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METHODOLOGY FOR COMPUTER-SUPPORTED COMPARATIVE NAVAL SHIP DESIGN

by

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ABSTRACT

Comparative Naval Ship Design is used to compare new designs for trend analysis or to determine new technology impact on the "whole" ship. This process is at present manually time intensive and tailored to the individual study. This thesis proposes a standardized methodology to display and compare ship designs using present computer technology. With full preparation for it's implementation into a computer program, applicability is shown for direct interactive data base extraction, interfacing with the Navy's Advanced Surface Ship Evaluation Tool (ASSET) or simply using a microcomputer spreadsheet.

The proposed methodology will provide for a direct detailed graphical or tabular comparative analysis of any two ships, a bar graph analysis of up to six ships simultaneously, or a trend analysis to compare a new design to past similar designs. All proposed comparison parameters and indices are fully documented with definitions and significant relationships to overall ship impact. Additionally, a comparative analysis help option is presented to assist the designer in determining "impacts of" and "reasons for" significant differences of a two ship comparison.

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CHAPTER 1

INTRODUCTION

1.1 Purpose

Naval architects and design engineers continuously show an interest in how a new design compares to previous ships of the same type or how a new technology impacts a design. The process of comparing designs is referred to as comparative naval ship design and the basic methods are documented in references (1) through (8) and (12) and (13). All these methods, however, are tailored to the particular presentation or comparison being performed and no "standardized" methodology exists. It is the intent of this thesis to provide this standard which can be applied to any naval ship in any stage of ship design. The thesis will further establish the methodology to allow these comparisons to be rapidly and interactively applied through the use of current computer technology. Although the theory will be similar for all ships, this thesis will concentrate only on naval combatants of the destroyer, frigate, and cruiser type.

1.2 Basic Methodology

Today's computers allow for the use of large, complex data bases and design synthesis models. These tools have the capability of generating and storing many different new design ships and new technology variants. While providing this extensive amount of

information, it is presently time consuming and difficult to absorb and analyse it manually to find feasible, realistic designs. Since the computer can generate the information, it also provides the capability to compare it. This thesis will concentrate on how the computer can store and display the data to allow the user to make quantitative, judgements on the comparison of different designs to:

a. perform realistic technological assessments on existing ships, future ships or ship variants.

a. identify major differences and explain reasons why the differences occured for:

- baseline ships versus variants
- existing data bank ships versus new designs
- existing data bank ships versus foreign designs

b. determine the design requirements, technical design standards and overall design philosophy which governed the development of the designs.

The comparative naval ship design problem has in the past been treated primarily in a manual mode. The author will present new methodology to perform the analysis using three new tools: the design synthesis model, the integrated data base and the microcomputer spreadsheet. Primary emphasis will be placed on the most complex of the new methods, which will be the proposed methodology to interactively interface with a data base and/or a synthesis model. The methodology developed here will be general to allow for application to any synthesis model program or

integrated data base. A chapter of the thesis, however, will provide specific tailoring for implementation with the Navy Advanced Surface Ship Evaluation Tool (ASSET) program.

1.3 Ship Design Synthesis Models

A ship design synthesis model is defined as an engineering procedure which converts a set of performance requirements into a physical description of a ship which can satisfy these requirements. It is in most cases an iterative procedure providing continuous comparisons of the new iteration to the last "best" design. This process can be extremely time consuming for today's large and complex models in use. It is the author's opinion that the developed methodology may be adapted to any ship synthesis model output either directly or through a storage data base. This will allow the designer to compare the synthesized designs in a more rapid and accurate manner.

The primary ship synthesis models in use today for naval combatant ship design are the Naval Sea Systems Command (NAVSEA) DD08 and the David Taylor Naval Ship Research and Development Center ASSET. The Advanced Surface Ship Evaluation Tool (ASSET) is an interactive computer based total ship technology evaluation tool which would benefit greatly by the addition of a comparative ship design capability. The program itself, as well as the interface requirements of the developed methodology will be further discussed in section 7.

1.4 Data Bases

A data base in the context of this thesis is defined as an electronic filing system where information is stored in a pre-determined structure or hierarchy. In a naval ship design environment, the data base must be a consistent and unambiguous source of information about the ship's configuration and equipment.

At present, the Navy design community does not have a central data base storage facility for past designs or future conceptual designs. There is, however, a large effort underway to achieve this capability, which should be available within the next two years. Since a data base has the ability to store almost unlimited information about a design, it is with this premise and for this primary use that the methodology was developed. A further discussion regarding the comparative methodology interface to a data base is discussed in section 6.

1.5 Spreadsheet Analysis

The simplest method of applying this methodology is through the use of a "spreadsheet" type of software program available for almost all microcomputers. This requires that the basic input information be available in the first part of the spreadsheet thus allowing for a simple input with the actual mathematics being performed by the computer. Although the initial setup and programming of the spreadsheet is time consuming, the basic format can be copied, saved, and then used again and again for different

comparative analysis requiring only that the parameters be input for each ship or variant. In fact, this type of a spreadsheet serves to function as both a data base and computational model. Appendices C and D used this type of comparison to provide an example of how the methodology is used.

1.6 Interactive Computer Technology

The best method of presenting the methodology introduced in this thesis is through the use of a computer program written specifically for this application, using the latest in interactive computer graphics technology.

Computer graphics is defined as the use of a computer to define, store, manipulate, and present pictorial output. Interactive technology allows the user to influence the program to allow him to see the picture he desires. Although, the basic graphics used in the methodology is in the form of bar charts and graphs, the interactive ability to shift between different presentations is the key to the successful and rapid utilization of the program for comparative analysis. This could be performed with current technology by the use of "graphic windows" or "screen partitioning" which open on the screen and allow a new menu selection. These methods are now common to even many of the smaller microcomputers and readily available on the larger mainframe graphics packages. Specifics regarding the type of

computer aided selection process and computer programming notes will be presented in each major section of the thesis, as required.

1.7 Approach

The thesis will first provide an overview of the types and details of analysis required in chapter 2. Chapters 3 through 5 will then concentrate on the details of the three primary methods selected to perform a comparative naval ship design analysis. The interface requirements to an integrated data base and to the ASSET program are described in chapters 6 and 7. Finally conclusions and recommendations are drawn in chapters 8 and 9. Appendix F concentrates largely on the definitions and significances of the indices that were selected and appendices C and D are sample investigations performed to verify the methodology and program flow.

CHAPTER 2

COMPARATIVE METHODOLOGY

2.1 Definition of Analysis

The framework of the comparative ship design analysis established in this thesis is based on the current methods of analysis used by C. Graham, J. Kehoe, et al in references (4), (5), (12), and (13). These analysis were limited to existing ships and were not easily applied to the case of a two ship comparison for technology assessment. This type of analysis required a further in-depth study of specific weight and volume changes. Based on these assessments, the approach was modified to meet the need.

Since the comparative process would be computer based, the determination was made to use computer graphics as much as possible to assist the user by graphical interpretation of data. When graphics were not possible, a direct tabular comparison would be used. Additionally, the use of the storage and calculation capability of the computer allowed for a larger assortment of data to be examined, which was previously limited due to the extensive time required for these type of cumbersome calculations, as well as the nonavailability of a centralized ship design data base.

The approach stressed not only the comparative analysis but also the use of the methodology as a design and technology assessment tool.

2.2 Detail of Analysis

The guiding principles to the level of detail required in the analysis were:

a. to allow sound naval architectural explanation of the differences which exist in the compared designs.

b. to allow assessment of whether a new design or a variant is "good" or "bad" and why.

c. to allow the designer to make sound judgements on how to best improve the design.

d. to analyse tradeoffs and the impact of changes made to a baseline design.

e. to analyse the impact of adding a new technology to an existing or new design.

2.3 Methods of Analysis

The selection of the proper indices and parameters for examination, as well as the types of analysis to be performed were critical to the proper flow of the methodology. The determination was made to perform analysis and comparison of the ship's primary characteristics, resource allocation and functional investigation. The primary method of comparison would be in the form of percentages, rather than real values.

2.3.1 Selection of Indices

The following criteria was used for selection of the parameters and indices:

a. The design indices and parameters must serve to provide meaningful indicators that provide quantitative comparisons for:

- performance requirements
- design standards
- design philosophy

b. Design indices and parameters must be:

- meaningful (provide indication of design practice and standards)
- simple to calculate
- simple to analyse

c. Design indices and parameters are based on a functional breakdown of the ship and include the use of a:

- standardized weight classification system (SWBS)
- standardized space/volume classification system (SSCS)
- standardized electrical classification system
- standardized manning classification system
- standardized cost accounting system

d. Standard ratios and fractions to be used included:

- weight fractions
- weight densities
- volume fractions
- energy fractions
- manning fractions

- specific ratios
- capacity/size ratios

The definitions and significances of these types of design indices are discussed in appendix F.

2.3.2 Weight Classification System

The present standard Navy weight classification system, Ships Work Breakdown Structure (SWBS), was selected to categorize all weight indices. The system groups the various weight items into seven categories, which are formed according to functional area. The sum of these weight groups make up the lightship displacement. These seven groups are:

- 100 Structures
- 200 Propulsion
- 300 Electrical
- 400 Command and Surveillance
- 500 Auxiliary
- 600 Outfit and Furnishings
- 700 Armament

The full load displacement is then obtained by adding an eighth group (F00), referred to as the ships variable loads. This group includes crew and effects, potable water, ordnance, fuel, stores and aircraft.

A more detailed listing of the components in each weight group is available in reference (22).

2.3.3 Volume/Space Classification System

The current Ships Space Classification System (SSCS) was selected for all volume related indices. The utilization of all space is divided into five functional areas:

- Mission Support
- Human Support
- Ship Support
- Ship Mobility
- Unassigned

The sum of these five groups will encompass the total enclosed volume, including the superstructure.

The breakdown of these groups is available in reference (23).

2.3.4 Electrical Classification System

The current electrical classification system in use follows the Ships Work Breakdown Structure (SWBS) exactly, except that it does not include Group 100, since structures requires no electrical power. All other equipment's electrical requirements will be classified in the same three digit category as its corresponding weight.

2.3.5 Manning Classification System

There is no "standard" manning classification system, however, a useful breakdown was not difficult to obtain. Manning is classified by the number of accomodations, or berths, onboard and the actual total complement required to operate the ship. This is

further broken down into the rating structure of Officer, Chief Petty Officer (CPO) and Enlisted crew. A second breakdown is by departmental utilization of personnel, where in the case of combatant ships, the departments include:

- Navigation/Administration
- Combat Systems
- Operations
- Engineering
- Supply
- Aviation

2.3.6 Cost Accounting System

The Navy Standard Simplified P8 Cost Breakdown was selected as the easiest method of comparing actual dollar costs. The input P8 values were then manipulated to provide the most meaningful direct comparison. The P8 input cost values required are:

- Planning
- Basic Construction (including full breakdown by SWBS)
- Change Order
- Electronics
- H.M.&E.
- Other Cost
- Ordnance
- Escalation
- Project Manager Growth

2.4 Types of Analysis

Three different types of analysis methods will be available to the user. The first and most complex involves a direct comparison between two ships, designated as a baseline and variant where all comparisons relate the variant to the baseline ship. A comparative analysis routine will be available in this mode to assist the designer in his search for differences.

The second method of analysis is a multi-ship comparison, whereby the user has the option, for a limited number of available indices, to compare up to six data bank ships on a "one indice at a time" basis.

The third type of comparison is a trend analysis which will allow the user to plot his selected design with established present and past fleet combatants, for a selected number of indices. This will allow him to analyse where his design fits into current trends.

Each of the above types of analysis will be discussed in detail in their respective chapters.

2.5 Programming Notes

Since it may be desired to program this methodology at a future date, this topic will be used where necessary to amplify information regarding the author's views on how the section should or could be programmed. Additionally, a flow chart to assist the programmer will be presented for each type of analysis.

Figure 2.1 shows the basic entry into the program or module. Letters and numbers in circles indicate continuations of either input or output from other flow charts discussed in the thesis.

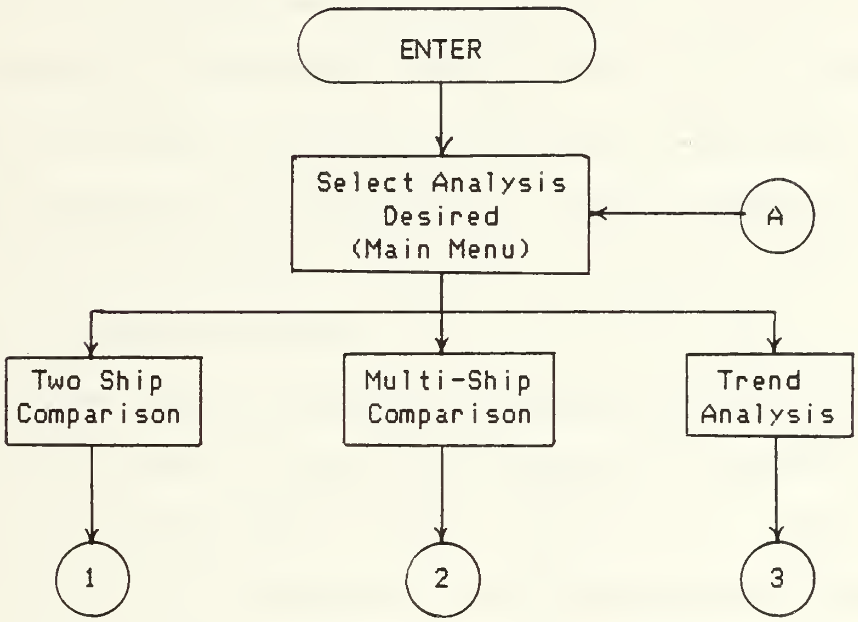

Figure 2.1 Program Entry Flow Chart

CHAPTER 3

TWO-SHIP COMPARATIVE ANALYSIS

3.1 Methodology

This is the most detailed comparison of all analysis options, allowing the user to compare any two ships available in the data bank. He must select one to be the baseline and the second to be a variant, where all comparisons will be variant to baseline. Ships will be compared in three major levels. The first will consist of comparing the primary characteristics of the two designs. The subsequent second tier of comparison is used to compare resource allocations and the third level will involve more detail in a functional investigation mode.

The three levels are each further subdivided into "screens". This method was used to allow the grouping of similar indices together while maintaining a usable screen size. All graphic screens will be in the form of bar charts comparing the indices in a "singular" comparison as in figure 3.1 or a "composite" comparison as displayed in figure 3.2. All graphic screens have been limited to no more than eight items for display. This number was selected to be the most that could effectively be displayed on the average terminal. Tabular screens may be multi-page and thus have no restriction on the number of items allowed. Multi-page screens should have a prompt to display the number of pages and allow the user to select the page number desired. An example of

the recommended format of a tabular screen is shown in figure 3.3. Using "control keys", the user will have the ability to either go directly to a new screen if he knows the screen number or he may request an option screen which will open a screen "window" with available paths. These options will be further explained with the flow chart in section 3.6.

The "singular" and "composite" displays were developed to provide the designer with the maximum amount of information pertaining to each parameter and indice. To perform an accurate and meaningful comparison, the designer must know both the absolute difference of a parameter as well as the relative differences when the parameter is related to the group it belongs to. As in the appendix C example of screen 2-5 displayed in figures 3.1 and 3.2, the deckhouse volume absolute difference is -29.1%, indicating that DDG51 has a smaller deckhouse than DD963. The relative difference of the indice, deckhouse volume to total volume fraction (V_{dh}/VOL), however, is 25% for DD963 versus 19% for DDG51, which is only a -6% difference. Additionally from the example screen it can be noted that the hull volume fractions also show a 6% change in the positive direction, as expected, but with only a 1.2% absolute change.

The convention that is therefore established is to calculate all differences or "delta's" in the same manner as:

[(Variant - Base)/(Base)] * 100

ex: [(184057 - 259738)/259738] * 100 = -29.1%

For indices that result in percentages, such as V_{dh}/VOL or W_1/DSP.fl, the differences will be calculated as the absolute value of the primary parameter (i.e. V_{dh} or W_1) which is always the numerator. For indices that do not result in percentages, such as W_2/SHP or L_{bp}, the difference will be calculated for the complete indice. In the former case of the absolute value comparison, the designer can easily note or even calculate the relative indice difference of the comparison by viewing the "composite" screen.

The "singular" type display, as shown in figure 3.1, is graphed on the bar-graph as the absolute value of the primary parameter (numerator) in the indice being investigated. An annotated absolute scale is shown at the bottom of the screen. Each bar will additionally contain the name of the parameter, the actual absolute value and the indice percentage. At the extreme right of the variant bar, the absolute percentage difference is displayed. As noted before, all differences will be calculated as variant related to baseline and will be annotated as positive (+) or negative (-) change.

The "composite" type stacked bar-graph display of figure 3.2 groups together all indices that account for 100% of the parameter used as the denominator of the indice. This display compares directly the relative percentage of each of the parameters without relating it to the absolute value. In this case, the actual indice percentage is used. Annotation of the graph shall include the percentage plus the name of the indice, as shown.

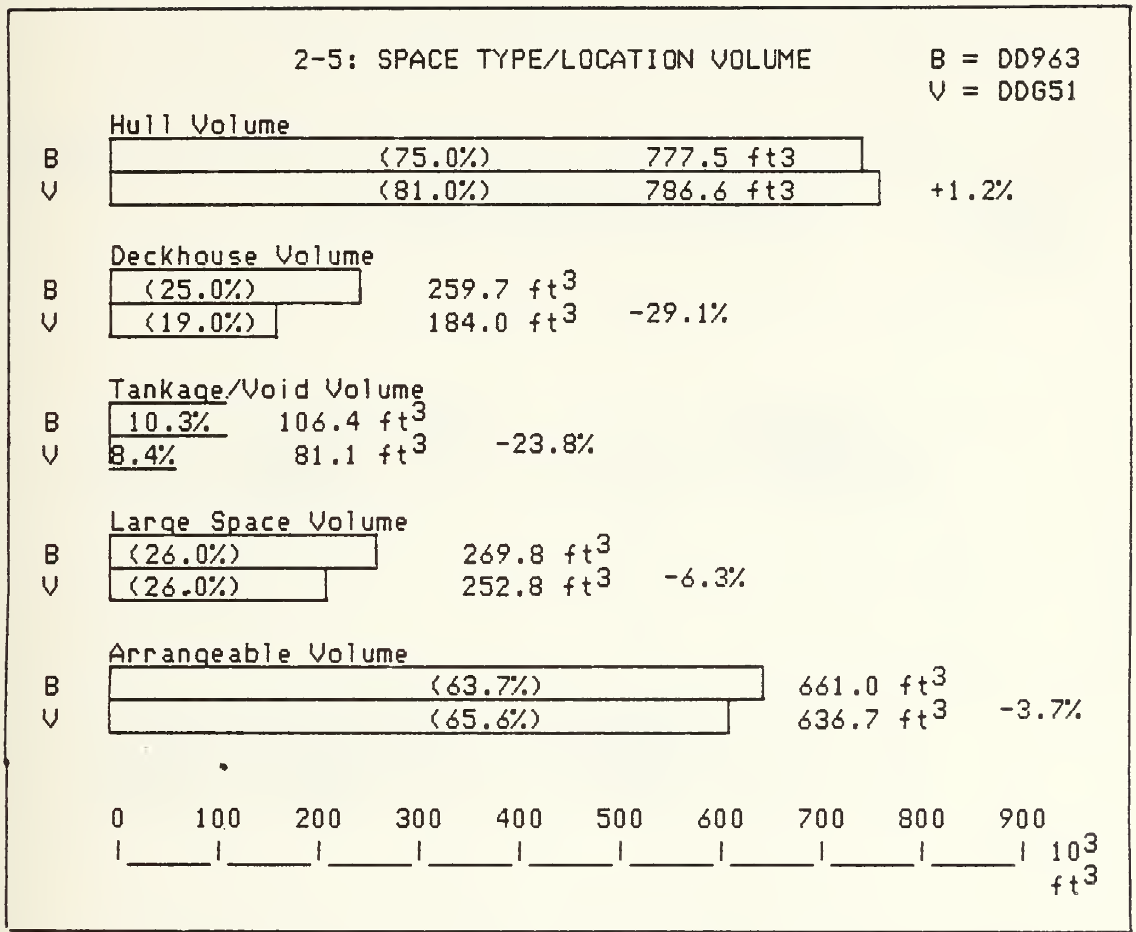

Figure 3.1 "Singular" Display Graphic Screen Example

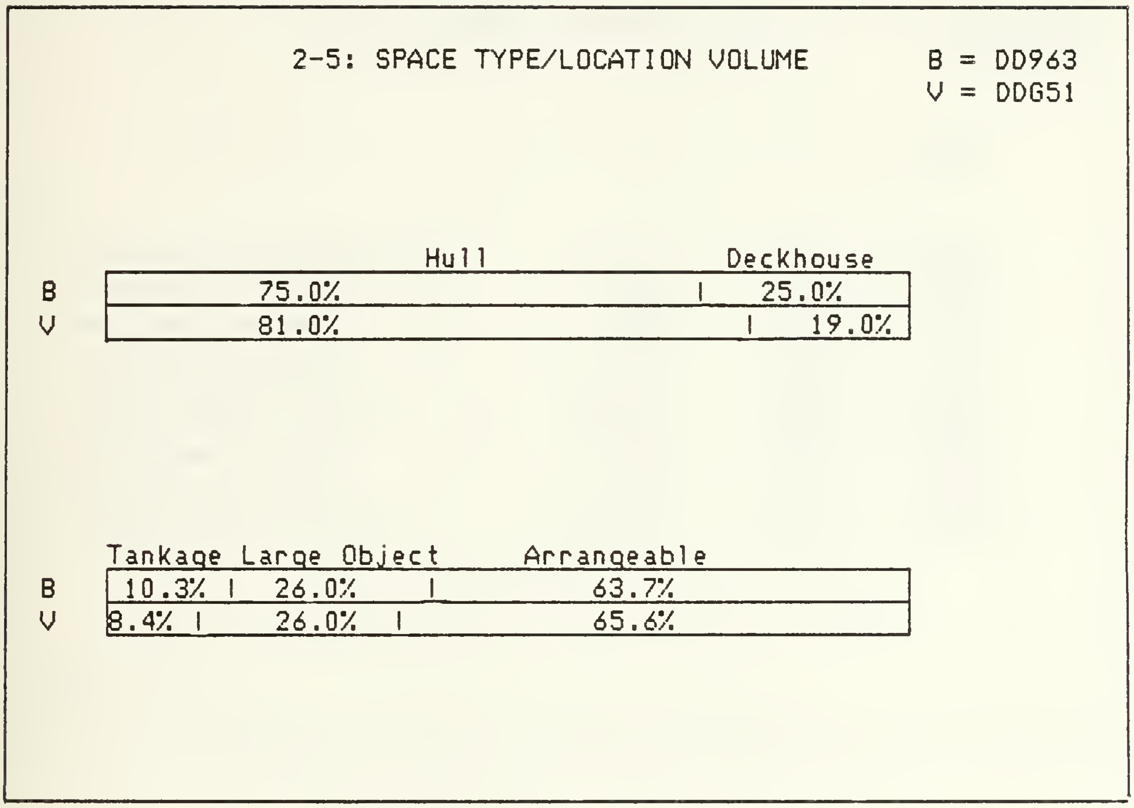

Figure 3.2 "Composite" Display Graphic Screen Example

1-2: SHAPE CHARACTERISTICS

B = DD963
V = DDG51

	B	V	DELTA
Displacement/Length rat.	52.9	83.5	57.8%
Prismatic Coeff	.570	.604	6.0%
Max Section Coeff	.823	.825	.2%
Waterplane Coeff	.724	.780	7.7%
Length/Beam ratio	9.62	7.90	-17.9%
Length/Draft ratio	29.39	23.30	-20.7%
Beam/Draft ratio	3.06	2.95	-3.5%
Draft/Depth ratio	.43	.48	11.6%
Length/Depth ratio	12.60	11.15	-11.5%

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Figure 3.3 Tabular Display Screen Example

The tabular screen of figure 3.3 is displayed similar to the spreadsheet analysis performed in appendices C and D where the "Delta" value is calculated as previously explained. All other aspects of the tabular display are self-explanatory.

Upon entering this level of analysis, the user will be prompted by menu for the screen he desires to examine. If the screen has both a "singular" and "composite" display available, the user will be prompted to make a choice. While the screen is displayed, the user may exercise a "control key" for further options, where one of the options will be to change from "singular" to "composite" or vice versa. The exact program flow will be explained in greater detail in section 3.6.

During the comparisons, the user will have the option to highlight major differences in reverse video. If this option is exercised then the user selects a "Delta" percentage that he considers to be a "major difference". He may change his selection by increasing or decreasing the percentage at any time during his analysis. To assist him in discovering the "reason for" or "impact of" a significant change, he may select the "computer-assisted comparative analysis" option explained in section 3.5.

The three levels of analysis and the types of indices or parameters investigated in each level are:

LEVEL 1: Primary Characteristics

- Size

- Shape

- Ship Performance

- HM&E System Selection

- Combat Systems Selection

LEVEL 2: Resource Allocation

- Weight

- Volume

- Energy

- Manning

- Cost

LEVEL 3: Functional Investigation

- Combat System

- Containment

- Main Propulsion

- Electrical & Auxiliary

- Human Support

- Margin Summary

- Survivability (*)

  * recommended for future implementation as survivability parameters and requirements are further defined.

The subsequent sections provide a brief overview of each level and the indices used on each screen. Each title of the screen indicates in parenthesis whether the recommended format is graphical or tabular. It the screen is graphical, an indication

will be present whether the screen should have a "singular", [s], display or a "composite", [c], display or both, [s,c]. Each indice and parameter is explained in detail in appendix F. Additionally, a summary of all screens by title and subtitle may be found in appendix A.

3.2 Level 1: Primary Characteristics

The initial step of viewing the primary characteristics of the design and comparing them to a baseline or data bank ship involves the availability of five screens. These describe and compare the size, shape, ship performance, HM&E selection and combat system selection. All comparisons for these screens will be tabular.

Each screen is listed below with its associated indices, symbol, and units, where applicable.

Screen 1-1: Cost and Size Characteristics (tabular)

TOTAL COSTS:

NOTE: Choice of selection of "lead ship" or "follow ship" costs

- Basic Construction Cost	C_{bc}	$
- Combat System GFE Costs	C_{csgfe}	$
- Other Costs (see Appendix F for breakdown)	C_{oth}	$
- Total Ship Cost ($C_t=C_{bc}+C_{csgfe}+C_{oth}$)	C_t	$

SHIP SIZE:

- Full Load Displacement	Δ_{fl}	tons

- Light Ship Displacement	Δ_{ls}	tons
- Total Enclosed Volume	∇	ft^3
- Ship Density Full Load	Δ_{fl}/∇	lbs/ft^3
- Ship Density Light Ship	Δ_{ls}/∇	lbs/ft^3
- Length between perpendiculars	L_{bp}	ft
- Length overall	L_{oa}	ft
- Beam at waterline	B_{wl}	ft
- Beam (max at deck edge)	B_{max}	ft
- Depth at midships	D	ft
- Draft (maximum)	T	ft

Screen 1-2: Shape Characteristics (tabular)

- Displacement/Length ratio	$\Delta_{fl}/(.01L_{bp})^3$	tons/ft
- Prismatic Coefficient	C_p	
- Maximum Section Coefficient	C_x	
- Waterplane Coefficient	C_w	
- Length/Beam ratio	L_{bp}/B_{wl}	
- Length/Draft ratio	L_{bp}/T	
- Beam/Draft ratio	B_{wl}/T	
- Draft/Depth ratio	T/D	
- Length/Depth ratio	L_{bp}/D	

Screen 1-3: Ship Performance (tabular)

- Mobility:

* Max Sustained Speed (80% power)	kts
* Max Trial Speed (100% power)	kts

* Range at Endurance Speed NM @kts
* Endurance Period due to:
  - Fuel at endurance speed days
  - Stores days
  - Chilled Stores days
  - Frozen Stores days
* Shaft Horsepower Available SHP
* Shaft Horsepower Reqd at endurance speed SHP
* Shaft Horsepower Reqd at sustained speed SHP

- Hull Efficiency
  * Drag (sustained speed) R_{Ts} lbf
  * Drag (endurance speed) R_{Te} lbf
  * Bales Rank
- Survivability:
  * Blast psi
  * Fragmentation level
  * Shock ksf
  * NBC
  * Noise Signature
  * IR Signature
  * Radar Signature

Screen 1-4: HM&E System Selection (tabular)

Length of information will require a menu driven multi-page screen.

- Main Propulsion:

  * Total Boost Pwr Avail/Reqd at Sust. Spd/Growth Potential

  * Boost Engine Type/Number/Rating

  * Cruise Engine Type/Number/Rating

  * Transmission System Type

  * Propeller Type/Number/RPM

  * Propeller Open Water Efficiency (sustained spd)

  * Propeller Open Water Efficiency (endurance spd)

  * Propulsion Coefficient (PC)

  * Specific Fuel Consumption Rate (SFC) @ Endurance Spd

  * Specific Fuel Consumption Rate (SFC) @ Sustained Spd

  * Other (Comment Array)

- Electric Power:

  * Total 60 Hz KW Available/Maximum Load/Growth Potential

  * Total 400 Hz KW Available/Maximum Load/Growth Potential

  * 60 Hz Generator Type/Number/Rating

  * 400 Hz Generator Type/Number/Rating

  * Specific Fuel Consumption Rate (SFCA)

  * Other (Comment Array)

- Auxiliary

  * Total AC Available/Maximum Load/Growth Potential

  * AC Type/Number/Rating

  * Heating Type/Rating

  * Firepump Type/Number/Rating

  * Seawater Pump Type/Number/Rating

* HP Air Compressor Type/Number/Rating
* LP Air Compressor Type/Number/Rating
* Distilling Plant Type/Number/Rating
* Boats Type/Number
* Steering units Type/Number
* Anchors Type/Number/Length of Chain
* UNREP Capability
* Other (Comment Array)

- Structure/Materials
  * Hull Materials (array)
  * Deckhouse Materials (array)
  * Hull Frame Type/Spacing
  * Deckhouse Frame Type/Spacing
  * Other (Comment Array)
- Deck Heights
  * Number of Internal Decks in Hull
  * Number of Internal Decks in Deckhouse
  * Internal Deck Heights (array)
  * Hull Average Deck Height
  * Other (Comment Array)
- Manning
  * Total Accomodations/Total Complement/Growth Potential
  * Total Complement (OFF/CPO/ENL)
  * Habitability Classification
  * Flag configured

* Other (Comment Array)

Screen 1-5: Combat Systems Selection (tabular)

Combat systems are compared by warfare areas. This may require some systems to be displayed in more than one area or category. Length of information will require a multi-page menu driven screen.

- Anti-Air Warfare (AAW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Anti-Submarine Warfare (ASW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Surface/Strike Warfare (SUW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Command, Control, Communications & Intelligence (C_{3I})
    * Communications
    * Electronic Warfare
    * Control

3.3 Level 2: Resource Allocation

This level consists of thirteen screens which depict the allocation of ship physical resources. These resources include weight, volume, energy, manning and cost, and are classified by using existing consistent conventions.

Each of the screens is listed as being either graphical or tabular and indicates whether the display should be "singular", "composite", or both. Where a "composite" screen is indicated, the parameters that should equal 100% are annotated. In some cases, only one "composite" bar-graph will exist in this mode of display.

Screen 2-1: SWBS Weight Fractions (graphical [s,c])

Uses the standard Navy Ship Work Breakdown Structure (SWBS)[22].

Option will exist to select either full load or light ship displacement as the denominator of the fraction. The sum of the weight groups will only equal 100% for the light ship case since load weight is not included in this screen.

General symbol: Δ => select either Δ_{ls} or Δ_{fl}

- Structural	W_1/Δ
- Main Propulsion	W_2/Δ
- Electrical	W_3/Δ
- Command and Surveillance	W_4/Δ
- Auxiliary Systems	W_5/Δ
- Outfit & Furnishing	W_6/Δ

- Armament W_7/Δ
- Margin W_m/Δ

$= 100\%$

Screen 2-2: Load Weight Fractions (graphical [s,c])

Parameters are based on load weights as specified in the Navy standard Ships Work Breakdown Structure (SWBS)[22].

- Liquid (fuel & lubricants) (F4) — W_{fuel}/W_{ld}
- Crew and Effects (F1) — W_{ce}/W_{ld}
- Ordnance (F2-F23-F26) — W_{ord}/W_{ld}
- Aviation (F23+F26) — W_{av}/W_{ld}
- Others (F3+F5+F6) — W_{oth}/W_{ld}

$= 100\%\ W_{ld}$

- Total Load Weight to Full Load Ratio ($W_{ld} = W_{fuel}+W_{ce}+W_{ord}+W_{av}+W_{oth}$) — W_{ld}/Δ_{fl}
- Light Ship Weight to Full Load Ratio — Δ_{ls}/Δ_{fl}

$= 100\%\ _{fl}$

Screen 2-3: Functional Weight Allocation Fractions (graphical [s,c])

For this screen, weight margin is proportionally distributed throughout the weight groups SWBS W_1 to W_7.

W_{mx} = portion of margin allocation to SWBS group 'x'

$W_{mx} = (\%W_x/(\text{sum } \%W_1 \ldots W_7)) * W_m$

$\%W_x$ = percentage of SWBS group 'x' (screen 2-1)

- Light Ship Combat System Weight ($W_{csl} = W_4+W_7+W_{m4}+W_{m7}$) — W_{csl}/Δ_{ls}
- Light Ship Machinery Weight ($W_{mal} = W_2+W_3+W_5+W_{m2}+W_{m3}+W_{m5}$) — W_{mal}/Δ_{ls}
- Light Ship Containment Weight ($W_{cl} = W_1+W_6+W_{m1}+W_{m6}$) — W_{cl}/Δ_{ls}

$= 100\%\ \Delta_{ls}$

- Full Load Combat System Weight ($W_{csf} = W_4+W_7+W_{ord}+W_{av}+W_{m4}+W_{m7}$) — W_{csf}/Δ_{fl}
- Full Load Machinery Weight ($W_{maf} = W_2+W_3+W_5+W_{fuel}W_{m2}+W_{m3}+W_{m5}$) — W_{maf}/Δ_{fl}
- Full Load Containment Weight ($W_{cf} = W_1+W_6+W_{ce}+W_{oth}+W_{m1}+W_{m6}$) — W_{cf}/Δ_{fl}

$= 100\%\ \Delta_{fl}$

Screen 2-4: SSCS Volume Fractions (graphical [s,c])

Uses standard Navy Ships Space Classification System (SSCS)[23].

- Mission Support — V_1/∇
- Human Support — V_2/∇
- Ship Support — V_3/∇
- Ship Mobility — V_4/∇
- Unassigned — V_5/∇

$= 100\%\ \nabla$

Screen 2-5: Space Type/Location Volume Fraction (graphical [s,c])

- Hull Volume — V_{hull}/∇
- Deckhouse Volume — V_{dh}/∇

$= 100\%\ \nabla$

- Tankage/Voids Volume V_{tK}/∇
  ($V_{tK} = V_{3.9}$)

- Large Space Volume V_{lo}/∇
  ($V_{lo} = V_{1.2}+V_{1.34}+V_{4.1}$)
  $V_{1.2}$ = Weapons and Ammo
  $V_{1.34}$ = Aircraft Stowage
  $V_{4.1}$ = Propulsion Systems

- Arrangeable Volume V_a/∇
  ($V_a = V-V_t-V_{lo}$)

  = 100% ∇

Screen 2-6: Functional Volume Allocation Fractions
(graphical [s,c])

Since the unassigned volume may be reserved for a specific function or allocation area, rather than being a straight margin, as in weight, it will not be distributed.

- Combat Systems Volume V_{cs}/∇
  ($V_{cs} = V_1$)

- Machinery Related Volume V_{ma}/∇
  ($V_{ma} = V_4+V_{3.5}+V_{3.9}$

- Containment Volume V_c/∇
  ($V_c = V_2+V_3-V_{3.5}-V_{3.9}$)

- Unassigned Volume V_5/∇

  =100% ∇

Screen 2-7: Electrical Energy Allocation Fractions
(graphical [s,c])

NOTE: (1) follows the same classification as the Navy Standard Ships Work Breakdown Structure (SWBS) [22].

(2) Menu driven input selection:

Select:
E_t = maximum functional electric load
E_i = installed electric capacity
(90% total capacity without one generator)

Select:
10^{o} day
90^{o} day

Select:
Battle Condition
Cruise Condition

E = symbol to select either max or installed capacity
E_m only applicable when E_i selected

- Propulsion Plant	E_2/E
- Electric Plant	E_3/E
- Command & Surveillance	E_4/E
- Auxiliary	E_5/E
- Outfit and Furnishings	E_6/E
- Armament	E_7/E
- Margin (Aquisition + Service Life)	E_m/E
	= 100% E

Screen 2-8: Functional Energy Allocation Fractions
(graphical [s,c])

INSTALLED HP:

NOTE: HP_{shpi} = Total shaft horsepower installed

HP_{geni} = Total generator horsepower installed

$HP_t = HP_{shpi} + HP_{geni}$

- Propulsion Horsepower Allocation	HP_{shpi}/HP_t
- Electrical Horsepower Allocation	HP_{geni}/HP_t
	= 100% HP_t

FUEL USAGE:

Propulsion fuel usage is based on endurance speed. Electrical fuel usage is based on average 24 hour load.

NOTE: $SFCA_e$ = Generator SFC at 24 hr average load

SFC_e = Propulsion SFC at endurance speed

HP_{gene} = Generator Horsepower at 24 hr avg load

HP_{shpe} = Propulsion horsepower at endurance spd

FF_{gen} = Generator Fuel flow (lbm/hr)
($FF_{gen} = SFCA_e * HP_{gene}$)

FF_{mp} = Main Propulsion fuel flow (lbm/hr)
($FF_{mp} = SFC_e * HP_{shpe}$)

FF_t = Total fuel flow (lbm/hr)
($FF_t = FF_{gen} + FF_{mp}$)

- Propulsion Fuel Allocation	FF_{mp}/FF_t
- Electrical Fuel Allocation	FF_{gen}/FF_t
	= 100% FF_t

ELECTRICAL:

NOTE: (1) same selections as Screen 2-7 above

(2) Electric margin is proportionally distributed to E_3 through E_7 for E_i selection only. E_2 does not have a service life margin.

E_{mx} = portion of margin allocation to SWBS group 'x'

$E_{mx} = (\%E_x/(\text{sum } \%E_3 \ldots E_7)) * E_m$

$\%E_x$ = percentage of SWBS group 'x' (screen 2-7)

- Combat System Electrical ($E_{cs}=E_4+E_7+E^*_{m4}+E^*_{m7}$)	E_{cs}/E

- Machinery Electrical ($E_{ma}=E_2+E_3+E_5+E^*_{m3}+E^*_{m5}$) — E_{ma}/E

- Containment Electrical ($E_c=E_6+E^*_{m6}$) — E_c/E

E^* = for E_i selection only — $= 100\%\ E$

Screen 2-9: Manning Allocation Fraction (graphical [s,c])

General symbol: M_a = total accomodations (OFF+CPO+ENL)

M_{xxx} = manning for 'xxx' personnel

- Officer ratio — M_{off}/M_a

- CPO ratio — M_{cpo}/M_a

- Enlisted ratio — M_{enl}/M_a

- Margin ($M_m = M_a-M_{off+cpo+enl}$) — M_m / M_a

$= 100\%\ M_a$

SCREEN 2-10: Functional Manning Allocation Fractions (graphical [s,c])

NOTE: Manning margins are proportionally distributed

- Combat Systems manning ratio — M_{cs}/M_a

- Operations manning ratio — M_{ops}/M_a

- Engineering manning ratio — M_{eng}/M_a

- Nav/Admin manning ratio — M_{na}/M_a

- Supply manning ratio — M_{sup}/M_a

- Aviation manning ratio — M_{av}/M_a

$= 100\%\ M_a$

Screen 2-11: Basic Construction Cost Allocation (tabular)

NOTE: Uses standard Navy P8 Cost Breakdown structure.

Choice of selection of "lead ship" or "follow ship" costs.

$$C_{bc}=C_1+\ldots+C_7+C_m+C_{de}+C_{con}+C_{pr}$$

$$C_{BC}=C_1+\ldots+C_7+C_m+C_{de}+C_{con}+C_{pr}+C_{HM\&E}$$

- Hull Structure	C_1/C_{bc}
- Propulsion Plant	C_2/C_{bc}
- Electric Plant	C_3/C_{bc}
- Command and Surveillance	C_4/C_{bc}
- Auxiliary Systems	C_5/C_{bc}
- Outfit and Furnishing	C_6/C_{bc}
- Armament	C_7/C_{bc}
- D & C Margin	C_m/C_{bc}
- Design and Engineering (Group 8)	C_{de}/C_{bc}
- Construction Services/Assembly (Group 9)	C_{con}/C_{bc}
- Profit	C_{pr}/C_{bc}
	= 100% C_{bc}
- HM&E GFE	$C_{HM\&E}/C_{BC}$

Screen 2-12: Functional Cost Allocation Fractions
(graphical [s,c])

Choice of selection of "lead ship" or "follow ship" cost fraction

All non-SWBS related basic construction costs are distributed proportionally in the proportion allocated in screen 2-11.

All "Other Costs" are distributed proportionally as allocated in Screen 2-11 with the exception of P.M. Growth which is added directly to Combat Systems Costs.

C_{xd} = distributed costs

$C_{xd} = [C_x/(\text{sum } \%C_1 \text{ thru } \%C_7)] * (C_{m+de+con+pr+oth-pmg})$

C_x = % cost of SWBS group 'x' (screen 2-11)

- Combat Systems Costs ($C_{cs} = C_{4+7+csgfe+pmg+4d+7d}$) — C_{cs}/C_t

- Machinery Costs ($C_{ma} = C_{2+3+5+2d+3d+5d}$) — C_{ma}/C_t

- Containment Costs ($C_c = C_{1+6+1d+6d}$) — C_c/C_t

= 100% C_t

Screen 2-13: Cost fractions (tabular)

C_{ls} = Lead Ship Total Cost

C_{fs} = Follow Ship Total Cost

- Combat System GFE/Lead Ship Cost	C_{csgfe}/C_{ls}	
- Combat System GFE/Follow Ship Cost	C_{csgfe}/C_{fs}	
- Basic Construction/Lead Ship Cost	C_{bc}/C_{ls}	
- Basic Construction/Follow Ship Cost	C_{bc}/C_{fs}	
- Total Follow Ship Cost/Weight ratio	C_{fs}/Δ_{fl}	\$/ton
- Total Follow Ship Cost/Volume ratio	C_{fs}/∇	\$/ft^3

3.4 Level 3: Functional Investigation

This level further breaks down levels 1 and 2 into functional areas to allow further investigation into why the differences occurred and what the impact is on the overall design. The areas which are further investigated are combat systems, main propulsion, containment, electrical, auxiliary, human support, margins and survivability (for later implementation).

Each of the functions uses two screens, the first examines detailed weight and volume allocations while the second uses indices to aid in determining what drives the particular changes associated with that function.

Screen 3-1: Containment Weight Breakdown (graphical [s,c])

STRUCTURE WEIGHT:

- Shell and Supports	W_{11}/W_1
- Hull Structural Bulkheads and Decks	$W_{12+13+14}/W_1$
- Deckhouse	W_{15}/W_1
- Foundations	W_{18}/W_1
- Other Structural	$W_{16+17+19}/W_1$
	$= 100\%\ W_1$

OUTFIT AND FURNISHINGS WEIGHT:

- Crew Related	$W_{64+65+66+67}/W_6$
- Non-Crew Related	$W_{61+62+63+69}/W_6$
	$= 100\%\ W_6$

Screen 3-2: Containment Indices (tabular)

CONTAINMENT DRIVERS:

- Structural Weight Fraction	W_1/Δ_{fl}	
- Outfit and Furnishings Weight Fraction	W_6/Δ_{fl}	
- Total Hull Structure Specific Weight	W_1/∇	lbs/ft^3
- Outfit and Furnishings Specific Weight	W_6/∇	lbs/ft^3
- Ship Specific Volume	∇/Δ_{fl}	ft^3/ton

RELATED CONTAINMENT RATIOS:

- Containment Density W_{cf}/V_c lbs/ft^3
- Basic Hull Structure Density $W_{11+12+13+14}/\nabla_{hull}$ lbs/ft^3
- Deckhouse Structure Density W_{15}/∇_{dh} lbs/ft^3
- Foundations Weight Fraction $W_{18}/(W_{2+3+4+5+7})$
- Containment Cost/Weight Ratio C_c/W_{cf} \$/ton

Screen 3-3: Main Propulsion Breakdown (graphical [s,c])

WEIGHT:

- Propulsion Units Wt W_{23}/W_2
- Transmission and Propulsor Wt W_{24}/W_2
- Propulsion Support System Wt $W_{25+26+29}/W_2$
- Other Propulsion Wt W_{21+22}/W_2

$= 100\%\ W_2$

VOLUME:

NOTE: $(V_{pt} = V_{4.1+4.2-4.15})$
$V_{4.1}$ = Propulsion Systems
$V_{4.2}$ = Transmission and Propulsor
$V_{4.15}$= Machinery Box Electric

- Propulsion Systems Volume $V_{4.1-4.15}/V_{pt}$
- Transmission and Propulsor Volume $V_{4.2}/V_{pt}$

$= 100\%\ V_{pt}$

Screen 3-4: Main Propulsion Indices (tabular)

MAIN PROPULSION DRIVERS:

- Main Propulsion Weight Fraction W_2/Δ_{fl}
- Main Propulsion Specific Weight W_2/SHP lbs/SHP

- Main Prop Ship Size Ratio	SHP/Δ_{fl}	SHP/ton
- Drag to Displacement Ratio (endurance)	R_{Te}/Δ_{fl}	lbf/ton
- Drag to Displacement Ratio (sustained)	R_{Ts}/Δ_{fl}	lbf/ton
- Propulsion Coefficient	PC	

RELATED MAIN PROPULSION RATIOS:

- Main Propulsion Density	W_2/V_{pt}	lbs/ft^3
- Main Propulsion Volume Fraction	V_{pt}/∇	
- Propulsion Units Specific Weight	W_{23}/SHP	lbs/SHP
- Transmission/Propeller Specific Weight	W_{24}/SHP	lbs/SHP
- Support/Fluids Specific Weight	$W_{25+26+29}/SHP$	lbs/SHP
- Propulsion & Trans Specific Volume	V_{pt}/SHP	ft^3/SHP
- Propulsion Systems Specific Volume	$V_{4.1-4.15}/SHP$	ft^3/SHP
- Trans/Propeller Specific Volume	$V_{4.2}/SHP$	ft^3/SHP
- Propulsion KW/Weight Ratio	E_2/W_2	KW/ton
- Propulsion Cost/Weight Ratio	C_2/W_2	$/ton

Screen 3-5: Electrical Plant Breakdown (graphical [s,c])

WEIGHT:

- Power Generation Wt	W_{31}/W_3
- Power Distribution Wt	W_{32}/W_3
- Lighting Wt	W_{33}/W_3
- Support System Wt	W_{34+39}/W_3
	= 100% W_3

VOLUME:

NOTE: ($V_e = V_{4.15+4.33}$)
$V_{4.15}$= Machinery Box Electric
$V_{4.33}$= Auxiliary Space Electric

- Machinery Box Electric Volume $V_{4.15}/V_e$
- Auxiliary Space Electric Volume $V_{4.33}/V_e$

$= 100\%\ V_e$

Screen 3-6: Electrical Indices (tabular)

ELECTRICAL DRIVERS:

- Electrical Weight Fraction	W_3/Δ_{fl}	
- Electrical Specific Weight	W_3/E_i	lbs/KW
- Electrical Capacity Ship Size Ratio	E_i/Δ_{fl}	KW/ton

RELATED ELECTRICAL RATIOS:

- Electrical Density	W_3/V_e	lbs/ft^3
- Electrical Volume Fraction	V_e/∇	
- Power Generation Specific Weight	W_{31}/E_i	lbs/KW
- Electrical Specific Volume	V_e/E_i	ft^3/KW
- Electrical System KW/Weight Ratio	E_3/W_3	KW/ton
- Electrical System Cost/Weight Ratio	C_3/W_3	$/ton

Screen 3-7: Auxiliary Breakdown (graphical [s,c])

WEIGHT:

- Climate Control Wt W_{51}/W_5
- Sea Water/Freshwater Systems Wt W_{52+53}/W_5
- Fluid Systems Wt $W_{54+55+59}/W_5$
- Ship Control Wt W_{56}/W_5
- Replenishment/Mechanical Handling Wt W_{57+58}/W_5

$= 100\%\ W_5$

VOLUME:

NOTE: $(V_{ax} = V_{3.5+4.3-4.33})$
$V_{3.5}$ = Deck systems
$V_{4.3}$ = Auxiliary Machinery
$V_{4.33}$= Auxiliary Space Electric

- Deck Systems Volume	$V_{3.5}/V_{ax}$	
- Auxiliary Machinery Volume	$(V_{4.3}-V_{4.33})/V_{ax}$	
	$= 100\%\ V_{ax}$	

Screen 3-8: Auxiliary Indices (tabular)

AUXILIARY DRIVERS:

- Auxiliary Weight Fraction	W_5/Δ_{fl}	
- Auxiliary Specific Weight	W_5/∇	lbs/ft^3
- Ship Specific Volume	∇/Δ_{fl}	ft^3/ton

RELATED AUXILIARY RATIOS:

- Auxiliary Density	W_5/V_{ax}	lbs/ft^3
- Auxiliary Volume Fraction	V_{ax}/∇	
- Auxiliary KW/Weight Ratio	E_5/W_5	KW/ton
- Auxiliary Cost/Weight Ratio	C_5/W_5	$/ton

Screen 3-9: Combat Systems Breakdown (tabular)

NOTE: may require multipage screen

COMBAT SYSTEMS WEIGHT:

- Command and Surveillance Wt	W_4/W_{csf}
- Armament Wt	W_7/W_{csf}
- Aviation Wt	W_{av}/W_{csf}
- Ordnance Wt	W_{ord}/W_{csf}
	$= 100\%\ W_{csf}$

COMMAND AND SURVEILLANCE WEIGHT:

- Interior/Exterior Communications Wt	W_{43+44}/W_4
- Surface Surveillance Wt	W_{45}/W_4
- Underwater Surveillance Wt	W_{46}/W_4
- Other C&S Wt	$W_{41+42+47+48+49}/W_4$
	$= 100\%\ W_4$

ARMAMENT WEIGHT:

- Guns and Ammo Wt	W_{71}/W_7
- Missiles and Rockets Wt	W_{72}/W_7
- Other Armament Wt	$W_{73\ \text{thru}\ 79}/W_7$
	$= 100\%\ W_7$

COMBAT SYSTEMS VOLUME:

- Command and Surveillance Volume	$V_{1.1}/V_1$
- Armament Volume	$V_{1.2}/V_1$
- Aviation Volume	$V_{1.3}/V_1$
	$= 100\%\ V_1$

COMMAND AND SURVEILLANCE VOLUME:

- Interior/Exterior Communications Vol	$V_{1.11+1.15}/V_{1.1}$
- Surface Surveillance Vol	$V_{1.121}/V_{1.1}$
- Underwater Surveillance Vol	$V_{1.122}/V_{1.1}$
- Other C&S Vol	$V_{1.13+1.14+1.16}/V_{1.1}$
	$= 100\%\ V_{1.1}$

ARMAMENT VOLUME:

- Guns and Ammo Vol	$V_{1.21}/V_{1.2}$

- Missiles & Rockets Vol $V_{1.22+1.23}/V_{1.2}$

- Other Armament Vol $V_{1.24+1.25+1.26+1.27}/V_{1.2}$

$= 100\% \; V_{1.2}$

Screen 3-10: Combat Systems Indices (tabular)

COMBAT SYSTEMS DRIVERS:

- Armament Weight Fraction	W_7/Δ_{f1}	
- Armament Capacity Size Ratio ($\#_1$ = number of launchers)	$\#_1/\Delta_{f1}$	1chr/1Ktons
- Armament Specific Weight	$W_7/\#_1$	1Ktons/1chr
- C&S Weight Fraction	W_4/Δ_{f1}	
- C&S Capacity Size Ratio ($\#_s$ = number of sensors)	$\#_s/\Delta_{f1}$	snsr/1Ktons
- C&S Specific Weight	$W_4/\#_s$	1Ktons/1chr

RELATED COMBAT SYSTEM RATIOS:

- Combat System Density	W_{csf}/V_1	lbs/ft^3
- Command and Surveillance Density	$W_4/V_{1.1}$	lbs/ft^3
- Armament Density	$W_7/V_{1.2}$	lbs/ft^3
- Combat System KW/Weight Ratio	E_{cs}/W_{csf}	KW/ton
- Combat System Cost/Weight Ratio	C_{cs}/W_{csf}	$/ton

Screen 3-11: Human Support Breakdown (graphical [s,c])

M_a = total accomodations

M_{axxx} = accomodations for 'xxx' personnel

WEIGHT:

$$W_{HS}=W_{ce}+W_{6cr}+W_{pw}$$

W_{HS} = total human support weight

W_{ce} = crew and effects load weight (F1)

W_{6cr}= crew related group 6 outfit and furnishings ($W_{6cr} = W_{64+65+66+67}$)

W_{pw} = potable water weight (F52)

- Crew and Effects Weight	W_{ce}/W_{HS}
- Outfit and Furnishings Weight	W_{6cr}/W_{HS}
- Potable Water Weight	W_{pw}/W_{HS}
	= 100% W_{HS}

VOLUME:

- Living Volume	$V_{2.1}/V_2$
- Food Service/Messroom/Lounge Volume	$V_{2.2}/V_2$
- Medical/General Services/Other Vol	$V_{2.3 \text{ thru } 2.7}/V_2$
	= 100% V_2

Screen 3-12: Human Support Indices (tabular)

HUMAN SUPPORT DRIVERS:

- Human Support Weight Fraction	W_{HS}/Δ_{fl}	
- Human Support Specific Weight	W_{HS}/M_a	tons/man
- Total Accomodations Ship Size Ratio	M_a/Δ_{fl}	men/1Kton

RELATED HUMAN SUPPORT RATIOS:

- Human Support Density	W_{HS}/V_2	lbs/ft^3
- Personnel Living Space Specific Vol ($V_{2.1}$ = Living Space)	$V_{2.1}/M_a$	ft^3/man
- Human Support Specific Volume	V_2/M_a	ft^3/man
- Human Support Specific Area	A_2/M_a	ft^2/man
- Officer Living Area per man	$A_{2.11+2.211}/M_{aoff}$	ft^2/man

- CPO Living Area per man $A_{2.12+2.212}/M_{acpo}$ ft^2/man

- Enlisted Living Area per man $A_{2.13+2.213}/M_{aenl}$ ft^2/man

- Officer Ship Size Ratio M_{aoff}/Δ_{fl} men/1Kton

- CPO Ship Size Ratio M_{acpo}/Δ_{fl} men/1Kton

- Enlisted Ship Size Ratio M_{aenl}/Δ_{fl} men/1Kton

Screen 3-13: Margin Summary (graphical [c])

Where both an aquisition and service life margin exists, both will be displayed together in a "composite" bar-graph with aquisition margin on the bottom and service life on top.

