.
16.	.227	21040.	4776.	3553.	2350.	31719.	.00677	1558.
17.	.241	23611.	6223.	3906.	2699.	36439.	.00777	1901.
18.	.256	26322.	7887.	4271.	3078.	41558.	.00886	2296.
19.	.270	29173.	9775.	4647.	3488.	47083.	.01004	2746.
20.	.284	32164.	11898.	5035.	3928.	53025.	.01131	3255.
21.	.298	35293.	14264.	5434.	4399.	59390.	.01267	3828.
22.	.312	38561.	17921.	5843.	4986.	67312.	.01436	4546.
23.	.327	41967.	21255.	6263.	5559.	75044.	.01601	5298.
24.	.341	45509.	24459.	6694.	6133.	82795.	.01766	6099.
25.	.355	49189.	23194.	7135.	6361.	85879.	.01832	6590.
26.	.369	53005.	26610.	7585.	6976.	94176.	.02009	7516.
27.	.383	56956.	30068.	8046.	7606.	102676.	.02190	8510.
28.	.397	61043.	33655.	8516.	8257.	111471.	.02378	9581.
29.	.412	65265.	37490.	8996.	8940.	120692.	.02574	10744.
30.	.426	69622.	41733.	9485.	9667.	130507.	.02784	12018.
31.	.440	74113.	46582.	9984.	10454.	141133.	.03010	13430.
32.	.454	78738.	52281.	10491.	11321.	152831.	.03260	15012.
33.	.468	83497.	59123.	11008.	12290.	165917.	.03539	16807.
34.	.483	88388.	64272.	11533.	13135.	177329.	.03782	18507.
35.	.497	93413.	70111.	12067.	14047.	189639.	.04045	20374.
36.	.511	98570.	76234.	12610.	14998.	202473.	.04319	22374.
37.	.525	103860.	82830.	13162.	15988.	215840.	.04604	24514.
38.	.539	109281.	89729.	13722.	17019.	229751.	.04900	26799.
39.	.554	114835.	97001.	14290.	18090.	244216.	.05209	29236.
40.	.568	120519.	104656.	14866.	19203.	259245.	.05530	31831.

Details of the ship performance can be seen in Table 3-22 where drag, propulsive coefficient, propulsion power, specific fuel consumption and range, in particular, have been calculated for various speed/displacement rations of interest for the operations of the HIGH TECH SHIP.

Table 3-22

Ship Performance

PERFORMANCE	MAX FLD SPEED	DESIGN SPEED	MAX OPER SPEED	SUSTAINED SPEED	OPERATING SPEED #1	OPERATING SPEED #2	OPERATING SPEED #3	ZERO SPEED
SPEED/POWER PERFORMANCE								
DISPLACEMENT (LT)	2093.	2093.	1863.	1863.	1863.	1863.	1863.	1863.
SPEED (KTS)	38.61	38.00	40.00	37.37	40.00	20.00	15.00	.00
DRAG (LB)	238270.	229487.	231541.	205346.	231538.	49164.	25892.	0.
EHP POWER (HP)	28241.	26768.	28429.	23931.	28429.	3018.	1192.	0.
PROPULSIVE COEFFICIENT								
PROPULSOR EFFICIENCY	.668	.666	.672	.666	.672	.592	.565	.000
HULL EFFICIENCY	1.053	1.053	1.053	1.053	1.053	1.053	1.053	.000
TRANSMISSION EFFICIENCY	.980	.980	.980	.980	.980	.980	.980	.000
PROPULSIVE COEFFICIENT	.689	.687	.694	.687	.694	.611	.583	.000
POWER AND FUEL CONSUMPTION								
POWER PLANT CONFIGURATION	EL	EL	EL	EL	EL	EL	EL	EL (SSG)
DIESEL PROPULSION POWER (HP)	0.	0.	0.	0.	0.	0.	0.	0.
DIESEL ENGINES SFC (LB/HP/HR)	.000	.000	.000	.000	.000	.000	.000	.000
GAS TURBINE PROP. POWER (HP)	0.	0.	0.	0.	0.	0.	0.	0.
GAS TURNINE SFC (LB/HP/HR)	.000	.000	.000	.000	.000	.000	.000	.000
ELECTRIC PROP. POWER (KW)	30576.	29068.	30579.	25991.	30578.	3687.	1526.	0.
PROP. GENSETS SFC (LB/KW/HR)	.000	.000	.000	.000	.000	.000	.000	.000
TOTAL PROPULSION POWER (HP)	41409.	39367.	41413.	35200.	41412.	4993.	2067.	0.
TOTAL PROPULSION POWER (KW)	30891.	29368.	30894.	26259.	30893.	3725.	1542.	0.
AVG ELECTRIC LOAD (KW)	539.	539.	539.	539.	539.	539.	539.	539.
SERVICE GENSETS SFC(LB/KW/HR)	.338	.337	.338	.337	.338	.334	.330	.329
OVERALL AVG FUEL CONS.(LB/HR)	10516.	9987.	10517.	8942.	10516.	1410.	681.	177.
RANGE AND ENDURANCE								
REQUIRED ENDURANCE (HRS)	NA	NA	.00	.00	75.02	.00	66.67	578.30
REQUIRED RANGE (NM)	NA	NA	0.	0.	3001.	0.	1000.	0.
MAXIMUM ENDURANCE (HRS)	NA	NA	89.08	104.77	89.08	664.61	1375.98	5287.85
MAXIMUM RANGE (NM)	NA	NA	3563.	3978.	3563.	13292.	20640.	0.

