J. HARVEY EVANS

BASIC DESIGN CONCEPTS

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Granted that the ultimate end to the endeavors of all technology is to improve the lot of mankind, the only significant difference between "engineers" and "scientists" is in the immediacy of their concern for the implementation of this ideal. In their highest manifestations the projection of creativity and the tool of analysis are essential to both views. In education, the birth of wisdom should be sought no less than the development of intellectual brilliance.

Especially in design integration and optimization is the former quality absolutely necessary, and the training of engineers should reflect this emphasis, for design is surely one of the prime facets they must cope with thereafter in their professional lives.

H. L. Cox is quoted as saying that, "Design is, after all, an art, and the art of design may be defined as the attempt to achieve a precise object only vaguely known, by the application of strict rules only imperfectly understood". As an improvement on this statement one could only hope for a word other than "art" to acknowledge more pointedly the contribution of the mind as well as of the eye, for the process must be reasoned and orderly. Matters of taste enter, but also far more.

GENERAL DESIGN

Should the structural design of a bridge be contemplated, immediately it becomes apparent that, while the live portion of the total design load may be known, the dead load, including the structure's own weight, can not be known accurately until the complete design has been effected. Furthermore, the dead load may be a major part of the whole. Thus an iterative procedure must be adopted and early gross estimates must be made, refined subsequently and re-entered into the solution. In more complex problems, which necessarily involve more compromises owing to the increased state of incompatibility resulting from the many more requirements, these initial estimates and decisions may be critical. They form the nucleus about which the final design is ultimately crystalized. With a high degree of compromise, no unique, optimum solution may be readily discernible. In such a case, only time and service experience can demonstrate the part that wisdom may have played in the initial stages.

Ships and aircraft are examples of such extremely complex problems. Not only are they structures, but vehicles as well. Furthermore, they are vehicles whose efficiency or, in fact, whose very ability to perform at all, is strongly dependent upon weight economy. Quite obviously their structural loadings are of a dynamic nature and highly imponderable. Ships, because of their size, cost, and length of building time are built to any particular design in but limited numbers and no mock-up or test model can be afforded. Nor can the feedback of measured loading data or other service experience be more than a fraction as voluminous as for aircraft. Only fragmentary statistical samples are available. If, in fact, there is any more conservatism in the structural design of ships than in aircraft, it is hardly to be wondered at. But competitive economic pressures operate to limit any excesses. Despite the rigour of the limitations, the demand for the over-all optimum design solution is equally severe.

Figure 1 is an attempt, by means of a model, to display a rational over-all design procedure as applied to a hypothetical but typical, surface cargo ship problem. The purpose is to assist in organizing the thought process, having in mind particularly the use for such, so as to enable ship design problems to be solved most efficiently, and by means of automatic computers, if desired. The radial lines of the diagram represent the salient considerations of the designer arranged, it is believed, in the logical order most conducive of rapid convergence on the ultimate, refined and balanced solution indicated by the inner closed circle.

Achievement of this end result may conceivably be initiated from any of several points, but the preference expressed by the diagram is first for a rudimentary concept of the ship's general arrangement which will come to mind as soon as cargo density and the size of unit shipment are specified. A cargo density in the region of 45 ft.^{3}/ton seems to mark the boundary between those cargo ships designed as weight limited as opposed to those which are volume limited. The double hulled bulk ore carrier type is

