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An Integrated Approach to Design and Production

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An integrated approach to design and production

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The paper briefly surveys some of the computer based systems now available for the preliminary design of ships up to the final tendering stage; the paper then outlines techniques currently used for the computer production of control tapes for plate definition and cutting etc., by numerical control and/or the presentation of information through automatic draughting.

Research now in progress which will extend from the preliminary design into the detail design of steelwork is described, and a system is discussed by which the first phase of real integration of design and production will be produced for use by the industry in the next few years.

The final part of the paper suggests some of the longer term and comprehensive developments towards integration which could be undertaken during the latter part of the 1970s in order to meet what may be the design and production requirements for the 1980s.

An attempt is also made to assess both the need and advantages of integration for the shipbuilding industry quite apart from the exciting challenge any solutions will present to those concerned with the furthering of an inter-disciplinary and systems approach to industrial advancement.

Introduction

There are three immediate questions to be asked and answered in way of an introduction to the topic of integration of design and production for the 1980s:

(1) Why integrate?

(2) Even if there appears to be a strong case for integration on paper, can it be achieved in practice?

(3) What will be the nature of ships required for the 1980s and what design and production techniques will be needed for them?

I will deal first with question (3). On the assumption that the mean annual growth rate is maintained during the coming decade and that the apportioning between the main commodities will be roughly the same (with the exception of the liquid natural gas trade which may require a higher growth rate than other trades) we can arrive at the following extrapolations:

tankers	from 150 million tonnes dwt (1970) to 350 million tonnes dwt (1980)
bulk carriers	from 80 million tonnes dwt (1970) to 150 million tonnes dwt (1980)
general cargo	from 100 million tonnes dwt (1970) to 130 million tonnes dwt (1980)
container ships	from 2 million tonnes dwt (1970) to 10 million tonnes dwt (1980)
special (e.g. l.n.g.)	from 2 million tonnes dwt (1970) to 10 million tonnes dwt (1980)

In terms of numbers of ships to be built these figures give roughly 4000 tankers, 2500 bulk carriers, 1000 general cargo, 2000 container ships and about 1000 liquid gas carriers.

Apart from a continued increase in size, these new ships can be classed as conventional and therefore the basic principles of design and assembly will remain valid even though the size of tankers may well reach 2 million tonnes dwt (with even more 'beamy' forms the draught should be acceptable), round-the-world container ships will permit a jump from *Panamax* (~ 2500 containers) to a ship size capable of carrying 5000–10000 containers and the l.n.g. carriers may go to a maximum capacity of about 500000 m^3.

Design and production must be made more efficient and this is the case for integration – to be more specific, I will maintain that by the adoption of the integrated approach, the design *and* production staff in a shipyard will be able rapidly to explore alternative arrangements of steel distribution for given structural criteria with real lead time: other properties such as sea-keeping and vibration will also be capable of assessment for different designs and the integrated system will contain a basic flexibility which should ensure that the greater the initiative of the user, the larger the number of alternative designs he can explore and hence maximize the capabilities of the system.

The practical achievement (question (2)) will be by the computer. During the development of the integrated system, it will be necessary to establish a continuous dialogue between the experts on computer science and the experts in shipbuilding and allied sciences, particularly engineering. In particular those of us who cannot claim to be experts in any of these fields, but who are convinced from experience that for the success of future applications of science a much greater degree of the merging of the traditional scientific disciplines is essential, carry a special responsibility to advance and further these dialogues.

Before concluding this introduction, I would like briefly to refer back to the problem of trying to look ahead for a period of say, 10 to 15 years. It is essential to identify any possible 'step functions' because these may radically change the basis and direction of the research and development required. Failure to recognize potential step functions can, in the long run, prove more expensive than making the necessary plans to meet a possible change even if the latter does not take place at the predicted time. There does seem to be a reluctance on the part of those concerned with science-based industries to chance their arm in making 10–15 year forecasts; this reluctance seems to be generated from experience coupled with prudence; I think it also stems from surprise at what can happen in the short term linked with uncertainty regarding financial investment and future markets. The presumed permanence of conventional restraints can be erroneous.

Returning therefore to our ships for the 1980s, I admit that after much discussion with colleagues in research, shipbuilding and shipowning, I have not been able to suggest the existence of types of ship radically different from those we have today; hence I am assuming that the basic principles of design and production (and the material used, steel) will remain. Even so, one cannot but recall the foresight of the man who, if I remember correctly, placed a bet in the 1950s at odds of about $10^5:1$ concerning man's ability to land on the Moon in the 1960s!

I propose to present my proposals for integration systems in three parts: § 1 will briefly review the current computer aids to ship design and production; § 2 will outline a way in which real integration might be achieved by about 1975 in the limited field of structural design, and § 3 will attempt to suggest the manner in which integration might have to be extended to meet the needs of the 1980s.

I shall interpret integration in its widest sense as I think this is the right approach; not only should the data arising from design be capable of direct use for production, but the users must be able to converse with the computer without the assistance of expert computer personnel.

I have to emphasize, of course, that the views I express are personal and therefore do not necessarily reflect the opinions of my colleagues in the marine industry.

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1. Current computer aids to design and production

(*a*) *Preliminary design*

It was natural that the initial application of computers to shipbuilding was to deal with the numerous, but relatively small routine arithmetical calculations dealing with hydrostatics, hull geometry, and macroscopic structural features; extension to include empirical relations covering powering, vibration, etc., was rapidly achieved and today the shipbuilder has at his disposal about 100 programs available for preliminary design.

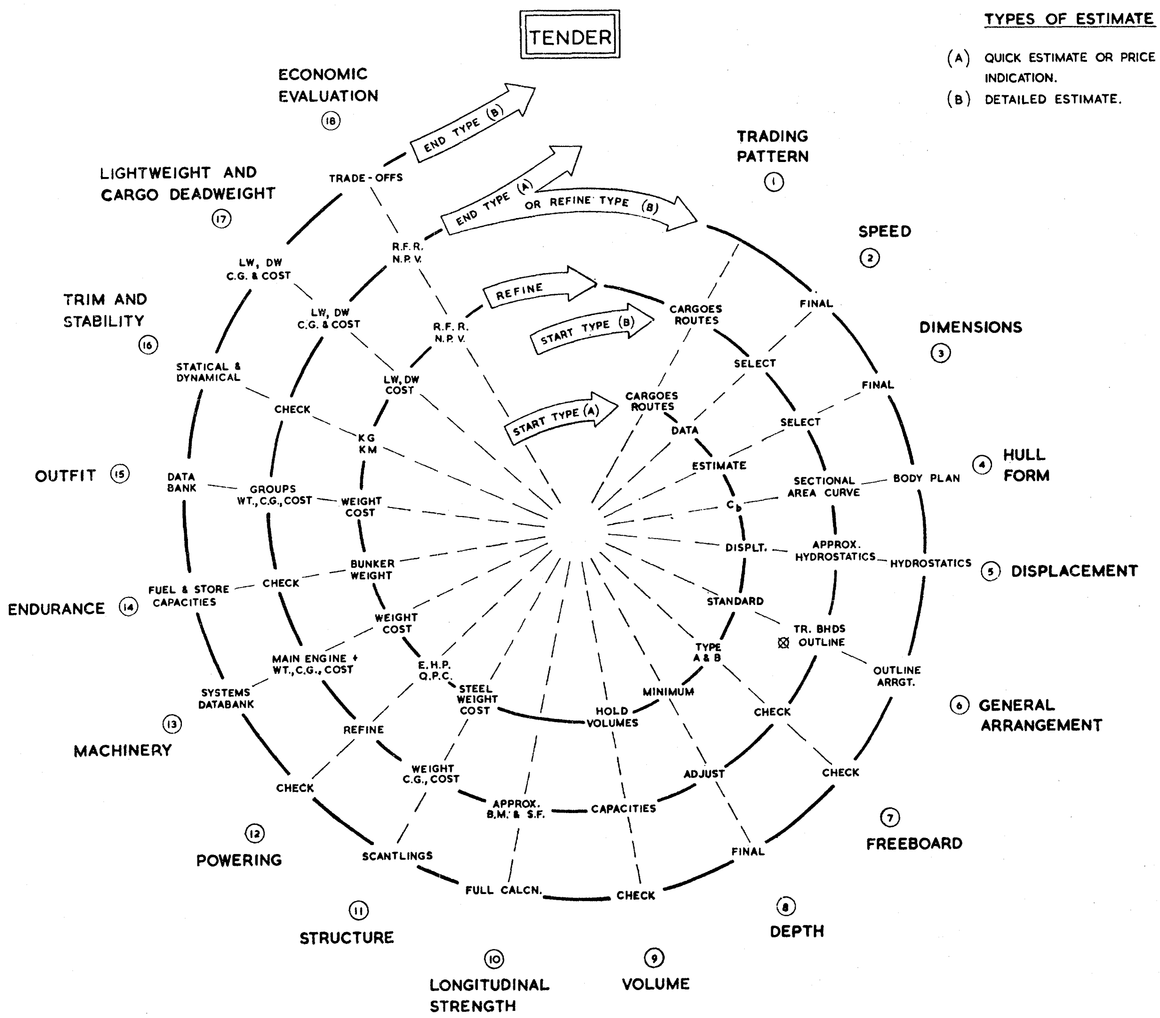

Figure 1. The design spiral.