It can be seen that the range of the HIGH TECH SHIP at 20 kts is more than 13,000 nm because the requirements were for design range to be achieved at the top speed of 40 kts (3000 nm). However, because of the fuel efficiency of the fuel cell plant, the proportion of fuel carried by the HIGH TECH SHIP is comparable to that of a conventional ship.

The seakeeping performance of the HIGH TECH SHIP cannot be assessed without model testing because of the non-conventional hullform used. However, the following premises may be offered concerning that aspect of the design:

- The high waterline length will provide a large pitch stiffness to the HIGH TECH SHIP.
- The wave-piercing bow is expected to provide smooth passage through head seas. Where a conventional hullform would likely slam in heavy seas, the HIGH TECH SHIP should cut through the waves without sudden vertical accelerations.
- Roll motions on the other hand may be expected to be a delicate issue with this hullform although resonance should be encountered for relatively small sea states due to the small beam. However, what makes this hullform less stable, also makes it easier to stabilize by the action of waterjet steering control similar to the rudder-roll technique used with propeller driven vessels. The waterjet may actually be expected to provide greater stabilizing forces than rudders, especially at low speed. The stabilizing effect may be further improved if vertical control of the steering nozzle is provided.

Stability is undoubtedly an issue with the hullform selected for the HIGH TECH SHIP. The calculations made so far for an estimate of the vertical center of gravity and metacentric height lead to the conclusion that adequate stability will be obtained to sustain typical U.S. Navy criteria such as 100-kts lateral wind (see Table 3-23). Damaged stability calculations, however, have not been conducted and would need to be investigated as soon as possible in the next design.

Table 3-23

Stability Characteristics

			CRITERIA	PASS
VCG LIGHTSHIP	4.72 M	15.5 FT		
VCG FULL LOAD	3.88 M	12.7 FT		
VCG FULL LOAD - MAX LIFETIME	4.18 M	13.7 FT		
LIGHTSHIP METACENTRIC HEIGHT (GM)	.92 M	3.0 FT	USN 80kts	yes
FULL LOAD METACENTRIC HEIGHT (GM)	1.77 M	5.8 FT	USN 100kts	yes
END OF LIFE METACENTRIC HGHT (GM)	1.46 M	4.8 FT	USN 80kts	yes
MINIMUM METACENTRIC HEIGHT (GM)				
US NAVY CRITERIA FOR 100 KTS WIND	1.29 M	4.2 FT		
US NAVY CRITERIA FOR 80 KTS WIND	.83 M	2.7 FT		
JAPANESE CRITERIA FOR 30 KTS WIND	.13 M	.4 FT		
IMO CRITERIA	.11 M	.3 FT		

It should be noted that acceptable stability is obtained by the fact that all accommodations, weapon systems and auxiliary systems have been located within the hull. No subsystem was left protruding over the main deck except for the pilothouse and the detection/communication sensors which are all contained in a relatively small submarine-like superstructure.

The advantages of the high length-to-beam hullform with the features listed above are believed to outweigh the potential stability problem and deck wetness inherent to this concept. In order to validate these basic design features, a comprehensive model test program should be carried out. If the stability and/or seakeeping prove to be inadequate, some fall-back solutions may be envisioned such as:

- Adding lateral floats (thin, short sidehulls) to provide trimaran type configuration for improved stability. Those sidehulls may be retractable or fixed.