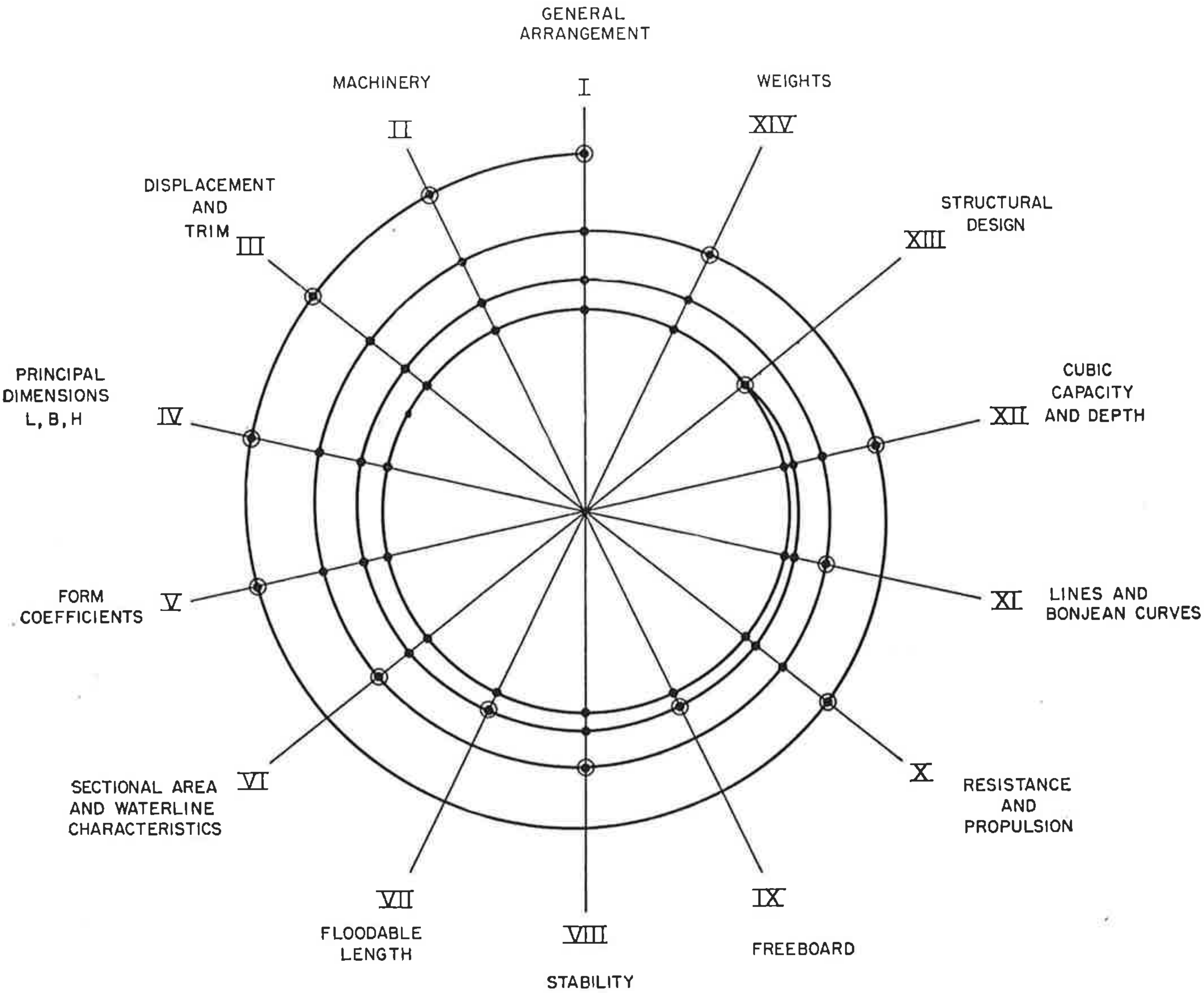

Figure 1. General Design Diagram.

characteristic of one extreme and the deep shelter decker of the other.

Also an arbitrary but tentative choice of the type of main propulsion machinery is a practical necessity.

Whether the vessel be a bulk or volumetric carrier, the deadweight ratio provides the first means of translating the cargo deadweight into a ship displacement and thus a first impression of ship's size is gained. This third consideration of the first design cycle may be conveniently designated III-1.

Gross estimates of the principal dimensions of the underwater form, viz. length, breadth and draft, follow naturally with some guidance from accumulated data on the geometric proportions of earlier, good designs.

The underbody form coefficients require attention at about this point and they are chosen most logically with resistance and propulsion in mind.

From such elementary beginnings some estimate of power requirements may also be made by incorporating the additional factor of speed required, as prescribed by the owner.

The depth of ship and topside characteristics then follow, to suit volume requirements, most of which will be devoted to cargo or payload of whatever type. Over-all hull form coefficients extrapolated from the underwater counterparts will be found useful for this purpose. The vessel's range of operation, plus the shaft horsepower previously estimated, permit evaluation of that portion of the volume to be occupied by fuel.

