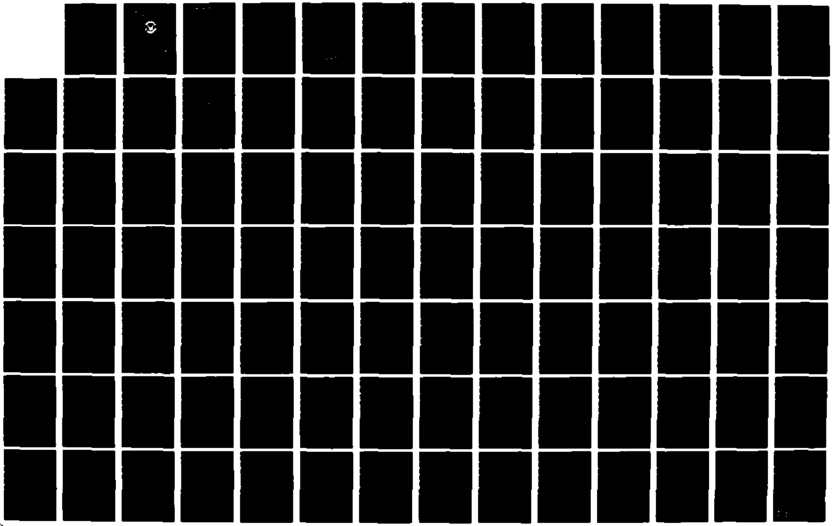
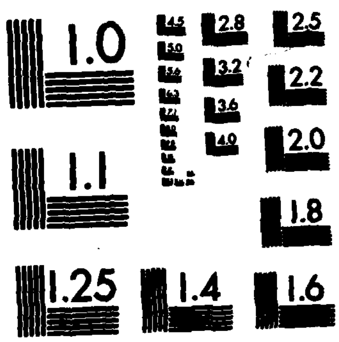
AD-A125 271 APPLICATION OF OPTIMIZATION TECHNIQUES TO NAVAL SURFACE COMBATANT SHIP SYNTHESIS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J L JENKINS OCT 82 1/1

UNCLASSIFIED F/G 13/10 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

APPLICATION OF OPTIMIZATION
TECHNIQUES TO NAVAL SURFACE
COMBATANT SHIP SYNTHESIS

by

James L. Jenkins

October, 1982

Thesis Advisor: Garret N. Vanderplaats

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A125271	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Application of Optimization Techniques to Naval Surface Combatant Ship Synthesis		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis October, 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James L. Jenkins		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE October, 1982
		13. NUMBER OF PAGES 95
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship synthesis
Optimization
Numerical optimization
Computer-aid design (CAD)
Ship design
Conceptual design
Naval architecture

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis presents a method of reducing the time required to accomplish ship design feasibility studies by coupling a naval surface combatant synthesis model with a general purpose nonlinear optimizer. Brief descriptions of optimization techniques and synthesis models are presented. The selection of design variables, constraints, and objective function is presented via a design example. Further examples are given illustrating the ability

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Con't

20. ABSTRACT (Continued)

to start with infeasible designs and proceed, through optimization, to feasible designs. Examples of ships developed using different objective functions are also presented. The synthesis/optimizer system provides results in a rapid and descriptive manner which compare favorably with existing designs and provides the naval architect with an efficient tool to use in the conceptual design phase of naval surface combatants.

Approved for public release; distribution unlimited.

Application of Optimization Techniques to Naval Surface Combatant Ship Synthesis

by

James L. Jenkins
Lieutenant, United States Navy
B.S.E., University of Michigan, 1975

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
October, 1982

Author: James L. Jenkins

Approved by: Garit V. Vanderplaats, Thesis Advisor

M R Mlaar, Second Reader

P. J. Marto, Chairman, Department of Mechanical Engineering

William M. Tolles, Dean of Science and Engineering

ABSTRACT

This thesis presents a method of reducing the time required to accomplish ship design feasibility studies by coupling a naval surface combatant synthesis model with a general purpose nonlinear optimizer. Brief descriptions of optimization techniques and synthesis models are presented. The selection of design variables, constraints, and objective function is presented via a design example. Further examples are given illustrating the ability to start with infeasible designs and proceed, through optimization, to feasible designs. Examples of ships developed using different objective functions are also presented. The synthesis/optimizer system provides results in a rapid and descriptive manner which compare favorably with existing designs and provides the naval architect with an efficient tool to use in the conceptual design phase of naval surface combatants.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

I would like to express my gratitude to Professor Vanderplaats for his endless patience and willingness to stop whatever he was doing and provide much needed assistance. His positive attitude and encouragement were a tremendous support.

I would also like to thank my wife and children for their faith, encouragement, and prayers during the last six months. They provided much needed motivation to keep on plugging when things got sticky.

Finally, I would like to thank the original Naval Architect, who delivered to Noah the first set of design requirements and ship's plans. Thank you Father in Heaven for granting me Your strength, wisdom, and patience.

I. INTRODUCTION

A. BACKGROUND

In today's environment of rapidly increasing costs, technological complexity, and growing threats, we must actively pursue ways in which to improve the effectiveness with which we apply the limited resources available to the design of naval combatants. Currently, the design process, from feasibility studies through keel laying of the lead ship takes almost a decade to complete. There is growing pressure to accelerate this process wherever possible in the design sequence. Inflation appears to be the primary motivator for this pressure; as we can look to painfully expensive examples of construction projects, which when delayed for whatever reason resulted in increased costs without significant platform improvements as compensation.

The naval architect and naval engineer involved in the design process today can turn to the high speed digital computer for a viable means of reducing the time required for the design process and thereby achieve significant monetary gains while maintaining or improving the quality of the design product. The goal of "best ship at least cost" and the "computer revolution" have resulted in a very successful software development effort within naval research activities. Reference [1] provides a catalog of computer-aided design and construction (CASDAC) programs currently used by the Naval Sea Systems Command. The programs range from routines used for data management to complex synthesis model and arrangements packages.

The design of naval vessels can be categorized into three major phases. These are:

1. Conceptual Design
2. Preliminary Design
3. Contract Design

At each phase, the ship is defined in greater detail than the previous phase.

Conceptual design can be further subdivided into two components; 1) the feasibility study and, 2) the concept design. These too, represent levels of design detail with feasibility studies being the first and the crudest estimate of the ship, and concept design being the development and optimization of a single or several ships selected from feasibility studies.

Mills, in [Ref. 2], defines feasibility studies as

> "...an estimate of the ship system level physical characteristics and cost related data for a design which represents a feasible solution to a specific set of performance requirements."

Restated, a feasibility study is a shortcut estimate of a ship's principal characteristics, machinery systems and various coefficients which when taken as a whole, are a feasible solution to the owner's specifications or desires.

Feasibility studies can be used for trade-off studies where new designs are evaluated; for subsystems trade-off studies, i.e. how different propulsions systems might work in a DD-963 hull, for evaluating changes in design standards and practices, or for determining an optimum feasible design with which to start the preliminary design phase.

It is evident from the brief descriptions above that large numbers of feasibility studies are required to satisfy all of the designers needs. This demand for volumes of output and information has resulted in feasibility studies being successfully computerized in the form of synthesis models. A synthesis model is an engineering design procedure for converting a set of requirements into the physical description of a ship which can satisfy those requirements. The ultimate result of using the synthesis model as a design tool is the ability to produce a far more detailed and accurate design earlier in the design sequence, thereby saving precious time and money and providing more reliable guidance in the design selection process.

B. PROBLEM STATEMENT

The main problem, simply stated, is that the design of naval surface combatants must be accomplished as quickly and as inexpensively as possible to prevent inflationary overruns and technology lag. The past three decades have provided numerous examples of the consequences of "too long and too much." This thesis is intended to provide the designer a tool with which he can confidently accelerate the conceptual design phase and still produce high quality designs. The synthesis system will further free the designer to try innovative design concepts heretofor stymied by the burden of manual calculations and routine decisions.

C. SCOPE

The purpose of this thesis is to couple two existing computer programs; a naval surface combatant synthesis model [Ref. 3], and a general purpose non-linear optimizer [Ref. 4], to produce a synthesis system which will further enhance the ability of the naval architect during the conceptual design phase. Instead of using a synthesis model to generate hundreds of designs and then manually selecting one which appears to be the "best," the synthesis system will let the computer make the decision based on the limitations or constraints, and design requirements, coded in mathematical terms.

This process may be illustrated using the traditional design spiral. Synthesis models currently in use reflect a computerized version of the spiral which iterate until they converge to a feasible design or diverge and terminate with no design. Figure 1.1 illustrates this concept. Figure 1.2 presents the optimizer/synthesis cycle proposed in this thesis. Here only one cycle is generated in the spiral with

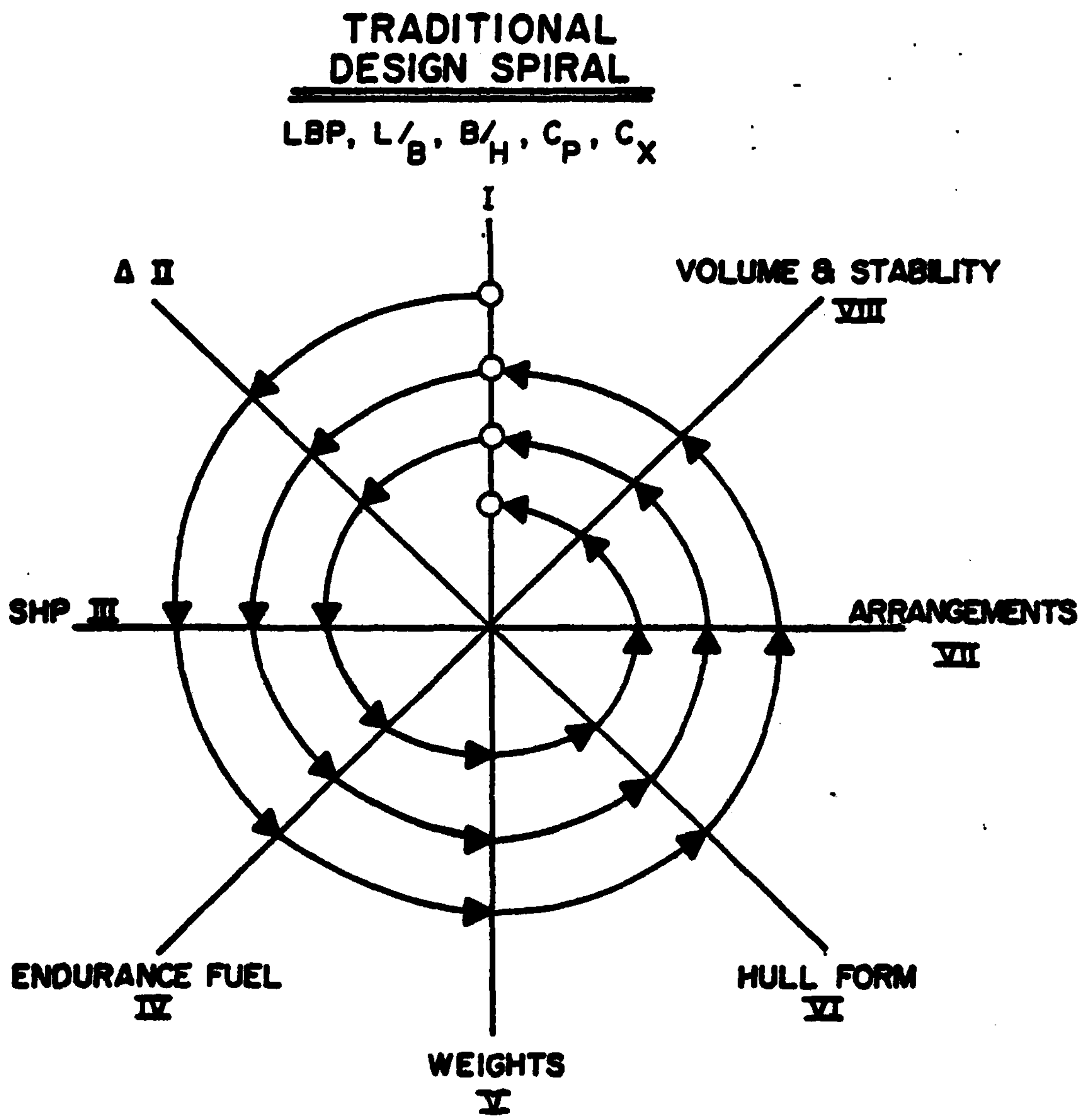


Figure 1.1 Traditional Design Spiral.

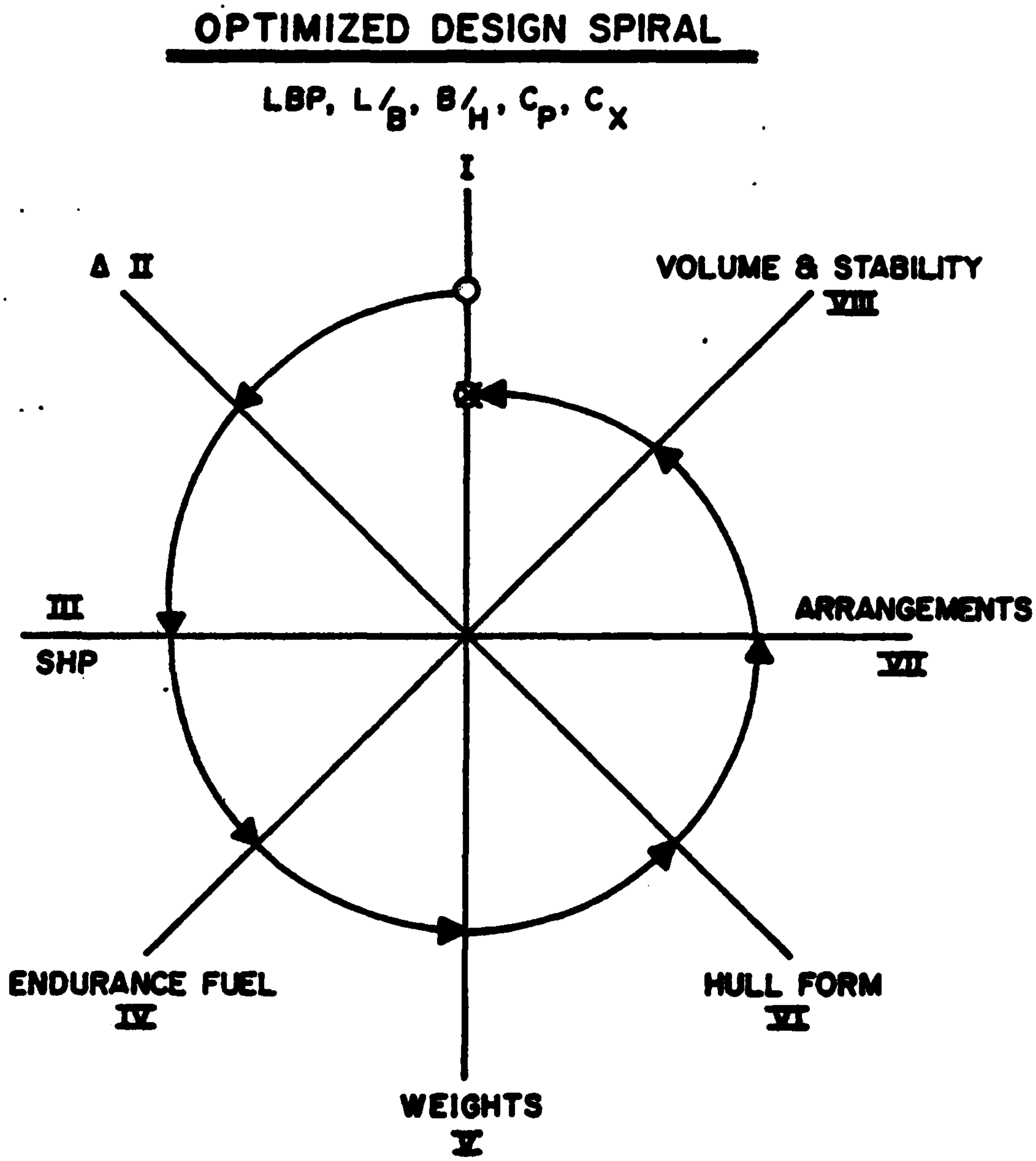


Figure 1.2 Optimized Design Spiral.

the optimizer changing design variables to meet the requirements of the design simultaneously with the calculations around the path. Differences between the desired and calculated values of specified parameters are treated as constraints which the optimizer works to satisfy. As can be seen graphically, much time and computational effort has been saved as a result of this process.

It must be emphatically stated at this point that the synthesis system is a design tool, as are the individual synthesis model and the optimizer routine, and all of them must be used carefully with considerable common sense and good engineering judgement.

The benefits of such a system are manifold and represent some of the best aspects of the individual programs. Several are listed below.

1. An automated, optimized synthesis system further reduces the computational time necessary to do a feasibility study.

2. The results are consistent throughout the design with the computer making decisions and calculations as a matter of routine. This consistency is important when considering designs of radical character.

3. The results are more comprehensive. The synthesis model produces detailed output of essential data while the optimizer generates an easily traceable optimization trail, from which any design other than the optimum may be selected and evaluated.

4. The ability to conduct studies on designs optimized with respect to different design objectives, i.e. minimum displacement versus minimum cost, while maintaining the same repeatable design practices and standards.

5. And finally, the freedom to be innovative and creative in design as a result of no longer being tied to long, tedious manual calculations.

D. PRESENTATION OF THESIS

The remaining chapters of this thesis are outlined as follows. Chapter II presents a brief background on the optimization methods used in the COPES/CONMIN optimizer. A two variable design example is presented as an illustration to further highlight the optimization procedures.

