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PRACTICAL ASPECTS OF COMPUTER-AIDED DESIGN OF SHIPS

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SYNOPSIS

The advent of powerful yet inexpensive minicomputers has literally revolutionized the capabilities of the ship design community. A design group equipped with a complete computer-aided design software package and an in-house "supermini" has the potential to produce better ship designs faster and cheaper than groups relying on the conventional manual approach.

This paper examines the potential for increased efficiency and quality in the ship design process through the use of a computer-aided design procedure. A distinction is made between the practical use of a network of ship design programs and the use of a so-called integrated system with specialized command languages and automatic interaction between program elements. As discussed in the paper, the use of an evolving network of computer-aided ship design programs at Giannotti & Associates, Inc. in recent years highlights this distinction and suggests that the successful incorporation of increasingly complex and sophisticated design tools requires a reappraisal of present trends towards "automation".

1.0 INTRODUCTION

The fact that virtually any size ship design group can now afford extremely powerful computers will have a major impact on the course of computer-aided ship design. A design group equipped with modern computational hardware has the potential to produce better ship designs faster and cheaper than groups without such equipment. Whether this potential is realized depends on a number of factors. For the practicing ship design group, large computers and sophisticated ship design or analysis software can be a double-edged sword. On one side, they help by cutting through laborious computations, organizing information, performing complex analyses not previously economical to do, and freeing the designer for the creative aspects of ship design. On the other side, computer programs may be used without full knowledge of the theory and limitations involved, computer output may be unquestioned and accepted as correct and final, "over-analysis" may be performed, the amount of generated information may exceed the capabilities of the designers to assimilate, and the computer-aided ship design process may actually incur more total costs than a conventional procedure.

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It is the purpose of this paper to discuss some of the important factors that influence the successful and practical application of computer-aided ship design programs and methods. The evolution of a computer-aided ship design procedure and the development of a number of programs and techniques at Giannotti & Associates, Inc. is presented to illustrate many of the points. The benefits of computer-aided ship design are illustrated through several examples.

2.0 EMERGING ISSUES IN COMPUTER-AIDED SHIP DESIGN

2.1 INTEGRATED SYSTEM VS. NETWORK - IN DEFENSE OF MODULARITY

In the design of an integrated system to perform some function, in this case -- ship design, the first step is to reduce the overall procedure to series of effectively isolated submodules. In the conventional ship design process, representative of these submodules are such tasks as lines development, hydrostatic calculations, and resistance estimates. The modularity that results from this partitioning permits us to work with more detailed and accessible units of analysis. The functional goal of developers of integrated ship design systems is to successively synthesize larger and larger segments of the partitioned system. The problem is in determining just what the appropriate level of integration might be.

At Giannotti & Associates, Inc. we have arrived at a level of integration appropriate, we feel, for any marine design group that must be eminently practical, employ rationally-based design techniques, and where the designers must maintain positive control over the flow and processing of information. At the level of integration at which our computer-aided ship design system has evolved, a more appropriate description is perhaps a "network", rather than an integrated system. For reasons to be described, it is felt that the concept of a fully integrated system is not a completely desirable approach to practical and responsible ship design. Although our concept of "network" still embodies a relatively advanced level of system integration, the use of a new name helps coalesce the various themes that underly our approach to the computer-aided design process.

Another reason that the term "network" has been adopted rather than "integrated system" is that regardless of the actual meaning of the integrated system concept as applied to ship design, the perceived -- if not implied -- meaning is often "automatic ship design" where ultimately the designer merely gives the machine the design requirements, chooses between several options generated by the computer at the appropriate stages of the process, and then waits momentarily while the lines plan and other drawings roll off the plotter. Even if this might now be possible, it is not desirable, as will be explained.

From the perspective of systems theory, there are several advantages to the maintenance of a certain degree of modularity. As the system theorist might say, the partitioning of the system into semi-autonomous subsystems localizes dysfunctional reverberations. For example, in a fully-integrated ship design system being used to derive optimum seakeeping ship particulars for a given set of sea conditions and headings, a number of "dysfunctional reverberations" may occur. Perhaps the hull form is optimized on the statistical characteristics of the motion response derived from frequency domain predictions. The system might

well develop the conclusion that the smaller the metacentric height, the less roll amplitude. This is certainly likely considering the misleading character of roll RAO's, where the peak amplitude of response typically decreases with decreasing metacentric height. The range of optimized designs would then have insufficient stability.

2.2 THE PRACTICALITY OF THEORY

The capacity of modern non-mainframe computers encourages ship design groups to acquire and use sizeable, theoretically complex and numerically intricate programs. The pressure of tight schedules, or perhaps the simple desire to use something advanced as soon as possible typically create an atmosphere of "Just get it working! We can figure out the details later." More often than not, the so-called details never are figured out. The consequence of what can be termed the "expedience school" of computer-aided ship design is inaccurate results in the majority of cases.

At Giannotti & Associates, Inc., for example, we require that at least one individual educates him or herself on every aspect of the theoretical basis and numerical methods used in the code. It then becomes the responsibility of that person to ensure that the program is not misapplied.

In short, the efficient and responsible use of large, complex analytical capabilities demands a thorough understanding of the theoretical and numerical basis of the codes involved.