The foregoing procedures are not dealt with here in detail since they are well known and may be accomplished with the aid of such material as is presented in References 1 through 18, which list is by no means all inclusive. The rough outline is included simply to illustrate the manner in which, with proper sequencing, one item builds on others previously established and how it in turn will contribute to the solution of succeeding ship characteristics.

To complete the first rough hewn cycle, a preliminary light ship weight estimate must be made, probably in terms of the several major weight groupings such as hull steel, machinery and outfit which latter may be subgrouped depending upon whether it is variable with cargo, numbers of passengers and crew, or with size of ship. As references, the sort of data and the methods of items 3, 4, 9, 10 and 19 through 23 of the Bibliography will be of use and thus a new, somewhat more refined, estimate of total displacement will be possible which can also incorporate a more exact fuel oil weight now that a first estimate of power has been made.

In the foregoing remarks, it has been assumed that the owner's ship performance requirements have been set forth by his specifying, as a minimum, merely (1) total weight and density of cargo or payload to be carried, (2) vessel's speed and (3) length of voyage, these having resulted from an economic analysis of the owner's experience and future plans. Fixing additional characteristics, such as maximum draft, type of machinery, evaporator capacity, etc., although reducing the number of decisions to be made by the naval architect, may make the ultimate, absolute optimum design more difficult to achieve. In somewhat more specific naval architectural terms as applied to the general cargo carrier type, this optimum design will require that the vessel, when laden with the specified cargo plus fuel, fresh water and stores sufficient for the specified voyage at the specified speed, shall have all holds completely full and be down to her maximum limiting draft based on considerations of her freeboard, internal subdivision and strength of hull. In this "full and down" condition the cost of the voyage shall be a minimum, also the cost of construction, insofar as these are compatible. This represents idealized operation of the ship but it serves to clarify the issues involved. For design purposes, the naval architect should also assume the cargo to be homogeneous, i.e. having the same density in all holds unless the owner's requirements specifically dictate otherwise. This is the one inflexible condition of loading and thus it becomes the worst reasonable one. With a shipment of varying density, the manner of stowage can be made to improve transverse stability, trim and ship bending moment situations over the homogeneous cargo case. True, stowage of nonhomogeneous cargo can also make these situations worse but it need not do so.

Whenever the ship's desired performance characteristics fall within usual limits, the procedure outlined so far is more a matter of minutes than of hours, even if manually performed, provided a full range of background data is available and in readily usable form. Despite considerable reference to papers of value for this first phase of development, there is actually no substitute for such material having been analyzed and compiled by the user himself or with his full knowledge. This is because certain unifying steps will have been taken to reduce the information from each ship to some common basis for plotting and the user should be aware of their nature. In addition, ship data points of such a gross, over-all sort cannot be expected to plot as a well defined fair curve regardless of which simple coordinate system is chosen. The inference here is that any of several bases may be equally suitable for some of the data since any one by itself neglects parameters which may be important. The coordinate system to be preferred is the one which shows the greatest consistency among the points by minimizing their spread and most nearly aligns them along a fair curve. In the ultimate, however, it will still remain that a detailed knowledge of the unique idiosyncracies of individual ship spots is necessary in order that their compliance or noncompliance with the norm may be explained and the proper emphasis placed on the norm as representative of the new design. Despite the practical problems indicated, reliance on unified data from many ships is preferable to dependance on one close prototype, even when the details of such a ship are available. The "weight equation" is a valuable means of emphasizing the interrelationship of different weight groups and the ballooning effect on displacement of adding to one. However its precision suffers markedly if the extrapolation from prototype to new design is anything but very small. Worse still is the danger of unwittingly perpetuating redundancies and other faults of the parent design along with its virtues.

In the figure, the intersections designated by circumscribed dots denote first considerations or estimates of these items. A simple, solid dot indicates that the previous estimate of that item is verified or modified to suit changes at other points made earlier during that cycle and using more complete information and more precise methods of calculation wherever available and warranted. Relocation of a point on a radial line (or the error of closure) is evidence that a change in the previous estimate of that item has been made or that some new information has been added. Thus, each succeeding spiral represents a more and more refined and firmly crystallized conception of the ultimate design.

