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A COMPUTER MODEL FOR PRELIMINARY DESIGN AND ECONOMICS OF CONTAINER SHIPS

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Submitted as a Thesis for the degree of

Doctor of Philosophy

Department of Naval Architecture
and Ocean Engineering

University of Glasgow
July 1982

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This thesis is dedicated to

MY PARENTS

Author's statement: All the material in this thesis is original except where reference is made to other sources.

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1. SUMMARY

This thesis is concerned with the development of a computer algorithm for determining the principal dimensions of a container ship at the preliminary design stage. The algorithm was devised to aid a Naval Architect to design the most economical ship, given the ship owner's requirements. The emphasis has been on developing an algorithm which acts as an aid in the design process.

There are basically four models of the computer aided ship design which can be used in stages. The first model or algorithm is based on a deterministic approach with parametric variation of principal dimensions to locate the optimum design with minimum required freight rate. The second model incorporates optimisation techniques to arrive at the optimum ship. Though the optimisation technique is very powerful in the search of an optimum both in computer time and computing cost, the parametric method is preferred where a designer has little faith in the optimisation process or as an aid to check the answer arrived at in the optimisation process. The third model of the computer aided design can be used once the optimum has been found. A new approach to carry out sensitivity analysis is introduced. This approach overcomes the deficiencies of the past approach, in the sense that sensitivity analysis is carried out for achievable variation in variables rather than an arbitrary variation. The third model of computer aided design may be used once the designer has identified the variables, the variation of which, influences the required freight rate most. The use of the third model of the ship design may be adequate in identifying the total risk of the project. Together with sensitivity analysis, the designer can evaluate the total risk involved in an investment since the third model also incorporates a simple approach to risk analysis. However three estimates are required in the third model compared to single estimates of variables in the first and the second model. The fourth model incorporates the risk analysis by Monte Carlo method of simulation. In this model the designer can assess the

total risk of the project by generating the risk profile of the Required Freight Rate. The designer must either subjectively or objectively input the probability distribution of each of the influencing variables before using the fourth model.

The four computer aided design models form a complete suite of computer programs, which can either be used in a deterministic mode, (first and second model), or in a probabilistic mode, (third and fourth model). Compared to previous ship design algorithms developed solely to deal with deterministic phase, this thesis incorporates ideas on how to incorporate uncertainty and assess risk in capital investment in a shipping venture.

The designer can either use these computer models in stages, from deterministic phase to probabilistic phase or the models can be used on their own.

2. AIMS OF THE PROJECT

The main aims of the project are:-

(1) To develop a computer aided ship design model which could be used at the preliminary design stage for fully cellular container ships together with the desirable feature of stages whereby different levels of sophistication may be attained to suit the needs of the user.

(2) The computer model must be flexible enough to incorporate changes in the empirical data and design relationships, and must be modular in nature so that many of the algorithms can be used on their own for various other applications. It should have a user interface which would allow a variety of users e.g. Transport Economists, shipowners, Route planners, Port Authorities and Naval Architects to use it.

(3) The computer model must be able to incorporate uncertainty and must include an extension to the deterministic approach, which would enable a user to choose not only the best design but also one that is less risky.

(4) To show the use of this computer model as an aid to decision making at various stages of preliminary design.

3. INTRODUCTION

This thesis, as the title suggests, is about the choice of principal dimensions of container ships at the preliminary design stage, taking into account both the technical as well as economic aspects of ship design and operation.

The work is mainly concerned with developing a computer algorithm which will enable a naval architect at the preliminary design stage to choose the main particulars, given the owner's requirement of speed, trade route characteristics and the number of containers to be carried.

The research work is basically divided into two major divisions, a deterministic approach to ship design and a probabilistic approach to ship design. The former was the framework for developing the probabilistic approach.

In spite of the fact that during the past 20 years so many preliminary ship design algorithms have been written, it is rare that they have been applied, except perhaps during a few years after their appearance in periodicals and journals. This is primarily due to the fact that cost data, on which they were based were difficult to update or the technical data were invalidated, due to advances in ship design and production methods. The algorithm presented in this thesis has been sufficiently elaborated so that the designer can tailor the weight, cost and design relationships to his own needs. Moreover the cost data can readily be updated without recourse to an extensive cost data bank.

All the algorithms have been extensively tested and validated with existing containership data and checked by carrying out step-by-step hand calculation. The primary aim was to output reasonable results.

One way of generating large numbers of alternative ship design is by parametrically varying the main variables; such as length, breadth, depth, draft and block coefficient. The optimum design is then chosen according to some chosen economic measure of merit such as Required Freight Rate.

An attempt was made to automate the procedure of selection of the optimum design. This entails applying non-linear programming algorithm or optimisation algorithm.

Many authors in the past have successfully applied such algorithms to ship design problems (1). However it was found that availability of well tested optimisation algorithms for solving problems with non-linear objective function and non-linear as well as linear equality and inequality constraints was less satisfactory. The direct search method of optimisation by either Hooke & Jeeves (2) or Nelder & Mead (3) utilising the external penalty technique was adopted.

Lastly if one is designing a ship, many of the dependent and independent variables cannot be accurately estimated. Particularly costs in the future cannot be predicted accurately. This does not mean that one cannot deal with the future, but one cannot easily predict it. However methods exist which allows one to objectively assess the risks involved in various projects in face of uncertainty. Such a method is the Monte-Carlo technique (4). An application of such an approach is shown in this thesis. The probabilistic approach forms an extension of the deterministic approach.

The project develops and uses a computer algorithm which allows the user to select the design most appropriate to his requirements, bearing in mind that the data base used for validation is of limited extent.

A sensitivity analysis is always a useful first step in evaluating the risks inherent in a shipping venture. It involves first calculating the Required Freight Rate (RFR) based on the "most likely" (or best) estimates of the variables like costs, weights etc., and then observing the effect on the RFR of changes in each of these most likely estimates. Sensitivity analysis is usually carried out for $\pm$ 10% variation in variables without taking into account that for many of the variables a 10% change is not achievable in real life. In this thesis a new concept of sensitivity analysis is introduced. It however involves making three estimates instead of one for each of the variables, the "optimistic" estimate, the "pessimistic" estimate and the "most likely" estimate. The new method (4) therefore takes into account the achievable variation in the variables and its influence on RFR. It is also shown in this thesis how an investment's risk can be calculated by this new method of sensitivity analysis.

After the designer has identified the total risk of the project, and identified the variables which are most likely to affect the RFR, the sensitivity analysis might be adequate. However the next step can be the production of a risk profile of RFR. "Pessimistic" and "optimistic" estimates provide an indication of the uncertainty surrounding the best estimate made for a particular variable, but, for a complete description of that uncertainty, a probability distribution is required. Thus in the final step of evaluation the designer estimates the probability distribution of each of the variables. The designer also can test the dependence of one variable on another and judge if the dependence can be ignored. Thus the algorithm is also designed to deal with dependencies which is very important in risk analysis. Finally the output from the risk simulation is the distribution of RFR or the risk profile. A risk profile does not definitely answer the question: should the investment be accepted or rejected? This would be impossible. An investment which is considered acceptable to a large organisation might well be considered too risky for a small organisation. A risk simulation does however provide a considerable increase in a decision maker's understanding of how different factors interact to form the total risk in the project. The thesis introduces two basic ideas which are new to computer aided ship design model, first the estimation of risk from sensitivity analysis and second, the calculation of risk profile of the measure of merit.

The risk simulation algorithm and the sensitivity analysis algorithm developed in this project are a set of standard algorithms which can be applied to extend ship design models developed for other ship types. It also contains an algorithm for generating a histogram type of risk profile on a line printer. Graphical plotting algorithms which are more sophisticated than the one used in the thesis can readily be incorporated.

Finally an accept or reject decision can only be made when a risk analysis is carried out. For comparing alternatives a deterministic approach with sensitivity analysis may be adequate, but once an optimum design has been found, it is necessary to know the risk inherent in undertaking such a capital investment venture. Thus this suite of programs not only helps a Naval Architect to compare alternative designs but also helps him to study the acceptability of the final design.

CHAPTER 4

DEVELOPMENT OF CONTAINERISATION

4.0. INTRODUCTION

4.1. A SHORT PREVIEW OF HISTORICAL DEVELOPMENT

4.2. CHANGES IN STRUCTURE OF SHIPPING

4.3. ROUTE DEVELOPMENT

4.4. TECHNOLOGICAL DEVELOPMENT

4.5. CONTAINERS

4.0. INTRODUCTION

From the history of containerisation lessons can be drawn. Thus in this chapter an abbreviated overview of 'containerisation' is given. If we take the view that historical facts are nothing but the sum total of the experiences of successes and failures, then the empirical assimilation of experiences properly analysed provides an insight into the reasons for the successes and failures.

The chapter is basically divided into five subsections each concentrating on one aspect of containerisation. The first section is devoted to the various chronological developments, and it is noted that the container concept is not a new one, but it took quite a long time before it became a viable concept which could be applied. The second section shows how the shipping companies once able to operate independently, with the advent of containerisation were forced to combine or share their resources across their national boundaries. The third section discusses the new route developments and how wrong it is to assume that 'containerisation' will be slow to penetrate the trade between developed and underdeveloped countries. The fourth section deals with the technology involved in the containerisation and the main emphasis is on the container ships and how they evolved. The last section outlines the development of standardisation, the incorporation of certain other standards, the problem of nine high stacking, lashing of containers on deck and lastly the overtonnage in containers. The definition of the various types of unit load carriers is given in Table 4.1. In the thesis, only fully cellular container ships will be considered although the computer programs could be adjusted for container carrying ships without guides.

TABLE 4.1. Definition of unit load carriers.

FULLY CELLULAR CONTAINERSHIPS - These ships are designed to carry about 60% of the total container capacity under the deck in holds fitted with cell guides. The hold containers are stacked vertically one on top of another from 4 up to 9 high in the cell guides. The rest of the containers are carried on deck stacked up to 4 tiers high one on top of another and secured to the deck by lashings. The ships usually do not have any container handling cranes on board, the loading and the unloading of the containers being carried out by shore based container gantry cranes (13, 15).
ROLL-ON, ROLL-OFF SHIPS - A wide variety of ships are included in this category e.g. Passenger/vehicle ferries, short sea freight Ro-Ro's, deep sea Ro-Ro's, Car carriers, train ferries (15). These are designed to carry a wide variety of standard units, including containers which may be carried on trailers or by fork lift trucks, pallets, vehicles, loaded lorries as well as uncrated export cars, and large indivisible loads such as heavy plants (15). The holds are provided with large uninterrupted deck area, internal ramps and/or lifts. Loading and unloading is done either by ramps or by shipboard handling equipment/cranes (13, 15).
COMBINATION CARRIERS - These are designed primarily for carriage of roll-on-roll-off cargoes and cellular stowage of containers in one or more cargo holds (usually located forward). Container loading/unloading is usually done by means of shipboard travelling cranes (13, 15).
BARGE CARRIERS - These are designed to carry barges (lighters) each of which is capable of carrying about 300-850 tons of break-bulk cargo, palletised cargo, heavy loads and containers. The 'mother ship' which is the barge carrier loads and unloads barges, either by elevators/lifts or by the float-in

TABLE 4.1 (Contd.).

principle. The barge carrier can berth outside a port and the barges individually or in trains can then load and unload at shallower drafts, thus it reduces the need for any shore facilities (13, 15).
PALLET SHIPS - These ships are not designed to carry containers, but the general cargo is palletized forming a single unit, which can be easily handled by a fork lift truck. Pallets are not standardized but most are of about size 1.2 x 1.0 m wooden platforms. The pallets are loaded and unloaded through a side door (13, 15).

4.1. A SHORT PREVIEW OF HISTORICAL DEVELOPMENTS

Table 4.2 summarises the historical development of containerisation since its inception in 1906 to the first deep sea container service in 1968. This historical development is described briefly. Kummerman (6) and Rath (7) give detailed historical development of all aspects of containerisation.

There is considerable evidence that the concept of containerisation was applied as far back as 1906, and was reported in the National Geographic magazine in April 1911 (5, 6). However the concept was not exploited on a large scale until about 1950.

Shortly after World War I, Charles Brasch organised Seatrain Lines to provide a railway wagon service by water between Cuba and the coast of the United States (7). His system was the first perhaps to exploit the deep sea route, and consisted of specially designed shoreside cranes equipped with trays with railroad tracks installed on them. The lack of cooperation of the railroads eventually led to the abandonment of this idea by Seatrain Lines (7).

On this side of the Atlantic large containers of various kinds have been used in inland and overseas distribution for many years. London Midland and Scottish Railways first used containers in 1926 and unit load systems have been a feature of Great Britain-Ireland trade since the Second World War (8).

It is debateable whether the effort to promote containerisation at the International Road Transport Congress in September 1928 or the presentation of a movie at the International Chamber of Commerce in May 1929 in the U.S.A. at the same time covering rail transport, had any significant influence on the overall development of containerisation (7).

The potentialities of containerisation were recognised on this side of the Atlantic also, when in 1931 the Royal Commission on Transport in the U.K. reported their surprise that the advantages of containerisation were not recognised by the shipping fraternity (8).

TABLE 4.2. Outline sketch of historical development of containerisation

Year	Description
1906	First published evidence of application of concept of containerisation.
1916	Railroad car service by water from Cuba - coast of U.S.
1926	London Midland&Scottish Railways used containers.
1928	International road transport congress organised a conference to promote the idea of containerisation.
1929	Promotion of idea of containerisation in May 1929 by International Chamber of Commerce by presentation of a movie, together with coverage of Rail Transport.
1931	Royal Commission of Transport in U.K. pointed out the advantages of containerisation in their report.
1933	Formation of Pan-Atlantic Steamship Corporation.
World War II	Use of 'conex' containers by the U.S. Army transportation corps and development of the first extensive container transport operation.
Post-war period	Resurgence of interest in containerisation by commercial operators.
	Building of first C3 class cargo ship by Maritime Commission, U.S. to carry containers.
	Alaska becomes the first part of United States to take advantage of unitization.
	Korean war gave a further boost to the containerisation.
1956	First commercial container operation started between New York and Houston by Pan-Atlantic Steamship Company in converted T2 tankers.
1957	Converted C2 type vessel 'Gateway City' became the first Lift-on/Lift-off type of ship.
1957-1958	Pan Atlantic converted further 6 tankers after the initial success.
	Matson Navigation Co. introduced 6 - C3 type vessels converted to carry containers on the West Coast of U.S.A. to Hawaii.
1959	Pan Atlantic became Sealand Services Inc. first container shipping company.

TABLE 4.2. (Contd.)

Year	Description
1961	American Material Handling Society, American Society of Mechanical Engineers and American Standards Association (ASA) adopted the first standards for containers.
1962	Standards for container strength adopted. Standards for container fittings adopted. Rochdale Report on British ports.
1964	Associated Steamships, Australian shipping line began a container service between Melbourne and Fremantle.
1965	International Organisation for Standardisation, ISO, adopted the ASA container size and strength standards. Sealand announced its intention to enter the transatlantic trade.
1966	First liner service introduced by Sealand Services Inc. between Europe and U.S.
1966	Japanese government announced marine development plans.
1967	International standards organisation agreement signed in Moscow.
1968	First purpose built container ship introduced on the North Atlantic route.

In 1933, the Waterman Steamship Corporation established a coastwise service designated as Pan-Atlantic Steamship Corporation, for handling of general cargo, which extended from Boston, Massachussetts to Houston, Texas, and serviced the major ports on the Atlantic Coast between these two ports (9). This was a crude form of containerisation, the more valuable and fragile cargoes were carried in protective cages or wooden boxes to deter pilferage and breakage as much as possible.

As we have seen above until World War II, containers of various forms and dimensions were used within the rail systems in Europe and America. A few attempts were made by small ship operators to consolidate their cargo into boxes primarily to avoid damage and pilferage.

However credit must go to the U.S. Army Transportation Corps for the development of the first extensive container transport operation during the war. Also an exhaustive analysis of the full spectrum of military cargo established the fact that approximately 40% of the total cargo could be containerised (10). The containers used during the war were called 'Conex' containers, they were small units and were handled by conventional cargo gear, namely derricks and tackles (6). Like the prewar period, the original decision during the war by the U.S. military was not based on strictly economic reasons. The main reason was the protection against mechanical damage and inclement weather, provided by the metal container. Thus the full economic potential of containerisation was not realised by the commercial shipping operators.

However, whether by coincidence or example, a sudden flurry of interest in containerisation also appeared in the shipping field in the early post-war period (10). It was realised that improved handling of general cargo in and out and within the ship was an economic necessity. Consequently during the 1950's detailed studies were made of existing methods of handling break bulk cargo, palletization, fork lift operation, improved cargo gear, hatch configuration, roll on-roll off ships, containers and so on (5). The studies were aimed at the use of containers but these containers were relatively small units. Overlooked and not identified was a common denominator, a large enough unit in common use ashore that could be readily adapted to the ships. The railway wagon was one possibility and the highway trailer the other (6). Other factors which were overlooked were, that the ships were not designed to handle this type of cargo efficiently, with the result that the boxes were frequently damaged. There was also serious loss of cubic because, the containers were stowed in the wing spaces of 'tween decks and lastly the vexing problem of return cargoes, which were not available (10).

The U.S. Maritime Commission even built a C3-Class cargo ship with over deck bridge cranes capable of handling unit loads up to 30 tons, which were strikingly similar to the ship mounted cranes of today (10).

It was left to the ingenuity of the private shipowners to develop the containerisation system and show that it worked.

A U.S. stevedore contractor was the first to develop the use of 40 ft. containers for cargo, which was much bigger than what his predecessors had experimented with. The containers were carried in barges to Alaska. He experimented with double decking and with stacking, and was perhaps the first to prove that containerisation could be so effective that the attributes of the vessels themselves would be overshadowed by the economy obtained in unitization. Alaska was thus the first part of the United States to take the full advantage of unitization (7). At the same time, two commercial groups, one a trucker turned shipper and the other a non-subsidized steamship company were independently experimenting with the intermodel containerised sea transportation of goods (6). Their ingredients for the success were the same; large containers that could be married to over-the road equipment, could be lifted aboard the ship without the highway wheels, could be stacked in cells aboard the ship and moved to their stowed position in a vertical direction only.

Also this breakthrough in sea going containerisation received its greatest impetus from increased trade between the United States mainland and the islands of Puerto Rico and Hawaii and later Alaska (5). Malcolm McLean, a trucker turned shipowner and founder of Sealand Services, stimulated by profit motive and annoyed by the restrictive state highway regulations, conceived the bold idea of carrying his trucks on a ship for the long haul from Florida to New York (10).

Since the highway vehicle was made up of easily separable units consisting of tractor, trailer and container, the ship need only carry the latter, with the use of wheeled highway components confined to the land segments of the system. So the modern container ship was born. This must be recorded as one of the most significant and remarkable innovations in the history of sea transport. Economics now had replaced protection as the principal motivation. High cargo handling productivity, with attendant reduction in direct labour costs and port time of the vessel, coupled with the low cost/ton mile at sea, spelled success. The increase in the size of the unit load represented a quantum jump and was able to eliminate many handlings at the system interfaces (10).

For the above reasons in 1956, Pan Atlantic the predecessor to Sealand Service Inc., fitted two T2 type tankers the 'Ideal X' and 'Almena' with elevated platforms above the tankers deck and was used for carrying 35 feet trailer vans between New York and Houston (6). Simultaneously, another study was made by the company of roll-on/roll-off trailer vans but was abandoned in favour of container ships (5).

After their experimental run, Sealand in 1957, converted a C2 type vessel to a lift on lift off ship, and 'Gateway City' became the world's first container ship (6).

This conversion was an absolute departure from anything contemplated before. Each container was stacked in cells one on top of another seven high, with vertical guides at four corners preventing them from toppling. The containers were fitted with corner castings with openings for the engagement of a bayonet type twist lock device for lifting with a crane suspended frame (6). The scheme used in this first vessel is essentially the same as used today with very little modification.

'Gateway City' was followed by five other sister ships, all coming into service between New York, Miami, Tampa and Houston (6).

Following the same pattern Matson Navigation Company for years a dominant shipper in the U.S. West Coast to Hawaii trade converted six of their C3 vessels to carry 75 containers on deck. Subsequently it was Leslie A. Harlander, who developed the carrying of containers in cell guides. Matson used 8' x 8' x 24' containers compared to Sealand's 35' because two 24' vans loaded on the chassis could be moved by one tractor under Californian Highway laws (7).

By 1959, Pan Atlantic became Sealand Service Inc. (7), the first shipping company to adopt containerisation. In the next year, 1960, Matson converted one of its C3 vessels to a full container ship, the 'Hawaiin Citizen' (6).

Another shipping company Grace Lines converted two C2 vessels in 1959 to full container ships using 17 ft. containers, intended for South American service, New York to Venezuala (11). The early services multiplied rapidly; by 1960 an extensive range of ports on both the East and West Coasts of the U.S. were connected by the container ships of Sealand, while Matson built up a comprehensive set of sailings to and from Hawaii. Grace Lines service from New York to Venezuala was the first outside the protected U.S. coastal trade, but although the operations of all three U.S. companies continued to prosper, very little was done on the international front (11). There were early opposition to containerisation.Grace Lines two ships on their maiden voyage in 1959 were held up because the stevedores in South American ports refused to unload them and the service was subsequently scrapped (6). In 1957 a similar fate was met by Sealand's 'Gateway City' on her first voyage to Puerto Rico (6).

Besides general cargo, other forms of cargoes were also being containerised. In 1961, two T2 tankers were converted by Union Carbide for transportation of granular chemicals in special containers. These containers were 30 ft. long, of relatively heavy all-welded aluminium construction (6).

On the other side of the Atlantic in 1962, the Rochdale Report on British ports came to the conclusion that the British ports and possibly the British shipowners were less forward looking than their overseas U.S. competitors (8).

However the most important stimulus was standardisation. Little interchangeability existed between the various forms and sizes of equipment developed by various railroads and shipping companies. As pointed out above container sizes varied from 17' to 40'. Lifting and securing fittings were all different. If this newly developed method of transportation were to have widespread success and its full benefits realized, standardisation had to be brought about. As far back as 1961 the American Standards Association (ASA) adopted container size standards, and strength standards in 1962. The International Organisation for Standardisation (ISO) tentatively adopted the ASA standards in all aspects except the strength standards which were based on stacking containers four instead of six high (5). The final agreement of container standardisation was signed in Moscow as late as June 1967 (8). In addition to the main purpose, that of easy interchange, the subsidiary benefits of standardisation include lower cost of the container through mass production and the opportunity to standardize transport vehicles and transfer equipment (6). In compromising spirit Sealand released for royalty free use, a key patent having to do with the container corner fittings and making twist lock lifting fitting (6). Ironically the standards adopted by ISO omitted the Sealand's 35 ft. size as well as the 24 ft. used by Matson.

During 1962-1965 many container ships were built or converted in the U.S.; these included 16 conversions by Sealand; 4 by Matson (2 new buildings) and 20 other vessels either of full or part container capacity by several other American shipping companies (6). The Americans had realized the potentialities of containerisation while European ship owners remained sceptical. The Australian shipping line, Associated Steamships, was however an exception, which began in 1964 a container service between Melbourne and Freemantle with the first specially built container ship 'Kooringa' (6).

In the meantime in 1966 Sealand obtained the largest shipping contract ever awarded by the U.S. Government for the supply of military hardware to Vietnam (6). This provided a considerable stimulus to shipping lines; in fact a large part of Sealand's revenue came from military contracts. Thus the Korean war and subsequently the Vietnam war provided a much needed impetus to containerisation.

In the same year 1966, Sealand and U.S. lines put converted container ships into Transatlantic service. Hitherto it was U.S. coastwise and Puerto-Rican service only (6). In 1966 there were 5 shipping lines operating container services from the U.S. In January 1967, it was reported that there were 38 lines serving over 100 ports in Europe, Latin America, the Near East, the Far East, Africa, Australasia from the U.S. East and West Coast and Great Lakes ports (8). The step of Sealand to enter the North Atlantic route certainly removed any doubt from the minds of those who were hesitating about containerisation as reflected in the growth in containerisation after 1966.

The year 1966 also marked the commitment of many European owners to container services including Overseas Containers Ltd. (OCL), Associated Container Transportation (ACT), Atlantic Container Line (ACL) and Johnson Lines (6). This also heralded an era of new buildings in container ships, specialist ships which were designed to carry only containers, i.e. fully cellular container ships. By June 1969 the number of lines had risen to 88, and the number of ports served to almost 200 (8).

Table 4.3 gives the differing views of different generations of container ships. Fig. 4.1 gives the chronological change in the principal dimensions, power, speed and carrying capacity of the different generations of the container ships. Table 4.4 outlines the chronological development of fully cellular container ships since 1960 for ships over 500*Teu. Table 4.4 shows that the first purpose built container ships came into operation in 1968, these were the first generation container ships. There were equal numbers of conversions in that year and the size of these vessels were about 835 Teu. The size of the purpose built were about 1000 Teu. 1969-71 saw the advent of the second generation container ships of 1000 Teu and the average size of purpose built container ships was about 1200-1300 Teu. The third generation container ships came into operation in 1972 with an average size of purpose built container ship of 1800 Teu. This was also the year when the highest numbers of container ships were built. After the oil crisis of 1973-74, the number of container ships to come into operation fell to 11 in 1975. It was not until 1977-79 that there was again a resurgence of new building activity. The size of the vessel was the same as those of the second generation ships about 1200-1300 Teu.

In the early years, port throughputs have increased very much in line with the growth rates of the container carrying fleet capacity (27). Quite naturally in the early years of the intercontinental containerisation involving the major liner trade routes growth rates were higher (between 1966-1973) than during the subsequent period until 1979. During the former, container throughput doubled

* Teu(Twenty Foot Equivalent Units).All container spaces in a ship can be expressed as 20 ft. equivalent spaces,e.g. one 40 ft. container is equal to 2 Teu's.

TABLE 4.3. Definition of different generations of cellular container ships.(From various articles)

(12)	Capacity TEU	DWT tons	Loa m	Bext m	d m	V knots
First generation	750	14000	180	25.0	9	22-23
Second "	1500	30000	225	29.0	11.5	26-27
Third "	2500-3000	40000	275	32.0	12.5	22-23

Year of Introduction

First Generation: 1966 – 1972

Second Generation: 1971 – 1977

Third Generation: 1973 – 1977

1966 "The first generation of major container ships were built in the late sixties for the Australian trade having container capacities up to 1500 TEU's and service speed around 22 knots from a single shaft arrangement". (16)

"These were ships of length between 175-200 m, with single screw arrangement, developing horse power between 28000-34200 PS and average speed of 23 knots with container capacity less than 1000 TEU". (17)

1971

1972 "The second generation ships were two- or three shafts arrangement and power supplied by steam turbine, gas turbine or three slow speed diesel engines and a container capacity of approximately 2500 TEU's. These were mainly

1973 introduced in early 70's for the Far East/ Australian trade."(16)

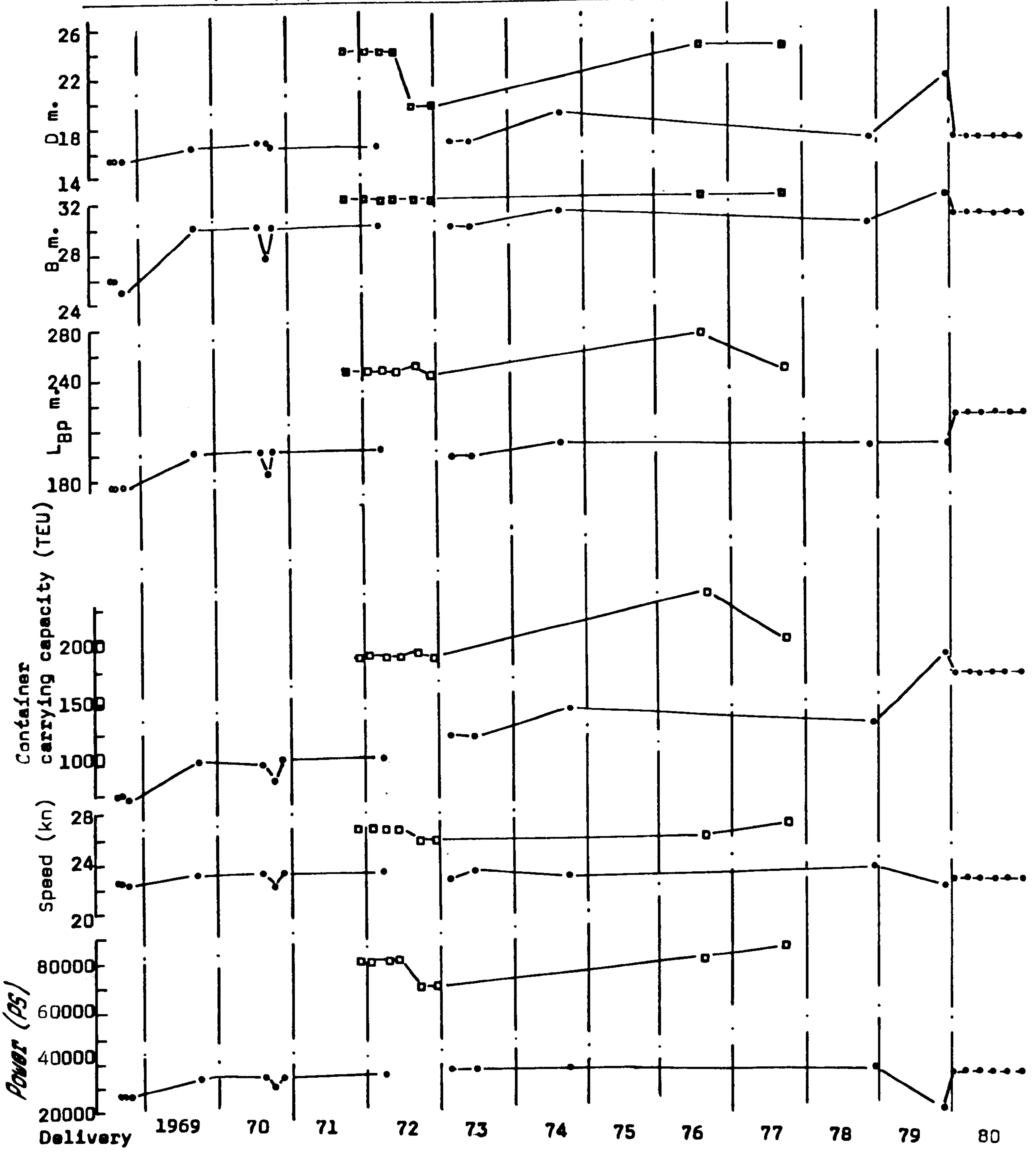
"The second generation of container ships are characterized by larger size about 245-273 m. in length, higher propulsion power about 70000 - 80000 PS, higher service speed about 26-27 knots and larger container capacity about 1800-2300 TEU". (17).

1977

TABLE 4.3. (Contd.).

1977	"The third generation of container ship came about after the oil fuel crises in 1973. The initial success of 2nd generation of ships was greatly reduced by world-wide inflation and high fuel prices resulting in operation at reduced speed. Thus a slower, shorter but equal container capacity to 2nd generation was developed". (16). The third generation are again the handy sized single screw ships with almost the same dimensions, power and speed as the 1st generation but designed with more stress on economical aspects, such as larger container carrying capacity and higher propulsive performance. (17). Klaus Hoppe (13) however has a different viewpoint:- "He defines the first generation vessels as those built during 1968 with 700-900 TEU. In 1970 the first of the so-called second generation about 1200-1700 TEU were put into service. In 1972 the third generation of container ship came into service about 2300-3000 TEU. A further development of still bigger and faster container vessels of the fourth generation was no longer followed up during or after the oil crisis. There developed the so called new second and new third generation of about 1100-1900 TEU as vessels of this size had been proved to be the most suitable for requirements of the trade".

Fig. 4.1. Chronological change of principal dimensions, power, speed and container capacity (17). (Japanese built)



- ∘ Ist. generation
- ▫ 2nd. generation
- • 3rd. generation

TABLE 4.4. Fully cellular container ships, number, cargo capacity, average TEU/vessel.

Year Built	Number of ships			Cargo Capacity in TEU			Average TEU per vessel		
	Purpose Built	Convert-ed	Total	Purpose Built	Convert-ed	Total	Purpose Built	Convert-ed	Total
1960	-	1	1	-	586	586	-	586	586
61	-	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-	-
65	-	3	3	-	3007	3007	-	1002	1002
66	-	4	4	-	4311	4311	-	1078	1078
67	-	3	3	-	2593	2593	-	864	864
68	15	11	26	15142	9190	24332	1009	835	922
69	21	9	30	25627	7228	32855	1220	803	1012
70	18	14	32	22022	11880	33902	1223	849	1036
71	25	5	30	32815	4082	36897	1313	816	1065
72	50	9	59	91368	10137	101505	1827	1126	1477
73	30	1	31	53379	1094	54473	1779	1094	1437
74	14	-	14	18949	-	18949	1354	-	1354
75	7	4	11	8372	3064	11436	1196	766	981
76	18	-	18	21414	-	21414	1189	-	1189
77	41	7	48	53967	7984	61951	1316	1140	1229
78	44	25	69	56449	28378	84827	1283	1135	1209
79	41	22	63	53242	19034	72276	1298	865	1082
80	37	7	44	52642	3876	56518	1423	554	989
Total	361	125	486	505388	116444	621832	-	-	-

Compiled from (14) containerships over 500 TEU as on November 1, 1980.

every 15 months on average, while after 1973 the growth slowed to an average duplication period of around $3\frac{1}{2}$ years (27). The growth rate for container demand will be in line with the global gross national product (GNP) (26). It is apparent that future expansion of containerisation will be in tapping the potential of the developing world which will be very much dependent on the provision of port and other facilities (27). In line with limited or zero growth rates in general economic activity of the developed world, the primary container routes will only generate modest container volume increases.

Wing and Hillman (32)give a clear exposition of the trade forecasting techniques which can be used to project the future demand and supply of general cargo vessels. Turnbull (33) based on these forecasting techniques estimates that between 1980-85 the number of general cargo vessals required per annum would be 500 assuming an average size of 16000 dwt and this would fall to 450 ships per annum between 1985-90.

4.2. CHANGES IN STRUCTURE OF SHIPPING

One of the main effects of containerisation has been to radically alter in little more than a decade, the profile of the world cargo liner fleet, as well as the structure and the operating practices of most of the world's major cargo liner shipping companies.

Before the advent of container ships in the early 1960's the general cargo trade or break bulk trade was carried by and large in the scheduled services of cargo liners. When business was good two deck tramp ships were often chartered to 'double head' the berth and sometimes even three ships in all would carry out a given cargo liner scheduled sailing. Occasionally with break bulk cargo a tramp ship would be chartered to travel between two ports, as was common for bulk commodities and could offer a lower freight-rate. The main impact of the container ship was on cargo liner operation and had replaced it in the major trades by the late seventies.

As the container ship numbers increased the number of cargo liners decreased and this decrease during the period 1970-1973 was equivalent to one container ship replacing four conventional general cargo vessels (11).This is because a container ship is much more efficient in terms of cargo carrying capacity, e.g. a cargo liner built in 1966 has 870×10^6 dwt tonne miles/annum compared to 5612×10^6 dwt tonne miles/annum of a container ship built in 1972, a factor of 6.45 (9). Although the cargo liner has seen a change in style it has not disappeared ten years later, since the container ship arrived in 1969. Meek (13) points out that the simpler the ship is to design and construct, the better it will be to provide an economic return; and the way to obtain a simple ship is to allocate to it a single cargo type. Thus the cargo liner of today is a less sophisticated vessel carrying cargoes which are not yet containerised. So the first effect of containerisation has been to shrink the total number of ships required to carry the general cargo trade.

While the Americans worried about the tooling up of containerisation, Olof Wallenius, a leading shipper of automobiles worried about how to finance the economy of scale. The recognition of the size of the ship investment required to be effective in containerships led Wallenius in the mid sixties to offer the idea of "Consortium" to many shipowners. His offer to the United States lines had to be rejected because of the Anti-trust legislation in America and the subsidy nationality issue (7).

But Cunard Lines (Great Britain), French Lines (France), Holland-America Lines (Netherlands) and two Swedish Lines, Swedish Transatlantic and Swedish Lines formed the world's first consortium with Wallenius Lines (7).

British and Japanese owners were well established in the liner trade, thus they could easily make the transition from conventional to container operations without recourse to international partnership (11).

While the Japanese and the Americans were slow to the idea of consortia, a majority of Scandinavian and Continental shipowners motivated by recognition of the implications of economy of scale in the construction and operating stages and identification of the massive capital investment this would call for, formed consortia to pool their resources (7) similar to OCL and ACT.

Thus the Wallenius idea of amalgamation of shipping interests has proven to be the greatest institutional change in world shipping. Joint services became most significant in areas where the largest ships and most containers were required.

The effect of containerisation on port development has also been significant. During the last 10-15 years port authorities all over the world have invested heavily in container facilities. This investment was brought about without coordination at a national and international level. The number of container/Ro-Ro berths rose from zero at the end of 1975 to 55 by the end of 1983 in the Arabian Gulf alone (11).

The rush of new buildings during 1968-1973 (Table 4.4) while containerisation was establishing itself in major trade routes may be one of the factors in the overinvestment in ports. The rush in new buildings was followed in 1974-1975 by a slump of orders which was mainly due to the oil crisis, the onset of recession and overtonnage in certain routes. Overtonnage on trans-Pacific trades led to mass resignations from conferences in 1975 and to rate competition severely affecting the profitability of certain shipping companies (11).

To summarise we can say that with the advent of containerisation fewer but more expensive ships were needed in the general cargo trade which called for heavy investment in ship and port facilities. To offer the door-to-door concept of delivery required pooling of resources of various shipping companies across their national boundaries by formation of consortia.

4.3. ROUTE DEVELOPMENT

Table 4.5 outlines the chronology of service inauguration of cellular container ships since the advent of containerisation. Table 4.6 gives the characteristics of the container ships on major trade routes. The maximum number of ships are on the West Coast of North America - Far East (WCNA-FE) and the Europe-Far East (Eur-FE) routes.The largest number of non-conference operators are on the WCNA-FE and the Northern Europe-Middle East (N.Eur-ME) route.The largest ships are on the N.Eur-FE and the N.Eur-South African route. Influence of the Panama Canal beam restriction of 32.30 m is evident in many routes connecting Europe and North America to the Far East, Europe-North America and the South African routes. The principal trade routes are shown in Fig. 4.2 together with the year they came into service. Drewry (11) gives the historical development of principal trade routes and Kieselhorst (26) gives statistical analysis of different trade routes together with the potential for further containerisation of these routes. A brief summary of the salient points of these trade routes is given here.

In no more than seven years containerisation has captured the liner trades between the developed continents e.g. North America, Europe, Australia and the Far East. Although as early as 1972 the first developing countries were integrated into the network connecting the Far East to the developed nations of the West (26), the relative share of the developing world in terms of total port handlings arose from under *5% in 1971 to around 24% in 1978 (26). There has also been an increase in the relative share in port handlings of the Far East and South East Asian countries from about 9% to over 24% during the same period. The global growth rate has been around 15% to 17% whereas the growth rate between the developed world has declined from about 32% in 1972 reaching its peak in 1974 to about 6-7%/annum in 1978. In the developing world there has been a sustained growth rate of around 18 to 19%/annum. Therefore

* Container growth rates in fleet deployments or port throughput in percentage per annum.

TABLE 4.5. Chronology of service inauguration of cellular containerships (26).

1955	United States coastal services
1958	North America - Hawaii
1959	Australian coastal services
early 60's	New Zealand coastal services
1963	North American East Coast - Puerto Rico
1964	North American West Coast - Anchorage
	Australia/New Zealand
mid-60's	European coastal services
1966	North American East Coast - North Europe
1968	North American West Coast - Far East
	Canadian Atlantic - North Europe
1969	Australia - Europe
	Australia - North American East Coast
	Australia - Far East
	North American West Coast - North Europe
	North America/Atlantic - Mediterranean
1971	Australia/New Zealand - North American West Coast
	Mediterranean - North American West Coast
1972	Europe - Far East
	North Europe - United States-Gulf
1973	North America - Indian Subcontinent
	Mediterranean - Far East
1975	Europe - South Pacific
	Europe - Middle East
	North America - Middle East
	Europe - Morocco
1976	Far East - South Pacific
	North Europe - Caribbean/Central America East Coast
	North American Atlantic - West Africa
	Miami - Ecuador

TABLE 4.5. (Contd.).

1977	North America/Far East - Panama/Venezuela
	Australia/New Zealand - Middle East
	Australia - Sri Lanka
	Australia/New Zealand - South East Asia
	Europe - South Africa
	Europe - West Africa
	Europe - Indian Subcontinent/Indonesia
	Europe - New Zealand
	Far East - Middle East
	Australia - South East Asia
	Australia - Papua New Guinea
	Mediterranean/Caribbean
	South American East Coast - Coastal services
1978	North American Atlantic - South American East Coast
	Brazil - West Africa
	North American West Coast - South Pacific
	North Europe - Central American West Coast
	North American West Coast - Central American West Coast
1979	North Europe - Mexican Atlantic
	Mediterranean - Venezuela/Mexican Atlantic
	Europe - Mozambique
	North American Atlantic - Colombian Atlantic
1980	North Europe - South American East Coast
	Far East - Indonesia
	Australia - South Africa
	China - Australia
	China - Europe
	Black Sea - India
	North Europe - Sri Lanka/India
	Australia/New Zealand - (South American West Coast) Venezuela/Caribbean
	Mediterranean - East Africa
1981-82	Far East - South Africa
	Europe - Indonesia
1982	Europe - South American West Coast

TABLE 4.6. Characteristics of container ships on major trade routes.

ROUTE	No. of ships		TEU container capacity		Knots speed		metres length		Ext. Beam		Draft	
	C	NC	Min.	Max	Min.	Max	Min	Max	Min	Max	Min.	Max
1. North Europe - North America east coast	31	7	456	1968	17	27	145	288.4	19.0	32.3	7.8	11.5
2. U.S. east coast - Mediterr.	7	3	560	1070	16	20	120	185.9	21.6	23.8	5.1	9.9
3. North Europe - North America West coast.	9	-	560	1214	18	21.5	143	201.9	21.5	25.9	7.8	10.1
4. Europe - Far East	41	-	1342	3010	21	27	208	289.6	30.5	32.3	9.3	13.0
5. Europe - Australia	20	1	1404	1950	21	23	217	248.6	29.1	32.3	10.4	12.0
6. West Coast North America - Far East	67	23	492	1800	17.5	27	144	261	21.6	32.3	7.6	11.7
7. East Coast " " - Far East	5	2	860	1887	20	26	174	263.3	24.1	32.3	9.8	11.7
8. West Coast North America - Australasia	2	-	-	750	-	25.6	-	161	-	25.6	-	9.4
9. East Coast " " Australasia	11	-	750	1708	19	22.5	161	247.8	25.6	29.4	9.4	10.8
10. Far East - Australasia	11	-	554	1748	16	26	161	237.8	19.4	32.3	8.2	11.5
11. North Europe - South Africa	5	-	-	2450	21	22.7	247	258.5	-	32.3	12	13
12. Mediterranean - South Africa	3	-	-	1309	-	21	-	208.3	-	30.6	-	10.4
13. North Europe - Middle East	6	14	550	1089	15	20	145	208.8	20.6	31.2	8.3	11.4
14. East Coast North America - Middle East	1	-	-	750	-	18	-	171.4	-	25.4	-	10.6
15. Far East - Middle East	-	4	430	1040	15	18	145	192	20.6	23.9	8.3	9.3

C - Conference operators
NC - Non-conference operators

Contd.

TABLE 4.6. (Contd.).

	No. of ships		TEU container capacity		Knots speed		metres length		Ext. beam		Draft	
	C	NC	Min.	Max	Min	Max	Min	Max	Min	Max	Min	Max
16. North Europe - Caribbean	6	-	-	1202	-	21	-	204	-	30.9	-	10
17. U.S. East Coast - Caribbean	4	-	581	630	15	16	159.4	159.6	20.8	22	9.3	9.6
18. North Europe - West Africa	6	-	900	1000	-	22	173.8	201.8	26	27	9.1	9.5
19. Mediterranean - Far East Australia		2	-	410	-	16		133.4	-	17.3	6.6	7.1
20. Mediterranean - North America - Far East	7	-	1566	1654	22	23.5	208.1	218.6	29.6	30.6	10.4	11.5

C - Conference operators

NC - Non-conference operators

(Compiled from Ref. (11))

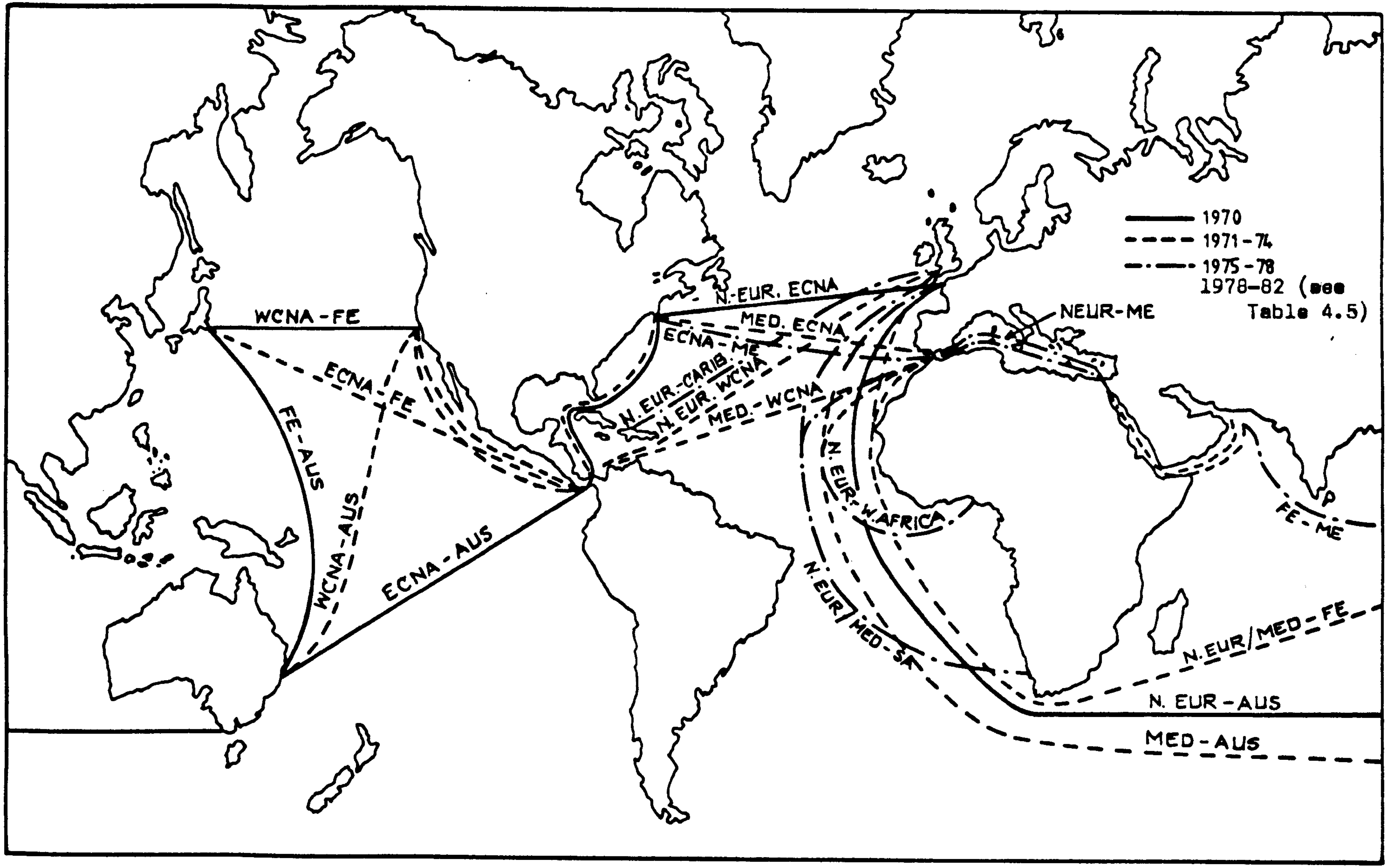


Fig. 4.2 Principal trade routes commencing since 1970

it can be inferred that there is no untapped potential for containerisation in the developed world. The growth of containerisation will come from new routes to developing countries. These emerging regions together with their high growth rates/annum are; Africa (62%), Latin America (47%), Middle East (76%), Indian subcontinent (179%) and the South Pacific (611%)*. However routes to these emerging regions as potential for containerisation can only come about if the port infrastructure can be provided, until then the growth will be sustained at the current level of around 4%/annum. Estimating available future potentials requires an appraisal of the situation in the various major world regions. These regions are briefly reviewed below.

Europe Mediterranean:

The growth in port throughputs until 1973 was largely due to the finalisation of the first phase of containerisation on major trade routes i.e. North America, Australia/New Zealand and the Far East. In that year the Far Eastern regions contributing nearly 60% of the tonnage for that year. This growth declined after 1974 principally due to the fuel oil crises and low level of economic activity. Further growth in ensuing years was sustained by inauguration of new routes to the developing countries i.e. Middle East, Africa, the Carribean and the South Pacific. This area has considerable untapped potential especially in short sea trades.

North America:

In respect of deep sea trade routes North America is less diverse than Europe-Mediterranean as only two major routes, Europe/Mediterranean and the Far East account for 78% of the 1980 deep sea container fleet employed in American waters.

Growth rates are lower than Europe due to the predominance of the above cited trade routes whose container potentials seem to be already exploited.

There are extensive land bridges across North America and the Pacific ports have profited more from the land-bridging than others, this is because of the huge

* High growth rate per annum caused by low base value.

Asian trade and the Australia/New Zealand route. But now the new container routes to the Middle East, Latin America and Africa will again strengthen the Atlantic side.

Far-East and South East Asia:

Of all the major container trading regions, the Far East/South East Asia have contributed most to the rapid growth of containerisation. Growth rates in port through -puts have been above average.

North America, Europe/Mediterranean and Australia/New Zealand still account for more than 90% of the container fleet activity in this area.

Since 1975 countries like Hong Kong, Taiwan, S. Korea and Singapore had a growth rate higher than Japan which at that time controlled nearly 50% of the containers handled.

Although Thailand, Philippines, Indonesia, Malaysia and China still have large untapped potential, future growth may not come from these regions because of slow economic activity and port development programmes. Most of the growth will therefore be sustained by the economic activity of Japan, Hong Kong, Taiwan, South Korea and Singapore which accounted for more than 90% of the region's container activity.

Australia/New Zealand:

Overall growth rates have been more continuous than in other regions both in terms of fleet deployment and port throughput.

Australia overcame the recession which affected all other regions by advancing containerisation of its Asian trades. New services were also introduced in 1977 notably between Europe and New Zealand.

This area's potential for growth will not be dramatically changed by the introduction of new routes since most of the cargo has already been containerised.

Middle East:

This region has in recent years shown the largest growth rates and will continue to sustain high growth rates because of their low resources of industrial and agricultural goods. It is estimated that by 1980 only 15% of the total estimated potential has been tapped. But the speed of containerisation of the available potentials will be largely governed by the development of ports.

Africa:

In recent years major events in intercontinental containerisation were the full scale conference coordinated containerisation of the South African trade in 1977 and the progressive containerisation of the West African trade (see Fig. 4.2). There has been a considerable amount of reefer installations in fully cellular container ships in the South African trade whereas West African trade has been hampered by lack of adequate port facilities. This explains the smaller ship sizes and the high proportion of non-cellular tonnage (Ro-Ro and semi-container ships) in this trade.

Latin America:

This area has also been identified as a major growth area. Full scale containerisation has yet been limited to the Carribean and Central America, while Mexico and the South American continent remain largely untapped. Apart from one Ro-Ro operation with the United States, the tonnage employed is essentially composed of semi-container ships.

Indian Subcontinent:

The Indian subcontinent is the last but not the least significant area where containerisation will advance. Apart from semi-container tonnage all types of small and large container carrying ships can be found on this continent, involving all major trade routes, including coastal operations. Because of the proximity to busy container routes this region can be quickly containerised as soon as adequate port facilities are built.

Having discussed the growth of containerisation and potential for future growth, it is necessary to see this against the overall trade in dry cargo.

The liner transport related to the dry cargo section of the world trade was 22.3% in 1965 and fell to 18.5% in 1972 with 17.2% forecast for 1985(18).Also the liner transport failed to participate in the trade growth to the same extent as non-liner dry cargo ships. While container cargo grew in absolute terms and steadily increased its market share in the liner section, conventional liner cargo fell drastically in absolute terms.

4.4. TECHNOLOGICAL DEVELOPMENT

The technological development of container ships has reflected experience in operation giving rise to many improvements in detail and economies of scale which have been reached by considerable increase in size. Values of Froude number did not change much from the first to the second generation indicating that the same relative speed was sought, although the absolute value increased by a few knots. From the second to the third generation Froude number fell indicating the effect of much higher fuel costs and the relatively high speeds of the second generation of container ships may not return. Some of the problems associated with the container ships and their subsequent improvement over the years are discussed in this section.

The initial problems to be resolved when the first generation of container ships were being built were

(a) Actual weight of an average loaded container was not known, although the maximum permissible weight was known (18, 19).

(b) The optimum clearance between cell guides and containers were not known (18, 19).

(c) The optimum deck width at side to meet the strength requirements.

(d) Other structural problems related to open type of ships (20,21,22,23) such as,

(i) Necessity of obtaining the same section modulus against longitudinal bending with considerably reduced deck plating.

(ii) Concentrated loading on the double bottom.

(iii) Reduction in support of side framing due to reduced width of deck plating.

(iv) An 'open section' lacks torsional rigidity and is prone to warp, causing additional longitudinal stresses which augment those due to longitudinal bending.

(e) There were problems related to propulsive performance, seakeeping quality, manoeuvrability and propellers designed to deliver the high horsepowers. Investigation into these problems are outlined in Table 4.7 for the different generations of container ships.

(f) Improvement in stability characteristics were needed due to the larger deck loading of containers as ship size, constrained by the Panama Canal dimensions and the speed increased (13).

An interesting study of the trends in containership design is presented in (24) and some of the article is reproduced in the following pages. Unfortunately the word improvement is often used whereas the word change could be more appropriate. Some of the changes mentioned in the article are the results of economies of scale or differences in Froude Number. Among these effects however, will be the steady improvement in structural arrangement, hull form, hull surface finish and machinery over period 1968 to 1976.

TABLE 4.7. Major items of investigations for development (Propulsive performance, seakeeping, manoeuvrability and propeller design) (17)

Ship \ Item	Propulsive performance: Hull form	Propulsive performance: Appendage	Propeller	Manoeuvrability	Seakeeping quality
1st generation ships	Application of wave resistance theory Study on flow around a propeller by wake survey		Application of propeller theory. Study on propeller with modified pitch ratio and expanded area ratio. Study on strength of blade.		Application of strip theory and wave statistics. Advancement of model test technique. Full scale tests in service.
2nd generation ships	Application of wave resistance theory. Development of new hull form.	Study on hydrodynamic characteristics of large sized bossings. Develop. of slender shaped bossing.	Development of propellers for twin screw ships. Study on propellers for very high powered ship.	Comparative study on rudder and propeller configurations.	The same as above
3rd generation ships	Devel. of new hull form with high economical performance. Improvement of flow around propeller.		Study on propellers with lower level of vib. excitation. Design of prop. compromising efficiency, erosion and vib. excitation.	Confirmation of proper manoeuvrability.	Contribution to rationalization of struct. design. Improvement of soft ware system for calculation.

The vehicle efficiency (VE) may be defined as the necessary energy for transporting cargoes a certain distance. This can be expressed as (24)

$$VE = \frac{\text{Number of containers or weight of cargo x distance}}{\text{Specific fuel consumption x power x time}}$$

$$= \frac{N \times dist.}{Sfc \times SHP \times \frac{dist.}{24V_s}} \propto \frac{N \times V_s}{Sfc \times SHP}$$

where SHP = horse power in PS

V_s = service speed in knots and

N = container capacity in Teu.

If we take the specific fuel consumption to be constant

Then $VE \propto \frac{NV_s}{SHP}$ or $\left(\frac{SHP}{\Delta V_s}\right)^{-1} \times \left(\frac{N}{\Delta}\right)$

where Δ = displacement on tons.

The two parameters $\frac{SHP}{\Delta . V_s}$ and N/Δ are used to trace the development of containerships (24,25,17).

4.4.1. $SHP/\Delta . V_s$ (24).

If we denote $\frac{SHP}{\Delta . V_s} = K$, then the factor K denotes the energy consumption per ton-mile. The value of K is plotted against speed in Fig. 4.3 for the conventional cargo liners, first generation of container ships and the current generation of container ships. It is evident that the energy consumption per ton mile has progressively decreased from the cargo liners of the early years to the container ships of today. The improvement in the hull form can be shown by expressing $\frac{SHP}{\Delta . V_s} = \frac{R}{\Delta} \quad \alpha \quad CV_s^2$ where R is the drag and C is the drag coefficient. The value of $(\frac{SHP}{\Delta . V_s}) \times \frac{1}{V_s^2}$ which is proportional to C is plotted against the service speed and shown in Fig. 4.4. It is evident that the drag coefficient C has decreased for the current generation of container ships and the difference between each straight line represents this improvement.

To see the improvement in the factor K for different sizes of container ships, $\frac{SHP}{\Delta . V_s}$ was plotted against service speed V_s for ships of different size and is shown in Fig. 4.5. These straight lines can be given by the following equation

$$\frac{SHP}{\Delta . V_s} = (8.80 - 1.243 \times B + 2.653 \times V_s) \times 10^{-2}. \text{ PS}^*/\text{ton-mile}$$

Thus larger breadth and lower speeds gives lower values of energy consumption/ton-mile.

4.4.2. N/Δ (24).

In the case of conventional cargo liners the deadweight/displacement (dwt/Δ) ratio decreases as the speed increases. If we denote the dwt as similar to container capacity N, then in the case of container ships the value of N/Δ increases as the speed increases or the displacement increases. This can be partly explained by the fact that as the speed increases, the hull form becomes finer and in the case of a

* PS= metric horsepower

Fig. 4.3. The effect of improvement in Energy Consumption (24).

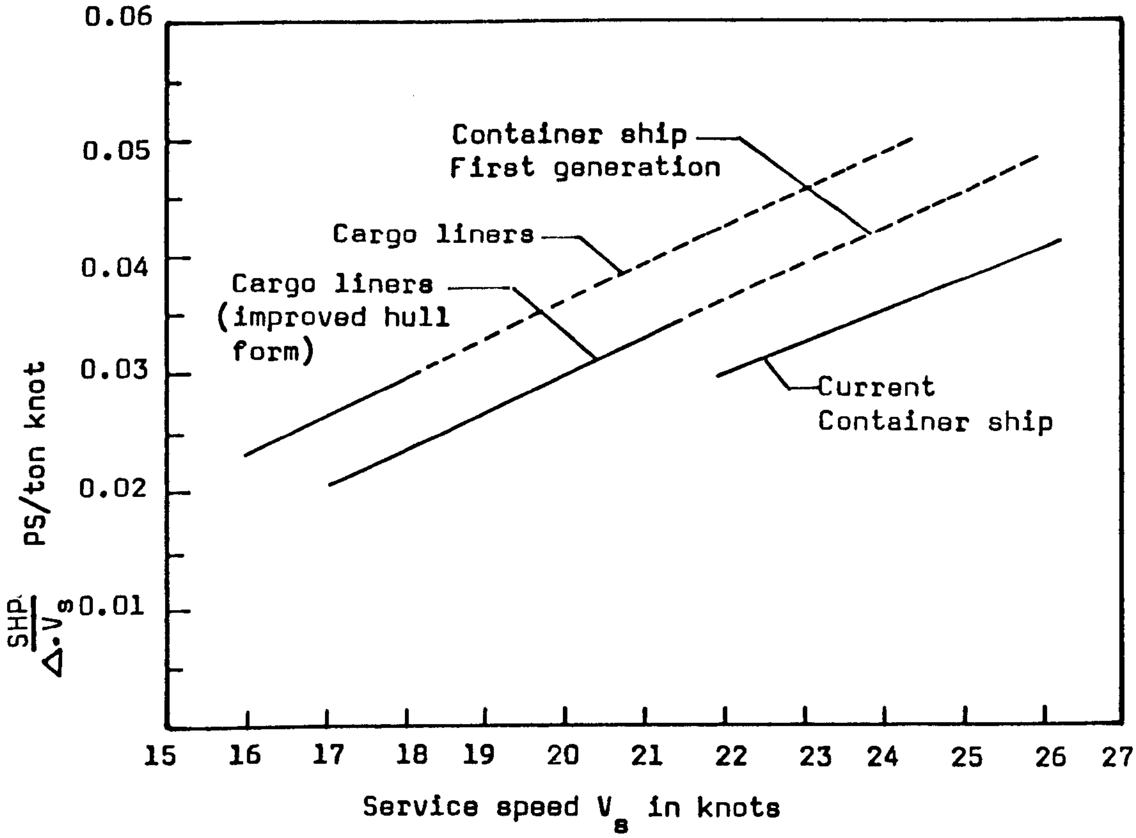


Fig. 4.4. The effect of improvement of ship hull form (24).

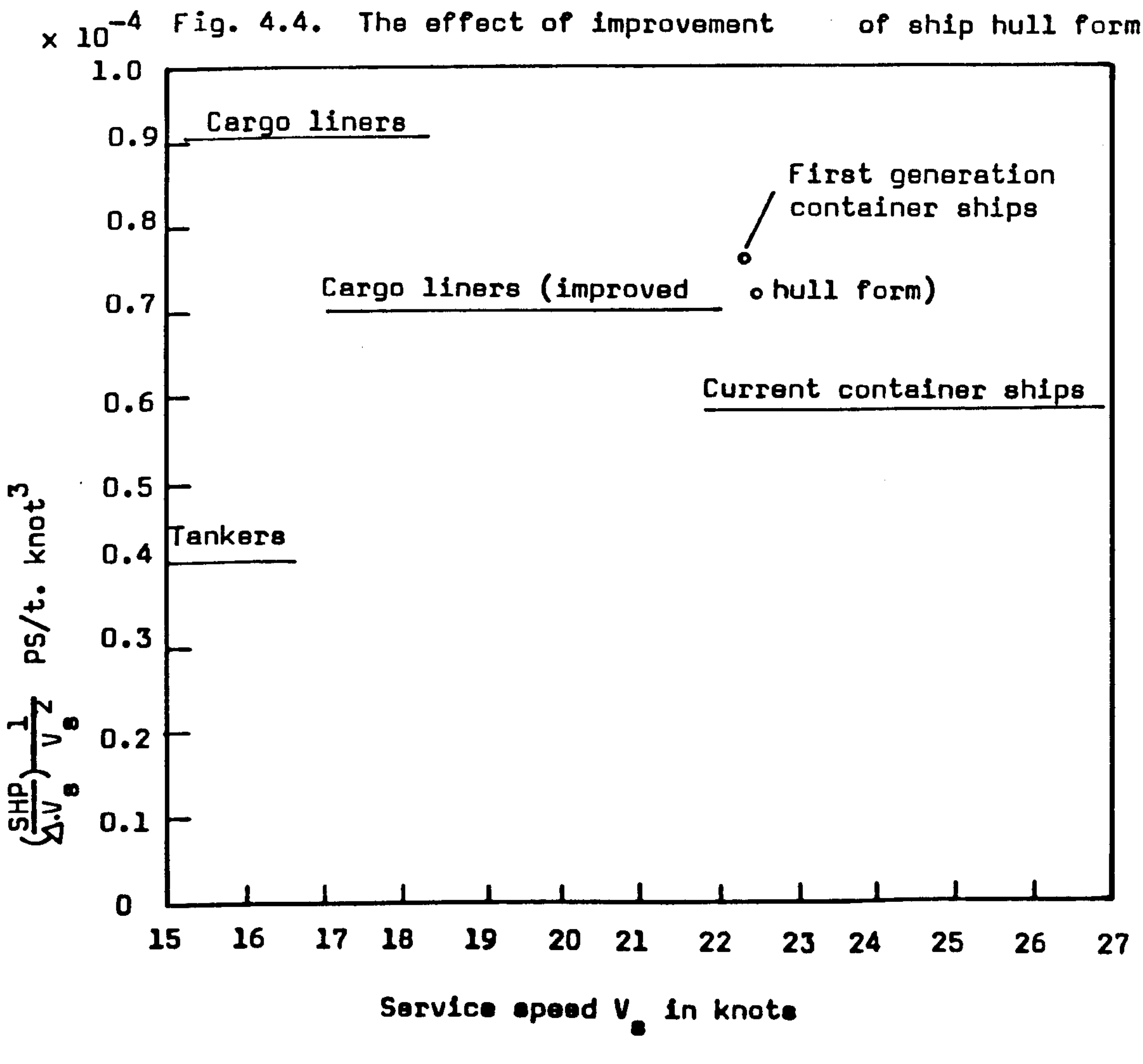


Fig. 4.5. The effect of improvement in K on the ship size (24).

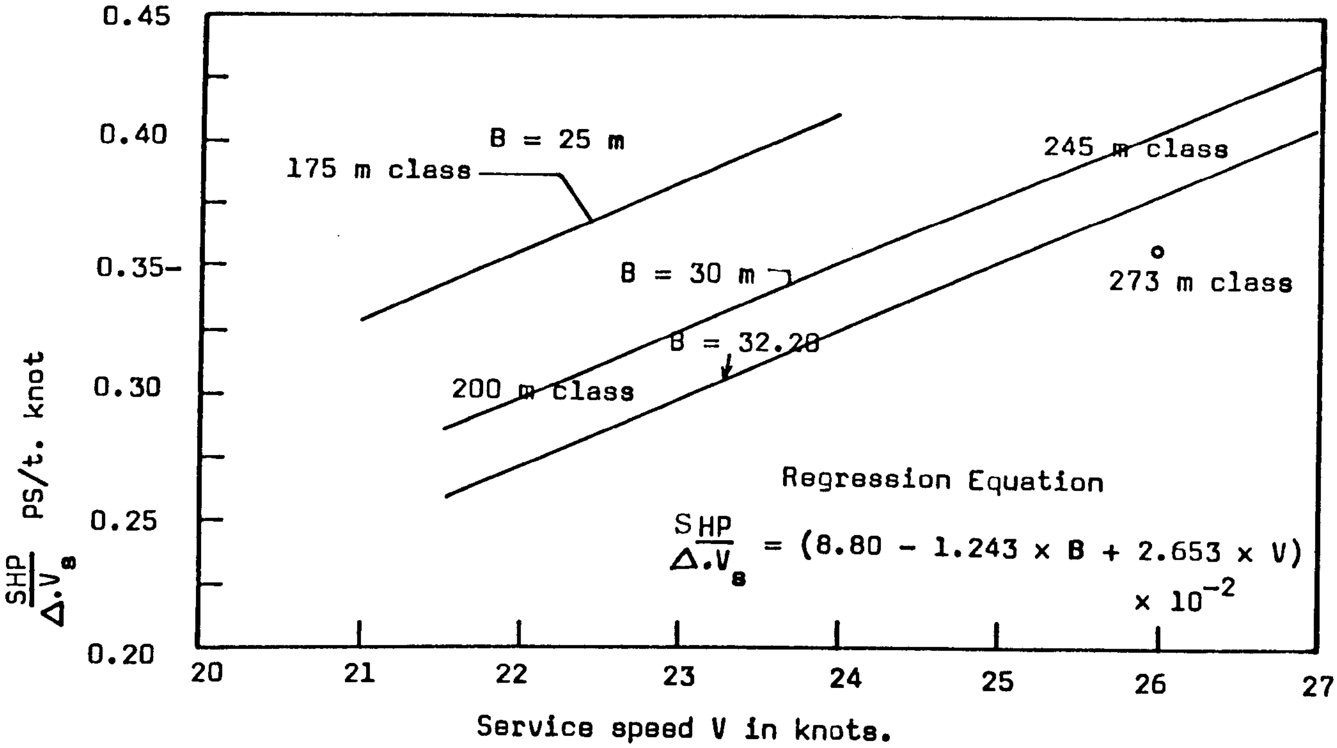
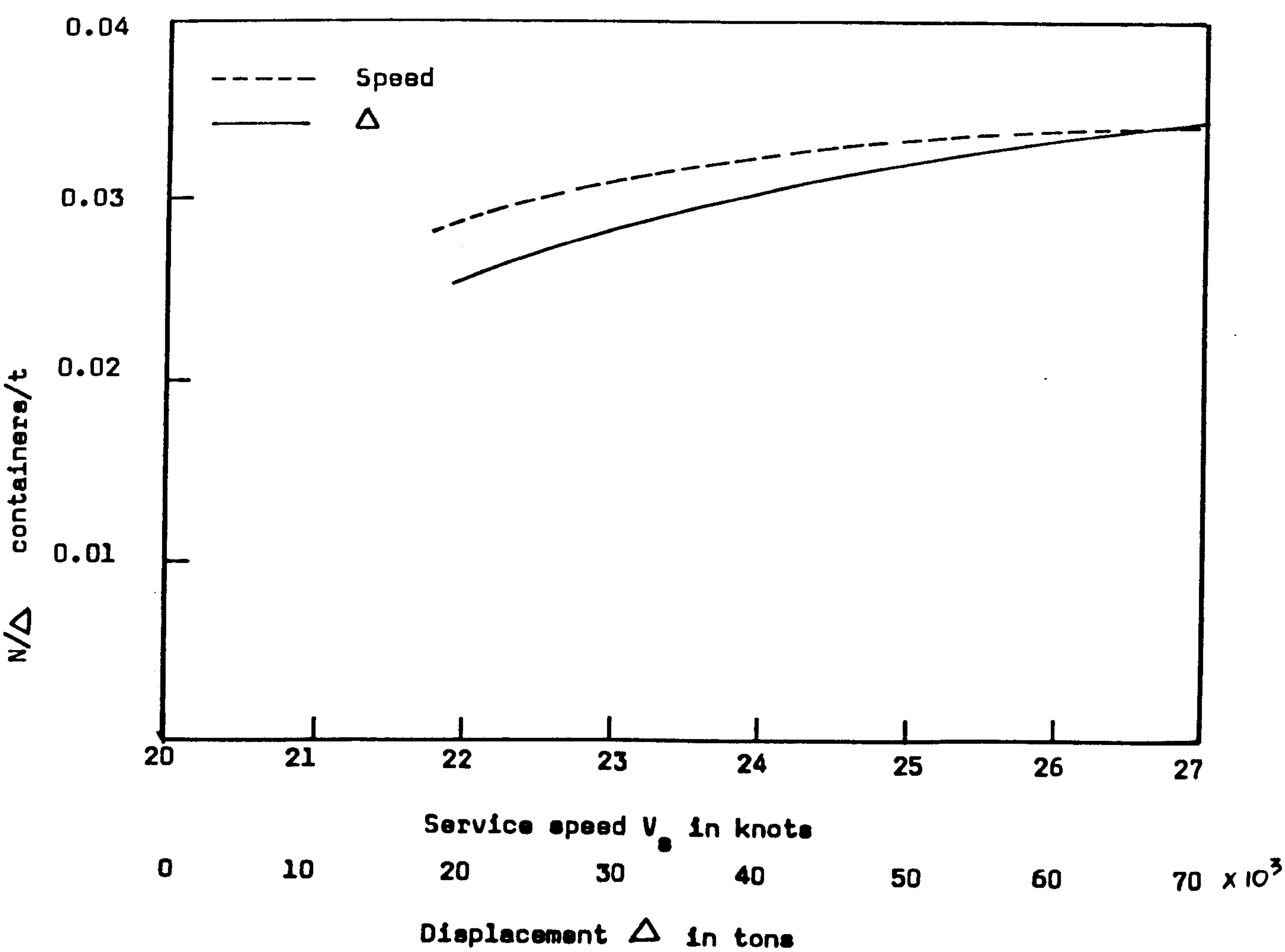


Fig. 4.6. $\frac{N}{\Delta}$ versus speed and displacement (24).



conventional cargo liner its ability to carry more deadweight becomes limited. Whereas the container ship can achieve higher speeds by carrying some of the containers on the deck from the hold thus allowing it to achieve a finer hull form. Fig. 4.7 shows the improvement in N/Δ as the deck tiers of containers are increased.

4.4.3. $SHP/N.V_s$ (24).

Now combining $\left(\frac{SHP}{\Delta.V_s}\right)$ and $\left(\frac{N}{\Delta}\right)^{-1}$ we have $\frac{SHP}{N.V_s}$. The improvement in the vehicle efficiency due to speed increase for container ships of different sizes is shown in Figure 4.8. It is evident that the vehicle efficiency is improved as the size and speed of the ship increases. Fig. 4.9 shows the vehicle efficiency plotted against ship size for container ships of different speeds. In Fig. 4.8 the container ships of different sizes have similar slopes indicating a gradual improvement and similarly in Fig. 4.9 the container ships of different speed shows gradual improvement in the vehicle efficiency $\frac{SHP}{N.V_s}$ as the speed increases.

4.4.4. Reduction in hull steel weight (24).

In order to analyse the trend of hull steel weight the coefficient $WH/(L \times B \times D \times C_b)$ (t/m^3), was plotted against the date of delivery as shown in Fig. 4.10 where WH = weight of steel hull in tonnes. As the number of rows of hatchways increases the hull steel weight WH increases. The trend of the hull steel weight as shown in Fig. 4.10 is given by: for container ships

$$\frac{WH}{L \times B \times D \times C_b} = 0.232 + 0.135 \times r_H + 0.00525 \times \frac{L}{D} - 0.00228 \text{ del} \quad t/m^3 \qquad \text{Eq.}(4.1)$$

and for cargo liners

$$\frac{WH}{L \times B \times D \times C_b} = 0.155 + 0.00538 \times r_H + 0.00589 \times T_D + 0.00242\, L/D - 0.00107 \text{ del.} \quad t/m^3 \qquad \text{Eq.}(4.2)$$

Fig. 4.7. Improvement in N/Δ contributed by the deck loading (24).

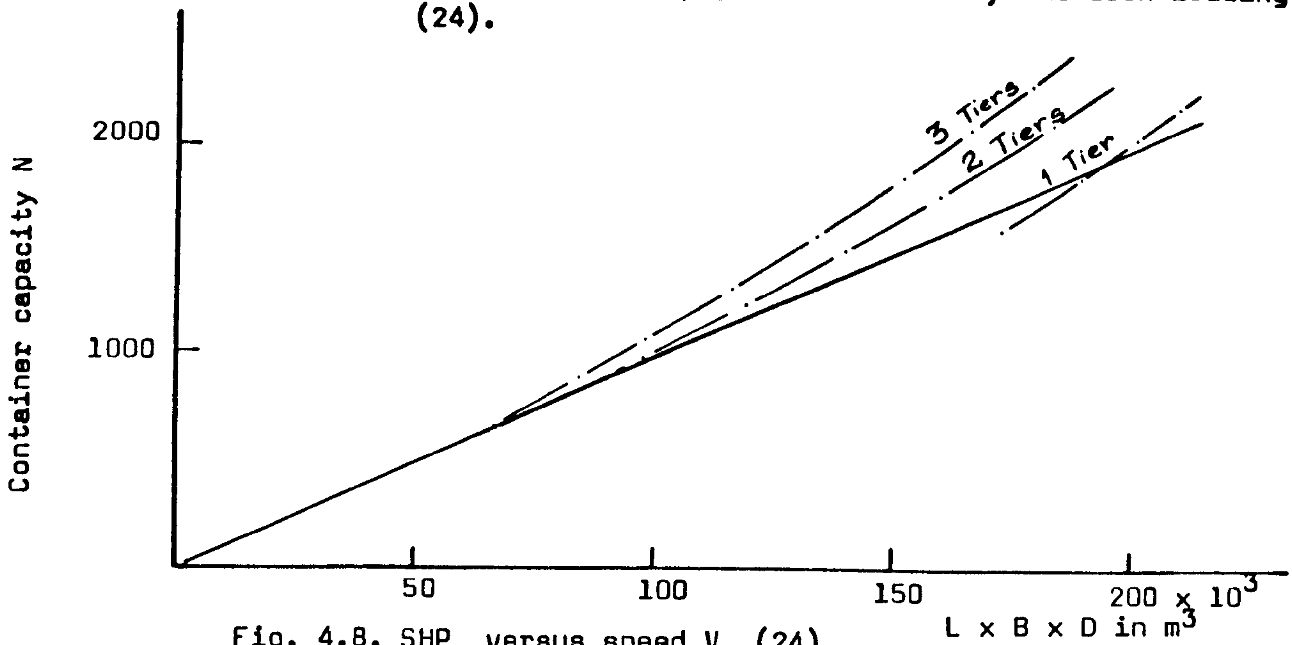


Fig. 4.8. $\frac{SHP}{NV_s}$ versus speed V_s (24).

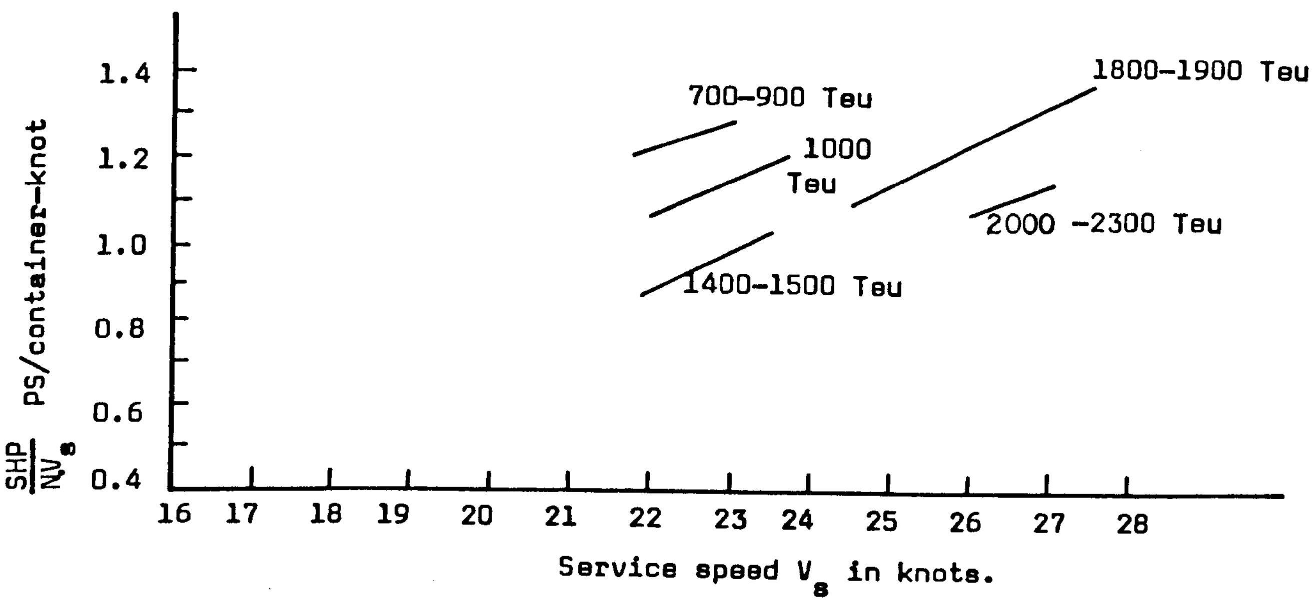


Fig. 4.9. $\frac{SHP}{NV_s}$ versus capacity (24).

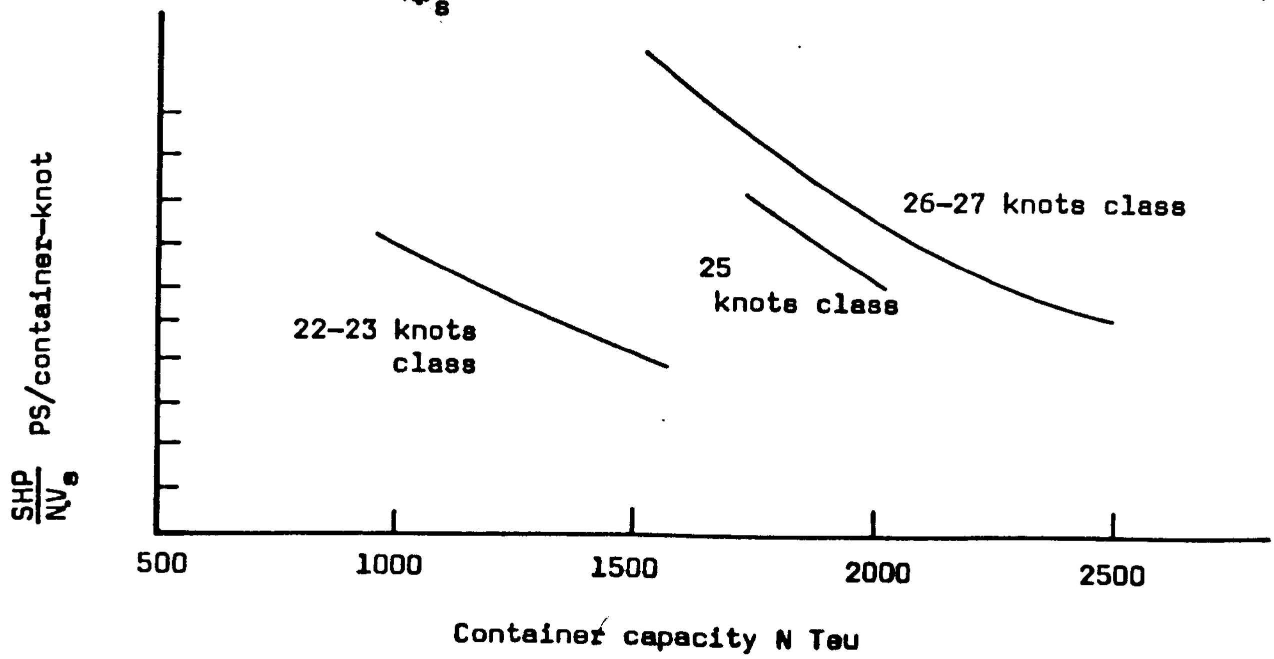
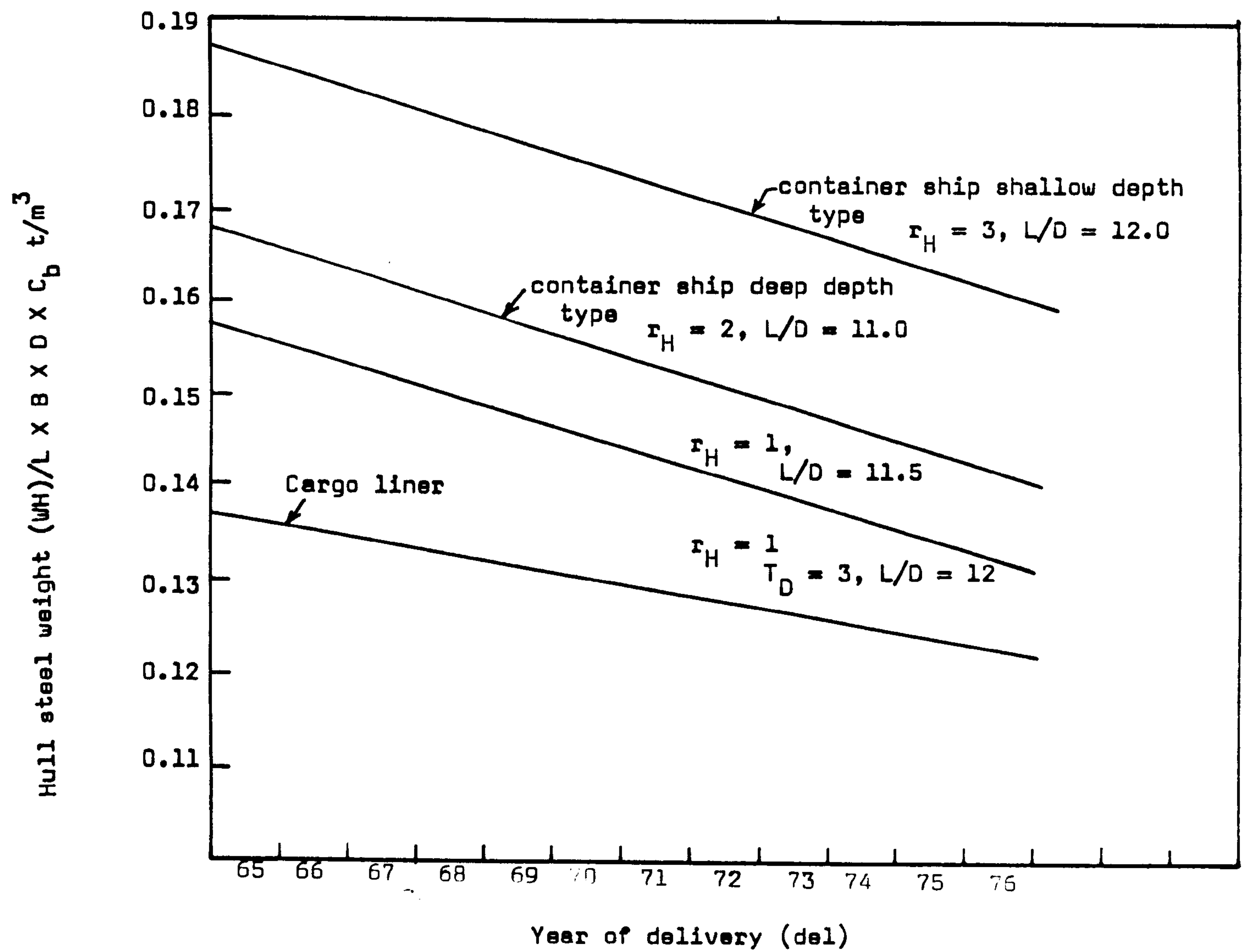


Fig. 4.10. Reduction in hull steel weight (24).



where r_H = number of hatchways, T_D = number of decks, and del = date of delivery in years A D e.g. a ship delivered in 72 October is expressed as 72.83 etc.

It is evident that there has been progressive decrease in the hull steel weight of container ships and the rate of decrease is twice that of a cargo liner. If the hull steel weight is plotted as N/WH against the year of delivery then the number of containers/t (N/WH) of deep depth type vessel will be less than that of the shallow depth type (24). Table 4.8 outlines the major characteristics of the fully cellular container ship of different sizes. The influence of the Panama Canal constraint on length, beam and draft is evident for ships over 2000 Teu.

4.5. CONTAINERS

It was Morris Forgash, organizer of the world's largest freight forwarding organisation, United States Freight Company who proposed the geometry of ISO standards. He proposed the 8 ft. height by 8 ft. width dimensions with length variations of 10 ft, 20 ft, 30 ft and 40 ft. Heights of 8'6" were subsequently also accepted. It has already been mentioned in Section 4.1 that ISO standards were adopted in Moscow in 1967. Though the first container size standards were adopted as far back as 1961 by ASA, the developments were delayed mainly because of opposition from Sealand (8' x 8' x 35'), Matson's (8' x 8' x 24') and Grace Lines (non standard corner castings). This opposition resulted in a law under which Congress ordered equal treatment in the use of all container sizes (7).

Besides the ISO standards it has been recommended that shipowners must have these additional standards for mutual benefit (146).

a) Stricter inside dimensions
b) Uniformity of door openings (as large as possible)
c) Roof openings for open top containers
d) Uniformity in stacking loads

TABLE 4.8. Main characteristics of container ships. (Compiled from (14) and Lloyd's Register 81 of ships) over 500 TEU as on November 1, 1980.

Size TEU	Numbers			Cargo Capacity in TEU			Cargo Capacity in Dead Weight tons			Length BP m.	
	Purpose Built	Convert-ed	Total	Purpose Built	Convert-ed	Total	Purpose Built	Convert-ed	Total	Min.	Max
1. 500-599	18	16	34	9884	8709	18593	219080	243299	462329	133.99	152.38
2. 600-799	35	24	59	24915	16112	41027	579375	307805	887180	134.83	175.04
3. 800-999	46	24	70	39053	21137	60190	759313	405505	1164818	145.17	183.0
4. 1000-1199	54	37	91	60126	38827	98953	1074389	694645	1769034	155.0	206.41
5. 1200-1399	40	7	47	50991	8400	59391	925767	168700	1094467	167.01	206.36
6. 1400-1599	61	-	61	90546	-	90546	1682942	-	1682942	190.13	220.91
7. 1600-1799	49	-	49	81931	-	81931	1383960	-	1383960	192.75	237.80
8. 1800-1999	26	6	32	49184	11169	60353	817940	124506	942446	211.0	268.38
9. 2000-2199	6	-	6	12296	-	12296	190403	-	190403	223.96	224.85
10. 2200-2399	6	-	6	13776	-	13776	205292	-	205292	259.09	274.00
11. 2400-2599	11	-	11	27402	-	27402	451396	-	451396	247.02	273.97
12. 2600-2799	9	-	9	24450	-	24450	416645	-	416645	247.40	273.97
13. 2800-2999	6	-	6	17118	-	17118	294598	-	294598	273.01	273.97
14. 3000	4	-	4	12064	-	12064	193792	-	193792	273.01	273.03

Contd.

TABLE 4.8 (Contd.)

	Size TEU	Breadth m.		Depth m.		Draft m.		Shaft horsepower		Speed in Knots	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1.	500-599	19.18	21.51	11.08	14.64	8.262	8.587	8000	16380	14	20
2.	600-799	21.51	26.61	11.10	15.73	8.221	10.453	9630	28000	17	22.5
3.	800-999	22.79	28.01	13.29	17.45	7.20	11.421	12000	30400	18	23.0
4.	1000-1199	23.78	30.82	13.42	16.69	9.442	10.821	13300	3600	17.7	23.0
5.	1200-1399	25.40	31.02	13.52	19.51	9.50	10.85	17400	38000	19.5	23.5
6.	1400-1599	26.0	32.21	13.42	19.53	9.675	11.773	28500	40900	21	26
7.	1600-1799	27.44	32.24	15.93	19.03	9.260	11.583	28500	48000	21.5	25
8.	1800-1999	32.06	32.24	15.83	24.40	10.608	12.03	36000	120000	22.75	33
9.	2000-2199	30.48	32.24	19.18	21.52	10.704	12.027	53260	58600	18.0	26
10.	2200-2399	-	32.21	21.49	24.49	11.06	12.04	78200	80000	-	26.25
11.	2400-2599	-	32.26	20.65	24.62	11.28	13.03	26640	81132	21.0	27.5
12.	2600-2799	32.19	32.26	19.89	24.16	11.99	13.031	53600	88000	23.6	25.5
13.	2800-2999	-	32.26	21.19	25.0	12.04	13.02	81100	88000	-	26
14.	3000	32.19	32.25	20.45	25.02	12.02	12.73	-	81132	26	27

e) Maximum tare weights to achieve a uniform payload

f) Standard cargo lashing points; and

g) Removable door headers for open top containers.

Since 1972 container vessels have been in service with cell guides capable of 9 high stacking. ISO has not changed the test procedure and requirement is still only for 6 high stacking. Of course one can recalculate 9 high stacking test loads based on 6 high figures, and thus be on the safe side. However other aspects should also be taken into consideration such as (a) ships with 9 high cells should have an acceleration factor less than 1.8g.

(b) In the forward section where the bigger acceleration takes place, the hull shape often allows only 7 high or possibly 8 high stacking.

(c) Fully loaded 40' containers up to maximum rating of 30 tons are seldom used.

(d) It is unlikely that all containers stacked 9 high in one cell will all lie packed to the maximum weight.

(e) To help stability, heavy containers are generally stowed at the bottom of the stack.

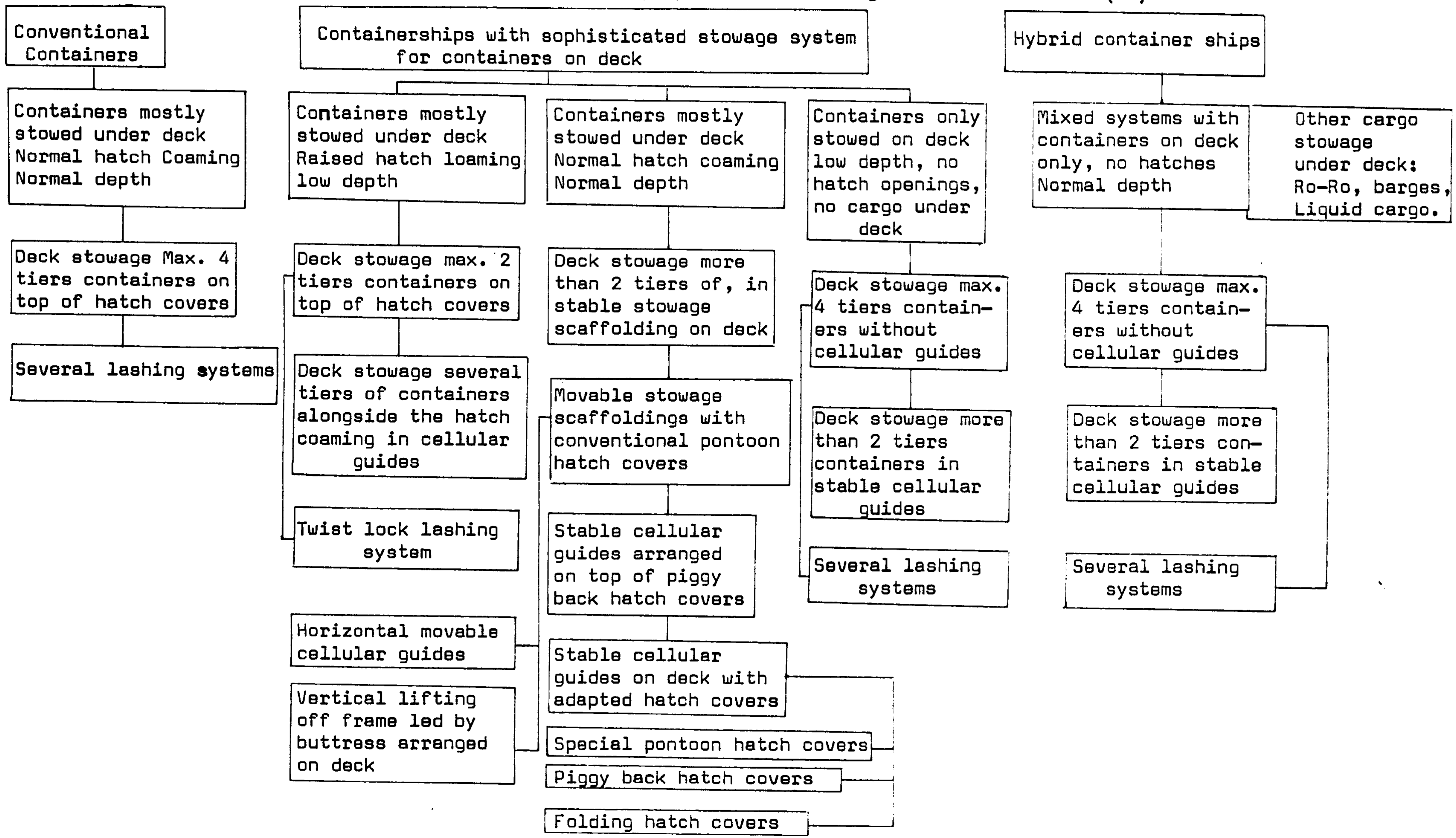
Table 4.9 outlines the various possible concepts in use or proposed for securing containers on deck.

The world's container population increased from some 450,000 Teu in 1970 to some 3,100,000 Teu in 1980 (31).

Containership productivity in the use of container boxes and the container productivity in terms of the amount of cargo carried per annum in a box can be analysed from the available data on the number of boxes in Teu, trade figures in tons and the available slots in the container fleet (31).

The container ship productivity development as shown in Fig. 4.11 is derived by dividing the available trade by the number of Teu's per slot/annum. It shows that Teu's/slot/annum increased fairly consistently till 1973 when due to the oil crisis there was a slump in the trade and therefore Teu's/slot/annum fell. There was growth in

TABLE 4.9. Various possible concepts, already in use or proposed for securing containers on deck (28).



1975-1978 and is on the decline since then. A similar analysis performed for the productivity of the indivual container, Fig. 4.12, shows that after a fairly consistent period of 50 tons/box/annum level over 1970-74, output per Teu increased to this same level over 1976-78 after falling dramatically in 1975. The container productivity, Fig. 4.12, in 1980 was 39 tons/box/annum which may fall to 37 tons/box/annum in 1983 and level at 39 tons/box/annum in 1985(31). Similarly containership productivity, Fig. 4.11, was 159 t/slot/annum in 1980 and will fall to 149 to 151 t/slot/annum in the period 1981-85(31).

It is evident that there is an excess number of container boxes and at current level of trade growth this excess container box capacity will not be absorbed by 1985 or experience may show that substantial excess number of containers continue to be a feature of the container traffic.

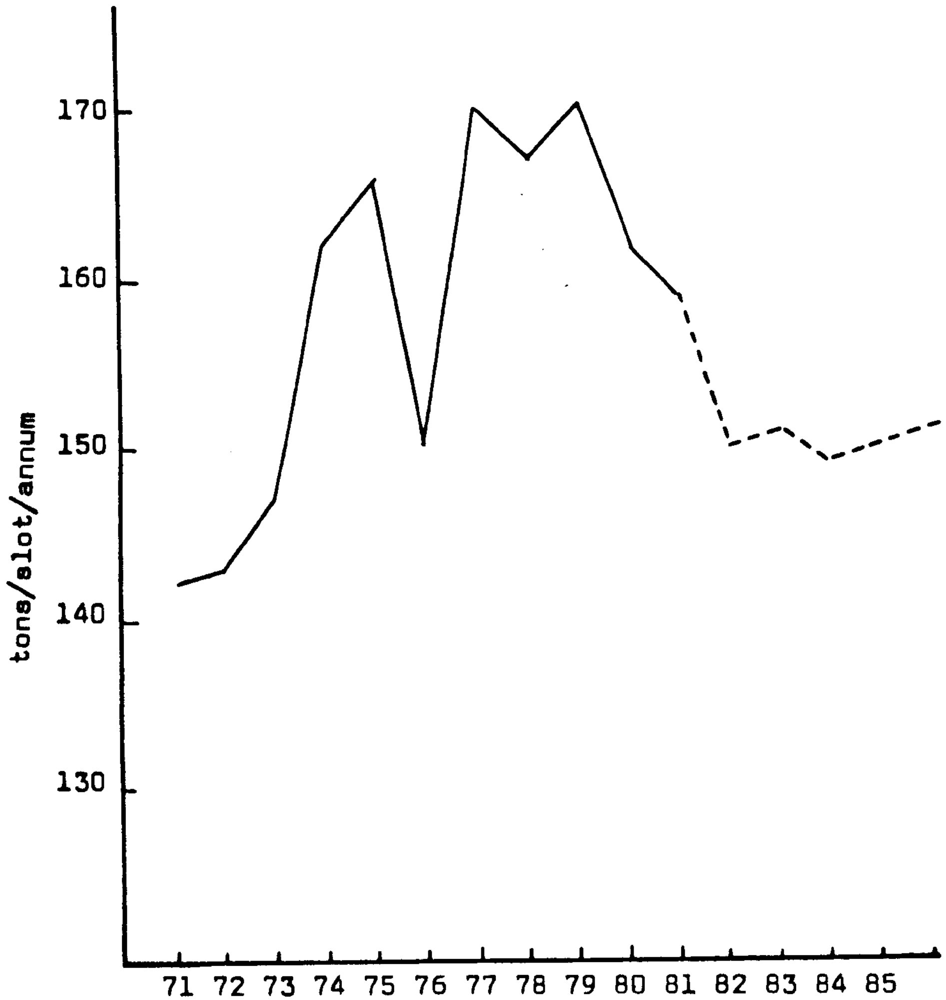


Fig. 4.11. Container ship productivity development (31).Fig. 4.12. Container productivity development (31)

CHAPTER 5

ESTIMATING THE MAIN PARTICULARS

5.0 INTRODUCTION

This chapter considers the main particulars of container-ships. It indicates how the dimensions must reflect integer multiples of container sizes with due regard for clearance and structure. Main dimensions of container ships are compared with existing formulae and the approach of the program indicated. The main dimensions suit the number and stowage of containers with the usual design allowances to ensure that structure and seakeeping requirements will not pose serious problems.

Some general observations may be made concerning the main dimensions of ships which are usually taken to be Length L, Breadth B, Depth D and Draft T. Since the surface of a ship represents cost and its volume earning power, the simplest possible analysis would indicate that all ships would be spheres or cubes with least surface and maximum volume. Actual ship shapes are distortions from this simple concept imposed by the demands of propulsion, stability, strength, seakeeping, deck cargo and indeed harbours and canals. Generally particular influences predominate on each main dimension while others are secondary.

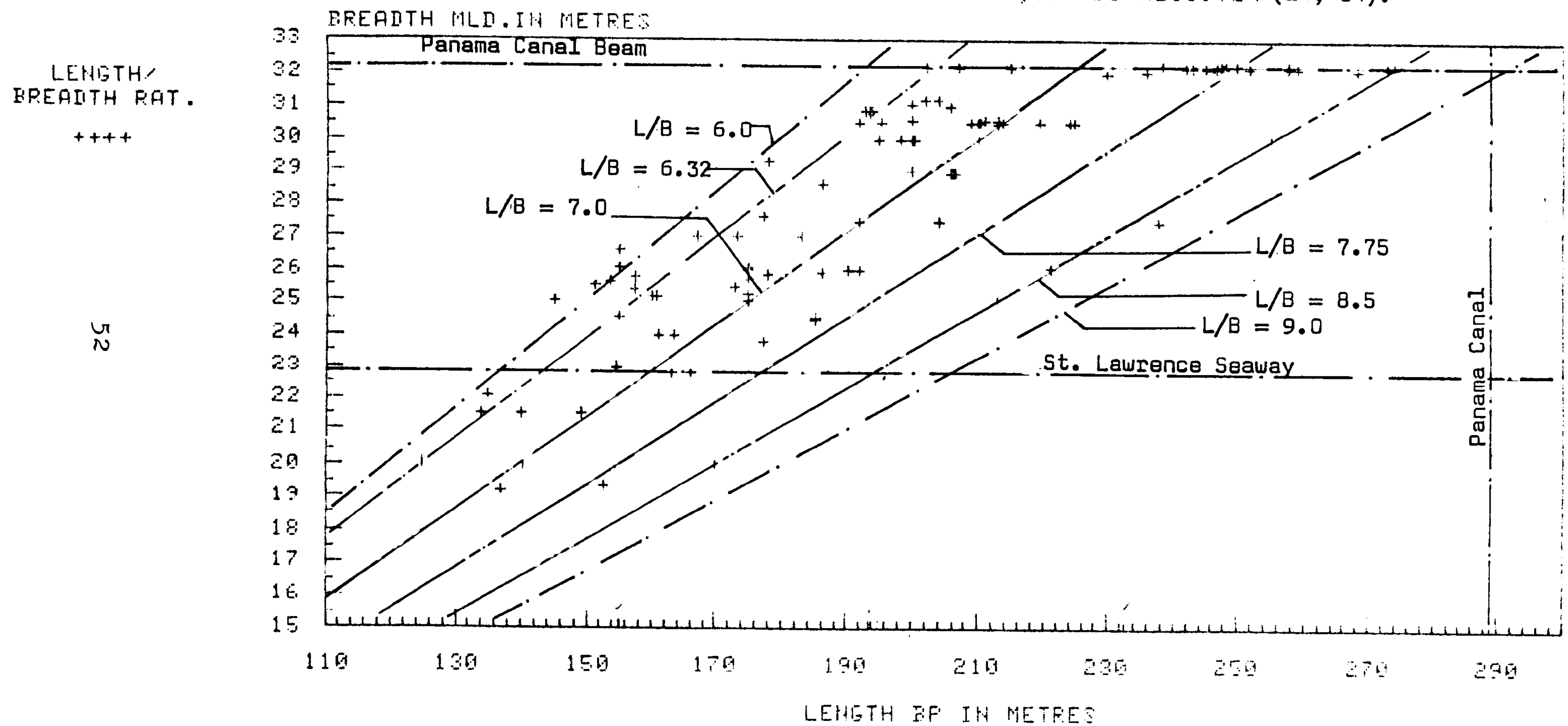
The following are listed in (35) B = f(L); D = f(B); T = f(D); D = f(L); T = f(L) and T = f(B) and are now considered for container ships.

(a) B = f(L) is shown in Fig. 5.1. A small L/B ratio leads to a lower capital cost (13, 35) but is detrimental to course keeping, and propulsive efficiency and also powering if residuary resistance predominates (11)(35).

In the program L/B is kept between 6 and 9. First generation container ships built in 1968 had L/B ratios about 6.3; The second generation built in 1970 had these ratios about 7.1 and they ran to about 8.5 as speeds increased faster than size. The fuel crisis reduced the value in third generation ships to about 6.3 similar to those of the first generation; although by 1979 values of 7.7 were recorded. Table 4.3 describes the different generations, although increasing numbers and special cases have blurred distinctions.

Fig. 5.1. LENGTH BP VERSUS BREADTH MOULDED

REF.CONTL.INT.YR.BOOK-81,LLOYDS REGISTER (14, 34).



(b) D = f(B). This is shown in Fig. 5.2. This relationship influences stability as KM is a function of breadth and KG is influenced by Depth. In containerships where much cargo is on deck, Depth is not an over-riding influence on KG which is largely influenced by deck containers and ballast carried. However Beam is influenced by the Panama Canal and B/D is usually close to 1.65.

(c) T = f(D). This is shown in Fig. 5.3, and shows that most containerships have a working design draft well below the maximum permitted by geometry as defined in the freeboard calculation.

(d) D = f(L). This relationship is shown in Fig. 5.4. The L/D ratio has an upper limit to avoid undue flexibility, and in the program L/D is restricted to be between 10 and 14.5. There is an attraction in limiting the steel weight associated with Depth and Langenberg (36) gives a net saving of 4% on hull steel weight with a trunk type of ship which has a depth at side less than the conventional double skin construction.

(e) T = f(L). This relationship is shown in Fig. 5.5. For good seakeeping T/L should exceed 0.045 to avoid slamming in a seaway (27). Most containerships meet this requirement. Seakeeping considerations are discussed in Chapter 13.

(f) T = f(B). This relationship is shown in Fig. 5.6. Most container ships have B/T lower than 3.15 and the program has limits of 2.25 and 3.75. Panama Canal restrictions are important. Some important canal and river draft restrictions are listed below.

Fig. 5.2. BREADTH MLD. VERSUS DEPTH MLD.

REF.CONT.INTL.YR.BOOK-81,LLOYDS REGISTER (14, 34).

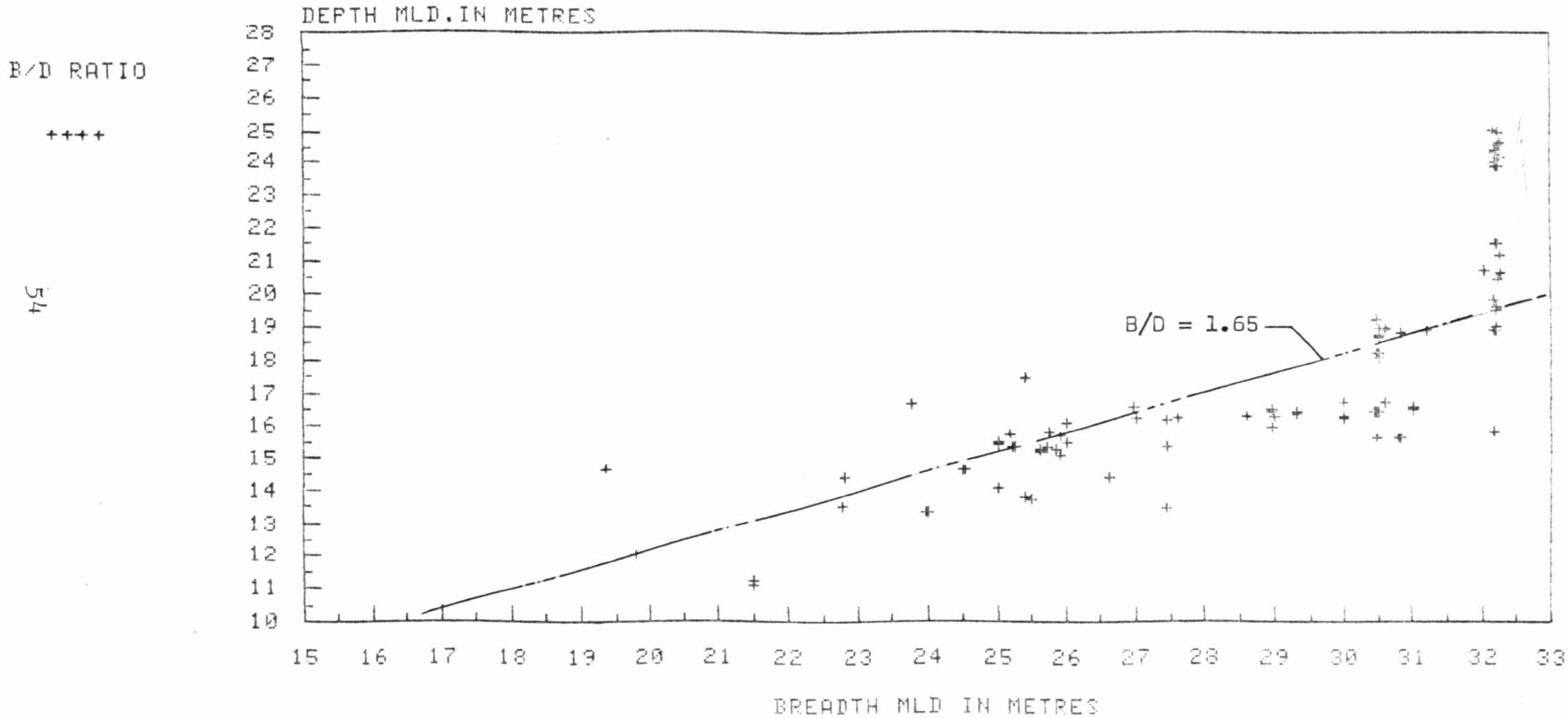
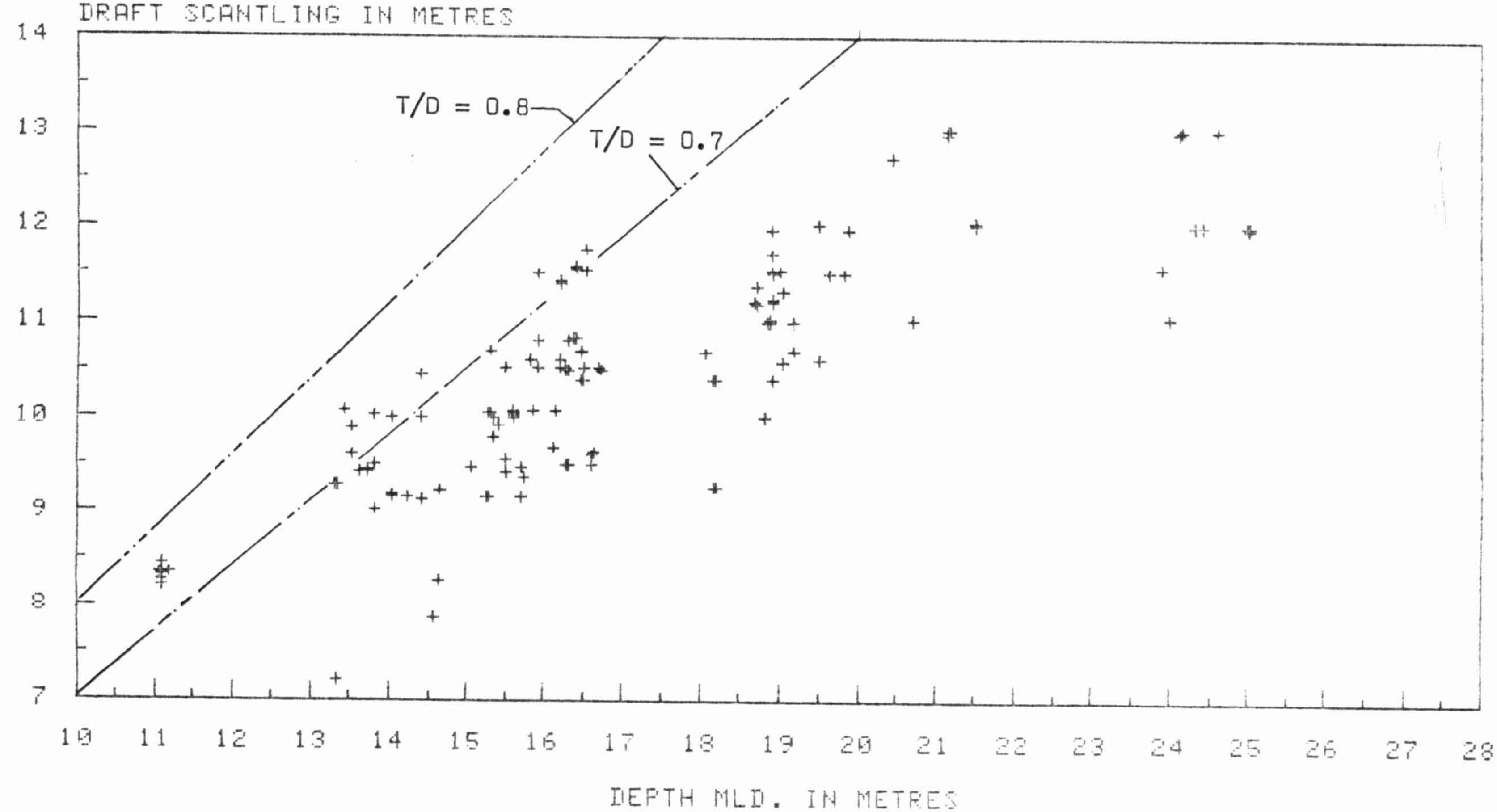


Fig. 5.3. DEPTH MLD. VERSUS DRAFT SCANTLING

REF.CONT.INTL.YR.BOOK-81,LLOYDS REGISTER (14, 34).