2.3 HUMAN-AIDED DESIGN

Scholors of the ship design process always preface a description of their computer-aided ship design system with a discussion of the importance of the human designer -- the human designer who must remain the creative force and who contributes all the uniquely human qualities required for good design. It is probably still well accepted by most that completely computerized design will surely lead to a mediocre product. Yet at the same time, there appears a growing interest in so-called artificial intelligence and its application to the design process. Although any proposed computer-based ship design system seems to always allow the designer to assume complete control when necessary, there may be more and more points in the design process where the designer has the choice to let the computer be the "expert" and make a design decision for him. Given human nature compounded by the perception that computers are usually, if not always right, the human designer may increasingly opt for the "expert" computer to make the decision. If the designer is given an apparently easier path towards the end product, then it is natural for him to take it: even knowing that he or she may be able to do a better job or make a better decision. We will then have human-aided design -- where the human aids the computer, rather than the reverse.

Clearly, the trend in computer-aided design is not only to give the user a choice between alternative technical items, but a choice between choosing for himself or letting the computer choose for him. The impact of such a trend on the quality of the design product must be carefully monitored.

In fact, in many of the programs in the commercial ship design series of the Giannotti & Associates, Inc. CAD network, the computer will instruct the naval architect to refer to a certain figure in a certain report and "pick-off" values from a plot. Even though it would have been a simple matter in most cases to do the line-fitting and equation-coding that would represent the plot, we believe it is worth the extra time required to manually refer to a plot. Such an exercise forces the naval architect to refer to reports and documents that form the basis of the programs and creates the opportunity for further reading of a document that he may never have bothered to review if the computer did everything for him. This technique requires active participation in the process, which we believe imbues to some degree, a greater sense of responsibility in the computed results. The human designer is not permitted to completely abdicate his responsibility to choose and control. The process thereby remains one of computer-aided rather than human-aided design.

2.4 COUNT-ABILITY VS. ACCOUNTABILITY

Computer-aided ship design methods are typically developed in an engineering context. For the practicing ship design group, however, successful ship design must consider profitability and liability. The large investment involved in a ship design and construction effort requires a certain level of accountability throughout the entire process.

As the computer becomes increasingly important in the ship design process, eventually performing all "calculations", the design engineer may have a tendency to feel less responsible for computational aspects of the process. There would seem to be some sense that the computer is responsible for itself, for its methods, for its results. In contrast to such a perception, the reality of the situation is that the human designer must always be held accountable for every computation, whether performed personnally or by his silicon assistants.

Members of the design team using computer-aided design techniques must be regularly reminded of this requirement. For the practical ship design group, it is imperative that members of a computer-aided design team are instilled with a healthy distrust of computer generated results. There is a natural inclination to accept computer output, whether tabular or graphical, as correct. There is also the tendency to accept it as final -- discouraging further iterations or changes. These tendencies must also be considered.

2.5 QUALITY CONTROL OF INFORMATION

In a manual system of design, many people look at the results of computations as calculation sheets or summary sheets flow through the system. Errors can be spotted by any of a number of people through whose hands these calculations pass. The fact that several people work "interactively" as a team performing subtasks of the design effort also adds to the quality control of the information being generated. The redundancy inherent in this system localizes errors, and personal involvement in the "nitty-gritty" of the design process requires attention to details. Furthermore, conventional design is an empirically-based process, while not necessarily producing optimum designs, neither does it easily allow gross errors to be made.

In contrast, most integrated systems, by design, attempt to remove redundancy and emphasize the use of common data. An error which may have been localized in the manual system may, in the integrated computer design system, affect a variety of other facets of the design -- the so-called dysfunctional reverberation. A system of human quality control and a system of automated quality control must be incorporated in the practical computer-aided ship design process. This is critical to the successful and responsible employment of computer-aided design systems.

3.0 PRACTICAL COMPUTER-AIDED SHIP DESIGN

On one hand, rationally-based design methods are gradually changing the philosophy of ship design. On the other hand, the macro-economics of marine transportation demand increasingly efficient and optimum designs, and the micro-economics of ship design firms and shipyards demand increasingly efficient and optimum design procedures. In order for a design group to successfully respond to such dimorphic trends, the use of the present generation of non-mainframe computers coupled with an array of design software is an absolute necessity.

At Giannotti & Associates, Inc., a major effort to develop a set of interlinking computer programs employing rationally-based design methods, yet practical and efficient, has been underway since 1980 with the acquisition of a VAX 11/750 (Digital Engineering Corporation). Many of the issues addressed in Section 2.0 of this paper were resolved as the computer-aided design procedures evolved within the context of the day-to-day practical design experience. It may therefore be worthwhile to present what has become a "network" of computer programs for the evaluation, interactive design, and optimization of ships, as well as ocean platforms and other marine systems. This network is called POSEIDON*, and represents an established group of interlinked programs which are continuously being enhanced.

For mainly administrative purposes, the POSEIDON programs have been classified into six groups, as listed in Table I. Specific areas of application are commercial ships, naval ships, ocean platforms (both fixed and floating), buoys and cables, small craft, and a group of interdisciplinary programs. Within each group there are levels which help organize the types of programs within that group. A typical breakdown structure is shown in Table II, representing the first level breakdown for the C-series or commercial ship design group of programs. Thus, a particular code is given both an identifier, such as N140, and a name, which is in this case a program used in the naval ship design process called SHCP for hydrostatic, stability and longitudinal strength calculations. A roughly comparable program exists in the commercial ship series - identified as C140 and named HYDRO -- similar in capabilities yet quite different in method.