On the assumption that, in this hypothetical example, there is no call for changes in displacement and principal dimensions great enough to radically disturb the other first cycle estimates, the underwater sectional area curve and the waterline shape should be developed as indicated at VI-2. (References 1, 24 and 35)

The most elemental measure of a vessel's stability is given by its transverse metacentric radius and this may be obtained by locating the instantaneous metacenter from the geometry of the underbody and estimating vertical centers of gravity for component weight items of the deep displacement and amalgamating them to give the over-all center in the usual way.

In reconsidering power requirements under X-2, it is probably not too early to make use of residuary resistance data such as found in Taylor's work (Reference 25) or in the Series 60 hull family (Reference 26).

Appropriate to XI-2 is the delineation of a small scale ship's body plan including only a few stations. The sectional area and waterline curves of VI-2 provide the basis. These "lines" should extend to the upper deck so that an underdeck area curve showing the fore and aft volume distribution within the hull may be obtained. From this will come the first reliable estimates of cargo cubic.

Any preconceived notion that the machinery space will be located amidships may well be examined with reconsideration of the internal arrangement under I-3 and a decision may be forthcoming from the study of machinery layouts at II-3 and the deep displacement trim calculated at III-3.

In vessels carrying more than twelve passengers an analysis of floodable length is mandatory, of course, but in other cases also it may be felt desirable. Webster's approximate method (Reference 27) has the advantages of being quick and simple. Wherever the margin line follows other than a standard parabolic sheer, however, its results are questionable, especially toward the ends of the ship.

A shorthand approach to the legal freeboard determination (Reference 28) is hardly worthwhile as the full calculation is not lengthy. If, thereafter, significant changes are made to the vessel's characteristics, they may be reinserted into the original computation quite readily.

At X-3 it may be advantageous to select the basic characteristics of the propeller and, as a result, an improved extrapolation from effective horsepower to shaft horsepower should be possible. The uncertainties remaining in this procedure presently are the prediction of thrust deduction and wake.

Consideration of the ship's tonnage (Reference 29) is anticipated at XII-3.

By XIII-3 the basic structural elements such as midship section and typical bulkheads should be available for whatever aid they may afford in making possible weight estimates from a more detailed breakdown as desired for XIV-3.

The "light and air" space anomoly in present tonnage regulations may make minor arrangement alterations in the region of the machinery space beneficial. Also, at about I-4, detailed deck and cargo handling layouts are necessary. Cargo handling is of such importance to the operation economics that its first consideration should have been included in the early arrangement studies.

At least in steam power plants, optimization of over-all thermal efficiency through the selection of the component parts is a matter worthy of investigation at II-4.

For the purposes of this illustrative outline it will probably be sufficient to mention only a few additional points. A floodable length calculation by one of the "exact" methods is intended at VI-4 and at VII-4 curves of statical and dynamical stability are presumed. For passenger vessels the necessary analysis of stability in damaged condition falls most naturally in this cycle.

As a final refinement to the power estimate, propeller performance, underwater form or seaway performance, towing tank model tests are uniquely valuable.

The figure attempts to show that after a sufficient number of design cycles has been negotiated the differences involved become so small as to be insignificant. Ultimately all the mutually dependent variables are in accord and the final refined and balanced design is achieved. The closure is shown here to occur with the structural design but this is of no significance and might just as well have been at any other point.

The last cycle could appropriately be designated the "analysis" cycle as the processes taking place within it are in the form of analyses of characteristics previously established and the design is reshaped from the findings. The first cycles are synthesizing stages and from this interplay it is clear that both thought processes are essential to the final objective.

Considerable confidence is felt with the order of operations presented here for application over a wide range of merchant ship types. However, unique conditions for some types may make it desirable to perform certain of the detailed estimates during earlier cycles than in the illustration. For example, with a dense cargo carrier it may be advisable to determine the freeboard limit sooner whereas, with an extremely light cargo, stability considerations may be uncommonly critical. Furthermore, a few matters of not such general concern and not included in the figure may dictate some design aspects in other special cases. In passenger ships, fire protection requirements must be complied with. With high powers, vibration becomes of more importance and it is possible that some preventive steps may be taken in these design phases. Of somewhat more universal interest are the light draft ship characteristics in which connection Comstock's data of Reference 30 should be noted.