With each margin index, a third bar-graph will display the expected NAVSEA standard value.

- Weight[29]

  Symbol: Δ_{al} = architecural weight limit

  * Acquisition Margin $W_m/(\Delta_{ls}-W_m)$

    - NAVSEA Standard $.1 * (\Delta_{ls}-W_m)$

  * Service Life Margin $(\Delta_{al}-\Delta_{fl})/\Delta_{fl}$

    - NAVSEA Standard $.1 * \Delta_{fl}$

- KG[29]

  Symbol: KG_{al} = KG Architectural limit

  * Acquisition Margin KG_m/KG_{ls}

    - NAVSEA Standard $.1 * KG_{ls}$

  * Service Life Margin $(KG_{al}-KG_{fl})/KG_{fl}$

    - NAVSEA Standard $1.0/KG_{fl}$ = (1.0 ft KG_{fl})

- Electric Power[28]

Symbols: E_g = KW rating of one generator

E_{am} = acquisition margin

E_{slm} = service life margin
= $\{.9*(E_i-E_g)-(E_t+E_{am}\}$

$E_m = E_{am}+E_{slm}-E_2$

* Acquisition Margin	E_{am}/E_t
- NAVSEA Standard	$.2 * E_t$
* Service Life Margin	$E_{slm}/(E_t+E_m)$
- NAVSEA Standard	$.2 * (E_t+E_m)$
- Volume	
* Service Life Margin	V_5/∇
- NAVSEA Standard	0%
- Manning	
* Service Life Margin	$(M_a-M_t)/M_t$
- NAVSEA Standard	$.1 * M_t$

3.5 Computer-Assisted Comparative Analysis

The methodology proposed has in excess of 200 parameters and indices available for comparison. These are grouped by type and category in 31 different screens using three levels of analysis. This has the potential of making the search for differences and impacts due to various indices difficult for the inexperienced user.

The use of a computer-assisted comparative analysis type of approach rests upon the simple proposition that the designer should

use all of the significant information available about the comparative naval ship design problem. Without some type of available structure to assist the designer in organizing the multitude of possibilities, the designer tends to polarize around only a few of the causes and impacts of the differences in the design and may miss important aspects of the problem.

The analysis of comparitive naval ship design involves a very large number of alternatives and possibilities to examine. Even when they are narrowed to the 200-plus proposed, it is, in many cases, not immediately obvious what the cause and impacts of the design differences are. People have a tendency to focus on a simple, clear cut solution and tend to avoid the complicated paths. This strategy may result in a high probability of missing an important cause or impact. The computer lends itself easily to assist the designer in this manner by examining many different applicable indices and providing a listing of those indices that have resulted in a "major change" which is defined by the user as a significant percentage of change for a given group of indices. The designer has the option to change this percentage at any time by the use of a "control" key.

This section proposes the implementation of an effective technique for assisting the designer in his analysis.

3.5.1 User Interface Methodology

The proposed method is that of a "decision tree" type analysis. A "decision tree" is a conceptual device for displaying a group of possible decisions that can be made. The choice is then up to the user or designer. In the comparative analysis adaptation, the user is presented with a group of differences or impacts that are the result or cause of the indice he is investigating. The user must then decide which of these new indices he now wishes to investigate further. Subsequent investigations result in the same type of display, supplying the user with related indices that are scanned by the analysis program for a "major change". Although these indices could be examined manually by the designer by shifting through several applicable screens, the computer's speed allows it to rapidly scan all the selected indices and provide all the differences on one "Comparative Analysis" screen as shown in figure 3.4. In the event that all indices will not fit on one screen, the screen will prompt the user with the number of pages of data available and a "control" key will allow the user to change to any page desired. The user may additionally exercise the option to print the differences to a file. The output file will be structured similar to the screen displayed as figure 3.4.

Some comparisons are easily performed without the aid of the analysis module, either due to designer experience or a simple

technology change with obvious results. The user, therefore, must select the comparative analysis module as an option.

To enter the comparative analysis option, the user must select the indice for examination from those available on the screen. The exact method of selection and option execution will be left to the programmer. Upon selection of the indice and option, the user will be prompted for a "major change" percentage. All analysis indices with differences less than this percentage will not be displayed. Since the option will exist to allow the user to change this percentage at any time using a "control" key, it is recommended that the user first select the default value of 0% to view all results and then change the percentage to eliminate what he does not desire to see. This will ensure that all information is viewed at least once. When the user has completed his analysis of the "Comparative Analysis" screen, he must decide which screen he desires to go to next. Each indice is displayed with its respective screen number to assist him. The appropriate "control" key will select the next screen. The user may now again select the comparative analysis option for an indice on the new screen thus repeating the process until he has completed his analysis to his satisfaction.

The actual flow chart for this module will be presented in section 3.6.

COMPARATIVE ANALYSIS

B = TECH BASE
V = IRGT VAR

Screen	Indice	B	V	Delta
1-1	Full Load Displacement	5537.3	5328.5	-3.8%
1-1	Total Enclosed Volume	658110.0	650232.0	-1.2%
2-3	FL Machinery Wt Frac	44.8%	43.0%	-7.7%
2-3	LS Machinery Wt Frac	34.7%	35.3%	2.1%
2-5	Tankage Volume Frac	9.4%	8.0%	-15.9%
2-6	Machy Func Alloc Vol Frac	37.6%	36.8%	-3.3%
2-8	Propulsion Fuel Alloc	68.0%	57.8%	-35.7%
2-10	Engr Manning Alloc Frac	16.6%	15.9%	-4.0%
2-12	Machy Func Cost Alloc	38.9%	42.1%	14.8%

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Figure 3.4 Sample Comparative Analysis Screen

3.5.2 Structure Methodology

The logical solution of a module of this type is to have the computer search "each and every" possible related indice to the one being examined. This solution, however, has several drawbacks. First, it is very time consuming for the author who is required to determine and list each indice, and for the programmer who must program the extensive logical paths that must be examined. Second, if the paths are extensive, then the program will require additional computation time to perform the checks, thus resulting in a greater waiting time for the user. Third and most important is that for some parameter differences, such as displacement or volume, the end result may be that the list of changed indices is so long that the comparative analysis only makes the analysis more complicated instead of easier.

The alternative solution, adopted for this program, was to use the three levels of analysis to create a hierarchial type of comparative analysis which only examines one step of differences at a time in a closed loop type of structure. In any given level of analysis, the comparative module option examines only the same level and the next lower level and when in level three, the analysis looks only at level one. The exact methodology is explained in subsequent paragraphs.

The user may enter this option in any level of two-ship comparative analysis, while in any screen. If the user selects a level one, primary characteristic indice for comparative analysis,

then the module methodology is set up to ask the following questions of the level indicated.

- Level 1: What related characteristics are affected by the difference being examined?

- Level 2: Which resources are affected by the change in level 1?

  * Weight, Volume, Energy, Manning, Cost
  * Look at functional fraction first

The methodology adopted for a Level 2, Resource Allocation, analysis asks the following questions.

- Level 2: What related resources must be examined to provide sufficient information regarding the effect of the change on level 2 resources?

- Level 3: For any given resource change, how was any related function affected?

  * Containment, Main Propulsion, Electrical, Auxiliary, Combat System, Human Support, Margin.

The level 3, functional investigation, then seeks to find the cause of the difference from level 1 primary characteristics by asking the question.

- Level 1: What could have caused the function to change?

Using the above methodology, the parameters for comparison by this option were selected and are listed in appendix F under the subheading "comparative analysis examines".

In this manner, the user will only receive the next level of information and although he does not receive all significant differences at once, it is the opinion of the author that he

receives the information in a logical sequence without being overwhelmed by excess information.

3.5.3 Example Investigations

Appendices C and D are sample spreadsheet investigations performed on a microcomputer, simulating the two-ship analysis discussed in this chapter. Although no graphics are available in this type of comparison, the author has found this to be a powerful tool that can be used on almost any microcomputer with spreadsheet capability. The first section of each spreadsheet acts as a data base and lists the input parameters required. The remainder of the spreadsheet simulates, in a tabular format, the screens discussed in sections 3.2 to 3.4. It is now possible to manually use the comparative analysis paths presented in appendix F to perform an analysis on a certain aspect of the variant design.

The appendix C example simulates an analysis of ships for which a full data base would be available, and relates an existing design, the DD963 at delivery, with a new design, the DDG51. Additional discussion relating this thesis methodology to integrated data bases is included in chapter 6. It should be noted that since no central data bank facility currently exists within the Naval Sea Systems Command for any given ship, the parameters used were obtained from various sources and may not reflect the current design. Although every effort was made to obtain the most accurate information, extreme accuracy was not as important as

having sufficient information to present a good example of how the two ship analysis is presented and how a comparative analysis would be performed. Sources of the information used in this analysis are included in the appendix.

Appendix D is an ASSET technology study performed by Goddard in reference (40), of a baseline technology frigate versus a variant with Inter-cooled Regenerative Gas Turbine main engines. It should be noted that parameters not supported by the Advanced Surface Ship Evaluation Tool (ASSET) are listed as "NA" in the input section. All subsequent indices impacted by the nonavailability of these parameters are listed as "NA" in their respective screens. The application of this comparative ship design model to ASSET will be discussed in greater detail in chapter 7.

To assist in the understanding of how this comparative procedure is to be implemented, two examples will be presented using the data of appendices C and D and the comparative analysis paths proposed in appendix F.

3.5.3.1 New Technology Impact Evaluation

One of the primary uses of the proposed comparative ship design model is to perform impact assessments of emerging HM&E technologies on a relatively detailed level. In this example, adapted from Goddard in reference (41), a baseline frigate was developed to perform technology impact evaluations. All tradeoffs

were performed on ASSET with basic performance characteristics such as combat system selection, mobility (range, endurance), survivability and operability being held constant. Design standards and practices such as margins, stability, strength criteria and thus arrangement tightness were also held constant. The impact of the new technology would therefore become evident through changes in the ship size, characteristics and cost.

The new technology selected for this case study is the tradeoff of an Inter-cooled Regenerative Gas Turbine (IRGT) propulsion plant vice the standard LM2500-30 plant installed in the baseline. The ASSET results were placed in the simulated data bank, two-ship analysis spreadsheet of appendix D.

This example is for demonstration of the principles and concept of the methodology developed and is not intended to be a rigorous tradeoff analysis of the IRGT.

To perform a computer-assisted comparative analysis, the user would first enter the two-ship analysis section and select the baseline and variant he chooses to evaluate. He may then go freely through the available screens to analyse the differences.

Assume that while in screen 1-4, the designer chooses to investigate the impact of the BOOST ENG TYPE difference of GT vs IRGT. Upon selection, through the use of a "control" key, of the computer-assisted analysis mode, the program logic would enter the "Comparative Analysis" screen and scan automatically the related indices proposed for BOOST ENG TYPE listed in appendix F. Since

the user is aware of the fact that several minor differences may occur that are not significant, he chooses to set the "major change" significant percentage at 1%, thereby preventing the display of any changes or "delta's" that are less than that value. The programmed comparative analysis option then displays the following relative differences on the screen.

Screen	Indice	B	V	Delta
1-1	Full Load Displacement	5537.3	5328.5	-3.8%
1-1	Total Enclosed Volume	658110.0	650232.0	-1.2%
2-3	FL Machinery Wt Frac	44.8%	43.0%	-7.7%
2-3	LS Machinery Wt Frac	34.7%	35.3%	2.1%
2-5	Tankage Volume Frac	9.4%	8.0%	-15.9%
2-6	Machy Func Alloc Vol Frac	37.6%	36.8%	-3.3%
2-8	Propulsion Fuel Alloc	68.0%	57.8%	-35.7%
2-10	Engr Manning Alloc Frac	16.6%	15.9%	-4.0%
2-12	Machy Func Cost Alloc	38.9%	39.6%	2.8%

The designer may then draw certain conclusion from this information:

- the desired goal of reducing displacement and volume has been achieved

- although light ship machinery weight increased, the net full load machinery weight decreased, indicating a decrease in fuel requirements.

- tankage volume and propulsion fuel allocation has shown dramatic decrease.

- cost of new machinery plant has increased.

Although this information has already provided the user with a good sense of the impact, let us assume that the user desires to find additional information on where the full load machinery weight savings originate. He would then select screen 2-3 by using a "control" key which will prompt him for the desired screen. Screen

2-3 will then be displayed and the user may select the comparative analysis option for FULL LOAD MACHY WT FRAC. The program again enters the "Comparative Analysis" screen and displays:

2-1	Main Prop Wt Frac	10.1%	10.9%	8.2%
2-1	Elec Wt Frac	5.8%	5.9%	1.1%
2-1	Aux Wt Frac	14.7%	14.8%	-1.7%
2-2	Liquid Fuel Load Frac	78.8%	74.3%	-22.1%

This verifies the previous conclusion that fuel requirements have decreased dramatically while the main propulsion weight fraction has increased. Since performance was required to remain constant, the range could not have changed, therefore the new engines must be much more fuel efficient, but heavier.

The user may now desire to investigate further the main propulsion weight fraction increase by selecting first new screen 2-1 then the comparative analysis option for MAIN PROP WT FRAC. The new screen will display:

2-11	Prop Plant Constr. Cost	8.2%	8.6%	6.6%
3-3	Prop Units Wt Frac	47.4%	52.1%	18.7%
3-3	Trans/Propel Wt Frac	29.1%	26.2%	-2.9%
3-4	Main Prop Spec Wt	18.33	19.83	8.2%
3-4	Main Prop Ship Size Ratio	9.48	9.85	3.9%
3-4	Drag/Disp Ratio (Endur)	18.30	19.83	8.2%
3-4	Drag/Disp Ratio (Sust)	60.00	63.00	5.0%
3-4	Prop Units Spec Wt	8.70	10.30	18.7%
3-4	Transm/Propel Spec Wt	5.30	5.20	-2.9%
3-4	Propul Cost/Wt Ratio	$94.76	$93.40	-1.4%

This screen confirms the increased weight fraction of the propulsion units, it shows changes in specific weights of propulsion related items and actually shows a slight decrease in the propulsion plant cost to weight ratio. It additionally provides the user with an increased drag/displacement ratio which

may be attributed to a variant hull form change. The new hull form may have a worse set of shape characteristics or an increased displacement to length ratio. The user may make a mental note and investigate this later.

To demonstrate the "closed loop" effect of this method of analysis, the example will continue under the assumption that the user may have started his analysis on this screen and desires to find a cause or reason for the large change in propulsion units specific weight. He would then go to screen 3-3 and select the comparative analysis option for PROP UNITS SPEC WT, which will provide him with the following level one information:

1-3	Max Sustained Spd	27.9	27.5	-1.4%
1-3	Max Trial Spd	29.0	28.7	-1.0%
1-3	SHP Reqd (Endurance)	9861	10064	2.1%
1-4	Boost Eng Type	GT	IRGT	*
1-4	SFC @ Endurance	.544	.343	-36.9%
1-4	SFC @ Sustained	.433	.330	-23.8%

This display provides the cause directly as being the change in the boost engine type. It also shows that the engine is drastically more efficient than the present LM2500 installed.

The user may now draw his final conclusions and recommendations regarding the IRGT tradeoff or he may continue to examine other aspects of the design, such as the decrease in sustained speed, the increase in drag/displacement ratio or the decrease in total ship volume. Using the same procedure, the designer will find that the new variant ship is shorter and beamier, resulting in the powering loss. This module will assist

the designer until he has completed the tradeoff analysis to his satisfaction.

Using the data of appendix C and the comparative analysis paths proposed in appendix F, the reader may choose to continue the investigation for his own edification.

3.5.3.2 DDG51 Comparison to DD963

Another use of the methodology developed is the detailed comparison of a new ship design to an existing ship. This example will investigate the effects of the unusual displacement to length ratio of the DDG51 as compared to the DD963. This is only one of many comparisons that could be performed using even the simplest method of spreadsheet analysis of appendix C. Again, a manual comparison will be performed using the suggested "comparative analysis" paths listed in appendix F. The reader should by now have an appreciation for the capability of a computer program to do this analysis automatically, rather than manually. Yet, the assistance that can be provided by appendix F is both helpful and meaningful in any analysis performed.

Again, the intent of this analysis is to demonstrate the application of the "comparative analysis" path in a real situation without actually performing an extremely rigorous analysis. All references to screens and indice values are from appendix C.

Assume that the user is in screen 1-2 of appendix C and selects the "comparative analysis" option to investigate the

DISPLACEMENT TO LENGTH RATIO difference of +57.8%. Upon selection, through the use of a "control" key, of the computer-assisted analysis mode, the program logic would enter the "Comparative Analysis" screen and scan automatically the related indices proposed for the DISPLACEMENT TO LENGTH RATIO indice listed in appendix F. Since the user is aware of the fact that several minor differences may occur that are not significant, he chooses to set the "major change" significant percentage at 1%, thereby preventing the display of any changes or "delta's" that are less than that value. The programmed comparative analysis option then displays the following relative differences on the screen.

Screen	Indice	B	V	Delta
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-3	Range at Endurance Spd			-25.0%
1-3	Endurance Period (Fuel)			-33.0%
1-3	Shaft Horsepower Avail	80000.0	100000.0	25.0%
1-3	Shaft Horsepower (Endur)	16000.0	16800.0	5.0%
1-3	Shaft Horsepower (Sust)	64000.0	80000.0	25.0%
1-3	Drag (Sust)			34.4%

The conclusions drawn are that both direct drivers, displacement and length, contributed to the increased ratio. Additionally, since this ratio is used as a powering indicator, it is evident that the resistance has increased dramatically resulting in the need for the higher shaft horsepower installed. The range is also 25% less than that of the DD963. Although speed is one of the search parameters, it is not displayed on the screen because it is not listed in this study due to security considerations. It is,

however a known fact that the DD963 has a higher trial speed and if it were available in the data base, it would have been displayed.

The user may now desire to determine the effects of, and reasons for, the increase in displacement. He first selects screen 1-1 by using the screen call "control" key and then selects the comparative analysis option for FULL LOAD DISPLACEMENT, which presents the following information on a multi-page screen.

1-1	Basic Construction Cost	490404.0	500358.0	2.0%
1-1	Combat Sytem GFE cost	219272.0	292451.0	33.4%
1-1	Other Costs	144668.0	147605.0	2.0%
1-1	Total Ship cost	873961.0	960430.0	9.9%
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-1	Light Ship Displacement	5852.9	6592.0	12.6%
1-1	Total Enclosed Volume	1037193.0	970663.0	-6.4%
1-1	Ship Density Full Load	16.9	19.5	15.3%
1-1	Ship Density Light Ship	12.6	15.2	20.3%
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Length Overall	563.0	504.0	-10.5%
1-1	Beam at Waterline	55.0	59.0	7.3%
1-1	Beam (max at deckedge)	55.0	66.9	21.6%
1-1	Draft (max)	18.0	20.0	11.1%
1-2	Displacement/Length rat.	52.9	83.5	57.8%
1-2	Prismatic Coeff	.570	.604	6.0%
1-2	Waterplane Coeff	.724	.780	7.7%
1-2	Length/Beam ratio	9.62	7.90	-17.9%
1-2	Length/Draft ratio	29.39	23.30	-20.7%
1-2	Beam/Draft ratio	3.06	2.95	-3.5%
1-2	Draft/Depth ratio	.43	.48	11.6%
1-2	Length/Depth ratio	12.60	11.15	-11.5%
2-3	FL Combat Sys Weight Frac	7.6%	11.0%	56.5%
2-3	FL Machinery Weight Frac	44.5%	42.1%	2.1%
2-3	FL Containment Weight Frac	47.6%	46.9%	6.3%
2-6	Combat Sys Volume Frac	22.2%	22.3%	-6.0%
2-6	Machinery Volume Frac	42.0%	41.7%	-4.9%
2-6	Containment Volume Frac	38.5%	39.9%	-5.3%
2-6	Unassigned Volume Frac	1.3%	.4%	-90.3%
2-8	Propulsion HP Alloc	90.3%	87.7%	25.0%
2-8	Electrical HP Alloc	9.7%	12.3%	63.7%

2-8	Propulsion Fuel Alloc	80.9%	78.5%	20.5%
2-8	Electrical Fuel Alloc	19.1%	21.5%	40.2%
2-9	CPO Ratio	6.7%	6.2%	5.0%
2-9	Crew Ratio	77.0%	78.2%	14.7%
2-9	Manning Margin	8.7%	8.8%	15.4%
2-12	Combat Sys Cost Frac	35.2%	40.8%	27.5%
2-12	Machinery Cost Frac	44.5%	42.6%	5.1%
2-12	Containment Cost Frac	18.1%	14.5%	-11.5%

Although this appears to be a tremendous amount of information, it is essentially an overview of the cause and effect of the displacement change. It should again be noted that the cost figures displayed are not intended to be the actual cost figures and are used only to aid in the explanation of the methodology. This is one of the largest comparative analysis screens in this type of an analysis allowing several conclusions to be drawn from the information obtained above.

- DDG51 is shorter and beamier with greater draft explaining the need for the increased horsepower even at the lower maximum speed. This indicates a less efficient hullform.

- Although the displacement is greater, there is a net decrease in total enclosed volume resulting in the higher ship density indicated. This in turn should hold the volume driven functional weights such as structures, auxiliary and outfitting.

- The primary increase in weight appears to be due to the combat system installed.

- An interesting weight aspect is that it has already been shown that the DDG51 has 25% higher installed shaft horsepower, yet there is only a slight net increase in machinery weight. Contrarily, there is not the expected decrease in containment weight that would normally be expected with a high ship density and short length relative to its displacement. The user would want to explore both of these anomalies.

- Because of the method of calculating and displaying the "delta" value, as explained in section 3.1, it can be seen that propulsion horsepower and fuel allocations support the increased absolute shaft horsepower installed. The electric plant also shows a significant increase in allocation, which appears reasonably consistent.

- All volume areas show a proportional absolute volume decrease, thereby supporting the higher ship density of screen 1-1. Again this points out some areas for further investigation. The higher combat systems weight but lower volume would indicate a significantly higher combat systems density and the lower machinery volume is inconsistent with the large increase in installed power.

- Some increase in crew manning is evident, which appears inconsistent with the lower absolute containment volume.

- Cost has increased primarily for the combat system, as would be expected, but has decreased in the containment area indicating a possible structural savings.

The above conclusions provide several continuing paths for analysis. Only two will be explained further: the increased horsepower obtained without a proportional increase in machinery weight and volume, and the increase in containment weight despite the higher ship density and shorter length.

Investigating the propulsion power increase first, select screen 2-3 and then enter the "comparative" analysis option with the selection of FL MACHINERY WEIGHT. The analysis will display:

2-1	Main Prop Wt Frac	15.0%	13.0%	-4.9%
2-1	Electrical Wt Frac	5.9%	6.9%	36.6%
2-1	Auxiliary Wt Frac	14.6%	14.2%	7.0%
2-2	Liquid Load Wt Frac	87.8%	78.5%	-13.0%

This indicates that the main propulsion weight fraction has actually decreased instead of the expected increase. Since the range is less, the liquid fuel weight decrease is anticipated. The electrical weight and auxiliary weight increases are significant and the user may desire to investigate them later. Assume the user desires to continue his main propulsion investigation. He then selects screen 2-1 and the comparative analysis option for MAIN PROP WT FRAC which displays.

2-11	Prop Constr. Cost Frac	8.6%	9.9%	17.5%
3-3	Prop Units Wt Frac	13.9%	13.2%	-9.3%
3-3	Transm/Propel Wt Frac	48.5%	56.7%	11.2%
3-3	Prop Support Wt Frac	37.7%	30.1%	-24.0%
3-4	Main Prop Spec Wt	21.31	16.21	-23.9%

3-4	Main Prop Ship Size Ratio	10.22	11.84	15.9%
3-4	Main Prop Density	9.81	8.99	-8.3%
3-4	Prop Units Spec Wt	2.95	2.14	-27.4%
3-4	Trans/Propel Spec Wt	10.32	9.19	-11.0%
3-4	Prop Sup Fluids Spec Wt	8.03	4.88	-39.2%
3-4	Prop KW/Wt Ratio	.55	.68	24.0%
3-4	Prop Cost/Wt Ratio	$55.63	$68.74	23.6%

Since the propulsion units weight fraction and specific weight both decreased, it is obvious that a higher power density prime mover was used to achieve the additional horsepower with less weight and space allocation. In fact, if the user investigates further he will find that both ships use the same LM2500 engine, except that the DDG51 has a power upgrade from 21500 HP to 26250 HP. This higher power density (power installed relative to its weight) of the propulsion plant helps explain the higher cost of the propulsion plant.

Assume now that the user has assimilated all the information he desires about the propulsion plant at this point and wants to investigate the containment feature. If he does not remember the screen number that contains the SWBS Weight Fractions, he can use a "control" key to call up a window prompt which offer the selection of printing the information on the screen or returning to the screen menu. Upon selecting the screen menu option, he could now request to view screen 2-1 with light ship parameters. On the display, he would note that the structural weight fractions are 52.6% and 44.5% for the DD963 and DDG51 respectfully with an absolute delta of -4.8%. The selection of the comparative analysis option for this indice would result in the following display.

		B	V	DELTA
2-11	Hull Structure Cost Frac	5.5%	3.3%	-38.1%
3-1	Shell & Supports Wt Frac	34.6%	29.4%	-19.3%
3-1	Hull BKhds/Decks Wt Frac	37.1%	36.9%	-5.4%
3-1	Deckhouse Wt Frac	6.3%	9.1%	35.9%
3-1	Foundations Wt Frac	9.6%	11.6%	14.3%
3-1	Other Struc Wt Frac	12.3%	13.1%	1.4%
3-2	Hull Struc Spec Wt	6.65	6.76	1.7%
3-2	Basic Hull Struc Density	6.40	5.50	-13.1%
3-2	Deckhouse Struc Density	1.70	3.20	91.8%
3-2	Foundations Wt Frac	13.0%	13.1%	14.3%
3-2	Containment Cost/Wt Ratio	$54.40	$45.98	-15.5%

This confirms that the hull structure is considerably more efficient and weight is saved in the basic hull. The deckhouse weight and its corresponding structural density has, however, increased noticeably. Assume the user desires to investigate further the differences in the deckhouse. Selection of screen 3-1 and comparative analysis for DECKHOUSE WT FRAC will result in the following "Comparative Analysis" screen.

		B	V	DELTA
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-1	Light Ship Displacement	5852.9	6592.0	12.6%
1-1	Total Enclosed Volume	1037193.0	970663.0	-6.4%
1-1	Ship Density Full Load	16.9	19.5	15.3%
1-1	Ship Density Light Ship	12.6	15.2	20.3%
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Length Overall	563.0	504.0	-10.5%
1-1	Beam at Waterline	55.0	59.0	7.3%
1-1	Beam (max at deckedge)	55.0	66.9	21.6%
1-1	Draft (max)	18.0	20.0	11.1%
1-3	Fragmentation			*
1-3	NBC			*
1-3	Noise Signature			*
1-3	Radar Signature			*
1-4	Deckhouse Materials	Alum	HTS	
1-4	Hull Frame Type/Spacing	long/27in	long/26in	
1-4	DKhs Frame Type/Spacing	long/27in	long/26in	

The analysis above partially goes full circle to again provide the user with information on how the difference in the weight may have impacted the ship size. The reason for the significantly larger beam could be explained by the much heavier deckhouse and the heavier weight in turn is caused by the selection of steel vice aluminum as the deckhouse structural material.

It should be clear from the short example above, that as the user goes through his analysis, he will continue to find other interesting aspects of the variant design in relation to the baseline. If this were incorporated in a computer program as a computer-assisted module, the analysis could be performed more rapidly and more efficiently. Additionally, the graphics capability would more dramatically highlight the differences. It is obvious at this point that there are many more analysis that could be performed on a data base of this type.

The author again cautions the reader that the data used in the study is notional and may not reflect the actual designs. It is the methodology development that is most important and no verification was made of any data obtained.

3.5.4 Comparative Analysis Conclusion

It should be noted that as the analysis paths suggested in appendix F are explained by different users, more efficient investigative paths will be identified. An analogy can be made to a detective looking for clues in order to piece together a logical

investigation to identify a "culprit" in a crime. The objective in this comparative methodology is to identify differences in completed ship designs and then to determine the causes and effects of these differences. This helps the designer to better understand their design practices and standars.

3.6 Programming Notes

Figure 3.5 illustrates the flow chart to be used for this section of the overall program methodology. Examples of several individual paths have been discussed in detail in previous sections of this chapter and require little further explanation. The examples of section 3.5 show how the overall comparative analysis section interfaces with the module.

There are, however, several "control" keys which are referred to in the text of the examples. These will be further explained to ensure the programmer understands all possible exit paths used by these keys. A "control" key is, by definition, any key or combination of keys that will result in some action on the screen, either directly, or by opening a "window" type prompt for user decision. Some of the possible paths for the "control" keys are displayed on figure 3.5. Listed below is a summary of all required keys, some of which will be used in other sections of the program.

Data Base Access Key - provides the user the ability to directly query the data base in use. Should be available in all sections of the program.

Window Prompt Menu Key - provides the user a menu of all available exit options from the particular module that he is accessing. Options are all possible paths out of the "window prompt", as displayed in the appropriate flow chart. Used in all modules.

New Screen Key - user may select next screen directly either by system prompt or by typing in the new screen number with the control key. Exact implementation left to the programmer. Used in Two-ship analysis section only.

Switch Singular/Composite Key - allows user to shift his screen from singular to composite display or vice versa, as explained in section 3.1. Pertains to two-ship analysis option only.

"Major Change" Percentage Key - Prompts the user to enter the new percentage that he considers to be a major change. In the regular screens of the two-ship analysis, any difference, or "delta" greater than this percentage will be highlighted in reverse video. For the "comparative analysis" option screen, only indices with differences greater than this percentage will be displayed. If no selection is made, the default value will be zero, to allow all indices of the selected screen to be displayed. Pertains to two-ship analysis option only.

"Comparative Analysis" Key - prompts the user directly for the indice he wishes to perform a comparative analysis

option on. The exact method of inputting the indice could be through keyboard entry, or ideally, by direct graphic screen interaction. The detailed implementation is left to the programmer. Used in two-ship analysis section only.

When providing the full "SCREEN MENU" for the user to make a selection, it should be complete enough to ensure he understands what information is available. This should include the name of the level that the screen is in (i.e. Primary Characteristics), the screen number (i.e. 1-1,1-3), used also for direct selection, the area that the screen pertains to (i.e. weight, volume, containment, etc), as discussed in section 3.1, and the name of the screen.

A detailed definition and significance of each of the suggested indices, along with the applicable equation and suggested comparative analysis paths, are available in appendix F to assist the programmer and the user.

Since the user may not have all available parameters to input, the programmer must ensure that the program will continue to function if parameters are missing. A check loop, is therefore necessary to ensure that "divide by zero" problems do not occur. The program should instead provide a statement of non-applicability for any indice that cannot be calculated due to lack of information.

All other sections of the flow chart are either self explanatory or are explained in detail in sections 3.1 to 3.5.

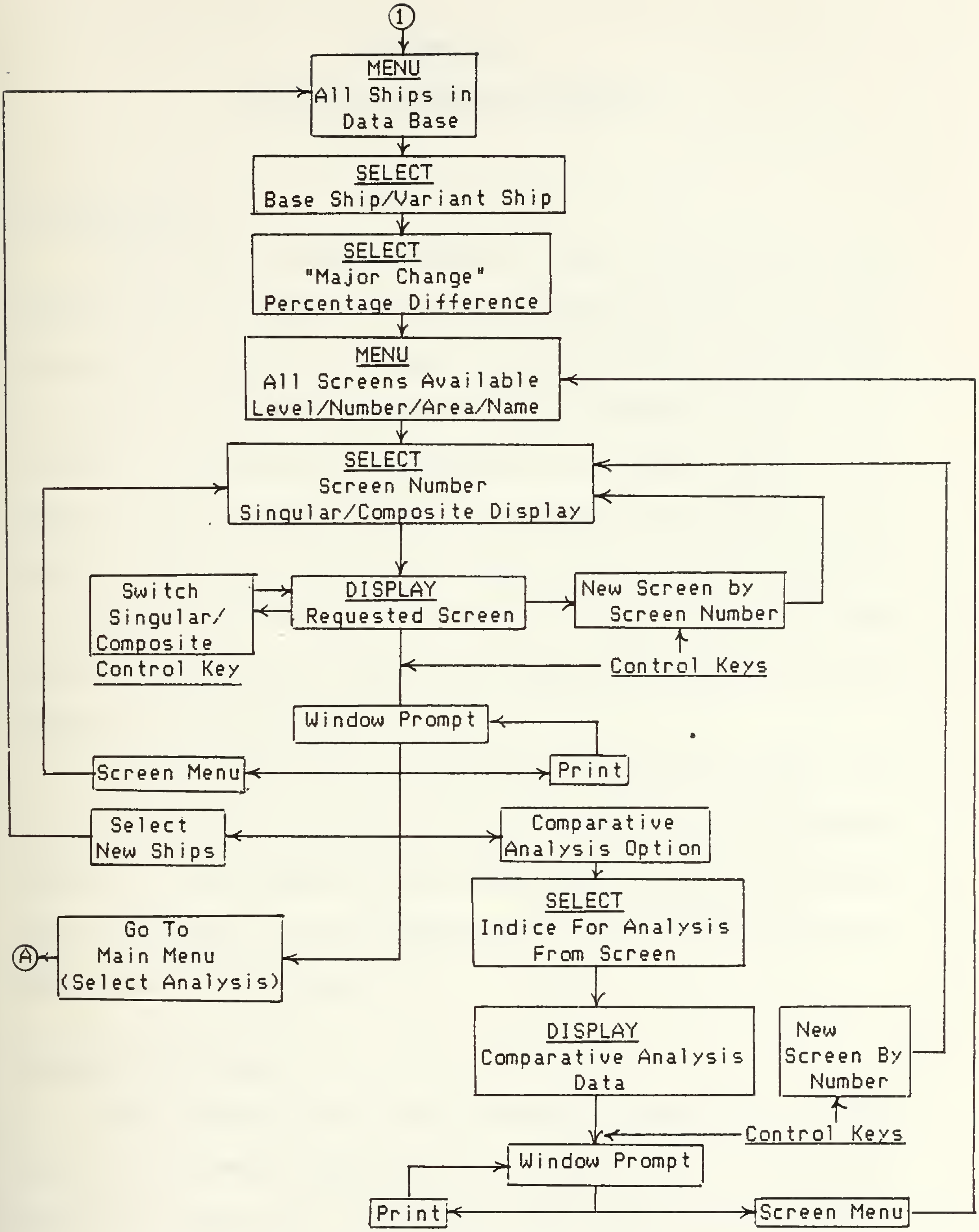


Figure 3.5 Two Ship Comparative Analysis Flow Chart

CHAPTER 4

MULTI-SHIP COMPARATIVE ANALYSIS

4.1 Methodology

To provide a broader perspective than that provided in the two-ship analysis, this option allows the user to display up to six data bank ships for direct comparative analysis of a selected group of "stacked" parameters or indices. This provides the user with the ability to observe related parameters and compare them to other similar ships in the data bank. The parameters available for this type of display are limited to the most important and are discussed in section 4.2. Once this section of the program has been selected, the user may change the ships he is displaying or the parameter he has selected.

To allow for several related parameters to be grouped, the graphical display will be in a vertical "stacked" bar graph format. Figure 4.1 is an example of the displacement light ship and full load relationship. Other examples would be the "stacking" of all SWBS groups or SSCS groups.

4.2 Selected Indices

Those parameters and indices considered most useful for ship size and performance comparison were selected to be available for multi-ship comparison. To allow for a meaningful and uncluttered

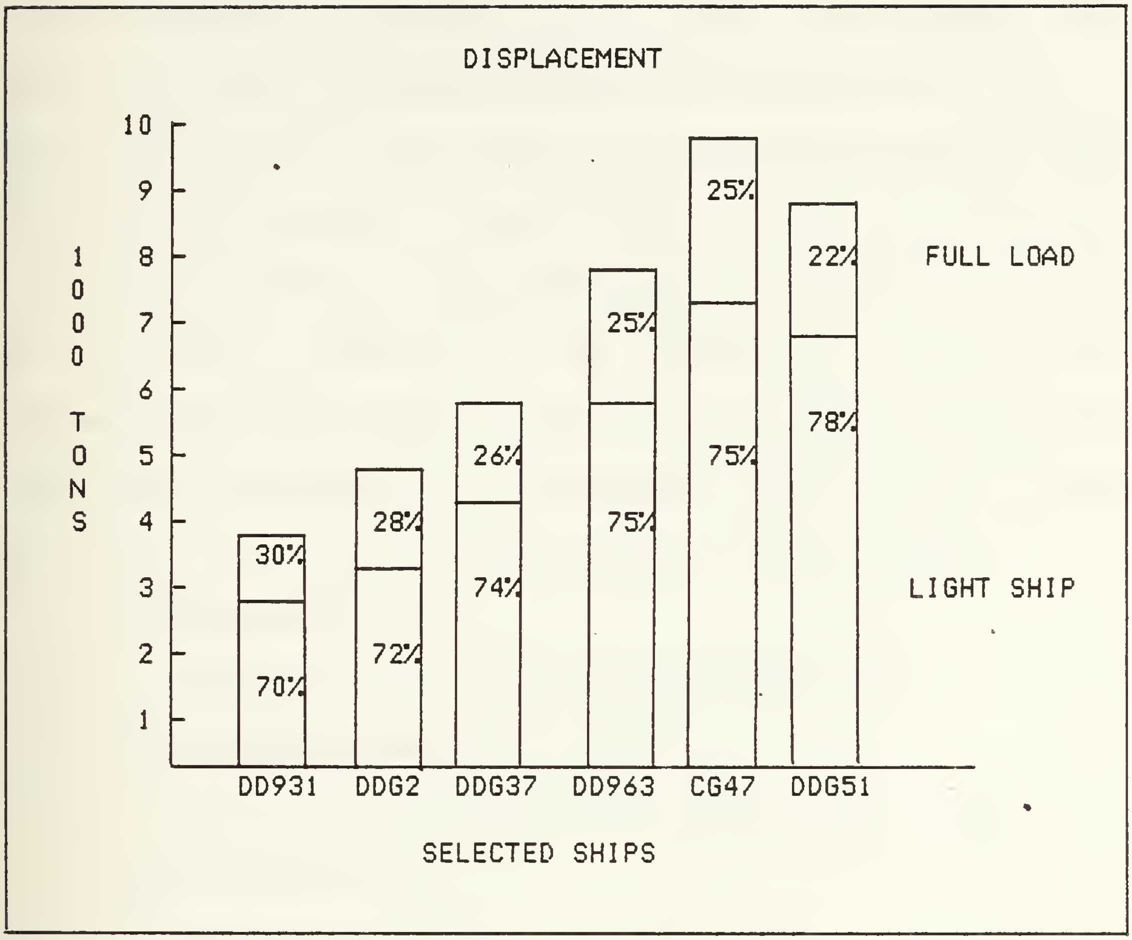


Figure 4.1 Example Mult-Ship Plot (Displacement)

display with sufficient space for necessary text, a maximum of six ships may be selected from the data base.

Each of the available indices are listed below with a short explanation of what parameters are included in the display. The same basic display methodology developed in section 3.1 will be used in this section. The Y-axis will display only absolute values of the primary parameter or whole indice. In the case where the indice is a percentage, the percent value will be placed inside the bar as shown in figure 4.1. The computer will determine the maximum value of the selected ships for the indice selected and scale the Y-axis accordingly. The number in parenthesis following each indice is its origin screen, added for reference only.

- Displacement (1-1)

  Stacked bar graph with light ship and load.

- Total Enclosed Volume (1-1, 2-5)

  Stacked bar graph with hull and deckhouse volumes.

- Ship Density (1-1)

  Select either light ship or full load.

- SWBS Weight Fraction (Full Load) (2-1, 2-2)

  Stacked bar graph with seven SWBS groups, acquisition margin and load weight.

- Functional Weight Fraction (2-3)

  Select either light ship or full load.

  Stacked bar graph with combat system, machinery, and containment weight percentages.

- SSCS Volume Fraction (2-4)

  Stacked bar graph with all five SSCS volumes.

- Functional Volume Allocation Fraction (2-6)

  Stacked bar graph with combat system, machinery, containment and unassigned volume percentages.

- Electrical Energy Allocation Fractions (2-7)

  Same selections as in screen 2-7.

  Stacked bar graph with all electrical groups and acquisition margin.

- Speed (1-3)

  Stacked bar graph showing endurance, sustained and trial speeds.

- Range (1-3)

  Single bar graph with endurance range.

- Fuel Usage Allocaction Fraction (2-8)

  Stacked bar graph with propulsion and electrical fuel allocation percentages.

- Horsepower (1-3)

  Stacked bar graph showing required endurance horsepower, required sustained horsepower, total installed horsepower.

- Displacement to Length Ratio (1-2)

  Single bar graph with displacement to length ratio.

- Length Between Perpendiculars / Length Overall (1-1)

  Stacked bar graph with Length overall on top of length between perpendiculars.

- Length to Beam Ratio (1-1)

  Single bar graph with length to beam ratio.

Although there are many other indices that could be selected for this type of analysis, the author chose to select these as among the most important.

4.3 Programming Notes

Figure 4.2 illustrates the general flow path for this section of the program. Upon selection of the multi-ship comparison option, the user will be prompted to select up to six ships from a displayed list of ships available in the data bank. Upon selection of the ships, a menu will be displayed listing all indices available to be viewed. This menu should correspond with the selected indices of section 4.2.

After the data has been displayed, the user should be able to select a "control" key which will open a window on the screen and prompt him to select either:

- select new ships
- select new parameter
- print screen
- return to main menu (select analysis type)

The program will then branch accordingly.

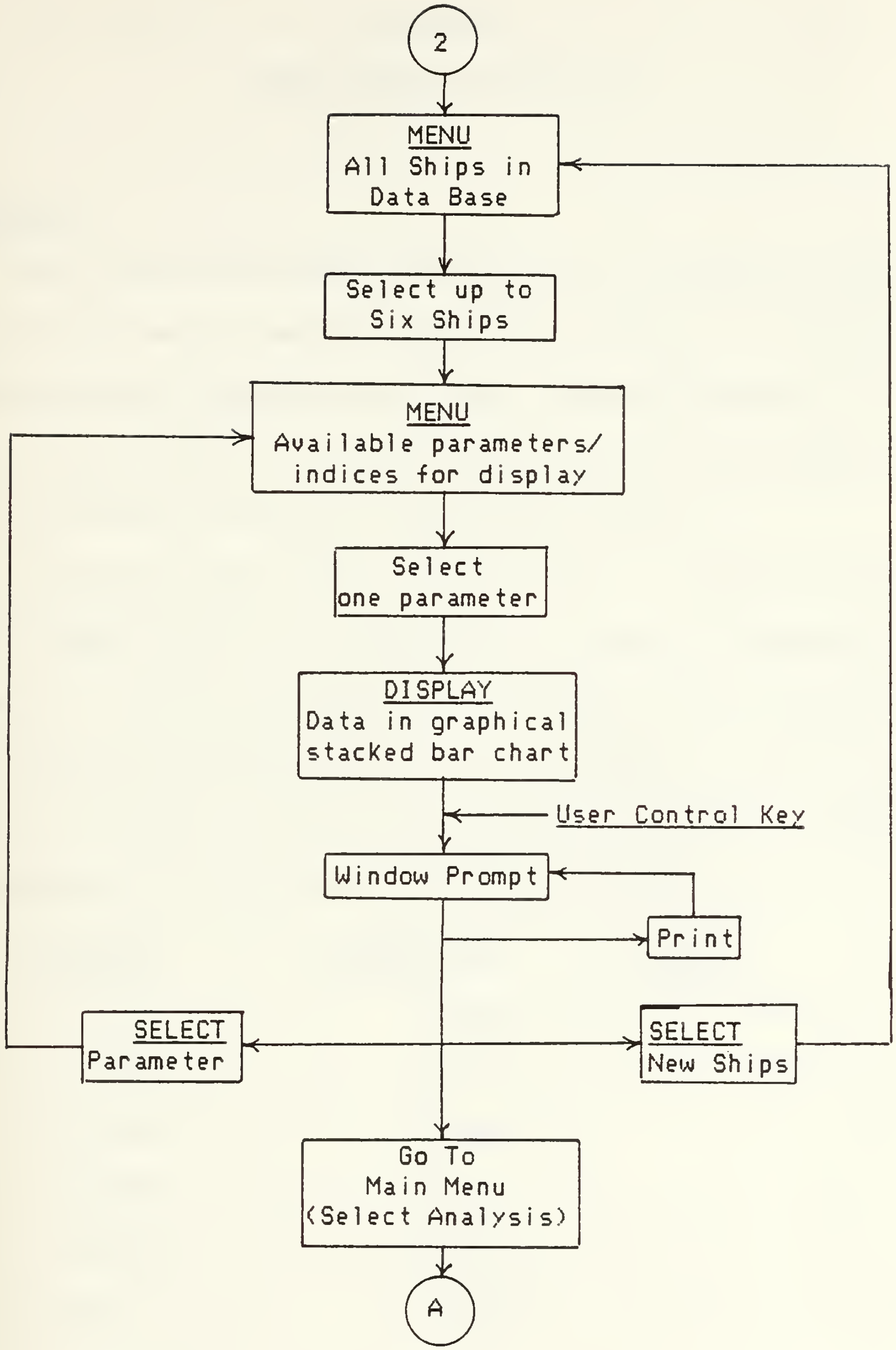


Figure 4.2 Multi-Ship Comparative Analysis Flow Chart

CHAPTER 5

TREND COMPARATIVE ANALYSIS

Methodology

The trend analysis option path provides the user the ability to plot his new or variant design and compare it directly to existing and past ships of the fleet. These plots may be in the form of "time history" or "triple plots" which are explained, along with the available indices, in sections 5.2 and 5.3.