A useful way to represent this collection of programs is in the form of a spiral superimposed upon a pattern of radial spokes as shown in figure 1. Several spokes represent parameters necessary to define the ship not just as a floating body, but as a unit within a transportation system, i.e. to fulfil a specific purpose in a defined manner under agreed restraints.

The important feature of the spiral concept is that at each traverse, the accuracy of the value of each parameter is increased and this means that the number of possible designs to meet the specification is reduced. Thus the first traverse will yield up to a hundred different designs; the

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second traverse may reduce this to say ten alternatives and the third traverse could define only one design – and if the tender is accepted, the builder will be able to proceed with confidence to the production planning stage in parallel with any further detailed design which may be necessary for certain types of ship.

Although there are many features within the spiral worthy of special attention, at this stage I will confine myself to two points which have a direct bearing on matters to be discussed later in the paper.

The first is that at each intersection of a spoke with the spiral, one has what appear to be independent programs or data banks: secondly, the spoke labelled eleven, structure, has the three intersections with the spiral as follows:

(1)	First traverse	steel weight and cost
(2)	Second traverse	steel weight, centre of gravity, cost
(3)	Third traverse	scantlings, cost

For what may be termed conventional ships such as dry cargo vessels, and where the rules set out by the Classification Society have been well established, it has been possible to devise some 20 small programs to aid in the final determination of the scantlings: these programs allow a designer to explore different steel configurations within the overall constraint of the rules. The greater the initiative of the designer the more variations he can explore and for British shipbuilders these 20 programs, initially independent, are now linked by a control segment which provides automatic data transfer through the computer.

One thus sees that by the introduction of integration within an admittedly very limited field of 20 small programs, the user is able to benefit by this ability to make rapid explorations of alternatives to assist him in the process of decision making.

If, therefore, it was possible to link all the intersections of the spiral and spokes by means of a single data bank, the decision making process might be made much more rapid and flexible. I shall return to this point later.

(*b*) *Detailed structural design*

I wish now to turn to the subject of structural design for the specialized ship: the rapid increase in size of tankers and container ships over the past 5 years (and the probable impending increase in size in l.n.g. ships), has resulted in putting considerable research and development pressure on both shipbuilders and classification societies regarding techniques for the prediction of stress levels to be compared with limits established from practice: as well as stress levels, buckling and fatigue criteria need to be assessed.

The difficulty in the design of very large tankers arises from the need to determine the interaction between the longitudinal and transverse structure; for container ships there is the need to establish the relation between the longitudinal and torsional behaviour. No single suite of programs such as was described for the conventional dry cargo vessel, is available and it has been necessary for the very large crude carriers, for example, to seek out more advanced methods of analysis which will give a three-dimensional solution for the main cargo tank region.

The large computers now available have made it possible to utilize the finite element technique for successful solution of this problem and its role as an analytical tool can briefly be described as follows. There is first the need for a coarse idealization of the cargo tank region: a typical idealization is shown in figure 2. From the three dimensional calculations it is possible

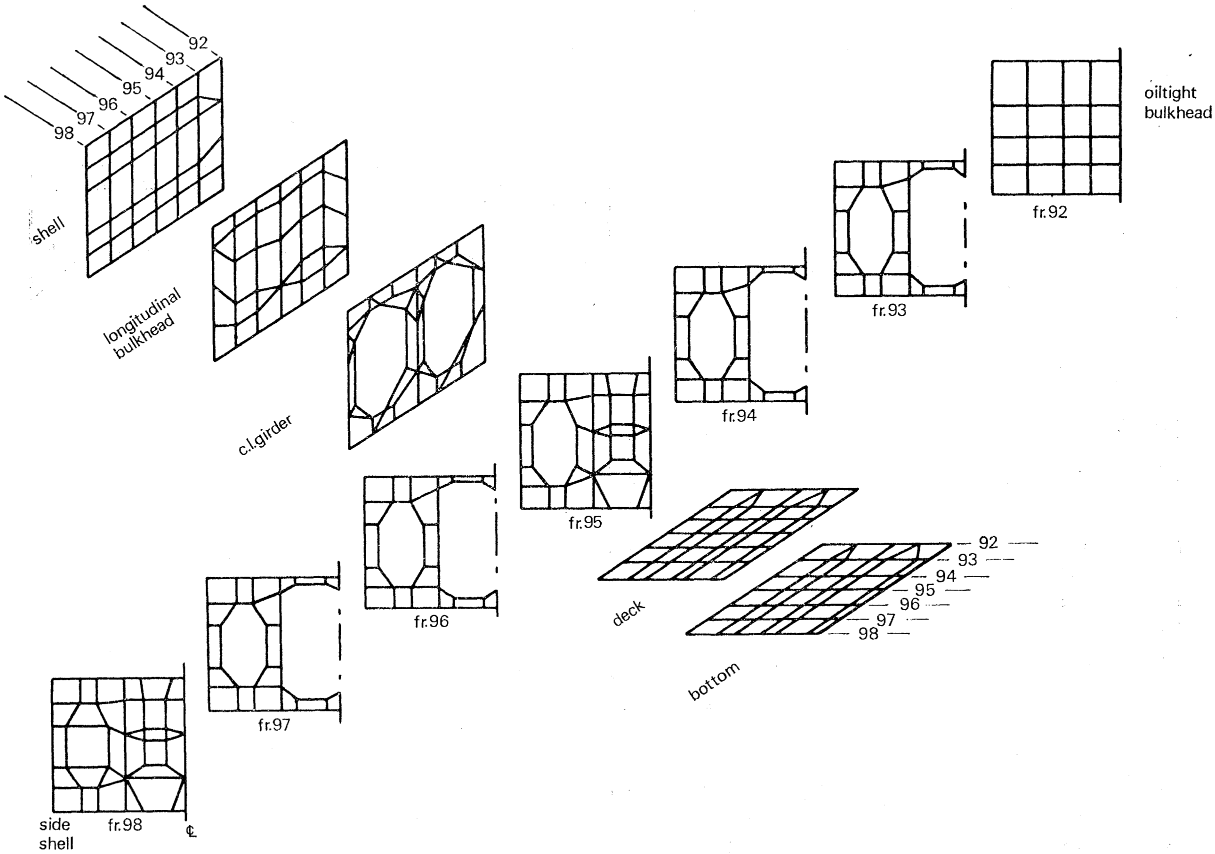

Figure 2. Idealization of a tank for a 250000 tonne dwt tanker

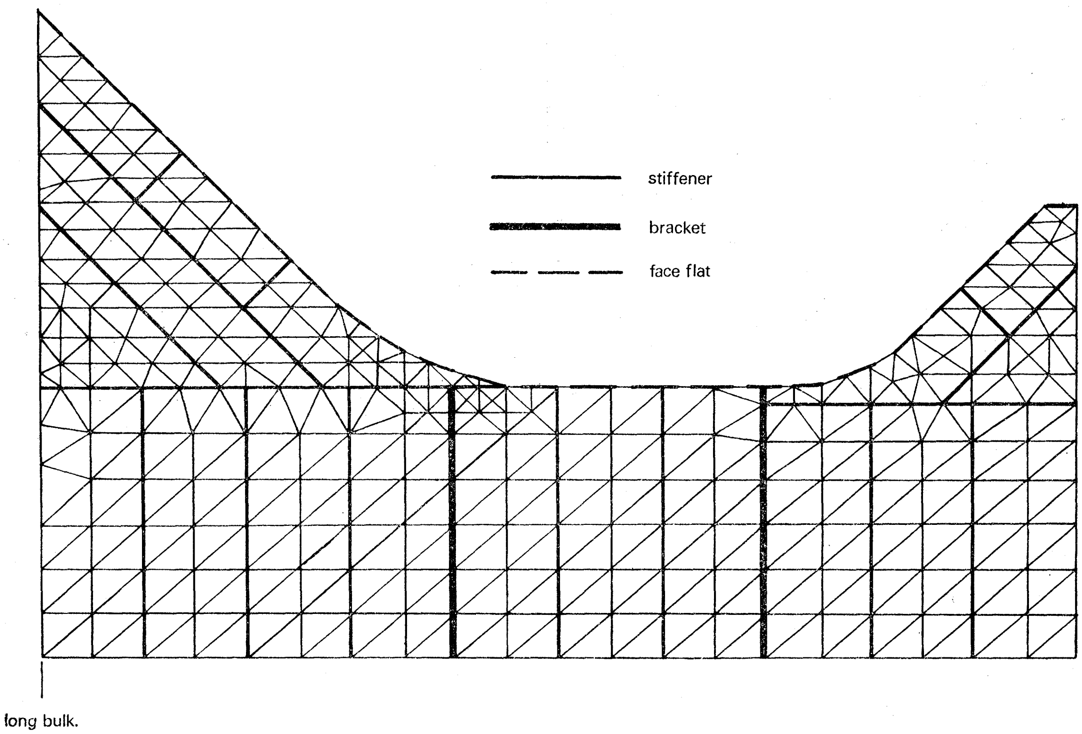

Figure 3. 2D fine idealization of part of a transverse for a 250000 tonne dwt tanker.