As an incidental comment, it might be added that a filing system for design data based on the dual numbering system adapted herein has been found very convenient, and it appears to offer some promise for use with library coding and retrieval or similar techniques of electronic data processing.

For the design now in hand, the type of power plant was held constant. For any others which are pertinent, a similar design iteration is required to account for the differing fuel rates and specific densities, machinery weights and the like. From among them the final solution may be made or at least the direction for further studies is clarified. As another independent variable, if the machinery space location has been a subtle matter, it will be advisable to work out the over-all ship design in some detail with the various locations fixed for each.

Returning once more to the model . . . . The peripheral cycle is clearly indicative of the infinite wideness of choice available to the initiating preliminary designer but with each round the maneuvering room diminishes and the latitude for change becomes smaller as, in fact, do the alterations deemed necessary. The smaller amplitudes and the increasing amount of labor involved in each successive spiral make it both possible and necessary to increase progressively the concentration of man power until numerous subgroups may be proceeding simultaneously and independently to analyze the aspects in which they specialize. In the sense that a modification may be wrought in some area of the total project as a result of his development, even the detail draftsman may contribute to the final stages of "design." Thus the several man hours of the first cycle advance to hundreds of thousands in the last. (Now the model has a third dimension—an altitude in terms of man hours—and has become a truncated conical spiral, but the scale had better be logarithmic!)

Some of the contributory studies appropriate for the late design stages may themselves be conceived as operations research problems and treated so with advantage. In fact, the ones in mind are already well advanced toward the possibility of programming. The steam cycle, heat balance analysis of II-4 is one of these and a suitable analytical optimization method for it was presented before the New England Section of the Society of Naval Architects and Marine Engineers in May 1959 by E. C. House and B. J. Wooden.*

STRUCTURAL MIDSHIP SECTION—LONGITUDINALLY FRAMED

The structural design of longitudinally continuous material amidships, appropriate to XIII-3, is another. Where the fore and aft stiffening members are more closely spaced than the transverse, as in a typical longitudinally framed ship, St. Denis in Reference 33 has presented an orderly approach applicable to naval practice. For longitudinally framed merchant types a similar procedure should be found usable but criteria insuring the satisfaction of classification societies have yet to be completely worked out.

Figure 2 is a representation of the general method expressed in the flow diagram form of Figure 1. First, tentative and arbitrary spacings of transverse web frames and longitudinals must be selected

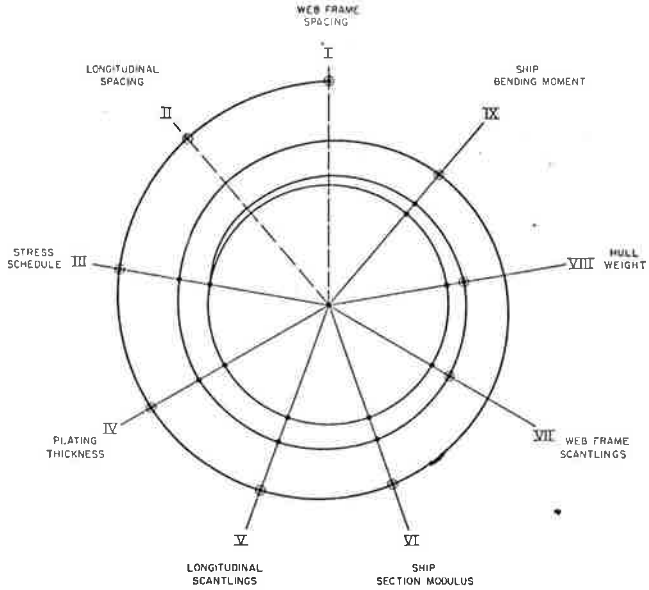

Figure 2. Midship Section Structural Design Diagram —Longitudinal Framing.

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* This paper also contained an interesting example of an optimized general design study.

which thereafter are held constant and provide the basis of that particular solution. Thus the corresponding radial lines I and II are shown dotted to indicate that, once established, they are not reconsidered with each cycle. In an operations research analysis, these are the restraints.