Chapter III is a summary of the Reed synthesis model's salient features including logical program flow and a brief description of the program's subroutines.

Chapter IV presents the modifications that were necessary in the Reed model to couple it with the COPES/CONMIN optimizer. Constraints that were added are justified and presented.

Chapter V is a short design example using mission requirements similar to those of an FFG-7 as a baseline design. The example is used to present arguments supporting selection of objective functions and design variables.

Chapter VI presents design examples using different objective functions and comments on the merits of the synthesis system.

Chapter VII offers conclusions and recommendations.

Appendix A is a computer listing of the design example presented in Chapter V.

Appendix B is a listing of the elements in the GLOBCM COMMON block, identifying their global locations and meanings.

Appendix C is a listing of nomenclature used in this thesis.

II. OPTIMIZATION TECHNIQUES

A. INTRODUCTION

This chapter will present some of the fundamental concepts and definitions required to understand the optimization methods used in the COPES/CONMIN optimization program. COPES/CONMIN is then discussed in brief and a short two variable design example is presented to illustrate the methods used in determining the optimum solution. The explanations are necessarily short as it is assumed that the reader is already familiar with optimization methods. Should further details be desired, Fox [Ref. 5] and Himmelblau [Ref. 6] are very good texts which may be consulted.

B. DEFINITIONS.

It is important to define several key terms used in the optimization problem formulation. These are:

Design variables--The parameters for which values are to be chosen in producing a design will be called design variables. In the conceptual ship design phase these might be length, speed, beam to draft ratio, length to beam ratio, block coefficient, etc. Design variables may be constrained to a limited range, i.e. 300 to 700 feet for the length between perpendiculars, or they may take on any value.

Objective function--The single valued function with respect to which the design is optimized is called the objective function. Selection of the objective function can be one of the most important decisions in the design process. For ship designs, parameters such as displacement, economic measures of merit, speed, structural member fabrication costs and weight may be used. It is also possible to combine several important parameters to form a weighted combination which is to be optimized. This procedure is discussed extensively by Leopold and Reuter [Ref. 7].

Constraints--The design restrictions which must be satisfied in order to produce an acceptable design are collectively called constraints. In the design of a ship, many constraints are specified by the owner prior to any calculations being done. Some of these may be maximum navigational draft, maximum or minimum length or displacement, and certainly some measure of stability. If a parameter is beyond the value of a specified constraint, the constraint is said to be violated.

Infeasible Design--A design in which constraints are violated is called an infeasible or unacceptable design.

Feasible Design--A design which satisfies the specified constraints is called a feasible or acceptable design.

Side Constraint--A constraint which restricts the range of a design variable for reasons other than the direct consideration of performance is called a side constraint. A side constraint in the design of a ship may be the minimum length or draft.

C. COPES/CONMIN

The COPES/CONMIN optimization program is a general purpose, non-linear optimizer capable of handling large, constrained problems. It has been successfully used in connection with aircraft synthesis models [Ref. 8], structural optimization [Ref. 9], airfoil design [Ref. 10], and numerous other engineering applications. Although the code itself is very sophisticated, the primary methods of optimization used are conjugate directions for locally unconstrained problems and feasible directions for locally constrained problems.

It solves the general non-linear optimization problem stated as follows:

Minimize	$OBJ = F(\underline{X})$		2.1
subject to;	$G_i(\underline{X}) \leq 0$	for $i = 1,m$	2.2
	$X_i^{\ell} \leq X_i \leq X_i^{u}$	for $i = 1,n$	2.3

where OBJ is the objective function. The vector $\underline{X}$ contains the "n" design variables. $G_i(\underline{X})$ define the constraints imposed by the designer on the optimization problem and "m" is the total number of constraints. $F(\underline{X})$ and $G_i(\underline{X})$ may be either implicit or explicit functions of the design variables $\underline{X}$, but must be continuous. The variables X_i^{ℓ} and X_i^{u} define the lower and upper bounds, respectively, on the design variable X_i and are the limits over which $F(\underline{X})$ and $G_i(\underline{X})$ are defined.

The n-dimensional space spanned by the design variables $\underline{X}$ is referred to as the design space. As stated previously, any design which satisfies the inequalities of equation 2.2 is referred to as a feasible design. If the design violates one or more of the inequalities, it is said to be infeasible. The minimum feasible design is said to be optimal.

The optimization program begins with an initial $\underline{X}$ vector which is input to the program and may or may not define a feasible design. The optimization process then proceeds iteratively by the following recursive relationship:

$$\underline{X}^{(q+1)} = \underline{X}^{(q)} + \alpha^*\underline{S}^{(q)} \qquad 2.4$$

where q is the iteration number, vector $\underline{S}$ is the direction of search in the n-dimensional design space, and α^* is a scalar which defines the distance of travel in the direction $\underline{S}$.

The optimization process then proceeds in two steps. The first is the determination of a direction $\underline{S}$ which will reduce the objective function without violating constraints. The second is the determination of the scalar α^* so that the objective function is minimized in this direction, a new constraint is encountered, or a currently active con-traint is encountered again.

Consider for example, a hypothetical problem in which we wish to minimize the displacement of a naval combatant in terms of two design variables; length between perpendiculars (LBP), and the length to beam ratio (L/B). There are also two constraints for this problem: constraint G1 requires that the calculated full load displacement is equal to or greater than the displacement estimated by an empirical formula, and constraint G2 requires that, in a similar manner, the calculated vertical center of gravity be greater than or equal to the empirical estimation.

Figure 2.1 is a graphical representation of such a problem showing the contours of constant objective function value as well as the constraint boundaries. Assume that a design at point A is given so that initially no constraints are active or violated. The program then begins by initially perturbing each of the $\underline{X}$ variables to determine its effect on the objective function (full load displacement). That is, the gradient of the displacement function is calculated by the finite difference method. Because no constraints are violated or active, it is obvious that the greatest improvement in the objective function is obtained by moving in the negative gradient or steepest descent direction so that $\underline{S} = -\underline{\nabla}(\mathrm{DISPFL})$. Having determined $\underline{S}$, the scalar α^* in equation 2.4 must now be determined so that either the objective function is minimized in this

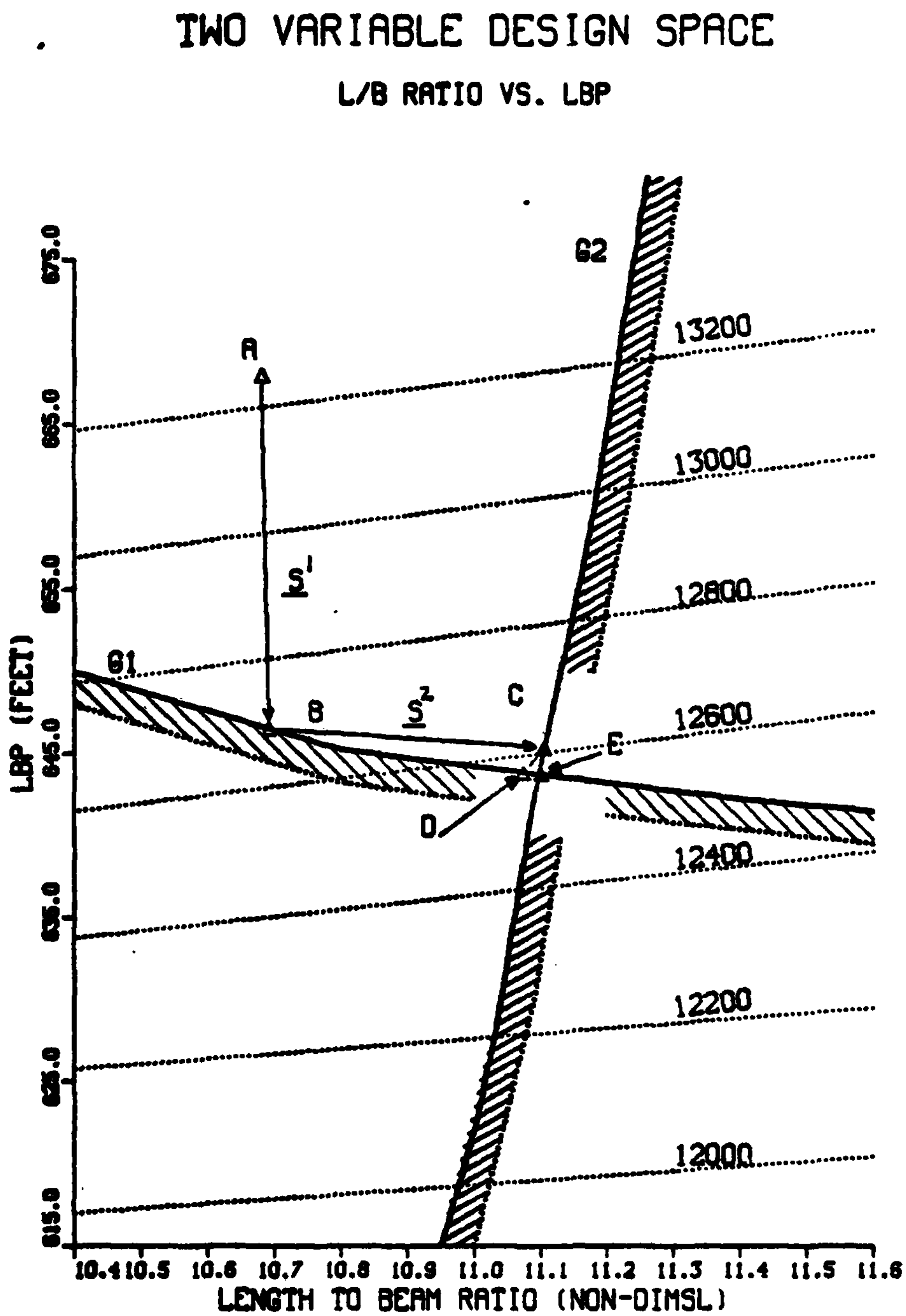


Figure 2.1 Two Variable Design Space Example.

direction or some constraint boundary is encountered. A one-dimensional search is done in the direction $\underline{S}$ to determine the appropriate value for α^* so that an improved design can be achieved at point B. No further improvement can be achieved in this direction as the constraint G1 is encountered. Now a search direction must be found which will reduce the objective function without violating the displacement constraint, G1. Such a direction can be found by solving a linear programming subproblem with a single quadratic constraint. The details of such a problem are given in [Ref. 9] and [Ref. 11].

The goal of the subproblem is to find a search direction which will minimize the objective and yet not violate any constraints. If no such direction exists, then the current point is considered optimal or at least a local minimum. In the example, a direction can be found and the design proceeds from point B to point C where constraint G2 is encountered. The subprogram is solved again, resulting in a further reduction of the objective and an active constraint at point D. From point D, the one-dimensional search yields a solution at point E in Figure 2.1 which is the vertex of the two constraints. Once again the design variables are perturbed to obtain the gradient of the objective and both active constraints, thus the linear subproblem is solved. This time the solution is zero, indicating the optimal design has been achieved. Point E is clearly the optimum since no direction exists at this point which will reduce the objective function any further without violating one or both of the constraints.

For preliminary designs, it is often quite possible for the initial design to start in the infeasible region. Logic is included in the optimization program so that if this situation occurs, a direction vector $\underline{S}$ is obtained which will point toward the feasible region with a minimal increase in the objective function.

The methods used in this example are, in principle, directly extendable to the n-dimensional problem. Also, additional constraints can be imposed without increasing the complexity of the design process. For the Reed/COPES/CONMIN system it appears that the optimizer is comprehensive enough to easily handle all the design variables and constraints the designer could possibly want without any significant increase in computational time. Also, ship designs are noted for their condition of flat-laxity in terms of similar ships having similar dimensions and design parameters. This condition increases the probability of the optimizer achieving an optimal solution.

III. SHIP SYNTHESIS MODELS

A. HISTORY

As stated in Chapter I, a synthesis model is an engineering procedure which converts a specific set of performance requirements into the physical description of a ship which satisfies those requirements. There have been several synthesis models available for the naval ship designer since the late 1960's. Two of these models, currently used by the Navy, were the primary reference sources for the development of the Reed model used in this thesis. They are the U.S. Navy's destroyer model DD07 [Ref. 2] and Center for Naval Analysis Conceptual Design of Ships Model (CODESHIP) [Ref. 3]. A third model developed by the Coast Guard patterned primarily after the DD07 synthesis model was also used as a reference in constructing the Reed model [Ref. 12].

The destroyer model, DD07, was first developed in the 1960's and has been continually updated since then. This model was developed to represent only U.S. destroyer type ships.

The general framework for the method of analysis used in the CODESHIP model was also conceived in the sixties at the Center for Naval Analysis. CODESHIP was created to model ships which range in size from patrol craft to aircraft carriers. Because of the wide range of ship types in the data base, the CODESHIP model is not as accurate in predicting actual values as a model designed for a specific ship type, e.g. DD07 for surface combatants. The greatest asset CODESHIP provided in the development of the Reed model was its highly versatile input and output features.

B. REED MODEL DESCRIPTION

The Reed model used in this thesis was developed to provide a more versatile synthesis model than CODESHIP and DD07. Specifically, the model allows the designer to control the design standards and practices to which the ship is designed and to observe the resulting ship characteristics from a more functional level than existing models provided. Although based on standard calculations derived from functionally similar ships, the designer is still given the opportunity to be flexible in his selection of values reflecting different design standards and practices. The resulting synthesis model enables the user to explore a significantly greater number of design options and provides a greater freedom than previously allowed with manual calculations or even other synthesis models.

The Reed model has been used at the Massachusetts Institute of Technology since 1976. The primary purpose for the use there has been academic, although the results the model produces are certainly consistent with current design practices. In addition to its applications during conceptual design, the Reed model can also be used during later design phases as a design aid for updating predictions, and as a tool for conducting comparative naval architecture studies.

The Reed model is limited to surface displacement ships configured as naval combatants. The data base was created using ships which ranged in full load displacement from 1,770 to 16,294 tons and which had lengths between perpendiculars of 301 to 700 feet. No cost characteristics are calculated by the model.

C. REED MODEL ORGANIZATION

The Reed model, as it was received, is controlled by a main program. The main program calls the various subroutines as required to calculate information for output and to let program execution proceed. Program control organization is shown in Figure 3.1.

The logical program organization or program flow is shown in Figure 3.2. The program begins by reading the following data:

1. Names of items to be printed in the output,
2. Residual resistance coefficient values taken from the Taylor Standard Series [Ref. 13], and
3. Data for all the items in the payload shopping list.

If more than one ship is to be run, the specifications for the second ship are then read using subroutine DATA2.

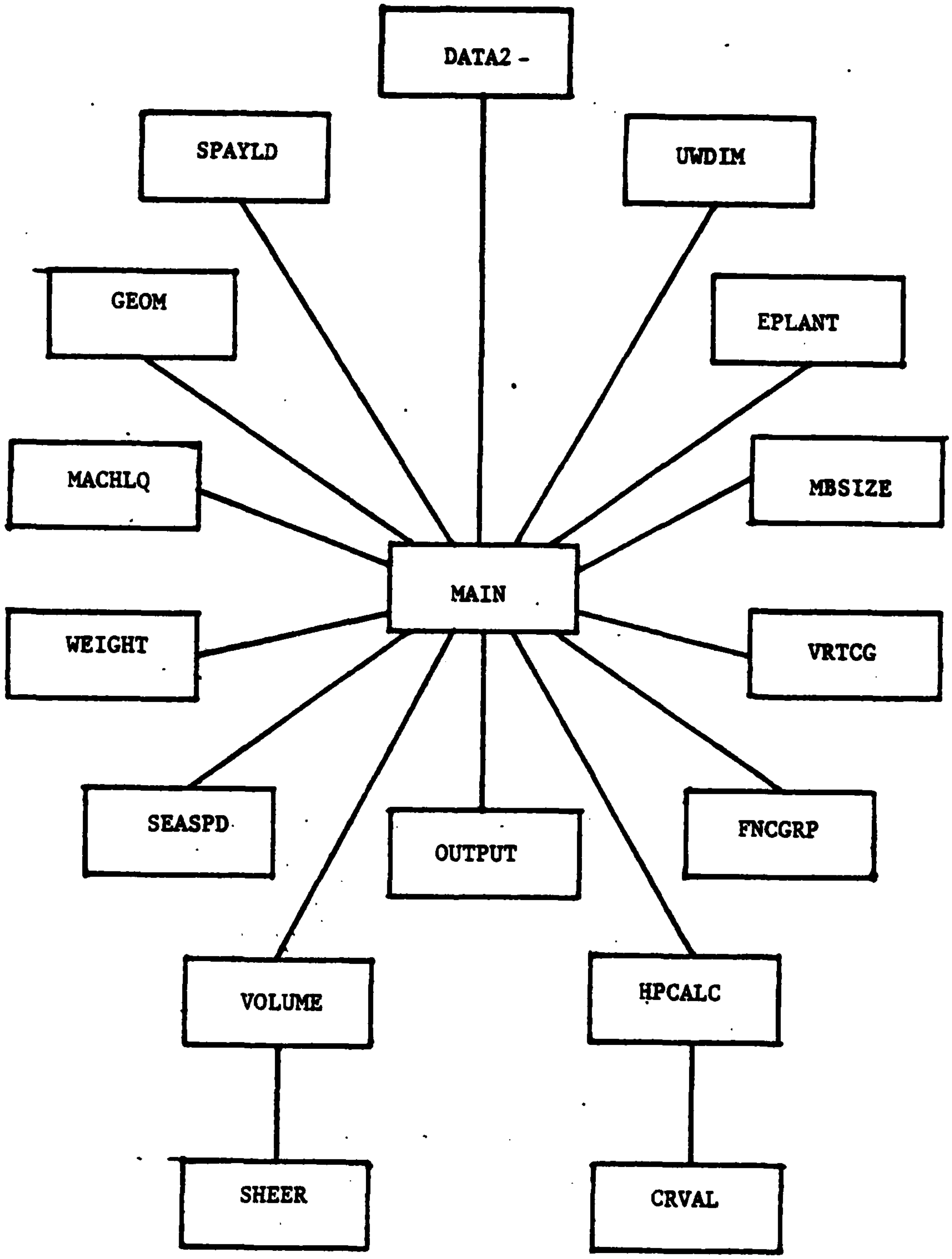


Figure 3.1 Reed Model Program Organization.