The trend analysis will allow the user to compare his design to any combination of pre-plotted frigates, destroyers, or cruisers. If the user is designing a frigate, he may choose to see only the trend established by previous frigates, or he may choose to have his design plotted along with all available combatants. The ships selected to provide the initial trend data are:

FRIGATES	DESTROYERS	CRUISERS
FF-1006	DD-692	CG-26
FF-1033	DD-931	CG-47
FF-1037	DD-963	
FF-1040	DDG-2	
FF-1052	DDG-37	
FFG-7	DDG-993	
	DDG-51	

The trend analysis data base required to incorporate these trends into the computer program is included as Appendix E. Further ships

may be included at a later date or prior to implementation, if desired.

During any trend analysis, each class of combatants will be plotted with a unique symbol, including a separate unique symbol for the new ship being compared. Examples of this are included in section 5.2.

At anytime during the execution of this option, the user should have the ability to change the trend plot he is viewing or select a new ship from the data bank.

5.2 Time History Trends

A simple graph showing the commissioning year on the x-axis versus the selected indice on the y-axis, scaled by the computer to provide the largest viewing area for the class or classes of ships selected. The initial setup will be to use the years 1940 to 2000 to allow the plotting of a range of ships from post-World War II combatants to ships scheduled to be commissioned in the near future. The user may then plot his new ship to receive an immediate graphical interpretation of how his ship fits into the current trend.

The time trends considered to be most important for this type of analysis are based on those selected in references (12) and (13), which include:

(numbers in parenthesis indicate two-ship analysis screen where the indice may be found for further explanation in Appendix F)

- Displacement Full Load (1-1)

  Y-axis: 1000 tons

- Total Enclosed Volume (1-1)

  Y-axis: 1000 ft^3

- Ship Density (Full Load) (1-1)

  Y-axis: lbs/ft^3

- Combat Systems Weight Fraction (Full Load) (2-3)

  Y-axis: percent

- Main Propulsion Ship Size Ratio (3-4)

  Y-axis: HP/Ton (SHP/ $_{fl}$)

- Electrical Capacity Ship Size Ratio (3-6)

  Y-axis: KW/Ton (KW/ $_{fl}$)

- Human Support Specific Volume (3-12)

  Y-axis: ft^3/man (V_2/M_a)

Figures 5.1 through 5.4 show examples of how the graphs for this option should be portrayed and how they may be used. The new ship plotted in reference to the overall time trend is the new technology baseline frigate of appendix D developed in a separate thesis on technology assessment, reference (40). In figure 5.1, it is noted that the new frigate follows the general frigate trend, with the exception of the downturn created by the weight constrained FFG-7 class. Figure 5.2 shows the same result for volume trend. In figure 5.3, only the frigate type of ship is plotted as a comparison and clearly shows a variance from the past decreasing ship density trend of frigates. Additionally, figure

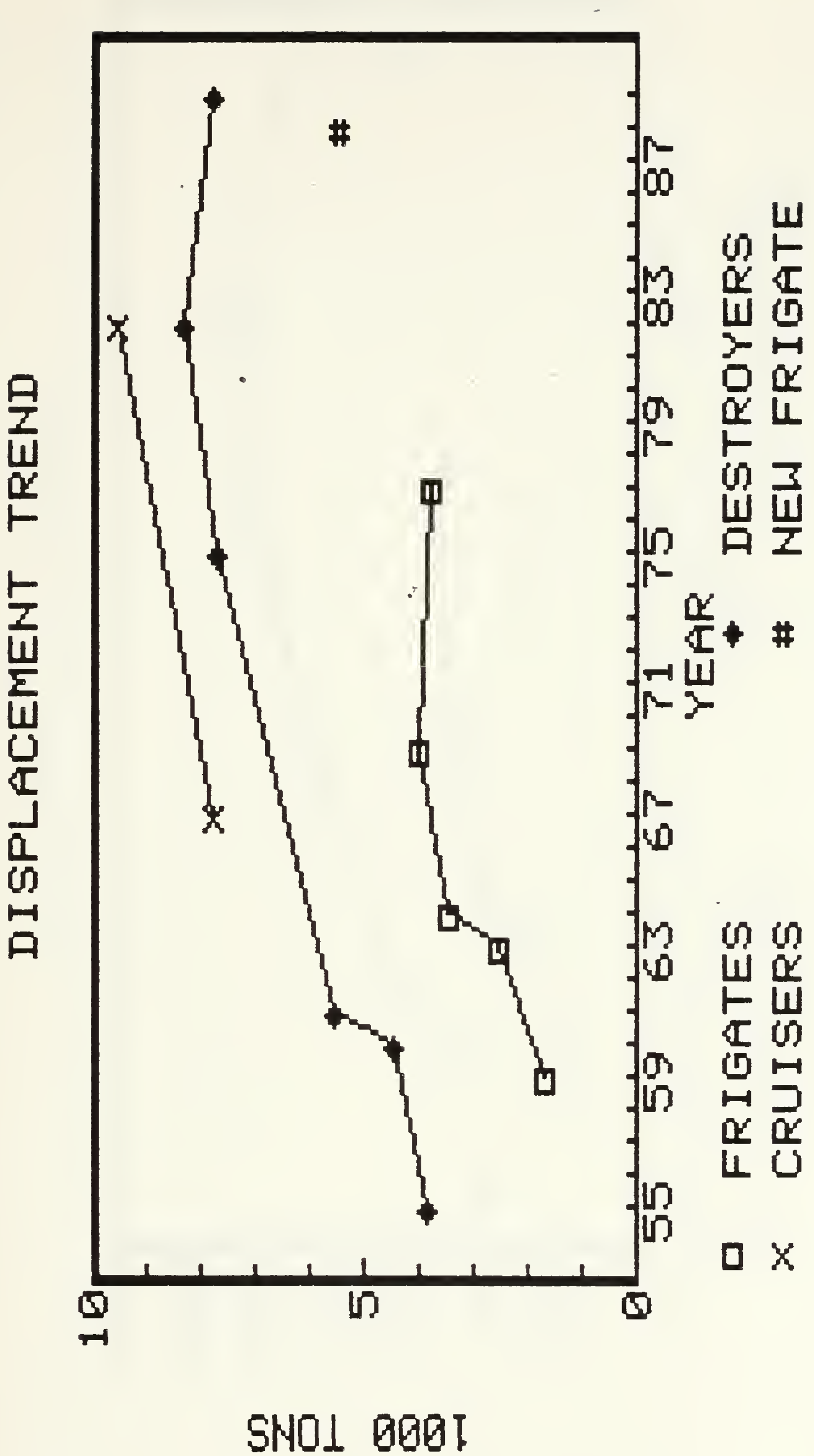


Figure 5.1 Example Displacement Trend Analysis

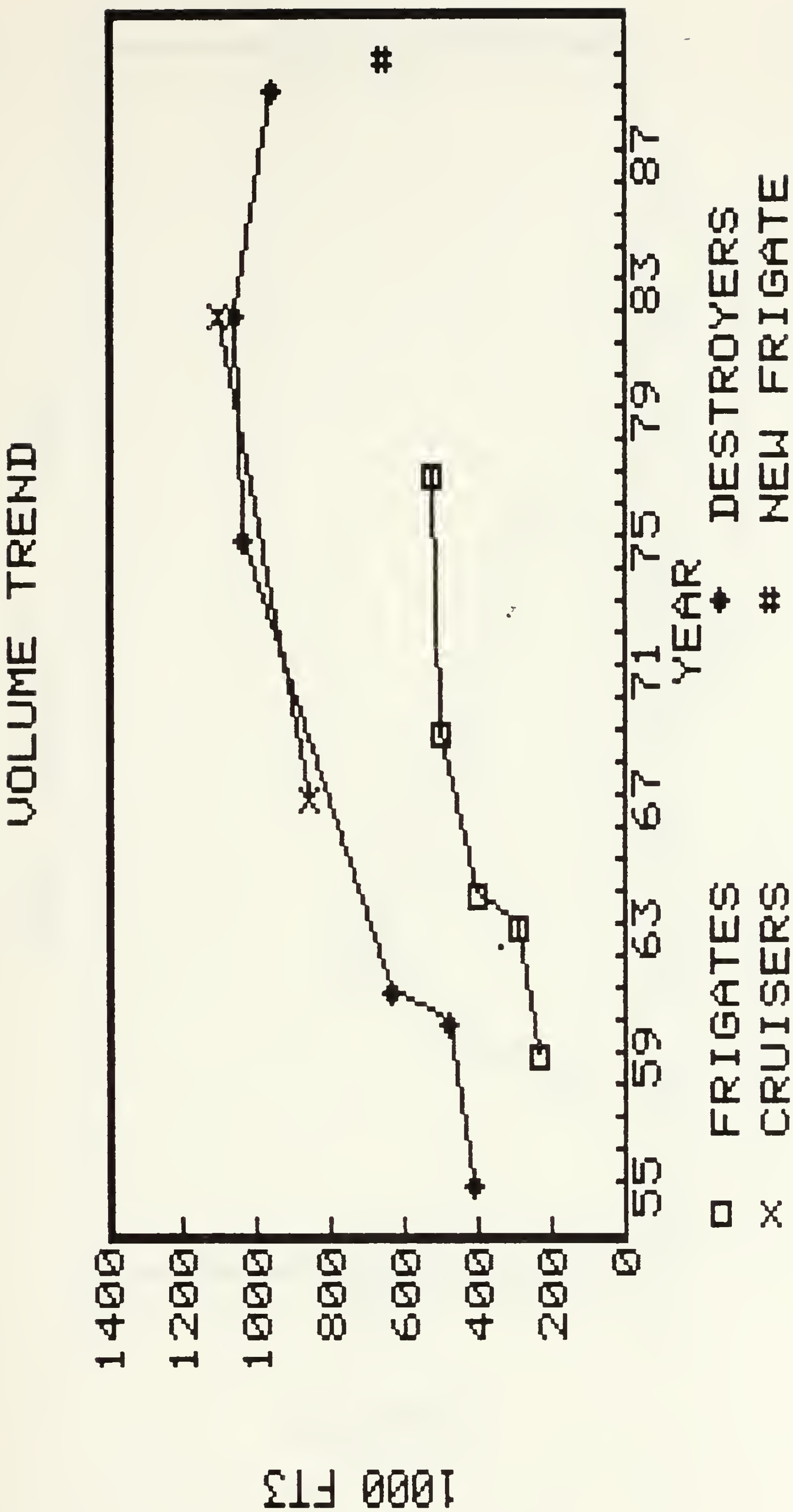


Figure 5.2 Example Volume Trend Analysis

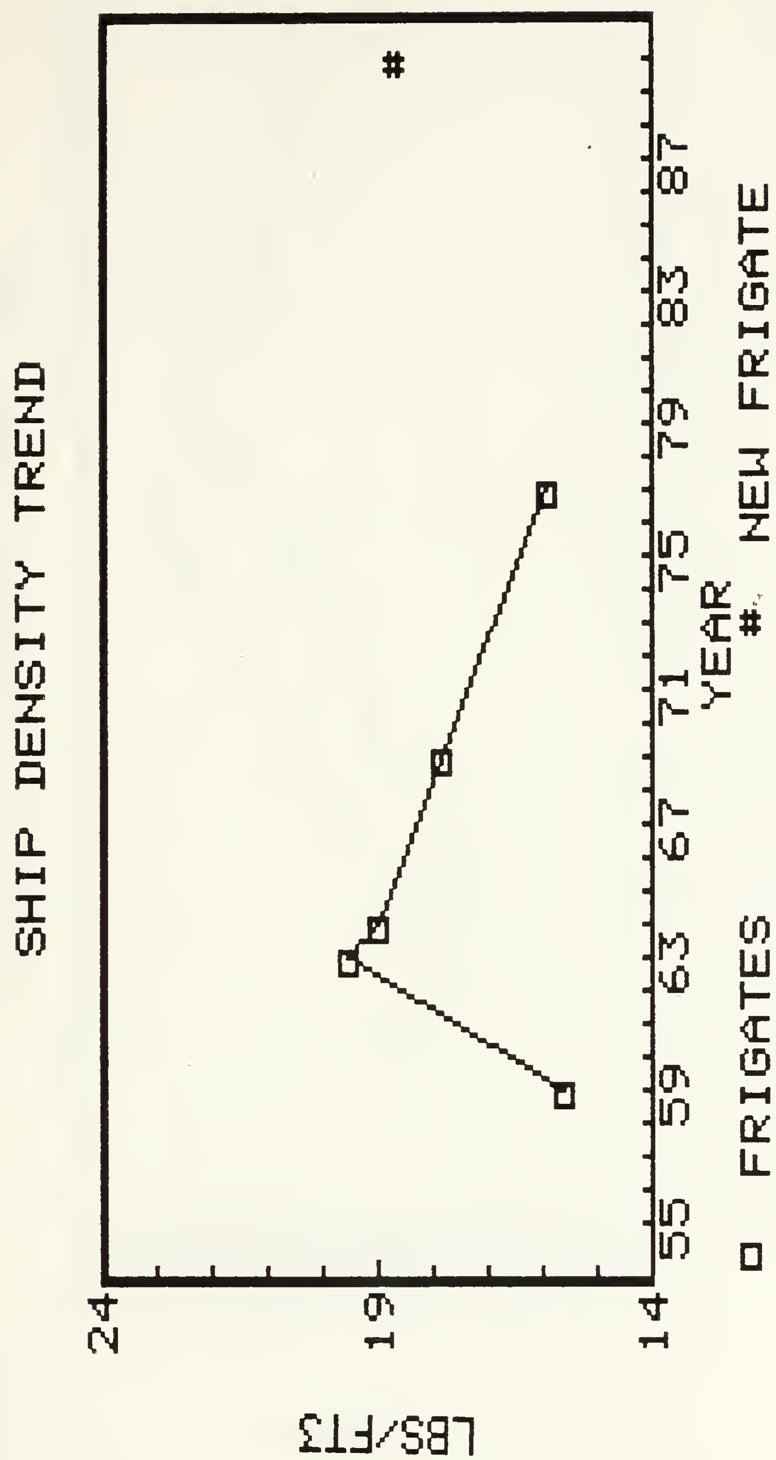


Figure 5.3 Example Ship Density Trend Analysis Selecting Only One Type of Ship For Comparison

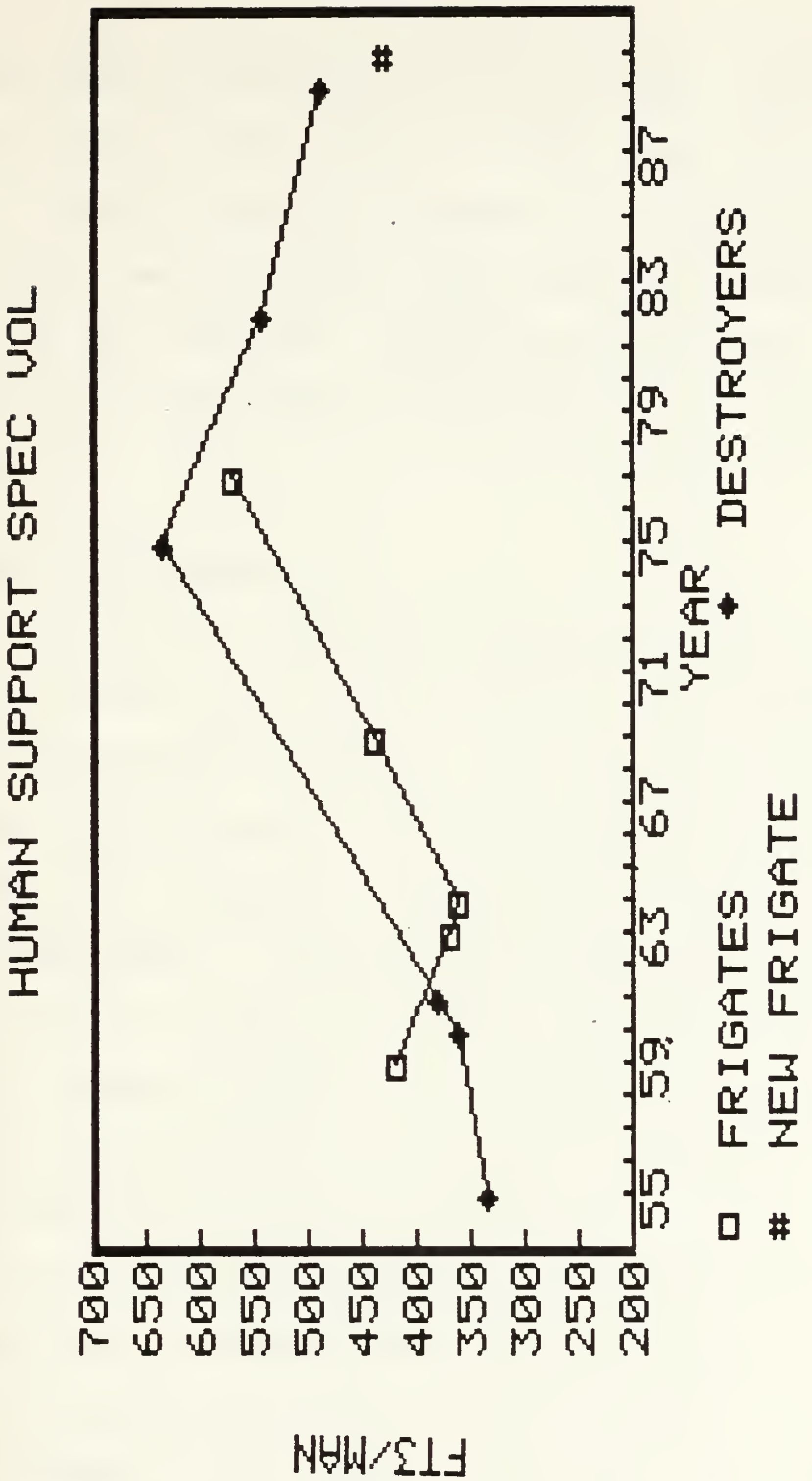


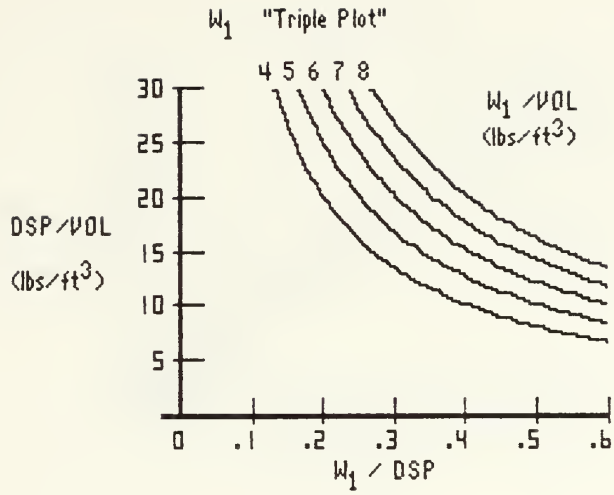
Figure 5.4 Example Human Support Trend Analysis Selecting Two Types of Ships for Comparison

5.4, which plots the new ship with both frigate and destroyer trends for human support specific volume, shows that the new frigate is following more of a destroyer trend than that of a frigate. The remainder of the indices could be examined by the designer in the same way, providing him with the type of information that he may need to justify his design in a historical trend sense.

5.3 "Triple-Plot" Trends

In the level 3 functional investigation of the two-ship comparative analysis, the primary "drivers" contributing to the parameters of a specific functional area are examined. In each case, these drivers may be related to each other in a triple relationship first introduced by Heller and Clark in reference (9) for the SWBS group 1 structures and expanded by Cassedy in reference (8). In this portion of the trend analysis, these drivers are graphed in relation to each other and can be compared to existing combatants of the same type or all types similar to the way the comparison was performed in section 5.2.

Figures 5.5 through 5.8 are the exact graphs that should be incorporated into the program. These graphs are based on current designs and provide sufficient overlap to include all combatant designs discussed in this thesis. All values which should be entered in the data base to be available for plotting by the user are listed in appendix E. The ships used for the initial



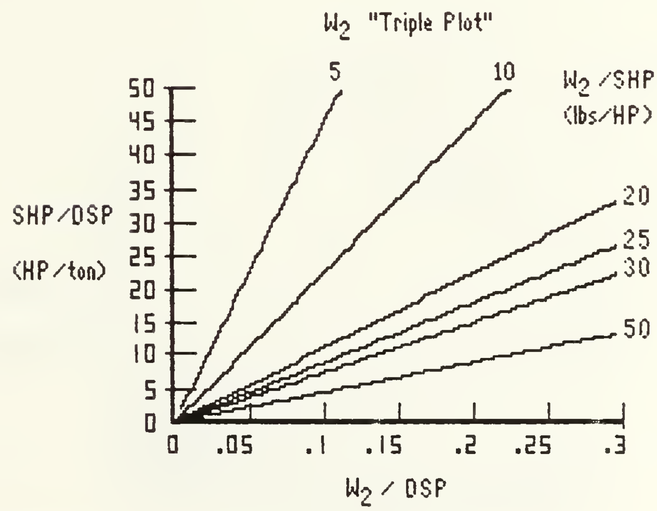
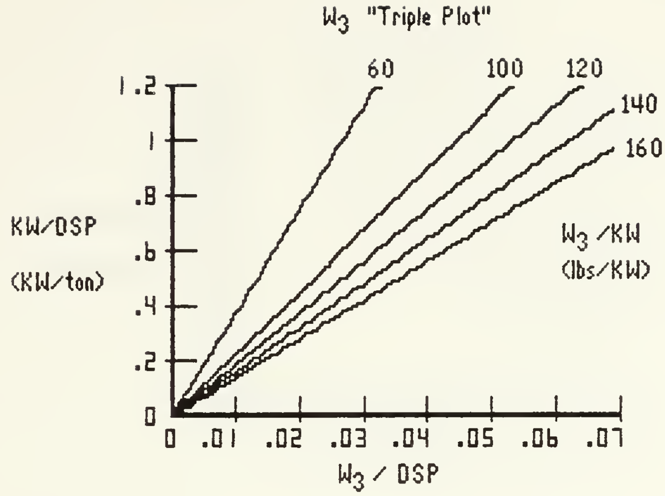


Figure 5.5 Basic "Triple Plots" W_1 and W_2



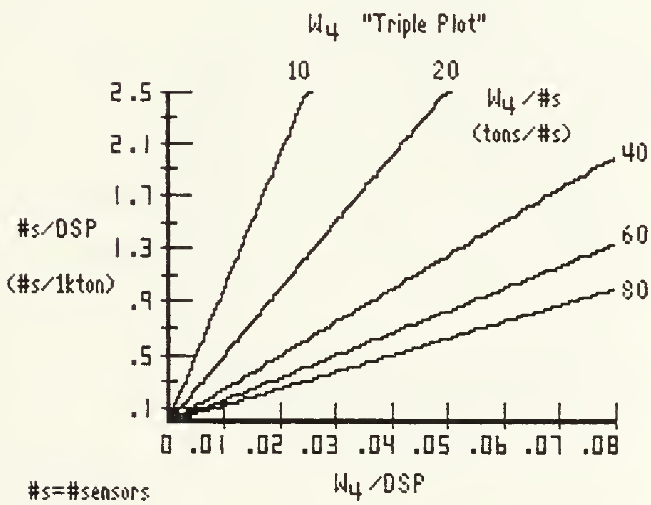
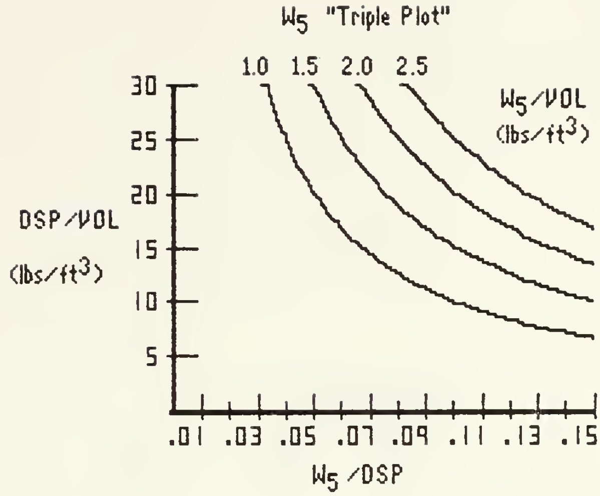


Figure 5.6 Basic "Triple Plots" W_3 and W_4



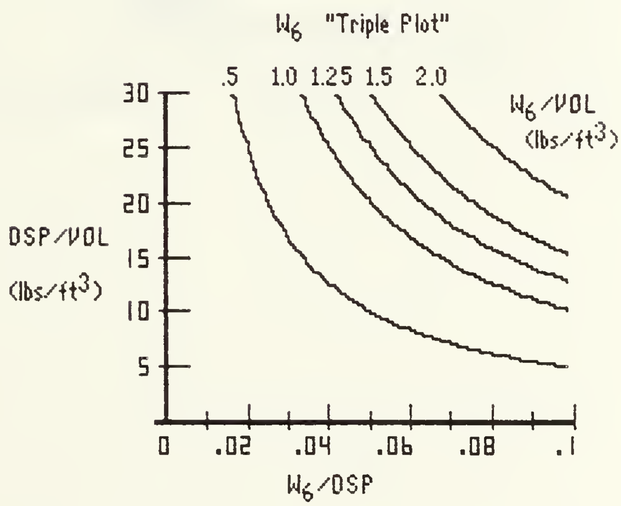


Figure 5.7 Basic "Triple Plots" W_5 and W_6

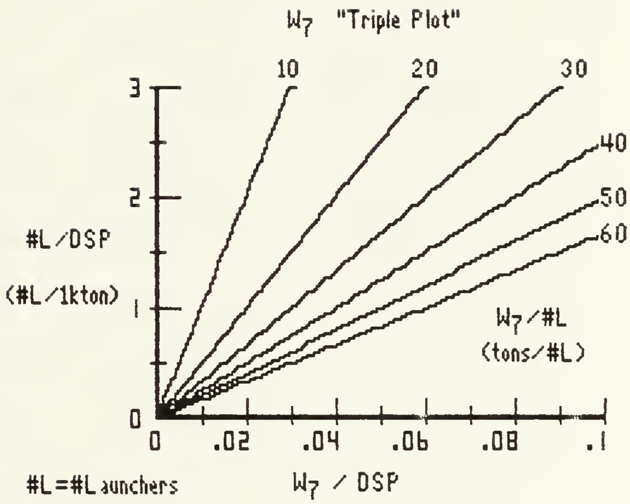


Figure 5.8 Basic "Triple Plot" W_7

implementation are the same as those used for the historical trend data base. It should be noted that the units are, in some cases, of a different magnitude to allow for better scaling and more meaning. This is accounted for by the use of conversion constants in the equations used to create the plots. All "triple plots" are referred to by the respective SWBS group to which they apply. The equations used to create the graphs, using the units as indicated in the data base of appendix E, are as follows:

1. $(W_1/\nabla) = (W_1/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
2. $(W_2/SHP) = (W_2/\Delta_{f1}) * [2240/(SHP/\Delta_{f1})]$
3. $(W_3/KW) = (W_3/\Delta_{f1}) * [2240/(KW/\Delta_{f1})]$
4. $(W_4/\#s) = (W_4/\Delta_{f1}) * [1000/(\#s/\Delta_{f1})]$
5. $(W_5/\nabla) = (W_5/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
6. $(W_6/\nabla) = (W_6/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
7. $(W_7/\#l) = (W_7/\Delta_{f1}) * [1000/(\#l/\dot{\Delta}_{f1})]$

The values used for the left hand side of the equations, which create the curves, should be the same as those shown in the graphs, figures 5.5 through 5.8.

In all of the triple plots above, the left hand side of the equation is the specific weight or weight allocation per capacity of the particular function under investigation. It provides an indication of the subsystem design practice. The first term on the right hand side is the weight fraction or allocation of weight to the function under investigation. The last term of the equation is the capacity to ship size ratio or the capacity of the function

designed into the ship relative to its size. Each of the triple plot drivers are discussed individually in their appropriate screen explanation of appendix F.

Figure 5.9 provides an example of how this analysis can be used. Again, as in section 5.2, the new technology frigate of appendix D is examined in the structural "triple-plot" trend analysis where it obviously stands out from the given historical data base for previous frigates. From equation (1) above, it can be seen that the driving capacity for structures is volume and the new frigate has an average ship density of 18.8 lbs/ft^3. This indicates an average volumetric tightness and weight density of the ships subsystems. The hull structural weight fraction is computed as 23.5%. Using equation (1) above, the hull structure specific weight is therefore 4.43, which is lower than any other frigate in the data base. This is an indication of an extremely efficient structural design which combines with the ship density to cause the low structural weight fraction. This implies that for this specific sized frigate, more weight is available for use by other ships functions.

This type of analysis is extremely useful for rapid determination of what the primary design "drivers" are and how the design relates to existing ships.

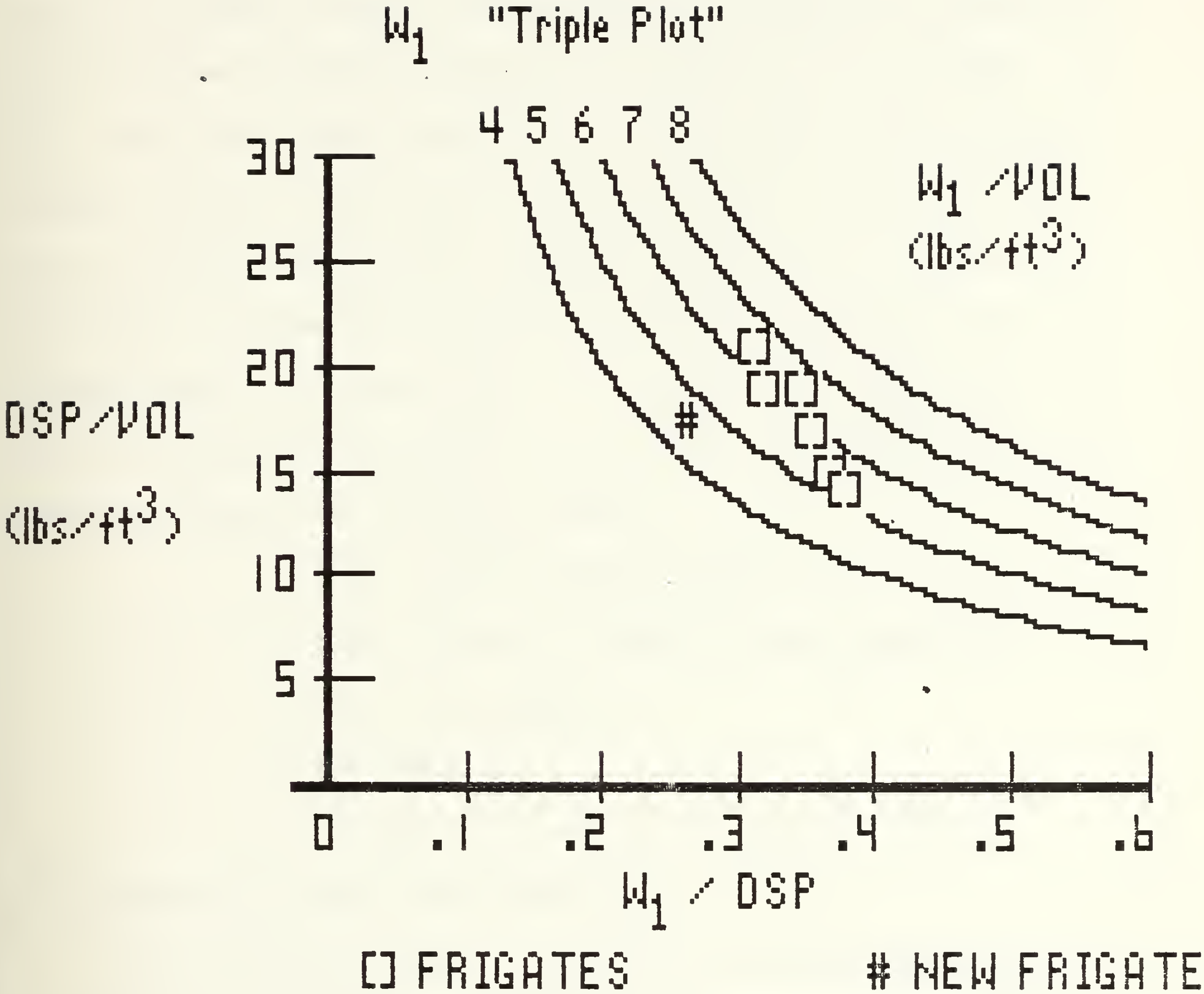


Figure 5.9 Example of New Frigate vs. Standard Frigates "Triple Plot" Structural Trend Analysis

5.4 Programming Notes

Figure 5.10 illustrates the general flow path for the trend analysis section of the program. The menu section will include both the time history and "triple plots" available, of which the user will select only one. He will then be prompted to select the type of ships to which he desires to compare his new design. He may select any combination of, or all of the three available groups; frigates, destroyers, cruisers. After this selection, the user will be provided with a complete listing of all ships in the data base to allow him to select the design he wishes to do the trend analysis on. The plot is then displayed, after which the user may depress a "control key" which will open a window on the screen and prompt him to select either:

- select new ship from data base
- select new type of ships for trend comparison
- select new trend plot
- print screen
- return to main menu (select analysis type)

The program will then branch accordingly.

The selected data base of existing ships provided in appendix E should be incorporated directly into the main data base in use with the appropriate parameters being called up automatically as a specific screen is requested. The importance of providing different, unique symbols for each type of ship and the new design is again emphasized. Another recommendation that would be

beneficial, but not necessary, is the ability to be able to see directly what actual ship each symbol represents. This, however, could result in an extremely cluttered screen if a large existing data base were used. The exact method of internal storage of variables and the drawing and computing of the trend plot graphs is left to the programmer.

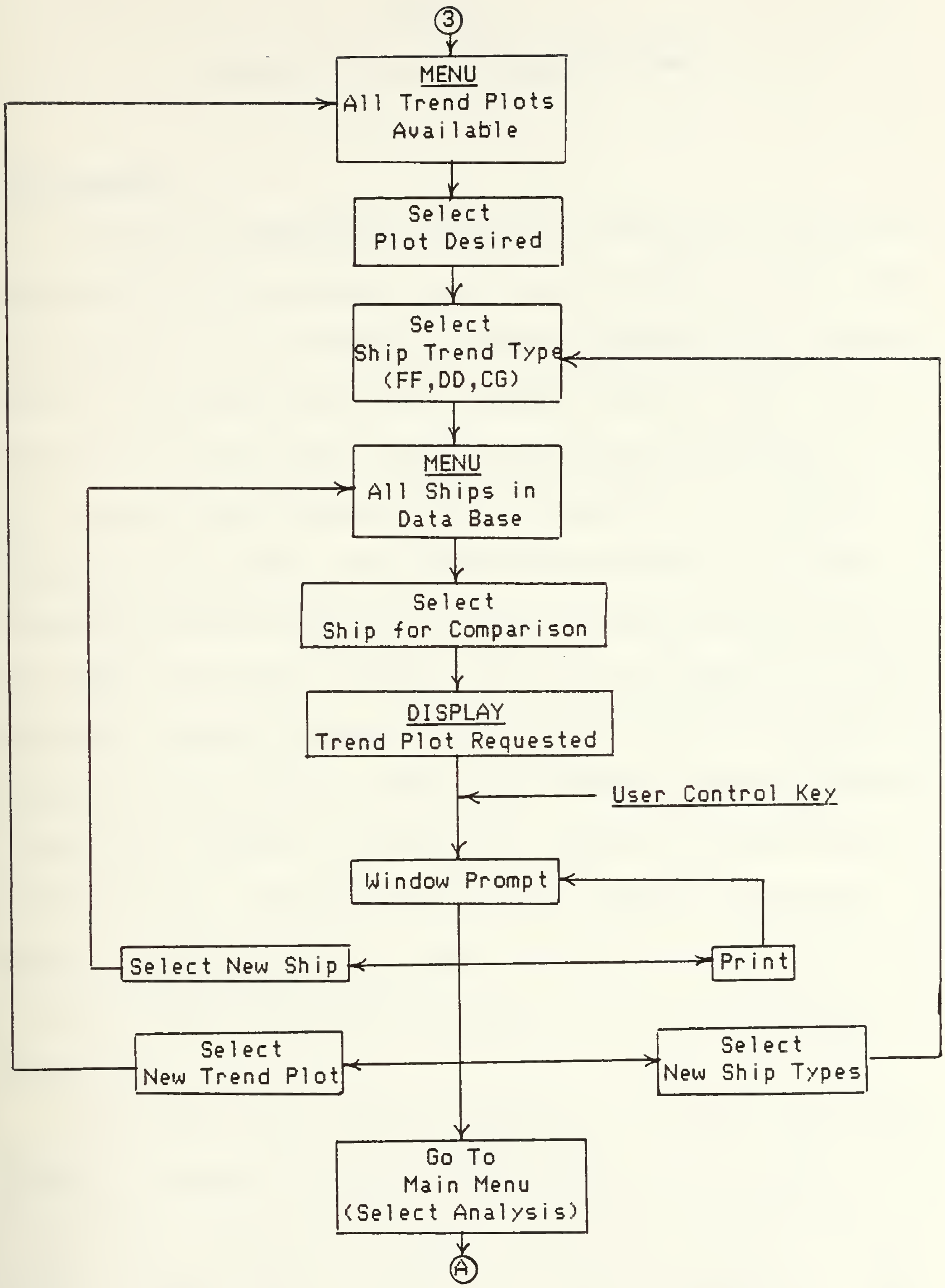


Figure 5.10 Trend Comparative Analysis Flow Chart

CHAPTER 6

INTERFACE TO AN INTEGRATED DATA BASE

6.1 Discussion

Using the methodology proposed in this thesis requires an extensive list of parameters to define the ship or ships under investigation. It is therefore extremely important that these be stored in a central electronic storage facility, more commonly referred to as a data base. When this data base has the ability to use internal relationships between parameters, it becomes an integrated data base. All further discussions will relate to integrated data bases only. Once the data base has been defined, the number of ships and data that can be stored is almost unlimited. As new designs or variants are created, they may be stored for later recall or comparison. Different data bases may be created for conceptual designs, for working designs, and for existing ships. Provided they all use the same structure, or schema, a single application program could be written to access any of the data bases individually allowing selection of any design for comparison.

Two efforts are presently underway at the Naval Sea Systems Command to establish integrated data bases for ship design. The larger effort involves an integrated data base (IDB) for the later stages of design that will serve as a detailed analysis of ships that are in the preliminary to contract design stages. The second

effort is referred to as an "Early Stage Integrated Data Base", which is considerably smaller and is being developed at the David Taylor Model Basin for use in feasibility studies. The model developed in this thesis could be used with either IDB or a seperate data base could be developed to store only the required information suggested.

The data base management system selected by the Naval Sea Systems Command is BCS RIM, a Relational Information Management System developed by the Boeing Company. It is powerful, easy to learn, user-oriented, and can be accessed without any knowledge of the physical structure of the data base. It provides easy access to its files, either directly, through an easy-to-use, English-like command language and menu selection facility, or through an application program interface using FORTRAN-callable subroutines. This allows the user to input new data directly, without any interface at all, while providing the tool to call the data using a FORTRAN program to display it in a desired format.

6.2 Implementation Requirements

The initial requirement for implementation of this comparative ship design model for direct use with a data base, is the data base selection. If a new data base is constructed for the sole purpose of supporting this model, it must be directly accessible and requires an application program interface as discussed above. Appendix B lists all required inputs that must be stored in the

data base for later recall by the model. The application program interface, as discussed in earlier sections, is then written in FORTRAN or equivalent programming language to access the data base, retrieve the required information and display the requested screen or data. Existing ships, new designs and variants can be initially added to the data base manually or they may be added with a second data base application interface that creates the design parameters, opens the data base and stores the data under a new design name. This type of application is discussed in section 7.

If an existing data base, such as that under development at the David Taylor Model Basin, is used then the parameters presently stored in the data base should be examined to ensure that all those listed in appendix B are supported. If they are not, the RIM data base management system will allow them to be easily added without disrupting the existing data base structure. The application program is then written in the same manner as discussed in the paragraph above.

Once a single application interface program has been written, it can be easily modified to support any existing data base available. If the data bases are of the same type, i.e. RIM, then the task is even easier. Additionally, if care is taken to use the same naming criteria for the schema relations in different data bases, then the interface may be directly compatible. It is in this manner that several data bases may be individually established for different stages of design and the application program merely

needs to ask the user to which data base he desires access to retrieve the ship he wishes to analyse. Since the computer processing time required for the application program to search the data base for the required information to be retrieved is directly proportional to the size of the data base, this method of using several data bases is recommended, however, the final decision should rest with the programmer, who is familiar with the data base in use.

As more ships become available in the data base, the model allows for a greater selection of comparisons and becomes an increasingly powerful tool for comparative ship design analysis.

CHAPTER 7

INTERFACE TO ASSET

7.1 Discussion

The Advanced Surface Ship Evaluation Tool (ASSET), which has been under development since 1980, is an interactive computer-based total ship technology evaluation tool. It employs computational modules with state-of-the-art engineering capabilities appropriate for feasibility level studies. ASSET has been carefully constructed for compatibility to Naval Sea Systems Command standards, nomenclature, practices and philosophy for early stage ship design. Elements addressed within the program include the areas of geometric definition of the hull and superstructure, hull structures, resistance and propulsion, machinery, weights, hydrostatics, seakeeping, cost and manning. Although its primary module in use at this time is in the area of surface naval combatants, a current model exists for hydrofoils and SWATH's (Small Waterplane Area Twin Hull) and future ship types to be included are naval auxiliaries, aircraft carriers, planing craft and air cushion support craft.

The primary focus of ASSET is to determe the impact of a broad spectrum of technologies on a whole ship system. The method of performing these technology studies is addressed in depth by Goddard in reference (40). It is in this context of comparing impacts of technological advancements on either existing or new

design ships that the model developed in this thesis will benefit the designer. Presently, a technology tradeoff is performed by establishing a baseline ship on ASSET, then making appropriate changes to reflect the new technology, thus obtaining a variant design. Both the baseline and new technology ships are then individually output to a printer in an extensive data file. Currently the designer then manually compare these two outputs in detail to draw conclusions of the overall impact of the new technology. It is the author's opinion that a great deal of time and effort could be saved if the capability to perform this comparative analysis was available from within the ASSET program. If the results are not as expected, the designer has the immediate option to perform another design iteration without ever leaving the ASSET Executive. Section 7.2 will discuss how the methodology developed in this thesis could be directly coupled to the ASSET program while minimizing the impact on the present ASSET system.

Additional information pertaining to the capabilities and development of the ASSET program is available as an overview in reference (41) with detailed theory available in reference (16).

7.2 Implementation Requirements

An example of the possible interaction of an ASSET technology assessment with this proposed methodology has already been demonstrated in section 3.5.3.1. This example, using a simple spreadsheet type of analysis, used only available output from

ASSET. The actual data used is available as appendix D. When comparing the inputs required for this proposed methodology with the information available and already calculated by ASSET, it is evident that the only immediate shortcomings are in the area of electrical energy allocation, survivability and detailed auxiliaries equipment analysis. The lack of these items did not noticeably impact the overall technology study. Appendix B illustrates directly which required inputs are supported by ASSET and which are not. As demonstrated by the notes of appendix B, some parameters require only slight modification which could be written directly into the new code when the module is incorporated. This thesis will not address the areas not supported by ASSET but makes the recommendation that these areas be implemented in a future version in the manner suggested by this thesis.

In the actual implementation of this methodology as a module for the ASSET program, it is recommended that it be incorporated as a parallel module in the manner described in figure 7.1. This type of implementation would allow the user to move back and forth freely between the ASSET Executive and the Comparitive Ship Design Module. The data base for the comparison module would be seperate from the MPL and information would be stored from ASSET to the comparative data base only on command from the user. The data base would then be similar to those discussed in chapter 6 and the impact on the present ASSET Executive and MPL would be minimized. An additional advantage to this type of structure is that the

module and/or data base could be constructed to allow access from outside the ASSET program which would allow different types of non-ASSET ships to be entered and compared either internally or externally. This type of structure would serve both the ASSET users and non-users.

The ASSET Executive would interact to the comparitive data base in a similar manner as its interaction to the MPL. It should be able to query the ships stored and allow the user full access to all stored information. The Executive would interact with the comparative design module by entering and exiting only. Once the comparative module is called, the user will be in that mode, as described in the previous chapters of the thesis, until he again requests to return to the ASSET Executive, through some type of menu or "control" key. The ASSET Executive also controls the output to the data base from the ASSET Computational Programs. If the user makes the decision to store his ASSET "Current Model" in the comparison data base, he would provide the executive with the appropriate store command, select the name of the ship it is to be stored as, and the executive would then run the appropriate computational programs and output the applicable parameter data to the comparison data base. A warning should be issued any time existing data may be overwritten, such as the case where the user has given a ship name that already exists in the data base.

Using this type of structure would allow the user to enter ASSET, design a baseline ship, as was done in appendix D. He could

then store the ship in the comparison data base. The user would then modify the ship with some new technology, again as in appendix D with the IRGT propulsion, and then place the variant in the data base. The user may then prompt the ASSET Executive to send him to the Comparative Ship Design Module, where he may assess the overall full ship impact of the new technology as proposed in this thesis. If he sees an error in one of the models, or just wants to make a change, he may return to the ASSET Executive, make all of his changes, "design" and rebalance his ship and then store it back in the data base by overwriting the old file with the new information.

To ensure that the current ship MPL is available for any ASSET ship in the data bank, when a current model is computed and saved to the comparison data base, the current model is simultaneously stored in the MPL under the same name. This will allow the user to recall his ship into ASSET as a current model.

The purpose of ASSET is to provide a total ship evaluation tool for technology evaluation. The addition of the type of comparative analysis module discussed in this thesis would provide the "real-time" comparative analysis necessary to perform this evaluation in relatively short time and on-line without spending a large amount of time analyzing multiple pages of paper output.

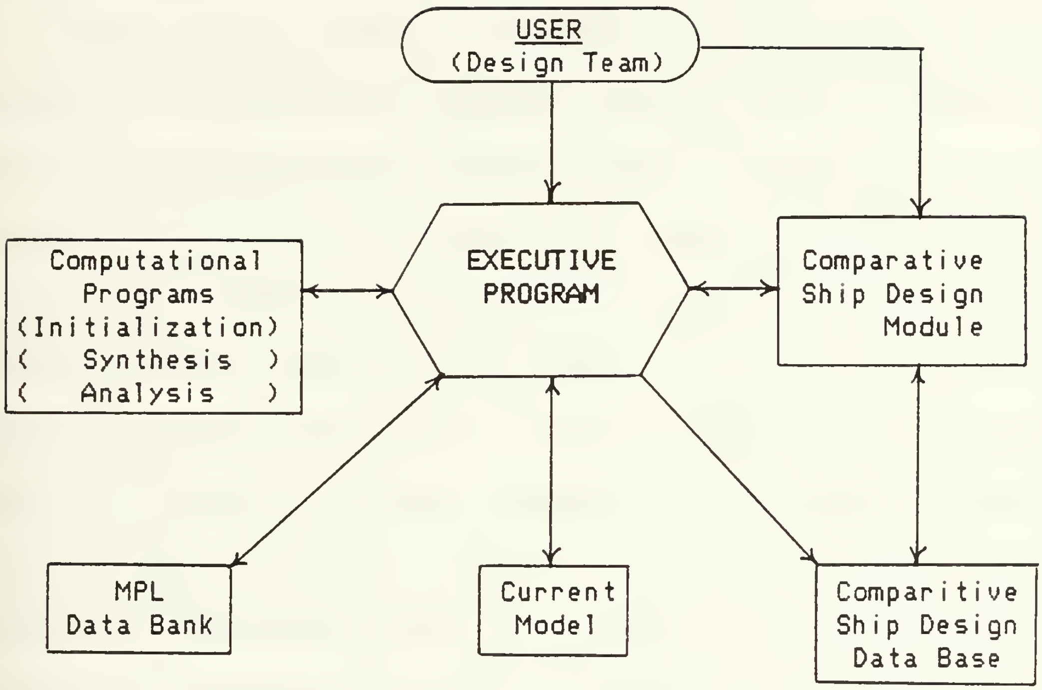


Figure 7.1 Proposed Comparative Ship Design Module Interface to ASSET

CHAPTER 8

CONCLUSIONS

The purpose of this thesis was to develop a methodology that could be implemented on a computer to rapidly and interactively compare new ship designs and technology studies.