T /D RATIO

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Fig. 5.4. LENGTH BP VERSUS DEPTH MOULDED

REF.CONT.INTL.YR.BOOK-81,LLOYDS REGISTER (14, 34).

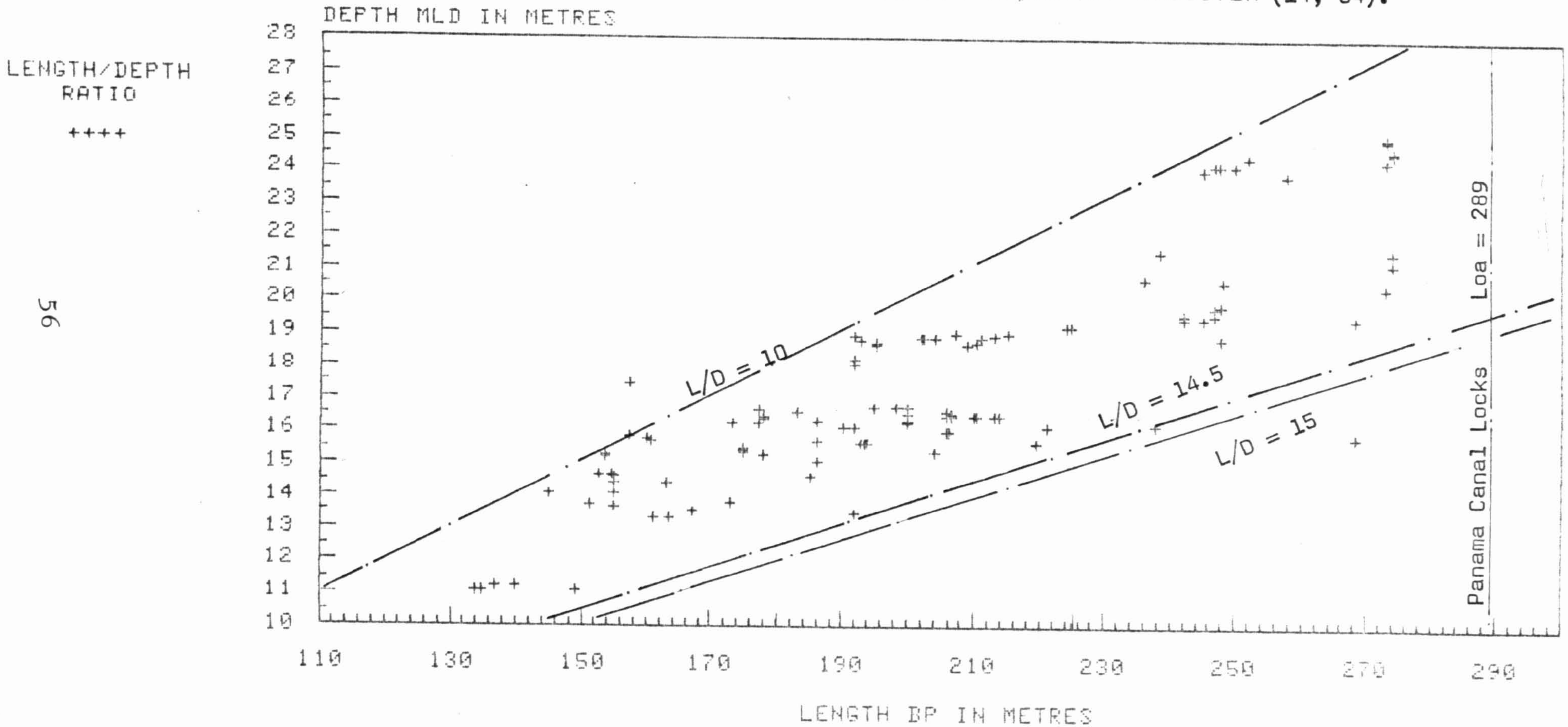
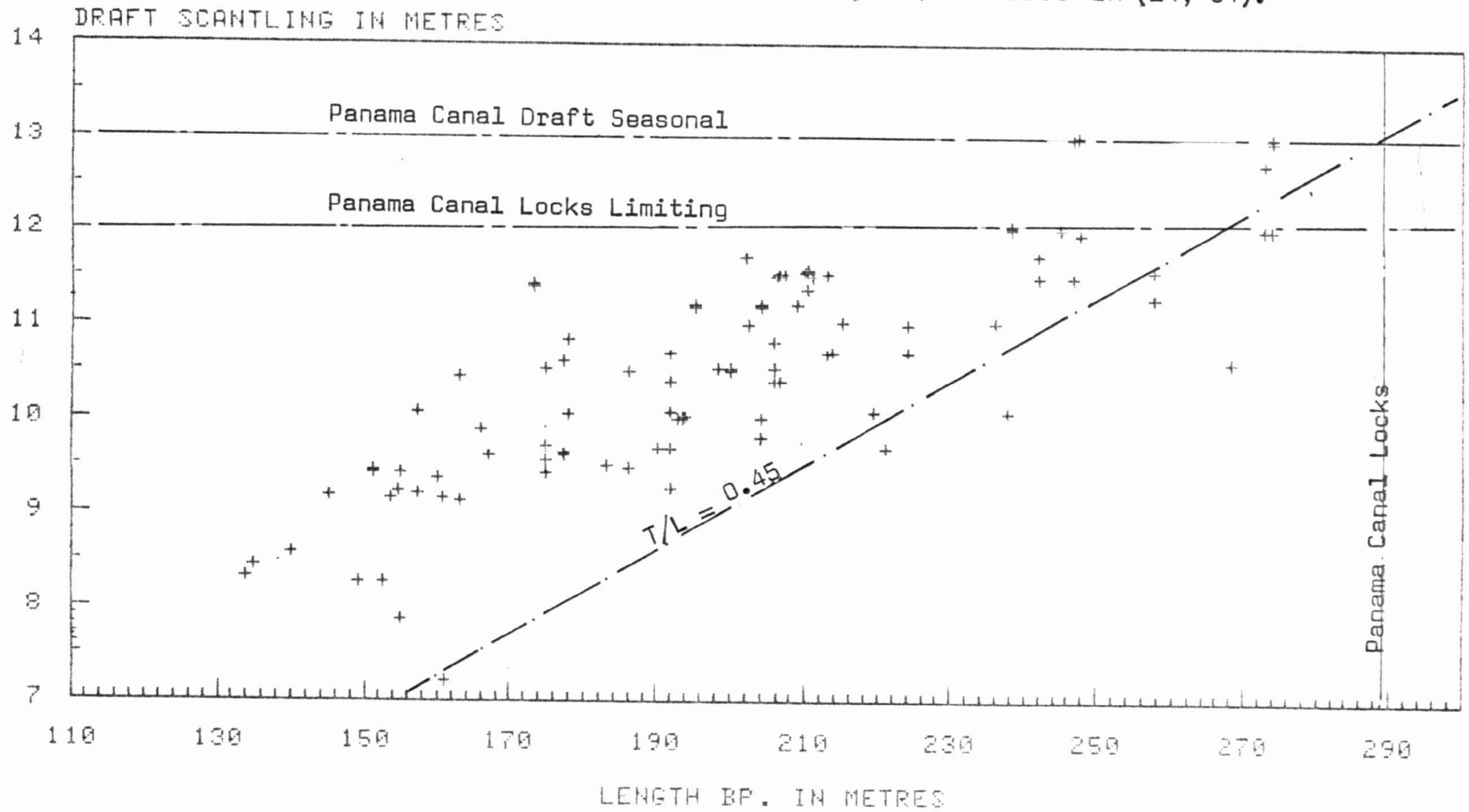


Fig. 5.5. LENGTH BP. VERSUS DRAFT SCANTLING

REF.CONT.INTL.YR.BOOK-81,LLOYDS REGISTER (14, 34).



T/L RATIO

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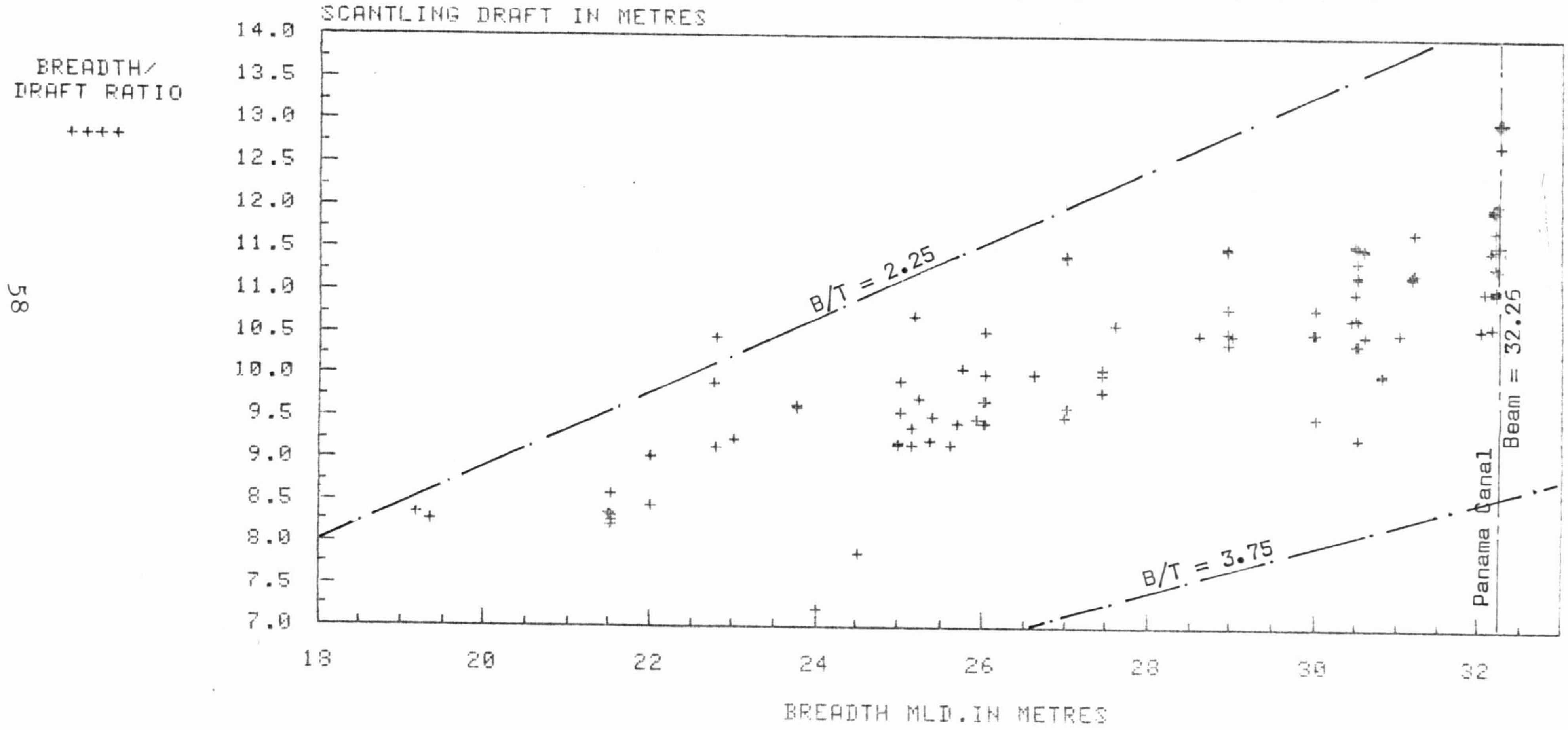
Fig. 5.6. BREADTH MLD.VS SCANTLING DRAFT

REF.CONT.INTL.YR.BOOK-81,LLOYDS REGISTER (14, 34).



	Suez Canal	Panama Canal	Kiel Canal	Amsterdam Canal
draft in m.	11.6*	11.7	9.0	10.7

	Welland Canal	Schelde Antwerp	St. Lawrence Seaway
draft in m.	7.8	11.6	7.6

5.1 Container Stacking

The vertical cell type container ships have containers stacked in vertical cells formed by angle corner guides. The container cells are arranged so that the long dimensions of the containers are fore and aft; principally because this stowage is better suited to handling with a gantry crane over the side and it is also easier to integrate with the ship structure. Cell guides provide an efficient lateral support at the four corners of the container against transverse and longitudinal movement caused by dynamic forces. The deck containers can be stacked up to 4 high and are lashed to the deck or hatch cover. For the containers stacked in holds it is important that the tolerances and clearances necessary for the loading, unloading, stacking and inspection be taken into consideration.

Table 5.1 summarises the various tolerances and clearances which have been suggested in the literature. At the preliminary design stage container/container clearances is what a designer is concerned with. A value of 230 mm is chosen as indicative of an average value, since hold and/ container clearances are much less (see Fig. 5.8). In the program the user inputs the container dimensions only, as

* Recently increased.

TABLE 5.1. Container/cell tolerances and clearances (All dimensions in millimetres).

Container Size	Container Tolerance		Container/cell guide				Cell guide tolerance		Container/container clearance			Ref.
			longl.		transverse							
	longl.	Trans.	Max.	Min.	Max.	Min.	longl.	trans.	Flip/ Flop	Fixed even peaks	High low peaks	
20'	6055 $^{+3}_{-3}$	2435 $^{+3}_{-2}$	44	28	28	18	± 10	± 5	152	381	-	(19)
20'	6055 $^{+3}_{-3}$	2435 $^{+3}_{-2}$	35	32	25	22	± 5	± 4	153	263 273	119	(20)
ISO 20'	6058 $^{+0}_{-6}$	2438 $^{+0}_{-5}$	←	13	→	→	-	-	-	-	100	(27)
40'	12190 $^{+2}_{-8}$	2435 $^{+3}_{-2}$	42	32	25	22	± 5	± 4	153	263 273	119	(20)
ISO 40'	12192 $^{+0}_{-10}$	2438 $^{+0}_{-5}$	←	13	→	→	-	-	-	-	100	(27)

(Subject to latest revisions.)

shown in Fig. 5.7, the values of container length (CL), width (CW) and the container height (CH). A 20' x 8' x 8' ISO container is assumed in the program. If 8'6" high containers are to be used, the user can change the value of CH in the program.

5.2. Breadth

The breadth of a container ship is mainly determined by the following requirements

(a) Container capacity
(b) External constraints (e.g. width of the locks, e.g. Panama Canal and the St. Lawrence Seaway, outreach of container cranes etc.)
(c) Hatch division and systematic container grid for ease in cargo handling
(d) Stability
(e) Strength.

Given the number of rows of containers athwartship, beam is a function of container width plus tolerances and clearances between container and cells plus the 'lead in' or 'gather' i.e. the distance that the cell guide splays out at the top to catch the downcoming containers plus sufficient deck width outside the hatches for required strength and stability. The container hold dimensions are thus decided from geometric considerations. The deck width on either side is however governed by factor (b), (d) and (e). Since beam largely governs the value of KM and hence the stability, adequate beam must be provided.

Container ships have very wide hatch openings, sometimes in excess of 80%, see Table 5.2. This open type of ships has introduced two basic problems to the structural design of ships: firstly the open type section creates difficulties in providing sufficient cross sectional material to satisfy the longitudinal strength, and secondly, the geometry of the cross section lacks torsional rigidity. For ships with 9-10 rows of containers, for strength and stability reasons Hoppe (13) for third generation ships, recommends a deck width of 2.2m to 3.5 m. Similarly Meek (19) took 20% of the beam for the first generation ships.

Fig. 5.7. Container dimensions, tolerances (All dimensions in mm.)

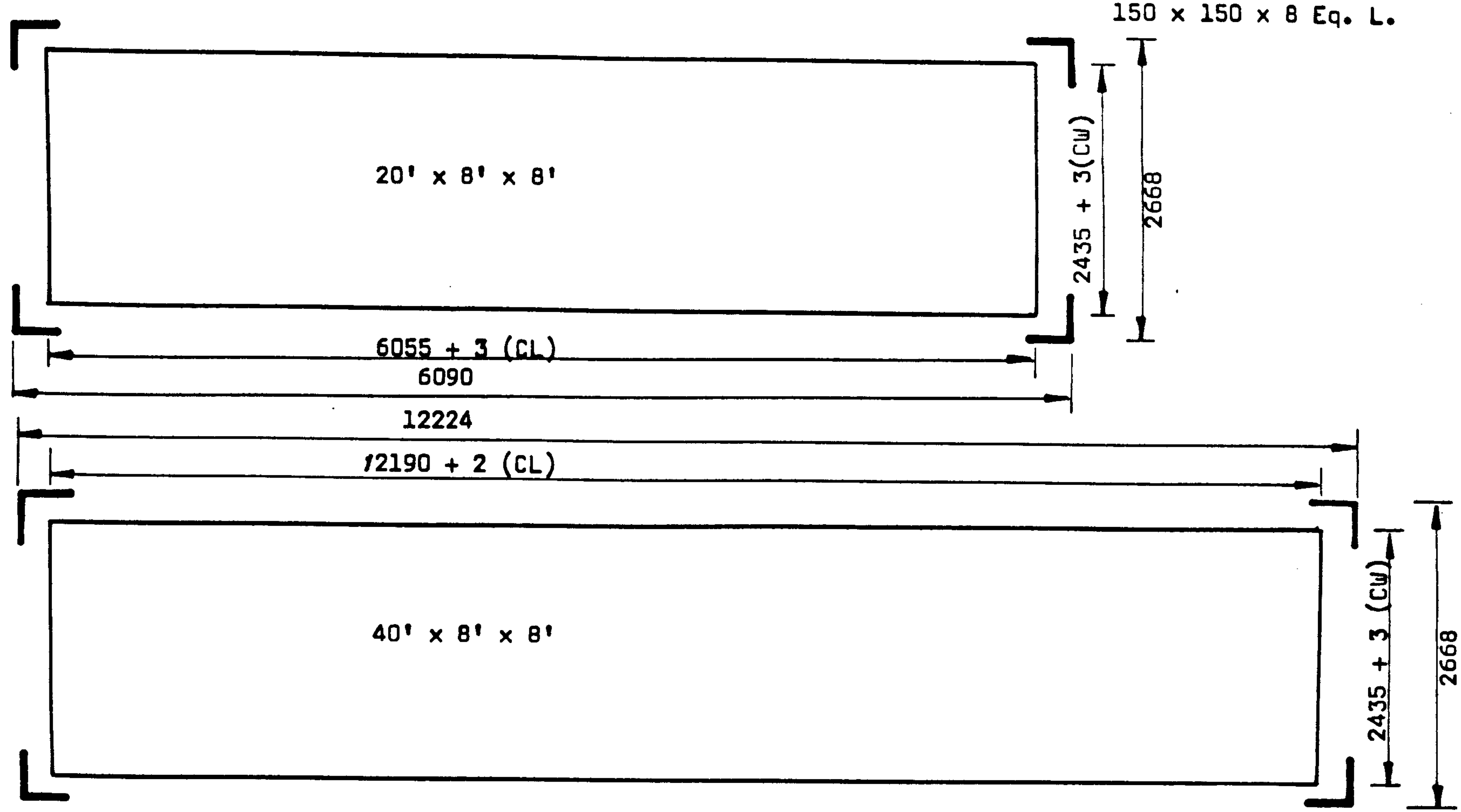


TABLE 5.2. Container stacking characteristics Athwartship. (From various shipping and shipbuilding Journals.)

No.	Ship's Name	Breadth (B) m.	Hold Width (HW) m.	Deck Width (DW) m.	Deck width / B % age	Rows	Breadth / Rows m.	Hold Width / Rows m.	Container/ container clearance athwartship mm.	No. of Girders	Width of girder mm.
1	Sealand Galloway	32.16	-	2.553	-	10	-	-	-	2	-
2	A	32.15	27.044	2.553	15.88	10	3.215	2.704	266	2	-
3	B	32.00	25.448	3.276	20.48	9	3.555	2.828	390	2	-
4	C	31.70	24.690	3.505	22.12	9	3.522	2.743	305	2	-
5	D	30.50	25.014	2.743	17.98	9	3.388	2.779	341	2	-
6	Encounter Bay	30.48	24.69	2.895	19.00	9	3.386	2.743	305	2	500
7	F	28.96	21.95	3.505	24.21	8	3.62	2.743	305	-	-
8	ACT 2-3	28.96	22.712	3.124	21.57	8	3.62	2.839	401	1	750
9	Sydney Express	30.50	25.60	2.450	16.06	9	3.388	2.844	406	2	600
10	Kashu Maru	25.70	-	-	-	7	3.671	-	-	-	-
11	Tokyo Bay	32.26	26.69	2.785	17.27	10	3.226	2.669	231	1	700

TABLE 5.2. Container stacking characteristics Athwartship. (Contd.)

No.	Ship's Name	Breadth (B) m.	Hold Width (HW) m.	Deck Width (DW) m.	Deck width / B % age	Rows	Breadth / Rows m.	Hold Width / Rows m.	Container/ container clearance athwartships mm.	No. of Girders	Width of girder mm.
12	Manchester Vigour	15.55	-	-	-	5	3.110	-	-	-	-
13	Verra zano Bridge	32.20	26.64	2.78	17.27	9	3.577	2.960	522	-	-
14	Remuera	32.08	25.478	3.301	20.57	9	3.564	2.831	393	2	700
15	Euroliner	30.50	-	-	-	9	3.388	-	-	-	-
16	California Star	25.85	22.032	1.909	14.77	8	3.231	2.754	316	1	430
17	ACT 1	28.96	22.718	3.121	21.55	8	3.62	2.839	401	1	750
18	Columbus New Zealand	29.30	22.43	3.405	23.24	8	3.663	2.811	373	2	400
19	Dart America	30.48	25.72	2.38	15.62	9	3.386	2.857	419	2	700
20	Hawaian Enterprise	28.96	21.95	3.505	24.21	8	3.62	2.743	305–459	-	-
21	Sea Witch	23.77	-	-	-	7	3.396	-	-	Asymmetrical 1	-

TABLE 5.2. Container stacking characteristics Athwartship. (Contd.)

No.	Ship's Name	Breadth (B) m.	Hold Width (HW) m.	½ Deck Width (DW) m.	Deck width / B % age	Rows	Breadth / Rows m.	Hold Width / Rows m.	Container/ container clearance athwartships mm.	No. of Girders	Width of girder mm.
22	New Jersey Maru	32.20	-	-	-	9	3.577	-	-	-	-
23	Oriental Chevalier	26.00	21.60	2.20	16.92	8	3.25	2.7	262	-	-
24	Elbe Maru	32.20	-	-	-	10	3.22	-	-	1	-
25	Sealandia	32.20	27.15	2.55	15.84	10	3.22	2.715	277	2	739
26	Atlantic Marseille	23.00	19.20	1.90	16.52	7	3.286	2.743	305	-	-
27	Hakozaki Maru	30.00	-	-	-	8	3.75	-	-	-	-
28	Elbe Express	24.50	20.24	2.13	17.38	7	3.15	2.891	453	2	550
29	Manchester Challenge	19.35	-	-	-	6	3.225	-	-	-	-
30	CP Voyager	25.60	20.534	2.533	19.78	7	3.657	2.933	495	2	-

To provide adequate deck stringer width for structural reasons the minimum value was assumed to be 14% of the beam, and the maximum 20% of the beam.

Three methods were available to estimate the minimum beam of container ships, these are described briefly together with the approach adopted in the program.

Method 1.

Let Fig. 5.8 represent the geometry of a container ship. Then the breadth B (20) is given by

$$B = 2W + 2C_1 + n_i d + (n-2)C + n\ bo \qquad \text{Eq. 5.1}$$

W = width of the deck stringer, which varies from 2.25 m to 2.98 m for a Panamaxbeam of 32.26 m;

C_1 = clearance between the inner hull to the first cell guide

n_i = number of girders

d = overall width of a deck girder

n = number of container rows

C = clearance between adjacent cell guides

bo = width of the container + thickness of the cell guides

= (2460 + 2t)mm.

t = thickness of the cell guides.

The value of C will depend on the type of precentring device adopted as shown in Fig. 5.9.

Method 2.

Chryssostomidis (37) calculates the minimum breadth as follows:

$$\text{Hold width} = n \times bo + nC + n_i d \qquad \text{Eq. 5.2}$$

where C = 152 mm for shipboard cranes

= 228 mm for shore based cranes

d = width of the deck girder is taken as 305 mm

n_i = number of girders, assumed to be one if number of rows is even and two if it is odd

The breadth of the ship is then given by

$$B = \text{Hold width} + W$$

Fig. 5.8. Midship container arrangement showing dimensions & clearances (20).

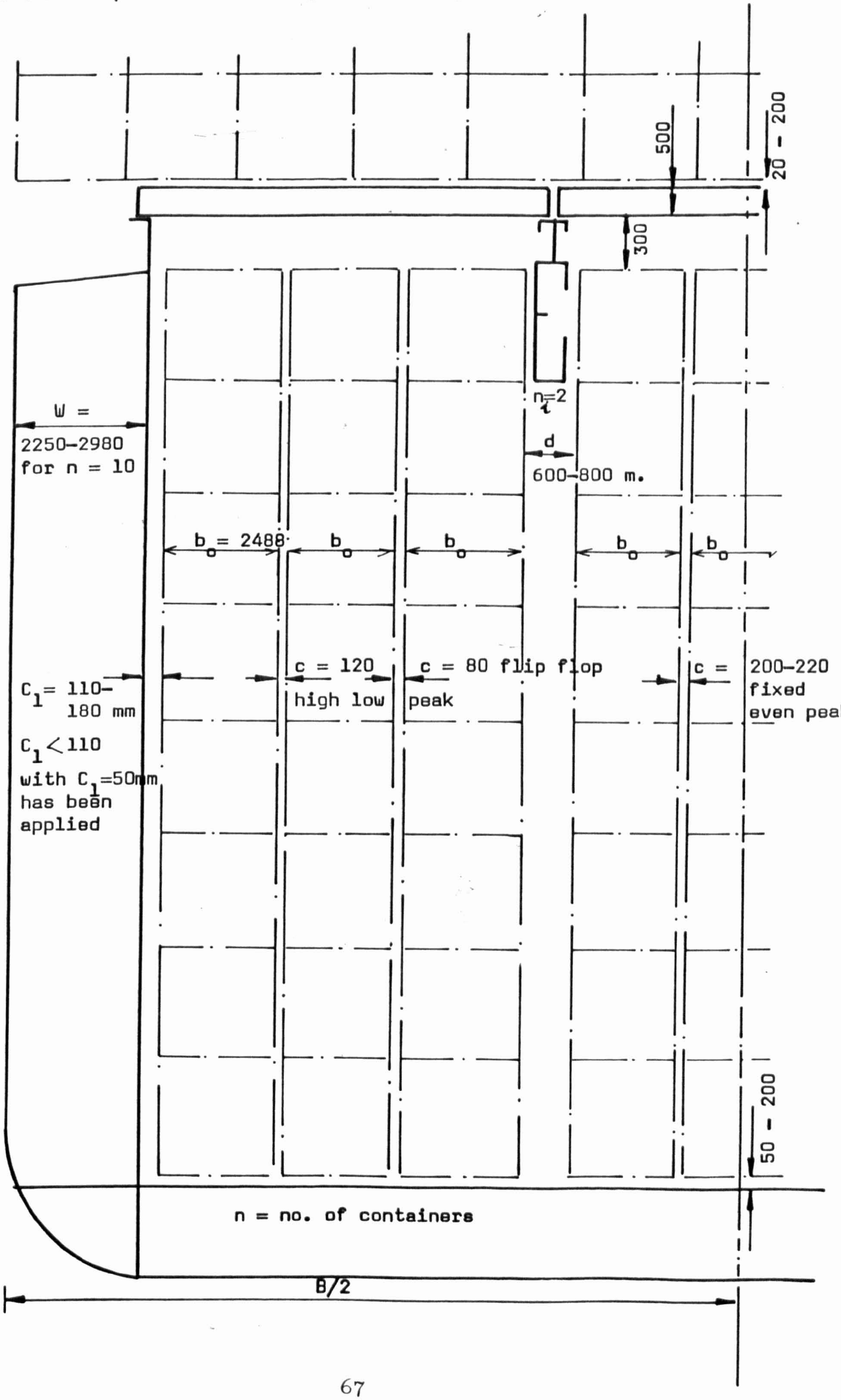
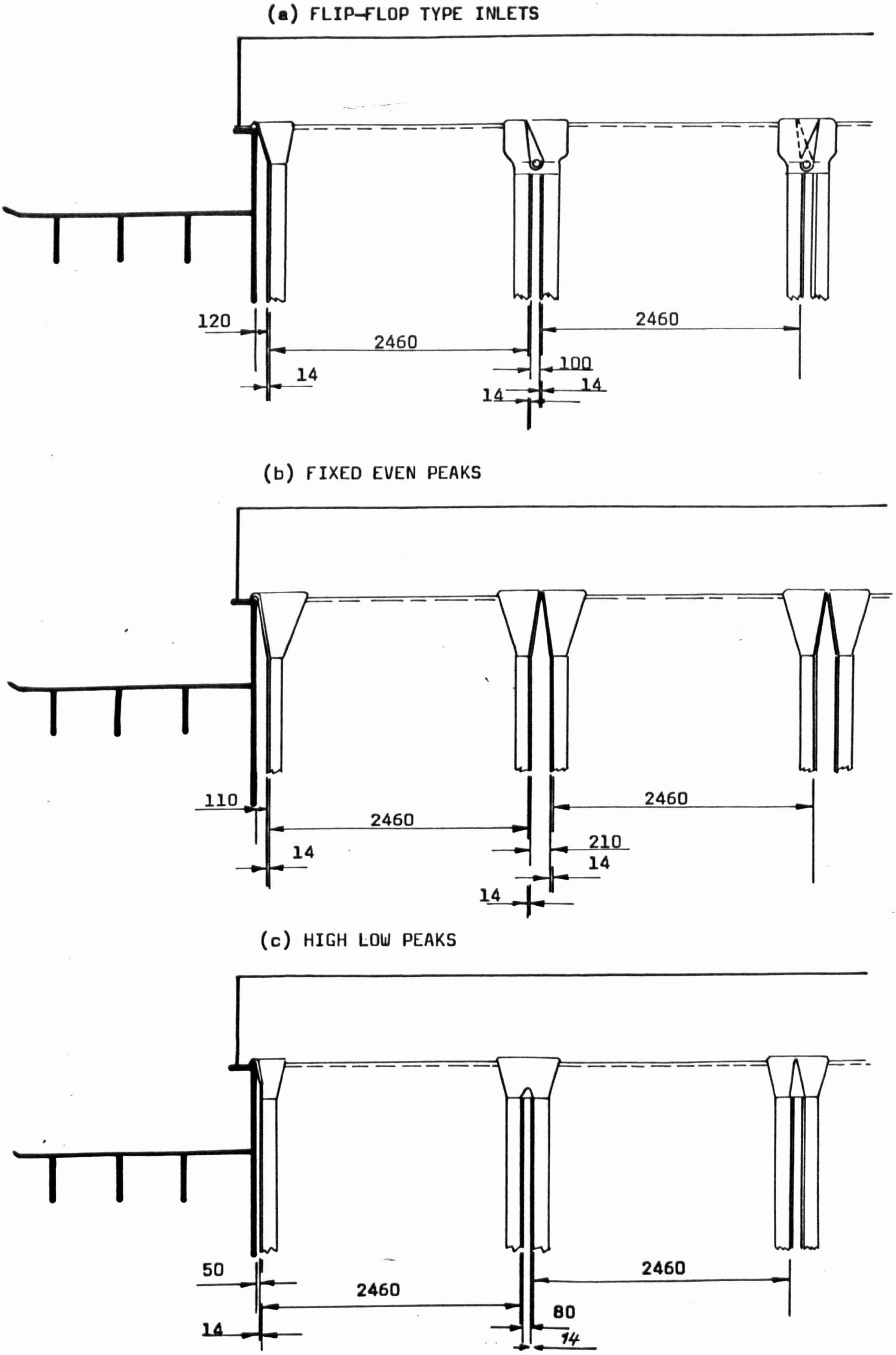


Fig. 5. 9. Container clearances for different types of precentring arrangements (20).



where W = 3.962 m for 7 rows of containers
= 4.572 m for 8 rows of containers
= 5.182 m for 9 rows of containers

Method 3.

Nakamura (24) gives the following relationship for calculating the breadth:

$$B = \text{Rows} \times CW + (n_H - 1)b_1 + 2 \times \text{Clear } W_1 \times n_H + (\text{rows} - n_H) \times \text{Clear } W_2 \qquad \text{Eq. } 5.3$$

Rows = no. of container rows athwartship
C_W = width of the containers taken as 2461 mm
n_H = number of rows of hatchways 2 or 3
b_1 = distance between hatchways = 650 mm
Clear W_1 = clearance between side structure and container
$= \frac{455}{2}$ mm
Clear W_2 = clearance between adjacent cell guides = 130 mm

In the program the minimum and the maximum breadth is calculated as follows:-
Total width of the block of containers (BLOCK W) is given by

$$\text{BLOCK W} = \text{CONTW} + \text{CLEARW} + \text{CLEARF} \qquad \text{Eq. } 5.4$$

CONTW = total space taken by containers alone = number of rows of containers (ROWS) x CW
where CW = width of one container = 2438 mm

The total clearance between containers is CLEARW and is given by

CLEARW = CLEAR 1 x ROWS, where clearance between each container given by CLEAR 1 is assumed to be 230 mm. CLEARF is the clearance for the width of the flanges. If there are even numbers of rows of containers, a single centre line hatch girder is assumed and if there are odd numbers of rows of containers then two longitudinal hatch girders are placed symmetrically on either side of the centre line. It is also possible to have asymmetrically placed girders on either side of the centre line (20) of the ship. The usual space required for such a girder is 600-

800 mm (20). Then the minimum breadth is given by

$$B_{MIN} = \frac{BLOCKW}{0.86} \quad m \qquad \text{Eq. 5.5}$$

and the maximum breadth is given by

$$B_{MAX} = \frac{BLOCKW}{0.80} \quad m \qquad \text{Eq. 5.6}$$

or B_{MAX} = 32.26 m whichever is less.

As shown in Table 5.2 the width of the deck at side can vary from 14.77% of the breadth to 24.21% of the breadth for ships with 8 rows of containers (ship no. 16 & 20). Though these were the extreme limits, such a large variation was kept in the program, because at the preliminary stage it is best to explore the extreme limits, without imposing unnecessary constraints.

A comparative evaluation with the other methods, see Table 5.3, indicates that the minimum and the maximum breadth calculated by the program lies in between the values calculated by method 2 and 3.

5.3. Depth

The depth at side to uppermost continuous deck of a containership is a function of the following five items:

(a) Double bottom height (DBHM)

Previous containership studies (37) have either taken the double bottom as a function of the number of tiers of containers under deck or as required by the classification rules (38) to ensure adequate strength. Chryssostomidis (37) takes the double bottom height as 1372 mm for 8 tiers and 1220 mm for 7 tiers in hold, and the minimum depth of the centre girder (minimum double bottom height) is given by

$$DBHM = \frac{1000 \times B}{36} + 205\sqrt{T} \text{ in mm.}$$

Most ships however have height of the double bottom in excess of those required by strength considerations alone, since adequate space is to be provided for the fuel, freshwater and the ballast. Double bottom height of some containerships are given in Table 5.4. To provide adequate space as mentioned above the following equation was used

TABLE 5.3. Estimation of breadth by different methods (all dimensions in millimetres).

		Rows	5				6				7			
	Item	Method / Formulae	1	2	3	PROGRAM	1	2	3	PROGRAM	1	2	3	PROGRAM
1	Container space	bo	2488	2438	2461	2438	2488	2438	2461	2438	2488	2438	2461	2438
2	Total cont. space	nbo	12440	12190	12305	12190	14928	14628	14766	14628	17416	17066	17227	17066
3	Clearance between cell-cont.	(n-2)c	240/ 660	152-	540	230mm	320/ 880	152-	720	230	400/ 1100	152-	900	230
4	Clearance container hold	2C1	220/ 360	228	455		220/ 360	228	455		220/ 360	228	455	
5	Total clearance for cell guides	Min/Max (3) + (4)	460/ 1020	762/ 1143	995	1150	540/ 1240	914/ 1372	1175	1380	620/ 1460	1067/ 1600	1355	305
6	Width of girder	d	600/ 800	305	650	305	600/ 800	305	650	305	600/ 800	305	650	305
7	No. of girders	n_1	2	2	2	2	1	1	1	1	2	2	2	2

TABLE 5.3. (Contd.)

		Rows	5				6				7			
	Item	Method / Formulae	1	2	3	PROGRAM	1	2	3	PROGRAM	1	2	3	PROGRAM
8	Clearance for girders	$n_1 d$	1200/ 1600	610	1300	610	600/ 800	305	650	305	1200/ 1600	610	1300	610
9	Overall min. hatch width	(2) + (5) + (8)	13500	13562	14600	13950	16068	15847	16591	16313	19236	18743	19882	19286
10	Overall max. hatch width	"	15060	13943			16968	16305			20476	19276		
11	Width of side tk. min.	WMIN		2000		2271		2580		2655		3051		3139
12	Width of the side tank	WAVG/ WMAX		2855/ 3487		3488		3339/ 4076		4078		3926AV/ 4819		4822
13	B min.			15770		16221		18427		18968		21794		22425
14	BAVG/B MAX			16798/ 17429		17438		19645/ 20381		20391		23240/ 24095		24108

* t = thickness of the cell guide

c = 80 – 220 mm

c_1= 110–180 mm

d = 600 – 800

TABLE 5.3 (Contd.)

	Item	Formulae \ Method	8: 1	8: 2	8: 3	8: PROGRAM	9: 1	9: 2	9: 3	9: PROGRAM	10: 1	10: 2	10: 3	10: PROGRAM
1	Container space	bo	2488	2438	2461	2438	2488	2438	2461	2438	2488	2438	2461	2438
2	Total container space	n x bo	19904	19504	19688	19504	22392	21942	22149	21942	24880	24380	24610	24380
3	Clearance cell and container	80–220	480/ 1320	152–	1080	230	560/ 1540	152–	1260	230	640/ 1760	152–	1440	230
4	Clearance cell & hold	110–180	220/ 360	228	455		220/ 360	228	455		220/ 360	228	455	
5	Total clearance	(3) + (4)	700/ 1680	1219/ 1829	1535	1840	780/ 1900	1372/ 2057	1715	2070	860/ 2120	1524/ 2286	1895	2300
6	Girder width	600–800	600/ 800	305	650	305	600/ 800	305	650	305	600/ 800	305	650	305
7	No. of girders		1	1	1	1	2	2	2	2	1	1	1	1
8	Clearance for girders		600/ 800	305	650	305	1200/ 1600	610	1300	610	600/ 800	305	650	305
9	Minimum hatch width	(2)+(5)+(8)	21204	21028	21873	21649	24372	23924	25164	24622	26340	26209	27155	26985
10	Maximum hatch width	"	22384	21638			25892	24609			27800	26971		
11	Minimum tank width			3423	3560	3524		3894	4096	4008	4500	4267	4420	4393
12	Maximum tank width			4572/ 5410	5468	5412		5182/ 6152	6291	6155	5960	5524/ 6743	6788	5275
13	Minimum breadth			24451	25433	25173		27818	29260	28630	-	30475	31575	31378
14	Maximum breadth			26210/ 27048	27341	27061		29790/ 30761	31455	36777	32300/	32495/ 33714	33943	32260

TABLE 5.4. Container stacking characteristics in tiers.

Ship no.	Depth (D) m.	Height of Double Bottom (DBHM) m.	D–DBHM m.	Tiers	D–DBHM / Tiers m.	Height of hatch coaming mm.	Plating Thickness mm	Camber mm	Clearance from under-side of hatch cover to top of container mm.	Depth of hatch cover mm.	Depth / Tiers m.	Doubler Plating mm.
1	19.51	–		7								–
2	19.51	–	–	7	–	–	–	–	–	–	2.787	–
3	19.51	–	–	7							2.787	–
4	18.288	–	–	7							2.613	–
5	19.203	–	–	7							2.743	–
6	16.459	–	–	6							2.743	–
7	16.459	–	–	6							2.743	–
8	15.926	2.000	13.926	6	2.321	1135	14.5	90	523	700	2.654	–
9	16.400	1.885	14.515	6	2.419	–	–	0	300	–	2.733	–
10	15.30	–	–	6	–	–	–	–	–	–	2.550	–
11	24.60	1.960	22.64	9	2.515	1000	16	–	321	–	2.733	–
12	10.65	–	–	5	–	1500	–	–	–	–	2.13	–
13	19.90	1.990	17.91	7	2.558	–	–	–	–	–	2.843	–
14	20.725	2.000	18.725	8	2.341	1489	15.5	115	–	–	2.59	–
15	19.20	–	–	7	–	–	–	–	–	–	2.743	–
16	15.29	1.40	13.89	6	2.315	1403	13.5	0	885	500	2.548	15

TABLE 5.4. Container stacking characteristics in tiers. (Contd.)

Ship no.	Depth (D) m.	Height of Double Bottom (DBHM) m.	D-DBHM m.	Tiers	D-DBHM/Tiers m.	Height of hatch coaming mm.	Plating Thickness mm	Camber mm	Clearance from under-side of hatch cover to top of container mm.	Depth of hatch cover mm.	Depth/Tiers mm.	Doubler Plating mm.
17	15.926	2.00	13.926	6	2.321	1135	14.5	90	418.5	-	2.654	-
18	16.40	1.80	14.60	6	2.433	1050	16.5	229	1022-104	-	2.733	-
19	18.60	1.80	16.80	7	2.400	1610	13	0	300	400	2.657	-
20	16.459	1.828	14.631	6	2.438	1320	14	-	533	800	2.743	-
21	16.61	-	-	6		762.5	-	-	-	533	2.769	-
22	19.80	-	-	7	-	-	-	-	-	-	-	-
23	16.12	2.000	14.12	6	2.353	2020	-	0	594	-	2.686	-
24	24.40	2.090	22.31	9	2.478	-	-	-	-	-	2.711	-
25	23.90	1.70	28.20	9	2.466	950	15.0	0		-	2.655	-
26	14.63	1.450	13.18	5	2.636	-	11.5	-	-	-	2.926	-
27	16.30	-	-	6	-	-	-	-	-	-	2.716	-
28	14.60	1.40	13.20	6	2.2	2375	12		1000	500	2.433	-
29	14.63	-	-	6	-	-	-	-	-	-	2.438	-
30	15.25	1.350	13.90	6	2.316	-	-	-	-	-	2.542	-
31	15.50	1.690		6		1100	14	400	342			

$$DBHM = (0.15 \times TIERB + 0.65)\ m \qquad \text{Eq. 5.7}$$

where TIERB = tiers of containers in the hold which ranges from 5 to 9.

(b) Centre strake thickness (PLTHK)

The centre strake thickness is given by

$$PLTHK = 0.52 + \frac{(L_{Bp} - 440)}{1250} + 0.08 \text{ inches}, \quad L_{Bp} = \text{length in feet (37)}$$

or

$$PLTHK = 0.00136(S + 660)\ \sqrt[4]{L_{Bp} \times T}\ \text{mm} \qquad (38)$$

where S = frame spacing in mm.

Since the main dimensions are not known at this stage of the design the centre strake thickness is approximated by the following formula

$$PLTHK = (1.25 \times TIERB + 1.75)/1000.0\ m \qquad \text{Eq. 5.8}$$

(c) Container blockheight (CBH)

$$CBH = TIERB \times CH + DTHK + CLEAR2 \qquad \text{Eq. 5.9}$$

where CH = container height in m. either 2.438 m.(8') or 2.591 m.(8' 6").

DTHK = thickness of the doubler plate, 25 mm.

CLEAR2 = clearance between the uppermost container tier below deck and the underside of the hatch cover. Table 5.4 gives some typical values for containerships. Chryssostomidis (37) and Nakamura (24) give a value of 100 mm. A value of 300 mm was taken in the program. It is possible to specify 8'6" containers also by changing the value of CH.

(d) Camber (CAMBER)

The deck chamber of containerships is assumed to increase linearly to its maximum value at the side of the hatch opening. In the program CAMBER = 0.075 m, which is also the value taken by Chryssostomidis (37). As shown in Table 5.4 some containerships have no camber or very high camber of 400 mm. A camber of 75 mm seems reasonable.

(e) Hatch coaming height (HATCHT)

The minimum hatch coaming height in position 1, i.e.

hatchways exposed on freeboard decks is 600 mm (38). Chryssostomidis (37) gives a value of 915 mm and Nakamura (24) 760 mm, though actual practice is to give large hatch coaming height, to reduce the depth of the ship, thereby reducing the steel weight (36) and also to stack as many containers below the deck as practicable. Table 5.4 indicates that hatch coaming height of 1000 mm is usual practice. As mentioned earlier in Section 5.2, the minimum value is adopted in the program together with a maximum value, and the most economic depth determined. Thus to calculate the minimum depth, hatch coaming height was taken as 1000 mm.

With the knowledge of the preceding 5 items, the minimum depth D_{min} at side is given by

$$DMIN = DBHM + PLTHK + CBH - CAMBER - HATCHT \quad m \qquad \text{Eq. } 5.10$$

and the maximum depth is approximated by

$$DMAX = DMIN + 1.2 \quad m \qquad \text{Eq. } 5.11$$

For a given number of tiers in hold, statistical analysis shows that the depth at side can vary by 1.2 m for TIERB = 5 to 9. This gives a variation in $\frac{\text{Depth}}{\text{TIERB}}$ of 2.569 m to 2.809 m. Table 5.4 indicates that for actual ships the extreme variation of Depth/TIERB is 2.13m (Ship no.12) to 2.926 m (Ship no.26) for TIERB=5. The average variation is much less and the values adopted in the program are reasonable.

Two methods which were used in past studies to determine the depth are described briefly.

Method 1. Erichsen (39) gives the minimum depth as follows:

$$D \geqslant 8 \times TIERB + \left(\frac{L_{Bp}-500}{100}\right) \text{ ft, } L_{Bp} \text{ in ft,} \qquad \text{Eq. } 5.12$$

where TIERB = 5 for 400 < CNT ⩽ 700

= 6 for 700 < CNT ⩽ 1700

= 7 for CNT > 1700

where CNT = total number of containers

$$D \leqslant 60 + \left(\frac{L_{Bp}-500}{100}\right) \text{ ft, } L_{Bp} \text{ in ft.}$$

when TIERB = 7

Method 2.

Nakamura (24) gives the following equation for determining the depth

$$D = CH \times TIERB + DBHM + CLEAR2 - HATCHT - CAMBER \quad m \qquad \text{Eq. } 5.13$$

where DBHM = B/16 in m.; CLEAR2 = 0.100 m, HATCHT = 0.760 m
CAMBER = B/2 x 45/1000 m.

A comparative evaluation with the above two methods is given in Table 5.5 together with that adopted in the program. This shows that the minimum and the maximum values calculated are reasonable.

5.4. Length BP

The length of the containership was subdivided into container hold length, machinery space length and fore and aft peak length. Each of these are considered in turn.

(a) Container hold length (BLOCKL)

The container hold length is composed of length of the container, manufacturer's tolerance on container length, clearance between container and cell guide, tolerance in cell guide construction, (Table 5.1), container lead-in (Fig. 5.9), structure to support cell guides and bulkheads and/or other transverse ship structure. Because the containers are supported at their corners only, the position of the ship's transverse strength members and transverse frame spacing are directly related to the container length. The same underlying reasoning applies to depth and breadth of the ship.

Table 5.6 shows the container stacking characteristics in bays. For a 20' container the minimum distance per bay varies from 6.748 m to a maximum of 7.979 m/bay. Buxton (15) gives a value of 1.5 - 2.5 m for clearance between adjacent bays. As shown in Table 5.6, total clearance/hold, will depend on the container size, mix of the containers (40' and 20'), number of bays of containers in each hold, type of container (e.g. Reefers require more space) and the location of the container (e.g. container in 'ford. holds require more space), which explains the large variation in the hold clearances.

TABLE 5.5. Estimation of depth by different methods. (All dimensions in mm.).

	Tiers →	Symbol	5				6				7			
	Method	Formula	*1.) 1	*1.) 2	*2.) 3	PROGRAM	1	2	*2.) 3	PROGRAM	1	2	*2.) 3	PROGRAM
1	Container HT	do	2438/ 2591	2591	2591	2438	2438/ 2591	2591	2591	2438	2438/ 2591	2591	2591	2438
2	Total block cont. space	ndo	12190/ 12955	12955	12955	121900	14628/ 15546	15546	15546	14630	17066/ 18137	18137	18137	17066
3	Double bottom height	DBHM		1438	1400	1400		1810	1550	1500		2012	1700	1700
4	Centre strake thickness	CST		–	8	8		–	9.25	9.25		–	10.5	10.5
5	Doubler thickness	DTHK		–	25	25	–		25	25		–	25	25
6	Vertical tolerences	CLEAR2		100	100/ 300	100/ 300		100	100/ 300	100/ 300		100	100/ 300	100/ 300
7	Total vert. height	(2)+(3)+ (4)+(5)+ (6)		14993	14488/ 14688	13723/ 13923		17456	17230/ 17430	16315/ 16515		20249	19973/ 20173	18902/ 19102
8	Hatch coaming height	HATCHT		760	1000	1000		760	1000	1000		760	1000	1000
9	Camber	CAMBER		518	75	75		652	75	75		725	75	75

TABLE 5.5. (Contd.).

	Tiers	Symbol	5				6				7			
	Method	Formula	*1.) 1	*1.) 2	*2.) 3	PROGRAM	1	2	*2.) 3	PROGRAM	1	2	*2.) 3	PROGRAM
10		(8) + (9)		1278	1075	1075		1412	1075	1075		1485	1075	1075
11	Depth at side min.		12215/ 12977	-	13413/ 13613	12648/ 12848	15163/ 16078	-	16155/ 16355	15240/ 15440	18025/ 19091	-	18898/ 19098	17827/ 18027
12	Depth at side avg.		-	13215			-	16044			-	18764		-
13	Depth at side max.		-	-	14613/ 14813	13848/ 14048	-	-	17355/ 17555	16440/ 16640	19244	-	20098/ 20298	19027/ 19227

Note.

*1.) For methods 1 & 2 following ships were chosen.

*2.) Program values assuming 8'6" containers.

*1.

TIERS	L(m)	B(m)	D(m)	DBHM(m)	Ship's Name
5	154.70	23.00	14.63	1.450	Atlantic Marseille
6	205.74	28.96	15.926	2.000	ACT 1
7	248.00	32.20	19.90	1.990	Verranzano Bridge

TABLE 5.5. (Contd.

	Tiers	Symbol	8			9		
	Method	Formula	*1.) 2	*2.) 3	PROGRAM	2 *2.)	3	PROGRAM
1	Container HT	do	2591	2591	2438	2591	2591	2438
2	Total block container space	ndo	20728	20728	19504	23319	23319	21942
3	Double bottom height	DBHM	2005	1850	1850	2012	2000	2000
4	Centre strake thickness	CST	-	12	12	-	13	13
5	Doubler thickness	DTHK	-	25	25	-	25	25
6	Vertical tolerances	CLEAR2	100	100/ 300	100/ 300	100	100/ 300	100/ 300
7	Total vert. height	(2)+(3)+(4) +(5)+(6)	2283	22715/ 22915	21491/ 21691	25431	25457/ 25657	24080/ 24280
8	Hatch coam-ing height	HATCHT	760	1000	1000	760	1000	1000
9	Camber	CAMBER	722	75	75	725	75	75
10		(8) + (9)	1482	1075	1075	1485	1075	1075
11	Depth at side (min)	(7) - (10)		21640/ 21840	20416/ 20616		24382/ 24582	23005/ 23205
12	Depth at side avg.	"	21351			23946		
13	Depth at side max.	"		22840/ 23040	21616/ 21816		25582/ 25782	24205/ 24405

TABLE 5.5. (Contd).

Note:

*1.) For Method 2. The following ships were chosen.

Tiers	L(m)	B(m)	D(m)	DBHM	Ship's Name
8	236.00	32.08	20.725	2.000	Remuera
9	257.60	32.20	23.90	1.70	Selandia

TABLE 5.6. Container stacking characteristics in Bays.

	Length of Container hold m.	Container size ft.	No. of bays	Per 20' container bay space m.	Clearance per 20' container bay m.	Longitudinal Clearance (in metres)									
						Number of container bays/hold									
						1		2		3		4		5	
						Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max	Min.	Max.
1	174.10	35 x 8 x 8.5	15	-		35′ 0.732	-	35′ 1.463	4.56	35′ 4.56	-	-	-	-	-
2	174.10	35 x 8 x 8.5	15	-		-	-	-	-	-	-	-	-	-	-
3	165.36	20 x 8 x 8.5	24	6.890	0.794	-	-	-	-	-	-	3.176	-	-	-
4	170.08	40 x 8 x 8.5	12	7.086	0.989			40′ 2.386	40′ 4.745	-	-	-	-	-	-
5	169.42	40 x 8 x 8.5	12	7.059	0.963	40′ 1.828	40′ 2.997	40′ 3.096	4.085	-	-	-	-	-	-
6	140.90	20 x 8 x 8	18	7.827	1.731	-	-	2.408	5.007	-	-	4.815	10.16	-	-
7	118.872	24 x 8 x 8.5	13	-	-	-	-	-	-	-	-	24′ 7.315	-	24′ 9.144	-
8	148.80	20 x 8 x 8	20	7.44	1.343	-	-	2.007	3.507	-	-	-	-	-	-
9	154.20	20 x 8 x 8	20	7.66	1.564	4.108	5.408	-	-	-	-	4.516	6.315	-	-
10	-	20 x 8 x 8	-	-	-	-	-	-	-	-	-	-	-	-	-
11	221.90	20 x 8 x 8 40 x 8 x 8	18/ 5	7.925	1.828	40′ 5.608	-	40′ 4.916	-	(2)20′ 5.616	(2)20′ 5.416	-	-	-	-
12	74.23	20 x 8 x 8	11	6.748	0.652	-	-	1.878	-	-	-	2.275	-	3.019	-

TABLE 5.6. Container stacking characteristics in Bays. (Contd.)

	Length of Container hold m.	Container size ft.	No. of bays	Per 20' container bay space m.	Clearance per 20' container bay m.	Longitudinal Clearance (in metres)									
						Number of container bays/hold									
						1		2		3		4		5	
						Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max	Min.	Max.
13	189.42	20 x 8 x 8	26	7.285	1.189	-	-	-	-	-	-	-	-	-	-
14	-	-				-	-	-	-	-	-	-	-	-	-
15	181.50	40 x 8 x 8.5	13	7.03	0.934	40' 0.608	40' 1.807	40' 3.015	40' 4.116						
16	139.953	20 x 8 x 8 40 x 8 x 8	17/ 1	7.366	1.269	40' 1.773	20' 1.704	1.108	3.978						
17	151.98	20	20	7.599	1.503	-	-	-	-	-	-	-	-	-	-
18	143.10	20 x 8 x 8 R	19	7.606	1.510	-	-	1.208	3.808R	2.612R	-	3.616	8.816R	-	-
19	157.23	20 x 8 x 8 40 x 8 x 8	11/ 6	6.836	0.739	-	-	40' 2.066	40' 2.616	2.992	-	-	3.376	-	-
20	118.872	24 x 8 x 8.5	13	-		-	-	-	-	-	-	24' 7.315	-	24' 9.144	-
21	112.70	20 x 8 x 8.5	16	7.044	0.948	-	-	-	-	-	-	-	-	-	-
22	189.59	20	26	7.292	1.196	-	-	-	-	-	-	-	-	-	-
23	140.5	40 x 8 x 8	10	7.276	1.180	-	-	40' 3.716	-	(2)20' 5.016	(1)40' 6.695	-	-	-	-

TABLE 5.6. Container stacking characteristics in Bays. (Contd.)

	Length of Container hold m.	Container size ft.	No. of bays	Per 20' container bay space m.	Clearance per 20' container bay m.	Longitudinal Clearance (in metres)									
						Number of container bays/hold									
						1		2		3		4		5	
						Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max	Min.	Max.
24	181.45	20 x 8 x 8 40 x 8 x 8	11/ 7	7.258	1.162	–	(1)20′ 1.962	(1)40′ –	–	5.992		40′ 5.016	–	–	–
25	199.478	20 x 8 x 8 40 x 8 x 8	17/ 5	7.979	1.883	–	–	2.448	40′ 3.732	(2)20′ 4.392/ 3.812	(1)40′ 5.798	(2)20′(1)40′ 4.656	–	–	–
26	124.00	20 x 8 x 8	18	6.888	0.792	–	–	1.808	–	–	–	3.116	–	–	–
27	147.0	20 x 8 x 8	19	7.737	1.641	0.904	–	2.308	3.808			6.116	7.616		
28	109.86	20 x 8 x 8.5 40 x 8 x 8.5	5/ 5	7.324	1.228			2.451	6.641	3.667	(2)20′ 5.66	(1)40′			
29	103.472	20 x 8 x 8	14	7.391	1.295			2.888		3.809					
30	94.85	20 x 8 x 8 40 x 8 x 8	8/ 3	6.775	0.679			2.438				4.106			

NOTE: R = Reefer containers.

To take into account the different mixes of container sizes that can be stacked in a hold and also the variation in size of the hold (e.g. 2 bays or 3 bays of container/hold) the following method was adopted.

The procedure described here is done by subroutine subprogram DESIGN and the procedure is similar to one given by Chryssostomidis (37).

(i) Determine the total number of containers amidship in one bay from the number of rows of containers athwartship and tiers of containers below deck.

$$CNPR = ROWS \times TIERB \quad \text{container/bay} \qquad \text{Eq. 5.14}$$

(ii) The hold capacity of the containerships is approximated by Eq. 13.12 and the deck capacity by Eq. 13.11 (Section 13.2.1).

(iii) Since there is a loss of cubic space due to the ship shape form, a certain value of shape coefficient (CSHAPE) is assumed, (Section 13.2.2).

(iv) Then CNRI, the number of containers that can be accommodated in N-bays (BAYS) if the shape coefficient is 1, is given by

$$CNRI = BAYS \times CNPR$$

$$\text{and} \quad CNRA = CNRI \times CSHAPE \qquad \text{Eq. 5.15}$$

The number of BAYS is incremented in steps of 1 until the integer value of CNRA is equal to the hold capacity (CNTHLD) estimated in step (ii).

(v) The number of bays/hold (NCLPH) which is input by the user, is then used to determine the hold length. The user can input 1 bay/hold to 4 bays/hold which gives for a 20' container, the largest possible hold dimensions from floodable length considerations (37).

(vi) The number of holds (HOLDSN) is then given by

$$HOLDSN = BAYS/NCLPH \qquad \text{Eq. 5.16}$$

and HOLDSN can either be an odd, or even or exact multiple of NCLPH.

(vii) The total container hold length (BLOCKL) is then calculated as, where HOLDN = HOLDSN.

Bays	No. of bays/ hold NCLPH	Total container hold length in m. (BLOCKL)
Even	2	HOLDN x (2 x CL + 2.286)
Odd	2	HOLDN x (2 x CL + 2.286) + CL + 1.524
Exact multiple	3	HOLDN x (3 x CL + 3.048)
" +1	3	HOLDN x (3 x CL + 3.048) + CL + 1.524
" +2	3	HOLDN x (3 x CL + 3.048) + 2 x CL + 2.286
Exact multiple	4	HOLDN x (4 x CL + 3.81)
" +1	4	HOLDN x (4 x CL + 3.81) + CL + 1.524
" +2	4	HOLDN x (4 x CL + 3.81) + 2 x CL + 2.286
" +3	4	HOLDN x (4 x CL + 3.81) + 3 x CL + 3.048

The total clearance/hold was chosen as average of the values indicated in Table 5.6 and given below. These values are for 20' ISO general cargo containers. Clearances for other types of containers can easily be introduced in the program. Table 5.6 gives some indicative values for Reefers and different mixes of containers (e.g. two bays of 20' and one bay of 40' container in a hold).

No. of bays/hold	1	2	3	4
Total clearance/ hold in m.	1.524	2.286	3.048	3.81

Following are the values of the container hold length calculated by the program and that of some actual ships assuming a 20' container (6058 mm + 35 mm = 6093 mm).

The program results are in most cases lower than the actual ship's data, this being the minimum length possible, and within acceptable limits.

Ship Ref. No.	No. of Bays	HOLDSN	No. of bays/ hold NCLPH	Container hold length in m.	
				Table 5.6	Program
13	26	Even	2	189.42	188.14
12	11	odd	2	74.23	79.98
16	18	Exact.Mlt.	3	132.85	127.96
21	16	" "+1	3	112.70	114.25
19	23	" "+2	3	157.23	163.76
24	24	Exact.Mlt.	4	181.45	169.09
22	26	" "+2	4	189.59	183.56
25	27	" "+3	4	199.48	190.42

(b) Machinery space length

There were very few formulae for calculating the length of the engine room. Those that were available were mainly for steam turbine or gas turbine machinery (37,40). Others for diesel machinery (41) were found to be valid for a very small power range or not suitable for parametric studies (42) because it was given as a function of the length of the ship, and as shown in Table 5.7 valid for ships with single screw installation.

To calculate the length of the machinery space, the diesel machinery were subdivided into (a) direct drive diesel (b) geared diesel.

<u>Direct drive diesel</u>:

The ships shown in Table 5.7 were used to develop the engine room length. Different estimating equations were developed for ships with machinery position aft and those with machinery position 3/4 aft. Straight line equations of the form y = m x SHP + C gave good correlation and are indicated.

(a) Single screw ships with machinery aft

The length of the engine room (FLMC) is given by,

TABLE 5.7. Length of engine room for ships with direct drive diesel plant.

No.	Ship's Name	Length BP in m.	No. of engines	Position of m/c room	# Power in British H.P.	Length of eng.room Actual m.	Program	*(42)
1	Goldenfels	144.00	S.S.	Aft	12250	28.0	26.97	-
2	Table Bay	248.20	T.S.	¾Aft	51360	26.5	27.77	36.73
3	New Jersey Maru	247.00	T.S.	"	69600	33.1	32.84	-
4	Oriental Chevalier	192.00	S.S.	Aft	29000	37.5	35.14	-
5	Elbe Maru	252.00	Triple	¾Aft	84600	49.97	†37.00	37.29
6	Selandia	257.60	"	"	78600	34.14	†35.34	38.12
7	Hakozaki Maru	200.00	S.S.	"	34200	30.40	30.17	29.60
8	Elbe Express	155.00	"	Aft	15750	29.05	28.68	-
9	C.P.Voyageur	153.00	"	"	15000	30.40	28.31	-
10	Neptune Emerald	165.00	"	¾Aft	23100	25.60	24.76	24.42
11	Kiso Maru	242.00	T.S.	"	80000	45.00	35.73	-
12	Verranzano Bridge	248.00	"	"	80000	35.64	35.73	-
13	Tamara	196.20	"	"	34800	23.20	23.17	-
14	Svendborg		S.S.	Aft	9900	21.50	25.83	-
15	California Star	178.00	"	"	26100	24.75	33.72	-
16	Act I	205.74	"	"	30000	30.48	35.63	-
17	Arafura	200.00	"	¾Aft	34200	29.80	30.17	29.60
18	Dart America	218.01	"	Aft	29000	34.40	35.14	-
19	Hawaiin Enterprise	206.35	"	"	32000	33.53	36.60	-
20	Fushimi Maru	147.00	"	¾Aft	12000	19.40	19.35	21.75
21	City of Plymouth	96.31	"	Aft	5500	14.5	23.68	-
22	Kashu Maru	175.00	"	¾Aft	27600	25.70	26.96	25.90
23	Golden Gate Bridge	175.00	"	"	27500	25.00	26.91	"
24	America Maru	175.00	"	"	28000	25.00	27.15	"
25	Hakone Maru	175.00	"	"	27800	28.00	27.05	"
26	Japan Ace	175.00	"	"	28000	25.50	27.15	"
27	Astronomer	193.10	"	Aft	29000	37.95	35.14	-

Note 1.* Pawlowski (42) gives the following expression for calculating the length of engine room (FLMC) for ships with direct drive diesel.

$$FLMC_{(\frac{3}{4}\ Aft)} = 0.148 \times L \quad m.$$

2.† Assumed twin screw.

3.# British horsepower=746 watts and PS(Metric horsepower)= 736 watts.

* (correlation 0.82, 9 data points)

$$FLMC = 4.665 \times 10^{-4} \times SHP + 20.958 \ \text{m} \qquad \text{Eq. 5.17}$$

(b) Single screw ships with machinery 3/4 aft

$$FLMC = 4.583 \times 10^{-4} \times SHP + 13.704 \ \text{m} \qquad \text{Eq. 5.18}$$

(correlation 0.933, 10 data points)

The engine room length is equal to the length of the engine plus some space ford, and aft of the engine. The length of direct drive diesel engines was plotted for various makes of engines, which gives an equation of the form (mean line)

$$\text{length of direct drive engine} = 4.875 \times 10^{-4} \times SHP + 5.82 \ \text{m} \qquad \text{Eq. 5.19}$$

The Equations 5.17 and 5.18 were therefore modified to give the slope given by Eq. 5.19; and are given by

$$FLMC_{SS}(\text{aft}) = 4.875 \times 10^{-4} \times SHP + 21 \ \text{m} \qquad \text{Eq. 5.20}$$

$$FLMC_{SS}(3/4 \ \text{aft}) = 4.875 \times 10^{-4} \times SHP + 13.50 \ \text{m}. \qquad \text{Eq. 5.21}$$

Eq. 5.19, 5.20, 5.21 are shown in Fig. 5.10. The choice of machinery position is input by the user through the control parameter IPMC.

(c) Twin screw installation.

The maximum power that can be delivered through a single shaft is assumed to be 50,000 h.p.. Therefore the program automatically assumes that above this power the ship is a twin engine, twin screw installation and the machinery position is 3/4 aft.

The shaft horse power of the ship is scaled as follows:

$SHP = \frac{SHP}{2} \times 1.14$ and the Eq. 5.21 used to calculate the engine room length. e.g. for Ship No.12 $SHP = \frac{80000}{2} \times 1.14$ $= 45600$ h.p. and Eq. 5.21 gives FLMC = 35.73, actual value is 35.64. As Table 5.7 indicates these equations give a fairly good approximation to machinery space length.

Geared Diesel:

Container ships of smaller size usually have geared diesel installation. Table 5.8 indicates some container

* Correlation coefficient is a measure of degree of association between the the random variables $(x_1, y_1), \ldots (x_n, y_n)$. This correlation coefficient is denoted by r and is calculated by the following expression

$r = m \, \sigma_x / \sigma_y$, where m is the slope of the st. line

Fig. 5.10. Engine Room Length versus installed power
(Direct Drive Diesel plant)

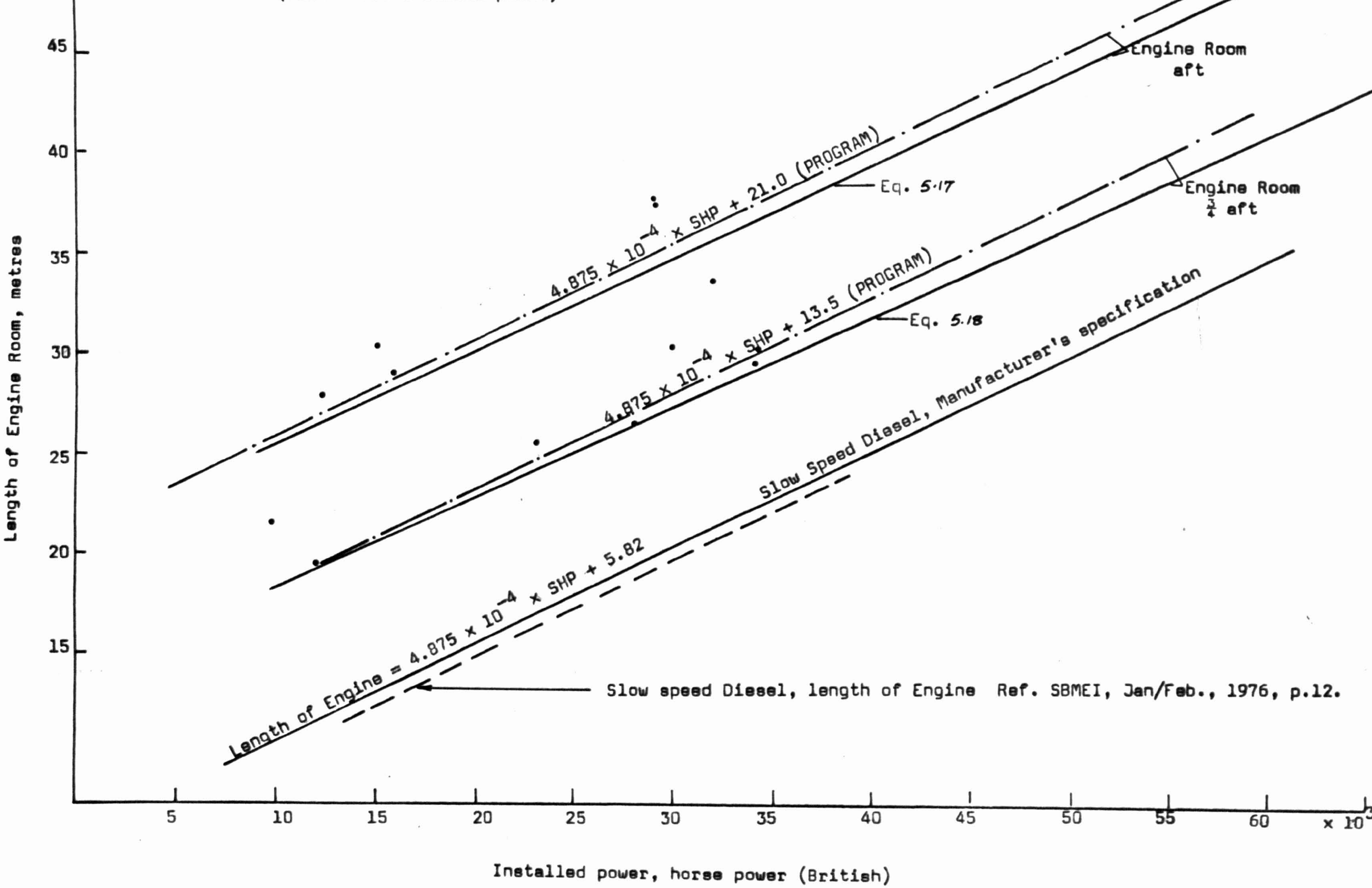


TABLE 5.8. Length of engine room for ships with geared diesel installation.

No.	Ship's Name	Length BP in m.	No. of engines/ propeller		Position of m/y room	Power in British H.P.	Length of Eng.Room		
							Actual	Program	*(42)
1	Fiery Cross Isle	133.60	1	1	Aft	17500	21.9	24.36	-
2	Manchester Vigour	103.10			"	6000	13.4	15.567	-
3	Atlantic Jamaican	79.15			"	3200	12.81	13.43	12.26
4	Brian Boromime	99.97	2	2	"	4200	14.70	14.19	15.49
5	Atlantic Marseille	154.70	2	1	"	18000	26.00	24.74	-
6	Fort Royal	198.00	2	2	$\frac{3}{4}$Aft	36000	28.09	-	-
7	Axel Johnson	157.20	4	2	"	26000	17.68	-	-
8	Sea Freight liner	111.56	2	2	Aft	3780	17.70	13.87	-
9	Manchester Challenge	151.79	2	1	"	16380	24.38	23.50	-
10	Hustler Class	78.84	1	1	"	3200	12.81	13.43	12.22
11	Tarross	78.84	1	1	"	3200	12.81	13.43	12.22
12	Strider	105.00	1	1	"	7000	18.20	16.33	-
13	Wicklow	92.00	1	1	"	3900	15.24	13.96	14.26
14	Rohdri Mawr	99.98	2	2	"	4200	13.50	14.19	15.49
15	Barbel Bottom	79.00	1	1	"	2500	10.00	12.89	12.24
16	Jeddah Crown	104.00	1	1	"	8900	17.60	17.78	-
17	Bell 'R' Class	72.00	1	1	"	2100	21.26	12.58	11.16

Note 1. * Pawlowski (42) gives the following equation for ships less than 100 m. and machinery position aft. Length of machinery space FLMC is given by,

$$FLMC_{(aft)} = 0.155 \times LBP \quad m.$$

ships with geared diesel installation and the length of the engine room. Fig. 5.11 shows the plot of the length of the medium speed diesel engine, valid for 2600-30600 hp range. Because of the gearbox and other ancillaries it was found that the length of the engine room could not be derived directly from the length of the engine.

Instead the ships shown in Table 5.8 were used to estimate the length of the engine room and is given by:
For single screw installations with machinery room aft,

$$FLMC_{SS} = 6.887 \times 10^{-4} \times SHP + 10.75 \text{ m} \qquad \text{Eq. 5.22}$$

(8 data points, correlation 0.897)
As shown in Table 5.8 most ships with geared diesel installation are of low power and the machinery position is usually aft. So a single equation was fitted for both twin screw and single screw installation which gave better correlation (13 points, correlation 0.92). In the program therefore ships with less than 10000 h.p. are assumed to have geared diesel installation with machinery room aft, and engine room length is given by

$$FLMC(S.S. \,\&\, T.S.) = 7.645 \times 10^{-4} \times SHP + 10.98 \qquad \text{Eq. 5.23}$$

A comparative evaluation (Table 5.8) shows that the equation gives a good approximation to machinery room length, with the method given by Pawlowski (42).

(c) Length of peaks

Table 5.9 shows the length of the aft peak and ford peak of containerships as a percentage of LBB Whereas aft peak length compared to the ford peak length as a percentage of LBP shows a larger variation, the overall length of the peaks as a percentage of LBP shows lesser variation. The value of $\frac{LFP + LAP}{LBP}$ varies from 6% to 15%. In the program the combined length of peaks is assumed to be 10% of LBP. The minimum length between perpendiculars is then given by

FLMIN = length of the container holds (BLOCKL) + length of the machinery spaces (FLMC) + length of peaks m

Eq. 5.24

The program ensures that the designs generated have LBP

Fig. 5.11. Length of Engine Room versus installed power (Geared Drive Diesel plant)

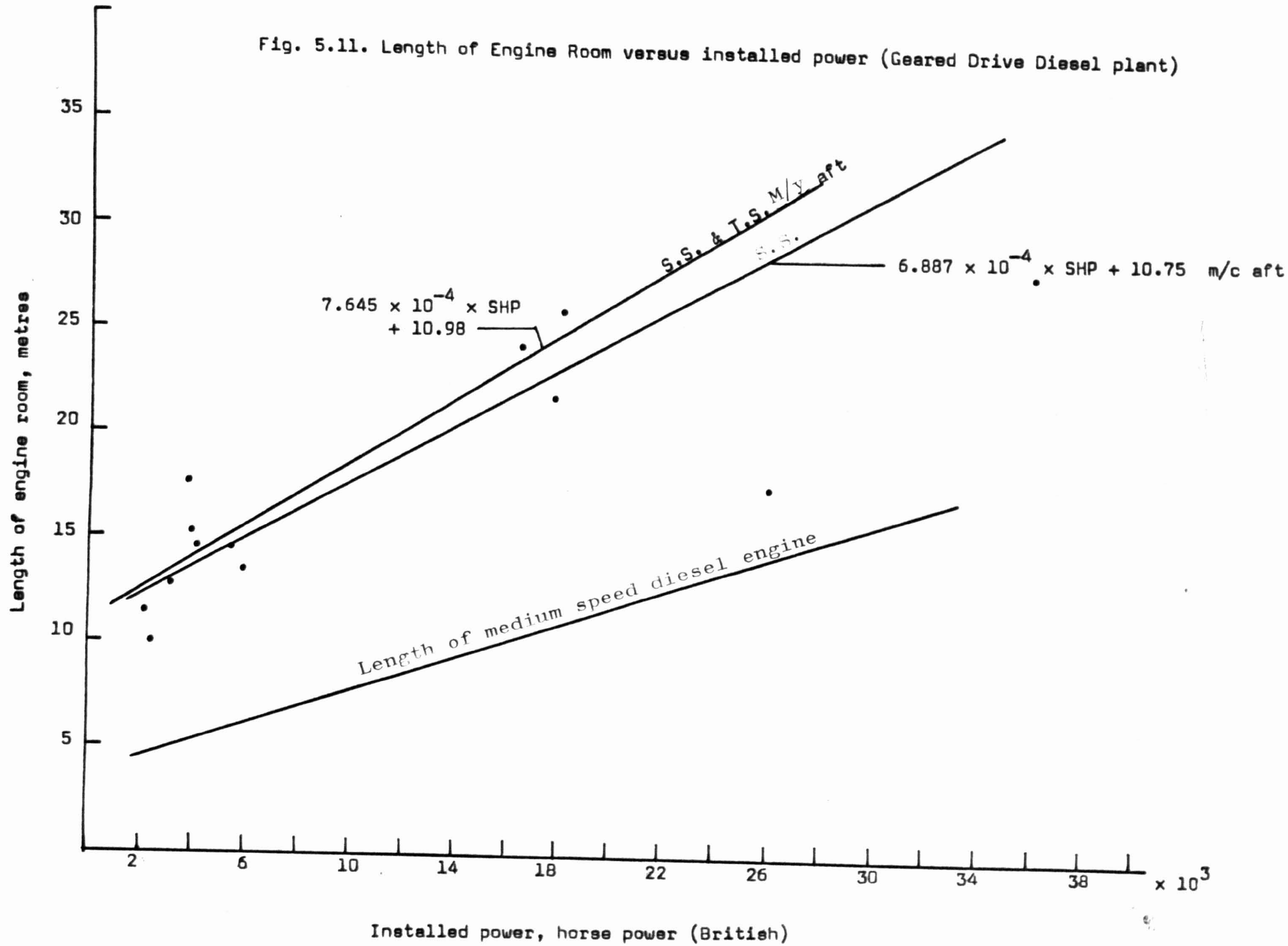


Table 5.9. Length of peaks.

	LFP length of fore-peak m.	Length of cargo spaces m.	Length of deep tk. m.	LAP length of aft peak m	LFP/LBP % age	LAP/LBP % age	(LFP + LAP)/LBP % age
1	15.86	35.182	-	7.014	5.91	2.61	8.52
2	37.03		-	AP+FP =21.03			7.84
3	13.41	27.58	-	19.96	5.10	7.59	12.69
4	11.81	-	6.85	4.88	5.1	2.11	7.21
5	12.32	-	14.40	1.168	5.5	0.52	6.02
6	-	-	-	-	-	-	-
7	10.972	30.17		12.19	5.33	5.92	11.25
8	11.500	-	-	9.0			
9	10.80	9.1	-	10.80	4.79	4.79	9.58
10	10.37			9.15	5.93	5.23	11.16
11	12.00			4.5	4.37	1.64	6.01
12	8.87	-	-	6.6	8.6	6.4	15.00
13	16.44			6.5	6.63	2.62	9.25
14	-	-	-	-	-	-	-
15	12.68	-	14.385	2.44	5.64	1.08	6.72
16	10.797	-	13.3	9.60	6.06	5.39	11.45
17	11.08	-	-	12.20	5.39	5.93	11.32
18	9.186	-	13.45	12.20	5.16	6.85	12.01
19	12.18	-	2.28	10.20	5.59	4.67	10.26
20	10.97	30.17		12.19	5.33	5.92	11.25
21	9.754	-	19.278	10.363	5.50	5.84	11.34
22	17.59	-	-	6.75	7.12	2.73	9.85

TABLE 5.9 (Contd.)

	LFP length of fore-peak m.	Length of cargo spaces m.	Length of deep tk. m.	LAP length of aft peak m.	$\frac{LFP}{LBP}$ % age	$\frac{LAP}{LBP}$ % age	$\frac{LFP + LAP}{LBP}$ % age
23	14.70	-	-	8.82	7.66	4.59	12.25
24	16.47	-	24.28	4.11	6.53	1.63	8.16
25	18.47	-	21.0	4.8	7.17	1.86	9.03
26	11.20	-	-	9.5	7.24	6.14	13.38
27	18.00	-	-	7.4	9.0	3.70	12.70
28	8.995	-	6.95	8.4	5.80	5.42	11.22
29	7.86	-	7.54	8.53	5.18	5.62	10.80
30	12.95	-	7.48	7.32	8.46	4.78	13.24

greater than this (FLMIN) value. The subroutine subprogram DESIGN calculates the minimum length between perpendiculars.

5.5 Draft

Container ships are never very deep draught ships. The reasons are (a) the design deadweight of most container ships can be obtained at a draft less than that obtainable with a Type B-freeboard.

(b) Containerships are essentially stability limited ships and therefore the total containers that can be carried are governed by the stability constraints.

(c) Though a 20' container can carry 18.29 tonnes (18 tons) of cargo the average cargo weight carried is about 12-15 tonnes (15) and on the North Atlantic route on nearly 60% of the time the average weight per container is 14.8 tonnes (203).

Other factors which determine draft are depth at the harbour approach and channel restrictions if any. The largest containerships have drafts of about 13 m (see Fig. 5.5), and the design draft of a containership is usually about 1 to 2 m below that allowable by the minimum freeboard.

Since the average container weight is dependent on the route characteristics, the user can input a constraint on the maximum allowable average weight of each container.

In Chapter 13, it is shown how a reasonable design draft can be selected. In the program the draft is constrained by the B/T ratio and the minimum freeboard requirements.

The minimum draft (TMIN) allowable by B/T constraint is

$$TMIN = \frac{B}{3.75} \text{ m} \qquad \text{Eq. 5.25}$$

and the maximum draft (TMAX) allowable by B/T constraint is

$$TMAX = \frac{B}{2.25} \text{ m or } TMAX = D - \text{minimum freeboard m} \qquad \text{Eq. 5.26}$$

whichever is less.

5.6. Block Coefficient

In order to maximise the number of containers it would be desirable to have a high block coefficient. Thus the optimum containership from a stowage point of view would be a rectangular barge.

There are various formulae being used for preliminary design studies, of which the more common are given below.

$$Cb = 1.137 - 0.6 \frac{V}{\sqrt{L}} \quad \text{(Van Lammeren)} \qquad (43) \qquad \text{Eq. 5.27}$$

$$Cb = 1.06 - 0.5 \frac{V}{\sqrt{L}} \quad \text{(Ayre)} \qquad (43) \qquad \text{Eq. 5.28}$$

$$Cb = 1.22 - 0.709 \frac{V}{\sqrt{L}} \quad \text{(Minorsky)} \qquad (43) \qquad \text{Eq. 5.29}$$

$$Cb = 1 - \frac{3}{8} x (B/L + 1) \frac{V_T}{\sqrt{L}} \quad \text{(Telfer)} \qquad (43) \qquad \text{Eq. 5.30}$$

$$Cb = 0.65 + 0.95 \frac{V}{\sqrt{L}} - 1.2 \left(\frac{V}{\sqrt{L}}\right)^2 \quad \text{(Sabit)} \qquad (43) \qquad \text{Eq. 5.31}$$

$$Cb = K - V/3.62 \times \sqrt{L} \quad \text{(Alexander)},$$
$$K = 1.12 \text{ to } 1.03 \qquad (35) \qquad \text{Eq. 5.32}$$

$$Cb = 1.216 - 0.392 x \frac{V}{\sqrt{L}} \quad \text{(Silverleaf)} \qquad (43) \qquad \text{Eq. 5.33}$$

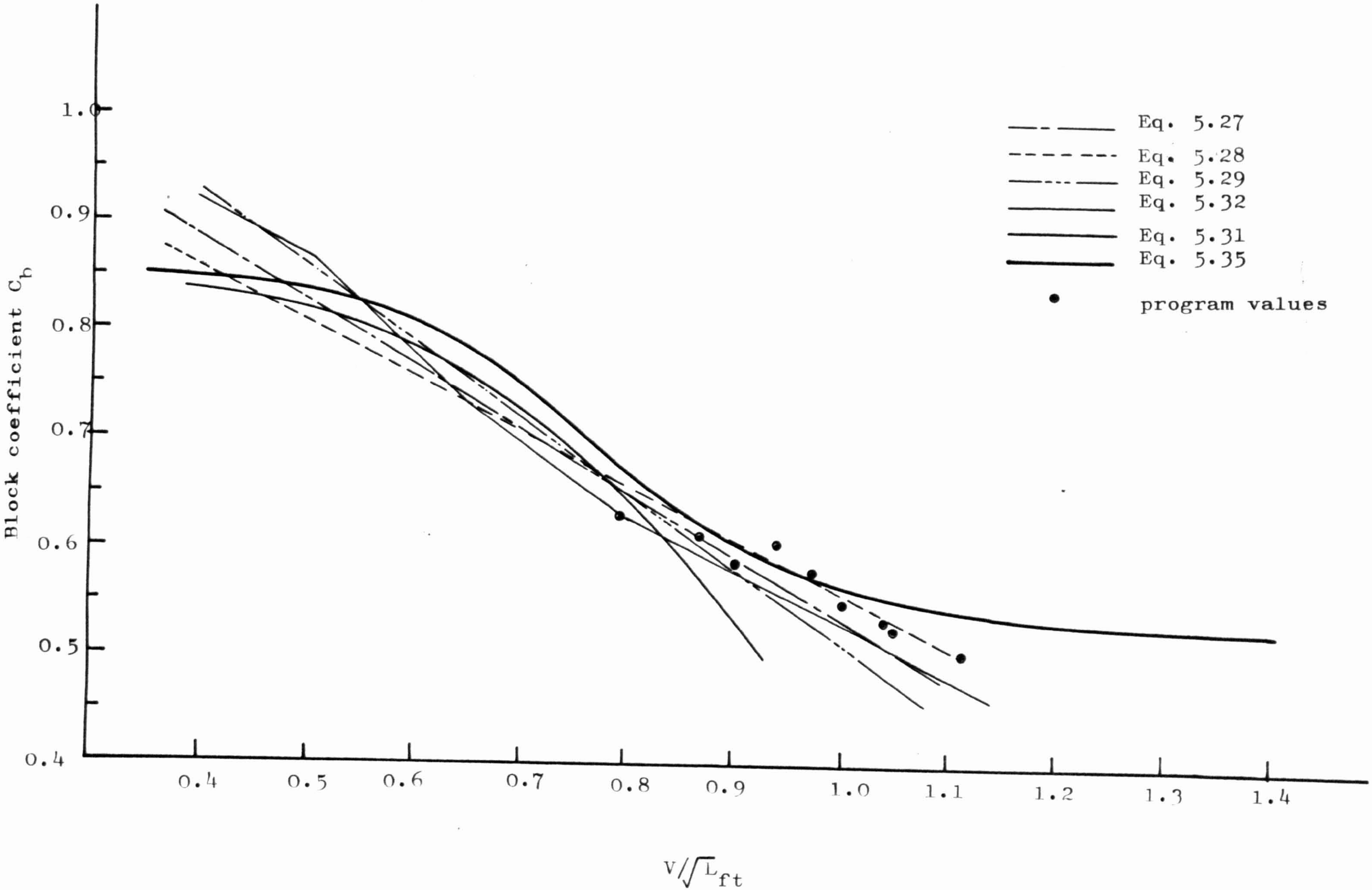
$$Cb = 0.8217 x L_x^{0.42} B_x^{-0.3072} T_x^{0.1721} Vs^{-0.6135}$$
$$\text{(Katsoulis)} \qquad (44) \qquad \text{Eq. 5.34}$$

$$Cb = 0.7 + 1/8 \tan^{-1} 25(0.23 - Fn)$$
$$\text{(Townsin)} \qquad (45) \qquad \text{Eq. 5.35}$$

Eq. 5.27 to Eq. 5.31 the dimensions are in feet, for Eq. 5.32 to Eq. 5.35 the dimensions are in metres; and the speed is in knots in all equations. These empirical formulae are either the result of regression analysis of existing ships or models, and do not take into account, when choosing the block coefficient the economic factors such as fuel price, shipbuilding costs and other operating conditions.

Therefore in the program block coefficient is made an independent variable and the optimum is determined taking into account the various operating conditions and economic factors. Figure 5.12 shows the optimum block coefficient determined by the program together with the above equations.

Fig. 5.12. Block coefficient versus speed length ratio.



The block coefficient was varied from 0.50 to 0.70 which covers most of the containerships for speeds length ratio of 0.40 to 1.5.

5.7. Structural design considerations

Containerships are 'open' ships because they have total hatch width of nearly 80% of the ship's breadth and extending nearly 60-77% of the ship's length. This has given rise to two basic problems as far as structural strength is concerned. Firstly difficulty in providing sufficient section material to satisfy requirements of longitudinal strength and, secondly that an 'open' section lacks torsional rigidity and is prone to warp, causing additional longitudinal stresses which augment those due to longitudinal bending (22). Meek (21) and Clemmetsen (23) discuss these problems in detail, and Rapo (20) gives a simple approach which can be incorporated in the preliminary design stage to ensure adequate structural strength.

To ensure adequacy of hull girder stiffness requirements as given by Classification Society Rules (38) an upper limit on the value of L/D = 15 is given (27).

Nakamura (24) arrives at the following limiting values of L/D ratios for ships designed with adequate longitudinal strength.

L_{BP} in m.	150	175	200	214.67	250	275
Limiting L/D	16.45	14.45	13.20	12.55	11.65	11.25
Rows of containers	7	8	9	9	10	10
Tiers of containers	-	-	$\geqslant 6$	$\geqslant 7$	>8	9
Rows of hatchways	1	2	3	3	2	2
Breadth in m.	22.5	26.25	30	32.20	32.20	32.20

Though Rapo (20) and Nakamura (24) give some simplistic approach to structural design of containerships, this was not incorporated, since it was found that the preliminary design program will require input data which are not readily available, and therefore left for future development.

Therefore the only structural consideration that the program incorporates is to ensure adequate hull girder stiffness by limiting the value of L/D between 10 and 14.5.

5.8. Gross and net tonnage

Gross registered tonnage was made a function of L, B and D and the net register tonnage was made a function of GRT. Straight line equations fitted to existing container-ships gave good correlation.

$$\text{Gross Register tonnage (GRT)} = 0.237 \times L \times B \times D + 995 \text{ tons} \qquad \text{Eq. 5.36}$$

$$\text{Net Register tonnage (NRT)} = 0.585 \times GRT + 110 \text{ tons} \qquad \text{Eq. 5.37}$$

A check with another estimating equation developed by Chapman (46) showed them to lie in good agreement. The relationship between GRT and LBD is shown in Fig. 5.13 and Fig. 5.14 shows the relationship between GRT and NRT.

5.9. Freeboard Type-B

Cameron and Martin (47) gives a computer algorithm for the calculation of freeboard for Type-A and Type-B ships. In this thesis a simpler approach was adopted. The subroutine subprogram FREBRD calculates the tabular free-board as well as the minimum freeboard by taking into account the correction for block coefficient, depth and sheer. The procedure is similar to one given by Kupras (48). The tabular freeboard given by the Load Line Regulations (49) was approximated by two polynomials. Tabular freeboards from length BP 100 m to 250 m and length BP 251 m to 365 m was fitted by two sixth order polynomials by the method of Least Squares (50). The method is valid for Type-B ships of length greater than 100 m.

(a) Tabular freeboard (TABFBD) is given by

$$TABFBD = A_0 + A_1x + A_2x^2 + A_3x^3 + A_4x^4 + A_5x^5 + A_6x^6 \text{ in mm.} \qquad \text{Eq. 5.38}$$

where the values of coefficients are as given overleaf.

Fig. 5.13. L x B x D versus Gross Registered Tonnage.

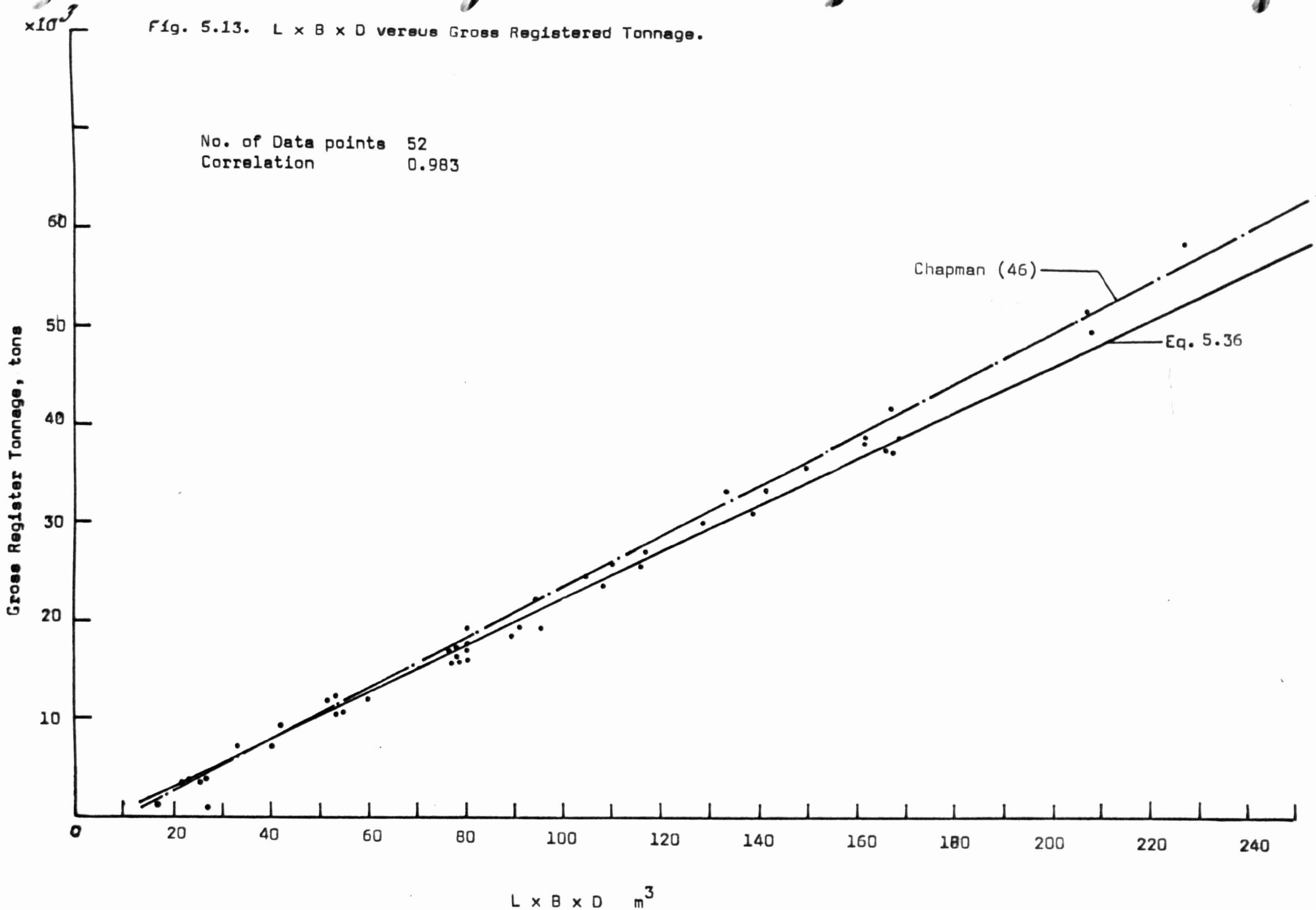
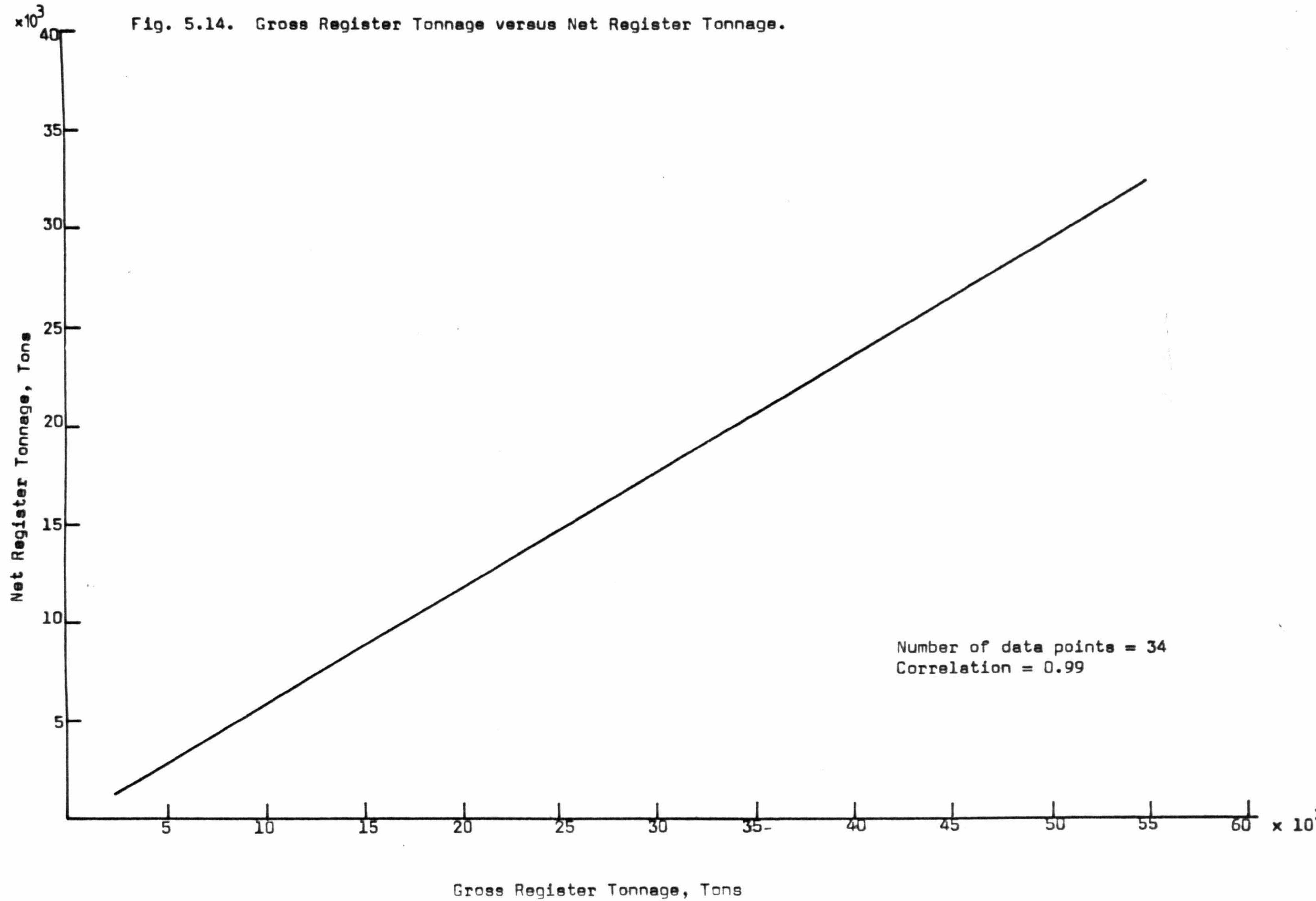


Fig. 5.14. Gross Register Tonnage versus Net Register Tonnage.



No. of data	Length BP metres	A_0	A_1	A_2	A_3	A_4	A_5	A_6	Sum of Diff
151	100 - 250	230.09	-5.925	0.2451	-0.913×10^{-3}	0.796×10^{-6}	0.239×10^{-8}	-0.508×10^{-10}	0.989×10^{6}
115	251 - 365	-15996.63	373.45	-3.367	0.171×10^{-1}	-0.491×10^{-4}	0.744×10^{-7}	0.464×10^{-11}	0.109×10^{4}

(b) Correction for block coefficient

Block coefficient at 0.85 depth = Cb + (1.0 - Cb) x

$$((0.85 \times D - T)/(3.0 \times T)) \qquad \text{Eq. 5.39}$$

for Cb at 0.85D > 0.68

Corrected tabular freeboard TABFBD = TABFBD (Eq. 5.38)

$$\times \frac{(Cb_{0.85D} + 0.68)}{1.36} \text{ mm} \qquad \text{Eq. 5.40}$$

(c) Correction for depth (CORRDE)

for $D \leqslant \frac{LBP}{15}$ correction for depth (CORRDE) = 0 mm

for $D > \frac{LBP}{15}$ correction for depth (CORRDE) = $(D - \frac{LBP}{15}) \times R$ mm Eq. 5.41

where for LBP < 120.0 m, R = LBP/0.48 mm

LBP $\geqslant$ 120.0 m, R = 250 mm

(d) sheer correction; assuming actual sheer is zero and the effective length of superstructure is 0.3xLBP (48). Standard sheer (SHEERS) is given by,

SHEERS = (200.0 x LBP + 6000)/48.0 mm

Then sheer correction (CORSHR) = $(0.75 - \frac{S}{2.0}) \times$ SHEERS mm Eq. 5.42

where S = 0.3 x LBP

(e) Therefore minimum freeboard (FBCAL) is

FBCAL = TABFBD + depth correction (CORRDE) + sheer correction (CORSHR) mm. Eq. 5.43

FBCAL = FBCAL x 0.001 in m. Eq. 5.44

Containerships attain their dead weight requirements at drafts which are less than those allowed by minimum freeboard rules. A check of actual freeboards with those calculated by the program shows that the available freeboard is more than the minimum freeboard in all cases.

Ship's Name	L(m)	D(m)	T(m)	CB	D-T Actual (m)	Freeboard Minimum* (m)
Tokyo Bay	274.32	24.60	13.03	0.595	11.57	5.14
Nihon	257.60	23.91	11.58	0.576	12.33	7.418
Euroliner	224.96	19.18	10.702	0.550	8.478	6.860
Verranzano	248.04	19.89	11.989	0.594	7.901	4.183
Maersk Ship	194.50	18.70	11.190	0.530	7.510	4.180

* By Program

CHAPTER 6

LIGHTSHIP WEIGHT AND CENTRE OF GRAVITY ESTIMATES

6.0 INTRODUCTION

The light ship weight is composed of

(a) steel weight
(b) outfit weight
(c) machinery weight
(d) guide weight
(e) margin on light ship weight.

The following subsections deal with methods of estimating each of these weights. Though many estimating equations have been suggested in the past for estimating each of the above weight groups, they are not consistent with actual data and with each other.

This is mainly due to the fact that many of these empirical relationships were established when there were very few purpose built or newly built container ships. The empirical relationships were verified with general cargo ships which were converted into container ships, resulting in higher lightship weight.

Also because of technological advance the weight of containerships today are much lighter and structurally stronger than their predecessors.

The second reason for the formulae not being consistent with each other is due to the grouping of items in each of the major categories of steel, outfit and machinery. Often the range of ship size over which the estimating equations are valid differ and therefore are not comparable with each other. In the following subsections the weights estimated by different formulae suggested in past studies, are compared with the one adopted in the algorithm.

A family of ships of size 600 TEU to 3000 TEU and speed 18 knots to 27 knots and some other containerships for which weight data were available are compared with the one adopted in the program and the error indicated.

The literature search for estimating the centre of gravity of steel, outfit, machinery and guide weight was less satisfactory. So the latest available formulation is adopted, validated with some ships data.

6.1. STEEL WEIGHT (WS)

The steel weight is obviously the most significant percentage of the total light ship weight, and as such, it is essential that a good and reliable weight be estimated. Additionally, the construction cost of the ship is also related to the steel weight.

There were many methods available for calculating the net steel weight. Most of the methods or formulae are derived by application of regression analysis on existing ship data and indices allotted to the various dimensions i.e. Length (L), Breadth (B), Depth (D), draft (T) and block coefficient (Cb). These indices vary widely depending on the influence of each of the dimensions. Moreover in many cases the influencing parameters appear to have little physical significance.

The various methods suggested in the literature specifically for calculating steel weights of containerships are mentioned below, together with their comparative evaluation with some actual ship data. A summary of the various equations are shown in Table 6.1.

METHOD 1: The first method was suggested by Benford (51) in 1965 and was modified and adopted by Miller (52) in 1970 as a part of containership design model. Miller verified that the steel weight of a containership is very close to the equivalent steel weight of a conventional cargo ship.

METHOD 2: The first method used by Miller was subsequently modified in another study by Marad (53) 1973 and also used by Hancock (54) 1972 in his containership study. The first term 340 in the equation (see Table 6.1) was updated to 380 in both the studies, reflecting a higher steel weight for a containership compared to general cargo ships for which it was originally developed.

METHOD 3: The third formulation was used in a containership study by Chryssostomidis (37) 1968, and was developed at a time when the first generation of containerships were just being built. It was subsequently used in another container ship

TABLE 6.1. Summary of steel weight equations.

Method Ship type	Equation: Dimensions in feet, Weight in long tons	Equation: Dimensions in metres, Weight in tonnes	Ref.	Yr.
1	$WS1 = 340 \times (\frac{CN}{1000})^{0.9} \times (0.675 + \frac{CB}{2}) \times (0.00585 \times (\frac{L}{D} - 8.3)^{1.8} + 0.939)$	$WS1 = 8407(\frac{CN}{1000})^{0.9} \times (0.675 + \frac{CB}{2}) \times (0.00585 \times (\frac{L}{D} - 8.3)^{1.8} + 0.939)$	51*(1) 52	65 70
2	$WS2 = WS1 \times 380/340$	$WS2 = WS1 \times 9396/8407$	53 54	73 72
3	$WS3 = 2.107 \times (\frac{L\times(B+D)\times K9}{100})^{1.19}$ where $K9 = 0.986$.	$WS3 = 35.558(\frac{L\times(B+D)}{100})^{1.19}$	37 40	68 74
4	$FSTWT1 = 7 \times 10^{-4} L^{1.76} B^{0.712} D^{0.374}$ $DHWT1 = 129.63 \times 10^{-4} \times CN$ $CN = L \times B \times D/100.$	$FSTWT1 = 205.86 \times 10^{-4} L^{1.76} B^{0.712} D^{0.374}$ $DHWT1 = 4555 \times 10^{-4} \times CN$ $WS4 = FSTWT1 + DHWT1$ $CN = L \times B \times D/100.$	46 39 55	69 71 74
5		$FSTWT2 = VU \times C1 \times C2 \times C3 \times C4 \times C5 \times C6 \times C7$	56	72
		$DHWT2 = DHWT1$	46	69
		$WS5 = FSTWT2 + DHWT1$		
6		$WS6 = FSWT2 + DHWT3$		
		$WTFCLS = 0.014 \times L \times B$ $DKHWT = 160 + 0.00874 \times L \times B$ $DHWT3 = WTFCLS + DKHWT$	48	75
7		$WS7 = FSTWT1 + DHWT3$		
8		$WS8 = WS'(1 + 0.5(CBD-0.70))$ $WS' = K \times E^{1.36}$	35	77
9	$WS9 = 681.82 + 227.27 \times (\frac{LBD}{100}) \times 10^{-3}$ (based on standard freighters) equation estimated from graph	$WS9 = 6\ 93 + 0.08154 \times L \times B \times D$	58	62
10		WS10 = (See main text)	59	70

NOTE (1) Benford had another term in the equation $(1 + 0.36 \times \frac{L_s}{L_{BP}})$ where L_s = length of the superstructure.

(2) $CN = L \times B \times D/100.$

study by Fortson (40) in 1974.

<u>METHOD 4</u>: The fourth formulation was the first steel weight estimating equation to be proposed, specifically for containerships. It was developed by Chapman (46) in 1969 and has been used subsequently in other containership studies, e.g. Erichsen (39) 1971 who validated it with eleven ships with known steel weight and later on by Swift (55) in 1974 who further validated it with 7 ships with known steel weight. The formula is applicable for ships of size from 800 Teu to 3500 Teu and speeds between 20 to 35 knots. The net steel weight is subdivided into hull steel weight or flush steel weight (FSTWT1) and deck house weight (DHWT1). Later in the section it is shown that this formula may be used for currently built ships too, and is adopted in the parametric study.

<u>METHOD 5</u>: This method was proposed by Schneekluth (56) 1972 for calculating the hull steel weight (FSWT2). The method developed was verified with actual steel weight of ships built during 1967-1971. It was found for containerships that the steel weight is 2-10% higher than the corresponding general cargo ships.

The hull steel weight is given by

$$FSTWT2 = VU \times C_1 \times C_2 \times C_3 \times C_4 \times C_5 \times C_6 \times C_7$$

where $C_1 = 0.103\ (1 + 17(L-110)^2/10^6) \quad (t/m^3)$

where C_1 varies from $0.103\ t/m^3$ for LBP = 110 m to $0.16\ t/m^3$ for LBP = 290 m.

$$C_2 = (1.0 + 0.033\ (L/D - 12))$$

$$C_3 = (1.0 + 0.06(n - \frac{D}{4(m)})),$$ where n = number of decks

$$C_4 = (1.0 + 0.04(L/B - 6.5))$$

$$C_5 = (1.0 + 0.2(T/D - 0.85))$$

$$C_6 = (0.96 + 1.2(0.85 - CBD)^2)$$

$$C_7 = (1.0 + 0.75 \times CBD \times (C_{[illegible]} - 0.98))$$

where CBD = block coefficient of T = D and estimated as

$$CBD = Cb + (1 - Cb)(D-T)/3T$$

$$VU = L \times B \times D \times CBD \times 1.02 \quad (m^3)$$

Other corrections for differences in mode of construction, material or ship type are given in (56). This equation was used to verify the flush steel weight calculated by Method 4. To calculate the steelweight it was assumed deckhouse weight is equal to deckhouse weight given by Method 4.

METHOD 6:

Nowacki (48) 1975 proposed an equation to determine the deckhouse weight (DHWT3), this was added to the flush steel weight (FSTWT2) of Method 5 to see if the accuracy of Method 5 was improved or not.

METHOD 7:

In this method the flush steel weight (FSWT1) was added to the deckhouse weight (DHWT3) estimated by Nowacki to see if the accuracy of Method 4 was improved or not.

METHOD 8:

This method was also used in the computer algorithm as an alternative to Chapman's, Method 4. It is based on a method developed by Watson & Gilfillan (35) 1977. The steel weight is estimated as follows:

The net steel weight (WS8) is assumed to be directly related to the hull numeral E. This numeral was chosen because it was applicable to a wide range of ship types. The value of E is given by

$$E = L \times (B + T) + 0.85 \times L \times (D - T) + 0.85 \sum l_1 h_1 + 0.75 \sum l_2 h_2 \quad (m^2)$$

where l_1, h_1 are length and height of full width erections and l_2, h_2 are the length and height of houses.

The value of the third term and the fourth term in the equation was assumed to vary between 200-300 m^2 in the algorithm. Since E attaches no importance to fullness, the steel weight (WS) was related to a standard block coefficient of 0.70 at 0.8 of the depth. Where

$$WS' = K \times E^{1.36} \quad \text{(tonnes)}$$

where K is the steel weight factor (STEELF) input by the user. The value of K given in (35) was assumed to vary from 0.033

to 0.040 for 6000 < E < 13000 and validated for 3 container ships. In the present thesis the steel weight of 45 containerships (Nos.1 to 32 (1968)(57)) and 32 to 45 collected for this study, (Table 6.2) was used to establish an estimating equation for the value of K.

Four values of K were determined K_{min_i} and K_{max_i}, (i=I,2), corresponding to the two values of E_{min} and E_{max}.

$$E_{min} = L \times (B + T) + 0.85 \times L \times (D - T) + 200 \quad m^2$$

and $$E_{max} = L \times (B + T) + 0.85 \times L \times (D - T) + 300 \quad m^2$$

The values of K_{min_i} and K_{max_i} are given in Table 6.3 corresponding to E_{max} and E_{min} respectively. The minimum E value was 5000 and maximum 16800. KMIN1 and KMAX1 are steel factors w.r.t. actual steel weight and KMIN2 and KMAX2 are the steelweight factors w.r.t. weight determined by Method 4 and also used in the algorithm. The values of KMAX2 and KMAX1 are plotted against E in Fig. 6.1. With increase in speed for a particular Teu, KMAX1 tends to decrease from a maximum value to a minimum value whereas opposite seems to be the case for KMAX2, with increase in speed for a particular Teu, the value increases from a low value to a higher value. This is only for data points 1-32 which are a bit dated. And it is apparent from Fig. 6.2, which shows the L x (B + D)/100 plotted against actual ship data (1-45) and the line of representative containership data from (27) 1980 that the actual steel weight at lower speeds for a particular Teu are overestimated for data points (1-32). The trend is obviously increasing value of K with increase in E and speeds. An analysis of weights for (1-45) by Method 4 gave the following approximate equations of K

$$\begin{aligned} K &= mE' - C \\ &= (n \times Teu + b) \times E' - C' \\ &= (1267 \times 10^{-10} \times Teu + 6067 \times 10^{-7})E' - 0.00842 \end{aligned}$$

where $E' = L \times (B + D)/100 \quad m^2$

There was lack of data to establish a better equation. E versus K gave a poorer fit to the data available. K is thus left as an input data by the user. For parametric study Method 4 was used as indicated earlier.

Table 6.2 Principal Particulars and weights of containerships

	L_{bp}	B	D	T	C_b	V	RPM	SHP	NO. Prop.	W_s	W_o	W_m	W_g
1.	147.22	23.77	13.41	9.14	0.631	18.0	115	15100	1	4355	2287	980	549
2.	150.57	23.77	13.41	9.14	0.609	19.0	115	18000	1	4406	2296	1178	544
3.	156.06	23.77	13.41	9.14	0.562	21.0	115	22400	1	4460	2312	1483	530
4.	160.93	23.77	13.41	9.14	0.516	23.0	115	28200	1	4490	2327	1889	520
5.	159.41	27.43	15.85	9.14	0.652	18.0	110	18000	1	5970	2435	1178	679
6.	162.15	27.43	15.85	9.14	0.628	19.0	110	20600	1	6001	2445	1356	675
7.	166.72	27.43	15.85	9.14	0.581	21.0	110	26100	1	6021	2461	1747	668
8.	171.60	27.43	15.85	9.14	0.536	23.0	110	31600	1	6061	2477	2113	650
9.	179.20	27.43	15.85	9.14	0.683	18.0	110	18300	1	6814	2513	1194	959
10.	180.44	27.43	15.85	9.14	0.657	19.0	110	21100	1	6775	2517	1392	955
11.	184.41	27.43	15.85	9.14	0.610	21.0	110	27000	1	6764	2530	1803	945
12.	188.98	27.43	15.85	9.14	0.564	23.0	110	33500	1	6773	2546	2260	927
13.	193.55	27.43	15.85	9.14	0.521	25.0	110	41000	1	6783	2561	1600	924
14.	196.90	30.48	15.85	9.14	0.703	18.0	110	21161	1	8239	2668	1392	1198
15.	198.12	30.48	15.85	9.14	0.679	19.0	110	24083	1	8195	2672	1600	1194
16.	201.48	30.48	15.85	9.14	0.632	21.0	110	30899	1	8145	2684	2077	1186
17.	205.43	30.48	15.85	9.14	0.588	23.0	110	36544	1	8125	2699	1483	1176
18.	210.00	30.48	15.85	9.14	0.546	25.0	110	48299	1	8129	2717	1859	1162
19.	215.19	30.48	15.85	9.14	0.504	27.0	110	31027	2	8149	2737	2154	1146
20.	235.61	35.05	18.29	10.67	0.744	18.0	100	31250	2	12445	3032	1910	1995
21.	237.14	35.05	18.29	10.67	0.721	19.0	100	32202	1	12391	3038	2159	1989
22.	239.58	35.05	18.29	10.67	0.676	21.0	100	41237	1	12250	3048	2794	1981
23.	242.32	35.05	18.29	10.67	0.632	23.0	100	49228	1	12128	3059	1905	1973
24.	246.89	35.05	18.29	10.67	0.592	25.0	100	33386	2	12112	3079	2245	1958
25.	252.99	35.05	18.29	10.67	0.556	27.0	100	40603	2	12186	3108	2479	1936
26.	264.87	37.80	21.34	11.58	0.766	18.0	100	35000	1	16063	3335	2215	3152
27.	267.31	37.80	21.34	11.58	0.747	19.0	100	38508	1	16070	3340	2600	3145
28.	269.75	37.80	21.34	11.58	0.704	21.0	100	49033	1	15889	3357	1899	3137
29.	273.71	37.80	21.34	11.58	0.665	23.0	100	32218	2	15823	3375	2194	3123
30.	278.59	37.80	21.34	11.58	0.626	25.0	100	41028	2	15799	3399	2499	3104
31.	285.91	37.80	21.34	11.58	0.590	27.0	100	48771	2	15926	3437	2718	3082
32.	177.10	23.80	16.60	8.20	0.628	20.1	97	17500	1	4629	1495	826	268
33.	212.44	30.48	16.46	9.14	0.599	22.0	140	32000	1	8718	2699	1547	963
34.	206.30	28.90	16.50	9.50	0.587	22.8	110	32000	1	8761	2059	1158	357
35.	234.40	27.40	16.20	8.80	0.631	20.7	106	28500	1	10058	2050	1035	451
36.	215.12	30.63	17.37	8.84	0.558	27.0	135	60000	1	10446	2230	1941	376
37.	185.00	32.20	18.70	11.00	0.500	25.0	110	42000	1	6650	2150	-	-
38.	215.00	32.20	18.70	11.00	0.521	27.2	110	60000	1	8700	2800	-	-
39.	250.00	32.20	19.50	11.00	0.538	26.8	110	60000	1	11500	3300	-	-
40.	259.08	32.00	18.29	9.14	0.558	27.0	110	60000	1	14427	3556	3352	-
41.	268.38	32.16	19.51	9.14	0.539	31.0	135	60800	2	17350	1990	3950	-
42.	248.20	32.26	24.15	12.00	0.652	21.0	126	51360	2	14800	9473		-
43.	271.00	32.20	24.00	10.96	0.650	24.0	135	59138	2	16385	2864	4280	1031
44.	135.00	22.00	13.80	8.45	0.615	18.0	140	24943	1	3156	997	543	255
45.	234.39	27.43	16.15	10.06	0.640	23.0	110	-	1	10058	2546	1050	93

Dimensions in metres and weights in tonnes

ship no. 1-31 are not actual built ships.

Table 6.3 Calculation of KMIN and KMAX

	Steel Chapman	wt. Actual	E_{MIN}	E_{MAX}	K_{MIN1}	K_{MAX1}	K_{MIN2}	K_{MAX2}
1	3608.8	4355.0	5579.3	5679.3	0.0350	0.0358	0.0290	0.0297
2	3748.7	4406.0	5701.8	5801.8	0.0347	0.0356	0.0295	0.0303
3	3986.3	4460.0	5902.4	6002.4	0.0344	0.0351	0.0307	0.0314
4	4202.3	4490.0	6080.3	6180.3	0.0340	0.0348	0.0318	0.0326
5	4916.4	5970.0	6938.8	7038.8	0.0350	0.0357	0.0288	0.0294
6	5061.9	6001.0	7054.6	7154.6	0.0348	0.0354	0.0293	0.0299
7	5308.6	6021.0	7247.8	7347.8	0.0344	0.0350	0.0303	0.0309
8	5577.6	6061.0	7454.1	7554.1	0.0340	0.0346	0.0313	0.0319
9	6009.0	6814.0	7776.3	7876.3	0.0338	0.0344	0.0298	0.0304
10	6079.3	6775.0	7827.8	7927.8	0.0337	0.0343	0.0303	0.0308
11	6310.6	6764.0	7995.7	8095.7	0.0334	0.0340	0.0312	0.0317
12	6581.4	6773.0	8188.8	8288.8	0.0331	0.0336	0.0321	0.0327
13	6857.0	6783.0	8382.0	8482.0	0.0327	0.0333	0.0331	0.0336
14	7625.7	8239.0	9124.2	9224.2	0.0327	0.0332	0.0303	0.0307
15	7707.0	8195.0	9179.5	9279.5	0.0326	0.0331	0.0307	0.0311
16	7932.8	8145.0	9331.8	9431.8	0.0324	0.0328	0.0315	0.0320
17	8201.8	8125.0	9510.8	9610.8	0.0321	0.0325	0.0324	0.0328
18	8517.9	8129.0	9717.9	9817.9	0.0318	0.0322	0.0333	0.0338
19	8883.0	8149.0	9953.2	10053.2	0.0314	0.0319	0.0343	0.0348
20	12183.2	12445.0	12498.1	12598.1	0.0318	0.0321	0.0311	0.0315
21	12319.4	12391.0	12578.0	12678.0	0.0317	0.0320	0.0315	0.0319
22	12537.9	12250.0	12705.4	12805.4	0.0315	0.0319	0.0323	0.0326
23	12875.2	12128.0	12848.4	12948.4	0.0313	0.0317	0.0330	0.0334
24	13202.3	12112.0	13086.9	13186.9	0.0311	0.0314	0.0339	0.0342
25	13768.0	12186.0	13405.3	13505.3	0.0308	0.0311	0.0348	0.0351
26	16763.9	16063.0	15476.6	15576.6	0.0304	0.0306	0.0317	0.0320
27	17029.8	16070.0	15617.4	15717.4	0.0302	0.0305	0.0320	0.0323
28	17297.5	15889.0	15758.1	15858.1	0.0301	0.0303	0.0327	0.0330
29	17735.7	15823.0	15986.5	16086.5	0.0298	0.0301	0.0334	0.0337
30	18282.1	15799.0	16268.0	16368.0	0.0296	0.0298	0.0342	0.0345
31	19115.0	15926.0	16690.1	16790.1	0.0292	0.0295	0.0351	0.0354
32	5410.6	4629.0	7131.7	7231.7	0.0261	0.0266	0.0305	0.0310
33	8823.6	8718.0	9938.7	10038.7	0.0322	0.0326	0.0326	0.0330
34	8079.2	8761.0	9349.4	9449.4	0.0354	0.0359	0.0327	0.0331
35	9609.4	10058.0	10159.7	10259.7	0.0355	0.0359	0.0339	0.0343
36	9249.3	10446.0	10250.5	10350.5	0.0373	0.0378	0.0330	0.0334
37	7636.9	6650.0	9402.8	9502.8	0.0278	0.0282	0.0320	0.0324
38	9877.8	8700.0	10895.2	10995.2	0.0296	0.0299	0.0336	0.0340
39	13018.0	11500.0	12806.3	12906.8	0.0310	0.0314	0.0351	0.0355
40	13424.2	14427.0	12873.5	12973.5	0.0378	0.0382	0.0351	0.0355
41	14696.6	17350.0	13649.7	13749.7	0.0419	0.0424	0.0355	0.0359
42	14057.4	14800.0	13748.6	13848.6	0.0341	0.0345	0.0324	0.0327
43	16278.6	16385.0	14900.1	15000.1	0.0336	0.0339	0.0334	0.0337
44	2973.3	3156.0	4924.7	5024.7	0.0299	0.0307	0.0282	0.0289
45	9604.4	10058.0	10200.6	10300.6	0.0355	0.0360	0.0339	0.0344

Weight in tonnes, E_{min} and E_{max} in m^2 .

Fig. 6.1. E VERSUS STEELFACTOR K(STEELF)

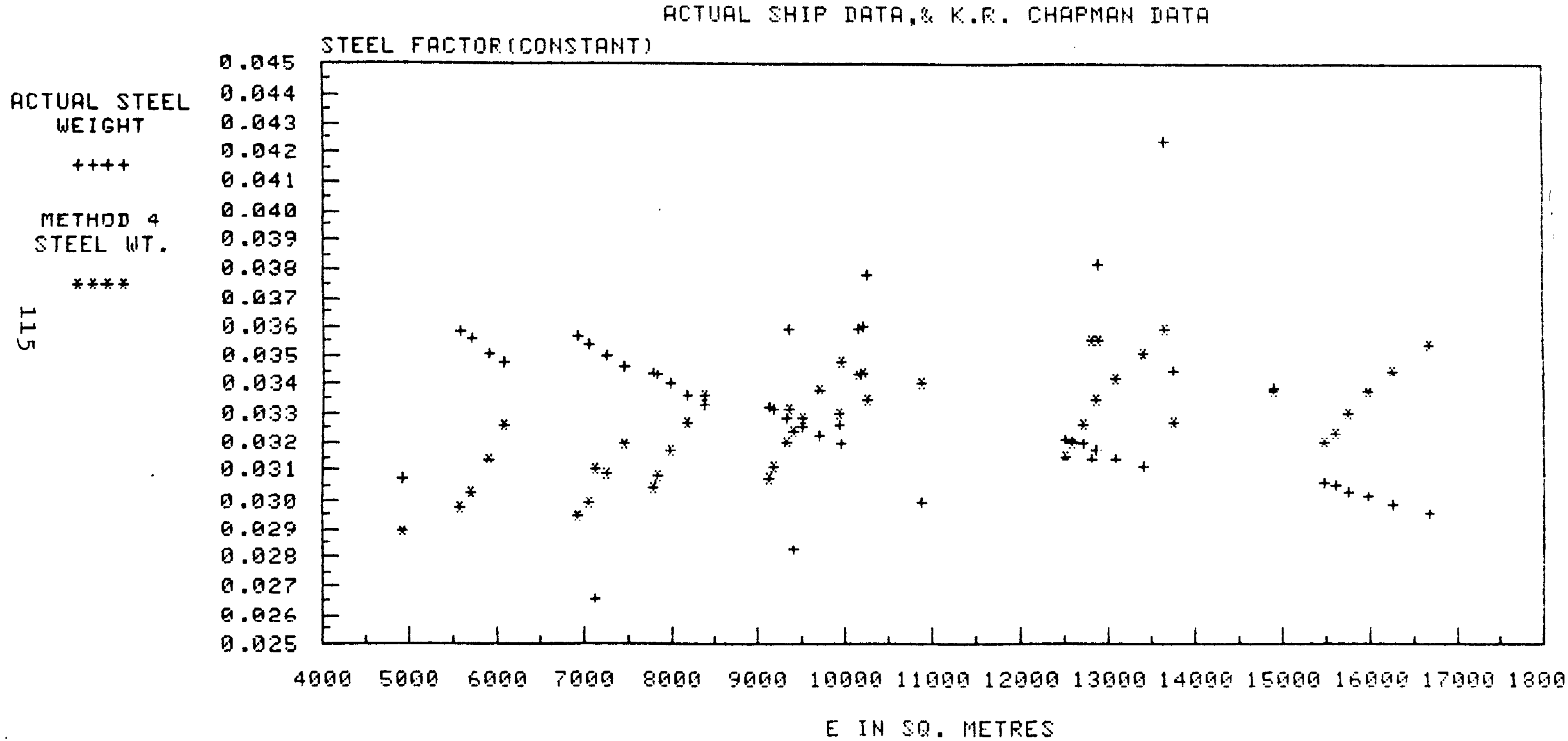
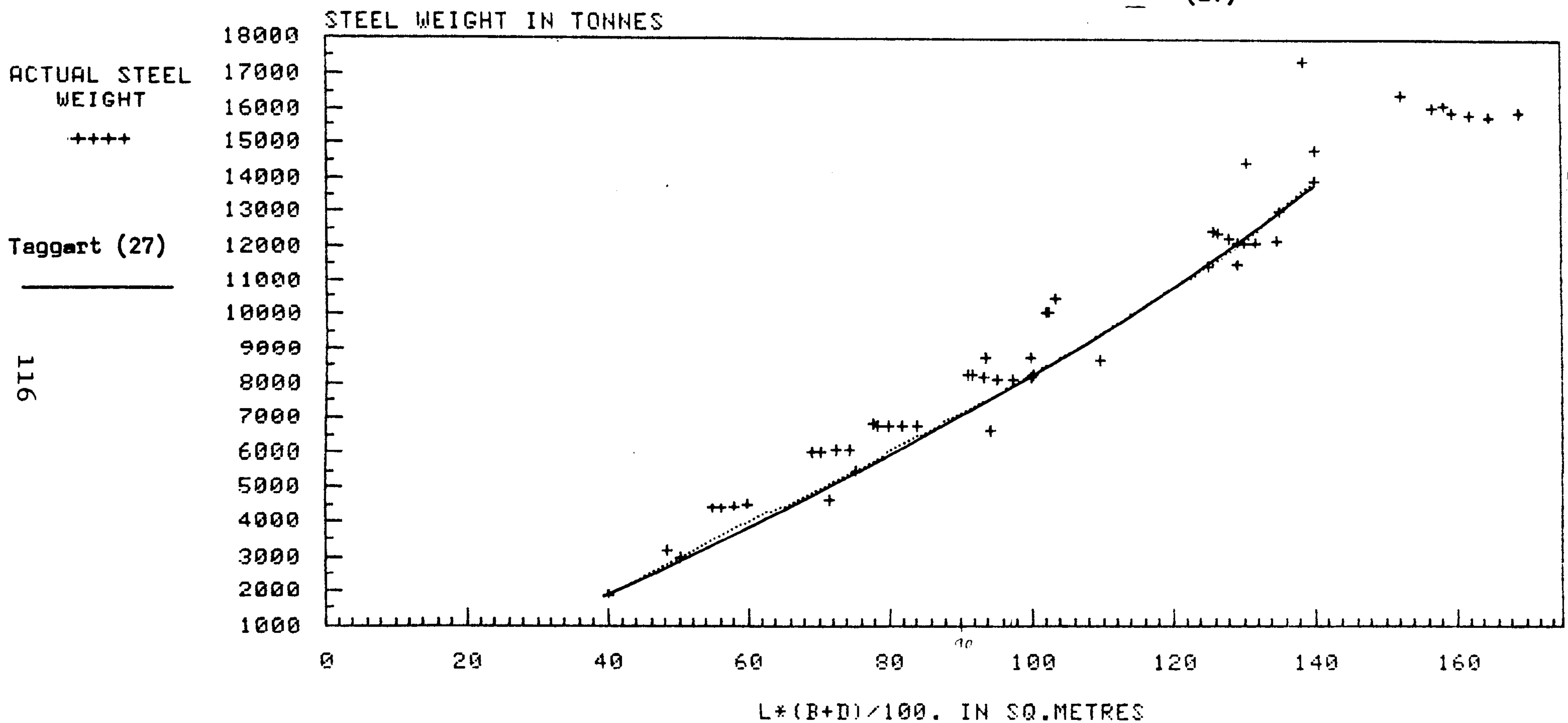


Fig.6.2 ACTUAL STEEL WEIGHT VS SNAME'80 PLOT

REF.SHIP DG.& CONST. -TAGGART (27)



The WS' is assumed to be at a standard fullness of 0.70 measured at 0.8D. Thus correction for steelweight for variation in Cb from 0.70 is made using the following two relationships

$$WS8 = WS' \, (1.0 + 0.5 \, (Cbd - 0.70)) \text{ (tonnes)}$$

$$\text{where } Cbd = Cb + (1.0 - Cb)(0.8 \times D - T)/3T$$

<u>METHOD 9</u>: This method is dated but mentioned here for completeness. It was used in the containership study by Scott (58) 1962, and was derived from standard freighters, taking into account the modifications, and reflecting the containerships built in that time, i.e. mostly converted ships.

<u>METHOD 10</u>: This method was developed by Carstens(59) 1970, and it was found that the unit area values of bulk carrier and container ships are in fact just about the same, with allowance for T/D corrections, since containerships have lower draft. The method is too detailed to apply for a study such as this, but is a good one-off type estimating method. No guidance is however given to adjust for use of higher tensile steel and its effect on steelweight. Further the method is applicable to ships of $L \times B \times D < 100{,}000 \text{ m}^3$ i.e. ships of Encounter Bay size 1500 Teu.

<u>Comparative Evaluation of Methods 1-8</u>

Steel estimating methods can be summarised broadly into four categories

(a) A method based on volume or cubic number
(b) A method based on area or surface numeral
(c) A method based on simple beam analogy
(d) A method based on classification rules.

In design studies, such as this, methods (c) and (d) are too detailed to be of much use. So basically methods (a) and (b) were preferred in earlier studies. However it has been found (35) that the steel weight is partly volume dependent, and partly dependent on section modulus. However estimating the factors suggested in (35) is beyond the scope of this study, due to the scarcity of data on actual steel weight.

The various methods can be categorised as follows:-

Method	Type	Function Type
1	(a)	f(LxBxD) + corrections (Cb,L/D, super-structure)
2	(a)	f(LxBxD) + corrections (" " ")
3	(b)	$f(L \times (B+D))^x$
4	(a)	$f(L^x x B^y x D^z)$
5	(a)	f(L,B,D,T,Cb) + corrections (L/D, L/B, T/D, Cb, C)
6	(a)	f(L,B,D,T,Cb) + " (" " " " ")
7	(a)	$f(L^x x B^y x D^z)$
8	(b)	f(L,B,D,T,Cb)
9	(a)	f(LxBxD)
10	a,b,c	

Method 8 and Method4 were adopted in this thesis. In Method 8, the designer inputs the steel weight factor (STEELF) to determine the steel weight whereas in Method 4, the steel weight is calculated automatically, The choice of method is given by using the controlling parameter ISTEEL = 1 for Method 8, and ISTEEL = 2 for Method 4.

The steel weights calculated by various methods are indicated in Table 6.4, the ratio of the difference between actual steel weight and the estimated weights divided by actual steel weight is shown in Table 6.5. The flush steel weight (FSTWT1) was validated with FSTWT2, as shown in Table 6.4, and found to be nearly 20% higher than FSTWT2 for data (1-32) but in closer agreement to data (32-45).

An analysis of different methods shows that Methods 1 and 2 underestimate the steel weight whereas Methods 3-7 overestimated the steel weight. As Table 6.6 is based on analysis of Table 6.5 indicates Method 4 has a mean percentage error of only 0.5% from actual steel weight, and standard deviation of 10%, hence both are within tolerable limits. Therefore Method 4 was used in the algorithm, with Method 8 left as an option for the user, since an estimating equation could not be established for the steel weight factor.

Table 6.4 Steel weight calculated by different methods

	Actual Steel weight	WS_1	WS_2	WS_3	WS_4	WS_5	WS_6	WS_7	$FSTWT_1$	$FSTWT_2'$	$DMWT_1$	$DHWT_2$	$DHWT_3$
1.	4355	4102	4585	4101	3606	2913	2939	3632	3393	2699	213	213	239
2.	4406	4165	4655	4213	3748	2977	3000	3771	3530	2758	218	218	241
3.	4460	4265	4744	4396	3986	3055	3073	4004	3759	2828	226	226	244
4.	4490	4304	4810	4560	4202	3111	3125	4215	3968	2878	233	233	247
5.	5970	5778	6458	5402	4916	4130	4073	4860	4660	3814	315	315	259
6.	6001	5815	6499	5513	5061	4183	4123	5001	4740	3862	321	321	261
7.	6021	5854	6543	5698	5308	4252	4186	5242	4978	3922	330	330	264
8.	6061	5907	6602	5897	5577	4343	4270	5504	5237	4003	339	339	267
9.	6814	6700	7488	6210	6009	5263	5180	5925	5654	4908	354	354	271
10.	6775	6668	7452	6261	6079	5230	5145	5994	5721	4873	357	357	272
11.	6764	6686	7472	6425	6310	5274	5184	6220	5945	4909	365	365	275
12.	6773	6730	7521	6615	6581	5358	5262	6485	6207	4984	374	374	277
13.	6783	6781	7578	6806	6857	5454	5351	6754	6473	5071	383	383	280
14.	8239	8364	9348	7533	7625	7009	6872	7488	7192	6575	433	433	296
15.	8195	8333	9314	7588	7707	6971	6832	7568	7271	6535	436	436	297
16.	8145	8323	9302	7742	7932	6974	6830	7789	7489	6530	443	443	299
17.	8125	8352	9335	7922	8201	7039	6889	8052	7749	6587	452	452	302
18.	8129	8421	9412	8133	8517	7162	7005	8361	8055	6700	462	462	305
19.	8149	8520	9522	8372	8883	7332	7168	8718	8409	6859	473	473	309
20.	12445	13134	14679	11029	12183	12581	12241	11843	11495	11893	688	688	347
21.	12391	13104	14645	11114	12319	12546	12203	11976	11627	11854	692	692	349
22.	12250	12999	14528	11250	12357	12416	12067	12189	11838	11716	699	699	351
23.	12128	12917	14436	11403	12785	12342	11988	12430	12077	11634	707	707	353
24.	12112	12990	14518	11660	13202	12539	12175	12838	12481	11818	720	720	356
25.	12186	13199	14751	12004	13768	12975	12597	13390	13029	12236	738	738	362
26.	16063	17852	19952	14334	16763	18874	18288	16178	15790	17900	973	973	387
27.	16070	17905	20011	14491	17029	19046	18453	16437	16047	18063	982	982	389
28.	15889	17749	19837	14649	17297	18877	18278	16698	16306	17886	991	991	392
29.	15823	17753	19841	14905	17735	19057	18446	17125	16730	18051	1005	1005	395
30.	15799	17830	19927	15222	18282	19417	18793	17658	17258	18394	1023	1023	399
31.	15926	18142	20276	15699	19115	20300	19655	18470	18064	19249	1050	1050	405
32.	4629	5827	6513	5641	5410	4604	4541	5347	5091	4285	318	318	255
33.	8718	8940	9992	8375	8823	7774	7595	8645	8338	7288	485	485	307
34.	8761	8155	9114	7773	8079	6917	6765	7926	7631	6469	448	448	295
35.	10058	9438	10548	8623	9609	9258	9091	9441	9135	8785	473	473	306
36.	10446	9170	10249	8729	9249	8043	7831	9037	8727	7521	521	521	309
37.	6650	8162	9122	7822	7636	5861	5649	7425	7129	5354	507	507	295
38.	8700	9786	10938	9354	9877	8118	7845	9605	9288	7528	589	589	317
39.	11500	12234	13675	11405	13018	11935	11565	12646	12505	11202	715	715	345
40.	14427	12601	14084	11513	13424	13259	12917	13082	12733	12569	691	691	348
41.	17350	13491	15078	12399	14696	14854	14444	14285	13929	14087	767	767	356
42.	14800	14608	16327	12542	14057	13574	13035	13518	13176	12693	881	881	342
43.	16385	16041	17928	13863	16278	17114	16518	15683	15324	16160	954	954	358
44.	3156	3519	3933	3537	2973	2385	2426	3014	2786	2199	187	187	227
45.	10058	9481	10596	8618	9604	9202	9035	9437	9131	8729	473	473	306

All weights in tonnes.

Table 6.5 Difference from actual steel weight expressed as a fraction of actual steel weight.

	WS_I	WS_2	WS_3	WS_4	WS_5	WS_6	WS_7
I	0.058	-0.053	0.058	0.I72	0.33I	0.325	0.I66
2	0.055	-0.057	0.044	0.I49	0.324	0.3I9	0.I44
3	0.048	-0.064	0.0I4	0.I06	0.3I5	0.3II	0.I02
4	0.04I	-0.07I	-0.0I6	0.064	0.307	0.304	0.06I
5	0.032	-0.082	0.095	0.I76	0.308	0.3I8	0.I86
6	0.03I	-0.083	0.08I	0.I56	0.303	0.3I3	0.I66
7	0.028	-0.087	0.054	0.II8	0.294	0.305	0.I29
8	0.025	-0.089	0.027	0.080	0.283	0.295	0.092
9	0.0I7	-0.099	0.089	0.II8	0.228	0.240	0.I30
I0	0.0I6	-0.I00	0.076	0.I03	0.228	0.240	0.II5
II	0.0I2	-0.I05	0.050	0.067	0.220	0.234	0.080
I2	0.006	-0.III	0.023	0.028	0.209	0.223	0.043
I3	0.000	-0.II7	-0.003	-0.0II	0.I96	0.2II	0.004
I4	-0.0I5	-0.I35	0.086	0.074	0.I49	0.I66	0.09I
I5	-0.0I7	-0.I37	0.074	0.060	0.I49	0.I66	0.076
I6	-0.022	-0.I42	0.049	0.026	0.I44	0.I6I	0.044
I7	-0.028	-0.I49	0.025	-0.009	0.I34	0.I52	0.009
I8	-0.036	-0.I58	-0.00I	-0.048	0.II9	0.I38	-0.029
I9	-0.046	-0.I69	-0.027	-0.090	0.I00	0.I20	-0.070
20	-0.055	-0.I80	0.II4	0.02I	-0.0II	0.0I6	0.048
2I	-0.058	-0.I82	0.I03	0.006	-0.0I3	0.0I5	0.033
22	-0.06I	-0.I86	0.082	-0.024	-0.0I4	0.0I5	0.005
23	-0.065	-0.I90	0.060	-0.054	-0.0I8	0.0I2	-0.025
24	-0.072	-0.I99	0.037	-0.090	-0.035	-0.005	-0.060
25	-0.083	-0.2II	0.0I5	-0.I30	-0.065	-0.034	-0.099
26	-0.III	-0.242	0.I08	-0.044	-0.I75	-0.I39	-0.007
27	-0.II4	-0.245	0.098	-0.060	-0.I85	-0.I48	-0.023
28	-0.II7	-0.248	0.078	-0.089	-0.I88	-0.I50	-0.05I
29	-0.I22	-0.254	0.058	-0.I2I	-0.204	-0.I66	-0.082
30	-0.I29	-0.26I	0.036	-0.I57	-0.229	-0.I90	-0.II8
3I	-0.I39	-0.273	0.0I4	-0.200	-0.275	-0.234	-0.I60
32	-0.259	-0.407	-0.2I9	-0.I69	0.005	0.0I9	-0.I55
33	-0.025	-0.I46	0.039	-0.0I2	0.I08	0.I29	0.008
34	0.069	-0.040	0.II3	0.078	0.2I0	0.228	0.095
35	0.062	-0.049	0.I43	0.045	0.079	0.096	0.06I
36	0.I22	0.0I9	0.I64	0.II5	0.230	0.250	0.I35
37	-0.227	-0.372	-0.I76	-0.I48	0.II9	0.I50	-0.II7
38	-0.I25	-0.257	-0.075	-0.I35	0.067	0.098	-0.I04
39	-0.064	-0.I89	0.008	-0.I32	-0.038	-0.005	-0.I00
40	0.I27	0.024	0.202	0.070	0.08I	0.I05	0.093
4I							
42							
43	0.02I	-0.094	0.I54	0.006	-0.045	-0.008	0.043
44	-0.II5	-0.246	-0.I2I	0.058	0.244	0.23I	0.045
45							

TABLE 6.6. Analysis of steel wt. estimation methods.

Method	Mean of Percentage Difference	Standard Deviation	Variance
1 (WS1)	-5.43	1.060	1.097
2 (WS2)	-14.89	9.566	89.329
3 (WS3)	3.826	8.231	66.144
4 (WS4)	0.412	10.23	102.33
5 (WS5)	11.712	23.195	525.19
6 (WS6)	11.990	16.270	258.42
7 (WS7)	2.390	9.303	84.485

6.2. OUTFIT AND HULL ENGINEERING WEIGHT (WO)

Unlike steel weight, outfit weight determination may be simpler but due to the variety of items included in the outfit it is much more difficult to rationalise. There can be wide variation of the weight of outfit items recorded in two different shipyards because of the differences in accounting procedures, in respect of subcontracted jobs. It may be recorded as material cost or as labour cost. The best procedure at the preliminary design stage , is to ascertain the outfit weight from a basis ship item by item and proportion outfit weight in relation to the square number (L X B).

We consider here the various formulae suggested over the years for container ships, and then indicate the method used in this study. A comparative evaluation of the different methods is then carried out later in the section. The summary of equations used in different methods is shown in Table 6.7.

METHOD 1: The first formulation was given by Miller (52) 1970 and was based on an earlier work of Benford (5) 1965 on break -bulk ships. The assumption was that the container ship weight was less than that of a break bulk ship, and was ascertained by validation with existing data of first generation container ships, (conversion vessels mainly). The wood/outfit and hull engineering (WOHE1) was made a function of cubic number.

METHOD 2: Later in two studies on containership (53) 1973 and (54) 1972 the same formula as in Method 1 was used to estimate the wood/outfit and Hull engineering weight (WOHE2).

METHOD 3: In a study on containership carried out by Chryssostomidis (37) in 1968 a formula specifically for containerships was suggested. Wood/outfit and hull engineering (WOHE3) was made a function of $(L \times B)^{1.6}$.

METHOD 4: The fourth formulation was given by Erichsen (39) 1971 and also used in a later study by Swift (55) 1972. The weight equation was like Method 1, derived from Benford's equation (51) 1965.

TABLE 6.7. Summary of equations for wood/outfit and hull engineering weight.

Method	Ship Type	Dimensions in feet Weight in long tons	Dimensions in metres Weight in tonnes	Ref.	Yr.
1	BB /C	$WOHE1 = -0.71(CN/1000)^2 + 93.5 \times (CN/1000) - 104$	$WOHE1 = -885.39\,(CN/1000)^2 + 3302\,(CN/1000) - 105.66$	51 52	65 70
2	BB /C	WOHE2 = WOHE1	WOHE2 = WOHE1	53 54	71 72
3	C	$WOHE3 = 0.15\left[\frac{(LxB)\times 0.986}{100}\right]^{1.6}$	$WOHE3 = 6.673\,\left(\frac{LxB}{100}\right)^{1.6}$	37 40	68 74
4	GC /C	$WO4 = 8.5 \times (CNC/1000)^{0.825}$ $WHE4 = 53 \times (CNC/1000)^{0.825}$ WOHE4 = WO4 + WHE4	$WO4 = 86.36\,(CNC/1000)^{0.825}$ $WHE4 = 53.85 \times (CNC/1000)^{0.825}$ WOHE4 = WO4 + WHE4	39 55 51	71 72 65
5	A/C		WOHE5 = CO1 x L x B CO1 = 0.32 for container ships	35	77
6	C		WOHE6 = CO6 x L x B CO6 = 0.44 fitted equation	27	80
7	C	$BOFWT = (LxBxD)^{0.425}$ $SOFWT = (LxBxD/10^6)^{0.65}$ $HATWT = (L \times B)^{0.57}$ WOHE7 = BOFWT + SOFWT + HATWT	$BOFWT = 4.62 \times (LxBxD)^{0.425}$ $SOFWT = 10.31 \times (LxBxD/10^6)^{0.65}$ $HATWT = 3.94 \times (L \times B)^{0.57}$ WOHE7 = BOFWT+SOFWT + HATWT	46 61	69 74
8	GC		$WOHE8 = CO8 \times L^{1.3} \times B^{0.8} \times D^{0.3} \times Cb^{0.3}$ CO8 = 0.065	Katsoulis P.S. 35 (discussion)	77
9	A		$WOHE9 = CO8 \times L^{1.3} \times B^{0.8} \times D^{0.3}$ CO8 = 0.065	Katsoulis P.S. 35 (discussion)	77
10	OC C	$WOHE10 = CO10 \times \frac{LxBxD}{100}$ CO10 = REF. (62) '58 $2000 < \frac{LBD}{100} < 150000\ ft^3$		62 58	58 62

Ship Type: BB - Break bulk; C - Container; GC - General cargo; A - All ship type; OC - Ore carrier.

Benford's equation was subdivided into wood/outfit (WO4) weight and Hull engineering (WHE4),

$$WO4 = C_O(CN/1000)^{0.825} \text{ tons, and } WHE4 = CHE(CN/1000)^{0.825} \text{ tons}$$

where CN = L x B x D/100 ft^3.

It was assumed that 23% of weight was for items not belonging to container ships, e.g. booms and fittings, riggings and blocks and refrigerated cargo insulation, and additional weights of hatch covers. Since containerships compared to ordinary dry cargo vessels have higher cubic displacement ($CN/\triangle$) ratio, the cubic number (CN) was replaced by a modified cubic number (CNC). The modified equation is

$$WO4 = 85\ (CNC/1000)^{0.825} \text{ tonnes, } WHE4 = 53\ (CNC/1000)^{0.825} \text{ tonnes}$$

where CNC = 17.66 x CN + 0.442 x $\triangle$ in m^3, $\triangle$ = displacement in tonnes, CN in m^3.

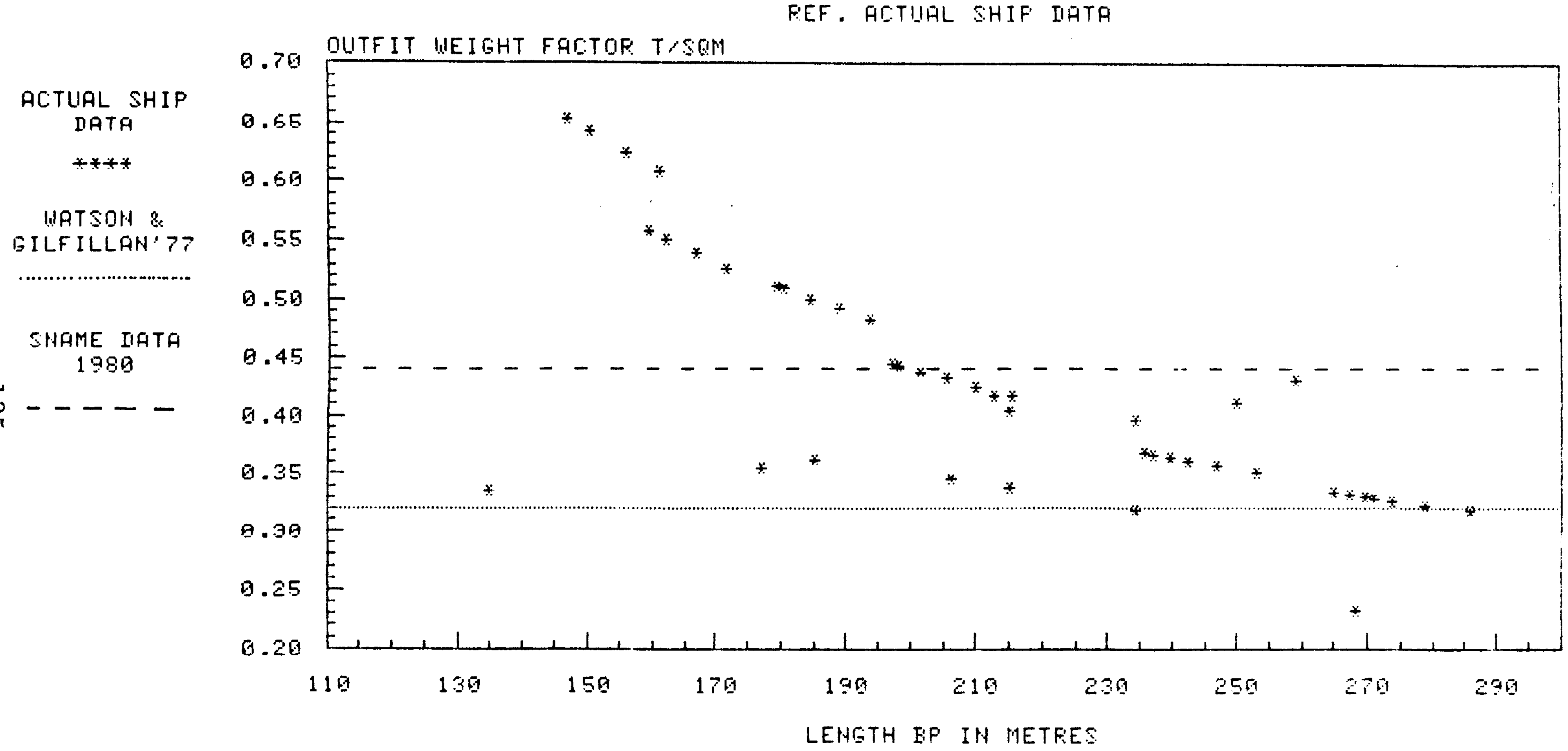
METHOD 5: This method was adopted in the computer program, since it is the latest formulation available and reflects the current practice in container ship outfitting. The method is based on the square number (L x B), and shows that the outfit weight/(L x B), tonnes/m^2, for containership does not increase with increase in length of the ship. It is interesting to note that one of the co-authors in (60) 1962 gave the following equation for general cargo ships

$$WOHE = 0.36 \times (L \times B) \quad \text{tonnes}$$

This value of 0.36 when compared with 0.39 value given in (35) for general cargo ship corresponds to a 10% increase in outfit weight since 1962. And the outfit weight of containership does not vary with ship size as shown in Fig. 6.3, where outfit weight (WOHE5)/(L x B) plots as a horizontal line against length L. Similar conclusion is reached from another source (27) 1980 in Method 6.

METHOD 6: This method is also based on square number (L x B) and is given by a straight line, which was fitted to the curve given in (27) 1980.

Fig. 6.3. OUTFIT WEIGHT /(LENGTH*BREADTH)



$$WOHE6 = 0.437 \times (L \times B) + 9.09$$
(correlation 0.99)
$$WOHE6 \simeq 0.44 \times (L \times B) \text{ in tonnes}$$

The index 0.44 is higher than that suggested in Method 5 of 0.32 for containerships. This shows that the variability of outfit weight can be as much as 38% from one shipyard practice to another, in this case probably between American built ships which are heavier compared to European built ships plus demarcation differences.

METHOD 7: In this method, first proposed by Chapman (46) 1969 and also used in a later design study by Volker (61) 1974, the wood/outfit and hull engineering weight was subdivided into the following categories:-

(i) Bought in outfit material (BOFWT), all items bought in from outside suppliers fall into this category. All the major items fall into this category.
(ii) Shipyard outfit material (SOFWT), generally a fraction of the total weight and supplied by the shipyard.
(iii) Hatch cover weight (HATWT), generally supplied from outside as standard equipment. This method is considered here as a reference only, it gives very low outfit weight as shown in Table 6.8.

METHODS 8 and 9: These equations were suggested by Katsoulis (35) 1977 for all types of ships. Since the value of K is a bit dated, some recently built container ship weight data were used to evaluate a new value of K. For containerships it was found that the block coefficient term can be dropped because the formula gave lower values of outfit weight compared to Method 9 or the actual weights. The value of K by Method 9 was found to lie between 0.0354 to 0.0714 with three values close to 0.065 as suggested by Katsoulis.

METHOD 10: This method (58) 1962 was developed prior to any purpose built container ships and is included to complete the analysis. It was assumed that the ore carrier outfit and Hull engineering (WOHE10) most closely approximates the weight of a containership and the formula is based on

Table 6.8 Outfit and Hull Engineering weights by different methods

	Actual WOHE	$WOHE_1$	$WOHE_2$	$WOHE_3$	$WOHE_4$	$WOHE_5$	$WOHE_6$	$WOHE_7$	$WOHE_8$	$WOHE_9$
1.	2287	1250	1250	1940	1455	1119	1539	860	1024	1175
2.	2296	1276	1276	2011	1460	1145	1574	870	1043	1210
3.	2312	1319	1319	2129	1454	1187	1632	885	1067	1268
4.	2327	1356	1356	2237	1441	1224	1683	899	1082	1320
5.	2435	1759	1759	2770	1897	1399	1924	997	1352	1537
6.	2445	1783	1783	2847	1895	1423	1957	1005	1367	1571
7.	2461	1824	1824	2977	1881	1463	2012	1019	1384	1629
8.	2477	1866	1866	3117	1869	1506	2071	1034	1403	1691
9.	2513	1931	1931	3342	2130	1573	2163	1056	1596	1790
10.	2517	1941	1941	3378	2108	1583	2177	1060	1592	1806
11.	2530	1974	1974	3498	2084	1618	2225	1071	1601	1857
12.	2546	2011	2011	3638	2063	1658	2280	1085	1615	1918
13.	2561	2047	2047	3779	2044	1698	2336	1097	1627	1978
14.	2668	2235	2235	4598	2542	1920	2640	1166	1980	2201
15.	2672	2245	2245	4644	2518	1932	2657	1170	1975	2218
16.	2684	2271	2271	4771	2480	1965	2702	1179	1967	2268
17.	2699	2300	2300	4921	2450	2003	2755	1191	1983	2325
18.	2717	2334	2334	5098	2426	2048	2816	1204	1996	2393
19.	2737	2371	2371	5301	2404	2098	2886	1219	2011	2470
20.	3032	2863	2863	7663	3833	2642	3633	1410	2969	3244
21.	3038	2869	2869	7743	3802	2659	3657	1414	2966	3272
22.	3048	2878	2878	7871	3731	2687	3694	1421	2948	3316
23.	3059	2888	2888	8016	3664	2717	3737	1430	2932	3365
24.	3079	2903	2903	8259	3626	2769	3807	1443	2946	3448
25.	3108	2922	2922	8588	3612	2837	3901	1460	2984	3559
26.	3335	2908	2908	10429	5009	3203	4405	1605	3880	4203
27.	3340	2899	2899	10583	4994	3233	4445	1613	3897	4253
28.	3357	2888	2888	10738	4909	3262	4486	1620	3874	4304
29.	3375	2869	2869	10992	4855	3310	4552	1631	3881	4386
30.	3399	2844	2844	11307	4811	3369	4633	1646	3900	4488
31.	3437	2801	2801	11786	4806	3458	4755	1667	3962	4642
32.	1495	1772	1772	2612	1775	1348	1854	989	1387	1595
33.	2699	2409	2409	5193	2579	2072	2849	1221	2107	2457
34.	2059	2287	2287	4550	2429	1907	2623	1173	1933	2268
35.	2050	2372	2372	5125	2558	2055	2825	1212	2222	2552
36.	2230	2515	2515	5340	2582	2108	2899	1246	2139	2548
37.	2150	2475	2475	4544	2556	1906	2621	1206	1810	2228
38.	2800	2686	2686	5779	2937	2215	3046	1299	2228	2709
39.	3300	2897	2897	7357	3431	2576	3542	1412	2771	3338
40.	3556	2866	2866	7712	3236	2653	3647	1413	2865	3413
41.	1990	2945	2945	8225	3413	2762	3797	1462	3038	3657
42.	-	2970	2970	7294	4174	2562	3523	1480	3106	3531
43.	2864	2927	2927	8370	4318	2792	3839	1541	3467	3945
44.	997	1100	1100	1492	1231	950	1306	798	860	996
45.	2546	2369	2369	5134	2713	2057	2828	1212	2232	2551

Weight in tonnes.

an earlier study by Benford (62) 1958.

Comparative Evaluation of Methods 1-10

Actual wood/outfit and Hull engineering (AWOHE) of 45 containerships were compared with each of the above methods. The WOHE by each of these methods is indicated in Table 6.8. WOHE weights gave wide variation in weights by different methods. This wide variation is clearly indicated in Table 6.9 where, the percentage difference from actual WOHE weights as a ratio of AWOHE is indicated. Method 3 gave the worst results and was eliminated. Analysis of this percentage error is carried out in Table 6.10, where Method 9 gave the least percentage (mean) error.

Method 5 was, however, selected since it was felt that it reflects the trend in WOHE of recently built container ships.

A plot of outfit factor (OUFITF) defined as Actual wood/outfit and Hull engineering/(L x B) tonnes/m^2, Fig. 6.3, shows that the value of OUFITF for containerships lie between 0.44 to 0.32, where OUFITF = 0.44 as given by Method 6. The parametric study was carried out with OUFITF = 0.32 as recommended by Method 5 (35)1977.

Moreover since the grouping of steel weight and outfit weight was taken as given in (35), Method 5 was adopted. The user can input any value to the outfit factor (OUFITF) in the program.

6.3. MACHINERY WEIGHT (WM)

The various types of machinery fitted and proposed for containerships include

- Direct drive slow speed diesels
- Geared medium speed diesels
- Geared steam turbines
- Geared gas turbines (a) Aero type (b) industrial type
- Nuclear power.

Factors which affect the choice of the type of machinery include:- the specific weight, the space required, and the fuel consumption rate which often means that the weight is based

Table 6.9 Difference in percentage from actual Outfit weight

	WOHEI	WOHE2	WOHE3	WOHE4	WOHE5	WOHE6	WOHE7	WOHE8	WOHE9
I.	45.23	45.32	I5.I7	36.35	5I.04	32.67	62.37	55.22	48.59
2.	44.39	44.39	I2.40	36.39	50.I2	3I.4I	62.09	54.56	47.27
3.	42.93	42.93	7.88	37.08	48.66	29.40	6I.68	53.85	45.I4
4.	4I.70	4I.70	3.86	38.04	47.40	27.67	6I.34	53.49	43.27
5.	27.76	27.76	-I3.79	22.06	42.54	20.99	59.04	44.47	36.86
6.	27.05	27.05	-I6.46	22.46	4I.79	I9.96	58.86	44.09	35.7I
7.	25.88	25.88	-20.97	25.53	40.54	I8.24	58.56	43.74	33.78
8.	24.65	24.65	-25.86	24.5I	39.I9	I6.39	58.24	43.35	3I.70
9.	23.I5	23.I5	-32.99	I5.2I	37.40	I3.93	57.94	36.46	28.76
I0.	22.87	22.87	-34.23	I6.22	37.07	I3.48	57.87	36.74	28.25
II.	2I.97	2I.97	-38.27	I7.63	36.02	I2.03	57.63	36.69	26.57
I2.	2I.0I	2I.00	-42.89	I8.95	34.85	I0.4I	57.39	36.56	24.67
I3.	20.05	20.05	-47.59	20.I9	33.66	8.79	57.I3	36.47	22.75
I4.	I6.2I	I6.2I	-72.37	4.7I	28.02	I.02	56.28	25.77	I7.50
I5.	I5.97	I5.97	-73.82	5.74	27.68	0.56	56.2I	26.06	I6.96
I6.	I5.39	I5.39	-77.76	7.59	26.78	-0.67	56.04	26.37	I5.50
I7.	I4.75	I4.75	-82.35	9.23	25.76	-2.08	55.86	26.5I	I3.82
I8.	I4.08	I4.08	-87.64	I0.7I	24.6I	-3.66	55.67	26.53	II.9I
I9.	I3.35	I3.35	-93.69	I2.I4	23.3I	-5.44	55.46	26.5I	9.73
20.	5.57	5.57	-I52.76	-26.44	I2.84	-I9.84	53.49	2.07	-7.02
2I.	5.55	5.55	-I54.89	-25.I6	I2.45	-20.38	53.63	2.36	-7.7I
22.	5.56	5.56	-I58.25	-22.43	II.84	-2I.22	53.35	3.27	-8.79
23.	5.57	5.57	-I62.05	-I9.79	II.I5	-22.I7	53.25	4.I3	-I0.02
24.	5.69	5.69	-I68.24	-I7.78	I0.06	-23.66	53.I3	4.3I	-II.99
25.	5.98	5.98	-I76.32	-I6.23	8.70	-25.53	53.00	3.97	-I4.52
26.	I2.78	I2.78	-2I2.74	-50.2I	3.93	-32.09	5I.85	-I6.35	-26.04
27.	I3.20	I3.20	-2I6.88	-49.52	3.I9	-33.II	5I.7I	-I6.69	-27.36
28.	I3.96	I3.96	-2I9.89	-46.24	2.80	-33.65	5I.74	-I5.4I	-28.22
29.	I4.96	I4.96	-225.69	-43.87	I.90	-34.88	5I.65	-I5.00	-29.98
30.	I6.3I	I6.3I	-232.67	-4I.56	0.86	-36.32	5I.57	-I4.75	-32.06
3I.	I8.49	I8.49	-242.93	-39.85	-00.62	-38.35	5I.49	-I5.30	-35.08
32.	-I8.58	-I8.58	-74.77	-I8.79	9.78	-24.05	33.68	7.I8	-6.72
33.	I0.73	I6.73	-92.4I	4.43	23.23	-5.56	54.75	2I.93	8.95
34.	-II.09	-II.09	-I2I.0I	-I7.98	7.34	-27.4I	43.02	6.I0	-I0.I7
35.	-I5.75	-I5.75	-I50.04	-24.78	-00.25	-37.85	40.87	- 8.43	-24.50
36.	-I2.79	-I2.79	-I39.47	-I5.80	5.45	-30.0I	44.09	4.07	-I4.27
37.	-I5.I3	-I5.I3	-III.37	-I8.9I	II.34	-2I.9I	43.90	I5.80	-3.67
38	4.05	4.05	-I06.42	-4.90	20.88	-8.79	53.6I	20.42	3.23
39.	I2.20	I2.20	-I22.94	-3.98	2I.94	-7.33	57.I9	I6.0I	-I.I6
40.	I9.38	I9.38	-II6.87	8.99	25.39	-2.58	60.27	I9.43	4.02
4I.	-48.0I	-48.0I	-3I3.32	-72.52	-38.79	-90.84	26.52	-52.70	-83.8I
42.									
43.	-2.22	-2.22	-I92.27	-50.77	2.50	-34.06	46.I7	-2I.07	-37.77
44.	-I0.39	-I0.39	-49.67	-23.49	4.67	-3I.07	I9.88	I3.66	0.I0
45.	6.92	6.92	-I0I.67	-6.59	I9.I9	-II.II	52.40	I2.33	-0.23

TABLE 6.10. Analysis of wood/outfit & hull eng. estimation methods.

Method	Mean of Percentage Difference	Standard Deviation	Variance
1 (WOHE1)	11.85	17.86	312.00
2 (WOHE2)	11.85	17.86	312.00
3 (WOHE3)	-107.66	79.79	6222.00
4 (WOHE4)	-6.009	27.928	762.26
5 (WOHE5)	20.186	18.137	321.50
6 (WOHE6)	-9.743	24.938	607.79
7 (WOHE7)	52.54	8.762	75.03
8 (WOHE8)	16.025	24.438	583.67
9 (WOHE9)	3.044	27.762	753.00

on the sum of the machinery weight plus fuel weight for a given fuelling range. Naturally items such as reliability, the type of ship and cargo and the number of propellers may also be important.

Nuclear power has been discussed for containerships but the usual difficulties of acceptability in ports and high capital cost have prevented this plant being used so far.

Table 6.11 shows the distribution of the various types of machinery fitted on existing containerships. The increase in bunker fuel prices since 1973 had a significant effect on the choice of the main propulsion unit. This is well illustrated in Table 6.11 where 69% of newly built ships above 1000 Teu were equipped with steam turbine before 1974, compared to 37% after this date. Recent increases in oil prices, after 1979, had forced many shipowners to convert (63,64,65,66) existing ships with steam turbine installation to diesel propulsion. Medium speed propulsion has been confined to ship sizes less than 1000 Teu, due to their lighter weight and volume, Table 6.12. This advantage of higher cargo capacity is more than offset by lower specific fuel consumption of slow speed diesel, particularly for ship's size over 1000 Teu.

A summary of formulae for calculating the machinery weight, together with the machinery position, type of installation, for single or twin screw and the range of power for which it was developed is shown in Table 6.13. The machinery weight is subdivided into the main engine weight and the weights of auxiliaries. Each type of installation is discussed briefly and the weight equations selected in the algorithm is indicated.

Direct drive slow speed diesel

Most of the newly built containerships above 1000 TEU, after the oil price increases of 1973 and 1979 were installed with this type of engine as shown earlier, so in the program, all ships above 1000 Teu are assumed to have this type of installation. The various methods of estimating the weights are:-

METHOD 1: This formula* 1 , 2 was suggested by Watson in

*Note: Equations are mentioned in Table 6.13.

TABLE 6.11. Propulsion plants of container ships till November 1978 (11).

Propulsion	TEU	400 - 599	600 - 799	800 - 999	1000 - 1199	1200 - 1399	1400 - 1599	1600 - 1799	1800 - 1999	2000 - 2199	2200 - 2399	2400 - 2599	2600 - 2799	2800 - 2999	3000 +	Sub Total	Total
Slow-speed Diesel	Pre-1974	1	10	6	13	5	8	-	5	1	3	1	-	-	-	53	116
	1974 onwards	2	12	6	6	9	8	4	6	2	-	7	-	1	-	63	
Med.-speed Diesel	Pre-1974	10	5	2	-	-	-	-	-	-	-	-	-	-	-	17	42
	1974 onwards	15	4	5	-	-	-	1	-	-	-	-	-	-	-	25	
Steam Turbine	Pre-1974	-	-	-	15	19	14	12	10	3	-	-	-	8	7	88	114
	1974 onwards	-	-	-	1	14	7	3	-	-	-	1	-	-	-	26	
Gas Turbine	Pre-1974	-	-	-	-	-	-	-	4	-	-	-	-	-	-	4	4
	1974 onwards	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	
																162	276

TABLE 6.12. Specific weights of some engine types, and comparison with formula adopted in the program.

Engine type	Maker	Type	Horsepower (PS)	RPM	KG/PS	Weight in tonnes	Weight in tonnes Eq.(10)
Slow speed diesel	B&W	12L90GF	40,900	94	31.8	1300	1544
	Sulzer	9RND105M	41,400	108	32.1	1329	1388
	Sulzer	9RND105	36,000	108	35.4	1274	1234
	B & W	12K90GF	40,900	114	31.4	1284	1312
	MHI	10UEC85/180E	38,000	120	27.5	1045	1182
	B & W	9L55GF	12,100	150	23.6	285	374
	MHI	8UET52/90D	9,000	198	16.8	151	232
Medium speed diesel (V type)	PC	12PC4V	18,000	400	9.7	175	229
	MAN	12V40/54	6,700	430	11.4	76	146
	MAN	12V52/55A	12,660	450	10.3	130	155
	PC	12PC2-5V	7,800	520	8.6	67	91
High speed diesel (for electric generation)	Diahatsu	8PSHTb 26D	1,000	720	12.1	12.1	12.36
	"	8VSHTb 26D	2,000	720	10.1	20.2	22.13
	Yanmar	6GL-DT	850	720	11.3	9.61	10.78
	"	6ZL-DT	1,400	720	10.9	15.26	16.39
	MHI	8SH24Ac-5	1,600	900	7.2	11.52	15.21
	"	S16NTK	1,000	1,200	6.0	6.0	8.05
Gas turbines *	GE(aero)	LM2500	20,700	3,600	0.24		
	GE(heavy duty)	Model 5000B	28,000	4,670	6.9		
Steam turbine *	MHI	MS40(HP)	20,000	6,307	1.2		
	MHI	MS40(LP)	20,000	3,420	2.1		

NOTE: In the case of steam turbine, it will be 10 kg/PS if reduction gears and condensers are included and for gas turbines reduction gears are not included.

TABLE 6.13. Summary of machinery weight equations.

TYPE	SHIP TYPE	Single Screw Main	Single Screw Aux.	Eq. No.	Twin Screw Coeff.	Twin Screw Factor	Range of SHP × 10^3	Machinery position	Ref. No.	Year
Direct drive slow speed diesel	G	BHP/10 + 200		1	–	1.10	SS 3-15	Amidships	60	62
		0.95(BHP/10 + 200)		2				Aft(-5%)		
	C	(3) 4(BHP/100) (4) 2.3 (BHP/100)					SS 8-60		39	70
		WET	6.3(BHP/100)	5	–	1.0	TS 61-120	Aft	55	74
	C	$302(BHP/1000)^{0.55}$		6	–	1.02	–	Aft	53	72
	B	* BHP(895-0.0025 × BHP)/10^4		7	–	–	–	Aft	48	75
	L	* 6.4(BHP/100)		8	–	–	–	Aft	41	75
	G	BARASS	BHP/18 + 300	9	–	–	–	Amidships	35	76
	A	* $9.38\left(\frac{BHP}{RPM}\right)^{0.84}$		10						
		$0.56(BHP)^{0.70}$		11	–	–	–	Aft mainly	35	77
Steam turbine plant	G	SHP/17 + 280		12	–	1.10	SS 3-15	Amidships	60	62
		0.95(SHP/17+280)		13				Aft		
	G G & C	AVG $247(SHP/1000)^{0.5}$		14	313	1.267	–	Amidships		
		MIN 230		15	301	1.309	–	"	51	65
		MIN 213		16	289	1.357	SS 0-60	Aft		
		AVG 225		17	301	1.338	TS 61-120		39, 55	70, 74
	C			18	367	1.631	TRP 121-180	Aft	39	70
				19	426	1.893	Quad-181-240	Aft	55	74
	C	$214\ (SHP/1000)^{0.5}$		20	–	1.15	SS 0-20 TS 20	Aft	52,54 53	70,74 72
	C	WET	$7.18(SHP)^{0.495}$	21	–	–	–	Aft	37	68
	G	BARASS	SHP/30 + 500	22	–	–	SS 17.5-32.5	Amidships	35	76
	C	* CARREYETTE $244(SHP/1000)^{0.58}$		23	–	–	12.5-8.0	–		OLD
	A	* WATSON	$0.16(SHP)^{0.89}$	24	–	–	–	Aft	35	77
	T	* BUXTON	$8.8(SHP)^{0.5}$	25	–	–	–	–		

Contd.

TABLE 6.13 (Contd).

TYPE	SHIP TYPE	Single Screw Main	Single Screw Aux.	Eq. No.	Twin Screw Coeff.	Twin Screw Factor	Range of SHP x 10^3	Machinery position	Ref. No.	Year
	A	* WATSON modified	$8.8(SHP)^{0.5}$	26	12.2	1.386	15–120	Aft		
			$5.0(SHP)^{0.5}$	27	-	-	SS 0–15	Aft		
	C	WET	$200(SHP/1000)^{0.57}$	28	-	-	-	Aft	61	78
Gas turbine	C	Aero type $100(SHP/1000)^{0.5}$		29	-	1.10	-	-	53	72
Gas turbine	C	Indus type $172(SHP/1000)^{0.5}$		30	-	1.10	-	-	53	72
Medium speed diesel	C	$182\ (BHP/1000)^{0.62}$		31	-	1.12	-	-	53	72
Medium speed diesel	C	WET $180(BHP/1000)^{0.57}$		32	-	-	-	-	61	78

<u>Ship Type</u>

C - Container

T - Tanker

B - Bulk carrier

G - General cargo

A - All types

L - Liner

* All formulae marked like this BHP or SHP is in metric horse power and weight in tonnes.

1962 (60) for general cargo ships. The horsepower range was limited to 15000, highest possible during that period. Since that date there has been a reduction of main engine weight of 14%, and containerships with 120,000 h.p. are in operation. This method has been superceded by Method 7.

METHOD 2: These formulae 3,4,5 were developed for container ships by Erichsen in 1970 (39). It is applicable for both single and twin screw installation. It was later validated with existing containerships in another study by Swift in 1974 (55).

METHOD 3: This formula 6 used in a computer program for container ship design developed by Marad in 1973 (53) and compared to earlier formula had an index of SHP of 0.55 similar to that of steam turbine installation weight equation.

METHOD 4: This formula 7 was used in a bulk carrier preliminary design program in 1975 (48), but originally developed by Groeneweg & Polko 1971 (67) as a set of diagrams. The weight equation is for the mean line and used here for comparison only.

METHOD 5: This formula 8 was used in a cargo liner design program by Sen in 1978 (41) and is the same formula as used in earlier containership design study by Erichsen (39) and Swift (55) but the constant changed from 6.3 to 6.4 reflecting higher weight for cargo liners.

METHOD 6: This formula 9 was suggested by Barrass in 1977 (35) and was compared by Watson and Gilfillan (35) and found to give higher weights than formulae 10,11 because formula 9 is for ships with machinery amidships.

METHOD 7: This formula 10,11 is the latest available and suggested for all ship types by Watson & Gilfillan in 1977 (35). The total weight is broken into main engine weight and weight of auxiliaries. The formula is also applicable for medium speed diesel installation. A cross check with weights of some main engines both slow speed diesel as well as medium speed diesel is shown in Table 6.12.
Equation 10 estimates the main engine weight quite accurately.

Comparative Evaluation of Methods 1-7

The formulae given in Table 6.13 for estimating the machinery weight is shown in Fig. 6.4. For the weights of auxiliaries two formulae were available Eq. 4 and Eq 11 . Up to 40,000 hp the weight of auxiliaries estimated by Eq. 11 are greater than that by Eq. 4 and above 40,000 hp vice versa, and the difference is the same on either side of 40,000 hp . Eqs.1 & 2 gave quite high specific weight/h p . Eq. 7 for bulk carriers lies above all other equations. Eqs. 5,8,9,6 lie close to each other, with Eq.6 giving overestimates at horse power less than 30,000 and underestimates at higher horse powers . Eq. 9 gives intermediate results between Eq.6 and Eq. 5 & 8 at low powers.

A few points plotted for actual ships gave good agreement with Eq. 6 . Eq. 10 & 11 was selected because it reflects the current practice and it is applicable for a wider range of horse power and r.p.m. as shown in Table 6.12 . Also the auxiliary weight given by Eq.11 is in close agreement with Eq. 4 .

Medium Speed Diesel

Medium speed diesel engines have lower specific weight (see Table 6.12) and volume. Its lower engine height makes it an attractive mode of propulsion for RO-RO ships, because of the requirement of fore and aft access for trailer loading and unloading. As pointed out earlier, for higher power requirements the slow speed diesels have the advantage of lower fuel bills. Before the oil crisis of 1973, 10% of ships were equipped with this type of engine and this rose to 22% of the ships completed after 1974, as shown in Table 6.11. They are largely confined to ships of size less than 1000 Teu.

The formulae available for estimating the weight, Eq. 31 developed by Marad in 1973 (53) and the other developed by Volker in 1978 (61), shown in Table 6.13, was compared with Eq. 10 & 11 which was used in the program. These are shown in Fig. 6.5. The Eq. 10 & 11 gives lighter machinery weight than either Eq. 31 or Eq. 32 , with equation 31 giving the heaviest machinery weight. The difference between eq. 32 from eq. 10 & 11 is between

Fig. 6.4. Machinery weight of slow speed direct drive diesel plant.

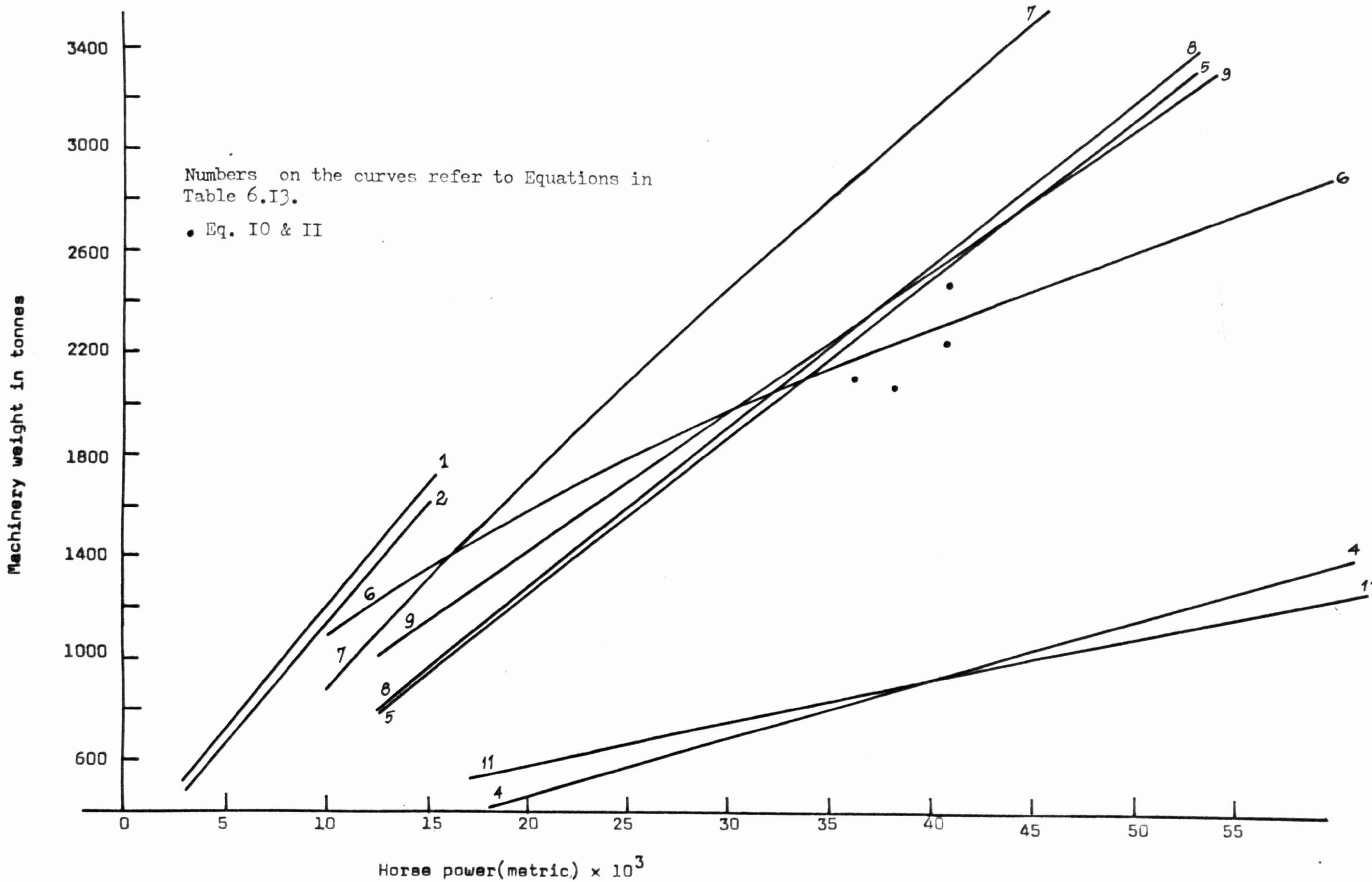
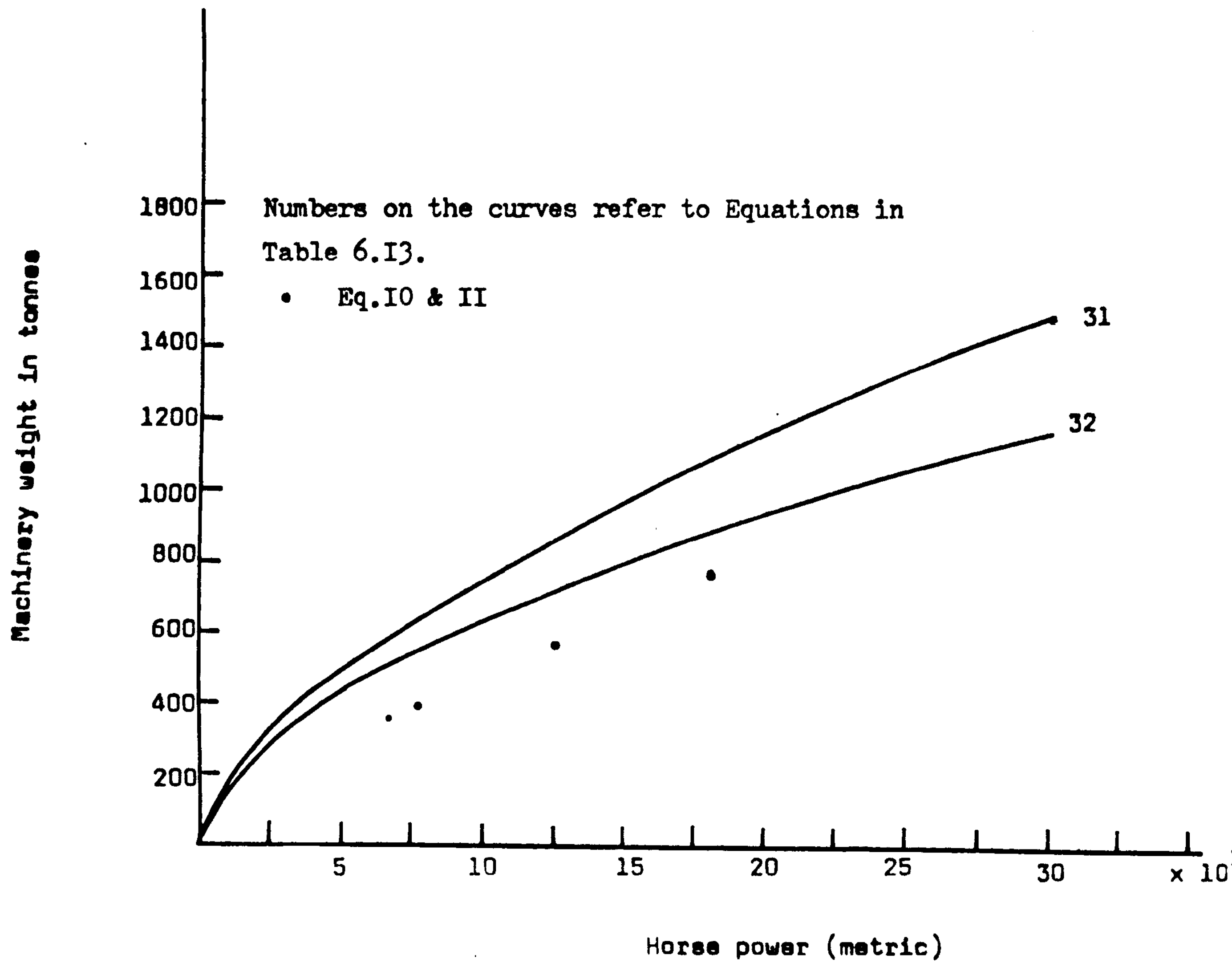


Fig. 6.5. Machinery weight of Geared drive diesel plant.



23% to 50%. Eq. 10 & 11 was used in the program because it gives fairly good main engine weight as shown in Table 6.12 and it is applicable for estimating both slow speed diesel and medium speed diesel weights.

Steam Turbine

The advantages of this simple rotary engine are considerable, particularly in the higher ranges of power, because of their very low specific weight (Table 6.12) and volume. Equally true is the benefit of having steam on board for auxiliary drives, heating and washing of tanks etc. Also in steam boilers the lowest grade (quality) of bunker fuel can be burned. However very few newly built ships are installed with this type of engine because of the relatively higher specific fuel consumption (200 gm/bhp-hr) compared to (140 gm/bhp-hr) of slow speed diesel engines. The quantity of fuel saved, rather than the difference in fuel quality is a decisive factor now. It is apparent from Table 6.11 that many shipowners were forced to change over to diesel propulsion after the oil crisis of 1973 and subsequently rises in fuel costs in 1979 even forced the shipowners to convert existing containerships with steam plant to diesel propulsion (63,64,65,66).

Various formulae have been suggested for estimating the weights of steam turbine plants since 1962 and are shown in Table 6.13. Of these many were derived from converted containerships. Each of these formulae are reviewed here, although steam turbine installation is not considered as an alternative propulsion plant.

METHOD 1: This formula 12,13 developed by Watson in 1962 (60), and subsequently updated, eq. 27, by the author in (35) 1977, reflecting a decrease in weight of 48% for 15000 h p and the upper limit of the range increased from 15,000 in 1962 to 120,000 h p.

METHOD 2: This formulae eq. 14,15,16 (Table 6.13) was suggested by Benford in 1965 (51) for general cargo ships and was later modified for container ship studies by Erichsen (39) and Swift (55). These formulae are generally of this form

$$WM = K \times SHP^{0.5} \qquad \text{eq. } 14 \text{ to } 19$$

Erichsen expanded the formula to include triple and quadruple screw configurations.

METHOD 3: This formula eq. 20 was developed by Miller in 1970 (52), and subsequently used in other containership studies by Marad in 1973 (53) and Hancock in 1972 (54). Eq. 20 gives machinery weight less than Method 2 for ships with machinery aft.

METHOD 4: This formula eq. 21 was developed by Chryssostomidis in 1968 (37) and derived from weights of converted container ships since the first purpose built containership came into operation in 1968, therefore eq. 21 gives higher machinery weights.

METHOD 5: This formula eq. 24 was given by Watson & Gilfillan in 1977 (35) for all ship types. Shp had an index of 0.89 unlike the equations previously suggested Eq. 14 to 21 , Eq. 23 , Eq. 25 and Eq. 28 . This was modified to reflect recently built ships and the index of Shp was given as 0.5, eq. 26 and eq. 27 as in Methods 2, 3 and 4.

An analysis of weights was not considered in the thesis, but validating the weight given by eq. 26 & 27 with some actual ship data gave good agreement.
The user can easily introduce these equations in the program if steam installation is considered.

Gas Turbines

This type of installation has the highest fuel consumption (230 gm/bhp-hr) and its performance is sensitive to fuel quality, thereby requiring costly grades of fuel. Its space and weight advantages, Table 6.12, do not compensate for the extra fuel costs. The failure of 'Euro liner' (68) one of the 4 ships installed with gas turbines have proved that they are not economical for merchant ships, although much better for naval ships, where design requirements are quite different.

Since only 4 ships have been built so far it is difficult to get a new formula. However Frankel (53) suggests two formulae one for aero type eq. 29 and the other for industrial type eq. 30 , the latter being $1\frac{1}{2}$ times heavier than the former. This type of installation is not considered in the program but like steam turbine equations, can be introduced by the user.

6.4. GUIDE WEIGHT (WG)

For estimating the guide weight (GWT) only one equation was available (46) 1970. This has been used subsequently in various containership studies without modification, (39,53,55). The guide weight is given by

$$GWT = 0.713 \times CNT^{0.92} \text{ tons} \qquad \text{Eq. 6.33}$$

where CNT = Container capacity in Teu.
The container capacity of a ship is dependent on the stability and the operational requirements. And the container capacity of two ships of the same dimensions may be different. For this reason this equation can give misleading weights. Therefore it is suggested that the following form of the equation be adopted

$GWT = K \times CNTHLD^{0.92}$ tons, where guide weight (GWT) is made a function of hold container capacity, which is largely a function of the geometry of the ship, and thus constant for a ship of given dimensions. This assumption was checked against some actual ship data (Table 6.2) as shown in Table 6.14.

Ships 1-8 are older data probably based on conversion ships, and thus of heavier construction giving nearly twice the calculated guide weight of eq. 6.33 . Ships 9-10-11 are of recent design and the actual weight is about 2/3 of the calculated weight.

Assuming that 2/3 of the containers are carried in the hold and the rest 1/3rd on the deck. It follows that guide weight can be made directly a function of the hold container capacity.

$$GWT = 0.713 \times 1.016 \times CNTHLD^{0.92} = 0.724 \times CNTHLD^{0.92} \text{tonnes} \qquad \text{Eq. 6.34}$$

or alternatively if the total capacity is only known then

TABLE 6.14. Comparative evaluation of guide weight.

No.	Year Built	Ship Ref. No. Table 6.2	Total Capacity TEU	Hold Capacity	Actual Guide Wt. Tons (1)	Cal. Guide Wt. Tons (2)	Actual / Cal. (1)/(2)	Guide weight Eq. (6.35) tons
1	1968	36	1200	NA	376	485	0.775	340
2	1968	33	1300	774	963	522	1.84	366
3	1968	1-4	600	-	increas- 512-540	256	2.00	180
4	1968	5-8	750	-	ing guide wt. 640-668	315	2.03	221
					for incr.			
5	1968	9-13	1000	-	in speed 910-944	410	2.22	288
6	1968	14-19	1250	-	1128-1180	504	2.23	353
7	1968	20-25	2000	-	1906-1964	776	2.46	544
8	1968	26-31	3000	-	3034-3102	1127	2.69	790
9	1980	32	928	612	268	383	0.699	268
10	1980	34	1336	746	357	535	0.666	375
11	1980	35	1712	1186	451	672	0.669	472
12	Under	43	3045	-	1031	1145	0.903	
13	construct-ion	44	550	-	255	236	1.080	

Ship no. 1-31 not actual built ship.

$$GWT = 0.713 \times \frac{2}{3} \times 1.016 \times CNT^{0.92} = 0.483\ CNT^{0.92}$$

$$\sim 0.5\ CNT^{0.92} \text{ tonnes} \qquad \text{Eq. 6.35}$$

The estimated weights by either of these equations is shown in Table 6.14.

However checks against two ships 12-13 show that eq. 6.33 estimates the guide weight quite accurately. Therefore in the program eq. 6.33 is retained without modification until some more data are available to validate eq. 6.34 and eq. 6.35 . Each of these equations are plotted in Fig. 6.6 together with some actual ship data.

6.5. CENTRE OF GRAVITY OF STEEL, OUTFIT, MACHINERY AND GUIDE WEIGHT

A literature search for equations for estimating the centre of gravity of steel, outfit, machinery and guide weight showed that there were very few methods available. Most were simple, relating the centre of gravity of weights to the depth of the ship, thereby neglecting the effect of fullness.

Various methods for estimating the centre of gravity (KG) of steel (KG_S), outfit (KG_{OUT}), machinery ($KG_{M/C}$) and guide (KG_{GW}) weights are indicated below, and a comparative evaluation is carried out. There were very few data points to validate the equations chosen in the program, so equations which gave reasonable results were selected. Table 6.15 summarises the formulae for estimating the centre of gravity of steel, outfit, machinery and guide weight.

STEEL(FKGS)

Seven equations were available for estimating the centre of gravity of the steel weight, the equations are referred to as per Table 6.15.

METHOD 1: This equation 1 is the latest and specifically developed for containerships by Taggert in 1980 (27). As the ship size increases, the KG/D value decreases.

METHOD 2: This equation 3,4,5 was developed by Schneekluth in 1972 (56) for dry cargo vessels, taking into account the

Fig. 6.6. Guide weight versus container capacity.

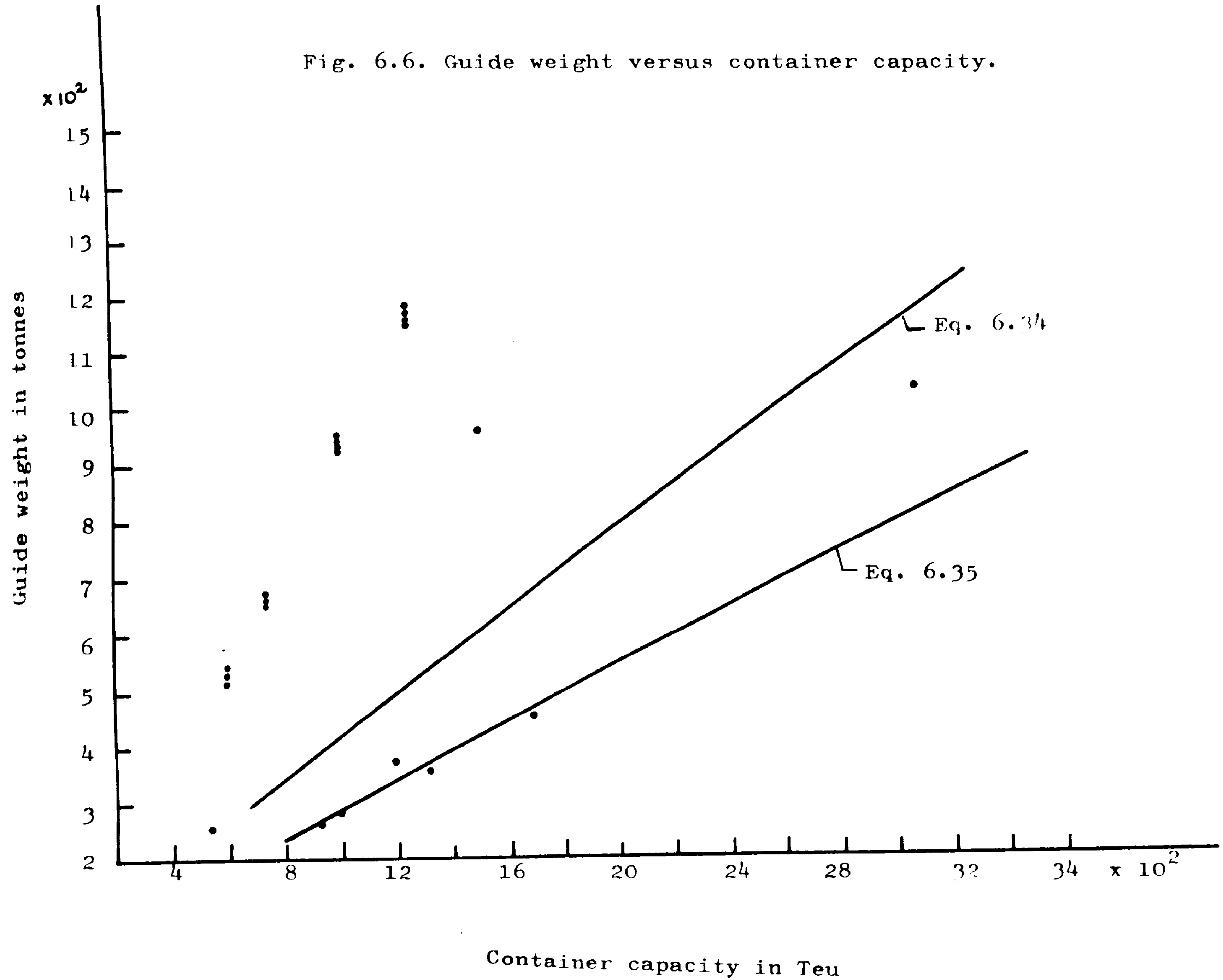


TABLE 6.15. Formulae of estimating the centre of gravity.

Eq. No.	Weight Item	Ship Type	Computer Nomenclature	Equations, all dimensions in metres	Author	Year	Ref. No.
1	STEEL	C	STLKG1	$(0.725 - 0.0007218 \times L) \times D$	Taggert	1980	27
2		BC	STLKG2	$0.01 \times D \times (46.6 + 0.135 \times (0.81 - CB) \times (\frac{L}{D})^2 + (\frac{L}{B} - 6.5) \times 0.008\ D$	Kupras	1975	48
3		GC	STLKG3	$0.01 \times D \times (45.0 + 0.155 \times (0.85 - CBD1) \times (\frac{L}{D})^2 \times \frac{D1}{D} + (\frac{L}{B} - 6.5) \times 0.008\ D$	Schneekluth	1972	56
4		GC	STLKG4	$0.01 \times D \times (45.0 + 0.155 \times (0.85 - CBD2) \times (\frac{L}{D})^2 \times \frac{D1}{D} + (L/B - 6.5) \times 0.008\ D$	Schneekluth	1972	56
5		GC	STLKG5	$0.01 \times D \times (46.0 + 0.135 \times (0.81 - CB) \times (\frac{L}{D})^2 \times \frac{D1}{D} + (L/B - 6.5) \times 0.008\ D$	Schneekluth	1972	56
6		C	STLKG6	$0.61 \times D$	Chryssostomidis	1968	37
7		C	STLKG7	$0.64 \times D$	Scott	1962	58
8	OUTFIT	C	WOKG1	$(1.005 - 0.000689 \times L) \times D$	Taggert	1980	27
9		BC	WOKG2	$D + 1.25$ for $L \leqslant 125.0$ $D + 1.25 + 0.01 \times (L - 125.0)$ for $125 < L \leqslant 250$ $D + 2.5$ for $L > 250.0$	Kupras	1975	48
10			WOKG3	$1.0 \times D$	Chryssostomidis	1968	37
11	Machinery	C	WMSKG1	$0.47 \times D$ (Steam turbine)	Taggert	1980	27
12		BC	WMDKG1	$0.17 \times T + 0.36 \times D$ (Diesel)	Kupras	1975	48
13		C	WMSKG2	$0.55 \times D$ (Steam turbine)	Chryssostomidis	1968	37
14	Guides	C	GWTKG	$0.65 \times D$	-	-	-

C = Container ships; BC = Bulk carrier; GC = general cargo.

variation in type of construction, L/D ratio, block coefficient C_b and L/B ratio. The formulae were validated with actual ships giving a deviation of -0.5% D and +0.2% D, and applicable for ships of length less than 180 m. Other values in equations are defined as follows:

D_1 = D + (sheer ford. + sheer aft)/7.0 for parabolic sheer.

$C_{BD1} = C_b + 0.25\ (1 - C_b)(\frac{D-T}{T})$ ships with light framing

$C_{BD2} = C_b + 0.5\ (1 - C_b)(\frac{D-T}{T})$ ships with heavier framing

This equation was used in bulk carrier study by Kupras in 1975 (48), eqn 2, with minor modifications, the D1/D term was dropped from eq. 5 . And for length of ship less than 120 m, steel centre of gravity was given by

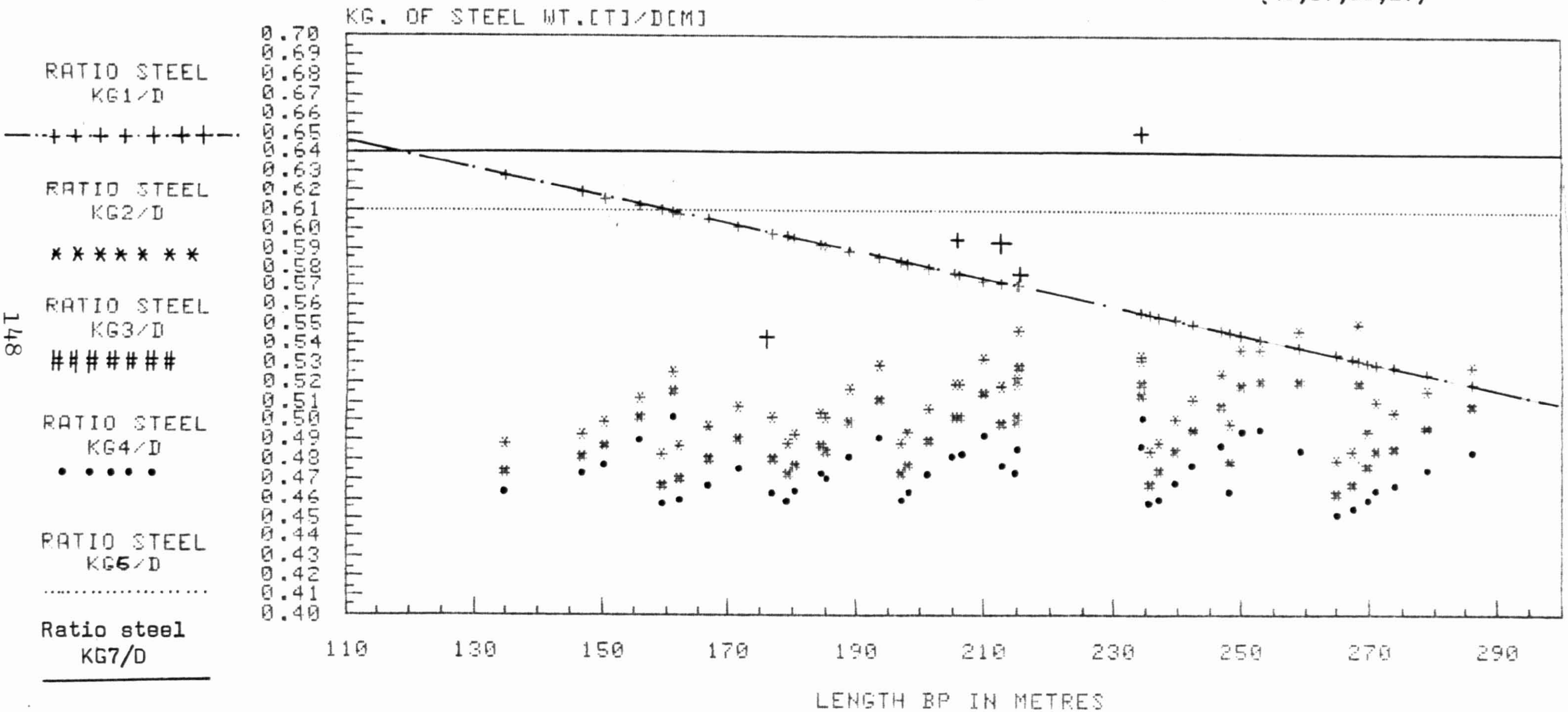
$$STLKG2 = STLKG2(Eq.2) + (1 - (\frac{L-60}{60}) \times 0.001 \times D \quad m$$

<u>METHOD 3</u>: These equations 6 and 7 were both developed for containership studies and are a bit dated. They relate the centre of gravity as a function of depth. The centre of gravity of the steel divided by the depth was plotted against the length of the ship for ships 1-45 (Table 6.2) for each of these methods, and shown in Fig. 6.7. Equations 2 to 5 show the same characteristics, with increasing size for a particular speed the KG/D values remains constant and the KG/D value increases with speed. The values of KG/D lie between 0.45 to 0.55. A check against 5 actual ship data gives the following KG/D values.

Ship's Ref.No. Table 6.2	Actual KG/D	Calculated KG/D Eq. 1 Table 6.15	% Diff. in KG/D from actual
36	0.572	0.5697	0.40
33	0.590	0.5717	3.10
32	0.542	0.5972	-10.18
34	0.593	0.5761	2.85
35	0.648	0.5558	14.22

FIG. 6.7. KG. OF STEEL WT./D VS. LENGTH

REF. KUPRAS, CHRISSOS., SCHNEEKLUTH, SNAME (48,37,56,27)



Except for Ships 32 and 35, other ships are within $\pm$ 5% of the equation 1 . Eqns. 6 and 7 show good agreement with eqn. 1 for ships of length less than 170 m and Eqn 2 to 5 show good agreement with eqn. 1 for ships of length greater than 250 m and speeds 25 to 27 knots.

Eqn. 1 was adopted in the program since it is the latest available and also it gives good agreement with the sparse data that was available.

<u>OUTFIT</u> (FKGO)

There were three equations available for estimating the outfit centre of gravity. These are summarised in Table 6.15 and described briefly.

<u>METHOD 1</u>: This equation 8, was developed specifically for containerships by Taggert in 1980 (27) and is similar to eq. 1 for the estimation of centre of gravity of steel. The centre of gravity of outfit weight divided by depth decreases as the length increases (see Fig. 6.8), though the rate of decrease as indicated by the slope is lower than that of Steel (Eq. 1).

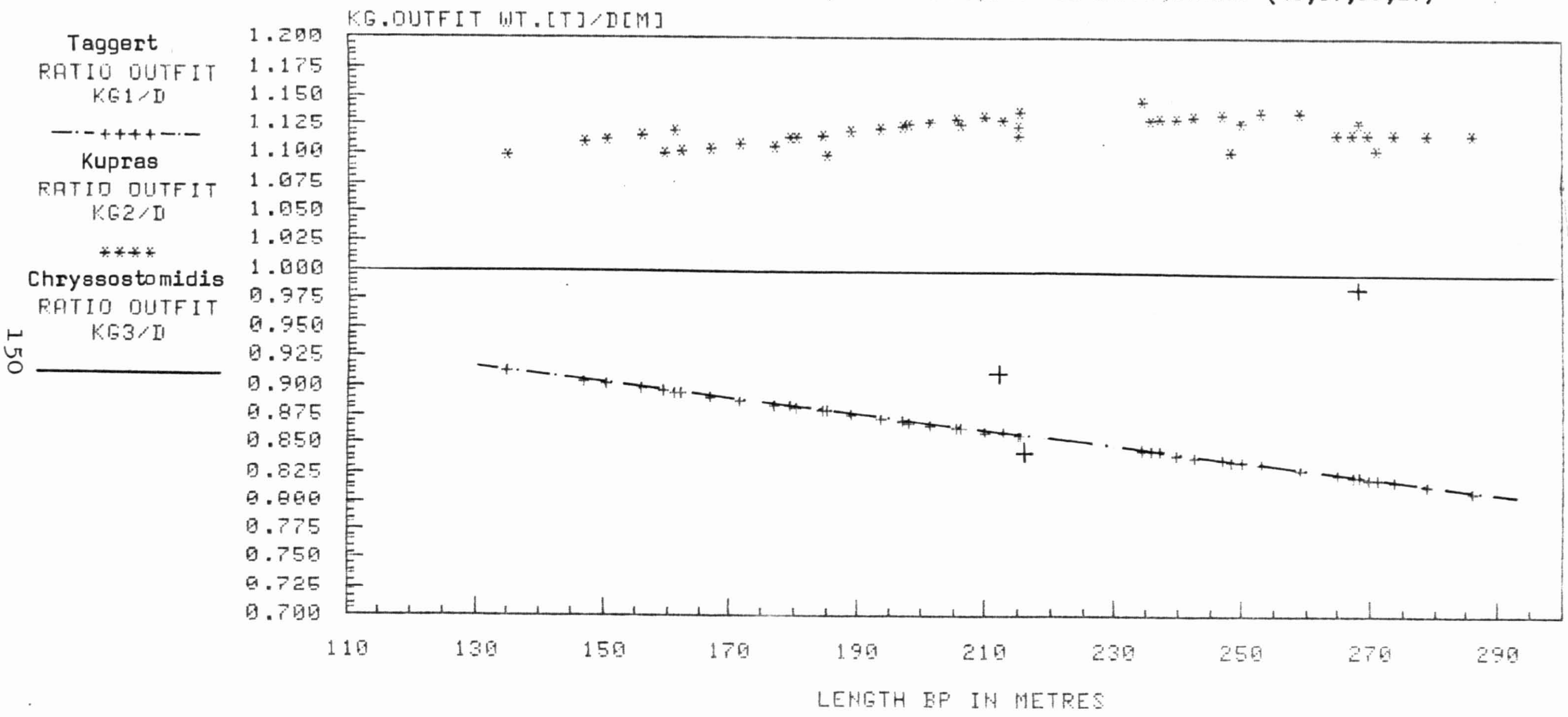
<u>METHOD 2</u>: This formula 9 was developed by Kupras in 1975 (48) for a bulk carrier study and used here for comparison only. The centre of gravity of the outfit weight lies above the deck by this equation, from 1.2 m above deck for smaller ships to 2.5 m above deck for bigger ships.

<u>METHOD 3</u>: This formula 10 was developed for a containership study by Chryssostomidis in 1968 (37) and derived from converted containership and is a bit dated.

A comparative evaluation of these methods were carried out by plotting KG/D values against length of the ship and shown in Fig. 6.8. Eq. 9 gives the highest value with KG/D between 1.10 to 1.15 for ships of length 110 m to 300 m. Eq. 8 gives the lowest value with KG/D between 0.80 to 0.925. A check against three actual ship data shows that except ship No.41, which shows good agreement to Eq. 11 , ships 36 and 33 gives results which overestimate by +5% of the eq. 8 . Eq. 8 was included in the program to estimate the centre of gravity of wood/outfit and Hull

FIG. 6.8. KG. OF OUTFIT WT./DEPTH VS. LENGTH

REF. KUPRAS, CHRISSOS., SCHNEEKLUTH, SNAME (48,37,56,27)



engineering weight.

Ship Ref. No. Table 6.2	Actual KG/D	Calculated KG/D Eq. 8	% Diff.
36	0.837	0.8567	+2.36
33	0.907	0.8586	+5.33
41	0.984	0.8201	+16.66

MACHINERY (FKGM)

Container ship studies (37, 39, 40, 52, 54, 55, 58) in the past had steam turbine installations and therefore the centre of gravity of diesel machinery installations was not considered. Three formulae were available one for diesel and two for steam turbine installations and these are discussed briefly.

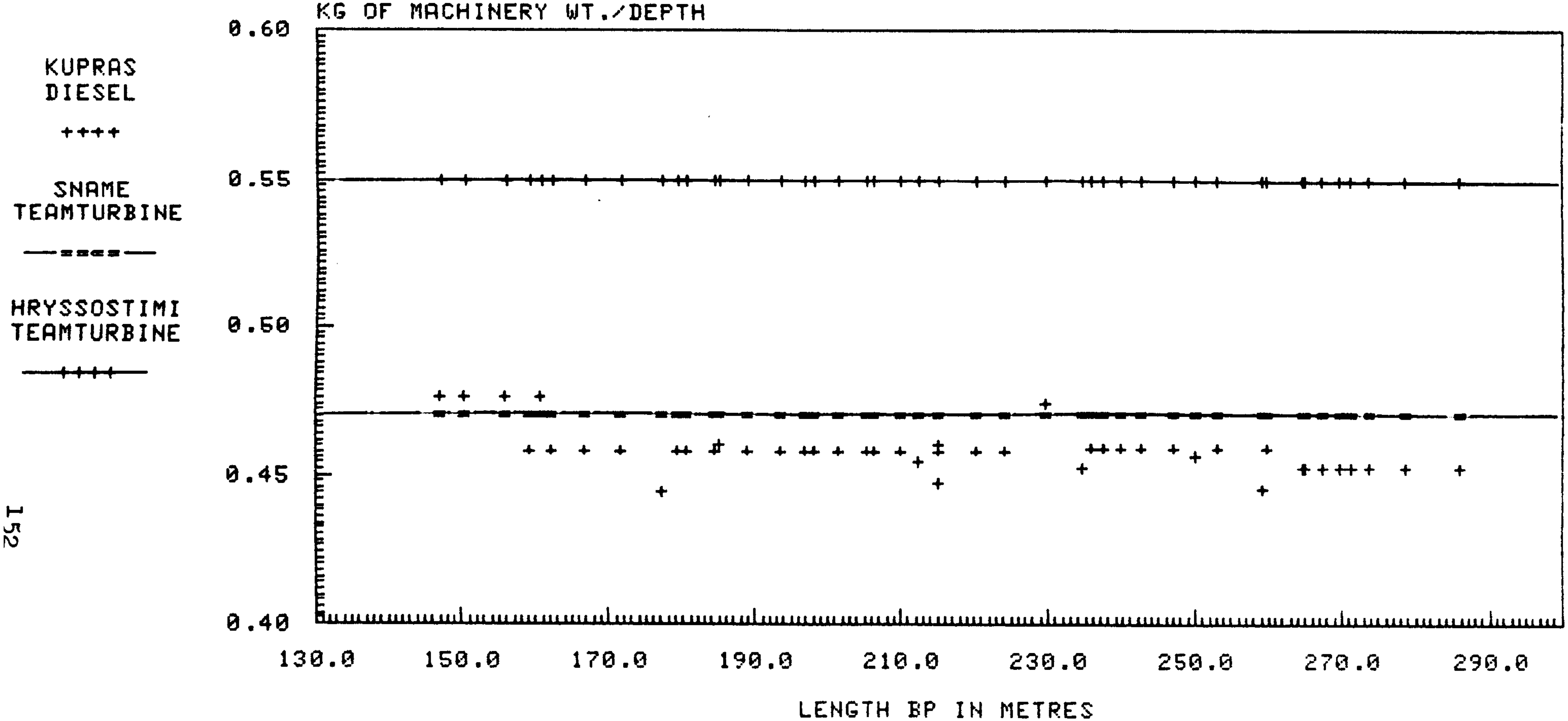
METHOD 1: This eqn. 12 was proposed by Kupras in a bulk carrier study in 1975 (48) for slow speed diesels, where the centre of gravity of machinery weight was made a function of draft and depth of the ship.

METHOD 2: These equations were proposed for steam plant installations in container ship studies, eq. (11) by Taggert in 1980 (27) and eq. 13 by Chryssostomidis in 1968 (37). The centre of gravity was given as a function of depth.

The centre of gravity of machinery divided by the depth by these methods were plotted against the length of ship and shown in Fig. 6.9. A check was made against data for six ships with steam installations and as shown below.

Fig. 6.9. LENGTH BP VS KG MACHINERY/DEPTH

COMPARISON KUPRAS;SNAME;CHRISSOSTIMIDIS (48,27,37)



Ships Ref.No. Table 6.2	Depth m.	Draft m.	Actual CG	Calcul. CG eq. 11	Calcul. CG eq. 12	Calcul. CG eq. 13
36	17.37	8.84	7.833	8.16	7.756	9.55
33	16.46	9.14	11.27	7.74	7.48	5.05
32	16.60	8.20	9.0	7.80	7.37	5.13
34	16.50	9.50	8.4	7.76	7.55	9.08
35	16.20	8.8	8.8	7.61	7.33	8.91
41	19.51	9.14	12.0	9.17	8.58	10.73

The above table shows that the ships with diesel installation will have centre of gravity of machinery lower than the ships with steam turbine plant. For steam turbine plant eq. 11 may be used, and for diesel engine eq. 12 is included in the program.

CONTAINER GUIDES (FKGW)

There was no separate estimation method available for estimating the centre of gravity of the guide weight. Previous studies had either taken the guide weight as a part of the steel weight or outfit weight, and therefore no separate equations were developed. Centre of gravity of guide weight of 'Encounter Bay' was 10.72 m , which gives a centre of gravity/depth value of 0.65 (ship ref. No.33, Table 6.2). Therefore in the program centre of gravity of container guide weight was taken as 65% of the depth of the ship.

6.6. LIGHT SHIP WEIGHT AND CENTRE OF GRAVITY (WTLT, FKGLTW)

The final item required to make up the light ship weight is the margin. And light ship weight = steel weight x allowance + outfit weight + machinery weight + guide weight + light ship weight margin.

Watson & Gilfillan (35) suggest an allowance for weld metal deposited and the rolling margin of 1% of the net steel weight. This figure is adopted in the program. The purpose of the light ship weight margin is to ensure the attainment of a specified dead weight even if there is an underestimate of the light weight or an overestimate of the load displacement. Besides the light ship weight margin another margin to be considered is that of the centre of gravity. The margin on the centre of gravity is given because of the weight growth as the construction of the ship progresses, and later verified by carrying out the inclining experiment of the completed ship.

A detailed exposition of how the centre of gravity margin and the light ship weight margin can be reduced and their influence on the cost of construction is given by Gale (69) and the parametric study of various ship design margins is given by Hockberger (70,71). Following are the indicative figures from the above studies.

Percentage growth figures which 50% of the past ships did not exceed.

Margin Category	Preliminary Design	Detailed Design
Weight	10.9	2.6
Rise in CG	4.6	2.0

Taggert (27) gives light ship weight margin of 3-6% of light ship height and a margin of +0.1 m to + 0.3 m for rise in light ship weight centre of gravity. Watson & Gilfillan (35) recommends a light ship weight margin of 2% of light ship weight.

A check was made for some actual ship data on light ship weight margin.

Except Ships 43 and 45, all other ships have weight margin of about 2 to 3%. A weight margin of 3% of the light ship weight is therefore taken in the program. And a centre of gravity growth margin of +0.3 m is taken in the program. Therefore; Light ship weight = (steel weight x 1.01 + outfit weight + machinery weight + guide weight) x 1.03 tonnes

Ref. Ship No. Table 6.2	Light ship weight	Light ship Wt. margin	% of light ship weight
36	15425	432	2.800
40	21844	508	2.326
32	7296	77	1.055
34	12762	427	3.345
-	14201	190	1.337
43	24560	1031	4.198
44	5020	69	1.375
45	14872	1125	8.184
33	14227	300	2.109

And light ship weight centre of gravity is given by

$$FKGLTW = (WS \times FKGS + WO \times FKGO + WM \times FKGM + WG \times FKGW)/WTLT \text{ m}$$

$$FKGLTW = FKGLTW + 0.3 \text{ m}$$

The light ship weight was then validated for actual ship data, Table 6.2. The light ship weight calculated by the program together with other weights and centre of gravity are shown in Table 6.16. The difference in light weight as a percentage of the actual light ship weight gives a mean error of -9.0% and standard deviation of 12.15% for 45 ship sample, which is within acceptable limits. There were 23 ships with diesel propulsion and 21 with steam plant in the sample. There were 7 ships with known light ship weight centre of gravity and following are the actual and calculated values.

Ship Ref. No. Table 6.2	Actual Light ship CG (m)	Program Light ship CG. (m)	% Diff.
32	10.08	10.59	-5.06
33	10.97	10.19	+7.11
34	10.18	10.26	-0.785
35	11.27	9.79	+13.13
36	10.38	10.59	-2.02
41	12.47	11.13	+10.75
42	13.97	14.03	-0.429

As seen from above the program gives reasonable results for both light ship weight and its centre of gravity.

Table 6.16. Weight and centre of gravity (actual versus calculated)

	Container Capacity CNT	Speed V	Actual Steel wt. AWS	Cal. Steel wt. WS	Centre of Gravity KG_s	Actual outfit wt. AWO	Cal. Outfit wt. WO	Centre of Gravity KG_O	Actual m/y weight AWM	Cal. m/y weight WM	Centre of gravity KG_m	Actual guide wt. AGWT	Cal. guide wt. GWT	Centre of Gravity KG_W	Actual lightship wt. ALTWT	Cal. lightship wt. LTWT	Centre of Gravity FKGLTW	Percentage Diff.
1	600.0	18.00	4355.0	4675.6	8.30	2287.0	1119.8	12.12	980.0	1047.1	6.38	549.0	256.4	8.72	8461.0	7360.1	8.93	13.01
2	600.0	19.00	4406.0	4860.6	8.26	2296.0	1145.3	12.09	1178.0	1200.2	6.38	544.0	256.4	8.72	8722.1	7736.5	8.86	11.30
3	600.0	21.00	4460.0	5170.5	8.21	2312.0	1187.1	12.04	1483.0	1422.7	6.38	530.0	256.4	8.72	9094.5	8331.0	8.77	8.39
4	1600.0	23.00	4490.0	5452.2	8.16	2327.0	1224.1	11.99	1889.0	1477.8	6.38	520.0	632.2	8.72	9549.0	9106.0	8.74	4.64
5	750.0	18.00	5970.0	6360.5	9.67	2435.0	1399.2	14.19	1178.0	1225.4	7.26	679.0	314.9	0.30	10631.3	9644.5	10.35	9.28
6	750.0	19.00	6001.0	6549.9	9.64	2445.0	1423.3	14.16	1356.0	1361.1	7.26	675.0	314.9	0.30	10853.1	10006.1	10.29	7.80
7	750.0	21.00	6021.0	6871.1	9.58	2461.0	1463.4	14.11	1747.0	1636.9	7.26	668.0	314.9	0.30	11285.9	10665.6	10.18	5.50
8	750.0	23.00	6061.0	7221.3	9.53	2477.0	1506.2	14.06	2113.0	1900.5	7.26	650.0	314.9	0.30	11702.5	11345.6	10.08	3.05
9	1000.0	18.00	6814.0	7783.0	9.44	2513.0	1573.1	13.97	1194.0	1241.2	7.26	959.0	410.3	0.30	11894.6	11418.0	10.17	4.01
10	1000.0	19.00	6775.0	7874.6	9.43	2517.0	1583.8	13.96	1392.0	1386.8	7.26	955.0	410.3	0.30	12058.0	11674.3	10.13	3.18
11	1000.0	21.00	6764.0	8175.8	9.38	2530.0	1618.7	13.92	1803.0	1680.8	7.26	945.0	410.3	0.30	12472.9	12326.4	10.03	1.17
12	1000.0	23.00	6773.0	8528.6	9.33	2546.0	1658.8	13.87	2260.0	1989.2	7.26	927.0	410.3	0.30	12950.9	13052.4	9.93	-0.78
13	1000.0	25.00	6783.0	8887.8	9.28	2561.0	1696.9	13.82	1600.0	1781.9	7.26	924.0	410.3	0.30	12293.9	13253.7	9.93	-7.81
14	1250.0	18.00	8239.0	9880.0	9.24	2668.0	1920.5	13.78	1392.0	1389.9	7.26	1198.0	503.8	0.30	13986.8	14206.8	10.01	-1.57
15	1250.0	19.00	8195.0	9985.9	9.22	2672.0	1932.4	13.77	1600.0	1537.4	7.26	1194.0	503.8	0.30	14155.2	14481.1	9.98	-2.30
16	1250.0	21.00	8145.0	10280.1	9.19	2684.0	1965.2	13.73	2077.0	1867.5	7.26	1186.0	503.8	0.30	14598.7	15160.9	9.89	-3.85
17	1250.0	23.00	8125.0	10630.6	9.14	2699.0	2003.7	13.69	1483.0	1682.3	7.26	1176.0	503.8	0.30	13971.2	15374.4	9.88	-10.04
18	1250.0	25.00	8129.0	11042.3	9.09	2717.0	2048.3	13.64	1859.0	1934.0	7.26	1162.0	503.8	10.30	14366.7	16107.9	9.80	-12.12
19	1250.0	27.00	8149.0	11518.1	9.03	2737.0	2098.9	13.58	2154.0	2149.0	7.26	1146.0	503.8	10.30	14695.5	16876.5	9.72	-14.84
20	2000.0	18.00	12445.0	15773.3	10.15	3032.0	2642.6	15.41	1910.0	2113.8	8.40	1995.0	776.3	11.89	20091.6	22107.6	10.99	-10.03
21	2000.0	19.00	12391.0	15950.5	10.13	3038.0	2659.8	15.39	2159.0	2022.1	8.40	1989.0	776.3	11.89	20291.9	22215.2	10.98	-9.48
22	2000.0	21.00	12250.0	16234.9	10.10	3048.0	2667.1	15.36	2794.0	2455.1	8.40	1981.0	776.3	11.89	20801.4	22985.2	10.91	-10.50
23	2000.0	23.00	12128.0	16556.9	10.06	3059.0	2717.9	15.33	1905.0	1952.5	8.40	1973.0	776.3	11.89	19761.9	22834.2	10.93	-15.55
24	2000.0	25.00	12112.0	17099.8	10.00	3079.0	2769.1	15.27	2245.0	2229.2	8.40	1958.0	776.3	11.89	20100.6	23736.8	10.85	-18.09
25	2000.0	27.00	12186.0	17836.3	9.92	3108.0	2837.5	15.19	2479.0	2458.3	8.40	1936.0	776.3	11.89	20425.8	24809.4	10.75	-21.46
26	3000.0	18.00	16063.0	21680.2	11.39	3335.0	3203.9	17.55	2215.0	2311.2	9.65	3152.0	1127.3	15.87	25673.4	29395.5	12.35	-14.50
27	3000.0	19.00	16070.0	22025.9	11.35	3340.0	3233.4	17.52	2600.0	2326.6	9.65	3145.0	1127.3	15.87	26075.2	29801.4	12.31	-14.29
28	3000.0	21.00	15889.0	22374.0	11.32	3357.0	3262.9	17.48	1899.0	1948.6	9.65	3137.0	1127.3	15.87	25174.1	29804.6	12.30	-18.39
29	3000.0	23.00	15823.0	22943.8	11.26	3375.0	3310.8	17.42	2194.0	2189.8	9.65	3123.0	1127.3	15.87	25413.4	30695.2	12.23	-20.78
30	3000.0	25.00	15799.0	23654.5	11.18	3399.0	3369.8	17.35	2499.0	2471.2	9.65	3104.0	1127.3	15.87	25707.8	31785.1	12.13	-23.64
31	3000.0	27.00	15926.0	24737.9	11.07	3437.0	3458.4	17.24	2718.0	2694.3	9.65	3082.0	1127.3	15.87	26081.9	33233.2	12.01	-27.42
32	928.0	20.10	4629.0	7008.9	9.91	1495.0	1348.8	14.66	826.0	1164.1	7.37	268.0	383.0	13.79	7482.2	10274.1	10.59	-37.31
33	1512.0	22.00	8718.0	11435.1	9.41	2699.0	2072.1	14.13	1547.0	1574.2	7.48	963.0	600.2	12.70	14227.0	16269.7	10.19	-14.36
34	1336.0	22.60	8761.0	10470.3	9.51	2059.0	1907.9	14.24	1156.0	1574.2	7.55	357.0	535.6	12.73	12780.0	15030.4	10.26	-17.61
35	1712.0	20.70	10056.0	12472.7	9.00	2050.0	2055.2	13.66	1035.0	1485.6	7.33	451.0	672.8	10.53	13800.0	17315.5	9.79	-25.47
36	1200.0	27.00	10446.0	11980.5	9.90	2230.0	2108.5	14.88	1941.0	2155.6	7.76	376.0	485.2	11.29	15425.0	17355.1	10.59	-12.51
37	1600.0	25.00	6650.0	9865.9	11.06	2150.0	1906.2	16.41	0.0	1803.5	8.60	0.0	632.2	12.16	11250.0	14735.7	11.81	-30.98
38	2000.0	27.20	8700.0	12780.2	10.66	2800.0	2215.4	16.02	0.0	2155.6	8.60	0.0	776.3	12.16	14650.0	18596.9	11.44	-26.94
39	2400.0	26.80	11500.0	16858.5	10.62	3300.0	2576.0	16.24	0.0	2155.6	8.89	0.0	915.1	12.68	17650.0	23357.1	11.48	-32.33
40	1800.0	27.00	14427.0	17402.6	9.84	3556.0	2653.0	15.12	3352.0	2155.6	8.14	0.0	704.8	11.89	21844.0	23782.4	10.65	-8.87
41	1968.0	31.00	17350.0	19043.9	10.37	1990.0	2762.0	16.00	3950.0	3005.2	8.58	0.0	764.9	12.68	23290.0	26542.5	11.13	-13.97
42	2436.0	21.00	14800.0	18158.1	13.18	9473.0	2562.2	20.14	0.0	2773.8	10.73	0.0	930.7	15.70	24273.0	25344.6	14.03	-4.41
43	3045.0	24.00	16385.0	21046.9	12.71	2864.0	2792.4	19.64	4280.0	2993.2	10.50	1031.0	1142.9	15.60	24560.0	29031.4	13.58	-18.21
44	550.0	18.00	3156.0	3851.5	8.66	997.0	950.4	12.59	543.0	1414.4	6.40	255.0	236.7	8.97	5020.0	6686.3	9.06	-33.19
45	1708.0	23.00	10056.0	12466.5	8.98	2546.0	2057.4	13.62	1050.0	0.0	7.52	93.0	671.4	10.50	14872.0	15779.5	9.97	-6.10

CHAPTER 7

POWERING ESTIMATES

7.0 INTRODUCTION

The algorithm described in this chapter to calculate the installed horse power forms an important part of the total suite of programs. The method described here refers to containerships or fine hull forms but can easily be extended to incorporate all ship types.

Containership studies in the past have used one of the following methods of power prediction:

(a) A method based on regression analysis of trial and service horse power of existing ships and relating it to the main particulars of the ship e.g. Chapman (46) 1969 .

(b) A method based on statistical analysis of full scale ships and models for prediction of various components of installed power i.e. effective horse power, delivered power, and various components of the propulsion e.g. propeller open water efficiency, wake, thrust deduction etc. e.g. Holtrop (72) 1977 , (73) 1978 .

(c) A method based on methodical series (e.g. series 60) for prediction of effective horse power Erichsen (39) 1971 , Swift (55) 1974 , and then application of method by Silverleaf (74) 1967 for prediction of propeller open water efficiency. Other propulsion factors are derived from empirical relationships to derive the delivered power.

In this thesis a different approach to the ones mentioned above have been adopted. This is based on deriving the effective horse power from average attainable performance of resistance by combining several methodical series. Up to this step the method adopted is similar to (c). The propeller open water efficiency is however derived from charts of propeller open water tests i.e. BP-δ charts of the Wageningen B-series. The diameter restrictions and the need to try various values of revolutions of propeller means that the propeller efficiency may depart from the optimum efficiency. Consequently these features and also the ability to relate propeller efficiency to a blade area ratio that is likely to be acceptable for cavitation are included in the program. Other propulsion factors are based on well-known empirical relationships to derive the quasi propulsive coefficients, which in turn gives the delivered horse power. Further allowances such as shaft losses, service conditions and machinery derating are applied to derive the installed power.

Thus the program is not only able to give a first approximation to the installed power requirements, but also the characteristics of the propeller required to deliver this power.

The program is modular in nature and thus can readily be used for other studies e.g. parametric studies for changes in diameter, revolutions of the propeller, blade area ratio or propeller efficiency etc. The propeller design program can also be used on its own with effective horse power calculated by other methods.

The calculations within the program are in imperial units, and the input and output values are in metric units.

7.1 STANDARDS OF SHIP PERFORMANCE

A 'standard of performance' is defined as that level of performance for a given set of design parameters which would be estimated by a precise known method (75). And the simplest standard is the 'last design'. But even if the 'new design' performance is better than the 'last design' there is no guarantee that it is the best design.This notion as given by Moor (75) is introduced because at the estimation stage the designer has no idea of how the ship performs until real tests are carried out to evaluate the performance. Therefore the designer must have some standards based on past data against which he can judge if the ship is likely to give the performance for which it is designed. Performance standards for each of the elements of powering estimates are discussed briefly and those adopted for the program indicated. A detailed exposition of standards of ship performance is given by Moor (75) (1974).

RESISTANCE

Methodical series can be a good starting point as a standard of performance. But the methodical series do not ensure the best attainable performance. For predicting ship resistance, collation of a large amount of data on resistance of ships taken from many standard series results and plotting them as average attainable and optimum attainable level of performance seems reasonable. Such data was collected by Moor et al. both for single and twin screw ships (76, 77, 78) and forms the basis of prediction of resistance in this thesis.

PROPULSION FACTORS

The quality of resistance performance having been decided as above, the quality of propulsive performance is determined by that of the quasi propulsive coefficient. Simple relationships have been suggested for the prediction of quasi propulsive coefficients by Emerson (79) updated by Watson & Gilfillan (35), Lap (80) and Moor (81). However these relationships can be misleading since they do not take into account the effects of speed and fullness. It is more correct to break up the quasi propulsive coefficient and determine the constituent components of propeller open water efficiency, hull efficiency and relative rotative efficiency. Such an approach has been taken in this thesis.

(a) Propeller open water efficiency

While today many advanced propellers are designed against a theoretical background, the most suitable standard for assessment is the Wageningen-Troost B-series results at NSMB (82) and presented as regression equations in (83, 84). These computer faired data can be stored easily in a computer. In the program Wageningen B-series results for prediction of propeller open water efficiency given in the form of Bp-δ by Sabit (83) was used.

(b) Hull efficiency and relative rotative efficiency

The hull efficiency elements are usually determined for the methodical series and presented as regression lines e.g. BSRA Series, and as with resistance, the series values are particular to those series and not of any known standards. However collation of random data are the best available for estimation of hull efficiency elements such as wake and thrust deduction and relative rotative efficiency was therefore calculated from Schoenherr's equations (84). A comparative evaluation of different equations developed for wake, thrust deduction can be found in Comstock (85) and Cameron (86). Cameron (86) recommends Schoenherr's equations because both single and twin screws propulsion factors can be calculated, and give reasonable results.

(c) Ship model correlation

Since all the standards mentioned so far apply to models in controlled conditions, these must be extrapolated to ships under trial conditions. The delivered power of the ship dhp, is then given by

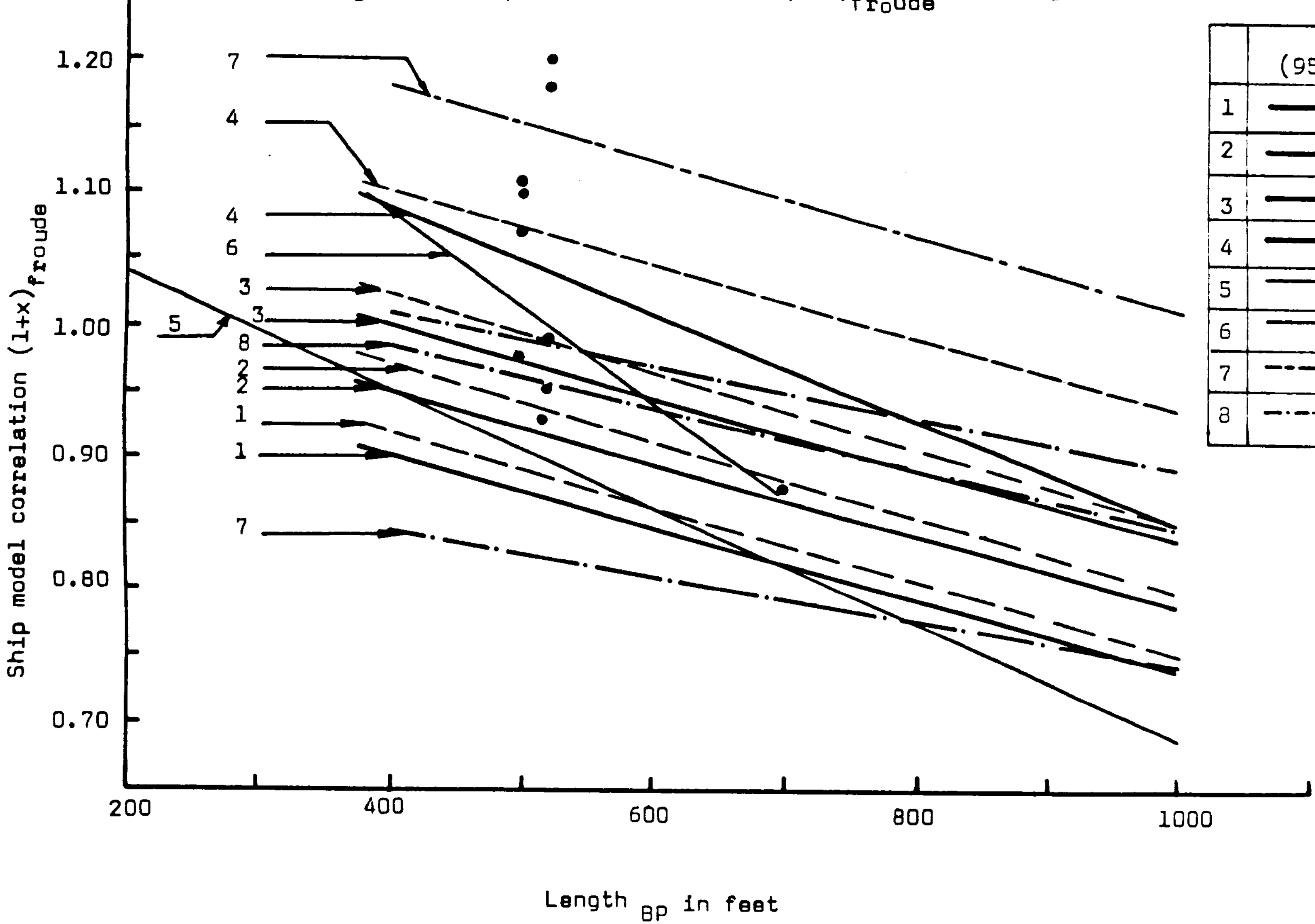
$$dhp = (1+x)_{froude} \times EHP/\eta_D \quad hp \qquad \text{Eq. 7.1}$$

where $(1+x)_{froude}$ is the ship-model correlation factor. For single screw the interim standards as adopted by ITTC were developed by Scott (87). For twin screws the BTTP 1965 (88) has so far been used but is recommended by Moor (75) that they be superceded by data presented by Scott (89).

The various formulations for $(1+x)_{froude}$ were plotted in Fig. 7.1 for single screw ships and in Fig. 7.2 for twin screw ships together with some actual published data on $(1+x)_{froude}$.

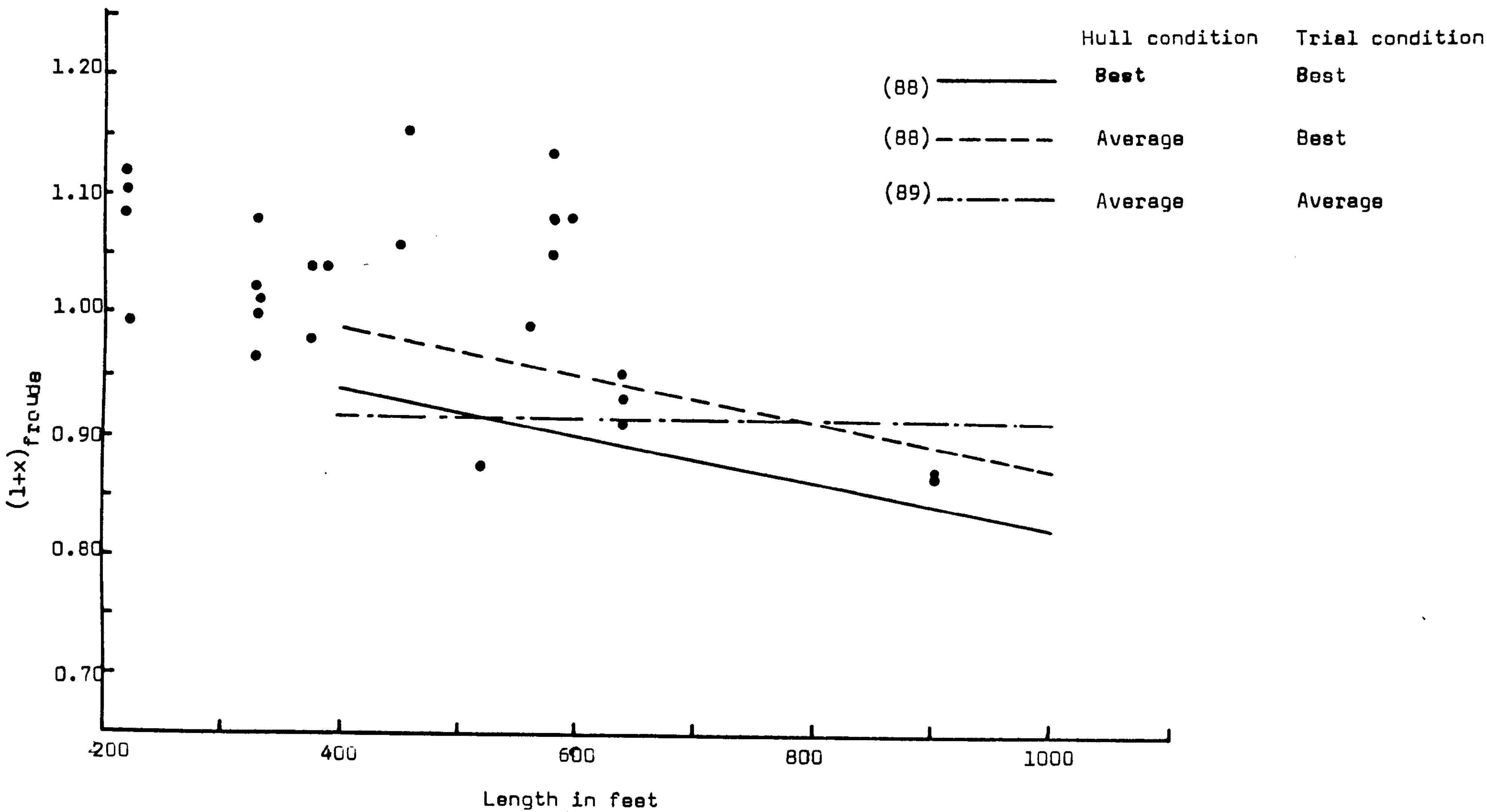
As can be seen from Fig. 7.1 that Scott's (simplified) formula given by 8-8 mean trend line, lies close to the average hull condition and best trial condition of Moor line 3-3 and BTTP 65 line 3'-3'. Therefore Moor's line 3-3 for average hull condition and best trial condition was chosen, and is given by

Fig. 7.1. Ship model correlation $(1+x)_{froude}$ for Single Screw Ships.



	(95)	(88)	Hull condition	Trial condition
1	━━━	- - - -	Best ever achieved	
2	━━━	-‑‑‑‑‑	Best	Best
3	━━━	- - - -	Average	Best
4	━━━	- - -	Average	Average
5	———	(76)	"	"
6	———	(96)	"	"
7	—·—	(87)	"	"
8	—·—·—	(87)	"	"

Fig. 7.2. Ship model correlation $(1+x)_{froude}$ for Twin Screw Ships.



$$(1+x)_{froude} = 0.367 + 2.5 \times L_{BP(ft)}^{-0.25} + 27.5\ L_{BP(ft)}^{-1.0}$$

single screw Eq. 7.2

For twin screw, the Scott's data (mean line 3-3) plots as a straight line equation for average hull and average trial conditions. Since Scott's data is not accepted as a standard for twin screw ships, BTTP 1965 line of average hull condition and best trial condition was chosen in the program and given by

$$(1+x)_{froude} = 1.07 - 0.0002 \times L_{BP(ft)} \quad \text{twin screw} \quad \text{Eq. 7.3}$$

(d) <u>Service margin</u>

The service margin serves as an allowance for differences in the power requirements of a ship between its trial condition and its 'average' service condition. The standard practice is to adopt a service margin; by adopting a fixed power margin, such that design speed is reached on trials at 80% of the normal power and this power margin is usually 25%. In the program the service margin was assumed to vary linearly from 15% at $V/\sqrt{L}$ of 0.45 to 25% at $V/\sqrt{L}$ of 1.05 as given by Cameron (86). Therefore the service margin (WEAIRA) over trial conditions is given by

$$WEAIRA = 1.075 + 0.1667 \times \frac{V_{knots}}{\sqrt{L}\ ft} \quad \text{Eq. 7.4}$$

Swift (55) 1974 found that a container ship in the North Atlantic route, taking into account the voluntary and involuntary reductions in speeds due to seakeeping and also taking into account loss in speed due to hull deterioration due to fouling and corrosion requires a service margin of 18%. For the same ship Eq. 7.4 gives a value of 18.7% which is close to the above figure of 18%. Taggert (27) gives a value of 15% for large ships on relatively smooth-water routes to 35% service margin for smaller ships on the North Atlantic route, indicating a decrease in service margin as the length of the ship increases, as in Eq. 7.4.

7.2. PROGRAM STRUCTURE

The calculation of the effective horse power and then the delivered and installed horse power is given by the flow chart in Appendix 1. Our objective is to select a propeller with maximum permissible diameter, highest propeller efficiency and lowest blade area ratio possible.

The whole program is subdivided into three parts, the main (MAIN) program containing the input, output and the CALL statements, effective horsepower calculation subroutine (EFECHP) and subroutine (POWER) to calculate the installed power and select the propeller. The program structure is shown in Fig. 7.3 together with the nature, size and the functions of the various programs in Table 7.1.

The various programs are now discussed below.

7.3. EFFECTIVE POWER ESTIMATION

A digital computer program for estimation of effective power is usually based on standard series results. However a choice must be made between true standard-series data where results are presented for a family of models varied in a logical manner and series which presents results of many model tests reduced to a logical presentation. The former group are generally difficult compared to the latter group for computerization and as pointed out earlier the latter group is to be preferred.

7.3.1. MOOR-SMALL METHOD (76)

This approach which falls into the second category was adopted in the program for computerization. Circular C (C) values for ships of length 400 feet and standard values of corresponding draft and beam are presented in a tabular form as functions of block coefficient (C_b), speed length ratio ($V/\sqrt{L}$) and longitudinal centre of buoyancy position (LCB). First the actual ship is converted to a geosim of length 400 feet and appropriate tabulated (C) is obtained based on the particular values of C_b, $V/\sqrt{L}$ and LCB position.

FIG. 7.3. MAIN STRUCTURE OF THE POWERING PROGRAM

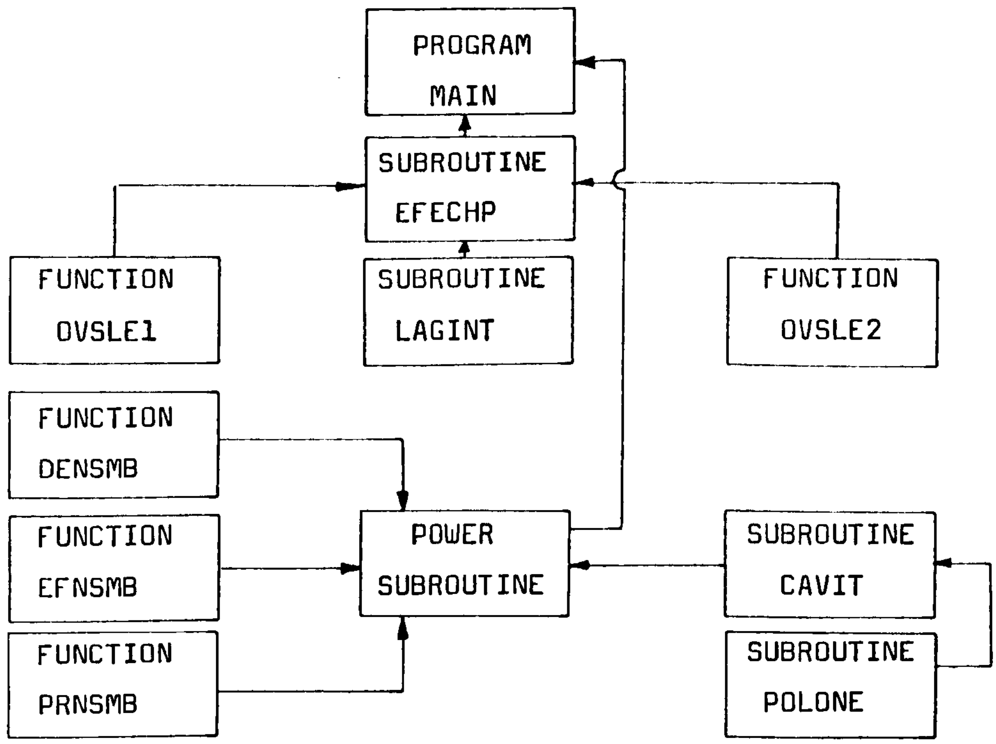


TABLE 7.1. ATTRIBUTES OF THE VARIOUS PROGRAMS.

NAME	ATTRIBUTE	OCCUPANCY SIZE,BYTES	DESCRIPTION
MAIN	PROGRAM	3245	Main program for READ, CALL and write statements. Used for validation of powering subroutine.
EFECHP	SUBROUTINE	3210	Subroutine to calculate the effective horsepower, naked hull of the ship based on method of Moor & Small
POWER	SUBROUTINE	1950	Calculates the shaft horsepower and selects the best propeller based on Wageningen B-series 5 bladed propeller.
CAVIT	SUBROUTINE	530	Check for cavitation, for selection of minimum required blade area ratio based on Burrill's chart.
LAGINT	SUBROUTINE	212	Carries out lagrangian interpolation.
OVSLE1	FUNCTION	168	Circular O values for ship of length from 30.48 m to 122 m.
OVSLE2	FUNCTION	134	Circular O values for ship of length from 122 m to 365 m.
DENSMB	FUNCTION	266	Values of delta (δ) on the optimum efficiency line.
EFNSMB	FUNCTION	266	Values of optimum efficiency (η_o).
PRNSMB	FUNCTION	266	Values of pitch/diameter ratio on the optimum efficiency line.
POLONE	SUBROUTINE	156	Value of a polynomial by nested multiplication.

This value of (C) is then corrected to the actual beam and draft by application of Mumford's indices (90, 76). Finally a skin friction correction is applied to correct for the ship's actual length to get the (C) value for the ship. The next subsection describes the program procedure in detail.

7.3.2. COMPUTER ALGORITHM

The optimum (C) values as given by Moor (78) for single screw ships and by Moor & Pattullo(77) for twin screw ships was stored as a two-dimensional array of C_b and $V/\sqrt{L}$. It was assumed that the optimum (C) values and the best position of LCB are always attainable. The (C) values are tabulated for C_b values of 0.48 to 0.78 and $V/\sqrt{L}$ of 0.40 to 1.5. Containerships usually have C_b in the range of 0.52 to 0.72 and $V/\sqrt{L}$ 0.40 to 1.20 at partial to full load draft. Where the (C) for single screw (S.S.) and twin screw (T.S.) overlap, mean of the two values is taken to be the optimum attainable. The (C) values are for a standard ship of size 400' x 55' x 18'.

The input to the program are the length bp (LBP), beam (B), design draft (T), C_b and speed V and the output is the effective horse power of the ship. For the given value of C_b and $V/\sqrt{L}$ the required value of circular (C), $(C)_m$ is calculated by interpolating first for C_b and then for $V/\sqrt{L}$. The Lagrangian method of interpolation between three points is applied for this purpose in subroutine LAGINT.

The correction for deviation of beam and draft from the standard beam of 55' and draft of 18' is done by using the Mumford's Indices (76, 90). The value of the $(C)_m$ after the beam correction is given by $(C)_1$, where

$$(C)_1 = (C)_m \times \left(\frac{400}{LBP} \times \frac{B}{55}\right)^{x\ -2/3} \qquad \text{Eq. 7.5}$$

And the value of $(C)_1$ after the draft correction is given by $(C)_2$, where

$$\text{(C)}_2 = \text{(C)}_1 \times \left(\frac{400}{LBP} \times \frac{T}{18}\right)^{Y-2/3} \qquad \text{Eq. 7.6}$$

where the value of x = 0.90 for $V/\sqrt{L}$ = 0.40 to 1.10 (78) and assumed to be the same at $V/\sqrt{L}$ = 0.40 to 1.5. A regression analysis of (Y - 2/3) and $V/\sqrt{L}$ gives

$$Y - 2/3 = 0.447 \times V/\sqrt{L_{ft}} - 0.360 \quad ; \text{(corr. = 0.981)} \qquad \text{Eq. 7.7}$$

A skin friction correction is then applied for deviation of the length from the standard length of 400'. The tabulated values of circular O, (O) versus length as given by Acevedo (91) was fitted by least squares method (50) and given by ;for 100' $\leqslant$ L $\leqslant$ 400'

$$\text{(O)} = 0.11 - 0.39 \times 10^{-3} \times L + 0.24 \times 10^{-5}L^2 - 0.81 \times 10^{-8}L^3 + 0.14 \times 10^{-10}L^4 - 0.10 \times 10^{-13}L^5 \qquad \text{Eq. 7.8}$$

and for L > 400'

$$\text{(O)} = 0.85 \times 10^{-1} - 0.37 \times 10^{-4}L + 0.26 \times 10^{-7}L^2 - 0.75 \times 10^{-11}L^3 \ldots \qquad \text{Eq. 7.9}$$

The wetted surface (S) is calculated by using Mumford's formula (76)

$$S = 1.7 \times L \times T + C_b \times L \times B \qquad \text{Eq. 7.10}$$

$$\text{(S)} = \frac{0.0935 \times S}{\Delta^{2/3}} \qquad \text{Eq. 7.11}$$

$$\text{(L)} = 1.055\ V/\sqrt{L} \qquad \text{Eq. 7.12}$$

$$\text{and (O) correction} = \text{(O)}_L - 0.0741 \qquad \text{Eq. 7.13}$$

The skin friction correction correction (SFC) from eq. 7.11, 7.12, 7.13 is

$$SFC = \frac{\text{(O) correction} \times \text{(S)}}{\text{(L)}^{0.175}} \qquad \text{Eq. 7.14}$$

Therefore the required value of circular (C) from 7.6 and 7.14 is

$$\text{(C)} = \text{(C)}_2 + SFC \qquad \text{Eq. 7.15}$$

And the effective horse power, (EHPN) is then calculated from eq. 7.15

$$EHP_N = \frac{ⓒ \times V^3 \times \Delta^{2/3}}{427.1} \text{ in H.P.} \qquad \text{Eq. 7.16}$$

7.4. PREDICTION OF DELIVERED POWER

Once the effective power of the ship is known, the power delivered to the propeller can be predicted by estimating the value of the quasi propulsive coefficient. The quasi propulsive coefficient as mentioned earlier is divided into its constituent parts and each of them is estimated separately.

$$\text{Quasi propulsive coefficient } \eta_D = \frac{EHP}{P_D} = \eta_H \eta_R \eta_O \qquad \text{Eq. 7.17}$$

and P_D = delivered horsepower.

Where η_H is the hull efficiency, η_R is the relative rotative efficiency and η_0 is the propeller open water efficiency.

The hull efficiency is determined from the wake fraction (W) and thrust deduction fraction (t).

7.4.1. PROPELLER DESIGN BY Bp-δ DIAGRAMS

The Wageningen-B series are usually used in the preliminary design stage to ascertain the propeller open water efficiency. The Wageningen-B series (82) are usually presented in the form of Bp-δ, Bu-δ or K_T, K_Q-J diagrams. Each type of presentation has its own advantages (92).

In most cases the nearest standard engine is selected, and the design problem is the choice of an optimum or near optimum propeller given the propeller rate of rotation, delivered power and advance velocity. In such a case the 'power approach' or 'marine engineer's approach' is adopted and use is made of Bp-δ diagram.

The computer algorithm has been written with a view that the propeller open water efficiency can be other than optimum. Any propeller efficiency lying away from the optimum efficiency line η_{opt} in a Bp-δ diagram is referred to as field efficiency η_0.

(a) SELECTING THE PROPELLER RPM (Revolutions per minute)

To obtain a highly efficient propeller, its RPM should be reasonably low. Since the standard engine is chosen, the propeller RPM is equivalent to the engine RPM in the case of direct drive diesel engines and in other cases the gear ratio of the reduction gear allows us to calculate the RPM. However to improve the propeller efficiency when the diameter is restricted, it is necessary to change the RPM. This can be done in the program by assigning the value 2 to the control parameter IREVLD otherwise a value of 1 is assigned.

(b) SELECTING THE DIAMETER

The propeller open water efficiency increases as the propeller diameter increases. Therefore it is logical to choose the maximum propeller diameter which fits the hull aperture after considering all clearances. To ensure enough head of water above the propeller tip such that the blades are completely immersed the diameter of the propeller is restricted to be 70% of the design draft. There are also manufacturing limitations on the largest possible diameter that can be cast. This is assumed to be 11.0 m.

(c) SELECTING THE NUMBER OF SCREWS

Single screws are more efficient than twin screws as far as the propeller efficiency is concerned. There are limitations on the amount of power that can be delivered through a single shaft. Therefore it is assumed that the maximum power that can be delivered through a single shaft is 50,000 hp. The program automatically chooses two shafts once this upper limit is reached.

(d) SELECTING THE BLADE AREA RATIO

Cavitation consideration govern the selection of appropriate value of Blade Area ratio (BAR). For maximum propeller efficiency the BAR must be as small as possible and cavitation considerations requires that the BAR must be above a minimum value. Therefore the program selects the smallest value of BAR which also satisfies the cavitation criterion. The cavitation criterion was one given by Burill (93) as permissible upper limit of back cavitation. And the line representing $7\frac{1}{2}\%$ of back cavitation was thought to be acceptable.

(c) SELECTING THE OPTIMUM EFFICIENCY

The regression equations for the 4 and 5 bladed propellers published by Van Lammeren (82) 1969 and subsequently updated by Oosterveld (83) 1975 have been used to define the optimum efficiency lines.

For a given set of design parameters i.e. rate of rotation, speed of advance and delivered power i.e. B_p, to obtain the optimum efficiency and the corresponding values of δ and consequently the optimum diameter and pitch ratio Sabit (145) gives the regression equations of the form

$$\delta,\ P/D,\ \eta_{opt} = a_0 + a_1 \ln B_p + a_2(\ln B_p)^2 + a_3(\ln B_p)^3 + a_4(BAR) + a_5(BAR)^2 + a_6(BAR)^3 + a_7(\ln B_p)(BAR) + a_8(\ln B_p)(BAR)^2 + a_9(\ln Bp)^2 BAR \qquad \text{Eq. 7.18}$$

Therefore for predetermined values of B_p and BAR, the values of η_{opt} is given by the subprogram EFNSMB and corresponding values of δ is given by the subprogram DENSMB and P/Dia. is given by the subprogram PRNSMB. The optimum efficiency lines have been defined for 5 bladed propellers in the program but can be changed to 4 simply by changing the values of the coefficients $a_0 \ldots\ldots a_9$ in Eq. 7.18 from (83).

7.4.2. FIELD EFFICIENCY

In an earlier section it was mentioned that when diameter is restricted or when there is a need to try various values of RPM the propeller efficiency may no longer lie on the optimum efficiency line. In such cases it must be possible to determine the η_0. There are no established formulae for determining η_0, so a simple empirical relationship was established which gives the value of η_0 once the value of η_{opt} is known. For an assumed BAR, the BP is calculated from given values of delivered power, rate of rotation and the speed of advance. From subroutines EFNSMB, PRNSMB, DENSMB the values of η_{opt}, the P/D and the δ at that point can be calculated.

As shown in Fig. 7.4 the Bp- δ diagram was subdivided into grids. At a particular value of Bp a perpendicular line was erected which intersects the η_{opt} line and the corresponding value of δ is read off. Next η_0 are read off at $\delta_{0.95}$ i.e. δ corresponding to optimum efficiency line x 0.95, $\delta_{0.90}$, $\delta_{0.85}$ and $\delta_{0.80}$ etc. This is repeated for more values of Bp until we get sufficient numbers of points to construct $\delta_{0.95}$ lines,and as shown in Fig. 7.4. Similarly for other BAR on a BP- δ diagram grids are constructed and the field efficiency (η_0) values read off. All these lines at $\delta_{0.95}$ to $\delta_{0.80}$ have characteristics of the η_{opt} line.

Let value of delta at η_{opt} be denoted by basic delta (δ_b) and any other value delta as δ , then knowing the values of δ_b, δ and η_{opt} the field efficiency (η_0) is given by

$$\eta_0 = \eta_{opt} - (1.5(1.0 - \frac{\delta}{\delta_b}) + 0.065) \times (1.0 - \frac{\delta}{\delta_b}) \times (\frac{\delta}{\delta_b+10}) \qquad \text{Eq. 7.19}$$

A check was made between the values of η_0 calculated by Eq. 7.19 and those lifted from the graphs (82) and found to be in good agreement. Cameron (86) first used this expression for BAR = 0.60 and it was found that it is equally applicable for BAR of 0.75 and 1.05, as shown in Table 7.2. The η_{opt} in Eq. 7.19 is defined for a particular BAR. The field efficiency η_0 can be derived for any value of BAR equal to 0.45 to 1.05 by Eq. 7.19.

Fig. 7.4. Determination of field efficiency from Bp- δ charts
(open water test results of Wageningen B-screw series).

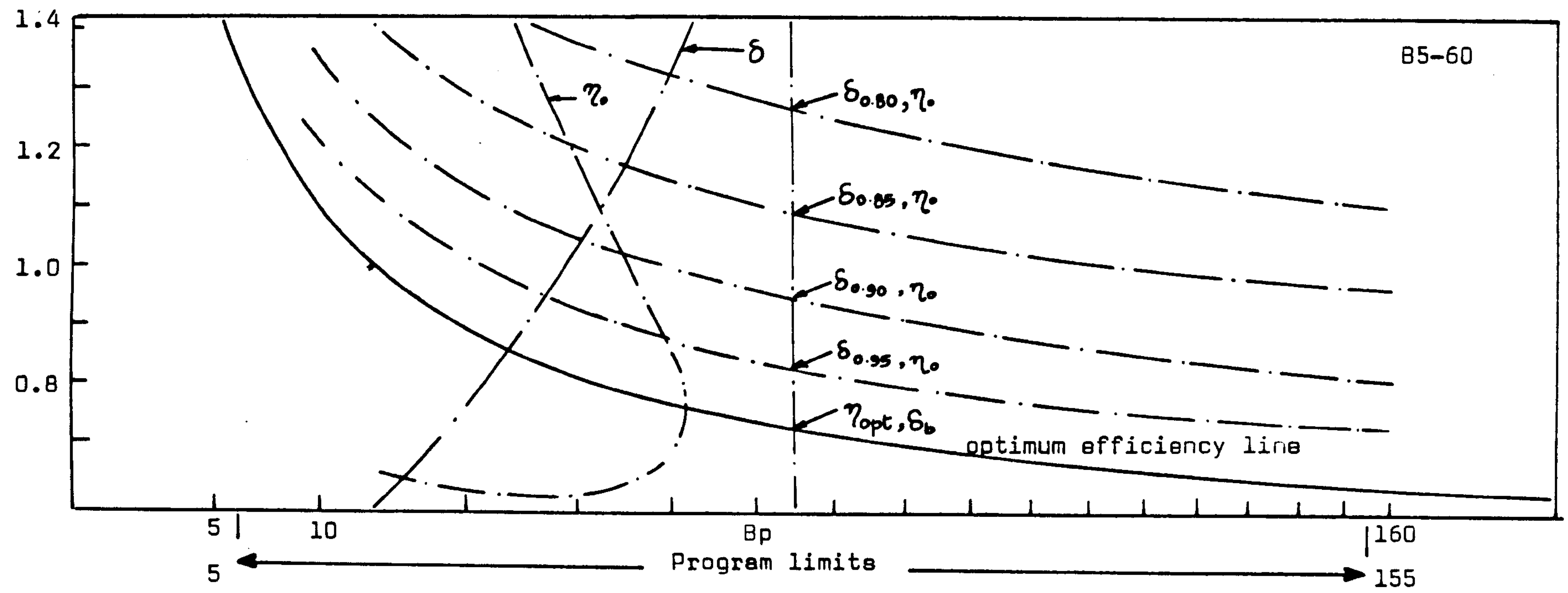


TABLE 7.2. COMPARATIVE VALUES OF FIELD EFFICIENCY (CALCULATED AND FROM BP-6 CHARTS)

Bar = 0.60	Delta (δ)	120	140	160	180	200	220	240	260	280
$\delta \times$ 1.0	η opt	0.700	0.665	0.634	0.601	0.571	0.543	0.518	0.492	
$\delta \times$ 0.95	η charts	0.696	0.660	0.627	0.595	0.563	0.535	0.510	0.486	0.46
	η cal.	0.694	0.659	0.627	0.594	0.564	0.536			
$\delta \times$ 0.90	η charts		0.648	0.614	0.580	0.549	0.520	0.495	0.470	0.45
	η cal.		0.645	0.614	0.581	0.551	0.522			
$\delta \times$ 0.85	η charts		0.629	0.592	0.558	0.525	0.500	0.474	0.450	0.43
	η cal.		0.625	0.593	0.560	0.529	0.501			
$\delta \times$ 0.80	η charts						0.472	0.448	0.425	0.40
	η cal.			0.565	0.532	0.502	0.473			
Bar = 0.75										
$\delta \times$ 1.0	η opt.	0.671	0.642	0.612	0.584	0.555	0.526	0.500		
$\delta \times$ 0.95	η charts	0.666	0.636	0.605	0.577	0.545	0.521	0.495		
	η cal.	0.665	0.636	0.605	0.577	0.548	0.519			
$\delta \times$ 0.90	η charts	0.658	0.620	0.590	0.560	0.532	0.505	0.480		
	η cal		0.622	0.592	0.564	0.535	0.505			
$\delta \times$ 0.85	η charts			0.565	0.538	0.510	0.484	0.460		
	η cal.		0.602	0.571	0.543	0.514	0.484			
$\delta \times$ 0.80	η charts					0.481	0.460	0.435		
	η cal.			0.543	0.515	0.485	0.456			
Bar = 1.05										
$\delta \times$ 1.0	η opt.	0.645	0.615	0.585	0.553	0.523	0.495	0.469	0.445	
$\delta \times$ 0.95	η charts	0.639	0.610	0.580	0.549	0.517	0.490	0.464	0.440	
	η cal.	0.639	0.609	0.578	0.546	0.516	0.488			
$\delta \times$ 0.90	η charts	0.621	0.591	0.562	0.532	0.503	0.476	0.450	0.426	
	η cal.		0.595	0.565	0.533	0.503	0.474			
$\delta \times$ 0.85	η charts			0.538	0.511	0.484	0.457	0.432	0.410	
	η cal.		0.575	0.544	0.512	0.482	0.453			
$\delta \times$ 0.80	η charts				0.489	0.459	0.432	0.408	0.385	
	η cal			0.516	0.484	0.454	0.425			

7.4.3. CALCULATION OF WAKE, THRUST DEDUCTION AND RELATIVE ROTATIVE EFFICIENCY (84, 86)

For single screw

$$\text{Wake} = 0.1 + \frac{W_1}{W_2} \times W_3$$

$$\text{where } W_1 = \frac{4.5 \times B \times C_b^2}{L \times C_W \times C_{\blacksquare}}$$

$$W_2 = \left(7.0 - \frac{6 \times C_b}{C_W}\right)\left(2.8 - \frac{1.8\ C_b}{C_{\blacksquare}}\right)$$

$$W_3 = 0.5 \times \left(\text{dia.} \times \frac{0.625}{T} - 0.873 - \frac{\text{dia.}}{B}\right)$$

Thrust deduction = wake x $\left(0.5 + 0.4 \times \left(\frac{V}{\sqrt{L}} - 0.5\right)\right)$ Eq. 7.21

Relative rotative efficiency = 1.02 Eq. 7.22

Twin screw

Wake = 2 x $C_b^5(1.0 - C_b) + 0.2 \times 0.866^2 - 0.02$ Eq. 7.23

Thrust deduction = 0.25 x wake + 0.14 Eq. 7.24

Relative rotative efficiency = 0.985 Eq. 7.25

7.4.4. DESIGN PROCEDURE

The program accepts as input the speed (V), length (L), Beam (B), block coefficient (C_b), draft (T), the effective power (naked hull), the rate of rotation (RPM), and the control parameter IREVLD. The program logic is given by a flow chart of subroutine POWER in Appendix 1. The design problem can be formulated as; given the rate of rotation and the delivered power, to select a propeller of the largest possible diameter and the smallest blade area ratio with constraints on diameter, RPM and cavitation.

The design procedure for the choice of the appropriate propeller is iterative in nature. A certain value of quasi -propulsive coefficient is assumed to get the approximate value of shaft horse power (SHP) from EHP_N. The SHP is assumed to be 1.5 times the EHP_N, an initial value of propeller efficiency of 0.1 and blade area ratio of 0.60. The initial approximation of SHP decides the number of propellers. A value of SHP higher than 50,000 hp is assumed to be delivered on twin shafts. The values of wake Eq. 7.20 or 7.23, thrust deduction Eq. 7.21 or 7.24, relative rotative efficiency Eq. 7.22 or 7.25 and B_p are determined. The B_p is constrained to lie between a value of 6 to 155 this being the range of the η_{opt} line in a BP- δ diagram. The η_{opt}, Pitch-diameter ratio (P/Dia)and the value of the δ_b is determined from the calculated value of B_p and assumed BAR. From basic value of delta (δ_b), the propeller diameter is calculated and given by

$$\text{propeller dia.} = \delta_b \times \frac{V_a}{\text{rpm}} \qquad \text{Eq. 7.26}$$

If the diameter is greater than either 0.70 x T' or 28' than the lesser of the two values is taken as the new propeller diameter. In such a case the propeller efficiency obviously lies away from η_{opt} line, therefore the value of δ is recalculated from the new diameter. The field efficiency η_0 is calculated from Eq. 7.19. If the propeller efficiency (PFNEW) is less than that assumed earlier, this is accepted as the correct value and the program then goes on to check for cavitation. However the initial value of propeller efficiency (PFBNEW) is kept at 0.1 so that absurd values of propeller efficiency are not calculated.

The value of quasi propulsive coefficient (QPC) is calculated with the value of PFNEW, hull efficiency and RRE and the new value of shaft horse power (SHPNEW) is calculated.

$$\text{SHPNEW} = \frac{EHP_N}{\text{NOPROP}} \times \text{CF} \times \frac{\text{WEAIRA}}{\text{QPC}} \quad \text{H.P.} \qquad \text{Eq. 7.27}$$

This value of Shp (SHPNEW) is compared to the initial value of the Shp which was calculated assuming SHP = 1.5 x EHP_N. If the difference in the two values of the shaft horse power is greater than 3% of the SHP then the new value of Shp (SHPNEW) becomes the initial approximation to the shaft -horse power and the whole procedure is repeated until the difference between successive values of shaft horse power is less than 3%.

If the diameter restrictions exist, the only way to absorb the necessary power is to increase the RPM. The user can input through the control parameter IREVLD = 2 an increase in the RPM.

The propeller RPM is increased in steps of 15% of the initial value and the last value of propeller efficiency (PFNEW) is taken as the starting point of the iteration and the value of B_p recalculated. When the successive values of the propeller efficiency are within 3% of each other the iterations on RPM stop and the new value of the propeller efficiency and the RPM is output.

The cavitation check is made for the initial assumption on BAR. A 7½% back cavitation is accepted as the upper limit which gives an acceptable blade area ratio (DBAR). If the developed blade area ratio (DBAR) is less than that assumed initially the design is accepted. Otherwise the iteration is restarted with a new value of blade area ratio equal to DBAR. The acceptable range of blade area ratio is 0.45 to 1.05.

The machinery derating and the mechanical losses is assumed to be 10% of the calculated power.

7.5. SHAFT POWER VALIDATION

To validate the horse power given by the program, over a wide range of ship size and speed, data from (57, 94) were taken. The ship size varies from 600 TEU to 3000 TEU and speed from 18 to 27 knots. As shown in Table 7.3, the shaft horse power calculated by the program and those from (57, 94) are in close agreement giving a mean error of 4.95% and standard deviation of 8.07%.

TABLE 7.3. Comparison of shaft horse power.

Speed in Knots	18		19		21		23		25		27	
Container Capacity TEU	Ref. 57,94	Program	Ref. 57,94	Program	Ref. 57,94	Program	Ref. 57,94	Program	Ref. 57,94	Program	Ref. 57,94	Program
600	15100	13265 (12.15)	18000	15419 (14.34)	22400	21626 (3.45)	28200	27298 (3.19)				
750	18000	15745 (12.53)	20600	18217 (11.56)	26100	24647 (5.57)	31600	32526 (−2.93)				
1000	18300	17598 (3.83)	21100	19093 (9.51)	27000	24233 (10.24)	33500	34539 (−3.10)	41000	27110x2 =54220 (32.24)		
1250			24083	22550 (6.36)	30000	28081 (6.39)	36545	38589 (−5.59)	48299	26993x2 =53986 (11.77)	31027x2 =62054	35100x2 =70200 (13.12)
1500							40046	38273 (4.43)	49517	26684x2 =53368 (−7.77)	34828x2 =69656	35654x2 =71308 (−2.37)
1750							–					
2000			32000		41200	41410	49228	49424 (−0.398)	33386x2 =66772	33635x2 =67270 (0.745)	40603x2 =81206	43207x2 =86414 (−6.41)
2250												
2500							31978x2 =63956	30648x2 =61296 (4.16)	39862x2 =79724	37536x2 =75072 (5.83)	48546x2 =97092	49625x2 =99250 (−2.22)
2750												
3000			38500		49000		32218x2 =64436	32054x2 =64108 (0.509)	41028x2 =82056	38351x2 =76702 (6.52)	48771x2 =97542	48441x2 =96882 (0.676)

Note: Figures in brackets indicate the % difference from actual, mean error = 4.95%, Std. Dev. = 8.07%, Variance 63.08.
Power in British horse power units.

CHAPTER 8

DEADWEIGHT AND CAPACITY ESTIMATES

8.0 INTRODUCTION

In the program the main dimensions L, B, T, D and C_b are systematically varied to generate a number of designs which satisfy all the constraints. Since the displacement is known and the lightship weight can be calculated from these main dimensions, the deadweight of the ship can be ascertained. The deadweight is then apportioned into its constituent elements to estimate the cargo deadweight. Since most of the deadweight items like fuel, fresh water, stores are dependent on the time spent at sea and/or port an estimate of time spent at sea and port is required.

Once the weights of fuel, fresh water, stores have been estimated a check has to be made to ascertain if there is adequate space to carry these. Besides fuel and fresh water, containerships usually require some space to carry temporary/permanent ballast to improve the stability. The estimate of round voyage time, cargo deadweight estimate and the capacity estimates are discussed in turn.

8.1. ROUND VOYAGE TIME

The round voyage time is composed of

(a) Sea time for transiting the distance between each ports of call.

(b) Port time for berthing/unberthing and loading and unloading.

(c) Delays in port due to unforeseen circumstances.

<u>Time at sea</u>

In the program the time at sea (DAS) in days/round trip is calculated from the following equation

$$DAS = DIST/(24 \times V_s) \quad \text{in days} \qquad \text{Eq. (8.1)}$$

where DIST = round trip distance between ports in nautical miles, and V_s = service speed in knots.

Swift (55) introduces an approach where the 'expected speed' is determined taking into account the deterioration in speed with age due to hull fouling and corrosion, and loss in speed due to voluntary or involuntary speed reduction to maintain the seakeeping performance of the ship. Such a model will require extensive data on the intended route and weather conditions.

Hancock (54) in a containership study takes into account the speed made good, inbound and outbound from Benford's (51) equation for speed increase or reduction due to change in deadweight. Frankel & Marcus (53) used the same equations for the containership model developed for MARAD (Maritime Administration).

Fortson (40) gives a similar type of expression for service speed reduction given the calm water design speed. Erichsen (39) takes a more simplistic view taking the speed loss of 3.5% of the service speed for containerships on the North Atlantic route.

However in this thesis a much more simplistic approach has been adopted. A service margin is included in the installed power so as to maintain the design speed under most weather conditions and also to take into account the deterioration in speed with age of the ship due to hull fouling and corrosion. The power service margin is given in Section 7.1 by Eq. (7.4).

Time in port

There are three basic approaches to estimating the time spent in port:

(a) Analytical methods

In this approach the container port facilities and operations is simulated by Queuing theory. UNCTAD (12), Novaes & Frankel (97) and Nehrling (98) employ such an approach for container ship and terminal simulation. However these models require extensive input data on terminal and ship operations.

(b) Methods based on average values

This is the usual method employed in most containership studies. The total time spent in port is composed of

(i) Time spent in berthing and unberthing of the ship.

(ii) Time spent in loading and unloading of containers.

(iii) Delays in port due to unforeseen circumstances, such as, waiting for an empty berth at a congested port, tidal variations in the approach channel, lower productivity due to inefficient use of resources.

Such an approach was adopted by Erichsen (39) and Hancock (54) in their containership study.

The time to berth/unberth a ship is usually taken as constant value, e.g. 3 hours/port of call (39). The time spent in loading and unloading containers is based on an average container handling rate of 12.5 - 25 lifts/hr (39,54) and that the ship discharges all its cargo at that port (54) or a part of the cargo is discharged at port (39). This leads to the assumption that larger ships spend more time at port. Delays in port are taken as a constant value e.g. Erichsen (39) assumes 2 hours/port of call.

(c) Methods based on statistical analysis

The turnaround time in port is estimated by carrying out statistical analysis of actual port and ship data. Regression analysis is performed on actual data to investigate the relation between ship size, cargo loaded and unloaded and ship turnaround time in port. Edmond and Maggs (99) carried out such an analysis on data of 5 U.K. container terminals. Ross (100) carried out a similar analysis on a container terminal in Hong Kong.

It is difficult to develop any general formula which reflects the conditions at various ports. This is evident from the general conclusions reached by Edmond and Maggs (99) and Robinson (100). Whereas Robinson concludes that larger vessels turnaround more quickly than the smaller vessels, Edmond and Maggs conclude that turnaround time of container ships are extremely varied, and that there are no satisfactory simple linear relationships between the turnaround time and ship size or cargo handled.

Edmond and Maggs found that turnaround time can be predicted by the following equation

$$\text{Turnaround time} = 17.5 + 0.0558 \times \text{number of containers handled} \quad \text{hours} \qquad \text{Eq. (8.2)}$$

And Eq. (8.2) gave reasonable values of the turnaround time compared to turnaround time as a function of ship size or handling rate. Therefore Eq. (8.2) was adopted in the program to calculate the time in port.

To calculate the number of containers handled in each port the method given by Edmond & Maggs (99) was adopted and is described below.

(a) The ship's container capacity in TEU was multiplied by the maximum load factor i.e. maximum of the outbound load factor (ALFO) or the inbound load factor (ALFI) and is given by

$$\mathrm{ALFMAX} = \text{maximum of } (\mathrm{ALFO},\ \mathrm{ALFI}) \qquad \text{Eq. (8.3)}$$

(b) The total number of containers handled (CONTHA) is

$$\mathrm{CONTHA} = \mathrm{CNT} \times \mathrm{ALFMAX} \times 4.0 \quad \mathrm{TEU} \qquad \text{Eq. (8.4)}$$

The factor 4.0 indicates that the containers are loaded and unloaded at each end of the sea leg, giving a factor of 2, and a further factor of 2 for the round voyage.

(c) Then the number of containers at each port of call (CONTHP) is

$$\mathrm{CONTHP} = \mathrm{CONTHA}/\mathrm{NPORT} \quad \mathrm{TEU} \qquad \text{Eq. (8.5)}$$

where the total number of ports NPORT = PORTD + PORTF, and is limited to 12.

PORTD = number of home ports

PORTF = number of foreign ports

(d) Then total number of days in port per voyage is

$$\mathrm{DIP} = (17.5 + 0.0558 \times \mathrm{CONTHP}) \times (\mathrm{PORTD} + \mathrm{PORTF})/24.0 + \mathrm{DELAY} \quad \text{days} \qquad \text{Eq. (8.6)}$$

where DELAY = delays in port which is input by the user. In the program no delay in port is assumed for the parametric study i.e. DELAY = 0.

<u>Round voyage time</u>

The round voyage time in days (RVYTIM) is calculated from Eq. (8.1) and Eq. (8.6) and is given by

$$\mathrm{RVYTIM} = \mathrm{DIP} + \mathrm{DAS} \quad \text{days} \qquad \text{Eq. (8.7)}$$

The ship is assumed to be offhire for 15 days in a year for dry docking, general repairs, maintenance etc. Therefore the number of round trips/annum (RTPA) is

$$RTPA = 350/RVYTIM \qquad \text{Eq. (8.8)}$$

and days at sea per annum (DASPA) and days in port per annum are (DIPPA)

$$DASPA = DAS \times RTPA \quad \text{days} \qquad \text{Eq. (8.9)}$$

$$DIPPA = DIP \times RTPA \quad \text{days} \qquad \text{Eq. (8.10)}$$

The above calculations are carried out in the subroutine subprogram VOYTIM.

8.2. CARGO DEADWEIGHT ESTIMATES

The cargo deadweight is calculated by subtracting the light shipweight and the following items of deadweight from the displacement

a) Weight of crew and effects
b) Weight of fresh water
c) Weight of stores and provisions
d) Weight of heavy fuel oil, diesel oil and lub. oil
e) Weight of ballast

and are estimated as described below.

8.2.1. Weight of crew and effects

The total number of officers (OFF), petty officers (PO) and crew (CREW) is input by the user, therefore total crew (TMAN) is

$$TMAN = OFF + PO + CREW$$

and the weight of crew and effects (WTCREW) is given by

$$WTCREW = TMAN/6.0 \quad \text{tonnes} \qquad \text{Eq. (8.11)}$$

Eq. 8.11 was taken from Benford (51).

(b) Weight of fresh water

The weight of fresh water (WTFW) required is assumed to be 0.167 tonnes per man per day at sea (51)

$$WTFW = 0.167 \times TMAN \times DAS \quad \text{tonnes} \qquad \text{Eq. (8.12)}$$

8.2.2. Weight of provisions and stores

The weight of provisions and stores (WTSTOR) is assumed to be 0.01 tonnes per man per day at sea (51)

$$WTSTOR = 0.01 \times TMAN \times DAS \quad \text{tonnes} \quad \text{Eq. (8.13)}$$

The weight of crew and effects, weight of fresh water and the weight of provisions and stores is termed as the miscellaneous weight (WTMISC) and is given by

$$WTMISC = WTCREW + WTFW + WTSTOR \quad \text{tonnes} \quad \text{Eq. (8.14)}$$

and the centre of gravity (FKGMX) of these miscellaneous weights is assumed to be (37, 106)

$$FKGMX = 1.0 \times D \quad \text{m.} \quad \text{Eq. (8.15)}$$

These are calculated in the subroutine subprogram PAYLOD.

8.2.3. Weight of fuel

The endurance (ENDUR) is assumed to be half the round voyage distance (DIST), but the user can specify as input other values of ENDUR.

Fuelling range (FRANGE) is given by

$$FRANGE = ENDUR/(240 \times V)$$

The procedure adopted is given by Buxton (101) and Femenia (102)

(i) Weight of fuel consumed at sea

Weight of main engine heavy fuel oil (WFMAIN) = SFC x

$$SHP \times 0.90 \times FRANGE \times 1.10 \times 24 \times 10^{-6} \quad \text{tonnes}$$

where SFC is the specific fuel consumpstion. Eq. (8.16)

Weight of auxiliary engine diesel oil (WDAUXS) = SFC x

$$AUXKW \times 1.34 \times \frac{0.5}{0.95} \times FRANGE \times 10^{-6} \quad \text{tonnes}$$

Eq. (8.17)

Weight of main engine system luboil (WLSYS) = 0.26 x SHP x

$$0.90 \times 24.0 \times FRANGE \times 10^{-6} \quad \text{tonnes} \quad \text{Eq. (8.18)}$$

Weight of main engine cylinder Luboil (WLCYLS) = 0.37 x

$$SHP \times 0.9 \times 24 \times FRANGE \times 10^{-6} \quad \text{tonnes} \quad \text{Eq. (8.19)}$$

Total weight of Luboil consumed at sea (WTLUBS) = WLSYS + WLCYLS tonnes Eq. (8.20)

(ii) Weight of fuel consumed in port

Weight of auxiliary engine diesel oil (WDAUXP) = SFC x

$$AUXKW \times 1.341 \times \frac{0.75}{0.95} \times 24 \times DIP \times 10^{-6} \text{ tonnes} \quad \text{Eq. (8.21)}$$

Weight of auxiliary engine Luboil (WTLUBP) = 1.29 x AUXKW x

$$1.341 \times \frac{0.75}{0.95} \times 24 \times DIP \times 10^{-6} \text{ tonnes} \quad \text{Eq. (8.22)}$$

(iii) Therefore total weight of heavy fuel oil (WTFUEL) = WFMAIN tonnes Eq. (8.23)

Weight of diesel oil (WTDESL) = WDAUXS + WDAUXP tonnes Eq. (8.24)

Weight of Luboil (WTLUB) = WTLUBS + WTLUBP tonnes Eq. (8.25)

and the total weight of fuel (TWFUEL) = WTFUEL + WTDESL + WTLUB Eq. (8.26)

The following assumptions are made for calculating the weight of fuel.

(i) The main engine is a low speed direct drive diesel installation, continuous service rating is 90% of the maximum continuous rating, the specific fuel consumption is 162 +gm/HP hr (101) and carries a reserve fuel of 10% of the weight of fuel.

(ii) Auxiliary machinery is composed of two medium speed geared drive diesel with one of them as standby. The installed capacity of each of these generators (AUXKW) is 1500 KW. For refrigeration machinery the installed capacity would be higher and can be specified by the user as input. The auxiliary engine operates at 50% of the maximum continuous rating at sea and at 75% in port and the efficiency is 95% (102). The specific fuel consumption is 162 gm/HP.hr (101).

(iii) The luboil consumption in port and at sea is calculated on the basis of the following specific fuel consumption

+ Recent improvement in specific fuel consumption has lowered this to 135.

Auxiliary engine (in port) = 1.29 gm/HP.hr., Femenia (102)
Main engine cylinder (at sea) = 0.37 gm/HP.hr, Buxton (101)
Main engine system (at sea) = 0.26 gm/HP.hr, Buxton (101)

(iv) The main engine heavy fuel oil consumption in port is 24 tonnes/day and comes out of the reserve fuel (101).

The total fuel weight (TWFUEL) is calculated in the subroutine subprogram FEULWE.

8.2.4. Weight of ballast

Container ships must have adequate ballast capacity to improve their initial stability and hence increase their ability to carry more containers on deck. However carrying additional ballast means that the cargo deadweight capacity decreases, therefore average weight per container decreases, though the number of containers increases (see Section 13. 2).

The user can specify if ballast is to be carried by assigning a value of 1 to the control parameter IBALAS. The amount of ballast is specified by giving a value to ABALAST, which is taken as a percentage of the total displacement.

The cargo dead weight (CDWT) is given by

$$CDWT = DISPL - (WTCREW + WTFW + WTSTOR + TWFUEL + WTLT) \quad \text{tonnes} \quad \text{Eq. (8.27)}$$

and assuming homogeneous loading per container,

weight of each container (WEC) = CDWT/CNT tonnes Eq. (8.28)

where DISPL = displacement of the ship tonnes Eq. (8.29)

8.3. CAPACITY ESTIMATES

The total volume capacity is generally divided into volume under the deck and volume above the deck. At the preliminary design stage while comparing alternative ship design only the former is estimated. The latter is usually required for general arrangement plans etc. The under deck volume capacity is subdivided into

(a) the hold volume (b) engine room volume (c) volume of peaks (d) volume of double bottom (e) volume of wing tanks (f) volume of deep tank, if any.

The estimation of under deck volume however requires knowledge of the hull form, which can either be derived from offsets or assuming a standard hull form. Kupras (48) uses volume coefficients of the whole ship, of the engine room and of double bottom, which are derived from series 60 hull form and block coefficient of 0.70 to 0.84. These volume coefficients are multiplied by the main dimensions of the ship e.g. L, B, T, D, C_b which are known at the preliminary design stage and corrections for camber, sheer, fore peak, cargo hatches, wing tanks are introduced using simple geometrical relationships. You and Rengyi (103) have developed similar volume coefficients for the BSRA series hull (C_b = 0.65 to 0.80) to represent medium V section hull form, and series 60 hull to represent ships with U section hull form (104). A simpler approach based on assuming a sectional area curve up to the upper deck is given by Cameron (86), and Watson & Gilfillan (35) give design charts for estimating the under deck volume based on main particulars only.

The volume of the machinery space can be deduced from Watson & Gilfillan (35), Cameron (86), Taggert (27), Sen (41), Kupras (48), You & Rengyi (103) for ships with various types of machinery installation. The volume of the peaks can be deduced from Sen (41), Kupras (48) and You & Rengyi (103). Wing tank spaces can be deduced from You & Rengyi (103). The volume of the double bottom can be deduced from You & Rengyi (103), Sen (41), Kupras (48), Lamb (105), Mandel & Leopold (106) or Chryssostomidis (37).

The hold volume is then calculated by subtracting the volume of the machinery space, peaks, double bottom and wing tanks. Assuming certain space losses, the number of containers in the hold can be estimated.

However in container ship studies, the hold capacity can be estimated easily by statistical analysis of under deck container capacity of existing containerships (see Section 13.2.1.). The length of the peaks are estimated as a percentage of the L_{BP}, the machinery room length as a function of SHP (see Section 5.4), therefore only the volume of the double bottom and wing tank has to be estimated. This approach was preferred compared to the above approach because of the lack of good estimating equations for lower block coefficient.

Table 8.1 gives the actual capacity of wing tank spaces, double bottom spaces, fore peak spaces, miscellaneous tank spaces and settling tank spaces.

<u>Volume of double bottom</u>

The volume of the double bottom spaces (VOLDB) is given by (37)

$$VOLDB = L \times B \times DBHM \times C_b \times 0.69 \quad m^3 \qquad \text{Eq. (8.30)}$$

Table 8.2 shows the comparative evaluation of double bottom volume by different estimating equations together with double bottom volume of some actual ships (Table 8.1). All the equations gave good results, the equation developed by Chryssostomidis (37) was selected because it was used previously in a containership study.

The weight of fuel in double bottom (WFDB) is then

$$WFDB = VOLDB \times 0.95 \quad \text{tonnes} \qquad \text{Eq. (8.31)}$$

Assuming space lost due to framing etc., the stowage coefficient of fuel oil is 0.95 t/m^3.

The weight of fuel oil in settling tank was assumed to be 166 tonnes (106, 37). The rest of the fuel oil was assumed to be in the double bottom spaces. A check is made with the amount of oil that can be carried in the double bottom spaces (Eq. 8.31). If the space is insufficient, the rest of the fuel oil is carried in the wing tank spaces.

The centre of gravity (FKGFB) of the fuel oil/and ballast in double bottom spaces is given by (37, 106)

$$FKGFB = 0.67 \times DBHM \quad m. \qquad \text{Eq. (8.32)}$$

and the centre of gravity (FKGFD) of the fuel oil in the settling tank is given by (37)

TABLE 8.1. Double bottom, wing tank, forepeak and aft peak capacities.

Ship's Name	Double bottom capacity m^3	Settling tank capacity m^3	Wing tank capacity m^3	After peak capacity m^3	Fore peak capacity m^3	Hold length m	Double bottom height (DBHM) m	Fore peak length m	Aft peak length m	Miscell-aneous tank m^3	Total capacity m^3
1. Coloumbus New Zealand	3226	313	5930	-	599+	121.693	1.8	9.186	12.2	-	10068
2. Euroliner	4154	783	9746	706	714	183.15	1.7	12.68	2.44	241	16344
3. Tokyo Bay	6495	985	10799	817	463	221.32	1.96	12	4.5	269	19828
4. Sealand Galloway	10758	1022	No wing tk2399	559	600	210.45	2.0	15.86	7.014	-	15338
5. Astronomer	2045	290	1824NA	-	-	-	1.7	-	-	233	-
6. C.P.Voyageur	2144	128	5088	38	295	102.33	1.35	12.95	7.32	181	7874
7. Encounter Bay	4048	195	4651	163	272	-	1.55	-	-	-	9329
8. Selandia	7249	656	18789	-		200.16	1.70	18.47	4.8	518	27211
9. Taeping	7247	487	6254	456	575	-	1.55	-		93	15112
10. Oriental Class	3787	307	7320	399	614	130.98	2.0	14.70	8.82	336	12765

$$FKGFD = DBHM + 0.60\,(D-DBHM) \quad m \qquad \text{Eq. } (8.33)$$

Most of the parametric study is carried out for ships without temporary or permanent ballast. If some ballast is to be carried, to improve the ship's stability, it is assumed that the space remaining after providing adequate space for fuel can be used for ballast.

TABLE 8.2. Comparative evaluation of double bottom volume.

Extent of double bottom (L-Lpp)	Lamb (105)		Mandel & Leopold (106)		Kupras (48)		Chryssostomidis (37)
m	K_3	Double bottom m^3	settling tank m^3	double bottom m^3	CBDB	double bottom m^3	double bottom m^3
1. 156.614	0.57	2471	160	3360	0.372	3496	3400
2. 209.84	0.60	3532	"	5333	0.409	4697	4353
3. 257.82	0.654	6163	"	9694	0.476	8435	7266
4. 245.50	0.585	4975	"	6784	0.434	7503	6416
5. 173.79	0.684	3858	"	5188	0.496	5018	4323
6. 132.73	0.717	2131	"	2896	0.507	2679	2364
7. 192.02	0.660	3592	"	4818	0.471	4744	4173
8. 234.33	0.594	4152	"	8085	0.429	7111	5302
9. 172.80	0.624	2505	"	4546	0.433	3928	3569
10. 168.48	0.684	3715	"	3734	0.487	3770	4271

TABLE 8.2. (Contd.).

Lamb ,	Double bottom volume = $(L_{BP}-L_{pp}) \times B \times DBHM \times C_b \times K_3 .. m^3$, and $K_3 = 1.2\ C_b - 0.06$, L_{pp} = combined peak length in m.
Mandel & Leopold,	Double bottom volume = $L_{BP} \times B \times D \times K_6 \times K_9 \times 0.69 \times C_b\ ..m^3$ $K_6 = 0.11$, $Kg = 0.986$
Kupras,	Double bottom volume = $L_{BP} \times B \times DBHM \times C_{BDB} ...m^3$, $C_{BDB} = 2.068 \times \left(\frac{DBHM}{T}\right)^{0.5} - 1.5004 \times \left(\frac{DBHM}{T}\right) - 1.265 \times (0.70 - C_b)$
Chryssostomidis,	Double bottom volume = $L_{BP} \times B \times DBHM \times C_b \times 0.69\ ..m^3$

CHAPTER 9

SHIPBUILDING COSTS

9.0. INTRODUCTION

The cost estimation process can be categorised into the following three stages (107):

(a) Feasibility study (or preliminary or budget estimate)

(b) Design study (or detailed investigation)

(c) Fully detailed estimate

The first stage feasibility study or preliminary design study is what this thesis is concerned about. It is concerned with ranking different alternative ship designs on the basis of some merit criterion. At this stage absolute values are not that important but the cost must reflect the right magnitude of differences in the cost of alternatives.

The second stage is undertaken at a stage when a smaller number of alternatives, which are very near to the optimum design are compared.

In the third stage fully detailed estimate is carried out at tendering stage, when sufficient technical and economical data will be available for the proposed design. This type of study is usually undertaken by professional cost estimators who have recourse to considerable amountsof data on the same or similar designs. In this thesis we are concerned only with the first stage or feasibility study.

Usually in this type of study the cost grouping is

(i) Steel

(ii) Outfit and hull engineering

(iii) Machinery

These may be further categorised into

(a) Material (b) Labour

(iv) Overheads and other expenses

The method adopted in this thesis is that developed by Carreyette (108) 1978 and the costs are at early 1980 level in pounds sterling and reflecting the cost of containership built in an average U.K. shipyard.

Wherever possible the data have been checked with other methods and the results show good agreement. Finally it is shown that the model is quite simple to be updated.

First the labour costs are established, then the material costs and then the overheads, certain assumptions are made regarding profit to get the overall ship cost.

9.1. LABOUR COSTS

The labour costs can be subdivided as pointed out earlier into,

(i) Steel labour manhours and costs

(ii) Outfit labour manhours and costs

(iii) Machinery labour manhours and costs.

Total labour manhours are the basis of all direct labour costs, and once estimated, it is only necessary to apply wage rates prevailing in that year to get a fairly good estimation of labour costs. This is the approach adopted in this model, total manhours are validated with other methods and then the wage rates are applied to calculate the labour costs associated with steel, outfit and machinery respectively.

9.1.1. STEEL LABOUR MANHOURS AND COSTS

For the steel labour costs, the steel labour manhours were validated with another method, developed by K.R. Chapman (46) in 1970.

Steel labour manhours:

Method 1: This formula was suggested by Chapman (46), and the steel labour manhours (SWLMH1) is given by

$$SWLMH1 = 1072 \times (GSTWT)^{0.71} \text{ hours} \qquad \text{Eq. 9.1}$$

where GSTWT = Gross steel weight including forging and castings and scrap in tonnes.

The guide labour man hours (GWLMH1) is estimated separately, because it takes longer to fabricate and erect the guide structure

$$GWLMH1 = 314.96 \times GWT \quad \text{hours} \qquad \text{Eq. 9.2}$$

where GWT = weight of guide structure in tonnes.
Eq. 9.1 and Eq. 9.2 was used in containership study by Erichsen (39), Swift (55) and Volker (61).

<u>Method 2</u>: This formula was suggested by Carreyette (108) and is used in the computer program to estimate the steel labour manhours. The steel labour manhours from a variety of sources was related to the steel weight by the following relationship

$$K = R_h \; C_b \; (W_s/L_{BP})^{1/3} \qquad \text{Eq. 9.3}$$

where R_h = actual labour manhours per tonne of steel,
C_b = block coefficient at summer loaded draft,
W_s = Net steel weight in tonnes and
L_{BP} = Length bp in metres

K is constant for a shipyard but would vary between shipyards. Carreyette uses a value of K = 227, which he feels is high because of the mixed nature of type of ships, and gives a value of K = 180 for any shipyard building one-or-two types of ships.

Using K = 227 and rearranging equation (9.3)

Steel labour manhours SWLMH2 = $R_h W_s = 227 \; W_s^{2/3} \; L^{1/3}/C_b$ hours

Eq. 9.4

For ships with known steel weight and guide weight, the steel labour manhours was calculated by Method 1 and Method 2 and are as shown in Table 9.1. For Method 1 the guide labour manhour was calculated separately. It is not indicated in Method 2 that the guide labour manhours are included. Chapman's labour manhours were found to be less than Carreyette's labour manhours (see Table 9.1). Compared to a constant value of K = 227 as assumed in Method 2, Method 1 gives the value of K between 177 to 219, i.e. there is a variation of 3.5% to 22% in the steel labour manhours. Thus it is assumed that guide labour manhours can be included in the total steel labour manhours by including the weight of the guide structure in the net steel weight.

TABLE 9.1. Comparison of steel labour manhours.

No.	TEU	LBP	Net Steel wt.	C_b	GW 1. Guide weight	CHAPMAN			CARREYETTE Total M/H	Calcul. K
						Steel 2. Labour	Guide 3. Labour	Total M/H		
1	1200	215.12	10446	0.558	485	756415	150350	906765	1164801	177
2	1512	212.44	8718	0.599	600	665275	186000	851275	957830	202
3	1600	185.00	6650	0.500	632	548920	195920	744840	916635	185
4	2000	215.00	5700	0.521	776	664300	240560	904860	1104106	186
5	2400	250.00	11500	0.538	918	809843	284580	1094423	1354218	183
6	1800	259.08	14427	0.558	705	951307	218550	1169857	1536927	173
7	928	177.10	4629	0.628	383	424425	118730	543155	563806	219
8	1336	206.3	8761	0.587	535	667604	165850	833454	971082	195
9	1712	234.40	10058	0.631	672	736358	208320	944678	1033530	207

1. Guide Wt. = $0.713 \times N^{0.92} = GW$
2. Steel labour MH = $1060 \times WS_G^{0.71}$
3. Guide labour MH = $310 \times GW$
4. Steel labour MH = $227 \times WS^{2/3} L^{1/3} / C_b$

Indeed Carreyette in his paper mentions that the value of $K = 227$ is rather high due to the mixed nature of his sample of ship type, which includes small tugs to large bulk carriers, and that a shipyard specialising in building a few ship types will have a value of $K = 180$.

In the thesis it is assumed that the shipyard is not a specialist yard and therefore will have a value of $K = 227$.

Steel labour costs

To convert steelwork labour man-hours to total steel work labour costs, it is necessary to apply an average wage rate (reflecting both skilled and unskilled trade), overheads and profit. The 1980 average shipyard wage rate was £2.40/hour. This can be conveniently updated by using current wage rates published in (109). Fig. 9.1 shows the average hourly rate in shipbuilding industry since 1969, from £0.5768/hr in 1969 to £2.4/hr in 1980 - a four fold increase in eleven years.

Steel labour costs (CSL) is given by (108) from eq. (9.4)

$$CSL = \frac{A_1 \times W_s^{0.667} \times L^{0.334}}{C_b} \quad £ \qquad \text{Eq. (9.5)}$$

where A_1 is a constant which includes the wage rate, overhead, profit margin and the value of K. If $K = 227$, overheads are 100% and profit margins are 10% then

$$A_1 = 2.4 \times 227 \times 2.0 \times 1.10 = 1198.56 \qquad \text{Eq. (9.6)}$$

The values of A_1 are plotted against this wage rate in £/hr for various overheads in Fig. 9.2. The value of A_1 can be given by the following equation, for different wage rates and overheads for $K = 227$ and profit margin of 10%.

$$A_1 = WR \times (437.5 + 62.5 \times (0.4 \times OVHEAD - 3.0)) \qquad \text{Eq. (9.7)}$$

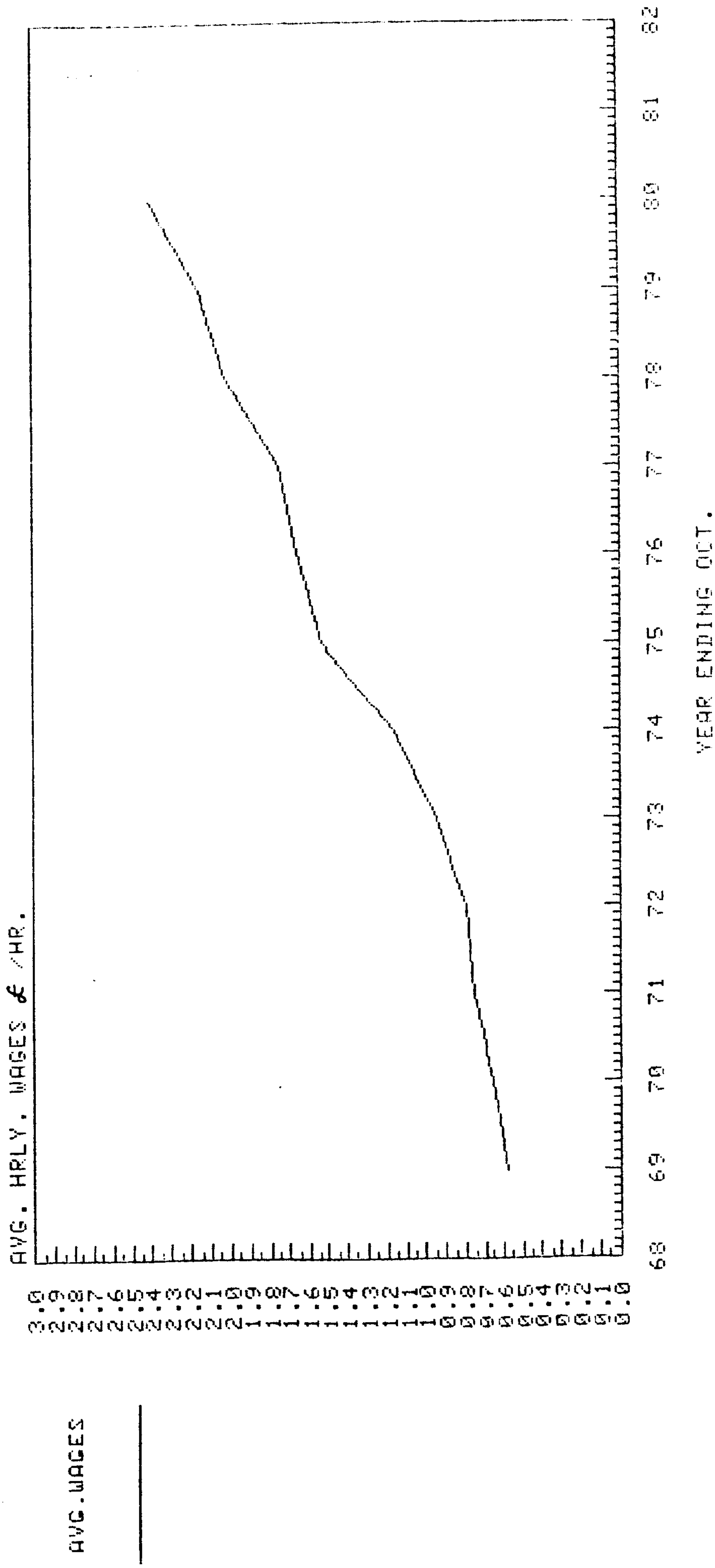
where WR = average hourly wage rates in £/hour.

OVHEAD = overheads and expressed as a percentage.

9.1.2. OUTFIT LABOUR MANHOURS AND COSTS

The outfit labour manhours was difficult to validate, since the shipyards vary in their accounting practices, e.g.

FIG 9.1 AVG.HOURLY EARNINGS SHIPBUILDING



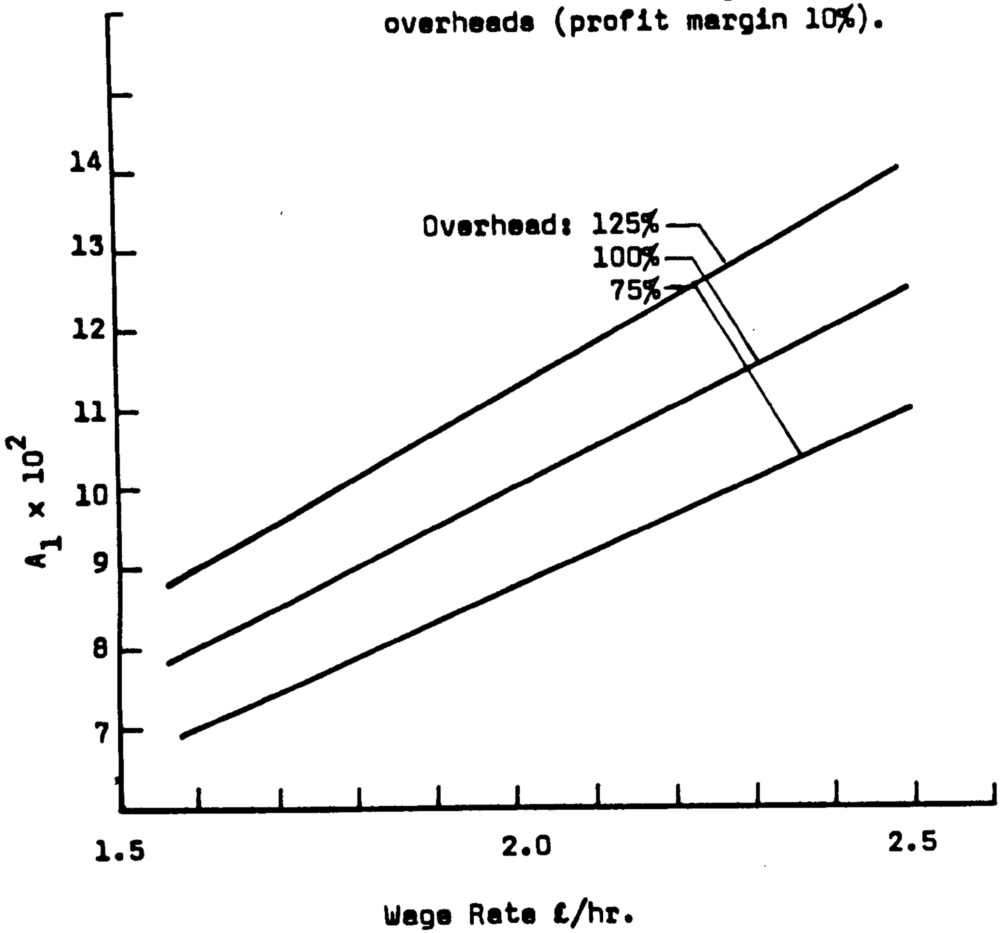


Fig. 9.2. Steel labour cost constant A_1 for various values of wage rates and overheads (profit margin 10%).

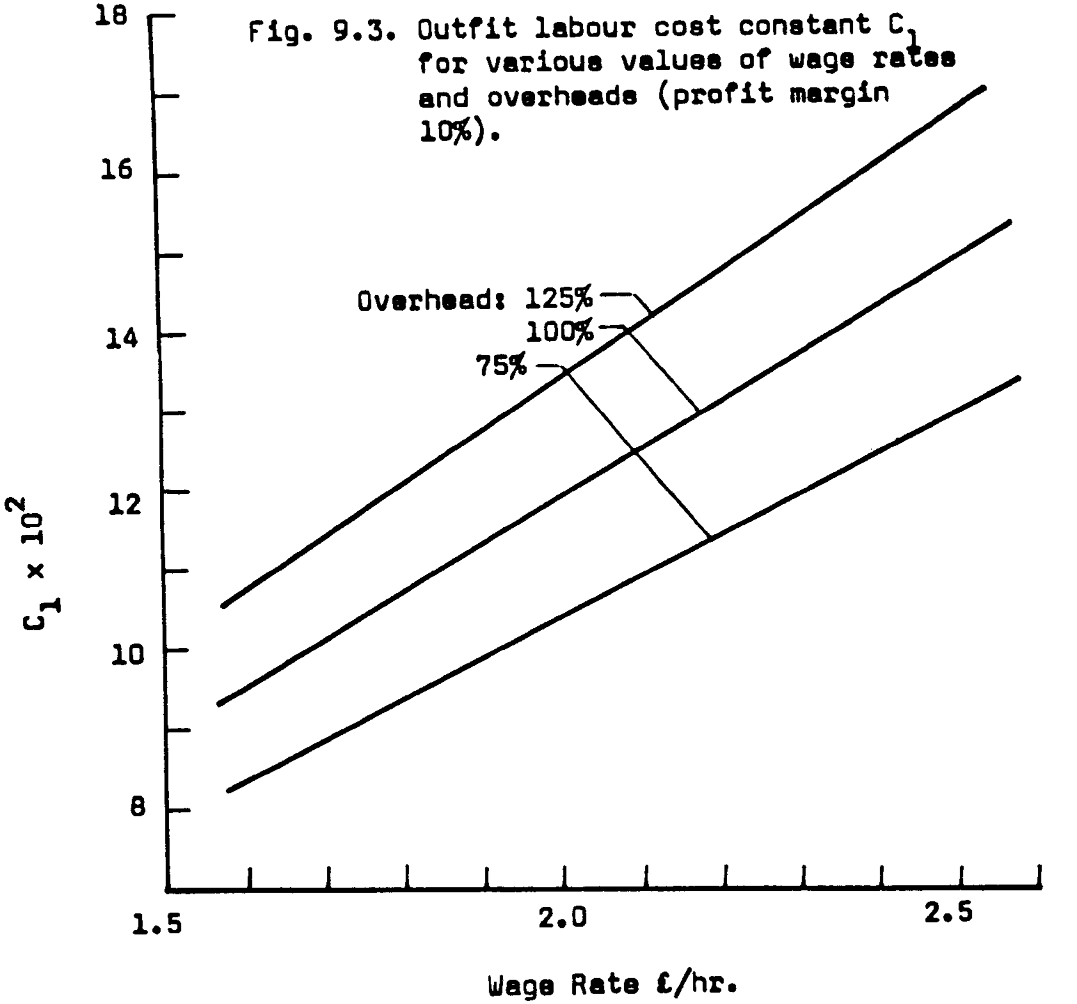


Fig. 9.3. Outfit labour cost constant C_1 for various values of wage rates and overheads (profit margin 10%).

one shipyard may put the subcontracted items as labour costs and others as material costs. Therefore, outfit labour costs were validated.

Method 1: The first method calculates the outfit labour manhours and is from the same source as used for validating the steel labour manhours. Though developed in the early 1970's (46) it has found subsequent uses in (61) 1974, 1978 and other studies (53) 1973, (55) 1974.

The outfit labour manhours (OLMH1) is given by

$$OLMH1 = 349324 \times (L \times B \times D/10^6)^{0.60} \quad \text{hours} \qquad \text{Eq. (9.8)}$$

where L, B, D are in metres.

Method 2: Carreyette found that it is difficult to analyse outfit labour manhours since accountancy practice is to charge subcontracting labour to 'materials', that is, something 'bought in' and therefore not chargeable to the shipyard labour accounts. He found that outfit labour costs followed the same pattern as steel labour costs i.e. $H = \alpha x^n$ where H = total manhours, x is the size or quantity, α is a constant and $n \leqslant 1$.

The general form of the equation for estimating outfit labour cost (COL) is therefore given by

$$COL = C_1 \times W_0^{2/3} \quad \text{£} \qquad \text{Eq. (9.9)}$$

COL = total cost of outfit labour, assuming no subcontracting

C_1 = factor which includes levels of productivity, wage rates, overheads and profit.

The value of C_1 and its variation with overhead and wage rates for a profit margin of 10% is shown in Fig. 9.3. The value of C_1 can be expressed by the following equation,

$$C_1 = WR \times (30.0 \times OVHEAD + 2937.5) + 50 \qquad \text{Eq. (9.10)}$$

where wage rate (WR) is assumed to be £2.4/hour (1980) and can be updated from Employment Gazette (109).

Table 9.2 gives the comparitive outfit labour costs by Method 1 and Method 2. Chapman's outfit labour costs

TABLE 9.2. Comparison of outfit labour costs

No.	TEU	L m.	B m.	D m.	Actual WO tonnes	Labour Man hrs.	Labour costs (£) (1)	Labour costs (£) (2)	Exclude Overhead (£) (3)	Diff. (1)-(3)	$\frac{(1)-(3)}{(1)}$	SHP	$SHP^{0.82}$
1	1200	215.12	30.63	17.37	2230	951514	2283634	2440839	1211885	1071749	0.469	60000	8281
2	1512	212.44	30.48	16.46	2699	911690	2188057	2772073	1376343	811713	0.371	32450	5002
3	1600	185.00	32.20	18.70	2150	936182	2246837	2382109	1182726	1064111	0.474	42000	6181
4	2000	215.00	32.20	18.70	2800	1024519	2458848	2840805	1410469	1048378	0.426	60000	8281
5	2400	250.00	32.20	19.50	3300	1150104	2760250	3169655	1573744	1186505	0.430	60000	8281
6	1800	259.08	32.00	18.29	3556	1126464	2703514	3331531	1654116	1049398	0.388	60000	8281
7	928	177.10	23.80	16.60	1459	708241	1699778	1839527	913331	786446	0.463	17500	3015
8	1336	206.30	28.90	16.50	2059	868895	2085348	2314409	1149112	936235	0.449	32000	4946
9	1712	234.40	27.40	16.20	2050	898613	2156672	2307660	1145761	1010910	0.469	28500	4498

1. Labour rate £2.40/hr, W/O overhead; K.R. Chapman's
2. C_1 = 14300; OVHEAD = 100%; Wage rate = £2.40/hr; Carreyette
3. C_1 = (30.0 × OVERHEAD + 2937.5) × WR + 50.0; PUT OVERHEAD = 0; C_1 = 7100: profit = 0%. C_1 = 6454.5; Carreyette

excluding overheads and profit is equal to Carreyette's outfit labour costs including overheads and profit. If the overheads are neglected in Carreyette's method, the outfit labour costs are half of Chapman's outfit labour costs.

Another reason for the difference between Carreyette's and Chapman's outfit labour costs is because, Chapman does not consider the machinery labour costs separately but takes account of all the labour costs other than steel and outfit as miscellaneous labour costs. The miscellaneous cost (46) is calculated as

$$\text{Miscellaneous labour costs} = 16\% \text{ (steel labour costs + outfit labour costs)} \quad £ \qquad \text{Eq. (9.11)}$$

9.1.3. MACHINERY LABOUR COSTS

The recorded manhours for machinery installation suffers from the same drawbacks as that of outfit labour manhours i.e. since most of the work is subcontracted, it is recorded as 'material costs'. Therefore the machinery labour costs (CML) is calculated directly from the equation given below (108)

$$CML = F_1 \times SHP^{0.82} \quad £ \qquad \text{Eq. (9.12)}$$

where SHP = total installed horsepower in PS.

The value of F_1 was calculated from the equation given below and shown in Fig. 9.4

$$F_1 = (OVHEAD \times 1.125 + 117.92) \times WR \qquad \text{Eq. (9.13)}$$

The value of F_1 can be updated by inputting the current wage rate in shipyards from Employment Gazette (109).

Chapman as pointed out earlier in Section 9.1.2 calculates the machinery labour costs as 16% of the steel and outfit labour costs.

Fig. 9.4. Machinery labour cost constant F_1 for various values of wage rates and overheads (Profit margin 10%).

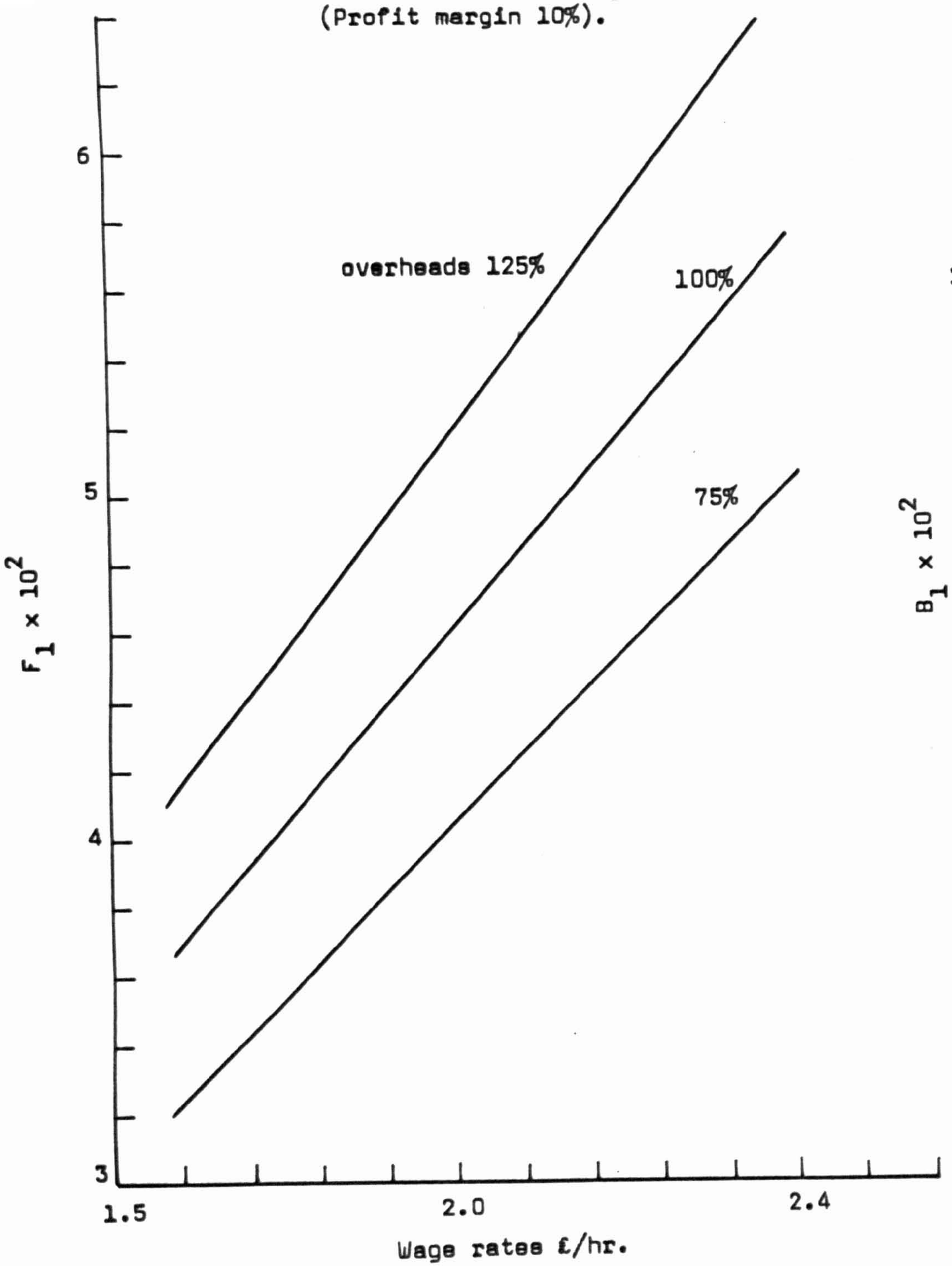
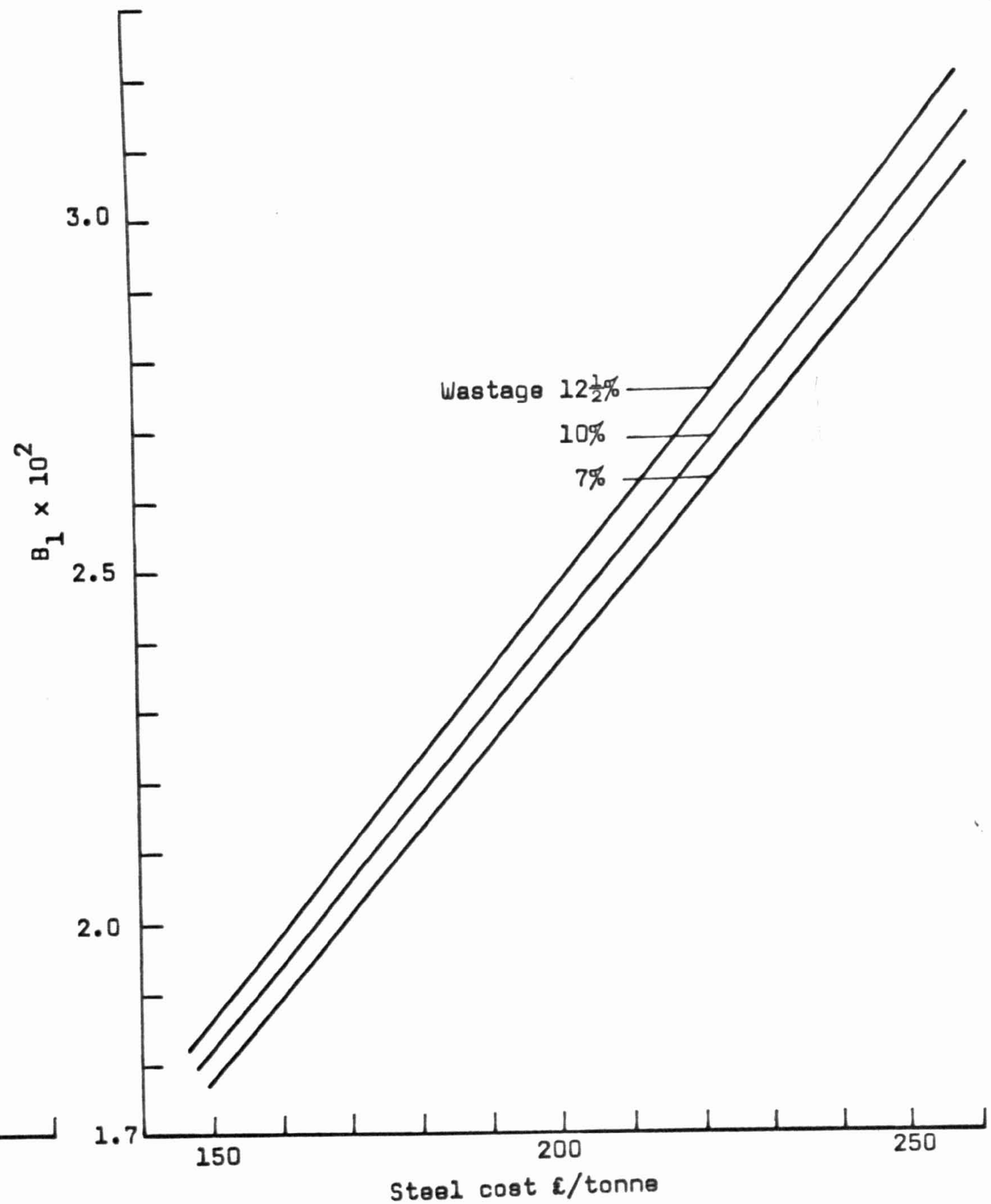


Fig. 9.6. Steel material cost constant B_1 for various values of steel cost/tonne and wastage (Profit margin 10%).



9.1.4. TOTAL LABOUR COSTS

The total labour costs was validated by comparing the total manhours calculated by Chapman's method, which was updated to 1974 by Volker (61) and further updated to 1980 from Burness & Corlett (57). The outline of Chapman's method both for material cost estimation and labour cost estimation is shown in Table 9.4. Carreyette's method was updated in the program to reflect early 1980 costs.

A comparative evaluation of total labour costs as shown in Table 9.3 between the two methods indicates that except for one ship i.e. No.7 which is smaller than the others, Chapman's method underestimates by 18% the total labour costs. For a 1200 TEU ship Carreyette's method overestimates the total labour costs by about 14% compared to Chapman's total labour costs, but for the rest of the ships the difference is within ± 12%.

Carreyette's method was adopted in the program for its simplicity of updating. It is based on actual shipyard estimates and the accuracy reported is between ± 5%. As can be seen in Table 9.3, the difference between Chapman's total labour costs and Carreyette's is within ± 5% in certain cases.

9.2. MATERIAL COSTS

As for labour cost the material cost is also subdivided into three groups:

(a) steel material cost

(b) outfit material cost

(c) machinery material cost.

There were two methods available for cost estimation, one by Carreyette (108) 1978 and the other by Chapman (46) 1970. Carreyette's method used in the computer model was updated to reflect 1980 costs by referring to (110, 111) for cost of steel plates and angles and other materials from (112, 113). The material cost indices for shipbuilding material and equipment was hard to find but it was ascertained

TABLE 9.4. K.R. Chapman's capital cost model (46, 61, 57).

Item	Formula	(1) K.R.Chapman 1969 (46)	(2) Volker 1974(61)		(3) Burness & Cor. 1980 (57)
Steel Weight 1)Flush Steel Wt.	$FSW = 0.0007L^{1.76} \times B^{0.71} \times D^{0.37}$	1$ = 0.4258£ 1974 exchange rate (3) updated from (1) by multiplying by General Index of Retail Prices = 2.2076			
2)Deck House Wt.	$DW = 129.63 \times LXBXD/10^{6}$	Mild steel £44.4/ton High tensile £55-£57/ton Avg. steel cost	$236/ton		
3) Container guide wt.	$GW = 0.713 \times N^{0.92}$ $NS = FSW + DW + GW$				
Gross Steel Weight	$GS = 1.10 \times NS$				
Total Steel Weight	$WS = 1.17 \times GS$				
1.Steel Material cost	$+CSM = WS \times$ steel £	£45.5/ton	£100.48/ton		£205/tonne
1)Steel work 2)Guide	$SM = 1060 \times (GS)^{0.71}$ $GM = 310 \times GW$		$4.10/hr		
2.Steel labour cost	$+CSL = WR \times (SM + GM)$	£0.5	£1.745/hr		£2.50/hr
3.Outfit material cost 1)Brought in outfit mat. factor	$WOB = (LXBXD)^{0.425}$	(2)/(1) = 1.022 $(1.0055)^4 = 1.022$ i.e. @ 0.55%/annum			
2)Shipyard outfit material factor 3)Hatch cover factor	$WOS = (LXBXD/10^{6})^{0.65}$ $WHC = (LXB)^{0.57}$	(3)/(2) = 2.16 $(1.137)^6 = 2.16$ @ 13.7%/annum			
4)Total factor	$WOF = WOB + WOS + WHC$		$	£	
1)Brought in 2)Shipyard 3)Hatch cover 4)Outfit mat. cost	$COMB = C1 \times WOB$ $COMS = C2 \times WOS$ $COMH = C3 \times WHC$ $COM = COMB + COMS + COMH$	650 149600 189	1560 359040 454	644 152879 193	1435 330230 417
Outfit man hours	$OL = 411600(LXBXD/10^{6})^{60}$	60			
4.Outfit labour cost	$+COL = WR \times OL$	£0.5/hr.	$4.10/hr £1.745/hr.		£2.50/hr

TABLE 9.4 (Contd.)

Item	Formula	K.R.Chapman 1969 (46)	Volker 1974 (61)	Burness & Cor. 1980 (57)
5. Miscell-aneous labour costs	+CML = 16% (CSL + COL)			
6. Over-heads & charges	+OVHEAD = 50% (CSL + COL + CML)			
Machinery weight 1. Single screw geared two cycle steam turb.	$WM = 200(SHP/1000)^{0.57}$			
2. Geared medium speed diesel	$WM = 180(SHP/1000)^{0.57}$			
7. Machinery cost 1. Steam plant (A) Chapman SS ship, SHP 50,000	$+ CMM = C4 \times (SHP)^{0.535}$	253600		
TS ship 30000 < SHP < 100000	$CMM = C5 \times (SHP)^{0.527}$	315600	$37000	
(B) Volker 50000	$CMM = C6 \times (SHP)^{0.5}$		£15755	
(C) Burness & Corrlett	CMM = C7 × (CSL + CSM + COM + COL + OVHEAD + CML)			0.32
2. Medium speed dies.	$CMM + C8 \times (SHP)^{0.622}$		$9550 £4066	
8. Automatic logging	+ CAL	110000/SHP	$264000 £112,411	
9. Profit	+ PROFIT = C9 × (CSL + COM + COL + CML + OVHEAD + CMM + CAL)	0.05	0.05	0.05
Total cost	1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9			

Note: Dimensions L, B, D in feet, SHP in British horsepower and costs in £ sterling.

TABLE 9.3. Comparison of total labour costs.

No.	TEU	K.R. Chapman, 50% overhead, 0% profit					2. Carreyette, 50% overhead, 10% profit				0% profit		
		Steel labour costs (£)	Outfit labour costs (£)	Miscellaneous costs (£)	Over heads &charges (£)	Total labour costs 1 (£)	Steel labour costs (£)	Outfit labour costs (£)	Machinery labour costs (£)	Total labour costs (£)	Total labour costs 2 (£)	Diff. 2 - 1	%Diff. (2 - 1)/2
1	1200	2176236	2283634	713579	2586724	7760174	4612612	1826362	3461534	9900508	9000462	+1240288	+13.78
2	1512	2043060	2188057	676979	2454048	7362144	3793007	2074208	2091128	7958343	7234857	-127287	- 1.759
3	1600	1787616	2246837	645512	2339983	7019948	3629875	1782417	2583741	7996033	7269121	+249173	+ 3.428
4	2000	2171664	2458848	740882	2685697	8057091	4372260	2125637	3461534	9959431	9054028	+996937	+11.011
5	2400	2626615	2760250	861898	3124382	9373145	5362703	2371699	3461534	1195936	10178123	+804978	+7.909
6	1800	2807656	2703514	881787	3196479	9589436	6086230	2492824	3461534	12040588	10945989	+1356553	+12.39
7	928	1303572	1699778	480536	1741943	5225829	2232672	1376429	1260305	4869406	4426733	-799096	-18.052
8	1336	2000289	2085348	653702	2369669	7109009	3845485	1731761	2067319	7644565	6949605	-159404	-2.294
9	1712	2267227	2156672	707824	2565862	7697585	4092779	1726711	1879998	7699488	6999535	-698050	-9.973

1. Wage rate assumed = £2.4/hr.
2. Assumed wage rate including overhead 50%;profit 10% = 1.50 × 1.10 × 2.4 =£3.96/hr
3. C_1 = 10700, (30 × 50 + 2937.5) × 2.4 + 50.0 = 10700.

that structural steel wholesale price indices (112) were a good guideline and is shown in Fig. 9.5. For ships built elsewhere the indices published for material as well as labour in (113) provide a good guideline.

The material costs as given by Chapman (46) were updated to reflect 1980 costs and is shown in Table 9.4. The breakdown of the various elements of the material costs are also shown in Table 9.4. Chapman's method was used to validate the material costs given by Carreyette's method. Carreyette found that material costs showed similar characteristics as those obtained for the labour costs. Thus the general form of the equation is given by,

$$\text{Material Cost} = \alpha\ x^{n}$$

where α is a constant, x is the size or the quantity variable and n is the index, which is $\leqslant 1$. Further the material cost functions did not show the same degree of economy of scale in size or quantity increases as the labour cost functions (108). Steel labour costs, steel weight has an index of 0.667 compared to 1.0, for steel material costs. Outfit labour costs, outfit weight has an index of 0.667 compared to 0.95, for outfit material costs. And for machinery labour costs and material costs, the installed horse power has the same index of 0.82.

9.2.1. STEEL MATERIAL COST

The steel material cost (CSN) is given by the equation (108)

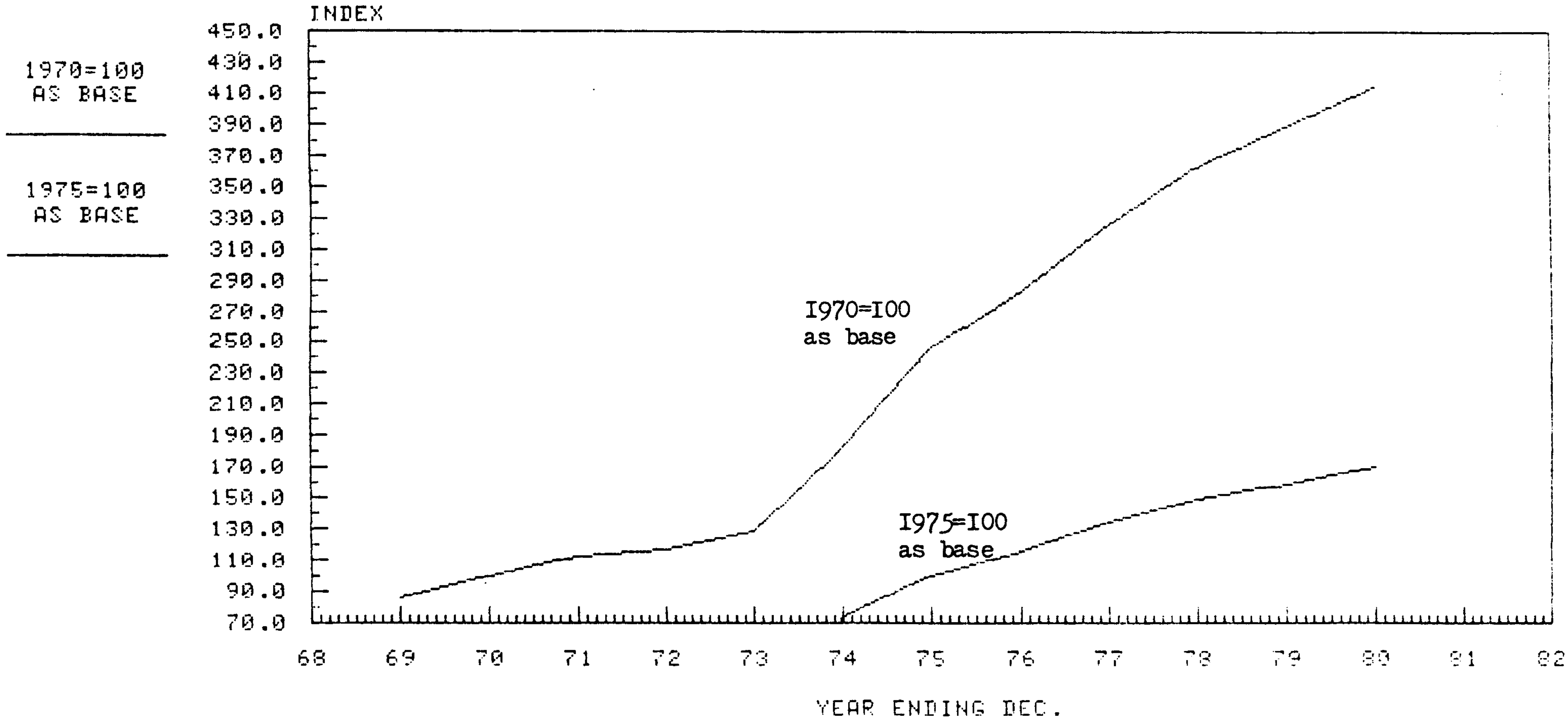
$$CSM = B_1 x WS \quad £ \qquad \text{Eq. (9.14)}$$

WS = steel weight in tonnes.

where B_1 is a constant reflecting the cost of steel/tonne and the scrap percentage. The values of B_1 for various values of cost of steel/tonne (STLCOS) and scrap percentage is shown in Fig. 9.6. The value of B_1 increases linearly as the value of STLCOS increases. For a fixed value of STLCOS, increase in scrap percentage increases the value of B_1. The value of B_1 can be estimated from the following equation

FIG 9.5. STRUC.STEEL WHOLESALE PRICE INDEX.

REF.TRADE & INDUSTRY,HMSO APRIL ISSUES



$$B_1 = STLCOS \times 1.18\times((SCRAP - 7.5)/100.0 + 1.0) + 0.20 \qquad \text{Eq. (9.15)}$$

STLCOS = Cost of steel material in £/tonne is taken from (110,111). The average value of steel material (plates and sections) works out to be £214/tonne.

SCRAP = the scrap percentage or the wastage of material, and is calculated from the following 4th order polynomial of C_{b1} (35)

$$SCRAP = S(1) + S(2) \times C_{b1} + S(3) \times C_{b1}^2 + S(4) \times C_{b1}^3 + S(5) \times C_{b1}^4 \quad \% \qquad \text{Eq. (9.16)}$$

where C_{b1} = block coefficient at 0.80 of the depth of the ship and is estimated from Eq. (9.17)

$$C_{b1} = C_b + (1 - C_b)(0.8D - T)/3T \qquad \text{Eq. (9.17)}$$

where C_b = block coefficient at design draft
D = Depth of the ship at side in m.
T = Design draft of the vessel in m.

9.2.2. OUTFIT MATERIAL COST

Outfit material cost (COM) is calculated from the following equation

$$COM = D_1 W_O^{0.95} \quad £ \qquad \text{Eq. (9.18)}$$

D_1 is a constant which reflects the equipment costs from manufacturer's quotations. The value of D_1 since mid 1975 is shown in Fig. 9.7. The formula for calculating D_1 is given by

$$D_1 = 1500.0 \times \text{material index}/100.0 \qquad \text{Eq. (9.19)}$$

Mid 1975 was taken as the base year and value of Material Index is taken as 100. The values of D_1 given by Carreyette (108) are compared with those calculated by Eq. (9.19) and shown in Table 9.5. Since outfit material cost indices were not available, shipbuilding structural steel price index (112) was used.+ As Table 9.5 shows it gives fairly

+ other indices may be preferred.

Fig. 9.7. Outfit material cost constant, D_1
(Profit margin 10%).

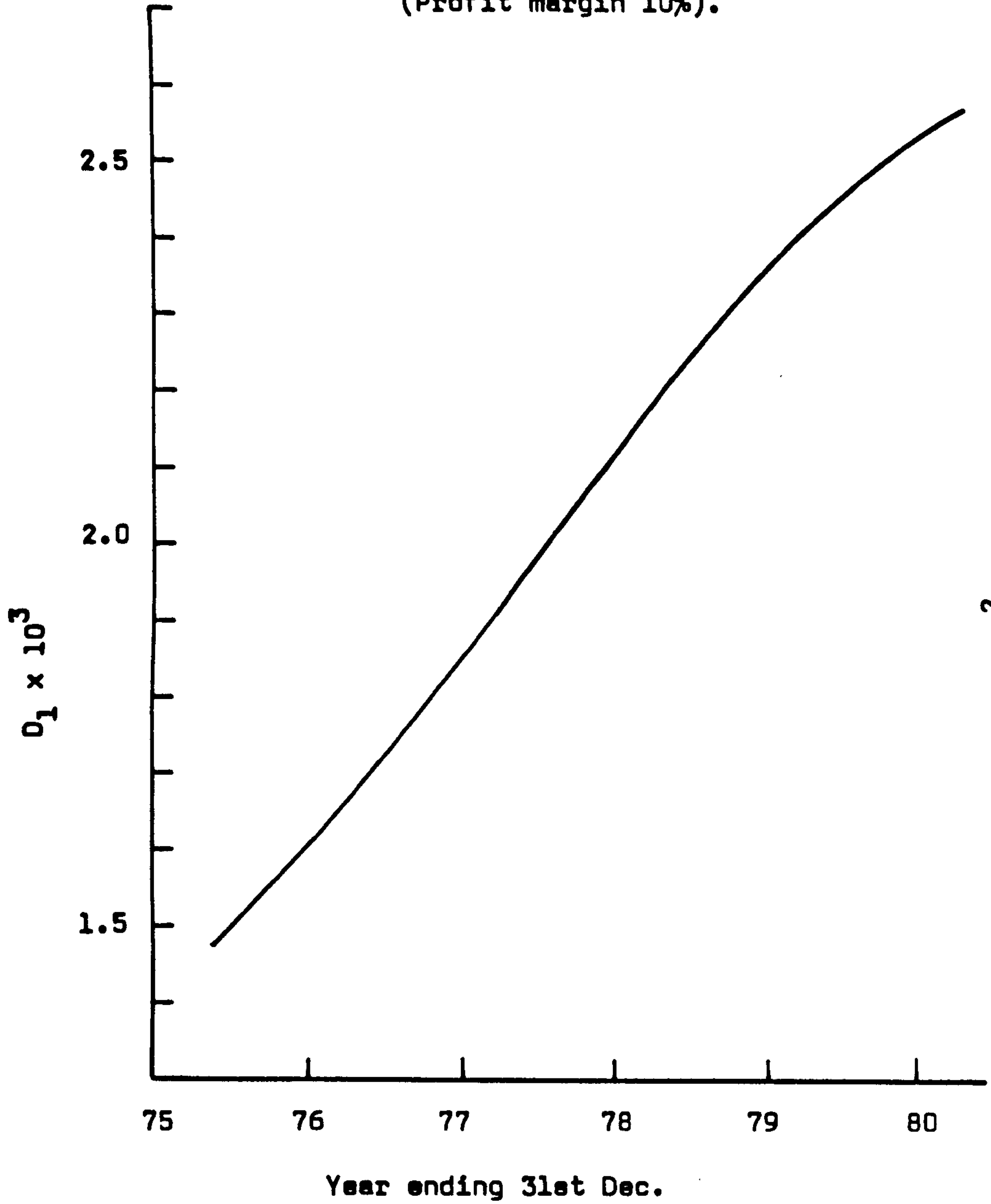


Fig. 9.8. Machinery material cost constant, G_1
(Profit margin 10%).

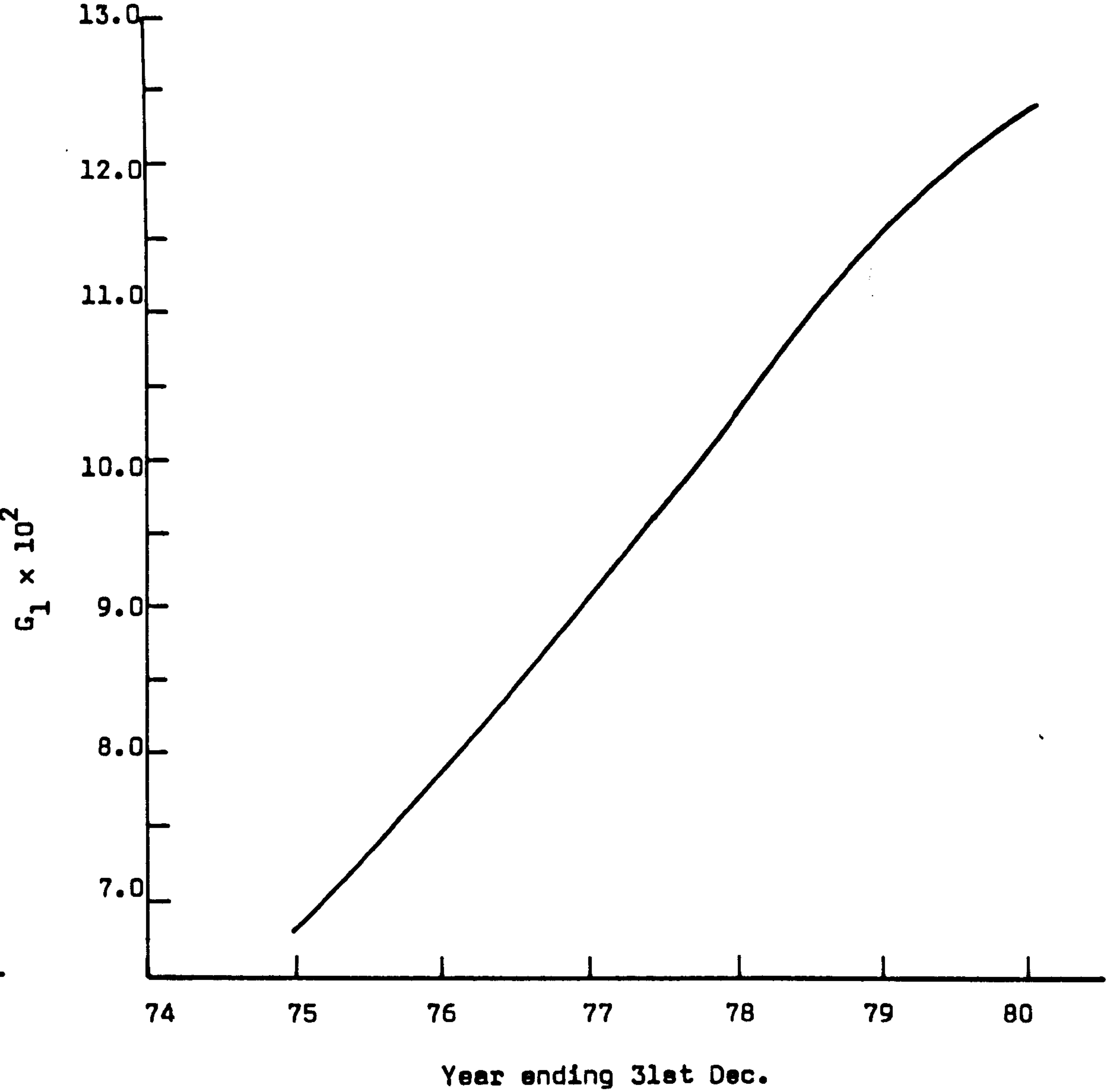


TABLE 9.5. Comparative values of D_1 & G_1 and updated values as per Fig. 9.5.

Year	D 1		G1	
	Given	Calc.	Given	Calc.
6/75	1500	1500	735	735
6/76	1725	1724	845	845
6/77	2011	1989	980	975
1/78	-	2111	-	1034
1/79	-	2369	-	1161
1/80	-	2531	-	1240

good results for the limited points that were available.

9.2.3. MACHINERY MATERIAL COST

Machinery material costs are assumed to be for ships with diesel installation. The cost equation is not sensitive enough to show accurately the difference from other types of installation (108). Since other types of engine installation are not considered in the program, the cost of engine is calculated by the following equation

$$C_{MM} = G_1 \times SHP^{0.82} \quad £ \qquad \text{Eq. (9.20)}$$

The value of G_1 since mid 1975 is shown in Fig. 9.8. The formula for calculating G_1 is given by

$$G_1 = 735.0 \times \text{Material Indices}/100.0 \qquad \text{Eq. (9.21)}$$

The values of material indices as in Eq. (9.19). The values of G_1 calculated by Eq. 9.21 are shown in Table 9.5 and are found to be in good agreement with the limited data that was available.

9.3. MISCELLANEOUS ITEMS

The various other items which may be added to the cost equation are:-

(1) Application of higher tensile steel, where used may be adjusted by upgrading the value of B_1 in Eq. (9.14). The following mix of steel grades are assumed in the calculation of steel material cost; 75% to 85% of Grade A, remainder Grades B, E, AH, DH or EH as given by Carreyette (108).

(2) Where twin screw propulsion is assumed machinery material cost may be increased by multiplying Eq. (9.20) by 10% (108).

(3) If controllable pitch propeller is fitted, e.g. triple screw containerships have the centre line propeller of this kind, the cost of this item must be included separately. The cost difference between fixed and controllable pitch

propeller (δC_p) is given by (108)

$$\delta C_p = 38200 \quad Q_0^{1/2} \qquad £ \qquad \text{Eq. (9.22)}$$

where Q_0 = overall torque = $0.728 \dfrac{SHP}{RPM}$ tonne metres

In the program it was assumed that even at higher powers twin screw installation will be sufficient, therefore no adjustment for controllable pitch propeller is included.

(4) The cost of thruster (C_T) is estimated by the following equation (108)

$$C_T = 58000 + 42000\ T \qquad £ \qquad \text{Eq. (9.23)}$$

where T = thrust in tonnes.

Containerships are sometimes fitted with thrusters. But this cost item is not included in the program, since it forms a small fraction of the total cost.

(5) The cost of fin type of stabilisers (CST) is given by (108)

$$C_{ST} = 400\,\triangle^{3/4} \qquad £ \qquad \text{Eq. (9.24)}$$

where $\triangle$ = displacement in tonnes.

Containerships are sometimes fitted with either fin type stabilisers or flume tank system. This cost item is not included in the program. It is assumed that the containerships are not fitted with any stabilisers.

(6) Cost differences from diesel installation, as assumed in the program, can be calculated separately and added to Eq. (9.20). Some equations given for slow speed diesels, medium speed diesels and steam turbines, developed by Buxton (107) at 1977 cost levels are:

<u>Slow speed diesel</u>

machinery (material + labour) costs, CMM + CML =

$$2708 \times SHP^{0.75} \qquad £ \qquad \text{Eq. (9.25)}$$

<u>Geared medium speed diesel</u>

$$CMM + CML = 3752 \times SHP^{0.70} \ £ \qquad \text{Eq. (9.26)}$$

TABLE 9.6. Outfit material cost comparison.

	K.R. Chapman (Symbols defined in Table 4)							Model (weight in tonnes)			Diff.	%
	WOB	WOS	WHC	COMB	COMS	COMH	COM_1	Actual WO	$WO^{0.95}$	COM_2	COM_2-COM_1	Diff.
1	642	2.5	582	921270	825575	242694	1,989,539	2230	1517	3,838,678	1849139	48.17
2	623	2.36	576	894005	779342	240192	1,913,539	2699	1818	4,601,875	2688336	58.42
3	635	2.44	549	911225	804440	228933	1,944,598	2150	1464	3,707,734	1763136	47.55
4	677	2.69	598	971495	886667	249366	2,107,528	2800	1883	4,765,322	2657794	55.77
5	735	3.044	652	1054725	1005220	271884	2,331,829	3300	2200	5,570,323	3238494	58.14
6	724	2.976	663	1038940	979792	276471	2,295,203	3556	2363	5,980,063	3684860	61.62
7	521	1.80	451	747635	594414	188067	1,530,116	1459	1014	2,565,338	1035222	40.35
8	602	2.247	550	863870	742027	229350	1,835,247	2059	1406	3,558,489	1723242	48.43
9	617	2.33	574	885395	769436	239358	1,894,189	2050	1400	3,543,711	1649522	46.54

Geared steam turbine

$$CMM + CML = 36865 \times SHP^{0.50} \quad £ \qquad \text{Eq. (9.27)}$$

These when compared with Carreyette's CMM+CML figure give comparable results as shown below, and thus can be updated to reflect present cost levels and introduced in the program by the user.

H.P. (metric)	Buxton £ x 10^6 (1977) costs			Carreyette £ x 10^6		
	slow speed diesel	medium speed diesel	steam turbine	Material	Labour	Total
30,000	6.1718	5.1075	6.3852	4.282	1.946	6.228

9.4. TOTAL CAPITAL COST

The total Capital Cost of the ship (BLDGCO) is therefore given by

BLDGCO = steel labour cost + steel material cost + outfit labour cost + outfit material cost + machinery labour cost + machinery material cost £ Eq. (9.28)

$$\therefore \text{ BLDGCO} = \frac{A_1 x Ws^{2/3} L^{1/3}}{C_b} + B_1 x WS + C_I x W_O^{2/3} + D_I x W_O^{0.95} + F_I x SHP^{0.82}$$
$$+ G_I x SHP^{0.82} \quad £ \qquad \text{Eq. (9.29)}$$

A 10% profit margin is included in the factors A_1, B_1, C_1, D_1, F_1 and G_1. In the program the user can specify any profit margin (PROFIT in percentage) and the capital cost is then given by

$$\text{BLDGCO} = \text{BLDGCO Eq. (9.29)} \times \left(\frac{100 + \text{PROFIT}}{110}\right) £ \qquad \text{Eq. (9.30)}$$

Other factors such as overhead (as percentage), labour wage rate/hr., steel cost £/tonne and material indices for a particular shipyard and year may be input by the user.

Cost derived from the program is meant to indicate how much money a shipyard will pay for shipyard labour and materials and overheads and also make some fixed profit. Price however is influenced by various factors such as market conditions, competition, number of vessels on order of the same type, interest rates, loan, subsidies and numerous other factors. So to validate the results given by the program, published prices of ships cannot be a good indication. This is evident from Fig. 9.9 where the cost of a standard Fairplay container ship of 1200 TEU was plotted against actual ship prices published in various journals. The 1200 TEU fairplay container ship cost was calculated without the set of containers as £/TEU and as shown in Table 9.7. Actual ship prices were converted in £ from the quoted figure with the average exchange rate in that year and the price was converted into £/TEU. Until the oil crises of 1973 the ship cost/TEU was less than the price/TEU, after that the ship price/TEU has always been less than the cost/TEU except for some ships. This is mainly due to the depressed shipbuilding market, heavy subsidies by the national government to shipyards, liberal credit terms to shipowners and other political factors, such as decision by various governments to keep the shipyards open at any costs brought about a fierce competition for shipbuilding orders.

The capital cost of the ship was thus validated with data from another source (57) for ships of 600 TEU to 3000 TEU and speeds of 18 to 27 knots. The same assumptions were made in the program as those in deriving the cost of ships in (57) and are indicated in Table 9.8 together with the actual cost of the ships and those calculated by the program.

The general trend and magnitude of the cost figures for 1980 seems to be of the right order. A cross check with the Fairplay 1200 TEU ship which costs £25.64 x 10^6 with a 1250 TEU ship of 23 knots (shown in Table 9.8) by the program gives a cost difference of 3.8%, which is within the accuracy of the ± 5% quoted by Carreyette (108) for this method.

Table 9.7 shows that there was dramatic increase in the shipbuilding costs after the oil price rise of 1973-74, of about 110% and the escalation has been less than 5% per annum

Fig. 9.9. CONTAINER SHIP PRICE VS. YEAR OF ORDER

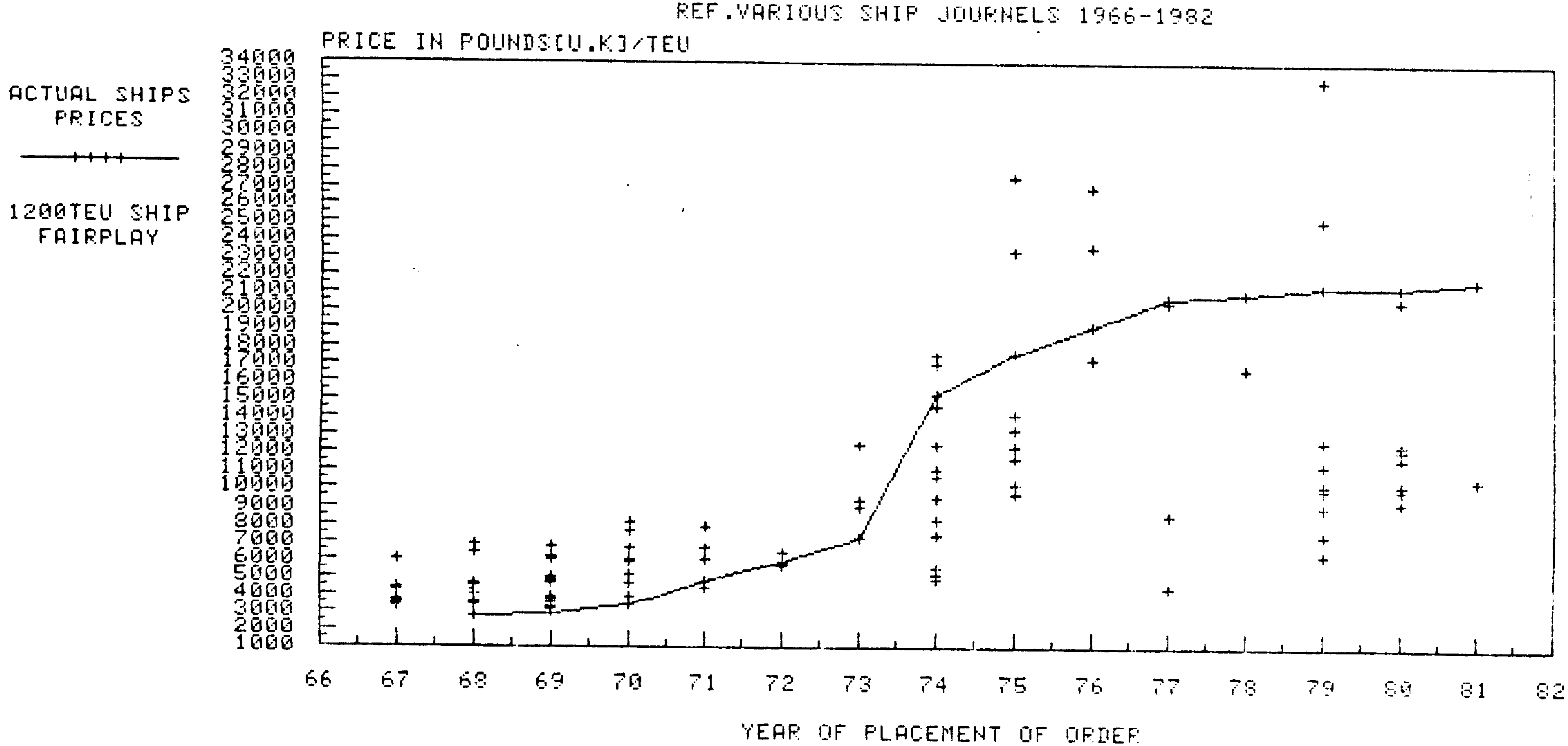


TABLE 9.7. Fairplay standard container ship prices.

25,000 DWT, 1200 TEU, 22 Knots, 9 Cylinder Sulzer, 30,100 BHP, 15% service margin, 85% MCR, Aux. 4 x 1000 KW Diesel Engine Alternators.

Year	Price of ship + 1 set containers (£ x 10^6)	Price of one dry container	Price of one reefer container	Price of 800 dry containers (£ x 10^6)	Price of 400 reefer containers	Price of 1200 TEU ship (£ x 10^6)	% price escalation
1968	4.0	450	890	0.36	0.356	3.284	
1969	4.4	600	1100	0.48	0.440	3.480	+5.968
1970	5.0	675	1200	0.54	0.480	3.980	+14.368
1971	6.8	700	1300	0.56	0.520	5.720	+43.719
1972	8.2	750	1400	0.60	0.560	7.040	+23.077
1973	10.0	820	1650	0.656	0.660	8.684	+23.352
1974J	20.0	1200	1800	0.96	0.720	18.320	+110.963
1974D	22.0	1200	1800	0.96	0.720	20.320	+10.917
1975J	23.0	1400	1900	1.12	0.760	21.120	+3.937
1975D	25.0	1400	1900	1.12	0.760	23.120	+9.469
1976J	25.0	1500	2000	1.20	0.800	23.00	-0.519
1976D	26.0	1500	2000	1.20	0.800	24.00	+4.348
1977J	27.0	1600	2250	1.28	0.900	24.82	+3.417
1977D	27.5	1600	2250	1.28	0.900	25.32	+2.014
1978J	28.0	2000	2850	1.60	1.140	25.26	-0.237
1978D	28.2	2000	2850	1.60	1.140	25.46	+0.792
1979J	28.5	2100	2900	1.68	1.160	25.66	+0.779
1979D	28.7	2200	3100	1.76	1.240	25.70	+0.156
1980J	29.0	2500	3400	2.00	1.360	25.64	-0.233
1980D	29.2	2600	3600	2.08	1.440	25.68	+0.156
1981J	29.8	2700	3800	2.16	1.520	26.12	+1.713

TABLE 9.8. Comparative evaluation of shipbuilding cost.
Capital Costs in £ millions (1980).

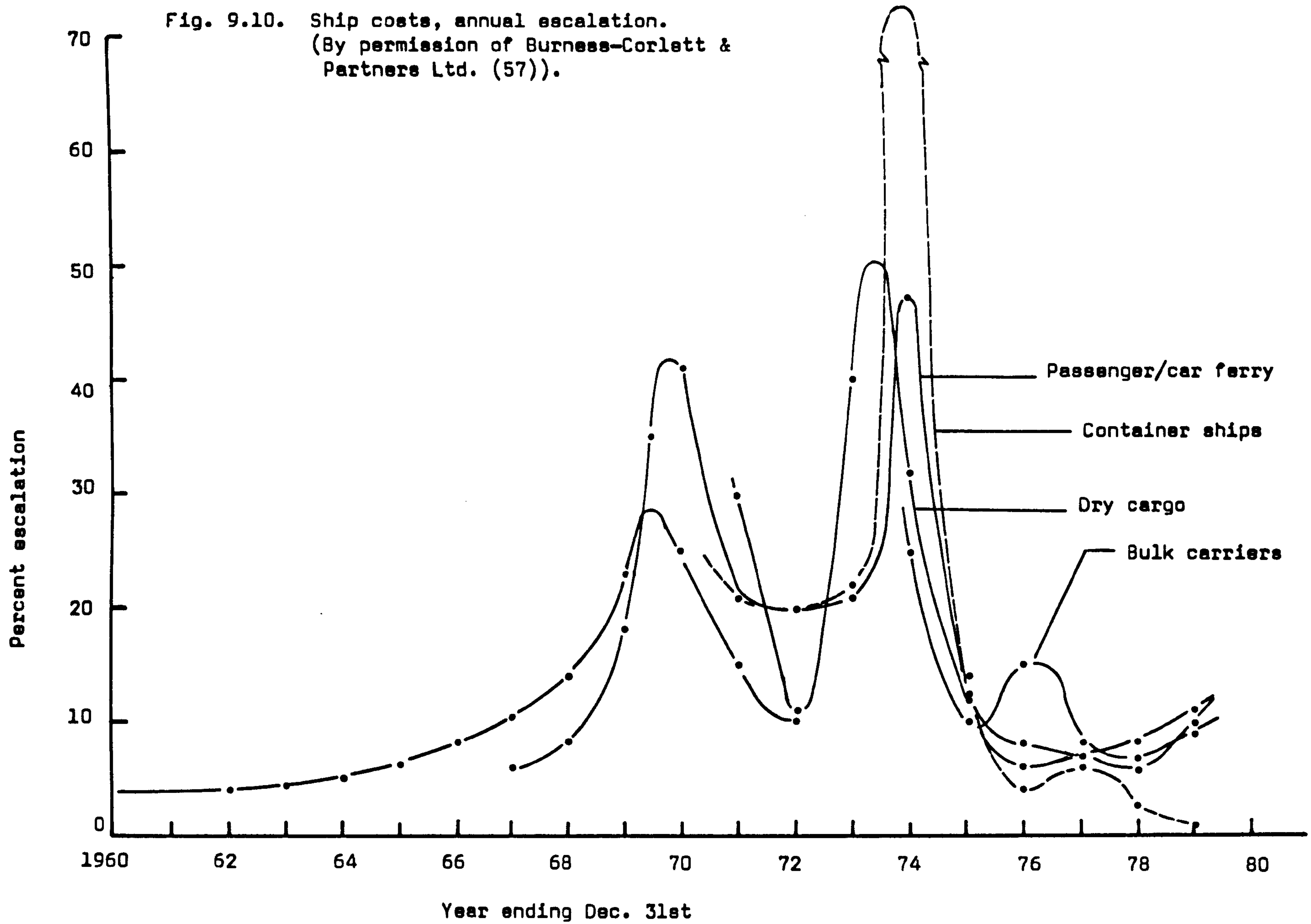
Speed	18 knots	19 knots	21 knots	23 knots	25 knots	27 knots
<u>600 TEU</u>						
Program Results	12.21	13.05	15.17	17.07		
S.Gilman's (94,57)		11.0	12.60			
<u>750 TEU</u>						
Program Results	14.70	15.61	17.79	20.29		
S.Gilman's (94,57)		13.0	14.70	15.50		
<u>1000 TEU</u>						
Program Results	16.26	16.87	18.67	21.71	26.49	-
S.Gilman's (94,57)		16.1	17.80	19.0	21.10	
<u>1250 TEU</u>						
Program Results		19.74	21.63	24.66	28.66	32.59
S.Gilman's (94,57)						
<u>1500 TEU</u>						
Program Results				25.50	29.48	34.04
S.Gilman's (94,57)		20.4	22.6	23.50	26.5	29.50
<u>2000 TEU</u>						
Program Results	-	-	29.34	31.71	36.26	41.10
S.Gilman's (94,57)		23.2	25.00	27.00	30.10	33.20
<u>2500 TEU</u>						
Program results				37.48	41.20	47.01
S.Gilman's (94,57)		25.6	27.7	30.10	33.40	36.80
<u>3000 TEU</u>						
Program Results	-	-	-	39.18	42.68	47.81
S.Gilman's (94,57)	-	27.9	30.0	33.00	36.1	40.00

Assumptions: 15% Profit
100% overhead
£215/tonnes steel price shipbuilding average
£2.40/hr wage rate

since early 1976. Fig. 9.10 represents the escalation factors versus the year of construction for various types of ships, and shows that container ship costs have fallen in comparison to the costs of other ship types after 1977.

Swift (114) gives two formulae for estimating the cost of the ship when the prices are not fixed but subject to escalation. Also the economic complexities involved in quoting prices in different currencies and subject to fluctuations are also dealt with by Swift (114). In this thesis the container ship costs are assumed to be of fixed contract type at 1980 cost levels in U.K. pounds sterling.

Fig. 9.10. Ship costs, annual escalation.
(By permission of Burness-Corlett & Partners Ltd. (57)).



CHAPTER 10

SHIPS OPERATING COSTS

10.0 INTRODUCTION

The estimation of operating costs is one of the most difficult cost items to rationalise. The operating costs vary for ship type, flag of the vessel, age of ship, operating pattern, trade route etc., and even identical ships belonging to the same owner can have different operating costs. The operating costs were built up from equations developed from previous containership studies and validated with some actual operating cost data to reflect 1980 costs. The operating costs therefore reflect average operating cost figures for a U.K. shipowner.

As in developing other cost models such as capital cost and container cost the operating cost model must reflect the correct magnitude of the differences in costs between alternatives as much as the absolute values. The operating costs can be escalated by escalation factors given in Section 10.10 to reflect the costs in a particular year.

Differing accounting procedures and subdivision of the cost elements also makes it difficult to compare costs of two shipping companies. The operating costs are usually subdivided as shown in Fig. 10.1. Containerships are usually operated under the liner conference system where the shipowner may pay all the costs associated with the ship and the profits are pooled together and subdivided amongst the conference member according to their share of the cargo.

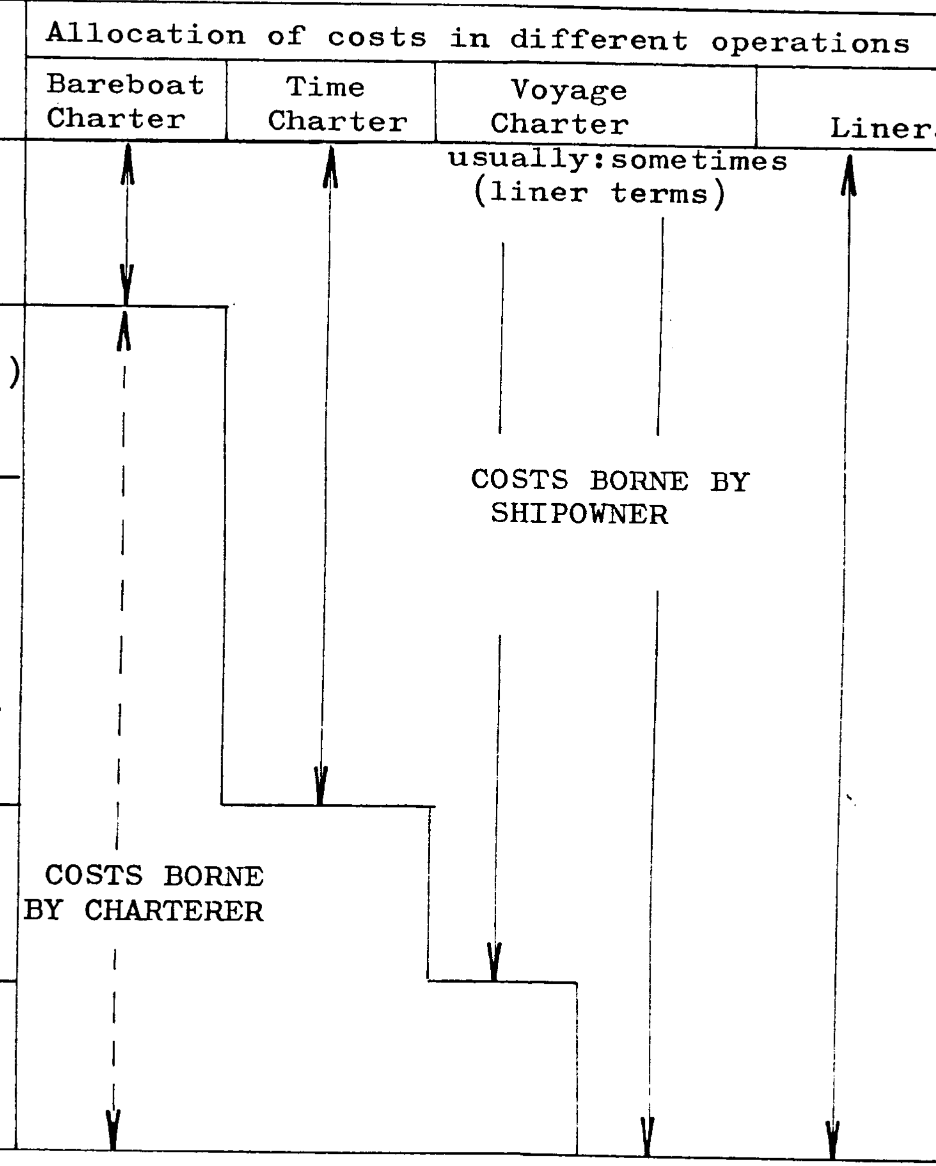
To estimate the annual operating costs, it was subdivided into daily running costs which forms a part of the fixed costs, and variable costs which comprises voyage costs and cargo handling costs.

The daily running costs were estimated from

- Crew costs, comprising the crew wages, overtime, leave, study, social security, travel and training.
- Victualling
- Insurance, comprising the hull and machinery, protection and indemnity (P & I) and war risk

Fig. 10.1. Breakdown of the total ship costs (115).

Economic Classification		Main Categories		COST ITEMS
Fixed Costs		Capital Costs	1 2 3	Cost of ship (loans etc.) Interest Profit (return on capital)
		Overhead Costs	4 5	Management (Head Office, Supervision etc.) Selling & marketing
	Operating Costs	Daily Running Costs	6 7 8 9 10 11 12	Maintenance Repairs Surveys & Dry Docking Insurance P & I Stores Crew (Direct wages+Catering+ Social Security+Leave+ Subsistence+Training)
Variable Costs		Voyage Costs	13 14 15 16	Fuel Port (excluding cargo) Canal Transits Extra Insurance
		Cargo Expenses	17 18	Cargo Claims Cargo Handling



- Maintenance and repairs, comprising the hull/outfit and accommodation and hull engineering and machinery.
- Deck and engine stores
- Miscellaneous costs.

The voyage costs were estimated from
- Fuel oil costs, comprising the heavy fuel oil, diesel fuel oil and lub oil costs.
- Port costs, comprising the port entry and exit costs and daily port costs.

To the operating cost was added the container handling costs to get the annual cost of operating the ship.

A brief description for estimating each of the above costs in pounds sterling and 1980 cost figures are outlined in this chapter. Table 10.1 outlines the operating costs of some ships against which the operating cost model was validated from confidential sources.

10.1. MANNING

One of the principal components of the operating costs is the crew cost and forms about 18% of the total operating cost. The vast difference in crew costs to a shipowner in a particular country is well illustrated in Table 10.2, with American shipowners paying the highest costs. Usually the ships have officers from the developed world and the rest of the crew are from the developing world, who are paid ITF rates or rates negotiated between the seamen's union of a particular country and the shipowners. This is one way of cutting costs, but in many countries there is agreement between the union and government, not to allow seamen from other countries to be employed on ships registered in that country.

The only way to reduce costs in such circumstances is to reduce manning. A typical example is that of Japan ranking 9th w.r.t. to crew costs for a typical bulk carrier/ tanker with 32 crew in 1978 (117). A comprehensive experiment

TABLE 10.1. Operating costs of ships (all cost figures in £/annum).

Ship No.	Ship Type	M/C Type	Year	Crew Wages	Other Costs	Total Crew	Victual-ing	Hull Ins.	War Risk	P & I	Total Ins.	Stores	Hull Mant.	M/C Mant.	Total Mant.	Overheads	Total Fixed cost AVG.
1	GC	D	78	230835	87233	318068	33624	23134	2599	55734	81467	31737	98657	111589	210287	47055	722238
2	GC	D	78	227082	82664	309747	28350	"	"	55539	81272	30115	82722	111589	194311	47055	660735
3	GC	D	78	227085	82661	309746	29669	"	"	55539	81272	30926	89456	111589	201045	47055	699718
4	GC	D	78	227082	82664	309746	29009	"	"	55539	81272	30115	88768	117743	206511	47055	673593
5	GC	D	78	227085	82661	309746	27032	"	"	55539	81272	30115	30720	91732	122452	47055	617672
6	GC	D	78	227085	82661	309746	30987	"	"	55539	81272	30926	30769	92223	122992	47055	622979
7	GC	D	78	216296	87482	303778	22417	35331	4873	60092	102243	25303	30720	94822	125542	51318	630601
8	GC	D	78	217157	74506	291663	22417	"	"	60092	102243	25163	30720	85970	116690	49549	607725
9	GC	D	78	216294	74506	290800	22417	"	"	60092	102243	24979	30720	92857	123577	51318	590355
10	GC	D	78	215089	68608	283697	22417	"	"	60052	102243	24719	30720	84989	115709	51318	600103
11	GC	D	78	212792	63889	276681	22417	"	"	60092	102243	24330	30720	71221	101941	51318	578930
12	GC	D	78	–	–	–	–	–	–	–	–	–	49152	–	221184	–	4423 – 4915[1]
13	GC	D	77	–	–	–	–	30000		10000	40000	55000	–	–	80000	–	–
14	BC	D	78	138561	114653	253214	28704	65861	1475	32539	99875	30473	30473	34183	64656	–	–
15	BC	D	77	–	–	–	–	41976		–	–	–	–	–	62944	–	–
16	T	T	78	–	–	–	–	–	–	–	–	–	172032	–	344064	–	14745 – 19661[1]
17	Cont.	D	79	–	–	–	–	146133	3597	22482	172212	–	–	–	–	–	–
17	Cont.	D	79	–	–	–	–	179856	4496	26978	211330	–	–	–	–	–	–
18	Cont.	D	78	–	–	–	–	–	–	–	–	–	98304	–	294912	–	9830– 14745[1]
19	Cont.	T	78	–	–	–	–	–	–	–	–	–	–	–	231014	–	–
20	Cont.	D	79	445243	64144	509387	39511	75878	1599	101483	178960	97392	108186	97531	205717	44166	1075133
21	Cont.	D	79	445243	64144	509387	39511	75878	1599	101483	178960	105618	83649	76129	159778	44166	1037420
22	Cont.	T	80	–	–	191127	17986	–	–	–	76439	67446	–	–	148381	22482	523861
23	Cont.	D	80	–	–	150660	19784	–	–	–	36870	80935	–	–	33723	22482	344454
24	Cont.	D	78	–	–	360284	61440	–	–	–	206438	39321	–	–	245760	–	913243
25	Cont.	D	78	–	–	308183	56525	–	–	–	88474	24576	–	–	172032	–	649790
26	RoRo	D	78	–	–	344064	61440	–	–	–	147456	34406	–	–	238387	–	825753
27	RoRo	D	78	–	–	308182	54067	–	–	–	92160	27034	–	–	172032	–	653475
28	CL	D	78	–	–	261120	49152	–	–	–	129024	19661	–	–	98304	–	557261

NOTE: GC = General Cargo, BC = Bulk Carrier, T = Tanker, Cont. = Container, Ro–Ro = Roll on – Roll off, CL = Cargo liner, D = Diesel, T = Steam Turbine.
1 = Daily costs.

TABLE 10.2. Representative costs of ships under different flags. 1981. (116)

	Annual Crew Costs to Owner in £	Basic Annual Crew Wages Able Seaman in that Country £	Number of Crew	Factor to convert basic annual crew wages to annual crew costs
U.K.	524332	3538	26	5.7
Norway	668382	5330	22	5.7
Japan	571895	4973	23	5.0
U.S.A.	933274	5952	32	4.9
Greece	265188	3080	21	4.1
Philippines	198573	1633	32	3.8
ITF (FE)	229779	3122	32	2.3
ITF (WW)	293613	4402	29	2.3

concerning ship manning systems showed that for a container vessel a crew of 24 could be reduced to 18 by adopting general purpose manning and high degree of automation e.g. 1584 TEU container ship 'Hakuba Maru' (118). Amongst the countries which have been able to reduce their manning successfully are West Germany, Japan, Taiwan, Norway and Sweden (116).

Some typical container ship manning is shown in Table 10.3. An analysis of manning level of 139 container ships was carried out as shown in Fig. 10.2. The ships were categorised into 6 groups according to the flag. Japan, U.S., Far East, Middle East, U.K. and Europe and flag of convenience, and subdivided according to container capacity in Teu into 5 groups, (500-999), (1000-1499), (1500-1999), (2000-2499) and (2500-3000 and above). U.S. manning levels were the highest in all container capacity categories about 40 and Japanese flag ships had the lowest, about 26. Reduced manning was observed in Japanese flag ships about 18 crew for 1576-1588 Teu ship and Liberian flag ship about 16 crew for 1800 Teu ship. U.K. manning was about 30-38 crew and above that of some Far Eastern flag ships.

The range of ship size considered in this thesis is 500 Teu to 2500 Teu, the manning of a U.K. flag ship will be between 34 to 38 crew.

10.2. CREW COSTS

As shown in Fig. 10.3, for a 1288 Teu, 23 knots container-ship the crew costs are about 49% of the daily running costs. Crew costs are easier to calculate though the crew costs for ships under different flags can differ by a factor of 8.

Detailed crew cost estimates were available for 35 general cargo ships and a bulk carrier. Also available were detailed estimates of a shipping company with general purpose manning under British flag and conventional manning under American flag. The methodology is the same once the basic wages (readily available from press and journals) and the

TABLE 10.3. Typical manning of some container ships.

No.	Ship's Name	TEU	Gross Tonnage	SHP	No. of officers	No. of PO	No. of crew	Total	Flag
1	Ida Lundrigan		7200					35	
2	Fiery Cross Isle	436	7289	17500	9	4	25	38	
3	Remuera	1703	42006	48600	17	7	17	41	U.K.
4	Schaunberg		5859		14	-	19	33	
5	Euroliner	1088	21838	59420	10		15	25	W.Ger.
66	Atlantic Jamaican	Ro-Ro	999		6	3	8	17	
7	Colombus New Zealand	1187	19145	25000	18	5	15	38	W.Ger.
8	Kashu Maru	728	16500	27600				31	Japan
9	Japanese	723	16500	28000				31	"
10	Japanese	716	16100	27500				32	"
11	Japanese	752	16900	27800				31	"
12	Hakone Maru	708	16500	27800				32	"
13	Oriental Leader	1278	18937	29000	15	6	19	40	Lib.
14	Oriental Chevalier Deck Engine General	1278		29000	8 6 1	2 3 1	7 5 7	40	
15	New Jersey Maru	1887	37799	69600				31+4	Japan
16	Elbe Maru	1842	51623	84600				32	"
17	Selandia	2200	49961	78600				33	
18	Atlantic Marseille	709	13332	18000	10		17	27	
19	Act 1	1223	24820	30000				34	U.K.
20	Dart America	1556	33400	29000				31	U.K.
21	Liverpool Bay	2500			15	5	16+ 2cads.	38	U.K.
22	Encounter Bay	1572			13	4	16GP +4 cad. =1 re-frig	37	U.K.

Fig. 10.2. REPRESENTATIVE MANNING LEVEL

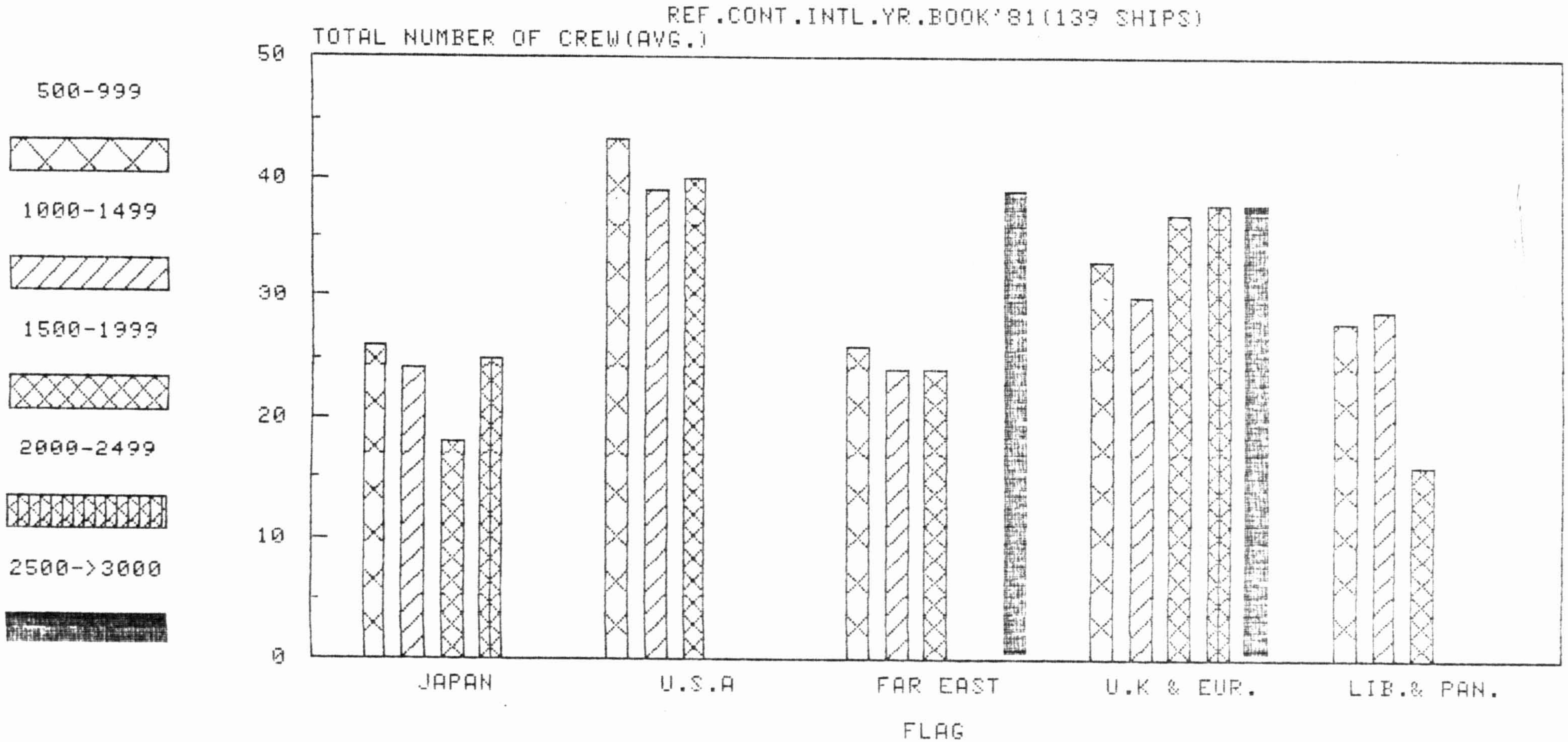
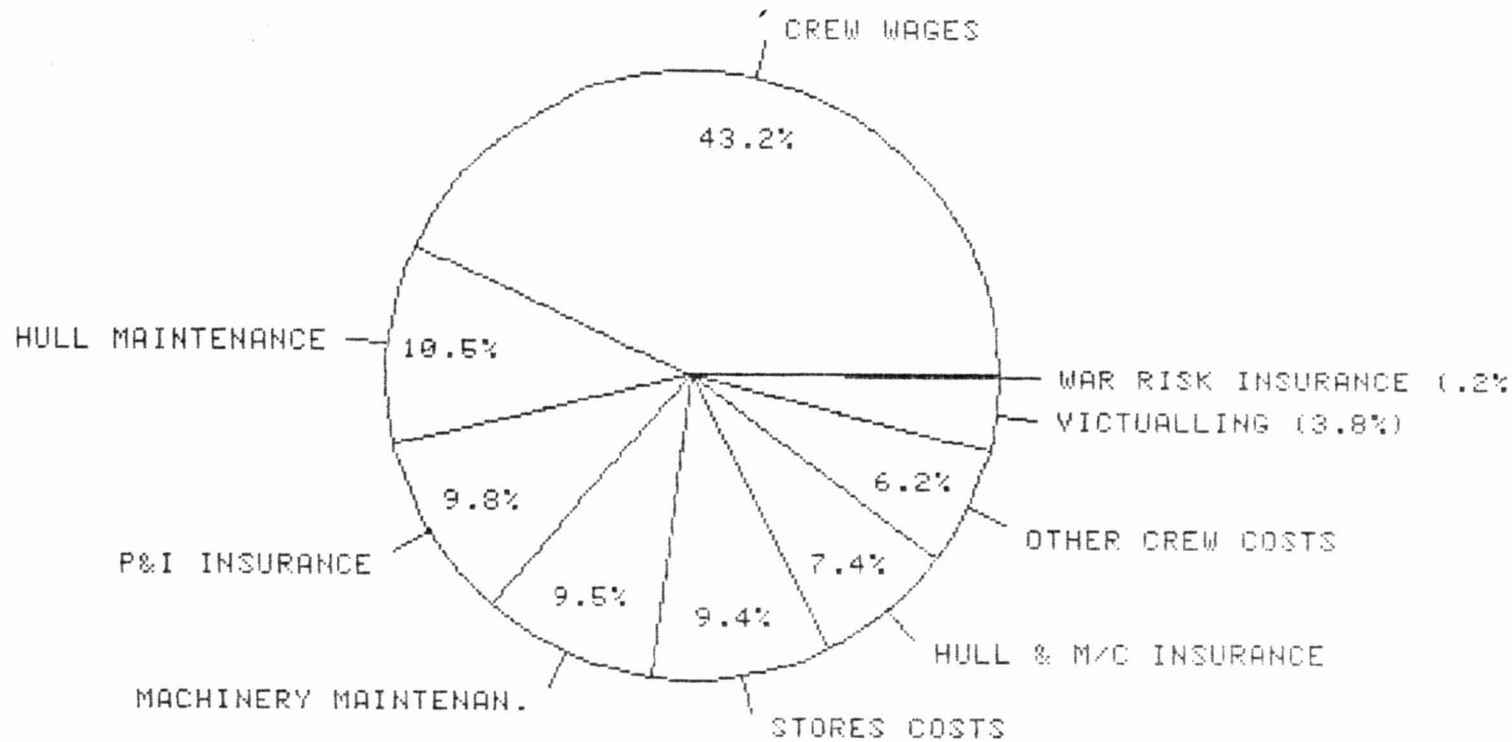


Fig. 10.3. DAILY RUNNING COST OF 1288TEU,23KNOT

ACTUAL DATA FOR CONTAINER SHIP



number of officers, petty officers and ratings are known. The total crew costs were subdivided into:

- Basic wages	) Basic crew wages
- Overtime - Study allowance - Security and insurance - Travel allowances - Cost of training - Leave allowances	) Other crew costs

Fig. 10.4. shows the contribution of the different elements to the crew costs for an actual container ship.

The costs shown are base rates and can be used for all vessel types with certain additions. Most countries do have minimum rates but owners in many instances exceed these to meet the operational requirements of their trade. The cost figures shown are considered representative.

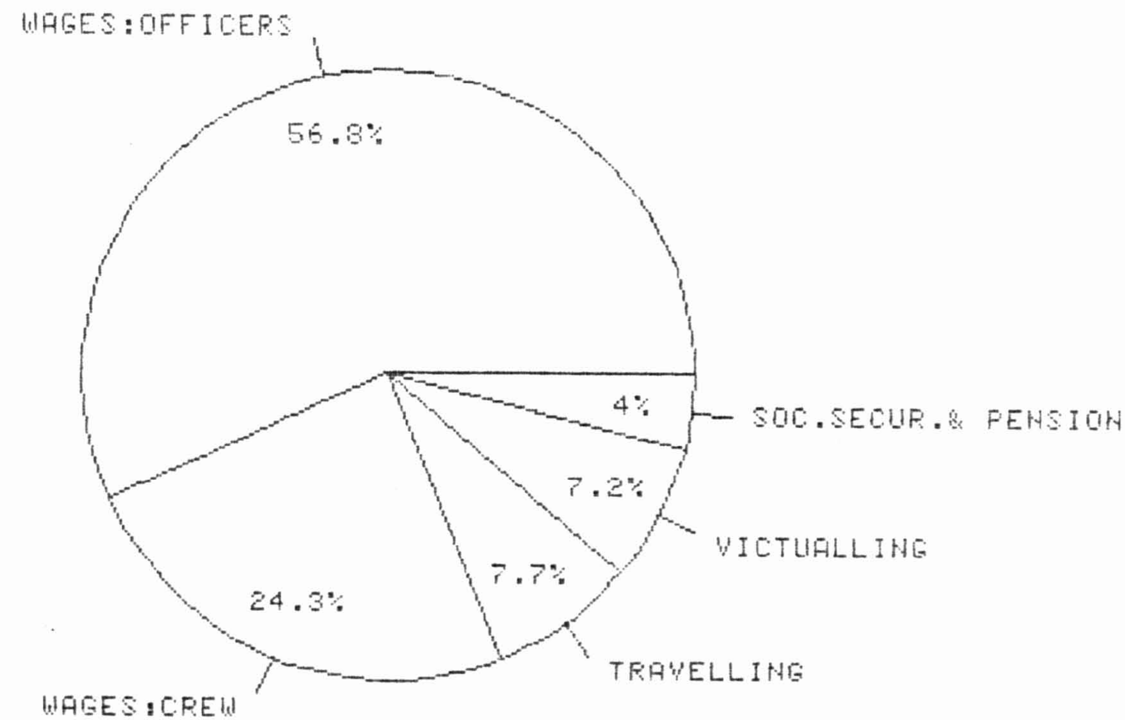
The following is a brief description of the methodology.

(1) The basic wages of each of the officers, petty officers and ratings were collected for ships under British flag from the trade press and shipping companies. For other flags (116, 117) and (118) give representative values. The basic wages of the officers, ratings and petty officers were averaged to simplify the calculation, alternatively the procedure can be repeated for each individual member. The program input therefore requires only the average wages of officers, petty officers and ratings (3 data values) compared to data values of say 36 (for 36 men crew). The basic wages of officers is taken as £8400/annum, petty officers as £5400/annum and ratings as £5300/annum for a 38 man crew comprising of 12 officers, 6 petty officers and 20 ratings.

(2) Overtime is available to petty officers and the ratings and was taken as 30% of the basic wages.

(3) The leave for officers is taken as 50% of the basic wage and 30% of the basic wage for petty officers and ratings.

Fig. 10.4. CREW COSTS FOR A 1288 TEU, 23 KNT. SHIP
ACTUAL VALUES AT 1979 COST LEVEL (Developed World Flag)



(4) Study allowances of up to 6 months is allowed for selected officers, and taken as half the number of officers.
(5) Social security payments of up to 25% of the salary to cover pensions and health insurance (company and government) was assumed.
(6) Travel allowances represents 3 changes/annum for officers and 2 for petty officers and ratings. The cost is based on an average relieving trip.
(7) Training is an estimated cost to cover cadet programmes and in-house facilities.

Table 10.4 outlines the calculation of the above procedure and is adopted in the program. A comparative evaluation for an American owned ship showed that the average basic wages of officers were 1.62 times higher, petty officers 1.17 times higher and ratings 1.37 times higher than a British owned ship for the same manning level, although the former will have higher manning requirements and thus higher costs. This is borne out by Table 10.2 which shows that the American flag ship will have crew costs 1.78 times that of a ship under British flag. Table 10.2 also gives a quick estimating method for derivation of total crew costs for ships under different flags.

10.3. INSURANCE

Insurance consists of Hull and Machinery insurance, protection and indemnity insurance and war risk insurance. There are no precise formulae or methods to calculate insurance costs, and lots of factors are considered e.g. composition of the fleet, previous history, age of the vessels in the fleet, extent of risk an owner is willing to cover etc. Some owners do not cover their ships against all types of risks, when the profits are low. Insurance costs however do not vary as much as crew costs as the shipowner is often free to buy the cheapest in the world market. It is assumed in the thesis that the shipowner is able to buy the cheapest insurance in the world market and he covers most of the risks. Each of the insurances are considered briefly here.

TABLE 10.4. Calculation procedure of crew costs for 38 men crew.

	Item	Computer Symbol	Calculation	% of Total	Total costs in £
Basic crew costs	Basic Wages	CWAGES	WCREW*CREW + WPO* PO + WOFF*OFF = 5300*20 + 6*5400 + 8400*12 =	39.95	239200
	Overtime	COVTIM	0.30*WCREW*CREW + 0.30*WPO*PO = 0.30 x 5300*20 + 0.30 x 5400*6 =	6.93	41520
	Cost of study	CSTUDY	0.25*OFF*WOFF = 0.25*12 x 8400 =	4.21	25200
	Cost of leave	CLEAVE	0.30*WCREW*CREW + 0.50*WPO*PO + 0.50*WOFF* OFF = 0.30*5300*20 +0.50*5400*6 +0.50*8400*12 =	16.43	98400
			SALARY		404320
Other crew costs	Cost of security and insurance	CSECUR	0.25(CWAGES + COVTIME + CSTUDY +CLEAVE) = 0.25 x SALARY	16.88	101080
	Cost of travel, U.K. - Persian Gulf	CTRAVL	1500 x OFF + 1000*(CREW + PO) = 1500 x 12 + 1000 x (20 + 6)	7.35	44000
	Training costs	CTRAIN	1300.0 x TMAN	8.25	49400
			TOTAL	100.00	598800

WCREW, WPO, WOFF - Wages of ratings, petty officers and officers/annum.

CREW, PO, OFF - Number of ratings, petty officers and officers.

Fig. 10.5 shows the contribution of the different elements of the insurance costs for an actual containership.

HULL AND MACHINERY INSURANCE

The hull and machinery insurance covers a shipowner against damage or total loss of the vessel and is mainly dependent on the owner's past safety record. Usually hull and machinery insurance is expressed as a fraction of the price of the ship (54, 119, 120, 46) or Teu (39), (55) or as a function of the machinery acquisition cost (102, 61). (See Table 10.5). The hull and machinery insurance cost in this thesis was expressed as a function of the price of the ship. A check was made with the actual ship data as shown below.

Ref. No.	Type	Year	DWT	TEU	Capital Cost in £ x 10^6	Actual HMINS in £	Actual as a % of CAPCOS
1	Gen. Cargo	1978	16845	-	3.93	23134	0.588
2-6	"	1978	16896	-	3.93	23134	0.588
7-11	"	1978	19506	-	7.37	35331	0.479
13	"	1978	15022	-	5.43	30000	0.552
14	Bulk Car.	1978	69889	-	20.27	65861	0.325
15	"	1977	26468	-	7.072	41976	0.593
17	Container	1980	48544	3000	43.24- 48.0	160615- 197680	0.371- 0.457
20	"	1979	23016	1288	25.8	67244	0.26
21	"	1979	28295	1684	30.0	67244	0.24

A further check was made with two equations which were developed in 1978, one by Alderton (119) for all ship types and the other by Validakis (120). The formulae are given in Table 10.5.

Actual shipping company records showed that hull and machinery insurance is 0.63% of the value of the ship in the previous year plus 0.283% of the increase in value of the ship for the present year, e.g. for ship 1, the 1978 cost of hull and machinery is calculated as follows

Fig.10.5 INSURANCE COSTS FOR 1288TEU,23KNOT SHIP
ACTUAL VALUES AT 1979 COST LEVEL (European shipowner).

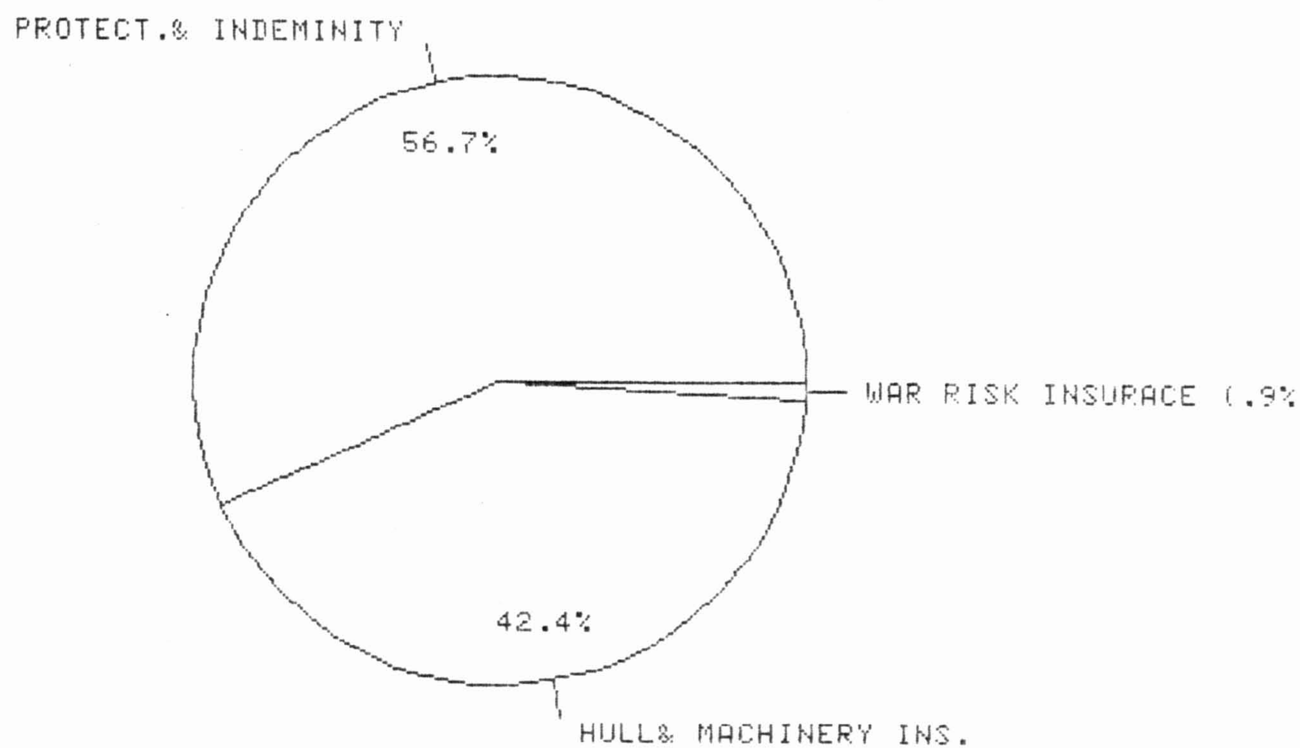


Table 10.5. Summary of operating cost formulae (updated vide operating cost indices)

Ship Type				Container		Container	Cargo Liner	Container	
			Formula	Erichsen (39)		Swift (55)	Sen (41)	Volker (61)	
				1969	1980	1973	1973	Formula	1974
Crew Costs		Wages Victualling Other crew costs	$C_0 x 10^5 x Teu^{0104} x 1.05^t$	0.43	1.29	0.59	C_0 x (NCREW + 1.98) C_0 = 7748	C_0(92,500 + 11,200 x NCREW)	0.48
Maintenance and Repairs	Hull	Hull engineering	$C_1 x (CNC)^{0.616} x e^{0.027t}$	165	339	25.46	21.52	<u>Slow Speed Diesel</u> $C_{11}(\frac{BHP}{1000})DAS + C_{12}(\frac{BHP}{1000})^{0.66}$	M & R (71) 5.5% 5350%
		Hull outfit & accommodation	$C_2 x (CN)^{0.685} x e^{0.0345t}$	211	434	25.46	21.95		
	Machinery	Diesel	C_3 x BHP	1.67	3.27	2.32	2.02	<u>Medium Speed Diesel</u> $C_{21}(\frac{BHP}{1000})DAS + C_{22}(\frac{BHP}{1000})^{0.66}$	C_{21} = 4.045 C_{22} = 2076
		Steam Turbine	C_4 x $SHP^{2/3}$	20	41	27.8		S.T. (2 Heater) $C_{31}(\frac{SHP}{1000})^{0.66} + C_{32}$	C_{31} = 2597 C_{32} = 2129
		Gas Turbine							
Stores & Supplies									
Insurance		Hull & m/c	C_5 x $Teu^{0.7}$	753	907	1042	$0.022x(BUILDING\ COST)^{0.99}$	C_{51} x MACHINERY COST	0.014
		War Risk							
		P & I						C_{52} x BUILDING COST	0.0175
Overheads & Miscellaneous									

Note: CNC and CN in m^3, Costs in £ unless indicated otherwise.

Table 10.5. Contd.

Ship Type			Container			All ship types			
			Hancock (54)			Alderton (119)			
			Formula	1971	1980	Formula	1978	1979	1980
1) Crew Costs		Wages + other crew costs	$C_1 \times NCREW$	11,754	27,680	$C_1 \times 365 \times \frac{NCREW}{BASIC\ CREW}$	930	1000	-
		Victualling	$C_2 \times NCREW$	313	592	$C_2 \times 365 \times NCREW$	3.0	3.10	3.53
		Number of crew	$\left.\begin{matrix}\text{Engine}\\ \text{crew}\end{matrix}\right\} = 0.1 \times \frac{SHP}{1000} + 8$ $\left.\begin{matrix}\text{Deck}\\ \text{crew}\end{matrix}\right\} = 0.167\left(\frac{CN}{1000}\right) + 5$ Total = 1.25 x (ENG + DECK)			BASIC CREW	34	32	32
Maintenance and Repair	Hull	Hull outfit & accommodation 2)	$C_3 \times \left(\frac{CN}{1000}\right)^{0.67}$	51,211	57,356	**Stores & repairs** For GRT < 16,000: $C_3 \times (GRT/1000) \times 365$	29.7	30.0	-
		Hull engineering							
	Machinery	Diesel							
		Steam Turbine 3)	$C_4 \times \left(\frac{SHP}{1000}\right)^{0.28}$	7,444	8,337	16,000 < GRT < 30,000: STLWT x (2.8 -(GRT-16,000) x 0.0002) x (C_3/1000) x 365			
		Gas Turbine 3)	$C_5 \times (SHP)$	1.65	1.85				
Stores and Supplies 4)			$C_6 \times NCREW$	980	1,666	GRT > 30,000: $C_3 \times \frac{STLWT}{1000} \times 365$			
Insurance		Hull and machinery 5)	$C_7 \times$ BUILDING COST	0.0128	0.0128	$C_4 \times DWT + \frac{C_5 \times C_6 \times 365}{1000 \times 0.05}$ $C_6 = LTWT \times C_7 \times 0.06 \times V/13$ st.line depreciation @ 6%, V = speed			
		War Risk 6)	$C_8 \times$ BUILDING COST	0.002	0.002	C_4 C_5 C_7	1.5 3 999	1.5 3 1150	
		P & I 7)	$C_9 \times NCREW$	392	337	GRT<9,000: $C_8 \times GRT \times 365$ GRT>9,000: $C_8 \times GRT \times (0.07 + 9,000/GRT) \times 365$			
Overheads & Miscellaneous			12% of (1+2+3+4+5+6+7+PORT + FUEL			$C_8 \times 365$	86	94	-

Table 10.5. Contd.

Ship Type			Container			General Cargo		
			Chapman (46)			Validakis (120)		
			Formula	1969	1980	Formula	1978	
Crew Costs		Wages	C_1 x NCREW	1885	6349	CREW x WCREW + OFF x WOFF		
		Other crew costs				WCREW WOFF	7500 16,000	
		Victualling	C_2 NCREW	175	352			
Maintenance and Repair	Hull	Hull outfit and accommodation	1)Salvage Association		1629			
		Hull engineering	$C_3 \times \left(\frac{CN}{100}\right)^{2/3}$ 2)Norwegian Shipowners' Association	269	552	$C_1 + C_2 \times DWT_{tonnes}$ C_1 C_2	 120,000 0.5	
	Machinery	Diesel						
		Steam Turbine	$C_4 \times (SHP)^{2/3}$	12	1) 72 2) 25			
		Gas Turbine						
Stores and Supplies			$C_5\left(\frac{NCREW}{10}\right)^4$	23	46	$C_3 + C_4 \times 350 \times$ NCREW C_3 C_4	 38,500 1.5	
Insurance		Hull & m/c.	C_6 + 0.0075 x PRICE	1430		0.005 x PRICE		
		War Risk						
		P & I	0.0175 x CAPITAL CHARGE			C_5 x GRT	1.1	
Overheads and Miscellaneous			$C_7 + C_8\left(\frac{CN}{100}\right)$ C_7 C_8	 12,800 141	 43,448 479			

The value of the ship in previous year (1976) 3.145×10^6 @

0.63% = £19818

Increased value (1977) 786432 @ 0.283% = £2229

£22047

Add 10% increase for 1978 = £ 1087

£23134

Ref. No.	Alderton '78 £ fn(DWT)	fn (PRICE)	(1) Total	Validakis (2) in £	(1)/(2)	(1) actual	(2) actual
1	25268	31890	57158	53150	1.075	2.221	2.065
2-6	25344	31890	57234	53150	1.076	2.224	2.065
7-11	28799	33900	62698	56500	1.109	1.488	1.340
13	22533	16250	38823	27150	1.429	1.294	0.905
14	104834	60810	165643	101350	1.634	2.515	1.538
15	39000	21216	60216	35360	1.703	1.435	0.842
17	72816	129720	202536	216200	0.937	1.261-1.024	1.346-1.094
20	34892	77400	112292	129000	0.870	1.669	1.918
21	34604	90000	124604	150000	0.830	1.853	2.231

While Alderton's and Validakis' figures are comparatively equal, they are twice the actual figures. The following equation was adopted in the thesis

$$\text{Hull and machinery insurance} = \frac{0.40}{100} \times \text{CAPITAL COST OF SHIP} \quad £ \qquad \text{Eq.(10.1)}$$

PROTECTION AND INDEMNITY INSURANCE

Protection and indemnity (P & I) insurance protects the shipowner against special liabilities. The P & I insurance varies considerably from ship to ship and depends on the size of the ship (GRT), shipowner's loss record, whether or not cargo is included, amount deductable and size of the ship's complement (102 , 54). Past container studies have expressed P & I as a function of building cost of the ship (61)or GRT (120, 119) or number of crew (54, 51) or capital charge (46), Table 10.5. P & I rates are usually quoted in terms of GRT (51) so the P & I insurance was made a function of GRT. A check was made with actual ship data and with the method given by Alderton (119) and Validakis (120).

Ref. No.	Actual P & I Insurance	GRT	P&I / GRT	Validakis / GRT Year = 78	Alderton / GRT Year = as given
1	55734	12057	4.623	1.1	1.825
2-6	55539	12015	4.622	1.1	1.825
7-11	60092	14434	4.163	1.1	1.825
13	10000	9112	1.097	1.1	1.825
14	20938	40689	0.515	1.1	1.850
17	24710	58889	0.419	1.1	1.850
20	89935	25993	3.46	1.1	1.850
21	89935	24433	3.46	1.1	1.850

whereas Validakis gives a low value of £1.1/GRT, Alderton's figure of £1.850/GRT seems reasonable. Actual 1978 costs of a general cargo ship was calculated on the basis of £2.8/GRT to which was added further premiums to arrive at a figure of £4.6/GRT for a shipowner from the developing world. For an average shipowner with satisfactory past record protection and indemnity insurance (P & I) is given by

P & I Insurance = 2.0 x GRT £ Eq. (10.2)

WAR RISK INSURANCE

This insurance covers a shipowner against damage in case of hostilities and would cover a shipowner until the vessel reached a port of refuge where a government war-risk scheme could be introduced (121). Benford (51) expresses war risk insurance as 0.1% of the capital cost whereas Hancock (54) takes a higher percentage of 0.2% of the capital cost, Table 10.5. A check for the actual percentage is made for some actual ship data.

Ref. No.	Actual (1) war risk ins. £	Capital (2) cost £ x 10^6	(1)/(2) as % x 10^{-3}
1-6	2599	3.93	63
7-11	4873	7.37	63
14	1475	20.27	7.27
17	3597 - 4496	48 (upper)	8.24 - 10.29
		43.24(lower)	9.14 - 11.43
20	1417	25.8	5.47
21	1417	30.0	4.72

These values show that the war risk insurances are less than what is given by Benford or Hancock. A shipping company's actual records showed that it is calculated on the basis 0.063% of the value of the ship. In this thesis a value of .01% of the capital cost is taken as a representative figure.

$$\text{War risk insurance} = \frac{.01}{100} \times \text{CAPITAL COST} \quad £ \qquad \text{Eq. (10.3)}$$

TOTAL INSURANCE

Instead of calculating each of the insurance costs, the total insurance cost can be expressed as a function of Teu (39, 55) or the capital cost (101, 41). Buxton gives a figure of 1.3% of the capital cost (101). A check made against actual data shows that the total insurance costs varied between 1.5% to 2% of the price of the ship, as shown in Table 10.6.

Table 10.7 gives the total insurance costs calculated by the program which are about 0.6% of the capital costs, and shows that there are large variations between the actual data and those calculated by the program.

The program calculates the war risk and hull and machinery insurance as a percentage of the capital cost of the ship. The capital cost of a container ship is about 20 to 40% higher than the price (see Fig. 9.9, 1978), therefore the

TABLE 10.6. Insurance costs as a percentage of the price of the ship.

Ref. No.	Ship Type	Actual Total Insurance £	Price of the ship £ x 10^6	Percentage of Capital Cost
1	G.C.	81467	3.93	2.07
2-6	G.C.	81272	3.93	2.067
7-11	G.C.	102243	7.37	1.387
24	Cont.	206438	13.76	1.50
25	Cont.	88474	5.90	1.499
26	Ro-Ro	147456	9.83	1.50
27	Ro-Ro	52160	6.14	1.50
28	Car.liner	129024	8.60	1.50

TABLE 10.7. Insurance costs, actual versus calculated.

Ref. No.	Vessel Type	Actual Total Insurance £	PROGRAM VALUES (1978) P & I	War Risk	Hull + M/C	Total	Percentage of Capital Cost	% Diff. from actual
14	Bulk.Car.	99875	74257	2027	81080	157364	0.776	-57.56
1	Gen. Car.	81467	22004	1063	42520	65587	0.616	19.49
2-6	Gen. Car.	81272	21927	1063	42520	65510	0.616	19.39
7-11	Gen. Car.	102243	26342	1130	45200	72672	0.643	28.92
13	Gen. Car.	40000	16629	543	21720	38892	0.716	2.77
17	Container	172212-211330	117778	4324	172960	295062	0.682	-39.62
20	Container	178960	48087	2580	103200	153867	0.596	14.02
21	Container	178960	69350	3000	120000	192350	0.641	-7.48
22	Container	76439	42566	3700	148000	194266	0.525	-154
23	Container	36870	27748	1221	48840	77809	0.637	-111
24	Container	206438	78088	4243	169720	252051	0.594	-22.09
25	Container	88474	28457	1424	56960	86841	0.609	1.84
26	Ro-Ro	147456	25320	-	-	-	-	-
27	Ro-Ro	92160	9077	-	-	-	-	-
28	Car.liner	129024	18354	-	-	-	-	-

total insurance costs as 0.6% of the capital costs seems reasonable.

10.4. MAINTENANCE AND REPAIR COSTS

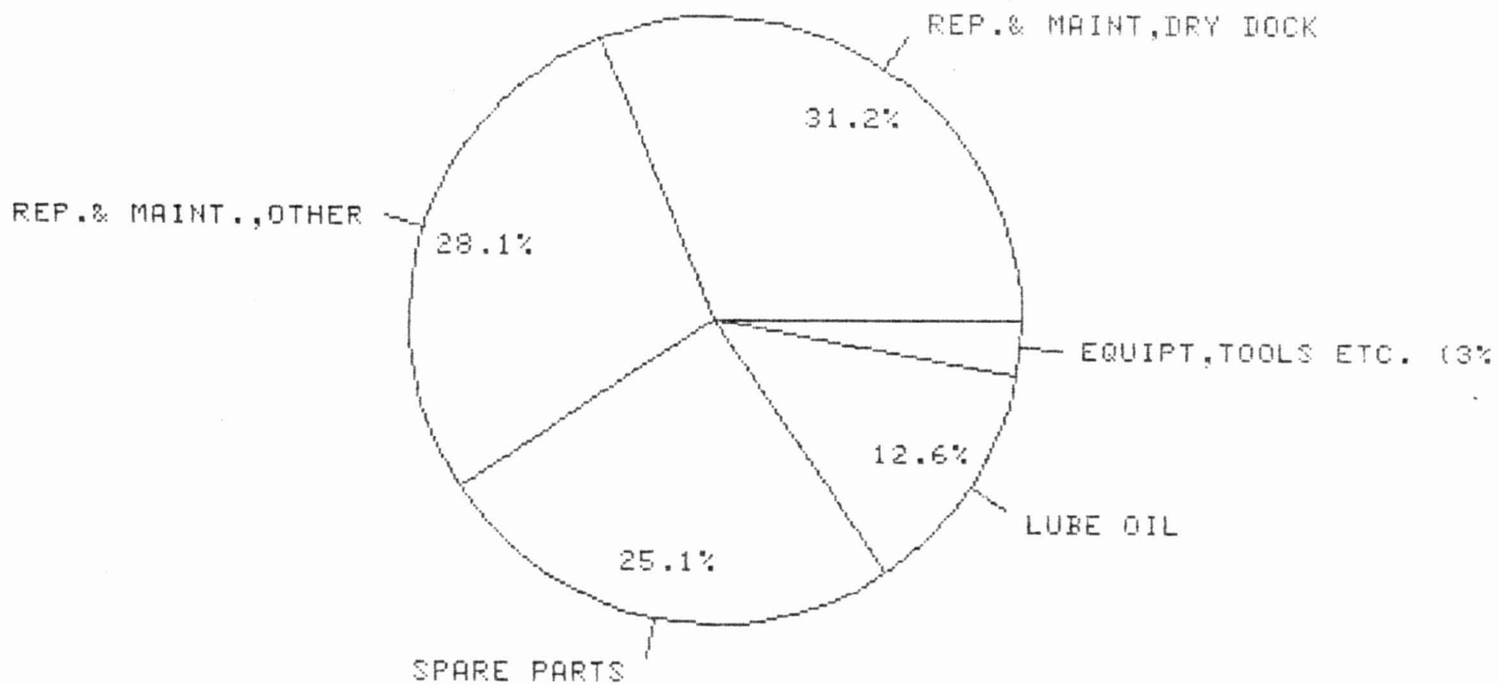
Maintenance and repair costs usually consist of the cost related to dry docking of the ship, maintenance of engines, the main systems, cost associated with other preventive maintenance, repair to damages, cost of inventory related to spares and equipment and tools.

The maintenance and repair costs were subdivided into hull and outfit maintenance and machinery maintenance. Machinery maintenance is usually subdivided according to the type of engine e.g. diesel, steam turbine or gas turbine. In the program only diesel engine maintenance and repair costs are estimated. Figure 10.6 shows the percentage contribution of elements of the maintenance and repair costs for an actual container ship. In the program, however, luboil costs are calculated separately.

HULL AND OUTFIT MAINTENANCE AND REPAIRS

The hull and outfit maintenance costs comprises mainly of drydocking costs of the ship as shown in Fig. 10.6. Past container ship studies have expressed the hull and outfit maintenance cost as a function of the cubic number (54), (46), (55), (41), (39). A similar approach has been taken in the thesis. Formula developed for general cargo ships by Benford (51) and subsequently incorporated for a container ship study by Hancock (54) & Chapman (46) was updated to 1980 cost levels. Two indices were available for updating the cost figures. One published by the Salvage Association is based on world wide figures and cost indices, for major ship repairing facilities are given together with the cost of hull and machinery repair for a typical ship at different ship repairing facilities (122). The other was the operating cost indices published annually by the Norwegian Shipowners Association (123). The indices given by the latter was

Fig.10.6.REPAIRS&MAINT.COST FOR 1288TEU,23KT SHIP
ACTUAL VALUES AT 1979 COST LEVEL (European shipowner).



adopted because the indices for various other operating costs were also available, and were used for updating other cost items. The hull and outfit maintenance (CHMANT) cost is given by

$$\text{CHMANT} = 450\ (\text{CN})^{0.67} \quad £ \quad (1980)\ \text{Eq. (10.4a)}$$

$$= 440\ (\text{CN})^{0.67} \quad £ \quad (1978)\ \text{Eq. (10.4b)}$$

MACHINERY MAINTENANCE AND REPAIR

Machinery maintenance and repair forms a substantial part of the total maintenance and repair cost particularly for diesel machinery plant. Steam turbine plants have substantially lesser maintenance and repair costs, Table 10.1. But due to increases in fuel costs, the diesel plant with its lower fuel consumption is preferred.

The machinery maintenance and repair costs for container ships with diesel plant is usually expressed as a function of BHP (39), (55) and (41). A similar expression was adopted in the thesis, and Erichsen's (39), Swift (55), Sen (41) figures were updated by indices given by the Norwegian Shipowner's Association (123).

The machinery maintenance and repair cost (CMMANT) is given by

$$\text{CMMANT} = 3.27 \times \text{BHP} \quad £ \quad (1980)\ \text{Eq. (10.5a)}$$

$$= 2.57 \times \text{BHP} \quad £ \quad (1978)\ \text{Eq. (10.5b)}$$

The machinery maintenance costs are of the right magnitude, e.g. 1976 costs for diesel plant was £2.47 to £3.46/bhp/annum (124) with £2.72/bhp/annum as the average cost and 1980 costs were £2.5/bhp/annum (66).

TOTAL MAINTENANCE AND REPAIR COSTS

The total maintenance costs are difficult to correlate to actual data. The percentage variation of total ship maintenance and repair costs as given by the Salvage Association (122), with U.K. costs as 100, showed that world wide repair and maintenance costs can vary between 57 to

225. It is difficult to validate the equations for hull and outfit and machinery separately. Since machinery maintenance is of the correct magnitude, a check on the total maintenance and repair costs with total costs of actual ships (Table 10.1) would show if the hull/outfit maintenance and repair costs are of the correct magnitude.

Actual maintenance and repair costs were twice the calculated values as shown in Table 10.8.

A further check was made with two other equations which were available for 1978, one by Validakis (120) for general cargo ships and the other by Alderton (119) for all ship types. These methods also gave values which were of the same magnitude, Table 10.9, as those calculated by Eq. (10.4a and 10.5a). So these equations were adopted in the program to represent maintenance and repair costs.

10.5. STORE COSTS

Store costs include the cost of deck and engine stores and the cabin stores. Included in the deck and engine stores are paints (excluding paint cost in dry dock), ropes, packing and engine spares etc. and cabin stores includes all supplies, soft furnishings, laundry etc. Store costs are usually a function of the number of crew (46), (120), (54), (51). Three forms of equations were used in the past studies as shown in Table 10.5 and are:

Stores and supplies cost = $C_0\left(\frac{NCREW}{10}\right)^4$, Benford (51) and Chapman (46)

or Stores and supplies cost = $C_0 + C_1 \times NCREW$, Validakis (120)

or Stores and supplies cost = $C_0 \times NCREW$, Hancock (54)

Since store costs form only 9.4% of the daily running costs (Fig. 10.3) Hancock's linear relationship was adopted and coefficient C_0 determined from actual ship data (Table 10.1).

TABLE 10.8. Maintenance and repair costs, actual versus calculated.

Ref. No.	Ship Type	M/C Type	BHP/SHP	Actual (£) maintenance & repair cost	Cal. Hull/Outfit Maint. & Repair (£) 1978	Cal. M/C Maint. & Repair (£) 1978	Cal. Total (£) 1978	Actual / Cal.
16	Tanker	T	40000	344064		*102800		
18	Cont.	D	35000	294912		89950		
19	Cont.	T	35000	231014		*17724		
13	Gen.Car.	D	8400	80000	21051	21588	42639	1.87
14	Bulk Car	D	17400	64656	56587	44718	101305	0.638
15	Bulk Car	D	22400	62964	32297	57568	89865	0.700
20	Cont.	D	34200	159778	45000	87894	132894	1.202
21	Cont.	D	34200	205717	44300	87894	132194	1.556
24	Cont.	D	47500	245760	62700	122075	122702	2.003
25	Cont.	D	18300	172032	31904	47031	78935	2.179
22	Cont.	T	50500	148381	59631	* 19640	79271	1.872
23	Cont.	D	7000	33723	24572	17990	42562	0.792
26	Ro-Ro	D		238387				
27	Ro-Ro	D		172032				
28	Car.lin.	D		98304				
1	Gen.Car.	D	13700	210287	26094	35209	61303	3.43
2	Gen.Car.	D	13700	194311	26094	35209	61303	3.17
3	Gen.Car.	D	13700	201045	26094	35209	61303	3.28
4	Gen.Car.	D	13700	206511	26094	35209	61303	3.37
5	Gen.Car.	D	13700	122452	26094	35209	61303	1.99
6	Gen.Car.	D	13700	122992	26094	35209	61303	2.00
7	Gen.Car.	D	13700	125542	30311	35209	65520	1.916
8	Gen.Car.	D	13700	116690	30311	35209	65520	1.781
9	Gen.Car.	D	13700	123577	30311	35209	65520	1.866
10	Gen.Car.	D	13700	115709	30311	35209	65520	1.766
11	Gen.Car.	D	13700	101941	30311	35209	65520	1.555
12	Gen.Car.	D	25000	221184		64250		

* For steam turbine the machinery maintenance and repair costs for 1978 were taken as

$$\text{CMMANT} = 6550(\text{CN})^{0.67} \quad \text{CN in } m^3$$

TABLE 10.9. Comparative evaluation of maintenance and repair costs.

	(1) Maint. & Repair Cost 1978 Ref. (120)	Actual / (1)	(2) Stores + Sup. and Maint. Repair Cost 1978 Ref. (119)	Gross Steel Wt.	Actual maintenance repairs + Stores / (2)
1	128422	1.637	130703	-	1.849
2	128448	1.513	130248	-	1.723
3	128448	1.607	130248	-	1.781
4	128448	0.953	130248	-	1.817
5	128448	0.957	130248	-	1.171
6	128448	0.977	130248	-	1.182
7	129753	0.899	156471	-	0.964
8	129599	0.900	156471	-	0.906
9	129599	0.953	156471	-	0.949
10	129599	0.893	156471	-	0.897
11	129599	0.786	156471	-	0.807
12	123000	1.798	-	-	-
13	127511	0.627	98778	-	1.367
14	154944	0.417	167767	15476	0.567
15	133234	0.472	77542	7153	0.812
16	310000	1.109	-	-	-
17	-	-	-	23579	-
18	136500	2.160	-	-	-
19	-	-	-	-	-
20	131508	1.564	79691	9173	3.80
21	134147	1.191	136416	12584	1.945
22	-	-	230779	12211	0.935
23	130000	0.259	150401	3754	
24	135000	1.820	142888	13181	1.995
25	125000	1.376	169035	-	
26	130000	1.834	-	-	
27	125000	1.376	-	-	
28	127500	0.771	-	-	

TABLE 10.10. Actual stores and supplies costs vs. estimated.

Ref. No.	Actual stores (£)	No. of crew	Actual Stores / Crew	Validakis (120) incl. lub. £	Validakis excl. lub. oil costs	Program Values (1978)£
1	31737	43	738	61075	45638	-
2	30115	41	734	60025	44588	-
3	30926	41	754	60025	44588	-
4	30115	41	734	60025	44588	-
5	30115	41	734	60025	44588	-
6	30926	41	754	60025	44588	-
7	25303	37	683	57925	42226	-
8	25163	37	692	57925	42226	-
9	24979	37	675	57925	42226	-
10	24719	37	668	57925	42226	-
11	24330	37	657	57925	42226	-
13	55000	32	1486	55300	42226	-
14	30473	27	1128	52675	23075	-
20	97392	38	2562	58450	14775	51034
21	105618	38	2779	58450	Negative	51034
22	67446	40	1686	59500	46011	53720
23	80935	41	1974	60025	15061	55063
24	39321	40*	983	59500	-	53720
25	24576	40*	614	59500	-	53720
26	34406	44*	782	61600	-	59092
27	27034	44*	614	61600	-	59092
28	19661	35*	561	56875	-	-

A linear regression on the above data gave the following equation

Stores and supplies costs = 41279 - 20.95 x NCREW

with a correlation of (-.0033) showing an extremely poor fit to the data. Validakis (120) stores and supplies includes luboil costs, once the actual luboil costs are subtracted gives reasonable values for general cargo vessels but gives poor results for container ships (Table 10.10). Store costs were updated from Hancock (54) by operating cost indices (123) and was adopted in the program. Table 10.10 shows

*Estimated number of crew.

the calculated values at 1978 cost levels which seem reasonable. For 1980 cost levels the store costs are given by

$$\text{Stores costs} = 1666 \times \text{NCREW} \quad £ \qquad \text{Eq. (10.6)}$$

10.6. MISCELLANEOUS COSTS

Miscellaneous costs include the cost to cover crew recruitment, communications, standby, medical and short backup directly linked with crewing, sundries and administration.

This cost is either taken as a fixed cost (119) or is made a function of cubic number of the ship (46), (51) (see Table 10.5). Following equations were available.

METHOD 1: The following equation was used for a container ship study by Chapman (46), and was updated from an equation suggested by Benford (51) for a general cargo ship. The equation was updated by operating cost indices given by Norwegian Shipowner's Association (123).

$$\begin{aligned} \text{CADMIN1} &= 12800 + 141\left(\frac{\text{CN}}{1000}\right) \quad £ \quad \text{(1969 cost level), CN in m}^3 \\ &= 32906 + 363\ (\text{CN}/1000)£ \quad \text{(1978 cost level)}\ \# \\ &= 36419 + 402\ (\text{CN}/1000)£ \quad \text{(1979 cost level)}\ \# \\ &= 43444 + 479\ (\text{CN}/1000)£ \quad \text{(1980 cost level)}\ \# \end{aligned}$$

METHOD 2: The following equation was suggested by Alderton (119) for all ship types and was updated by operating cost indices (123).

$$\begin{aligned} \text{CADMIN2} &= 7942 \quad £ \quad \text{(1969 cost level)} \\ &= 31390 \quad £ \quad \text{(1978 cost level)} \\ &= 34310 \quad £ \quad \text{(1979 cost level)} \\ &= 40880 \quad £ \quad \text{(1980 cost level)}\ \# \end{aligned}$$

These equations were compared with some actual data (see Table 10.1).

# indicates updated equation.

Ref. No.	Actual Costs (£)	Method 1 (£)	Method 2 (£)	Program (£)
1	47055	33066	31390	46612
2-6	47055	33066	31390	44444
7,9,11	51318	33107	31390	40108
8	49549	33107	31390	40108
20	44166	36821	34310	45600
21	44166	36812	34310	45600
22	22482	44172	40880	57240
23	22482	43638	40880	58671

Method 1 and Method 2 gave comparable results as shown above, although for Ship No. 21 and 22, the calculated costs were twice the actual figure. Actual cost estimates of 2 shipping companies showed that the miscellaneous cost or cost of administration is apportioned for each vessel in the fleet according to the number of crew. Since this relationship gives acceptable results, it was used in the program and is given by

CMISC = 1300.0 x NCREW £ (1980 cost level) Eq. (10.7)

10.7. PORT CHARGES AND DUES

A ship incurs two types of costs when calling at a port. One cost is associated with entering and exiting the port, such as pilotage, towage, canal dues etc. The second is related to the time a ship stays in the port which consists of daily charges for berthing privileges, watchman fees, utility hook ups for water and electricity at the pier etc.

Port costs (Table 10.11) are usually made a function of the net registered tonnage (119), (107), cargo dead weight (41) or bale cubic (125) per port of call, or as a fixed cost per round trip (40). Container ship study by Swift (55) subdivided the port costs into those incurred per day and the others which are incurred per call for

TABLE 10.11. Summary of formulae for port cost estimation.

Method	Cost level	Formulae	Constants		Ref.
1	1978	TCPORT = C_1 x GRT + C_2 x GRT X DIP in £/call	C_1 C_2	0.512 0.01	120
2	1978	TCPORT = C_3 x DWT + C_4 x DWT x DIP in £/call	C_3 C_4	0.306 0.009	120
3	1978	TCPORT = C_5 x NRT in £/call	C_5	3.32 to 2.40	119
	1979	TCPORT = C_6 x NRT in £/call	C_6	2.50	
4	1978	TCPORT = C_7 x NRT in £/call	C_7	0.3 to 3.0	107
5	1973	TCPORT = C_8 x Cargo deadwt. in £/call	C_8	0.147	41
6	1968	TCPORT = C_9 x bale cubic capacity (m^3) in £/call	C_9	14.75	125
7	1973	Cost/call = $C_{10} + C_{11} \times \frac{CN(m^3)}{1000}$ in £ Cost/day in port = $C_{12} + C_{13} \frac{CN(m^3)}{1000}$ in £.	C_{10} C_{11} C_{12} C_{13}	222 638 18.94 274	55
8	1974	Cost/round trip = C_{14}	C_{14}		40

every port of call.

There is however wide variation in port costs. Buxton (107) gives a variation between £0.3 to £3.0 per net registered tonnage per port of call, a factor of ten. Because of these wide variations, in the program the method developed by Frankel (53) 1973 was adopted to reflect world wide port costs. This method was updated and subsequently used by Hancock (54) 1972 in a container ship study. The method is described briefly here, and validated with actual port costs of two container ships and with disbursement accounts of ships published by BIMCO (126).

Entry and exit costs:

The port entry and exit costs/port of call is given by

$$P_E = K_i e^L \, GRT^{0.585} \quad i = 1,2,3,4,5 \quad \text{£/call} \qquad \text{Eq. (10.8)}$$

where L = labour ratio in the trade area, $0 < L \leqslant 1$

K_i = port entry and exit costs constant (see Table 10.12 Col. 2)

Daily costs:

The cost in port/day is given by the following equation

$$P_D = 34 + K_j L^{0.5} \, GRT^{0.67} \quad j = 1,2,3,4,5 \quad \text{£/day} \qquad \text{Eq. (10.9)}$$

where K_j = Port daily cost constant (see Table 10.12 Col. 3)

GRT = Gross registered tonnage in tons.

The K_i and K_j terms shown above in each of the equations were given five values. These correspond to three values, high, low and average and two values between high-average and low-average.

Frankel while arriving at these equations got a correlation of about 0.90, but the magnitude of variation was extremely large (53) which was primarily due to institutional, geographical and political factors surrounding each port and the different methods used by various ports.

TABLE 10.12. Port cost constants.

Foreign countries in the trade area	I/J	Labour Ratio	Const. entry & exit cost	Const. daily cost	Port examined in the trade area
Greenland, Iceland, Ireland, England, Scotland	1	0.42	11.6	2.7	London, Dublin
Denmark, Norway, Sweden, Finland	2	0.92	3.6	2.10	Gothenberg, Oslo
W.Germany, France, Holland	3	0.89	7.6	2.7	Bremen, Le Havre, Rotterdam
Portugal, Spain, Italy, Switzerland, Austria, Yugoslavia, Greece, Albania	4	0.33	11.6	1.50	Genoa, Bilbao
U.S.S.R., Poland, Bulgaria, Hungary, Czechoslovakia, E. Germany	5	0.39	11.6	3.3	Gdynia, Wismar
Turkey, Lebanon, Syria, Iraq, Iran, Israel, S. Arabia & Peninsula	6	0.26	5.6	0.70	Kurramshahr, Beirut
Africa West Coast & Central Africa	7	0.029	7.6	0.70	Lagos, Matadi, Monrovia
Morrocco, Algeria, Tunisia, Libya, UAR	8	0.27	7.6	0.70	Tripoli, Casablanca
Angola, S. Africa, Mozambique, Zimbabwe	9	0.27	9.6	2.10	Capetown, Beira
Sudan, Ethopia, Repub. of Kenya, Tanzania, Uganda, Rwanda, Malawi, Zambia	10	0.029	11.6	0.70	Djibouti, Mombasa
Afghanistan, Pakistan, India, Nepal, Ceylon	11	0.018	7.6	3.3	Calcutta, Karachi
Burma, Thailand, Malaysia, Cambodia, S.Vietnam Philippines, Indonesia	12	0.039	5.6	2.1	Tandjong, Priok, Manila
Australia, New Zealand	13	0.68	7.6	3.3	Auckland, Sydney
Japan, Ryukyus, S. Korea, Taiwan	14	0.39	5.6	0.70	Keelung, Yokohama
China, N. Korea, Vietnam Hong Kong, Singapore	15	0.05	5.6	1.5	Hong Kong, Singapore

TABLE 10.12 (Contd.)

Foreign countries in the trade area	I/J	Labour Ratio	Const. entry & exit cost	Const. daily cost	Port examined in the trade area
Guatemala, Honduras, Costa Rica, Panama, Nicaragua, San Salvador	16	0.09	11.6	2.1	Balboa, Kingston
Antilles, Colombia, Venezuala, Surinam, Caracao, Guyana	17	0.17	9.6	2.1	La Guarira, Cartagena
Brazil, Uruguay, Paraguay	18	0.14	9.6	3.3	Rio de Janeiro, Montevideo
Ecuador, Peru, Bolivia, Chile	19	0.095	11.6	1.5	Callao Valparaiso
U.K. Coastal Area East Coast	20	0.51	11.6	2.7	
West Coast	21	0.51	11.6	2.7	
United States East Coast	22	1.00	11.6	2.1	Baltimore, Boston, New York
Gulf Coast		1.00	11.6	2.1	Houston, Mobile, New Orleans
Pacific Coast		1.00	5.6	1.5	Los Angeles Longview, San Francisco, Seattle
		L (1)	*1 K_i (2)	*1 K_j (3)	

* 1. See note 1 for updating these factors.

Heggie (127) based on port dues published in (128) has compared various port costs for four general cargo vessels in nine ports found that the structure of dues varies substantially between the nine ports. Amongst the various factors, there were also subsidies for national flag ships and reduced tariff for liner services etc. Such factors are neglected in constructing this model and the basis of costing is rationalised by assuming that all costs are dependent on the gross registered tonnage of the ship.

The labour ratio col. 1 Table 10.12 was updated by dividing the average per capita income of each trade area by the per capita income of the U.S.A. and is shown in Table 10.13. Table 10.12, col. 2, the entry and exit cost constants and col. 3, the daily cost constants were updated by material and labour indices given in Table 10.14 (see note 1).

The program uses as input the following values:-
PORTD and PORTF, the number of domestic and foreign ports;
PCFD and PCFF, the daily port costs constants;
PECFD and PECFF, the port entry and exit costs constants;
RLABD and RLABF, the labour ratio; at domestic and foreign ports respectively.

The daily port costs are calculated by Eq. (10.9) for the domestic ports and the foreign ports. The average of the daily costs of domestic and the foreign ports is the total daily port costs. The total entry and exit costs is the sum of the entry and exit costs at domestic ports and foreign ports calculated by Eq. (10.8).

Daily costs at the domestic ports, $PCOSTD = DIP \times (34.0 + PCFD \times RLABD^{0.5} \times GRT^{0.67})$ £

Daily costs at the foreign ports, $PCOSTF = DIP \times (34.0 + PCFF \times RLABF^{0.5} \times GRT^{0.67})$ £

Annual daily port costs, $PDCOST = \left(\frac{PCOSTD + PCOSTF}{2}\right) \times RTPA$

where RTPA = no. of round trips per annum.

TABLE 10.13. Labour ratio.

Area	Average (1) per capita income US$	Labour ratio US = 1.00
1	3655	0.42
2	7997	0.92
3	7725	0.89
4	2830	0.33
5	3391	0.39
6	2270	0.26
7	250	0.029
8	2305	0.27
9	2320	0.27
10	247	0.029
11	160	0.018
12	333	0.039
13	5855	0.68
14	3410	0.39
15	463	0.05
16	850	0.09
17	1464	0.17
18	1200	0.14
19	828	0.095
20	4430	0.51
21	4430	0.51
22	8640	1.00
PER CAPITA INCOME 1977		

(1) Ref. World Bank Atlas (Population, per capita, products and growth rates) 1978.

Note: 1.

Ref. Frankel & Marcus (53) Table exhibit I-11 was updated in the following way.

<u>Daily Costs</u>

17 x Material Index x Matl. Index x Exchange Rate

(1967-70)(1970-79)1979

17 x 1.048 x 3.885 x 0.4915
= 34.0

<u>Port Constant Col.3</u>
<u>Daily Costs</u>

Col. 3 exhibit 1-11 x Matl.Index x Matl. Index
(67-70) (70-79)

*Exchange rate

= Col. 3 x 1.048 x 3.885
0.4915 = 2.0

<u>Port Constant Col.2</u>
<u>Entry & Exit Costs</u>

Col. 2 exhibit I-11 x Matl. Index (67-70) x Matl. Index (70-79) x Exchange Rate

= Col.2 x 1.048 x 3.885
0.4915 = 2.0

TABLE 10.14. Material and labour indices.

Year	Material	Labour	
	Indices	Indices	Av. Weekly Pay £/Wk.
68	97.04	76.77	29.16
69	98.47	82.78	31.44
70	100.00	100.00	37.98
71	113.00	94.63	35.94
72	117.40	106.21	40.34
73	129.10	139.42	52.95
74	183.20	160.32	60.89
75	245.90	188.05	71.42
76	282.6	218.25	82.89
77	326.2	240.76	91.44
78	363.0	273.22	103.77
79	388.5	289.63	110.00
80	415.0	315.95	120.00

Exit and entry costs at domestic ports, PCENTD = PORTD x

$$\text{PECFD} \times e^{\text{RLABD}} \times \text{GRT}^{0.585} \quad £$$

Exit and entry costs at foreign ports, PCENTF = PORTF x

$$\text{PECFF} \times e^{\text{RLABF}} \times \text{GRT}^{0.585} \quad £$$

Annual entry and exit costs, PECOST = (PCENTD + PCENTF) x RTPA £

Then the total annual port costs, CPORT = PDCOST + PECOST £

The method was validated with two container ship data and is shown in Table 10.15. The port costs calculated for ship A was 5.50% from the actual costs, and the ship B was overestimated by about 12%. At the preliminary design stage cost differences of this magnitude are acceptable and therefore the method was adopted in the program.

10.8. FUEL OIL COSTS

The fuel oil costs were subdivided into cost of heavy fuel oil, diesel oil and lub oil. The costs were estimated from the weights of oil consumed at sea and port and multiplying the weights with the cost/tonne of heavy fuel oil, diesel oil and lub oil. The ship was assumed to bunker at the last foreign port of call, after bunkering at the first home port. A diesel generator of 1500 KW was assumed to be used at sea and port for generating electricity, running the ventilation plant etc. A 10% reserve for heavy fuel oil was carried above the requirements. (see also section 8.2.3. for assumptions).

Oil consumed at sea/day:

(1) Heavy fuel oil consumed/day = $162 \times 0.90 \times \text{BHP} \times 1.10 \times 24/10^6$ tonnes

where 162 gm/hp-hr is the specific fuel oil consumption (1) 0.90 is a factor to convert the installed horse power, to normal continuous rating, 1.10 is the 10% reserve fuel.

(2) Diesel oil consumed/day = $162 \times \text{AUXKW} \times \frac{1.341}{\text{KW}}\text{hp} \times$

TABLE 10.15. Validation of port costs.

Distance between ports = 14000 nautical miles.

(i)	Ports of call:	Domestic	Foreign	ii) PORTIME in days:	
	Regular	3	4 (Japan)	Australia	= 8.0
	Irregular	(Australia)	1 (Korea)	Japan	= 5.3
				Korea	= 1.0

(iii) Annual Costs 80-81

Ship A (1288 TEU)	246909	130278		
		8003	=	£ 385191
Ship B (1684 TEU)	272410	96138		
		37328	=	£ 405877

(iv) Seatime in days = 14000/23 x 24.0 = 25.36

Round trip time in days = 39.66

No. of round trips/annum = 350/39.66 = 8.825

	Ship A	Ship B
PCOSTF	2714	3409
PCOSTD	20033	25527
PDCOST	11373	14468
PCENTD	17216	21329
PCENTF	12656	15679
PECOST	29872	37008
PDCOST + PECOST	41245	51476
CPORT	£ 363991	£ 454275
Actual port costs	385191	405877
% difference from actual costs	5.50	-11.92

$\frac{0.50 \text{ load}}{0.95 \text{ eff.}} \times \frac{24}{10^6}$ tonnes.

The diesel generator is assumed to be a medium speed diesel engine.

(3) Cylinder luboil consumption/day = 0.37 g/HP-hr x BHP x

$$0.90 \times 24/10^6 \text{ tonnes}$$

(4) System luboil consumption/day = 0.26 g/HP-hr x BHP x

$$0.90 \times 24/10^6 \text{ tonnes}$$

where the system and cylinder luboil consumption was taken from Buxton (101).

Oil consumed in port/day:

(5) Heavy fuel oil consumed/day = 24.0 tonnes

(6) Diesel fuel oil consumed/day = 162 gm/BHP hr x AUXKW x

$$\frac{1.341}{KW} \text{ hp} \times \frac{0.75 \text{ load}}{0.95 \text{ eff.}} \times \frac{24}{10^6} \text{ tonnes}$$

Cost of heavy fuel oil, diesel oil, cylinder luboil and system luboil is fed in as an input and the values for 1980 were

Heavy fuel oil, £80/tonne; Diesel oil, £145/tonne; cylinder luboil, £560/tonne; system luboil, £470/tonne.

Cost of fuel/annum at sea

Cost of fuel/annum = Days at sea per round voyage (SEATIM) x round trips/annum (RTPA) x ((1) x 80 + (2) x 145 + (3) x 560 + (4) x 470) £

Cost of fuel/annum in port

Cost of fuel/annum = Days in port per round voyage (PORTIM) x RTPA x((5) x 80 + (6) x 145) £

Total fuel oil costs per annum is the sum of the cost of fuel/annum at sea and cost of fuel/annum in port.

The heavy fuel oil and marine diesel oil costs are regularly published in (131) for some major ports. Luboil costs were ascertained from suppliers and reflect higher than average costs.

10.9. CONTAINER HANDLING COSTS

Container handling costs do not vary much from port to port. Buxton (107) gives for 1978 cost levels, the handling cost of a 20 ft. container, ship to quay, or vice versa as £40 to £60 and similarly for a 40 ft. container to be £50 to £80. These handling costs do not include stuffing and stripping the containers which will cost extra. These are not included in the sea freight, so it is not paid by the ship operator (107). A port authority contacted for 1982 costs, quoted £60 - £90 per container move. There were no charges either for the size of the container or the contents of the container and the charges in many cases depended on a particular customer.

Some ports however do differentiate between loaded and empty containers, typical values from port of Israel are, (129), at 1980 costs

20' container, full	£53.21	20' container, empty	£25.88
40' container, full	£79.77	40' container, empty	£38.83

with the full containers costing twice as much. There was however no rebate on imported or exported containers.

Based on a U.K. port figure, the cost to handle a 20' container was taken as £50/container move at 1980 cost level.

The maximum load factor was calculated as the maximum of the inbound or the outbound load factor.

Then the total handling cost = number of containers carried x container handling cost/move x max. load factor x 4 x round trips/annum. The factor 2 is for loading and unloading a container and a further factor of 2 for the round voyage.

10.10. OPERATING COSTS

The operating cost elements are calculated as discussed in the previous sections. Some of these cost elements can be escalated to reflect costs in the future. The average escalation over the last 15 years is a good guideline. Such escalation rates are given in Table 10.16 (123).

Section 12.6 gives details on how the escalation rates can be introduced in the computer program. Cameron (142), Laing (143) and Buxton (101) give average escalation rates for various elements of the operating costs. Table 10.16 also gives indices of certain operating costs which can be used to update cost equations valid for different periods. Gardner (130) gives cost increases per slot (1971-76) which includes all the costs associated with container ship operation such as charges allocated to depreciation for container ships including feeder vessels, and containers and rolling stock, positioning costs, equipment leasing and operating costs etc. Thus if the inland sector of cost is to be considered these elements of costs can be updated from (130). Operating costs were validated with a limited data base, since most shipowners were reluctant to disclose even past years operating costs. However two shipping companies responded favourably and therefore the costs developed reflect the average of these two shipowners' operating costs.

TABLE 10.16. Index of operating costs and the average cost increase/annum (123, 144).

ITEM	1965 = 100 66	67	68	69	70	71	1971 = 100 72	73	74	75	76	77	78	79	80	Av. Incr. in %/ annum
Wages	107 (6.54)	124 (13.71)	128 (3.13)	130 (1.54)	137 (5.11)	177 (22.60)	103 (2.91)	117 (11.96)	132 (11.36)	154 (14.28)	169 (8.88)	194 (12.88)	203 (4.33)	209 (2.87)	211 (0.948)	8.24
Other crew costs	106 (5.66)	124 (14.52)	133 (6.76)	135 (1.48)	148 (8.78)	202 (26.73)	112 (10.71)	132 (15.15)	156 (15.38)	185 (15.67)	195 (5.13)	221 (11.76)	239 (7.53)	236 (-1.27)	260 (9.23)	10.32
Provisions	103 (2.91)	100 (-3)	97 (-3.09)	92 (-5.43)	92 (0)	98 (6.12)	103 (2.91)	116 (11.21)	131 (11.45)	134 (2.24)	141 (4.96)	150 (6)	157 (4.46)	166 (5.42)	189 (12.17)	3.90
Stores	112	110	108	110	122	130	100 (0)	105 (5)	131 (19.85)	132 (0.75)	130 (-1.54)	146 (10.96)	137 (-6.57)	155 (11.61)	170 (8.82)	+ 6.89
Lubricating oil							101 (0.99)	99 (-2.02)	124 (20.16)	135 (8.15)	145 (6.89)	138 (-5.07)	146 (5.48)	169 (13.61)	210 (19.52)	+ 7.52
P & I	106	118	123	140	160	196	(93)* 99.5 (-0.50)	(87)* 96 (-3.65)	(78)* 86.5 (-10.98)	(83)* 83 (-4.22)	85 (2.35)	79 (-7.59)	79 (0)	75 (-5.33)	86 (12.79)	3.07
Other insurances	(5.66)	(10.17)	(4.06)	(12.14)	(12.5)	(18.37)	(106)*	(105)*	(95)*	(83)*						
Administration	111 (9.91)	108 (-2.78)	115 (6.09)	126 (8.73)	143 (11.89)	182 (21.43)	104 (3.84)	115 (9.56)	141 (18.44)	166 (15.06)	174 (4.60)	182 (4.40)	178 (-2.25)	197 (9.64)	235 (16.17)	8.98
Repair & mainten.	111 (9.91)	110 (-0.91)	138 (20.29)	132 (-4.55)	166 (20.48)	242 (31.40)	91 (-9.89)	95 (4.21)	121 (21.48	107 (-13.08)	83 (-28.92)	89 (6.74)	88 (-1.14)	102 (13.73)	112 (8.93)	5.24
Total	108 (7.41)	113 (4.42)	120 (5.83)	124 (3.23)	138 (10.14)	175 (21.14)	101 (0.99)	109 (7.34)	125 (12.80)	131 (4.58)	132 (0.76)	144 (8.33)	148 (2.70)	156 (5.13)	168 (7.14)	6.77 6.80

TABLE 10.16 (Contd.).

NOTES: (1) + calculated from 1971-1980 only,

(2) ( )% increase/annum,

(3) ( )* index for that year.

CHAPTER 11

CONTAINER COST MODEL

11.0 INTRODUCTION

11.1 NUMBER OF SETS OF CONTAINERS

11.2 CAPITAL COST

11.3 MAINTENANCE AND REPAIR COST

11.4 INSURANCE COST

11.5 LIFE OF CONTAINER

11.6 FINANCIAL MODEL

11.0 INTRODUCTION

Fairplay (132) gives an early 1981 price for a 25000 dwt, 1200 Teu, 22 knots diesel container ship to be £26.12 x 10^6 excluding containers. If the ships are assumed to require 3 sets of 20' dry containers, then the cost of container sets @ £2700/Teu is £9.72 x 10^6. Thus the initial ship capital cost is 73% and container costs are 27% of the total cost,nearly one third. This shows the importance of the box/slot ratio in a container ship and the overall importance of the container cost.

Independent sources estimate the world container population at the beginning of 1979 to be between 2.25 to 2.75 million Teu. Of these the leasing companies own between 38 to 54%, depending on the survey one selects (133).

In any intermodal or through transport concept there are at least six major sections or operating cost centres, mainly:-

(a) Inland transportation - exporting area
(b) Terminal operations - exporting area
(c) Ocean transit
(d) Terminal operations - importing area
(e) Inland transportation - importing area

but all of the above functions are subordinate to the common link throughout the system.

(f) Containers.

The containers and their associated services and cost of

(a) Systems control and coordination
(b) Storage
(c) Maintenance and repair
(d) Insurance and claim (Cargo and container)
(e) Owning or leasing of containers/associated handling equipment play a major role.

In this thesis we will neglect the inland sector of the operating costs such as storage, stuffing/unstuffing, stripping, inland transportation and cargo insurance. This is justified in the sense that in inland transportation costs vary from country to country but the shipping costs are relatively international in nature. Though containers have introduced the concept of door to door service, when comparing the alternative ship design, if it is assumed that inland sector costs will remain the same for all ship alternatives (Inland sector costs are not associated with faster sea transit times).

The following aspects of the container costs are discussed below:-

1) Container sets
2) Container Acquisition cost
3) Container Maintenance cost
   (a) Container Refurbishing cost
   (b) Container Repair cost
4) Container Insurance costs
5) Container Life

11.1. NUMBER OF SETS OF CONTAINERS (SETCNT)

Edmond & Wright (134) have published a method of estimating the total number of container sets. The model takes into account the container dwell time inland, number of ships in the fleet, ships turnaround time, number of containers loaded and unloaded etc. They found that the ratio of the number of containers required/ship slot can vary from less than 2 up to 10 or more and in most cases, it was found to be virtually independent of the number of ships in service.

Frankel and Marcus (53) gives the following equation for the number of sets of containers (SETCNT) on each end of the sealeg as

$$SETCNT = 0.465 + 13.66/FREQ \qquad \text{Teu} \qquad \text{Eq. 11.1}$$

where FREQ is the frequency of service in days.

Therefore container inventory (CNTINV) for one ship is (53)

$$CNTINV = CNT \times ALFMAX \times (1.0 + 2.0 \times SETCNT) \text{ Teu} \quad Eq.(11.2)$$

CNT = container carrying capacity of the ship in Teu.
ALFMAX = maximum ship's load factor in percentage
and if FREQ is not known then it is estimated as (53)

$$FREQ = 0.565 \times RVYTIM^{0.85} \quad \text{days} \quad Eq.(11.3)$$

RVYTIM = Round voyage time in days.

These formulae are based on statistical analysis of first generation of container ships and thus may not be valid for newer generations of container ships. Moreover Edmond & Wright (134) have shown that the number of sets of containers are dependent on many other factors, besides the ships turnaround time. Therefore such simple expressions for calculating the number of sets of containers cannot be used.

Fig. 11.1 shows the number of container sets per ship against the number of round voyages per ship per year (134). On the deep sea route the inland turnaround time $\bar{t}$ of the container is 20 to 23 days (134, 135). As is evident from Fig. 11.1 the number of container sets/ship or box/slot ratio is very sensitive to the turn around time $\bar{t}$ of the container. Realistic data on container berth dwell time for 5 container terminals is given by Dally et al. (136). For numbers of round voyages per annum of 14 (137) Europe-Far East route from Fig. 11.1 the box/slot ratio varies from 2 to 3.2. Since container turn around time varies from route to route (134), and the box/slot ratio is very sensitive to the $\bar{t}$, therefore to observe the influence of number sets of containers (SETCNT) on the overall profitability of the ship, SETCNT was left as an input data.

The most likely estimate for SETCNT is taken as 2.5 sets/ship but later in the thesis a sensitivity analysis is carried out with the optimistic estimate of 1.8 sets of container and a pessimistic estimate of 3 sets of containers.

Therefore the container inventory is given by (CNTINV)

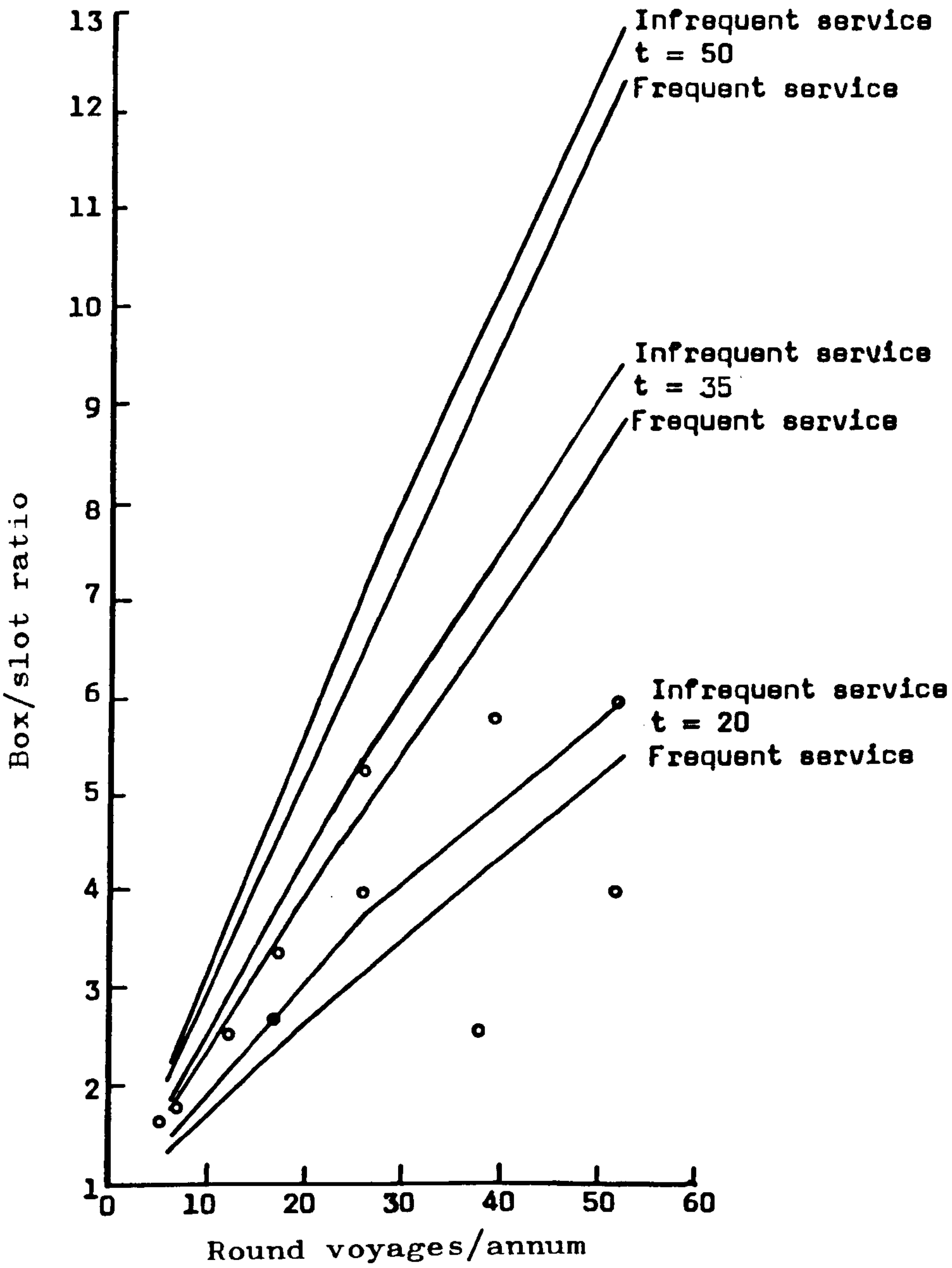


Fig. 11.1. Box/slot ratios and number of round voyages/ Year, Load Factor = 0.8 (134)

$$CNTINV = CNT \times SETCNT \qquad \text{Teu} \qquad \text{Eq. (11.4)}$$

11.2. CAPITAL COST (CNCOST)

Fairplay (132) gives representative prices for 20' dry containers and 20' insulated containers. If a mix of containers are carried the total price of containers will accordingly be in the ratio of this mix .

At early 1980 prices the following figures are adopted in this thesis. Dry 20' Container (COSCNT) = £2500/unit and Reefer 20' = £3400/unit (132) and the total capital cost (CNCOST) of containers is

$$CNCOST = CNTINV \times COSCNT \qquad £ \qquad \text{Eq. (11.5)}$$

The analysis in this thesis is carried out with 20' dry containers. Other specialised types of container are not taken into account, but are feasible, once the type and number of mix of containers are known. Since other associated costs like insurance and maintenance are taken as a percentage of the first cost similar equations for other types of containers can easily be developed.

11.3. MAINTENANCE AND REPAIR COST (CMCOST)

Major refurbishing of containers is undertaken to extend their life. Pentimonti (138) recommends that steel containers can be refurbished every 5 years and aluminium and FRP containers every 8 years.

In this thesis only minor refurbishing is considered and the containers are assumed to be replaced by new sets of containers after the expiry of their expected life.

Annual refurbishing or maintenance and repair costs of the containers is usually calculated as a percentage of the total capital cost of containers. Some values used in past studies is indicated below.

Butcher (139) gives absolute values of maintenance costs and repair costs for 1976 cost levels, average

Type of container	PERCENTAGE OF CAPITAL COST			Days out of service /annum	
	Refurbishing or maintenance	Repair	Total		
GP	-	-	10	-	Edmond & Wright (134)
GP	1.5	6.5	8	5-7	Abbott (134)
GP	1.5	4.7	6.2	-	Maguire (134)
Insulated	1	3.75	4.75	-	Abbott (134)
Insulated	1	2.70	3.7	-	Maguire (134)

number of repairs/unit/annum and the average days out of service/repair for different types of containers. For a 20' steel container average numbers of repairs/annum is 1.23, and taking the price of a 20' container as £1500 (132) gives an average repair cost/unit/annum of 5.78% and maintenance cost/unit/annum of 2.06% of capital cost. Similar calculations can be carried out for other types of containers. The annual maintenance and minor refurbishing costs/annum (COSREF) is assumed to be 1.5% of the capital cost. And the annual repair costs (COSREP) is assumed to be 6.5% of the Capital Cost.

$$\text{COSREF} = 1.5 \times \text{CNCOST}/100.0 \quad £ \qquad \text{Eq. (11.6)}$$

$$\text{COSREP} = 6.5 \times \text{CNCOST}/100.0 \quad £ \qquad \text{Eq. (11.7)}$$

and the annual maintenance and repair cost (CMCOST) is given by

$$\text{CMCOST} = \text{COSREF} + \text{COSREP} \quad £ \qquad \text{Eq. (11.8)}$$

11.4. INSURANCE COST (COSINS)

Operators often self-insure their containers or merely insure against catastrophic loss by maintaining a high deductable. The model includes a container insurance cost. The insurance cost is an average annual cost and assumed to be 2% of the capital cost (54) and is expressed as

$$\text{COSINS} = 2 \times \text{CNCOST}/100.0 \quad £ \qquad \text{Eq. (11.9)}$$

11.5. LIFE OF CONTAINER (LIFEC)

The container life (LIFEC) forms an input data to the model. There is a lot of controversy about the probable life of different types of containers. This is evident from the following table.

Container Type	Container Life in Years	
GP	8-10	Edmonds (134)
GP	12-16	Abbott (134)
GP	12-16	Maguire (134)
Steel	15	Sherwood (140)
-	8-12	Brokaw (141)
Steel	10-12	Butcher (139)

This controversy arises because many of the containers on purpose built container ships are less than 12 years old, and therefore definitive data are not available.

In the program a container life of 8 years is assumed. Later in the thesis a sensitivity analysis is carried out for variation of container life to determine its influence on the overall profitability of the ship.

11.6. FINANCIAL MODEL

The last cost element considered in the overall model of container ship design and operation was the cost associated with the container. Therefore in addition to the operating costs, common to all ship operations, the operator of a container ship is faced with the additional cost of providing and maintaining the containers. It was pointed out that furnishing adequate numbers of sets of containers required to permit unconstrained movement of cargo involves a rather substantial investment on the part of the operator. To avoid this capital expenditure and the subsequent maintenance costs, containers are often leased. If containers are leased, the shipowner makes an annual payment to the leaser.

Fig. 11.2 outlines the procedure followed in evaluation of the discounted cash flow for all costs associated with the container. Subroutine subprogram CONDCF is the container cost model. A short description of the procedure is given below.

In the model it is considered that the shipowner buys the containers with the help of a loan and thus the annual cost he incurs is the annual repayment of the loan, the annual maintenance and repair cost and the cost of insurance. The capital cost (CNCOST) is transformed into an equal annual sum of money.

$$CPAY = CNCOST \times CRF \qquad £ \qquad \text{Eq. (11.10)}$$

where CRF = capital recovery factor.

The interest rate (CPINT) for calculating the CRF is assumed to be 10% (135), and (141) quotes that the variation of eight year rates CPINT has been 6% per annum to over 10% per annum. Brokaw (141) also gives details of the factors governing the container purchase and leasing. A container escalation factor is assumed, ECONT(I), which takes into account the cost of replacing the containers every LIFEC years. The salvage value of the container at the end of the container life is assumed to be zero.

The annual payment is divided into the principal and the interest (CINT), where $CINT(I) = CNCOST \times CPINT/100.0$ £ Eq. (11.11)

And the Principal $CP(I) = CPAY - CINT(I)$ .....£ Eq. (11.12)

The principal already paid is accumulated in the array CPAID(I) and the interest is charged on the remaining amount of the borrowed sum i.e.

$$CINT(I) = CPINT/100.0 \times (CNCOST - CPAID(I-1)) \quad £ \quad \text{Eq. (11.13)}$$

The future annual repayments of the loan, i.e. interest CINT(I) and the principal CP(I) are then converted into present sum of money by converting them into present worth

Fig. 11.2. Container cost and financial model (Flow chart of subroutine subprogram CONDCF)

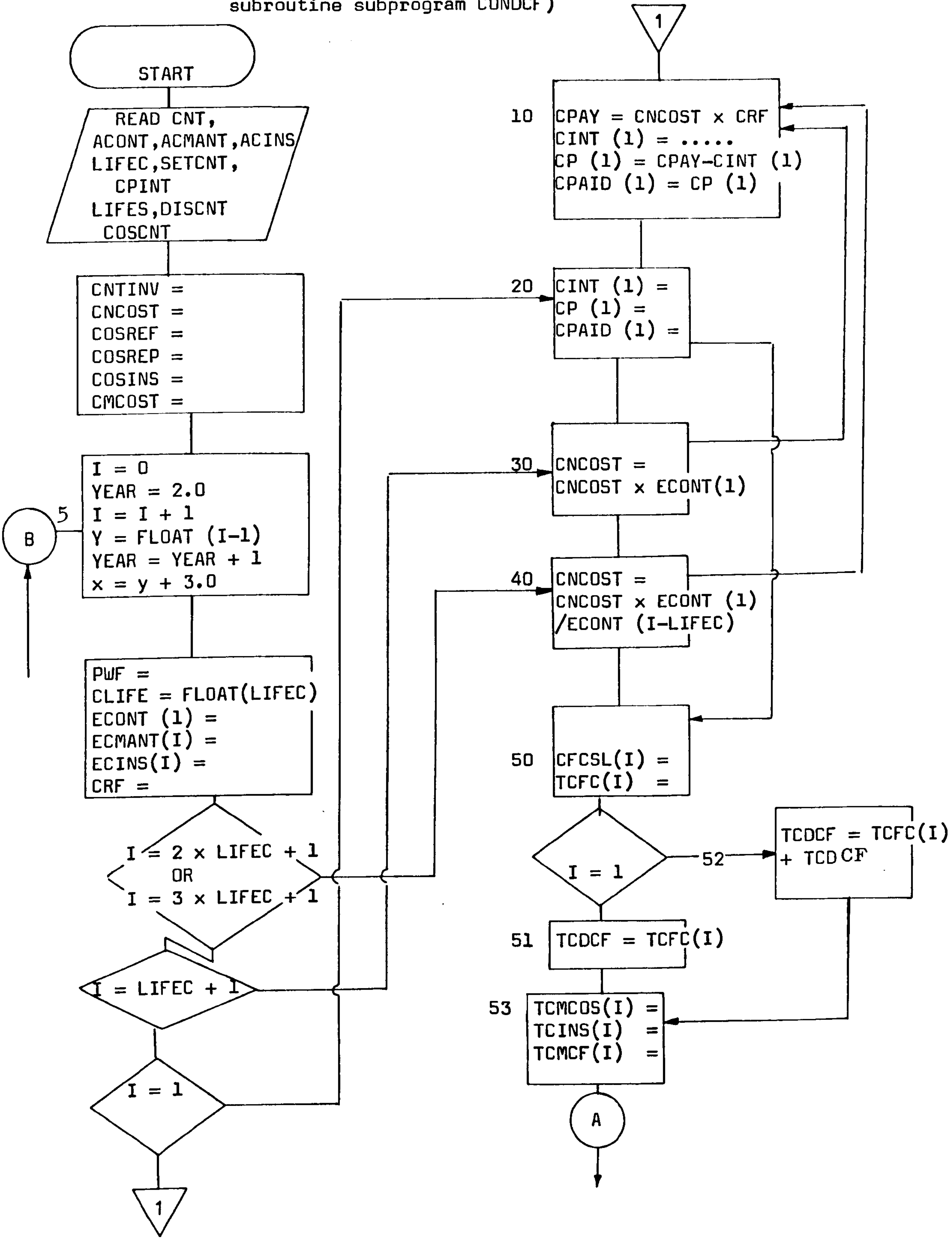
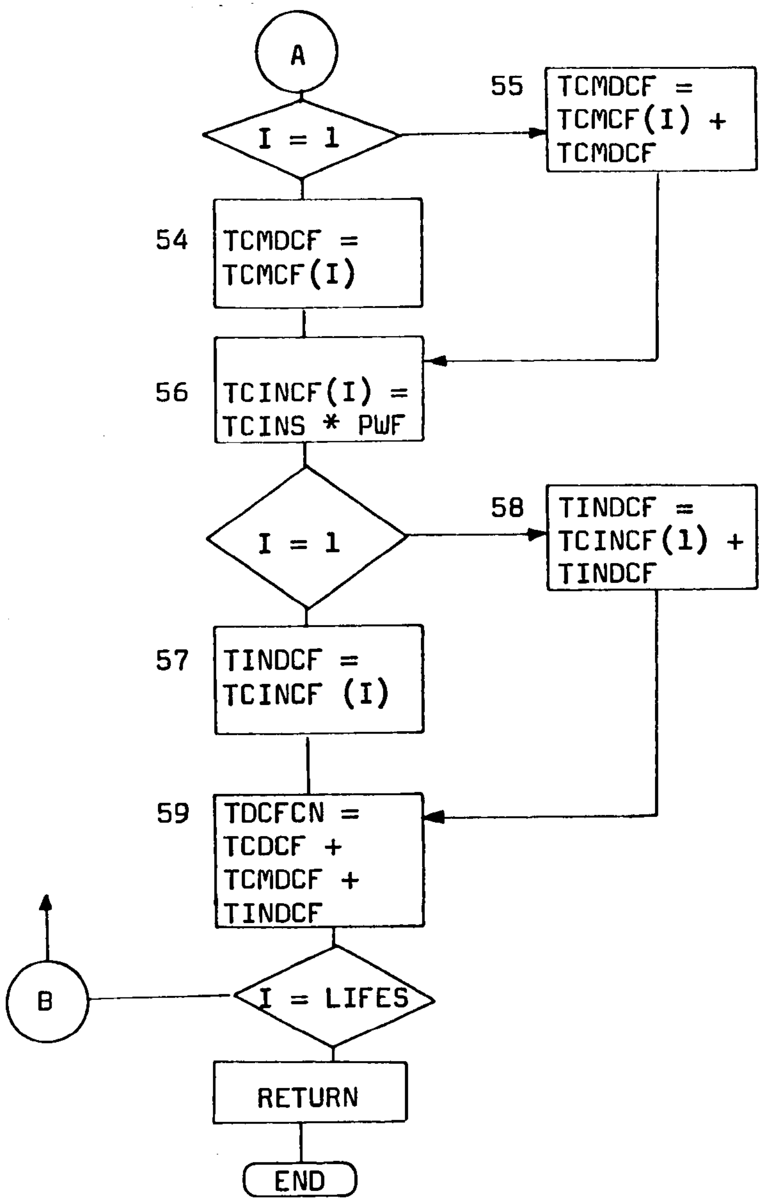


Fig. 11.2 (Contd.)



at (DISCNT) rate of discount specified in the input. Therefore the present value of the future annual repayment is

$$TCFC(I) = CFCSL(I) \times PWF \quad £ \qquad \text{Eq. (11.14)}$$

where $$CFCSL(I) = CP(I) + CINT(I) \quad £ \qquad \text{Eq. (11.15)}$$

The future maintenance cost, insurance costs are similarly discounted at (DISCNT) rate of interest,

TCMCF(I) = TCMCOS(I) x PWF = Present value of total maintenance cost in Ith yr. Eq. (11.16)

TCINCF(I) = TCINS(I) x PWF = Present value of insurance cost in the Ith year £ Eq. (11.17)

The escalation in container acquisition cost, container maintenance and repairs and the cost of insurance are input as annual escalation factor ACONT, ACMANT and ACINS respectively.

The total escalation in the Ith year Y is given by ECONT(I), ECMANT(I) and ECINS(I)

$$ECONT(I) = (1.0 + ACONT/100.0)^Y \qquad \text{Eq. (11.18)}$$

$$ECMANT(I) = (1.0 + ACMANT/100.0)^Y \qquad \text{Eq. (11.19)}$$

$$ECINS(I) = (1.0 + ACINS/100.0)^Y \qquad \text{Eq. (11.20)}$$

Therefore the book value of the container cost in the Ith year, otherwise the replacement cost is

$$CNCOST = CNCOST \times ECONT(I) \quad £ \qquad \text{Eq. (11.21)}$$

Similarly for the maintenance and insurance cost the escalated cost equations are

$$TCMCOS(I) = CMCOST \times ECMANT(I) \quad £ \qquad \text{Eq. (11.22)}$$

$$TCINS(I) = COSINS \times ECINS(I) \quad £ \qquad \text{Eq. (11.23)}$$

The discounting is done for the life of the ship (LIFES) which is higher than the life of the container (LIFEC).

The present value of container cost, maintenance and insurance are accumulated in TCDCF, TCMDCF and TINDCF respectively.

Therefore the present value of the container cost, maintenance and insurance is

$$TDCFCN = TCDCF + TCMDCF + TINDCF \quad £ \qquad \text{Eq. (11.24).}$$

CHAPTER 12

ENGINEERING ECONOMY

12.0 INTRODUCTION

12.1 INTEREST RELATIONSHIPS

- 12.1.1. SIMPLE INTEREST
- 12.1.2. COMPOUND INTEREST

12.2 TIME ADJUSTING MONEY VALUES

- 12.2.1. COMPOUND AMOUNT FACTOR AND PRESENT WORTH FACTOR
- 12.2.2. CAPITAL RECOVERY FACTOR AND SERIES PRESENT WORTH FACTOR

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12.5 CALCULATION OF CAPITAL CHARGE

12.6 REQUIRED FREIGHT RATE BEFORE TAX

12.7 REQUIRED FREIGHT RATE AFTER TAX

12.0 INTRODUCTION

Economics may be defined as the task of allocating a finite supply of investment funds in the face of infinite possibilities (147).

Engineering may be defined as the use of scientific knowledge for the benefit of society. Engineering economy, then, is an approach to design aimed at meeting society's needs with a maximum effectiveness in the use of resources: manpower, materials, and investment funds (147).

The goal of the engineering design process or ship design process may be defined as given a functional requirement (e.g. transportation of a certain number of containers from A to B) which also satisfies a number of constraints of technical, physical, or legal nature (stability, strength, ship safety, classification rules etc.) to seek an optimal technical solution judged on the basis of a concrete measure of merit (148).

This chapter introduces the basic principles of engineering economy calculation, the choice of measure of merit and the various other economic complexities e.g. tax, depreciation, inflation, etc. and the various assumptions made in the thesis are also indicated. Taxation, depreciation, tax allowances etc. are calculated for a shipowner building and operating his ship in the U.K.

The last three sections of the chapter gives details of calculating the builder's account, operating account and the measure of merit for a design taking into account the tax, tax allowances, depreciation, inflation and cost escalation.

The subroutine subprogram CAPCHR, ECONOM and ANPVAL can be used with little modification for other ship types.

12.1 INTEREST RELATIONSHIPS

Money has not only a nominal value, expressed in some monetary unit, but also a time value (161). Therefore the notion of time value of money is fundamental to any economic calculation. This time value of money is usually expressed in terms of the interest, which is generally expressed as an annual charge in percent of funds invested. And this interest can be: (147)

(a) Contracted interest, is the type used in saving deposits, bank loans, mortgages and bonds which carry mutually agreed interest rates.

(b) Implied interest is also called the lost opportunity interest, which is foregone when the capital is tied up without any resulting interest being earned e.g. cargo in transit or a ship being laid up.

In this thesis only the former is taken into account. The contracted interest may either be simple or compound.

12.1.1. SIMPLE INTEREST: The total repayments after N years is expressed as $F = P(1 + Ni)$
where F = future sum of money; P = Principal or a present sum of money; N = number of years of loan and i = interest rate expressed as a fraction/annum.

12.1.2. COMPOUND INTEREST: This is usually the method employed for most of the economic calculation concerning ship design economics and the future repayment after N years is expressed as, $F = P(1 + i)^N$. As far as decision making in ship design is concerned, the assumption of annual compounding is usual. Other non-annual compounding methods and their application to investment is given by Benford (149). Container financing is however done on the basis of quarterly or half yearly compounding (141). Annual compounding is assumed in all cases in this thesis.

12.2. TIME ADJUSTING MONEY VALUES

There are six basic compound interest relationships (101). Two are related to single payments and the others to series payments.

12.2.1. COMPOUND AMOUNT FACTOR AND PRESENT WORTH FACTOR: These relationships are used for single payments and is shown in Fig. 12.1(a). The compound amount factor (CA) is the multiplier to convert a present sum into a future sum and expressed as

$$F = (CA) \times P \quad \text{where } CA = (1 + i)^N \qquad \text{Eq. (12.1)}$$

If the interest is compounded T times per year, with the interest rate expressed annually as i, then:

$$CA = (1 + i/T)^{NT}$$

This relationship can be used if the containers are leased instead of being bought as assumed in this thesis, since the lease repayment is usually made half yearly or quarterly (141).

The reciprocal of the compound amount factor is the present worth factor (PW), which is the multiplier to convert a future sum into the present sum and expressed as

$$P = (PW) \times F \quad \text{where } PW = \frac{P}{F} = \frac{1}{CA} = (1 + i)^{-N} \quad \text{Eq. (12.2)}$$

In the program, the PW is generated by a subroutine subprogram PREWOR given the year and the discount rate. An interest rate of 15%/annum before taxes is assumed in the thesis for discounting cash flows and is referred to as the discount rate.

12.2.2. CAPITAL RECOVERY FACTOR AND SERIES PRESENT WORTH FACTOR:

These relationships are used for series payments and is shown in Fig. 12.1(b). For a loan repaid by series of annual instalment of principal plus interest. There are two common arrangements:

(a) principal repaid in equal instalments with interest paid on the declining balance, which is used in the capital charge program to calculate the builder's account.

(b) Uniform payments, which is the usual method for leasing and mortgages, interest predominating in early years, repayment of principal in later years.

The capital recovery factor (CR) is used to convert an initial capital investment to an equivalent annual capital

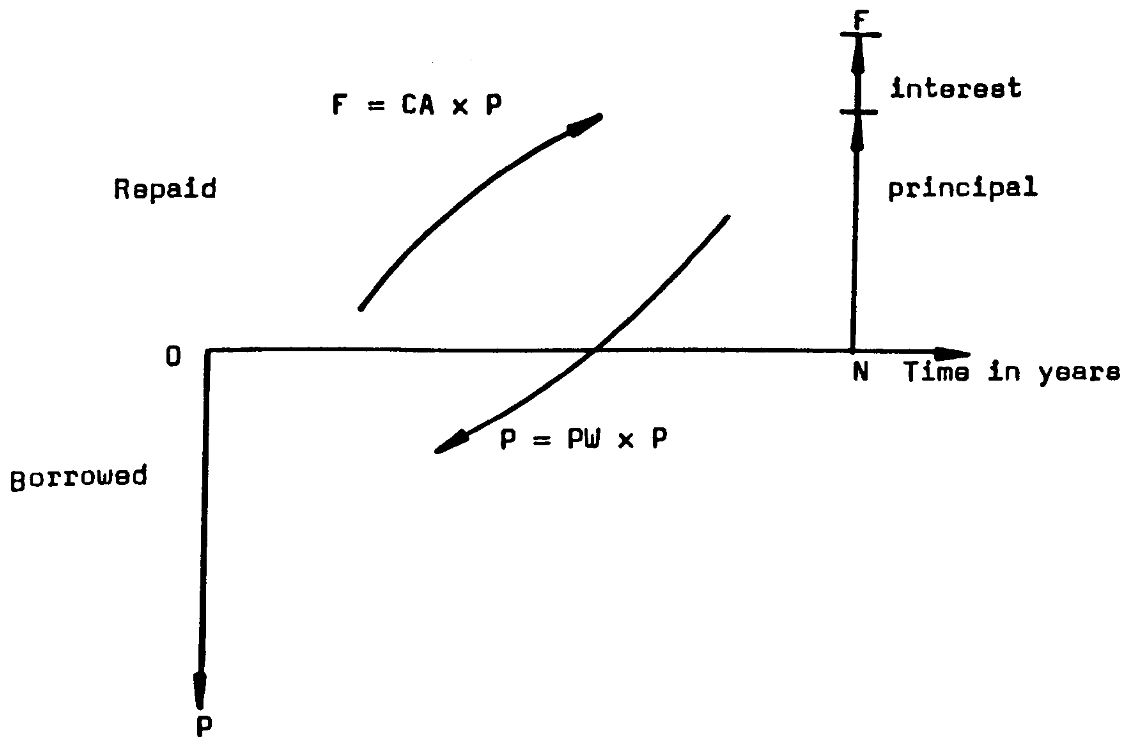


Fig. 12.1a. Compound amount factor and present worth factor.

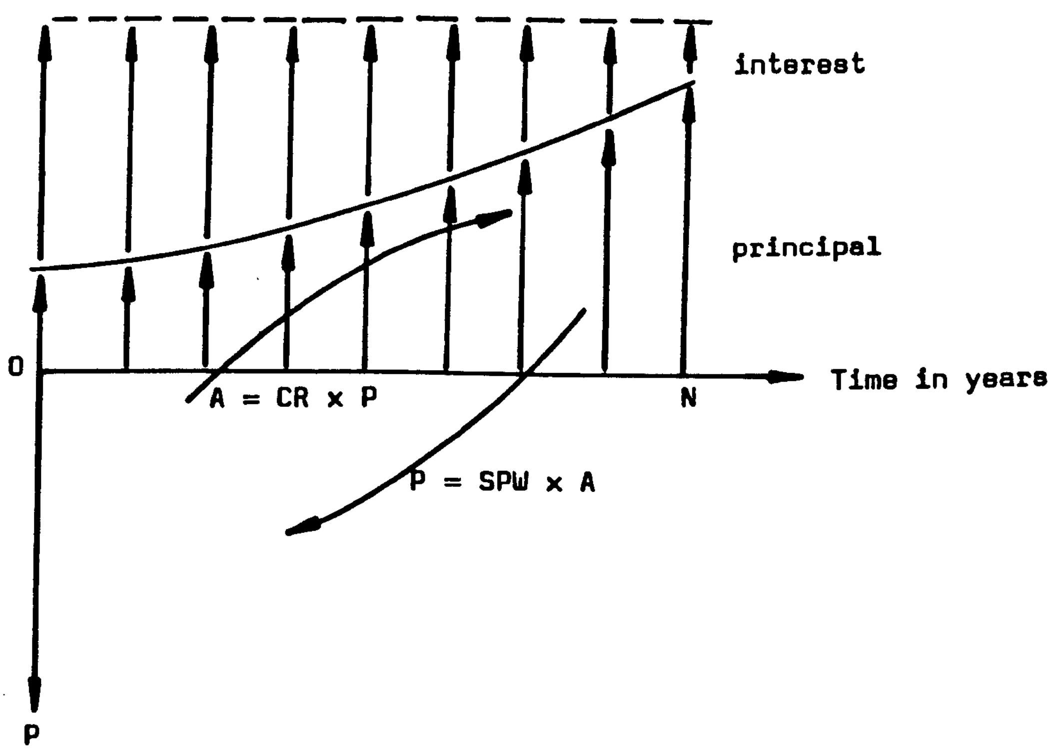


Fig. 12.1b. Capital recovery factor and series present worth factor.

charge, which includes both the principal and the interest. It is a relationship between the uniform amount (A) and the principal P and expressed as A = (CR x P)

$$\text{where } CR = \frac{i}{1 - (1 + i)^{-N}} \qquad \text{Eq. (12.3)}$$

and this equation is used in the container cost model to convert the initial investment in containers to an annual capital charge repaid over the life of the container.

The reciprocal of capital recovery factor is the series present worth factor (SPW) which is a multiplier to convert a number of regular annual payments into a present sum, and is given by P = (SPW) x A

$$\text{where } SPW = P/A = 1/CR = \frac{(1 + i)^N - 1}{i(1 + i)^N} \qquad \text{Eq. (12.4)}$$

The other two basic relationships known as the sinking fund factor (SF) and its reciprocal the series compound amount factor is not used in the thesis. These relationships are given by Buxton (101) and Benford (147).

12.3. ECONOMIC MEASURE OF MERIT

The different measures of merit used in ship design studies are shown in Table 12.1. Though this is not an exhaustive list, it has been drawn up to indicate the usage of different economic measures of merit in previous design studies with particular emphasis on those concerning containerships. The popular usage of required freight rate is apparent. Buxton (101), Goss (162), Oostinjen (161), Benford (163,164), Hettena (165) give the advantages and disadvantages of the various measures of merit. Details on calculation of these measures of merit are given by Buxton (101) and Benford (163,164) or any standard textbook on capital investment (166).

Table 12.2 gives a decision chart which can be used for selecting a measure of merit, depending on the type of input data available at the design stage. Therefore

TABLE 12.1. Summary of economic criteria and their use in past design studies.

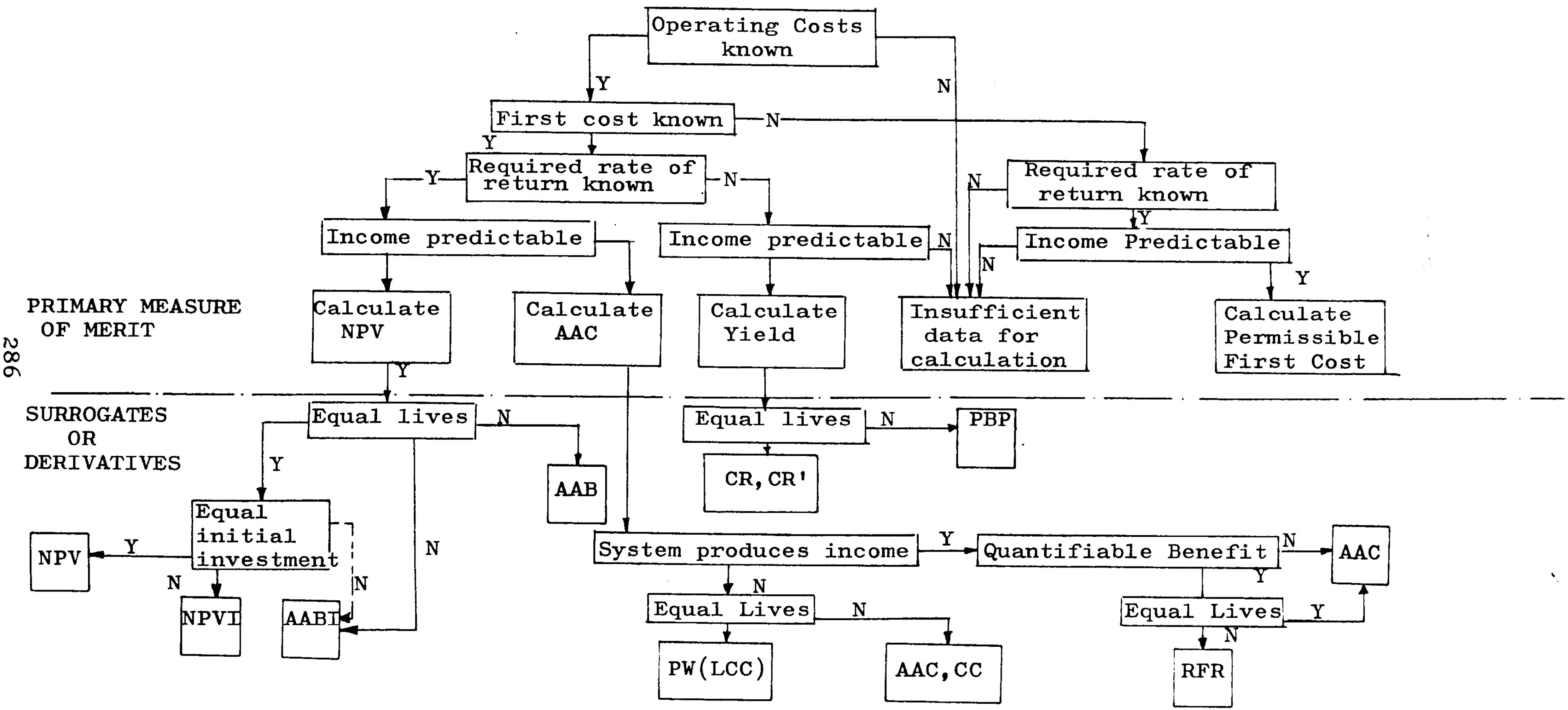
Economic Criteria	Definition (160)	Maximise or Minimise	Ship Type	Ref.	Yr.
1 (NPV) Net present value	The present value of all cash flows in or out, discounted to present time at a stipulated interest rate that reflects the minimum acceptable level of profitability.	Max.	TK, VC, MP	150 103	76 82
2 (NPVI) Net present value index	The net present value per pound invested.	Max.	(CN+ ports) TK	39	71 72
3 (IRR) Yield or internal rate of return	The interest rate that brings the net present value to zero.	Max.	TK, CN	86	70
4 (RFR) Required Freight Rate	The unit charge to the customer that must be earned if the owner is to gain a reasonable yield on investment.	Min.	TK, PC, CN, TK, CN CL, BC, OC CN BC RO CN MP OC	151 55 152 40 104 153 61 103 154	74 74 67 74 76 78 78 82 67
5 (AAC) Average Annual Cost	A uniform annual expense equivalent in present value to the investment and operating costs. Discounts future amounts at an interest rate reflecting the investor's time value of money.	Min.	TK CN CN RO, CN CL CN	155 52 37 156 125 157	79 70 68 78 68 77

TABLE 12.1 (Contd.)

Economic Criteria	Definition (160)	Maximise or Minimise	Ship Type	Ref.	Yr.
6 (PW) Present Worth	The present worth of both investment and operating costs. Uses same interest rate as AAC to discount future amounts.	Min.			
(LCC) Life cycle cost	Same as PW	Min.	CN	54	72
7 (CC) Capital-ised cost	The present worth of provid-ing perpetual service.	Min.			
8 (A') Returns	Uniform annual after tax cash flow.	Max.			
9 (Y) Operat-ing costs	Uniform annual operating costs. Marginal costs of operation, exclusive of costs of capital recovery.	Min.			
10 (CRF) Capital recovery factor	Ratio of uniform annual returns before tax to initial investment.	Max.	CN OC	40 62	74 58
11 (PBP) Pay back period	Years to regain initial investment. If cash flows are uniform, this is reciprocal of CRF.	Min.	MP	103	82
12 (SMF) Ship Merit Factor	Reciprocal of RFR (158)	Max.	GC	148 158	68 70
13 Annual costs/ tonne mile	Total annual costs of operating the ship per ton mile	Min.	GC	159	81

Note: BC = Bulk Carrier; CN = Containership; CL = Cargo Liner;
GC = General Cargo ship; MP = Multipurpose ship;
OC = Ore Carrier; PC = Products Carrier; RO = Roll on - Roll off; TK = Tanker; VC = VLCC.

TABLE 12.2. Decision chart for choice of economic criterion (101, 164, 160).



Note: Table 12.1 for definitions and abbreviations

------ connectors applicable at that particular decision level.

there is no ideal, universally applicable criterion although the choice of the optimum itself depends on the economic criteria (161,164). And a measure of merit which is suitable for finding the optimal design may fail when deciding yes or no on the entire project. This is primarily one of the drawbacks of RFR, since there is no point in designing a ship with the minimum acceptable RFR when the expected RFR are well below that level (160). Further RFR cannot be used as a profitability criterion since it neglects the revenue. Moreover RFR neglects demand and also fails to take into account the supply considerations (165). In the case of perfect competition, the freight rates will be determined by the demand for tonnage and supply of ships. Since a ship takes 2 to 3 years to construct, extra demand cannot be met in the shorter term. Higher freight rates will attract shipowners to order new ships but supply is fixed in the shorter term. If demand does not rise then there will be overtonnage which will force the freight rates to fall. This cyclic behaviour in freight rate will determine supply of ships to be ordered in the future. Hettna (165) and Buxton (101) describe this behaviour in more detail. Constructing such an econometric model will be quite complicated, and it can be assumed that the required freight rate will fluctuate between an average mean value in the longer term (167). Though the container ship conference system cannot be deemed as operation under perfect competition.

Oostinjen (161) carried out a comparative evaluation of commonly used economic measures of merit, such as Net Present Value (NPV), Capital Recovery Factor (CRF), RFR and Absolute Profit (AP). Where AP is calculated as an average of the real profits during the operational life of a ship by multiplying the total present worth of the profit by the CRF.

A sensitivity analysis of the various criteria with uniformly increasing costs and revenues showed that the RFR method leads to no difference in the optimal speed, whereas AP and NPV gives higher speed optimum and CRF leads to lower optimal speed and depends on the discount rate.

Compared to other criteria the characteristics of the curve in the region of the optimum found by RFR was much flatter signifying that larger deviations from the optimum are possible. So far the salient characteristics of the Required Freight Rate has been discussed, which pointed out the various pitfalls or drawbacks of the RFR as a criterion. All criteria have some drawbacks, none of them are universally applicable as pointed out earlier, but when incomes are not predictable, as is usually the case, RFR is to be preferred as a criterion (101).

Since container ships operate under conference system, the freight rates are fixed in the shorter term and the income can be ascertained. Fig. 12.2 shows representative freight rates in the period 1977-1980. However because of the flat laxity in the region of the optimum, the optimum chosen by the RFR will not lead to a wrong decision compared to one reached by NPV or yield.

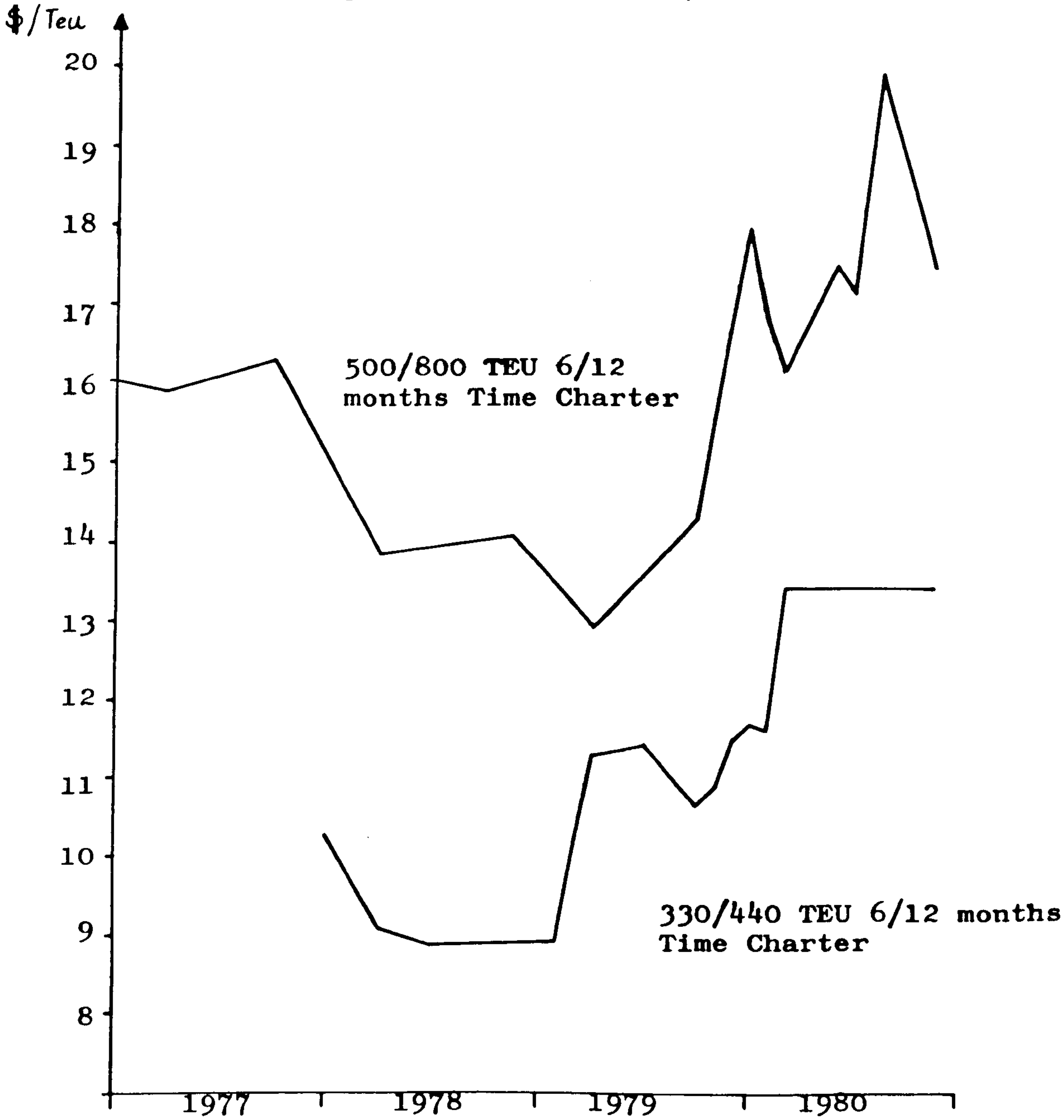
12.4. ECONOMIC COMPLEXITIES

Whereas in simple short cut studies uniform cash flows can be assumed and economic complexities like tax, depreciation and inflation incorporated (101, 160, 168, 169) in interest relationships like CR and SPW, a year by year calculation is preferred to correctly assess the influence of tax allowances such as depreciation and interests on loans. Therefore computer programs have been written for ships built under the U.K. tax regime and a shipowner utilising domestic credit terms offered by the government.

12.4.1. Tax

Taxes generally have pronounced effects on the choice of the optimum design. This is made apparent by Benford (164) where the effect of ignoring taxes leads to higher speeds by NPV and AAC and lower speed by RFR. Tax is

Figure 12.2. Average Representative Time charter Rates per Container Unit.(132)



assumed to be 52% levied on taxable profit and one year in arrears (101). Tax considerations for other countries are given by Gardner (170).

12.4.2. INFLATION

Normally in engineering studies the calculations are carried out for constant-value pounds which means that inflation or deflation is neglected. As long as a shipowner is free to adjust his freight rates to reflect his changing costs this is a reasonable assumption (164). Therefore since both income and costs are rising inflation can be neglected. However whereas other costs may well rise uniformly, depreciation allowances do not and therefore a shipowner in effect pays higher than the stipulated tax rate (160) e.g. with an assumed rate of inflation of 8% the effective tax rate which was 50% without inflation, works out to be 56.5% (171). In the program escalation in costs due to inflation can be given by either assigning absolute values of escalation rates or relative values of escalation rates. Historic data on escalation can be used as a guide line e.g. Cameron (142), Buxton (101) give escalation rates in percentage/annum for the costs as well as the income. Escalation rates of certain items of costs are indicated in Section 9.4 and Sections 10.10 and incorporation of these in the program is indicated in Section 12.6. Benford (160) gives the procedure on how to incorporate inflation when calculating in constant value pounds. Most of the parametric studies carried out in Chapter 14 are in constant value pounds without inflation.

12.4.3. DEPRECIATION

There are various types of depreciation and these are given by Buxton (101), Cameron (142). Since the economic study is carried out for a shipowner under the U.K. tax regime 'free depreciation' is assumed. Free depreciation allows the shipowner to extinguish all liability for tax until the depreciation allowances have been exhausted (101).

12.5. CALCULATION OF CAPITAL CHARGE

After the building cost of the ship is estimated, the builder's account is calculated in the subroutine CAPCHR. It uses as input the capital cost of the ship, life of the ship, discount rate in percentage interest on loan repayment and the number of years of loan. The procedure given by Buxton (101) is followed.

The following assumptions are made:

(1) The loan taken by the shipowner to finance the ship is 70% of the Capital Cost, the other 30% is the owner's own account

(2) The number of years of loan is 7 years and the interest on the loan is 12% per annum.

(3) The discounting is done with a discount rate of 15% per annum.

(4) Year 0 is the year contract is signed and the ship delivered in year 2.

(5) Building Instalment: 30% when the contract is signed, 15% when the keel is laid i.e. year 1.5, 50% when launched i.e. year 1.75 and 5% when delivered i.e. year 2.

(6) The loan is repaid in equal instalments over the period of the loan and is paid every year.

The procedure is carried out in subroutine subprogram CAPCHR and is shown in Fig. 12.3. The capital charge program calculates the builder's account. The interest payable on the loan every year is stored in an array TINT(K), to be set off against profits as tax allowances.

The present value of the Capital Cost based on the cash outflow is accumulated in BLDDCF.

Table 12.3 shows for a container ship the building account based on the above assumptions, the same procedure is followed in the algorithm. The program was validated by carrying out step by step hand calculation.

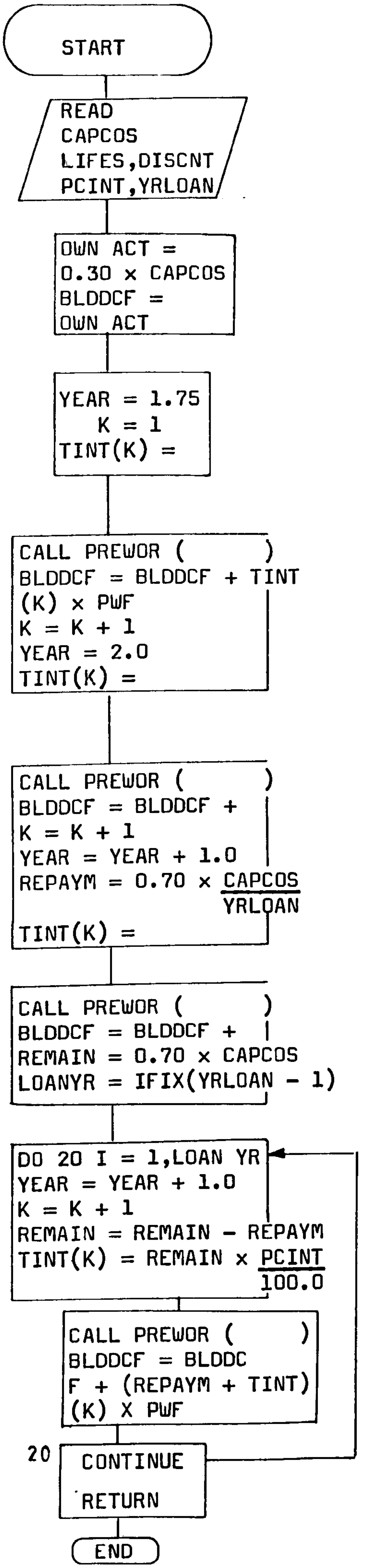


Fig. 12.3. Flow chart of capital charge program (CAPCHR).

TABLE 12.3. Builder's account.

Year	Building Instalment	Owner's 30%	Loan 70%	Loan Repayment	Loan Outstanding	Loan interest @ 10%	Cash Outflow	PWF @ 12%	DCF	
Computer Nomenclature	-	OWNACT	-	REPAYM	REMAIN	TINT(K)	-	PWF		BLDDCF
0	30% 12.24	12.24	-		-	-	-	1.000	12.24	12.24
1.5	15% 6.1185		6.1185		6.1185	-	-	0.8437	-	-
1.75	50% 20.395		20.395		26.5135	0.1475	0.1475	0.8201	0.12	12.3610
2	5% 2.0395		2.0395		28.553	0.6393	0.6393	0.7972	0.5097	12.8707
3				4.079	24.474	2.8553	6.9343	0.7118	4.9358	17.8065
4				4.079	20.395	2.4474	6.5264	0.6355	4.1475	21.954
5				4.079	16.316	2.0395	6.1185	0.5674	3.4716	25.4256
6				4.079	12.237	1.6316	5.7106	0.5066	2.8929	28.3185
7				4.079	8.158	1.2237	5.3027	0.4523	2.3984	30.7169
8				4.079	4.079	0.8158	4.8948	0.4039	1.9770	32.6939
9				4.079	0	0.4079	4.4869	0.3606	1.6179	34.318

Capital cost = 40.793 (CAPCOS) BLDDCF = 34.318

All cash in £ 1980 costs in millions (10^6). All dimensions in m. For the following container ship $L = 274.32$; $B = 32.26$; $T = 10.97$; $D = 24.60$; $C_b = 0.529$; SHP=80000 HP; REVS = 137.5 RPM.

12.6. REQUIRED FREIGHT RATE BEFORE TAX

The Required Freight Rate is the calculated freight income needed per unit of cargo to cover all operating costs and to provide the required rate of return on the capital invested in the ship and containers (101).

Since the acquisition cost of the ship and the containers, the required rate of return, all the operating costs, and the annual cargo transported are known, the level of freight rate which produces equal present worths of income and expenditure can be ascertained, i.e. zero NPV. The general form of the equation is,

$$\text{Required Freight Rate (RFR)} = \sum_{\text{year}=0}^{\text{year}=N}\left[\frac{\text{PW(annual operating costs ship + containers)} + \text{PW(Acquisition Cost ship + containers)}}{\text{PW(annual cargo quantity)}}\right] \quad \text{£/tonne} \qquad \text{Eq. (12.5)}$$

In the previous chapters we have estimated all the factors on the RHS of Eq. 12.5, therefore RFR can be calculated. Thus RFR can be regarded as a calculated long term average freighting cost, which can then be compared with actual market freight rates to ascertain that building the ship is an economic proposition or not.

Since the cash flows are not uniform, an initial freight rate is assumed so that an initial NPV can be calculated. As this NPV may not be exactly zero, an iterative procedure is adopted to find the exact freight rate which gives zero NPV.

The ship which gives the minimum Required Freight Rate (RFR) is then chosen as best design or the optimum design.

The procedure adopted in the program is explained below.

(1) The program is capable of accepting escalation in operating cost of the ship and the containers, and container cost escalation, since the life of the containers is less than the ship's life.

(2) The first estimation to RFR is calculated in the subroutine subprogram ECONOM. The taxation and the tax allowances are not considered, so this is the RFR before tax. This value of RFR is used as a first estimation of income and income tax and tax allowances, such as depreciation and interest on loan are considered in another subroutine subprogram ANPVAL.

(3) The ECONOM subroutine calls the various subroutines which calculate the weights, costs and the operating characteristics of the ship and the containers (see Fig. 13.10).

(4) The year 3 is the year of operation since year 0 to year 2 is assumed to be time taken to deliver the ship.

(5) The cargo carried per annum (CDWTPA) is given by

$$\text{CDWTPA} = \text{CNT} \times \text{WEC} \times 2.0 \times \text{ALFMAX} \times \text{RTPA} \text{ tonnes} \quad \text{Eq.}(12.6)$$

where CNT is actual ship capacity in Teu, WEC is the weight of each container assuming homogeneous distribution of weights in containers, factor of 2 derives from the ability to carry one cargo outwards, another homewards, on a round trip and RTPA is the number of round trips per annum.

(6) Each of the operating cost elements can be escalated with a differing rate and the escalation in cost in a given year is given by the general formula

$$\text{ECOST(I)} = (1.0 + \text{ARATE}/100.0)^{Y} \qquad \text{Eq. } (12.7)$$

where ARATE is the percentage rate of escalation and Y is the number of years for escalation.Following are the elements of operating cost which are assumed to be escalating at different rates.

(a) Handling Costs (AHANDL, EHANDL(I))

(b) Port Costs (APORT, EPORT(I))

(c) Fuel Costs (AFUEL, EFUEL(I))

(d) Basic Wages Crew, PO officers (AWAGES, EWAGES(I))

(e) Other Crew Costs such as cost of overtime, leave, study, security and insurance, travel and training (ACREW,ECREW(I))

(f) Victualling or Provisions Costs (APROV, EPROV(I))

(g) Store costs (ASTORE, ESTORE(I))

(h) P & I insurance (APIINS, EPIINS(I))
(i) War Risk and Hull Insurance (AWHINS, EWHINS(I))
(j) Maintenance and Repair Costs (ARMANT, ERMANT(I))
(k) Administrative Costs (AADMIN, EADMIN(I))

The escalation rate in the basic program is taken to be zero since we are comparing alternatives, but to calculate the shadow price, escalation rates must be considered. Typical values are indicated in Section 9.4 and Section 10.10.

(7) Then each of the elements of the operating costs are stored in an array after multiplying by the escalation factor for each year, which is

$$\text{CCOST(I)} = \text{Operating Cost element} \times \text{ECOST(I)} \quad £ \qquad \text{Eq.}(12.8)$$

(8) These values are discounted by the equation

$$\text{PWCOST(I)} = \text{CCOST(I)} \times \text{PWF} \qquad £ \qquad \text{Eq.}(12.9)$$

where PWF is the present worth factor for year I, of discount rate DISCNT and calculated in subroutine PREWOR.

(9) From year 3 to the life of the ship this process is repeated until we have the present value of the running cost (DF RCOS), and the present value of the cargo carried/annum (DCFDWT).

(10) The present value of the building account (BLDDCF), Section 12.5, was calculated in the building account subroutine CAPCHR, and the present value of container cost and operating cost (TDCFCN) was calculated in the subroutine CONDCF (Eq. 11.24).

Then

$$\text{RFR} = (\text{TDCFCN} + \text{BLDDCF} + \text{DFRCOS})/\text{DCFDWT} \quad £/\text{tonne} \quad \text{Eq.}(12.10)$$

12.7. REQUIRED FREIGHT RATE AFTER TAX

Once the first estimation of the required freight rate is available, the program ECONOM calls another subroutine ANPVAL. As pointed out in the last section ANPVAL was an iterative procedure to determine the required freight rate for a particular design (RFRMIN) in £/tonne.

The program flow chart is shown in Fig. 12.4 and the main steps of the procedure are described below:

(1) Since we know the first estimation of Required Freight Rate RFR, the annual income, AINCOM(I), in the year I can be calculated

$$\text{AINCOM(I)} = \text{RFR} \times \text{CDWTPA} \qquad £ \qquad \text{Eq. (12.11)}$$

And annual expenditure, EXPEND(I), in the year I is given by

$$\text{EXPEND(I)} = \text{TRCOS(I)} + \text{TCMCOS(I)} + \text{TCINS} + \text{CFCSL(I)} \quad £ \quad \text{Eq.(12.12)}$$

Therefore cash flow before tax, CASHBT(I), is

$$\text{CASHBT(I)} = \text{AINCOM(I)} - \text{EXPEND(I)} \qquad £ \qquad \text{Eq. (12.13)}$$

(2) Up to the year of loan (LOANYR) the interest is set off as a tax allowance and the rest of the cash flow before tax is set off as depreciation. Free depreciation is assumed in the program and the depreciation allowance is used to extinguish tax liability until the capital cost of the ship is exhausted. Year I = 1, is the year of operation and is designated as YEAR = 3.0.

(3) The general form of the equation of cash flow for taxable profit and tax are

$$\text{TAXPROF(I)} = \text{CASHBT(I)} - \text{tax allowances (interest and depreciation)} \quad £ \qquad \text{Eq.(12.14)}$$

and $\text{TAX(I)} = \text{TAXPROF(I)} \times \text{TAXPCT}/100.0 \qquad £ \qquad \text{Eq.(12.15)}$

where percentage of tax (TAXPCT) is an input data.
The tax (TAX(I)) is assumed to be paid one year later, and the general form of the equation for cash flow after tax, CASHAT(I), is

$$\text{CASHAT(I)} = \text{CASHBT(I)} - \text{TAX(I)} \qquad £ \qquad \text{Eq.(12.16)}$$

At the end of life of the ship however, there will be one more tax to be paid, then for year I = LIFES + 1, the balancing charge (101, 140) assuming the scrap value to be zero is, $\text{CASHAT(I)} = -\text{TAX(I-1)} \qquad £ \qquad \text{Eq. (12.17)}$

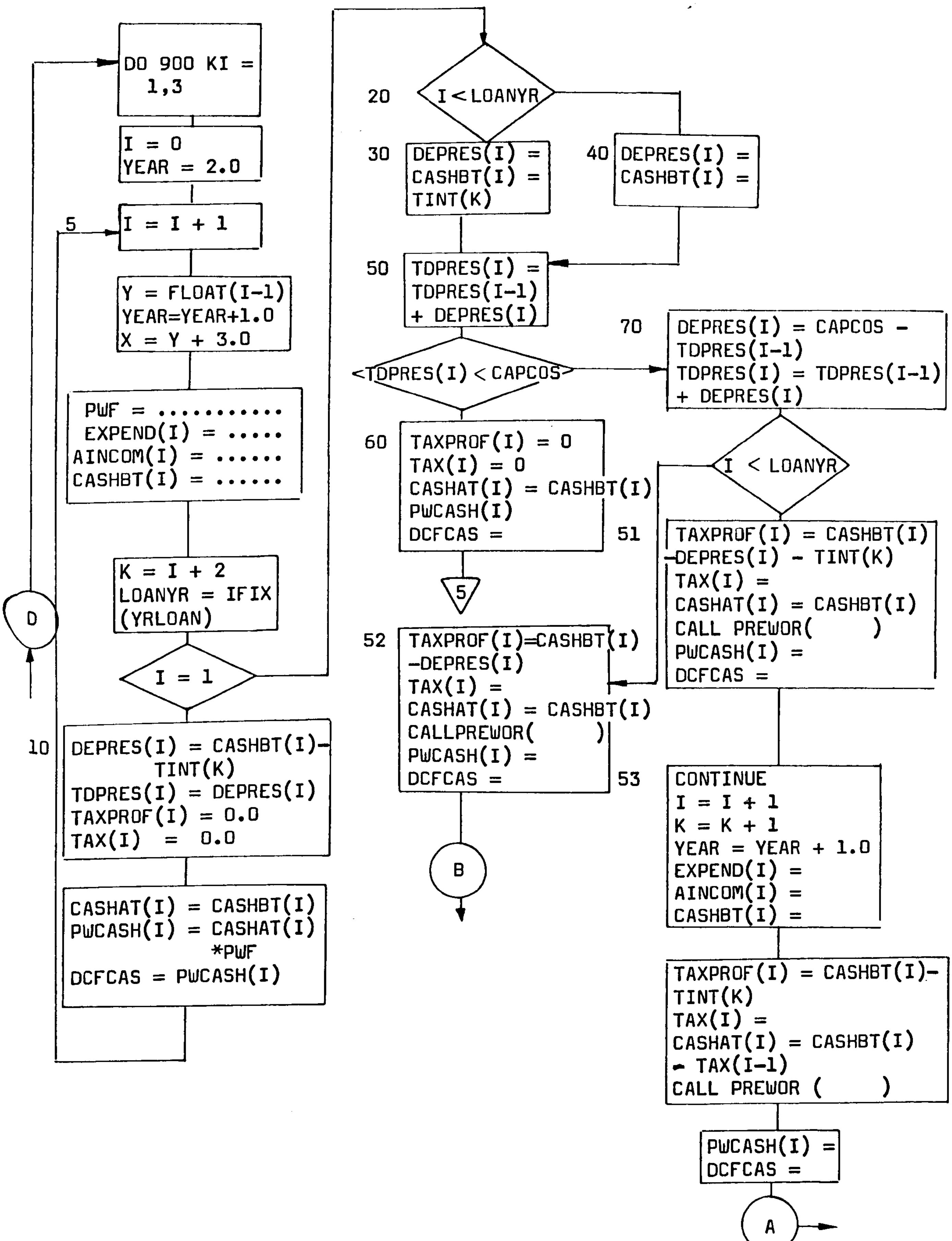


Fig. 12.4. Flow chart for calculating the minimum required freight rate.

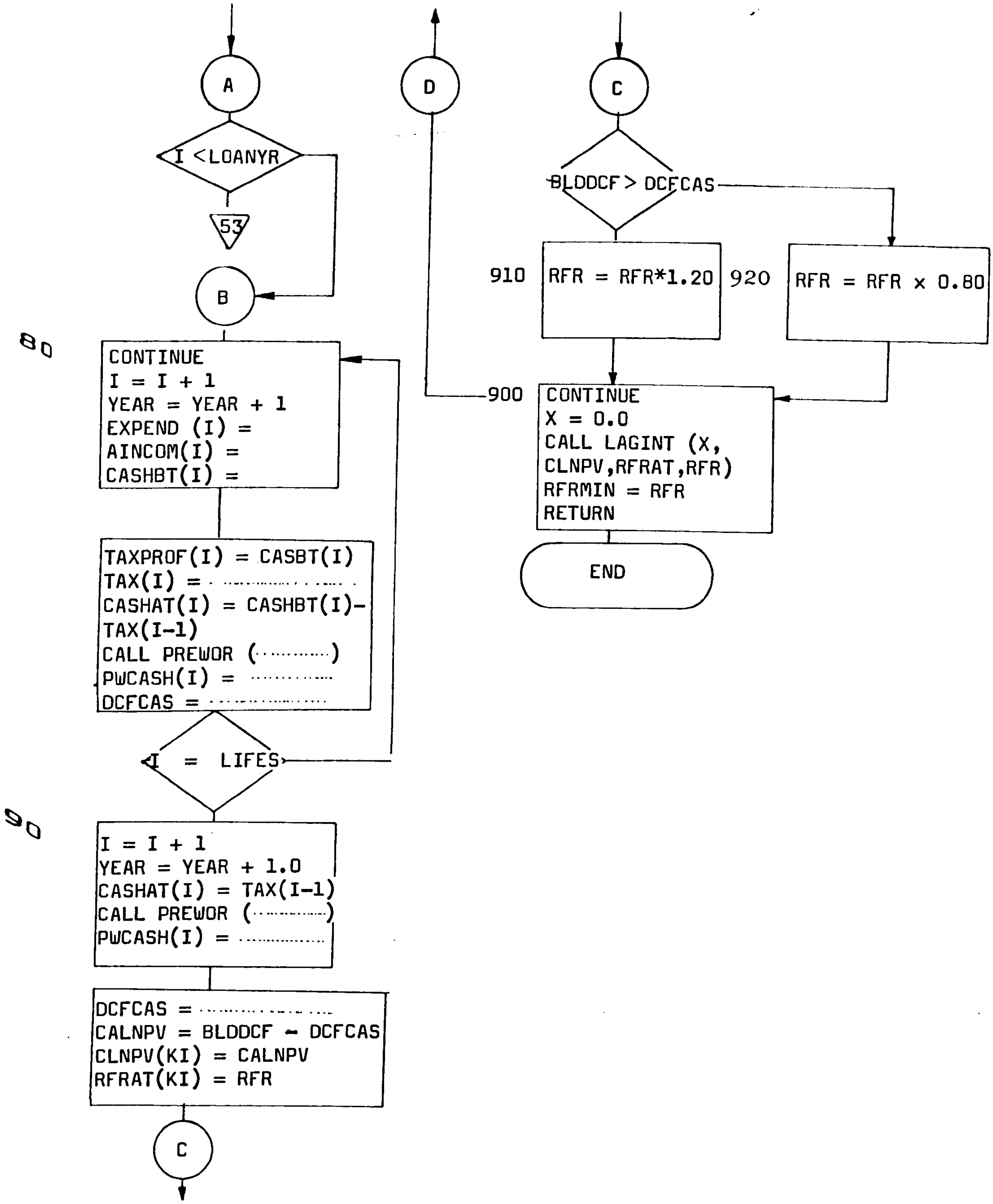


Fig. 12.4. (Continued).

The cash flow after tax is discounted at the input discount rate (DISCNT) and is stored as

$$PWCASH(I) = CASHAT(I) \times PWF \qquad £ \qquad \text{Eq. (12.18)}$$

where PWF is the present worth factor for the year I and is calculated in subroutine PREWOR.

The summation of all the cash flows in each year is accumulated as discounted cash flow (DCFCAS) and is the present value of all the cash flows over the operating life of the ship.

(4) The net present value is then calculated as

$$CALNPV = BLDDCF - DCFCAS \qquad £ \qquad \text{Eq. (12.19)}$$

and is the difference between the present worth of the building account, BLDDCF (Section 12.5) and the present worth of the operating account DCFCAS.

(5) The procedure from step 1 to 4 is repeated for two other values of RFR i.e. 1.20 RFR and 0.80 RFR, which gives us 3 values of RFR and 3 values of NPV's, then by using an interpolating subroutine LAGINT, we calculate the required freight rate which gives the NPV equal to zero. This Required Freight Rate (RFRMIN) is the freight rate after tax which can then be compared with the actual freight rates as shown in Fig. 12.2.

CHAPTER 13

DETERMINISTIC APPROACH TO CONTAINER SHIP DESIGN

13.0 INTRODUCTION

The container moulds the cargo to units of preset size and shape. The ship's form, being that of a curved stream line shape, cannot accommodate the modular make-up of the cargo without some loss in cargo space. This loss in cargo space can, however, be made up by stowing containers on deck. Further this inefficiency in cargo stowage in containerships compared to a general cargo ship is tolerated because of the higher handling rate of containers, thereby increasing its annual carrying capacity.

The container capacity below the deck and above the deck is to a certain extent a function of hull geometry and deck geometry of the ship. But the number of containers stowed on deck is largely a function of ship's stability. Thus stability, as opposed to geometry, of the ship plays a major role in determining the number of containers carried on deck and hence the total container capacity of the ship.

In this chapter, the different estimating methods which have been proposed in past studies are compared, and a better estimating method proposed. The notion of maximum container slot capacity and container load capacity is introduced. The stability of the container ship and the various other operating parameters which govern the container load capacity are discussed.

Since only principal dimensions of the vessel are known at the preliminary design stage, certain approximations are needed as to the distribution of the containers in the hold and the deck without recourse to ship's lines to establish the centre of the container cargo. Therefore how this can be established is described.

Statical stability criteria and a simple seakeeping criteria which are incorporated in the program are described.

The two ship design algorithms, for determining the optimum design are then discussed. The first is based on a simple parametric variation of principal dimension to generate large numbers of feasible designs and the optimum design is located manually by the designer by selecting one with the minimum required freight rate. The second design model is based on automatic selection of the optimum design, by application of optimization techniques. These two ship design algorithms form the stage 1 and stage 2 of the deterministic phase of the ship design respectively.

13.1 CONTAINER SHIP CAPACITY

Maximum slot capacity is defined as the maximum allowable number of containers that can be stowed based on the ship's hull and deck geometry. Whereas actual or load container capacity is defined as the maximum number of containers that can be stowed limited by a ship's stability and deadweight requirements. All empirical relationships given below estimate the maximum slot capacity.

The total container capacity of a ship can be subdivided into containers carried below deck and containers above deck. The preferred method in the past was to estimate container capacity below deck as a function of volumetric underdeck capacity and then estimate the deck capacity as a function of deck area or deck area and permissible deck loading (39,52); Or the total container capacity simply as a function of volumetric capacity of the ship (54). Some of the methods are outlined below:

13.1.1. EXISTING ESTIMATION METHODS

METHOD 1: This method assumes that the total container capacity is a linear function of cubic number (54).

$$TCONT1 = 1260.687 \times CN/1000.0, \quad \text{Teu} \qquad \text{Eq. (13.1)}$$

where $CN = L \times B \times D/100\ m^3$ and all dimensions are in metres and container capacity in Teu. Equation (13.1) is valid for ships of 800 to 2400 Teu.

METHOD 2: This method divides the total container capacity as below deck and above deck container capacity and estimates these as functional relations of volume under deck and deck area respectively (39,55)

$$TCONT2 = \overbrace{1.307 \times Cb \times CN}^{\text{hold}} + \overbrace{55.648 \times L \times B/1000}^{\text{deck}} \ \text{Teu} \qquad \text{(Eq. 13.2)}$$

Equation (13.2) is valid for containers staked up to 7 tiers high below the deck, two tiers of containers on deck and for ships of 200-1800 Teu.

METHOD 3: This is similar to Method 2 above. The total container capacity is the sum of the under deck capacity, which is a function of under deck volume and deck capacity which is a function of deck area and deck loading (52).

$$TCONT3 = \underbrace{7.607 \times 10^{-4} \times (C_b \times CN)^2 + 0.862 \times C_b \times CN}_{\text{Hold}} + \underbrace{58.0 + WABV/CDEN}_{\text{Deck}} \quad \text{Teu} \qquad \text{Eq. (13.3)}$$

where weight above deck (WABV) = 791 x DKAR + 160 tonnes and DKAR = function of deck area = $L \times B \times 10^{-4} \times 10.764\ m^2$.

It is assumed that each container weighs 10 to 18 tonnes (CDEN). There are no shipboard cranes and deck containers are secured to the deck with standard lashing cables. Equation (13.3) is valid for ships of 400-2400 Teu.

METHOD 4: This method (39) estimates the container hold capacity as a function of modified cubic number (CN x CB) and the deck capacity as a function of deck area expressed as (L x B).

$$TCONT4 = 3.306 \times (CB \times CN)^{0.852} + 3.380 \times 10^{-3} \times (L \times B)^{1.329} \quad \text{Teu} \qquad \text{Eq. (13.4)}$$

Equation (13.4) is valid for ships 200-1800 Teu, other factors same as Equation (13.2).

METHOD 5: This method (39) estimates the total container capacity as a function of L,B,D and prismatic coefficient C_p.

$$TCONT5 = 567.275 \times 10^{-4}\, L^{0.984} B^{0.573} D^{1.13} C_p^{0.965} \quad \text{Teu} \qquad \text{Eq. (13.5)}$$

Validity of Eq. (13.5) is the same as Eq. (13.4, 13.2).

METHOD 6: This method (46) is based on regression analysis of ships existing in the early seventies and the total container capacity is expressed as a function of cubic number and speed.

$$TCONT6 = 8.88 \times (CN)^{1.190} \times \left(\frac{1}{V}\right)^{1.08} \quad \text{Teu} \qquad \text{Eq.}(13.6)$$

where V = speed in knots.

This equation is valid for ships of 800 to 3500 Teu and speed of 20 to 35 knots.

METHOD 7: This method (61) estimates the container hold capacity as a function of (L x B x D) and the container deck capacity as a function of deck area expressed as (L x B).

$$TCONT7 = 7.681 \times 10^{-3}\, L \times B \times D + 32.614 \times 10^{-3}\, L \times B + 100 \quad \text{Teu} \qquad \text{Eq. }(13.7)$$

For ships in Table 13.1, the container capacity was estimated by Eq. 13.1 to Eq. 13.7 and shown in Table 13.2. There was wide variation in each of these estimation methods both for containers in holds and containers carried on deck.

13.1.2. DRAWBACKS OF EXISTING METHODS

It seems natural to assume that the fixed dimensions of the containers will force the breadth and the depth of the ships to be fixed on the basis of structural and stacking considerations alone, taking into account constraints on beam and depth for passage through certain canals and harbours.

To a certain extent this is true, but stability requirements and individual choice seem to be as strong factors as anything else in the choice of beam and depth of the vessel. This is made apparent in Table 13.1 where the beam varies from 3.071 m. to 3.714 m/row and the depth varies from 2.038 m. to 2.843 m/container tier below the deck.

The percentage variation from actual container hold capacity as well as deck capacity is shown in Table 13.2a. It is apparent that the percentage variation is quite large in certain cases. This is because most of these

TABLE 13.1. Container stacking characteristics.

	Ship's Name	LBP in m	B in m	D in m	Maxm Section Hold W	Maxm Section Hold H	Maxm Section Deck 1 High	Total	CB	CN = LxBxD /100	B/W in m	D/H in m	Teu U Deck	Teu ABVDK 2 High	LxB in m²	LxB ABVDK 1 high m2/Teu
1.	KASHU MARU	175.00	25.70	15.30	7	6	8	728	0.569	688.12	3.6714	2.550	504	224	4497.5	40.156
2.	JAPAN ACE	175.00	25.20	15.30	7	6	8	730	0.566	674.73	3.6000	2.550	472	258	4410	34.186
3.	GOLDEN GATE BR	175.00	25.00	15.40	7	6	9	716	0.580	673.75	3.5714	2.5666	484	232	4375	37.715
4.	HAKONE MARU	175.00	26.00	15.50	7	6	9	752	0.560	705.25	3.7143	2.5833	486	266	4550	34.211
5.	AMERICAN MARU	175.00	25.00	15.50	7	6	8	708	0.570	678.13	3.5714	2.5833	488	220	4375	39.77
6.	ENCOUNTER BAY	213.36	30.48	16.46	9	6	10	1138	0.600	1070.43	3.3866	2.7433	770	368	6503.21	35.343
7.	ACT 1	205.74	28.96	15.926	8	6	10	1134	0.605	948.91	3.6200	2.6543	754	380	5958.23	31.360
8.	ELBE EXPRESS	155.00	24.50	14.60	7	6	9	736	0.612	554.44	3.500	2.4333	508	228	3797.5	33.311
9.	SEA WITCH	177.34	23.77	16.61	7	6	9	928	0.640	700.17	3.3957	2.7666	612	316	4215.37	26.680
10.	MANCHESTER CHL.	151.79	19.35	14.63	6	6	6	612	0.600	429.70	3.2250	2.4383	452	160	2937.14	36.714
11.	SEA FREIGHTLINER	111.56	16.15	8.53	5	3	5	274	0.670	153.68	3.2300	2.8433	162	112	1801.69	32.173
12.	STRIDER CLASS	105.00	16.75	9.40	5	3	5	238	0.570	165.32	3.3500	3.1333	128	110	1758.75	31.977
13.	CP. VOYAGER	153.00	25.60	15.25	7	6	8	719	0.648	597.31	3.6572	2.5416	503	216	3916.8	36.267
14.	SELANDIA	257.6	32.21	23.90	10	9	12	2272	0.545	1983.05	3.2210	2.6555	1662	610	8297.296	27.205
15.	TAEPING	192.00	30.50	18.186	9	7	12	1262	0.576	1064.97	3.3888	2.5980	856	406	5856	22.847
16.	JEDDAH CROWN	104.00	18.90	8.15	6	4	6	318	0.590	160.20	3.1500	2.0375	198	120	1965.6	32.760
17.	FIERY CROSS ISLE	133.6	21.50	10.50	7	4	7	400	0.570	301.60	3.0714	2.6250	256	144	2872.4	39.894
18.	MANCHESTER VIGOUR	103.10	15.55	10.65	5	4	5	316	0.735	170.74	3.1100	2.6625	206	110	1603.205	29.149
19.	EUROLINER	224.96	30.00	19.20	9	7	11	1632	0.550	1295.77	3.333	2.7429	1088	544	6748.8	24.812
20.	CALIFORNIA STAR	178.00	25.85	15.29	8	6	10	910	0.610	703.54	3.2313	2.5483	596	314	4601.3	29.307
21.	DART AMERICA	218.01	30.48	18.60	9	7	10	1532	0.610	1235.96	3.3866	2.6571	1140	392	6644.95	33.902
22.	ELBE MARU	252.0	32.20	24.40	10	9	10	2104	0.572	1979.81	3.22	2.7111	1580	524	8114.4	30.971

Table 13.2. Container capacity calculated by different methods.

TCONT1	CTHLD2	CTDCK2	TCONT2	CTHLD3	CTDCK3	TCONT3	CTHLD4	CTDCK4	TCONT4	TCONT5	TCONT6	TCONT
1. 867	511	253	761	512	332	844	535	242	777	768	727	775
2. 850	499	245	744	498	326	824	524	235	759	757	700	762
3. 849	510	243	754	510	323	834	534	233	767	775	717	764
4. 889	516	253	769	517	336	853	539	245	785	773	745	790
5. 854	505	243	748	504	323	828	529	233	762	768	718	763
6.1349	839	361	1201	925	474	1399	816	395	1211	1163	1261	1134
7.1196	750	331	1081	803	436	1239	742	351	1093	1058	1114	1023
8. 699	443	211	654	438	282	720	474	193	667	670	638	649
9. 882	585	234	820	596	312	909	600	222	822	903	843	775
10.541	336	163	500	330	221	552	375	137	512	563	484	525
11.193	134	100	234	154	141	296	171	71	243	224	212	276
12.208	123	97	221	146	138	284	159	69	228	211	169	284
13.753	505	218	723	505	291	796	530	201	731	747	782	686
14.2500	1412	461	1873	1877	602	2479	1271	546	1817	2020	2192	1893
15.1342	831	325	1127	873	428	1301	785	343	1128	1142	1172	1109
16.202	123	109	232	146	152	299	159	80	240	195	173	287
17.380	224	159	384	228	217	445	265	133	398	355	279	425
18.215	164	89	253	178	127	305	203	61	264	308	141	283
19.1633	931	375	1306	1058	492	1550	892	414	1306	1349	1321	1315
20.886	560	256	816	567	339	907	579	249	828	832	784	790
21.1558	985	369	1354	1140	484	1624	935	406	1342	1384	1496	1266
22.2496	1479	451	1931	2009	589	2598	1323	530	1853	2125	2165	1885

Table I3.2(a) Percentage variation of container capacity

TCONT7	-6.5	-4.4	-6.2	-5.1	-7.8	0.3	9.8	11.7	16.5	14.1	-1.0	-19.5	4.5	16.6	12.1	9.7	-6.3	10.3	19.4	13.1	17.4	10.4
TCONT6	0.1	4.1	-0.3	0.9	-1.4	-10.8	1.7	13.2	9.1	20.8	22.5	28.7	-8.8	3.5	7.1	45.4	30.2	55.1	19.1	13.6	2.3	-2.9
TCONT5	-5.6	-3.8	-8.3	-2.9	-8.6	-2.2	6.6	8.8	2.6	7.9	18.2	11.3	-4.0	11.1	9.5	38.4	11.2	2.5	17.3	8.5	9.6	-1.0
TCONT4	-6.8	-4.1	-7.2	-4.4	-7.7	-6.4	3.6	9.3	11.3	16.3	11.2	4.0	-1.8	20.0	10.6	24.5	0.3	16.3	19.9	9.0	12.4	11.9
CTDCK4	-8.0	8.6	-0.5	7.6	-6.0	-7.3	7.5	15.2	29.7	14.2	36.0	36.8	6.8	10.5	15.4	32.9	7.4	44.2	23.7	20.6	-3.7	-1.2
CTHLD4	-6.2	-11.1	-10.5	-11.0	-8.5	-6.0	1.6	6.7	1.8	17.0	-5.9	-24.3	-5.4	23.5	8.3	19.4	-3.7	1.4	18.0	2.9	17.9	16.2
TCONT3	-16.0	-12.9	-16.6	-13.4	-17.0	-23.0	-9.3	2.1	2.0	9.7	-8.0	-19.4	-10.8	-9.1	-3.2	6.0	-11.4	3.4	5.0	0.3	-6.1	-23.5
CTDCK3	-48.4	-26.4	-39.5	-26.4	-47.2	-29.0	-14.8	-24.0	1.1	-38.6	-26.0	-25.6	-34.8	1.3	-5.6	-27.3	-50.8	-15.5	9.5	-8.2	-23.7	-12.4
CTHLD3	-1.6	-5.5	-5.6	-6.4	-3.4	-20.2	-6.6	13.8	2.5	26.8	4.5	-14.0	-0.5	-13.0	-2.0	26.1	10.7	13.5	2.7	4.7	-0.0	-27.2
TCONT2	-4.7	-2.0	-5.3	-2.3	-5.7	-5.5	4.6	11.1	11.6	18.2	14.3	7.1	-0.7	17.5	10.7	26.8	3.9	19.9	19.9	10.2	11.6	8.2
CTDCK2	-11.7	4.9	-4.9	4.8	-10.7	1.7	12.7	7.3	25.8	-2.2	10.5	11.0	-0.9	24.3	19.7	8.8	-11.0	18.9	31.0	18.5	5.7	13.8
CTHLD2	-1.5	-5.7	-5.5	-6.2	-3.5	-9.0	0.5	12.7	4.3	25.5	17.0	3.8	-0.5	15.0	6.3	37.6	12.3	20.4	14.4	5.9	13.6	6.3
TCONTI	-19.2	-16.5	-18.6	-18.2	-20.7	-18.6	-5.5	5.0	4.9	11.5	29.3	12.4	-4.7	-10.0	-6.4	36.5	4.9	31.9	-0.1	2.5	-1.7	-18.6

TABLE 13.3 Container Distribution on Deck

A. CONTAINERSHIPS WITH MACHINERY AFT

	Ship's Name	L in m.	B in m.	Cont. per Tier	Max. Rows Below Deck	Max. Rows Above Deck	LxB in m^2	Cont. / LxB
1.	ACT	205.74	28.96	190	8	10	5958	.032
2.	MANCHESTER CHALLENGE	151.79	19.35	80	6	6	2937	.027
3.	ENCOUNTER BAY	213.36	30.48	184	9	10	6503	.028
4.	STRIDER	105.00	16.75	55	5	5	1759	.031
5.	CP. VOYAGEUR	153.00	25.60	108	7	8	3917	.027
6.	SEA WITCH	177.34	23.77	158	7	9	4215	.037*
7.	ORIENTAL CHEVALIER	192.00	26.00	166	8	9	4992	.033
8.	JEDDAH CROWN	104.00	18.90	60	6	6	1967	.030
9.	FIERY CROSS ISLE	133.60	21.50	72	7	7	2872	.025
10.	MANCHESTER VIGOUR	103.10	15.55	55	5	5	1603	.034
11.	DARR AMERICA	218.00	30.48	196	9	10	6644	.029
12.	ATLANTIC MARSSIELLE	154.70	23.0	120	7	7	3558	.033

Mean = 0.035

B. CONTAINERSHIPS WITH MACHINERY 3/4 AFT OR AMIDHSIPS

Ship's Name	L in m.	B in m.	Cont. per Tier	Max. Rows Below Deck	Max. Rows Above Deck	LxB in m^2	Cont. / LxB
B	282.74	32.00	336	9	12	9048	.037
C	231.42	31.70	288	9	12	7336	.039
D	224.0	30.48	270	9	11	6828	.039
C-G-S-85 C&D	234.4	27.4					
TAEPING	192.00	30.50	202	9	12	5856	.035
SELANDIA	257.60	32.20	305	10	12	8295	.037
JAPAN ACE	175.00	25.20	129	7	8	4410	.029
EUROLINER	224.96	30.00	270	9	11	6749	.040
CALIFORNIA STAR	178.00	25.85	157	8	10	4601	.034
ELBE MARU	252.00	32.20	262	10	10	8114	.032
TABLE BAY	248.20	32.26	328	10	13	8007	.041
NEW JERSEY MARU	247.00	32.20	205	9	9	7953	.026

TABLE 13.4. Values of Shape Coefficient

	CB	CM	CP	$V/\sqrt{L}$	Position of M/C	LBP in m	Coeff. Shape
MANCHESTER CHALLENGER	0.60	0.974	0.616	0.870	Aft	153.0	0.911
STRIDER CLASS	0.570	0.961	0.593	0.970	Aft	105.0	0.91
ENCOUNTER BAY	0.600	0.978	0.613	0.832	Aft	213.36	0.82
HAIWAIAN ENTERPRISE	0.622	0.973	0.639	0.884	Aft	206.35	0.913
CP. VOYAGEUR	0.648	0.980	0.661	0.803	Aft	153.0	0.870
SEA WITCH	0.640	0.978	0.654	0.829	Aft	177.34	0.837
ACT	0.623	0.975	0.639	0.866	Aft	205.74	0.806
SELANDIA	0.545	0.972	0.561	0.894	3/4 Aft	257.60	0.733
TAEPING	0.570	0.966	0.589	0.933	3/4 Aft	192.00	0.716
JAPAN ACE	0.566	0.964	0.587	0.952	3/4 Aft	175.00	0.720
JEDDAH CROWN	0.590	0.968	0.609	0.920	Aft	104.00	0.861
FIERY CROSS ISLE	0.570	0.946	0.602	1.05	Aft	133.60	0.794
MANCHESTER VIGOUR	0.735	0.977	0.752	0.843	Aft	103.10	0.958
EUROLINER	0.550	0.963	0.571	0.957	3/4 Aft	224.96	0.712
CALIFORNIA STAR	0.610	0.972	0.627	0.889	3/4 Aft	178.00	0.702
DART AMERICA	0.610	0.979	0.623	0.823	Aft	218.00	0.815
ATLANTIC MARSIELLE	0.637	0.977	0.652	0.843	Aft	154.70	0.781
ELBE MARU	0.572	0.969	0.590	0.913	3/4 Aft	252.0	0.708

R.J. SCOTTS DATA

Fine ships carrying 40' containers	Aft		0.85
Full ships carrying 20' containers	Aft		0.90
Fine ships carrying 40' containers	Amidships		0.80
Full ships carrying 20' containers	Amidships		0.83

equations were based on regression analysis of data of containerships built during and prior to the early seventies, and therefore give poor results for ships built after this date which were of larger size and higher speeds. In many cases the number of tiers of containers carried on deck are not specified, so a valid comparison is difficult. Other factors which should be taken into consideration while determining the hold and the deck container capacity are discussed in the next two sections.

13.1.3. FACTORS DETERMINING CONTAINER CAPACITY IN HOLDS

One of the strongest factors determining the hold capacity is the type and position of the machinery space. Ships with steam turbine or gas turbine machinery have smaller machinery space than ships with diesel machinery installation. The machinery space is therefore usually located well aft with generally not more than one container hold between the machinery space and the stern. With the all aft location there is no interruption of crane movement in the way of container stowage or interference of a deck house with a shore crane. Also, there is no shaft tunnel to interfere with the container stowage; therefore in containerships, the machinery is usually located aft to give increased stowage of containers. This is also made apparent by the low shape coefficient for ships with machinery 3/4 aft (see Section 13.2.2. and Table 13.4) compared with ships with machinery aft.

Other factors which have a slight influence are the size of containers and the loss in available cargo space, due to allowances between containers. This is less for 40' containers than for the 20' containers. The variable depth of double bottom along the length of the ship has also a slight influence, the required double bottom volume being dependent on ballast and fuel capacities or the ship's trade route.

In spite of all these factors, the under deck container capacity can be approximated by relating it to the ship's under deck volume - the under deck volume being expressed as product of length, beam, depth and block coefficient or what is known as the modified cubic number.

Henry and Karsh (5) give a relationship between under deck container capacity and the modified cubic number. Taking the enclosed volume of the hull to be L x B x D x CB/ 100.0, it is reasonable to assume that bale capacity of the general cargo ship can be taken as 70% of the enclosed volume (30% being engine room, peaks and double bottom spaces). From this it is necessary to subtract 20% of the bale capacity, which may be assumed to be the containerisation loss. Thus 'containerised bale capacity' may be expressed as (0.70 x L x B x D x CB) x 0.80. The bale cubic capacity of a container varies from 81% to 89% of the extreme volume (average say 85%). If 'containerised bale capacity' represents the volume of general cargo to be carried on a containership and 'container bale cubic capacity' the volume to enter one container, then it may be assumed that the ratio of the two will give a fair approximation to under deck container capacity.

$$CTHLD = \frac{0.56 \times L \times B \times D \times CB}{0.85 \times 6.096 \times 2.438 \times 2.438} = 1.82 \ CN \times CB \ \text{Teu} \qquad \text{Eq. (13.8)}$$

Comparing the coefficient of Eq. (13.8) to that of Eq. (13.2), it is on the higher side; this is because of the above assumptions on the loss in cargo hold space, usable space and the available container bale cubic etc. But it shows that for actual ship's data equations of this form will give a fairly good approximation to the hold capacity and once the containerised bale capacity is established, equations of this form should be applicable for all container dimensions. An equation of this form is derived in Section 13.2.1.

13.1.4. FACTORS DETERMINING DECK CAPACITY

The containers on deck are usually correlated to deck area or are a function of length and breadth of the ship. It is , however, difficult to analyse the data to arrive at a good functional relationship between deck area and deck capacity. This appears to be because containers are stowed above deck in either two, three or four tiers, depending on the total container weight, corner support and tie down methods used. Therefore, to establish the above deck capacity one would need to know the cargo density, corner support and tie down method used for existing ships. Moreover, the number of containers above deck is largely independent of the block coefficient and in Table 13.1 coefficient for ratio of L x B by number of container per tier varies from 24 for larger ships to 40 for smaller ships. This variation can be explained by the fact that container rows on deck may be one or two container rows more than container rows below deck as shown in Table 13.1.

It is highly desirable to be able to load containers on deck since they increase the earning capacity without increasing the ship's volumetric capacity. The extent to which they can be stowed on deck is governed by the following considerations:

a) Owner's requirement for container protection from salt water damage.
b) Container ships have large wind sail area which may have to be reduced to provide adequate statical stability, and steering response.
c) Visibility problems especially with bridge located aft.
d) If shore based cranes are used, maximum number of tiers to which container could be stacked will depend upon both the distance from the water at high tide to crane boom as well as ship's freeboard and draft. When working cargo the limiting angle of heel is limited to 5^{o} to avoid containers jamming in cells (5). This requirement is often more severe than the seagoing requirements and will require ballast to be added on entering port or the ship goes to sea with more than the minimum GM.

e) The securing/lashing techniques become quite complex if the number of deck tiers exceeds three.

f) The hatchcovers are designed to withstand only certain loads and more than two tiers of containers usually results in heavier and smaller hatches. Weight of hatchcovers may be limited by the crane lifting capacity and smaller hatches may result in unacceptable handling time for pontoon hatches.

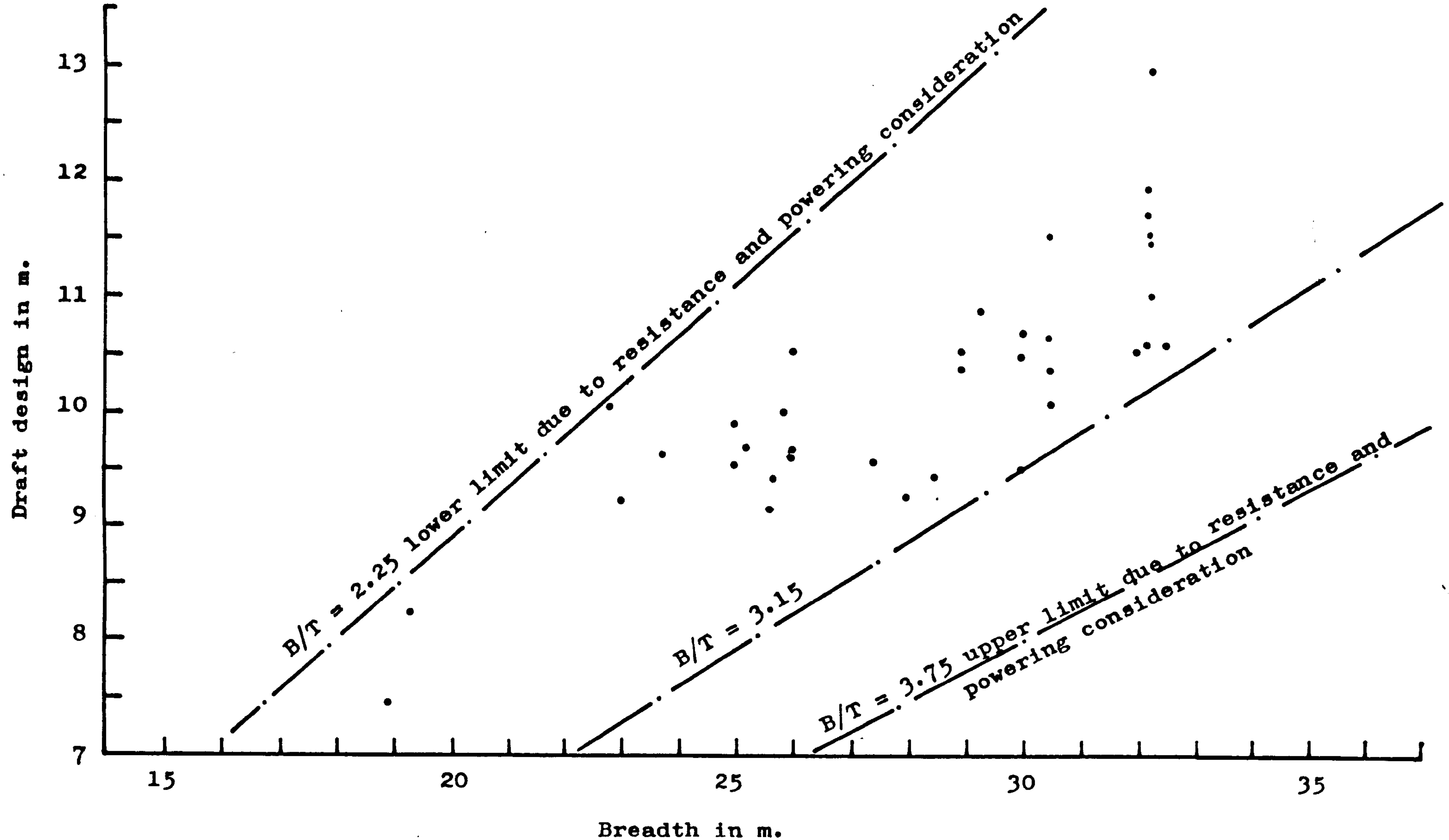
As is apparent from the above, many factors limit the containers on deck, foremost of which is perhaps the stability. The deck tiers of containers is limited to 4 in the program, it otherwise determines deck capacity exclusively on the basis of available deck area and stability. Later in Section 13.2.1 a formula is developed to determine deck capacity per tier solely based on deck area and then an iterative procedure is followed until the minimum GM and statical stability is satisfied.

13.2 DESIGN PHILOSOPHY OF THE APPROACH ADOPTED

For all containerships the design deadweight is obtained at a draft less than that obtainable with a type B freeboard. Also, since a large percentage of cargo is carried on deck, it is not possible to base the design on volume requirements (35). As shown in Fig. 13.1, most container ships acquire their design deadweight at B/T ratio lower than 3.15. This is because of the beam and draft restrictions of the Panama Canal for larger ships and the deadweight requirements are achieved at drafts lower than the scantling draft for smaller ships.

However, a container ship has unlimited stowage space in the vertical direction. The stacking height may be limited by nautical consideration, seakeeping, lack of adequate lashing arrangement or by stability. A ship with maximum stability would be able to increase the number of container tiers within the limits of deadweight requirements or draught

Fig. 13.1. Beam versus design draft.



limitations. To obtain the actual container capacity involves the solving of a stability problem in the sense that the righting arms must be maximised. This can be done either by increasing the ship's form stability, or by providing the necessary ballast either water or permanent in the lower part of the hull. In practice some ballast is carried even in load conditions.

The design problem can be best illustrated by Fig. 13.2 (36) which shows the number of containers that can be carried at a certain draft without ballast, satisfying the minimum stability requirements. Further, as shown in the figure, more containers can be carried with ballast than without ballast. With increase in draft, displacement increases, since all the other deadweight items other than cargo remain constant the average weight per container increases. On a ship of an optimum design* the maximum permissible draft for a given average container weight is reached, the container slots are fully utilised (including available deck containers stowing) and the available ballast capacity is adequate.

However two more problems still remain which are fundamental to container ship design. These are,

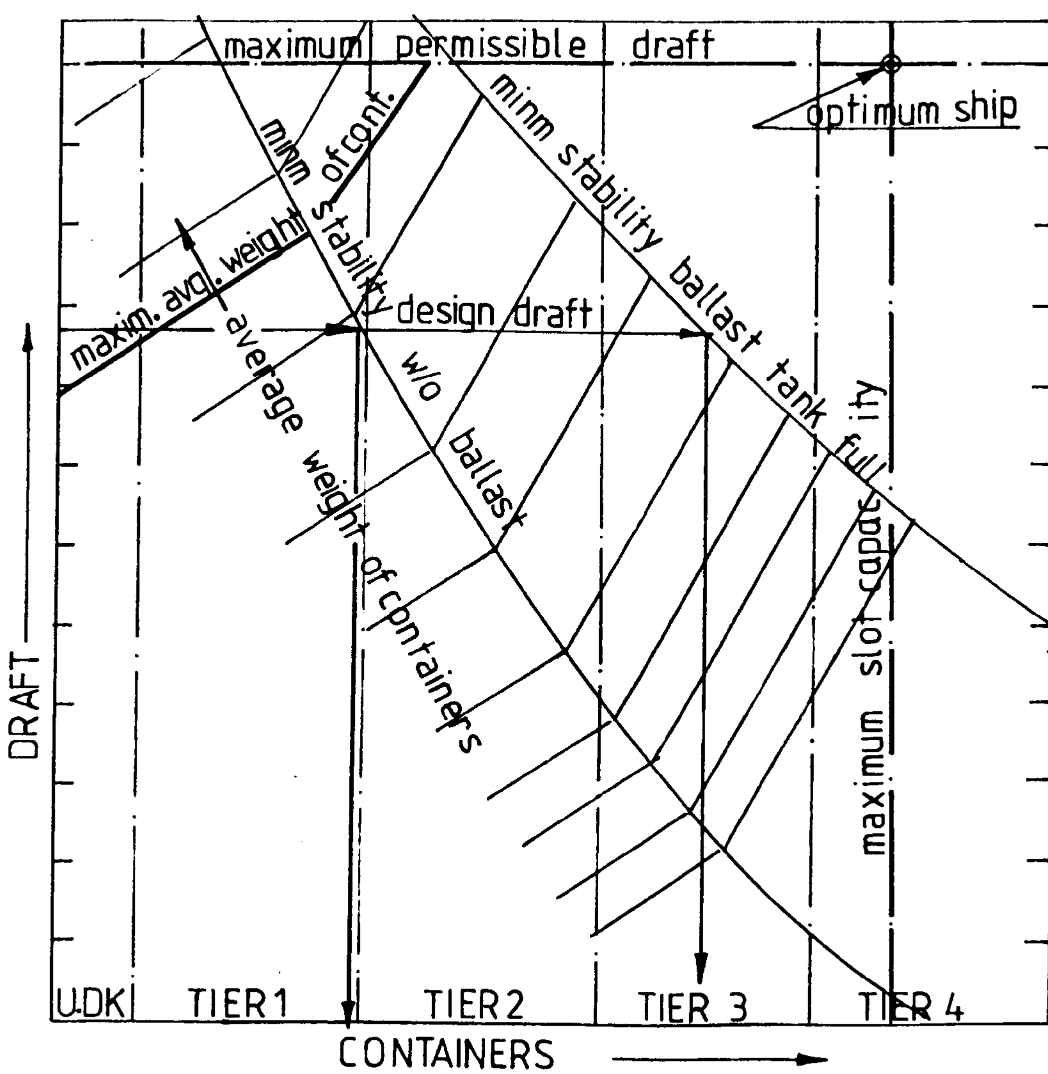
(a) Should a containership be designed with homogeneous cargo loading? If so what are the practical values of weight in each container? Alternatively if it is designed with a non-homogeneous cargo loading, what should be the weight of each container from the bottom tiers up to the top tiers?
(b) If the weight of each container is fixed at a particular value, this would enable the designer to optimise the design draft. Alternatively if the weight of each container is not fixed how does one optimise the design draft?

It is possible to design containerships with maximum container loading of 20 tons provided the number of tiers in the hold does not exceed 6, e.g. Maersk ships of 1200 Teu with rated container loading of about 20 tons each (172).

---

*The word optimum here is not used in context of a ship chosen based on economic optimisation, but merely refers to the ship which technically will be able to carry the maximum cargo.

Fig. 13.2. Influence of draft, GM_T and ballast on the containership capacity (36).



The OCL container ships were also designed assuming homogeneous loading and the average design draft was selected for a mean deadweight figure (19).
Thus for the first generation and possibly the second generation of purpose built container ships the stability was calculated on the basis of an average container weight (abt. 10-14 tons each) assuming homogeneous loading sometimes with about 10-20% of deadweight as water ballast.

In operation, however, often a considerably lower centre of gravity of the ship was ascertained as a consequence of non-homogeneous container load, leading to high GM-values with the consequence of short rolling periods (13, 173). These short rolling periods combined with high amplitudes due to the fine lines of container ships, gave disagreeable rolling motions. And the reduction of ballast water for improvement of rolling conditions has not yet led to a fully satisfactory solution (13, 173).

In order to overcome these problems and also to take into account that in actual operation, it is only the two or three lowermost tiers of containers in holds that carry the maximum rated load with progressive decrease in container weight up to the topmost tier of containers on deck which are possibly empty, most ships are designed today for non-homogeneous container load.

Following are some indicative GM-values on design for the drafts (13).

GM m.	TEU
0.50	700-800
0.40 - 0.45	1200-1500
0.30	2300-3000

To resolve some of the issues regarding container ship design a leading German ship builder was approached for guidance (174). Following are the conclusions that can be drawn about container ship design.

(a) The average weight of containers and the shipping companies stowage practice is of greatest importance for the layout of container ships, depends on the type of cargo and differs from leg to leg of the ship's route. Most shipowners design their ships under the assumption of homogeneous stowage, e.g. Danish shipowners normally specify 10t/Teu whereas German shipowners tend to specify higher average weights of 13t/Teu or more. Reefer containers will have much higher average weights per Teu.

(b) It is not realistic to base the design on a fixed container weight nor can an optimization process be done by using RFR-criterion exclusively.

The purpose of a container ship should be focussed as a part of a major aim which is related to a widespread transportation task.

Therefore the design process as illustrated before in Fig. 13.2 was used for a 205 m. containership assuming homogeneous loading and is shown in Fig. 13.3. The diagram gives the number of containers of a certain weight, the corresponding draft, the possible number of containers on deck and the amount of ballast water which is needed to keep the stability on a certain level of GM.

With regard to 'built in' capabilities, Fig. 13.3 stipulates a 'field of interest' which should be reached under all anticipated loading conditions. This is shown to be between average container weight of 10t to 14t and depending on the water ballast between 8.5 m. and 11.0 m. of draft.

As pointed out earlier selected stowage of containers is usual and has to be taken into account. This is illustrated by the double hatch lines, and less ballast water will be needed. Selected stowage is a typical operational problem and can be undertaken for a few competing designs.

For selection amongst large numbers of feasible designs, a homogeneous loading is assumed and a possible range of average weight per container. Optimum design draft in most

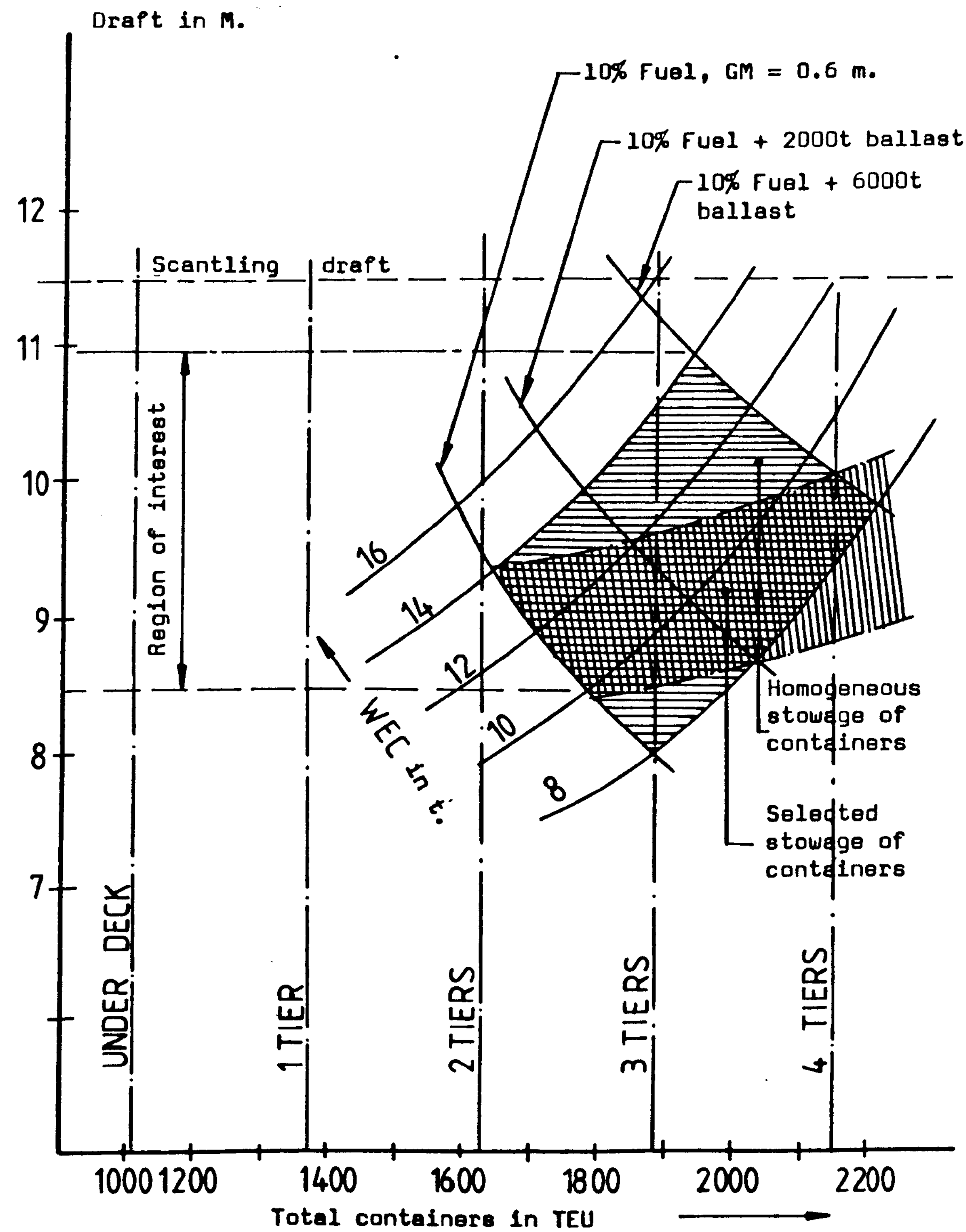


Fig. 13.3. Total container capacity versus draft for a 205 m. container ship.

cases will be the upper limit of this average weight per container, (see Chapter 14). A few competing designs in the region of the optimum can then be studied with selected stowage of containers. This procedure ensures a certain flexibility in design which is desirable since a ship designed for a certain route and cargo characteristics will not operate on the same route for the whole period of ship's life, and route conditions may alter.

13.2.1. MAXIMUM SLOT CAPACITY

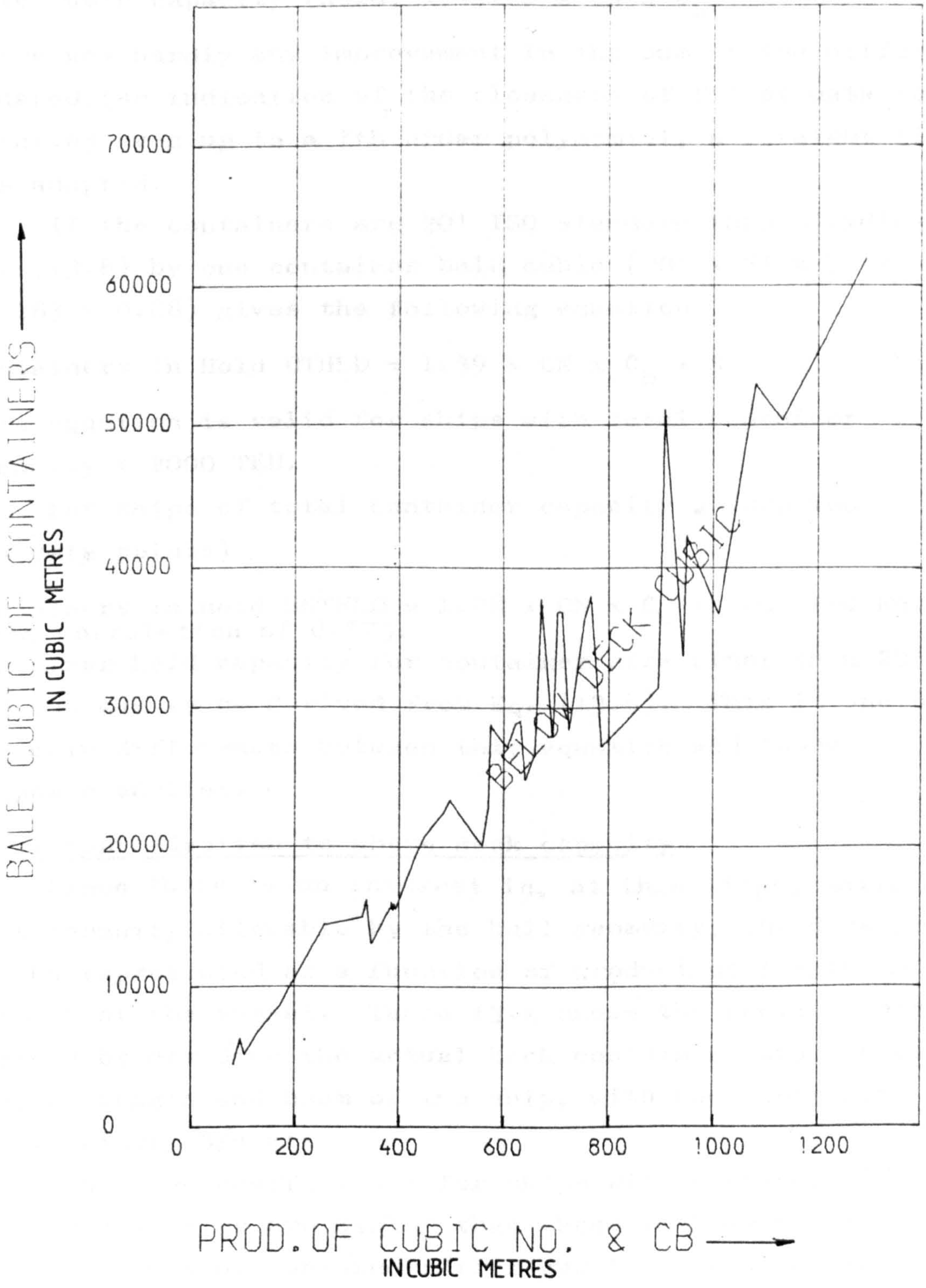
To determine the maximum slot capacity, two empirical equations are suggested. Once the maximum slot capacity of a ship is determined, the next step is to incorporate both initial and large angle stability criteria so that actual load capacity can be determined. The designer inputs the operating parameters such as route particulars and loading conditions. The program then determines the actual container load capacity until the stability requirements are met. This procedure is done in subroutine subprogram STABIL.

A good starting point in defining the upper limit to number of deck tiers is to imagine that the container stowage in the midship section is a square i.e. the number of rows of containers should be equal to the number of tiers, including deck tiers of containers. Thus, if container rows are 8 then containers are stacked 6 tiers high below deck and 2 tiers high above deck, or 5 tiers under deck and 3 tiers on deck. The proportion will be determined by the depth. If the ship is to carry permanent or water ballast or empty tiers of containers, the number of container tiers can be greater than container rows (175).

<u>First approximation to under deck capacity</u>

For large number of container ships modified cubic number (cubic number, CN x block coefficient, C_b)was fitted against the bale cubic of under deck capacity as shown in Fig. 13.4 so that container ships carrying different

Fig. 13.4 BALE CUBIC VS CUBICNO. X Cb



sizes of containers could be converted into a common denominator.

A straight line equation was of the form (47 data points)

Bale cubic capacity (hold) = $44.21 \times CN \times C_b + 148.0\ m^3$ Eq.(13.8)

There was hardly any improvement in the sum of the differences squared (an indication of the closeness of fit of data to a curve) even up to a 7th order polynomial, a straight line was adopted.

If the containers are 20' ISO standard then dividing Eq. (13.8) by one container bale cubic (20' x 8' x 8' x 0.0283 x 0.88) gives the following equation

Containers in Hold CTHLD = $1.39 \times CN \times C_b + 5$ Teu Eq.(13.9)

This equation is valid for ships with total container capacity < 2000 TEU.

For ships of total container capacity $\geq$ 2000 Teu (34 data points)

Containers in hold CNTHLD = $1.28 \times CN \times C_b + 220$ Teu Eq. (13.10)
with correlation of 0.773.

Container hold capacity for container size other than 20' ISO can easily be derived from Eq. (13.8). This is one of the main differences between this equation and those proposed earlier.

First approximation to above deck capacity

Since there is an interest in, at this stage, maximum slot capacity allowable by the hull geometry, the deck area can be represented as a function of product of length and breadth of the vessel. Table 13.3 shows the coefficients derived by dividing the actual deck container capacity per tier by length and beam of the ship, with machinery aft and machinery 3/4 aft.

Since the coefficients for ships with machinery 3/4 aft and amidships are higher than those with machinery aft, higher numbers of containers/tier can be stowed for ships with machinery 3/4 aft and amidships. Whereas the number of containers lost under deck and indicated by the shape

TABLE 13.5. Container Distribution of Some Containerships

	Below Deck										Above Deck	
	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Tier 6	Tier 7	Tier 8	Tier 9	Total	Tier 1	Tier 2
1. MANCHESTER CHALLENGE												
Actual	64	74	76	78	80	80				452	80	
Calculated	61	65	71	83	83	83				446	86	
2. CP VOYAGEUR												
Actual	69	82	84	90	90					503	108	96
Calculated	66	71	79	82	82	82				463	124	124
3. SEA WITCH												
Actual	76	96	100	108	116	116				612	158	158
Calculated	83	90	102	129	129	129				662	134	135
4. ACT												
Actual	104	118	129	129	135	139				754	190	190
Calculated	105	113	126	133	133	134				744	196	196
5. SELANDIA												
Actual	76	94	120	170	206	232	250	256	258	1662	305	305
Calculated	130	144	167	212	212	212	212	212	212	1714	280	279
6. TAEPING												
Actual	68	102	104	126	152	152	152			856	202	204
Calculated	104	111	123	135	135	135	136			879	193	193
7. JEDDAH CROWN												
Actual	42	48	52	56						198	60	60
Calculated	45	47	50	56						198	60	60
8. FIERY CROSS ISLE												
Actual	54	62	68	72						256	72	72
Calculated	59	61	65	71						256	72	72
9. MANCHESTER VIGOUR												
Actual	49	49	53	55						206	55	55
Calculated	43	46	51	58						198	59	59
10. EUROLINER												
Actual	84	88	140	170	194	206	206			1088	270	274
Calculated	123	134	154	193	193	194	194			1185	224	225
11./												

TABLE 13.5 (Contd.)

11. CALIFORNIA STAR												
Actual	58	84	91	109	125	129				596	157	157
Calculated	83	90	101	114	115	115				618	148	148
12. DART AMERICA												
Actual	114	144	156	169	181	187	189			1140	196	196
Calculated	123	133	148	172	172	172	173			1093	221	221
13. ATLANTIC MARSIELLE												
Actual	77	90	94	98	110					469	120	120
Calculated	82	87	95	98	110					485	111	111
14. ELBE MARU												
Actual	92	116	128	144	178	198	208	254	262	1580	262	262
Calculated	126	137	157	190	190	190	190	191	191	1562	273	273

coefficient, as shown in Table 13.4, is lower for ships with machinery amidships and 3/4 aft.

A containership with machinery amidships, or 3/4 aft, stores containers both in holds and on deck forward and aft of the machinery space. The aft position under deck being finer, results in more containers lost per tier. Whereas on deck the superstructure is more compact and there is more usable space aft of the ship besides housing the deck machinery. With a container ship with machinery aft under deck, capacity increases due to more containers per tier, but the space remaining after housing the deck machinery and a longer superstructure results in a lower number of containers/tier on deck.

A reasonable first estimate of the containers on deck per tier is:

$$\text{CTDCK} = 0.0355 \times L \times B - 15.0 \quad \text{Teu} \qquad \text{Eq. (13.11)}$$

with correlation of 0.96. Correlation of 1.0 being a perfect fit. Therefore maximum slot capacity CNT =

$$\text{CNTHLD} + (\text{CTDCK}) \times \text{tiers above deck} \quad \text{Teu Eq. (13.12)}$$

13.2.2. ACTUAL LOAD CAPACITY

Once the maximum slot capacity of the vessel is determined from Equation (13.12), the actual load capacity will depend on the operational parameters, i.e. draft, required initial GM and endurance of the vessel. Approximate volume of the double bottom is determined and depending on the volume required to store the oil fuel in double bottom, rest of the space can be taken up as ballast to improve the GM.

Shape coefficient (CSHAPE): shape coefficient is defined as the ratio of the total number of containers that can be carried in a ship shaped block to the total number of containers that can be carried in a rectangular block of the same dimensions as the ship's shape. The values of shape coefficient for some actual ships are given in Table 13.4. The shape coefficient suggested by Scott (58) and

Chryssostomidis (37) were found to be high particularly for ships with machinery 3/4 aft or amidships. This coefficient must be influenced by Froude number as well as the position and type of machinery. Some effort was made to express it in these terms but the correlation of shape coefficient expressed as a function of the speed length ratio $V/\sqrt{L}$ gave poor results. For machinery 3/4 aft or amidships

$$\text{CSHAPE} = 1.4805 - 0.8715 \times V/\sqrt{L_{ft}}$$ (16 data points, correlation -0.730)

For machinery aft

$$\text{CSHAPE} = 1.1788 - 0.4168 \times V/\sqrt{L_{ft}}$$ (18 data points, correlation -0.4168)

(See Appendix 4 for values of shape coefficient and container stacking characteristics of container ships). Great accuracy is not needed in determination of the shape coefficient (CSHAPE). The following values were adopted in the program and found to be adequate in predicting the number of bays and the loss in number of containers.

L_{BP} m.	$L_{BP} \leqslant 150$	$150 < L_{BP} \leqslant 175$	$175 < L_{BP} < 200$	$L_{BP} \geqslant 200$
CSHAPE	0.91	0.86	0.82	0.72

Container distribution

To calculate the vertical centre of gravity of the container cargo, distribution of the container in the hold and deck is required. This in turn requires the shape of the hull form and a procedure to estimate the number of containers in each bay along the length of the ship for every tier of containers in hold as well as on deck.

To find the number of containers stowable in holds taking into account the hull curvature from among the combinations of every conceivable principal dimensions is a difficult task. Therefore the best hull form to suit the required speed and propulsion power is prepared first and then the number of containers stowable are estimated geometrically (176). Otherwise for a standard hull form e.g. series 60 or BSRA, the container distribution is estimated (103).

However at the preliminary design stage a precise distribution of containers is not required as long as the vertical centre of gravity can be estimated fairly accurately.

Therefore the procedure adopted in the program calculates container distribution without recourse to ship's lines fairly accurately and also gives a good approximation for the vertical centre of gravity.

For a ship of given depth and beam, the number of container tiers below deck (TIERB) and the number of rows of containers athwartships (ROWS) can be determined from Fig. 13.5 and Fig. 13.6 respectively, or by calculating the double bottom height, deck plating width and taking into account appropriate allowances for container stacking.

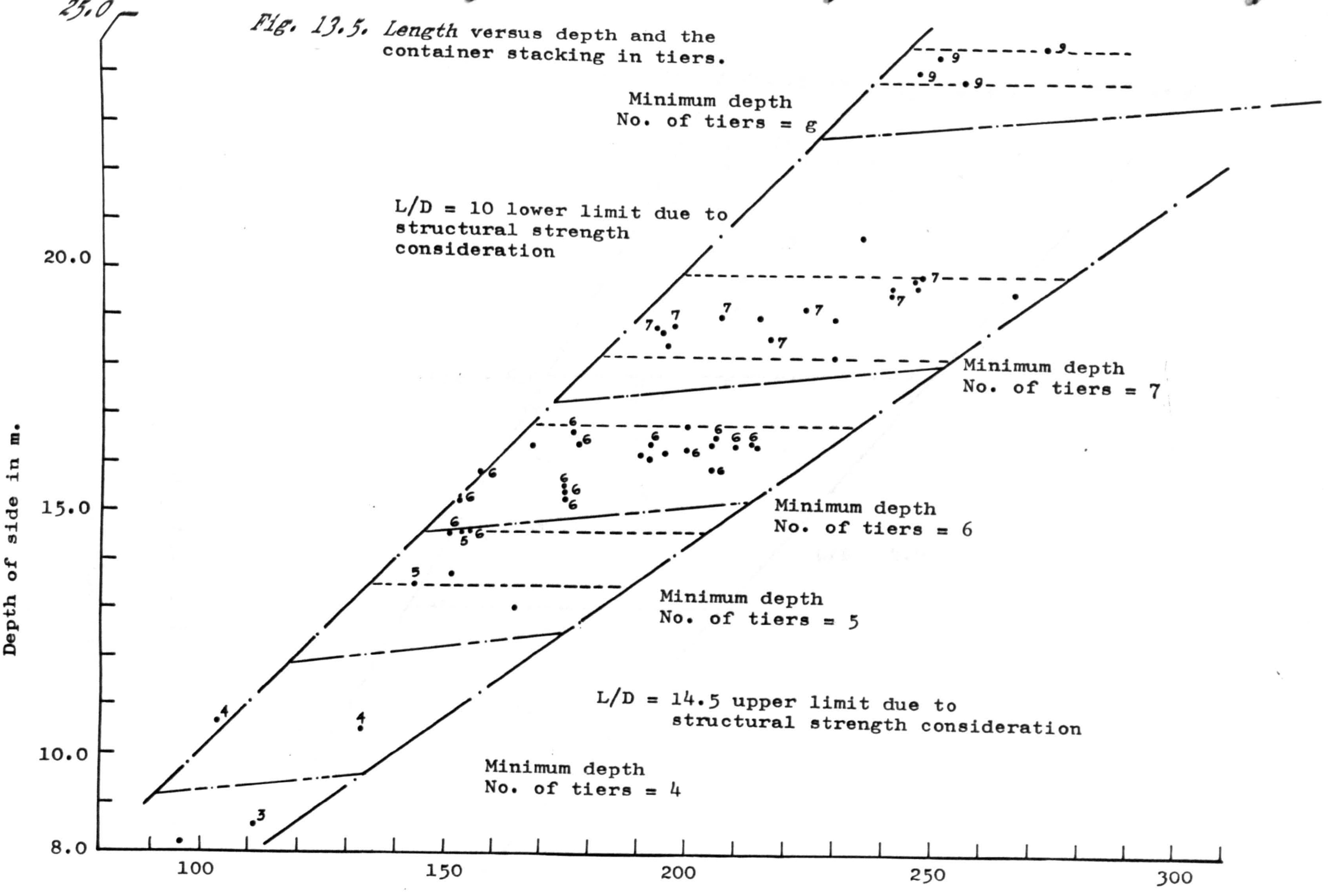
Watson and Gilfillan (35) give the ROWS and TIERB values as shown in Fig. 13.7 for a given number of containers in hold and speed.

For larger ships Buxton (15) gives ROWS x TIERB values. In the program ROWS and TIERB values are fed in as input data by the user. Various combinations of ROWS x TIERB values are possible, the most economic one is chosen. The number of rows (ROWS) can be varied from 6 to 10 and number of tiers under deck (TIERB) can be varied from 5 to 9. The number of tiers on deck (TIERA) are initially assumed to be 4. If CNT Eq. (13.12), is the number of containers to be accommodated, then the container bays (BAYS) is estimated by Eq. (5.14,5.15) Section 5.4.

The total number of containers lost due to hull shape (NCLOST) = CNRI - CNT

Further it is assumed that,

Fig. 13.5. *Length* versus depth and the container stacking in tiers.



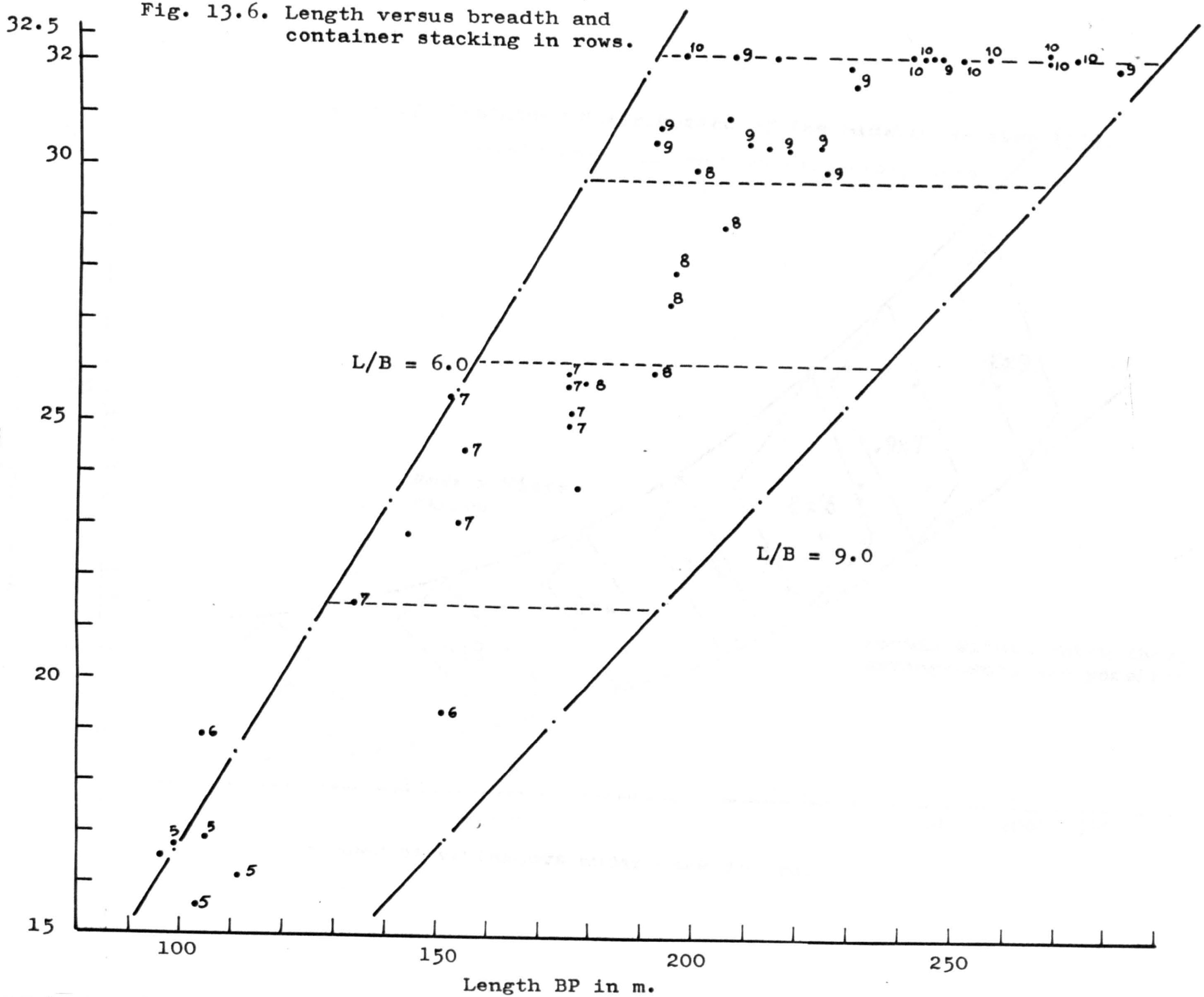
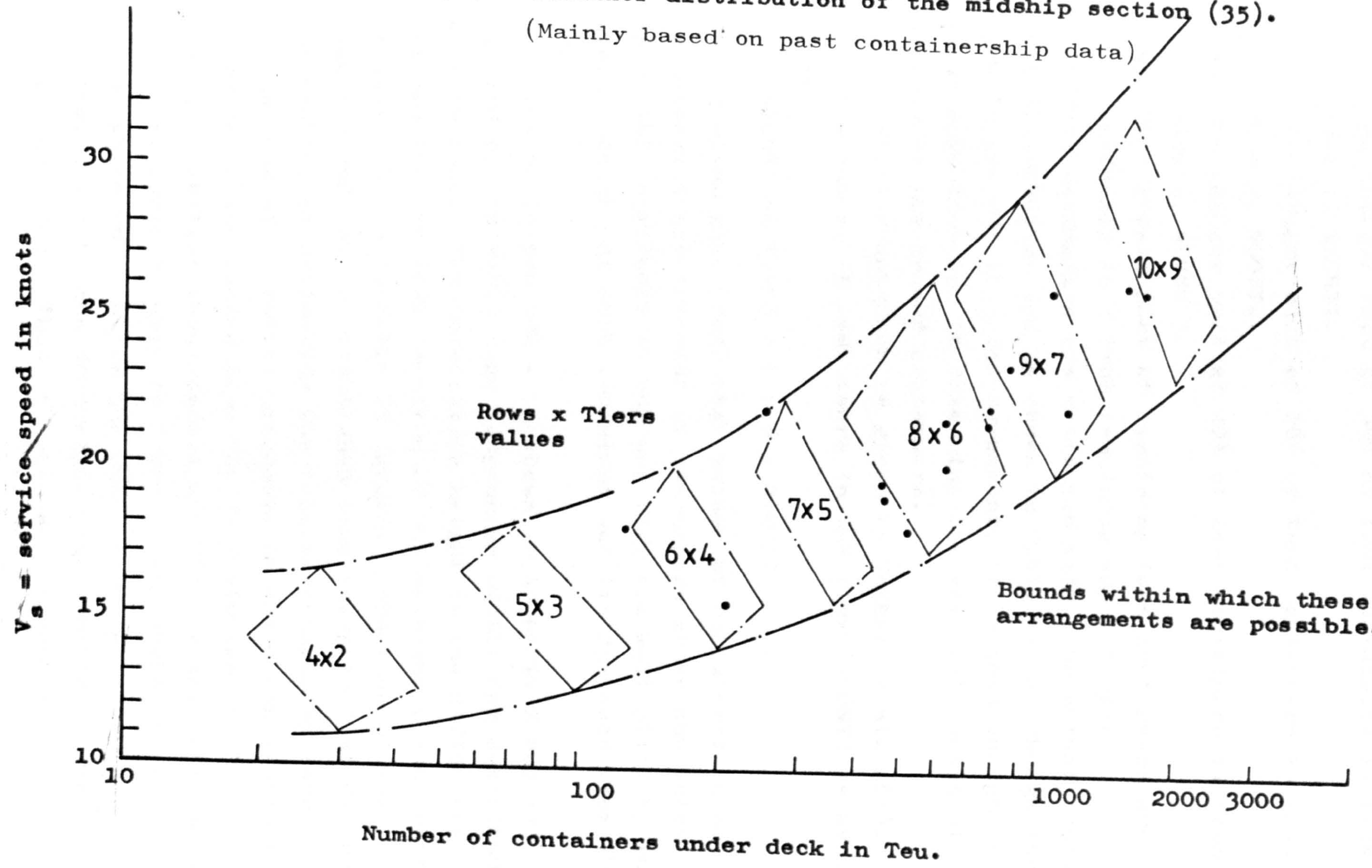


Fig. 13.6. Length versus breadth and container stacking in rows.

Fig. 13.7. Container distribution of the midship section (35).

(Mainly based on past containership data)



(i) The integer part of 30% of lost containers is from tier 1, NLOST1.

(ii) The integer part of 26% of lost containers is from tier 2, NLOST2.

(iii) The integer part of 20% of lost containers is from tier 3, NLOST 3.

(iv) The integer part of remaining lost containers are uniformly lost from remaining upper tiers.

This assumption was validated with some actual container ship distribution and is shown in Table 13.5. Though the results are not in close agreement, it is good enough as a first approximation to determine the vertical centre of gravity of the loaded containers.

A simpler approach is given by Volker et al. (61).

The number of containers in one tier (NCONT) is assumed to be

NCONT(one tier) = L x B x 0.0352 Teu

The equation gives very high values of containers in one bay. To determine the movement of containers above and below deck, the containers in bay per tier are multiplied by the average weight of each container and its distance from the keel.

The whole procedure is shown in Appendix 2 and is carried out in subroutine subprogram STABIL and described briefly here. The metacentric height is the difference between the vertical location of the metacentre and centre of mass. The metacentre is largely a function of hull geometry and can be established from the principal dimensions. The problem of estimating the container capacity then becomes one of iterative procedure in which containers are added to or subtracted from the deck stowage until the minimum stability requirements are met. A ship with maximum stability would be able to increase the number of container tiers, which would allow the hull to be shortened within the limits set by the deadweight requirements or draft limitations (36). Thus to maximise the number of containers that could be carried on deck the deadweight moment must be maximised without impairing the ship's operational qualities.

(i) The moment contribution of miscellaneous weights (WTMISC) (Section 8.2.2) is,

$$\text{FMMISC} = \text{FKGMX} \times \text{WTMISC} \quad \text{m. tonnes} \quad \text{Eq. (13.13)}$$

where FKGMX the vertical centre of gravity of miscellaneous items (see Section 8.2.2).

(ii) Moment of the oil fuel in the double bottom (FMFB)

$$\text{FMFB} = \text{FKGFB} \times \text{WFB} \quad \text{m. tonnes} \quad \text{Eq. (13.14)}$$

for weight and centre of gravity see Section 8.2.3.

(iii) Moment of the oil in settler tank (FMFD)

$$\text{FMFD} = \text{FKGFD} * \text{WFD} \quad \text{m. tonnes} \quad \text{Eq. (13.15)}$$

for weights and centre of gravity see Section 8.2.3.

(iv) Moment of ballast if required

$$\text{FMBAL} = \text{BALAST} * \text{FKGBAL} \quad \text{m.tonnes} \quad \text{Eq. (13.16)}$$

for weight and centre of gravity see Section 13.2.2.5.

(v) Moment of lightship weight

$$\text{FML} = \text{FKGLTW} \times \text{WTLT} \quad \text{m. tonnes} \quad \text{Eq. (13.17)}$$

for weights and centre of gravity see Section.

(vi) Moment of containers below deck is calculated as follows:
Total number of containers lost from tiers one to three

$$\text{N123} = \text{NLOST1} + \text{NLOST2} + \text{NLOST 3}$$

(See Appendix 2 for flow chart)

$$\text{Let NPLAY} = \overbrace{\text{NCLOST}}^{\text{NREM}} - \overbrace{\text{N123/(TIERS-3)}}^{\text{NREMV}}$$

If NPLAY is an integer, it represents the number of containers lost from each of the remaining tiers, i.e.

tier 4, tier 5 ......tier (TIERS-1), tier(TIERS)

If NPLAY is not an integer, the integer part of NPLAY represents the number of containers lost from tier 5, tier 6 tier(TIERS) and the number of containers lost from tier 4, NLOST4 is given by

$$\text{NLOST4} = \text{NPLAY} + \text{NREM} - \text{NREMA}$$

where NREMA is the integer part of NPLAY multiplied by NREMV. The number of containers (CONT(I), I = 1, TIERS) is now determined as follows:

$$\begin{aligned}
CONT1 &= ROWS \times BAYS - NLOST1 \\
CONT2 &= ROWS \times BAYS - NLOST2 \\
CONT3 &= ROWS \times BAYS - NLOST3 \\
CONT4 &= ROWS \times BAYS - NLOST4
\end{aligned}$$

The remaining layers of the number of containers in tier 5 to TIERS is given by

$$CONT = ROWS \times BAYS - NPLAY$$

Number of containers in the hold and deck is then given by.

$$CTHLDA = CONT1 + CONT2 + CONT3 + CONT4\ (TIERS-4)$$

$$CTDCKA = CNT - CTHLDA$$

This assumed number of deck containers is checked against the number of containers calculated by Eq. (13.11) termed as CTDCKC.

If CTDCKC the calculated number of containers is greater than the assumed number of containers given by CTDCKA, then the number of containers lost per layer is increased until the difference between the calculated number of deck containers and the assumed number of deck containers is less than five. Similarly if the CTDCKC is less than CTDCKA, the containers lost per layer is decreased until the difference between them is less than five containers.

If the containers in the 4th tier are greater than the containers in the 5th and subsequent tiers, the hold container capacity is

$$CTHLDC = CONT1 + CONT2 + CONT3 + CONT4 + CONT \times (TIERS-4)$$

otherwise

$$CTHLDC = CONT1 + CONT2 + CONT3 + CONT4B \times (TIERB - 3.0)$$

where containers in the subsequent tiers 4, to TIERB is given by

$$CONT4B = \frac{CONT4 + CONT \times (TIERB - 4)}{(TIERB - 3)}$$

The lever arm for first tier of containers is

ARM1 = BASE + CH/2.m, where CH = container height, assumed in the program as 2.4384 m. and the subsequent levers, ARMI = ARM1 + 2.4384 m. and BASE = double bottom height, Eq. (5.7) + Centre strake thickness, Eq. (5.8) + doubler thickness (25 mm).

The moment of containers in each tier is then

CMBT = container each layer (CONT1) x weight of each container (WEC) x the lever arm (ARM1) tonnes m. and the total moment of containers below deck (CMB) is the summation of all these moments.

Moment of containers above deck.

The lever arm (ARMA) is given by

$$ARMA = BASEA + \left(\frac{TIERA \times CH}{2}\right) \quad m.$$

where container height CH is 2.4384 m; TIERA = number of tiers of containers above deck and BASEA is given by

BASEA = Depth at side (D) + Camber (Section 5.3(d)) + Height of hatch coaming (Section 5.3(e)) + Depth of the hatch cover (Table 5.4, assumed to be 500 mm) m.

The moment of containers above deck (CMA) is

$$CMA = ARMA \times CTDCKC \times WEC \quad \text{tonnes m.}$$

(vii) The total moment of containers above and below the deck (FMC) is the sum of moment below deck (CMB) and the moment above deck (CMA).

$$FMC = CMA + CMB \quad \text{tonnes m.} \qquad \text{Eq.(13.18)}$$

(viii) The centre of gravity of the ship (FKG) in the loaded departure condition is

$$KG = FML(Eq.\ 13.17) + FMC(Eq.\ 13.18) + FMMISC(Eq.13.13) + FMFB(Eq.\ 13.14) + FMFD(Eq.13.15) + FMBAL(Eq.13.16) \ m \qquad \text{Eq.(13.19)}$$

the centre of buoyancy above the keel (KB) and the distance of the transverse metacenter from the centre of buoyancy (BM_T) is approximated by (86, 177, 120).

$$KB = \frac{1.0 + 2.0 \times C_b}{1.0 + 5.0 \times C_b} \times T \qquad m. \qquad \text{Eq. (13.20)}$$

and $BM_T = K_T \frac{B^2}{T}$ m. Eq. (13.21)

where T = design load draft in m. and K_T may be of the form

$$\text{or } K_T = C_w(0.17\ C_w + 0.13)^2/C_B.$$

Erichsen (39) gives separate relationships for single screw and twin screw ships of KB and BM_T based on regression analysis of data charts of Comstock (85). At drafts other than load draft, the values of KB and BM_T are given by Volker (61). Validity of the equations given by Erichsen and Volker were

$0.92 < C_m < 0.98$; $0.68 < C_p < 0.78$; $0.63 < C_b < 0.85$

In this study however, ships of block coefficient less than 0.63 were considered therefore the equations of KB and BM_T of either Erichsen or Volker could not be used.

The height of the transverse metacentre above keel KM_T is

$$KM_T = KB + BM_T \qquad m. \qquad \text{Eq. (13.22)}$$

If the value of KG is greater than the value of KM_T calculated the number of containers on deck is decreased by one and the value of KG recalculated (see Appendix 2) until the value of KG is less than the value of KM_T.

The transverse metacentric height GM_T is then given by

$$GM_T = KM_T - KG \qquad m. \qquad \text{Eq. (13.23)}$$

The required value of the transverse metacentric height *GM_r, which is fed in as an input data is compared with GM_T. An iterative procedure is followed whereby the number of containers on deck are incremented or decremented by one until the difference between the required metacentric height GM_r and the calculated GM_T is less than 0.02 m. This then gives us the total container capacity of a container ship in the loaded departure condition.

The subroutine subprogram STABIL was validated with some actual ship data, for which the operational data, container distribution, some hydrostatic particulars and in a few cases loaded departure condition were available. The program

*The required value of GM_T is denoted by GM_r

results and the actual data are shown in Table 13.6, assuming an initial GM value of 0.15 m. The values of under deck capacity gave reasonable results. It was difficult to validate the total container capacity since operational data were not fully available. Also the deck capacity mentioned in the trade journals is really the maximum slot capacity based on available deck space whereas in the program the limiting criteria was the stability and the available deck space. Therefore no valid comparison could be made with the deck capacity.

13.2.2.1. Initial stability

As mentioned earlier in Section 13.2 containerships should be designed with homogeneous container loading at the preliminary stage. This however may lead to high GM values with the consequence of short rolling periods in operation because of non-homogeneous container load. Since the container ships carry high deck load these would be exposed to damaging acceleration forces in case the rolling period became too short (39). At the same time they must have a reasonably high GM value when being loaded or unloaded lest the container get stuck in the cell structure (39,58). These two requirements cannot be met without the use of ballast tanks and stabilisers (39). In case of container ships sailing with metacentric height of 0.3 m to 0.9 m, active stabilisers are not necessary (178,13), but passive stabilisers may be fitted. In such a case the ballast water is used to improve the stability of the vessel. It was also pointed out that selected stowage was an operational problem and at the design stage it will be adequate if sufficient ballast capacity is provided. Indeed Taggert (27), based upon an analysis of existing container ships, now in service suggests that at the preliminary design stage a GM_T/B value of equal to or greater than 0.025 should be ensured and it is reasonable to assume that an adequate operational GM_T can be maintained by filling the segregated ballast double bottom tanks as

TABLE 13.6. Container Ship Data and Program Results

		Containership Directory				From Journals						Containers on Deck				Program Results			
	Ship's Name	Cont. Max. Slot	Cont. Max. Load	Cont. U Deck	Cont. ABV Dk.	Cont. Load	Cont. U Dk	Cont. A Dk	L	B	LxB	Tier 1	Tier 2	Tier 3	Tier 4	Cont. U Dk	Cont. ABV Dk	Cont. to-tal	Tiers
1.	KASHU MARU	794	794	476	318(3)														
2.	JAPAN ACE	819	819	468	351(3)	730	496	234(2)	175.00	25.20	4410.0	129	258	387	516	449	290	739	2.0
3.	GOLDEN GATE BRIDGE	800	-	-	-														
4.	HAKONE MARU	851	851	472	379														
5.	AMERICAN MARU	716	716	488	-														
6.	ENCOUNTER BAY	1572	1269	774	798(4)	1300	770	530(3)	213.36	30.48	6503.21	184	368	552	736	656	863	1518	4.0
7.	ACT 1	1294	1294	696	598	1223	768	453(3)	205.74	28.96	5958.23	190	380	570	760	743	627	1371	3.2
8.	ELBE EXPRESS	1068	-	642	426	736	228(2)												
9.	SEA WITCH	928	-	612	316(2)	928	612	316(2)	177.34	23.77	4215.37	158	316	474	632	662	181	843	1.3
10.	MANCHESTER CHALLENGE	542	542	456	86(1)	502	452	50(1)	151.79	19.35	2937.14	80	160	240	320	447	44	492	0.50
11.	SEA FREIGHT LINER	218	218	162	56														
12.	STRIDER CLASS					299	128	171(3)	105.00	16.75	1758.75	55	110	165	220				
13.	CP VOYAGER	779	779	593	276				153.00	25.60	3916.8	108	216	324	432	462	225	687	1.8
14.	SELANDIA	2512	2300	1662	850(4)	2272	1662	610(2)	257.60	32.21	8297.30	305	610	915	1220	1714	460	2174	1.6
15.	TAEPING	1394		856	538(3)	1394	856	538(3)	192.00	30.50	5856.0	202	404	606	808	879	524	1403	2.7
16.	JEDDAH CROWN	330	330	198	-	318	198	120(2)	104.00	18.90	1965.6	60	120	180	240				
17.	FIERY CROSS ISLE					400	256	144(2)	133,60	21.50	2872.4	72	144	216	288				
18.	MANCHESTER VIGOUR					316	206	110(2)	103.10	15.55	1603.21	55	110	165	220				
19.	EUROLINER	1920				1906	1088	818(3)	224.96	30.00	6748.8	270	540	810	1080	1181	554	1735	2.5
20.	CALIFORNIA STAR	1107	1107	618	489(4)	-	618	-	178.00	25.85	4601.3	157	314	471	628	614	297	911	2.0
21.	DART AMERICA	1595	1595	1119	476(3)	-	1140	-	218.01	30.48	6644.95	196	392	588	784	1093	555	1648	2.5
22.	ELBE MARU	2024	1842	1580	-	-	-	-	252.00	32.20	8114.4	262	524	786	1048	1558	313	1871	1.1
23.	ATLANTIC MARSIELLE	-	-	-	-	-	469	240	154.70	23.00	3558.1	120	240	360	480	483	227	710	2.0

Equation of the line for 1st tier CTDCKC = 0.0355 × L*B - 15.0

Correlation = 0.9678 No. of Data Points = 17.

bunkers are consumed. Erichsen (39) suggests a minimum GM/B value of 0.02 whereas Scott (58) suggests a higher value of 0.04 to 0.05. The three container ship data given by Erichsen (39) and Volker (61) had the following $GM_T/_B$ values; 2 ships 0.012 and one with 0.019.

The designer can input the required value of GM_r as a fraction of the breadth of the ship. Most of the studies in this thesis are carried out with a GM_r/B of 0.03. An acceptable minimum GM_T is not solely governed by safety requirements against capsizing, since adequate allowance for the operational requirements, such as a constant angle of heel in a lateral wind and the angle of heel when the ship is turning (172), and also reasonable values of GM_T while loading and unloading must be made. Taking these factors into consideration a higher initial GM_T was stipulated.

13.2.2.2. Statical stability

In spite of the relatively small GM_T values and large heeling moments caused by lateral wind pressure, container ships have a wide range of stability on account of their large freeboard. Albert (173) shows that even with a negative GM of 60 cm in Beaufort 12 weather conditions the large freeboard present in a containership will allow the vessel to survive.

Statical stability is calculated in the subroutine subprogram CROSSC. A set of linear equations developed by Kupras and Majewski (179) are given in the form of diagrams for displacement force lever KN.

The displacement force lever is expressed as a function of the ship's main particulars,

$$KN \sin \theta = \text{function}(B, T, D, W, C_b)$$

where W = the mean sheer, (sheer aft + sheer 'ford)/2. On the basis of the diagrams published by Kupras and Majewski (179), Kupras (48) carried out regression analysis and the following relationship between the displacement force lever and the ship's main particulars was suggested (see Fig. (A)).

$$KN'_{\theta} = KN \sin\theta = (A_{11} + A_{21} \times C_b + A_{31} \times \frac{W}{B} + A_{41} \times \frac{D}{B} \times A_{51} \times \frac{B}{T}) \times \frac{B}{20} \text{ m.} \quad \text{(Eq. 13.24)}$$

$$KN'_{\theta} = 1.025(A_1 + A_2 \times C_b + A_3 \times \frac{W}{B} + A \times \frac{D}{B} + A_5 \times \frac{B}{T}) \times \frac{B}{20} \text{ m.} \quad \text{(Eq. 13.25)}$$

The sets of coefficients A_1 to A_5 are given in Table 13.7. Once the values of KN'θ are known GZ at various angles of heel are calculated by

$$GZ = KN_{\theta} - KG \sin\theta \text{ m.} \quad \text{Eq. (13.26)}$$

Equation (13.25) is valid only for full load draft (design draft), ships with series 60 hull form with parabolic sheer but superstructures are not included.

The following conditions for statical stability were checked in accordance with the Load Line Rules (49).

(a) Area under the GZ curve from 0^{o} to 30^{o} should be greater than 0.055 metre radians.

(b) Maximum GZ should be greater than 0.20 m. and should occur at an angle more than 30^{o}.

(c) Area under the curve up to 40^{o} should be greater than 0.09 metre radians.

(d) Area under the curve between 30^{o} and 40^{o} should be greater than 0.03 metre radians.

(e) Initial GM_T should not be less than 0.15 m.

If any of these constraints are violated the program indicates this by printing out an error message.

13.2.2.3. Influence of draft

As the container ship design draft is less than that permissible by minimum Type-B freeboard, the containers on deck decrease with higher draft for the same initial GM_T but the average weight of each container increases. The form of the curve, see Fig. 13.8, is similar to the one

TABLE 13.7. Values of coefficients at various angles.

θ in degrees		A_1	A_2	A_3	A_4	A_5
10	D/B < 0.58	0.004	-	-	2.5	-0.004
20		-0.305	-	0.1333	5.0	0.1
30		-1.641	0.1	0.6467	7.3	0.65
40		-2.815	-0.2	1.1333	9.25	1.1
50		-3.0325	-0.3	1.6	10.375	1.23
60		-2.4045	-0.5	2.0	11.125	1.036
10	0.58≤D/B<0.62	0.671	-	-	1.35	-0.004
20		0.0876	-	0.1333	4.625	0.1
30		-2.192	-0.1	0.6467	8.25	0.65
40		-3.83	-0.2	1.1333	11.00	1.1
50		-4.1925	-0.3	1.6	12.375	1.23
60		-3.492	-0.5	2.0	13.000	1.036
10	D/B ≥ 0.62	1.043	-	-	0.75	-0.004
20		1.3385	-	0.1333	2.325	0.1
30		-0.301	-0.1	0.6467	5.2	0.65
40		-2.28	-0.2	1.1333	8.5	1.1
50		-2.5525	-0.3	1.6	10.375	1.23
60		-2.407	-0.5	2.0	11.25	1.036

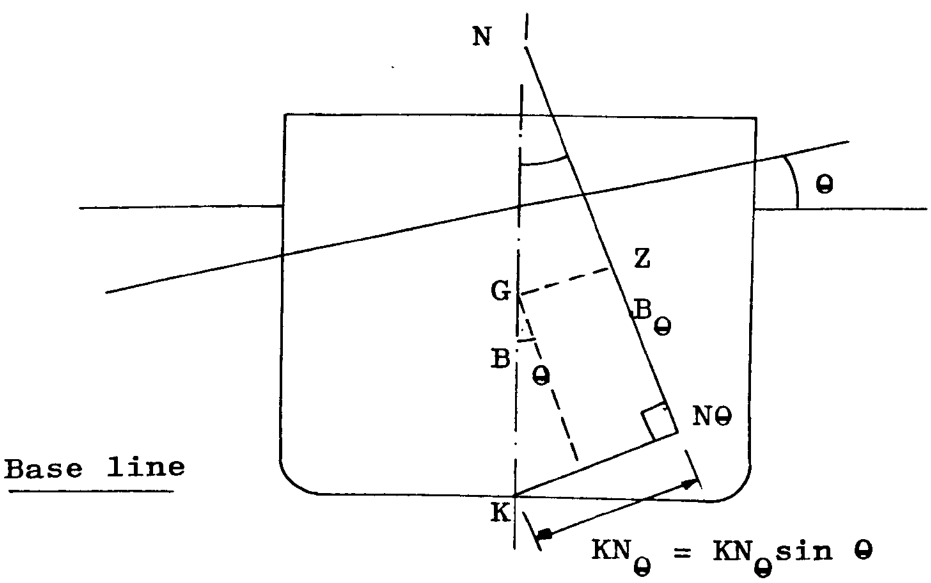
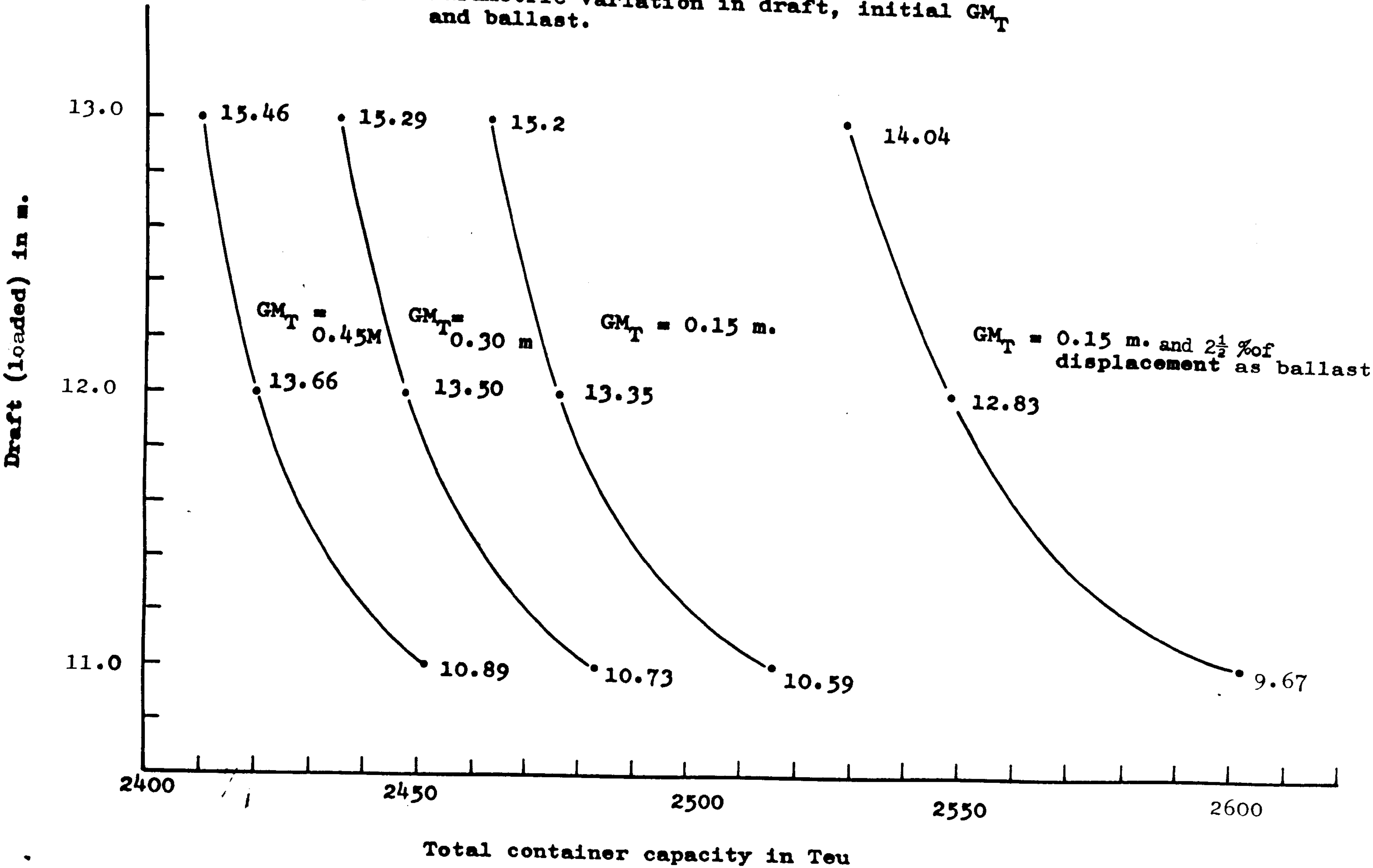


Fig. A

Fig. 13.8. Parametric variation in draft, initial GM_T and ballast.



shown in Fig. 13.2. Area under the GZ curve also increases as the draft decreases, because the freeboard increases thereby improving the area under the GZ curve (Fig. 13.9). Therefore by decreasing the draft a higher number of deck containers can be loaded but with lower average weight of each container.

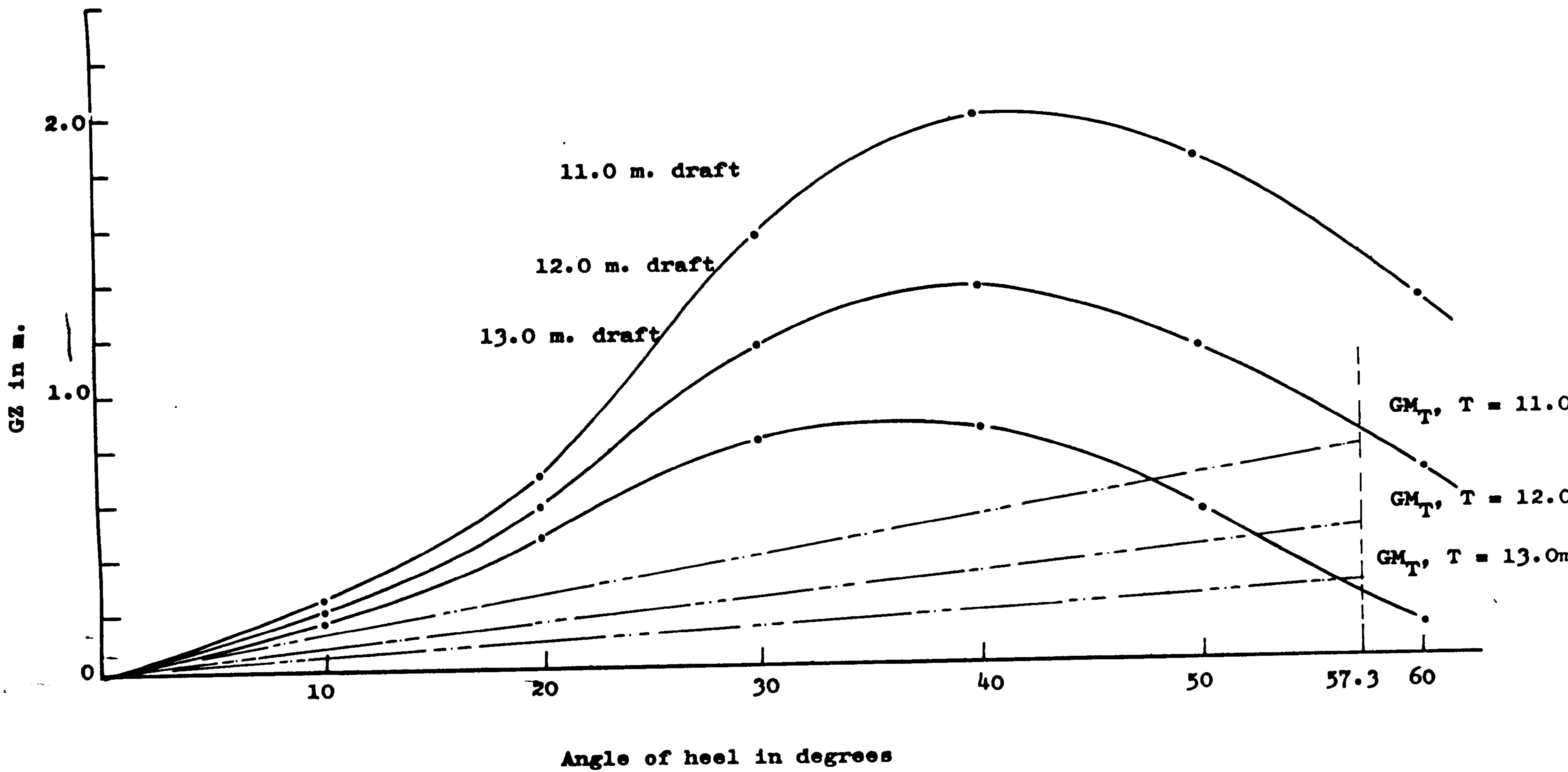
13.2.2.4. Influence of GM_T

Initial GM_T was increased to 0.30 m. and 0.45 m. from 0.15 m. The effect is shown in Fig. 13.8. As the initial GM_T is increased the container capacity decreases and the decrease with GM_T of 0.15 m. to 0.30 m. and from 0.30 m. to 0.45 m. is of the same magnitude. Moreover, this decrease is more or less constant with variation in draft. However the average weight of each container at corresponding draft increases with increase in GM_T.

13.2.2.5. Influence of adding ballast

As mentioned earlier, one way of improving the stability of the ship was to increase the metacentric height by increasing the beam. However, as the container ship becomes larger, the beam is restricted, for example, ships transiting through the Panama Canal have limiting beam of 32.26 m. Since transverse metacentre is largely governed by the hull geometry and the centre of gravity is a function of the disposition of the weights, the only way to improve the transverse metacentric height GM_T is to lower the centre of gravity of the ship. This can be achieved by adding ballast to the double bottom spaces. Erichsen (39) suggests a ballast weight of $2\frac{1}{2}$ % of displacement for container ships. As shown in Fig. 13.8, with ballast a container-ship can increase considerably its container carrying capacity. However the average weight of each container is less at corresponding draft compared to a ship without ballast.

Fig. 13.9. Effect of freeboard on the area under the GZ curve.



13.3. SEAKEEPING

Seakeeping is an important consideration in the preliminary design stage. Swift (55) had studied the effect of seakeeping on container ship design, and had come to the conclusion that deck wetness and slamming constraints were important. Journee (180) considers the speed reduction due to added resistance caused by wind and waves as well as voluntary speed reductions by the Captain due to severe motions. Beukelman & Huijser (181) have used a program 'TRIAL' to determine the seakeeping qualities in the head waves of systematically varied ship hull forms of Todd-60 series. They found (181) that the following parameters in descending order of importance had major influence on the ship's seakeeping qualities.

(a) Length. (b) Speed. (c) Forebody section shape. (d) Block coefficient. (e) Position of centre of buoyancy along the ship's length. (f) Radius of gyration. These computer models incorporating seakeeping criteria are quite extensive and their use requires detailed input data of the sea states and the probability of their occurrence as well as hull form particulars, intended routes and ship's heading. The sea state information is readily available but to input to the program requires considerable effort.

Since only the principal dimensions are known at the preliminary design stage and large numbers of alternative designs are possible, use of such programs are limited.

For the preliminary design stage Aertssen (182) gives a simpler equation for predicting the percentage loss in speed with special emphasis on the relation between wind and waves. The percentage loss in speed is expressed as

$$100 \frac{\Delta V}{V} = \frac{m}{L_{BP}} + n \qquad \text{percent.} \qquad \text{Eq. (13.27)}$$

where m and n are coefficients, values of which depend on the heading and the severity of the sea. Though this equation does not require knowledge of the hull form it assumes that the frequency of occurrence of the various sea states are known. And the results are reliable only if the frequency of the various sea states are known (182), which may not be possible to predict at the preliminary design stage.

Babbage (183) proposes another equation which can be used for the preliminary design of ships for which no voyage data are available. The form of the speed power curve is usually known at the preliminary design stage. A coefficient N which completely describes the shape of this speed power curve and expressed as $N = \frac{dP}{dV} \cdot \frac{V}{P}$ is used to predict the loss in speed.
The speed loss (ΔV) is given by

$$\Delta V = N \times L_{BP}^{0.63} \times 0.03 \text{ knots} \qquad \text{Eq.}(13.28)$$

The above equation was derived by regression analysis on a limited set of data (8 ships) and therefore can be regarded as the best value only for this set of data. Unfortunately, there does not seem to be any simple approach which considers ship motions and their coupling using only the principal dimensions. Therefore as far as seakeeping was concerned it was understood that any coupling between rolling, pitching or heaving would give rise to maximum motions. And for this it was essential that at least roll, pitch and heave characteristics should be examined. Lamb (105), Baxter (184) and Kupras & de Zwaan (185) have used the following expressions for calculating the natural periods of Roll, Pitch and Heave.

$$T_{Roll} = 2.0069 \times B \times ((0.13 \times (C_b \times (C_b + 0.2) - 1.1 \times (C_b + 0.2)(2.2 - \frac{D}{T}) \times (1 - C_b) + (D/B)^2))/GM_T)^{1/2} \text{ secs.} \qquad \text{Eq. } (13.29)$$

$$T_{Pitch} = (\frac{1.775}{C_W}) \times (T \times C_b \times (0.6 + 0.36 \times (\frac{B}{T})))^{1/2} \text{ secs.} \qquad \text{Eq. } (13.30)$$

$$T_{Heave} = 2.0069((T \times C_b \times (0.333 \times \frac{B}{T} + 1.2))/C_W)^{1/2} \text{ secs.} \qquad \text{Eq. } (13.31)$$

In order to prevent such extreme coupled motions, the ratios T_{roll}/T_{pitch} and T_{roll}/T_{heave} should never be equal to 2 and the ratio T_{pitch}/T_{heave} should not be equal to 1 (105, 184, 185) was assumed as a seakeeping criteria in the program. The calculation is carried out in the subroutine subprogram SEAKEP.

13.4. PARAMETRIC METHOD (COMPUTER MODEL I)

Early approaches to ship design were based on examining a few hypothetical ships over the range of interest, the calculation being done manually and the results plotted graphically to arrive at the optimum design, e.g. Benford 1957 (186) for tankers, Benford 1958 (62) for ocean ore carriers, Benford et al. 1962 (187) for iron ore ships, Mack-Forlist and Hettena 1966(188) for bulk carriers and Krappinger 1967 (154) for Great Lakes ore-carrier economics.

With the advent of computers, came the ability to study a greater number of designs than was possible by earlier manual methods. One of the first replications of the manual design techniques on computers was done by Murphy, Sabat and Taylor 1965 (189). Earlier approaches, where economic study was limited to examining a few possible designs the computer aided approach (189) extended the number of feasible designs to 1024 a factor of 100.A more interesting advancement was not the repetition of manual tasks on the computer butthat computers allowed one to do away with approximating equations due to the use of subroutines which gave better results (190), with more complex relationships.

The usual method for generating the large number of designs is by systematic variation of the independent variables by means of group of nested loops (191) with FORTRAN, 'DO' statements and searching for possible designs in a predefined feasible space. The constraints are solved either as equality constraints or as inequality constraints. Solving of equality constraints would usually require a larger number of iterations, therefore these are replaced by two inequality constraints. Such procedures have been successfully applied to design of dry cargo ships by Murphy, Sabat and Taylor, 1965; tankers, bulk carriers and combination carriers by Kuniyasu 1968 (192); bulk carriers by Gilfillan 1969 (193); oil tankers, bulk carriers, cargo liners and container ships by Cameron 1970 (86); warships by Eames and Drummond 1977 (194); general cargo by Validakis 1978 (120) and to tankers both crude and products carrier by the British Ship Research Association (195). Equal level contours for constraints and objective function is found by graphical or analytical interpolation in all these methods and displayed graphically to show the region near the optima.

In spite of the introduction of optimization techniques which allows one to automate the search procedure the parametric method has not lost its attraction. This is mainly because of the flat laxity in the region of the optimum, where large numbers of designs with required freight rate (RFR) very close to the minimum RFR are possible. At the preliminary design stage a designer is more interested in examining the region around the optimum rather than only the optimum. This is mainly because of the large number of approximating equations used in the preliminary design stage. Therefore this was the first step in building the total suite of programs containing four independent computer algorithms for preliminary design of container ships. Out of these four, two are used in the deterministic phase of the design and two in the probablistic phase of the design. In the deterministic phase, one of these computer models, henceforth designated as MODEL I uses parametric variation of the independent variables to generate large numbers of feasible designs. The designer then scans the various designs manually to locate the optimum design based on an economic criterion, here chosen as Required Freight Rate. The second computer model designated as MODEL II utilises the optimization technique to arrive at the optimum design and is described more fully in Section 13.5. The other two computer models used in the probablistic phase are designated as MODEL III and MODEL IV and are described more fully in Chapter 15.

MODEL I forms the basic building brick of the later computer models. The basic structure of MODEL I is shown in Fig. 13.10. The main program logic is shown in Appendix 2. It involves parametric variation of length, breadth, depth, draft and block coefficient. The method basically involves generating large numbers of designs from the possible combinations of L, B, T, D and C_b. The user can specify the following values of input which can expand or restrict the generation of large numbers of designs or enable a designer only to generate designs in the region of the optimum

(a) final and starting values of the block coefficient, and the step size.

(b) The number of rows and tiers.

(c) Maximum and minimum values of L/D, B/T, L/B ratios.

(d) The step sizes were for L =1.0 m, B = 0.5 m, D = 0.4 m. and T = 0.5 m.

These could be increased or decreased, but because of the simultaneous equality constraints of container capacity, initial stability criteria GM_T and weight of each container, the step width of draft had always to be kept around 0.5 m.

The explicit constraints which were considered in the program are,

(a) Circular C for certain values of C_b and $V/\sqrt{L}$ are not available, particularly for higher values of C_b and $V/\sqrt{L}$.

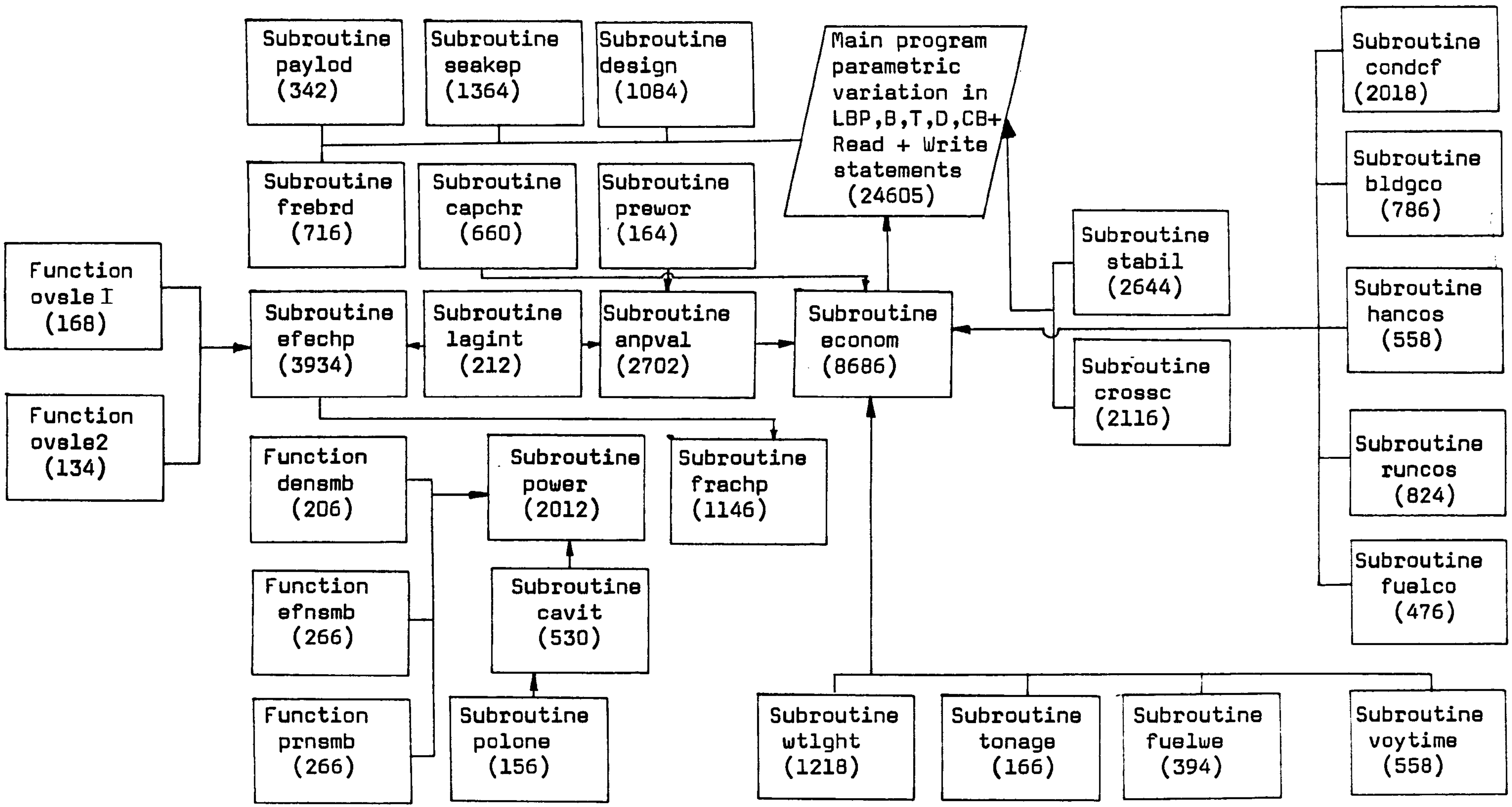
(b) Check that field efficiency is within the Bp-δ chart.

(c) The blade area ratio lies between 0.45 and 1.05.

(d) The calculated values of the container carrying capacity is within the limits of the required container capacity. In the program a tolerance limit of ± 1% was kept.

(e) The program generates design of ships with average weight/container from 8 tons to 20 tons. These values can be increased or decreased to narrow down the limits, to the specified weight of each container.

Fig. 13.10. Program structure deterministic phase with parametric variation of independent variables. (Computer Model I).



Note: Figures within brackets indicate the size of the algorithm (Total 132K).

(f) Messages are printed for designs which do not meet the seakeeping criteria and the statical stability criteria.

Implicit constraints which are satisfied by restricting the main particulars of the ship within those limits are

(a) Minimum and maximum values of block coefficient, denoted by SCB = 0.48 and FCB = 0.72.

(b) Minimum and maximum values of L/D ratio, between 10 and 14.5.

(c) Minimum and maximum values of B/T ratio, between 2.25 and 3.75.

(d) Minimum and maximum values of L/B ratio, between 6.0 and 9.0.

(e) Minimum and maximum values of $V/\sqrt{L}$ ratio, between 0.40 and 1.5.

The various subroutine subprograms, function subprograms and the main program attributes, and sizes are also shown in Fig. 13.10. There were two types of options for printing the input and the output. One was summary input and output used primarily for printing all the feasible designs and the other is an extended input and output option used only for generating designs in the region of the optimum. An extended input and output printout is shown in Fig. 13.11.

For generating about 2000 designs, for three values of block coefficient required 1500 secs. of computer time.

13.5. OPTIMISATION TECHNIQUES (COMPUTER MODEL II)

The parametric variation of principal dimensions to generate large number of designs is time consuming and expensive to run. Therefore an effort was made to automate the search procedure. Parsons (1) gives an excellent review of the existing techniques and their application to ship design in the past. Before the algorithm given by Parsons was adopted, various other algorithms were studied. These included the algorithm given by Box (196) and FORTRAN computer codes given by Kuester and Mize (197); Numerical

Fig. I3.II Input and Output by Computer Model I (Deterministic Phase)

```
0.250ALFOO.A00ALFI
4NCLPH 0.01ABALST 0.03 RGMRB
100.00OVHEAD 2.40WR214.00STLCOS169.30SINDEX15.00PROFIT
0.030STEELFO.3200UFITF
 80.00COFUEL145.00CDESL560.00CLUBCY470.00CLUBSY
 50.00CHANDL 0.68RLABD 0.39RLABF 3.30PCFD 0.70PCFF 7.60PECFD 5.60PECFF
20.0CREW 6.0PO12.00FF5300.0WCREW5400.0WPO8400.0WOFF
15.00DISCNT12.00PCINT 7.0YRLOAN
20LIFES52.0TAXPCT
120.00REVSIN2IREVLD2IBALAS 2IPMC 1IPRINT 2ISTEEL
 8LIFEC 2.50SETCNT10.00CPINT
 0.00ACONT 0.00ACMANT 0.00ACINS
 0.0AWAGES 0.0ACREW 0.0APROV 0.0ASTORE
 0.0APIINS 0.0AWHINS 0.0AADMIN 0.0ARMANT
 0.0APORT 0.0AFUEL 0.0AHANDL
                                    INPUT DATA

OWNERS REQUIREMENT          INTIAL VALUES          OPERATING COST                BUILDING COST             ESCALATICN FACTORS
CONTAINERS        = 1684.0 CONT BAYS/HOLD=    4 HANDLING/CONT    =     50.0 OVERHEAD         =100.00 CONTAINER COST          = 0.0
SPEED             =   23.00 STARTING TIERS=11.0 LAB RATIO HOME    =     0.68 PROFIT           = 15.00 CONT MAINTENANCE        = 0.0
DISTANCE          = 6766.0 FINAL TIERS     =13.0 LAB RATIO FORIEGN=    0.39 LAB WAGE RATE =  2.40 CONT INSURANCE          = 0.0
ENDURANCE         = 3383.0 STARTING ROWS = 9.0 PORT DLY COST HM=     3.30 STEEL COST       =214.00 CREW WAGES              = 0.0
FORIEGN PORTS     =     1.0 FINAL ROWS      =10.0 PORT DLY COSTFRN=     0.70 MATERIAL INDEX=169.30 OTHER CREW COST         = 0.0
HOME PORTS        =     1.0 BALLAST PERCNT= 0.0 PORT ENT/EXT HOM=     7.60 WEIGHT PARAMETERS        CREWS PRCVISION         = 0.0
PORT DELAY        =     0.0 GM REQUIRED     =0.03 PORT ENT/EXT FRN=     5.60 STEEL FACTOR    = 0.030 SHIPS STORE             = 0.0
INBOUND LOAD FAC =    0.80 CONTROL PARAMETER   OFFICER WAGE/YR = 8400.0 OUTFIT FACTOR   =  0.32 P&I INSURANCE           = 0.0
OUTBOUND LOAD FAC=    0.85 CHANGE IN RPM =    2 PETTYOFF WAGE/YR= 5400.0 MACHINERY RPM =120.00 WAR/RISKHULL INSUR      = 0.0
ECONOMIC FACTOR CONTAINER BALLAST       =    2 WAGE OF CREW/YR = 5300.0 SHIP ECONOMIC FACTOR    ADMINISTRATION          = 0.0
LIFE OF CONTAINER=         8 M/C POSITION   =    2 HEAVY FUELOIL/T =  80.00 LIFE OF SHIP   =    20 SHIP MAINTENANCE        = 0.0
NO. OF CONT SET   =     2.5 PRINT TYPE      =    1 DIESEL OIL/T     = 145.00 DISCOUNT RATE =  15.0 PORT COST               = 0.0
LOAN INTEREST     =    10.0 NUMBER OF CREW       CYLINDER LUBOIL = 560.00 LOAN INTEREST =  12.0 FUEL COST               = 0.0
STARTING VALUE CB=  0.580 NO OF OFFICER =12.0 SYSTEM LUBOIL/T = 470.00 NO OF YRS LOAN=   7.0 HANDLING COST           = 0.0
FINAL VALUE CB    =  0.580 NO OF PO        = 6.0                            TAX PERCENTAGE=  52.0
STEEL METHOD      =       2 NO OF CREW      =20.0
DESIGN NO=     1 DIMENSIONS IN METRES,WEIGHT IN TONNES  L/B= 8.42  B/T= 3.52  L/D=13.46  TIER=11.00  ROWS= 9.00  DESIGN NO=    1
LENGTH        =   265.19 TOTAL CONTAINERS=   1669  CARGO DEAD WEIGHT=13917.9 COST OF MATERIAL =0.1376E+08 TOTAL WAGES        =0.2392E+06
BREADTH       =    29.13 HLD CONTAINERS  =   1052  AVERAGE CONT WT  =     8.34 COST OF LABCUR    =0.1301E+08 CTHER CREW COSTS=0.3596E+06
DEPTH         =    18.22 DECK CONTAINERS =    617  WEIGHT OF STORES =    88.8 COST OF SHIP      =0.2799E+08 VICTUALLING        =0.3040E+05
DRAFT         =     8.27 CONTAIN ROWS    =    9.0  WEIGHT OF FUEL   =   845.4 COST OF CONT      =0.1043E+08 ADMINISTRATION     =0.4940E+05
BLOCK COEFF   =    0.580 TIERS IN HOLD   =    7.0  CONTAINER BAYS   =    21.0 CONT MAINTENANCE =0.8346E+06 P&I INSURANCE      =0.6367E+05
SPEED         =    23.00 TIERS ON DECK   =    2.6  PORT TIME IN DAYS=   14.65 CONT INSURANCE    =0.2087E+06 WAR RISK INSUR     =0.2799E+04
DISPLACEMENT= 35106.8 CG LOADED        =  11.70  SEA TIME IN DAYS =   12.26 FUELOIL COST      =0.1878E+07 HULL INSURANCE     =0.1120E+06
SHP           = 30798.6 CG OF LIGHTSHIP =  10.80  STEEL WEIGHT     =14760.5 DIESELOIL CCST    =0.2658E+06 HULL MAINTENANCE=0.5493E+05
BALAST        =      0.0 VERT CENT BOUY  =   4.58  OUTFIT WEIGHT    = 2285.5 LUBOIL COST       =0.3493E+05 M/C MAINTENANCE =0.1828E+05
SHAPE COEFF   =     0.80 MET. CENT.HT KMT=  12.57  MACHINERY WEIGHT = 1675.7 CONT HANDLINGCOST=0.1845E+07 STORE COSTS        =0.5130E+05
RPM           =   138.00 CALCULATED GM   =   0.88  LIGHTSHIP WEIGHT =20238.1 PORT DAILY COSTS =0.3194E+06 OPERATING COST     =0.5455E+07
LOAD KG/D     =    0.642 BMT              =   7.99  LIGHT KG/D       =    0.593 PORT ENTRY & EXIT=0.1304E+06 CARGOCARR./ANNUM= 307727.4
GROSS TONAGE= 31835.2 ROUND VOYTIM     =  26.91  ROUND TRIP/ANNUM =   13.01 TOTAL PORT COST   =0.4498E+06 REQD FREIGHTRATE=      45.82


DESIGN NO=     2 DIMENSIONS IN METRES,WEIGHT IN TONNES  L/B= 8.45  B/T= 3.52  L/D=13.51  TIER=11.00  ROWS= 9.00  DESIGN NO=    2
LENGTH        =   246.19 TOTAL CONTAINERS=   1679  CARGO DEAD WEIGHT=13939.3 COST OF MATERIAL =0.1380E+08 TOTAL WAGES        =0.2392E+06
BREADTH       =    29.13 HLD CONTAINERS  =   1055  AVERAGE CONT WT  =     8.30 COST OF LABCUR    =0.1307E+08 CTHER CREW COSTS=0.3596E+06
DEPTH         =    18.22 DECK CONTAINERS =    624  WEIGHT OF STORES =    88.8 COST OF SHIP      =0.2809E+08 VICTUALLING        =0.3040E+05
DRAFT         =     8.27 CONTAIN ROWS    =    9.0  WEIGHT OF FUEL   =   846.0 COST OF CONT      =0.1049E+08 ADMINISTRATION     =0.4940E+05
BLOCK COEFF   =    0.580 TIERS IN HOLD   =    7.0  CONTAINER BAYS   =    21.0 CONT MAINTENANCE =0.8397E+06 P&I INSURANCE      =0.6392E+05
SPEED         =    23.00 TIERS ON DECK   =    2.6  PORT TIME IN DAYS=   14.73 CONT INSURANCE    =0.2099E+06 WAR RISK INSUR     =0.2809E+04
DISPLACEMENT= 35249.8 CG LOADED        =  11.70  SEA TIME IN DAYS =   12.26 FUELOIL COST      =0.1874E+07 HULL INSURANCE     =0.1124E+06
SHP           = 30 00.0 CG OF LIGHTSHIP =  10.79  STEEL WEIGHT     =14864.7 DIESELOIL CCST    =0.2659E+06 HULL MAINTENANCE=0.5508E+05
BALAST        =      0.0 VERT CENT BOUY  =   4.58  OUTFIT WEIGHT    = 2294.8 LUBOIL COST       =0.3483E+05 M/C MAINTENANCE =0.1828E+05
SHAPE COEFF   =     0.80 MET. CENT.HT KMT=  12.57  MACHINERY WEIGHT = 1675.7 CONT HANDLINGCOST=0.1851E+07 STORE COSTS        =0.5130E+05
RPM           =   138.00 CALCULATED GM   =   0.88  LIGHTSHIP WEIGHT =20359.1 PORT DAILY COSTS =0.3210E+06 CPERATING COST     =0.5460E+07
LOAD KG/D     =    0.642 BMT              =   7.99  LIGHT KG/D       =    0.592 PORT ENTRY & EXIT=0.1303E+06 CARGOCARR./ANNUM= 307285.8
GROSS TONAGE= 31760.8 ROUND VOYTIM     =  26.99  ROUND TRIP/ANNUM =   12.97 TOTAL PORT COST   =0.4513E+06 REQD FREIGHTRATE=      46.03
```

Algorithm Group NAG library routines (198), E$\not{0}$4UAF; OPRQP (OPXRQP) in conjunction with OPND3 developed by Numerical Optimisation Centre of the Hatfield Polytechnic (199), flexible tolerance method (200) based on Nelder and Mead's Simplex Method (3) for which computer codes are given by Himmelblau, and Direct Search technique of Hookes and Jeeves for which computer codes are given by Kupras (201).

All these computer codes are developed for solving non-linear objective functions with non-linear as well as linear equality and inequality constraints. However except for Box's Algorithm all other computer codes could not be implemented on the ICL 2976 computer with VME-B operating system because of various reasons given below:

(1) NAG library routines can only be used in double precision. This increased the required memory space to twice the size for each of the variables. Though the routine does not require the evaluation of derivatives, it is intended only for functions and constraints which have continuous first and second derivatives.

(2) Similarly OPRQP (OPXRQP) and OPND3 also required continuity of first and second derivatives which could not be ensured, because of the large number of approximate equations used in the program needed to be tested. Moreover the source program was written for IBM machines which meant that lots of statements needed modification.

(3) FLEXIPLEX or flexible tolerance method failed to work on ICL 2976 because of either certain errors in the source program or printing errors.

(4) Better point algorithm by Kupras had computer codes only in ALGOL and therefore not accepted.

Two computer codes were therefore available, one given by Kuester and Mize (197) and the other by Parsons (1), both of which were implemented successfully on the ICL 2976 at Glasgow University Computing Centre. The computer code given by Parsons was adopted because of the following reasons.

(1) Box's algorithm is a Random Search Technique, which requires a library subroutine for generation of random numbers. Since generation of random numbers is machine dependent, implementation from one computer to another will be difficult. For ICL 2976, NAg library routine GØ5CAF was used to generate pseudo-random real numbers between 0 to 1 taken from a uniform distribution.

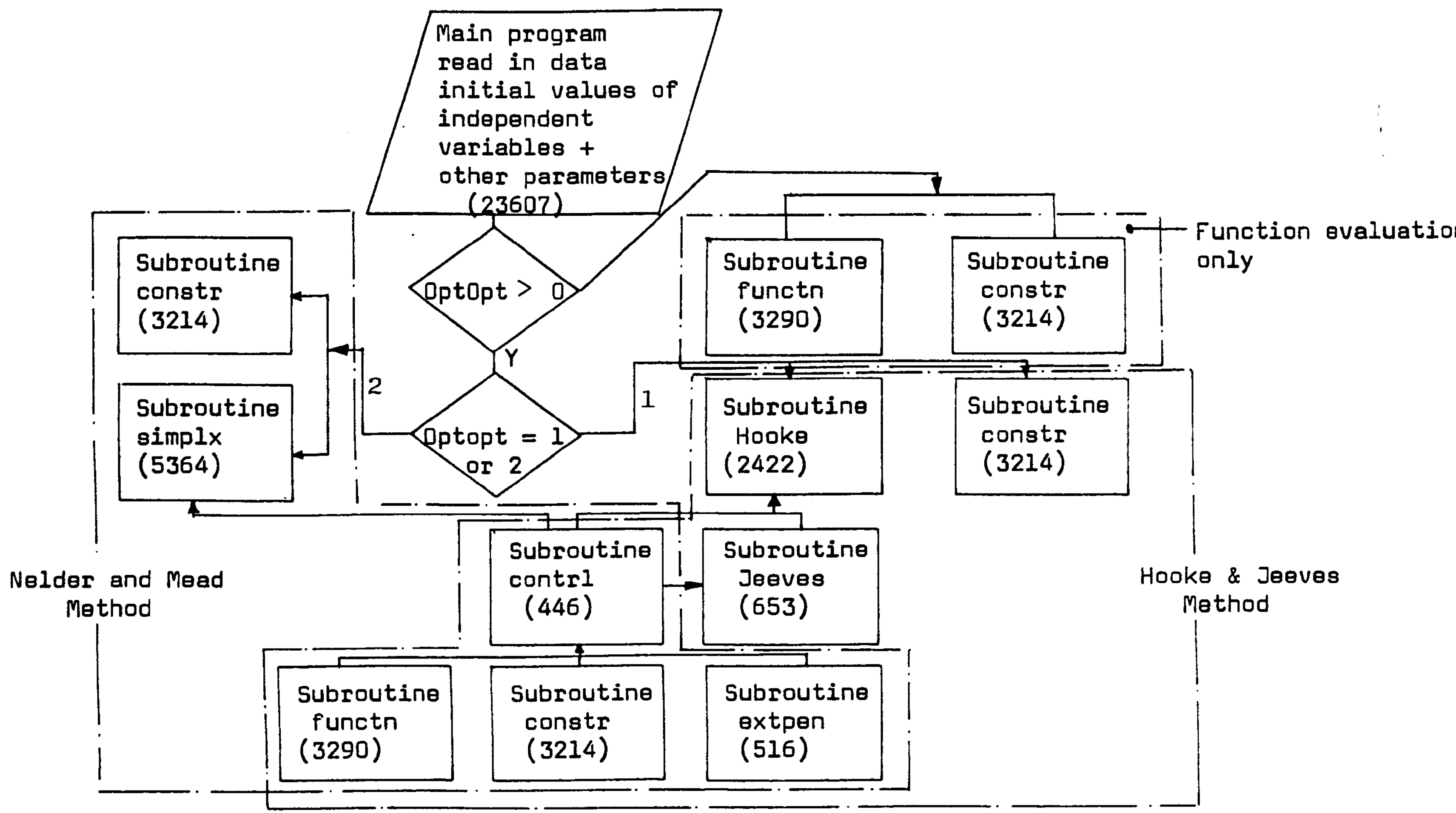
(2) The computer codes given by Parsons gives the user the option to use either Hooke and Jeeves (2) direct search or Nelder and Mead (3) simplex search with external penalty technique. Therefore if one of the optimization methods fails the other could be used.

The program structure employing Parsons' computer codes together with subroutines FUNCTN and CONSTR developed specifically for container shipsis shown in Fig. 13.12.

To use the computer codes given by Parsons the user need only supply subroutine FUNCTN and CONSTR. Except one small error in the program code i.e. the statement number 40 in subroutine Hooke is redundant, the rest of the program did not give any compilation or run time errors. The use and various functions of the subroutines are well covered by Parsons (1) and are not repeated here.

The search procedure to reach an optimum design was cut down from 1500 secs. for three block coefficient values in step sizes of 0.01 in Computer MODEL I to 200 ~ 400 secs. of computer time in Computer MODEL II. This however does not include the different starting points that must be attempted before a global optimum is reached. The parametric search procedure could only be run on a batch mode, with only limited amounts of interactive computing in the region of optimum. The optimisation technique allowed one to see the progress of the search procedure in an interactive mode. With experience, when a feel for the various possible starting values was developed, interactive computing took less than 5 minutes to arrive at the optimum. Obviously the optimisation method should be preferred once the user has

Fig. 13.12. Program structure deterministic phase with application of optimisation techniques (Computer Model II)



Note: Figures within brackets indicate the size of the algorithm. (Total 158K).

acquainted himself with the working procedure.

Optimisation techniques are criticised because it is often misunderstood as a black-box type of approach or the notion that only one optimum design is output. Print options are included in the program, which allows the user to follow the procedure quite easily and to observe which constraints are not being fully met. To observe designs in the region of the optimum the user can then use the parametric method using computer MODEL I.

CHAPTER 14

PARAMETRIC STUDY AND SENSITIVITY ANALYSIS

14.0. Introduction

In the previous chapters the various computer subprograms were described together with the methods employed, assumptions made regarding some of the variables and their testing and validation. Section 13.4 gave the basic linking of the subprograms for Computer Model I while Section 13.5 gave this for Computer Model II. These two computer models are used in the deterministic phase of the design.

Although individual subprograms may give reasonable results when used alone, tests are needed to ensure that they give reasonable results when linked together and these tests involve examining situations whose outcome is well established; such as the reduction of optimum speed with increase in fuel prices.

Sensitivity analysis is useful to indicate numerically, the gains resulting from improvement of particular variables. In particular cost and weight estimation may be improved with effort and the extent of this effort must be traded against the expected gain in the measure of merit.

This chapter shows that computer Models I and II can be used for ships of container capacity of 500 to 2500 Teu. Only nineteen container ships of carrying capacity above 2500 Teu are in operation (Table 4.8) today. Hence ships of container capacity above 2500 Teu were not included in the study, although the computer Models I and II can be used for ships of block coefficient 0.50 to 0.70 and speed length ratio, $V/\sqrt{L}$ of 0.40 to 1.5, which covers the range of speeds and powering requirements of most container ships.

Systematic variation of ship size and speed was carried out to find optimum values of these parameters. A sensitivity analysis was performed which illustrated the particular importance of steel weight estimation for container ships which are usually stability limited designs. Considerations such as certain number of calls per week to maintain a scheduled service, cargo inventory costs and cargo availability have not been included.

14.1. Systematic variation of ship size and speed

Systematic variation of ship size and speed were carried out for the following assumptions for a North Atlantic trade route of 6770 n. miles round trip.

Table A

Case	Assumption A	Assumption B		
	1	2	3	4
Dimensions of container	20' x 8' x 8'	20' x 8' x 8'6"		
Weight of empty container	2 tons	2.2 tons		
Gross weight of each container	14 t	14 t	10.5 t	7 t
Specific fuel consumption	162.0 gms/bhp.hr	135 gms/bhp hr.		
Discount Rate	15%	7 %		
Loan terms for ship acquisition	12%	0% interest		
Tax rate	52%	0%		

For case study 1 ship size was varied from a container capacity of 500 Teu to 2500 Teu in steps of 250 Teu. Ship speed was varied from 15 knots to 30 knots in steps of 1 knot. For case study 2 ship size was varied from a container capacity of 1000 Teu to 2250 Teu in steps of 250 Teu. Ship speed was varied from 15 knots to 30 knots in steps of 1 knot. For case studies 3 and 4 ship size was varied from a container capcity of 1000 Teu to 2250 Teu in steps of 250 Teu. Ship speed was varied from 15 knots to 27 knots in steps of 1 knot.

Further for case studies 2, 3 and 4 ballast of 5% of displacement and ballast of 10% of displacement were also considered.

The program only considers ballast in the double bottom and does not confirm that adequate tank space is available for ballast as well as bunkers but some spot checks indicate that there is ample provision for 5% ballast. A need for 10% ballast in all designs might impose a constraint on double bottom height although a program to incorporate ballast considerations would need to involve wing tanks.

The optimum dimensions for each ship was calculated at a particular speed. The principal dimensions of the ship together with the number of rows and tiers of container were input: Computer Model II was used in all cases to produce the results and the Nelder and Mead Search procedure option was preferred. The global solution was found by changing the initial starting point of L, B, T, D and C_b. The optimum hold arrangement was found by varying the configuration of rows and tiers, but this variation was limited to two possible configurations. There were four tiers of deck containers included in the input number of container tiers. The initial number of tiers in the hold is the total number of tiers less four. The number of deck containers are then varied in an iterative manner to meet the stability requirements.

Table B

Trial	Dimensions in metres							£/ tonne	
	L	B	T	D	C_b	Rows	Tiers	RFR	
1	210.25	29.50	11.00	20.0	0.55	9	11	-	Starting values, user
	218.71	28.63	10.45	19.56	0.552	"		42.720	Final values, computer
2	225.56	28.63	11.03	21.00	0.52	9	12		Starting values, user
	236.99	28.65	11.63	22.04	0.506	"		39.804	Final values computer

The above Table B shows the input values to achieve the optimum for a ship of container capacity 1250 Teu and speed of 29 knots. In this case the number of hold tiers will be 8 although 7 hold tiers is considered. The ship with 8 tiers in hold gives a lower value RFR. The ship with 7 hold tiers is eliminated at this speed and the global optimum found by initiating the search from three to four different values of L, B, T, D and C_b. The step sizes found adequate for the search procedure using Nelder and Mead's method were L = 5.0 m, B = 0.5 m, T = 0.5 m, D = 0.5 m and C_b = 0.3 and convergence limits were

L = 0.01, B = 0.01, T = 0.01, D = 0.01 and C_b = 0.001.

Nelder and Mead's simplex method was used throughout because the convergence to the optimum was faster compared to Hooke and Jeeves Direct Search method (see Section 13.5 for user option).

The following table shows the optimum hold configuration for various ship sizes over a range of speeds.

Table C

Container Capacity	500	750	1000	1250	1500	1750
Rows	6	7	8	9	9	9
Hld. Tiers	6	6	7	7	7	8
Container capacity	2000	2250	2500			
Rows	10	10	10			
Hld. Tiers	9	9	9			

The value of RFR for each ship size was plotted against speed as shown in Fig. 14.1 to Fig. 14.9. An important factor in the discontinuity in the curve is the jump from single to twin screw installations when the installed power is about 50000 hp.