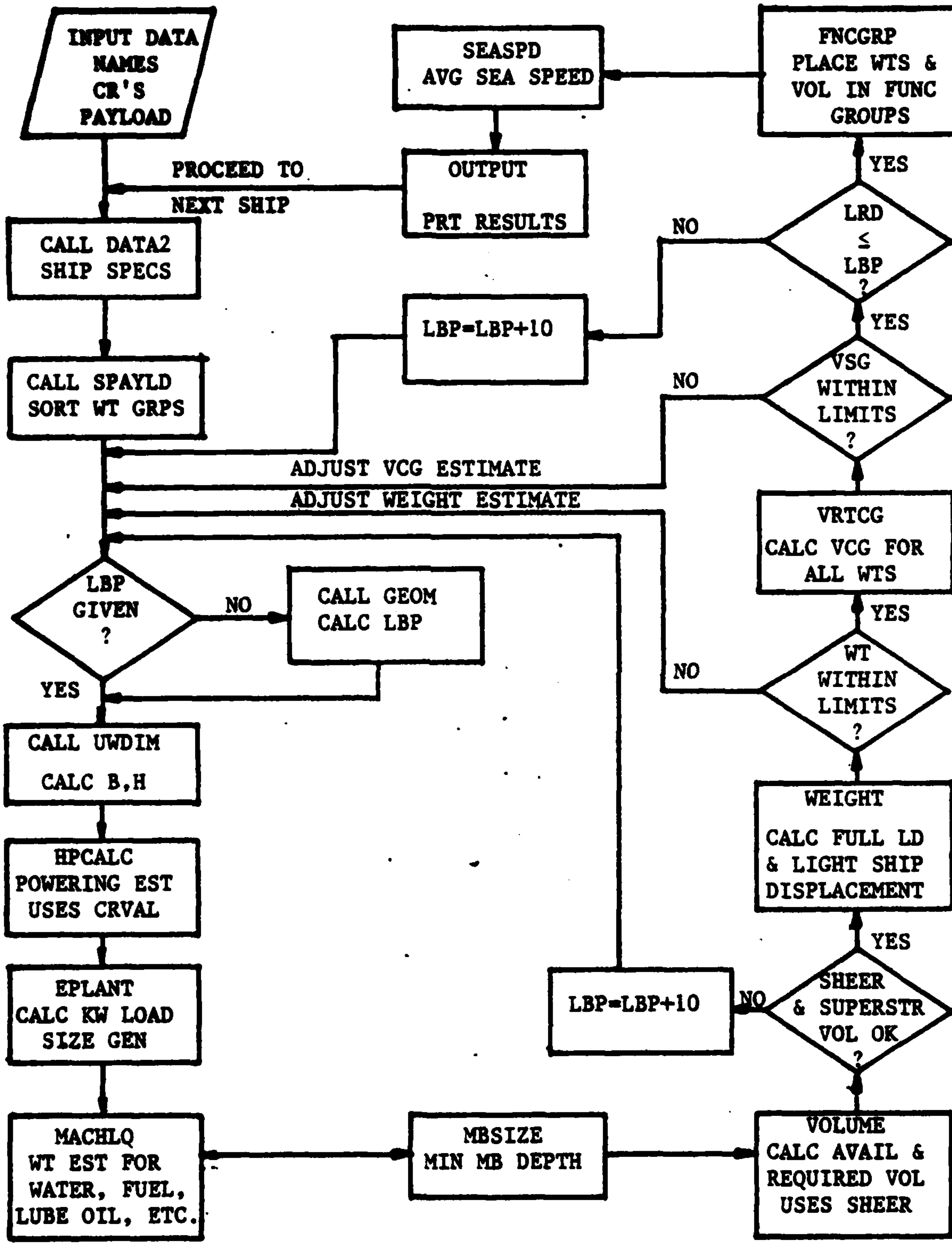


Figure 3.2 Logical Program Organization.

Following this, the main program calls subroutine SPAYLD which is used to sort the weights of the payload items input and place them in the proper BSCI[1] weight groups. The value of WPAYIN, the total weight of payload input, is calculated and is used for the initial estimation of the full load displacement, should the length between perpendiculars (LBP) not be specified.

Next, the underwater hull shape is determined in the subroutine UWDIM. Values input to this subroutine are LBP,[2] free surface effect correction, Cp, Cx, GM/B, as well as the estimated KG and full load displacement. Output values from UWDIM are beam, draft, and Cwp.

If the length between perpendiculars LBP, is not specified at the start of the program, it is calculated in the subroutine GEOM prior to transferring control to UWDIM. This feature was removed from the synthesis model when it was coupled to COPES/CONMIN and it is assumed that the designer will have a reasonable estimate of LBP to begin the design.

Subroutine HPCALC is called to determine either the maximum sustained speed, VSUS, or the horsepower required at

---

[1]BSCI--"Bureau of Ships Consolidated Index of Drawings, Materials, and Services, Related to Construction and Conversion" of February 1965 and given in an appendix to Reference [14].

[2]Variables used in this thesis are described in Appendix C, Nomenclature.

the maximum sustained speed, SHP. If VSUS is input, the HPCALC routine along with the CRVAL subroutine generate an estimate of the horsepower required to maintain the maximum sustained speed. If SHP is input, HPCALC is used to compute a corresponding VSUS through an iterative procedure. HPCALC is called a second time to find the horsepower required at endurance speed. Endurance speed must be input.

Next, the subroutine EPLANT is called to calculate cruise, battle, and 24 hour average electric loads. Based on these estimates, the required number and size of the generators is determined. The electric loads and number of generators may be input, in which case these calculations will be by-passed.

Subroutine MACHLQ is called to calculate machinery and other related liquid weights. Liquids considered machinery related are potable water, reserve feed water, lube oil, fuel oil, and diesel oil. These calculations are based on the military requirements of the ship. Liquid weights are used to determine the required tankage volume.

MBSIZE determines the minimum depth of the machinery box which then corresponds to the minimum depth the ship must have amidships.

The next step is to calculate the required and available volumes for the ship and to achieve a balance between the two. This is done in the VOLUME and SHEER subroutines. As most naval combatants are now considered volume-limited, this is one of the most important aspects of the synthesis model.

The subroutine WEIGHT next determines the weights of all light ship and load items that are not payload-related. Full load displacement is calculated and it is then compared to the estimated value of displacement used to proceed this far in the program. If the two values are not within a specified tolerance, say 10 tons, the program reestimates displacement and iterates through all previous calculations. If the two values are within the specified tolerance, then the program continues on and compares the estimated and calculated values for the vertical center of gravity. In a similar manner, if the two values are within a specified tolerance, the program continues; if not, there is a new estimate generated and an iterative process proceeds until agreement is made. The vertical center of gravity is calculated in the subroutine VRTCG. If after a specified number of iterations, the comparisons for either displacement or vertical center of gravity are still not within the desired tolerances, the program prints an error message and terminates.

At this point in the synthesis model, all essential calculations have been completed and the principal characteristics and coefficients of the "feasible" design have been determined. FNCGRP is called to place weights and volumes into their proper functional groupings as listed in Appendix C of Reference [15]. These groupings form a major portion of the detailed output from the synthesis model.

The subroutine SEASPD calculates the speed the vessel is able to sustain in the North Atlantic Ocean in order that relative comparisons may be made of seakeeping characteristics.

The final subroutine is OUTPUT which prints the input specifications first, followed by the payload items input, summary of results from the final estimate of principal characteristics, functional group results, BSCI weight listings, and the functional electrical loads. The OUTPUT routine is very versatile in that any portion of the above output may be supressed or printed as the designer desires.

The above descriptions of the subroutines in the Reed synthesis model were designed to give the reader a general idea of how the program functions. The routines are described in much greater detail in [Ref. 3] and [Ref. 12]. The reader is encouraged to use these to make changes to the synthesis model or to gain a greater understanding of the program.

IV. COUPLING COPES/CONMIN AND THE REED MODEL

A. SELECTION OF DESIGN VARIABLES AND OBJECTIVE FUNCTIONS

One of the most important decisions in the development of the synthesis system is the choice of parameters to be used as design variables and objective functions. Review of current literature pertaining to preliminary design synthesis and optimization models, [Ref. 16-22], produced two different approaches to the problem. Nowacki [Ref. 16], worked with a single economic measure of merit (required freight rate) for the objective function of tanker designs and used speed/length ratio, B/T, L/B, Cb, and L/D as design variables. Mandel and Leopold [Ref. 17], recommended that for tanker or general cargo vessels a three-term weighted optimization criterion be used as the objective function. One term would be an economic criterion, the second term would take into account payload weight and the third term payload volume. Both payload terms are based on the owner's requirements. They selected displacement, Cp, speed/length ratio, B/T and L/D as the five design variables. Leopold and Reuter [Ref. 7], carried the multiple term optimization criterion a step further in their paper on design methods and philosophies for the FDL, LHA, and DD-963. Here they proposed an optimization criterion containing seven terms; cost, effectiveness, flexibility, availability, habitability, vulnerability, survivability, innovation, and nonobsolesence. Through this was never expressed as a mathematical function, it indicates the attempts to quantify key parameters in optimization methods.

From the summary presented by Nowacki [Ref. 16], it was apparent that some sort of economic measure of merit was the dominant objective function for commercial vessels. This is to be expected as profit is the motivation for construction and operation of a commercial vessel. Military vessels, specifically naval combatants, are not required to be profitable. Their mission is to deliver a military payload at a specified time and place and to provide military services when and where needed. Therefore, economic criteria, though certainly important, are not as vital to the designer as are the ability of the vessel to carry its military payload and perform its military duties.

In recent years, the naval combatant has become area/volume critical in nature. Accordingly, this has become the dominant factor in establishing the ship size. Taking into account the fact that volume is critical and that there exists an implicit relationship between volume and displacement, it was decided that displacement would be the most representative variable for the objective function. According to Manning [Ref. 22: p. 101], using least displacement as a measure of merit for the military vessel gives the highest ratio of military payload to displacement. This selection is further supported by the fact that total ship cost can be roughly estimated by the displacement.

The design variables selected for the Reed/COPES/CONMIN system were LBP, L/B, B/H, Cp, and Cx. These variables were selected by running sensitivity studies on displacement with respect to each design variable over a specified range of values. The payload and all other factors remained constant in this analysis as each design variable was tested. It is felt that these variables are the most significant in the determination of the principal characteristics and provide the designer with considerable flexibility for innovation.

It should be noted that any one of the design variables may be designated as the objective function so that comparisons of designs with, say displacement as the objective function can be made with designs that may have used LBP or Cp as the objective function. Also, should the designer desire, he may designate any of the other variables used in the Reed model as objective functions and/or design variables. It is only necessary to ensure that the variable is listed in the GLOBCM statement.

B. THE GLOBCM STATEMENT

The GLOBCM COMMON statement is a requirement of the COPES/CONMIN program. All variables used as objective functions, constraints and/or design variables must be listed in the common statement and the statement must appear in each subroutine the variable is used in. It is used by the optimizer as a catalog to identify where the design variables, objective function(s), and constraints are, and what purpose they fulfill. In the Reed/COPES/CONMIN system the GLOBCM statement has DISPFL, full load displacement, and a 2500 element vector labelled $\underline{S}$ as entries. The $\underline{S}$ vector contains input parameters, payload items and quantities, BSCI weight group data, BSCI vertical center of gravity data, volume values for payload and input items, electrical load values, miscellaneous parameters and coefficients, and space for inputting any special payload items not included in the standard payload shopping list. DISPFL was added to GLOBCM because it was not in the $\underline{S}$ vector. All of the design variables used in this thesis are contained in the $\underline{S}$ vector. The element numbers are listed in Appendix B.

C. CONSTRAINTS

In order to couple the Reed model with COPES/CONMIN, it was necessary to make several major modifications to the synthesis program. In addition to the modifications, all default parameters were replaced by constraints.

The main program in the Reed model had two iterative loops which were removed. The first loop occurred after all the weight calculations had been done. The purpose of this loop was to check to see if the calculated value for the full load displacement equalled the estimated value for displacement within a user specified tolerance. If the difference was not within the tolerance, the program would estimate a new value for displacement, calculate a new full load displacement and make the check again. The iteration continued until the check was satisfied or a maximum number of iterations was achieved at which time an error message was printed and the program terminated. This loop was replaced with a single constraint. The quotient of the calculated displacement to the estimated displacement minus one is required to be less than or equal to zero.

$$G1 = DISPFL/DPTRY - 1.0 \leq 0.0$$

The second loop in the main program is exactly the same as the first except that it compares the initial and calculated values for the vertical center of gravity (VCG). This loop was replaced with a constraint similar to the first using calculated VCG and estimated VCG.

$$G2 = CGFLD/KGTRY - 1.0 \leq 0.0$$

In the subroutine UWDIM, two default values were replaced by constraints. These defaults required that the beam to draft ratio be greater than two and less than four in order to use the residual resistance coefficients in the Taylor Standard Series tables. The constraints are:

$$G3 = 2.0/BTR - 1.0 \leq 0.0$$

$$G4 = BTR/4.0 - 1.0 \leq 0.0$$

A third constraint is added here to satisfy a stability criterion. A variable R is introduced in the subroutine with a value of:

$$R = KB + BM - GM - KG - FSCORR$$

When R = 0, the stability criteria is just satisfied, therefore the constraint

$$G5 = -R/10 \leq 0.0$$

must be less than or equal to zero to ensure a stable design. R is divided by ten as a means of scaling in order that G5 will have the same relative magnitude as the other constraints.

Subroutines HPCALC and CRVAL have the greatest number of constraints in them due to the limitations of the Taylor Standard Series power estimation. The maximum ranges for the input variables that are accepted are listed below:

$$2.0 \leq B/H \leq 4.0$$

$$0.48 \leq Cp \leq 0.70$$

$$0.001 \leq Cv \leq 0.006 \quad \text{for} \quad 0.5 \leq V/\sqrt{L} \leq 1.3$$

$$0.001 \leq Cv \leq 0.003 \quad \text{for} \quad 0.5 \leq V/\sqrt{L} \leq 2.0$$

These are translated into the following constraints:

$$G3 = 2.0/BTR - 1.0 \leq 0.0$$

$$G4 = BTR/4.0 - 1.0 \leq 0.0$$

$$G6 = 0.48/Cp - 1.0 \leq 0.0$$

$$G7 = Cp/0.70 - 1.0 \leq 0.0$$

$$G8 = 0.5/SLRAT - 1.0 \leq 0.0$$

$$XX = SLRAT/1.3 - 1.0 \leq 0.0$$

$$G9 = 0.001/Cv - 1.0 \leq 0.0$$

$$G10 = Cv/0.006 - 1.0 \leq 0.0$$

$$G11 = SLRAT/2.0 - 1.0 \leq 0.0$$

$$XXX = Cv/0.003 - 1.0 \leq 0.0$$

$$G12 = -1.0$$

IF ((XX .GT. 0.0) .and. (XXX .GT. 0.0)) G12 = 1.0

The remaining constraints appear in the subroutines VOLUME and SHEER. In the routine VOLUME, there was a loop which iterated to match the total estimated ship volume with the total calculated ship volume by increasing the deck house size or by adding a raised deck to the ship. This loop was replaced by the following constraint:

$$G13 = RSSV/DHV - 1.0 \leq 0.0$$

D. FURTHER PROGRAM MODIFICATIONS

As stated previously, it is necessary for the operation of COPES/CONMIN to have the analysis portion (i.e. the synthesis model) of the program in subroutine form. The subroutine is called ANALIZ and has the calling parameter ICALC. When ICALC = 1, the data for the operation of COPES/CONMIN is read in. For ICALC = 2, all the analysis calculations are performed by the optimizer, and when ICALC = 3, the final results are printed out. Lines were inserted into the Reed program at the appropriate points to facilitate the operation of ANALIZ as stated above.

In the stand alone form, the Reed model is capable of analyzing one or more ships as the designer desires. The

Reed/COPES/CONMIN system will process only one design at a time. This is not considered a problem because changes to the input data files are made easily and the computational time for each run is short.

Subroutine GEOM was deleted from the program. This subroutine calculated a LBP based on the weight of the payload when no LBP was input to the program. It is felt that the designer can estimate a LBP which the optimizer can start with and proceed to an optimum design.

Extensive changes were made in the subroutine SHEER. It is assumed that the minimum depth amidships is the same or greater than the depth of the machinery box. This value is compared to LBP/16 and the largest of the two values is selected as the depth amidships. Having satisfied this criterion, an iterative routine was used to estimate the freeboard at the forward and after perpendiculars. The iterations were based on an assumption that sheer fractions of 0.01 and 0.03 forward and 0.001 and 0.0075 aft were esthetically and structurally satisfactory. If these fractions could not be met, the program printed an error message and terminated. This was changed so that when the depth amidships was established, the freeboard at the forward and after perpendiculars were assigned as:

$$F0 = (0.03*LBP + D10) - H$$

$$F20 = (0.0075*LBP + D10) - H$$

respectively. These values are comparable to those produced by the Reed model alone and simplify the design process. Should different values be desired, it is only necessary to change the two equations.