In brief, limiting values for three types of stress are established (III-1). With the first assumption that the longitudinals and web frames form panel boundaries of the plating which remain plane, these strength limits together with instability considerations result in two estimates of required plating thickness (IV-1). The more severe requirement rules, of course. Both strength and instability criteria are also used to determine scantlings of the longitudinal stiffening members which are subjected to tensile and compressive loads as the ship hogs and sags (V-1). When all longitudinally continuous plating panels and longitudinals have thus been tentatively sized to meet their local conditions, the ship section modulus may be found (VI-1). A first estimate of ship girder bending moment (IX-1) may be sufficient to indicate whether or not the section modulus is adequate or must be increased to keep the ship bending stress within its limit. Locating the true position of the neutral axis may, by itself, bring about minor scantling changes from those based upon the originally assumed position of the axis. As modifications and balancing proceed toward refinement, the transversely oriented stiffening members are sized (VII-2) and a good estimate of hull structural weight can follow (VIII-2). This enables calculation of a more exact bending moment (IX-2 or IX-3) and another cycle begins.

Here again, of necessity, the early design steps depend on simplifying assumptions and elementary relationships to yield a result on which the analyses of the last cycles may operate. As in the gaining of all significant new knowledge, this is the universal two-step process of proposal and criticism which ideally must contain precisely correct degrees of imagination and practicality.

For optimizing, several independent solutions with varying combinations of web frame and longitudinal spacing are necessary. Structural weight is the most valid, first basis of comparison as well as the most straightforward for quantitative purposes.

STRUCTURAL MIDSHIP SECTION—TRANSVERSELY FRAMED

Although it is hardly likely, if the framing system is also an open question, the optimum solution for the transverse framing system must also be found. The author's paper (Reference 34) presenting a design integration for the midship section of transversely framed ships is suitable, and Figure 3 is a model of the method. The typical transversely framed ship afloat at present has only very few, widely spaced longitudinally continuous stiffening members and of these, by law and by classification society practice, rightly or wrongly, only the vertical keel is given credit for contributing to longitudinal strength. The figure is therefore slightly simpler. Furthermore, several of the detailed methods of calculation are different as well as the loadings and criteria which, in their present form, have been developed to satisfy the requirements of a classification society, namely the American Bureau of Shipping. Values for any other standard or in compliance with new knowledge can be found easily.

Having made a tentative selection of the spacing of transverse frames, in broad philosophical terms, the method developed in the paper proceeds as before with each cycle building on information generated in the ones preceding. The stress schedule as such is not employed in the paper, but its effect is included in the formulations given.

As regards the merchant ship bending moment, a somewhat frustrating situation exists in that, even should the bending moment be unusually small in a particular ship, there is a lower limit on ship section modulus which will apply and is imposed by law or classification society edict. In such a situation, the calculation of bending moment serves only to enable the naval architect to decide if, in his judgment, a greater section modulus than the mandatory one is desirable.

Many transversely framed vessels of current design employ a closer spacing of intercostal side girders than formerly was usual. This is entirely fitting and is no doubt a trend which will be perpetuated. However, with this development, many primary-structure plate panels will have aspect ratios less than three to one, in which case the critical strength of the panels becomes a much stronger function of the spacing of these longitudinally continuous members forming the fore and aft panel boundaries and the exact spacing must be reckoned with. In time it is reasonable to expect that the contribution of the longitudinals to ship girder strength will also be acknowledged although this may take international action.

Provision for these modifications is indicated in Figure 3 and it then becomes similar to Figure 2 in its superficial aspects.

The model similarity as between Figures 2 and 3 makes it possible to adopt the solution outline for a wide combination of the two basic systems and from one or the other (Reference 33 or 34) detailed procedures which are suitable can be taken. For a complete optimization, therefore, the parameters can be: type of framing system, spacing of longitudinals and web frames, or floors, side frames and side girders. Basically, when found, the net scantlings should be increased in the amount of a corrosion allowance as desired. Actually, the expressions of Reference 34 have already included it.

