Design Procedures and their Implementation

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Design procedures and their implementation

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The requirements of a rational structural design procedure are given in the context of ship classification. The procedure centres on the simulation of the ship's structural response in an ocean environment by means of mathematical models whose implementation depends on the use of high speed digital computers. The ship motions and loads are treated in a statistical manner, while the structural response is treated in a deterministic manner by using numerical methods of structural analysis. A statistical approach to safety is introduced based upon probability theory. The prediction method is related to actual experience in service by monitoring the ship throughout its life. Implementation represents a large-scale data processing operation. The financial and economic problems arising from the implementation of such a procedure are likely to be at least as critical as the technical problems.

1. Introduction

Before proceeding to the subject of design procedures and their implementation, it would perhaps be beneficial for those members of the audience not directly connected with the shipping industry to describe briefly the role of a classification society in the shipping community. The classification society, in particular Lloyd's Register of Shipping, is an independent non-profit making international organization whose main purpose is the establishment of construction and maintenance standards for ships and other structures, and the provision of a technical

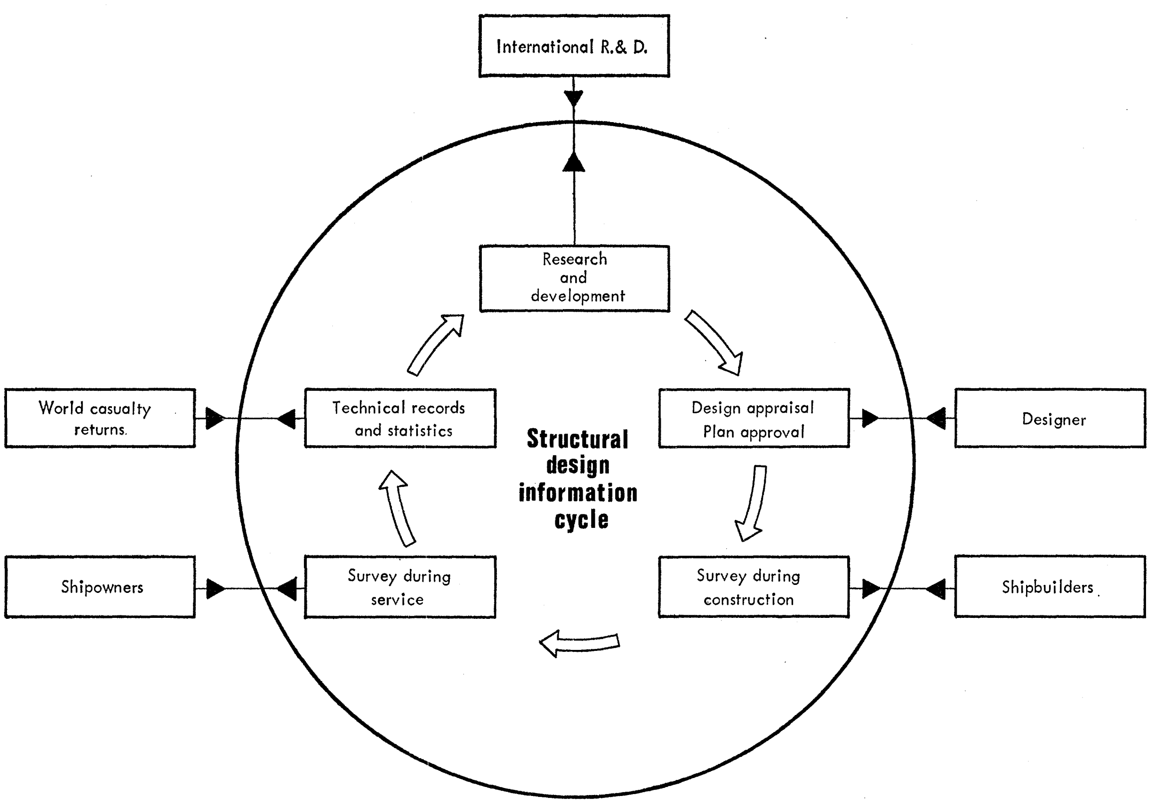

Figure 1. Relation between the classification society and industry.

service to help owners and operators to maintain these standards. It derived its description as a classification society from its initial practice of grading ships into classes of relative structural merit, but for many years now it has had only one standard symbolized by 100A1 to which all classed ocean-going ships are required to conform.