The Reed model was written giving the program the option to add a raised deck to the hull if the total required arrangements volume was greater than the total available arrangements volume. The option was deleted from the program and replaced by constraint G13. Should the designer wish to have a raised deck design, the calculations can be replaced but care must be taken to ensure that no design variables are altered by an internal loop, thereby short-cutting the optimizer.

There were numerous small changes made to the Reed model to make the coupling of the two programs more efficient. They are, however, insignificant and will not be documented here.

V. DESIGN EXAMPLE

A. INTRODUCTION

This chapter will present an example using the Reed/COPES/CONMIN synthesis system. It is assumed that the user is familiar with Appendix A, the User's Manual, of Reference [3] and the data description and input format for COPES presented in Reference [4]. The logic for the selection of the objective function, design variables, and constraints will be discussed as the method of problem presentation.

B. EXAMPLE DESCRIPTION

All designs start with the owner's requirements or in military terms, the Operational Requirements (OR). This delineates the military payload and mission to be accomplished over the lifetime of the ship. From the OR, the designer is able to select those parameters which will help him make an initial estimate of the ship, i.e. start the conceptual design phase. In this example, the operational requirements will be similar to those of an AAW/ASW capable escort ship like the Oliver Hazard Perry class frigate.

Mission requirements specified in the OR will generally dictate the type of equipment required in the design. Table 21 of Appendix A, [Ref. 3] can be used like a shopping list at this point. The designer can pick and choose the weapons systems, electronics suites, ammunition load-outs, preliminary liquid loads, and aviation items he desires to use. This list of items technically defines the military payload hardware. Additional men and materials are required to support and operate the payload. A partial list of payload items selected for this design example are listed in Table I.

TABLE I

Military Payload List

FF(ASW command and control) Radio communications

SPS-49 Radar w/IFF

SPS-55 Radar w/IFF

SQS-56 Sonar

FF/FFG Basic ECM suite

ASWC and C-FF-2C,7D Electronic Tactical Data Systems

Vulcan/Phalanx on 01Lv

76mm Gun, 01Lv

Mk-92 CIWS/STIR

800 3"/50 rounds

10000 20mm rounds

Mk-13 Tartar Missile Launcher w/40 Missiles

Mk-32 Triple Torpedo Tubes P/S w/24 Torpedos

Harpoon FCS

1 Lamps MK III Helo with support

Having made these decisions, which incidentally may have taken many, many weeks, the designer then proceeds to select those parameters which define the ship form. Here the designer has slightly more freedom than with the payload entries. It is possible to run systems trade-off studies comparing different propulsion plants, hull materials, and design standards. Items in this category come from Table 12 of Appendix A, Reference [3]. They are such things as type of propulsion plant desired, number of propellers, the endurance range and speed, geometric parameters such as length, L/B, B/H, coefficients of form, electric plant parameters, and crew accommodations.

Up to this point in the process the synthesis model and the Reed/COPES/CONMIN system are essentially the same. To continue further with the synthesis model will require that relatively accurate values of the ship specifications be input. The Reed/COPES/CONMIN system on the other hand allows any starting value that is within the specified limits of the design variables. That is, it is possible to start with an entirely infeasible design and yet end up with a feasible design after optimization. This is one of the strengths of the synthesis system.

From the specifications identified in this group of parameters, the designer selects the objective function(s). design variables, and constraints. He may also develop a function he considers viable as an objective function and insert it into the synthesis model. Table II lists those variables which must be input in the problem specifications.

TABLE II

Ship Specifications List

Sustained Speed	Emergency Electrical Plant Type
Endurance Speed	Type of ship heating
Endurance Range	Fin Stabilizers (Y/N)
LBP	Officers' Accommodations
L/B	CPO Accommodations
B/H	Enlisted Accommodations
Cp	Flag Accommodations
Cx	Troop Accommodations
Propulsion Plt Type	Passenger Accommodations
Sustained SHP	Basic Hull Material
Number of Main Engines	Basic Superstructure Material
Number of Shafts	GM/B Stability Value
Propeller Type	Design Margin
Shaft Type	Free Surface Correction
Ship Service Elect Plt Type	Passageway Type (P/S or CL)

C. PARAMETER DESCRIPTIONS

Selection of the objective function in this example is based on the comments of Manning in Reference [22] and Saunders in Reference [23]. From Manning:

"There are two criteria which may be used to measure the excellence of a design. The one usually applied

> to warships is that the best design is the one of least displacement. This design gives the highest value of the ratio of military load to displacement."

Accordingly, it was decided to use displacement (DISPFL) as the objective function. The intent will be to minimize the displacement required to support the specified payload items and to use this as an indicator of relative size and cost when compared with other designs. DISPFL is listed in global location one in the GLOBCM statement and identified as the objective function to be minimized in data block E.

Five parameters have been selected as independent design variables. The first is the length between perpendiculars. Justification for this selection is well stated by Saunders on page 343 of Reference [23].

> "In the group of underwater form coefficients and parameters developed through the years, the ship length L logically appears as one of the principal dimensions. It is related directly and indirectly to the beam, the draft, the displacement weight, the displacement volume, and to many other factors."

Length is designated by LBP and is in global location 5.

The second design variable is the ratio of length to beam (L/B). Although the L/B ratio can be related to the prismatic coefficient, Cp, and the B/H ratio and is therefore not strictly independent, it has still been selected as a design variable. Motivation for this selection comes from the methods used in the Reed synthesis model to determine the beam and initial powering estimates. It may also be used as a weak measure of turning characteristics [Ref. 23: p. 352] and course tracking when comparing designs. The L/B ratio is in global location 6.

The beam to draft ratio (B/H) is the third design variable. This ratio is used to determine the ship's draft and is used in estimating horsepower requirements. It is stored in global location 7.

The fourth design variable is the prismatic coefficient, Cp. This coefficient indicates the fullness of the underwater hull and is therefore indirectly related to displacement. A small Cp means the ship has fine ends and a full midbody. A large Cp means full or blunt ends similar to a tanker or barge. Cp is in global location 8.

The last design variable is the midship section coefficient. This relates the area of the midship section to a rectangle whose sides are equal to the draft and the beam at that section. It is used in estimating the hull strength and initial power requirements. It is located in global location 9.

With the design variables identified it is now necessary to specify their global location in the GLOBCM statement and to specify any side constraints that may be imposed on the design variables. COPES data block F is used to specify side constraints and data block G provides COPES with the design variable number and global location. Design variables 1-5 are located in global locations 5-9. Table III presents the side constraints that are imposed as a result of the restricted data base used in the synthesis system.

TABLE III

Side Constraints on Design Variables

PARAMETER	LOWER BOUND	UPPER BOUND
LBP	300 ft.	700 ft.
L/B	7.00	12.0
B/H	2.00	4.00
Cp	0.50	0.90
Cx	0.75	0.90

D. CONSTRAINT PHILOSOPHY

It is worthy to philosophize a bit at this point about side constraints and about constraints in general. The constraints imposed on the design variables in this example are used to maintain the design within the specifications of the synthesis model data base. Extrapolation of designs based on data and on empirical relationships derived for the model is considered risky at best and would probably be better accomplished with manual calculations. Further, the design is constrained by the limitations of the residual resistance coefficient values of the Taylor Standard Series used in the horsepower estimations. The obvious point to be made is that as the synthesis system is constrained, so the designer is constrained. He cannot develop feasibility studies for aircraft carriers or air cushion vehicles with a destroyer synthesis model. Also, he cannot justifiably try radically different design concepts for a destroyer if the concepts render the data base invalid. The manner in which the designer attacks this problem is an indication of his creativity and foresight. Improvement in the synthesis system is certainly an option to help eliminate some of the constraints required. For this synthesis model, the resistance coefficients could be expanded through the testing of ship models whose size is larger than those used to obtain the Taylor Standard Series data. This is an expensive and time consuming process and must be considered carefully in light of what is desired from the synthesis system. Again, the designer's ability to use the synthesis system as a tool is the key to his success.

Hypothetically, a synthesis system should be designed to model real world conditions and require only those constraints imposed by the real world, i.e. no negative areas or plate thicknesses. The Reed model is considered an excellent synthesis model and requires relatively few constraints to maintain real world conditions. In some problems, it is necessary to use constraints to prevent the optimizer from exploiting a weakness or undesirable trend in the analysis portion of the code. This is not the case with this system and this point is mentioned only in passing should the designer desire to make significant alterations to the synthesis model.

Having briefly discussed constraints, it is now appropriate to identify them specifically and illustrate how they are delineated in the COPES data cards. In Chapter IV thirteen constraints (G1-G13) were proposed to replace several iterative loops and termination criteria built into the original Reed model. All of these constraints are satisfied when they have a value less than or equal to zero. These constraints were assigned unused numbers in the $\underline{S}$ vector and occupy global locations 77 through 89. All of the constraints together form a constraint set as they are all of the same magnitude and are satisfied by meeting the same criteria. Data block H is used to specify the number of constraint sets, in this case one. Data block I identifies the first and last global locations of the constraint set, 77 and 89, and specifies the upper and lower bounds and any scaling desired for the constraints. For this example, the upper bound is zero, the lower bound is numerically minus infinity and the scaling value is defaulted to 0.1.

Should any further constraints be desired the designer need only identify them in the $\underline{S}$ vector, specify their global locations, their upper and lower limits and any scaling necessary via the appropriate data blocks. Table IV is a listing of the COPES/CONMIN data blocks illustrating the entries described above.

TABLE IV

COPES/CONMIN Data Blocks

```
$ BLOCK A
OPTIMIZED VERSION OF THE FFG-7
$ BLOCK B
2,5
$ BLOCK C
3,,,10,,,50
$ BLOCK D
0.,,-0.02
0.,
$ BLOCK E
0,1,-1.0
$ BLOCK F
$             LBP
300.0,700.0
$             L/B
7.0,12.0
$             B/H
2.0,4.0
$             Cp
0.50,0.90
$             Cx
0.75,0.90
$ BLOCK G
1,5
2,6
3,7
4,8
5,9
$ BLOCK H
1,
$ BLOCK I
77,89
-1.0E+15,0.0,0.0,0.0
$ BLOCK V
END
```

E. EXAMPLE RESULTS

The results of this example are best presented in tabular form. Table V illustrates the initial and the optimum values for the objective function, design variables, and constraints. Note that the initial design was infeasible with constraints G1, G2, and G13 violated. Physically, this meant that the initial design was unstable (G2) as a result of insufficient volume (G13) and displacement (G1) to support the required payload. The optimizer increased the displacement by manipulating the design variables until all the constraints were satisfied. Constraint G13 is indicated as active, which means that it lies within a specified tolerance value of the constraint zero value boundary.

TABLE V

Initial and Optimum Parameter Values

PARAMETER	INITIAL VALUE	OPTIMUM VALUE
Objective Function		
DISPFL	2865.05	3511.68
Design Variables		
LBP	300.0	394.38
L/B	9.07	8.76
B/H	3.14	3.32
Cp	0.59	0.50[1]
Cx	0.75	0.77
Constraints		
G1	6.22[2]	-0.015
G2	1.85[2]	-0.068
G3	-3.63	-0.398
G4	-2.15	-0.168
G5	-7.85	-2.062
G6	-1.90	-0.040
G7	-1.52	-0.285
G8	-5.66	-0.503
G9	-5.57	-0.501
G10	-6.23	-0.665
G11	-4.22	-0.496
G12	-10.0	-1.000
G13	11.86[2]	-0.0006[3]

[1]lower bound of design variable
[2]violated constraint
[3]active constraint

Figure 5.1 is a graph of the objective function versus the number of iterations required to reach the optimum. It can be seen that the optimizer is indeed efficient and in this example arrived at a value very near the optimum in five iterations. The remaining four iterations were done simply to "fine tune" the value of the objective function. The average run time for this example was approximately two and one half CPU second on an IBM 3033 system. The entire example with values for all the parameters at each iteration is provided in Appendix A.

Comparison of the data arrived at in this example using the general specifications of the FFG-7 were very good. Displacement was within five percent of the actual ship displacement. Most of the other parameters were within at least ten percent of the actual and could have been made more accurate by greater detail in the problem specifications.

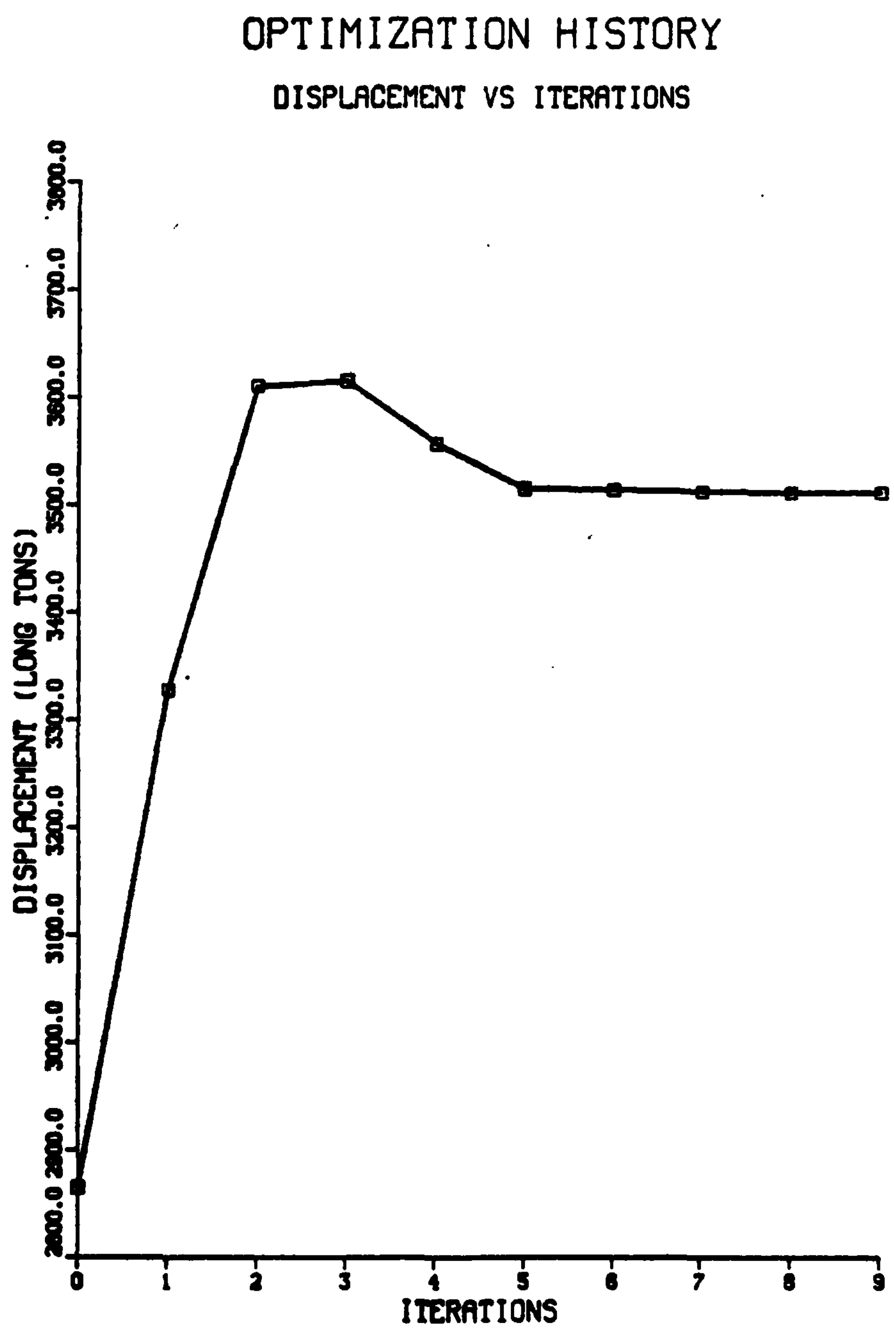


Figure 5.1 Objective Function vs Iterations.

VI. SYNTHESIS SYSTEM APPLICATION

A. DESIGN EXAMPLES USING DIFFERENT OBJECTIVE FUNCTIONS

The Reed/COPES/CONMIN system is extremely versatile in application. The designer is able to optimize a design for a specific payload with respect to a larger number of important and different parameters. One example has been shown using DISPFL as the objective. LBP could be used as an objective function. Based on the relationship between length and displacement, the designer would minimize length. Another parameter that could be used is SHP/TON. The designer would maximize this function in an effort to get the most horsepower in the smallest ship. Table VI presents several examples which were optimized with respect to different objective functions. The baseline ship is a close approximation to the FFG-7 ocean escort. The same design variables were used in all cases. The constraints were not altered and the payload was also maintained constant. Data produced by the original Reed synthesis model is included for comparison.

Several general comments can be made from an overall view of the data. First, is that there appears to be a rather well defined optimum ship regardless of the objective function. This supports the so called "flatlaxity" of ship designs [Ref. 16: p. 105] which allows the optimum ship to

TABLE VI

Comparison of Different Designs

PARAMETER	MIN DISPFL	MIN LBP	MAX SHP/TON	MAX FLD DEN	MAX WPA/FLD	MAX VPA/VOL	FFG-7 REED
LBP	394.39	394.26	394.38	502.57	394.41	394.38	418.00
BEAM	45.03	47.22	45.02	46.27	45.17	43.02	43.06
Cp	0.50	0.50	0.50	0.61	0.50	0.50	0.59
Cx	0.77	0.79	0.77	0.75	0.77	0.76	0.75
DRAFT	13.54	14.78	13.48	[illegible]	13.61	14.52	15.45
L/B	8.76	8.35	8.76	10.86	8.73	9.17	9.71
B/H	3.33	3.20	3.33	2.19	3.32	2.96	2.79
Vsus	28.56	28.57	28.56	29.04	28.56	28.65	30.83
DISPFL	3511	3514	3511	4754	3512	3513	3575
FLD DENS	15.62	15.63	15.62	19.45	15.62	15.63	15.81
WPAY/FLD	0.11	0.11	0.11	0.08	0.11	0.11	0.10
VPAY/VOL	0.20	0.20	0.20	0.19	0.20	0.20	0.20
SHP/TON	11.39	11.38	11.39	8.41	11.39	11.39	11.19

have slightly different principal dimensions yet remain optimum or very nearly so. The second comment is on the consistency of the synthesis system. When compared with the original synthesis model results, the optimized results accurately reflect the effect of changing the design variables to satisfy the design requirements. Additionally, specific parameters demonstrate excellent repeatability from design to design. This indicates that the final design is the optimum and not a relative maximum or minimum point in the design hyperspace.