The general impression intended by this discussion is that a framework exists which should permit solution of the over-all ship design problem and several of its most important subsidiary design

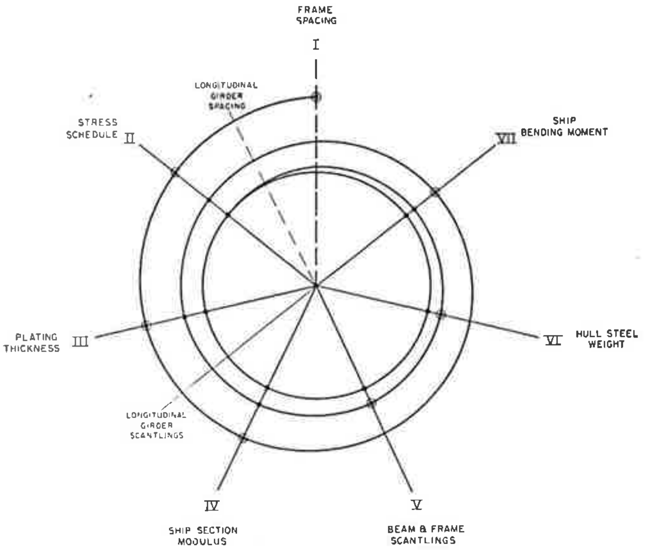

Figure 3. Midship Section Structural Design Diagram —Transverse Framing.

problems by operations research methods if desired. No oversimplification of the development still necessary is intended, although the impression may have been given that the end result is more immediately possible than is actually the case. It is clearly understood that one or two minor dislocations still exist and that much design information now in graphical form must be expressed in different terms and perhaps even be reanalyzed. Some operations within the primary model necessitate a small amount of drafting so the process is intermittent. Furthermore, the exact use of the Figure 1 model will not be ideal in all its aspects for design of extreme or unduly restricted character. A sequence of complex analyses will be required before this bare outline is filled out and readied for completely automatic solution. But even as things now stand, it is hoped that some clarification of design processes and problems has been achieved.

On the other hand, the structural models already are so far advanced as to be almost immediately usable in automatic computation. With modern computers, structural optimization is now possible (and on a much broader base) despite the pressure of production schedules.

The ordering of thoughts attempted here implies agreement with a statement of Herbert Spencer that "If a man's knowledge is not in order, the more of it he has the greater will be his confusion." Few, if any, of man's creations offer as many opportunities for the embodiment of such a wide range of man's knowledge as does a ship.

Yet the philosophy expressed visually by the models is not confined to ship design. It has much broader implications and is bounded only by the word "design" itself and it alone.