Such ships are under the Society's survey from the earliest days of their construction. Plans of hull and machinery are submitted by the builders for approval by the Society. The steel used in the construction is tested by the Surveyors at the makers' works, and the supervision continues throughout the entire construction of the hull and machinery up to the final trials.

It is also a requirement that inspections should be carried out by the Society's surveyors at regular intervals during the life of the ship, and particularly so when repairs are carried out whether arising from wear and tear, damage, or from structural failure.

This association with the ship throughout its working life leads to an information cycle, as shown in figure 1, which has an important bearing upon the development of a design system which is both rational and dynamic.

In carrying out the classification function the Society has developed particular technical skills and knowledge which are used by industry on a consultative basis. It is expected that in the 1980s the demand for this particular design function will be considerably increased, not only in the traditional area of surface ships as at present, but in the whole spectrum of ocean engineering including drilling rigs, platforms, underwater exploration vehicles, etc.

2. Rational design procedures

(a) General

Accepting that classification of a ship is required as a measure of quality of the product, the first and most critical step in obtaining classification is the approval of the structural design concept and the scantlings derived therefrom. It is desirable, therefore, that any rational design procedure should incorporate such approval. At present such approval is obtained by means of independent assessment of the design by the surveyors. In the 1980s it is envisaged that this wasteful duplication of effort will be eliminated by the adoption by the designers of the Society's procedure to develop a design which will receive approval instantly, since the Society's philosophy will already be incorporated into the mechanism which produced it. In this way the total process of design through to production may be a continuous one, as shown diagrammatically in figure 2.

The particular phase in which the Society is involved is the design of a reliable and economic structure suited to the particular environment in which it is to operate. In the 1980s it is likely that this will be achieved by the use of mathematical simulation models for both the ocean environment and the ship response. The practical application of such simulation techniques will be made feasible by the general availability of high speed digital computers and associated peripheral devices.

The procedure falls into three main categories, namely simulation of the environmental response, simulation of the structural response and determination of limiting safety criteria, and these are now dealt with in more detail.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