to derive the boundary conditions which will enable a selected part of the transverse structure to be analysed using a finer degree of idealization such as that shown in figure 3. The result of the analysis can be plotted in the manner shown in figure 4 which refers to the case of centre tank full, wing tanks empty with the ship in the light draught condition.

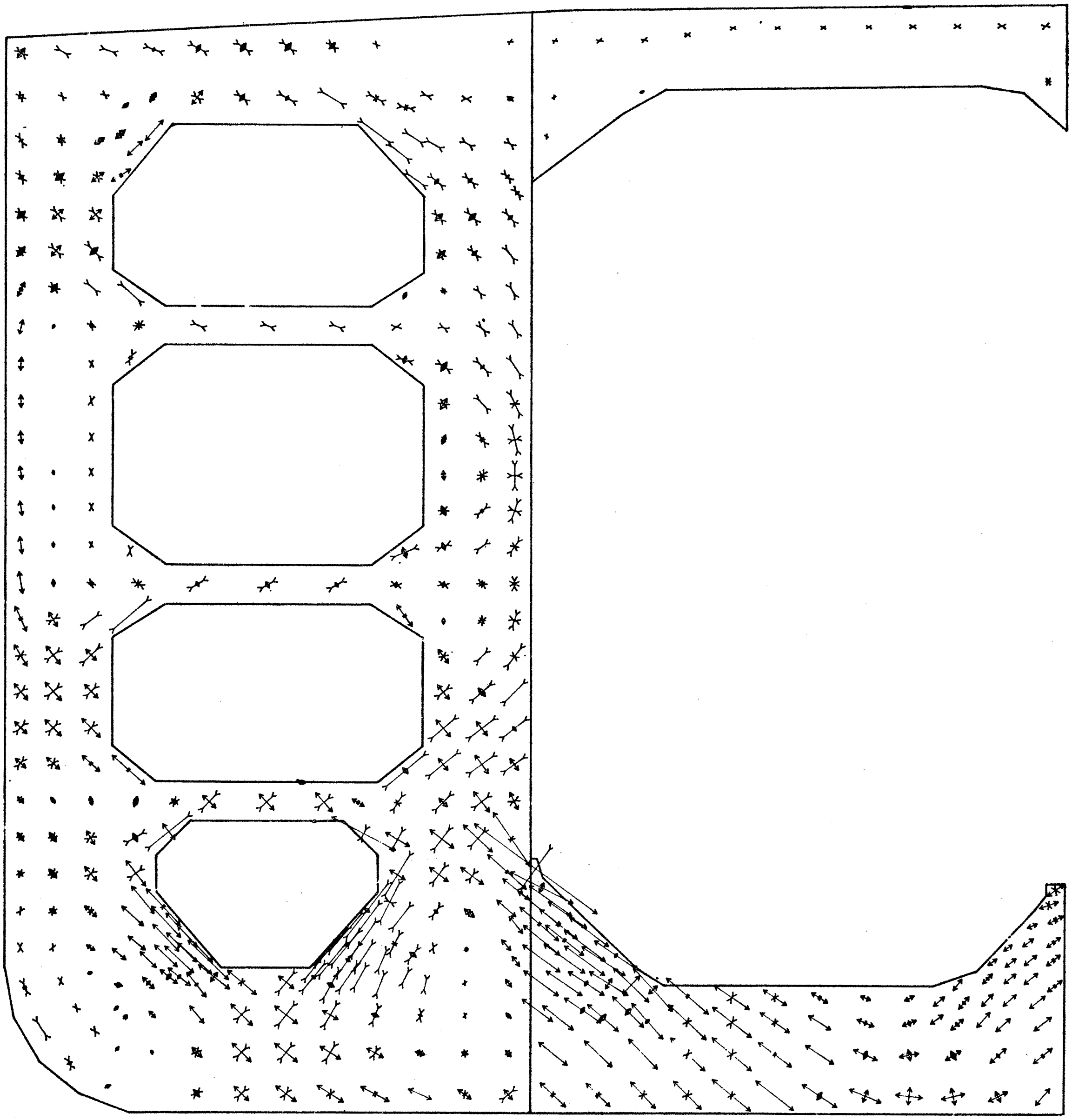

FIGURE 4. Plot of principle stresses in transverse structure of a large tanker.

Calculations of the estimated deflexions are important and figures 5 and 6 show the difference between the centre tanks full, wing tanks empty and vice versa: these diagrams refer to a design of tanker of about 1 million tons deadweight (ratio $\Delta X : X$ scales 72:1).

By comparison with full scale and model measurements, the predictions given by the finite element method have been shown to be valid and in many countries the technique has been well established as a routine analytical tool. However, the idealization, data generation and

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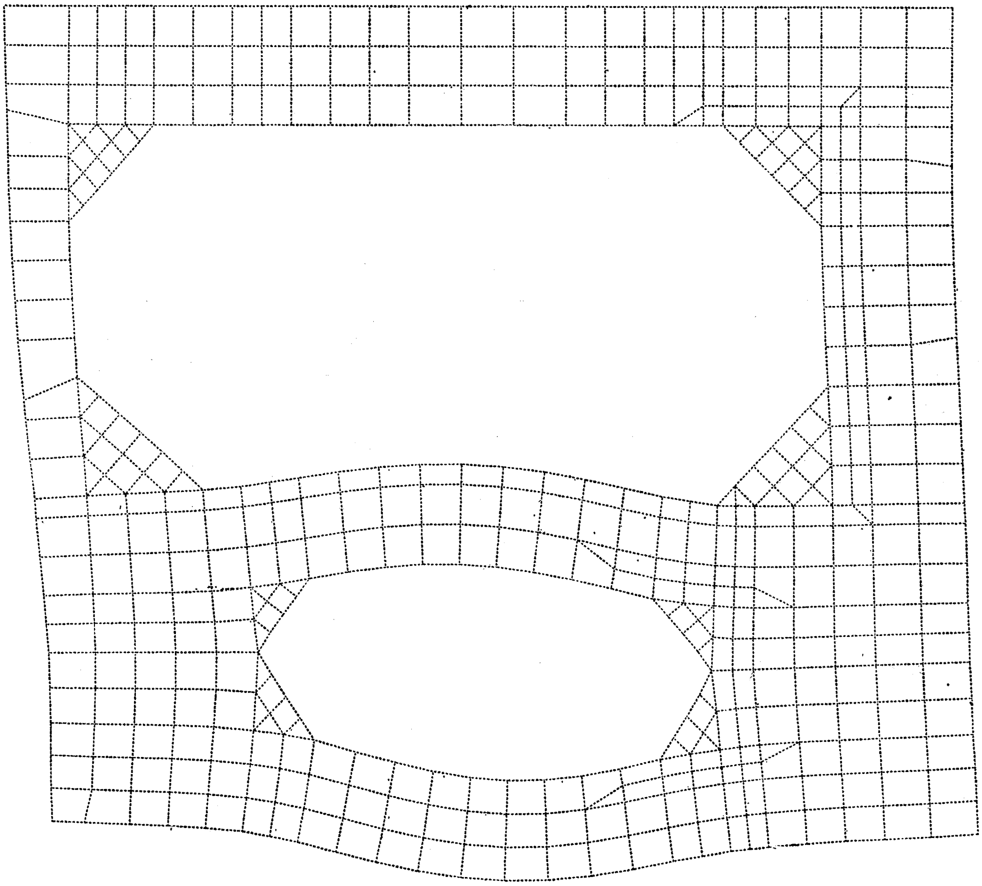

FIGURE 6. Deflexions for wing tanks full – centre tanks empty.