Although the POSEIDON programs apply to both preliminary and detail design of various types of marine systems, for illustrative purposes, the present discussion will be limited to preliminary design of commercial ships. However,

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* Platform (Ocean) and Ship Evaluation, Interactive-Design and Optimization Network.

to give some indication of the quantity and diversity of codes incorporated in POSEIDON, Table III has been prepared. Many of the programs exceed 10,000 lines of code and require in excess of 500 kb of addressable memory, yet are easily within the capabilities of the VAX.

The computer-aided preliminary design of commercial ships will be discussed in two-parts. The first will deal with all aspects of the process with the exception of structural design. The second part will address rationally-based structural design as incorporated in POSEIDON.

3.1 A PRACTICAL SHIP DESIGN PROCEDURE

3.1.1 Concept Design - "Blocking Out" the Ship

Given owner requirements of deadweight, speed and range, with perhaps some specified dimensional constraints, the first objective is to obtain the basic characteristics of several alternative ships that will meet the owner's requirements. The number of ships retained at the end of this process depends on the type of performance requirements that may have been specified.

Computer programs used for this purpose are listed below in Table IV. Most are interactive and are developed from empirical data. At a "session" with one of these programs, the user will derive a feasible ship that satisfies owner's requirements, where weight nearly equals displacement, GM is satisfactory and freeboard is adequate. If the user wants to "record" the results of the session, he will provide an identifier number. A data file will be created for use with the BOSUMMARY program.

The BOSUMMARY program asks for the identifier numbers associated with those "ships" he would like to present and compare in tabular and graphical form. Using this information, conclusions or decisions can be made regarding which ship or range of ships will be "best".

3.1.2 Master Files

The computer-aided ship design process at Giannotti & Associates, Inc. uses three direct access unformatted data files - (1) the ship design master file; (2) the ship performance master file; and (3) the ship structure master file or SDMF, SPMF and SSMF respectively. At the beginning of the design process, the files are empty except for the very basic information produced by the concept design - L, B, T, D, ∇ , deadweight, etc., and usually information on the selected operational and environmental parameters - a range of significant wave heights, modal periods, probability of occurrence of sea states, etc. As the process progresses the working files are written to with results from analyses, and read from to provide input data for subsequent calculations. At any time during the design process, the project manager can run program REPORT1 which provides a design summary sheet listing values in the work files at that time or indicating the accomplishment or nonaccomplishment of certain analyses, the results of which are too extensive to list in a design summary sheet. This is also used by the project manager to track changes in the design as the effort progresses.

There is also a program named DISPLAY1 which displays on the CRT screen the value of a selected item in the data base. Typically, in a time-critical design effort, where a number of people are working on different aspects of the design, important changes occur in the basic design rapidly. The engineer at a CRT, when there is some doubt in his mind what the design draft is for example, can find out through DISPLAY1.

With respect to changes in the design data as the effort progresses, the project manager is the only person with "permission" to modify the basic dimensions and hull form once they have initially become part of the ship design work file.

3.1.3 Hull Form

Despite the tremendous possibilities for interactive hull form generation, we have found that most naval architects still like to sketch out a rough set of lines on paper. Paper and pencil still remain the better medium through which to create a hull form. The interactive use of the computer, however, has turned out to be the most desirable approach to modification of hull lines once an initial set of offsets has been entered.

There are two methods of producing a rough set of moulded offsets:

(a) Using the offsets from a final ship design file (.FSD) of a pre-existing design.

(b) Lifting the offsets from a sketch created by the naval architect or from a body plan obtained from some other source - owner, magazine, design report, etc. In the event that the offsets are to be lifted from a sketch, an 11" x 15" digitizing tablet is employed in conjunction with the program LIFTOFF. (The program LIFTOFF is also used to "lift out" the offsets from a final ship design data file. In either case, the result of running LIFTOFF is the creation of a work file containing the rough offsets [.OFF].

The next step is to use the program REFORM to provide the means to modify the offsets and provide some initial checks on displacement, C_B, C_P, C_M, LCB, LCF, natural heave, pitch and roll periods, and GM. For the hydrostatic checks, linear interpolations are made between offset points, so the program is fast, there are no problems with ill-behaved spline formulations, and accuracy is typically within 5% of hydrostatic values calculated using more complex representations.

The modification process is iterative and takes advantage of the light pen. The naval architect is presented with his choice of three views of the lines on the CRT. Cubic splines are displayed running through the offset points. In order for the user to change the position of an offset point, he touches it with the light pen, and then types in how much he wants to move the point forward or aft ($\pm$ X) , up or down ($\pm$ Z) , inboard or outboard ($\pm$ Y).

Any number of points can be moved. When a display of the modified plan is desired, the user touches the appropriate "menu" item with the light pen, "DRAW BODY PLAN", for example, or when calculation of rough hydrostatics is desired, the user touches "HYDRO CHK" on the menu with his light pen. He then evaluates the effect of his modifications. He can continue this process of checking and changing until he feels he needs a larger drawing, at which point he can select "PLOT" which causes a three view drawing to be produced on the line printer. The user can then either continue modifications, stop with the idea that further modifications will be made sometime later (to the [.OFF] file), or the [.OFF] file contents can be written to the ship design master file. Once these offsets are in the SDMF, they are protected and can only be modified or replaced with the project manager's password for hull form change authorization.

Also written into the SDMF are the rough hydrostatics. These will be replaced later on through the execution of the complete and more accurate hydrostatics program HYDRO.