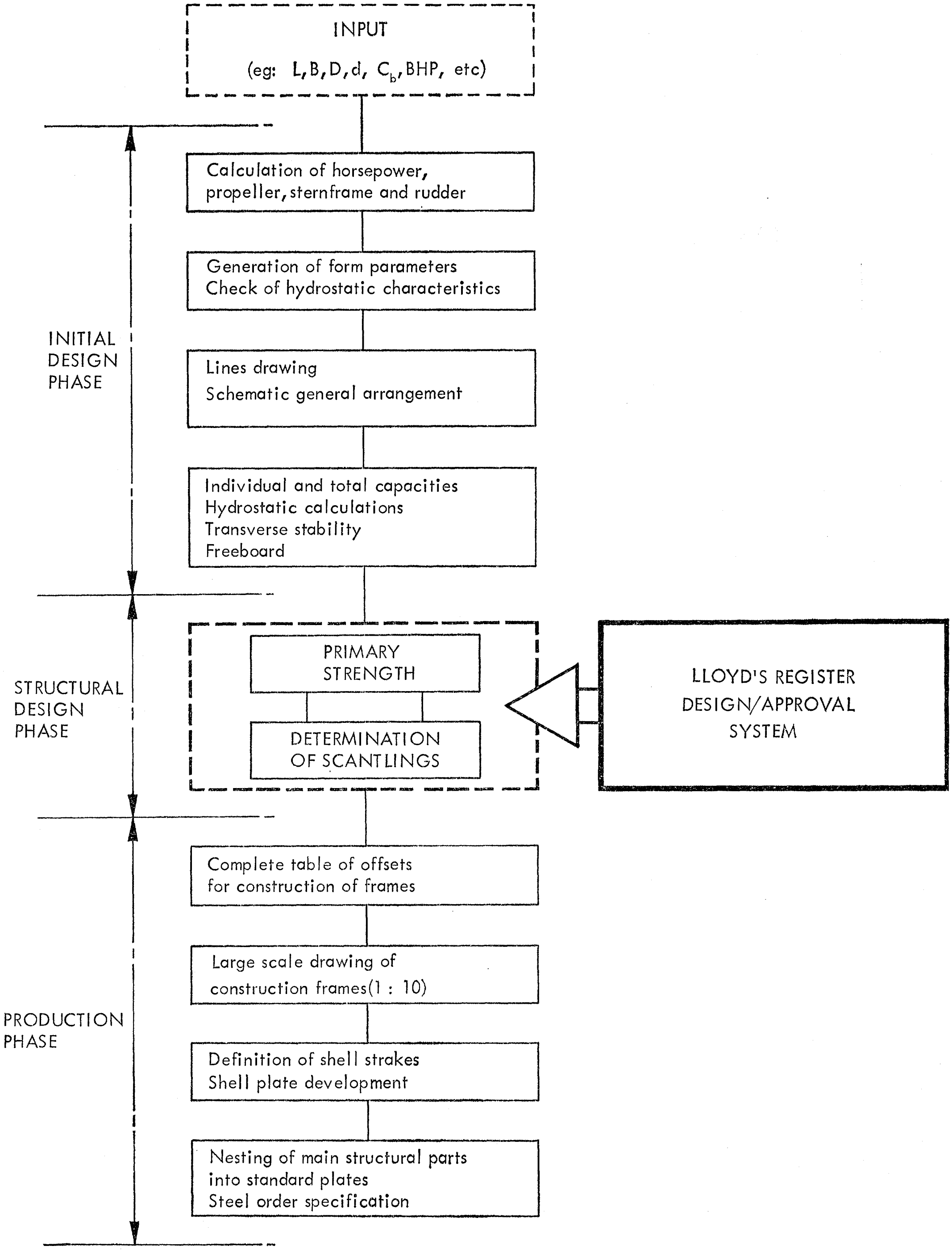

Figure 2. The rôle of classification in the design and production cycle.

(b) *Environmental response simulation*

As a result of transport optimization studies, the basic data available to the designer are likely to be the operating route of the ship, its speed, number of days at sea, and the type and quantity of cargo. The design problem is then to determine from these parameters the estimated load demands upon the structure in terms of magnitude and frequency of occurrence. There are two basic stages in this process. First, the determination of how the ship responds to regular waves in the form of transfer functions, i.e. response per unit wave height against wave frequency. Secondly, the prediction of short-term or long-term response maxima using the transfer function curves, wave energy spectra and long-term wave statistics.