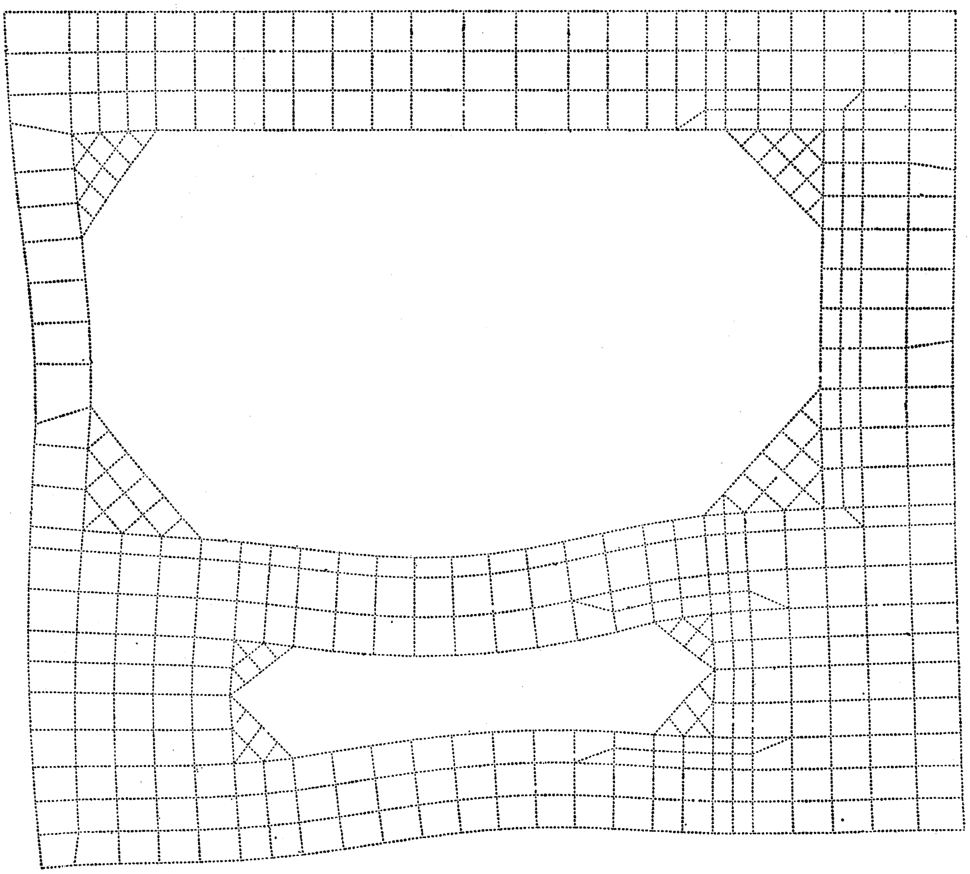

FIGURE 5. Deflexions for wing tanks empty – centre tanks full.

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checking is tedious; routines must be written to check for correct format, data consistency and correct geometry. Figure 7 gives an example of a topology check using a program which extracts the data relating to the idealization of plate and beam elements and outputs the information on a drawing machine for visual check. Figure 8 gives in block diagram form, the order of magnitude of the amount of data necessary for a three dimensional–two dimensional analysis of a large tanker.

If the finite element method is to be utilized as a dynamic design tool by which the user can try different alternatives while building up the structure, it is essential to incorporate within the system a means by which automatic data generation and checking is provided – and it must be done in such a manner that the user should not need to know the theory behind the finite element method.

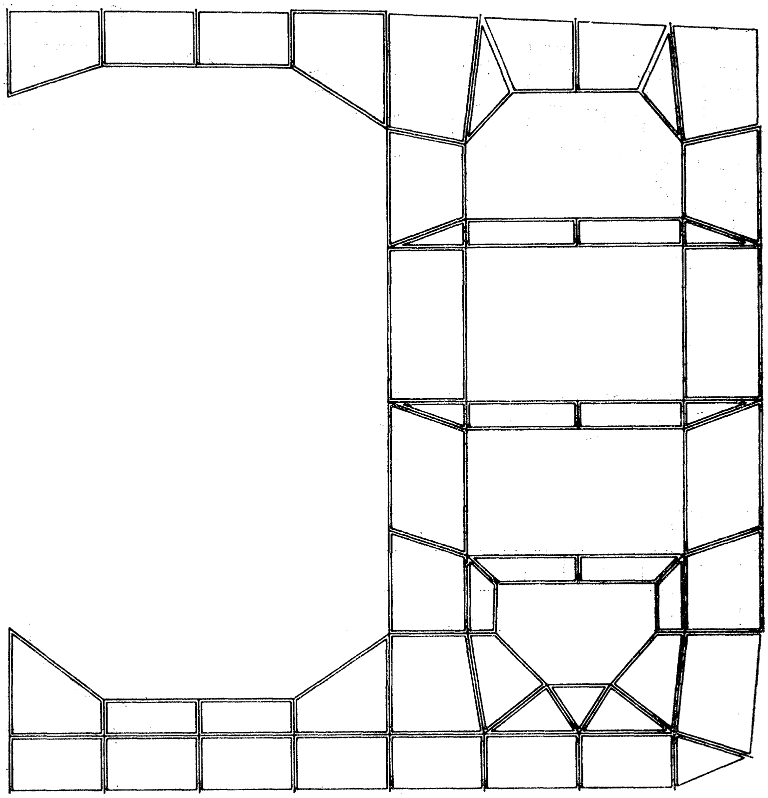

FIGURE 7. Example of geometry check using automatic draughting machine.

(c) *Steelwork definition for production*

Just as one obvious early task for the computer in ship design was to take the tedium out of the many routine calculations required, so in the production sphere, the use of numerically controlled machines for cutting steel needed the computer to aid in the preparation of control data for the machines.

This modest start has given us today a number of what are loosely termed n.c. systems and either a complete system or parts of one are to be found to be in common use in shipbuilding in most countries of the world. The end point of these systems can be broadly summarized as the control tapes for n.c. machines (cutting, bending, etc.,) hard copy of geometrical forms or data tables, 'soft' copy by graphic terminals such as storage tubes, schedules of information for planning purposes including the ordering of steel plates.