Three primary methods of comparison were presented and documented in preparation for implementation as part of a computer program. Applicability was shown for both a straight data base extraction or interfacing to the Navy's Advanced Surface Ship Evaluation Tool (ASSET). The proposed methodology will provide for new designs to be compared to a maximum of six existing data base ships in a bar graph analysis or all preprogrammed ships in a time history or "triple plot" trend analysis. A representative sample of initial data points for the time history and "triple plot" analysis were researched and are provided for the programmer. Additionally, the thesis provides for the detailed analysis of any two ships on a "one on one" basis. The level of detail available includes the ability to examine over 200 selected indices grouped through 31 available screens in 3 levels of analysis. To assist the user in selecting the proper analysis paths to determine reasons for, and impacts of, various differences in the two designs under investigation, the methodology provides for a computer assisted comparative analysis option which will serve as a help

function to provide the user with a listing of changes relative to the indice he is examining.

Different types of combatants may be compared against each other and all parameters are not required. The methodology is structured to provide the maximum information if all parameters are present, however, the model may be used with less. Those that are not available will merely be listed with a statement of non-applicability. It will be up to the designer to determine if he has sufficient information for the analysis he is performing.

The methodology may be used for all stages of design as well as in an educational environment to demonstrate to a student the overall ship impact of different design practices and standards. The basic methodology developed starts with the assembling of all applicable design data in a data base for future reference. The program then computes the design indices and displays them in three different user requested formats. The user may then either analyse the differences manually or in the case of the two-ship analysis, let the computer assist him with his comparative analysis. In this manner the user may identify differences in the performance requirements as well as design practices and standards thereby determining their impact.

Whereas the fastest and most meaningful method of use would be to implement the methodology in its own computer program, a simple method has been demonstrated to allow the two-ship comparisons to be performed manually on a microcomputer spreadsheet with the aid

of the comparative analysis paths presented in appendix F. This method has been demonstrated in two different studies performed to verify the methodology and convince the reader of the potential use that this type of program may have in the rapid determination of the feasibility of future designs, design changes and new technology assessments.

CHAPTER 9

RECOMMENDATIONS

9.1 Implementation

Since the recommended implementation of the actual computer program is similar for use with both an integrated data base and the ASSET program, it is recommended that a version be developed that will support both systems. This could be performed concurrently with the development of the early stage IDB under development at the David Taylor Model Basin. In this manner, the comparative naval ship design module could be used by both ASSET users and non-users, and would be available to compare ASSET ships to non-ASSET ships.

An additional recommendation involves the initial implementation of the two-ship analysis module on a spreadsheet in the Naval Construction and Engineering curriculum at MIT until a full program is developed. This implementation should be similar to that developed by the author in appendices C and D. It has the capability of being used as an immediate educational tool in naval ship design courses. The recommended system to be used is LOTUS 1-2-3 presently available in the 13A Computer Ship Design Lab on the ZENITH Z-120 personal computer.

9.2 Further Development

In addition to the three modules developed in this thesis, an effort should be established to investigate and implement a fourth module to compare the cost effectiveness of alternate ship designs. This module should provide an incentive curve ranking to allow ships of the data base to be ranked against each other with a subjective quantitative analysis. Their ranking could be by the major design areas of Combat System Effectiveness, Mobility, Survivability, and Cost. Each of these areas could be further subdivided into more subjective areas. In this manner, a ship will rank highest in its primary design area, instead of an overall ranking. This type of analysis would provide for an even more rapid comparison of variant designs to eliminate those that do not meet the requirements, thus concentrating the detailed analysis on only the best designs.

The comparative analysis methodology developed in this thesis concentrated solely on combatant type ships. Since many of the indices are compatible to other types of ships, it is recommended that modifications be implemented, as necessary, to make the methodology compatible to submarines, auxiliaries, amphibious ships, aircraft carriers and advanced marine vehicles, as the data bases are developed for them.

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APPENDIX A

SUMMARY OF SCREENS

Summary listing of all two-ship analysis levels, screens, and when used, subcategories of screens.

LEVEL 1: PRIMARY CHARACTERISTICS

Screen 1-1:	Cost and Size Characteristics	tabular
	Total Costs	
	Ship Size	
Screen 1-2:	Shape Characteristics	tabular
Screen 1-3:	Ship Performance	tabular
	Mobility	
	Hull Efficiency	
	Survivability	
Screen 1-4:	HM&E System Selection	tabular
	Main Propulsion	
	Electrical	
	Auxiliary	
	Structure/Materials	
	Deck Heights	
	Manning	
Screen 1-5:	Combat Systems Selection	tabular
	Anti-Air Warfare (AAW)	
	Anti-Submarine Warfare (ASW)	
	Surface/Strike Warfare (SUW)	

LEVEL 2: RESOURCE ALLOCATION

Screen 2-1:	SWBS Weight Fractions	graphical
Screen 2-2:	Load Weight Fractions	graphical
Screen 2-3:	Functional Weight Allocation	graphical

Screen 2-4:	SSCS Volume Fractions	graphical
Screen 2-5:	Space Type/Location Volume	graphical
Screen 2-6:	Functional Volume Allocation	graphical
Screen 2-7:	Electrical Energy Allocation	graphical
Screen 2-8:	Functional Energy Allocation	graphical
	Installed HP	
	Fuel Usage	
	Electrical	
Screen 2-9:	Manning Allocation Fraction	graphical
Screen 2-10:	Functional Manning Allocation	graphical
Screen 2-11:	Basic Construction Cost Allocation	tabular
Screen 2-12:	Functional Allocation Cost	graphical
Screen 2-13:	Cost Fractions	graphical

<u>LEVEL 3: FUNCTIONAL INVESTIGATION</u>

Screen 3-1:	Containment Weight Breakdown	graphical
	Structure Weight	
	Outfit and Furnishings Weight	
Screen 3-2:	Containment Indices	tabular
	Containment drivers	
	Related Containment ratios	
Screen 3-3:	Main Propulsion Breakdown	graphical
	Weight	
	Volume	

Screen 3-4:	Main Propulsion Indices	tabular
	Main propulsion drivers	
	Related Main Propulsion ratios	
Screen 3-5:	Electrical Plant Breakdown	graphical
	Weight	
	Volume	
Screen 3-6:	Electrical Indices	tabular
	Electrical drivers	
	Related Electrical ratios	
Screen 3-7:	Auxiliary Breakdown	graphical
	Weight	
	Volume	
Screen 3-8:	Auxiliary Indices	tabular
	Auxiliary drivers	
	Related Auxiliary ratios	
Screen 3-9:	Combat Systems Breakdown	tabular
	Combat Systems Weight	
	Command & Surveillance Weight	
	Armament Weight	
	Combat Systems Volume	
	Command and Surveillance Volume	
	Armament Volume	
Screen 3-10:	Combat Systems Indices	tabular
	Combat Systems Drivers	
	Related Combat Systems ratios	

Screen 3-11: Human Support Breakdown	graphical
Weight	
Volume	
Screen 3-12: Human Support Indices	tabular
Human Support Drivers	
Related Human Support ratios	
Screen 3-13: Margin Summary	graphical

APPENDIX B

SUMMARY OF REQUIRED INPUT PARAMETERS WITH ASSET RELATIONSHIP

All required input parameters for the methodology are summarized by major category and related to their support or non-support by the Advanced Surface Ship Evaluation Tool (ASSET). If the ASSET support is present with only minor modifications, then the modifications required are indexed by number and explained at the end of the appendix. If they are supported by ASSET then it is noted whether it is by calculation to the output file or within the Main Program Library (MPL), or both.

To use all indices in the two-ship analysis, all of the listed parameters are required in the data base for each ship analysed.

PARAMETERS REQUIRED:		SUPPORTED BY ASSET:	
		CALC	MPL
PRIMARY CHARACTERISTICS:			
DSP.FL	Full Load Displacement	X	X
DSP.LS	Light Ship Displacement	X	
VOL	Total Volume	X	X
L.BP	Length Between Perpendiculars	X	
L.OA	Length Overall		
B.WL	Beam at Waterline	X	
B.MAX	Beam maximum at Deck Edge		
D	Depth at Midships	X	
T	Draft (maximum)	X	
C.P	Prismatic Coefficient	X	X
C.X	Maximum Section Coefficient	X	X
C.W	Waterplane Coefficient	(1)	
WEIGHTS:			
W.1	HULL STRUCTURE	X	X
W.11	Shell and Supporting Structure	X	
W.12+13+14	Structure Bulkheads/Decks	X	
W.15	Deck House Structure	X	
W.16+17+19	Other Structures	X	
W.18	Foundations	X	
W.2	PROPULSION PLANT, GENERAL	X	X
W.23	Propulsion Units	X	
W.24	Transmission and Propulsor Sys	X	
W.25+26+29	Propulsion Support Sys	X	
W.21+22	Other Propulsion		
W.3	ELECTRIC PLANT, GENERAL	X	X
W.31	Electric Power Generation	X	
W.32	Power Distribution Sys	X	
W.33	Lighting System	X	
W.34+39	Electric Support Sys	X	
W.4	COMMAND AND SURVEILLANCE	X	X
W.43+44	Interior/Exterior Comms	X	
W.45	Surveillance Sys (Surface)	X	
W.46	Surveillance Sys (Underwater)	X	
W.41+42+47+ 48+49	Other Command & Surv	X	
W.5	AUXILIARY SYSTEMS	X	X
W.51	Climate Control	X	
W.52+53	Seawater/Freshwater Sys	X	
W.56	Ship Control Systems	X	
W.57+58	Replenishment/Mech Hdling Sys	X	
W.54+55+59	Fluid/Misc Support Sys	X	

W.6	OUTFIT AND FURNISHINGS	X	X
W.61+62+63+69	Non-Crew Related	X	
W.64+65+66+67	Crew Related	X	
W.7	ARMAMENT	X	X
W.71	Guns and Ammunition	X	
W.72	Missiles and Rockets	X	
W.73 thru 79	Other Armament	X	
W.m	D&C Margin Wt	X	
W.al	Architectural Limit Wt		
F1	Crew and Effects	X	
F2	Ordnance	X	
F23+F26	Aviation Related Support	X	
F4	Fuels and Lubricants	X	
F52	Freshwater	X	
F3+F5+F6	Other Loads	X	

KG:

KG.ls	Light Ship KG		
KG.fl	Full Load KG	X	
KG.m	KG Acquisition Margin		
KG.al	Architectural Limit KG		

VOLUMES:

V.hull	Hull Volume	X	
V.dkhs	Deckhouse Volume	X	
V1.	MISSION SUPPORT	X	
V1.1	Command, Communications, Surv.	X	
V1.11	Exterior Communications	X	
V1.121	Surface Surveillance	X	
V1.122	Underwater Surveillance	X	
V1.15	Interior Communications	X	
V1.13+1.14+1.16	Other C&S Volume	X	
V1.2	Weapons	X	
V1.21	Guns	X	
V1.22	Missiles	X	
V1.23	Rockets	X	
V1.24+1.25+ 1.26+1.27	Other Armament Vol	X	
V1.3	Aviation	X	
V1.34	Aircraft Stowage	X	
V2	HUMAN SUPPORT	(2)	
V2.1	Living	X	
V2.2	Commissary	X	
V2.3 thru V2.7	Other Spaces and Stowage	X	
V3	SHIP SUPPORT	(3)	
V3.5	Deck Systems	(4)	
V3.9	Tanks/Voids	(5)	

V4	SHIP MOBILITY	(6)	
V4.1	Propulsion Systems	X	
V4.15	Electric		
V4.2	Propulsor and Transmission Sys		
V4.3	Auxiliary Machinery	(7)	
V4.33	Electrical	(8)	
V5	UNASSIGNED	X	

<u>AREAS:</u>

A2.	HUMAN SUPPORT AREA	(9)	
A2.11+2.211	Officer Living/Messing	X	
A2.12+2.212	CPO Living/Messing	X	
A2.13+2.213	Crew Living/Messing	X	

<u>ENERGY:</u>

Note: Four possible combinations
10 degree day / 90 degree day
Battle / Cruise

E.i	Installed KW	X	
E.t	Maximum KW	(10)	
E.2	Propulsion Related KW		
E.3	Electrical Related KW		
E.4	Command and Control KW		
E.5	Auxiliary Related KW		
E.6	Outfit and Furnishings KW		
E.7	Armament KW		
E.am	Acquisition Margin KW	(11)	
E.slm	Service Life Margin KW	(11)	

<u>MANNING:</u>

M.a	Total Accomodations	X	
M.aoff	Officer Accomodations		X
M.acpo	CPO Accomodations		X
M.aenl	Enlisted Accomodations		X
M.t	Total Complement	(12)	
M.off	Officer Complement	X	
M.cpo	CPO Complement	X	
M.enl	Enlisted Complement	X	
M.m	Manning Margin		
M.cs	Combat Systems Dept. Manning	X	
M.ops	Operations Dept. Manning	X	
M.eng	Engineering Dept. Manning	X	
M.na	Nav/Admin Dept. Manning	X	
M.sup	Supply Dept. Manning	X	
M.av	Aviation Dept. Manning	X	

COST:

Note: Lead Ship or Follow Ship

C.1	Structural Related Cost	X	
C.2	Propulsion Related Cost	X	
C.3	Electrical Related Cost	X	
C.4	Command and Surveillance Cost	X	
C.5	Auxiliary Related Cost	X	
C.6	Outfit and Furnishings Cost	X	
C.7	Armament Related Cost	X	
C.m	Design/Const. Cost Margin	X	
C.de	Design/Engr. Costs (Gp 8)	X	
C.con	Const. Services (Assy-Gp 9)	X	
C.pr	Profit	X	
C.csgfe	Combat System GFE Costs	(13)	
C.oth	Total Other Costs	(14)	
C.HM&E	HM&E GFE	(15)	
C.pmg	Proj Mgr Growth	(16)	
C.ls	Total Cost-Lead Ship	(17)	
C.bcfs	Basic Constr. Cost-Follow Ship	(18)	
C.fs	Total Cost-Follow Ship	(17)	

SHIP PERFORMANCE:

Mobility:		
Max Sustained Speed (80% power)	X	
Max Trial Speed (100% power)	X	
Range at Endurance Speed	X	
Endurance Period due to fuel @ endurance speed	(19)	
Endurance due to Stores		X
Endurance due to Chilled Stores		X
Endurance due to Frozen Stores		X
Shaft Horsepower Available	X	
Shaft Horsepower Required @ Endurance Speed	X	
Shaft Horsepower Required @ Sustained Speed	X	
Hull Efficiency:		
Drag (Sustained Spd)	X	X
Drag (Endurance Spd)	X	X
Bales Rank	X	
Survivability:		
Blast		
Fragmentation		
Shock		
NBC		
Noise Signature		
IR Signature		
Radar Signature		

HM&E SYSTEM SELECTION:

Main Propulsion:		
Total Boost Power Avail/Reqd @ Sust Spd/Growth Pot	XXX	
Boost Engine Type/Number/Rating	XXX	XXX
Cruise Engine Type/Number/Rating	XXX	XXXX
Transmission System Type	X	X
Propeller Type/Number/RPM	XXX	XXX
Propeller Open Water Efficiency (sustained)	X	
Propeller Open Water Efficiency (endurance)	X	
Propulsion Coefficient	X	
Specific Fuel Consumption Rate @ Endurance	X	
Specific Fuel Consumption Rate @ Sustained	X	
Electric Power:		
Total 60Hz KW Avail/Maximum Load/Growth Pot.	XXX	X
Total 400Hz KW Avaail/Max Load/Growth Pot.		
60 Hz Generator Type/No./Rating	XXX	XXX
400 Hz Converter Type/No./Rating		
Specific Fuel Consumption Rate (SFCA)	X	
Auxiliary:		
Total AC Avail/MaxLoad/Growth Pot.		
AC Type/No./Rating		
Heating Type/Rating		
Firepump Type/No./Rating		
Seawater Type/No./Rating		
HP Air Compressor Type/No./Rating		
LP Air Compressor Type/No./Rating		
Distilling Plant Type/No./Rating		
Boats Type/No.		
Steering Units Type/No.		
Anchors Type/No./Length of Chain		X
UNREP Capability		X
Structure/Materials:		
Hull Materials (array)	X	X
Deckhouse Materials (array)	X	X
Hull Frame Type/Spacing	XX	
Deckhouse Frame Type/Spacing		
Deck Heights:		
Number of Internal Decks in Hull	X	
Number of Internal Decks in Deckhouse	X	
Internal Deck Heights (array)	X	
Hull Average Deck Heights	X	X
Manning:		
Total Accomodations/Total Complement/Growth Pot	XX	
Total Complement (OFF/CPO/ENL)	XXX	
Habitability Classification		X
Flag Configured		X

COMBAT SYSTEM SELECTION: (20)

Anti-Air Warfare (AAW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Anti-Submarine Warfare (ASW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Surface/Strike Warfare (SUW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Command, Control, Communications & Intelligence
Communications
Electronic Warfare
Control

MISCELLANEOUS INPUTS:

HP.shpi	Total installed SHP	X	
HP.geni	Total installed Generator HP		
HP.shpe	Prop HP @ endurance spd	X	
HP.gene	Gen HP @ avg 24 hr load	X	
SFC.e	Prop SFC @ endurance spd	X	
SFCA.e	Gen SFC @ avg 24 hr load	X	
E.24	Average 24 hr Elec Load	X	X
# lchr	Number of Launchers	(21)	
# snsr	Number of Sensors	(21)	
YEAR	Year Commissioned (IOC)		X

NOTES: Equivalent ASSET parameters

(1) Use (Waterplane Area)/(L.bp * B.wl)

NOTE: For volumes where only area is given, multiply area by average deck height to get volume.
(2) V2.0-V2.8-V2.9
(3) V3.0-V3.41-V3.51+V2.8+V2.9+V4.3
(4) V3.42
(5) V3.9+V2.8+V2.9+V4.3
(6) V4.0+V3.41+V3.51-V4.3
(7) V3.41
(8) V3.51

(9) A2.0-A2.9-A2.8

(10) Use Peak Electric Load
(11) Use (.40 * Elect Margin KW for Acquisition Margin)

(12) Use Required Manning Column

(13) Payload Cost
(14) Outfitting+Post Delivery+NAVSEA Support +
 + Change Orders + [.6 * (HM&E+Growth)]
(15) .4 * (HM&E + Growth)
(16) .6 * (HM&E + Growth)
(17) Ship Plus Payload Cost
(18) PRICE (follow ship)

(19) [usable Fuel Wt/(1ton/hr)]/(24 hrs/day) : Mach Module Menu 4

(20) List of Combat Systems is available in ASSET, however, a new array must be established to allow user to specify which warfare area and sub-area each system will be a part of. The module will then know where to put each system.

(21) Add array to allow user to mark which systems are to be counted as either sensors or launchers.

APPENDIX C

DD963 VS DDG51 COMPARISON

An example of a full data base analysis of an existing ship versus a new design. The DD963, at delivery, is compared to the current DDG51 design using a two-ship analysis simulated on a microcomputer spreadsheet.

The initial section of the analysis simulates a data base from which the indices in the screens draw their data. This is similar to the method that would be used if a real data base were available. The reader should note that to prevent the duplication of information, the data for screens 1-3, 1-4 and 1-5 are input directly into the screen and not placed with the simulated data base information. The screens of the spreadsheets have been programmed to draw the data from the data base portion and create the indices in a tabular display. The last column then manipulates the indices to provide the difference or "delta" as explained in section 3.5.

The parameters used for this study are notional and may not totally reflect the current designs. Although every effort was made to obtain the most accurate information available, extreme accuracy was not as important as having sufficient information available to present a good example of how the two-ship analysis is presented and how a comparative analysis would be performed. The input source data is therefore not published to prevent the reader

from being misled. The "delta" information, however, is included to show that significant differences do exist and can be easily extracted from the raw information for the comparative analysis.

PRIMARY INPUT SECTION:

		BASELINE DD-963	VARIANT DDG-51
PRIMARY CHARACTERISTICS:			
DSP.FL	Displ Full Load		
DSP.LS	Displ Light Ship		
VOL	Total Volume		
L.BP	Length btwn perp.		
L.OA	Length overall		
B.WL	Beam at waterline		
B.MAX	Beam (max)		
D	Depth.		
T	Draft (max)		
C.P	Prismatic Coef.		
C.X	Max Section Coef.		
C.W	Waterplane Coef.		
WEIGHTS:			
W.1	HULL STRUCTURE		
W.11	Shell/Supports		
W.12+13+14	Struct. blkhds/decks.		
W.15	Deckhouse Struct.		
W.18	Foundation		
W.16+17+19	Other Structure		
W.2	PROPULSION PLANT		
W.23	Propulsion Units		
W.24	Transm/propulsor		
W.25+26+29	Prop.Support		
W.21+22	Other Propulsion		
W.3	ELECTRIC PLANT		
W.31	Elec Power Generation		
W.32	Power Distribution Sys		
W.33	Lighting System		
W.34+39	Elec Support Sys		
W.4	COMMAND AND SURVEILLANCE		
W.43+44	Interior/Exterior Comms		
W.45	Surveillance (surface)		
W.46	Surveillance (subsurf)		
W.41+42+47+ +48+49	Other Command & Surv.		
W.5	AUXILIARY SYSTEMS		
W.51	Climate control		
W.52+53	Seawater/Freshwater sys		
W.56	Ship Control Sys		
W.57+58	Replen/Mech Hndling Sys		
W.54+55+59	Fluid/Misc Support Sys		
W.6	OUTFIT AND FURNISHINGS		
W.61+62+63+69	Non-Crew Related		

W.64+64+66+67	Crew Related
W.7	ARMAMENT
W.71	Guns and Ammunition
W.72	Missiles and Rockets
W.73 thru 79	Other Armament
W.m	D&C Margin Wt
W.al	Architecural Limit Wt
F1	Crew and Effects Load
F2	Ordnance Load
F23+F26	Aviation Support Load
F4	Fuels/Lubricant Load
F52	Freshwater Load
F3+F5+F6	Other Loads

KG:

KG.ls	Light Ship KG
KG.fl	Full Load KG
KG.m	KG aquisition margin
KG.al	Architectural Limit KG

VOLUMES:

V.hull	Hull Volume
V.dkhs	Deckhouse Volume
V1	MISSION SUPPORT
V1.1	Command, Comm, Surv.
V1.11	Exterior Comms
V1.121	Surface Surveillance
V1.122	Underwater Surveillance
V1.15	Interior Comms
V1.13+1.14 +1.16	Other C&S Volume
V1.2	Weapons
V1.21	Guns
V1.22	Missiles
V1.23	Rockets
V1.24+1.25 +1.26+1.27	Other Armament Vol
V1.3	Aviation
V1.34	Aircraft Stowage
V2	HUMAN SUPPORT
V2.1	Living
V2.2	Commissary
V2.3 Thru 2.7	Other Human Support Vol
V3	SHIP SUPPORT
V3.5	Deck Systems
V3.9	Tanks/Voids
V4	SHIP MOBILITY
V4.1	Propulsion Systems
V4.15	In Machy Box Electric

V4.2	Propulsor/Transmission
V4.3	Auxiliary Machinery
V4.33	Outside Machy Box Elect.
V5	UNASSIGNED

AREAS:

A2	HUMAN SUPPORT AREA
A2.11+2.211	Officer Living/Messing
A2.12+2.212	CPO Living/Messing
A2.13+2.213	Crew Living/Messing

ENERGY:

Note: for this analysis, use only
10 deg day at Battle condition

E.i	Installed KW
E.t	Maximum KW
E.2	Propulsion KW
E.3	Electrical KW
E.4	Command & Surv KW
E.5	Auxiliary KW
E.6	Outfit and Furn. KW
E.7	Armament KW
E.am	Elec Aquisition Margin
E.slm	Elec Service Life Margin

MANNING:

M.a	Total Accomodations
M.aoff	Officer Accom
M.acpo	CPO Accom
M.aenl	Crew Accom
M.t	Total Complement
M.off	Officer Complement
M.cpo	CPO Complement
M.enl	Crew Complement
M.m	Manning Margin
M.cs	Combat Systems Manning
M.ops	Operations Manning
M.eng	Engr. Manning
M.na	Nav/Admin Manning
M.sup	Supply Manning
M.av	Aviation Manning

COST:

Note: Select Lead Ship for analysis
All Costs x1000

C.1	Structural Related
C.2	Propulsion Related
C.3	Electrical Related
C.4	Command/Surv. Related
C.5	Auxiliary Related

C.6	Outfit & Furn. Related
C.7	Armament Related
C.m	D+C Cost Margin
C.de	Design/Engr (Gp8)
C.con	Constr. Svcs (assy Gp9)
C.pr	Profit
C.csgfe	Combat Systems GFE
C.oth	Total Other Costs
C.HM&E	HM&E GFE
C.pmg	Project Mgr Growth
C.ls	Total Cost Lead Ship
C.bcfs	Basic Const-Follow Ship
C.fs	Total Cost Follow Ship

MISCELLANEOUS INPUTS:

HP.shpi	Total Installed SHP
HP.geni	Total Installed Gen HP
HP.shpe	Propul HP @ Endur. Spd
HP.gene	Gen HP @ avg 24 hr load
SFC.e	Prop SFC @ Endur. Spd
SFCA.e	Gen SFC @ avg 24 hr load
E.gen	KW Rating per Generator
E.24	Avg 24 Hr Elec Load
# lchr	Number of Launchers
# snsr	Number of Sensors
YEAR	Year Commissioned

NOTE: Input Screens 1-3, 1-4, 1-5 directly

		DD963	DDG51	Delta
SCREEN 1-1:	COST & SIZE CHARACTERISTICS			
TOTAL COSTS:	(use lead ship)			
C.bc	Basic Construction Cost			2.0%
C.csgfe	Combat Sytem GFE cost			33.4%
C.oth	Other Costs			2.0%
C.t	Total Ship cost			9.9%
SHIP SIZE:				
DSP.fl	Full Load Displacement			7.9%
DSP.ls	Light Ship Displacement			12.6%
VOL	Total Enclosed Volume			-6.4%
DSP.fl/VOL	Ship Density Full Load			15.3%
DSP.ls/VOL	Ship Density Light Ship			20.3%
L.bp	Length Between Perp.			-11.9%
L.oa	Length Overall			-10.5%
B.wl	Beam at Waterline			7.3%
B.max	Beam (max at deckedge)			21.6%
D	Depth at midships			-.5%
T	Draft (max)			11.1%

SCREEN 1-2: SHAPE CHARACTERISTICS

DSP/(.01L)^3	Displacement/Length rat.	57.8%
C.p	Prismatic Coeff	6.0%
C.x	Max Section Coeff	.2%
C.w	Waterplane Coeff	7.7%
L.bp/B.wl	Length/Beam ratio	-17.9%
L.bp/T	Length/Draft ratio	-20.7%
B.wl/T	Beam/Draft ratio	-3.5%
T/D	Draft/Depth ratio	11.6%
L.bp/D	Length/Depth ratio	-11.5%

NOTE: * in difference column indicates that a difference exists for non-numeric items

SCREEN 1-3: SHIP PERFORMANCE

MOBILITY:	
Max Sustained Spd (80% Power)	0.0%
Max Trial Spd (100% Power)	NA
Range @ Endurance Speed	-25.0%
Endurance Period (Fuel @ Endur Spd)	-33.3%
Endurance Period (Stores)	0.0%
Endurance Period (Chilled Stores)	0.0%
Endurance Period (Frozen Stores)	0.0%
Shaft Horsepower Available	25.0%
Shaft Horsepower Req @ Endurance	5.0%
Shaft Horsepower Req @ Sustained	25.0%
HULL EFFICIENCY:	
Drag (sustained spd)	34.4%
Drag (endurance spd)	-9.5%
Bales Rank	106.2%
SURVIVABILITY:	
Blast	
Fragmentation	*
Shock	
NBC	*
Noise Signature	*
IR Signature	
Radar Signature	*

SCREEN 1-4: HM&E SYSTEM SELECTION

MAIN PROPULSION:	
Total Boost Power Avail	22.1%
Boost Reqd at Sustained Spd	25.0%
Boost Growth Potential	13.6%
Boost Engine Type	
Boost Engine Number/Rating	*
Cruise Engine Type	
Cruise Engine Number/Rating	
Transmission Sys Type	

Propeller Type	
Propeller Number/RPM	*
Propeller Open Wtr Effy (sustained)	2.8%
Propeller Open Wtr Effy (endurance)	4.3%
Propulsion Coefficient (PC)	11.9%
SFC @ Endurance Spd	*
SFC @ Sustained Spd	*
Other	
ELECTRIC POWER:	
Total 60 Hz Available	25.0%
Total 60 Hz Max Load	31.9%
60 Hz Growth Potential (all Gen)	18.9%
Total 400 Hz Available	20.0%
Total 400 Hz Max Load	33.3%
400 Hz Growth Potential	12.3%
60 Hz Generator Type	
60 Hz Generator Number/Rating	*
400 Hz Converter Type	*
400 Hz Converter Number/Rating	*
SFCA	*
Other	
AUXILIARY:	
Total AC Available	20.0%
AC Maximum Load	33.3%
AC Growth Potential	33.3%
AC Type	
AC Number/Rating	*
Heating Type	*
Heating Rating	*
Firepump Type	
Firepump No./Rating	
Seawater Pump Type	
Seawater Pump No./Rating	*
HP Air Compressor Type	
HP Air Compressor No./Rating	
LP Air Compressor Type	*
LP Air Compressor No./Rating	*
Distilling Plant Type	*
Distilling Plant No./Rating	*
Boats Type/No.	*
Steering Units Type/No.	
Anchors Type/No.	
Anchors Length of Chain	
UNREP Capability	
Other	
STRUCTURE/MATERIALS:	
Hull Materials (array)	
Deckhouse Materials (array)	*
Hull Frame Type/Spacing	*

Deckhouse Frame Type/Spacing	*
Other	
DECK HEIGHTS:	
Number internal decks in hull	
Number internal decks in deckhouse	
Internal Deck Heights (array above BL)	*
	*
	*
	*
Hull Avg Deck Height	*
Other	
MANNING:	
Total Accom/Complement/Growth Pot.	*
Total Complement (OFF/CPO/ENL)	*
Habitability Classification	*
Flag Configured	
Other	

<u>SCREEN 1-5: COMBAT SYSTEMS SELECTION</u>

ANTI-AIR WARFARE:	
Armament	*
	*
	*
Sensors	*
	*
	*
Aviation Capabilities	*
ANTI-SUBMARINE WARFARE:	
Armament	
Sensors	*
	*
Aviation Capabilities	*
SURFACE/STRIKE WARFARE:	
Armament	*
	*
Sensors	*
	*
Aviation Capabilities	*
COMMAND/CONTROL/COMM/INTEL:	
Communications	
Electronic Warfare	

Control

SCREEN 2-1: SWBS WEIGHT FRACTIONS

LIGHT SHIP:		
W.1/DSP.LS	Structural	-4.84%
W.2/DSP.LS	Main Propulsion	-4.9%
W.3/DSP.LS	Electrical	36.6%
W.4/DSP.LS	Command & Surveillance	7.0%
W.5/DSP.LS	Auxiliary	8.5%
W.6/DSP.LS	Outfit & Furnishings	22.3%
W.7/DSP.LS	Armament	94.1%
W.m/DSP.LS	Margin	7.8%
FULL LOAD:		
W.1/DSP.FL	Structural	-4.84%
W.2/DSP.FL	Main Propulsion	-4.9%
W.3/DSP.FL	Electrical	36.6%
W.4/DSP.FL	Command & Surveillance	7.0%
W.5/DSP.FL	Auxiliary	8.5%
W.6/DSP.FL	Outfit & Furnishings	22.3%
W.7/DSP.FL	Armament	94.1%
W.m/DSP.FL	Margin	6.1%

SCREEN 2-2: LOAD WEIGHT FRACTIONS

W.fuel/W.ld	Liquid (fuel & Lube)	-13.0%
W.ce/W.ld	Crew and Effects	15.2%
W.ord/W.ld	Ordnance	149.1%
W.av/W.ld	Aviation	-100.0%
W.oth/W.ld	Others	-8.9%
W.ld/DSP.FL	Load to Full Load ratio	-6.2%
DSP.ls/DSP.fl	Lightship to Full ratio	12.6%

SCREEN 2-3: FUNCTIONAL WT. ALLOCATION

W.csl/DSP.LS	LS Combat Sys Weight	44.7%
W.mal/DSP.LS	LS Machinery Weight	16.4%
W.cl/DSP.LS	LS Containment Weight	7.0%
W.csf/DSP.FL	FL Combat Sys Weight	56.5%
W.maf/DSP.FL	FL Machinery Weight	2.1%
W.cf/DSP.FL	FL Containment Weight	6.3%

SCREEN 2-4: SSCS VOLUME FRACTIONS

V1/VOL	Mission Support	-6.0%
V2/VOL	Human Support	-6.5%
V3/VOL	Ship Support	-13.1%
V4/VOL	Ship Mobility	5.1%
V5/VOL	Unassigned	-90.3%

SCREEN 2-5: SPACE TYPE/LOCATION VOLUME

V.hull/VOL	Hull Volume			1.2%
V.dh/VOL	Deckhouse Volume			-29.1%
V.tk/VOL	Tankage/Void Volume			-23.8%
V.lo/VOL	Large Space Volume			-6.3%
V.a/VOL	Arrangeable Volume			-3.7%

SCREEN 2-6: FUNCTIONAL VOLUME ALLOCATION

V.cs/VOL	Combat Sys Volume			-6.0%
V.ma/VOL	Machinery Related Vol			-4.9%
V.c/VOL	Containment Volume			-5.3%
V.5/VOL	Unassigned Volume			-90.3%

SCREEN 2-7: ELECTRICAL ENERGY ALLOCATION

Note: max load/ 10 deg day/Battle

E2/E	Propulsion Plant			17.9%
E3/E	Electric Plant			26.0%
E4/E	Command and Surveillance			92.0%
E5/E	Auxiliary			-12.3%
E6/E	Outfit & Furnishings			136.4%
E7/E	Armament			-29.8%
Em/E	Margin (Acq.+Serv Life)	NA	NA	

Note: installed load/10 deg/Battle

E2/E	Propulsion Plant			17.9%
E3/E	Electric Plant			26.0%
E4/E	Command and Surveillance			92.0%
E5/E	Auxiliary			-12.3%
E6/E	Outfit & Furnishings			136.4%
E7/E	Armament			-29.8%
Em/E	Margin (Acq + Serv Life)			73.6%

SCREEN 2-8: FUNCTIONAL ENERGY ALLOCATION

INSTALLED HP:		
HP.shpi/HP.t	Propulsion HP Allocation	25.0%
HP.geni/HP.t	Electrical HP Allocation	63.7%
FUEL USAGE:		
FF.mp/FF.t	Propulsion Fuel Alloc.	20.5%
FF.gen/FF.t	Electrical Fuel Alloc.	40.2%
ELECTRICAL:		
Note: max load/10deg day/Battle		
E.cs/E.t	Combat System Elec	47.8%
E.ma/E.t	Machinery Elec	-.1%
E.c/E.t	Containment Elec	136.4%
Note: instal load/10deg day/Battle		
E.cs/E.i	Combat System Elec	65.5%
E.ma/E.i	Machinery Elec	11.9%
E.c/E.i	Containment Elec	164.7%

SCREEN 2-9: MANNING ALLOCATION

M.off/M.a	Officer Ratio	0.0%
M.cpo/M.a	CPO Ratio	5.0%
M.enl/M.a	Crew Ratio	14.7%
M.m/M.a	Manning Margin	15.4%

SCREEN 2-10: FUNCTIONAL MANNING ALLOCATION

M.cs/M.a	Combat Systems Manning	18.7%
M.ops/M.a	Operations Manning	15.1%
M.eng/M.a	Engineering Manning	15.4%
M.na/M.a	Nav/Admin Manning	5.9%
M.sup/M.a	Supply Manning	22.9%
M.av/M.a	Aviation Manning	-100.0%

SCREEN 2-11: BASIC CONSTRUCTION COST ALLOCATION

Note: Lead Ship Costs

C1/C.bc	Hull Structure	-38.1%
C2/C.bc	Propulsion Plant	17.5%
C3/C.bc	Electric Plant	-39.6%
C4/C.bc	Command and Surveillance	3.2%
C5/C.bc	Auxiliary	5.9%
C6/C.bc	Outfit and Furnishings	29.3%
C7/C.bc	Armament	88.3%
C.m/C.bc	D+C Margin	NA
C.de/C.bc	Design/Engr (Gp 8)	2.1%
C.con/C.bc	Constr. Svcs/Assy (Gp9)	1.6%
C.pr/C.bc	Profit	2.0%
C.HM&E/C.BC	HM&E GFE	2.0%

SCREEN 2-12: FUNCTIONAL COST ALLOCATION

Note: Lead Ship Costs

C.cs/C.t	Combat Systems	27.5%
C.ma/C.t	Machinery	5.1%
C.c/C.t	Containment	-11.5%

SCREEN 2-13: COST FRACTIONS

C.csgfe/C.ls	Combat Sys GFE/Lead Ship	33.4%
C.csgfe/C.fs	Combat Sys GFE/Follow	33.4%
C.bcls/C.ls	Basic Constr/Lead Ship	2.0%
C.bcfs/C.fs	Basic Constr/Follow	1.9%
C.fs/DSP.fl	Follow Ship Cost/Weight	5.3%
C.fs/VOL	Follow Ship Cost/Volume	21.4%

SCREEN 3-1: CONTAINMENT WT BREAKDOWN

STRUCTURE WEIGHT:

W.11/W.1	Shell and Supports	-19.3%
W.12+13+14/W.1	Hull Struc Blkhds/Decks	-5.4%
W.15/W.1	Deckhouse	35.9%
W.18/W.1	Foundations	14.3%

W.16+17+19/W.1	Other Structural	1.4%

OUTFIT AND FURNISHINGS:

W.64+65+66+ 67/W.6	Crew Related	51.8%
W.61+62+63+ 69/W.6	Non-crew Related	10.9%

SCREEN 3-2: CONTAINMENT INDICES

CONTAINMENT DRIVERS:

W.1/DSP.FL	Structural Wt Fraction	-4.8%
W.6/DSP.FL	Outfit & Furn. Wt. Frac	22.3%
W.1/VOL	Hull Struc Specific Wt	1.7%
W.6/VOL	Outfit & Furn. Spec Wt	30.7%
VOL/DSP.FL	Ship Specific Volume	-13.3%

RELATED CONTAINMENT RATIOS:

W.cf/V.c	Containment Density	12.3%
W.11+12+13+ 14/V.Hull	Basic Hull Struc Density	-13.1%
W.15/V.dh	Deckhouse Struc Density	91.8%
W.18/W.2+3+ 4+5+7	Foundations Wt Fraction	14.3%
C.c/W.cf	Containment Cost/Wt rat.	-15.5%

SCREEN 3-3: MAIN PROPULSION BREAKDOWN

WEIGHT:

W.23/W.2	Propulsion Units Wt	-9.3%
W.24/W.2	Transmission/Prop Wt	11.2%
W.25+26+29/W.2	Propulsion Support Wt	-24.0%
W.21+22/W.2	Other Propulsion Wt	0.0%

VOLUME:

V4.1-4.15/V.pt	Propulsion Sys Volume	-1.5%
V4.2/V.pt	Transmission/Prop Vol	-81.3%

SCREEN 3-4: MAIN PROPULSION INDICES

MAIN PROPULSION DRIVERS:

W.2/DSP.FL	Main Propulsion Wt Frac	-4.9%
W.2/SHP	Main Propulsion Spec Wt	-23.9%
SHP/DSP.FL	Main Prop Ship Size Rat	15.9%
R.Te/DSP.FL	Drag/Disp Ratio (endur)	-16.1%
R.Ts/DSP.FL	Drag/Disp Ratio (sust)	24.6%
PC	Propulsion Coefficient	11.9%

RELATED MAIN PROPULSION INDICES:

W.2/V.pt	Main Propulsion Density	-8.3%
V.pt/VOL	Main Prop Volume Frac	-6.1%
W.23/SHP	Prop Units Specific Wt	-27.4%
W.24/SHP	Trans/Prop Specific Wt	-11.0%
W.25+26+29/SHP	Support/Fluids Spec Wt	-39.2%
V.pt/SHP	Prop & Trans Spec Vol	-24.9%
V4.1-4.15/SHP	Prop Systems Spec Vol	-21.2%

V4.2/SHP	Trans/Prop Spec Vol	-85.0%
E.2/W.2	Prop KW/Weight Ratio	24.0%
C.2/W.2	Prop Cost/Weight Ratio	23.6%

SCREEN 3-5: ELECTRICAL PLANT BREAKDOWN

WEIGHT:

W.31/W.3	Power Generation Wt	-4.8%
W.32/W.3	Power Distribution Wt	58.4%
W.33/W.3	Lighting Wt	2.4%
W.34+39/W.3	Support Systems Wt	629.4%

VOLUME:

V4.15/V.e	Machinery Box Elec Vol	-100.0%
V4.33/V.e	Aux Space Elec Vol	-33.2%

SCREEN 3-6: ELECTRICAL INDICES

ELECTRICAL DRIVERS:

W.3/DSP.FL	Electrical Wt Fraction	36.6%
W.3/E.i	Electrical Spec Wt	9.3%
E.i/DSP.FL	Elec Capac Ship Size Ra	15.9%

RELATED ELECTRICAL RATIOS:

W.3/V.e	Electrical Density	124.5%
V.e/VOL	Electrical Vol Fraction	-39.1%
W.31/E.i	Power Gen Specific Wt	-23.9%
V.e/E.i	Electrical Spec Vol	-51.3%
E.3/W.3	Elec KW/Weight Ratio	38.9%
C.3/W.3	Elec Cost/Weight Ratio	-33.4%

SCREEN 3-7: AUXILIARY BREAKDOWN

WEIGHT:

W.51/W.5	Climate Control Wt	-4.7%
W.52+53/W.5	Seawater/Freshwater Wt	24.2%
W.54+55+59/W.5	Fluid Systems Wt	18.3%
W.56/W.5	Ship Control Wt	-11.7%
W.57+58/W.5	Replenish/Mech Hndlg Wt	4.4%

VOLUME:

V3.5/V.ax	Deck Systems Volume	-51.8%
V4.3-4.33/V.ax	Auxiliary Mach Volume	54.4%

SCREEN 3-8: AUXILIARY INDICES

AUXILIARY DRIVERS:

W.5/DSP.FL	Auxiliary Wt Fraction	8.5%
W.5/VOL	Auxiliary Spec Wt	16.0%
VOL/DSP.FL	Ship Specific Vol	-13.3%

RELATED AUXILIARY RATIOS:

W.5/V.ax	Auxiliary Density	-17.4%
V.ax/VOL	Auxiliary Volume Frac	31.4%
E.5/W.5	Auxiliary KW/Wt Ratio	15.4%
C.5/W.5	Auxiliary Cost/Wt Ratio	39.3%

SCREEN 3-9: COMBAT SYSTEMS BREAKDOWN

COMBAT SYSTEMS WEIGHT:		
W.4/W.csf	Command & Surv Wt	7.0%
W.7/W.csf	Armament Wt	94.1%
W.av/W.csf	Aviation Wt	-100.0%
W.ord/W.csf	Ordnance Wt	149.1%
COMMAND AND SURVEILLANCE WEIGHT:		
W.43+44/W.4	Interior/Exter Comm Wt	17.7%
W.45/W.4	Surface Surv Wt	1004.3%
W.46/W.4	Underwater Surv Wt	-35.9%
W.41+42+47+48+ 49/W.4	Other C&S Wt	2.3%
ARMAMENT WEIGHT:		
W.71/W.7	Guns and Ammo Wt	-44.5%
W.72/W.7	Missiles/Rockets Wt	359.6%
W.73thru79/W.7	Other Armament Wt	59.7%
COMBAT SYSTEMS VOLUME:		
V1.1/V1	Command and Surv Volume	16.8%
V1.2/V1	Armament Volume	24.3%
V1.3/V1	Aviation Volume	-92.6%
COMMAND AND SURVEILLANCE VOLUME:		
V1.11+ 1.15/V1.1	Interior/Exter Comm Vol	20.0%
V1.121/V1.1	Surface Surv Vol	238.6%
V1.122/V1.1	Underwater Surv Vol	21.5%
V1.13+1.14+ 1.16/V1.1	Other C&S Vol	-7.9%
ARMAMENT VOLUME:		
V1.21/V1.2	Guns & Ammo Vol	-6.0%
V1.22+ 1.23/V1.2	Missiles/Rockets Vol	81.2%
V1.24+1.25+ 1.26+1.27/V1.2	Other Armament Vol	-40.3%

SCREEN 3-10: COMBAT SYSTEMS INDICES

COMBAT SYSTEMS DRIVERS:		
W.7/DSP.FL	Armament Wt Fraction	94.1%
#L/DSP.FL	Armament Cap Size Ratio	-7.3%
W.7/#L	Armament Spec Wt	94.1%
W.4/DSP.FL	C&S Weight Fraction	7.0%
#S/DSP.FL	C&S Capacity Size Ratio	11.2%
W.4/#S	C&S Specific Wt	-10.8%
RELATED COMBAT SYSTEM RATIOS:		
W.csf/V1	Combat System Density	66.4%
W.4/V1.1	Command & Surv Density	-8.3%
W.7/V1.2	Armament Density	56.2%
E.cs/W.csf	Combat Sys KW/Wt Ratio	5.8%
C.cs/W.csf	Combat Sys Cost/Wt Ratio	-18.5%

SCREEN 3-11: HUMAN SUPPORT BREAKDOWN

WEIGHT:		
W.ce/W.HS	Crew and Effects Wt	15.2%
W.6cr/W.HS	Outfit & Furn Wt	51.8%
W.pw/W.HS	Potable Water Wt	11.9%
VOLUME:		
V2.1/V2	Living Volume	-15.8%
V2.2/V2	Food Svs/Mess/Lounge Vol	-12.3%
V2.3thru2.7/V2	Medical/Gen/Other Vol	51.4%

SCREEN 3-12: HUMAN SUPPORT INDICES

HUMAN SUPPORT DRIVERS:		
W.HS/DSP.FL	Human Support Wt Frac	38.0%
W.HS/M.a	Human Support Spec Wt	22.1%
M.a/DSP.FL	Total Accom Ship Size Ra	4.7%
RELATED HUMAN SUPPORT RATIOS:		
W.HS/V2	Human Support Density	47.5%
V2.1/M.a	Persnl Living Spec Vol	-25.5%
V2/M.a	Human Support Spec Vol	-17.2%
A2/M.a	Human Support Spec Area	-21.3%
A2.11+2.211/ M.aoff	Officer Lvng Area/Man	-17.3%
A2.12+2.212/ M.acpo	CPO Living Area/Man	-23.9%
A2.13+2.213/ M.aenl	Enlisted Lvng Area/Man	-48.2%
M.aoff/DSP.FL	Officer Ship Size Ratio	-7.3%
M.acpo/DSP.FL	CPO Ship Size Ratio	5.9%
M.aenl/DSP.FL	Enlisted Ship Size Ratio	5.8%

SCREEN 3-13: MARGIN SUMMARY

WEIGHT:		
W.m/(Dls-W.m)	Acquisition Margin NAVSEA Standard	8.5%
(W.al-Dfl)/Dfl	Service Life Margin NAVSEA Standard	8.5%
KG:		
KG.m/KG.ls	Acquisition Margin NAVSEA Standard	5.0%
(KG.al-KG.fl) /KG.fl	Service Life Margin NAVSEA Standard	-29.4%
ELECTRIC POWER:		
E.m/E.t	Acquisition Margin NAVSEA Standard	18.1%
E.slm/(E.t-E.2 +E.ma+E.slm)	Service Life Margin NAVSEA Standard	-.2%

VOLUME:		
V.5/VOL	Service Life Margin NAVSEA Standard	-90.3%
MANNING:		
(M.a-M.t)/M.t	Service Life Margin NAVSEA Standard	15.4%

APPENDIX D

ASSET BASELINE VS NEW TECHNOLOGY VARIANT COMPARISON

This appendix presents an example of how the two ship analysis would differ if the Advanced Surface Ship Evaluation Tool were used to perform a new technology tradeoff study. In this case, a new technology frigate developed by Goddard in reference (41) was used as the baseline. A variant was created by holding performance constant and changing the main propulsion system from the standard LM2500-30 to an Intercooled Regenerative Gas Turbine (IRGT) system. The output from ASSET was then used for both ships and placed into a spreadsheet data base to simulate the two-ship technology tradeoff comparison discussed in chapter 3.

This study should convince the reader that ASSET already supports the greater majority of the indices selected for analysis by the author. The only serious shortcomings appear in the area of electrical, auxiliaries and survivability. The basic methodology, however, is not impacted and a satisfactory analysis can be easily obtained, as shown in the study performed in section 3.5.3.1.

All parameters were obtained from either the output or the MPL of ASSET. Some output was modified, as discussed in appendix B, to obtain the proper comparative analysis parameter used in this methodology. These changes were made manually outside the realm of the spreadsheet. The existing logic and calculations of ASSET

could be easily modified to implement these changes internally in the program.

Those input parameters and their associated indices not supported by ASSET are listed as "NA" and cannot be implemented in the existing versions of ASSET. The recommended method of interfacing the comparative analysis methodology to the ASSET program is discussed further in chapter 7.