The program REFORM can be used to modify the offsets even after they are entered into the ship design master file, using the appropriate password. However, another program, FAIRB is presently under development to assist in fairing up the hull form. The basis for FAIRB is surface definition using B-spline surface representation. Such a program would be used at the initial phase of the design process if there is time and money to carry out further fairing of the lines. If there is not time, the offsets resulting from the use of REFORM are in most cases sufficient for all analyses in the preliminary design phase.

3.1.4 Resistance and Propulsion

There are now a large number of reports providing model test based resistance data for a wide range of ship types and sizes. The results presented by Guldhammer and Harvald [6] have proved particularly useful and represent consideration of model test data from at least ten sources. The program SPROP uses their results to estimate resistance.

The wake, thrust deduction and relative rotative coefficients are calculated using data from Harvald and Hee [7]. For propeller characteristics, the program uses data for the Wageningen B and BB-series, reported by Oosterveld and Oossanen [8].

The procedure we selected for resistance and powering follows one developed at the Technical University of Denmark. It is anticipated that more resistance data and propeller data will be incorporated, the selection of which will be at the option of the naval architect. However, for the first level of development, the data and approach presently employed are quite satisfactory. Similar to the capabilities of the Danish resistance and propulsion programs, two procedures can be followed for a given ship. In the first instance, given propeller data, the program can calculate the machinery power and RPM's for a number of ship speeds. In the second case, with the propeller unknown, the user can provide one of three sets of ship and propeller parameters, and the program will estimate the missing propeller characteristics and ship powering data.

There is also the option for the user to enter his own data for resistance and coefficients.

3.1.5 Partitioning or Arrangements

Coincident with resistance and propulsion computations, the hull form can be partitioned with plane surfaces representing decks, transverse and longitudinal bulkheads, double bottoms, wing tank bulkheads, etc. Additionally, superstructures can be added constructed of plane surfaces. An interactive program named PARTITION assists in the partitioning of the interior volume of the ship and the addition of the superstructure. At various points in the creation process, a printout of compartment volumes, dimensions, areas (and capacities if used for cargo) can be printed. Watertight bulkheads are identified as such and this information becomes useful in subsequent calculations of floodable length and damaged stability.

Typically the designer will simply specify the height above baselines of continuous decks, and additionally the longitudinal limits of partial decks. He will then have the deck outlines printed on the plotter to provide drawing board size plots. He then can work with these outlines at the drawing board to rough out further internal partitioning, ensuring for example that the engineroom is sufficiently large for the propulsion machinery that has been selected or hopefully will soon be sized based on the resistance and propulsion calculations.

In any event, specification of bulkheads, decks, etc. is presently done through the keyboard, where the user responds to prompts from the program. During the course of this arrangements process, information created or used is contained in a work file [.ARR]. When a satisfactory arrangement has been derived, the information is transferred to the master design file.

3.1.6 Weight

Weight related information is derived through the use of the interactive program WEIGHT. Using data existing in the ship design master file as a result of previous analyses, the program WEIGHT can provide information about light ship and loaded weight curves, buoyancy, bending momenht and shear curves, and the vertical and longitudinal location of the center of gravity. There are actually several possible techniques from which the user can choose. The following subroutines in the WEIGHT program can be employed for various items of interest.

Name	Description
WTWATSON	Weight estimate for various types of ships for steel weight, machinery and outfit weight. Based on the formulae from Watson and Gilfillan [2].
WTJOHNSON	Weight estimates for tankers based on a large data base of historical information. Categories are Hull Steel, Cargo Oil System, Propulsion System and Outfit. Based on R.P. Johnson [9].
WTWOOD	Weight estimate for tankers based on proprietary data.

KGWATSON1	Estimates lightship KG by volume density method using procedure from Watson and Gilfillan [2]. Partition information from ship design master file required.
KGWATSON2	Estimates lightship KG by profile stability method using procedure from Watson and Gilfillan [2].
LCGWATSON	Estimates LCG and weight distribution using a method which relates sectional area curve to weight curve. Also from Watson and Gilfillan [2].

The user can either specify a lightship weight curve, or use one of the weight estimating subroutines to derive magnitudes of weight for hull, machinery and outfit. The user can either specify cargo weight magnitude and distribution or using the information derived from running the partitioning program, assign added weight to specific spaces as identified through the PARTITION program. The KG subroutines then determine a KG, and the LCG subroutine derives a weight curve from the values derived from the subroutines (or user specified).

Once the light ship and loaded weight curves are derived, the WEIGHT program applies a still waterline buoyancy load, or either and L/20 or $1.1\sqrt{L}$ wave for static design hogging and sagging conditions to be used for roughing out the midship section. Note that the midship section may have been already designed so that the weight information derived from its design can be used in specifying the steel weight curve. Both graphical and tabular displays of weight curves, buoyancy, bending and shear moment are produced.

3.1.7 Midship Section Design

The program MIDSHIP has been developed to assist the naval architect in designing a midship section appropriate for the preliminary design phase. At present the user must sketch a rough section on paper and make some scantling estimates. He then enters the type of element (plate, beam, or several types of stiffeners), the location and thicknesses into the computer via the keyboard, responding to prompting from the machine. Once all the elements are entered, the calculated section moduli, weight, VCG and neutral axis are displayed. Also a plot of the section is made, with each element numbered. This plot is used by the naval architect to assist in modifying the section to help optimize for weight and strength.

The modification process is done interactively. The user can specify a change, addition, or deletion of an element, its characteristics and location. After each modification, a recalculation of weight, section moduli and neutral axis is displayed. The process continues until the user is satisfied. The results are contained in a work file (.MID). If the weight program has been executed already, the user can cause maximum stresses to be calculated using the bending moment curve derived in WEIGHT. The stresses are displayed in addition to the other values of interest when the bending moment is already in the master file.