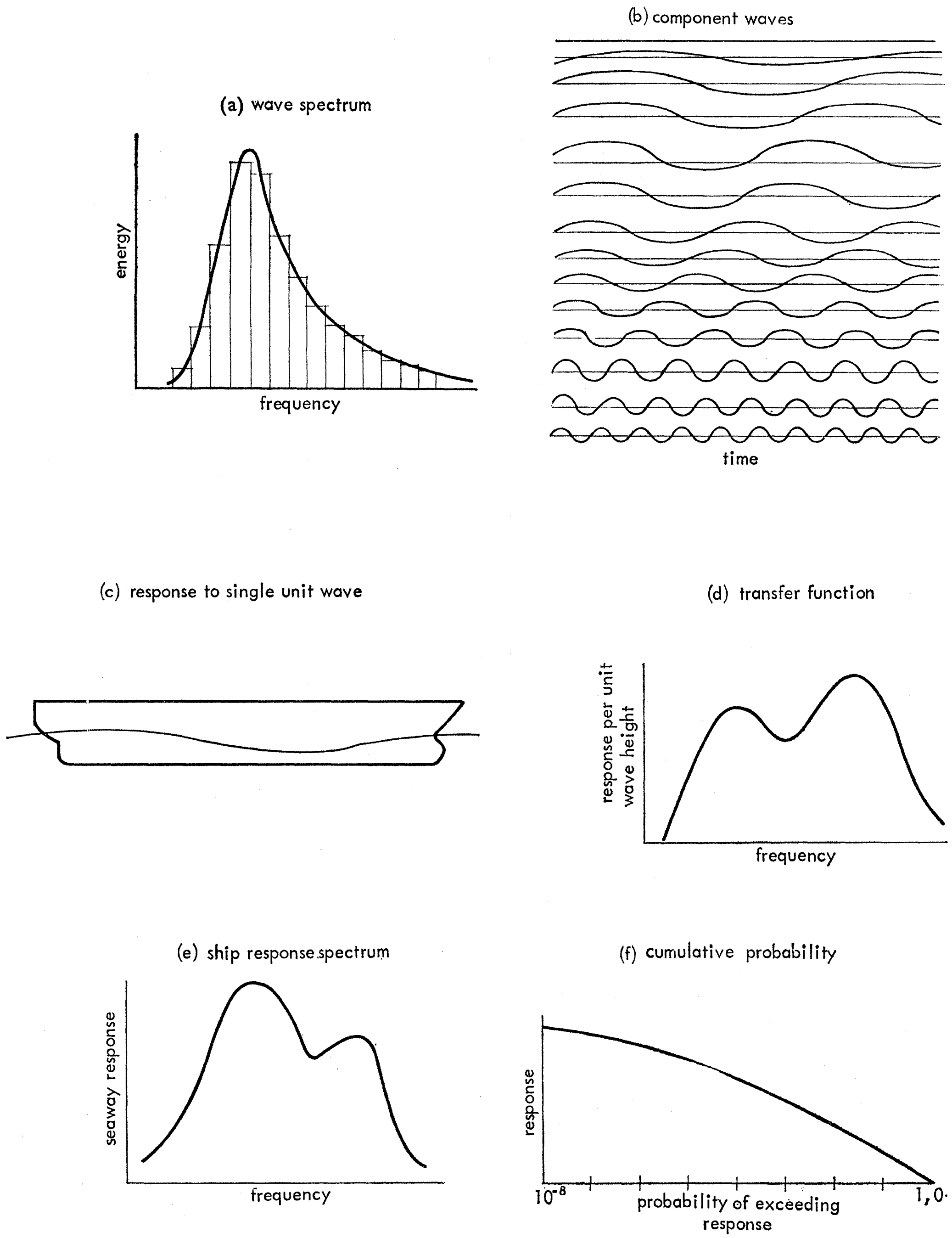

FIGURE 3. Environmental response simulation.

The transfer functions can be for individual loads such as vertical bending moment, horizontal shear force, etc., from strip theory, or for the derived total stress associated with such forces. Strip theory represents the ship mathematically by a number of sections or strips, and

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

considers the hydrodynamic and inertia forces on each to obtain the coefficients of the equations of motions, and hence forces and moments, on the ship due to the action of regular waves. Six degrees of freedom are recognized, three displacements and three rotations known in nautical terms as surge, sway, heave, roll, pitch and yaw. Regular uni-directional waves, however, are rare in practice, and irregular waves are simulated by considering the summation of regular waves using statistical methods.

The transfer function is used in conjunction with standard sea energy spectra to provide a response spectrum, and hence the statistical response variance, from which the short-term probability of response is obtained using a Rayleigh distribution. The long-term probability of response is then obtained by multiplying the short-term probability at a particular sea state by the probability of obtaining that sea state and summating over the entire sea state range (see figure 3). To be able to complete this last phase, accurate forecasts of sea states have to be obtained.

At the present time, the principal sources of information about the ocean environment are the visual estimates of wave height, direction and period compiled by oceanographers from observations from weather ships and merchant ships on main shipping routes. The information so derived is stored on computer files for individual sea areas, from which statistical probability distributions of sea states are obtained for use in the type of procedure outlined above.

Wave data has been collected for a considerable number of years, mainly by visual observation, but tends to be somewhat sparse for certain areas. It is to be hoped that the quality and quantity of this basic data will have improved substantially by the 1980s due to the efforts of oceanographers. It is also envisaged that sea state data for principal ocean routes may be available on a real time basis updated at regular intervals from accurate meteorological forecasts supported by orbiting observation satellites and ship-borne recording devices.

(*c*) *Structural response simulation*

The late 1960s and the early 1970s have seen the development of the finite element concept as the most general method of structural analysis. In this technique the structure is described as an assembly of plates and rods whose individual response to loads is known accurately. The accuracy of the response of the total structure as an assembly of such elements is then dependent upon the degree of sophistication with which this mathematical model is constructed (see figure 4). This, in turn, depends largely upon the number of elements employed. At present, finite element methods are almost entirely restricted to analysis. It is envisaged that much effort in the 1980s will be directed at devising means of incorporating finite element methods within a computer aided design environment.