PRIMARY INPUT SECTION:

		BASELINE TECH BASE	VARIANT IRGT VAR
PRIMARY CHARACTERISTICS:			
DSP.FL	Displ Full Load	5537.3	5328.5
DSP.LS	Displ Light Ship	4260.1	4274.0
VOL	Total Volume	658118.0	650232.0
L.BP	Length btwn perp.	425.0	410.0
L.OA	Length overall	NA	NA
B.WL	Beam at waterline	50.0	50.8
B.MAX	Beam (max)	NA	NA
D	Depth.	38.0	38.0
T	Draft (max)	18.8	18.5
C.P	Prismatic Coef.	.600	.600
C.X	Max Section Coef.	.803	.803
C.W	Waterplane Coef.	.798	.805
WEIGHTS:			
W.1	HULL STRUCTURE	1300.7	1289.7
W.11	Shell/Supports	383.5	373.9
W.12+13+14	Struct. blkhds/decks.	481.3	486.1
W.15	Deckhouse Struct.	156.5	155.9
W.18	Foundation	224.9	230.0
W.16+17+19	Other Structure	54.5	53.9
W.2	PROPULSION PLANT	429.6	464.7
W.23	Propulsion Units	203.8	242.0
W.24	Transm/propulsor	125.2	121.6
W.25+26+29	Prop.Support	100.7	101.1
W.21+22	Other Propulsion	0.0	0.0
W.3	ELECTRIC PLANT	248.4	251.2
W.31	Elec Power Generation	94.7	94.7
W.32	Power Distribution Sys	91.3	94.4
W.33	Lighting System	20.9	20.6
W.34+39	Elec Support Sys	41.5	41.5
W.4	COMMAND AND SURVEILLANCE	649.6	648.5
W.43+44	Interior/Exterior Comms	39.1	38.7
W.45	Surveillance (surface)	5.9	5.9
W.46	Surveillance (subsurf)	350.0	350.0
W.41+42+47+ +48+49	Other Command & Surv.	254.6	253.9
W.5	AUXILIARY SYSTEMS	634.6	624.1
W.51	Climate control	148.7	147.2
W.52+53	Seawater/Freshwater sys	128.0	126.9
W.56	Ship Control Sys	91.0	88.3
W.57+58	Replen/Mech Hndling Sys	109.2	107.9
W.54+55+59	Fluid/Misc Support Sys	157.6	153.8
W.6	OUTFIT AND FURNISHINGS	394.0	391.0
W.61+62+63+69	Non-Crew Related	220.7	217.8
W.64+64+66+67	Crew Related	173.3	173.2

W.7	ARMAMENT	130.0	130.0
W.71	Guns and Ammunition	45.9	45.9
W.72	Missiles and Rockets	78.2	78.2
W.73 thru 79	Other Armament	5.9	5.9
W.m	D & C Margin Weight	473.3	475.0
W.al	Architecural Limit Wt	NA	NA
F1	Crew and Effects Load	33.9	33.9
F2	Ordnance Load	144.2	144.2
F23+F26	Aviation Support Load	50.7	50.7
F4	Fuels/Lubricant Load	1006.6	783.9
F52	Freshwater Load	44.7	44.7
F3+F5+F6	Other Loads	92.6	92.6
<u>KG:</u>			
KG.ls	Light Ship KG	NA	NA
KG.fl	Full Load KG	21.79	22.36
KG.m	KG aquisition margin	NA	NA
KG.al	Architectural Limit KG	NA	NA
<u>VOLUMES:</u>			
V.hull	Hull Volume	550657.0	543075.0
V.dkhs	Deckhouse Volume	107462.0	107150.0
V1	MISSION SUPPORT	148287.5	148339.9
V1.1	Command, Comm, Surv.	62082.7	62144.2
V1.11	Exterior Comms	4590.0	4590.0
V1.121	Surface Surveillance	3400.0	3400.0
V1.122	Underwater Surveillance	29707.5	29707.5
V1.15	Interior Comms	3859.8	3813.9
V1.13+1.14 +1.16	Other C&S Volume	20524.1	20632.9
V1.2	Weapons	20754.4	18988.7
V1.21	Guns	4896.0	4896.0
V1.22	Missiles	14093.0	14093.0
V1.23	Rockets	0.0	0.0
V1.24+1.25 +1.26+1.27	Other Armament Vol	1765.4	1756.7
V1.3	Aviation	65450.1	65450.0
V1.34	Aircraft Stowage	53550.0	53550.0
V2	HUMAN SUPPORT	131590.5	131588.1
V2.1	Living	80054.2	80052.7
V2.2	Commissary	36461.7	36461.0
V2.3 Thru 2.7	Other Human Support Vol	15074.6	15075.1
V3	SHIP SUPPORT	200219.4	189093.5
V3.5	Deck Systems	7912.7	7784.3
V3.9	Tanks/Voids	61760.9	51952.3
V4	SHIP MOBILITY	177723.9	179494.3
V4.1	Propulsion Systems	133591.1	135591.0
V4.15	In Machy Box Electric	NA	NA
V4.2	Propulsor/Transmission	NA	NA

V4.3	Auxiliary Machinery	23623.2	23393.7
V4.33	Outside Machy Box Elect.	20509.7	20509.7
V5	UNASSIGNED	0.0	0.0
AREAS:			
A2	HUMAN SUPPORT AREA	15481.0	15481.0
A2.11+2.211	Officer Living/Messing	3153.0	3153.0
A2.12+2.212	CPO Living/Messing	1312.9	1312.9
A2.13+2.213	Crew Living/Messing	7208.0	7208.0
ENERGY:			
Note: for this analysis, use only 10 deg day at Battle condition			
E.i	Installed KW	6000.0	6000.0
E.t	Maximum KW	2841.0	2824.0
E.2	Propulsion KW	NA	NA
E.3	Electrical KW	NA	NA
E.4	Command & Surv KW	NA	NA
E.5	Auxiliary KW	NA	NA
E.6	Outfit and Furn. KW	NA	NA
E.7	Armament KW	NA	NA
E.am	Elec Aquisition Margin	500.0	497.0
E.slm	Elec Service Life Margin	709.0	729.0
MANNING:			
M.a	Total Accomodations	301	301
M.aoff	Officer Accom	29	29
M.acpo	CPO Accom	21	21
M.aenl	Crew Accom	251	251
M.t	Total Complement	273	268
M.off	Officer Complement	26	24
M.cpo	CPO Complement	19	19
M.enl	Crew Complement	228	225
M.m	Manning Margin	28	33
M.cs	Combat Systems Manning	62	60
M.ops	Operations Manning	65	64
M.eng	Engr. Manning	50	48
M.na	Nav/Admin Manning	19	19
M.sup	Supply Manning	35	35
M.av	Aviation Manning	42	42
COST:			
Note: Select Lead Ship for analysis All Costs x1000			
C.1	Structural Related	12125.0	12046.0
C.2	Propulsion Related	40710.0	43401.0
C.3	Electrical Related	16256.0	16423.0
C.4	Command/Surv. Related	26668.0	26640.0
C.5	Auxiliary Related	32281.0	31865.0

C.6	Outfit & Furn. Related	15307.0	15214.0
C.7	Armament Related	1465.0	1465.0
C.m	D+C Cost Margin	18012.0	18382.0
C.de	Design/Engr (Gp8)	255434.0	259783.0
C.con	Constr. Svcs (assy Gp9)	40948.0	41479.0
C.pr	Profit	36744.0	37336.0
C.csgfe	Combat Systems GFE	307900.0	307900.0
C.oth	Total Other Costs	146332.0	148690.0
C.HM&E	HM&E GFE	19841.6	20161.0
C.pmg	Project Mgr Growth	29762.4	30242.0
C.ls	Total Cost Lead Ship	970115.0	980787.0
C.bcfs	Basic Const-Follow Ship	237445.0	241063.0
C.fs	Total Cost Follow Ship	583691.0	588377.0

MISCELLANEOUS INPUTS:

HP.shpi	Total Installed SHP	52500	52500
HP.geni	Total Installed Gen HP	NA	NA
HP.shpe	Propul HP @ Endur. Spd	9861	10064
HP.gene	Gen HP @ avg 24 hr load	3651	3627
SFC.e	Prop SFC @ Endur. Spd	.544	.343
SFCA.e	Gen SFC @ avg 24 hr load	.693	.694
E.gen	KW Rating per Generator	1500	1500
E.24	Avg 24 Hr Elec Load	2669	2652
# lchr	Number of Launchers	5	5
# snsr	Number of Sensors	7	7
YEAR	Year Commissioned (IOC)	2005	2005

NOTE: Input Screens 1-3, 1-4, 1-5
directly

		TECH BASE	IRGT VAR	Delta
SCREEN 1-1:	COST & SIZE CHARACTERISTICS			
TOTAL COSTS:	(use lead ship)			
C.bc	Basic Construction Cost	495950.0	504034.0	1.6%
C.csgfe	Combat Sytem GFE cost	307900.0	307900.0	0.0%
C.oth	Other Costs	146332.0	148690.0	1.6%
C.t	Total Ship cost	970115.0	980787.0	1.1%
SHIP SIZE:				
DSP.fl	Full Load Displacement	5537.3	5328.5	-3.8%
DSP.ls	Light Ship Displacement	4260.1	4274.0	.3%
VOL	Total Enclosed Volume	658118.0	650232.0	-1.2%
DSP.fl/VOL	Ship Density Full Load	18.8	18.4	-2.6%
DSP.ls/VOL	Ship Density Light Ship	14.5	14.7	1.5%
L.bp	Length Between Perp.	425.0	410.0	-3.5%
L.oa	Length Overall	NA	NA	NA
B.wl	Beam at Waterline	50.0	50.8	1.6%
B.max	Beam (max at deckedge)	NA	NA	NA
D	Depth at midships	38.0	38.0	0.0%
T	Draft (max)	18.8	18.5	-1.3%

SCREEN 1-2: SHAPE CHARACTERISTICS

DSP/(.01L)^3	Displacement/Length rat.	72.1	77.3	7.2%
C.p	Prismatic Coeff	.600	.600	0.0%
C.x	Max Section Coeff	.803	.803	0.0%
C.w	Waterplane Coeff	.798	.805	.9%
L.bp/B.wl	Length/Beam ratio	8.50	8.07	-5.0%
L.bp/T	Length/Draft ratio	22.67	22.16	-2.2%
B.wl/T	Beam/Draft ratio	2.67	2.75	3.0%
T/D	Draft/Depth ratio	.49	.49	-1.3%
L.bp/D	Length/Depth ratio	11.18	10.79	-3.5%

NOTE: * in difference column indicates that a difference exists for non-numeric items

SCREEN 1-3: SHIP PERFORMANCE

MOBILITY:			
Max Sustained Spd (80% Power)	27.9	27.5	-1.4%
Max Trial Spd (100% Power)	29.0	28.7	-1.0%
Range @ Endurance Speed	4500	4500	0.0%
Endurance Period (Fuel @ Endur Spd)	9.4	9.4	0.0%
Endurance Period (Stores)	45.0	45.0	0.0%
Endurance Period (Chilled Stores)	30.0	30.0	0.0%
Endurance Period (Frozen Stores)	45.0	45.0	0.0%
Shaft Horsepower Available	52500	52500	0.0%
Shaft Horsepower Req @ Endurance	9861	10064	2.1%
Shaft Horsepower Req @ Sustained	42011	42000	-.0%
HULL EFFICIENCY:			
Drag (sustained spd)	332156	335576	1.0%
Drag (endurance spd)	101383	103483	2.1%
Bales Rank	9.31	8.96	-3.8%
SURVIVABILITY:			
Blast	NA	NA	
Fragmentation	NA	NA	
Shock	NA	NA	
NBC	NA	NA	
Noise Signature	NA	NA	
IR Signature	NA	NA	
Radar Signature	NA	NA	

SCREEN 1-4: HM&E SYSTEM SELECTION

MAIN PROPULSION:			
Total Boost Power Avail	52500.0	52500.0	0.0%
Boost Reqd at Sustained Spd	42011.0	42000.0	-.0%
Boost Growth Potential	10489.0	10500.0	.1%
Boost Engine Type	GT	IRGT	*
Boost Engine Number/Rating	2/26250	2/26250	
Cruise Engine Type	-	-	
Cruise Engine Number/Rating	-	-	
Transmission Sys Type	AC/AC	AC/AC	

Propeller Type	FP	FP	
Propeller Number/RPM	2/140	2/140	
Propeller Open Wtr Effy (sustained)	.750	.748	-.3%
Propeller Open Wtr Effy (endurance)	.780	.780	0.0%
Propulsion Coefficient (PC)	.718	.716	-.3%
SFC @ Endurance Spd	.544	.343	-36.9%
SFC @ Sustained Spd	.433	.330	-23.8%
Other			
ELECTRIC POWER:			
Total 60 Hz Available	6000.0	6000.0	0.0%
Total 60 Hz Max Load	2841.0	2824.0	-.6%
60 Hz Growth Potential (all Gen)	3159.0	3176.0	.5%
Total 400 Hz Available	NA	NA	NA
Total 400 Hz Max Load	NA	NA	NA
400 Hz Growth Potential	NA	NA	NA
60 Hz Generator Type	GT	GT	
60 Hz Generator Number/Rating	4/1500	4/1500	
400 Hz Converter Type	NA	NA	
400 Hz Converter Number/Rating	NA	NA	
SFCA	.693	.693	0%
Other			
AUXILIARY:			
Total AC Available	NA	NA	NA
AC Maximum Load	NA	NA	NA
AC Growth Potential	NA	NA	NA
AC Type	NA	NA	
AC Number/Rating	NA	NA	
Heating Type	NA	NA	
Heating Rating	NA	NA	
Firepump Type	NA	NA	
Firepump No./Rating	NA	NA	
Seawater Pump Type	NA	NA	
Seawater Pump No./Rating	NA	NA	
HP Air Compressor Type	NA	NA	
HP Air Compressor No./Rating	NA	NA	
LP Air Compressor Type	NA	NA	
LP Air Compressor No./Rating	NA	NA	
Distilling Plant Type	NA	NA	
Distilling Plant No./Rating	NA	NA	
Boats Type/No.	NA	NA	
Steering Units Type/No.	NA	NA	
Anchors Type/No.	NA/2	NA/2	
Anchors Length of Chain	NA	NA	
UNREP Capability	STREAM	STREAM	
Other			
STRUCTURE/MATERIALS:			
Hull Materials (array)	HTS	HTS	
Deckhouse Materials (array)	HTS	HTS	
Hull Frame Type/Spacing	TRANS/4.0	TRANS/4.0	

Deckhouse Frame Type/Spacing	NA	NA
Other		
DECK HEIGHTS:		
Number internal decks in hull	4	4
Number internal decks in deckhouse	3	3
Internal Deck Heights (array above BL)	4.0	4.0
	12.5	12.5
	21.0	21.0
	29.5	29.5
Hull Avg Deck Height	8.5	8.5
Other		
MANNING:		
Total Accom/Complement/Growth Pot.	301/273/28	301/268/33
Total Complement (OFF/CPO/ENL)	26/19/228	24/19/225
Habitability Classification	MODERN	MODERN
Flag Configured	NO	NO
Other		

SCREEN 1-5: COMBAT SYSTEMS SELECTION

ANTI-AIR WARFARE:		
Armament	1-76mm Gun	1-76mm Gun
	2-20mm CIWS	2-20mm CIWS
	VLS Seasp.	VLS Seasp.
Sensors	MK92 FCS	MK92 FCS
	IR DETECTOR	IR DETECTOR
Aviation Capabilities	3-Lamps III	3-Lamps III
ANTI-SUBMARINE WARFARE:		
Armament	VLS ASROC	VLS ASROC
	2-TT MK32	2-TT MK32
Sensors	CA Sonar	CA Sonar
	Towed Array	Towed Array
Aviation Capabilities	3-Lamps III	3-Lamps III
SURFACE/STRIKE WARFARE:		
Armament	1-76mm Gun	1-76mm Gun
	VLS Harpoon	VLS Harpoo
Sensors	Nav Radar	Nav Radar
	Surf Radar	Surf Radar
Aviation Capabilities	3-Lamps III	3-Lamps III
COMMAND/CONTROL/COMM/INTEL:		
Communications	Ext Comms	Ext Comms
Electronic Warfare	Active ECM	Active ECM
	Acous Decoy	Acous Decoy
	SRBOC	SRBOC

Control		C/C Suite	C/C Suite	
SCREEN 2-1: SWBS WEIGHT FRACTIONS				
LIGHT SHIP:				
W.1/DSP.LS	Structural	30.5%	30.2%	-.8%
W.2/DSP.LS	Main Propulsion	10.1%	10.9%	8.2%
W.3/DSP.LS	Electrical	5.8%	5.9%	1.1%
W.4/DSP.LS	Command & Surveillance	15.2%	15.2%	-.2%
W.5/DSP.LS	Auxiliary	14.9%	14.6%	-1.7%
W.6/DSP.LS	Outfit & Furnishings	9.2%	9.1%	-.8%
W.7/DSP.LS	Armament	3.1%	3.0%	0.0%
W.m/DSP.LS	Margin	11.1%	11.1%	.4%
FULL LOAD:				
W.1/DSP.FL	Structural	23.5%	24.2%	-.8%
W.2/DSP.FL	Main Propulsion	7.8%	8.7%	8.2%
W.3/DSP.FL	Electrical	4.5%	4.7%	1.1%
W.4/DSP.FL	Command & Surveillance	11.7%	12.2%	-.2%
W.5/DSP.FL	Auxiliary	11.5%	11.7%	-1.7%
W.6/DSP.FL	Outfit & Furnishings	7.1%	7.3%	-.8%
W.7/DSP.FL	Armament	2.3%	2.4%	0.0%
W.m/DSP.FL	Margin	8.5%	8.9%	.4%
SCREEN 2-2: LOAD WEIGHT FRACTIONS				
W.fuel/W.ld	Liquid (fuel & Lube)	78.8%	74.3%	-22.1%
W.ce/W.ld	Crew and Effects	2.7%	3.2%	0.0%
W.ord/W.ld	Ordnance	7.3%	8.9%	0.0%
W.av/W.ld	Aviation	4.0%	4.8%	0.0%
W.oth/W.ld	Others	7.2%	8.8%	0.0%
W.ld/DSP.FL	Load to Full Load ratio	23.1%	19.8%	-17.4%
DSP.ls/DSP.fl	Lightship to Full ratio	76.9%	80.2%	.3%
SCREEN 2-3: FUNCTIONAL WT. ALLOCATION				
W.csl/DSP.LS	LS Combat Sys Weight	20.6%	20.5%	-.1%
W.mal/DSP.LS	LS Machinery Weight	34.7%	35.3%	2.1%
W.cl/DSP.LS	LS Containment Weight	44.8%	44.2%	-.8%
W.csf/DSP.FL	FL Combat Sys Weight	18.4%	19.1%	-.1%
W.maf/DSP.FL	FL Machinery Weight	44.8%	43.0%	-7.7%
W.cf/DSP.FL	FL Containment Weight	36.7%	37.9%	-.8%
SCREEN 2-4: SSCS VOLUME FRACTIONS				
V1/VOL	Mission Support	22.5%	22.8%	.0%
V2/VOL	Human Support	20.0%	20.2%	-.0%
V3/VOL	Ship Support	30.4%	29.1%	-5.6%
V4/VOL	Ship Mobility	27.0%	27.6%	1.0%
V5/VOL	Unassigned	0.0%	0.0%	0.0%

SCREEN 2-5: SPACE TYPE/LOCATION VOLUME

V.hull/VOL	Hull Volume	83.7%	83.5%	-1.4%
V.dh/VOL	Deckhouse Volume	16.3%	16.5%	-.3%
V.tk/VOL	Tankage/Void Volume	9.4%	8.0%	-15.9%
V.lo/VOL	Large Space Volume	31.6%	32.0%	.1%
V.a/VOL	Arrangeable Volume	59.0%	60.0%	.4%

SCREEN 2-6: FUNCTIONAL VOLUME ALLOCATION

V.cs/VOL	Combat Sys Volume	22.5%	22.8%	.0%
V.ma/VOL	Machinery Related Vol	37.6%	36.8%	-3.3%
V.c/VOL	Containment Volume	39.8%	40.1%	-.5%
V.5/VOL	Unassigned Volume	0.0%	0.0%	0.0%

SCREEN 2-7: ELECTRICAL ENERGY ALLOCATION

Note: max load/ 10 deg day/Battle				
E2/E	Propulsion Plant	NA	NA	NA
E3/E	Electric Plant	NA	NA	NA
E4/E	Command and Surveillance	NA	NA	NA
E5/E	Auxiliary	NA	NA	NA
E6/E	Outfit & Furnishings	NA	NA	NA
E7/E	Armament	NA	NA	NA
Em/E	Margin (Acq.+Serv Life)	NA	NA	
Note: installed load/10 deg/Battle				
E2/E	Propulsion Plant	NA	NA	NA
E3/E	Electric Plant	NA	NA	NA
E4/E	Command and Surveillance	NA	NA	NA
E5/E	Auxiliary	NA	NA	NA
E6/E	Outfit & Furnishings	NA	NA	NA
E7/E	Armament	NA	NA	NA
Em/E	Margin	29.9%	30.3%	1.4%

SCREEN 2-8: FUNCTIONAL ENERGY ALLOCATION

INSTALLED HP:				
HP.shpi/HP.t	Propulsion HP Allocation	NA	NA	NA
HP.geni/HP.t	Electrical HP Allocation	NA	NA	NA
FUEL USAGE:				
FF.mp/FF.t	Propulsion Fuel Alloc.	68.0%	57.8%	-35.7%
FF.gen/FF.t	Electrical Fuel Alloc.	32.0%	42.2%	-.5%
ELECTRICAL:				
Note: max load/10deg day/Battle				
E.cs/E.t	Combat System Elec	NA	NA	NA
E.ma/E.t	Machinery Elec	NA	NA	NA
E.c/E.t	Containment Elec	NA	NA	NA
Note: instal load/10deg day/Battle				
E.cs/E.i	Combat System Elec	NA	NA	NA
E.ma/E.i	Machinery Elec	NA	NA	NA
E.c/E.i	Containment Elec	NA	NA	NA

SCREEN 2-9: MANNING ALLOCATION

M.off/M.a	Officer Ratio	8.6%	8.0%	-7.7%
M.cpo/M.a	CPO Ratio	6.3%	6.3%	0.0%
M.enl/M.a	Crew Ratio	75.7%	74.8%	-1.3%
M.m/M.a .	Manning Margin	9.3%	11.0%	17.9%

SCREEN 2-10: FUNCTIONAL MANNING ALLOCATION

M.cs/M.a	Combat Systems Manning	20.6%	19.9%	-3.2%
M.ops/M.a	Operations Manning	21.6%	21.3%	-1.5%
M.eng/M.a	Engineering Manning	16.6%	15.9%	-4.0%
M.na/M.a	Nav/Admin Manning	6.3%	6.3%	0.0%
M.sup/M.a	Supply Manning	11.6%	11.6%	0.0%
M.av/M.a	Aviation Manning	14.0%	14.0%	0.0%

SCREEN 2-11: BASIC CONSTRUCTION COST ALLOCATION

Note: Lead Ship Costs

C1/C.bc	Hull Structure	2.4%	2.4%	-.7%
C2/C.bc	Propulsion Plant	8.2%	8.6%	6.6%
C3/C.bc	Electric Plant	3.3%	3.3%	1.0%
C4/C.bc	Command and Surveillance	5.4%	5.3%	-.1%
C5/C.bc	Auxiliary	6.5%	6.3%	-1.3%
C6/C.bc	Outfit and Furnishings	3.1%	3.0%	-.6%
C7/C.bc	Armament	.3%	.3%	0.0%
C.m/C.bc	D+C Margin	3.6%	3.6%	2.1%
C.de/C.bc	Design/Engr (Gp 8)	51.5%	51.5%	1.7%
C.con/C.bc	Constr. Svcs/Assy (Gp9)	8.3%	8.2%	1.3%
C.pr/C.bc	Profit	7.4%	7.4%	1.6%
C.HM&E/C.BC	HM&E GFE	3.8%	3.8%	1.6%

SCREEN 2-12: FUNCTIONAL COST ALLOCATION

Note: Lead Ship Costs

C.cs/C.t	Combat Systems	47.1%	46.6%	.1%
C.ma/C.t	Machinery	38.9%	39.6%	2.8%
C.c/C.t	Containment	12.0%	11.8%	-.6%

SCREEN 2-13: COST FRACTIONS

C.csgfe/C.ls	Combat Sys GFE/Lead Ship	31.7%	31.4%	0.0%
C.csgfe/C.fs	Combat Sys GFE/Follow	52.8%	52.3%	0.0%
C.bcls/C.ls	Basic Constr/Lead Ship	51.1%	51.4%	1.6%
C.bcfs/C.fs	Basic Constr/Follow	40.7%	41.0%	1.5%
C.fs/DSP.fl	Follow Ship Cost/Weight	105.4	110.4	4.8%
C.fs/VOL	Follow Ship Cost/Volume	.887	.905	2.0%

SCREEN 3-1: CONTAINMENT WT BREAKDOWN

STRUCTURE WEIGHT:

W.11/W.1	Shell and Supports	29.5%	29.0%	-2.5%
W.12+13+14/W.1	Hull Struc Blkhds/Decks	37.0%	37.7%	1.0%
W.15/W.1	Deckhouse	12.0%	12.1%	-.4%
W.18/W.1	Foundations	17.3%	17.8%	2.3%

W.16+17+19/W.1	Other Structural	4.2%	4.2%	-1.1%
OUTFIT AND FURNISHINGS:				
W.64+65+66+ 67/W.6	Crew Related	44.0%	44.3%	-.1%
W.61+62+63+ 69/W.6	Non-crew Related	56.0%	55.7%	-1.3%

SCREEN 3-2: CONTAINMENT INDICES

CONTAINMENT DRIVERS:				
W.1/DSP.FL	Structural Wt Fraction	23.5%	24.2%	-.8%
W.6/DSP.FL	Outfit & Furn. Wt. Frac	7.1%	7.3%	-.8%
W.1/VOL	Hull Struc Specific Wt	4.43	4.44	.4%
W.6/VOL	Outfit & Furn. Spec Wt	1.34	1.35	.4%
VOL/DSP.FL	Ship Specific Volume	118.9	122.0	2.7%
RELATED CONTAINMENT RATIOS:				
W.cf/V.c	Containment Density	17.4	17.3	-.3%
W.11+12+13+ 14/V.Hull	Basic Hull Struc Density	3.5	3.5	.8%
W.15/V.dh	Deckhouse Struc Density	3.3	3.3	-.1%
W.18/W.2+3+ 4+5+7	Foundations Wt Fraction	10.7%	10.9%	2.3%
C.c/W.cf	Containment Cost/Wt rat.	$84.04	$83.89	-.2%

SCREEN 3-3: MAIN PROPULSION BREAKDOWN

WEIGHT:				
W.23/W.2	Propulsion Units Wt	47.4%	52.1%	18.7%
W.24/W.2	Transmission/Prop Wt	29.1%	26.2%	-2.9%
W.25+26+29/W.2	Propulsion Support Wt	23.4%	21.8%	.4%
W.21+22/W.2	Other Propulsion Wt	0.0%	0.0%	NA
VOLUME:				
V4.1-4.15/V.pt	Propulsion Sys Volume	NA	NA	NA
V4.2/V.pt	Transmission/Prop Vol	NA	NA	NA

SCREEN 3-4: MAIN PROPULSION INDICES

MAIN PROPULSION DRIVERS:				
W.2/DSP.FL	Main Propulsion Wt Frac	7.8%	8.7%	8.2%
W.2/SHP	Main Propulsion Spec Wt	18.330	19.827	8.2%
SHP/DSP.FL	Main Prop Ship Size Rat	9.481	9.853	3.9%
R.Te/DSP.FL	Drag/Disp Ratio (endur)	18.309	19.421	6.1%
R.Ts/DSP.FL	Drag/Disp Ratio (sust)	59.985	62.978	5.0%
PC	Propulsion Coefficient	.718	.716	-.3%
RELATED MAIN PROPULSION INDICES:				
W.2/V.pt	Main Propulsion Density	NA	NA	NA
V.pt/VOL	Main Prop Volume Frac	NA	NA	NA
W.23/SHP	Prop Units Specific Wt	8.695	10.325	18.7%
W.24/SHP	Trans/Prop Specific Wt	5.342	5.188	-2.9%
W.25+26+29/SHP	Support/Fluids Spec Wt	4.297	4.314	.4%
V.pt/SHP	Prop & Trans Spec Vol	NA	NA	NA
V4.1-4.15/SHP	Prop Systems Spec Vol	NA	NA	NA

V4.2/SHP	Trans/Prop Spec Vol	NA	NA	NA
E.2/W.2	Prop KW/Weight Ratio	0.00	0.00	0.0%
C.2/W.2	Prop Cost/Weight Ratio	$94.76	$93.40	-1.4%

SCREEN 3-5: ELECTRICAL PLANT BREAKDOWN

WEIGHT:				
W.31/W.3	Power Generation Wt	38.1%	37.7%	0.0%
W.32/W.3	Power Distribution Wt	36.8%	37.6%	3.4%
W.33/W.3	Lighting Wt	8.4%	8.2%	-1.4%
W.34+39/W.3	Support Systems Wt	16.7%	16.5%	0.0%
VOLUME:				
V4.15/V.e	Machinery Box Elec Vol	NA	NA	NA
V4.33/V.e	Aux Space Elec Vol	NA	NA	NA

SCREEN 3-6: ELECTRICAL INDICES

ELECTRICAL DRIVERS:				
W.3/DSP.FL	Electrical Wt Fraction	4.5%	4.7%	1.1%
W.3/E.i	Electrical Spec Wt	92.7	93.8	1.1%
E.i/DSP.FL	Elec Capac Ship Size Ra	1.084	1.126	3.9%
RELATED ELECTRICAL RATIOS:				
W.3/V.e	Electrical Density	NA	NA	NA
V.e/VOL	Electrical Vol Fraction	NA	NA	NA
W.31/E.i	Power Gen Specific Wt	35.4	35.4	0.0%
V.e/E.i	Electrical Spec Vol	NA	NA	NA
E.3/W.3	Elec KW/Weight Ratio	NA	NA	NA
C.3/W.3	Elec Cost/Weight Ratio	$79.76	$67.86	-14.9%

SCREEN 3-7: AUXILIARY BREAKDOWN

WEIGHT:				
W.51/W.5	Climate Control Wt	23.4%	23.6%	-1.0%
W.52+53/W.5	Seawater/Freshwater Wt	20.2%	20.3%	-.9%
W.54+55+59/W.5	Fluid Systems Wt	24.8%	24.6%	-2.4%
W.56/W.5	Ship Control Wt	14.3%	14.1%	-3.0%
W.57+58/W.5	Replenish/Mech Hndlg Wt	17.2%	17.3%	-1.2%
VOLUME:				
V3.5/V.ax	Deck Systems Volume	71.8%	73.0%	-1.6%
V4.3-4.33/V.ax	Auxiliary Mach Volume	28.2%	27.0%	-7.4%

SCREEN 3-8: AUXILIARY INDICES

AUXILIARY DRIVERS:				
W.5/DSP.FL	Auxiliary Wt Fraction	11.5%	11.7%	-1.7%
W.5/VOL	Auxiliary Spec Wt	2.160	2.150	-.5%
VOL/DSP.FL	Ship Specific Vol	118.9	122.0	2.7%
RELATED AUXILIARY RATIOS:				
W.5/V.ax	Auxiliary Density	128.9	131.0	1.6%
V.ax/VOL	Auxiliary Volume Frac	1.7%	1.6%	-3.2%
E.5/W.5	Auxiliary KW/Wt Ratio	NA	NA	NA
C.5/W.5	Auxiliary Cost/Wt Ratio	$320.57	$315.18	-1.7%

SCREEN 3-9: COMBAT SYSTEMS BREAKDOWN

COMBAT SYSTEMS WEIGHT:				
W.4/W.csf	Command & Surv Wt	70.3%	70.3%	-.2%
W.7/W.csf	Armament Wt	14.1%	14.1%	0.0%
W.av/W.csf	Aviation Wt	5.5%	5.5%	0.0%
W.ord/W.csf	Ordnance Wt	10.1%	10.1%	0.0%
COMMAND AND SURVEILLANCE WEIGHT:				
W.43+44/W.4	Interior/Exter Comm Wt	6.0%	6.0%	-1.0%
W.45/W.4	Surface Surv Wt	.9%	.9%	0.0%
W.46/W.4	Underwater Surv Wt	53.9%	54.0%	0.0%
W.41+42+47+48+ 49/W.4	Other C&S Wt	39.2%	39.2%	-.3%
ARMAMENT WEIGHT:				
W.71/W.7	Guns and Ammo Wt	35.3%	35.3%	0.0%
W.72/W.7	Missiles/Rockets Wt	60.2%	60.2%	0.0%
W.73thru79/W.7	Other Armament Wt	4.5%	4.5%	0.0%
COMBAT SYSTEMS VOLUME:				
V1.1/V1	Command and Surv Volume	41.9%	41.9%	.1%
V1.2/V1	Armament Volume	14.0%	12.8%	-8.5%
V1.3/V1	Aviation Volume	44.1%	44.1%	-.0%
COMMAND AND SURVEILLANCE VOLUME:				
V1.11+ 1.15/V1.1	Interior/Exter Comm Vol	13.6%	13.5%	-.5%
V1.121/V1.1	Surface Surv Vol	5.5%	5.5%	0.0%
V1.122/V1.1	Underwater Surv Vol	47.9%	47.8%	0.0%
V1.13+1.14+ 1.16/V1.1	Other C&S Vol	33.1%	33.2%	.5%
ARMAMENT VOLUME:				
V1.21/V1.2	Guns & Ammo Vol	23.6%	25.8%	0.0%
V1.22+ 1.23/V1.2	Missiles/Rockets Vol	67.9%	74.2%	0.0%
V1.24+1.25+ 1.26+1.27/V1.2	Other Armament Vol	8.5%	9.3%	-.5%

SCREEN 3-10: COMBAT SYSTEMS INDICES

COMBAT SYSTEMS DRIVERS:				
W.7/DSP.FL	Armament Wt Fraction	2.3%	2.4%	0.0%
#L/DSP.FL	Armament Cap Size Ratio	.903	.938	3.9%
W.7/#L	Armament Spec Wt	26.0	26.0	0.0%
W.4/DSP.FL	C&S Weight Fraction	11.7%	12.2%	-.2%
#S/DSP.FL	C&S Capacity Size Ratio	1.264	1.314	3.9%
W.4/#S	C&S Specific Wt	92.8	92.6	-.2%
RELATED COMBAT SYSTEM RATIOS:				
W.csf/V1	Combat System Density	15.43	15.40	-.2%
W.4/V1.1	Command & Surv Density	23.44	23.38	-.3%
W.7/V1.2	Armament Density	14.03	15.34	9.3%
E.cs/W.csf	Combat Sys KW/Wt Ratio	NA	NA	NA
C.cs/W.csf	Combat Sys Cost/Wt Ratio	$447.16	$448.13	.2%

SCREEN 3-11: HUMAN SUPPORT BREAKDOWN

WEIGHT:				
W.ce/W.HS	Crew and Effects Wt	13.5%	13.5%	0.0%
W.6cr/W.HS	Outfit & Furn Wt	68.8%	68.8%	-.1%
W.pw/W.HS	Potable Water Wt	17.7%	17.8%	0.0%
VOLUME:				
V2.1/V2	Living Volume	60.8%	60.8%	-.0%
V2.2/V2	Food Svs/Mess/Lounge Vol	27.7%	27.7%	-.0%
V2.3thru2.7/V2	Medical/Gen/Other Vol	11.5%	11.5%	.0%

SCREEN 3-12: HUMAN SUPPORT INDICES

HUMAN SUPPORT DRIVERS:				
W.HS/DSP.FL	Human Support Wt Frac	4.5%	4.7%	-.0%
W.HS/M.a	Human Support Spec Wt	.837	.837	-.0%
M.a/DSP.FL	Total Accom Ship Size Ra	54.4	56.5	3.9%
RELATED HUMAN SUPPORT RATIOS:				
W.HS/V2	Human Support Density	4.288	4.286	-.0%
V2.1/M.a	Persnl Living Spec Vol	266.0	266.0	-.0%
V2/M.a	Human Support Spec Vol	437.2	437.2	-.0%
A2/M.a	Human Support Spec Area	51.4	51.4	0.0%
A2.11+2.211/ M.aoff	Officer Lvng Area/Man	108.7	108.7	0.0%
A2.12+2.212/ M.acpo	CPO Living Area/Man	62.5	62.5	0.0%
A2.13+2.213/ M.aenl	Enlisted Lvng Area/Man	28.7	28.7	0.0%
M.aoff/DSP.FL	Officer Ship Size Ratio	5.24	5.44	3.9%
M.acpo/DSP.FL	CPO Ship Size Ratio	3.79	3.94	3.9%
M.aenl/DSP.FL	Enlisted Ship Size Ratio	45.33	47.11	3.9%

SCREEN 3-13: MARGIN SUMMARY

WEIGHT:				
W.m/(Dls-W.m)	Acquisition Margin	12.5%	12.5%	.4%
	NAVSEA Standard	10.0%	10.0%	
(W.al-Dfl)/Dfl	Service Life Margin	NA	NA	NA
	NAVSEA Standard	10.0%	10.0%	
KG:				
KG.m/KG.ls	Acquisition Margin	NA	NA	NA
	NAVSEA Standard	10.0%	10.0%	
(KG.al-KG.fl) /KG.fl	Service Life Margin	NA	NA	NA
	NAVSEA Standard	4.6%	4.5%	
ELECTRIC POWER:				
E.m/E.t	Acquisition Margin	17.6%	17.6%	-.0
	NAVSEA Standard	20.0%	20.0%	
E.slm/(E.t-E.2 +E.ma+E.slm)	Service Life Margin	17.5%	18.0%	2.8%
	NAVSEA Standard	20.0%	20.0%	

VOLUME:				
V.5/VOL	Service Life Margin	0.0%	0.0%	0.0%
	NAVSEA Standard	0.0%	0.0%	
MANNING:				
(M.a-M.t)/M.t	Service Life Margin	10.3%	12.3%	17.9%
	NAVSEA Standard	10.0%	10.0%	

APPENDIX E

TREND COMPARATIVE ANALYSIS DATA BASE

This appendix includes some representative data points of the initial ships selected for historical trend display for the Trend Analysis option of the comparative analysis model. Complex indices, are included for time history and triple plots.

These points should be placed in the data base directly for automatic recall when the user selects the appropriate trend chart. The same parameter or indice from the new ship under investigation may then be plotted with the historical data for comparison. The detailed methodology is discussed in chapter 5.

COMMISSIONING DATES OF SHIPS IN DATA BASE

SHIP	YEAR COMMISSIONED
FF-1006	1952
FF-1033	1959
FF-1037	1963
FF-1040	1964
FF-1052	1969
FFG-7	1977
DD-692	1943
DD-931	1955
DD-963	1975
DDG-2	1960
DDG-37	1961
DDG-993	1982
DDG-51	1989
CG-26	1967
CG-47	1982

FULL LOAD DISPLACEMENT, VOLUME, SHIP DENSITY TIME HISTORY TREND DATA

SHIP	DSP.FL (tons)	VOL (ft3)	SHIP DENSITY (lbs/ft3)
FF-1006	1923	199486	21.59
FF-1033	1698	242397	15.69
FF-1037	2537	290396	19.57
FF-1040	3469	407617	19.06
FF-1052	4014	503403	17.86
FFG-7	3782	531178	15.95
DD-692	3193	289030	24.75
DD-931	3925	414393	21.22
DD-963	7696	1034908	16.66
DDG-2	4505	484897	20.81
DDG-37	5563	639470	19.49
DDG-993	9029	1065367	18.98
DDG-51	8369	964013	19.45
CG-26	7839	857400	20.48
CG-47	9614	1105513	19.48

PROPULSION AND ELECTRIC PLANT RELATED
TIME HISTORY TREND DATA

SHIP	SHP RATIO (HP/ton)	KW RATIO (KW/ton)
FF-1006	10.40	.390
FF-1033	5.42	.589
FF-1037	7.88	.788
FF-1040	10.09	.577
FF-1052	8.72	.747
FFG-7	10.58	.793
DD-692	18.79	.313
DD-931	17.83	.637
DD-963	10.40	.780
DDG-2	15.54	.444
DDG-37	15.28	.719
DDG-993	8.86	.665
DDG-51	11.95	.896
CG-26	10.84	.880
CG-47	8.32	.780

COMBAT SYSTEM WEIGHT FRACTION
TIME HISTORY TREND DATA

SHIP	CS WT FRAC
FF-1006	.096
FF-1033	.084
FF-1037	.098
FF-1040	.093
FF-1052	.107
FFG-7	.069
DD-692	.164
DD-931	.132
DD-963	.076
DDG-2	.118
DDG-37	.111
DDG-993	.093
DDG-51	.107
CG-26	.121
CG-47	.102

HUMAN SUPPORT SPECIFIC VOLUME
HISTORIC TREND DATA

SHIP	HS SPEC VOL (ft^3/man)
FF-1006	380.67
FF-1033	421.44
FF-1037	369.35
FF-1040	362.52
FF-1052	440.95
FFG-7	569.95
DD-692	232.90
DD-931	335.72
DD-963	635.16
DDG-2	365.10
DDG-37	381.31
DDG-993	543.00
DDG-51	488.62
CG-26	428.57
CG-47	477.97

W1 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	VOL (ft^3)	DSP/VOL (lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

W2 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL	SHP INS	SHP/DSP
	(tons)	(SHP)	(HP/ton)
FF-1006	1923	20000	10.4
FF-1033	1698	9200	5.4
FF-1037	2537	20000	7.9
FF-1040	3469	35000	10.1
FF-1052	4014	35000	8.7
FFG-7	3782	40000	10.6
DD-692	3193	60000	18.8
DD-931	3925	70000	17.8
DD-963	7696	80000	10.4
DDG-2	4505	70000	15.5
DDG-37	5563	85000	15.3
DDG-993	9029	80000	8.9
DDG-51	8369	100000	11.9
CG-26	7839	85000	10.8
CG-47	9614	80000	8.3

W3 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	KW INS. (KW)	KW/DSP (KW/ton)
FF-1006	1923	750	.39
FF-1033	1698	1000	.59
FF-1037	2537	2000	.79
FF-1040	3469	2000	.58
FF-1052	4014	3000	.75
FFG-7	3782	3000	.79
DD-692	3193	1000	.31
DD-931	3925	2500	.64
DD-963	7696	6000	.78
DDG-2	4505	2000	.44
DDG-37	5563	4000	.72
DDG-993	9029	6000	.66
DDG-51	8369	7500	.90
CG-26	7839	6900	.88
CG-47	9614	7500	.78

W4 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	# SENS	#/DSP (sr/kton)
FF-1006	1923	4	2.08
FF-1033	1698	4	2.36
FF-1037	2537	4	1.58
FF-1040	3469	5	1.44
FF-1052	4014	6	1.49
FFG-7	3782	6	1.59
DD-692	3193	4	1.25
DD-931	3925	4	1.02
DD-963	7696	5	.65
DDG-2	4505	6	1.33
DDG-37	5563	5	.90
DDG-993	9029	6	.66
DDG-51	8369	6	.72
CG-26	7839	6	.77
CG-47	9614	6	.62

where sr = sensor
kton = 1000 tons

W5 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	VOL (ft^3)	DSP/VOL (lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

W6 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	VOL (ft^3)	DSP/VOL (lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

W7 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	# LCHR.	#/DSP (lr/Kton)	
FF-1006	1923	5	2.60	.033
FF-1033	1698	3	1.77	.024
FF-1037	2537	4	1.58	.028
FF-1040	3469	4	1.15	.028
FF-1052	4014	4	1.00	.037
FFG-7	3782	4	1.06	.026
DD-692	3193	8	2.51	.078
DD-931	3925	7	1.78	.070
DD-963	7696	6	.78	.020
DDG-2	4505	5	1.11	.057
DDG-37	5563	6	1.08	.051
DDG-993	9029	6	.66	.034
DDG-51	8369	6	.72	.039
CG-26	7839	5	.64	.041
CG-47	9614	7	.73	.038

where lr = launcher
Kton = 1000 tons

APPENDIX F

DETAILS OF PARAMETERS/INDICES

This appendix will provide specific information on all indices and parameters used in the proposed methodology. Each indice and parameter description will provide details with respect to what the parameter/indice is and its significance in the impact of the overall comparative analysis. Additionally, for some of the major parameters and indices, expected ranges of values will be provided for modern monohull combatants of the frigate to cruiser range only. The explanation will provide the foundation of the computer-aided comparative analysis methodology relating to the screens, indices and parameters that should be examined if the comparative analysis option is invoked.

In this manner, if each indice and parameter has a logical path to examine, the overall flow of comparitive analysis will be completed. Each indice and parameter is considered to be a "branch" on the overall "analysis tree" and is only examined to the next immediate level of analysis as discussed in section 3.5.

The appendix will provide the information that must be examined, either by screen or specific indice. The actual implementation of the logic used will be left to the programmer.

Nine different classes of ships were used to determine the expected range of values for selected parameters and indices. The

values were rounded to the nearest significant digit for the indice being examined. The classes of ships were:

FF-1052	DD-931	DDG-2	CG-26
FFG-7	DD-963	DDG-37	CG-47
		DDG-51	

Although it is understood that these ships do not include all classes of ships and some other classes may fall outside the ranges given in the explanations, it is felt that this is a good cross-section. The "expected range" value is for initial comparison only and these values are for parametric studies. It is the designers task to determine the impact of being outside the normal range of parametrics.

The indices and parameters are examined by screen grouping and levels.

LEVEL 1: PRIMARY CHARACTERISTICS

The initial comparative analysis path looks primarily at level 2 resource allocation to examine the affected resources of the change in a primary characteristic of level 1. The resources examined are:

- weight
- volume
- energy
- manning
- cost

The analysis path additionally, where necessary, examines related level 1 characteristics that may have been affected by, or affected, the change. If the indice is a function of another parameter, the decision path will direct the user to that parameter for further analysis.

SCREEN 1-1: COST AND SIZE CHARACTERISTICS

This screen is designed to give an overall view of the direct cost and size of the ships being compared in a tabular manner. The costs considered are the primary cost impacts in the ship design and are based on the Navy "P8" breakdown. It is important to note that in any cost comparisons, the user must be familiar with the source and accuracy of the cost data he is viewing and compare them accordingly.

TOTAL COSTS:

NOTE: User has the option to view either "lead" ship or "follow" ship costs:

Basic Construction Cost

Symbol: C_{bc}

Definition: Costs paid directly to the shipbuilder. These costs include and are broken into the following areas:

* all costs related to shipyard direct labor, overhead and material associated with each of the seven Navy standard SWBS [22] groups.
* Design and construction margin
* Design and Engineering (Group 8) Costs.
* Assembly Construction Services (Group 9) Costs.
* Shipbuilder Profit.

Significance: This cost is a function of the design complexity and the size of the ship. In general, this results in about 28-30% of lead ship cost and 35-40% of follow ship costs.

Comparative analysis examines:

- all Basic Construction Cost Allocation (2-11)

Combat Systems GFE Costs

Symbol: C_{csgfe}

Definition: Those costs related to Combat Systems Government Furnished Equipment (GFE). Includes costs for electronics

and ordnance equipment supplied by the government to the contractor for installation. Actual installation costs of this equipment are included in its respective SWBS cost group of the basic construction cost.

Significance: Function of the complexity and size of the installed electronics and weapons systems.

Comparative analysis examines:

- Combat Systems Cost fraction (2-12)
- Combat Systems GFE/Lead Ship Cost fraction (2-13)
- Combat Systems GFE/Follow Ship Cost fraction (2-13)

Other Costs

Symbol: C_{oth}

Definition: Includes all those miscellaneous costs that are generally fixed percentages of the total cost and do not affect the comparison individually. An additional cost that has been included in this area is that of HM&E GFE which is becoming increasingly smaller. These costs and the guideline percentages of total cost that they comprise include:

	Lead Ship	Follow Ship
- Plans	9.0%	0.5%
- Change orders	3.0%	2.0%
- NAVSEA support	2.5%	1.0%
- Escalation	5.5%	7.0%

- P.M. Growth	4.5%	5.0%
- HM&E GFE	3.0%	2.0%

Significance: Changes as overall total costs change, and is a function of ship size and complexity.

Comparative analysis examines:

- HM&E GFE Cost fraction (2-11)
- All Functional Allocation Cost fractions (2-12)

Total Ship Cost

Symbol: C_t

Definition: $C_t = C_{bc} + C_{oth} + C_{csgfe}$

Total cost of the ship.

Significance: Function of all individual cost components, which in turn are a function of the complexity and size of the ship.

Comparative analysis examines:

- All Ship Size (1-1)
- All Functional Allocation Cost fractions (2-12)
- All Cost fractions (2-13)

SHIP SIZE:

Full Load Displacement

Symbol: Δ_{fl} (Tons)

Definition: Equals the weight of the water displaced and is the sum of the light ship weight plus the loads, which

includes liquids, crew and effects, ordnance, and aviation weights.

Significance: U.S. ships have exhibited an almost constant growth in full load displacement in the years 1940 to 1975. This pattern has shown a reversal with the limiting in size and cost of DDG-51, FFG-7 and CG-47. A change may be the result of a change in load weights or a change in volume requirements, as well as a possible difference in shape characteristics.

Expected Range [24]: frigates 3700 - 4100 tons

destroyers 3900 - 8400 tons

cruisers 7800 - 9600 tons

Comparative analysis examines:

- All Cost and Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Full Load Functional Weight Alloc Fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Functional Cost Allocation fractions (2-12)
- All Functional Energy Allocation fractions (2-8)
- All Manning Allocation fractions (2-9)

Light Ship Displacement

Symbol: Δ_{ls} (Tons)

Definition: The weight of the ship including hull, machinery, outfit, equipment and liquids in machinery [11], which include the seven SWBS groups and the margin weight.

Significance: Light ship displacement has the greatest effect on the basic construction cost of the ship and is a function of ship size, ship systems and material used.

Expected Range [24]: frigates 2700 - 3000 tons

destroyers 2700 - 6700 tons

cruisers 5300 - 7200 tons

Comparative analysis examines:

- All Cost and Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Light Ship Functional Weight Alloc fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Functional Cost Allocation fractions (2-12)
- All Functional Energy Allocation fractions (2-8)
- All Manning Allocation fractions (2-9)

Total Enclosed Volume

Symbol: ∇ (ft^3)

Definition: The sum of the enclosed hull and deckhouse volume of the ship.