3.1.8 Hydrostatics and Intact/Damaged Stability

The program HYDRO calculates hydrostatic characteristics and produces curves of form and trim diagram. The HYDRO program uses a non-typical method for evaluation of underwater areas, volumes and centers. The hydrostatic pressure acting on the wetted surface is evaluated to determine the magnitude of the buoyant forces and moments when the vessel is placed at any angle of heel or trim, even with the deck submerged. In reality, the pressure gradient over the actual submerged volume is integrated in accordance with Gauss' Theorem. Thus, a volume integral approach is used.

The intact and damaged stability characteristics are evaluated using the program STAB. The partition data stored in the design master file is used. The program responds to the user's selection of damaged compartments and yields righting arm curves for various conditions. A plot of floodable length can also be requested. There is an option for the user to shift watertight transverse bulkheads in an effort to adjust the floodable length results to arrive at a required level of subdivision. Graphical and tabular output of intact and damaged righting arm curves are provided, using either the KG from the design master file, or for a range of KG's as provided by the user for analysis purpose.

3.1.9 Ship Motions and Loads

Giannotti & Associates, Inc. has developed two programs for the prediction of motions and loads. The first is a frequency domain strip-theory program and the second is a time-domain simulation program.

The frequency-domain program [Program SML] can use either Lewis forms or Frank close-fit method to calculate the sectional hydrodynamic coefficients. The coefficients for the equations of motion are assembled using the equations from Salvesen, Tuck and Faltinsen [10]. Statistical response values are calculated using operational and sea environmental data placed in the ship design master file at the outset of the design process.

Extreme values for both motion and wave loads, either hull girder or distributed pressure, is evaluated using either of Ochi's long term or short term extreme value methods [11].

The time domain simulation model [Program SSX] accounts for the actual wetted surface at any time, calculating hydrostatic and hydrodynamic forces based on the actual immersed hull. Thus, effects of variations of above water hull shape can be evaluated. This is particularly useful for evaluating the effect, if any, of bow flare on the motions of the vessel.

There are several post processing programs that (a) determine Motion Sickness Indicators for various locations on the vessel [Program SEASICK], (b) the quantity of green water shipped and the resultants loads [Program DKWET], (c) maneuvering characteristics [Program STEER], (d) the sensitivity of selected ship responses to variations in sea spectra characteristics [Program SEASENS] and, (e) 2-DOF Motion Optimization program [Program MOTOPT].

3.2 RATIONALLY-BASED STRUCTURAL DESIGN

There are three essential facets of ship structural design. The first is to determine the demand on the structure. This involves applying forces and evaluating stresses. The second is to determine the capability of the structure. This is related to such properties of the material of structure characterized by yield strength, buckling strength, fatigue limit, etc. depending on what mode of failure is being considerd. The third aspect relates to factors of safety -- the extent that capability exceeds demand. The techniques to evaluate demand and capability that have been traditionally employed are familiar to all naval architects, such as an empirical static design wave, the design head, allowable stress levels, and simple multiplicative safety factors. The conventional procedure is simple, time tested, is based on past experience and apparently works well for conventional ships.

Nevertheless, there are several disadvantages to the rulebook approach. The modes of failure are complex and interdependent and there was no way to know if the structure is "overadequate". Traditional design avoids structural failure based on generally applied formulae and procedures which do not necessarily represent the best approach for the particular design at hand. Lastly, conventional design incorporates a number of simplifying assumptions, the limits of which are frequently violated as increasingly larger and unique structures are desired to meet the demand for greater reliability, efficiency and economy.

Rationally-based structural design, on the other hand, provides the approach to design a ship structure using modern "demand" prediction techniques (ship motion/load programs and probabilistic extreme design value methods), scientifically based concepts of "capability" in all possible modes of failure, and the probabilistic concepts of reliability and failure.

According to Hughes [12], rationally-based structural design is "directly and entirely based on structural theory and computer based methods of structural analysis and optimization, and which achieves an optimum structure on the basis of designer-selected measure of merit". This type of design was first developed and applied for aircraft and continues to be applied because of its ability to achieve optimum structural efficiency, thereby reducing weight.

A program called MAESTRO has been developed by Professor Owen Hughes which now provides the capability to design ship structures, as well as other steel structures, fixed or floating, in an entirely rational manner. The program is the product of a 10 year development and testing effort. A partially complete and cruder forerunner was called SHIPOPT [13-15]. MAESTRO provides the capability to analyze, optimize, and evaluate large complex structures.

The rationally-based ship design procedure as applied to preliminary ship design can be described by six tasks:

1. The external loads are predicted as accurately as possible, using statistical methods where appropriate.

2. The load effects and limit values of load effects are calculated accurately throughout the structure for all loadcases.

3. The minimum required margins between the load effects and their limit values are all selected on the basis of a required degree of safety.

4. The resulting strength requirements are expressed in the form of mathematical constraints on the design variables (in most cases nonlinear constraints).

5. The designer is left free to specify the measure of merit of the structure, that is, the criteria that is to be used in achieving the best structure, and the influence of each design variable on the measure of merit. Also the designer is able to specify any number of other constraints on the design, of any form whatsoever, in addition to the strength-related constraints.

6. An optimization method automatically and efficiently solves for the values of the design variables which give the maximum value of the measure of merit while also satisfying all of the constraints.