The principal difficulty in achieving this objective lies in the sheer volume of data required to assemble the mathematical model. The manpower involved in the process is at present very high, as is the probability of human error. The next few years should see considerable advancement in the field of machine aids to alleviate this problem. The most fruitful area of development may be in the use of interactive graphics. By means of a light pen or similar device in association with a visual display unit, the engineer may rapidly build up an idealized structure to represent as closely as possible the actual structure. The data required by the finite element program is then automatically generated. By adopting such techniques the skill and judgement of the engineer is retained, while he is still able to operate in a visual mode to which he is accustomed.

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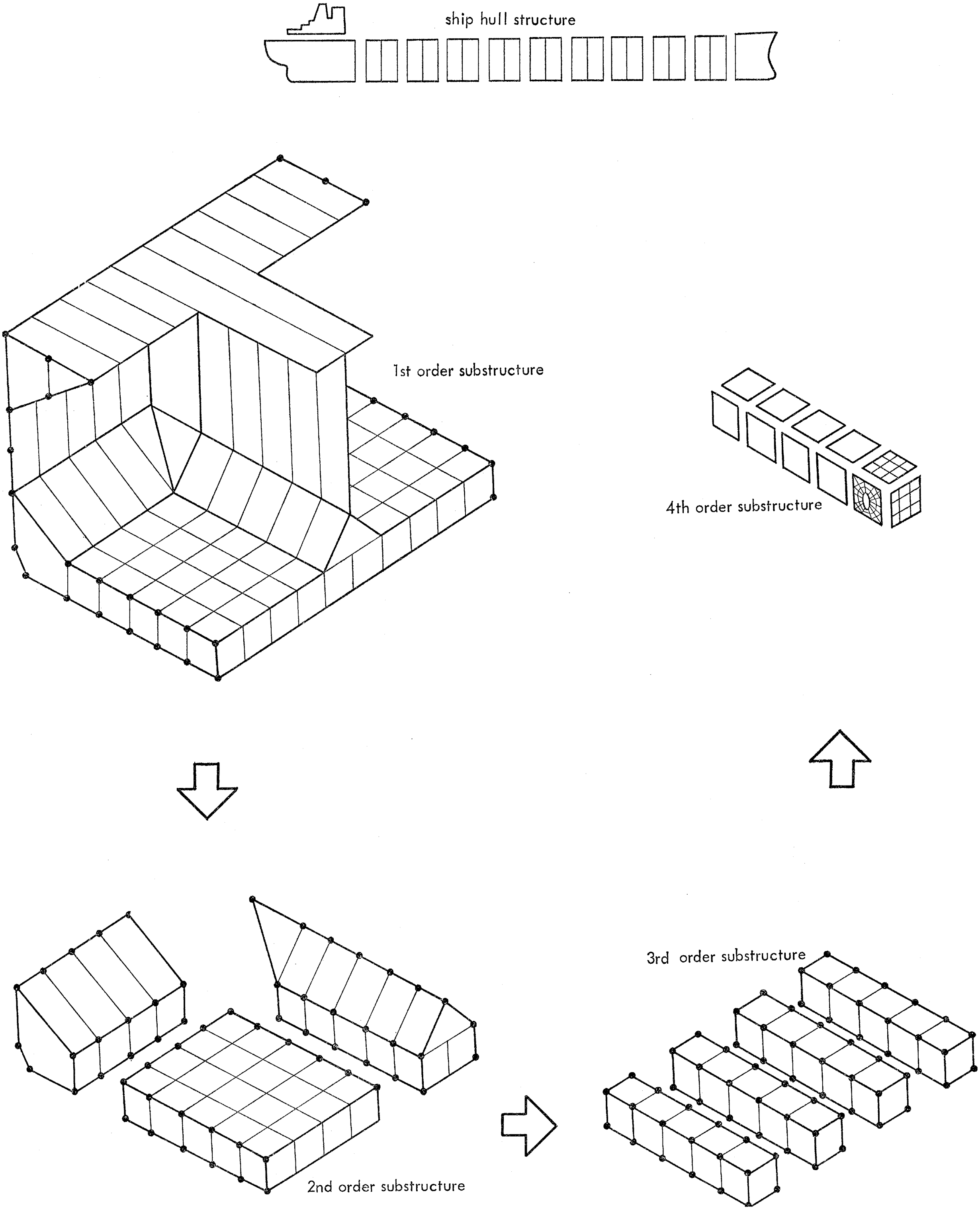

FIGURE 4. Mathematical model of hull structure.