BIBLIOGRAPHY

1. Comstock, J. P., "Introduction to Naval Architecture", (Part II).
2. Ridgely-Nevitt, C., "The Development of Graphic Aids to Preliminary Design", A.S.N.E., May 1950, p. 303.
3. Bustard, E. E., "Preliminary Calculations in Ship Design", N.E.C.I.E.S., 1940-41, p. 179.
4. Schokker, P. C. A., Nuverburg, E. M. and Vossnack, E. J., "The Design of Merchant Ships".
5. Munro-Smith, R., "Ship Design—Preliminary Determination of the Dimensions and other Technical Characteristics", The Shipbuilder and Marine Engine-Builder, October 1956, p. 585.
6. Calder, J. D., "The Length/Beam Ratio", Shipbuilding and Shipping Record, September 16, 1954, p. 369.
7. Witte, N., "Die Entwurfrechnung fur Frachtschiffe", Schiff und Hafen, March 1955, p. 123.
8. Diede, G., "Entwurf von Linienrissen fur moderne Handelschiffe", Schiff und Hafen, February 1956, p. 85.
9. Benford, H., "Engineering Economy in Tanker Design", S.N.A.M.E., 1957, p. 775.
10. Benford, H., "Ocean Ore-Carrier Economics and Preliminary Design", S.N.A.M.E., 1958.
11. Munro-Smith, R., "The Design of Coasters", Shipbuilding and Shipping Record, July 24, 1941, p. 79.
12. Todd, F. H., "The Fundamentals of Ship Form", I. Mar. E., 1944-45, p. 1.
13. Ayre, W., "The Propulsive Efficiency of Cargo Ships", I.E.S.S., 1931-32, p. 179.
14. Troost, L., "A Simplified Method for Preliminary Powering of Single Screw Merchant Ships", S.N.A.M.E., 1957, p. 737.
15. Minorsky, V., "A Nomograph for the Preliminary Powering of Merchant Ships", International Shipbuilding Progress, Vol. 2, No. 9, 1955, p. 226.
16. Bocler, H., "The Position of Longitudinal Centre of Buoyancy for Minimum Resistance," I.E.S.S., 1953-54, p. 11.
17. Allan, J. F., "Improvements in Ship Performance", I. Mar. E., 1953, p. 117.
18. Munro-Smith, R., "The Determination of Cargo Capacity and its Centroid", The Shipbuilder and Marine Engine-Builder, April 1958, p. 205.
19. Arnott, D., "Design and Construction of Steel Merchant Ships", Chapter II(A).
20. Powell, S. C., "Estimation of Machinery Weights", S.N.A.M.E., 1958.
21. Telfer, E. V., "The Structural Weight Similarity of Ships", N.E.C.I.E.S., 1955-56, p. 123.
22. Robinson, H. F., Roeske, J. F. and Thaeler, A. S., "Modern Tankers", S.N.A.M.E., 1948, p. 422.
23. Henry, J. J., "Modern Ore Carriers", S.N.A.M.E., 1955, p. 57.
24. van Lammeren, W. P. A. and Troost, L., "Resistance, Propulsion and Steering of Ships".
25. Taylor, D. W., "Speed and Power of Ships".
26. Todd, F. H., Stuntz, G. R. and Pien, P. C., "Series 60—The Effect upon Resistance and Power of Variation in Ship Proportions", S.N.A.M.E., 1957, p. 445.
27. Webster, G., "Subdivision of Passenger Vessels", I.N.A., 1920, p. 234.
28. U. S. Coast Guard "Load Line Regulations".
29. U. S. Treasury Dept., Bureau of Customs, "Measurement of Vessels".
30. Comstock, J. P., "Charts for Light-Draft Form Characteristics", Marine Engineering and Shipping Age, November, 1926, p. 639.
31. Baker, L., "Some Factors in the Selection of Machinery for Cargo Liners", I. Mech. E., 1955, p. 17.
32. Stewart, W. A., discussion of symposium "Advanced Machinery Installations Designed for the Maximum Saving in Weight and Space", I. Mar. E., 1955, p. 335.

33. St. Denis, M., "On the Structural Design of the Midship Section", David Taylor Model Basin Report C-555.
34. Evans, J. H., "A Structural Analysis and Design Integration—With Application to the Midship Section Characteristics of Transversely Framed Ships", S.N.A.M.E., 1958.
35. Todd, F. H., "Some Further Experiments on Single Screw Merchant Ship Forms—Series 60", S.N.A.M.E., 1953, p. 516.

ABBREVIATIONS

A.S.N.E.	JOURNAL of the American Society of Naval Engineers
I.E.S.S.	Institution of Engineers and Shipbuilders in Scotland
I. Mar. E.	Institute of Marine Engineers
I. Mech. E.	Institution of Mechanical Engineers
I.N.A.	Institution of Naval Architects
N.E.C.I.E.S.	North-East Coast Institution of Engineers and Shipbuilders
S.N.A.M.E.	Society of Naval Architects and Marine Engineers.

In a survey of the science of Undersea Warfare (USW), some of the possible salient features of the future are as follows:

—Underwater weapons with speeds up to 250-300 knots.
—Submarine carried anti-missile missiles to combat high speed torpedoes and missiles.
—45 knot hydrofoil craft for coastline ASW work.
—Underwater-to-surface missiles which will permit the submarine to attack a surface pursuer.
—Drone helicopters for search and attack operations against submarines.
—Submarine launched anti-aircraft missiles.
—Anti-POLARIS missiles designed to attack submarine launched missiles.
—Long range ASW weapons which could be fired from hundreds or thousands of miles.
—Fixed submerged missile bases, anchored to the ocean floor, which could be launched by remote control.
—Submarines and weapons capable of operating at great depths—up to 10,000 to 20,000 feet.
—Decoy missiles designed to divert an attacking missile from its target.
—High speed underwater drones for training.

—from MISSILES AND ROCKETS
August, 1959