Figure 1 shows the design process. It is not possible here to fully describe the details associated with each aspect of this process, or provide a full description of the MAESTRO program. The reader is encouraged to review References [12]-[15]. Emphasis will be placed instead on how MAESTRO forms the centerpiece of the computer-aided structural design network at Giannotti & Associates, Inc.

Figure 2 illustrates the structural analysis sequence. The first step is to perform a hull girder analysis. In most cases, this should have already been accomplished and the results would have been contained in the ship performance master file. The hull girder loading provides some of the boundary conditions for what is called a "hull module". This is the basic unit of analysis for MAESTRO. The process can stop here, using MAESTRO to provide the response of the structure to various load cases, to optimize for lower KG or weight and hence cost, and to evaluate the degree of safety, indicating any deficiencies in a "report card". MAESTRO allows the naval architect to build a ship structure using terminology and "construction methods" familiar to the naval architect. Thus, the user can "build" a ship model rather than a finite-element model.

If there is an indication of marginal degrees of safety in certain areas of the hull module structure, a submodule analysis is then carried out using a standard finite element program. Typically, SAP V or NASTRAN is used for this purpose. The loads for the finite element model are obtained from the MAESTRO hull module analysis. In finite element modeling of ship structures, determining the appropriate loading is critical. Using the process described here, this problem is generally solved. If the sub-module analysis indicates a problem area at or near some particular structural detail, then that detail can be further modeled with a finer mesh finite element model.

Thus, through a process of refinement of models representing the ship structure, any level of detail can be examined, using as loading values those response values from the previous larger scale analysis.

The input data required for the structural analysis process is available from various sources. From the ship design master file are read ship specifications, general characteristics, general arrangement, hull form, light ship and load condition weights and distribution, and environmental and operational parameters. From the ship performance master file comes design values of hull girder loading, and in some cases, distributed pressures. From the ship structure design file comes a definition of the hull module, sub-module or structural detail in terms of nodes and elements, material properties, allowable stress levels, and the relationship between weight, cost and stability.

After exercising MAESTRO, a number of working files are created. After the results have been checked and approved, the contents of the working files are moved to the ship structure master file. This includes deflections and stresses, evaluation of the safety factors for each element, optimized KG, weight, cost and other miscellaneous items. Some of these items, in turn may be read from the ship structure master file to be used for structural detail analysis.

4.0 CONCLUSIONS

The low cost availability of powerful non-mainframe computers is beginning to have a major impact on the ship design community. The potential for increased efficiency and quality in the ship design process through the use of computer-aided design procedures is great. Whether this potential is realized depends on such time worn concepts as personal accountability, double checking computations (in this case computer computations), thoroughly understanding the limitations and applications of an analytical tool as a precondition to responsible use of that tool, not always giving the designer the "easy way out" (or he is likely to take it), and the fact that the more complex the system, the greater the likelihood of something going wrong. These practical aspects of computer-aided ship design must not be lost in the push for greater automation in the various ship design "systems" now evolving throughout the world.

The commercial series of the POSEIDON programs presented in this paper have been used to a greater or lesser degree in recent ship designs at Giannotti & Associates, Inc., including the concept, preliminary and detail design of a 400 foot passenger ferry; preliminary and detail design of a 30,000 dwt tanker; the concept design of a luxury liner, and various conversions of containerships into U.S. Navy rapid deployment ships. In each case, the use of various segments of the computer-aided design network discussed in part in this paper, provides what we believe are more efficient, higher quality, and usually a more reliable and safer design by keeping sight of the practical side of computer-aided ship and ship structural design.

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TABLE I

Computer Program Groups in POSEIDON

Program Group	Application
C-Series	Commercial Ships
N-Series	Naval Ships
O-Series	Ocean Platforms
B-Series	Buoys and Cables
Y-Series	Small Craft
I-Series	General or Interdisciplinary

TABLE II

Program Levels Within the C-Series Group

Program Level	Program Types
100	Hull Form, Hydrostatics, Stability
200	Weights, Arrangements, Volumes, Capacities
300	Resistance and Propulsion
400	Seakeeping and Maneuvering
500	Structures
600	Marine Engineering/Shipboard Systems
700	Detail Design Support
800	Miscellaneous - Engineering
900	Miscellaneous - Non-Engineering

Table III A
Poseidon C-Series

Program Name	Purpose	Remarks
BOJOHNSON	Blocking out concept design for tankers and dry cargo ships	Interactive
BOLYON1	Blocking out conceptual design	Interactive
BOLYON2	Optimization version of BOLYON1	Interactive
BOWATSON	Determines weight, displacement and powering aspects of volume dependent designs	Data File
BOSUMMARY	Summarizes in graphical and report form the results of interactions with Bo programs which are stored in temporary work files	Uses Work Files
REPORT1	Reports on current data in ship design master file [SDMF]	
DISPLAY1	Responds to interactive queries regarding current values in ship design master file	Interactive
LIFTOFF	Assists in lifting off ship offsets from sketch, or, uses ship design master file of pre-existing vessel.	Creates work file of rough offsets [.OFF]
REFORM	Modifies offsets, displays hull lines, plots lines, calculates and displays rough hydrostatic	Interactive Graphics
FAIR-B	Hull fairing program using B-spline surface representation	Under Development
SPROP	Resistance estimation and propeller design	Interactive
PARTITION	Assists in partitioning the ship with decks, bulkheads, superstructure. Prints compartment volumes, dimensions, areas, capacities, etc.	Interactive. Creates work file [.ARR].