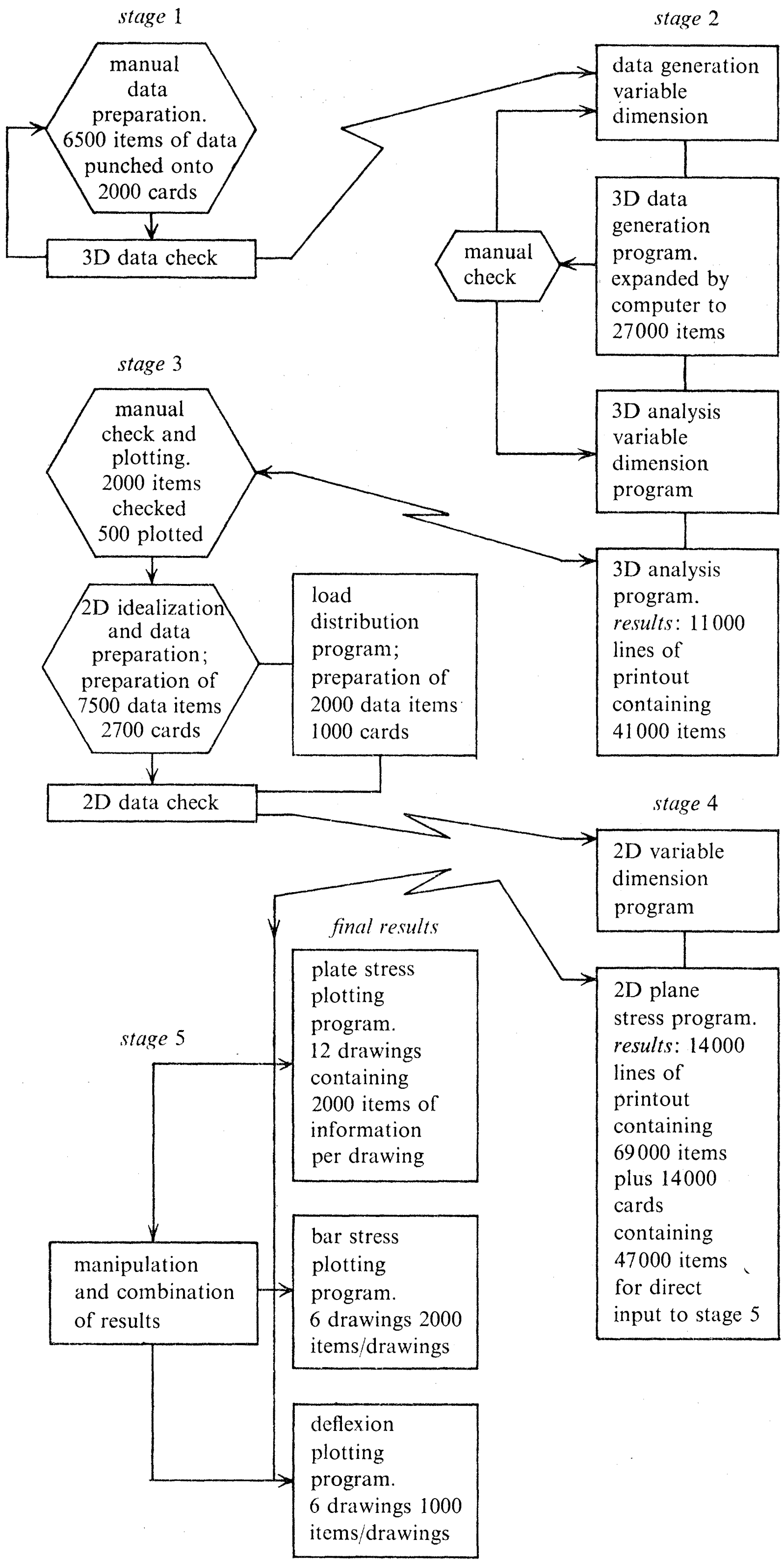

FIGURE 8. Block diagram for tanker structural analysis: typical 250000 tonne dwt tanker. Calculations for 5 tank lengths and 6 load cases.

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Systems differ internally regarding the number of programs, their languages and in particular the language by which the geometry is described, the formats by which data is stored and accessed, and in the mathematical treatment of ship parts.

The main systems in current use are given in the table below together with the organization responsible for the development:

name of system	organization responsible
Autokon	Shipping Research Services A/S, Norway
Britships	The British Ship Research Association
Cals	Netherlands Ship Model Basin TNO
Foran	Sener, Spain
G-Loft and Loftran	Nippon Kokan K.K., Japan
Hizac	Hitachi Shipbuilding & Engineering Co. Ltd, Japan
Steerbear	Kockums Mekaniska Verkstads A/B, Sweden

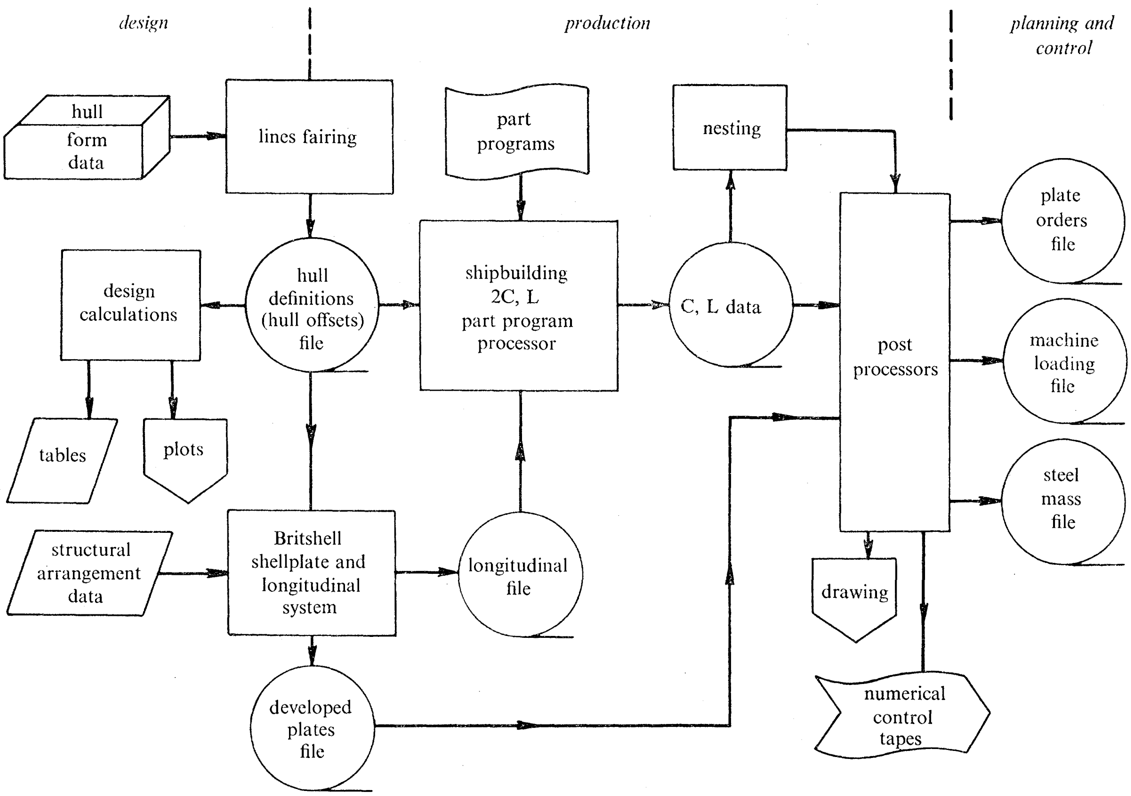

FIGURE 9. Simplified schematic diagram for Britships.

The starting point of the systems is a data file defining the faired hull form: since no single universally accepted method of lines fairing by computer exists, most of the systems incorporate their own individual lines fairing program. If the structural design has been settled then the computer accepts the form of the required steelwork parts as defined by a part programming language and will handle all the necessary data and through the appropriate post processor programs will yield output tapes for the machine as shown in the simplified schematic diagram for the Britships system, figure 9. The main computer programs included are:

(1) Lines fairing.

(2) Part program processor.

(3) Shell plate development.
(4) Plate nesting.
(5) Production information post processors as desired.

The point I wish to stress at this stage is the current manual interface in extracting the necessary information from the steelwork drawings to allow the part programming input (tape) to the array of computer programs waiting to manipulate the data. I have used the schematic diagram of the Britships system for convenience and not for any parochial reasons – it is, as I have indicated, a simplified diagram to stress the interface with the structural design.

(*d*) *Organization of production*

In addition to the steelwork manufacturing instructions and planning and control information provided by the n.c. systems I have mentioned, I should refer to three other aspects of production in which the computer plays an important part.

The first is concerned with a mathematical model of the whole activity of a shipyard or group of shipyards: the model is large in the sense that it may require solution of a matrix of some 600 rows and columns: nevertheless it can provide vital information concerning the relative merits of constructing different types of ships with a given distribution of labour force, the utilization of capital facilities and the gains that could be expected from investment in new facilities, the right mix of ships to be built and further information useful to higher management in planning future building programmes. The data preparation is, however, tedious.

A second aspect is in the simulation of the whole assembly process for which computer programs already exist, but can require long runs on large computers.

Thirdly, there is the overall production control problem which can be divided into the areas of material control, manufacturing control, shopwork control, and cost control: in a number of shipyards proprietary computer packages have been adapted to meet the needs of shipbuilding, but once again the time taken to prepare the input data, run the program, analyse the output, can be such as to prevent the required early warnings of difficulties being made available sufficiently quickly to allow positive remedial action.

2. First steps towards integration

We have seen that in the fields of preliminary design, structural design, steelwork definition for production, and management information for production, the computer has provided what are essentially stand alone packages which deal competently with the specific problems related to the given field. It is true that a measure of integration exists to different extents, within the various packages.

However, it is certain that additions, up-dates and refinements will be added to the systems and apart from the fact that it would appear that much of the same basic data is required for all packages – but prepared and used independently, there are additional reasons for reconsideration of the ultimate value of the utilization of these computer packages as independent systems. Simple diagrams prepared by some of my colleagues will explain the advantages of real integration of design and production activities.

Figure 10 shows how information about the design of a ship increases with time as the design develops.

The contribution of the computer can be added as shown in figure 11; although the description

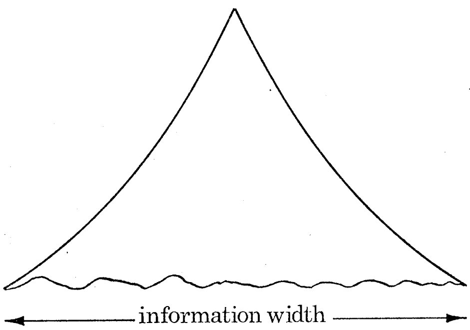

FIGURE 10. Information pyramidal growth.