The above comments are well supported by the data in Table VII. This data represents four designs: one starting with LBP equal to 300 feet, one with LBP equal to 500 feet, one with LBP equal to 700 feet, and a fourth design using parameters from the optimum design achieved with LBP equal to 300 feet. All cases were run with DISPFL as the objective function and all other parameters held constant run to run. Excellent repeatability and a well defined optimum are demonstrated.

A third and interesting point to note is that not all selected objective functions or variables are affected by the optimization process. Note the value of VPAY/VOL (Volume Payload/Total Volume). To bring about a change in this variable, the synthesis model msut be changed. This represents a change in the design standards or the designer's

TABLE VII

Repeatability of Data

PARAMETER	INIT 300'	OPT 300'	INIT 500'	OPT 500'	INIT 700'	OPT 700'	OPT 394'
LBP	300.00	394.39	500.00	394.53	700.00	394.45	394.35
BEAM	33.08	45.03	55.13	43.21	77.18	42.41	43.72
DRAFT	10.53	13.54	17.56	13.61	24.58	13.59	13.03
Cp	0.59	0.50	0.59	0.50	0.59	0.53	0.50
Cx	0.75	0.77	0.75	0.75	0.75	0.75	0.80
B/H	3.14	3.33	3.14	3.17	3.14	3.12	3.36
L/B	9.07	8.76	9.07	9.13	9.07	9.30	9.02
Vsus	34.06	28.56	28.87	28.60	25.88	29.09	28.55
DISPFL	2865	3511	4899	3512	9766	3523	3510
FLD DENS	13.40	15.62	16.85	15.52	12.35	15.66	15.61
SHP/TON	13.96	11.39	8.61	11.39	4.10	11.35	11.39

philosophy. The ability to be able to make such alterations is an indication of the strength and flexibility of the synthesis model. A particularly good example of another such change is with regard to habitability requirements, i.e. ft^3/man. Current designs have shown an increasingly large portion of internal volume devoted to habitability. It is possible through the use of scale factors to modify current design standards established for habitability and to determine the effect on the overall ship design of changes in these standards. An excellent example of this feature is presented in Reference [3] where an FF 1052 class frigate is redesigned using Soviet habitability standards and then compared to the actual frigate design.

From Table VI, the design which deviates most from the optimum is the one in which the objective function was full load density (FLD DENS). Here the objective function was to be maximized. The units of full load density are lbs/ft^3 and are therefore a measure of how dense the ship is. The difference between this design and the others is significant and leads to a consideration of which is more efficient from a space utilization standpoint. It would be a logical assumption that the larger ship could support a bigger payload more efficiently. Yet, is this the better design? The designer must remember that the synthesis system is a design tool and he must be judicious in the application of engineering judgement and common sense. Optimization cannot be blindly applied to a problem and the results accepted at face value. Clearly, other considerations would be necessary to choose between this and one or more of the other designs.

As with the example in Chapter V, all the designs began in the infeasible region and proceeded to a feasible design. This feature is of great benefit to the designer as numerous designs that the synthesis model would have rejected and required new information for are simply tried and identified as infeasible on the path to a feasible design. The synthesis system maintains a record of all the designs tried which the designer may scrutinize and use for future design decisions or historical data. The system also identifies those constraints and design variables that are active or violated, thus providing the designer information on what is most critical in the design.

B. SENSITIVITY STUDIES

It is possible to generate sensitivity studies with the Reed/COPES/CONMIN system. Once the designer has identified a design he wants to work with, he is capable of determining the effect of varying a single parameter at a time while maintaining all other parameters constant. This was one of the first forms of preliminary design optimization used and is described in the landmark paper by Murphy, Sabat, and Taylor in 1965 [Ref. 15]. This feature was especially helpful in determining the design variables and objective functions to be used in this thesis. Figure 6.1 illustrates a simple example where the optimum design minimized with respect to displacement is checked for sensitivity to variation in length. Note that while displacement can be reduced further by making the LBP less than 394 feet, this violates one or more constraints.

C. SYSTEM TRADE-OFF STUDY

An important and useful application of the synthesis system is systems level trade-off studies. The Reed/COPES/CONMIN system allows these studies to be conducted with consistency and confidence as the computer makes routine decisions and calculations the same in all cases. Table VIII presents data from a systems level trade-off study done on different types of propulsion plants. The second generation gas turbine (2 LM2500's) appears to be the best design while the steam and diesel plants are all comparable. Surprisingly, the COGAS plant appears to be the worst of the designs studied. This may be because the data used to synthesize the COGAS design may be dated and needs to be revised. As in the other examples presented in the thesis, the payload requirements for these ships are similar to an FFG-7 class frigate.

There are considerably more applications available with the Reed/COPES/COMIN system which have not been explored.

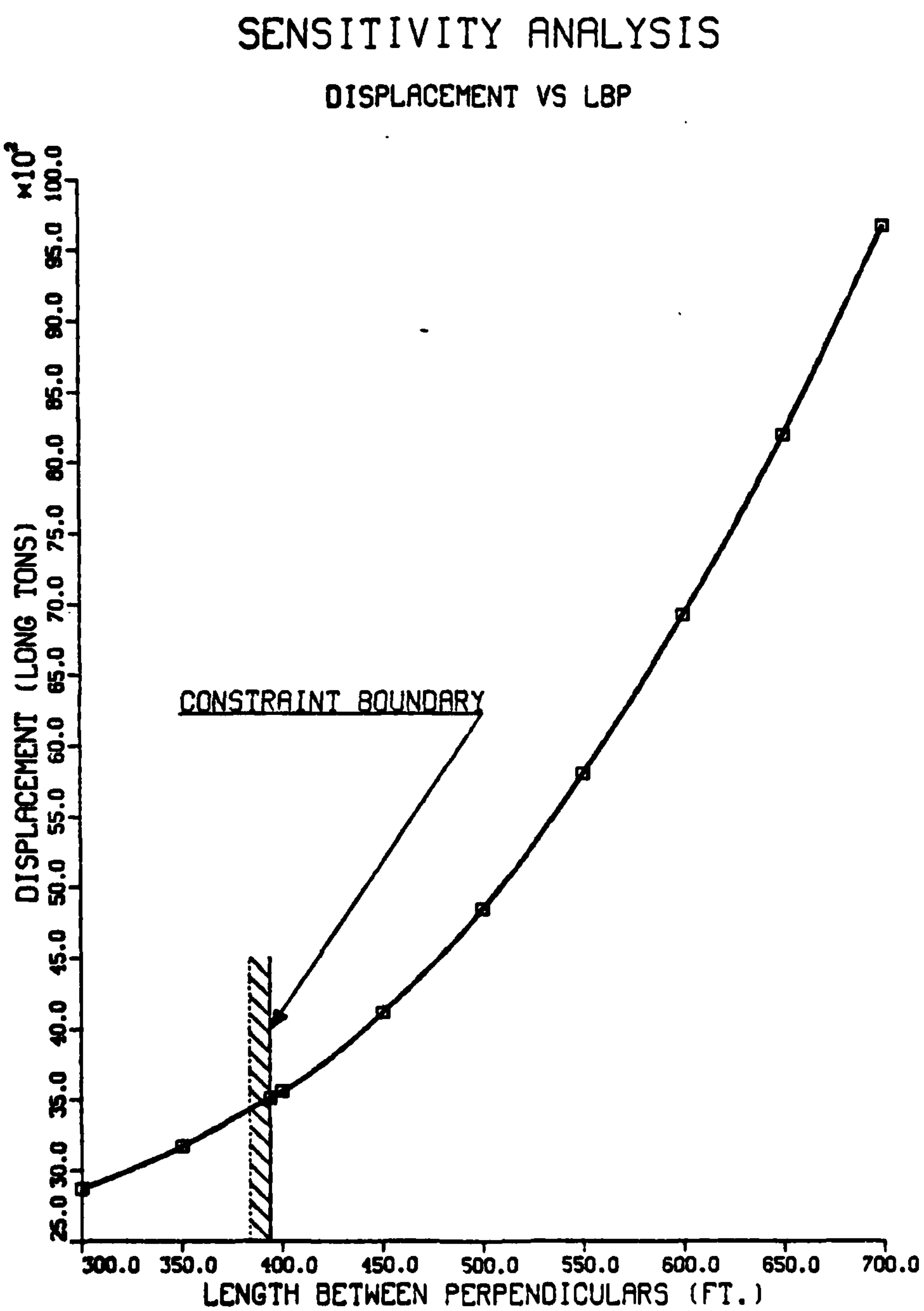


Figure 6.1 Sensitivity Displacement to Length.

TABLE VIII

Systems Trade-off Study on Propulsion Plants

PARAMETER	STEAM 600 lb	STEAM 1200 lb	GAS TURBINE	DIESEL PLANT	COGAS PLANT
LBP	417.49	418.86	394.33	416.84	468.74
BEAM	53.81	53.96	46.85	47.70	59.64
DRAFT	14.51	14.56	13.52	13.47	18.18
Cp	0.52	0.52	0.50	0.50	0.51
Cx	0.80	0.80	0.79	0.90	0.76
VCG FLD	16.58	16.68	15.40	16.13	15.20
L/B	7.76	7.76	8.42	8.74	7.86
B/H	3.71	3.71	3.46	3.54	3.28
Vsus	28.46	28.52	28.52	28.29	28.23
DISPFL	4129	4164	3511	4110	5558
DISPLS	2991	3029	2471	3091	3294
FLD DENS	16.85	16.99	15.61	15.93	21.97
WPAY/FLD	0.09	0.09	0.11	0.09	0.07
WPER/FLD	0.03	0.03	0.04	0.03	0.03
VOLPAY/VOL	0.19	0.19	0.20	0.18	0.18
VOLPERS/VOL	0.20	0.20	0.22	0.19	0.20
VMB/SHP	3.52	3.52	2.40	4.26	2.40
SHP/DISPFL	9.69	9.61	11.39	9.73	7.20

COPES/CONMIN is capable of performing optimum sensitivity studies, two variable function space studies, and approximate optimization techniques. Additionally, numerous combinations of variables and design standards are available in the Reed model. The examples presented here and in the previous chapters just begin to illustrate the utility of such a design tool.

VII. CONCLUSIONS AND RECOMMENDATIONS

The Reed/COPES/CONMIN system provides the naval architect with an efficient design tool, with which he is capable of reducing the time required to perform feasibility and concept design studies. The designer has at his fingertips all the benefits of a sophisticated synthesis model which has been proven to produce reliable designs, as well as the power of a nonlinear numerical optimizer. Combined together, the synthesis/optimizer system enables the designer to be more exhaustive in his search for a design solution at no greater cost in time. A greater number of design alternatives can be processed and compared as a result of the synthesis system's ability to start with an infeasible design and develop it into a feasible design. The designer is made aware of the design variables and constraints which are critical in each case and has the ability to alter those and other variables to achieve his goals.

In addition to being computationally fast, the synthesis system is very versatile. The COPES/CONMIN optimizer is capable of doing optimization analysis, sensitivity studies, optimum sensitivity studies, and optimization using approximation techniques. The Reed synthesis model is capable of accurate conceptual design calculations of greater detail than previously attempted in synthesis models. It allows for changes in design standards and philosophies as well as equipments and characteristics. Studies conducted using various combinations of features available from both programs greatly enhance the information available to the designer at any time.

There are several areas where further development would be desirable. The first is the addition of a cost estimating routine. This module could include lead ship and follow on ship acquisition costs as well as life cycle cost analysis. This would provide a second very significant variable to use as the objective function and would certainly be in line with the current philosophy of "design to cost."

The second feature would be a topsides arrangement routine. Naval surface combatant design has become sensitive to this area and in some cases the designs are driven by the requirements for deck area necessary to operate electronics and weapons systems. A feature that could be coupled with the above routine and used during the concept design phase would be a graphics module. There currently exist programs capable of generating rough hull forms with less information than the synthesis model is capable of providing. The British have developed software which will interactively, with the designer, develop the ship's arrangements and deckplans [Ref. 24].

A final possibility in the graphics area would be to develop a data base of three to five surface combatant hull forms which may be expanded, contracted, or mixed to achieve a desired hull form. This is similar to the approach taken with hydrofoil design synthesis and would provide the designer with additional design flexibility [Ref. 25].

Minor changes to the synthesis program could be made. Payload items used on naval combatants are continually changing, the items in the payload shopping list [Ref. 3], should be reviewed and updated as part of a periodic program maintenance action.

In conclusion, it is felt that the optimizer/synthesis system is a design tool which can, when properly used, significantly improve the quality of feasibility studies without increasing the time required to accomplish the studies. As computer hardware and software improve, the design procedure outlined in this thesis will become more commonplace and as a result the designers will further benefit by designs which are developed computationally to a much greater degree of detail than is currently observed at any given phase of design.

LIST OF REFERENCES

1. Navsea T0800-AA-RPT-010/CASDAC, "CASDAC, Abstracts of Computer Programs," Commander, Naval Sea Systems Command, 1981.

2. Mills, J., Feasibility Studies and Ship Synthesis Models, Lectures 7, 8, 9. Unpublished lecture notes for professional summer at Massachusetts Institute of Technology.

3. Reed, Michael Robert, Ship Synthesis Model for Naval Surface Ships, Master's Thesis, Massachusetts Institute of Technology, May 1976.

4. Madsen, Leroy E., and Vanderplaats, Garret N., COPES-A Fortran Control Program for Engineering Synthesis, NPS69-81-003, Naval Postgraduate School, March 1982.

5. Fox, Richard L., Optimization Methods for Engineering Design, Addison-Wesley Publishing Company, Reading, Massachusetts, 1971.

6. Himmelblau, D. M., Applied Nonlinear Programming, McGraw-Hill Book Company, New York, 1972.

7. Leopold, R., and Reuter, W., "Three Award Winning Designs--FDL, LHA, DD-963: Method and Selected Features," Transactions, SNAME Vol. 79, 1971, pp. 297-365.

8. Vanderplaats, Garret N., Automated Optimization Techniques for Aircraft Synthesis, AIAA Paper No. 76-909, AIAA Aircraft Systems and Technology Meeting, Dallas, Texas, September 27-29, 1976.

9. Vanderplaats, Garret N., and Moses, F., "Structural Optimization By Methods of Feasible Directions," Computers and Structures, Vol. 3, July 1973, pp. 739-755.

10. Vanderplaats, Garret N., Hicks, Raymond N., and Murman, Earl M., "Application of Numerical Optimization Techniques to Airfoil Design," Aerodynamic Analysis Requiring Advanced Computers, NASA SP-347, Part II, March 1975, pp. 749-768.

11. Zoutendijjk, G., Methods of Feasible Directions, Elsevier Publishing Co., Amsterdam, 1960.

12. Goodwin, Michael J., Ship Synthesis Model for Coast Guard Cutters, Massachusetts Institute of Technology, Department of Ocean Engineering, Master's Thesis, June 1975.

13. Gertler, Morton, A Reanalysis of the Original Test Data for the Taylor Standard Series, David W. Taylor Model Basin Report 806, Washington, D.C., Government Printing Office, 1954.

14. "Ship Work Breakdown Structure," NAVSHIPS 0900-039-9010, Naval Ship Systems Command, Department of the Navy, Washington, D.C. 20360, 01 March 1973.

15. Murphy, R.D., Sabat, D. J., and Taylor, R.S., "Least Cost Ship Characteristics by Computer Techniques," Marine Technology, Vol. 2, No. 2, April 1965, pp. 174-202.

16. Nowacki, Horst, Computer-Aided Ship Design Lecture Notes, The University of Michigan, Department of Naval Architecture and Marine Engineering, Report No. 018, January-April 1969.

17. Mandel, P., and Leopold, R., Optimization Methods Applied to Ship Design, Transactions, SNAME, Vol. 74, 1966, pp. 477-521.

18. Leopold, R., Mathematical Methods of Optimization Applied to Ship Design, Massachusetts Institute of Technology Report No. 65-15, 1965.

19. Nowacki, H., Brusis, F., and Swift, P. M., Tanker Preliminary Design--An Optimization Problem With Constraints, Transactions, SNAME Vol. 78, 1970, pp. 357-380.

20. Chyssostomidis, C., Optimization Techniques Applied to Containership Design, Massachusetts Institute of Technology Thesis, January 1968.

21. Parsons, Michael G., Optimization Methods for Use in Computer-Aided Ship Design, STAR Symposium, Washington, D.C., August 26-29, 1975.

22. Manning, George C., The Theory and Technique of Ship Design, Technology Press of Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, 1956.

23. Saunders, Harold E., Hydrodynamics in Ship Design, Vol. I, The Society of Naval Architects and Marine Engineers, 74 Trinity Place, New York, New York, 1957.

24. "Ship Design and Construction by CAD/CAM," Naval Architect, Vol. 33, pp. E147-E149, July 1982.

25. King, James H., and Devine, Matthew D., "HANDE-A Computer-Aided Design Approach for Hydrofoil Ships," Naval Engineers Journal, April, 1981, pp. 120-130.