Significance: Volume is the major driver of the weight of the ship through its influence on structure, outfitting and distributed systems. It is impacted by the selection of

both combat systems and HM&E systems, arrangement tightness standards, human support standards, deck heights, and arrangement efficiency of the hull. As with displacement, U.S. ships grew in volume from 1940 to 1975 but have shown a reversal of this trend in several of the more recent designs.

Expected Range [24]: frigates 500,000 - 532,000 ft^3

destroyers 414,000 - 1,034,000 ft^3

cruisers 850,000 - 1,103,000 ft^3

Comparative analysis examines:

- Ship Density (1-1)
- All Functional Volume Allocation fractions (2-6)
- All Full Load Functional Weight Alloc fractions (2-3)
- All Functional Cost Allocation fractions (2-12)
- All Functional Energy Allocation fractions (2-8)
- All Manning Allocation fractions (2-9)

Ship Density Full Load

Symbol: Δ_{fl}/∇ (lbs/ft^3)

Definition: The ratio of the full load displacement to the total enclosed volume.

Significance: This is an indication of spaciousness and how significantly the volume drives the design. The larger the ship density value, the more tightly packed (dense) the ship is. The trend since 1940 has shown a decrease in

density. This index is used in the trend analysis section "triple plots" to examine changes in structural, auxiliary, and outfit and furnishing weight groups W1, W5, and W6, respectively.

Expected Range [24]: frigates 16 - 18 lbs/ft^3

destroyers 16 - 22 lbs/ft^3

cruisers 19 - 21 lbs/ft^3

Comparative analysis examines:

- full load displacement (1-1)
- volume (1-1)

Ship Density Light Ship

Symbol: Δ_{ls}/∇ (lbs/ft^3)

Definition: The ratio of the light ship displacement to the total enclosed volume.

Significance: This is a second indication of spaciousness and how the volume drives the design. In this case, the density is that of just the light ship parameters without the load items.

Expected Range [24]: frigates 12 - 13 lbs/ft^3

destroyers 12 - 16 lbs/ft^3

cruisers 14 - 15 lbs/ft^3

Comparative analysis examines:

- light ship displacement (1-1)
- volume (1-1)

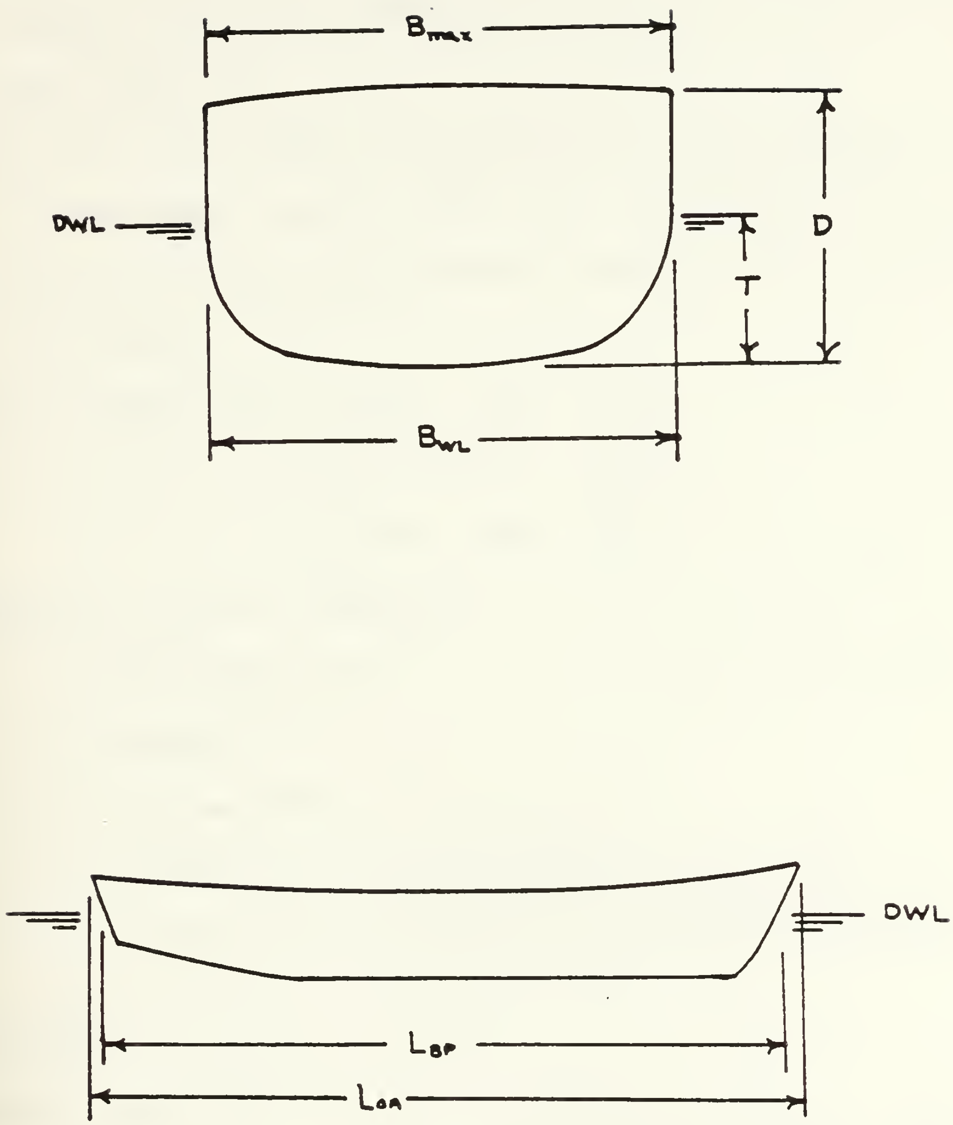

Figure F.1 Ship Size Parameters

Length Between Perpendiculars

Symbol: L_{bp} (ft)

Definition: The length of the ship between the forward and aft perpendiculars, as measured on the load waterline.[10] See figure F.1.

Significance: The change of the length will not only affect the displacement and the volume but is a major driver of powering, seakeeping, structural loading, ship arrangement efficiency.

Expected Range [24]:		
	frigates	407 - 415 ft
	destroyers	407 - 530 ft
	cruisers	524 - 529 ft

Comparative analysis examines:

- displacement (1-1)
- volume (1-1)
- all Shape Characteristics (1-2)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

Length Overall

Symbol: L_{oa} (ft)

Definition: The extreme length of the ship measured from the foremost point of the stem to the aftermost part of the stern.[11] See figure F.1

Significance: If this changes without a change in length between perpendiculars then the ship powering, seakeeping and efficiency may not be affected, however structural loading and ship arrangement will be.

Expected Range [25]: frigates 445 - 438 ft

destroyers 418 - 563 ft

cruisers 546 - 566 ft

Comparative analysis examines:

- Length Between Perpendiculars (1-1)
- Volume (1-1)
- Displacement (1-1)
- all Shape Characteristics (1-2)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

Beam at Waterline

Symbol: B_{wl} (ft)

Definition: Molded breadth of the ship measured at the maximum section design waterline.[11] See figure F.1

Significance: Changing the beam affects the shape of the underwater hull, thereby affecting powering, stability, and arrangeability.

Expected Range [24]: frigate 45 - 47 ft

destroyer 44 - 55 ft except DDG-51 @ 59 ft

cruiser 54 - 55 ft

Comparative analysis examines:

- Volume (1-1)
- Displacement (1-1)
- all Shape Characteristics (1-2)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

Beam (maximum at deck edge)

Symbol: B_{max} (ft)

Definition: Maximum breadth of the ship measured at the deckedge. See figure F.1

Significance: Increasing the beam at the deck edge without increasing the beam at the waterline is possible by producing a flare which may be used to reduce or enhance radar cross section or to improve deck wetness qualities.

Expected Range [25]: frigate 45 - 47 ft

destroyer 44 - 55 ft except DDG-51 @ 67 ft

cruiser 54 - 55 ft

Comparative analysis examines:

- Volume (1-1)
- Displacement (1-1)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

Depth at midships

Symbol: D (ft)

Definition: The vertical distance from the baseline to the tip of the freeboard deck beam at the side, measured at midships.[11] See figure F.1

Significance: A change in depth will generally result in a change in volume and displacement, as well as in the structural aspects of the depth of the box beams. If the draft additionally changes, then the powering, seakeeping and efficiency may be affected.

Expected Range [24]: frigates 30 - 31 ft

destroyers 24 - 42 ft

cruisers 38 - 42 ft

Comparative analysis examines:

- Volume (1-1)
- Displacement (1-1)
- Draft (1-1)
- all Shape Characteristics (1-2)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

Draft (maximum)

Symbol: T (ft)

Definition: The depth of the ship below the designed waterline measured vertically to the lowest point on the bottom of the Keel.[10] See figure F.1

Significance: A significant change in draft may result from a change in loading or size of the ship. This may affect powering, seakeeping or efficiency.

Expected Range [24]: frigates 14-15 ft

destroyers 15-20 ft

cruisers 18-22 ft

Comparative analysis examines:

- volume (1-1)
- displacement (1-1)
- depth (1-1)
- all Shape Characteristics (1-2)
- all Mobility on Ship Performance Screen (1-3)
- all Hull Efficiency on Ship Performance Screen (1-3)

SCREEN 1-2: SHAPE CHARACTERISTICS

All shape characteristics are standard naval architecture indices and ratios used for the evaluation of the hullform and for comparisons. Since they are made up of primarily parameters of screen 1-1 and are directly impacted by them, all of these characteristics will examine their related primary size characteristics in the comparative analysis. Therefore all analysis will be in regard to screen 1-1 only and no second level analysis exists for this screen.

Displacement to Length Ratio

Symbol: $\Delta_{fl}/(.01L_{bp})^3$ (tons/ft)

Definition: Used to express the displacement of a vessel in proportion it its length. This parameter was devised by Admiral D. W. Taylor and is used in calculating the power of ships and in recording the resistance data of models. The displacement is measured in tons, salt water and the length is the length between perpendiculars. The value of .01 was used only to give the coefficients convenient values. [10]

Significance: Most significant hull related parameter impacting on ship speed. Low displacement to length ratio ships have less resistance at high speeds than ships with high ratios.[13] High ratio ships will, therefore, require a higher shaft horsepower per ton displacement ratio.

Expected Range: The general rule of thumb for the ratio is about 50 for a very slender destroyer type hull and about 500 for a large tanker or bulk carrier of full form.[10] For the examined combatant ships [24].

frigates 56 - 57 tons/ft

destroyers 47 - 61 tons/ft except DDG-51 @ 83

cruisers 54 - 65 tons/ft

Comparative analysis examines:

- length between perpendiculars(1-1)
- full load displacement (1-1)

- all mobility in Ship Performance (1-3)
- drag at sustained speed (1-3)

Prismatic Coefficient

Symbol: C_p

Definition: C_p=V/(L_{bp} * Area of maximum section at draft T)

The ratio of the bare hull volume of displacement to the volume of a cylinder having a length and a cross section equal in area to that of the maximum section at the designed waterline. This is considered to be a measure of the longitudinal distribution of a ship's displacement.[11] See figure F.2

Significance: If two ships with different prismatic coefficients have the same length and same displacements, the one with the smaller prismatic coefficient will have the larger midship sectional area which implies a concentration of the displacement midships. The ship with the larger coefficient will have a smaller midship sectional area with more "filled out" ends. Since this distribution of displacement influences the amount of residuary resistance at a given speed, powering will be affected by difference is prismatic coefficient.[10]

Expected Range [10]: 0.55 - 0.80

Comparative analysis examines:

- length between perpendiculars(1-1)

- beam at waterline (1-1)
- draft (1-1)

Maximum Section Coefficient

Symbol: C_x

Definition: C_x = Max transverse section area / (B_{wl} * T)

Ratio of the maximum transverse section area to the area of the circumscribing rectangle, the width of which is the waterline beam and the draft at that section.[10] See figure F.3.

Significance: Since this is a function of the "fullness" of the design, changes in the coefficient will affect powering, arrangeability and total enclosed volume, which will additionally drive displacement.

Expected Range: .69-.90 [10]

Comparative analysis examines:

- beam at waterline (1-1)
- draft (1-1)

Waterplane Coefficient

Symbol: C_{wp}

Definition: C_{wp} = Area of Waterplane / L_{bp} * B_{wl}

The ratio of the area of the waterplane to its circumscribing rectangle at the load waterline of the ship.[10]. See figure F.4

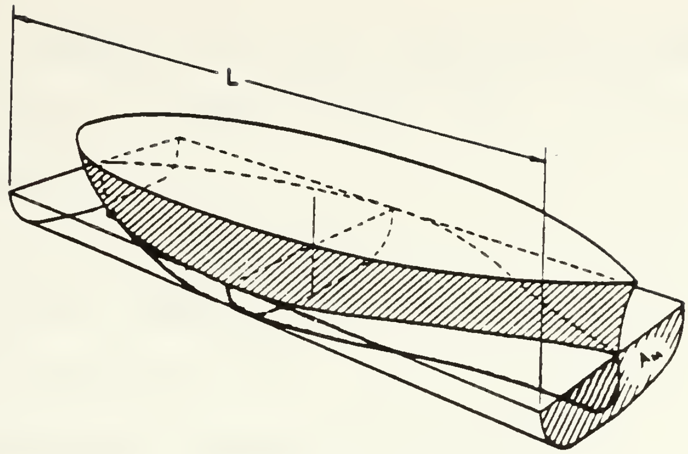

Figure F.2 Prismatic Coefficient

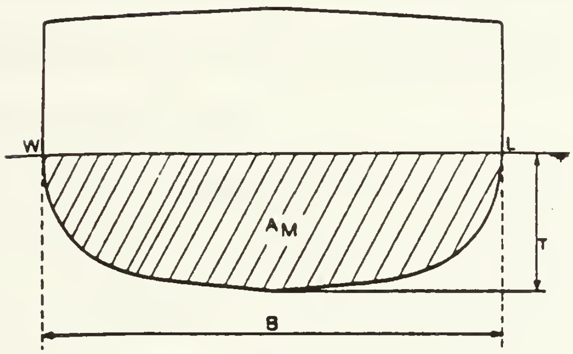

Figure F.3 Maximum Section Coefficient

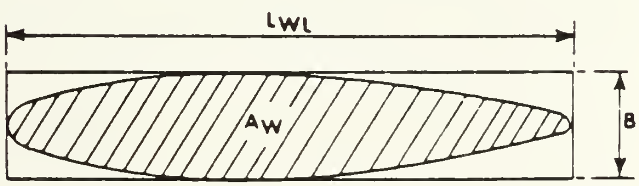

Figure F.4 Waterplane Coefficient

Significance: Changes will affect powering, resistance, and total enclosed volume, which will in turn drive displacement.

Expected Range: 0.67 - 0.87 [10]

Comparative analysis examines:

- beam at waterline (1-1)
- length between perpendiculars (1-1)

Ratios of Dimensions

Definition: These dimensions are commonly used for comparisons as an expression of relative proportions of the ship form as numerical quantities.

Significance: All are impacted by their parent parameters and since all differences involve changes below the waterline, powering, resistance and total enclosed volume will be affected, which may affect displacement, arrangeability, and structural strength.

NOTE: Individual ratios, along with their respective symbols, expected range of values for monohull displacement ships and Comparative analysis paths are given below:

Length to Beam Ratio

Symbol: L_{bp} / B_{wl}

Expected Range [24]: frigate 8.9 - 9.0

destroyer 8.9 - 9.9 except DDG-51 @ 7.9

cruiser 9.6 - 9.7

Comparative Analysis examines:

- length between perpendiculars (1-1)
- beam at waterline (1-1)

Length to Draft Ratio

Symbol: L_{bp} / T

Expected Range [24]: frigate 27.5 - 28.3

destroyer 23.3 - 28.2

cruiser 24.5 - 27.9

Comparative analysis examines:

- length between perpendiculars (1-1)
- draft (1-1)

Beam to Draft Ratio

Symbol: B_{wl} / T

Expected Range [24]: frigate 3.1 - 3.2

destroyer 2.9 - 3.2

cruiser 2.5 - 2.9

Comparative analysis examines:

- beam at waterline (1-1)
- draft (1-1)

Draft to Depth Ratio

Symbol: T / D

Expected Range [24]: frigate .48 - .50

destroyer .48 - .62

cruiser .49 - .51

Comparative analysis examines:

- draft (1-1)
- depth (1-1)

Length to Depth Ratio

Symbol: L_{bp} / D

Expected Range [24,25]: frigate 14.7 - 15.0

destroyer 12.1 - 18.2

cruiser 13.5 - 14.1

Comparative analysis examines:

- length between perpendiculars (1-1)
- depth (1-1)

SCREEN 1-3: SHIP PERFORMANCE

Mobility

Tabular data screen which relates the primary aspects of ship mobility regarding power, speed and range. These are each listed individually with the indices that impact or are impacted by that particular performance. Since these listings are tabular, symbols will not be required. Expected ranges are listed where appropriate.

Maximum Sustained Speed (80% power)

Definition: Based on the speed-power curve, the maximum speed (knots) obtainable at 80% maximum continuous shaft

horsepower, in calm water at full load weight and 100°F temperature.[17] Maximum sustained speed is determined at 80% horsepower to reflect the effect of fouling, sea conditions and propulsion plant degradation. It should be noted that other countries calculate maximum speeds at 100% horsepower and a trial displacement with only partial loads onboard. The speed-power curve can be determined analytically or experimentally and contains a power margin of approximately 10%. This curve is shown in figure F.5.

Significance: A difference in design speed can be attributed to either a change in the propulsion plant power available or in hull efficiency.

Expected Range [25]:

frigates	27 - 29 knots
destroyers	30 - 34 knots
cruisers	30 - 33 knots

Comparative analysis examines:

- shaft horsepower available (1-3)
- all Hull Efficiency of Ship Performance Screen (1-3)
- all size characteristics (1-1)
- all shape characteristics (1-2)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

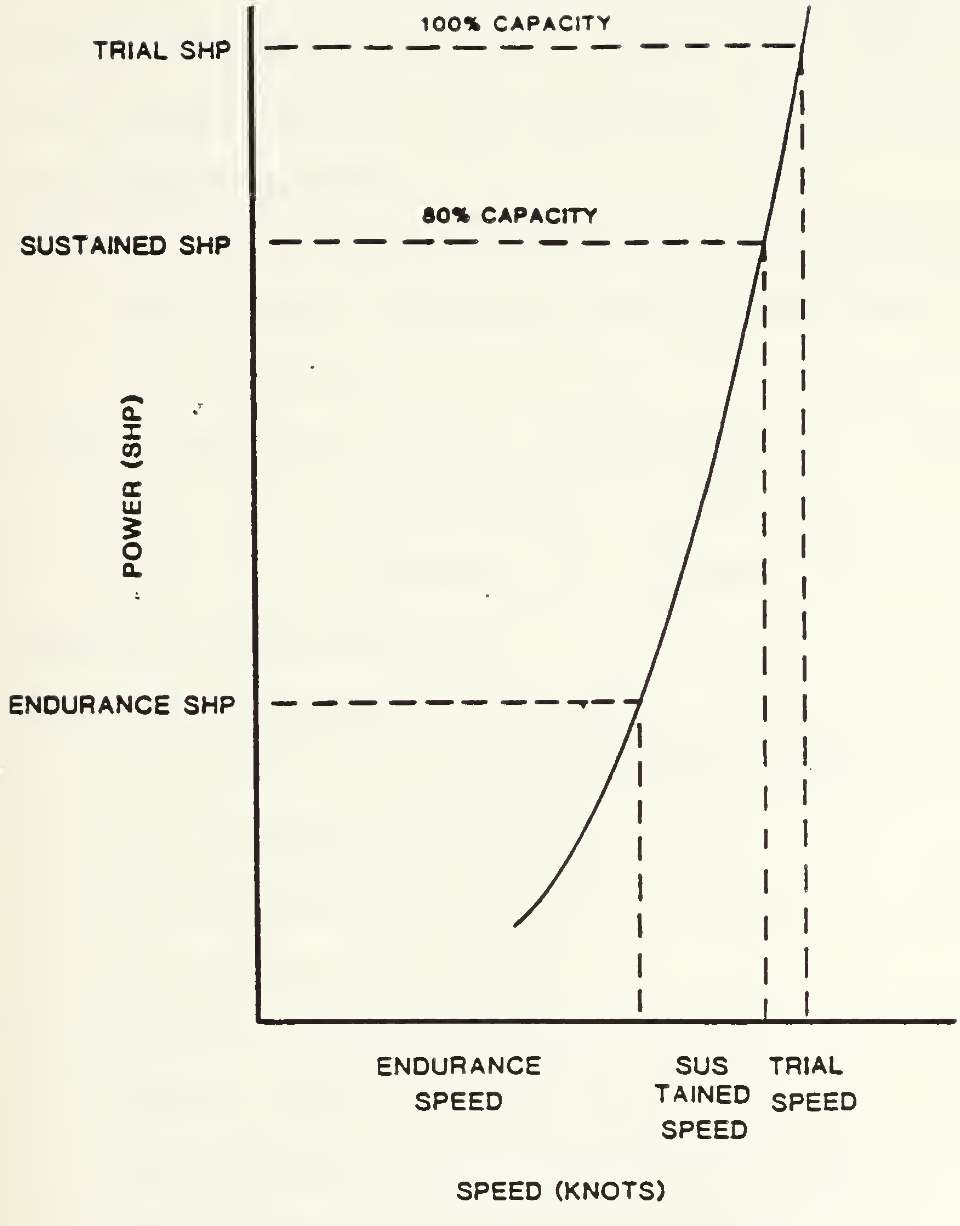

Figure F.5 Speed-Power Curve

Maximum Trial Speed (100% power)

Definition: Based on the speed-power curve, the maximum speed (Knots) obtainable at 100% installed (available) shaft horsepower, in calm water at full load weight and 100°F temperature.[17] See also definition for maximum sustained speed above.

Significance: A difference in trial speed can be attributed to either a change in the propulsion plant power available or in hull efficiency.

Expected Range [25]: frigates 27 - 29 Knots

destroyers 30 - 34 Knots

cruisers 30 - 33 Knots

Comparative analysis examines:

- shaft horsepower available (1-3)
- all Hull Efficiency of Ship Performance Screen (1-3)
- all size characteristics (1-1)
- all shape characteristics (1-2)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

Range at Endurance Speed

Definition: The theoretical maximum distance of travel in nautical miles utilizing all of its burnable fuel, at a specified endurance speed, and ambient conditions of 100°F and 40% humidity, in deep water at full load displacement, as calculated in the Design Data Sheet, reference (18).

Significance: Changes in range impacts fuel requirement, which directly impacts liquids weight and volume. Range may also change if the hull size or efficiency has changed, thereby requiring a powering change.

Comparative analysis examines:

- all Hull Efficiency of Ship Performance Screen (1-3)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

Endurance Period

Definition: The length of time, in days, that the ship can remain underway without replenishment. A function of the four subcategories that are examined independently:

* fuel at endurance speed
* dry stores
* chilled stores

* frozen stores

Significance: Period due to fuel may change as the amount of fuel carried or endurance speed is changed. Stores are generally fixed by the amount that the ship is designed to carry in its storerooms.

Comparative analysis examines:

- all Mobility of Ship Performance Screen (1-3)
- all Hull Efficiency of Ship Performance Screen (1-3)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

Shaft Horsepower Available

Definition: Available power to be delivered into the water by the propeller. As defined in reference (17), shaft power is a function of the ship total effective power divided by the propulsive coefficient. This includes transmission and propeller losses and is calculated for the total power available from boost and cruise engines together at ambient conditions of $100^{\circ}F$ and 40% humidity.

Significance: Power is needed to overcome ship drag (resistance). Differences directly affect maximum speed, propulsion weight and ship mobility volume.

Comparative analysis examines:

- Maximum Sustained Speed (1-3)
- Boost Engine Type/Number/Rating (1-4)
- Cruise Engine Type/Number/Rating (1-4)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

Shaft Horsepower Required at Endurance Speed

Definition: Using the procedure discussed above and detailed in reference (17), a speed-power plot, shown in figure F.5 is obtained for the shaft horsepower of the ship. This plot includes standard speed-power margin policy set by NAVSEA and is dependent on the stage of design.[17] The shaft horsepower required at the desired endurance speed is obtained from this curve. It is noted that other countries do not use large power margins during early stage design which may result in an inequitable comparison between U.S. and foreign ships.

Significance: A change in the required SHP may result in a change in the size of engines required to limit the amount of engines on-line at endurance speed. It may additionally affect efficiency of the engine at endurance

speed, which will directly affect range or fuel requirements.

Comparative analysis examines:

- Range at Endurance Speed (1-3)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Cost Allocation fraction (2-12)

Shaft Horsepower Required at Sustained Speed

Definition: Based upon the speed-power curve, discussed above, this is the shaft power required to make the maximum sustained speed.[17]

Significance: A change in the shaft horsepower required may result in a change in the number of engines required thus resulting in a propulsion weight and ship mobility volume change. The shaft horsepower available must be equal to 1.25 times the shaft horsepower required at sustained speed.

Comparative analysis examines:

- Maximum Sustained Speed (1-3)
- Full Load Machinery Weight (2-3)
- Machinery Functional Allocation volume (2-6)
- Machinery Electrical Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)

- Machinery Cost Allocation fraction (2-12)

Hull Efficiency:

Drag (sustained speed)

Symbol: R_{Ts}

Definition: The fluid force (water and air) acting on the ship in such a way as to oppose its motion. Another term generally used is resistance[11]. As defined in reference (17), sustained speed drag or resistance is the sum of the totals of the frictional resistance, residuary resistance, appendage resistance, and still-air drag at defined sustained speed and full load weight.

Significance: Drag is directly affected by the ship size and shape parameters. In general, for a fixed displacement, an increase in ship length, a decrease in beam or an increase in draft will decrease the ships resistance[10]. These in turn, affect the shape parameters directly, thereby indirectly affecting the powering, structural aspects and arrangeability of the ship.

Comparative analysis examines:

- all Size Characteristics (1-1)
- all Shape Characteristics (1-2)

Drag (endurance speed)

Symbol: R_{Te}

Definition: Ships resistance at endurance speed as defined above.

Significance: Same as for sustained speed drag above.

Comparative analysis examines:

- all Size Characteristics (1-1)
- all Shape Characteristics (1-2)

Bales Rank

Definition: A seakeeping figure of merit relating ship hull geometry to seakeeping characteristics of destroyer type hulls in long-crested, head seas. Based on empirical type data, the rank coefficients range from zero to ten, with ten being the optimum rank. The initial work and the parameters used along with a detailed explanation may be found in reference (19). An extension to the regression theory, which includes a displacement factor is introduced in reference (20).

Significance: In context with the indices used in this analysis, seakeeping is projected to improve with increasing waterplane area coefficient, or decreasing draft to length ratio (increasing length to draft ratio)[19].

Expected Range: Vary in range from 0 to 10 and may exceed 10. A hull with a rank of 7.5 or better is considered to be a very good seakeeping hull.[19]

Comparative analysis examines:

- all size characteristics (1-1)
- all shape characteristics (1-2)

Survivability

The exact method of categorizing the different classifications for survivability indices will be dependent on the synthesis model or data base in use. The impacts of the changes, however, are assessed in the same manner by comparing changes in weight, volume, size, machinery and cost. The trend in recent designs has been to provide increased survivability to the ships, when cost feasible.

Definitions and recommended methods of classification and quantification are discussed with each category.

Blast

Definition: That protection designed into the ship to protect it against the effect of nuclear blast. The general classification is in pounds per square inch (psi) blast overpressure, where the greater the value, the better the protection.

Significance: The protection against blast requires increased structural protection, by either going to a stronger or thicker steel, thus increasing the structural weight fraction directly.

Comparative analysis examines:

- structural weight fractions (2-3)

- structural cost fractions (2-11)

Fragmentation

Definition: That protection designed into the ship to protect its vital combat and HM&E system areas against the "cheap kill" of destroying the capability of the ships mission with metal fragments. General method of classification is by using Levels, where the higher, the level, the greater the protection. Individual spaces may have different levels of protection. Since a program of this type cannot address each space individually, the dominant level in vital spaces will be used for this analysis. Protection levels are defined in reference (26).

Significance: Providing fragmentation protection implies locating vital spaces in inherently protected areas of the ship and/or armoring of vital spaces with increased structure. The latter will affect the structural weight fraction of the ship directly and may affect stability indirectly.

Comparative analysis examines:

- structural weight fractions (2-3)
- structural cost fractions (2-11)

Shock

Definition: That protection designed into the ship to protect it against underwater shock effects. Unless

adequate protection is provided, the ship may experience a "cheap kill" due to damaged vital equipment which received no direct hit. Recommended unit of measure is the Navy standard keel shock factor (KSF), which is explained in detail in reference (27).

Significance: Increased protection against shock requires proper mounting of equipment adding weight in foundations and equipment shock strengthening, thereby resulting in an increase in equipments of SWBS groups 2,3,4,5, and 7. Most new combatant type ships are designed to a 0.3 KSF standard.

Comparative analysis examines:

- All SWBS Weight Fractions (2-1)

NBC

Definition: That protection designed into the ship to protect the crew against nuclear, biological and chemical warfare contamination. These may be as simple as providing masks, clothing and decontamination equipment at the low end to providing full collective protection by pressurizing the interior of the ship and filtering all incoming air. A partial collective protection system is obtained by not including the main engine spaces in the protected subdivided areas. This prevents the

contamination from entering the ship, thus protecting the crew. The recommended unit of measure is classified by:

austere	=	masks, clothing, decon equip
parcps	=	partial cps
fulcps	=	full cps

Significance: A full or partial cps system may result in all areas of the design being affected, from the energy required to power the extra required equipment to the volume required to store them. Therefore, all primary groups must be examined for differences and then analyzed further by the user.

Comparative analysis examines:

- all ship size characteristics (1-1)
- all functional weight allocation fractions (2-3)
- all functional volume allocation fractions (2-6)
- all energy functional allocation fractions (2-8)

Noise signature

Definition: The noise radiated by the ship with which it may be detected either by another surface ship sonar or a submarine sonar. Additionally, the own ships radiated noise affects its own sonar capabilities. Since the relative quieting of the DD-963 is well understood by most designers, the following are recommended classifications:

Normal = less than DD-963

Quiet = DD-963 comparable

Silent = quieter than DD-963

Significance: Noise may be reduced by the incorporation of inherently quiet equipment and increased use of noise suppression mounts on "noisy" equipment to keep the noise from being radiated to the sea through the hull. Prairie and Masker systems may be provided to suppress hull and propeller noise. All these systems result in increased weight and volume of equipment, as well as size and weight of foundations.

Comparative analysis examines:

- all ship size characteristics (1-1)
- all functional weight allocation fractions (2-3)
- all functional volume allocation fractions (2-6)
- all energy functional allocation fractions (2-8)

IR Signature

Definition: That protection designed into the ship to protect it against infra-red detection and decrease the capability of infra-red target acquisition by enemy missiles. Since no basis for measurement is presently available, it is recommended that the following be used to specify an improved signature:

None = no IR suppressors installed

Normal = DD963 type suppression installed

Decreased = Better suppression than DD963

Significance: Increased protection requires the addition of stack gas heat suppression or IR shielding techniques. These will affect weight and volume characteristics directly and may affect energy and manning indirectly.

Comparative analysis examines:

- all ship size characteristics (1-1)
- all functional weight allocation fractions (2-3)
- all functional volume allocation fractions (2-6)
- all energy functional allocation fractions (2-8)

Radar Signature

Definition: Protection designed into the ship to decrease the radar cross-section as seen by another radar looking at the ship being designed. This can be done by removing such reflection enhancers as "right angles" thus canting the sides to other than an orthogonal angle. The only U.S. Navy ship to be designed for radar signature reduction is the DDG51, it is therefore recommended that the following measurement be used.

Normal = no radar signature reduction

Reduced = equivalent to DDG51

Stealth = less signature than DDG51

Significance: By canting the sides of the hull and the superstructure, the weight and volume are increased due to unused volume addition for the flare.

Comparative analysis examines:

- all ship size characteristics (1-1)
- all functional weight allocation fractions (2-3)
- all functional volume allocation fractions (2-6)

SCREEN 1.4: HM&E SYSTEM SELECTION

The area of system selection offers one of the largest opportunities for comparative assessment of different HM&E subsystems. By use of synthesis models, such as ASSET and DD08, a baseline ship is easily varied. The variant may be formed using either new technology or a simple subsystem change and the results stored in the data base and then directly examined without ever leaving the computer terminal. This provides one of the greatest strengths of accessing a comparative naval architecture module directly from within a synthesis program.

The subsystems and their associated direct impact values of interest to the designer are listed on this screen and compared between the selected baseline and variant design. Differences will be highlighted using reverse video and impacts may be assessed directly by the designer or indirectly by using the comparative analysis option.

Each indice and parameter selected to describe the various subsystems is defined below.

Main Propulsion

Total Boost Power Avail/Reqd at Sustained Speed/Growth Potential

Definition: Total Propulsion horsepower available as compared to that required at sustained speed (80% power). The difference between required and available is the propulsion growth potential.

Significance: To get more available, the number of engines or size must change, and the number required is a function of the required speed and the hull efficiency. A significant change or difference will affect weight and volume, as well as manning and energy.

Comparative analysis examines:

- Full Load Machinery Weight fraction (2-3)
- Light Ship Machinery Weight fraction (2-3)
- Machinery Functional Allocation Volume fraction (2-6)
- Tankage Volume fraction (2-5)
- All Installed Hp Energy Allocation (2-8)
- All Fuel Usage Energy Allocation (2-8)
- Machinery Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Functional Allocation Cost fraction (2-12)

Boost Engine Type/Number/Rating

Definition: Installed number and type of boost (or main) engines (Gas Turbine, Diesel, Steam, etc.) and associated maximum continuous horsepower rating at 100°F per engine. Boost engines are those that are required to achieve maximum speed. In the case, where no cruise engines exist, boost engines are used at all speeds.

Significance: A change in type or number will directly affect weight and volume requirements, and may indirectly affect manning and energy. A change in rating will additionally affect ships powering and fuel requirements.

Comparative analysis examines:

- Full Load Machinery Weight fraction (2-3)
- Light Ship Machinery Weight fraction (2-3)
- Machinery Functional Allocation Volume fraction (2-6)
- Tankage Volume fraction (2-5)
- All Installed Hp Energy Allocation (2-8)
- All Fuel Usage Energy Allocation (2-8)
- Machinery Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Functional Allocation Cost fraction (2-12)

Cruise Engine Type/Number/Rating

Definition: If installed, the cruise (or secondary) engine is used to provide cruise power at endurance speed to

provide better fuel economy. This parameter provides information as to the type, number and continuous maximum horsepower rating of the secondary engines. These engines are additionally used during boost applications.

Significance: An upgrade in cruise engines will directly affect weight and volume requirements by increasing machinery but decreasing fuel. Since these engines are used primarily for endurance calculations, a change may additionally account for differences in either fuel required or ships range.

Comparative analysis examines:

- Range at Endurance Speed (1-3)
- Full Load Machinery Weight fraction (2-3)
- Light Ship Machinery Weight fraction (2-3)
- Machinery Functional Allocation Volume fraction (2-6)
- Tankage Volume Allocation fraction (2-5)
- All Installed Hp Energy Allocation (2-8)
- All Fuel Usage Energy Allocation (2-8)
- Machinery Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Functional Allocation Cost fraction (2-12)

Transmission System Type

Definition: Specifies the type of transmission system used to deliver propulsion power from the engines to the

propeller shaft. Electrical (AC/AC, AC/DC, etc) or mechanical (LTDR, Epicyclic, etc)

Significance: A change in transmission type will affect all propulsion weight and volume related factors and may affect structure or energy, especially if a change is made from electrical to mechanical or vice versa.

Comparative analysis examines:

- Full Load Machinery Weight fraction (2-3)
- Light Ship Machinery Weight fraction (2-3)
- Machinery Functional Allocation Volume fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Machinery Functional Allocation Cost fraction (2-12)

.Propeller Type/No./RPM

Definition: Number and type of propeller (CRP, fixed pitch, contra-rotating) and its associated maximum RPM at trial speed (100% power).

Significance: Change in propeller type and RPM will directly affect powering, thereby affecting speed, range, fuel and noise requirements. A change in fuel requirements may then indirectly affect volume and weight in the mobility area.

Comparative analysis examines:

- Max Trial Speed (1-3)

- Max Sustained Speed (1-3)

- Range at Endurance Speed (1-3)

- Full Load Machinery Weight fraction (2-3)

- Tankage Volume fraction (2-5)

- Machinery Electrical Energy Allocation fraction (2-7)

- Machinery Functional Allocation Cost fraction (2-11)

Propeller Open Water Efficiency (sustained speed)

Definition: The ratio between the power developed by the thrust of the propeller and the power absorbed by the propeller when operating in open water with uniform inflow velocity[17]. A function of the propeller torque at a given thrust, speed of advance and propeller revolutions at sustained speed.[10].

Significance: Function of the selected propeller for the design. An increase in efficiency may result in an improved sustained or trial speed, as well as a decrease in the horsepower required to achieve them.

Comparative analysis examines:

- all mobility of Ship Performance Screen (1-3)

Propeller Open Water Efficiency (endurance speed)

Definition: The ratio between the power developed by the thrust of the propeller and the power absorbed by the propeller when operating in open water with uniform inflow velocity[17]. A function of the propeller torque at a

given thrust, speed of advance and propeller revolutions at endurance speed.[10].

Significance: Function of the selected propeller for the design. An increase in efficiency may result in an improved sustained or trial speed, as well as the horsepower required to achieve them.

Comparative analysis examines:

- all mobility of Ship Performance Screen (1-3)

Propulsion Coefficient

Definition: Ratio of effective horsepower to delivered horsepower[10]. More rigidly defined as a function of the Taylor wake fraction, thrust deduction fraction, propeller open water efficiency and relative rotative efficiency[17].

Significance: Since hull-propeller interaction is a major factor in the associated wake and thrust fractions, the parameter is affected by the hull. A change in the parameter will affect speed directly and may affect range and fuel requirements indirectly.

Comparative analysis examines:

- All ship size characteristics (1-1)
- All mobility of ship performance screen (1-3)
- Full Load Machinery Weight fraction (2-3)
- Tankage Volume fraction (2-5)

- Machinery Electrical Energy Allocation fraction (2-8)
- Machinery Allocation Cost fraction (2-12)

Specific Fuel Consumption Rate @ Endurance Speed

Symbol: SFC_e

Definition: The specific fuel rate in lb/SHP-hr based on the total fuel consumption for propulsion machinery only when operating at the specified endurance speed, at ambient 100^oF and 40% humidity.[18]

Significance: SFC changes with horsepower output and most engines run more efficiently with a lower SFC at higher horsepower. If the endurance speed SFC changes, the range and/or the fuel load carried will be directly affected.

Comparative analysis examines:

- Range at endurance speed (1-3)
- Endurance Period due to Fuel (1-3)
- Tankage Volume fraction (2-5)
- Full load Machinery Weight fraction (2-3)

Specific Fuel Consumption Rate @ Sustained Speed

Symbol: SFC_s

Definition: The specific fuel rate in lb/SHP-hr based on the total fuel consumption for propulsion machinery only when operating at the specified sustained speed, at ambient 100^oF and 40% humidity.[18]

Significance: SFC changes with horsepower output and most engines run more efficiently with a lower SFC at higher horsepower.

Comparative analysis examines:

- Max Sustained Speed (1-3)
- Full load Machinery Weight fraction (2-3)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

Electric Power

Total 60Hz KW Available/Maximum Load/Growth Potential

Definition: The sum of the total 60Hz generation capacity available for use as compared to the actual maximum functional load. The growth potential in this case is the difference between the two. The Navy requirement is that a minimum of one generator be available as "standby".[16]

Significance: An increase in load or a decrease in available KW may result in the inability to meet the demand of a "standby" generator, thus necessitating the addition of

another generator or the increased size of the available number, which will directly impact weight and volume and may impact manning in the electrical and mobility area.

Comparative analysis examines:

- Electrical Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- All Electrical Energy Allocation fractions (2-7)
- Fuel Usage Energy Alloaction fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Electrical Allocation Cost fraction (2-11)

Total 400 Hz KW Available/Maximum Load/Growth Potential

Definition: The sum of the total 400 Hz conversion capacity available for use as compared to the actual 400 Hz maximum functional load. The margin is the difference between the two. The Navy requirement is that a minimum of one converter to be available as a "standby".[16]

Significance: An increase in load or a decrease in available KW may result in the inability to meet the demand of a "standby" 400 Hz converter, thus necessitating the addition of another 400 Hz converter on the ship, which will directly impact weight and volume and may impact manning in the electrical and mobility area. An additional impact is that since in most cases, the 400Hz converter

draws its power from one of the 60Hz generators, there may be an effect in the 60 Hz area.

Comparative analysis examines:

- Total 60 Hz KW available/maximum load/margin (1-4)
- Electrical Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- All Electrical Energy Allocation fractions (2-7)
- Fuel Usage Energy Alloaction fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Electrical Allocation Cost fraction (2-11)

60 Hz Generator Type/Number/Rating

Definition: Number and type of installed 60 Hz generators (Gas Turbine, Diesel, etc.) and individual "maximum continuous available KW" rating.

Significance: A minimum of three generators are required on surface combatants. All generators must be of the same rating. A change in this parameter will affect electrical weight, volume and electrical margin related indices directly, and may affect manning indirectly.

Comparative analysis examines:

- Electrical Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- All Electrical Energy Allocation fractions (2-7)
- Fuel Usage Energy Alloaction fraction (2-8)

- Engineering Manning Allocation fraction (2-10)
- Electrical Allocation Cost fraction (2-11)

400 Hz Generator Type/Number/Rating

Definition: Number and type of installed 400 Hz generators or converters and individual "maximum available KW" rating.

Significance: A change in this parameter will affect electrical weight and volume related indices directly, and may affect manning indirectly. Older ships tend to still use the motor-generator type converter, whereas the newer ships and all future ships use the solid-state static converters.

Comparative analysis examines:

- Electrical Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Fuel Usage Energy Alloaction fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Electrical Allocation Cost fraction (2-11)

Specific Fuel Consumption (electrical)

Symbol: SFCA

Definition: The specific fuel rate in lb/Hp-hr based on the total fuel consumption for the electric generators only at an average 24 hour electric load in KW at ambient 100°F and 40% humidity.[18]

Significance: A change in electrical SFC will directly affect the amount of fuel needed to meet the required endurance range.

Comparative analysis examines:

- Range at endurance speed (1-3)
- Tankage Volume fraction (2-5)
- Full Load Machinery Weight fraction (2-4)
- Fuel Usage Energy Alloaction fraction (2-8)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

Auxiliary

Total AC Available/Maximum Load/Growth Potential

Definition: Air conditioning is provided for the comfort of the crew and the protection of the vital electronics equipment and includes both temperature and humidity control. Total AC available and maximum load are rated in "tons" of cooling capacity and are based on the total

number of units available. The growth potential is the difference between available and required.

Significance: The extent of temperature and humidity control required drives the parameter, directly affecting weight, volume and energy. These affects may not only be in the area of installing extra or larger units, but also in specific spaces where additional weight and volume are required for the ducting and fan rooms. Indirect affects may include manning. This may drive the design choice to not cool some spaces where cooling was initially desired. AC plants have continuously grown in size over the last 40 years.

Comparative analysis examines:

- AC Type/No./Rating (1-4)
- Auxiliary Systems Weight fraction (2-1)
- Light Ship Containment Weight fraction (2-3)
- All Functional Volume Allocation fractions (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Auxiliary Systems Allocation Cost fraction (2-11)

AC Type/No./Rating

Definition: Specifies the type and number of AC units, as well as the rating in tons of cooling capacity of each.

Significance: Size and number vary with the functional equipment cooling load, growth margins, redundancy and plant rating. Impacts are as described in parameter above.

Comparative analysis examines:

- Total AC Available/Max Load/Margin (1-3)
- Auxiliary Systems Weight fraction (2-1)
- Light Ship Containment Weight fraction (2-3)
- All Functional Volume Allocation fractions (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Auxiliary Systems Allocation Cost fraction (2-11)

Heating Type/Rating

Definition: Predominant form of heating used on the ship as steam or electric. Rating would be electric power required per unit in KW for electric and steam pressure required per unit in psi for steam.[21]

Significance: The greatest impact results in the area of energy usage depending on whether the system uses steam or electric coils as the heat source. If electric heating is used, the winter daily energy load may vary considerably. The type of heater has little impact on volume or weight.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)

- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

Firepump Type/No./Rating

Definition: Number and type of firepumps installed rated by gallons per minute (gpm).

Significance: Little effect on other systems but vital to damage control organization.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

Seawater Pump Type/No./Rating

Definition: Number and type of seawater service pumps installed rated by gallons per minute (gpm).

Significance: Number required is a function of the type of other systems installed that require seawater cooling from the main cooling loop.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

HP Air Compressor Type/No./Rating

Definition: Number and type of HP air compressors installed rated by cubic feet per minute air flow (cfm).

Significance: Dependent on the requirements for HP air. Gas turbine ships use HP air for starting purposes, which makes it a critical system for this type of propulsion plant. Other uses include torpedo and gun systems.

Comparative analysis examines:

- Boost Engine Type (1-4)
- Cruise Engine Type (1-4)
- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

LP Air Compressor Type/No./Rating

Definition: Number and type of LP air compressors installed rated in cubic feet per minute air flow (cfm).

Significance: Dependent on the requirements for LP air, which are fairly general and widespread for all combatants.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)

- Auxiliary Systems Allocation Cost fraction (2-11)

Distilling Plant Type/No./Rating

Definition: Number and type of Distilling Plants installed where the rating is in gallons of freshwater produced per day (gpd). Type should specify whether the system is steam or electric.

Significance: A critical system to crew support. As the ship size increases, the crew size may increase proportionally and the distillers must be sufficient to meet their daily need. Additionally, an electrical type system will draw a larger electrical load.

Comparative analysis examines:

- Manning Total Complement (1-4)
- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

Boats Type/No.

Definition: Specifies the number and types of ships boats carried onboard.

Significance: Boats require external area and provide weight in the superstructure area, as well as requiring mechanical handling equipment. The type and number of

boats will directly affect weight and energy but will have little effect on internal volume.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

Steering Units Type/No.

Definition: Specifies the number and type of steering units installed onboard the design.

Significance: Steering units require volume and are inherently very heavy, thus affecting weight and volume parameters directly. Indirect effects may include manning and energy considerations.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Engineering Manning Allocation fraction (2-10)
- Auxiliary Systems Allocation Cost fraction (2-11)

Anchors Type/No./Length of Chain

Definition: Specifies the number and type of anchors installed, as well as the total length of chain carried aboard.

Significance: Anchors require a large amount of chain. Installation of an additional anchor or possibly a heavier anchor will directly affect weight and volume by requiring a chain locker and having to store the chain. Additional requirements may be in the form of energy for an upgraded or additional anchor windlass.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Full Load Machinery Weight fraction (2-3)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

UNREP Capability

Definition: Specifies type of underway replenishment capability installed or "none". Older ships have fixed padeyes and miscellaneous handling equipment. Newer combatants (FFG-7, DD-963, etc) have the STREAM (Standard Tensioned Replenishment Alongside Method) system.[16]

Significance: Underway replenishment capability requires deck space for receiving and mechanical handling equipment which may affect energy directly if an automated system is used. Although, external area is required, internal volume and weight impact are not expected to be too great, but should be checked at Comparative analysis anyway.

Comparative analysis examines:

- Auxiliary Weight fraction (2-1)
- Machinery Volume Allocation fraction (2-6)
- Machinery Electrical Energy Allocation fraction (2-8)
- Auxiliary Systems Allocation Cost fraction (2-11)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

Structure/Materials

Hull Materials

Definition: Specifies the principal materials with which the hull is constructed. Since the hull may be constructed of more than one type of material, this information must be available to be stored in an array which will specify type of material and location of usage.

Significance: The type of material specifies the material properties which result in scantling sizing and weight calculations. Different types of materials will result in radically differing structural weights, which may

indirectly affect all major groups of the ship design. All functional areas will, therefore, be examined in the Comparative analysis.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Functional Weight fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Electrical Energy Functional fractions (2-8)
- All Functional Manning Allocation fractions (2-10)
- All Functional Allocation Cost fractions (2-12)

Deckhouse Materials

Definition: Specifies the principal materials with which the deckhouse is constructed. Since it may be constructed of more than one type of material, the input must be an array that will allow the location and material to be specified.

Significance: The type of material specifies the material properties which result in scantling sizing and weight calculations. Different types of materials will result in radically differing structural weights, which may indirectly affect all major groups of the ship design. All functional areas will, therefore, be examined in the comparative analysis.

Comparative analysis examines:

- All Size Characteristics (1-1)

- All Functional Weight fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Electrical Energy Functional fractions (2-8)
- All Functional Manning Allocation fractions (2-10)
- All Functional Allocation Cost fractions (2-12)

Hull Frame Type/Spacing

Definition: Specifies hull framing type (transverse or longitudinal) and frame spacing used in the hull.

Significance: Longitudinal framing is much superior to the transverse system in longitudinal strength[10] and is used in Naval combatants. Present designs use widely spaced longitudinals and web frames to reduce construction labor[13]. The effect of decreasing the spacing will result in increased structural weight. The important aspect of adequate structure is adequate hull strength. All primary characteristics should be examined for changes, since they may be indirectly affected by a frame spacing or a type of frame change.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Functional Weight fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Electrical Energy Functional fractions (2-8)
- All Functional Manning Allocation fractions (2-10)

- All Functional Allocation Cost fractions (2-12)

Deckhouse Frame Type/Spacing

Definition: Specifies hull framing type (transverse or longitudinal) and frame spacing used in the deckhouse.

Significance: As with the hull framing, deckhouses are generally longitudinally framed to increase strength. Changing the spacing, again affects the weight of the superstructure directly. Other groups may be affected and must also be examined.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Functional Weight fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Electrical Energy Functional fractions (2-8)
- All Functional Manning Allocation fractions (2-10)
- All Functional Allocation Cost fractions (2-12)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

Deck Heights

Number of Internal Decks in Hull

Definition: Number of decks and platforms below the main deck.

Significance: Impacts directly on the structural weight and the amount of arrangeable area available.

Comparative analysis examines:

- Total Manning Complement (1-4)
- Structural Weight fraction (2-1)
- All Space/Type Location Volume fractions (2-5)

Number of Internal Decks in Deckhouse

Definition: Number of decks in the superstructure above the main deck.

Significance: Impacts on structural weight and arrangeable area available in the deckhouse.

Comparative analysis examines:

- Total Manning Complement (1-4)
- Structural Weight fraction (2-1)
- All Space/Type Location Volume fractions (2-5)

Internal Deck Heights

Definition: Array which will hold the height of each deck, hull and deckhouse, as a function of height above baseline.

Significance: Impacts arrangeable volume and area available.

Comparative analysis examines:

- All Space/Type Location Volume fractions (2-5)

Hull Average Deck Height

Definition: Total arrangeable volume divided by the comparable area.

Significance: Directly affects human support space available and impacts the crew.

Comparative analysis examines:

- Total Manning Complement (1-4)
- Structural Weight fraction (2-1)
- All Space/Type Location Volume fractions (2-5)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

Manning

Total Accomodations/Total Complement/Growth Potential

Definition: Accomodations are the actual berths onboard for each rating. The complement is the total number of

personnel, including officer, CPO, and enlisted expected to be assigned to the ship. The growth potential is the difference between the two.

Significance: A larger number of accomodations impacts the ship by requiring more space and using more weight and energy. The margin may be required to allow for future weapons system addition.

Comparative analysis examines:

- Crew and Effects Load Weight fraction (2-2)
- Full Load Containment Weight fraction (2-3)
- Human Support Volume fraction (2-4)
- Containment Electrical Energy Allocation fraction (2-8)
- All Manning Allocation fraction (2-9)
- All Functional Allocation Cost fraction (2-12)

Total Complement (OFF/CPO/ENL)

Definition: The total complement of personnel; officer, chief petty officer and enlisted. Manning level is most often determined by ship requirements at Condition III, which is underway with selected elements of combat systems energized and still having the ability to perform maintenance and training.

Significance: Each unit of manning adds both weight and volume to the design directly and energy indirectly. Officers require more than CPO's, which require more than

enlisted. This is therefore impacted whenever a new or updated subsystem, which requires additional personnel, is added to the ship.

Comparative analysis examines:

- Crew and Effects Load Weight fraction (2-2)
- Full Load Containment Weight fraction (2-3)
- Human Support Volume fraction (2-4)
- Containment Electrical Energy Allocation fraction (2-8)
- All Manning Allocation fraction (2-9)
- All Functional Allocation Cost fraction (2-12)

Habitability Classification

Definition: Determines the amount of "Human Support" designed into the ship. Human support includes both environmental control and the actual facility area required for living, messing and recreation. A recommended classification is, as in the ASSET program[16], either "plush", "standard", or "austere". An example of "plush" would be the DD963 class destroyer, whereas the DDG2 class would be classified as "austere". Habitability standards are set by the Office of Naval Operations.

Significance: The level of classification has an obvious direct volume, weight, and energy impact on the overall ship.

Comparative analysis examines:

- Crew and Effects Load Weight fraction (2-2)
- Full Load Containment Weight fraction (2-3)
- Human Support Volume fraction (2-4)
- Containment Electrical Energy Allocation fraction (2-8)
- All Manning Allocation fraction (2-9)
- All Functional Allocation Cost fraction (2-12)

Flag Configured

Definition: Either "yes" or "no" indicating whether the ship is designed to carry a squadron or group commander with staff.

Significance: The addition of this capability will add approximately 8-10 officer and 2-4 enlisted manning requirements to the ship. This directly relates to human support weight, volume and energy requirements.

Comparative analysis examines:

- Crew and Effects Load Weight fraction (2-2)
- Full Load Containment Weight fraction (2-3)
- Human Support Volume fraction (2-4)
- Containment Electrical Energy Allocation fraction (2-8)
- All Manning Allocation fraction (2-9)
- All Functional Allocation Cost fraction (2-12)

Other

Definition: Comment array to allow user to input manually any other systems that he feel significant under this heading. Items input into this category will display only and will have no impact on Comparative analysis. Recommend that array be one column and 10 rows, of which any portion may be accessed.

SCREEN 1-5: COMBAT SYSTEMS SELECTION

As in the HM&E system selection above, the ability to compare the whole ship impact of choosing an alternate combat system or group of combat systems in a real-time environment is extremely beneficial. A decision to update to a different combat system can be made directly from information obtained within a synthesis model or an existing data bank. This decision can be based on overall ship impact and not just on cost or weight analysis, as is often done. It must, however, be noted that this analysis examines only the ship impact of the alternate combat system as compared to the baseline and not the operational effectiveness of the combat system itself. It will provide information to compare both quality and quantity of combat systems. The assessment of quantity will be provided by the parameters such as the number and size of the missiles, whereas, the assessment of quality must come from the designers knowledge of the system.

Definition: Combat Systems are payload systems which are generally government supplied equipment. They are classified into one of three warfare areas and then further subdivided into a primary usage depending on the system. This may result in some systems being listed more than once. The three warfare areas listed are:

Anti-Air Warfare (AAW)

Anti-Submarine Warfare (ASW)

Surface/Strike Warfare (SUW)

Command, Control, Communications and Intelligence ($C3_I$)

Where the first three are each subdivided into:

Armament - all weapons related systems (guns, missiles)

Sensors - all sensor related systems (search radars, fire control radars, EW systems)

Aviation - all aviation related systems (helo & support)

The C^3I warfare area is subdivided into:

Command & Control - all command and control related systems

Communications - all communications related systems

Electronic Warfare - all electronic warfare systems

Significance: The screen is set up to allow direct one-on-one comparison of combat systems for each area and subarea addressed above. Changes in the variant to the baseline ship are highlighted and can be selected for Comparative analysis. It is noted, however, that if more than one combat system is changed, the resultant impact analysis obtained is for the overall combat system change, not only for the one selected. To perform a single system impact analysis, the single system must be the only one changed on the variant with all other systems being identical in all other respects.

Comparative analysis: Since changes in a combat system may affect everything from displacement to energy and powering, all four subsystem categories of this screen are analysed using the same decision "branch" which checks for first order changes in the new variant.

- All Functional Weight fractions (2-3)
- All Functional Volume Allocation fractions (2-6)
- All Space Type/Location Volume fraction (2-5)
- All Functional Electrical Energy fractions (2-8)
- All Functional Manning Allocation fractions (2-10)
- All Functional Allocation Cost fractions (2-12)

LEVEL 2: RESOURCE ALLOCATION

This second level of comparative analysis further investigates related resource screens of level 2 to narrow down the effect on the resource, as well as looking at level 3 to find how any specific resource change or difference has affected the functional area of:

- containment
- main propulsion
- electrical
- auxiliary
- combat system
- human support

SCREEN 2-1: SWBS WEIGHT FRACTIONS

This weight fraction is the relationship of the weight of the SWBS[22] group to the overall displacement weight either full load or light ship, as selected by the user. In many cases, this is the first check of where weight change has occured due to a change in a HM&E system, combat system or ship integration approach. Further analysis using the comparative analysis option allows further investigation into the exact impact or cause of the weight change.

Since this is a fraction, the sum totals must always equal 100% and interpretation of change must be made by the user. As an example, the addition of weight in one SWBS area will also result in an overall displacement change. All fractions then change

accordingly with the affected group increasing a given percentage. The sum of all other groups will then decrease that given percentage to maintain the 100% requirement. In the event that the variant has been affected in more than one SWBS group, the user will have to analyze the situation to the best of his ability. The comparative analysis option may help him in this regard.

Each screen indice is seperately addressed below.

General symbols: Δ_{fl} = full load displacement

Δ_{ls} = light ship displacement

Δ = select either full load or light ship displacement

Structural

Symbol: W_1/Δ

Definition: Hull structural weight fraction including all SWBS Group 1 weights as listed in reference (22).

Significance: $W_1/\Delta = (W_1/\nabla) * (\nabla/\Delta)$

This fraction is largely driven by the total hull structure specific weight and the inverse of the ship density. It is therefore, extremely dependent on volume. It is affected by many variables, including length, volume, displacement, hull form, local loading, ship dimension ratios, penetrations, frame spacing and materials. The recent trend to increased ship volume has resulted in an upward trend in structural weight.

Expected Range[24]: light ship 35 - 53 %

full load 24 - 40 %

Comparative analysis examines:

- Hull Structure Cost (2-11)
- All Structure Wt Breakdown Fractions (3-1)
- All W_1 Related Containment Indices (3-2)

Main Propulsion

Symbol: W_2/Δ

Definition: Main Propulsion weight fractions which includes all SWBS Group 2 weights listed in reference (22).

Significance: $W_2/\Delta = (W_2/SHP) * (SHP/\Delta)$

Driven primarily by main propulsion specific weight and propulsion ship size ratio. Here the subsystem designer may be able to control the specific weight, however, the propulsion ship size ratio is driven by the ship requirements for speed or by the efficiency of the hull. Recent trends have shown a decrease in this fraction, primarily due to the shift to gas turbine propulsion instead of steam.

Expected Range[24]:

light ship gas turbine	10 - 13 %
light ship steam	15 - 26
full load gas turbine	7 - 10
full load steam	11 - 18

Comparative analysis examines:

- Propulsion Plant Cost (2-11)
- All Main Propulsion Weight Breakdown (3-3)
- All Weight Related Main Propulsion Indices (3-4)

Electrical

Symbol: W_3/Δ

Definition: Electrical weight fraction including all SWBS Group 3 weights of reference (22).

Significance: $W_3/\Delta = (W_3/E_i) * (E_i/\Delta)$

Driven by electrical specific weight of installed power and electrical ship size ratio. The recent increasing trend is due to the increased installed KW/ton for the combat systems and the change from steam to gas turbine propulsion and steam to electrical auxiliaries.

Expected Range[24]: light ship gas turbine 5 - 7 %

light ship steam plant 4 - 5

full load gas turbine 4 - 5

full load steam plant 3 - 4

Comparative analysis examines:

- Electric Plant Costs (2-11)
- All Electric Plant Weight Breakdown (3-5)
- All Weight Related Electrical Indices (3-6)

Command and Surveillance

Symbol: W_4/Δ

Definition: Command and Surveillance Weight fraction including all SWBS Group 4 weights as listed in reference (22).

Significance: W_4/Δ = $(W_4/\#snsr) * (\#snsr/\Delta)$

Driven by the command and surveillance specific weight and capacity size ratio. This group includes all sensor and radar systems, including fire control. The recent increasing trend is due to the higher emphasis on radar, sonar and countermeasures.

Expected Range[24]: light ship 3 - 10 %

full load 3 - 7

Comparative analysis examines:

- Combat Systems Cost (2-12)
- All Combat System Weight Fractions (3-9)
- All C&S Weight Fractions (3-9)
- All C&S Related Combat System Indices (3-10)

Auxiliary Systems

Symbol: W_5/Δ

Definition: Auxiliary Systems weight fraction, including all SWBS Group 5 weights as listed in reference (22).

Significance: $W_5/\Delta = (W_5/\nabla) * (\nabla/\Delta)$

Driven by the auxiliary specific weight and ship specific volume. A function of the complexity of the auxiliary systems installed. The shift to gas turbine propulsion

and increased HVAC requirements for the combat systems and habitability has resulted in an increased W_5 fraction.

Expected Range[24]: light ship 11 - 14 % except FFG-7 @ 18%

full load 8 - 10 % except FFG-7 @ 13%

Comparative analysis examines:

- Auxiliary Systems Cost (2-11)
- All Auxiliary Weight Breakdown (3-7)
- All Auxiliary Indices (3-8)

Outfit and Furnishings

Symbol: W_6/Δ

Definition: Outfit and Furnishings weight fraction, including all SWBS Group 6 weights as listed in reference (22).

Significance: $W_6/\Delta = (W_6/\nabla)*(\nabla/\Delta)$

Driven by auxiliary specific weight and ship specific volume. Since much of this weight group relates to human support, it is directly affected by the manning size and the type of habitability installed in the design. Since the trend has been to improve habitability, this fraction has shown an increase in recent years.

Expected range[24]: light ship 8 - 12 %

full load 5 - 9 %

Comparative analysis examines:

- Outfit and Furnishings Cost (2-11)
- All Outfit and Furnishing Weight Breakdown (3-1)

- All W_6 Related Containment Ratios (3-2)

- Human Support Specific Weight (3-12)

- Outfit and Furnishing Human Support Wt Fraction (3-11)

Armament

Symbol: W_7/Δ

Definition: Armament Weight fraction including all SWBS Group 7 weights as listed in reference (22).

Significance: $W_7/\Delta = (W_7/\#1chr) * (\#1chr/\Delta)$

Driven by the armament specific weight and the capacity size ratio. Armament pertains to those actual systems that directly relate to weapons and its ammunition. Although the armament has actually increased in some recent designs, the weight has decreased due to the switch from heavy guns to lighter missiles.

Expected Range[24]: light ship 3 - 10 %

full load 3 - 7 %

Comparative analysis examines:

- Combat Systems Cost (2-12)

- All Combat System Weight Fractions (3-9)

- All Armament Weight Fractions (3-9)

- All Armament Related Combat System Indices (3-10)

Margin

Symbol: W_m/Δ

Definition: $W_m = \Delta_{ls} - (\text{sum } W_1+\ldots.+W_7)$

Indicator as to the size of the acquisition (design and construction) weight margin that exists for design and construction uncertainties and is dependent on the stage of design. Service life and future growth margin is not included in this weight statement since it is a part of the naval architecture limit.

Significance: Margin is an integration factor and the size is directly proportional to weight and cost.

Expected Range:

Early stage design: 10 - 12.5% light ship

Comparative analysis: no comparative analysis path exists for this indice.

SCREEN 2-2: LOAD WEIGHT FRACTIONS

Load weight fractions are variable loads and are added to the light ship weight. Since these items must be stored, they require volume and may result in an addition or reapportionment of existing volume if a change is made. All loads are based on the Navy standard SWBS load groups[22] and are listed as a fraction of the total load weight.

$$W_{ld} = W_{fuel}+W_{ce}+W_{ord}+W_{av}+W_{oth}$$

Liquid (fuel and lubricants)

Symbol: W_{fuel}/W_{ld}

Definition: W_{fuel} = F4

Load weight fraction of the sum of all fuel and lubricants stored onboard. Includes all applicable SWBS Groups F4, F5, and F7 loads listed in reference (22).

Significance: Any difference in liquid loads will result in a volume change in the tankage fraction, which indirectly may affect other volumes and weights.

Comparative analysis examines:

- All Space Type/Location Volume fractions (2-5)
- Ship Mobility Volume fraction (2-4)

Crew and Effects

Symbol: W_{ce}/W_{ld}

Definition: W_{ce} = F1

Load weight fraction which includes all crew and effects related loads of applicable SWBS Group F1.

Significance: Change in this group fraction will directly affect internal volume and weight, especially in the human support area.

Comparative analysis examines:

- All Space Type/Location Volume fractions (2-5)
- Human Support Volume Fraction (2-4)

Ordnance

Symbol: W_{ord}/W_{ld}

Definition: W_{ord} = F2-F23-F26

Load weight fraction including all non-aviation ordnance related variable loads.

Significance: Differences in this load group fraction directly affect weight and volume fractions in the area of mission support. A steady decrease since 1940 has occured primarily due to the increased emphasis from guns to missiles.

Comparative analysis examines:

- All Space Type/Location Volume fractions (2-5)
- Mission Support Volume fraction (2-4)

Aviation

Symbol: W_{av}/W_{ld}

Definition: W_{av} = F23+F26

Load weight fraction including all aviation variable loads.

Significance: A change in this group will involve weight and volume changes directly in the mission support and possibly in the large space allocation.

Comparative analysis examines:

- All Space Type/Location Volume fractions (2-5)
- Mission Support Volume fraction (2-4)

Others

Symbol: W_{oth}/W_{ld}

Definition: W_{oth} = F3+F5+F6

Includes all additional load weights not directly applicable to loadings listed above. These include stores, provisions, non-fuel related liquids, gases and any cargo carried onboard.

Significance: Direct affect on weight and volume. Since stores are additionally included in this category, the endurance period may be affected.

Comparative analysis examines:

- All Space Type/Location Volume fractions (2-5)
- All SSCS Volume fractions (2-4)

Total Load Weight to Full Load Displacement Ratio

Symbol: W_{ld}/Δ_{fl}

Definition: Sum of all variable loads listed above as a fraction of the total ships full load displacement.

Significance: A fraction too large may impact stability in a light-load condition. Large differences between baseline and variant may result in significant volume differences.

Expected Range[24]: frigate 24 - 27%

destroyer 24 - 31% except DDG-51 @ 20.3%

cruiser 25 - 32%

Comparative analysis: no further expansion information exists at this level beyond this screen or in level 3

Light Ship Displacement to Full Load Diplacement Ratio

Symbol: Δ_{ls}/Δ_{fl}

Definition: Light Ship to Full Load Displacement ratio, which is the complement to the Load to Full Load ratio above.

Significance: Significant differences in baseline to variant designs indicate differences in load weights.

Expected Range[24]: frigate 72 - 76 %

destroyer 69 - 76 % except DDG-51 @ 79.7%

cruiser 68 - 75 %

Comparative analysis: no further expansion information exists at this level beyond this screen, or in level 3.

<u>SCREEN 2-3: FUNCTIONAL WEIGHT FRACTIONS</u>

All functional weight fractions are combinations of SWBS and load weights with the margin proportionally distributed by the fraction of screen 2-1. The symbols used are:

W_{mx} = portion of margin allocation of SWBS group 'x'

$W_{mx} = (\%W_x/\text{sum of } \%W_1 \text{ thru } \%W_7) * W_m$

$\%W_x$ = percentage of SWBS group 'x' from screen 2-1

Light Ship Combat System Weight fraction

Symbol: W_{csl}/Δ_{ls}

where $W_{csl} = W_4+W_7+W_{m4}+W_{m7}$

Definition: Ratio of the sum of the SWBS command and control and armament weights to light ship displacement.

Significance: The larger the ratio, the more the design is driven by the combat system.

Expected Range[24]: frigate 7 - 12 %

destroyer 9 - 13 %

cruiser 12 - 15 %

Comparative analysis examines:

- Command and Surveillance Weight fraction (2-1)
- Armament Weight fraction (2-1)

Light Ship Machinery Weight fraction

Symbol: W_{mal}/Δ_{ls}

where $W_{mal} = W_2+W_3+W_5+W_{m2}+W_{m3}+W_{m5}$

Definition: Ratio of the sum of the SWBS main propulsion, electrical and auxiliary weights to the light ship displacement.

Significance: The larger the ratio, the more the design is driven by mobility related items.

Expected Range[24]: gas turbine plant 29 - 35 %

steam plant 33 - 43 %

Comparative analysis examines:

- Main Propulsion Weight fraction (2-1)
- Electrical Weight fraction (2-1)
- Auxiliary Weight fraction (2-1)

Light Ship Containment Weight fraction

Symbol: W_{cl}/Δ_{ls}

where $W_{cl} = W_1+W_6+W_{m1}+W_{m6}$

Definition: Ratio of the sum of the SWBS structural and outfit and furnishings weights to light ship displacement.

Significance: The larger the ratio, the more the design is driven by structural or human support related items.

Expected Range[24]:	frigate	55 - 58 %
	destroyer	43 - 61 %
	cruiser	52 - 57 %

Comparative analysis examines:

- Structural Weight fraction (2-1)
- Outfit and Furnishing Weight fraction (2-1)

Full Load Combat System Weight fraction

Symbol: W_{csf}/Δ_{fl}

where $W_{csf} = W_4+W_7+W_{ord}+W_{av}+W_{m4}+W_{m7}$

Definition: Ratio of the sum of the SWBS command and control, SWBS armament, load ordnance and load aviation weights to full load ship displacement.

Significance: The larger the ratio, the more the design is driven by the combat system.

Expected Range[24]:	frigate	9 - 10 %
	destroyer	9 - 13 %
	cruiser	11 - 12 %

Comparative analysis examines:

- Command and Surveillance Weight fraction (2-1)
- Armament Weight fraction (2-1)
- Ordnance Weight fraction (2-2)
- Aviation Weight fraction (2-2)

Full Load Machinery Weight fraction

Symbol: W_{maf}/Δ_{fl}

where $W_{maf} = W_2+W_3+W_5+W_{fuel}+W_{m2}+W_{m3}+W_{m5}$

Definition: Ratio of the sum of the SWBS main propulsion, electrical and auxiliary weights plus the fuel and lubricant liquid weight to the full load displacement.

Significance: The larger the ratio, the more the design is driven by mobility related items.

Expected Range[24]:	gas turbine plant	39 - 44 %	
	steam plant	46 - 51 %	[24]

Comparative analysis examines:

- Main Propulsion Weight fraction (2-1)
- Electrical Weight fraction (2-1)
- Auxiliary Weight fraction (2-1)
- Liquid Weight fraction (2-2)

Full Load Containment Weight fraction

Symbol: W_{cf}/Δ_{fl}

where $W_{cf} = W_1+W_6+W_{ce}+W_{oth}+W_{m1}+W_{m6}$

Definition: Ratio of the sum of the SWBS structural and outfit and furnishings weights plus the load crew and effects and other weights to full load displacement.

Significance: The larger the ratio, the more the design is driven by structural or human support related items.

Expected Range[24]:	frigate	45 - 49 %
	destroyer	35 - 49 %
	cruiser	38 - 46 %

Comparative analysis examines:

- Structural Weight fraction (2-1)
- Outfit and Furnishing Weight fraction (2-1)
- Crew and Effects Weight fraction (2-2)
- Other Weight fraction (2-2)

SCREEN 2-4: SSCS VOLUME FRACTIONS

The U.S. Navy Ships Space Classification System [23] seperates all volumes into one of the five major classifications used in this screen. These are displayed as a fraction of the total ship enclosed volume. The major classifications are each further divided into sub-categories, which are examined by the comparative analysis structure to provide the designer information regarding the specific area of volume change impact.

Mission Support fraction

Symbol: V_1 / ∇

Definition: Military mission support volume fraction including all SSCS Group 1 volumes listed in reference (23). For combatant destroyer type ships, these include all command and surveillance, communications, weapons and aviation related volumes.

Significance: Driven by mission and combat systems. The larger the fraction, the more significant the mission impact is on the ship. A change in the aviation area may result in "large space volume" changes. The recent increase in payload volume has been reflected due to the change from guns to missiles and the increased emphasis on command, control and communications.

Expected Range[24]: frigates 20 - 22 %

destroyers 13 - 19 %

cruisers 21 - 24 %

Comparative analysis examines:

- Combat Systems Volume Allocation (2-6)
- Large Space Volume fraction (2-5)
- All Combat System Volume Fractions (3-9)
- All Combat System Densities (3-10)

Human Support

Symbol: V_2 / ∇

Definition: Human support volume fraction including all SSCS Group 2 volumes as listed in reference (23). These

include living, messing, medical, and general service type volumes.

Significance: Driven by human support and manning requirements. A "plush" habitability ship would have a greater fraction than a ship designed for "austere" habitability, if manning were constant. Although there have been extensive increases in habitability requirements requiring additional volume per crewmember, the decrease in the overall manning has effectively caused a downward trend in this volume area.

Expected Range[24]: frigates 20 - 21 %

destroyers 16 - 27 %

cruisers 16 - 24 %

Comparative analysis examines:

- All Human Support Volume Breakdown (3-11)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)
- Personnel Living Space Specific Volume (3-12)

Ship Support

Symbol: V_3 / ∇

Definition: Ship support volume fraction including all SSCS Group 3 volumes as listed in reference (22). These volumes include ship control, damage control, administration, deck

systems, boats, maintenance, storerooms, access areas and tankage.

Significance: Ship support relates a large portion of ship required volumes that relate to auxiliaries and storage and may be impacted significantly by changes in range and endurance period requirements. Recent trends have shown an increase due to increased emphasis on storage to improve sustainability, more allocation to accesses for habitability and increased requirements of auxiliaries.

Expected Range[24]: frigates 27 - 34 %

destroyers 18 - 29 % except DD963 @ 34%

cruisers 28 - 30 %

Comparative analysis examines:

- Tankage Volume fraction (2-5)
- Machinery Related Volume fraction (2-6)
- Auxiliary Volume Breakdown (3-7)
- Auxiliary Density (3-8)
- Auxiliary Specific Weight (3-8)
- Auxiliary Volume fraction (3-8)

Ship Mobility

Symbol: V_4 / ∇

Definition: Ship mobility volume fraction including all SSCS Group 4 volumes as listed in reference (23). These include propulsion, propulsor and transmission, intake and

exhaust, auxiliary machinery and electrical power generation and distribution related volumes.

Significance: Size of fraction indicates the extent that the design is driven by mobility. Some of this volume may be directly related to "large-space" volume in the form of major machinery spaces. Recent designs show a downward trend in this fraction due to the decreased SHP/ton requirements of the gas turbine versus steam. The Comparative analysis path examines the primary area of volume impact.

Expected Range[24]:	gas turbine plant	26 - 32 %
	steam plant	30 - 42 %

Comparative analysis examines:

- Large Space Volume fraction (2-5)
- Machinery Related Volume fraction (2-6)
- Main Propulsion Volume Breakdown (3-3)
- Electric Plant Volume Breakdown (3-5)
- Main Propulsion Density (3-4)
- Main Propulsion Volume fraction (3-4)
- Electrical Density (3-6)
- Electrical Volume fraction (3-6)
- Auxiliary Volume Breakdown (3-7)
- Auxiliary Density (3-8)

Unassigned

Symbol: V_5 / ∇

Definition: Includes all volume and volume margin not assigned to any of the specific functions listed above.

Significance: May include volume margin which directly impacts displacement.

Expected Range: Zero or very small percentage

Comparative analysis: No Comparative analysis exists for this item.

SCREEN 2-5: SPACE TYPE/LOCATION VOLUME FRACTION

This screen is used to display where the main allocations of volume are located, as a fraction of the total enclosed volume. It provides a quick look at how much of the actual ship volume is in the superstructure and hull, as well as how much of it is considered arrangeable. It provides an excellent comparison for two radically different ship hulls.

Since these indices are used primarily to provide a large scale comparison, the analysis branch structure will send the designer back to the appropriate SSCS volume fraction where more detailed analysis is available and will examine affected level 3 specific weights.

Hull Volume

Symbol: V_{hull} / ∇

Definition: Total enclosed volume fraction of the hull area only.

Significance: Changes in hull volume will affect hull size and characteristics, thereby indirectly affecting powering and resistance. The recent trend has been to locate all vital equipment in the hull, thus increasing the hull volume fraction.

Comparative analysis examines:

- All SSCS Volume fractions (2-4)
- Basic Hull Structure Density (3-2)

Deckhouse Volume

Symbol: V_{dh} / ∇

Definition: Total enclosed volume fraction of the deckhouse area.

Significance: An increased volume in the deckhouse will increase radar signature as well as providing more weight high in the design, possibly affecting stability.

Comparative analysis examines:

- All SSCS Volume fractions (2-4)
- Deckhouse Structure Density (3-2)

Tankage/Voids Volume

Symbol: V_{tk} / ∇

Definition: $V_{tk} = V_{3.9}$: Total volume fraction of all tankage as defined by SSCS Group 3.9 [23].

Significance: The largest percentage of tankage is the ships fuel and any change in propulsion size or endurance required will affect the tankage volume and either make the ship larger or take away volume from other areas.

Expected Range[24]: 6.5 - 12.5 %

Comparative analysis examines:

- Ship Support Volume fraction (2-4)
- Machinery Related Volume fraction (2-6)

Large Space Volume

Symbol: V_{lo} / ∇

Definition: $V_{lo} = V_{1.2} + V_{1.34} + V_{4.1}$

Total volume fraction of all "large object" volume items, which include the SSCS groups [23] weapons and ammunition ($V_{1.2}$), aircraft stowage ($V_{1.34}$) and propulsion systems ($V_{4.1}$).

Significance: Changes in ships weapons, number of aircraft or propulsion plant size will significantly impact this indice, which may have direct impact on arrangeable volume or ship size.

Comparative analysis examines:

- Ship Mobility Volume fraction (2-4)
- Combat Systems Volume fraction (2-6)
- Machinery Related Volume fraction (2-6)

Arrangeable Volume

Symbol: V_a / ∇

Definition: $V_a = V - V_{tk} - V_{lo}$

Total volume fraction of arrangeable volume. Tankage and large object space is not considered as arrangeable space. This volume is used for general arrangements.

Significance: The greater the fraction, the more spacious the ship will be, thus allowing more area for maintenance spaces and habitability. If this area is excess, then it may be possible to decrease the size of the ship.

Comparative analysis examines:

- All Volume Allocation fractions (2-6)

SCREEN 2-6: FUNCTIONAL VOLUME ALLOCATION FRACTIONS

The indices on this screen are used to separate and analyze the volumes with respect to the major functional users of volume on a naval combatant ship. These indices are then further analyzed during the Level 3 Functional Investigation. The comparative analysis methodology will examine the functional area to provide further impact analysis study. Unassigned volume will not be distributed as margin was in weight. Instead, it will be treated as a seperate category.

Combat Systems Volume

Symbol: V_{cs} / ∇

Definition: $V_{cs} = V_1$

Volume fraction allocated to combat systems, which in this case, is the same as the mission support volume.

Significance: Driven by the ships mission and type of combat systems installed. The larger the fraction, the more significant the mission impact is on the ship. The specific area of emphasis may be determined by examining the functional allocation of level 3. The recent increase in combat systems volume has been reflected due to the change from guns to missiles and the increased emphasis on command, control and communications.

Comparative analysis examines:

- Large Space Volume fraction (2-5)
- All Combat System Volume Fractions (3-9)
- All Combat System Densities (3-10)

Machinery Related Volume

Symbol: V_{ma} / ∇

Definition: $V_{ma} = V_4 + V_{3.5} + V_{3.9}$

Volume fraction allocated to the machinery plant, including propulsion, transmission, electric plant, auxiliaries, auxiliary deck machinery and tankage.

Significance: Driven by the type of machinery plant and the speed and endurance required. The size of the fraction indicates how much the machinery plant drives the design.

The specific areas of impact and actual drivers are detailed in level 3 functional allocation.

Comparative analysis examines:

- Large Space Volume fraction (2-5)
- Main Propulsion Volume Breakdown (3-3)
- Electric Plant Volume Breakdown (3-5)
- Auxiliary Volume Breakdown (3-7)
- Main Propulsion Density (3-4)
- Main Propulsion Volume fraction (3-4)
- Electrical Density (3-6)
- Electrical Volume fraction (3-6)
- Auxiliary Density (3-8)
- Auxiliary Specific Weight (3-8)
- Auxiliary Volume fraction (3-8)

Containment Volume

Symbol: V_c / ∇

Definition: $V_c = V_2+V_3-V_{3.5}-V_{3.9}$

Volume fraction allocated to containment, which includes human support and ship support without deck machinery and tankage.

Significance: Driven primarily by human support and manning requirements to support the ships mission. Although the trend has been to increase habitability standards, the

manning has decreased, thus negating the anticipated increase in containment volume.

Comparative analysis examines:

- All Human Support Volume Breakdown (3-11)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)
- Personnel Living Space Specific Volume (3-12)

Unassigned

Symbol: V_5 / ∇

Definition: Includes all volume and volume margin not assigned to any of the specific functions listed above.

Significance: May include volume margin which directly impacts displacement.

Comparative analysis: No Comparative analysis exists for this item.

SCREEN 2-7: ELECTRICAL ENERGY ALLOCATION FRACTIONS

The energy allocation fractions are categorized by standard Navy SWBS groups [22]. Each fraction is user selectable to be a function of either maximum functional electric load or installed electric load capacity, which is defined as 90% of the total electric power available of all generators minus one. Navy standards require one generator available as an emergency standby at all times. Additionally, Navy standards look at the energy usage at a 10°F day and a 90°F day and at conditions of battle,

cruise, and anchor. If the data bank in use contains all the standard Navy conditions, the user will have the option of selecting either temperature and battle or cruise conditions. If no specific selection is made, the 10°F day at battle condition will be used for comparison purposes.

Since no level of analysis exists beyond the first level electrical SWBS groupings, no further comparative analysis will be available.

Standard symbols used are:

E_t = maximum functional electric load

E_i = installed electric load capacity

E = choice of max functional or installed capacity

Propulsion Plant

Symbol: E_2 / E

Definition: Fraction of electrical power used for the propulsion plant which includes all SWBS group 2 electric power usage. The propulsion plant electric power requirements are not expected to change for the life of the ship, therefore when calculating electric service life margin, this SWBS group will be excluded.

Significance: Dependent upon size and type of power plant in use on the design.

Electric Plant

Symbol: E_3 / E

Definition: Fraction of electrical power used for the electric power generation and distribution which includes all SWBS group 3 electrical power usage.

Significance: Dependent upon size and type of electric plant in use on the design.

Command and Surveillance

Symbol: E_4 / E

Definition: Fraction of electrical power used for command and surveillance systems which include all SWBS group 4 electrical power usage.

Significance: Dependent upon size and type of command and surveillance systems used in the design.

Auxiliary

Symbol: E_5 / E

Definition: Fraction of electrical power used for auxiliary systems which include all SWBS group 5 electrical power usage.

Significance: Dependent upon size and type of auxiliary systems used in the design. The largest user in this group is generally SWBS group 514, the HVAC system.

Outfit and Furnishings

Symbol: E_6 / E

Definition: Fraction of electrical power used for outfit and furnishings which include all SWBS group 6 electrical power usage.

Significance: Dependent upon manning and type of habitability installed in the design.

Armament

Symbol: E_7 / E

Definition: Fraction of electrical power used for armament systems which include all SWBS group 7 electrical power usage.

Significance: Dependent upon size and type of armament systems used in the design.

Margin

Symbol: E_m / E

Definition: E_m = .9*(E_i-KW rating of one generator)-E_t

Fraction of electrical load margin which includes both acquisition margin and service life margin. Acquisition margin is added during design to account for uncertainties of KW requirements during design. A completed design should have an acquisition margin of zero. In compliance with reference (28), the margin must be sufficient to allow one generator to stay off-line and be available in the event of a casualty. The ship peak power should then not exceed 90% of the available installed power of the

remaining generators. The margin is then the difference between the available power to use and the maximum functional load and is dependent on the stage of design. Navy expected values are listed below.

Significance: The addition or change of subsystems may result in an increase in power requirements that may cause an insufficient margin to maintain the Navy requirements, or the margin may be excess and allow a downgrade of generator number or rating.

Expected Range:

Ship Service Margins[28]:

End of preliminary design	44%
End of detail design	34%
Ship Delivery	20%

SCREEN 2-8: FUNCTIONAL ENERGY ALLOCATION FRACTIONS

The energy allocation is broken into three subcategories for horsepower, fuel and electrical usage. The first two categories provide for a propulsion versus electric plant comparison and the last provides the breakdown of electric power usage into the three primary users.

INSTALLED HP:

NOTE: HP_{shpi} = Total shaft horsepower installed

HP_{geni} = Total generator horsepower installed

$HP_t = HP_{shpi} + HP_{geni}$

Propulsion Horsepower Allocation

Symbol: HP_{shpi}/HP_t

Definition: Fraction of total horsepower installed that is allocated to main propulsion.

Significance: Dependent on the size and type of propulsion plant in use as compared to the electric plant. A larger fraction may indicate either a larger or less efficient propulsion plant or a more efficient electric plant. These two fractions may be misinterpreted if they are looked at individually.

Comparitive analysis examines:

- All Fuel Usage Allocation (2-8)
- All Main Propulsion Drivers (3-4)
- All Electrical Drivers (3-6)

Electrical Horsepower Allocation

Symbol: HP_{geni}/HP_t

Definition: Fraction of total horsepower installed allocated to electric power generation.

Significance: Dependent on the size and type of electric plant as compared to the main propulsion plant. Any comparisons must include the main propulsion horsepower allocation above to prevent misinterpretation of the results. An increase in this fraction may be due to either a less

efficient or larger electric plant or to a more efficient or smaller propulsion plant.

Comparitive analysis examines:

- All Fuel Usage Allocation (2-8)
- All Main Propulsion Drivers (3-4)
- All Electrical Drivers (3-6)

FUEL USAGE:

Propulsion fuel usage is based on endurance speed. Electrical fuel usage is based on average 24 hour load[18].

NOTE: $SFCA_e$ = Generator SFC at 24 hr average load

SFC_e = Propulsion SFC at endurance speed

HP_{gene} = Generator Horsepower at 24 hr avg load

HP_{shpe} = Propulsion horsepower at endurance spd

FF_{gen} = Generator Fuel flow (lbm/hr) ($FF_{gen} = SFCA_e * HP_{gene}$)

FF_{mp} = Main Propulsion fuel flow (lbm/hr) ($FF_{mp} = SFC_e * HP_{shpe}$)

FF_t = Total fuel flow (lbm/hr) ($FF_t = FF_{gen} + FF_{mp}$)

Propulsion Fuel Allocation

Symbol: FF_{mp}/FF_t

Definition: Average fuel flow fraction allocated to the propulsion plant at endurance speed.

Significance: Provides indication of propulsion plant fuel efficiency as compared to the electric plant. The actual

fuel efficiency of the engines can be compared by looking at actual specific fuel consumption (SFC).

Comparitive analysis examines:

- All Installed HP Allocation (2-8)
- All Main Propulsion Drivers (3-4)
- All Electrical Drivers (3-6)

Electrical Fuel Allocation

Symbol: FF_{gen}/FF_t

Definition: Average fuel flow fraction allocated to the electric plant based on 24 hr average load.

Significance: Provides indication of electric plant fuel efficiency as compared to the propulsion plant. The actual fuel efficiency of the electric plant can be compared by observing the actual electric specific fuel consumption (SFCA).

Comparitive analysis examines:

- All Installed HP Allocation (2-8)
- All Main Propulsion Drivers (3-4)
- All Electrical Drivers (3-6)

ELECTRICAL:

The selections of temperature and conditions available is the same as specified in screen 2-7.

When the installed electric capacity (E_i) is selected, the electric margin is proportionally distributed to groups E_3 to E_7 as

the fraction of use for the same temperature and condition as displayed in screen 2-7. No service life margin is allocated to group 2, propulsion.

E_{mx} = portion of margin allocation of SWBS group 'x'

$E_{mx} = (\%E_x/\text{sum of } \%E_3 \text{ thru } \%E_7) * E_m$

$\%E_x$ = percentage of SWBS group 'x' from screen 2-7

NOTE: Margin fractions added only when E_i is selected

Combat System Electrical

Symbol: E_{cs}/E

Definition: $E_{cs} = E_4+E_7[+E_{m4}+E_{m7}]$

Percentage of total installed electric load allocated to combat systems.

Significance: Driven by size and complexity of the combat system installed.

Comparitive analysis examines:

- Command and Surveillance Electric Allocation (2-7)
- Armament Electric Allocation (2-7)

Machinery Electrical

Symbol: E_{ma}/E

Definition: $E_{ma}=E_2+E_3+E_5[+E_{m3}+E_{m5}]$

Percentage of total installed electric load allocated to machinery.

Significance: Driven by size, type and complexity of the ships machinery, including propulsion, electrical and auxiliary.

Comparitive analysis examines:

- Main Propulsion Electric Allocation (2-7)
- Electric Plant Electric Allocation (2-7)
- Auxiliaries Electric Allocation (2-7)

Containment Electrical

Symbol: E_c /E

Definition: $E_c = E_6 [+E_{m6}]$

Percentage of total installed electric generation capability allocated to containment. Since SWBS group 1 (structures) uses no electric power, only the outfit and furnishings group is included.

Significance: Driven by human support requirements in the outfit and furnishings group.

Comparative analysis examines:

- Outfit and Furnishings Electric Allocation (2-7)

SCREEN 2-9: MANNING ALLOCATION FRACTION

A general definition and significance will suffice for all indices used, and then the symbols and expected ranges will be addressed independently with each indice.

Definition: Ratios of number of personnel by rank to the total number of accomodations.

M_a = total manning accomodations (OFF+CPO+ENL)

M_{xxx} = manning for 'xxx' personnel

Significance: Shipboard manning is dependent on the types and sizes of systems installed on the ship and is impacted by operational considerations, maintenance and support requirements, and scheduled workweek. A change in a ship system may result in a corresponding manning change. If the manning fraction goes up, the resulting living area or volume may not be able to increase accordingly, thus resulting in a degradation of habitability standards. This could be a substantial impact to a new technology assessment.

Officer Ratio

Symbol: M_{off} / M_a

Comparative analysis examines:

- All Human Support Drivers (3-12)
- Officer Living Area per man (3-12)
- Officer Ship Size Ratio (3-12)

CPO Ratio

Symbol: M_{cpo} / M_a

Comparative analysis examines:

- All Human Support Drivers (3-12)
- CPO Living Area per man (3-12)
- CPO Ship Size Ratio (3-12)

Enlisted Ratio

Symbol: M_{enl} / M_a

Comparative analysis examines:

- All Human Support Drivers (3-12)
- Enlisted Living Area per man (3-12)
- Enlisted Ship Size Ratio (3-12)

Manning Margin

Symbol: M_m / M_a

Definition: $M_m = M_a-(M_{off}+M_{cpo}+M_{enl})$

Accomodation growth margin to allow for uncertainties in manning estimates and future expansion.

Significance: Each accomodation requires space and weight. An insufficient margin may result in the inability to berth all necessary personnel, whereas a large margin may result in use of space and weight that could be better used elsewhere.

Comparative analysis examines:

- All Functional Manning Allocation (2-10)

SCREEN 2-10: FUNCTIONAL MANNING ALLOCATION FRACTIONS

A general definition and significance will suffice for all indices used, and then the symbols and expected ranges will be addressed independently with each indice.

Definition: Ratios of number of personnel by ship department to the total number of accomodations. The manning margin is

proportionally distributed based on the size of the departmental manning.

M_a = total manning accomodations (OFF+CPO+ENL)

M_{xxx}= manning for department 'xxx'

Significance: Shipboard manning is dependent on the types and sizes of systems installed on the ship and is impacted by operational considerations, maintenance and support requirements, and scheduled workweek. A change in a ship system may result in a corresponding manning change. If the manning fraction goes up, the resulting living area or volume may not be able to increase accordingly, thus resulting in a degradation of habitability standards. This could be a substantial impact to a new technology assessment.

Combat Systems Manning Ratio

Symbol: M_{cs} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)
- All Human Support Drivers (3-12)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)

Operations Manning Ratio

Symbol: M_{ops} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)
- All Human Support Drivers (3-12)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)

Engineering Manning Ratio

Symbol: M_{eng} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)
- All Human Support Drivers (3-12)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)

Nav/Admin Manning Ratio

Symbol: M_{na} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)
- All Human Support Drivers (3-12)
- Human Support Density (3-12)
- Human Support Specific Volume (3-12)

Supply Manning Ratio

Symbol: M_{sup} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)

- All Human Support Drivers (3-12)

- Human Support Density (3-12)

- Human Support Specific Volume (3-12)

Aviation Manning Ratio

Symbol: M_{av} / M_a

Comparative analysis examines:

- All Human Support Breakdown (3-11)

- All Human Support Drivers (3-12)

- Human Support Density (3-12)

- Human Support Specific Volume (3-12)

SCREENS RELATING TO COST

All costs are classified according to the standard Navy "P8" Cost Breakdown structure.

The accuracy of the cost comparisons during comparative analysis will be directly dependent on the source of data. The designer should be familiar with the accuracy of the source he is working with and should be extremely careful in comparisons that are not from the same source. As an example, to take the DD-963 from a very accurate database that has actual real costs and compare it to a variant from the ASSET program may result in a very poor and probably inaccurate comparison. This section of the module should then only be used as a rough comparison and then only when the ships being compared are from the same source, such as a baseline and a variant both developed on the ASSET program.

The cost comparative analysis should generally be used only after all other comparisons have been completed in the analysis and the designer is checking cost variance for a known change or impact. It is for this reason that there will be no automated comparative analysis path for the cost related screens.

SCREEN 2-11: BASIC CONSTRUCTION COST ALLOCATION

The user has the choice of selecting either "lead" or "follow" ship cost. Symbols used are:

$$C_{bc}=C_1+...+C_7+C_m+C_{de}+C_{con}+C_{pr}$$

$$C_{BC}=C_1+...+C_7+C_m+C_{de}+C_{con}+C_{pr}+C_{HM\&E}$$

SWBS Groups 1 thru 7 Related Costs

Symbol: Each parameter is given separately. May be either "lead" or "follow" ship costs as selected by user.

Hull Structure	C_1/C_{bc}
Propulsion Plant	C_2/C_{bc}
Electric Plant	C_3/C_{bc}
Command and Surveillance	C_4/C_{bc}
Auxiliary Systems	C_5/C_{bc}
Outfit and Furnishing	C_6/C_{bc}
Armament	C_7/C_{bc}

Definition: The cost of fabricating and constructing the ship is partially cataloged by SWBS groups. As a portion of the basic construction cost, this includes direct labor and overhead involved with the installation of all equipment

as well as the purchase of raw materials and contractor furnished equipment.

Significance: Direct relationship to the weight of the SWBS group and is additionally a function of the equipment and material used in the group. Actual calculations for preliminary designs are based on information obtained from earlier similar designs.

D & C Margin

Symbol: C_m/C_{bc}

Definition: Design and Construction cost margin, a fraction of the SWBS group cost, generally a function of the type and size of the ship, and may even be a function of the shipyard performing the construction.

Significance: Generally applied equally over all SWBS cost groups above.

Design and Engineering (Group 8)

Symbol: C_{de}/C_{bc}

Definition: A part of the basic construction cost of the shipbuilder, it includes all costs relating to waterfront engineering and testing.

Significance: Generally applied as a percentage of light ship construction and materials required.

Construction Services/Assembly (Group 9)

Symbol: C_{con}/C_{bc}

Definition: A part of the basic construction cost relating to the assembly of non-SWBS related material or equipment.

Significance: Generally applied as a percentage of light ship construction and materials required.

Profit

Symbol: $C_{pr/Cbc}$

Definition: Part of the basic construction cost pertaining to the shipbuilder's profit. Calculated as a percentage of cost of all SWBS groups 1 thru 7 plus groups 8 and 9.

Significance: Dependent on the competition environment, it is negotiated with the builder and is generally in the range of 5 - 15% of basic construction costs.

HM&E GFE

Symbol: $C_{HM\&E}/C_{BC}$

Definition: Cost fraction of government furnished HM&E equipment to the basic construction cost plus HM&E GFE.

Significance: Dependent on the amount of HM&E GFE being provided to the builder. In recent years, the builder has purchased more of the HM&E type equipment, thus driving this fraction down considerably.

SCREEN 2-12: FUNCTIONAL COST ALLOCATION FRACTION

Choice of selection of "lead ship" or "follow ship"

Total cost defined as:

$$(C_t = C_{1+..+7}+C_m+C_{de}+C_{con}+C_{pr}+C_{oth}+C_{csgfe})$$

Symbols defined in screen 1-1 and 2-11.

All non-SWBS related basic construction costs are distributed proportionally in the percentages allocated in screen 2-11.

All "Other Costs" are distributed proportionally as allocated in Screen 2-11 with the exception of P.M. Growth which is added directly to Combat Systems Costs.

C_{dx} = distributed costs for SWBS group 'x'

$= (C_x/\text{sum of } \%C_1 \text{ thru } \%C_7) * (C_{m+de+con+pr+oth-pmg})$

where C_x = % cost of SWBS group 'x' (screen 2-11)

Combat Systems Costs

Symbol: C_{cs}/C_t

Definition: $C_{cs} = C_{4+7+csgfe+pmg+d4+d7}$

Those costs directly relating to the combat systems of the ship including the combat system related construction cost as well as all combat system GFE and project manager growth costs.

Significance: Indication of how much the combat system drives the cost of the design.

Machinery Costs

Symbol: C_{ma}/C_t

Definition: $C_{ma} = C_{2+3+5+d2+d3+d5}$

Sum of all costs relating to machinery including main propulsion, electrical and auxiliary.

Significance: Indication of how much the machinery drives the cost of the design.

Containment Costs

Symbol: C_c/C_t

Definition: $C_c = C_{1+6+d1+d6}$

Sum of costs directly related to the containment of the ship including structures and outfit and furnishings.

Significance: Indication of how much the containment drives the cost of the design.

SCREEN 2-13: COST FRACTIONS

Symbols used:

C_{ls} = Lead Ship Total Cost

C_{fs} = Follow Ship Total Cost

Combat System GFE/Lead Ship Cost

Symbol: C_{csgfe}/C_{ls}

Definition: The fraction of "lead" ship cost that is directly related to combat system GFE (Government Furnished Equipment).

Significance: Driven by the size and complexity of the combat system installed in the design. The "rule of thumb" fraction for a combatant is approximately 42 - 45%.

Combat System GFE/Follow Ship Cost

Symbol: C_{csgfe}/C_{fs}

Definition: The fraction of "follow" ship cost that is directly related to combat ystem GFE (Government Furnished Equipment).

Significance: Driven by the size and complexity of the combat system installed in the design. The "rule of thumb" fraction for a combatant is about the same as the lead ship cost which is approximately 42 - 45%.

Basic Construction/Lead Ship Cost

Symbol: C_{bc}/C_{ls}

Definition: The fraction of "lead" ship cost that is paid for basic construction, where basic construction cost is as defined in screen 2-11.

Significance: Driven by the size and complexity of the ship construction. General "rule of thumb" percentage is 28-30%.

Basic Construction/Follow Ship Cost

Symbol: C_{bc}/C_{fs}

Definition: The fraction of "follow" ship cost that is paid for basic construction, where basic construction cost is as defined in screen 2-11.