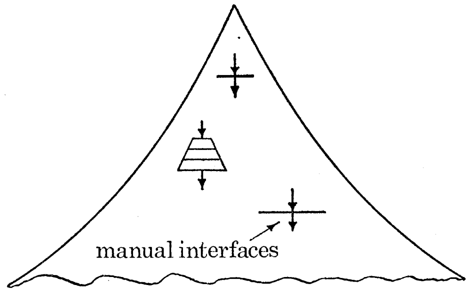

FIGURE 11. Piecemeal use of computer programs using manual interfaces.

of piecemeal might seem to be a little harsh, and is not intended in any way to underrate the value of these stand alone programs, nevertheless the time taken to deal with the manual interfaces could negate the time gained through the computer's intrinsic speed.

Since the amount of steel in a ship is so important as a major contribution to the cost of the ship (30 %) and since the positioning of the steel defines the reliability of the ship, and the detailed description of the shapes and sizes of the components of the steel determines the production and assembly flow, it would be an advantage to integrate all the relevant programs and make the computer handle the interfaces. Instead of asking the question 'what can the computer do for us?' we ask instead 'what do we want the computer to do for us?'.

Diagrammatically an integrated system for steelwork will appear as a zone within the pyramid as shown in figure 12.

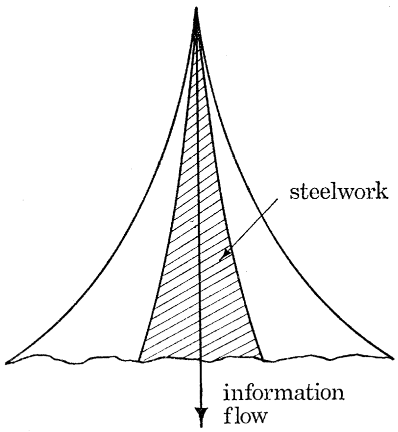

FIGURE 12. Integrated use of computer programs using central system environment.

I will explain, and I hope, justify, the need for a central system to provide a working environment very shortly, but in the meantime there is another important reason for considering the abandonment of the piecemeal approach. We have seen how programs have increased in both number and complexity: since the purpose of the programs is to aid those concerned with the practical task of designing and building ships, the programs must be capable of easy use by the designer or production man and should not become so complex as to require a computer expert to prepare and check the data and nurse the calculations in and out of the computer until it appears to give the correct answers: in a recent paper, I think from Holland, I noticed that the term integration was defined as referring to the direct use of the computer by designers who were not acquainted with details of hardware or software.

Hence we arrive at the conclusion that we should separate the specialist computer software from its application modules: the latter should be regarded as say simple programs written in, for example, Fortran and the specialist software which structures all the necessary data, provides, if required, say, graphics output on an interactive terminal, arranges for inter-program communication etc., and is made *central* – this is the 'central system environment' (c.s.e.) referred to and its role can be shown in a very simple diagrammatic manner as seen in figure 13.

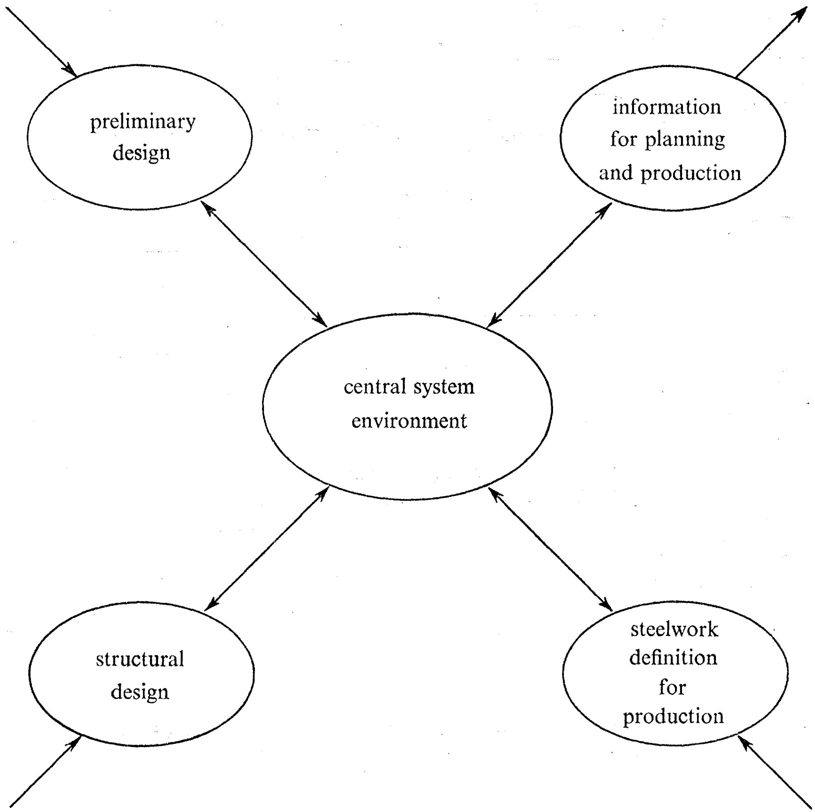

FIGURE 13. Principal parts of ship structural design system.

Such a system will allow for its use by personnel not cognisant with either programming or computer operation, but equally it must be capable of allowing the experienced user to decide for himself what statement he will next input. Also the applications programmer must be free to refine, up-date, and extend programs without having to know or concern himself with problems of data structure, computer efficiency, or input/output details. These latter tasks will be looked after by the central system programmers. For communication by the user with the central system environment a command language will be required which allows conversation with the computer to be similar to ordinary conversation: he must be able to ask 'what is the ratio of *A* to *B*?' or 'what will be the stress in a given region if the load is changed or if additional stiffeners of a suggested size are added?'.

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The main functions of this central system to supply the working environment – central systems environment for short – will be to provide:

facility for problem orientated languages (commands for user); graphical and draughting facilities;

user file handling; and

data table input.

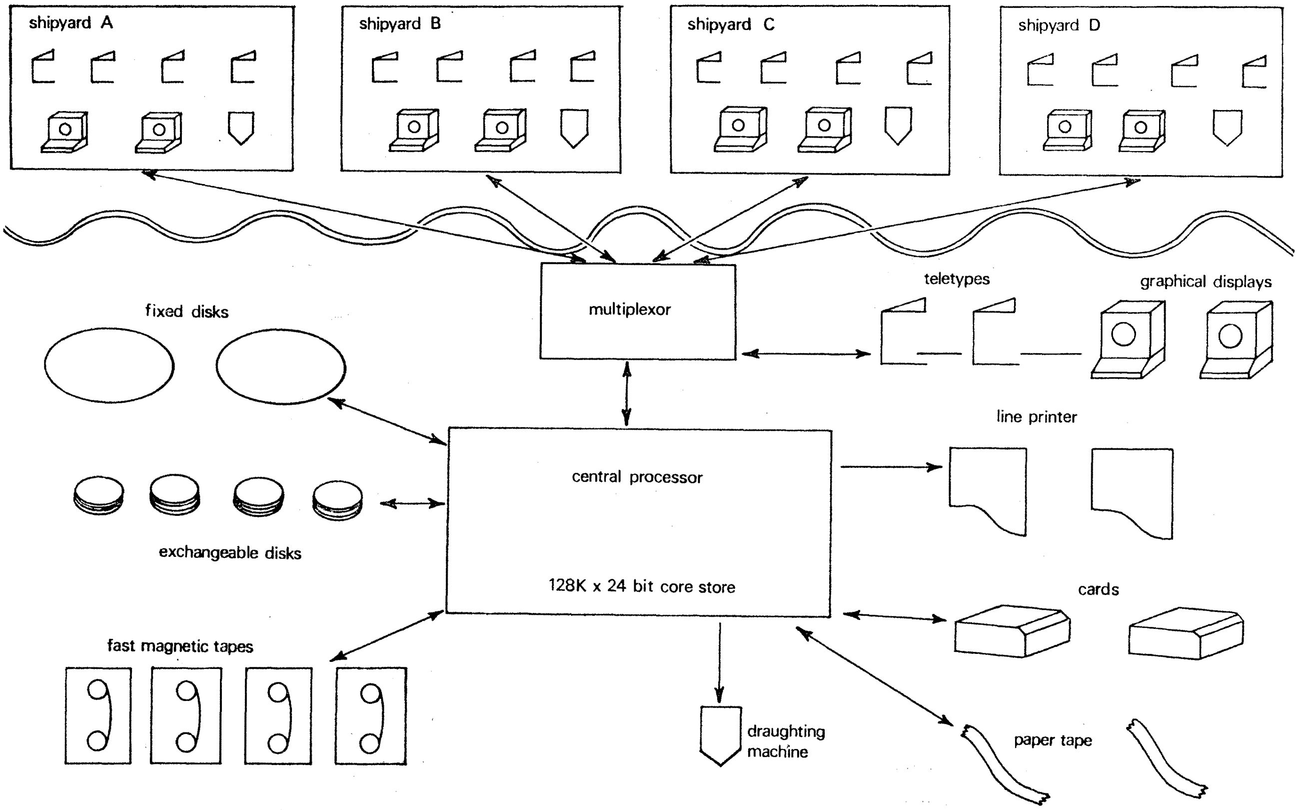

FIGURE 14. Suggested computer configuration to support the first implementation of computer aided structural design in four shipyards, each with six terminals.