APPENDIX A

DESIGN EXAMPLE

```
FILE: OPTFFG   OUTPUT   A   NAVAL POSTGRADUATE SCHOOL                         PAGE 001

      CCCCCCC  OOOOOOO  PPPPPPP  EEEEEEE  SSSSSSS
      C        O     O  P     P  E        S
      C        O     O  PPPPPPP  EEE      SSSSSSS
      C        O     O  P        E              S
      CCCCCCC  OOOOOOO  P        EEEEEEE  SSSSSSS

              C O N T R O L   P R O G R A M
                          F O R
            E N G I N E E R I N G   S Y N T H E S I S

                        T I T L E
      OPTIMIZATION OF PRELIMINARY DESIGN ON FFG-7
1     CARD IMAGES OF CONTROL DATA

      CARD                 IMAGE
0
        1)  $ BLOCK A
        2)  OPTIMIZATION OF PRELIMINARY DESIGN ON FFG-7
        3)  $ BLOCK B
        4)  2,5
        4)            2          5
        5)  $BLOCK C
        6)  3,,,10,,,50,
        6)            3                              10                       5
        7)  $ BLOCK D
        8)  0.,,-.02
        8)            0.                 -.02
        9)  0.,
        9)            0.
       10)  $ BLOCK E
       11)  0,1,-1.0
       11)            0          1       -1.0
       12)  $ BLOCK F
       13)  $       LBP
       14)  300.0,700.0
       14)          300.0      700.0
       15)  $       L/B
       16)  7.0,12.0
       16)            7.0       12.0
       17)  $       B/H
       18)  2.0,4.0
       18)            2.0        4.0
       19)  $       CP
       20)  0.50,0.90
       20)          0.50        0.90
       21)  $       CX
       22)  0.75,0.90
       22)          0.75        0.90
       23)  $ BLOCK G
       24)  1,5
       24)            1          5
       25)  2,6
       25)            2          6
```

```
      24)  3,7
      25)              3           7
      26)  4,8
      27)              4           8
      28)  5,9
      28)              5           9
      29)  $ BLOCK H
      30)  1,
      30)              1
      31)  $ BLOCK I
      32)  77,89
      32)              77          89
      33)  -1.0E+15,0.0,0.0,0.0
      33)      -1.0E+15            0.0         0.0         0.0
      34)  $ BLOCK V
      35)  END
1     TITLE:
      OPTIMIZATION OF PRELIMINARY DESIGN ON FFG-7


      CONTROL PARAMETERS:
      CALCULATION CONTROL,                          NCALC  =     2
      NUMBER OF GLOBAL DESIGN VARIABLES,              NDV  =     5
      NUMBER OF SENSITIVITY VARIABLES,                NSV  =     0
      NUMBER OF FUNCTIONS IN TWO-SPACE,             N2VAR  =     0
      NUMBER OF APPROXIMATING VAR.                 NXAPPX  =     0
      INPUT INFORMATION PRINT CODE,                IPNPUT  =     0
      DEBUG PRINT CODE,                             IPDBG  =     0

      CALCULATION CONTROL, NCALC
      VALUE     MEANING
        1       SINGLE ANALYSIS
        2       OPTIMIZATION
        3       SENSITIVITY
        4       TWO-VARIABLE FUNCTION SPACE
        5       OPTIMUM SENSITIVITY
        6       APPROXIMATE OPTIMIZATION


      * * OPTIMIZATION INFORMATION

      GLOBAL VARIABLE NUMBER OF OBJECTIVE                =    1
      MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = -0.1000E+01

      CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

      IPRINT   ITMAX    ICNDIR    NSCAL    ITRM    LINOBJ   NACMX1   NFDG
        3        0        0        10        0        0        50       0

       FDCH            FDCHM            CT                CTMIN
       0.0             0.0             -0.20000E-01       0.0

       CTL             CTLMIN           THETA             PHI
       0.0             0.0              0.0               0.0

       DELFUN          DABFUN           ALPHAX            ABOBJ1
       0.0             0.0              0.0               0.0

      DESIGN VARIABLE INFORMATION
      NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
      D. V.      LOWER          UPPER         INITIAL
      NO.        BOUND          BOUND          VALUE          SCALE
        1     0.30000E+03    0.70000E+03    0.0             0.0
        2     0.70000E+01    0.12000E+02    0.0             0.0
        3     0.20000E+01    0.40000E+01    0.0             0.0
        4     0.50000E+00    0.90000E+00    0.0             0.0
        5     0.75000E+00    0.90000E+00    0.0             0.0
```

```
DESIGN VARIABLES
       D. V.      GLOBAL     MULTIPLYING
ID      NO.      VAR. NO.      FACTOR
 1       1          5        0.10000E+01
 2       2          6        0.10000E+01
 3       3          7        0.10000E+01
 4       4          8        0.10000E+01
 5       5          9        0.10000E+01

CONSTRAINT INFORMATION

THERE ARE  1 CONSTRAINT SETS
     GLOBAL  GLOBAL  LINEAR        LOWER        NORMALIZATION      UPPER
ID   VAR. 1  VAR. 2    ID          BOUND           FACTOR          BOUND
 1     71      85      0       -0.11000E+16     0.11000E+16      0.0

TOTAL NUMBER OF CONSTRAINED PARAMETERS =   13


* * ESTIMATED DATA STORAGE REQUIREMENTS
        REAL                              INTEGER
INPUT  EXECUTION  AVAILABLE      INPUT  EXECUTION  AVAILABLE
  91     3202       10000          60      233        1000
     SHIP NUMBER    1
                          SHIP SPECIFICATIONS

     VSUS            0.0    DELTA CF       5.00    CPO ACC      15.00
     VEND           20.00                  0.0     CREW ACC    156.00
     RANGE        4500.00                  0.0     FLAG ACC      0.0
     LBP           300.00                  0.0     TRP ACC       0.0
     L/B             9.07                  0.0     PASS ACC      0.0
     B/H             3.14   SSEL TYP       5.00    DAYS DUR     45.00
     CP              0.59   EMEL TYP       4.00                  0.0
     CX              0.75   NU LOWSD       0.0                   0.0
                    30.00   NU MEDSD       4.00                  0.0
                    26.00   NU HI SD       0.0                   0.0
     PROP PLT        6.00   NU GT GN       0.0     HULL MAT      1.00
     SUS SHP     40000.00   NU ST GN       0.0     SUPSTMAT      2.00
     NU BOILS        0.0    KW/DIESL    1000.00                  0.0
     NU REACT        0.0    KW/GAS T       0.0     GM/B MIN      0.08
     NU ENGS         2.00   KW/STM G       0.0                   0.0
     NU SHAFT        1.00   ELC MARG       0.30    DISP TOL     10.00
     PROPELLR        2.00                  0.0     MXDIS IT     20.00
     SHFT TYP        1.00                  0.0     VCG TOL       0.10
     PROP RPM        0.0                   0.0     MXVCG IT     20.00
     PROP DIA        0.0    HEAT TYP       2.00    DCWTMARG      0.05
     DEPTH MB        0.0    FIN STAB       2.00    FS CORR       0.0
     LENTH MB        0.0                   0.0     PRNT TYP      2.00
     BEAM MB         0.0                   0.0     PRNTCNST      0.0
     PC EAC          0.0                   0.0                   0.0
     PC MAXSP        0.0    OFF ACC       14.00    PASSAGE       2.00

     PROP PLT    GASTURB2   SHFT TYP    HOLLOW     HULL MAT    STEEL
     SSEL TYP    MECSPDIE   PROPELLR    CONT PIT   SUPSTMAT    ALUMINUM
     EMEL TYP    MEDSPDIE   FIN STAB    YES        PASSAGE     PCRTSTBD
                            HEAT TYP    ELECTRIC
                          SPECIAL PAYLOAD INPUT

      WT GRP    VCL GRP    WT    VCG NU    VCG REF    AREA SUP    AREA HULL

     NO SPECIAL PAYLOAD INPUT
     SHIP NUMBER    1
                         PAYLOAD SPECIFICATIONS

       QNTY ITEM    QNTY ITEM    QNTY ITEM    QNTY ITEM    QNTY ITEM
```

```
       1.00   2        1.00 204
       1.00  24        1.00 208
       1.00  27        1.00 209
       1.00  21        2.00 214
       1.00  61        4.00 215
       8.00  64        1.00 221
       1.00  65       12.00 226
       1.00  75        1.00 230
       1.00 100        1.00 232
       1.00 102        1.00 190
       1.00 116        1.00 242
     800.00 115      193.00 217
   10000.00 124       10.00 219
       1.00 131        1.00  48
      40.00 168
       2.00 180
       1.00 165
       1.00 212
       2.00 213
       6.00 200
```

SUMMARY OF RESULTS

```
LBP              300.00   DISP FLD     2865.05   FLD DENS      13.40
BEAM              33.08   DISP LSP     1966.72   LSP DENS       9.20
DRAFT             10.53   VR LOADS      800.00   WPAY/FLD       0.13
D 0               30.11   WT MARG        98.34   WPER/FLD       0.05
D 10              21.11   WTGRP 1       847.65   WOPS/FLD       0.43
D 20              23.36   WTGRP 2       223.82   VPAY/VOL       0.21
D AVE             22.58   WTGRP 3       163.58   VPER/VOL       0.23
LEN F DK           0.0    WTGRP 4       127.47   VOPS/VOL       0.56
CP                 0.59   WTGRP 5       289.23   WTG2/SHP      12.53
CX                 0.75   WTGRP 6       225.10   VMB/SHP        2.40
VCG FLD           14.39   WTGRP 7        89.88   WT3/KWIN      91.60
VCG/EAVG           0.63   VOL TOT    478829.19   WTG1/VOL       3.97
L/B                9.07   VOL HULL   136638.00   WTG5/VOL       1.35
B/H                3.14   VOL SSTR   342191.19   VHAB/MAN     517.45
EXCES KG          -2.24   CRUISEKW     1616.17   WHAB/MAN     802.26
RANGE           4500.00   BATTLEKW     1127.58   MEN/DISP       0.06
SUS SHP        40000.00   24 HR KW      783.02   KWIN/FLD       1.40
END SHP         5173.56   NU LOWSD        0.0    SHP/DISP      13.56
VSUS              34.06   NU MEDSD        4.00   DP*V/SHP      16.79
VEND              20.00   NU HI SD        0.0    WPY*V/DP       4.39
AVSE/SPD          25.89   NU GT GN        0.0
NU ACCOM         185.00   NU ST GN        0.0
KW 1PST         4000.00   KW/DIESL     1000.00
KW SFSER        4000.00   KW/GAS T        0.0
KW EPERG           0.0    KW/STM G        0.0
```

```
* * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                   *
*                   C O N M I N                     *
*                                                   *
*              FORTRAN PROGRAM FOR                  *
*                                                   *
*        CONSTRAINED FUNCTION MINIMIZATION          *
*                                                   *
* * * * * * * * * * * * * * * * * * * * * * * * * * *
```

CONSTRAINED FUNCTION MINIMIZATION

CONTROL PARAMETERS

IPRINT	NDV	ITMAX	NCON	NSIDE	ICNDIR	NSCAL	NFDG
3	5	20	13	1	6	10	0

LINOBJ	ITRM	N1	N2	N3	N4	N5
0	3	7	23	50	50	100

```
      0        3        7        23       50       50      100

         CT              CTMIN             CTL              CTLMIN
   -0.20000E-01     0.40000E-02     -0.10000E-01      0.10000E-02
        THETA             PHI              DELFUN           DABFUN
    0.10000E+01     C.50000E+01      0.10C00E-03      0.28650E+01
         FDCH             FDCHM            ALPHAX           ABOBJ1
    0.10000E-01     0.10000E-01      0.10C0CE+00      0.10000E+00

LOWER BOUNDS ON DECISION VARIABLES (VLB)
  1)     0.30000E+C3  0.70000E+01  0.2C000E+01  0.50000E+00  0.75000E+00

UPPER BOUNDS ON DECISION VARIABLES (VUB)
  1)     C.70000E+03  C.12000E+02  0.400C0E+01  0.90000E+00  0.90000E+00

ALL CONSTRAINTS ARE NCN-LINEAR

INITIAL FLACTICA IAFORMATION

OBJ =    0.286505E+04

DECISION VARIABLES (X-VECTOR)
  1)     0.30000E+03  0.90700E+01  0.31400E+01  0.59300E+00  0.75100E+00

CCNSTRAINT VALUES (G-VECTOR)
  1)     0.62225E+01  0.18473E+01 -0.36306E+01 -0.21500E+01 -0.77717E+00 -0.19056E+01
  7)    -0.15286E+01 -0.56699E+01 -0.55709E+01 -0.62370E+01 -0.42265E+01 -0.10000E+02
 13)     C.11868E+02


BEGIN ITERATICN NUMBER    1

THERE ARE    0 ACTIVE CONSTRAINTS

THERE ARE    3 VIOLATED CONSTRAINTS
CCNSTRAINT NUMBERS ARE
    1    2   13

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
   -1

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)     0.10000E+01  0.10000E+01  0.10000E+01  0.0

CONSTRAINT PARAMETER, BETA =    0.98689E+00

SEARCH DIRECTION (S-VECTOR)
  1)     0.10000E+01 -0.57566E+00 -0.1140E+00  0.81599E-01  0.27834E-01

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE =  0.1882E+04  PROPOSED ALPHA =  0.2036E+00

CALCULATEC ALPHA =    0.20362E+00

OBJ =    0.332577E+04

DECISION VARIABLES (X-VECTOR)
  1)     0.36109E+03  0.80068E+01  0.30671E+01  0.60285E+00  0.75526E+00

CCNSTRAINT VALUES (G-VECTOR)
  1)     0.16955E+C1 -0.28421E+01 -0.34792E+01 -0.23322E+01 -0.78860E+01 -0.20379E+01
  7)    -0.13878E+01 -0.52494E+01 -0.52034E+01 -0.65255E+01 -0.47375E+01 -0.10000E+02
 13)     0.28348E+C1
```

```
BEGIN ITERATION NUMBER    2

THERE ARE    0 ACTIVE CONSTRAINTS

THERE ARE    2 VIOLATED CONSTRAINTS
CONSTRAINT NUMBERS ARE
    1   13

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)    0.10000E+01  0.10000E+01

CONSTRAINT PARAMETER, BETA =    0.10002E+01

SEARCH DIRECTION (S-VECTOR)
  1)    0.10000E+01  0.96427E-02  0.12389E-01 -0.94199E-01  0.59157E-03

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE =  0.2350E+04  PROPOSED ALPHA =  0.1028E+00

CALCULATED ALPHA =    0.11576E+00

OBJ =    0.360989E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39581E+03  0.80170E+01  0.30716E+01  0.59639E+00  0.75531E+00

CONSTRAINT VALUES (G-VECTOR)
  1)    0.26026E-01 -0.34468E+01 -0.34887E+01 -0.23210E+01 -0.92463E+01 -0.19515E+01
  7)   -0.14802E+01 -0.50262E+01 -0.50102E+01 -0.66598E+01 -0.49736E+01 -0.10000E+02
 13)   -0.10410E+00


BEGIN ITERATION NUMBER    3

THERE ARE    0 ACTIVE CONSTRAINTS

THERE ARE    1 VIOLATED CONSTRAINTS
CONSTRAINT NUMBERS ARE
    1

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)    0.10000E+01

CONSTRAINT PARAMETER, BETA =    0.10155E+01

SEARCH DIRECTION (S-VECTOR)
  1)    0.10000E+01  0.25442E-01  0.36929E-01 -0.17109E+00  0.57494E-02

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE =  0.2511E+04  PROPOSED ALPHA =  0.2100E-02

CALCULATED ALPHA =    0.20705E-02

OBJ =    0.361506E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39644E+03  0.80174E+01  0.30718E+01  0.59618E+00  0.75531E+00

CONSTRAINT VALUES (G-VECTOR)
  1)    0.95367E-05 -0.34529E+01 -0.34893E+01 -0.23204E+01 -0.92661E+01 -0.15487E+01
  7)   -0.14832E+01 -0.50223E+01 -0.50069E+01 -0.66621E+01 -0.49776E+01 -0.10000E+02
 13)   -0.14765E+00
```

```
FILE: CPTFFG    OUT      A    NAVAL POSTGRADUATE SCHOOL                                    PAGE 007

     BEGIN ITERATION NUMBER    4

     THERE ARE    1 ACTIVE CONSTRAINTS
     CONSTRAINT NUMBERS ARE
         1

     THERE ARE    0 VIOLATED CONSTRAINTS

     THERE ARE    0 ACTIVE SIDE CONSTRAINTS

     PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
       1)    0.10016E+01

     CONSTRAINT PARAMETER, BETA =    0.23323E+00

     SEARCH DIRECTION (S-VECTOR)
       1)    0.55332E-01  0.14905E+00  0.21759E+00 -0.10000E+01  0.33969E-01

     ONE-DIMENSIONAL SEARCH
     INITIAL SLOPE = -0.6414E+03  PROPOSED ALPHA =  0.5667E-01

     CALCULATED ALPHA =    0.16218E+00

     OBJ =    0.355612E+04

     DECISION VARIABLES (X-VECTOR)
       1)    0.39913E+03  0.82367E+01  0.31827E+01  0.50000E+00  0.75945E+00

     CONSTRAINT VALUES (G-VECTOR)
       1)   -0.33263E+00 -0.21277E+01 -0.37159E+01 -0.20434E+01 -0.53516E+01 -0.40000E+00
       7)   -0.28571E+01 -0.50055E+01 -0.49923E+01 -0.66718E+01 -0.49945E+01 -0.10000E+02
      13)   -0.33686E+00


     BEGIN ITERATION NUMBER    5

     THERE ARE    0 ACTIVE CONSTRAINTS

     THERE ARE    0 VIOLATED CONSTRAINTS

     THERE ARE    1 ACTIVE SIDE CONSTRAINTS
     DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
        -4

     PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
       1)    0.0

     CONSTRAINT PARAMETER, BETA =    0.99783E+00

     SEARCH DIRECTION (S-VECTOR)
       1)   -0.10000E+01  0.30043E-01  0.24818E-01 -0.74564E-08  0.67735E-02

     ONE-DIMENSIONAL SEARCH
     INITIAL SLOPE = -0.2725E+04  PROPOSED ALPHA =  0.1157E-01

     CALCULATED ALPHA =    0.16214E-01

     OBJ =    0.351587E+04

     DECISION VARIABLES (X-VECTOR)
       1)    0.39426E+03  0.82411E+01  0.31839E+01  0.50000E+00  0.75953E+00

     CONSTRAINT VALUES (G-VECTOR)
       1)   -0.13605E+00 -0.20381E+01 -0.37184E+01 -0.20402E+01 -0.51632E+01 -0.40000E+00
       7)   -0.28571E+01 -0.50360E+01 -0.50187E+01 -0.66542E+01 -0.49638E+01 -0.10000E+02
      13)    0.23556E-02
```

```
BEGIN ITERATION NUMBER    6

THERE ARE    1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
   13

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
   -4

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)    0.14434E+01  0.0

CONSTRAINT PARAMETER, BETA =    0.23053E-01

SEARCH DIRECTION (S-VECTOR)
  1)    0.33391E-01  0.10000E+01  0.83289E+00  0.28141E-06  0.21277E+00

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE = -0.5726E+02  PROPOSED ALPHA =  0.2632E-01

CALCULATED ALPHA =    0.36237E-01

OBJ =    0.351484E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39462E+03  0.85698E+01  0.32787E+01  0.50000E+00  0.76532E+00

CONSTRAINT VALUES (G-VECTOR)
  1)    -0.16219E+00 -0.12103E+01 -0.39000E+01 -0.18033E+01 -0.31348E+01 -0.40000E+00
  7)    -0.28571E+01 -0.50337E+01 -0.50167E+01 -0.66555E+01 -0.49661E+01 -0.10000E+02
 13)    -0.23516E-01


BEGIN ITERATION NUMBER    7

THERE ARE    0 ACTIVE CONSTRAINTS

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
   -4

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)    0.0

CONSTRAINT PARAMETER, BETA =    0.99853E+00

SEARCH DIRECTION (S-VECTOR)
  1)    -0.10000E+01  0.17061E-01  0.12320E-01  0.0          0.64678E-02

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE = -0.2476E+04  PROPOSED ALPHA =  0.8243E-02

CALCULATED ALPHA =    0.10976E-02

OBJ =    0.351214E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39430E+03  0.85700E+01  0.32787E+01  0.50000E+00  0.76533E+00

CONSTRAINT VALUES (G-VECTOR)
  1)    -0.14859E+00 -0.12039E+01 -0.39000E+01 -0.18032E+01 -0.31254E+01 -0.40000E+00
  7)    -0.28571E+01 -0.50358E+01 -0.50185E+01 -0.66543E+01 -0.49640E+01 -0.1000 E+02
 13)    0.0
```

```
BEGIN ITERATION NUMBER    8

THERE ARE    1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
    13

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
    -4

PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
  1)    0.10000E+01  0.0

CONSTRAINT PARAMETER, BETA =   0.14173E-01

SEARCH DIRECTION (S-VECTOR)
  1)    0.14243E-01  0.10000E+01  0.72148E+00 -0.87272E-06  0.37865E+00

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE = -0.3519E+02  PROPOSED ALPHA =  0.1630E-01

CALCULATED ALPHA =   0.21146E-01

OBJ =   0.351172E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39439E+03  0.87617E+01  0.33266E+01  0.50000E+00  0.77134E+00

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.15555E+00 -0.69681E+00 -0.39879E+01 -0.16835E+01 -0.20790E+01 -0.40000E+00
  7)   -0.28571E+01 -0.50352E+01 -0.50180E+01 -0.66546E+01 -0.49645E+01 -0.10000E+02
 13)   -0.64075E-02
1


FINAL OPTIMIZATION INFORMATION

OBJ =   0.351172E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.39439E+03  0.87617E+01  0.33266E+01  0.50000E+00  0.77134E+00

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.15555E+00 -0.69681E+00 -0.39879E+01 -0.16835E+01 -0.20790E+01 -0.40000E+00
  7)   -0.28571E+01 -0.50352E+01 -0.50180E+01 -0.66546E+01 -0.49645E+01 -0.10000E+02
 13)   -0.64075E-02

THERE ARE    1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
    13

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
    -4

TERMINATION CRITERION
    ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR  3 ITERATIONS

NUMBER OF ITERATIONS =    8

OBJECTIVE FUNCTION WAS EVALUATED        60  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED     60  TIMES
```