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Having overcome the obstacle of data preparation, the way will be clear to develop optimum design systems. Completely automated design is not an aim nor, with the large number of parameters, does it appear feasible. Rather, overall control of the process should be maintained by the engineer who directs operations by means of interactive graphics. The computer system carries out an optimization procedure for each of the structural lay-out variations specified by the engineer, who then selects the solution which best fulfils all requirements.

While finite element methods are used mainly to determine elastic response, the domains of non-linear response and time dependent loading, i.e. steady-state and transient vibration, are at present being explored. The next few years should see rapid advances in these fields, particularly with the development of design systems to ensure satisfactory dynamic response.

The ability to simulate stress distributions and structures with such accuracy will also lead to a requirement for further advancement of a detailed knowledge of material behaviour. There is, therefore, considerable scope for research and development in the field of fracture mechanics, possibly using finite element techniques.

(*d*) *Criteria against failure*

Failure may be said to occur when a particular level of structural response has been exceeded, and it will generally manifest itself in the form of instability and plastic deformation or fracturing. It has already been demonstrated how the applied loading arising from the ocean environment behaves in a statistical manner. In consequence, it is no longer valid to base structural

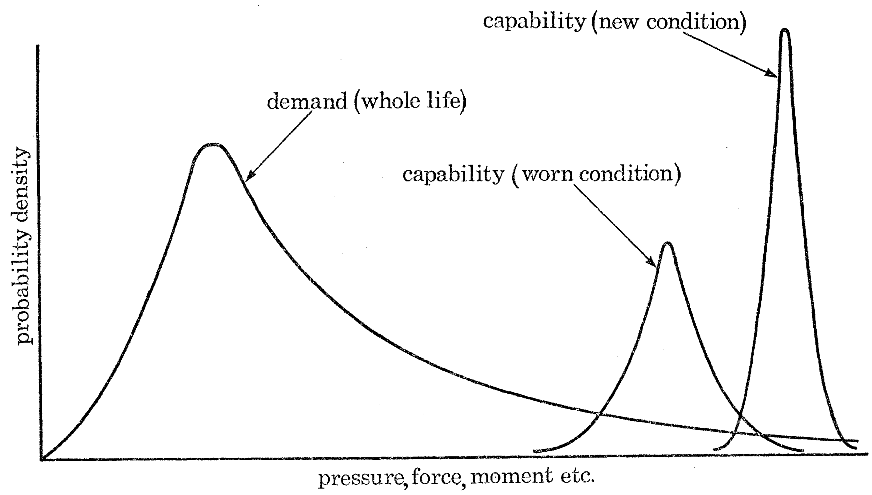

FIGURE 5. Structural demand and capability.

design solely on a unique value of a factor of safety. In a similar manner the strength or load carrying capability can be shown to behave in a statistical manner due to such variables as manufacturing tolerances of both material and structure, wear-down, etc. Any rational structural design procedure should reflect this variability in a logical manner by introducing the concept of acceptable levels of probability of failure within their useful life. This concept is illustrated in its simplest form in figure 5, where it may be seen that the load and strength aspects of the problem fall conveniently into two categories which are statistically independent, i.e. demand and capability.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

At the present time very few studies have been made in the area of strength variability, but it is expected that by the 1980s improved quality control and efficient monitoring of wear-down, etc., will provide sufficient data to establish this concept on a quantitative basis as at present.

Failure or loss of function may be considered on two very broad fronts, economic and social. It is likely that the 1980s will see a greater concern by governments, not only with the possible loss of human life, but also with the value of human life associated with the security of the environment against pollution, etc. In such a context the concept of an acceptable level of probability of occurrence is particularly valid, since it allows a proper basis for comparison with risks in other disciplines such as civil and aeronautical engineering.