There are three important features of such a system designed to meet the needs of the different users:

(1) All the application modules communicate with the central system and not between each other.

(2) It is possible to enter and use the system at any stage and there is no need for sequential use, i.e. if it is required to utilize the steelwork production applications program, the computer will say what input information is wanted – the amount will obviously be more than if the data table input in c.s.e. had been built up during the preliminary design and/or structural design.

(3) The only limitation on the sequence of the calculations is that the appropriate basic data must be available.

The main advantages for such an integrated structural design system are:

(1) It gives the ability to investigate a wide range of alternative designs within a limited time scale.

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(2) Preliminary steelwork arrangements can be quickly established to permit examination for possible savings in labour and material costs associated with alternative designs.

(3) Structural reliability of designs can be examined by using the stress analysis procedures and comparing the results with acceptance criteria.

(4) Better structural designs can be produced because of the use of comprehensive methods which can take account of more factors than current methods.

(5) Designs with better strength/weight ratio can be established.

(6) The effectiveness of design staff can be increased.

(7) There will be potential for reducing the building cycle time from contract to delivery by shortening the design preparation time.

(8) The use of standard production – engineered structural details would be encouraged.

(9) Series production benefits could be increased.

(10) Problems associated with late modifications can be reduced.

(11) Interfaces are created with steelwork management, estimating, and planning.

Shipyards using such a system will require the kind of computer configuration shown in figure 14: it is self-explanatory, but I would point out that the central hardware is not located at any of the shipyards using the system. The main computer could, within reason, be situated anywhere as current users of remote access systems are well aware.

3. Extension of integrated systems

The system I have outlined for the integrated design and production information for steelwork could technically be available by 1975, taking into account the pace of development of computer science and the very valuable way in which different industries are appreciating that they have more problems in common than was realized say 10 years ago.

I do not believe, however, that such a system alone will meet the requirements of the 1980s and beyond. This is not because I have changed my mind since preparing my introductory remarks regarding what I expect to see on the high seas in *ca.* 1980 – I have already admitted to failure in envisaging anything more strange than say a 2 million tonne tanker or even a Tri-Sec. The integrated system for the structural design I have outlined will, as I have already said, deal with either of these and the large container ships that I am readily prepared to expect to see in the 1980s. I might add that some radical re-thinking of the port facilities allocated to these ships will be required, but that is a subject outside the scope of this paper.

The reason for my call, as it will be, for consideration of the extension of the concept of the integrated system, is because I think the shipowner may have to ask for more than what I will term a very reliably structured ship. We therefore have to consider the way in which ship specifications may change by 1980, for a number of reasons.

(*a*) *Ship performance*

Let us consider first the performance of a ship in a sea-way. Assuming theoretical treatment of this proceeds along current lines, then the hull shape, distribution of mass and sea state would seem to be the only basic data required to calculate the mean power required to give a defined speed under conditions of a defined sea-state. In addition, strip theory will predict the mean and peak amplitudes of the ship's motions. The motions will determine the accelerations, which it may well be necessary to limit for given cargo loadings; equally, slamming forces will be capable of prediction as a function of sea-state, speed and ship loading and it may be important to specify limits for these forces also.

All the required data for such calculations can be made available in files within the central system environment which we have developed for the integrated structural design and therefore all that has to be done is to add a further application module which I will call 'ship motions and slamming'.

Before leaving the resistance/propulsion hydrodynamic field, I should mention that I am assuming that sufficient information will be available either as stored empirical data or through fundamental theory to dispense with model tests. I consider the towing tanks will be used primarily as research tools to improve our understanding of the physics of separation and the mechanisms of viscous drag in the micro boundary layer. I am sure that given the right experimental equipment (I admit to not being able to specify this now) it should be possible to elucidate the physics of viscous drag, and for example, to understand why homeopathic doses of long polymers at the water-hull interface can yield macroscopic reductions in the skin friction; the explanation may result in our having to change our conventional view of optimum hull shape or its micro surface. Admittedly it is a difficult problem, but we ought to see it solved and understood by 1980.

(*b*) *Steering and manoeuvring*

The next topic to consider for inclusion in the extended integrated system is that of steering and manoeuvring. If ship collisions and stranding are to be avoided and not merely reduced, it is, in my opinion, essential that theoretical work, paralleled with full scale verification, is carried to the stage at which dynamic behaviour at full scale must be capable of prediction at the design stage. This is a formidable task because of the complete non-linearity of all the parameters concerned; even if one restricts the available six degrees of freedom to three (two translational and one rotational about a vertical axis), we are left with three equations of the form

$$M\,(\dot{\upsilon}-r\nu) = X,$$
$$M\,(\dot{\nu}+r\upsilon) = Y,$$
$$I_z\dot{r} = N,$$

where the symbols have their usual meaning. The difficulty of solution is apparent when one notes that X, Y and N are functions of $\dot{\upsilon}$, $\dot{\nu}$, $\dot{r}$, υ, ν, r, δ, $\dot{\delta}$, where δ is the rudder deflexion.

The variation in dynamic instability currently encountered in practice is shown by figure 15 and the need for a better understanding of the basic physics extends from the short term which can be defined as the need to reduce the continual movement of the rudder (and hence wear and tear on the mechanism and also fuel consumption) to the longer term need for which it may be necessary to demand precise navigation using remote control with no human intervention.

Whatever new theoretical concepts may be brought in to yield the solution to the equations, these must eventually be related to practical matters such as hull shape, rudder area, and rudder position. I propose to assume that the problem will be solved by 1980 and therefore that the central system environment (c.s.e.) will contain all the necessary data to allow the attachment of a 'steering and manoeuvring' application module. In the meantime this will be empirical.

(*c*) *Automated ship*

Having touched briefly on the subject of automation in connexion with steering and manoeuvring, I see no technical difficulty in meeting the requirements of the completely unmanned ship