FILE: CPTFFG CUTPUT A NAVAL POSTGRADUATE SCHOOL

OBJECTIVE FUNCTICN
GLOBAL LOCATICN 1 FUNCTICN VALUE 0.35117E+04

DESIGN VARIABLES

ID	C. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	5	0.30000E+03	0.39439E+03	0.70000E+03
2	2	6	0.70000E+01	0.87617E+01	0.12000E+02
3	3	7	C.20000E+01	0.33266E+01	0.40000E+01
4	4	8	C.50000E+00	0.50000E+00	0.90000E+00
5	5	9	0.75000E+00	0.77134E+00	0.90000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	77	-0.11000E+16	-0.15553E-01	0.0
2	78	-0.11000E+16	-0.65682E-01	0.0
3	79	-0.11000E+16	-0.39879E+00	0.0
4	80	-0.11000E+16	-0.16835E+00	0.0
5	81	-0.11000E+16	-0.20791E+01	0.0
6	82	-0.11000E+16	-0.40000E-01	0.0
7	83	-0.11000E+16	-0.28571E+00	0.0
8	84	-0.11000E+16	-0.50352E+00	0.0
9	85	-0.11000E+16	-0.50180E+00	0.0
10	86	-0.11000E+16	-0.66546E+00	0.0
11	87	-0.11000E+16	-0.49645E+00	0.0
12	88	-0.11000E+16	-0.1C0C0E+01	0.0
13	89	-0.11000E+16	-0.63950E-03	0.0

SHIP NUMBER 1

SHIP SPECIFICATIONS

VSUS	0.0	DELTA CF	5.00	CPO ACC	15.00
VEND	20.00		0.0	CREW ACC	156.00
RANGE	4500.00		0.0	FLAG ACC	0.0
LBP	354.39		0.0	TRP ACC	0.0
L/B	8.76		0.0	PASS ACC	0.0
B/H	3.33	SSEL TYP	5.00	DAYS DUR	45.00
CP	0.50	EMEL TYP	4.00		0.0
CX	0.77	NU LONSD	0.0		0.0
	30.00	NU MEDSD	4.00		0.0
	26.C0	NU HI SD	0.0		0.0
PROP PLT	6.00	NU GT GN	0.0	HULL MAT	1.00
SUS SHP	40000.00	NU ST GN	0.0	SUPSTMAT	2.00
NU BOILS	0.0	KW/DIESL	1000.00		0.0
NU REACT	0.0	KW/GAS T	0.0	GM/B MIN	0.08
NU ENGS	2.C0	KW/STM G	0.0		0.0
NU SHAFT	1.00	ELC MARG	0.30	DISP TOL	10.00
PROPELLR	2.00		0.0	MXDIS IT	20.00
SHFT TYP	1.00		0.0	VCG TOL	0.10
PROP RPM	0.0		0.0	MXVCG IT	20.00
PROP DIA	0.0	HEAT TYP	2.00	DCWTMARG	0.05
DEPTH MB	0.0	FIN STAB	2.00	FS CORR	0.0
LENTH MB	0.0		0.0	PRNT TYP	2.00
BEAM MB	0.0		0.0	PRNTCNST	0.0
PC END	0.0		0.0		0.0
PC MAXSP	0.0	OFF ACC	14.00	PASSAGE	2.00

PROP PLT	GASTURB2	SHFT TYP	HOLLOW	HULL MAT	STEEL
SSEL TYP	MEDSPDIE	PROPELLR	CONT PIT	SUPSTMAT	ALUMINUM
EMEL TYP	MEDSPDIE	FIN STAB	YES	PASSAGE	PORTSTBD
		HEAT TYP	ELECTRIC		

SPECIAL PAYLOAD INPUT

WT GRP	VCL GRP	WT	VCG NU	VCG REF	AREA SUP	AREA HULL

NO SPECIAL PAYLOAD INPUT
SHIP NUMBER 1

PAYLOAC SPECIFICATIONS

QNTY	ITEM	QNTY	ITEM	QNTY	ITEM	QNTY	ITEM	QNTY	ITEM
1.00	2	1.C0	204						
1.00	24	1.00	208						
1.00	27	1.00	209						
1.00	41	2.00	214						
1.00	61	4.00	215						
8.C0	64	1.00	221						
1.00	65	12.00	226						
1.00	75	1.00	230						
1.CC	10C	1.00	232						
1.00	102	1.00	190						
1.00	116	1.00	242						
800.C0	119	153.00	217						
10000.00	124	10.00	219						
1.C0	131	1.00	48						
40.C0	168								
2.00	180								
1.C0	165								
1.00	212								
2.00	213								
6.00	200								

SUMMARY OF RESULTS

LBP	394.39	DISP FLD	3511.72	FLD DENS	15.62
BEAM	45.01	DISP LSP	2473.24	LSP DENS	11.00
DRAFT	13.53	VR LOADS	914.82	WPAY/FLD	0.11
D 0	36.48	WT MARG	123.66	WPER/FLD	0.04
D 10	24.65	WTGRP 1	1231.89	WOPS/FLD	0.41
D 20	27.61	WTGRP 2	250.03	VPAY/VOL	0.20
D AVE	27.11	WTGRP 3	168.72	VPER/VOL	0.22
LEN P DK	0.0	WTGRP 4	135.89	VOPS/VOL	0.58
CP	0.50	WTGRP 5	342.40	WTG2/SHP	14.C0
CX	0.77	WTGRP 6	254.43	VMB/SHP	2.40
VCG FLD	15.46	WTGRP 7	89.88	WT3/KWIN	94.48
VCG/DAVG	0.57	VOL TOT	503696.37	WTG1/VOL	5.48
L/B	8.76	VOL HULL	259269.50	WTG5/VOL	1.52
B/H	3.33	VOL SSTR	244426.87	VHAB/MAN	517.45
EXCES KG	1.16	CRUISEKW	2179.70	WHAB/MAN	802.77
RANGE	4500.00	BATTLEKW	1523.65	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1260.34	KWIN/FLD	1.14
END SHP	6455.81	NU LOWSD	0.0	SHP/DISP	11.39
VSUS	28.56	NU MEDSD	4.00	DP*V/SHP	17.25
VEND	20.00	NU HI SD	0.0	WPY*V/DP	3.05
AVSF&SPD	25.91	NU GT GN	0.0		
NU ACCOM	185.00	NU ST GN	0.0		
KW IAST	4C00.00	KW/DIESL	1000.00		
KW SFSER	4000.00	KW/GAS T	0.0		
KW EMERG	0.0	KW/STM G	0.0		

SHIP NUMBER 1

DETAILED RESULTS--FUNCTIONAL GROUPING

GROUF	NAME	WEIGHT TONS	WT FRAC	VOLUME CU FT	VOL FRAC	DENSITY LBS/CU FT
100	MIL MISS	375.5	0.1059	101418.	0.2013	8.29
110	COMP/DET	74.1	0.0209	29014.	0.0576	5.72
111	RADIOCCM	16.1	0.0045	7446.	0.0148	4.84
112	RACAR	11.9	0.0034	3230.	C.0064	8.25
113	SCNAR	9.3	0.0026	2015.	0.0040	10.34
114	ECM	4.5	0.0013	2295.	C.0046	4.39
115	EVALUATE	19.6	0.0055	11407.	0.0226	3.85
116	C/D SLPP	12.7	0.0036	2621.	0.0052	10.87
120	WEAPCNS	190.0	0.0536	22288.	0.0442	19.1C
121	GUNS	37.9	0.0107	8716.	0.0173	9.74
122	MISSILES	126.4	0.0356	9350.	0.0186	30.28
123	ASW	4.6	0.0013	935.	0.0019	11.11

124	MINE WAR	0.0	0.0	0.	0.0	0.0
125	SM ARMS	3.0	0.0008	765.	0.0015	8.78
126	CM AO EL	12.0	0.0034	0.	0.0	0.0
127	WEAP SUP	6.1	0.0017	2522.	0.0050	5.40
128	SPECWEAP	0.0	0.0	0.	0.0	0.0
130	AVIATICN	111.3	0.0314	50116.	0.0995	4.98
131	CONTROL	12.1	0.0034	2763.	0.0055	9.84
132	STOW/PKT	21.9	0.0062	34850.	0.0692	1.41
133	STORES	6.7	0.0019	10200.	0.0203	1.47
134	LIQUIDS	68.0	0.0192	2304.	0.0046	66.08
135	ORDNANCE	2.7	0.0008	0.	0.0	0.0
140	AMPH OPS	0.0	0.0	0.	0.0	0.0
150	CARGO	0.0	0.0	0.	0.0	0.0
160	FLAG	0.0	0.0	0.	0.0	0.0
170	PASSNGER	0.0	0.0	0.	0.0	0.0
180	SPEC MIS	0.0	0.0	0.	0.0	0.0
200	PERSONEL	141.1	0.0398	111150.	C.2207	2.84
210	LIVING	38.3	0.0108	68265.	0.1355	1.26
211	OFF BER	0.0	0.0	9217.	0.0183	0.0
212	OFF MESS	0.0	0.0	3456.	0.0069	0.0
213	OFF BATH	0.0	0.0	1034.	0.0021	0.0
214	CPO BER	0.0	0.0	4790.	0.0095	0.0
215	CPO MESS	0.0	0.0	1817.	0.0036	0.0
216	CPO BATH	0.0	0.0	1297.	0.0026	0.0
217	CREW BER	0.0	0.0	29722.	0.0590	0.0
218	CREWMESS	0.0	0.0	11412.	0.0227	0.0
219	CREWBATH	0.0	0.0	5520.	0.0110	0.0

SHIP NUMBER 1

DETAILED RESULTS--FUNCTIONAL GROUPING CONTINUED

GROUP	NAME	WEIGHT TONS	WT FRAC	VOLUME CU FT	VOL FRAC	DENSITY LBS/CU FT
220	SUPPORT	28.0	0.0079	27462.	0.0545	2.28
221	ADMIN FN	1.1	0.0003	1297.	0.0026	1.90
222	FOOD PGH	10.2	0.0029	7552.	0.0150	3.02
223	MED &DEN	1.3	0.0004	2824.	0.0056	1.05
224	PER SERV	8.2	0.0023	7450.	0.0148	2.47
225	REC &WEL	2.1	0.0006	6639.	0.0132	0.72
226	SEWAGE	5.0	0.0014	1700.	0.0034	6.55
230	STOWAGE	74.8	0.0211	15423.	C.0306	10.86
231	STORES	30.3	0.0085	5036.	0.0100	13.45
232	PER STOW	14.5	0.0041	4408.	0.0088	7.35
233	POTWATER	30.0	0.0084	5979.	0.0119	11.23
300	SHIP OPS	1440.8	0.4062	291129.	0.5780	11.09
310	CONTROL	36.7	0.0104	18146.	0.0360	4.53
311	SHIP CNT	28.3	0.0080	5609.	0.0111	11.29
312	DAM CONT	0.0	0.0	2550.	0.0051	0.0
313	OFFICES	8.5	0.0024	9987.	0.0198	1.90
320	MACH SYS	537.0	0.1514	130284.	0.2587	9.23
321	MACH BOX	393.4	0.1109	96170.	0.1909	9.16
322	UPTAKES	12.7	0.0036	20190.	0.0401	1.41
323	SH,BR,PR	67.4	0.0190	0.	0.0	0.0
324	MANEUVER	30.5	0.0086	4113.	0.0082	16.62
325	VENTILAT	33.0	0.0093	9811.	0.0195	7.53
330	DECK AUX	61.4	0.0173	15095.	0.0299	9.12
331	ANCH,M&T	40.0	0.0113	15000.	0.0298	5.97
332	UNREP	21.4	0.0060	85.	C.0002	563.95
340	MAINTAIN	46.9	0.0132	5975.	0.0119	17.58
341	MECHANIC	5.6	0.0016	3546.	0.0070	3.51
342	ELECTRIC	2.8	0.0008	1772.	0.0035	3.51
343	MISC	38.6	0.0109	657.	0.0013	131.55

350	STOWAGE	749.7	0.2114	37273.	0.0740	45.05
351	FUEL OIL	592.5	0.1671	24568.	0.0488	54.02
352	R FEED W	0.0	0.0	0.	0.0	0.0
353	LUBE OIL	14.3	0.0040	559.	0.0011	57.44
354	DIES OIL	82.3	0.0232	3267.	0.0065	56.41
355	MISC LIQ	0.0	0.0	0.	0.0	0.0
356	STORESUP	43.9	0.0124	8879.	0.0176	11.06
357	BOATS	16.7	0.0047	0.	0.0	0.0