In purely economic terms it is also likely that reliability, defined as the ability of a component or unit to carry out its designed function, will be at a premium since inflation will tend to increase the daily running costs to such an extent that the limitation or elimination of out-of-service periods for maintenance, repair, etc., will be of paramount interest to ship operators if economic success is to be achieved.

3. Correlation of prediction with experience

The true value of the efforts devoted to such simulation models can only be evaluated when the model has been shown to be a true representation of the real situation. In this respect the classification societies are fortunate, and in a unique position due to their intimate knowledge of the ship's structural performance throughout its working life. In Lloyd's Register this experience has, in the past, been obtained through the medium of its 1 500 surveyors at the rate of some 40 000 hull and machinery reports per annum. This information is analysed and stored in a data bank which provides an authoritative source for structural analysis of casualties and failures for correlation with the predictions. In the 1980s it is envisaged that this data will be collected, stored and retrieved in a more efficient manner by the greater use of a computer based real time file system available to designers on a direct access basis, possibly through a visual display unit.

In addition to the reports of the surveyors, it is envisaged that the monitoring of ships in service by ship-borne instrumentation will be widespread by the 1980s. Measured strains or pressures will be recorded in digital form by means of data logging devices, the output from which will form the input to a shipboard or land linked computer for interpretation.

4. Implementation

The technical philosophy of the design process having been established and programmed as a series of modular algorithms, the implementation of such a system is established as a large data processing exercise. The practical application of such a design procedure is dominated by the sheer volume of data involved, firstly to initiate the design loop, and secondly arising from the iterations generated within the system. Since the problem is one of large scale data transmission and manipulation, it is inevitable that high speed digital computers and associated peripheral devices hold the key to its practical and economic solution.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

(a) *Software*

By the 1980s the third generation of computer programs covering the aspects of environmental loads, response and limiting criteria, should be in use with a greater emphasis on ease of input and ouput by invoking greater utilization of machine generated simulation models in association with visual display units, graphic plotting devices and light pens, etc.

Problem or user orientated languages will have been developed so that the designer may communicate with the computer in an interactive mode using a language which is natural to him.

(b) *Hardware*

The fifth and sixth generation of computers will now be available having a cost/speed/capacity ratio which will make them more widely acceptable to commercial concerns. The very large companies, whether they be shipowners or shipbuilders, will possibly possess such a facility in-house, or alternatively, like the smaller organization, may tend to make use of such machine capacity by means of a terminal link. Alternatively, the entire design process may be sub-contracted to a consultant organization since the true value of the design procedure still lies in the engineering judgement associated with such systems. This skill is likely to be developed initially by engineering personnel closely associated with its development. In view of the international nature of shipping and shipbuilding such a design facility will have to be implemented on a world-wide basis, possibly through the medium of an international computer communication network.

(c) *Implementation in shipbuilding*

In design the use of a computer with an interface of interactive graphics should provide the designer with a powerful but flexible tool to enable him to develop the optimum structure for any specified task in the face of rapidly changing transport trends. In addition, a large part of the data utilized in the design process will be stored in digital form and be immediately available as lead-in to the production process, which in the 1980s will also be largely automated by extensive use of numerically-controlled machines.

(d) *Implementation in ship operation*

Once the ship is in service, the design procedure can still be used by the shipowner as an aid to planned maintenance by up-dating the structural model of the ship in the light of recorded wastage, etc., and re-analysing with a view to determining the minimum amount of steel renewals. Further, with the more widespread use in 1980 of shipboard computers the design simulation response model can be linked to an improved weather forecasting service to provide the master of the vessel with an optimum weather/ship relation to minimize motions, loading and related damages. In this way the simulation procedure can be regarded as part of the overall safety concept of the ship, since in many cases it is more economic to limit the loading conditions by operational control rather than penalize the structure in designing for the worst situation.

5. Conclusion

By the 1980s ship structural design will be firmly established as a science rather than an art. As a consequence the overheads for the design process will have risen to a level considerably in excess of those pertaining at present. These costs will reflect the improved technical quality of the design personnel and the increased investment in computers or computer services. As ship size and sophistication may, however, be expected to increase, this additional investment should be more than recovered from improved initial building costs and lower operating costs associated with greater reliability in service resulting from the adoption of rational design procedures.

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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF