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

Developments in Ships and Shipping [and Discussion]

D. Goodrich, G. Ward and A. S. Laughton

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Developments in ships and shipping

BY D. GOODRICH AND G. WARD
British Ship Research Association, Wallsend, Tyne and Wear NE28 6UY, U.K.

The theme of the paper is the technology by which ships and their operation are improved and the need to take account of the operational environment and diverse social influences, the outcome being, necessarily, a compromise. The implications of a range of the major requirements and influences on the final product are considered. The consequences for technology are described under headings of design, construction and operation.

The role of R & D in advancing the accepted level of application of this technology is emphasized. It is concluded that the shipbuilder will continue to lead in the application of R & D and will be instrumental in introducing high-technology solutions to the problems of improvement.

INTRODUCTION

The design of a ship is a compromise: while principally having to provide for the operator a product that will meet trading requirements efficiently, there are a large number of influences and requirements to be taken into account.

The paper is in three parts. Firstly it considers the environmental aspects, and secondly the influences of society, including Government requirements. These two parts review the current situation and the implications on the design and operation of ships.

The third part considers how technology can help provide solutions to the many requirements evident in the first two parts. These are briefly described in the three main areas of design, construction and operation.

The current position with regard to technology in these areas is stated, and developments in the areas postulated.

1. ENVIRONMENT

(i) *Wind and waves*

Wind and the resulting waves have always been of concern in the design of vessels, mainly from the points of view of strength and transverse stability. Today, ships are still designed with a heavy reliance on empiricism but, increasingly, structures are designed by taking a more rational account of the forces set up by the seas. There are, however, aspects of a ship's interaction with the sea with regard to hydrodynamic loading that have not been solved. Similarly for stability, small ships are still in danger of being designed without sufficient stability simply because the subject of large angles of roll in a seaway is not fully understood; physical model experiments are not necessarily the answer because of problems in scaling viscous behaviour.

With regard to ship operation, one can expect that weather routing will become more common to take advantage of savings in time and fuel and to reduce the risk of heavy weather damage.

(ii) *Ice*

The increased activity in the Arctic regions, in the search for offshore oil reserves, creates a demand for specialized vehicles to operate in ice conditions, both to service the offshore work and also to transport oil and gas. The design of ships to withstand ice conditions has been a traditional occupation for only a few countries; currently there is an increased awareness, among the classification societies for example, of the need for operational data and related research to assist in the design and assessment of ships for specific ice areas and ice conditions.

(iii) *Sea traffic*

A topic of increasing concern is the control of sea traffic by methods matching those used for airborne traffic. For particular areas of the world, for example the English Channel, there has been much activity with regard to observing and recording ship movements with attempts to control them. It is expected that this concern will increase and that one will see progressively tighter future control of the movement of ships in most of the more crowded sea lanes.

TABLE 1. SHIP TYPE AND FULLNESS COMPARISON

ship type	block coefficient	1970		1980	
		L/B	B/T	L/B	B/T
passenger/ferry	0.55–0.65	—	—	—	—
container	0.56–0.69	6.50	2.70	6.16	2.71
bulker	0.68–0.72	6.70	2.40	6.44	2.51
large bulker	0.70–0.85	6.57	2.72	5.97	2.76
v.l.c.c.	0.80–0.87	6.17	2.52	5.90	2.70

2. INFLUENCES OF SOCIETY

(i) *International trading*

No attempt is made is this paper to make an independent forecast of trade for the next decade. Forecasts have the common fault of not being able to anticipate sudden changes in the world situation and it is these that generally turn out to be the major factors in world trade. The current glut of oil and the associated reduction in fuel prices will have some effect, but it is difficult to imagine the drop in price lasting long enough to counteract the trend to conserve energy and seek alternative energy sources to lessen the dependence on oil. These changes may lead to a permanent reduction in the demand for oil and its transportation but, in part, such changes will be offset by an increase in demand for coal and its transport; for example, Japan is currently on this path in its trade with Australia. For the purposes of this paper one anticipates a general increase in world trade in the long term with short-term fluctuations that affect primarily the trade in bulk cargoes.

(ii) *Types of trade*

There is a continuing trend to specialization in ships to suit particular trade requirements. The most common examples are full-formed ships to carry the less expensive bulk cargoes at relatively slow speeds, and fine, relatively fast, ships for ferries and cruise liners. Between these two types there is a range of carriers of more specialist types, such as roll-on roll-off (RoRo) ships, container ships, barge carriers and gas carriers.

Table 1 shows the types of ship against their fullness, as defined by block coefficient (which is the ratio of displaced volume to length × breadth × depth) and length (L)/beam (B)/draught (T) proportions. With the current high cost of fuel one notes that the trend for large bulk carriers is to even beamier proportions and slower speeds. During the same period, ferries have increased their carrying capacity while retaining the same speed.

TABLE 2. COMPARISON OF THREE CONTAINER SHIPS

	Encounter Bay (1969)	*Liverpool Bay* (1972)	*Table Bay* (1977)
length overall/m	227.3	289.6	258.5
breadth moulded/m	30.5	32.3	32.3
depth moulded/m	16.4	24.6	24.1
draught moulded/m	10.7	13.0	13.0
deadweight/t	29500	48500	47200
gross registered tonnage	26750	58890	53780
container capacity			
under deck	774	1948	1780
in two tiers on deck	356	704	656
total containers	1130	2652	2436
crew numbers	37	38	38
speed/knot (km h^{-1})	23 (43)	26.5 (49)	21 (39)
machinery	2 Stal steam turbines	2 Stal steam turbines	2 MAN diesels
horsepower†	32400 (shaft)	81000 (shaft)	51300 (brake)
fuel consumption	150 t/day	390 t/day	170 t/day

† 1 horsepower = 746 W.

TABLE 3. LIMITING SHIP DIMENSIONS FOR INLAND WATERWAYS

	limiting dimensions of ship/m		
waterway	length	beam	draught
Rotterdam	not stated	not stated	19.81
Kiel Canal	160	20	9.5
Suez Canal	335	50	11.6
Panama Canal	274.3	32.2	11.28 (freshwater draught)
St Lawrence Seaway	222.5	23.16	7.92 (freshwater draught)

(iii) *Economies of scale*

The reduction in unit costs that can be achieved by increasing the size of the ship was best typified by the oil tanker, which rose in size from 20000 tonnes deadweight (t d.w.) to 400000 t d.w. in about 25 years. At the peak of the oil traffic trade these larger ships could earn their first cost in a surprisingly few trips. The situation since then has changed considerably with the laid-up tonnage constraining new building and also probably restraining the general trend towards the increase of size.

The same trend in economies of scale was demonstrated by container ships, as shown in table 2. The influence of fuel costs can be seen in the design of the *Table Bay*, which has a much reduced power and speed relative to the *Liverpool Bay*. The capital involved in building such large specialized ships is such that the shipping companies have generally grouped themselves into convenient units, sometimes internationally, for purchase and operation.

Restrictions in the size of ships have generally not been for technical reasons (although there have been problems at each major change in design), but have been more concerned with restrictions imposed by waterways, harbours and canals. Table 3 shows these.

(iv) *Canal influences*

Restrictions in ship dimensions for transit through canals have traditionally affected the design of ships, for example, for transit through the Suez Canal in ballast and around the Cape of Good Hope in load, the 250000 t d.w. tanker is about optimum. The Panama Canal has a similar influence on the American trade both for specialist ships such as container ships and for bulk carriers. The former have developed into rather long and relatively narrow forms because of the constraints of lock breadths (typified by the *Liverpool Bay*; table 2) and, for the latter, one refers to a Panamax ship, which is the maximum for transit through the Panama Canal because of depth constraints.

(v) *More detailed trade influences*

The liner trades provide a regular service, shipping a varied and generally highly valued cargo. A specialized form of this trade is that undertaken by the container ship. The packing of goods by manufacturers into standard containers has the obvious attraction of a factory to warehouse service with a much reduced risk of damage. The transport of containers by sea is currently experiencing increased competition with the now traditional and specialized container ships being challenged by general cargo ships and more recently by bulk carriers. So, despite a continuing and high level of specialization, general cargo ships are still being designed and built to accommodate a range of types of goods from bulk to containers.

The relative stability, in trade terms, of cargo liner transport against the fluctuating requirements of the bulker trade, has seen the introduction of a hybrid kind of bulker with an increased width of hatch suitable for carrying containers as well as bulk cargo. Such vessels can switch from one type of cargo to another and, although not as efficient in either service as the specialist ship, they can perhaps more readily sustain trading difficulties when the market is depressed in one sector. One can expect that the true bulk carrier will continue to be required with the range of ship sizes generally remaining about the same. The recent upsurge in orders for new bulk carriers will no doubt bring about a surplus of such tonnage, repeating the difficulties experienced by tanker owners and operators.

The increase in popularity of cruise holidays has seen an upsurge in the demand for passenger ships, which has been met by refitting existing liners and by building new special purpose vessels. An example of the former is the liner *France*, which has now become *Norway*, and an example of the latter is the recent order by P & O for a 40000 g.r.t. (gross registered tonnage) cruise liner.

There is also an increasing range of highly specialized ships, for example the now common gas carriers, the nuclear flask carriers and chemical cargo carriers. The last of these requires a most complex cargo handling arrangement with associated safety requirements.

Port facilities have an impact on ship design, and the reverse is also true as demonstrated by the special facilities that were built for container ships. In many ports there are poor discharge arrangements and to compensate for this the RoRo type of vessel has been developed.

Many variations to stern gantry have now been designed to allow transport to drive directly onto such ships. A particular example is the short-distance ferry, where both front loading and rear loading gantries are provided for quick turnround in port.

Expansion in offshore oil and gas exploration and production facilities has led to the development of a number of special purpose vessels, such as pipe-laying barges, heavy lift barges and special-purpose exploration vessels, all of which have required much ingenuity and skill on the part of the naval architect and the various engineering disciplines, both in their design and manufacture. One can expect that the skills of the naval architect and the civil engineer will increasingly be combined to design and construct new structures to meet the varied requirements of exploration and exploitation of the world's resources.

(vi) *Inter-Governmental Maritime Consultative Organization* (*IMCO*), *governments and marine authorities*

A number of incidents, such as that of the *Torrey Canyon*, have led to international pressure to introduce requirements to prevent, or minimize, the effects of such accidents in the future. A conference in 1978 introduced two protocols. The first of these was related to MARPOL (prevention of marine pollution) and the second to SOLAS (safety of life at sea). These two Conventions proposed far-reaching and quite costly changes in the design of tankers. The more important of these, which apply to new ships of more than 20000 t d.w. are as follows.

(*a*) *Segregated ballast tanks*, which are spaces dedicated to ballast and cannot be used for carriage of oil in the loaded condition (this had been a common procedure and was the cause of much pollution). These requirements mean that a tanker capable of carrying 120000 t of cargo can, in fact, now only carry about 80000 t.

(*b*) *Protective location*, which is to arrange the design of tanks such that ballast spaces are on the outside of the ship to prevent oil spillage in the event of a collision or grounding.

(*c*) *Crude oil washing*, which uses its own oil cargo rather than seawater to wash down the tank surfaces. During the washing phase it is necessary to prevent explosions by the use of inert gas.

(*d*) *Inert gas systems*, as indicated in the previous paragraph, are required to prevent the possibility of explosion during the dangerous phases of operation when the tank atmosphere becomes flammable. Suitable inert gas is usually obtained by piping boiler flue gas, after it has been cleaned, into the cargo tanks.

In total the above measures increase the cost of operation and reduce the earning capacity of the vessels.

In addition to the above for tankers there have been requirements issued for (*a*) passenger ships, (*b*) chemical tankers, (*c*) gas carriers, (*d*) crane carriers, (*e*) offshore drilling units, (*f*) offshore supply vessels, and (*g*) fishing vessels.

The working and living environment on board also receives the attention of IMCO. Recently a committee has drafted a code of practice for noise on board ships, and no doubt vibration will be considered in due course. These are natural trends, which add to the cost of the vessels and also require the application of a higher level of technology in their design.

A longstanding problem for the naval architect and approval authorities is the provision of adequate transverse stability to withstand the extremes of weather and specified damage conditions. This is a truly dynamic problem that has so far not been satisfactorily solved to predict the large angles of roll which, in some cases, may lead to capsize.

Safety involves many aspects of ship design and operation; for example it refers to personal injuries, pollution and economic aspects. Many papers have been written analysing the circumstances of documented casualties and in all of these the major cause has been human error in one form or another. This suggests a need for a more systematic organization as in the air traffic industry. For example, traffic flows in congested waters need to be controlled and also the procedures on board ship need to be improved to the best currently practised. There is an obvious need for high and consistent standards of training with, no doubt, the use of ship simulators playing an important part in providing 'concentrated' experience on a range of ship types and conditions.

Ratification of the various IMCO protocols is left to the individual governments. Unfortunately, certain governments are much slower than others in approving marine legislation. Those owners who, by their choice of country of registration, conform to the higher standards of safety will be at a commercial disadvantage, which in some cases will add to their decline. There is, it would seem, increasing concern by the shipping industry that the bulk, cost and complexity of current IMCO proposals is making them counterproductive.

An aspect of ships and shipping that is apparently less prevalent now is the introduction of defence requirements into the specification of new ships. For example, passenger liners can be envisaged as troop carriers. Perhaps the biggest impact of governments these days is in the policies adopted towards their shipping and shipbuilding industries. If it is required for nationalistic reasons that these should be developed, then there will be some form of subsidy, which will affect the world's balance to a greater or lesser extent, depending upon the size of the industry.

(vii) *Ship operator and ship owner*

The increased cost of fuel has had an important effect on ship operations. Liner trades have to maintain a service; therefore the drive for efficiency is by improvements in ship design, operation and hull maintenance. In the bulker trades, operating speeds have now generally reduced and new designs are actively being pursued to provide economies both by a change in ship proportions to correspond to the reduced speeds and by the provision of more efficient, large-diameter propellers directly coupled to slow-speed diesel engines.

TABLE 4. TYPICAL U.K. MANNING LEVELS

	total officers and crew	
type of ship	1968–9	1978–9
cargo liner, 12300 g.r.t.	42	30
tanker, 55000 t d.w.	45	31

Table 4 shows the reduction over a period of 10 years in the total officers and crew of two types of ship. Such reductions have been gained by the adoption of labour-saving devices in day-to-day servicing and maintenance on board by the transfer of some maintenance tasks to the periods in port and by the adoption of automation in various degrees. The last is having a considerable impact on the number of crew, there being designs that have reduced manning levels to 18. Those countries that pay higher wages to their crew are having to apply automation to remain competitive.

As indicated earlier, the owners have introduced specialization in their ships; for example, the old general cargo has separated into dry bulk in containers and liquids in special carriers such as chemical and product carriers. But the need to be flexible is still important and one sees that modern cargo liners are again multi-purpose.

(viii) *Shipbuilder and engine builder*

The shipbuilder will offer standard designs to meet market requirements, as he identifies them, and will also provide special-purpose ships to meet the specifications of an owner. For the former, the builder has to identify a market and then attempt to optimize his design for this market in the hope of producing a standard ship that will meet the requirements of a number of owners. Perhaps one of the most important objectives in optimizing standard ships is to ensure that the design chosen is not too sensitive to changes in the operating conditions. Such ships will tend to be fairly conventional.

Table 5. Some groups of chemicals carried, with containment method

cargo groups	epoxy	polyurethane	zinc silicate	stainless steel
non-oxidizing mineral acids	−	−	−	+
sulphuric acid	−	−	−	+
nitric acid	−	−	−	+
organic acids	−	−	−	+
caustics	+	+	−	+
ammonia	+	+	+	+
aliphatic amines	−	−	−	+
alkanolamines	−	−	−	+
aromatic amines	−	−	+	+
amides	−	−	−	+
organic anhydrides	−	+	−	+
isocyanates	−	+	−	+
vinyl acetate	+	+	+	+
acrylates	+	+	+	+
substituted allyls	?	+	+	+
alkylene oxides	−	−	+	+
epichlorohydrin	+	+	+	+
ketones	+	+	+	+
aldehydes	−	+	−	+
alcohols, glycols	+	−	+	+
phenols, cresols	−	−	+	+
caprolactam solution	+	+	+	+
olefins	+	+	+	+
paraffins	+	+	+	+
aromatic hydrocarbons	+	+	+	+
miscellaneous hydrocarbons mixture	+	+	+	+
esters	+	+	+	+
vinyl halides	−	?	+	+
halogenated hydrocarbons	+	+	+	+
nitriles	+	+	+	+
carbon disulphide	−	+	+	+
sulfolane	?	?	?	+
glycol ethers	−	+	+	+
ethers	−	+	+	+
nitro compounds	−	+	+	+

Notes. +, Suitable; −, unsuitable. Other cargo groups not included are described as extremely reactive and need special containment systems.