SHIP NUMBER 1

DETAILED RESULTS--FUNCTIONAL GROUPING CONTINUED

GROUP	NAME	WEIGHT TONS	WT FRAC	VOLUME CU FT	VOL FRAC	DENSITY LBS/CU FT
360	TANKAGE	0.0	0.0	23459.	0.0466	0.0
361	BALLAST	0.0	0.0	9000.	0.0179	0.0
362	PEAK	0.0	0.0	1459.	0.0029	0.0
363	VOIDS	0.0	0.0	13000.	0.0258	0.0
364	XFLCCDNG	0.0	0.0	0.	0.0	0.0
365	MISC TNK	0.0	0.0	0.	0.0	0.0
370	PASS&ACC	9.0	0.0025	60906.	0.1209	0.33
380	HULL MAR	0.0	0.0	0.	0.0	0.0
390	SUP MARG	0.0	0.0	0.	0.0	0.0
400	HULL GRP	1253.8	0.3535			
410	BASCHULL	536.7	0.1513			
420	SEC HULL	498.1	0.1404			
430	DECKHOUS	219.0	0.0617			
440	ARMOR	0.0	0.0			
450	FREEFLLQ	0.0	0.0			
500	SHIP SYS	335.7	0.0946			
	TOTAL	3546.8	1.0000	503697.	1.0000	15.77

SHIP NUMBER 1

DETAILED RESULTS--BSCI WEIGHT LISTING

GROUP	NAME	WEIGHT TONS	WT FRAC FULL LD	WT FRAC LITE SH	VCG FT
100	PLATING	266.8	0.0760	0.1079	10.5
101	FRAMING	157.1	0.0447	0.0635	9.9
102	INN BOTM	0.0	0.0	0.0	3.7
103	PLATFLAT	76.1	0.0217	0.0308	11.3
104		0.0	0.0	0.0	0.0
105		0.0	0.0	0.0	0.0
106		0.0	0.0	0.0	0.0
107	ALL DECK	185.1	0.0527	0.0748	24.0
108		0.0	0.0	0.0	0.0
109		0.0	0.0	0.0	0.0
110		0.0	0.0	0.0	0.0
111	SUPERSTR	219.0	0.0624	0.0885	34.8
112	PROP FND	41.9	0.0119	0.0169	7.8
113	AUX FNDS	60.1	0.0171	0.0243	13.8
114	STR BKHD	96.7	0.0275	0.0391	17.8
115	TRK&ENCL	37.2	0.0106	0.0151	16.7
116	STR SPCH	0.0	0.0	0.0	0.0
117	ARMOR	0.0	0.0	0.0	0.0
118	AC T STR	0.0	0.0	0.0	11.2
119	CAST&FOR	36.6	0.0104	0.0148	10.3
120	SEACHEST	1.8	0.0005	0.0007	4.6
121	BAL UNIT	0.0	0.0	0.0	0.0
122	SPEC DRS	0.0	0.0	0.0	18.0
123	DRS&HTCH	17.4	0.0050	0.0070	21.6
124		0.0	0.0	0.0	0.0
125	MASTKGPT	4.6	0.0013	0.0019	79.2
127	SONAR DM	2.5	0.0007	0.0010	-2.0
128	TOWRPLAT	0.0	0.0	0.0	0.0
150	WELDRIVT	29.0	0.0083	0.0117	15.0
151	FREEFLIQ	0.0	0.0	0.0	4.7
	GRP1 TOT	1231.9	0.3508	0.4981	17.7
200	BOILECON	0.0	0.0	0.0	15.3
201	PROPUNIT	111.5	0.0318	0.0451	12.0
202	MN CONDS	0.0	0.0	0.0	8.0

203	SH,BR,PR	67.4	0.0192	0.0273	3.4
204	COMB AIR	7.8	0.0022	0.0032	27.9
205	UPTAKES	12.7	0.0036	0.0051	45.2
206	PROP CNT	6.0	0.0017	0.0024	17.0
207	MN STP S	0.0	0.0	0.0	17.7
208	FW&CONCN	0.0	0.0	0.0	11.8
209	CIRC&CKS	3.6	0.0010	0.0014	6.7
210	FOSERSYS	8.5	0.0024	0.0034	9.8
211	LBCILSYS	11.0	0.0031	0.0045	7.6
250	REPAIPPT	5.0	0.0014	0.0020	15.1
251	OPER FLD	16.5	0.0047	0.0067	8.8
	GPP2 TCT	250.0	0.0712	0.1011	11.5

SHIP NUMBER 1
DETAILED RESULTS--BSCI WEIGHT LISTING CONTINUED

GROUP	NAME	WEIGHT TONS	WT FRAC FULL LD	WT FRAC LITE SH	VCG FT
300	EL PWGEN	96.2	0.0274	0.0389	15.3
301	POW SWBD	14.6	0.0042	0.0059	16.8
302	CABLE	36.8	0.0105	0.0149	21.4
303	LIGHTING	17.8	0.0051	0.0072	22.4
350	REPAIRPT	3.4	0.0010	0.0014	11.9
351	GEN FLCS	0.0	0.0	0.0	10.2
	GRP3 TCT	168.7	0.0480	0.0682	17.4
400	NAV ECUP.	3.6	0.0010	0.0014	40.6
401	IC SYSTS	22.7	0.0065	0.0092	20.9
402	GFC SYST	10.0	0.0028	0.0040	39.6
403	CM NO EL	12.0	0.0034	0.0049	19.5
404	ECM	4.5	0.0013	0.0018	40.1
405	MFC SYS	0.4	0.0001	0.0002	54.6
406	ASW FCS	11.1	0.0032	0.0045	43.2
407	TORP FCS	0.0	0.0	0.0	0.0
408	RADAR	11.9	0.0034	0.0048	42.0
409	RADIOCCM	16.1	0.0046	0.0065	19.1
410	ELEC NAV	2.0	0.0006	0.0008	55.0
411	SPACTRCK	0.0	0.0	0.0	0.0
412	SONAR	9.3	0.0026	0.0038	17.0
413	ELEC TOS	19.6	0.0056	0.0079	33.6
415	ELECTEST	0.0	0.0	0.0	0.0
450	REPAIRPT	4.7	0.0013	0.0019	26.4
451	CC CPFLD	8.0	0.0023	0.0032	-3.0
	GRP4 TCT	135.9	0.0387	0.0549	27.7
500	HEAT SYS	13.1	0.0037	0.0053	9.5
501	VENT SYS	41.2	0.0117	0.0167	26.3
502	AIR CCND	22.4	0.0064	0.0091	18.0
503	REFER PL	7.5	0.0021	0.0030	10.5
504	HEAF,ETC	5.6	0.0016	0.0023	13.2
505	PLUMBING	7.4	0.0021	0.0030	21.0
506	FIPEMAIN	30.4	0.0086	0.0123	17.0
507	FIRE EXT	8.1	0.0023	0.0033	20.2
508	BALSTSYS	8.5	0.0024	0.0034	8.7
509	FRESHWAT	13.3	0.0038	0.0054	18.9
510	SCUPPERS	2.2	0.0006	0.0009	29.4
511	FLELTRAN	20.9	0.0059	0.0084	10.1
512	TANKHEAT	0.0	0.0	0.0	5.1
513	COMF AIR	22.7	0.0065	0.0092	16.4
514	AUX STM	0.0	0.0	0.0	10.5
515	BUOY CNT	0.0	0.0	0.0	0.0
516	MISCPIPE	0.0	0.0	0.0	7.6
517	DISTILLG	5.6	0.0016	0.0022	15.2
518	STEERING	10.8	0.0031	0.0044	11.4
519	RLDDEFS	19.7	0.0056	0.0080	11.1
520	ANCF,MGT	28.2	0.0080	0.0114	19.2

SHIP NUMBER 1
DETAILED RESULTS--BSCI WEIGHT LISTING CONTINUED

GROUP	NAME	WEIGHT TONS	WT FRAC FULL LD	WT FRAC LITE SH	VCG FT
521	STOR ECP	5.0	0.0014	0.0020	29.6

522	ELOPGEAR	0.0	0.0	0.0	0.0
523	AIR ELEV	0.0	0.0	0.0	0.0
524	ACARGEAR	4.0	0.0011	0.0016	24.6
525	CATS&JBD	0.0	0.0	0.0	0.0
526	HYDROFLS	0.0	0.0	0.0	0.0
527	STAB FIN	24.9	0.0071	0.0101	6.6
528	UNREP	21.4	0.0061	0.0087	24.6
550	REPAIRPT	3.5	0.0010	0.0014	15.4
551	AUX FLCS	16.1	0.0046	0.0065	15.1
	GRP5 TOT	342.4	0.0975	0.1384	16.9
600	HULL FIT	11.8	0.0034	0.0048	31.0
601	BCATS	16.7	0.0048	0.0067	34.6
602	RIG&CANV	1.0	0.0003	0.0004	36.1
603	LAD&GRAT	27.0	0.0077	0.0109	14.8
604	NCNS BCD	19.7	0.0056	0.0080	24.6
605	PAINTING	36.5	0.0104	0.0148	18.2
606	DK COVER	14.9	0.0043	0.0060	21.3
607	HULL INS	29.1	0.0083	0.0118	24.2
608	STCREFMS	33.4	0.0095	0.0135	18.6
609	UTIL ECP	8.2	0.0023	0.0033	20.5
610	WKSF ECP	9.4	0.0027	0.0038	18.7
611	GALY ECP	10.2	0.0029	0.0041	23.5
612	LIV FURN	21.6	0.0061	0.0087	21.6
613	OFF FURN	11.9	0.0034	0.0048	25.5
614	MED FURN	1.3	0.0004	0.0005	25.6
615	RAD SHLD	0.0	0.0	0.0	0.0
650	REPAIRPT	1.7	0.0005	0.0007	13.8
651	DEF FLDS	0.0	0.0	0.0	0.0
	GRP6 TCT	254.4	0.0725	0.1029	21.9
700	GUN MATS	12.8	0.0036	0.0052	34.6
701		0.0	0.0	0.0	0.0
702		0.0	0.0	0.0	0.0
703	SP&EPMGS	0.0	0.0	0.0	0.0
704	MIS LHGS	66.0	0.0188	0.0267	21.6
705		0.0	0.0	0.0	0.0
706		0.0	0.0	0.0	0.0
707		0.0	0.0	0.0	0.0
708	TGRFTHGS	2.0	0.0006	0.0008	27.1
709		0.0	0.0	0.0	0.0
710	MINE H&S	0.0	0.0	0.0	0.0
711	SM ARMS	3.0	0.0009	0.0012	24.6
712	AIR HGST	0.0	0.0	0.0	0.0
713		0.0	0.0	0.0	0.0
720	CARGOHGS	0.0	0.0	0.0	0.0
750	REPAIRPT	5.5	0.0016	0.0022	14.9
751	ARM FLDS	0.6	0.0002	0.0002	32.7
	GRP7 TCT	89.9	0.0256	0.0363	23.4

SHIP NUMBER 1
DETAILED RESULTS--BSCI WEIGHT LISTING CONTINUED

GROUP	NAME	WEIGHT TONS	WT FRAC FULL LD	VCG FT
800	SHIP CCE	20.7	0.0059	18.9
801	TRPS&EFF	0.0	0.0	18.9
802	PASS&EFF	0.0	0.0	18.9
803	SHIPAMMO	41.4	0.0118	30.2
804	AV AMMO	2.7	0.0008	26.6
805	AIRCRAFT	17.9	0.0051	31.6
806	PROV&PST	30.3	0.0086	11.6
807	GEN STCR	8.1	0.0023	20.5
808	MARINEST	0.0	0.0	0.0
809	AERC STR	6.7	0.0019	24.6
810	ORDSTRSH	0.0	0.0	0.0
811	ORDSTRAV	0.0	0.0	0.0
812	POTWATER	30.0	0.0085	4.2
813	R FEED W	0.0	0.0	4.7
814	LUBEILSH	14.3	0.0041	13.4
815	LUBCILAV	3.7	0.0011	7.4
816	FUEL CIL	592.5	0.1687	7.7

817	DIES OIL	82.3	0.0234	12.5
818	GASCLINE	0.0	0.0	0.0
819	JP-5	64.3	0.0183	8.1
820	MISC LIQ	0.0	0.0	0.0
821	CARGO	0.0	0.0	0.0
822	BALL WAT	0.0	0.0	0.0
	WRLCAC TCT	914.8	0.2605	10.3
	LIGHT SHIP	2473.2	0.7043	18.1
	WT MARGIN	123.7	0.2605	0.0
	FULL LOAD DISP	3511.7	1.0000	15.5

DETAILED RESULTS--FUNCTIONAL ELECTRIC LOADS

GROUP	NAME	CRUISE KW	BATTLE KW	24 HR AVG KW
100	PAGSTEER	111.6	113.7	124.8
200	AUX MACH	203.7	251.9	170.9
300	DECKMACH	2.0	1.5	0.3
400	SHOPS	6.9	1.2	5.4
500	IC&ELEX	187.4	200.5	167.0
600	ORDA SYS	25.6	-34.1	12.1
700	HOTEL	119.7	93.0	139.5
800	A/C&VENT	789.7	329.7	250.0
900	PWR CCNV	110.0	214.6	99.4
	ELECMARG	503.0	351.6	290.8
	TOTAL KW	2179.7	1523.6	1260.3

1 PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	61
3	2

APPENDIX B

GLOBAL CATALOG

GLOBAL	FORTRAN	DEFINITION LOCATION NAME
1	DISPFL	Full Load Displacement, tons
2	Vsus	Maximum Sustained Speed, knots
3	Vend	Endurance Speed, knots
4	ENDUR	Endurance Range, naut. mi.
5	LBP	Length Btwn Perpendiculars, ft.
6	L/B	Length to Beam Ratio
7	B/H	Beam to Draft Ratio
8	Cp	Prismatic Coefficient
9	Cx	Midship Section Coefficient
.		
.		
.		
77	G1	DISPFL/DPTRY - 1.0
78	G2	CGFLD/KGTRY - 1.0
79	G3	2.0/BTR - 1.0
80	G4	BTR/4.0 - 1.0
81	G5	-R/10.0
82	G6	0.48/Cp - 1.0
83	G7	Cp/0.70 - 1.0
84	G8	0.5/SLRAT - 1.0
85	G9	0.001/Cv - 1.0

APPENDIX B

GLOBAL CATALOG

GLOBAL	FORTRAN	DEFINITION LOCATION NAME
86	G10	Cv/0.006 - 1.0
87	G11	SLRAT/2.0 - 1.0
88	G12	-1.0
89	G13	RSSV/DHV - 1.0
.		
.		
.		
2501		

Note: Elements 2-76 and 90-2501 are contained in the $\underline{S}$ vector described in Chapter II. Only those of interest to the thesis have been listed.

APPENDIX C

NOMENCLATURE

α*	Move Parameter
BTR	Beam to Draft Ratio
B	Beam at Midship Section, ft.
BM	Metacentric Radius, ft.
B/H	Beam to Draft Ratio
Ca	Transverse Moment of Inertia Coefficient
CASDAC	Computer-aided Ship Design and Construction
Cb	Block Coefficient
CGFLD	VCG @ Full Load Displacement, ft.
Cp	Prismatic Coefficient
Cr	Residual Resistance Coefficient
Cv	Volumetric Coefficient
Cwp	Waterplane Coefficient
Cx	Midship Section Coefficient
DISPFL	Full Load Displacement, long tons
DHV	Deck House Volume, ft^3
DPTRY	Displacement Estimate, long tons
FO	Freeboard at Station 0, ft.
F10	Freeboard at Station 10, ft.
F20	Freeboard at Station 20, ft.
FSCORR	Free Surface Correction Factor, ft.

APPENDIX C

NOMENCLATURE

$G_i(\ )$	Constraint Values
GM	Metacentric Height, ft.
GM/B	Ratio of Metacentric Height to Beam
H	Full Load Draft, ft.
KB	Height of Center of Bouyancy, ft.
KG	Height of Center of Gravity, ft.
KGTRY	KG Estimate, ft.
LBP	Length Between Perpendiculars, ft.
L/B	Length to Beam Ratio
OBJ	Objective Function
q	Iteration Number
RSSV	Required Superstructure Volume, ft^3
$\underline{S}$	Search Direction
S( )	Array for Storing Ship Specifications
SHP	Shaft Horsepower
SLRAT	Speed-Length Ratio
VCG	Vertical Center of Gravity, ft.
Vsus	Maximum Continuous Sustained Speed, kts.
$\underline{X}$	Design Variable Vector

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 69Mx Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	2
4.	Dr. Garret N. Vanderplaats, Code 69Vn Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	3
5.	Lt. James L. Jenkins, USN 8700 University Pt. Cir. Bremerton, Washington 98310	5
6.	Professor Dale Caulkins Mail Stop Fu10 Ocean Engineering University of Washington Seattle, Washington 98195	1
7.	LCDR Michael R. Reed, USN Board of Inspection and Survey Washington, D.C. 20320	1
8.	Michael G. Parsons Department of Naval Architecture and Marine Engineering University of Michigan Ann Arbor, Michigan 48104	1
9.	LCDR Dave Stone, USN Department of Ocean Engineering Room 5-317 Massachusetts Institute of Technology Cambridge, Massachusetts 02139	1

INITIAL DISTRIBUTION LIST (Continued)

		No. Copies
10.	Commander (NAVSEA 5011) ATTN: Kit Ryan Naval Sea Systems Command Washington, D.C. 20362	1
11.	Commander (NAVSEA 56D3) ATTN: CDR Dennis Mahoney Naval Sea Systems Command Washington, D.C. 20362	1
12.	Commander (NAVSEA 50112) ATTN: LCDR Ty Cassedy Naval Sea Systems Command Washington, D.C. 20362	1
13.	Commander (PMS 400D) ATTN: CDR Graham Project Manager Systems Naval Sea Systems Command Washington, D.C. 20362	1
14.	Lt. Fred A. Butterfield, III, USN 584-C Michelson Road Monterey, California 93940	1
15.	LCDR M. Maxiner, Code 69MQ Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	1

END