- Adding submerged foils/fins for additional pitch control.

- Providing wave deflectors for reduced deck wetness as part of the design of the bow.

4.0 CONCLUSIONS

The design of a High Tech Ship was carried out at a prefeasibility, or conceptual level.

This design incorporates a number of new and emerging technologies that are being pursued under the Surface Ship Technology program or under other auspices.

The combination of advanced technology showed that a HTS with improved performance and mission effectiveness would be feasible thanks to their cumulative benefits.

The HTS design described in this report, however, is not to be viewed as a product in itself, but merely as a support for showing the benefits of the technologies it uses. In this respect, it is envisioned that there should be as many HTS as there are combinations of technologies.

The HTS concept is, therefore, to be used as a tool for evaluating ship impact of technologies and combinations of technologies.

5.0 REFERENCES

1. "Corvette 2100 (2100 LT) Baseline," Band, Lavis & Associates, Inc., Working Paper No. 237A-14, Revision A, dated January 5, 1993.

2. "High Tech Ship Technology Review," Band, Lavis & Associates, Inc., Working Paper No. 237A-1, dated August 1992.

3. "High Tech Ship Hullform Selection," Band, Lavis & Associates, Inc., Working Paper No. 237A-12, dated August 1992.

4. "Optimum Voltage Selection - Fuel Cell Assessment," Band, Lavis & Associates, Inc., Technical Memorandum No. 261B-3, dated December 21, 1992.

5. "Initial Impact Assessment of Electro-Thermal-Chemical Gun Outfit Aboard the DDG 51 With Mechanical Drive," DTRC-PAS-91-53, dated February 1992.

6. "Propulsion Powered Electric Guns - A Comparison of Power Systems Architecture," DTRC-PAS-91-31, dated July 1991.

7. "A Comparison of Fuel Cell and Alternator Based Power Supplies for Electro-Thermal Chemical Guns Aboard Future Naval Combatants," CDNSWC-TR-82-93/34, September 1993.

APPENDIX A

HIGH TECH SHIP DESIGN REQUIREMENTS

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TECHNICAL MEMORANDUM NO. 237A-2 - REVISION E

TO: Jeffrey Benson, CDNSWC

FROM: David Lavis, BLA, Inc.

DATE: 26 July 1994

SUBJECT: High Tech Ship (HTS) Design Requirements

1.0 INTRODUCTION

The objective of this task is to develop a corvette-size combatant High Technology Ship (HTS) to allow quick intervention in remote places around the world. It is intended that this design be a showcase to illustrate a vision of the future that would demonstrate improvements in ship affordability, combat effectiveness and survivability made possible by integrating the synergistic effects of emerging surface-ship HM&E technology.

The HTS will incorporate a number of special measures to reduce its detectability and to improve its survivability in combat. The HTS will also incorporate a large number of emerging technologies under development through the 6.2 Block program.

The HTS is dedicated to surface warfare missions and is expected to face a threat from mainly third-world/developing countries.

The HTS is meant to be a small combatant (corvette size) that will provide an affordable alternative to a frigate or destroyer. However, it is not intended to replace these large combatants which will remain more capable in terms of range, payload and seakeeping, but to provide a complementary capability at a more reasonable cost.

2.0 MISSION NEED

2.1 Mission Requirements

2.1.1 Primary Missions

- Anti-surface warfare operations in limited scale conflicts.
- Shore bombardment in support of landing operations.
- Deployment in conjunction with a task force, or alone, as early-crisis intervention vessel.

2.1.2 Secondary Missions

- Conduct and support anti-terrorist and/or commando operations.
- Anti-air self defense against aircraft (helicopters) and against missiles (to include electronic warfare).
- Anti-submarine self defense against conventional (diesel) submarines.
- EEZ patrol.
- Pollution control.

Note that EEZ patrol and pollution control missions are not normally U.S. Navy missions, but were considered as means of making the best use of the HTS in peacetime.

2.2 Theater of Operations

Anywhere around the world. Potential conflicting zones are:

- Middle East (Persian Gulf - Mediterranean Sea)
- Indonesia - India (Indian Ocean)
- Korea
- China - Taiwan (China Sea)
- Yugoslavia (Adriatic Sea)
- Black Sea
- South America - Central America
- Etc.