Ships designed and built to meet an owner's particular requirements can be very specialized. In some cases, much development work will be required to ensure that the ship meets its specification on completion. It should be remembered that the builder does not have the luxury of building a prototype; his first ship must be satisfactory on trials, otherwise it may be rejected.

Legal disputes on whether or not a ship is satisfactory are not uncommon, especially when freight rates are low.

Much new technology was developed for the liquefied natural gas ships both with regard to containment and cargo handling. A similar situation applies to the chemical tanker which can have 50 or so separate tanks, each fitted with its own deep well tank and piping system. Table 5 shows the range of chemicals carried as cargo and the method of containment. Although much engineering work on containment is subcontracted, the builder still has the final responsibility for equipment, should it not perform satisfactorily at the trials.

The competition to win orders in these days of over-capacity is intense and this leads to designs being offered that have very little margin, if any, on power and speed requirements. Establishing, at the design stage, the necessary power to meet the owner's requirements with regard to speed, although a subject of long standing, is still an uncertain procedure and, should the ship not meet its contract speed, then the builder is liable to pay a penalty.

The standard main machinery these days is the slow-speed diesel engine burning heavy oil, and this is the norm against which other machinery must be compared. Steam turbines with oil-fired boilers are currently being replaced in existing ships by diesel engines and it is only in warships that gas turbines and nuclear propulsion have attractions. However, owing to the high cost of diesel fuel there is current interest in coal-fired boilers for which much originality is being shown in the methods used for handling the coal. Unfortunately, current designs cannot cater for variations in the quality of coal, and there is therefore a restricted use for ships with such engines. The fluidized bed combuster will overcome this lack of flexibility, but much research work will be required before it can be expected to be used on ships in service.

(ix) *Classification societies*

The major maritime nations each have their own classification society whose main function is to assess a ship's structural design and to ensure that it is built to satisfactory standards; they may also have other ship-surveying duties delegated to them by their governments. Although generally in competition with each other, they have joined together to form the International Association of Classification Societies (IACS), whose purpose is to work towards the improvement of standards of safety at sea. Liaison with IMCO, for example, is established through IACS.

Each classification society has its own set of rules, which have been evolved over a period of years, for the structural design and building of ships. Because, until recently, the evolution of ship types has been slow, the rules have been developed in great detail and have had an inhibiting effect on structural design. Even now shipbuilders rarely take the initiative in structural design as in other construction industries.

(x) *Labour organizations*

The various organizations that represent the workforce in the construction and operation of ships each pursue, in their respective sections of the total industry, their common objectives of ensuring continuity of employment, satisfactory remuneration and a healthy work environment. Taking an international view, these objectives will be pursued differently in each country, with the most progressive incurring the heaviest costs; these will need to be offset by increased productivity elsewhere if that part of the industry is to remain viable in an international business.

(xi) *Education and training*

The increased application of high technology in the design, building and operation of ships requires a higher level of ability from the technologists working in the industry and an improved standard of training. The next sections will indicate the extent and complexity of the technology for which suitable personnel need to be attracted and retained. Strangely, the U.K. is probably the most backward in the way it treats and ranks its various types of engineer. The recent Finniston report recognized this and made proposals to rectify the situation. One hopes that the current implementation, with its modifications to the original Finniston proposals, will bring about the changes so necessary and important for a country that depends on its productive industries for its standard of living.

3. Technology

As mentioned previously, the requirements that the ship designer and builder are expected to meet are becoming more and more onerous. Basically these requirements stem from the commercial pressures of operation, from all aspects of safety, and from improvements in habitability.

Commercial pressures on the shipowner lead him to require a low life-cycle cost. For the designer and builder this means producing an efficient product in terms of fuel economy, low level of manning, minimum first cost, reliability and ease of maintenance. Safety at sea is, of course, subject to Government Regulations; compliance requires a knowledge of the vessel's behavioural characteristics. Improvements in habitability can be achieved by the fitting of more advanced equipment, which is easier to operate and maintain, and by knowledge of noise and vibration effects. Protection of the environment involves designing to reduce the risks of an incident and to minimize the effect should there be one; this again requires a knowledge of the product's behavioural characteristics and of its strength, etc.

A number of these requirements necessitate high-technology solutions but, in any case, the development of the technology in general reduces risk, which risk may be the failure to meet contract requirements, e.g. speed (performance in any measure), or deficiency in the general quality of the product.

(i) *Design*

The reduction of risk by high-technology solutions implies better methods of prediction. It is in this area that effort tends to have been spent in improving prediction techniques. The dynamic behaviour of ships and other marine vehicles has traditionally been predicted by the construction and testing of physical models, and considerable sums have been invested in sophisticated model-testing facilities. The construction and testing of models is, however, a time-consuming and expensive process, which can involve a series of iterations gradually improving the design. Although for a conventional ship form the skill and experience of the designer and the experimenter will usually minimize this process, for a new or non-conventional product this is not so.

A design giving excellent dynamic characteristics in terms of steering, manoeuvring, stability and resistance does not in itself necessarily provide a satisfactory solution. Other fundamental problems such as propeller excited vibration can be a direct consequence of the form of the hull.

It is confidently expected that the emphasis for design prediction will gradually shift from physical to mathematical models. R & D work in this area has been under way for some time and is now being stepped up. This is not to say that physical models will not be tested in future, but it is expected that they will be used more for confirmatory tests. Indeed sophisticated model-testing facilities are, and will continue to be, required.

(*a*) *Ship behavioural characteristics*

There is an increasing need to consider the various behavioural characteristics of a ship in a seaway. The earlier requirements, as already mentioned, were concerned with transverse stability and main hull strength. Current criteria used to judge the acceptability of a ship with regard to its transverse stability are based on essentially static considerations of position of centre of gravity and ship's geometry. This is not really satisfactory for the smaller ships where large angles of roll in a seaway, with accompanying winds, make the problem one of dynamics for which one may have to consider the bounds of stability rather than a direct solution of the problem.

All motions in a seaway add dynamic loads to those calculated for still water, and the calculation of such loads now follows a fairly well defined procedure of representing the sea by spectra and, with the aid of transfer functions, calculating response spectra from which short-term and long-term statistics are derived. The application of derived loads in a seaway to the ship as a structure is a simplification that needs considerable full-scale experience before the results can be judged to be acceptable or otherwise. The problem of deriving dynamic stresses in the various parts of a ship structure requires complicated simulation where all component stress vectors, and their phases, are calculated at short time intervals over a representative period of time. Such detailed calculations are impracticable in a design procedure.

The manoeuvrability of ships both in calm water and in a seaway is of increasing importance from the point of view of accident prevention. It may seem surprising but there is no generally accepted criterion with which to judge a ship's manoeuvrability. Certain standard manoeuvres are carried out, such as turning circles and zig-zags, to demonstrate a ship's steering and manoeuvring characteristics, but research is still required to define them quantitatively and also to relate them to the ship's geometry.

Other behavioural characteristics, not necessarily related to the sea, are those associated with the propulsion system, i.e. vibration, noise and performance. Vibration and noise are increasingly of concern with regard to their effect on habitability. There are methods available, which are currently the subject of much research, for the estimation of vibration amplitudes and noise levels. Unfortunately, the accuracy of such methods is not as good as one would like and those used for vibration, in particular, are not sufficiently developed to be able to comply with specified limiting values.

(*b*) *Advanced mathematical procedures*

The mathematical representation of a ship and its reaction to the fluid environment has now developed to the point that, given enough time and effort, simulation can be carried out that, if not always sufficiently realistic in the absolute sense, is certainly realistic in a comparative sense.

Perhaps of greatest significance are the recent developments in mathematical models representing the flow around a ship, both its three-dimensional boundary layer and the surrounding potential flow. Such models have been developed to predict the flow into a working propeller, but the same procedures are being applied to derive the total resistance of a ship by calculating its frictional drag and wavemaking resistance. This has been an objective for many years and it will greatly facilitate decisions on hull form early in the design stage.

The flow régime around a ship is most complex and it is usual to consider it under two régimes, viscous and potential. As might be expected there is an interaction between the two, which makes the mathematical solution more difficult, especially for the slower ship of fuller form. For the faster fine forms, the wavemaking resistance is predominant and for this there are now generally acceptable numerical solution procedures. Most of this work is still only applicable to the assessment of changes in hull forms because the commercial requirement of guaranteeing a power and speed on completion of the ship demands associated towing tank tests on physical models and well tried methods of extrapolating model results to full scale. However, progress is being made and one can expect that mathematical models will be used increasingly to assess all the behavioural characteristics of a ship, with physical model tests used as a final check for contractual purposes.

(ii) *Construction*

The shipbuilder, having satisfied himself that his design will meet operational and safety requirements, now has the task of turning it into a product. ‘Design for production’ is a fairly well worked concept but, if done properly, it can significantly reduce the cost of manufacture. If one considers that, for a typical merchant ship, about 60 % of the total cost is in bought-in materials and equipment, it becomes apparent that the builder has to make substantial improvements in his productivity to affect the end cost significantly.

(*a*) *Computer-aided design and manufacture*

Traditionally, shipbuilding is a craft industry, that is one that is heavily weighted towards manual operation, albeit often requiring high skills. Despite this, the industry was one of the first in the U.K. to adopt computer techniques, firstly in the design analysis area. Subsequently, methods have been devised to define the shape of the ship form by computer and to translate this into information directly fed into numerically controlled plate-cutting machines. The advent of computer graphics has enabled the current advanced stage to be reached. Figure 1 shows a currently available system.

As can be seen from the figure, the system is a comprehensive steelwork design and production system. It uses computer graphics as its means of linking with other systems (figure 2), both production control and design. The drawings created in the graphics system are stored in a machine-readable form as computer files: geometrical, numerical and text data once created in a drawing may therefore be used in other computer processes. The system provides software enabling the computer graphics data for drawings to be used directly for technical and administrative purposes. The system supports the design process from the preparation of scantling plans to the final production definition and lofting.

Several of the programs may be used as aids to preliminary design but the system as a whole has been devised to meet the requirements of the later phases of design. Benefits of this system now available include reduction in lead time, reduction in production costs, reduction in loft costs, and reduction in direct technical costs. With the ever-increasing power of the computer, future developments will undoubtedly make available a comprehensive package for the examination of a wide variety of design considerations. It will be possible to produce a number of alternative designs very rapidly. In time the sophisticated mathematical modelling techniques for hydromechanics, etc., described before will form part of this whole package. The information required to manufacture the product and to control the production process will be a direct output of the computer-aided design and manufacture system.