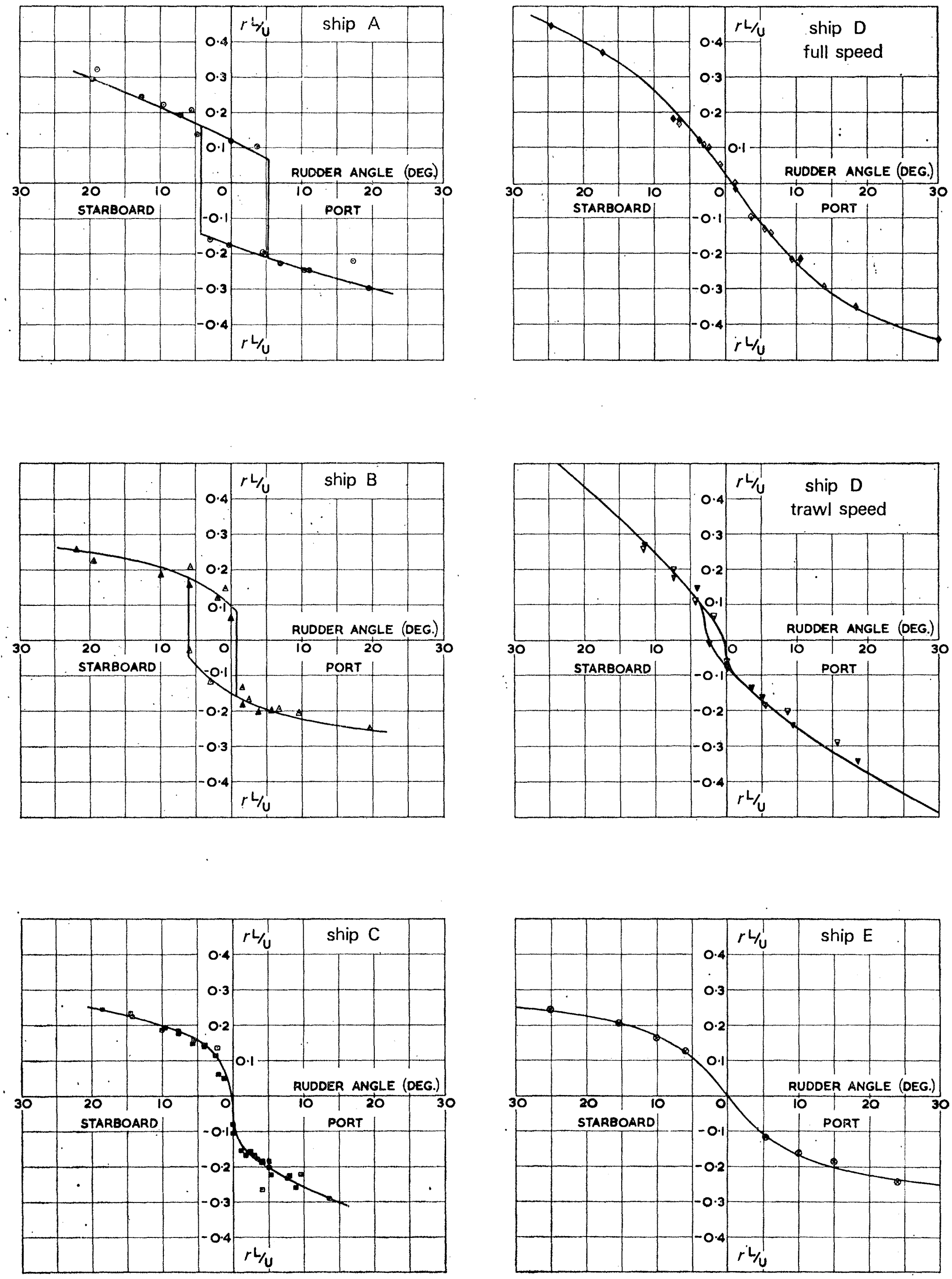

FIGURE 15. Results of Dieudonné spiral manoeuvres. Non-dimensional rate of turn plotted against rudder angle.

if this is a requirement for the 1980s. The pace at which electronics technology is advancing suggests that the necessary control equipment incorporating the correct redundancies will be straightforward; satellite navigation is, in my opinion, a concept for which the full potential has so far not been realized. It is true that a massive increase in machinery reliability will be required, but this again is a relatively straightforward technical problem dependent more on

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financial considerations than on new scientific understanding. As an example of the rate of electronic advance in, say, solid state and miniaturization, I do not think I would have forecast in the early 1960s that a fully reliable 3 channel domestic colour television system would have been available in 1970 at about £5 per month;

Apart from the steering module, all other extensions of automatic control up to the unmanned ship, will not demand in the design stage, any interaction with the central system environment.

(d) *Vibration*

We have to consider three separate components in order to achieve a full understanding of the problem of ship vibration; firstly, there are the excitation forces, secondly the response of the structure, and thirdly the coupling between the two. With regard to the response of the structure, the use of the finite element technique will enable sufficiently accurate predictions of frequencies to be made and the appropriate routines for carrying out such calculations will be included in the structural design applications module. The problem of quantifying the excitation forces is more difficult; at its simplest there are two main sources: first, we have the transmission through the propeller, shafting, and bearings, of the unsteady forces arising from the operation of the propeller in a wake field which may contain both spatial and temporal components of velocity change; secondly we have the incidence of varying pressure forces upon the hull surface in the stern area. If we assume that calculation methods will be available for the prediction of the magnitude of both these sources of excitation forces, we then need to estimate the coupling coefficient between the incident excitations and the structure as a whole.

In principle the central system environment will then contain all the necessary data – hull form (and hence flow pattern) structure and geometry – but I am hesitant to suggest that by 1980, the necessary theoretical understanding of the excitation phenomena will have been achieved to allow all the required calculations to be carried out from first principles. As a compromise, an applications module – 'vibration properties' – can be added, but a proportion of the calculations will probably have to be based on empirical data which will have been determined from full scale measurements on existing ships.

(e) *Production information and control*

Finally, we have to consider whether the extended central system environment is required to provide further information in order to assist in the control of the assembly and outfit processes. I think this is unlikely because the trend towards the automated shipyard will already have utilized the computer in optimizing the method of assembly of different types of ships according to the capital facilities which will be available, the nature of the labour force and the required throughput.

(f) *Computer facilities required*

I suggest that a computer configuration similar to that required for the 1975 integrated system will meet the needs of the extended system: by 1980, the technique of remote access to a large central machine via intelligent terminals, will have been developed, proved, and established in many industries including, I hope, shipbuilding.

4. Conclusion

Summing up therefore, I have suggested that for the ships of the 1980s, an efficient integrated system for the design and manufacture of any type of ship can be available through the utilization of advanced computer technology coupled with progress that is being made in the study of the basic sciences of hydrodynamics, structural engineering, and vibration physics. The principal components of the system are shown in figure 16.

This design system will allow ships of minimum cost to be produced and the cost will depend upon the content of the specification; this in turn will depend upon technical, statutory, and manpower considerations as well as market forces.

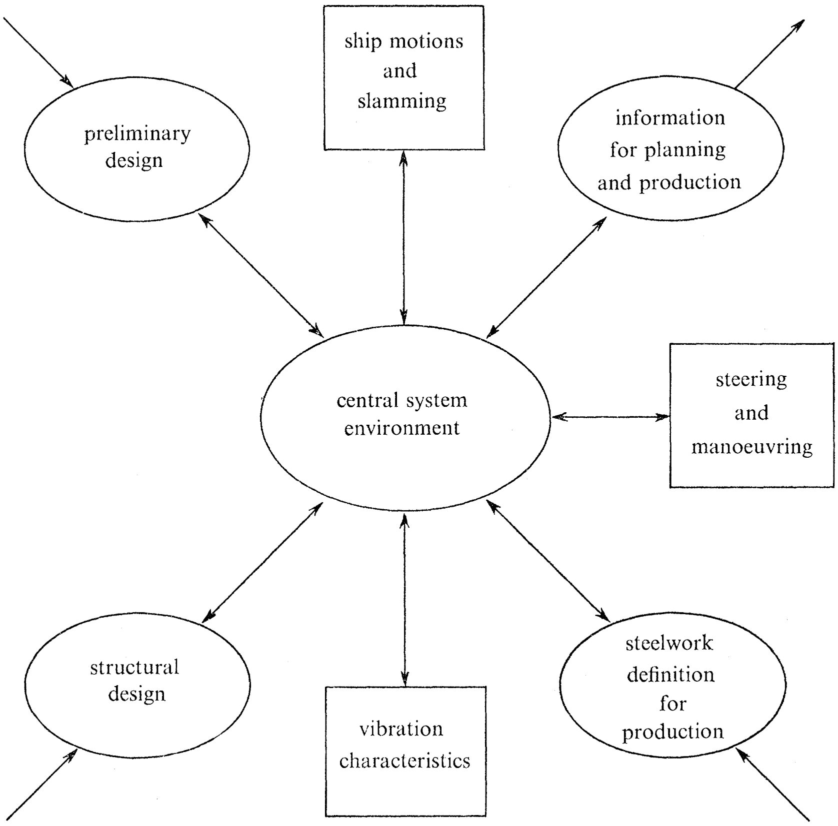

Figure 16. Extended integrated system for ship design.

In the development of the integrated system concept I admit to having disregarded the question of research and development resources in terms of manpower and money. Obviously the cost must ultimately determine the particular direction or directions in which progress is to be made whether the motivation be efficiency, safety, comfort, or even pure innovation. It may be, however, that during the next ten years the merchant marine industry may be fortunate enough to get (and deservedly so) a gradually increasing share of whatever research and development budget may be available for technological advance. It is difficult not to be aware of the fact that an aircraft costing less than a ship to manufacture, is supported by full scale prototypes costing over 50 times as much, whereas a new type of ship has no such prototype and is expected immediately to provide economic return to both the builder and owner.

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Finally, I have to apologize for the fact that in my paper, and in particular those sections referring to the current position of design techniques, I may have implied the existence of a fairly uniform state of development in the practical use of computers, for all shipbuilders, no matter in which country. My excuse for taking this view is firstly that in the time available it would have been impossible to allocate fairly the peaks and troughs of computer aided design on a geographical basis, and, secondly, and I think more important, that in attempting to assess the enormous potential of the computer in the next decade, we must consider ship operation, as well as shipbuilding and are thus presented with the opportunity for integration on a scale far wider than just the technology of design and production of ships, by bringing in operations as well.

In conclusion I wish to record the assistance I have received through discussion with my many helpful and patient colleagues.

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