Table III-A (Cont.)
Poseidon C-Series

Program Name	Purpose	Remarks
WEIGHT	Estimates and calculates light ship and loaded weight curves, buoyancy, bending moment and shear curves, KG and LCG.	Interactive. See subroutines in Section 3.1.6.
HYDRO	Hydrostatics - Curves of form and trim diagram.	
STAB	Damaged and intact stability righting arms, floodable length.	Interactive.
MIDSHIP	Midship or other section design assistance. Section moduli, neutral axis, weight, KG, etc.	Interactive.
SML	Frequency-domain strip theory ship motion and loads program.	Lewis form and/or Frank close-fit.
SSX	Time domain ship simulation program.	Strips and 3-D Source representation.
SEASICK	Computer motion sickness indicators for specified locations on the ship.	Uses data from SML program contained in ship performance master file.
DKWET	Predicts quantity of green water shipped and resultant loads.	Uses data from SML program.
STEER	Maneuvering characteristics program.	Use data from SML program.
SEASENS	Evaluating sensitivity of selected responses to variations in sea spectra characteristics.	Uses data from SML.
MOTOPT	2-DOF motion optimization program.	

Table III-A (Cont.)
Poseidon C-Series

Program Name	Purpose	Remarks
MAESTRO	Analyzes, evaluates and optimizes 3-D steel ship structures.	Owned and developed by Owen Hughes.
SAPV	General Purpose finite element program.	

Table III-B
Poseidon N-Series (Partial List)

Program Name	Purpose	Remarks
SHCP	Ship Hull Characteristics Program for hydrostatics, stability and longitudinal strength.	U.S. Navy Program
SMP	6-DOF Ship Motions/Loads Program	U.S. Navy Program
MITA, MITN, M	5-DOF Ship Motions/Loads/Hull Flexure and Sea Sickness	
HULDEF	Hull Fairing Program using cubic splines.	MARAD/USN
SDWE	Weight estimating data.	USN
UPDATE	Complimentary weight collection, maintenance, storage modification program.	USN
PIPLG	Program for sizing pipe networks for incompressible fluids.	USN
NGHG	Ship Electric Power Analysis.	USN

Table III-C
Poseidon O-Series

Program Name	Purpose	Remarks
DRIFTD	Predicts second order wave drift forces.	Developed and owned by B. Oppenheim.
SEML	Static Analysis of Mooring Lines.	Developed and owned by B. Oppenheim.
LAMVED	Linear Dynamic Analysis of Moored System.	Developed and owned by B. Oppenheim.
NAMVED	Non-Linear Dynamic Analysis of Moored System.	Developed and owned by B. Oppenheim.
EUREKA	Hydrostatics of floating platforms of arbitrary shape or a composite of geometric elements.	Developed and owned by J. Randolph Paulling, Inc.
HYDRO/CATMO	Strip theory hydrodynamics analysis of loads and motions of single or twin-hull ships or platforms.	Developed and owned by J. Randolph Paulling, Inc.
SPLASHD	Quasi-linear frequency domain analysis of platform response to waves/current.	Developed and owned by J. Randolph Paulling, Inc.
HYDRO3	Three-dimensional source distribution program for wave forces and motions of floating bodies with zero forward speed.	Developed and owned by J. Randolph Paulling,
WAVLODE	Source method and Morrison equation loads analysis of fixed structures.	Developed and owned by C.J. Garrison & Assoc.
WAVLODA	Same as WAVLODE with some numerical approximations for reduced run cost.	Developed and owned by C.J. Garrison & Assoc.
ARBOD	Source method for floating large, arbitrary-shaped bodies; motions in frequency domain.	

BOSUMMARY

BOWATSON

BOLYON2

BOLYON1

BOJOHNSON

Table IV

Interactive program to assist in blocking out concept design for tankers and dry-cargo ships. Relationships between displacement, deadweight, speed and range are included, along with relationships involving length, block coefficient, shaft horsepower, weight of steel, outfit and machinery. The data are old but useful for comparison and frame of reference. Data are from Johnson and Rumble [1].

Interactive program to assist in blocking out various types of ships. Uses data from Watson [2] for basic dimension relationships, from Shaher [3] for speed-power relationships, and several other formulas from Katsoulis [4] for GM, optimum speed, etc. The procedure is principally for general cargo ships and bulk carriers. The starting point is cargo deadweight, speed, and range. The output is block coefficient, L, B, T, D, Displacement, GM, SHP and Freeboard. The general procedure is based on Lyon [5], but does not perform optimization.

Optimization version of LYON1.

Determines weight displacement and powering aspects of volume dependent designs. From Watson and Gilfillan [2]. Requires data file.

This program takes the data generated by interactions with BOJOHNSON, BOWATSON, or BOLYON1 which was temporarily stored in data files and summarizes in tabular form and plots the results for comparison purposes.

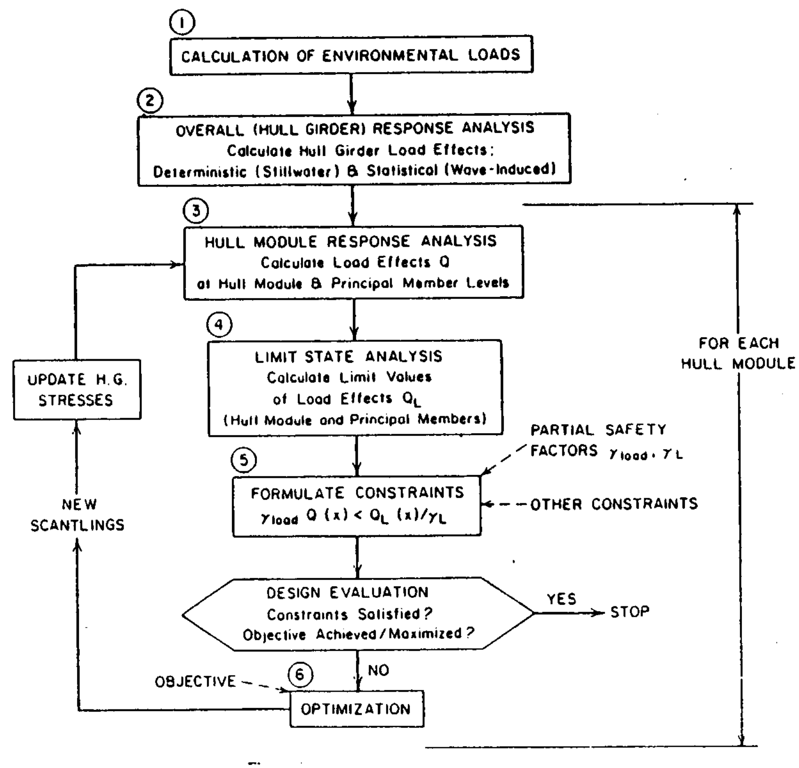

Figure 1
Rationally-Based Structural Design

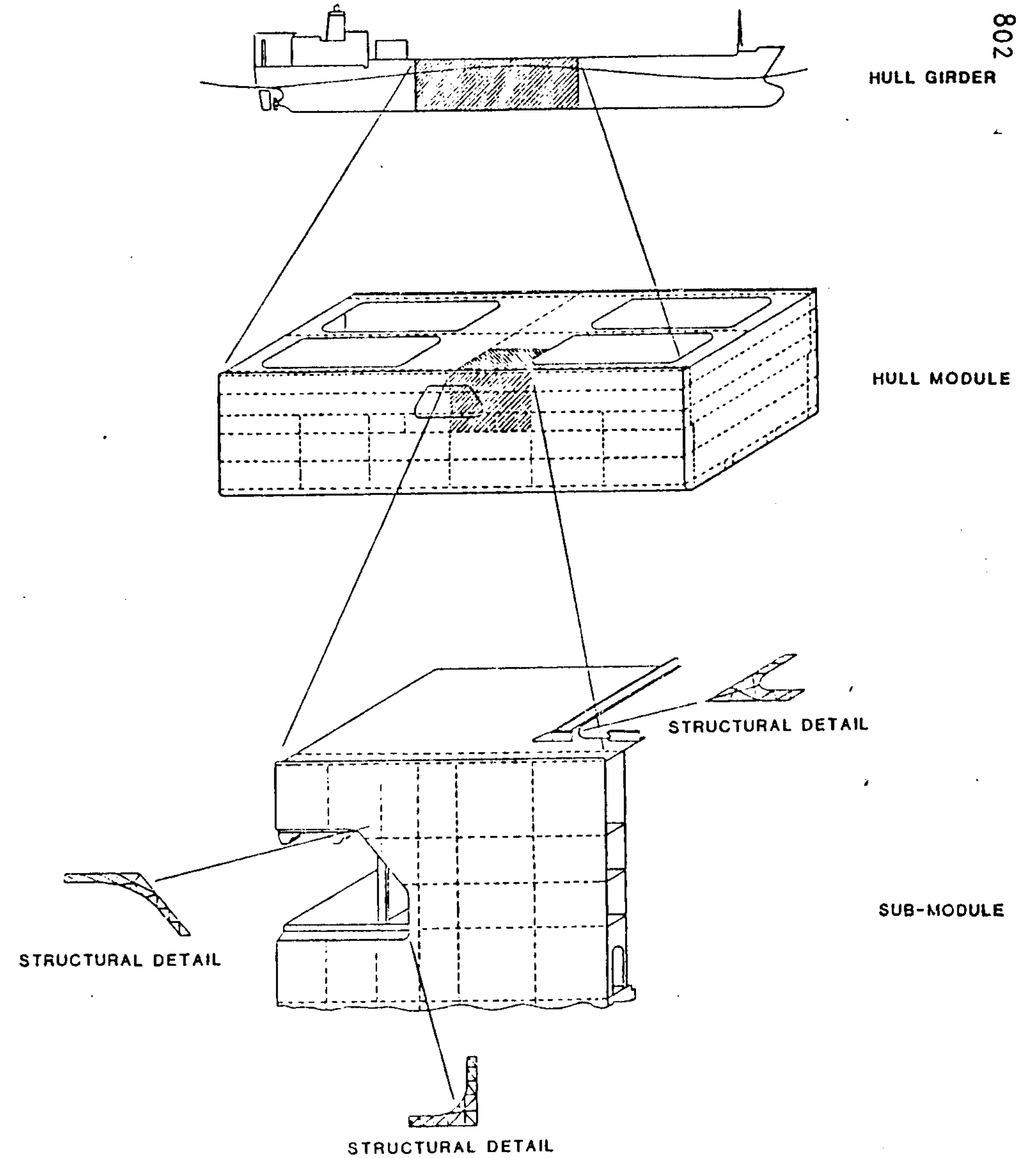

Figure 2
Structural Analysis Sequence