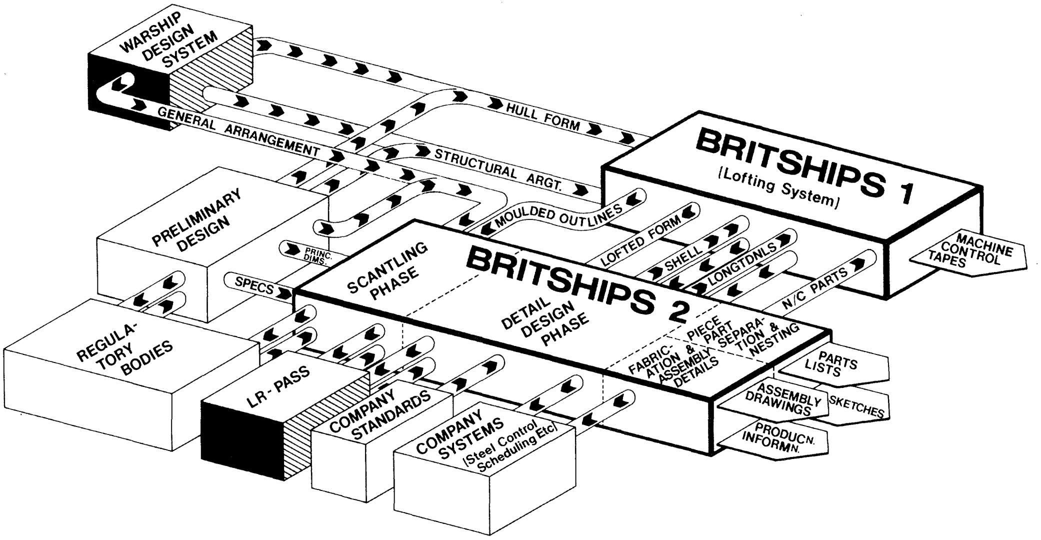

FIGURE 1. Information flow for Britships 2.

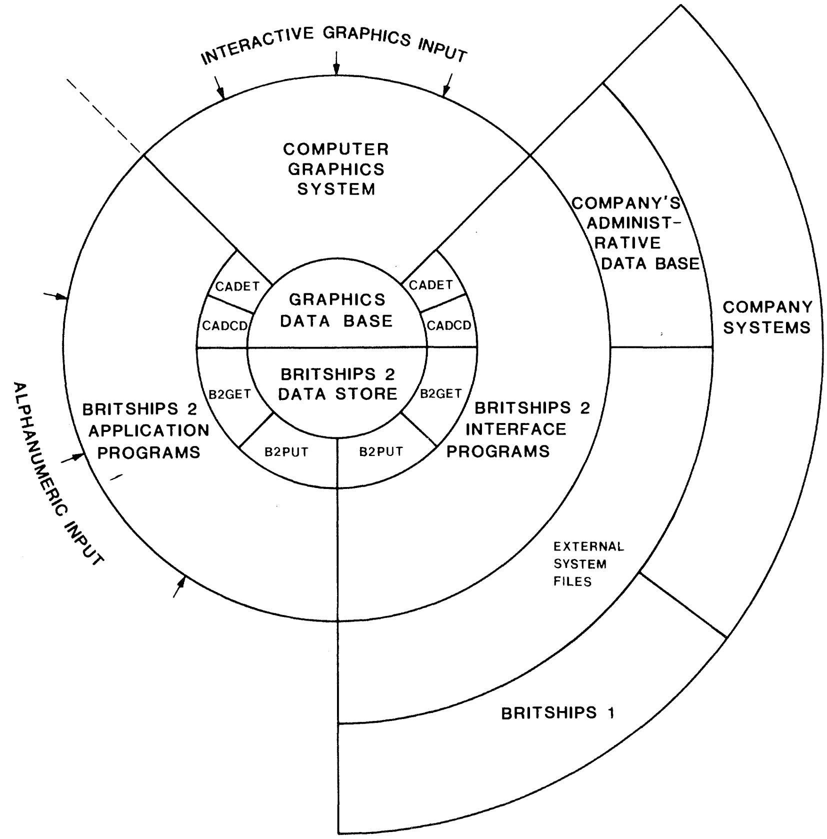

FIGURE 2. Structure of Britships 2 system software.

(*b*) *Ship construction methods*

With regard to the production process itself, this will become more and more automated. We have already described the automated production of the basic parts using a computer-aided design and production system. Shipbuilding, however, is largely an assembly industry often requiring 'one-off' solutions. It is clearly not straightforward to automate significantly in such a situation. The whole production facility can, however, be designed to improve the possibility of automation and improve productivity. Figure 3 shows a modern ship factory: completely under cover, and building in a dock for float-out eliminating the traditional launch. By changing the traditional method and order of building it is possible to do more construction work in a more productive situation. This can mean assembling large fully fitted modules.

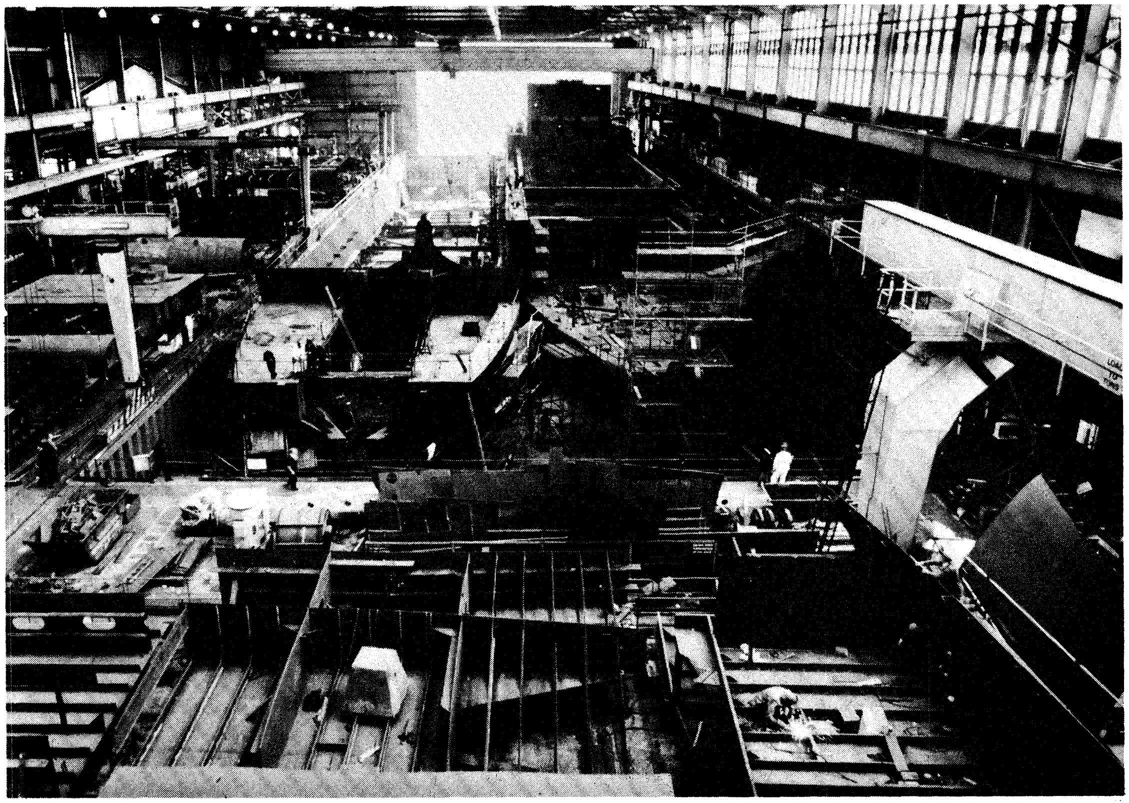

FIGURE 3. Modern ship factory.

A number of the processes have already benefited from automation, e.g. assembly lines for flat grillages, jigs for curved grillages, numerically controlled cutting machines, numerically controlled pipe-bending machines, and automatic welding equipment. Future developments will undoubtedly take place in individual processes, and work is currently under way on laser cutting, laser welding, electron beam welding, etc. The future will see the introduction of robotics into shipbuilding but it is likely that early installations will be exploratory. Repetition in shipbuilding is not high so the conventional robot is limited in its application. However, a number of operations are of a hazardous nature – welding or painting in confined spaces, for example – and it is in this context that the early applications of these techniques will be seen. They are likely, however, to be extensions of remote control rather than the direct use of unmanned robots.

(iii) *Operation*

Now, having applied high technology to the design and production of our vessel, what about its operation? Operating costs are dominated by fuel. The design technology previously described clearly contributes to minimizing fuel costs by the provision of an efficient hull form, machinery package, etc. The technology discussed under construction helps to minimize first cost to the owner.

(*a*) *Automation of ship operation*

There are, of course, many high technology facets of operation with regard to safety at sea, e.g. weather routing. This paper, however, only briefly looks at the impact of microelectronics on board ship.

There are two basic incentives for using sophisticated microelectronics on board: (1) possible reduction in manning costs, now the largest single operating cost after fuel, and (2) improvement in performance by the monitoring and control of machinery, etc., to produce the optimum results.

Considerable progress has already been made in this field, and microcomputers for specific functions are already in use at sea. Research has shown that the fully automated ship is feasible and, in the longer term, reductions of crew down to about 12 are to be expected. In the shorter term, microcomputers will be used for a variety of functions, including those listed in table 6. Indeed most of them are already in use in some form. A research project between British Shipbuilders, B.S.R.A. and a shipowner has resulted in a trial with microcomputers aboard vessels at sea. Most of the above functions are included in the trial. A typical display available in colour on board the ship is the cargo loading and calculation diagram.

TABLE 6. MICROPROCESSOR FUNCTIONS ON BOARD SHIP

navigation training
cargo planning and loading
machinery surveillance and control
Master's records
ship repair and maintenance information system
Chief Engineer's status report
satellite communications

In the longer term it is believed that the increasing demand to reduce operational costs will result in a centralization of bridge, cargo and engineering functions at a single location within the ship. The designer will need to consider the ship as an overall system in which control equipment, the engineering plant and the onboard work areas are designed in parallel and within an integrated framework. The specification, development and proving of the necessary software will become part of the overall ship design process. The need to validate software before its introduction will become more acute as computers play an increasing role in the on-line control of shipboard processes. This will involve the use of simulation as part of the design process.

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(*b*) *Ship operation and R & D*

In looking at high-technology solutions with respect to operation of the ship it is appropriate to review R & D work under way. It is in the operation of the ship (over its whole life) that the design consequences are apparent. The ship designer, on behalf of the owner, is usually working on a product as much for the next decade as for the present one. R & D work in any of the areas discussed is directly or indirectly of benefit to the ship operator.

Work is under way on the dynamic behaviour of ships in varying sea and weather conditions. This will lead to a greater understanding of the problem, and hence enable the product to be safer and capable of more predictable behaviour. This applies to seakeeping, steering and manoeuvring, and stability.

Work on advanced mathematical procedures will be of direct benefit to the operator, as it enables the designer to predict more accurately the performance of a number of design options. In the future these methods will be used to obtain an optimum hull form for maximum fuel efficiency. R & D work here allows the prediction of noise and vibration characteristics. Future work will improve the accuracy of prediction and improve the basic design with respect to these and other characteristics.

Computer-aided design and manufacture is developing very rapidly. Integrated design and production systems are being developed. These will enable the owner to examine a number of alternatives before choosing. It brings greater prospects of standardization and quality. Standardization clearly eases maintenance and support problems.

Ship construction methods are of interest to the operator in terms of cost and quality. R & D work to study the application of robotics, modern production methods and new materials is under way. Production will undoubtedly become more automated with consequent consistency of quality and reduced cost.

Microprocessors on board ship have already been discussed. More advanced ideas are being researched with the building of a simulated centralized control station. Use of microprocessors on board not only gives the opportunity to decrease manning levels but also increases safety. Built-in fail-safe routines can be incorporated in the software. This is an existing area of development with enormous potential. Associated R & D work in relation to reliability of engineering components, multiplexing and electromagnetic interference is underway.

Conclusion

The high-technology solutions and the associated R & D work described above all contribute to the operator's requirement of a highly efficient ship at minimum cost. The builder, in his role of designer and constructor, has to satisfy both the operator and the other demands of the environment and National Regulatory Bodies. It is therefore the builder, with assistance from others, who will continue to lead R & D to provide such solutions. R & D work is under way, or is anticipated, in the numerous areas described in this paper to support the growing use of high-technology in ships and shipping.

The authors express their thanks to the Chairman and Research Council of the British Ship Research Association for permission to publish this paper. Tables 2, 4 and 5 have been reproduced by permission of the Council of the Institution of Mechanical Engineers from *Developments in merchant ships over the last decade* by M. Meek (*Proc. Instn mech. Engrs* **194** (1980)). Figures

1 and 2 have been reproduced by courtesy of the Royal Institution of Naval Architects from *Steelwork design using computer graphics*, by P. D. Forrest & M. N. Parker (paper no. 3, Spring Meetings 1982).

Discussion

A. S. Laughton, F.R.S. (*Institute of Oceanographic Sciences, Wormley, U.K.*). The paper did not say anything about ship materials for the 1990s. Do the authors see anything on the horizon that might improve the problems of corrosion of mild steel construction, or any new materials that could economically replace mild steel?

D. Goodrich. We have seen developments for specialist ships in materials other than mild steel, e.g. aluminium, and in particular glass-reinforced plastic. However, mild steel is a cheap and easy material to work with, and research is continuing to reduce the problems of corrosion.

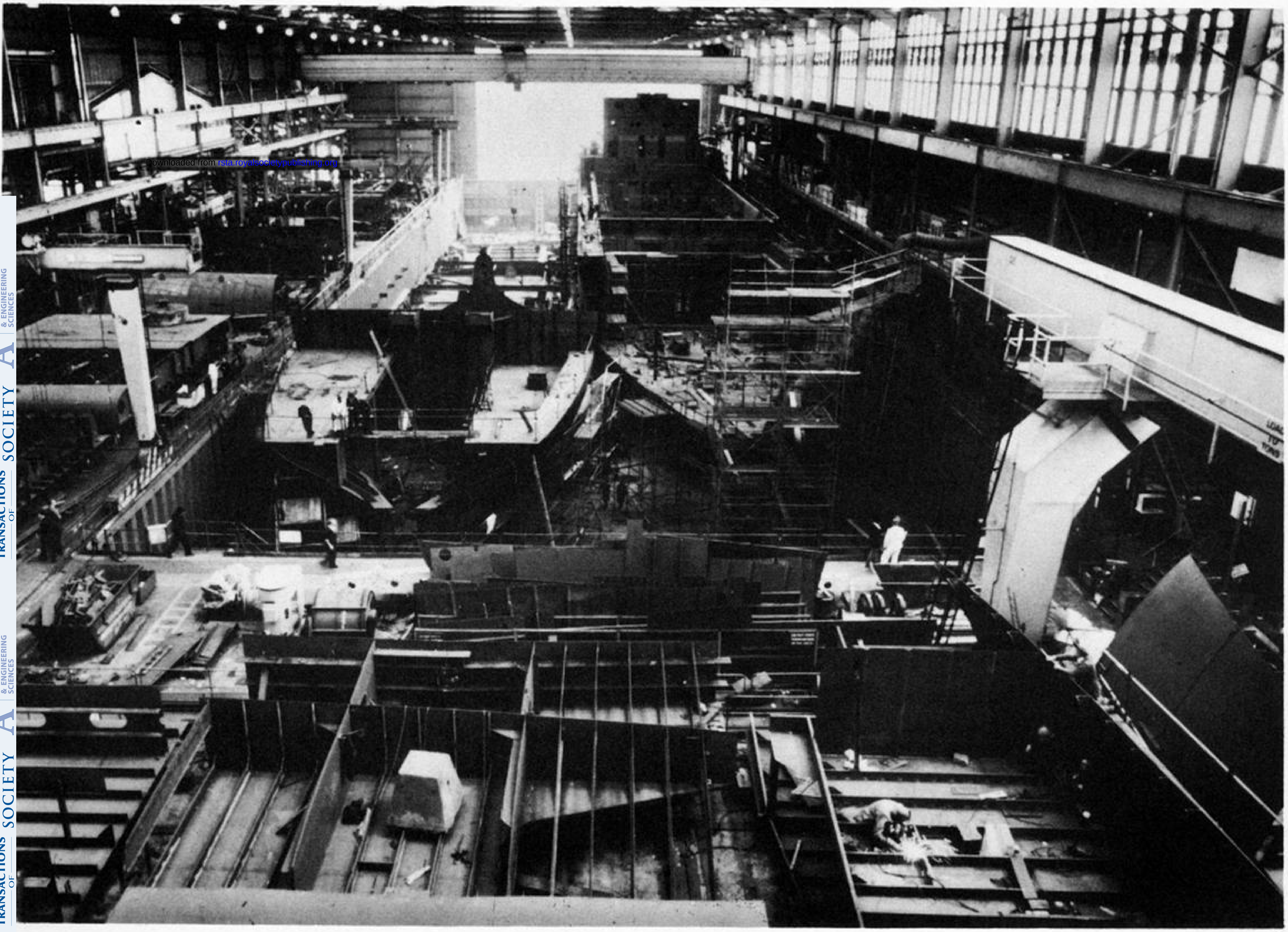

FIGURE 3. Modern ship factory.