Significance: Driven by the size and complexity of the ship construction. General "rule of thumb" percentage is higher than for the lead ship at 37-40%.

Total Follow Ship Cost/Weight ratio

Symbol: C_{fs}/Δ_{fl} (\$/ton)

Definition: Specific cost to weight ratio of the "follow" ship.

Significance: An efficient design may have a higher cost yet still maintain a more efficient cost to weight ratio. This may be a deciding factor in two closely related designs. The follow ship tends to be a better indicator since these costs will prevail throughout the life of the construction. The lead ship cost may be deceiving if it uses new expensive technology which may get cheaper in subsequent deliveries.

Total Follow Ship Cost/Volume ratio

Symbol: C_{fs}/∇ (\$/ft^3)

Definition: Specific "follow" ship cost to volume ratio.

Significance: Designer wants a lower ratio, which indicates that more volume is obtained per dollar spent.

LEVEL 3: FUNCTIONAL INVESTIGATIONS

This third level of analysis further investigates the impact of a Level 1 change. In the comparative analysis path, the Level 3 analysis will concentrate on finding the cause. Therefore, all indice comparative analysis branches will examine the appropriate Level 1 parameters to discover the reason the change occured. The primary questions asked by the comparative analysis path are:

* What drives the indice or parameter

* What caused the indice or parameter to change

Each of the six ships functions have a two screen display, the first serves as a further breakdown of weight and volume and the second screen is divided into the primary drivers for the functional area and related miscellaneous indices. The drivers addressed in the screens are additionally available to be viewed in the trend analysis section as a "triple plot" where the new design can be compared to existing designs for the functional area under investigation.

The last screen in this level is a summary of all acquisition and service life margins.

Where all indices are closely related and self-explanatory, as in the weight and volume breakdowns, only a single definition, significance and comparative analysis path will be provided.

All SWBS weight groups and subgroups are as defined in reference (22) and SSCS volume groups and subgroups as defined in reference (23).

SCREEN 3-1: CONTAINMENT WEIGHT BREAKDOWN

STRUCTURE WEIGHT:

Symbols:

Shell and Supports W_{11}/W_1

Hull Structural Bulkheads and Decks $W_{12+13+14}/W_1$

W_{12} = hull structural bulkheads

W_{13} = hull decks

W_{14} = hull platforms and flats

Deckhouse W_{15}/W_1

Foundations W_{18}/W_1

Other Structural $W_{16+17+19}/W_1$

W_{16} = special structures

W_{17} = masts, kingposts, service platforms

W_{19} = special purpose systems

Definition: The further distribution of containment weight within the ship as a ratio of total SWBS Group 1 weight.

Significance: A difference in these indices may occur due to a different type of material, frame spacing, a change in ship size, or in structural loading. These changes may be caused by differing survivability requirements.

Comparative analysis: All indices will be examined with the same comparative analysis branch which includes:

- All Size Characteristics (1-1)
- All Ship Performance Survivability (1-3)
- All Structure/Materials Selections (1-4)

OUTFIT AND FURNISHINGS WEIGHT

Symbols:

Crew Related $W_{64+65+66+67}/W_6$

W_{64} = Living Space

W_{65} = Service Space

W_{66} = Working Space

W_{67} = Stowage Space

Non-Crew Related $W_{61+62+63+69}/W_6$

W_{61} = Ship Fittings

W_{62} = Hull Compartmentation

W_{63} = Preservatives/Coverings

W_{69} = Special Purpose Systems

Definition: Broken into two subcategories of either crew related or non crew related and compared as a ratio of total SWBS Group 6 weight.

Significance: Directly affected by human support requirements and crew size for the crew related items and by hull compartmentation and fittings for the non crew related items.

Comparative analysis: All indices will be examined with the same comparative analysis branch which includes:

- All Size Characteristics (1-1)
- All Structure/Materials Selection (1-4)
- All Deck Heights (1-4)
- All Manning (1-4)

SCREEN 3-2: CONTAINMENT INDICES

CONTAINMENT DRIVERS:

Primary drivers of containment based on the "triple plot" relationships:

$$W_1/\Delta_{fl} = (W_1/\nabla)*(\nabla/\Delta_{fl})$$

$$W_6/\Delta_{fl} = (W_6/\nabla)*(\nabla/\Delta_{fl})$$

Structural Weight Fraction

Symbol: W_1/Δ_{fl}

Definition: The fraction of total full load displacement allocated to ship structures.

Significance: Extremely dependent on volume. It is affected by many variables, including length, volume, displacement, hull form, local loading, ship dimension ratios, penetrations, frame spacing and materials. The recent trend to increased ship volume has resulted in an upward trend in structural weight.

Comparative analysis examines:

- All Ship Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Survivability Ship Performance (1-3)
- All Structure/Materials (1-4)

Outfit and Furnishings Weight Fraction

Symbol: W_6/Δ_{fl}

Definition: The fraction of total full load displacement allocated to outfit and furnishings SWBS group 6.

Significance: Since much of this weight group relates to human support, it is directly affected by the manning size and the type of habitability installed, which in effect drive volume. Since the trend has been to improve habitability, this fraction has shown an increase in recent years.

Comparative analysis examines:

- All Ship Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Manning (1-4)

Total Hull Structure Specific Weight

Symbol: W_1/∇ (lbs/ft^3)

Definition: Ratio of ship structural weight to total enclosed volume.

Significance: Provides indicator as to which is the driving factor when both both structural weight and volume are changed, or the effect of loading changes which results in a heavier structure. Driven by changes in ship size, loading, materials used, or survivability requirements. An increase in this parameter will drive an increase in the structural weight fraction.

Comparative analysis examines:

- All Size Characteristics (1-1)

- All Shape Characteristics (1-2)

- All Ship Performance Survivability (1-3)

- All Structure/Materials Selections (1-4)

Outfit and Furnishings Specific Weight

Symbol: W_6/∇ (lbs/ft^3)

Definition: Ratio of ship outfit and furnishings weight to total enclosed volume.

Significance: Provides indicator of how much the outfit and furnishings weight drives the volume of the design. Directly impacted by the habitability requirements and the manning accomodations, as well as by some structural hull compartmentation requirements.

Comparative analysis examines:

- All Size Characteristics (1-1)

- All Shape Characteristics (1-2)

- All Structure/Materials Selections (1-4)

- All Manning (1-4)

Ship Specific Volume

Symbol: ∇/Δ_{fl} (ft^3/ton)

Definition: Ratio of total enclosed volume to full load displacement.

Significance: Indication of spaciousness and how the volume drives the design. The larger the specific volume, the more spacious the design is. Recent trends have been

toward an increase in specific volume. As the spaciousness increases, the associated weight fraction also increases.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Shape Characteristics (1-2)

RELATED CONTAINMENT RATIOS:

Containment Density

Symbol: W_{cf}/V_c

Definition: Ratio of full load containment weight to containment volume as defined in screens 2-3 and 2-6.

Significance: Provides information regarding the relative effect of containment weight to volume. Indicates spaciousness of containment items. Driven primarily by structure and habitability requirements.

Comparative analysis examines:

- All Ship Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Structure/Materials Selection (1-4)
- All Deck Heights Selection (1-4)
- All Manning (1-4)

Basic Hull Structure Density

Symbol: $W_{11+12+13+14}/\nabla_{hull}$ (lbs/ft^3)

where W_{11} = shell and supporting structure

W_{12} = hull structural bulkheads

W_{13} = hull decks

W_{14} = hull platforms and flats

Definition: Ratio of basic hull weight to hull volume.

Significance: Provides for information regarding the relative effect of hull weight and/or volume change. Driven by changes in ship size, loading, materials used, or survivability requirements.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Ship Performance Survivability (1-3)
- All Structure/Materials Subsystems Selections (1-4)

Deckhouse Structure Density

Symbol: W_{15}/∇_{dh} (lbs/ft^3)

Definition: Ratio of deckhouse weight to deckhouse volume.

Significance: Provides for information regarding the relative effect of deckhouse weight and/or volume change. Driven by changes in deckhouse size, loading, materials used, or survivability requirements.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Ship Performance Survivability (1-3)
- All Structure/Materials Subsystems Selections (1-4)

Foundations Weight Fraction

Symbol: $W_{18}/(W_{2+3+4+5+7})$

Definition: Fraction of foundation weight in relation to the sum of all non-structural weights.

Significance: Foundations and mountings are used for all equipment installed on the ship and their weights are directly affected by equipment sound insulation and shock requirements. The more stringent the requirements, the higher the fraction.

Comparative analysis examines:

- All Ship Performance Survivability (1-3)

Containment Cost/Weight Ratio

Symbol: C_c/W_{cf} ($/ton)

Definition: Ratio of containment costs to full load containment weight as defined in screens 2-12 and 2-3.

Significance: Indicates cost per ton of containment portion of design. Driven by ship overall cost, size, manning, and habitability requirements.

Comparative analysis examines:

- All Cost and Size Characteristics (1-1)
- All Shape Characteristics (1-2)
- All Manning (1-4)

SCREEN 3-3: MAIN PROPULSION BREAKDOWN

The main propulsion related parameters are further broken down into a more detailed analysis of weight and volume requirements.

WEIGHT:

Symbols:

Propulsion Units Wt	W_{23}/W_2
Transmission and Propulsor Wt	W_{24}/W_2
Propulsion Support System Wt	$W_{25+26+29}/W_2$

W_{25} = Propulsion Support sys

W_{26} = Fuel/Lube Oil Support sys

W_{29} = Special Purpose Support

Other Propulsion Weight	W_{21+22}/W_2

W_{21} = Energy Generation (nuclear)

W_{22} = Energy Generation (non-nuc)

Definition: Distribution of primary propulsion weights within Main Propulsion SWBS Group 2.

Significance: In comparison of a baseline to a variant, this section will assist in locating the source of the group 2 weight difference. Differences are a result of utilization of different propulsion systems.

Comparative analysis examines:

- all Main Propulsion HM&E System Selection (1-4)

VOLUME:

Symbols:

Propulsion Units Volume	$V_{4.1-4.15}/V_{pt}$
Transmission and Propulsor Volume	$V_{4.2}/V_{pt}$

Definition: Distribution of primary propulsion volumes as related to the total propulsion volume which is defined by:

$$V_{pt} = V_{4.1+4.2-4.15}$$

$V_{4.1}$ = Propulsion Systems

$V_{4.2}$ = Transmission and Propulsor

$V_{4.15}$= Electric

Significance: Assists the designer in determining where the propulsion volume change occured. Differences are a result of utilization of different propulsion subsystems.

Comparative analysis examines:

- all Main Propulsion HM&E System Selection (1-4)

SCREEN 3-4: MAIN PROPULSION INDICES

MAIN PROPULSION DRIVERS:

The primary drivers of main propulsion are based on the "triple plot" relationship:

$$W_2/\Delta_{f1} = (W_2/SHP)*(SHP/\Delta_{f1})$$

Since SHP can be related to drag and speed by:

$$SHP = (R_T*Speed)/PC$$

Speed can be derived to be a function of:

$$Spd = PC * 1/(R_T/\Delta_{f1}) * (W_2/\Delta_{f1}) * 1/(W_2/SHP)$$

Which relates speed, powering, efficiency and propulsion design practices.

Main Propulsion Weight Fraction

Symbol: W_2/Δ_{fl}

Definition: Fraction of full load displacement allocated to main propulsion.

Significance: An increase in this parameter will result in an increase in speed. Generally done by adding a larger propulsion plant, in effect, "brute-forcing" the increase.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Mobility Ship Performance (1-3)
- All Main Propulsion HM&E System Selection (1-4)

Main Propulsion Specific Weight

Symbol: W_2/SHP (lbs/SHP)

Definition: Ratio of main propulsion weight to shaft horsepower available.

Significance: Measure of overall weight to propulsion power efficiency of the propulsion plant. A lower ratio indicates that the plant will provide more power for a given propulsion plant weight, which may allow for an increase in ship speed without an appreciable effect in displacement, or may allow for a decrease in the size of the plant. The recent change to gas turbine plants has resulted in a 10-15% decrease in specific weight.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Main Propulsion Ship Size Ratio

Symbol: SHP/Δ_{fl} (SHP/ton)

Definition: Ratio of shaft horsepower to full load displacement.

Significance: Shaft horsepower is the forcing parameter for the propulsion plant weight and volume. The decrease in installed power of recent ships has resulted in a decreasing trend in the last 40 years. The exception to the rule is the DDG-51 which is higher due to the overpowering required to compensate for its inefficient hullform.

Comparative analysis examines:

- Full Load Displacement (1-1)
- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Drag to Displacement Ratio (endurance)

Symbol: R_{Te}/Δ_{fl} (lbf/ton)

Definition: The drag, or resistance, of the hull at endurance speed as a fraction of the full load displacement.

Significance: Provides indication of hull hydrodynamic efficiency and is a function of the hullform selected. An increase in this parameter results in a decrease in speed.

Comparative analysis examines:

- Full load displacement (1-1)
- All Shape Characteristics (1-2)
- All Hull Efficiency Ship Performance (1-3)

Drag to Displacement Ratio (sustained)

Symbol: R_{Ts}/Δ_{fl} (lbf/ton)

Definition: The drag, or resistance, of the hull at sustained speed as a fraction of the full load displacement.

Significance: Provides indication of hull hydrodynamic efficiency and is a function of the hullform selected. An increase in this parameter results in a decrease in speed. Allows for comparison of hydrodynamics at sustained speed versus endurance speed.

Comparative analysis examines:

- Full load displacement (1-1)
- All Shape Characteristics (1-2)
- All Hull Efficiency Ship Performance (1-3)

Propulsion Coefficient

Symbol: PC

Definition: Ratio of effective horsepower to delivered horsepower[10]. More rigidly defined as a function of the

Taylor wake fraction, thrust deduction factor, propeller open water efficiency and relative rotative efficiency[17].

Significance: Direct affect on speed since it is an indicator of the efficiency of the propeller/hull interaction. It is desired to have the largest PC possible, thus increasing speed as PC increases.

Comparative analysis examines:

- All Hull Efficiency Ship Performance (1-3)
- Propeller Type/No./RPM (1-4)
- Propeller Open Water Efficiency (1-4)

RELATED MAIN PROPULSION RATIOS

Main Propulsion Density

Symbol: W_2/V_{pt} (lbs/ft^3)

Definition: Ratio of SWBS Group 2 main propulsion weight to volume required for the propulsion plant.

Significance: Provides indication of spaciousness of the propulsion plant. The larger the fraction, the more tightly packed the propulsion plant is. Driven by speed, hull efficiency, type of plant, and survivability requirements. Gas turbines plants tend to be more spacious and thus have a smaller fraction than a steam plant.

Comparative analysis examines:

- All Mobility Ship Performance (1-3)
- Main Propulsion HM&E System selection (1-4)

Main Propulsion Volume Fraction

Symbol: V_{pt}/∇

Definition: $V_{pt} = V_{4.1+4.2-4.15}$

Volume fraction allocated to the main propulsion plant which includes the propulsion units and the transmission.

Significance: Driven by the size and type of propulsion plant installed.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All Mobility Ship Performance (1-3)
- All Main Propulsion Selection (1-4)

Propulsion Units Specific Weight

Symbol: W_{23}/SHP (lbs/SHP)

Definition: Ratio of propulsion units weight to shaft horsepower available.

Significance: Measure of propulsion unit weight to propulsion power efficiency. See also "Main Propulsion Specific Weight" above.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Transmission/Propeller Specific Weight

Symbol: W_{24}/SHP (lbs/SHP)

Definition: Ratio of transmission and propeller weight to shaft horsepower available.

Significance: Measure of transmission and propeller weight to propulsion power efficiency. Fixed pitch propellers have a more efficient ratio than CRP propellers. See also "Main Propulsion Specific Weight" above.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Support/Fluids Specific Weight

Symbol: $W_{25+26+29}/SHP$ (lbs/SHP)

Definition: Ratio of propulsion support and fluids weight to shaft horsepower available. Includes all support air, piping, control and seawater systems, as well as fuel oil and lube oil systems.

Significance: Measure of propulsion support and fluids weight to propulsion power efficiency. Fully dependent on the requirements of the type of plant installed. Gas turbine plants have a better weight power efficiency than steam. See also "Main Propulsion Specific Weight" above.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Propulsion & Trans Specific Volume

Symbol: V_{pt}/SHP (ft^3/SHP)

Definition: Ratio of the total propulsion and transmission systems volume to shaft horsepower available.

Significance: Measure of the density of the total mobility propulsion system installed. An increase in the ratio indicates less dense main engineering spaces. Recent designs have shown a consistency in this indice.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Propulsion Systems Specific Volume

Symbol: $V_{4.1-4.15}/SHP$ (ft^3/SHP)

Definition: Ratio of only propulsion systems volume to shaft horsepower available.

Significance: Measure of the density of the propulsion system installed. An increase in the ratio indicates less dense main engineering spaces. Recent designs have shown a consistency in this indice.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Trans/Propeller Specific Volume

Symbol: $V_{4.2}/SHP$ (ft^3/SHP)

Definition: Ratio of only transmission and propeller volume to shaft horsepower available.

Significance: Measure of the density of the volume required for the transmission system installed. Generally includes only the shaft alley, however may be significant for electric drive transmissions.

Comparative analysis examines:

- Ship Performance Mobility (1-3)
- Main Propulsion HM&E System selection (1-4)

Propulsion KW/Weight Ratio

Symbol: E_2/W_2 (KW/ton)

Definition: Ratio of propulsion electric power requirements to the propulsion system weight.

Significance: Driven by the type of propulsion plant installed. Provides an indication of the electrical efficiency of the propulsion system.

Comparative analysis examines:

- Total 60Hz KW available/Max Load (1-4)
- All Main Propulsion HM&E Selection (1-4)

Propulsion Cost/Weight Ratio

Symbol: C_2/W_2 ($/ton)

Definition: Ratio of propulsion system basic construction cost to propulsion system weight.

Significance: Indication of the cost per ton of the propulsion plant and is driven primarily by the size and complexity of the system. It should be noted that this cost will not include any government furnished HM&E equipment.

Comparative Analysis examines:

- All Main Propulsion HM&E Selections (1-4)

SCREEN 3-5: ELECTRICAL PLANT BREAKDOWN

The electrical plant parameters are further broken down into a more detailed analysis of weight and volume requirements.

WEIGHT:

Power Generation Wt

Symbol: W_{31}/W_3

Definition: The fraction of total electric power weight that relates to power generation. This includes all primary sources of ship power, including emergency generators.[22]

Significance: Dependent on the type, number and size of generators installed, which is indirectly related to the volume, manning, machinery, and combat systems of the ship.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All HM&E Systems selection (1-4)
- All Combat Systems selection (1-5)

Power Distribution Wt

Symbol: W_{32}/W_3

Definition: The fraction of total electric power weight that relates to power distribution. This includes all cables, wireways and bustie feeders.[22]

Significance: Dependent on size and rating of the electric plant, the size of the ship, and the combat systems installed.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All HM&E Systems selection (1-4)
- All Combat Systems selection (1-5)

Lighting Wt Ratio

Symbol: W_{33}/W_3

Definition: The fraction of total electric power weight that relates to lighting system distribution. This includes all distribution boxes, lighting panels and transformers.[22]

Significance: Dependent primarily on the volume of the ship.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- HM&E electric power system selection (1-4)

Support System Wt Ratio

Symbol: W_{34+39}/W_3

Definition: The fraction of total electric power weight that relates to power generation support systems.[22]

Significance: Function of the number, type and rating of generators installed.

Comparative analysis examines:

- HM&E electric power system selection (1-4)

VOLUME:

NOTE: $V_e = V_{4.15} + V_{4.33}$

Machinery Space Electric Volume Ratio

Symbol: $V_{4.15}/V_e$

Definition: The fraction of total electric power volume requirement that is related to or located in the main machinery spaces. It is noted that in the event that the electric generation plant is integrated to the propulsion plant it will be included with the propulsion plant indice.

Significance: Dependent on size and rating of the electric plant, the size of the ship, and the combat systems installed. A large fraction of electric generation in the machinery area will drive up the size of the machinery "large space" requirement.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All HM&E Systems selection (1-4)

- All Combat Systems selection (1-5)

Auxiliary Space Electric Volume Ratio

Symbol: $V_{4.33}/V_e$

Definition: The fraction of total electric power volume requirement that is related to or located in the auxiliary machinery spaces. This includes any generators located in their own spaces and all 400Hz conversion equipment.

Significance: Dependent on size and rating of the electric plant, the size of the ship, and the combat systems installed.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All HM&E Systems selection (1-4)
- All Combat Systems selection (1-5)

SCREEN 3-6: ELECTRICAL INDICES

ELECTRICAL DRIVERS:

The primary drivers of electrical power requirements are based on the "triple-plot" relationship:

$$W_3/\Delta_{fl} = (W_3/E_i) * (E_i/\Delta_{fl})$$

Electrical Weight Fraction

Symbol: W_3/Δ_{fl}

Definition: Fraction of full load displacement allocated to electrical related weight.

Significance: Indicates to which extent the electrical system drives the design.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Electric Power HM&E System Selection (1-4)

Electrical Specific Weight

Symbol: W_3/E_i (lbs/KW)

Definition: Ratio of total electric plant weight to total installed electric power.

Significance: Measurement of the electric weight to KW efficiency of the plant. A lower ratio indicates that the plant has the capability of delivering more power for a given weight. Diesel electric generators generally have a higher specific weight than gas turbine generators.

Comparative analysis examines:

- All Electric power HM&E System Selection (1-4)

Electrical Capacity Ship Size Ratio

Symbol: E_i/Δ_{fl} (KW/ton)

Definition: Ratio of installed electric power to full load displacement.

Significance: Impacted directly by ship size and is a function of the machinery and combat systems installed. The designs of the last 40 years have shown a consistent increase, primarily due to the increased emphasis on

electronics and weapons. Recent designs such as the DD-963 and DDG-51 have large electric plants providing a large future growth margin.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Electric power HM&E System Selection (1-4)

RELATED ELECTRICAL RATIOS:

Electrical Density

Symbol: W_3/V_e (lbs/ft^3)

Definition: Ratio of SWBS Group 3 electrical plant weight to the required electric plant volume.

Significance: Provides indication of spaciousness of the electric plant. The capacity of electric power is driven by the volume of the ship, manning, machinery, and combat systems installed. The capacity then drives the size of the plant, which coupled with ship size then drive the electric density.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All HM&E System Selection (1-4)
- All Combat System selection (1-5)

Electrical Volume Fraction

Symbol: V_e/∇

Definition: $V_e = V_{4.15}+V_{4.33}$

Volume allocation fraction of ship electrical power generation and distribution system. Note: earlier Navy SSCS versions used differing methods of storing electrical space allocation. The user must ensure that the data base ships he is using is consistent in this area.

Significance: Indicates how the design volume is driven by the electric power requirements. In general, ships with large or numerous combat systems tend to have a larger power demand.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All Electric Power HM&E System Selections (1-4)
- All Combat System Selections (1-5)

Power Generation Specific Weight

Symbol: W_{31}/E_i (lbs/KW)

Definition: Ratio of that portion of the electric plant weight dedicated to electric power generation to the total electric power installed.

Significance: Measure of the electric generation weight to installed KW efficiency of the plant. The smaller the ratio, the less overall weight impact per KW.

Comparative analysis examines:

- All Electric power HM&E System Selection (1-4)

Electrical Specific Volume

Symbol: V_e/E_i (ft^3/KW)

Definition: Ratio of electric systems volume to the total installed electric power.

Significance: Measure of the density of the electric plant installed. An increase in the ratio indicates a more spacious electric plant.

Comparative analysis examines:

- All Electric power HM&E System Selection (1-4)

Electrical System KW/Weight Ratio

Symbol: E_3/W_3 (KW/ton)

Definition: Ratio of electrical system electric power requirements to the electrical system weight.

Significance: Driven by the type of electric plant installed. Provides an indication of the electrical efficiency of the electric plant.

Comparative analysis examines:

- Total 60Hz KW available/Max Load (1-4)
- All Electric Power HM&E Selection (1-4)

Electrical System Cost/Weight Ratio

Symbol: C_3/W_3 ($/ton)

Definition: Ratio of electric plant basic construction cost to electric plant weight.

Significance: Indication of the cost per ton of the electric plant and is driven primarily by the size and complexity of the system. It should be noted that this cost will not include any government furnished HM&E equipment.

Comparative analysis examines:

- All Electric Power HM&E Selection (1-4)

SCREEN 3-7: AUXILIARY BREAKDOWN

WEIGHT:

Symbols:

Climate Control Wt	W_{51}/W_5
Sea Water/Freshwater System Wt	W_{52+53}/W_5
Fluid System Wt	$W_{54+55+59}/W_5$
Ship Control Wt	W_{56}/W_5
Replenishment/Mech Hndlg Wt	W_{57+58}/W_5

Definition: Further detailed distribution of auxiliary weight as a function of total auxiliary weight, SWBS Group 5.

Significance: Since many of the auxiliaries are distributed systems, the system size may vary due to changes in ship size, manning, machinery or combat systems.

Comparative analysis for all indices listed above examines:

- All Size Characteristics (1-1)
- All Auxiliary HM&E System Selection (1-4)

VOLUME:

NOTE: $V_{ax} = V_{3.5+4.3-4.33}$

$V_{3.5}$ = Deck Systems

$V_{4.3}$ = Auxiliary Machinery

$V_{4.33}$= Auxiliary Space Electric

Deck Systems Volume

Symbol: $V_{3.5}/V_{ax}$

Definition: That portion of the auxiliary volume allocated to deck systems, which includes anchor and line handling, transfer-at-sea and ships boats.[23]

Significance: Driven primarily by the type of systems installed.

Comparative analysis examines:

- All Auxiliary HM&E System Selection (1-4)

Auxiliary Machinery Volume fraction

Symbol: $(V_{4.3}-V_{4.33})/V_{ax}$

Definition: That portion of auxiliary volume allocated to auxiliary machinery. This includes all HVAC, refrigeration, pollution control and propulsion machinery related mechanical systems.[23]

Significance: Distributed systems depend on ship size, combat systems and manning. Machinery related systems are dependent on type and size of propulsion plant.

Comparative analysis examines:

- Main Propulsion HM&E System Selection (1-4)
- Auxiliary HM&E System Selection (1-4)
- Manning HM&E System Selection (1-4)

SCREEN 3-8: AUXILIARY INDICES

AUXILIARY DRIVERS:

The primary drivers of auxiliary are based on the "triple plot" relationship:

$$W_5/\Delta_{fl} = (W_5/\nabla) * (\nabla/\Delta_{fl})$$

Auxiliary Weight Fraction

Symbol: W_5/Δ_{fl}

Definition: The fraction of full load displacement allocated to auxiliaries.

Significance: Indicates the extent to which auxiliaries drive the design weight.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Auxiliary HM&E System Selection (1-4)

Auxiliary Specific Weight

Symbol: W_5/∇ (lbs/ft^3)

Definition: Ratio of main auxiliary weight to overall ship volume.

Significance: Provides indication of auxiliary weight impact on overall ship volume. Due to the fact that much of the auxiliaries are distributed systems, the indice is a function of type and rating of auxiliary systems used, as well as ship size, manning and combat systems installed.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Auxiliary HM&E System Selection (1-4)

Ship Specific Volume

Symbol: ∇/Δ_{fl} (ft^3/ton)

Definition: Ratio of total enclosed volume to full load displacement.

Significance: Indication of spaciousness and how the volume drives the design. The larger the specific volume, the more spacious the design is. Recent trends have been toward an increase in specific volume. As the spaciousness increases, the associated weight fraction also increases.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Shape Characteristics (1-2)

RELATED AUXILIARY RATIOS:

Auxiliary Density

Symbol: W_5/V_{ax} (lbs/ft^3)

Definition: Ratio of SWBS Group 5, auxiliaries weight, to related auxiliaries volume.

Significance: Provides indication of the spaciousness of the auxiliaries installed. Many of the auxiliaries are distributed systems and are therefore driven by ship size, manning, machinery and combat systems installed.

Comparative analysis examines:

- All Size Characteristics (1-1)
- All Auxiliary HM&E System Selection (1-4)

Auxiliary Volume Fraction

Symbol: V_{ax}/∇

Definition: Volume fraction allocated to the auxiliary systems, which include deck systems and auxiliary machinery systems but do not include auxiliary electrical power generation spaces.

Significance: Indicates the extent to which auxiliary volume drives the design.

Comparative analysis examines:

- Total Enclosed Volume (1-1)
- All Auxiliary HM&E System Selections (1-4)

Auxiliary System KW/Weight Ratio

Symbol: E_5/W_5 (KW/ton)

Definition: Ratio of installed auxiliary system electric power requirements to the auxiliary system weight.

Significance: Driven by the type of auxiliaries installed. Provides an indication of the electrical efficiency of the installed auxiliaries. Recent trends has been to go to more gas turbine ships which has resulted in less available steam, thereby requiring more electric auxiliaries. A gas turbine plant will, therefore, have a higher fraction than a steam plant.

Comparative analysis examines:

- Total 60Hz KW available/Max Load (1-4)
- All Auxiliaries HM&E Selection (1-4)

Auxiliary Cost/Weight Ratio

Symbol: C_3/W_3 ($/ton)

Definition: Ratio of auxiliaries basic construction cost to the auxiliary plant weight.

Significance: Indication of the cost per ton of the auxiliary plant and is driven primarily by the size and complexity of the system. It should be noted that this cost will not include any government furnished HM&E equipment.

Comparative analysis examines:

- All Electric Power HM&E Selection (1-4)

SCREEN 3-9: COMBAT SYSTEMS BREAKDOWN

This screen serves to break down the combat systems weight and volume to provide the user the ability to analyze which part of the combat system is driving the design.

COMBAT SYSTEMS WEIGHT:

Note: $W_{csf}=W_4+W_7+W_{ord}+W_{av}$

Command and Surveillance Weight

Symbol: W_4/W_{csf}

Definition: Ratio of the command and surveillance weight to the weight of the total combat system.

Significance: Provides an indication of the extent that command and surveillance drives the combat system, and ultimately the design.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)
- All Command, Control, Comm and Intel Warfare Area (1-5)

Armament Weight

Symbol: W_7/W_{csf}

Definition: Ratio of the armament weight to the weight of the total combat system.

Significance: Provides an indication of the extent that armament drives the combat system, and ultimately the design.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

Aviation Weight

Symbol: W_{av}/W_{csf}

Definition: Ratio of the aviation related weight to the weight of the total combat system.

Significance: Provides an indication of the extent that the aviation detachment drives the combat system, and ultimately the design.

Comparative analysis examines:

- All Aviation Capabilities in each Warfare Area (1-5)

Ordnance Weight

Symbol: W_{ord}/W_{csf}

Definition: Ratio of the load ordnance weight to the weight of the total combat system.

Significance: Provides an indication of the extent that the load ordnance drives the combat system.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

COMMAND AND SURVEILLANCE WEIGHT:

Symbols:

Interior/Exterior Communications Wt W_{43+44}/W_4

Surface Surveillance Wt W_{45}/W_4

Underwater Surveillance Wt W_{46}/W_4

Other C&S Wt $W_{41+42+47+48+48}/W_4$

Definition: Percentage of command and surveillance weight allocated to each of its major functions.

Significance: Provides the user an indication of the extent to which a major command and surveillance function drives the command and surveillance package installed in the design.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)
- All Command, Control, Comm and Intel Warfare Area (1-5)

ARMAMENT WEIGHT:

Symbols:

Guns and Ammo Wt W_{71}/W_7

Missiles and Rockets Wt W_{72}/W_7

Other Armament Wt $W_{73 \text{ thru } 79}/W_7$

Definition: Percentage of armament weight allocated to each of its major functions.

Significance: Provides the user an indication of the extent to which a major armament category drives the armament function.

Comparative analysis examines:

- All Armament of each Warfare Area (1-5)

COMBAT SYSTEMS VOLUME:

Command and Surveillance Volume

Symbol: $V_{1.1}/V_1$

Definition: Percentage of total mission support volume allocated to command and surveillance.

Significance: Indicates how much the command and surveillance function drives the total mission support.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)
- All Command, Control, Comm and Intel Warfare Area (1-5)

Armament Volume

Symbol: $V_{1.2}/V_1$

Definition: Percentage of total mission support volume allocated to armament.

Significance: Indicates how much the installed armament drives the total mission support.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

Aviation Volume

Symbol: $V_{1.3}/V_1$

Definition: Percentage of total mission support volume allocated to aviation capability.

Significance: Indicates how much the aviation detachment drives the total mission support.

Comparative analysis examines:

- All Aviation Capabilities in each Warfare Area (1-5)

COMMAND AND SURVEILLANCE VOLUME:

Symbols:

Interior/Exterior Comm Vol	$V_{1.11+1.15}/V_{1.1}$
Surface Surveillance Vol	$V_{1.121}/V_{1.1}$
Underwater Surveillance Vol	$V_{1.122}/V_{1.1}$
Other C&S Volume	$V_{1.13+1.14+1.16}/V_{1.1}$

Definition: Percentage of command and surveillance volume allocated to each of its major functions.

Significance: Provides the user an indication of the extent to which a major command and surveillance function drives the command and surveillance package installed in the design.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)
- All Command, Control, Comm and Intel Warfare Area (1-5)

ARMAMENT VOLUME:

Symbols:

Guns and Ammo Volume	$V_{1.21}/V_{1.2}$
Missiles and Rockets Volume	$V_{1.22+1.23}/V_{1.2}$
Other Armament Volume	$V_{1.24+1.25+1.26+1.27}/V_{1.2}$

Definition: Percentage of armament volume allocated to each of its major functions.

Significance: Provides the user an indication of the extent to which a major armament category drives the armament function.

Comparative analysis examines:

- All Armament of each Warfare Area (1-5)

SCREEN 3-10: COMBAT SYSTEMS INDICES

COMBAT SYSTEM DRIVERS

The combat system is driven by parameters of the set of "triple plots" for C&S and armament:

$$W_4/\Delta_{f1} = (W_4/\#s) * (\#s/\Delta_{f1})$$

$$W_7/\Delta_{f1} = (W_7/\#l) * (\#l/\Delta_{f1})$$

where #l = number of launchers installed

#s = number of sensors installed

Armament Weight Fraction

Symbol: W_7/Δ_{f1}

Definition: Fraction of full load displacement allocated to armament.

Significance: Indicates the extent to which the armament installed drives the full load weight of the design.

Comparative analysis examines:

- Full Load Displacement (1-1)

- All Armament in each Warfare Area (1-5)

Armament Capacity Size Ratio

Symbol: $\#1/\Delta_{fl}$ (1chr/1000tons)

Definition: The ratio of launchers per 1000 tons of full load displacement. In computing the number of launchers, each unit capable of launching a weapon is considered one launcher. In the case where multiple fire capability exists, the criteria shall be how many targets can it lock on and fire at simultaneously. If only one weapon can leave the launcher at a time, then it is one unit. Therefore, VLS is one unit, irrespective of how many cells it has. Harpoon is one unit since it can only fire one at a time, even though there may exist two canister sets. Torpedoes are considered one unit. Each gun is one unit, each CIWS-set (one or two) is considered one unit, small arms are not counted. Helos are not counted since they are not a permanent part of the ship and may or may not be aboard at any given time.

Significance: Since many comparisons are performed by comparing the weapons systems of the design, this provides an indication of armament carrying capacity and efficiency of the design. The greater the fraction, the more efficient the design from the perspective of ability to fight.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

Armament Specific Weight

Symbol: $W_7/\#l$ (1000 tons/launcher)

Definition: Ratio of total armament weight, as defined by SWBS group 7, to the number of launchers, where the number of launchers is as defined in "Armament Capacity Size Ratio" above.

Significance: Provides some analysis of the weight efficiency of the weapons carried, thereby determining the impact of the weapons on the ship on a "per weapon" basis.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

C&S Weight Fraction

Symbol: W_4/Δ_{fl}

Definition: Fraction of full load displacement allocated to command and surveillance.

Significance: Indicates the extent to which the command and surveillance system drives the full load weight of the design.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Sensors in each Warfare Area (1-5)
- All Command, Control, Comm & Intel (1-5)

C&S Capacity Size Ratio

Symbol: $\#s/\Delta_{fl}$ (sensors/1000tons)

Definition: The ratio of sensors per 1000 tons of full load displacement. In computing the number of senors, each major sensor is counted as one unit. This includes radar, sonar, and EW systems. The communications suite is counted as one unit, irrespective of size. A fire control system is not counted as a sensor since it is associated with a launcher system. The helo capability is not classified a sensor since it may or may not be aboard at any given time. To be classified a sensor, a unit must be able to transmit, detect, track or classify something external to the ship.

Significance: A method of comparing the efficiency of a design by comparing its sensor capability. The greater the fraction, the more efficient the design from the perspective of ability to detect, track and communicate with other units.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)

C&S Specific Weight

Symbol: W_4/#s (1000 tons/senser)

Definition: Ratio of total command and surveillance weight, as defined by SWBS group 4, to the number of installed sensors, where the number of sensors is as defined in "C&S Capacity Size Ratio" above.

Significance: Provides some analysis of the weight efficiency of the sensors carried, thereby determining the impact of the command and surveillance package on the ship on a "per sensor" basis.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)

RELATED COMBAT SYSTEMS RATIOS:

Combat Systems Density

Symbol: W_{csf}/V_1 (lbs/ft^3)

Definition: Ratio of total combat systems weight to mission support combat systems volume.

Significance: Provides indication of spaciousness and/or size of the combat system of the design. The larger the fraction the more tightly packed the combat system is. Driven primarily by the type and complexity of the combat systems installed.

Comparative analysis examines:

- All Combat Systems Selection (1-5)

Command and Surveillance Density

Symbol: $W_4/V_{1.1}$ (lbs/ft^3)

Definition: Ratio of SWBS group 4 command and surveillance weight to command and surveillance volume.

Significance: Provides indication of spaciousness of the command and surveillance package of the design. The larger the fraction the more tightly packed the C&S system is. Driven primarily by the type and complexity of the command and surveillance equipment installed.

Comparative analysis examines:

- All Sensors in each Warfare Area (1-5)

Armament Density

Symbol: $W_7/V_{1.2}$ (lbs/ft^3)

Definition: Ratio of SWBS group 7 armament weight to armament volume.

Significance: Provides indication of spaciousness of armament systems in the design. The larger the fraction the more tightly packed the armament systems are. Driven primarily by the type and complexity of the armament installed.

Comparative analysis examines:

- All Armament in each Warfare Area (1-5)

Combat System KW/Weight Ratio

Symbol: E_{cs}/W_{csf} (KW/ton)

Definition: Ratio of combat system KW requirements to the full load combat system weight as defined in screens 2-8 and 2-3 respectively.

Significance: Driven by the size and complexity of the combat system. Provides an indication of electrical efficiency of the combat system.

Comparative analysis examines:

- Total 60Hz KW Available/Max Load (1-4)
- All Combat Systems Selection (1-5)

Combat System Cost/Weight Ratio

Symbol: C_{cs}/W_{csf} ($/ton)

Definition: Ratio of combat system costs to full load combat system weight as defined in screens 2-12 and 2-3 respectively.

Significance: Indication of cost per ton of the combat system. Driven primarily by the size and complexity of the combat system installed.

Comparative analysis examines:

- All Combat Systems Selection (1-5)

SCREEN 3-11: HUMAN SUPPORT BREAKDOWN

M_a = total accomodations

M_{axxx} = accomodations for 'xxx' personnel

WEIGHT:

$W_{HS}=W_{ce}+W_{6cr}+W_{pw}$

W_{HS} = total human support weight

W_{ce} = crew and effects load weight (F1)

W_{6cr} = crew related group 6 outfit and furnishings

$(W_{6cr} = W_{64+65+66+67})$

W_{pw} = potable water weight (F52)

Symbols:

Crew and Effects Weight	W_{ce}/W_{HS}
Outfit and Furnishings Weight	W_{6cr}/W_{HS}
Potable Water Weight	W_{pw}/W_{HS}

Definition: Percentage of human support weights allocated to the primary human support loads.

Significance: Direct function of manning and habitability standards of the design.

Comparative analysis examines:

- All Manning in HM&E Selection (1-4)

VOLUME:

Symbols:

Living Volume	$V_{2.1}/V_2$
Food Service/Messroom/Lounge Volume	$V_{2.2}/V_2$
Medical/General Svcs/Other Vol	$V_{2.3 \text{ thru } 2.7}/V_2$

Definition: Percentage of the total human support volume allocated to its primary users.

Significance: Direct function of manning and habitability standard of the design and an indirect function of ship volume.

Comparative analysis examines:

- All Manning in HM&E System Selection (1-4)

SCREEN 3-12: HUMAN SUPPORT INDICES

HUMAN SUPPORT DRIVERS:

Drivers are those related to the "triple plot" relationship:

$$W_{HS}/\Delta_{fl} = (W_{HS}/M_a) * (M_a/\Delta_{fl})$$

where the individual parameters are as defined in screen 3-11.

Human Support Weight Fraction

Symbol: W_{HS}/Δ_{fl}

Definition: Percentage of full load displacement allocated to the function of human support.

Significance: Directly related to manning size and habitability standards.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Manning in HM&E System Selection (1-4)

Human Support Specific Weight

Symbol: W_{HS}/M_a (tons/man)

Definition: Ratio total human support weight to total complement of manning.

Significance: Manning level is established by the ship requirements at Condition III, which is underway with selected combat systems energized, with personnel still

available for training and maintenance. This indice is therefore an indication of the efficiency of personnel requirements.

Comparative analysis examines:

- All Manning in HM&E System Selection (1-4)

Total Accomodations Ship Size Ratio

Symbol: M_a/Δ_{fl} (men/1000 tons)

Definition: Ratio of total manning accomodations to full load displacement.

Significance: Provides an indication of efficiency of manning and amount of automatic controls and minimized maintenance requirements. The lower the indice, the more efficient the design from a manning perspective.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Manning in HM&E System Selection (1-4)

RELATED HUMAN SUPPORT RATIOS:

Human Support Density

Symbol: W_{HS}/V_2 (lbs/ft^3)

Definition: Ratio of total human support weight to human support volume.

Significance: Provides indication of human support spaciousness. The smaller the fraction, the more spacious

the design is. Driven primarily by manning and habitability standards used.

Comparative analysis examines:

- All Manning in HM&E System Selection (1-4)

Personnel Living Space Specific Vol

Symbol: $V_{2.1}/M_a$ (ft^3/man)

Definition: Ratio of volume assigned specifically to personnel berthing, sanitation, and recreation to the total manning accomodations.

Significance: A more concise representation of spaciousness of the design per man, which directly impacts the crew as space specifically assigned to them.

Comparative analysis examines:

- All Manning in HM&E System Selection (1-4)

Human Support Specific Volume

Symbol: V_2/M_a (ft^3/man)

Definition: Ratio of human support allocated volume to the total number of accomodations.

Significance: Direct function of habitability standards and total manning assigned. The trend in the last 40 years has consistently increased to the point where it has almost tripled. The recent DDG-51 design has used a more efficient, compact arrangement to bring this ratio back down.

Comparative analysis examines:

- All Manning in HM&E System Selection (1-4)

Human Support Specific Area

Symbol: A_2/M_a (ft^2/man)

Definition: Ratio of area allocated to human support to the number of accomodations.

Significance: Since volume is also affected by deck height, this indice provides a more realistic "amount of space" allocated to each accomodation. It may show the designer how much future expansion could be performed. In fact, the recent designs of FFG-7 and DD-963 used some of the large human support specific area initially installed to expand the manning they could support. The U.S. Navy 1979 standard of 45 ft^2/man was exceeded in both of these designs.

Comparative analysis examines:

- All Deck Heights in HM&E System Selection (1-4)
- All Manning in HM&E System Selection (1-4)

Officer Living Area per man

Symbol: $A_{2.11+2.211}/M_{aoff}$ (ft^2/man)

Definition: Ratio of area allocated to officer berthing, sanitary, recreation and messing to the number of officer accomodations.

Significance: Includes flag accomodations and transient berthing, if installed. Directly impacted by the habitability standard assigned to the ship and the number of officers required for the subsystems installed.

Comparative analysis examines:

- All Deck Heights in HM&E System Selection (1-4)
- All Manning in HM&E System Selection (1-4)

CPO Living Area per man

Symbol: $A_{2.12+2.212}/M_{acpo}$ (ft^2/man)

Definition: Ratio of area allocated to Chief Petty Officer berthing, sanitary, recreation and messing to the number of CPO accomodations.

Significance: Includes flag accomodations and transient berthing, if installed. Directly impacted by the habitability standard assigned to the ship and the number of CPO's required for the equipment installed.

Comparative analysis examines:

- All Deck Heights in HM&E System Selection (1-4)
- All Manning in HM&E System Selection (1-4)

Enlisted Living Area per man

Symbol: $A_{2.13+2.213}/M_{aenl}$ (ft^2/man)

Definition: Ratio of area allocated to enlisted berthing, sanitary, recreation and messing to the number of enlisted accomodations.

Significance: Includes flag accomodations and transient berthing, if installed. Directly impacted by the habitability standard assigned to the ship and the number of enlisted personnel to operate and maintaing the equipment installed.

Comparative analysis examines:

- All Deck Heights in HM&E System Selection (1-4)
- All Manning in HM&E System Selection (1-4)

Officer Ship Size Ratio

Symbol: M_{aoff}/Δ_{fl} (men/1000 tons)

Definition: Ratio of officer accomodations to full load displacement.

Significance: Provides indication of efficiency of design with respect to manning accomodations per tonnage. The smaller the value, the more efficient usage of personnel assigned.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Manning in HM&E System Selection (1-4)

CPO Ship Size Ratio

Symbol: M_{acpo}/Δ_{fl} (men/1000 tons)

Definition: Ratio of CPO accomodations to full load displacement.

Significance: Provides indication of efficiency of design with respect to manning accomodations per tonnage. The smaller the value, the more efficient usage of personnel assigned.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Manning in HM&E System Selection (1-4)

Enlisted Ship Size Ratio

Symbol: M_{aenl}/Δ_{fl} (men/1000 tons)

Definition: Ratio of enlisted crew accomodations to full load displacement.

Significance: Provides indication of efficiency of design with respect to manning accomodations per tonnage. The smaller the value, the more efficient usage of personnel assigned.

Comparative analysis examines:

- Full Load Displacement (1-1)
- All Manning in HM&E System Selection (1-4)

SCREEN 3-13: MARGIN SUMMARY

This screen serves as a summary screen to display ships margins and allow comparisons to the NAVSEA standards.

Definition: Two types of margins are examined. The first, "acquisition margin" relates to the design practice of accounting for uncertainties in design and construction. A completed ship will no longer have an acquisition margin. The second margin is the "service life margin"

which allocates for anticipated changes expected during the ship's normal operational service. In general, these margins can be explained by considering three phases of a ship design for each of the below indices, the "current" value at a particular stage of design, the anticipated "delivery" value and the absolute "limit". It is the difference between the "delivery" and "current" value that makes up the acquisition margin and the difference between the "limit" and "delivery" that is classified as service life.

Significance: The user should examine both designs for the use of standard margins. The use of standard margins in one design and not in the other may result in a significant impact in the design indice area. Additionally, the user may get a good appreciation for "excessive" margins which directly impact a design.

Since design margins are selected by the design team, they are a function of a given design. Therefore, no comparative analysis path exists for them in this level.

Each indice is further explained below. All margins are converted to percentages for use in this screen.

Weight[29]

Acquisition Margin:

Symbol: $W_m/(\Delta_{ls}-W_m)$

Definition: The ratio of the acquisition margin to the sum of the weights of SWBS groups 1 through 7. In this study, the light ship weight is the sum of these SWBS groups plus the margin.

- NAVSEA Standard $.1 * (\Delta_{ls} - W_m) = 10\%$

Service Life Margin:

Symbol: $(\Delta_{al} - \Delta_{fl}) / \Delta_{fl}$

Definition: The ratio of the architectural weight limit minus the full load delivery displacement to the full load displacement.

- NAVSEA Standard $.1 * \Delta_{fl} = 10\%$

KG[29]

Acquisition Margin:

Symbol: KG_m / KG_{ls}

Definition: Ratio of the KG acquisition margin to the light ship KG

- NAVSEA Standard $.1 * KG_{ls} = 10\%$

Service Life Margin:

Symbol: $(KG_{al} - KG_{fl}) / KG_{fl}$

Definition: Ratio of the architecural limit KG minus delivery full load KG to the full load KG.

- NAVSEA Standard $KG_{al} - KG_{fl} = 1.0$ ft

Electric Power[28]

General Symbols: E_g = KW rating of one generator

E_{am} = Acquisition Margin

E_{slm}= Service Life Margin

= $(.9*(E_i-E_g) - (E_t+E_{am})$

E_m = $E_{am}+E_{slm}-E_2$

Acquisition Margin:

Symbol: E_{am}/E_t

Definition: Ratio of electric power acquisition margin to maximum functional load.

- NAVSEA Standard .2 * E_t = 20%

Service Life Margin:

Symbol: $E_{slm}/(E_t+E_m)$

Definition: This margin exludes one of the generators which must remain in standby as an emergency generator. The remaining generators must not exceed 90% of their available installed load capability. If an acquisition margin is still being used in the design process then it is considered to be a part of the maximum functional load since it is by definition for design and construction uncertainties. There is no service life margin for the propulsion plant since it is not expected to grow electrically in the life of the ship. It is therefore subtracted from the full capacity when computing margin.

- NAVSEA Standard .2 * (E_t+E_m) = 20%

Volume

Service Life Margin:

Symbol: V_5/∇

Definition: SSCS V_5 is the volume that is not assigned in the ship. Although it is not a true margin, it is space that is available for future growth. It is the policy of NAVSEA that all space is to be allocated.

- NAVSEA Standard 0%

Manning

Service Life Margin:

Symbol: $(M_a-M_t)/M_t$

Definition: The ratio of the difference between the manning complement and the accomodations installed to the total manning complement.

- NAVSEA Standard $.1 * M_t$ = 10%

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c.1 Methodology for computer-supported comparative naval ship design.