The High Tech Ship may be prepositioned near the potential theaters of operations in order to allow a quick intervention in its primary role of crisis containment. Should the policy of the U.S. Navy favor the regrouping of its fleet within the U.S. territory, the HTS would be deployed together with resupply vessels up to an appropriate distance from the theater of operations or would resupply in friendly ports before carrying out its mission.

2.3 Threat

The seaborne threat shall be mainly constituted by modern corvettes/frigates with a limited, but sophisticated weapons (long range surface-to-surface missiles such as EXOCET, HARPOON, OTOMAT, etc.). In addition, smaller vessels (such as high-speed patrol boats) will be considered since they also carry potentially significant offensive weapons.

Although over-the-horizon targeting (OTHT) is not expected to be readily available to the enemy vessels, the HTS will have to be able to use OTHT to obtain a clear advantage.

Land-based aircraft and/or seaborne helicopters may constitute a threat to the HTS, thus anti-aircraft and anti-missile weapons will be required on the HTS for self-defense.

It is also expected that, in the conflicts where the HTS will be involved, a potential threat from mines shall be present. As a result, reduced signatures and increased survivability are required.

A minor submarine threat is anticipated, and some self defense capability against the threat of diesel submarines should be considered for the HTS.

2.4 Tactical Concept

2.4.1 Anti-Surface Warfare

The ship shall use long range weapons (SSM and/or electric gun) in association with RPVs for early detection and surveillance and for OTHT against major targets. Small and non-threatening targets shall be monitored with RPVs and ship borne radars. Neutralization, if required, may be made using conventional guns at short range. The vessel shall use high speed to reach the area of conflict in minimum time and, if required, for tactical repositioning on site. A low-speed, stealth mode, shall be used generally while in the theater of conflict.

Satellite communications, RPVs with secure link and passive (or, if available, non-detectable active) detection means shall be used to detect and monitor targets in the theater of conflict.

2.4.2 Shore Bombardment

Shore bombardment using the electric gun monitored by RPV video coverage shall be used to support land base and/or landing operations while keeping the ship at a safe distance (beyond the horizon) from the shore.

2.4.3 Special Warfare Operations

The ship shall deploy and support commando troops with RHIBs. RPVs may be used to survey the area of operation and provide information about the threat. Light guns (conventional) may be used to neutralize small strike boats (terrorists) at short range.

2.4.4 Anti-Air Warfare

Anti-air missiles and/or CIWS shall be used against aircraft and missiles threats. Detection shall be provided by surface - air search radars. It should be noted that, since it is expected that the RPVs will provide early detection of surface ships and will allow the HTS to strike before being threatened, the air threat would come mostly from land. However, the case of a helicopter used as an OTHT device by an enemy ship shall be considered. Chaff decoys (see below) shall be used as a last resort.

2.4.5 Electronic Warfare

The HTS shall operate in the theater of operation in a "stealth" mode, that is, at low speed (on electric drive) and with mostly passive systems. Radar detectors and jammers, as well as chaff decoy systems shall be used when required.

2.4.6 Anti-Submarine Warfare

Only conventional (diesel) submarines are considered here. Detection shall be provided by a hull-mounted sonar and neutralization shall be made by homing torpedoes. This task is only considered as a self defense capability.

2.4.7 EEZ Patrol

In peacetime, the HTS may be used as an EEZ patrol vessel. The RPVs will provide continuous surveillance together with shipborne radars. RPVs may also be used to assess and monitor vessels in the EEZ without intercepting them by the ship itself. The RHIB and special warfare troops may be used to board and seize vessels when required.

2.4.8 Pollution Control

The HTS may also be used in peacetime to enforce pollution control laws and to coordinate pollution control operations in case of environmental disaster and to carry out early containment. First intervention equipment shall be carried as part of the vessels payload for such purposes.

3.0 TECHNICAL CONSIDERATIONS

3.1 Mission-Related Considerations

3.1.1 Operating Profile

In peacetime, the HTS will make limited use of high speed and will operate most of the time at best economic speed on electric drive. Only in case of emergency, such as an oil spill or drug interdiction seizure, may high speed transit be required.

In time of crisis, however, a high speed transit to the theater of conflict shall be used, although high speed is not intended to be used once on site in order to keep a low profile (stealth mode).

3.1.2 Payload Description

A typical payload for the HTS may be as follows:

- 5-inch electric gun* or conventional 5-inch gun (for baseline Monohull)
- 2 x 20 to 30 mm guns
- 8 anti-surface warfare missiles (Harpoon or lighter missiles)
- Anti-air warfare missiles (SM2 or Sea Sparrow) in VLS cells or on pod mounting (RAM)
- CIWS (Phalanx) with autonomous detection/optronic director
- Triple torpedo tube (with 3 MK46 torpdoes)
- Small arms (12.7 mm machine guns and portable arms)
- 6 RPVs and support equipment. RPVs shall be of long endurance (>4 hours), low speed (<250 kts) type and shall carry video, radar and secure communication link as payload (no payload delivery).
- Multi-purpose surface/air search radar (with passive mode)
- Fire control radar
- Navigation radars (one dedicated to RPVs monitoring)
- UHF/VHF radio communications
- Satellite communications
- Satellite navigation system (GPS)
- Secure link with RPVs
- Hull mounted sonar
- ESM/ECM
- 2 chaff decoy system (Protean)
- 1 RHIB boats for 8 fully-equipped troops
- 8 troops fully-equipped for special warfare
- Pollution control equipment (containment booms).

The total payload weight is estimated at 150 LT, including electronics, armament and ammunition.

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*Total weight, including ammunitions, specific support and fire-control systems, shall not exceed 50 LT (equivalent to total weight of a conventional 5-inch gun).

3.1.3 Environmental Considerations

The HTS will be able to operate in open ocean at all seasons (year-round) with at least 80% year-round operability. Full operability in sea-state 6 and survivability in sea-state 8 should be considered.

3.2 Ship-Related Considerations

3.2.1 Hull

The hull shall be of a rugged and cost-effective construction. Consideration shall be given to composite materials as a possible alternative to high tensile steel for hull and superstructures.

3.2.2 Propulsion

The propulsion shall accommodate a multi-mode comprising of:

- High-speed "booster" power (gas turbine, for example)
- Low-speed "silent" drive (electric drive, for example).

The low-speed mode shall also be used as the economic mode.

3.2.3 Performance

	Minimum	Preferred	Corvette Baseline
Maximum Speed (kts)	40	50	27
Cruise Speed (kts)	35	45	27
Low Speed (Silent) (kts)	12	15	12
Range	3000 nm @ cruise speed plus 1000 nm @ low speed	3000 nm @ cruise speed plus 1000 nm @ low speed	2000 nm @ cruise speed plus 1000 nm @ low speed
Endurance	20 days	30 days	20 days
Motions	Full operability in sea-state 5* Survival in sea-state 7	Full operability in sea-state 6* Survival in sea-state 8	Operations up to sea-state 5
Stability	U.S. Navy Criteria	U.S. Navy Criteria	U.S. Navy Criteria

*Except for RPVs operability if wind limited.

The range requirement was made to allow (in the "preferred" configuration) an Atlantic crossing at full-speed for a rapid deployment in case of a crisis containment mission. In the minimum configuration, such a transit would require refueling or cruising at a lower speed.

3.2.4 Manning

Minimum manning shall be accomplished through automation and integration of monitoring and control systems for all ship operations.

3.2.5 Survivability and Vulnerability

Special attention shall be paid to reduce the detectability and increase the survivability of the HTS. The latest stealth technique shall be used to reduce the ship signature, in particular:

- Wake
- Radar Cross-Section
- Infrared Signature
- Underwater Acoustic
- Electro-Magnetic

Such measures are aimed at making the HTS undetected while it enters the theater of operation and also at reducing the risk of a missile hit and of damage from mines. In addition, the ship's survivability to combat damages shall be improved using such techniques as damage containment, quick automated power distribution reconfiguration, etc. Steps should be taken to maximize the ability of the HTS to carry out its combat tasks after being hit by a weapon (missile, mine, torpedo, etc.).

3.3 Other Considerations

3.3.1 Special Capabilities

The ship combat system shall be of a modular type so as to allow quick reconfiguration, modernization throughout the lifetime of the vessel. Standardization of the auxiliary modules, power modules and control units shall be made to allow easy reconfiguration after damage or during overhaul of the vessel.

3.3.2 Readiness and Availability

A high degree of readiness and availability shall be achieved for the HTS. Such capability is expected to be possible as a result of modularity and the reconfigurability as well as systematic standardization.

3.3.3 Overhaul, Maintenance and Logistic Support

Overhaul and maintenance are to be facilitated by systematic standardization and modularization. Subsystem maintenance may be achieved by simply replacing the subsystem by a module from a joint pool for all vessels and repairing the failed module on shore.