Fig. I4.I Speed variation series for 500 Teu container ship

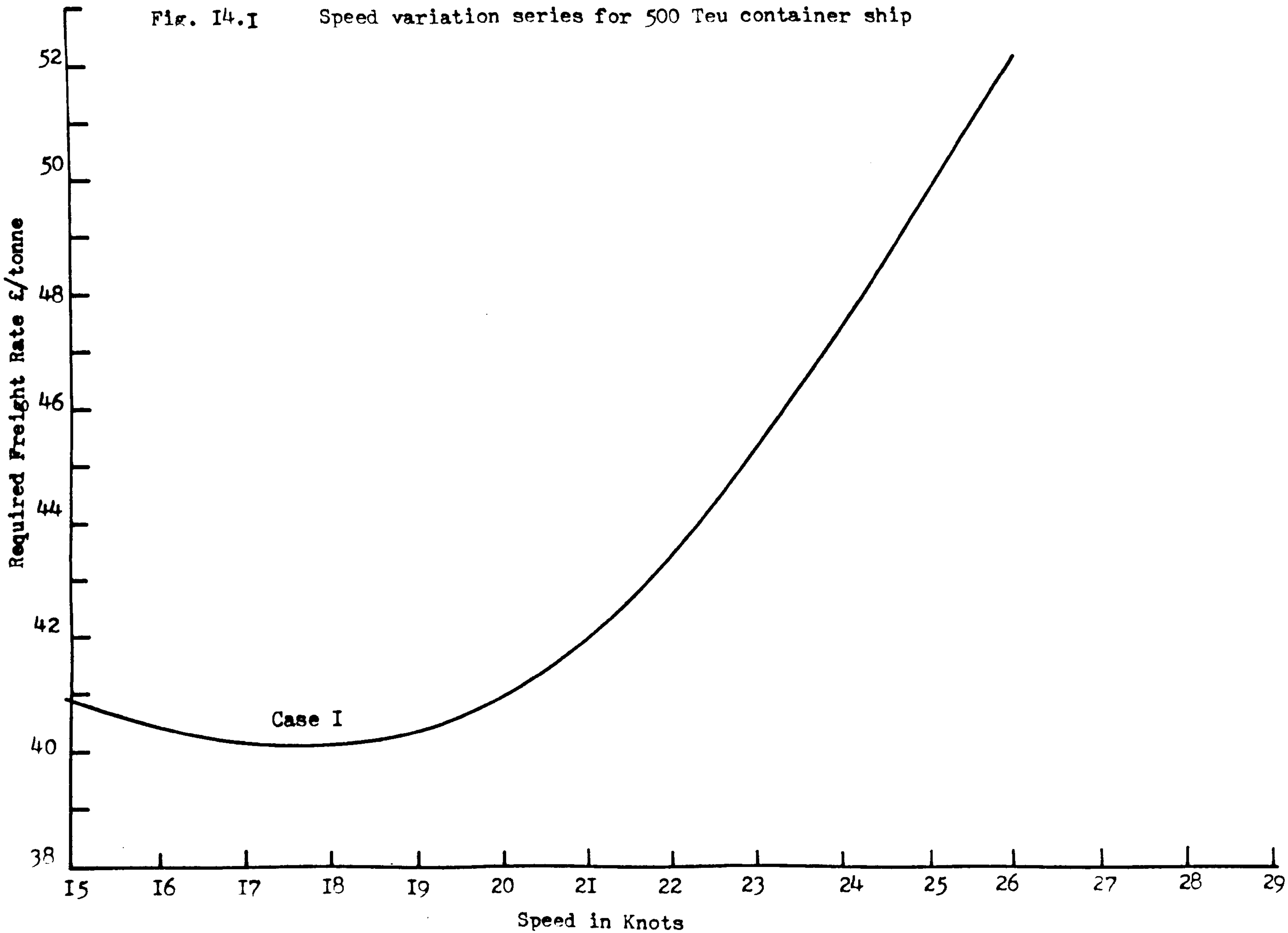
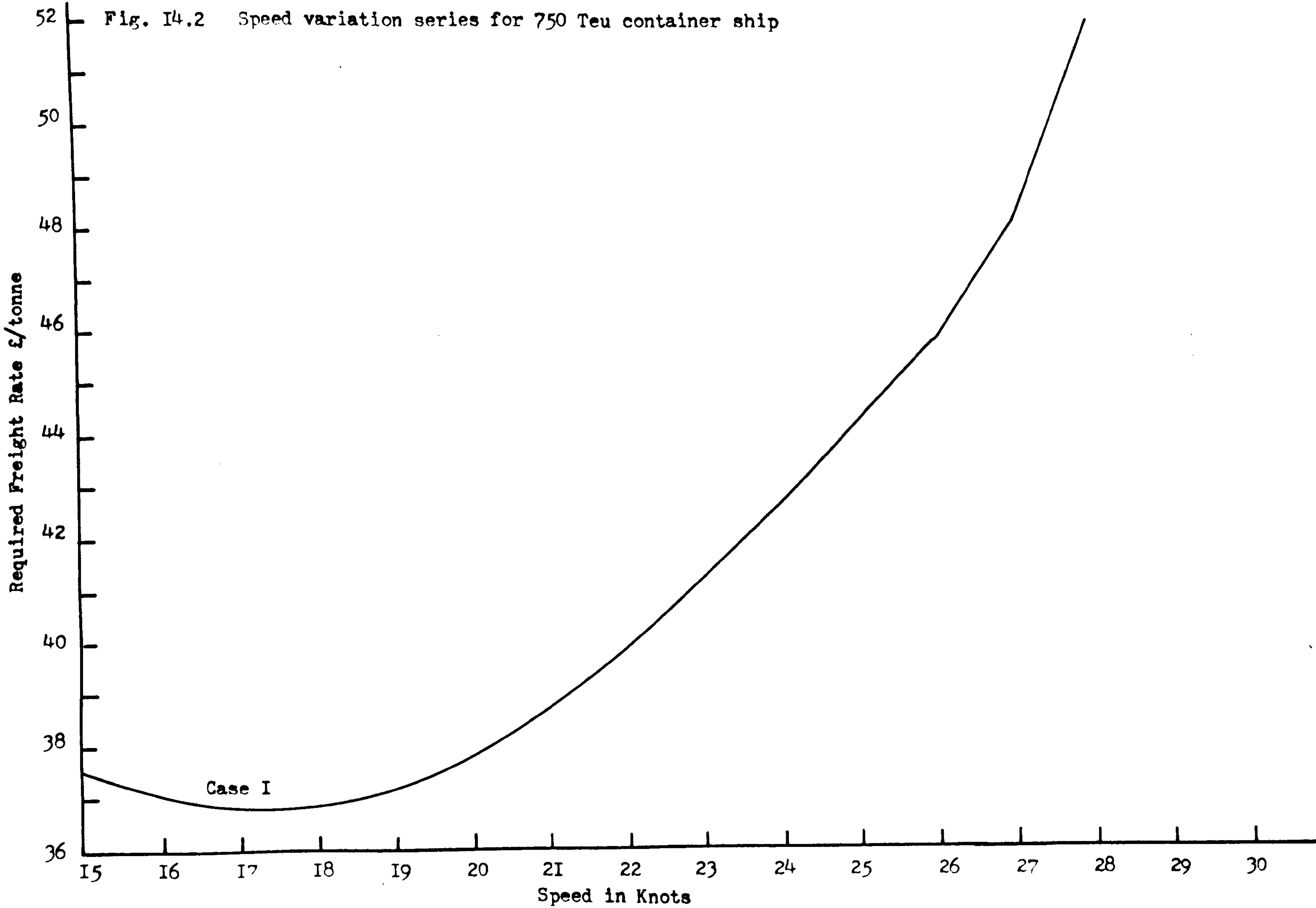


Fig. I4.2 Speed variation series for 750 Teu container ship



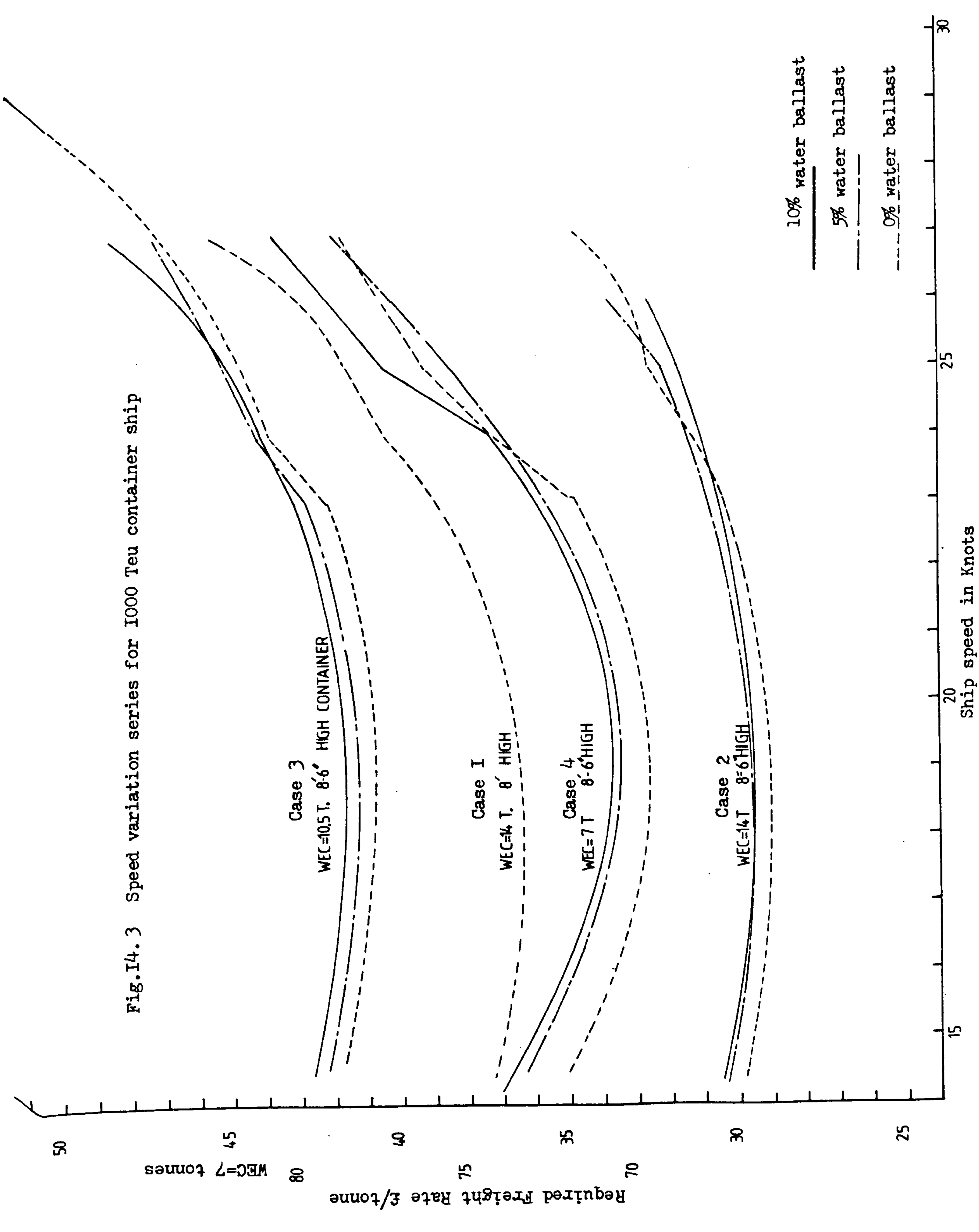


Fig.I4.3 Speed variation series for 1000 Teu container ship

Fig.I4.4 Speed variation series for I250 Teu container ship

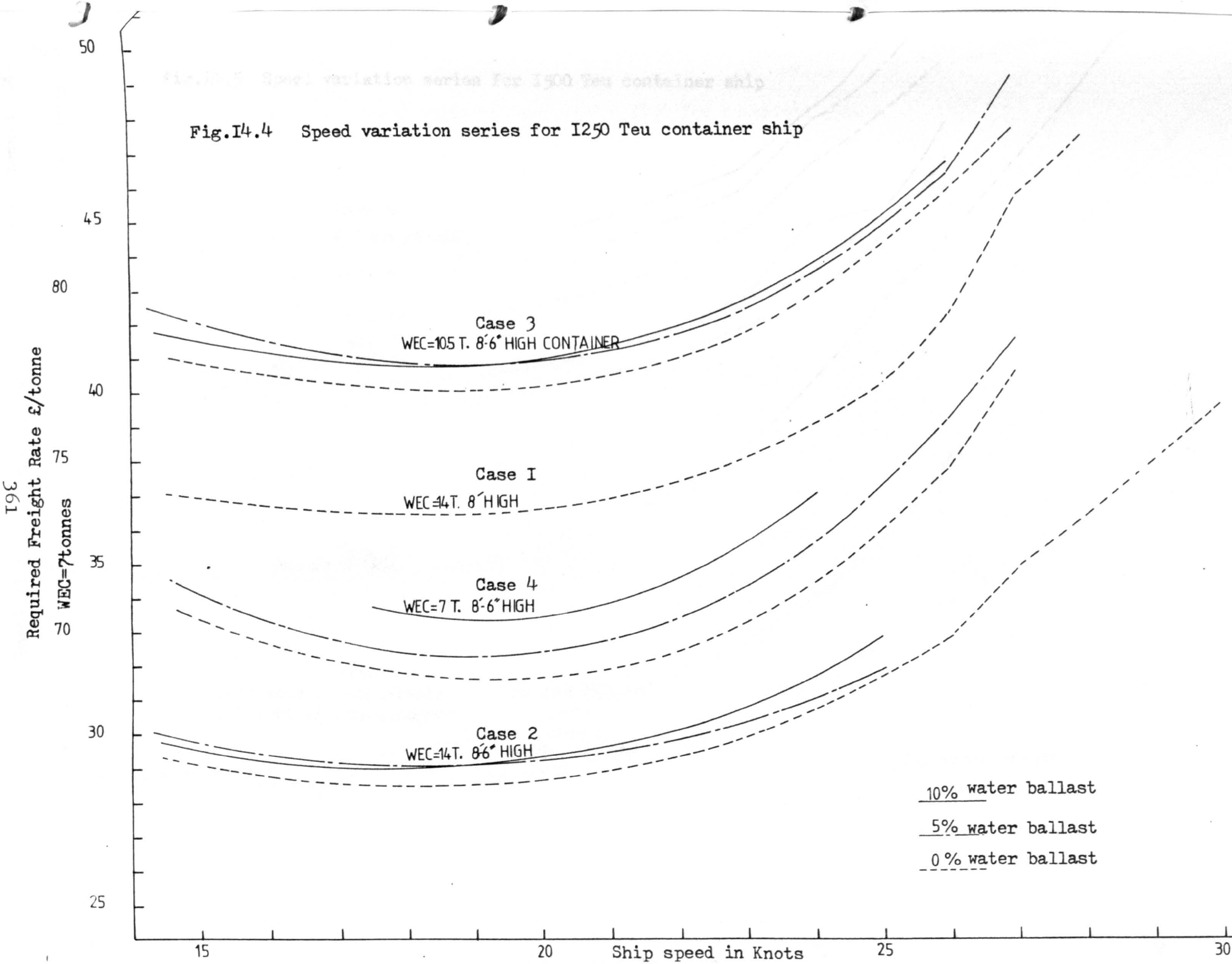
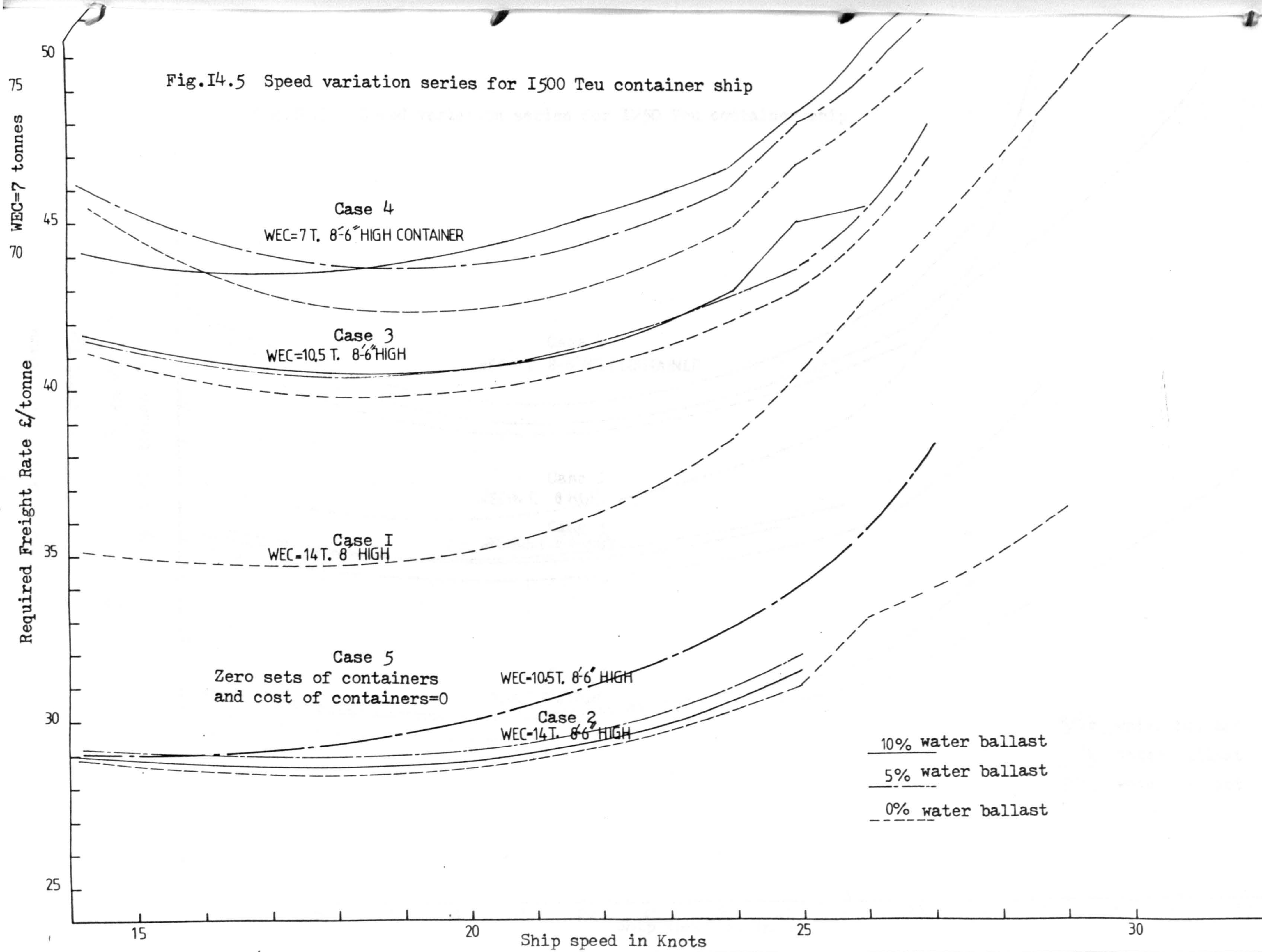


Fig.I4.5 Speed variation series for I500 Teu container ship



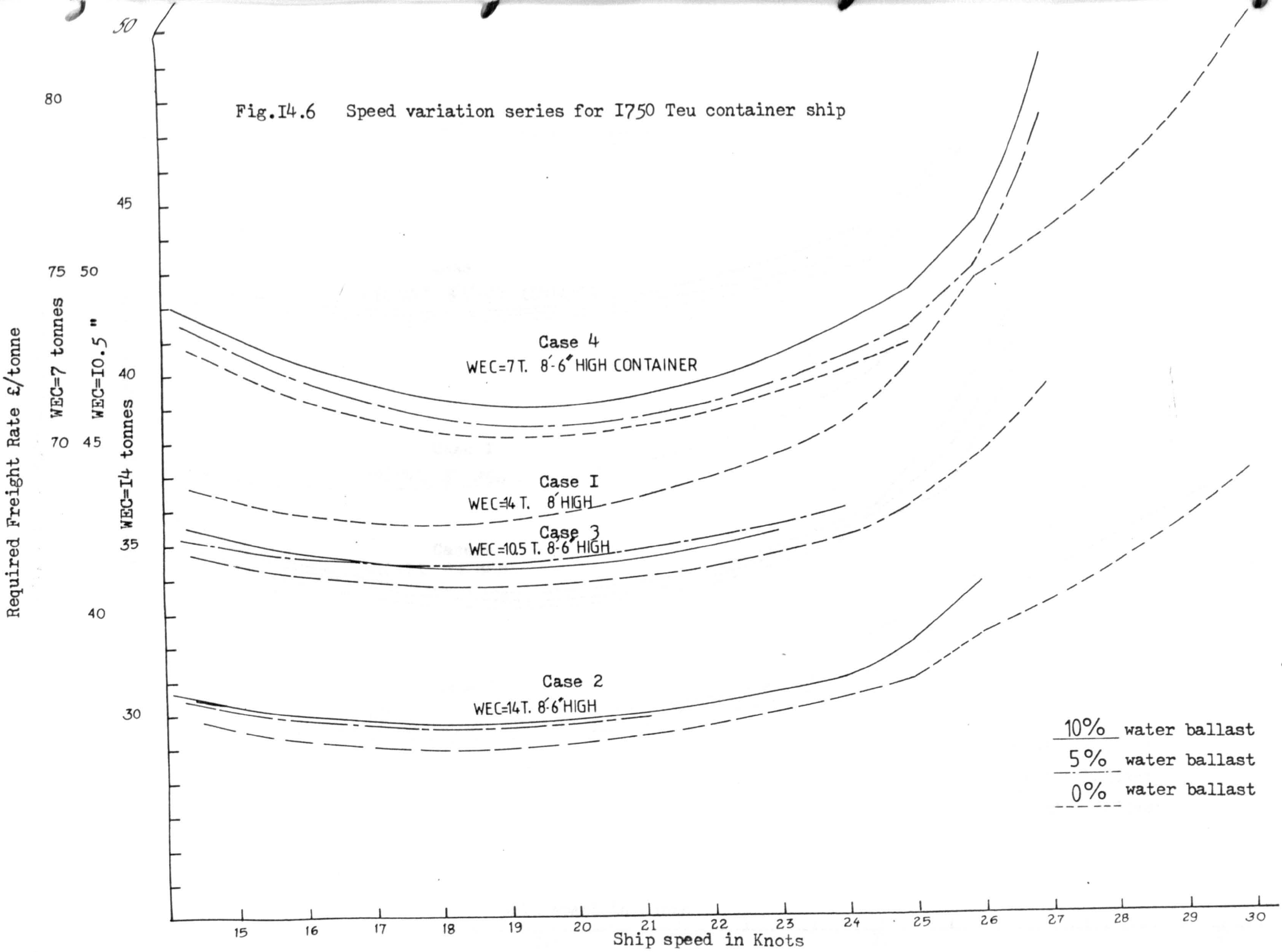
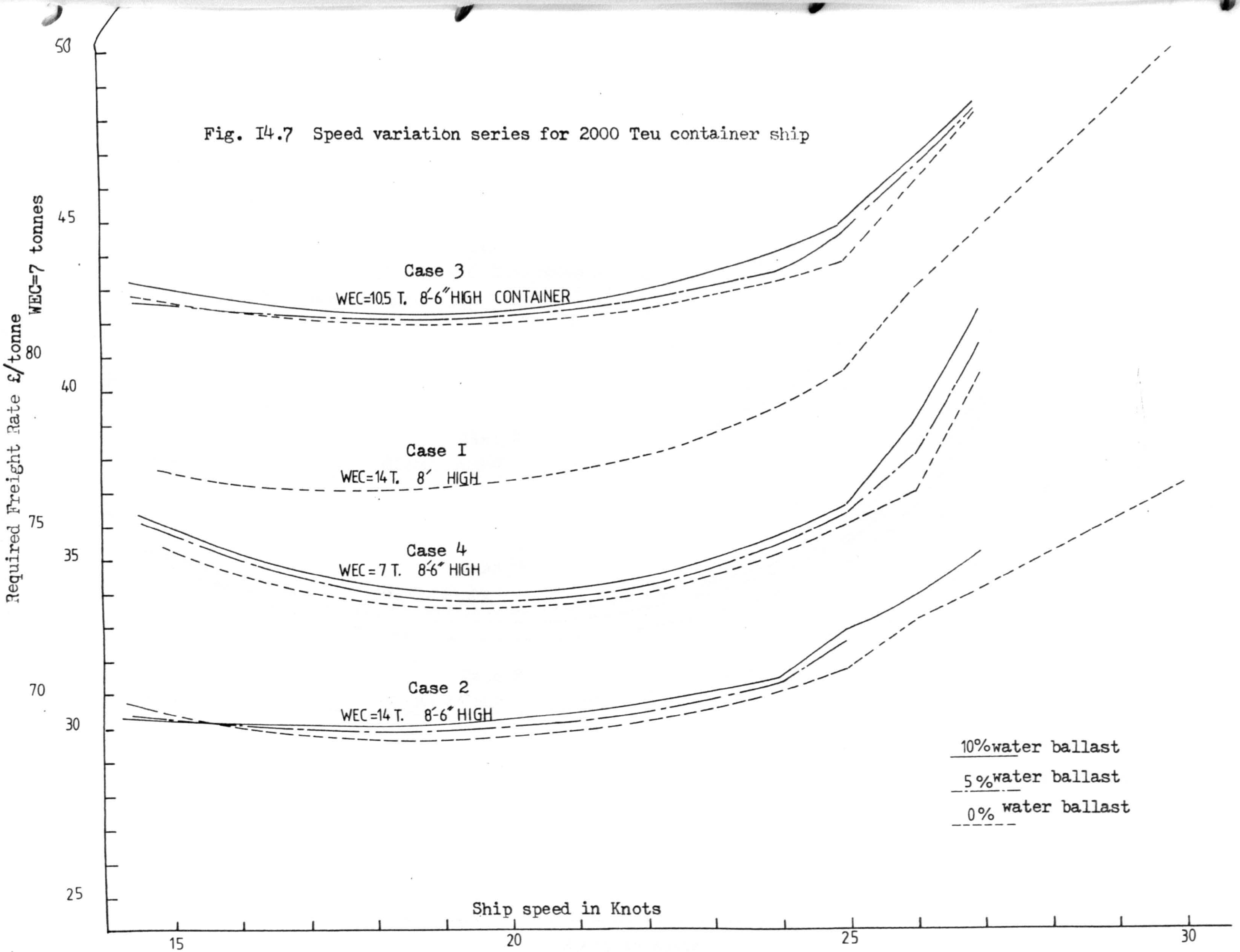


Fig.I4.6 Speed variation series for I750 Teu container ship

Fig. I4.7 Speed variation series for 2000 Teu container ship



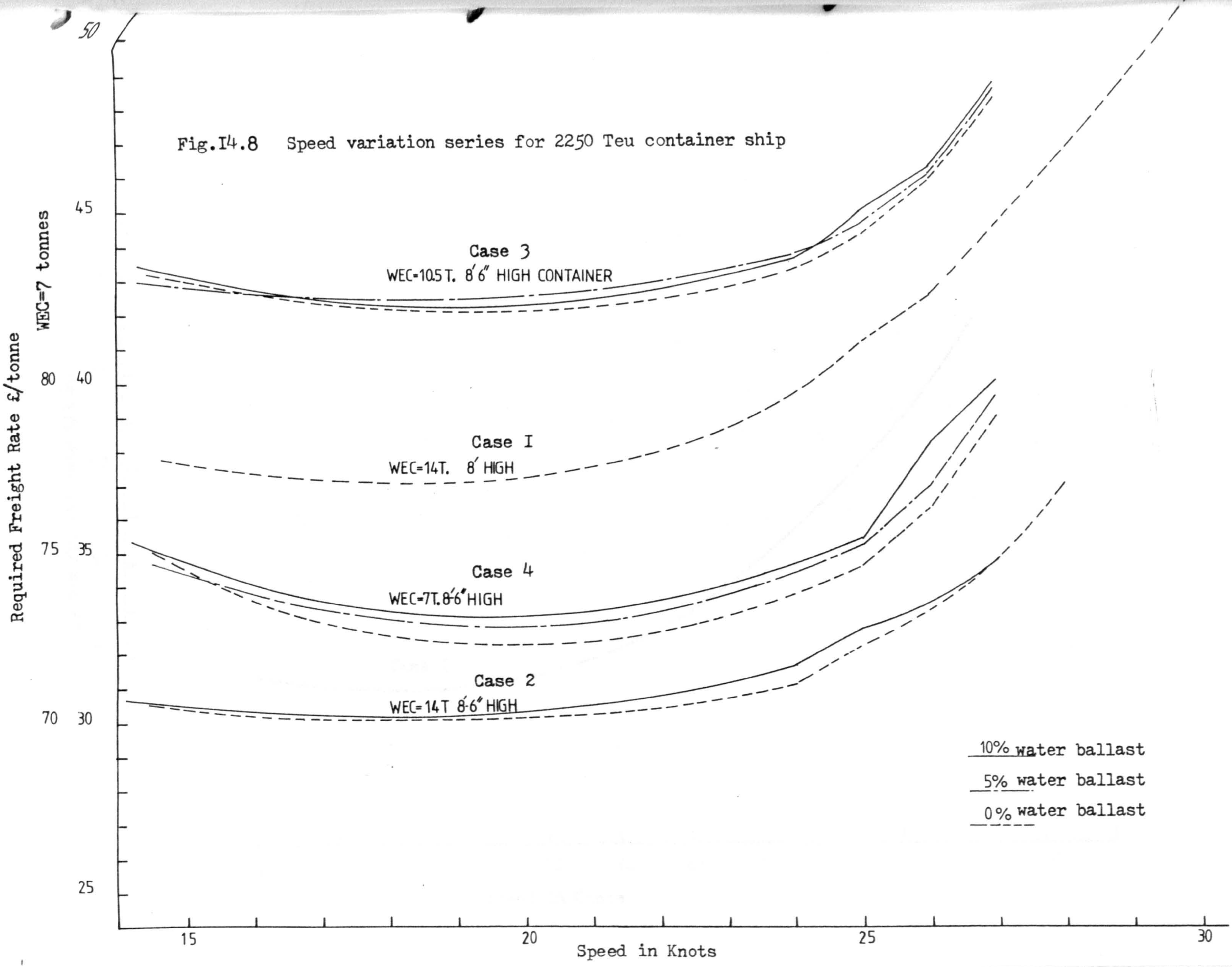
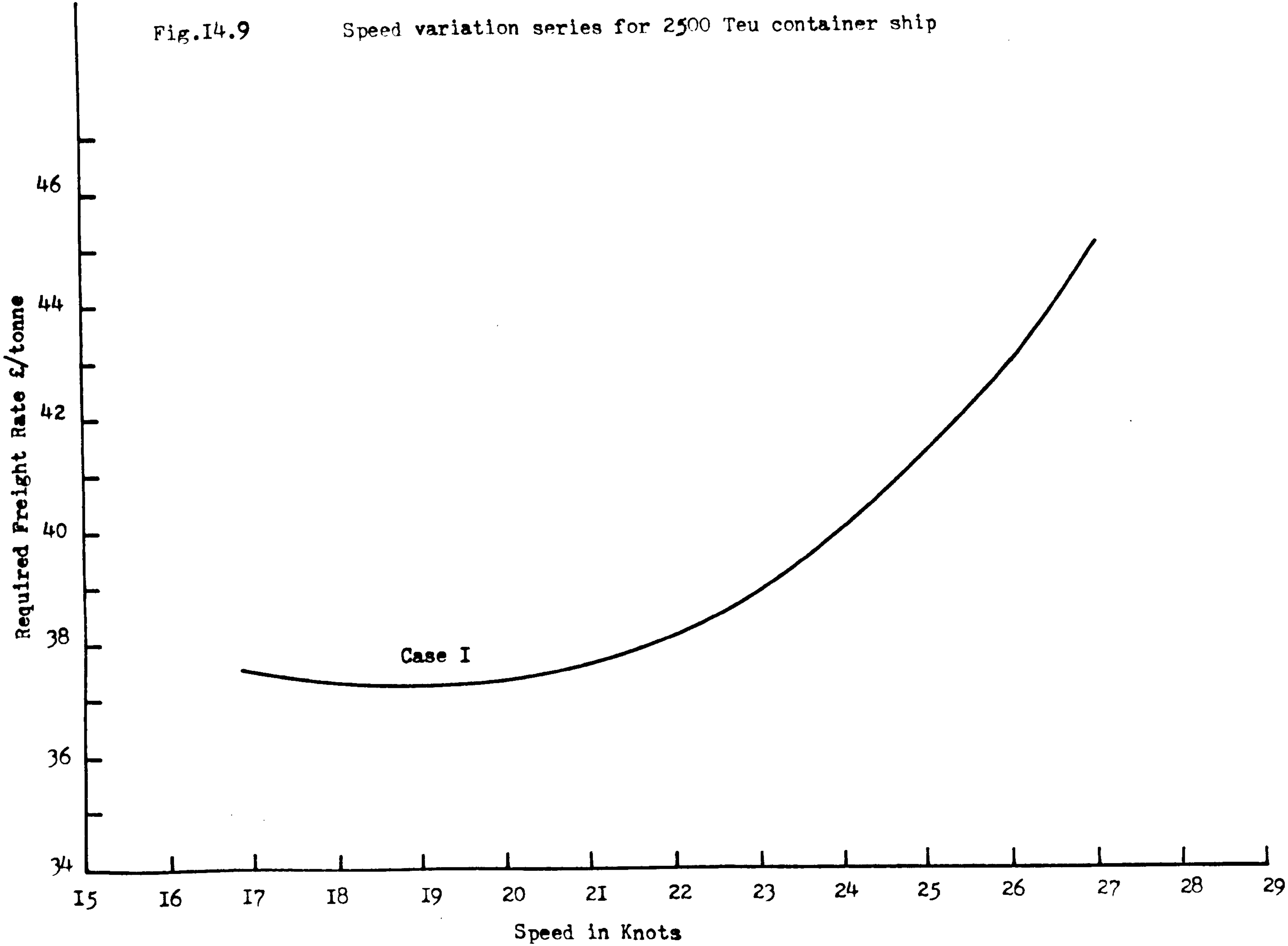


Fig.I4.8 Speed variation series for 2250 Teu container ship

Fig.14.9 Speed variation series for 2500 Teu container ship



Case 1

The optimum ship size is in the region of 1500 Teu to 1750 Teu and the optimum speed is between 15 to 20 knots as shown in Fig. 14.1 to Fig. 14.9.

The rate of increase outwith this region favours ships from 1500 Teu to 1750 Teu rather than 1500 to 1250 Teu. The value of RFR does not change much with speed over a reasonable range for ships above 1250 Teu. No doubt the reduction in Froude number is important.

For speeds of 18, 21, 24 and 27 knots the RFR was plotted against ship size as shown in Fig. 14.10 to Fig. 14.13. The optimum size occurs at 1500 Teu for speeds of 18 and 21 knots (Fig. 14.10 and Fig. 14.11). The flat laxity of ship size with RFR is apparent in Fig. 14.12 and Fig. 14.13 at the higher speeds of 24 and 27 knots, but at these higher speeds little is gained by increasing the ship size beyond 2000 Teu.

The range of sizes that are within a small defined departure from the optimum can be found. Increases of 2½ % and 5% in RFR were studied as shown in Fig. 14.10 to Fig. 14.13. The size variation for various speeds within these ranges if minimum RFR are shown below.

Table D

Speed in knots	Container Capacity in Teu	
	2½ % RFR variation	5% RFR variation
18	1000 - 1970	850 - 2250
21	990 - 2030	830 - 2440
24	1210 - 2250	1030 - 2530
27	1040 and above	870 and above

At 2½ % variation in RFR the size variation is about 1000 Teu and at 5% variation in RFR the size variation is about 1500 Teu at all speeds.

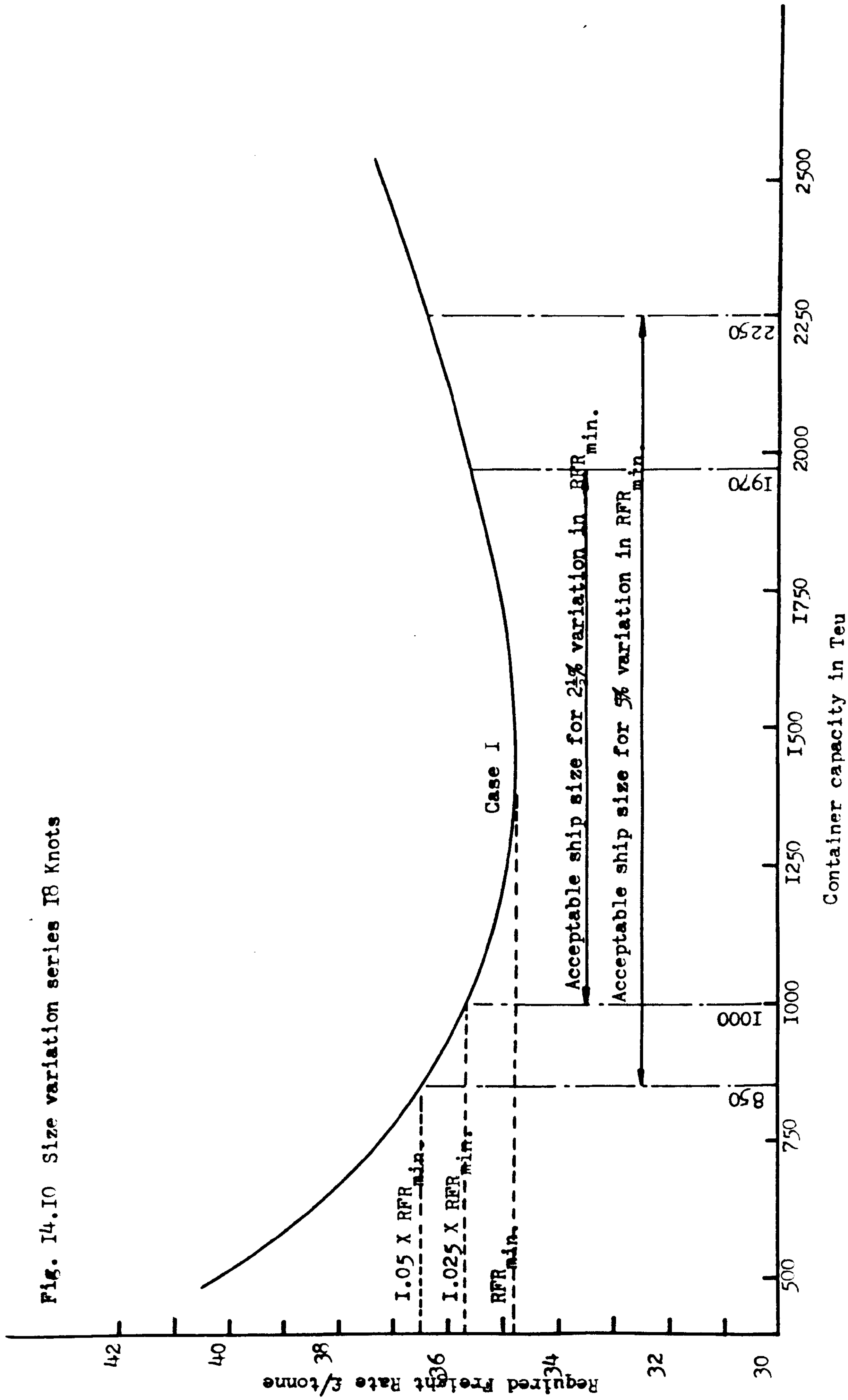


Fig. 14.10 Size variation series 18 Knots

Fig.I4.II Size variation series 2I Knots

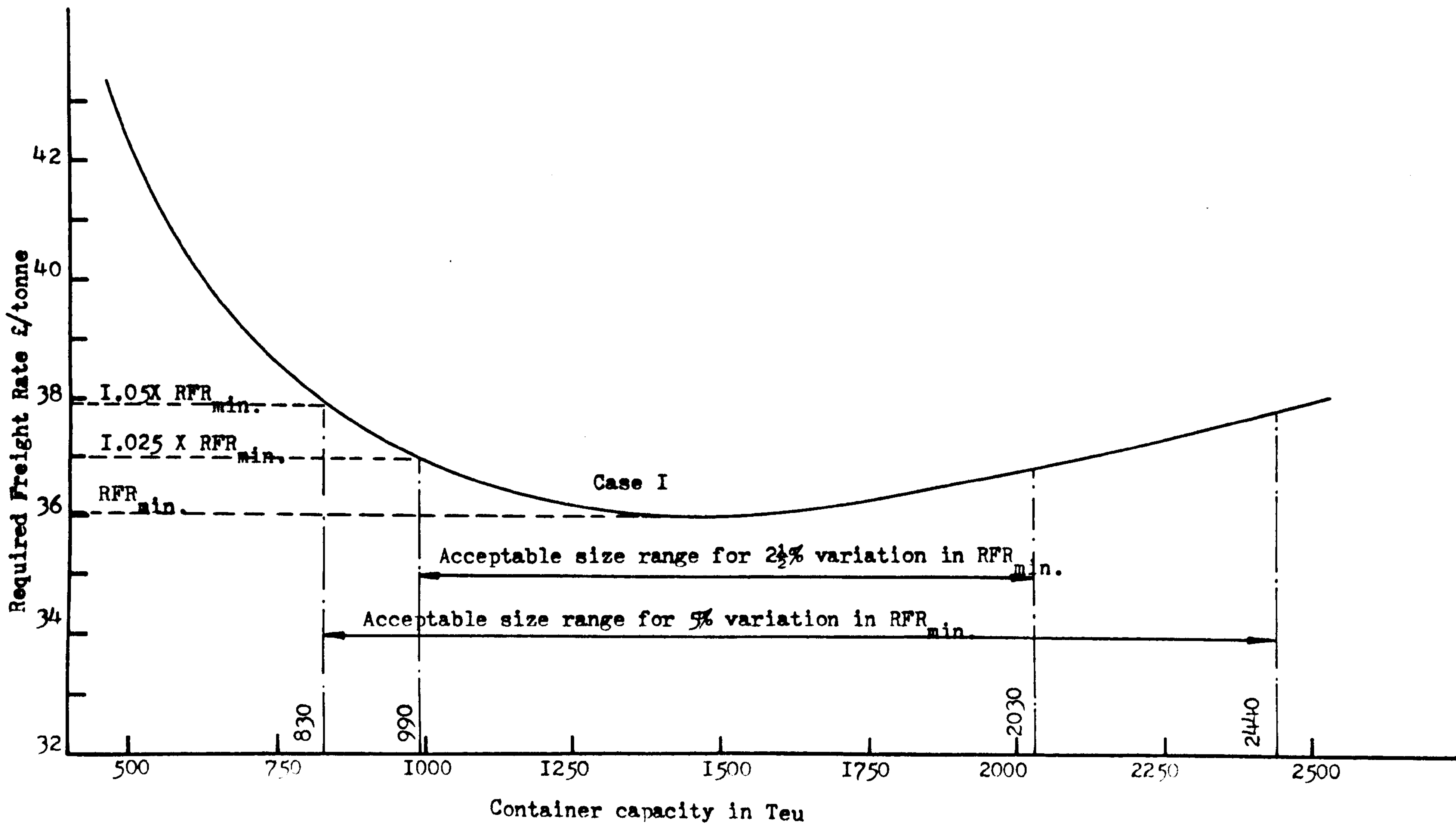


Fig.14.12 Size variation series 24 Knots

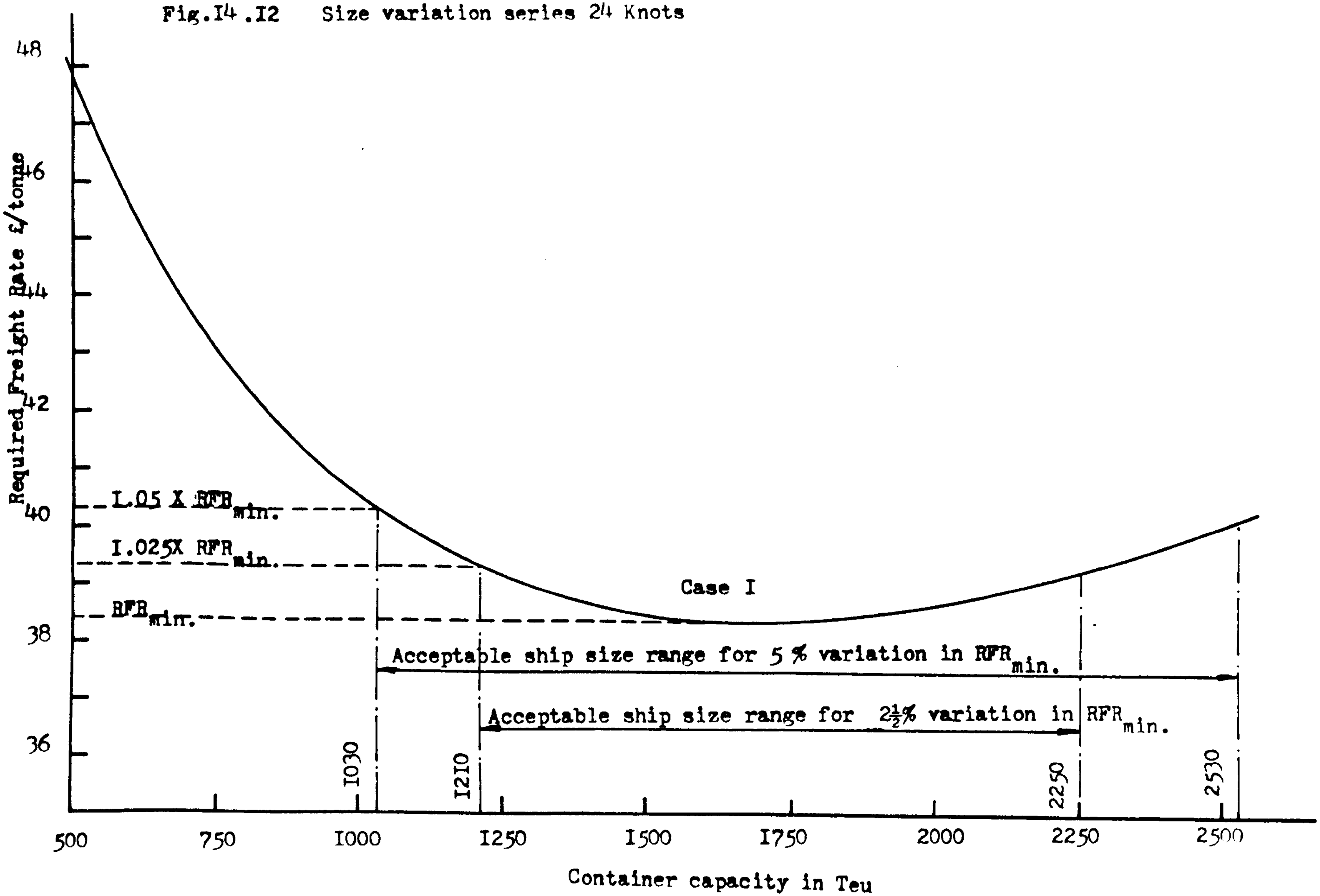
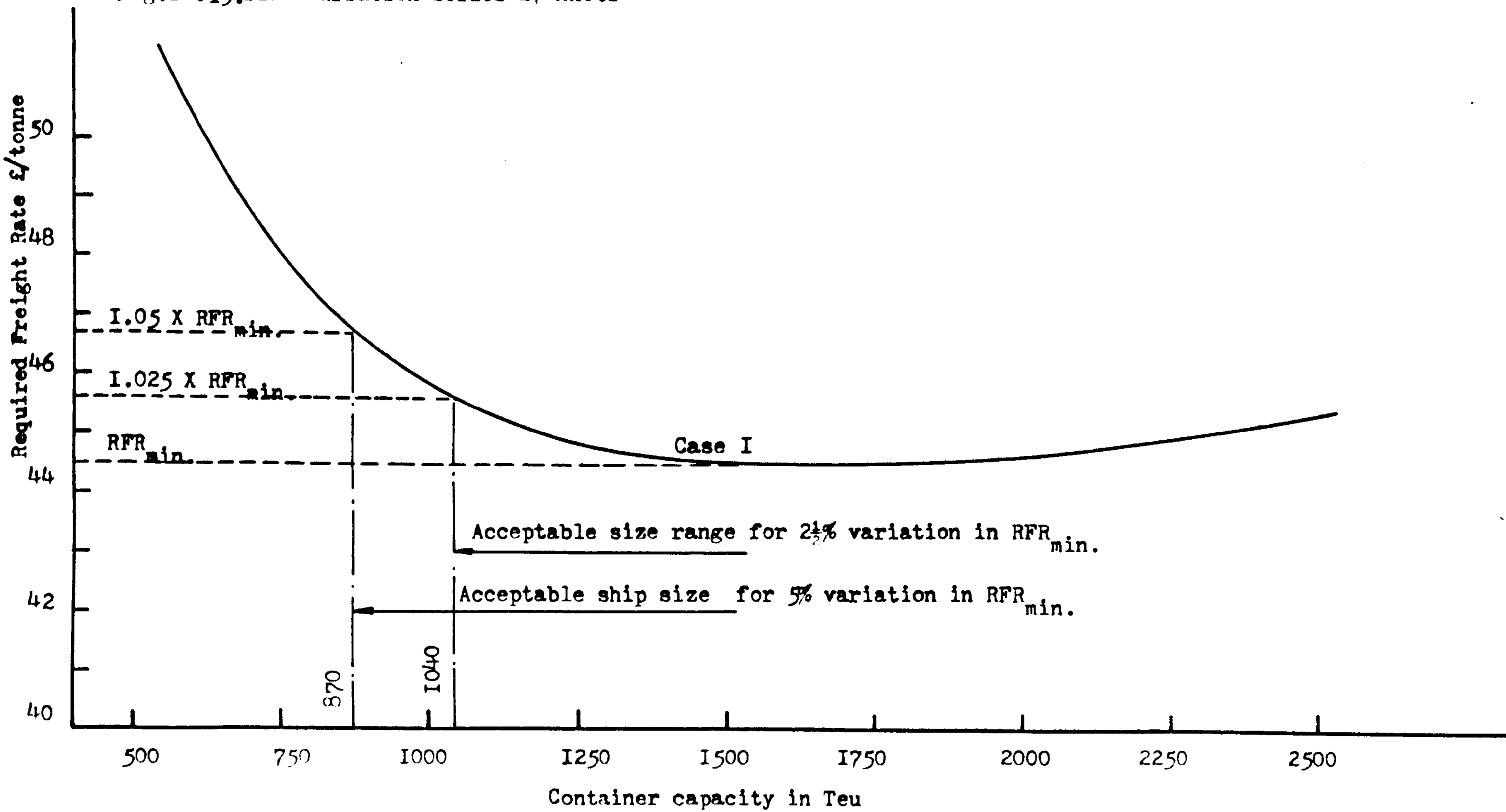


Fig.14.13.Size variation series 27 Knots



A main influence on the small change in RFR with size is the container handling cost. Container handling cost is directly proportional to the number of containers and has no economy of scale. In the ships considered this cost is about 50% of the operating cost. Costs that do have economy of scale such as fuel costs and crew costs etc. account for about 40% of the total operating costs. The remaining costs such as insurance tend to be related to the first cost. Consequently as the number of Teus increase any variation in RFR caused by size alone is modest for this length of trade route.

Fig. 14.10 to Fig. 14.13 indicate that for a certain speed there is an optimum number of Teu giving the lowest value of RFR. For smaller number of Teus the vessel is too expensive at sea mainly caused by high fuel costs in relation to payload and for larger values the vessel is too expensive in port mainly caused by inability to speed up the turnaround time. The influence of increase of speed is to flatten the curve to give a wider range of Teus without significant change in RFR and to increase the optimum number of Teus.

Cases 2, 3 and 4

Fig. 14.3 to Fig. 14.8 illustrates the effect of ballast on RFR for ships of container capacity 1000 to 2250 Teu at various speeds and average weight of each container of 14, 10.5 and 7 tonnes.

A careful study was made of the figures obtained when 5% and 10% ballast was incorporated but it is not possible to come to precise conclusions. Naturally when using a program where RFR is based on the mass of cargo carried the best values of RFR are without ballast. In most cases the RFR worsens as the ballast is increased from 5% to 10% of displacement. However in a number of cases 10% ballast is shown to be better than 5% ballast. This trend must be viewed in conjunction with the precision of the program and its optimising routines compared with the percentage change of RFR in moving from zero to 10% ballast situations.

In broad terms there is no exact explanation of this reversal of trend but when it occurs the length of the design chosen is less for 10% ballast than for 5% ballast condition and this is deemed to be the main reason for the fluctuation of RFR.

Case 5

Under assumption B, optimum ship dimensions were found for the weight of each container 10.5 tonnes and also assuming that there were zero sets of containers and the cost of maintaining and operating these containers was excluded.

Containers are usually leased and are operated for a fleet of vessels and therefore not included in the acquisition cost of the ship. However it has been assumed in this thesis that containers are owned by the shipping company.

Fig. 14.5 shows the Required Freight Rate at various speeds for a 1500 Teu containership, excluding the cost associated with a finite set of containers. This Required Freight Rate is designated as RFR_I and the Required Freight Rate including cost of acquisition and operating 2.5 sets of containers as RFR_2.

The ratio RFR_2/RFR_1 decreases progressively from a value of 1.40 at lower speeds of 15 knots to 1.22 at higher speeds of 27 knots and this decrease is almost linear.

14.2. Optimum Speed

The flat laxity of the RFR curves in the region of the optimum speed, about 17 knots, indicates that there must be little resistance to the influence of competitive pressures to raise the speed and actual speeds of containerships reflect this. Furthermore inclusion of inventory costs will raise the optimum speed. When freight rates are fixed, speed may be regarded as an extension to quality of service and thus higher speeds may bring improved load factors.

For a cost based criterion such as RFR the optimal speed obtained is the speed for minimum average costs and hence the cheapest speed, and this speed ignores the demand aspect of the problem of choice of speed.

14.2.1. Effect of higher fuel prices

A ship of container capacity 1500 Teu was chosen to determine the effect of fuel price changes on the optimum speed of the ship.

The price of fuel oil, diesel oil and lubricating oil was increased by 25% and by 50% and was reduced by 50%, although an improbable occurrence.

Fig. 14.14 shows the change in RFR with respect to speed when the speed was varied from 15 knots to 24 knots in steps of 3 knots. The optimum speed of 17.15 knots falls to 16.60 knots for a fuel price increase of 25% and to 16.05 knots for a fuel price increase of 50% and increases to 18.55 knots for a reduction of fuel price of 50%.

If the economic speeds including inventory costs were higher, then the absolute drop in speed would be accordingly greater and it might be that the relative drop in speed would also be greater. The route would also affect this result and this study has taken a short route; but the results show that higher fuel prices decrease the optimum speed.

14.2.2. Effect of higher crew costs

The crew costs were escalated at 5% per annum and 10% per annum relative to other operating costs to consider the effect of relatively higher crew costs on optimum speed. The effect is shown in Fig. 14.15 but is not significant for the range of crew costs considered.

14.2.3. Effect of higher discount rate

The discount rate at 15% was increased to 17½ % and 20% and decreased to 12½ % and to 10% and the effect of this is shown in Fig. 14.16. The effect on optimal speed is small.

Fig. I4.I4.Effect of higher fuel prices on the optimal speed
(Assumption A)

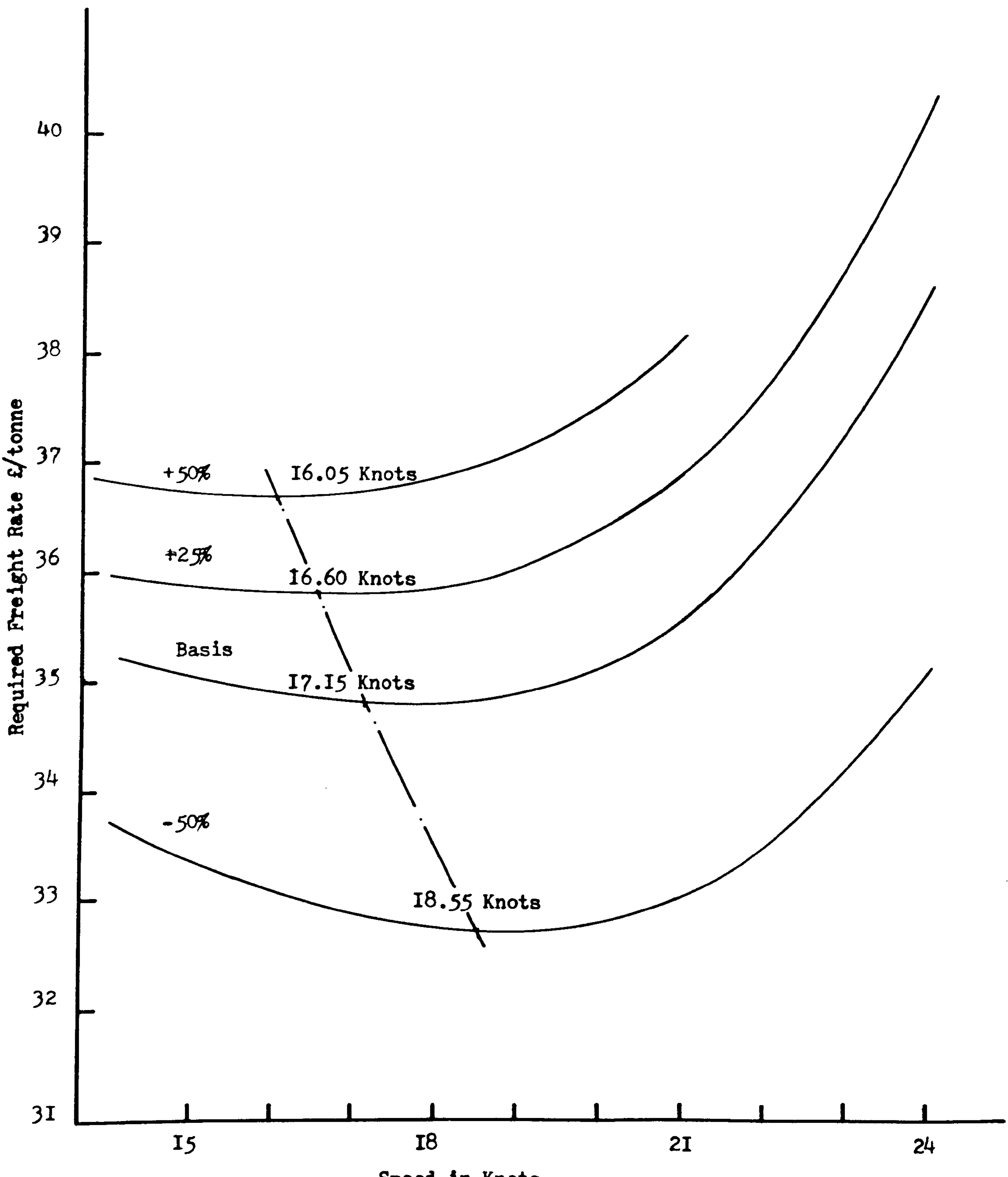


Fig.I4.I5 Effect of increase of crew costs on optimal speed (Relative escalation of crew costs per annum)

(Assumption A)

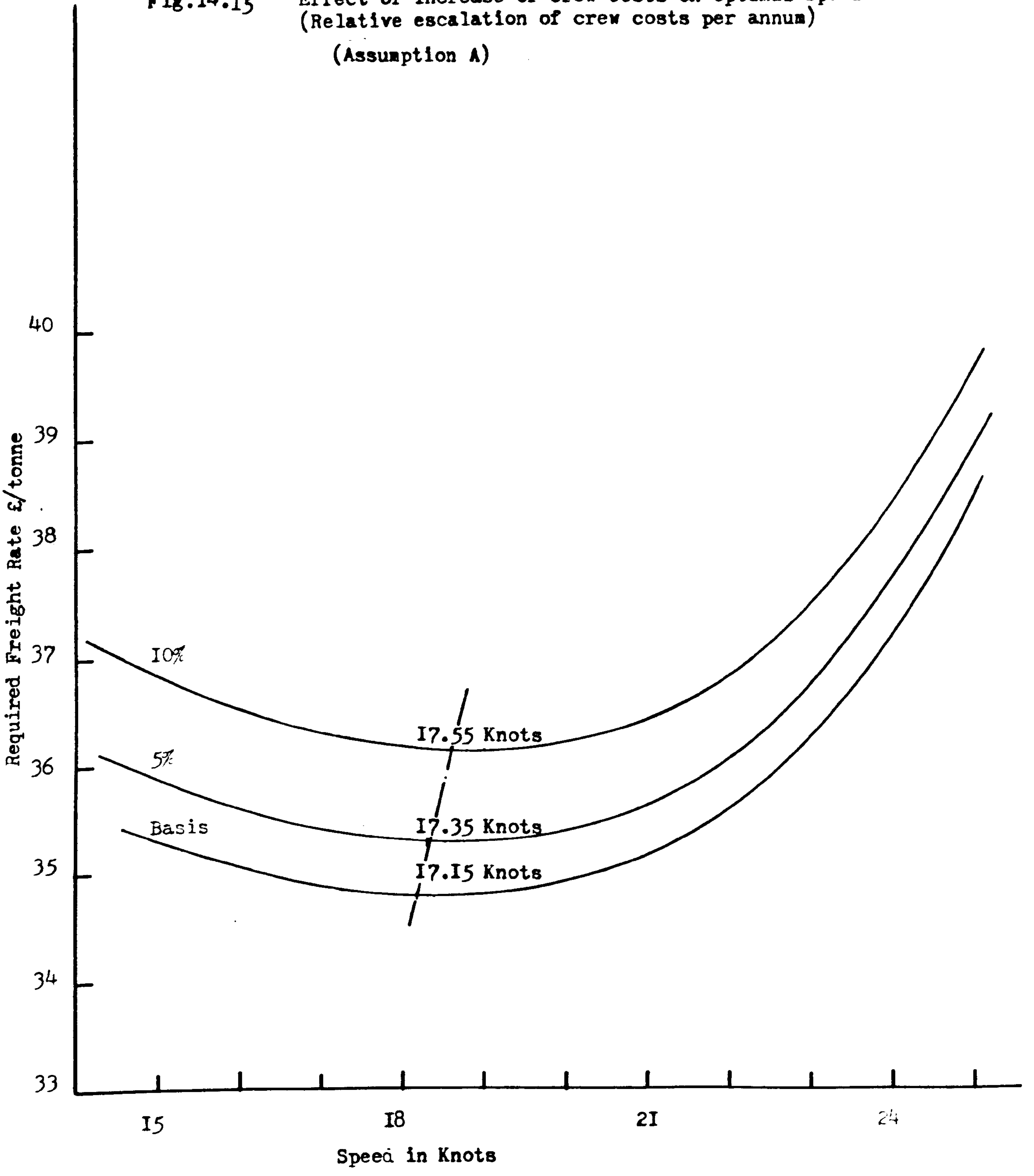


Fig.I4.I6.Effect of higher discount rate on optimal speed
(Assumption A)

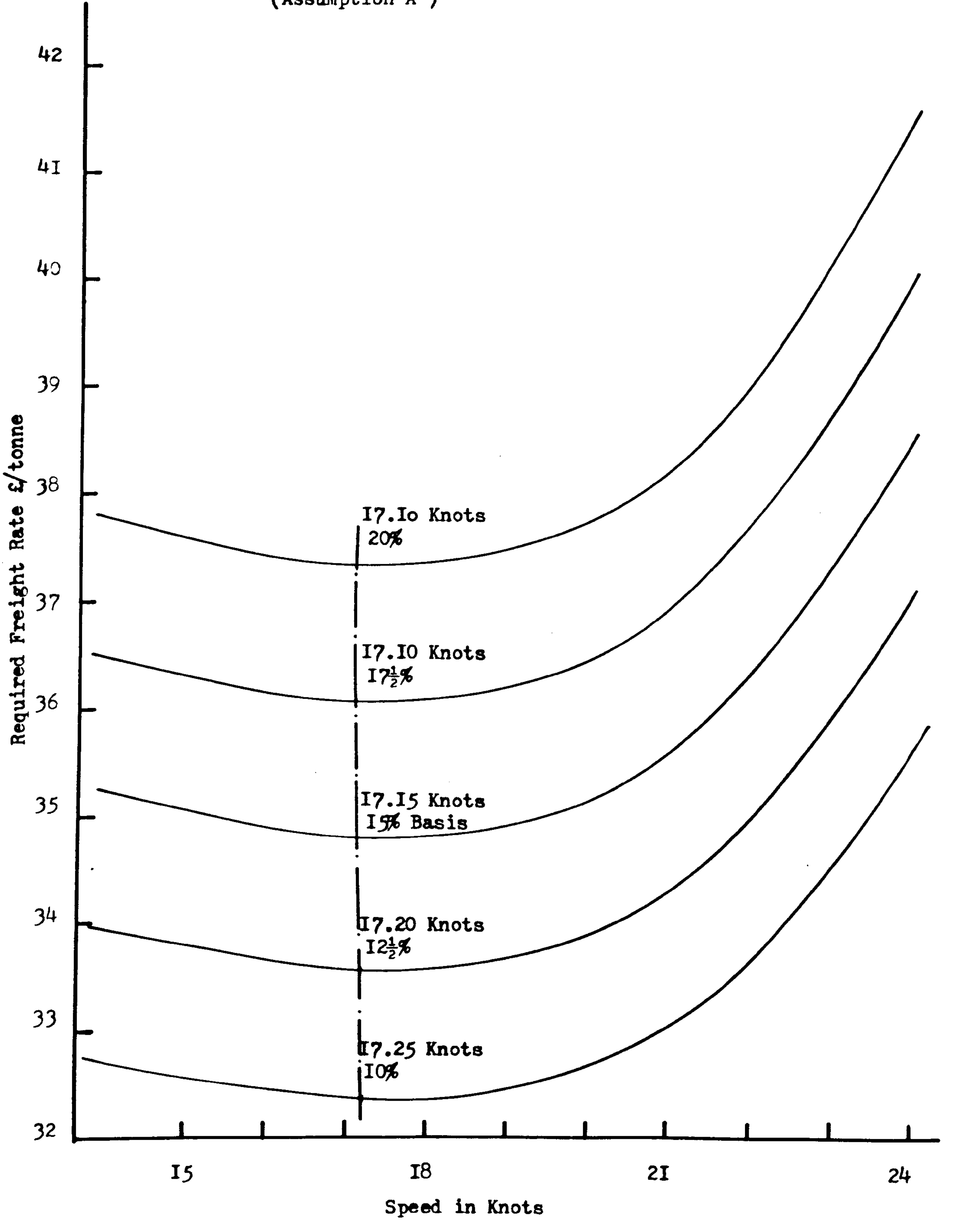
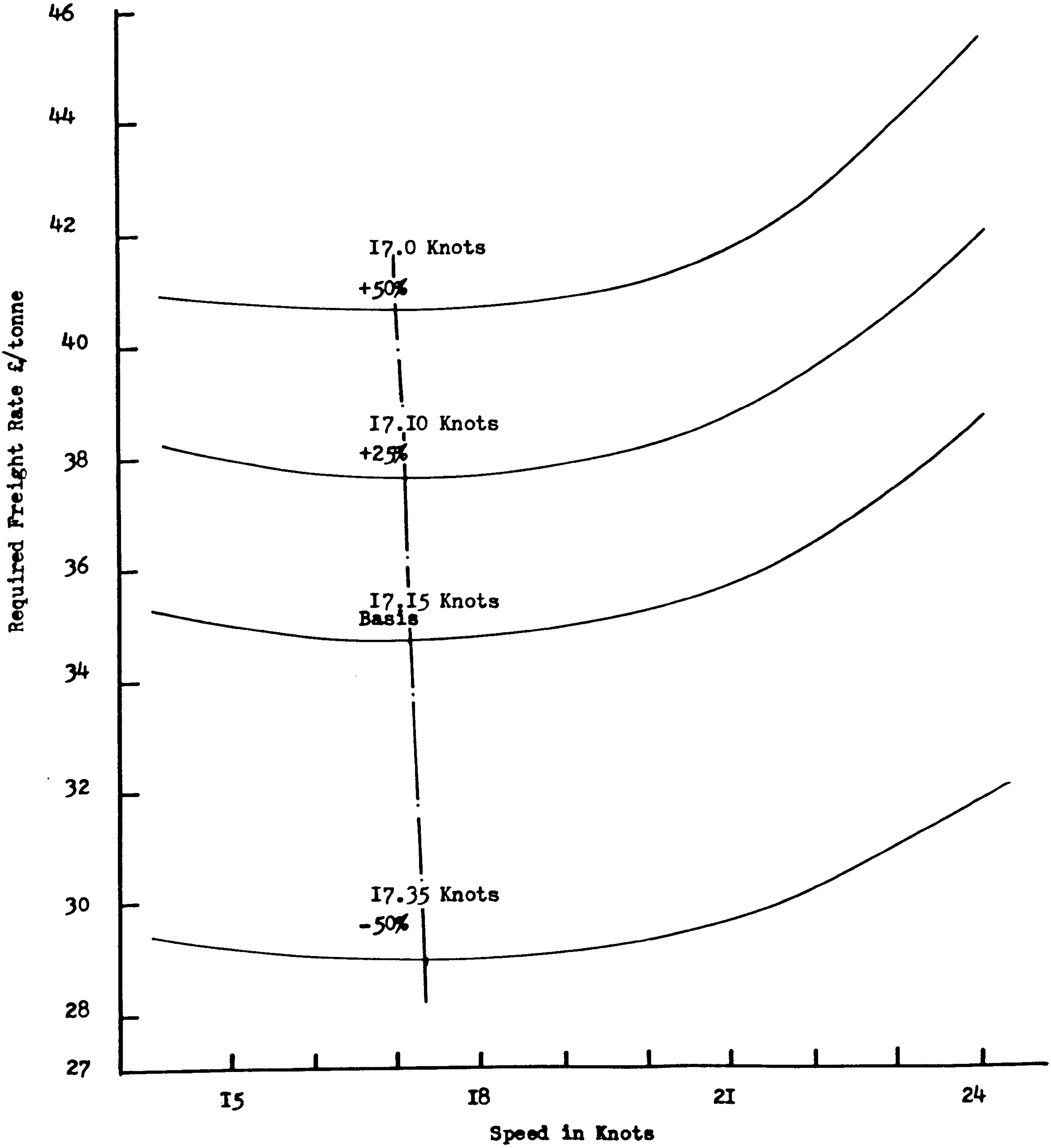


Fig. I4. I7 Effect of higher Shipbuilding cost on optimal speed



14.2.4. Effect of higher first cost

The first cost of the ship (excluding the containers) was increased by 25% and 50% and decreased by 50%. The effect on the optimal speed is shown in Fig. 14.17 and it is small.

14.3. Sensitivity Analysis

In the earlier sections it was shown how computer Model I or computer Model II could be used to generate an optimum design. Computer model II is preferred to computer model I to carry out such studies since it was found to be more economic in terms of computer costs and time. Once the optimum design has been selected a sensitivity analysis is carried out using either computer model I or computer model II.

14.3.1. Merit Ranking

Sensitivity analysis involves making incremental changes to some main items. The main items are those which are usually known to have major influence on the Required Freight Rate or items which cannot be estimated accurately at the preliminary design stage because of their inherent variability over the life of the vessel.

Nineteen major items as listed in Table 14.1, Table 14.2 and Table 14.3 were identified as items for carrying out such sensitivity analysis. A 10% improvement in each of these items was assumed and the life of the ship and the containers was increased by four years. The influence of these items was measured in terms of percentage change in RFR from the basic RFR by changing one item at a time.

The computer Model II was used to carry out sensitivity analysis on ships of container capacity 1500 Teu and a speed of 21 knots for three different weights.

Table 14.1 gives the merit ranking for a containership with average weight of each container 14 tonnes. Similarly

Table 14.1. Sensitivity Analysis with 10% improvement (Model II). Weight of each container = 14 tonnes.

No.	Items	Units	Initial Values	Final values	Computer Symbol	RFR £/tonne	% Diff. from Basis RFR	Merit Ranking
1	Basis ship	-	-	-	-	28.867		
2	Load Factor	%	0.85 0.80	0.935 0.88	ALFO ALFI	27.778	3.772	4
3	Round Voyage distance	n.miles	6766 3363	6090 3045	DIST ENDUR	27.648	4.223	3
4	Container handling cost	£/container /move	50	45	CHANDL	28.019	2.938	7
5	Ship's First Cost	£ $\times 10^6$	24.38	21.94	CAPCOS	28.307	1.939	11
6	Port time per round voyage	days	13.23	11.91	DIP	27.924	3.267	6
7	Ship's Life	years	20	24	LIFES	28.483	1.330	13
8	Average Crew Wages	£/annum	5300 5400 8400	4700 4860 7560	WCREW WPO WOFF	28.731	0.471	15
9	Installed power	British hp	25885	23297	SHP	28.040	2.865	8
10	Total port costs	£ $\times 10^6$/ annum	0.4238	0.3814	CPORT	28.759	0.374	16
11	Gross Register tonnage	tons	31954	28 759	GRT	28.781	0.297	17
12	Fuel oil costs	£/tonne	80 145 560 470	72 130.5 504 423	COFUEL CDESL CLUBCY CLUBSY	28.420	1.548	12

Table 14.1 (Contd.)

No.	Items	Units	Initial Values	Final Values	Computer Symbol	RFR £/tonne	% Diff. from Basis RFR	Merit Ranking
13	Specific fuel consumption	gms/bhp.hr	135 1.29 0.26 0.37	121.5 1.16 0.234 0.333	Section 8.2.3 and sec. 10.8	28.254	2.123	10
14	Labour Wage rate	£/hr.	2.4	2.16	WR	28.601	0.921	14
15	Operating Costs	£ $\times 10^6$/ annum	6.548	5.893	TRCOS(I)	27.197	5.785	2
16	Steel weight	tonnes	13020	11718	WS	26.594	7.874	1
17	Steel Cost	£/tonne	214	192.6	STLCOS	28.787	0.277	18
18	Cost of Container	£/unit	2500	2250	COSCNT	28.185	2.362	9
19	Number of sets of containers		2.5	2.25	SETCNT	28.185	2.362	9
20	Life of container	years	8	12		27.901	3.346	5

Basis ship. Container Capacity 1500 Teu, speed = 21 knots, North Atlantic Route, 2 ports of call. average weight of each container = 14 tonnes, without ballast.

L_{BP} = 221.472, B = 29.877, T = 9.291 D = 19.742, C_b = 0.631.

Life of ship and life of container increased by 4 years. steel weight estimation method 4 option used (Section 6.1). Dimensions in metres.

Table 14.2 and Table 14.3 gives the merit ranking for containerships with average gross weight of each container 10.5 tonnes and 7 tonnes respectively.

In all these cases assumption B as given in Table A was applicable.

Table 14.4 summarises the results of the sensitivity analysis for the three different average weights of each container. In practice however, it is rare that containerships with homogenous container loading of 7 tonnes will be considered. Normal homogenous container loads are between 10 tonnes to 13 tonnes. Danish shipowners design their ships with 10 tonnes container load whilst German ship owners tend to use higher average weights of 13 tonnes or even more, Langenberg (174)++.

Each of these major items are discussed below not necessarily in order of their merit ranking. The figures in the brackets indicate the percentage changes in the various parameters due to 10% improvement in each of these items.

Steel weight (WS)

It was found that the Required Freight Rate was very sensitive to steel weight. This is because steelweight in containerships is a relatively high fraction of the lightship weight. For the ships considered the steel weight was found to be 72% to 74% of the lightship weight. Also the steel costs are an important part of the ship's First Cost.

One interesting feature of the change in steel weight is its effect on the number of containers able to be carried on deck and the average weight of each container, if the displacement and GM remain constant. In containerships with homogeneous distribution of weight of each container the centroid of the containers is above the centroid of the steel weight. Consequently when steel weight is reduced at constant displacement additional cargo deadweight can be distributed among the containers. However to distribute it at the original centroid of containers would reduce the

++ Actual service figures may be less.

Table 14.2 Sensitivity Analysis with 10% improvement (Model II)
Weight of each container = 10.5 tonnes

No.	Items	Units	Initial Values	Final Values	Computer Symbol	RFR £/tonne	% Diff. from basis RFR	Merit Ranking
1	Basis ship	-	-	-	-	40.447		
2	Load factor	%	0.85 0.80	0.935 0.88	ALFO ALF1	38.980	3.627	4
3	Round voyage distance	n.miles	6766 3363	6090 3045	DIST ENDUR	38.714	4.285	3
4	Container handling cost	£/Teu/move	50	45	CHANDLE	39.242	2.979	8
5	Ship's first cost	£ x 10^6	23.74	21.36	CAPCOS	39.671	1.918	11
6	Port time per round voyage	days	13.21	11.89	DIP	39.109	3.308	6
7	Ship's life	years	20	24	LIFES	39.915	1.315	13
8	Average crew wages	£/annum	5300 5400 8400	4700 4860 7560	WCREW WPU WOFF	40.253	0.479	15
9	Installed power	British hp	23499	21149	SHP	39.145	3.219	7
10	Total port costs	£ x 10^6/annum	0.4284	0.3855	CPORT	40.292	0.383	16
11	Gross register tonnage	tons	32518	29266	GRT	40.323	0.306	17
12	Fuel oil costs	£/tonne	80 145 560 470	72 130.5 504 423	COFUEL CDESL CLUBCY CLUBSY	39.850	1.476	12
13	Specific fuel consumption	gms/bhp-hr	135 1.29 0.26 0.37	121.5 1.16 0.234 0.333	section 8.2.3 and sec. 10.8	39.563	2.185	10

(Contd.)

Table 14.2 (Contd.)

No.	Hems	Units	Initial Values	Final Values	Computer Symbol	RFR £/tonne	% Diff. from basis RFR	Merit Ranking
14	Labour wage rate	£/hr	2.4	2.16	WR	40.071	0.929	14
15	Operating costs	£ x 10^6/ annum	6.429	5.786	TRCOS(I)	38.113	5.771	2
16	Steel weight	tonnes	12748	11473	WS	36.203	10.493	1
17	Steel cost	£/tonne	214	192.6	STLCOS	40.336	0.274	18
18	Cost of container	£/unit	2500	2250	COSCNT	39.478	2.396	9
19	Number of sets of containers		2.5	2.25	SETCNT	39.478	2.396	9
20	Life of containers	years	8	12	LIFEC	39.076	3.389	5

Basis ship. Container Capacity 1500 Teu, speed 21 knots, North Atlantic Route, 2 ports of call, average weight of each container = 10.5 tonnes without ballast.

L_{BP} = 216.235, B = 30.190, T = 8.375, D = 20.375, Cb = 0.607

Life of Ship and Life of Container increased by 4 years

Steel weight estimation method 4 option used (Section 6.1)

Dimensions in metres.

Table 14.3 Sensitivy Analysis with 10% improvement (Model II)
Weight of each container = 7 tonnes

No.	Hems	Units	Initial Values	Final Values	Computer Symbol	RFR £/tonne	% Diff. from basis RFR	Merit Ranking
1	Basis ship	-	-	-	-	68.427		
2	Load factor	%	0.85 0.80	0.935 0.88	ALFO ALFI	66.065	3.452	7
3	Round voyage distance	n.miles	6766 3363	6090 3045	DIST ENDUR	65.295	4.577	3
4	Container handling cost	£/Teu/move	50	45	CHANDL	66.348	3.038	8
5	Ship's first cost	£ x 10^6	23.79	21.41	CAPCOS	67.100	1.939	11
6	Port time per round voyage	days	13.44	12.09	DIP	66.024	3.512	5
7	Ship's life	years	20	24	LIFES	67.518	1.328	13
8	Average crew wages	£/annum	5300 5400 8400	4700 4860 7560	WCREW WPO WOFF	68.097	0.482	15
9	Installed power	British hp	19998	17998	SHP	65.737	3.931	4
10	Total port costs	£ x 10^6/ annum	0.4253	0.3827	CPORT	68.163	0.386	16
11	Cross register tonnage	tons	31982	28784	GRT	68.218	0.305	17
12	Fuel oil costs	£/tonne	80 145 560 470	72 130.5 504 423	COFUEL CDESL CLUBCY CLUBSY	67.513	1.336	12
13	Specific fuel consumption	gms/bhp-hr	135 1.29 0.26 0.37	121.5 1.16 0.234 0.333	section 8.2.3 and sec. 10.8	66.724	2.489	9

(Contd.)

Table 14.3 (Contd.)

No.	Items	Units	Initial Values	Final Values	Computer Symbol	RFR £/tonne	% Diff. from basis RFR	Merit Ranking
14	Labour wage rate	£/hr	2.4	2.16	WR	67.768	0.963	14
15	Operating costs	£ x 10^6/ annum	6.283	5.655	TRCOS(I)	64.537	5.685	2
16	Steel weight	tonnes	13794	12415	WS	55.811	18.437	1
17	Steel cost	£/tonne	214	192.6	STLCOS	68.224	0.297	18
18	Cost of container	£/unit	2500	2250	COSCNT	66.741	2.464	10
19	Number of sets of containers		2.5	2.25	SETCNT	66.741	2.464	10
20	Life of containers	years	8	12	LIFEC	66.041	3.487	6

Basis ship. Container Capacity 1500 Teu, speed 21 knots, North Atlantic Route, 2 ports of call, average weight of each container = 7 tonnes.

L_{BP} = 233.611, B = 28.668, T = 7.186, D = 19.523, Cb = 0.607

Life of ship and Life of container increased by 4 years.

Steel weight estimation method 4 option used (Section 6.1)

Dimensions in metres.

Table 14.4. Summary of Sensitivity Analysis for different average weight of each container.

Item	% Diff. from basis RFR	Merit Rank-ing	% Diff. from basis RFR	Merit Rank-ing	% Diff. from basis RFR	Merit Rank-ing
Average Weight of Container	14		10.5		7	
Basis RFR £/tonne	28.867		40.447		68.427	
Load Factor	3.772	4	3.627	4	3.452	7
Round Voyage distance	4.223	3	4.285	3	4.577	3
Container handling cost	2.938	7	2.979	8	3.038	8
Ship's First Cost	1.939	11	1.918	11	1.939	11
Port-time per round voyage	3.267	6	3.308	6	3.512	5
Ship's life	1.330	13	1.315	13	1.328	13
Average crew wages	0.471	15	0.479	15	0.482	15
Installed power	2.865	8	3.219	7	3.931	4
Total port costs	0.374	16	0.383	16	0.386	16
Gross Register tonnage	0.297	17	0.306	17	0.305	17
Fuel oil costs	1.548	12	1.476	12	1.336	12
Specific fuel consumption	2.123	10	2.185	10	2.489	9
Labour wage rate	0.921	14	0.929	14	0.963	14
Operating costs	5.785	2	5.771	2	5.685	2
Steel wt.	7.874	1	10.493	1	18.437	1
Steel cost	0.277	18	0.274	18	0.297	18
Cost of Container	2.362	9	2.396	9	2.464	10
No. of sets of containers	2.362	9	2.396	9	2.464	10
Life of container	3.346	5	3.389	5	3.487	6

GM. Consequently if displacement is maintained the number of containers above the deck must be reduced to reduce their centroid although the average weight of each container will increase.

This characteristic is not present in most ships where the centroid of the cargo is generally below that of the steel weight and a reduction in steel weight will generally increase both deadweight and stability.

Containerships are stability limited ships and attain their deadweight requirements at drafts less than that allowable by the geometric free board. Therefore the ratio of cargo deadweight to steelweight will be a smaller fraction compared to a deadweight limited ship. Consequently, a 10% change in steelweight will have a larger impact on the change in cargo deadweight in containerships compared to deadweight limited ships. This is illustrated in Table 14.4 which shows that for ships designed for average weights of container of 14.0, 10.5 and 7.0 tonnes the change in RFR for 10% reduction in steel weight progressively increases as the average container weight reduces. Selective stowage of containers can result in improving stability and the subject is considered in Section 13.2. The program is not able to consider selective stowage without further development.

In the program a reduction of 10% in steelweight causes the number of containers on the deck to reduce by 2, 3 and 21 for ships of weight of each container 14, 10.5 and 7.0 tonnes respectively because of stability considerations. The additional deadweight allows the weight of each container to rise to 14.92, 11.41 and 8.07 tonnes respectively. The cargo carried per annum therefore rises by 7.8%, 11% and 21% respectively. The reduction in steel weight also reduces the first cost of the ship by 3%. Therefore the value of RFR reduces.

The sensitivity of RFR with reduction in steelweight also shows that better estimating equations than those used in this thesis need to be developed. The steelweight estimation method developed by Chapman in 1969 results in higher steel weight than is the case for recently built containerships. Moreover a German shipbuilder, Blohm and Voss when approached for guidance on weight and centre of gravity of containerships confirmed that weight discrepancies ranging around 10% were found on containerships which were built to the same main dimensions and same specification at different shipyards. It was also found by the shipyard that weight and centre of gravity cannot be put into simple formulae because these depend very much on individual hull structure and shipyard practice. Although some guidance was obtained from the shipyard in the form of graphs, it was difficult to translate them to a form suitable for computer programs.

Watson & Gilfillan's method of steelweight estimation depends very much on the choice of value of K (see Section 6.1 method 8).

To apply this method the value of K has to be derived from a basis ship of dimensions closer to the ship whose steelweight has to be estimated. For a study such as this where a very wide range of ship size and speed were studied, it was not possible to rationalise the value of K with the limited data that was available.

Reduction in steel weight can be achieved by considering either the single skin structure or the trunk type structure as proposed by Langenberg (36). The weight of hull structure in single skin construction can be expected to be about 6 per cent lower and in trunk type about 4 percent lower than the conventional double skin structure (36). A more careful approach to design e.g. 'Design for production' might save steel weight and a two or three percent reduction in lightship displacement could be achieved, especially if more higher tensile steel is adopted (202).

Operating Costs (TRCOS)

The operating cost includes the daily running costs, voyage costs and container handling costs but excludes the cost associated with operating the required sets of containers.

The influence on RFR due to reduction in operating cost is quite significant.

A 10% improvement in operating costs is more readily attainable since a shipowner has more direct control over the operating costs. A 10% improvement might be achieved either by reducing the fuel bill by selection of a main engine of lower specific fuel consumption or by reduced manning with engine room automation.

Round voyage distance (DIST, ENDUR)

The round trip distance (DIST) was 6770 n. miles and endurance (ENDUR) was assumed to be half this distance. A decrease in Round voyage distance reduces the time spent at sea by 1.3 days. Fuel costs are reduced by 2% but there is an increase in port costs and container handling costs (5%) which increases the total operating costs by (2.5%). Cargo carried per annum also increases by about 6% due to the increase in the number of round trips per annum. It is less easy to propose a reduction in this parameter. It is a mixture of distance travelled and time taken. Some improvement may be possible by close attention to weather routing. Great circle sailing is shown to be necessary unless weather influences are much against it.

The importance of this feature indicates that a reduction of ports of call may be an advantage but that advantage could be suboptimum when considered as a part of the wider transport system. It also encourages serving a country by one port to reduce coasting time.

Load factor (ALFO, ALFI)

Increasing the load factor by 10% increases the port time (9%) and decreases the number of round trips/annum (4%). Increase in port time increases the port costs (1.6%) and the reduction in the number of round trips/annum reduces the fuel costs (2%). The increase in load factor increases the container handling costs (5.3%). The overall operating cost however increases by merely 2.5%. Increasing the load factor also increases the amount of cargo carried per annum (5.2%) which more than offsets the detrimental effect of increased port time on RFR. In real life an improvement of 10% on load factor is rarely achievable. This is either due to the uneven flow of cargo in outbound and inbound legs of the round voyage whereby increasing cargo on one leg of the journey will have less impact on the overall load factor or due to overtonnage on certain routes. A realistic assumption of load factor would be 68% under open competition but by better balancing of demand and supply under co-ordinated competition a load factor of 85% might be achievable (130).

Another possibility is to make additional calls at one or more ports to get more cargo but with the attendant increase in the distance steamed. A trade-off between the extra revenue gained and the extra costs incurred may show this to be an economic choice.

Life of container (LIFEC)

A container life of 8 years was thought to be a reasonable assumption when the first purpose built containerships came into service. Presently it is thought to have a life of 12 to 15 years. There is no clear indication as yet on what the life of a container should be (see Section 11.5). This is mainly due to the fact that it is nearly 12 years (1968-1980) since the first generation of purpose built containerships came into operation which is less than the expected life. Moreover shipowners usually undertake major refurbishing so as to extend the life of the containers. Since in the model a new set of containers is added every 8 years, a large amount of negative cash flow occurs earlier than it would if the container life was extended to 12 years. This indicates that the present policy of shipowners to refurbish steel containers every 5 years (Section 11.3) is based on sound economic judgement.

Port time (DIP)

The proportion of port time to sea time of container ships is governed by the round voyage distance, the number of ports of call and the number of containers loaded and unloaded. The North Atlantic Route is a short route and it is assumed that the containership loads and unloads all of its containers at each end of the sea leg. This means that the ship considered spends roughly equal time at sea and in port.

Reduction in port time like the round trip distance increases the number of round trips per annum (5%). This in turn increases the fuel costs (3%), container handling costs (5%) and port entry and exit costs (5%). Port daily costs are reduced (5%) because of shorter port time and the overall port costs are reduced by 2%: the operating costs increase by 3% but the increased number of round trips/annum increases the amount of cargo carried per annum (5%) which more than offsets the increased cost of operation.

The importance of port time on longer routes will be less pronounced since the proportion of port time to sea time will be appreciably lower for this type of ship.

Container handling cost (CHANDL)

Container handling cost forms nearly 50% of the total operating cost. A 10% improvement in container handling costs reduces the operating costs by 5%.

Container handling costs are more or less uniform worldwide. Thus a change of container route will not bring about significant change in container handling costs. A 20' container costs as much to handle as a 40' container and there are hardly any rebates, except in a few ports (see Section 10.9), for empty containers. Therefore reduction in handling costs cannot be achieved either by a cargo mix of 20' and 40' container or by a reduction of the load factor.

However more sophisticated routing control of containers themselves may minimise the carriage of empties. Ports with flexibility of labour are to be preferred.

Installed power (SHP)

A 10% reduction in installed power reduces the machinery weight (7.8%) and the weight of fuel (8.5%). In a similar manner to reduction of steel weight the number of containers from the deck are reduced by 3, 5 and 8 for containership designed with average weight of each container 14, 10.5 and 7 t. The average weight of each container is able to rise by 0.8 t, 1 t and 1.4 t respectively. There is reduction in material cost (3.5%), cost of labour (1.5%) and cost of ship by (2.5%).

Operating costs reduced by 2% due to reduction in the fuel oil costs (7.5%), machinery maintenance costs (10%) and insurance cost of (2.5%). Cargo deadweight carried per annum increases by 1% to 2%.

Improvements in the installed power are steady but unlikely to achieve a break-through unless methods to reduce frictional resistance substantially, reach fruition. Practical trade off studies between the costs of frequent dry dockings or underwater hull polishing afloat and propeller polishing may indicate the advantage of these measures in reducing the installed power. However reserve power is always required from time to time to maintain schedules and it may be necessary to look carefully at diesel engine design to extend overload running. Standard definition of continuous service power would also be an advantage.

Cost of Container (COSCNT),
Number of Sets of Containers (SETCNT)

The cost of containers and the number of sets of containers will have a lesser impact on RFR than extending the life of the containers. A reduction of 10% in the cost of containers is less probable since the cost of containers world wide are more or less uniform at £ 2500 per container

(1980 cost level). However a larger variation is found in the number of sets of containers required (see Fig. 11.1). With the number of round trips per annum of 13, the number of container sets can vary from 1.8 sets per ship to 3.5 sets per ship depending on the frequency of service and the box turnaround time. Therefore reductions in the required number of sets of containers per ship is more probable.

Specific fuel consumption

A reduction in specific fuel consumption reduces the weight of fuel (10%) and the cost of fuel (10%). Similar to reduction in steelweight and installed power, the reduction in weight of fuel results in loss of 3 containers from the deck with negligible effect on the cargo deadweight.

Its effect on operating costs has ensured that steam machinery with its inherently higher fuel consumption is not being fitted in new vessels and is being replaced by diesel engines in existing ones. The benefit of relatively cheaper fuel in steam engines is quite outweighed by relatively higher fuel consumption when compared with diesel machinery.

Great effort is being made among diesel engine manufacturers to reduce fuel consumption and the present trend is towards uniflow scavenged long bore engines with very low RPM. The benefits in propeller efficiency from low RPM remain an important aspect of fuel economy.

Ship's First Cost (CAPCOS)

Container ships usually have very high values of First Cost because they are relatively sophisticated vessels. In unusual economic circumstances the purchase price may be below the cost but such circumstances either correct themselves by bankruptcy or become a permanent subsidy and thus essentially a lower first cost. Practical reduction in First Cost must include very careful scrutiny of specifications to ensure that unnecessary items are omitted, value is obtained for necessary items and any breakthroughs in new materials or cost of items are exploited. The other main source of reduction is that of exploiting to the full competitive pressures and state intervention. Also a reduction in First Cost reduces risk as it limits the amount of immediate investment.

Fuel Oil Costs (COFUEL, CDESL, CLUBSY, CLUBSY)

Fuel oil cost is about 27% of total operating cost and a 10% reduction in fuel cost will reduce operating cost by 2.5%.

Between 1973 and 1980 the price of fuel oil has increased by a factor of 7.7 and diesel oil by a factor of 8.5. Substantial fuel price increase usually results in lower economic speed as previously considered. The longer voyage times that result from lower speed increase crew costs and capital costs on a tonne mile basis. Since fuel prices are very liable to increase it would be important for the design to be as insensitive as possible to these increases which might otherwise demand premature slow steaming, a competitive disadvantage.

Life of Ship (LIFES)

An extension to the life of the ship has little effect on a comparison that uses present worth as does RFR, for with the high interest rates now common a future beyond twenty years has little influence. Perhaps this is more a weakness in the measure of merit than an accurate observation, for vessels aged twenty today are kept in service as long as they are profitable. Much must depend on technological change. If hull sizes and shapes are not profoundly influenced by change, re-engining and re-equipping may become commonplace, as a means of securing an effectively new ship at low cost. Certainly much change in the area of machinery and equipment is to be expected but technological obsolescence may very well overwhelm the whole vessel. If the life of the ship is to be preserved beyond twenty years more allowance for old age may need to be made in the new vessel with consequent increase in Capital Cost.

Shipbuilding Labour Wage Rates (WR)

A 10% improvement in labour wage rates decreases the labour costs by 10% and the capital cost by 5.0%. A shipowner has a choice here for improvement by placing his order in a country with lower wage rates and for a shipbuilder it shows that a decrease in labour costs can have significant effects on the overall economics of the ship. Improvements in labour productivity will have the effect of reducing the wage rate but with so many labour overhead costs dictated by government labour legislation, wage rates are liable to increase.

Wages of Crew, Petty Officers and Officers (WCREW, WPO, WOFF)

Crew costs which is normally 57% of the daily running costs, can vary by a factor of 8 for ships under different flags. Therefore a shipowner has more scope to achieve a 10% reduction if the political climate allows him, or the legal or national boundaries no longer constrain him, from selecting crew from the developing world with attendant lower costs. However a 10% improvement in crew costs brings about only 1% reduction in the operating costs.

The daily operating costs are crew costs, maintenance and repairs, hull and machinery, insurance and stores and provisions. Excluding crew costs the magnitude of other costs will vary little between similar ships of any flag engaged in a similar trade assuming a standard level of operating efficiency. Therefore a shipowner usually seeks a reduction in crew costs by either employing crew with lower wage demands or by reducing the number of crew where this is not possible and promoting interchangeability of crew within each ship.

Port Costs (CPORT)

Port costs form nearly 6.5% of the operating costs for the basis ship. Therefore a 10% improvement in port costs reduces the operating costs by 0.65%. Port costs will vary from port to port and will also depend upon the number of ports of call. Large variations in port costs are possible, even a factor of 10 (see Section 10.7). Although a shipowner will have little choice in influencing directly the port costs except perhaps by rebates given by certain port authorities which are negotiable. A considerable saving may be achieved by omitting certain ports of call with attendant benefit of lower steaming distance. But this must be traded off against any loss of earnings. The significance on the RFR is low, showing that simpler equations than those developed in this thesis may be incorporated in the program e.g. port costs expressed as a function of net registered tonnage.

Gross Registered Tonnage (GRT)

The total port costs were made a function of GRT, therefore a 10% reduction in GRT will decrease the port costs by (6.5%) and the operating costs (0.5%). There is little to be gained in reducing the GRT since port costs have little significance on the RFR. No great change is expected with the 1969 tonnage regulations.

Steel Costs (STLCOS)

A 10% reduction in the cost of a tonne of steel reduces the total material cost (3%) and the total cost of the ship (1.5%). The hull insurance and the war risk insurance reduces by the same amount but has negligible effect on the operating costs.

Containerships require some high tensile steel and some areas need attention to the notch toughness of the steel, consequently such vessels cannot take great advantage of a market surplus of mild steel. Ultimately greater efficiency within the steel industry may particularly benefit containerships. Steel pricing is a complicated function of amount, sizes and quantity. The builder by care in construction methods and by minimising scrap may be able to secure reduction in steel costs.

14.3.2. Variation in number of ports, ship size and speed. (Case 1)

Ships of container capacity 1000 Teu, 1500 Teu and 2000 Teu were selected to study the effect of increasing the number of Ports on Required Freight Rate. The speed of the ships were varied from 15 knots to 27 knots with a step size of 3 knots. Fig. 14.18 shows the effect of increasing the number of ports of call on the Required Freight Rate with changing ship size and speed. Fig. 14.19 shows the effect of increasing the ship's speed on the Required Freight Rate with changing ship size and the number of ports of call. Fig. 14.20 shows the effect of increasing the ship's size on the Required Freight Rate with changing speed and number of ports of call.

The rate of change of RFR with increasing number of ports of call is linear. The economy of scale of ship size at all speeds is apparent from the lower slopes of the lines with increasing ship size (Fig. 14.18).

The rate of change of RFR with increasing speed has a less pronounced effect on bigger ships compared to the smaller ships (Fig. 14.19) and at higher speeds of 27 knots for 4 and 8 ports of call (Fig. 14.20) ships above 1850 Teu show a lower Required Freight Rate.

For speeds up to 21 knots the 1500 Teu ship shows a lower Required Freight Rate for 8 ports of call (Fig. 14.19, Fig. 14.20). At higher speeds of 27 knots and increasing number of ports of call the larger ships above 1850 Teu are able to carry more cargo per annum which more than offsets the higher operating and capital costs and therefore show a lower Required Freight Rate.

Fig. I4.I8 Variation in number of ports, ship size and speed.
(Number of ports versus Required Freight Rate)

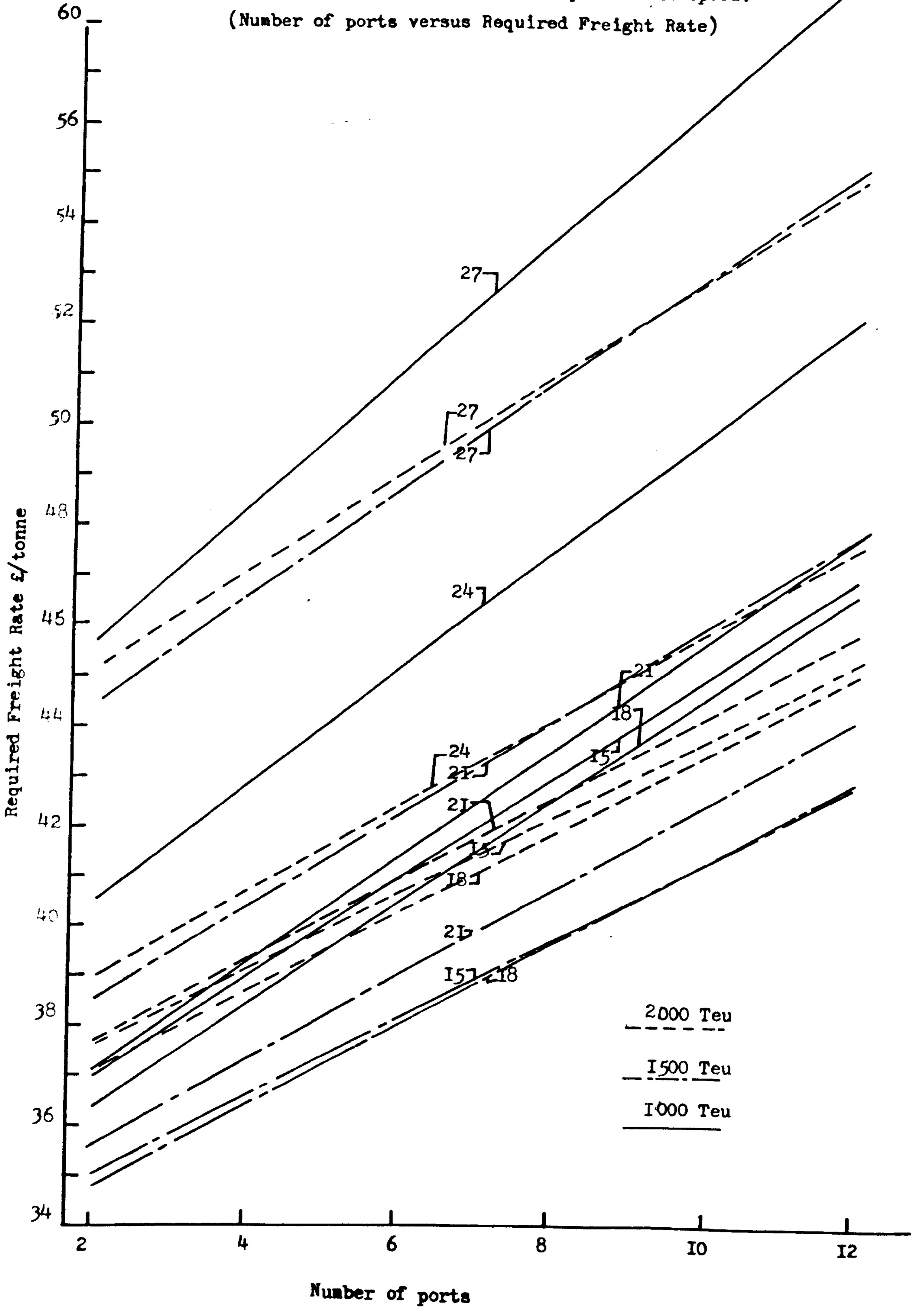
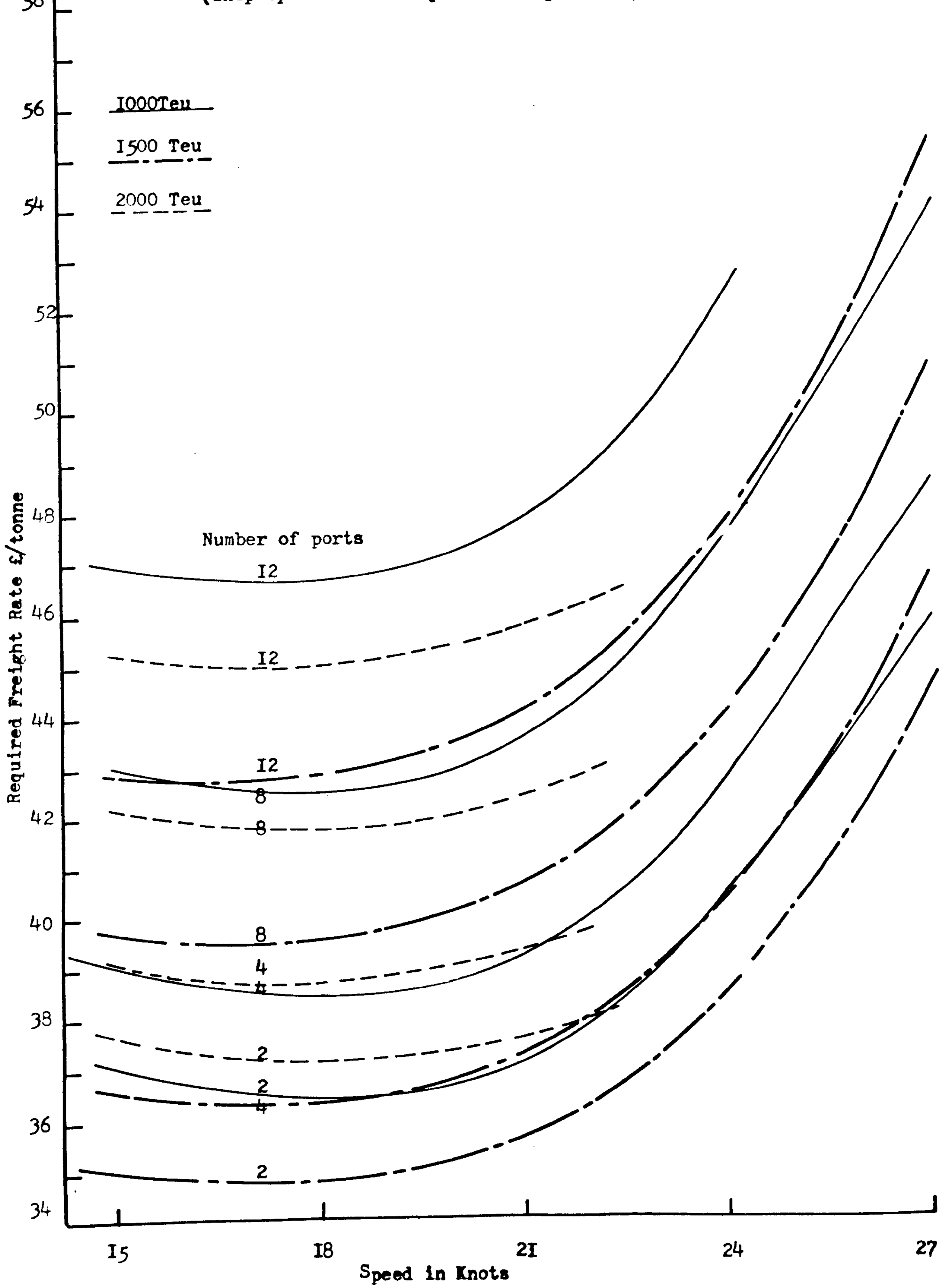


Fig.14.19 Variation in number of ports,ship size and speed.
(ship speed versus Required Frieght Rate)



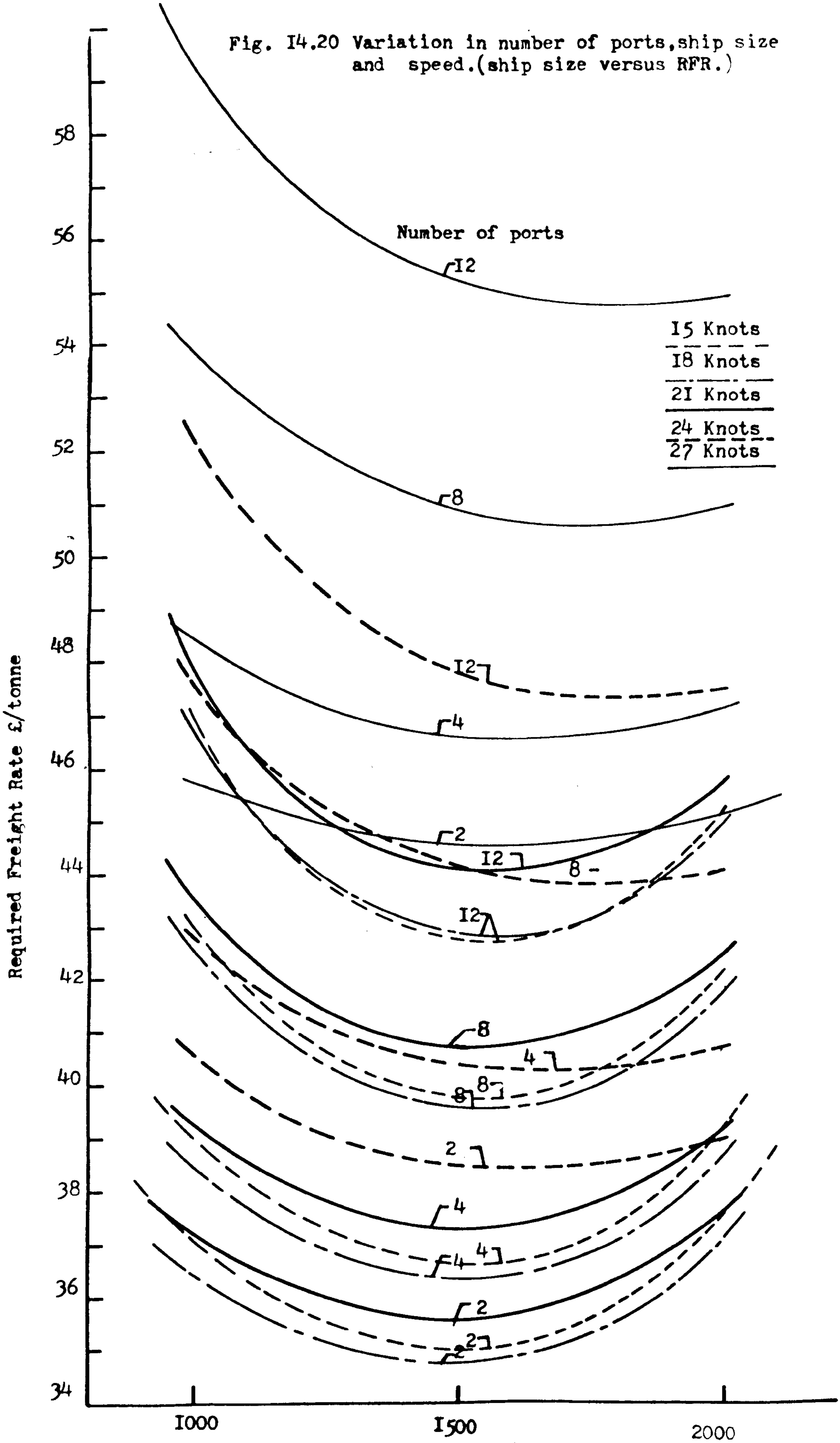


Fig. I4.20 Variation in number of ports, ship size and speed. (ship size versus RFR.)

14.3.3. Variation in delays, ship size and speed (Case 1).

The effect of delays in port on the Required Freight Rate was studied for ships of similar container capacity and speed as given in the previous section. The delay in port, was associated with any type of delay caused over and above the required time in port. Delays of one to five days were introduced.

Figure 14.21 shows the effect of increase in delay on the Required Freight Rate with changing ship size and speed.

Figure 14.22 shows the effect of increasing speed on the Required Freight Rate with changing ship size and delays of 3 and 5 days. It was assumed in Section 14.1 that there was no delay in port over and above the port time required for berthing/unberthing and loading/unloading the ship.

Figure 14.23 shows the effect of increasing the ship size on the Required Freight Rate with changing values of ships speed and delays.

Like previous sections the economy of scale in ship size is shown by the lower slopes of the lines of Required Freight Rate with increase in delay. This rate of increase in the RFR with delay is linear (Fig. 14.21).

Ships of 1500 Teu show a clear advantage over other ship sizes for speeds up to 27 knots for delays of 3 days (Fig. 14.22). For delays of 3 and 5 days at speeds higher than 24 knots, ships above 1900 Teu give a lower Required Freight Rate (Fig. 14.22, Fig. 14.23) than the 1500 Teu ship.

With increase in port time the port costs increase, but time spent in port does not much affect the optimal speed (Fig. 14.22) although it increases the cost per tonne mile and increases in these factors, therefore, tend to accentuate the penalty paid if the ship is operated away from its optimal speed. However a decrease in port time encourages higher speeds due to the higher proportion of sea time where the speed could be used.

Fig.I4.2I Effect of delays on ship size, speed and Required Freight Rate
(Delay versus Rrequired Freight Rate)

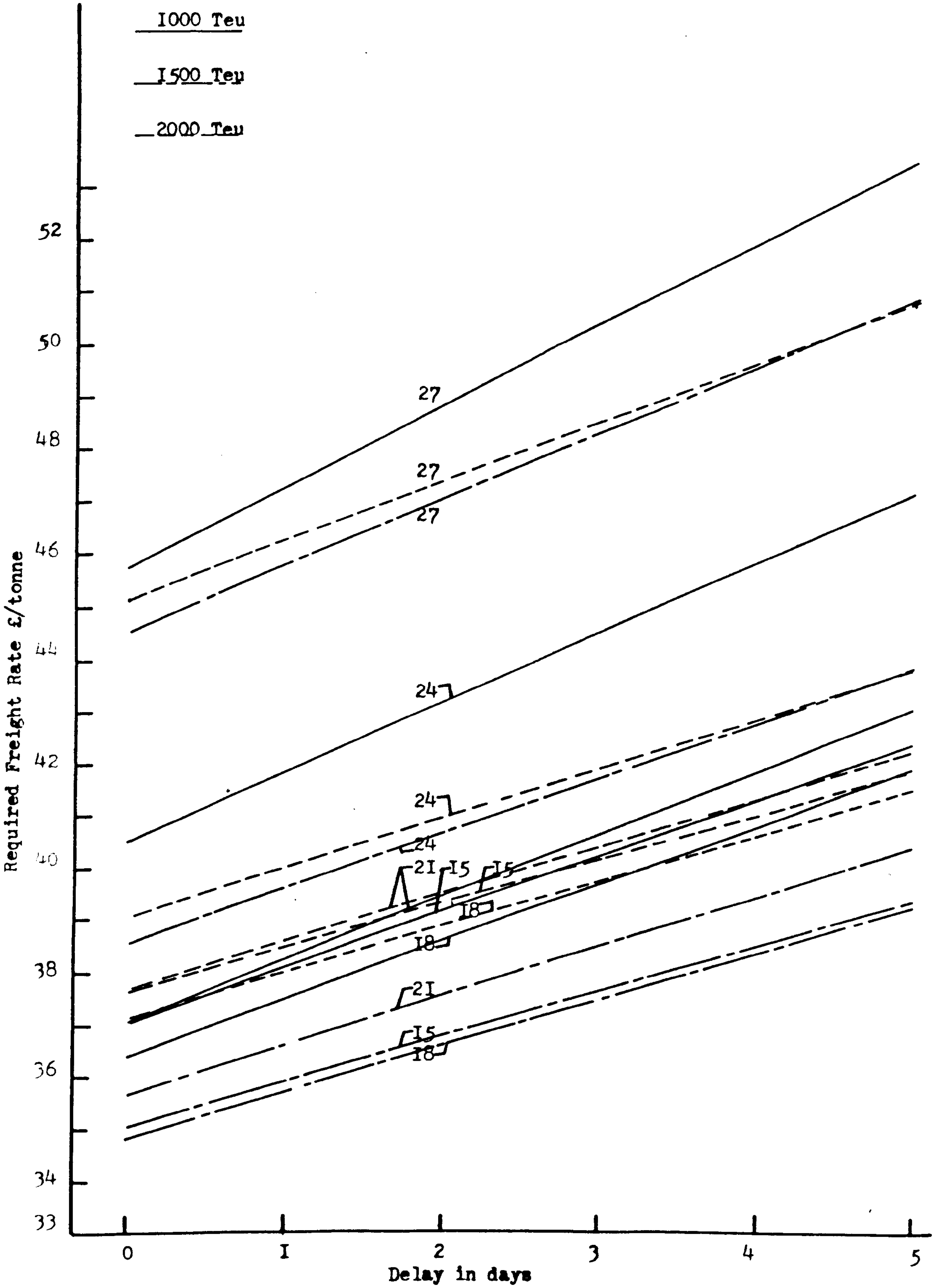


Fig.I4. 22 Variation in ship size,speed and delays.
(ship speed versus Required Freight Rate)

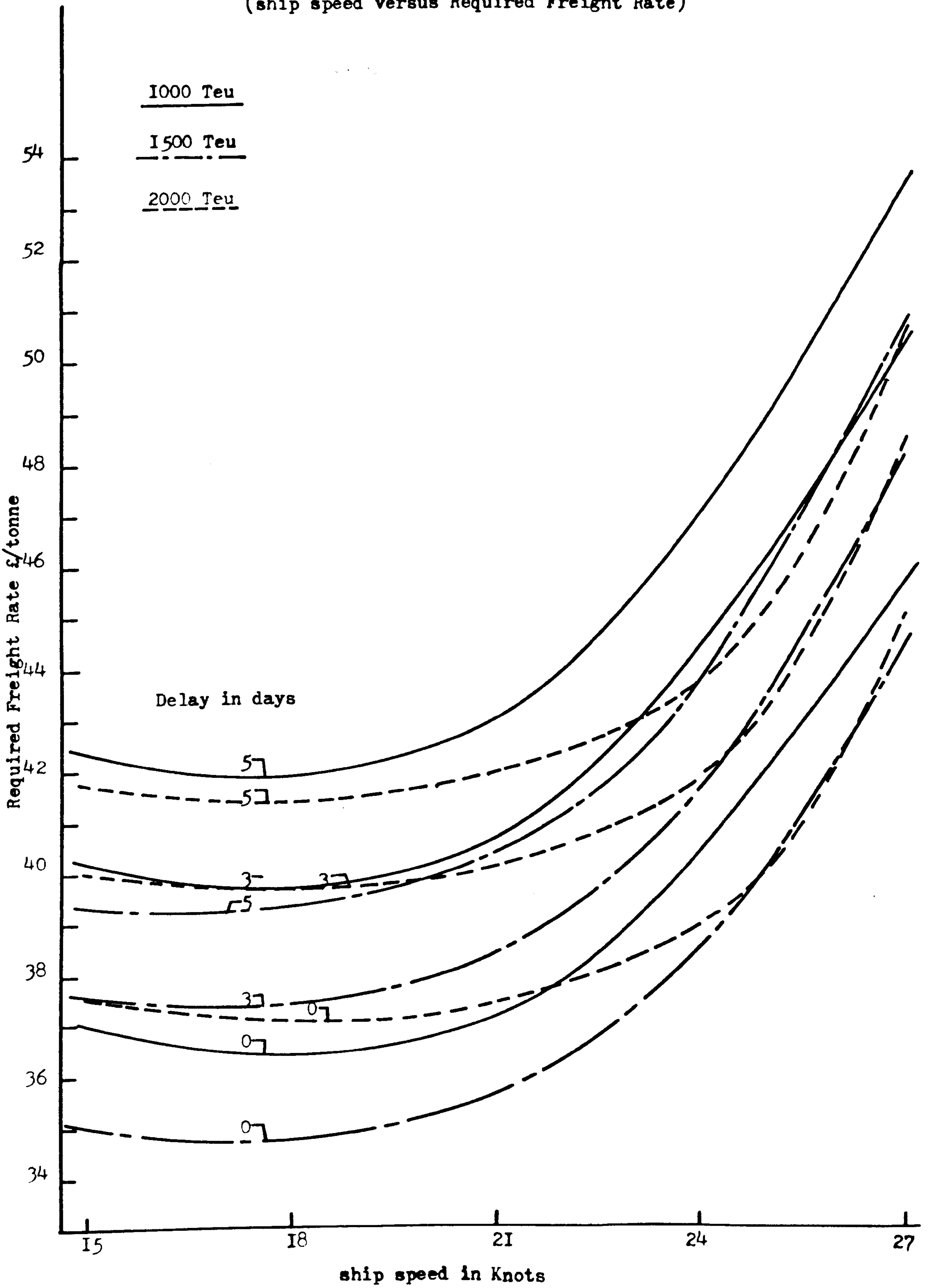
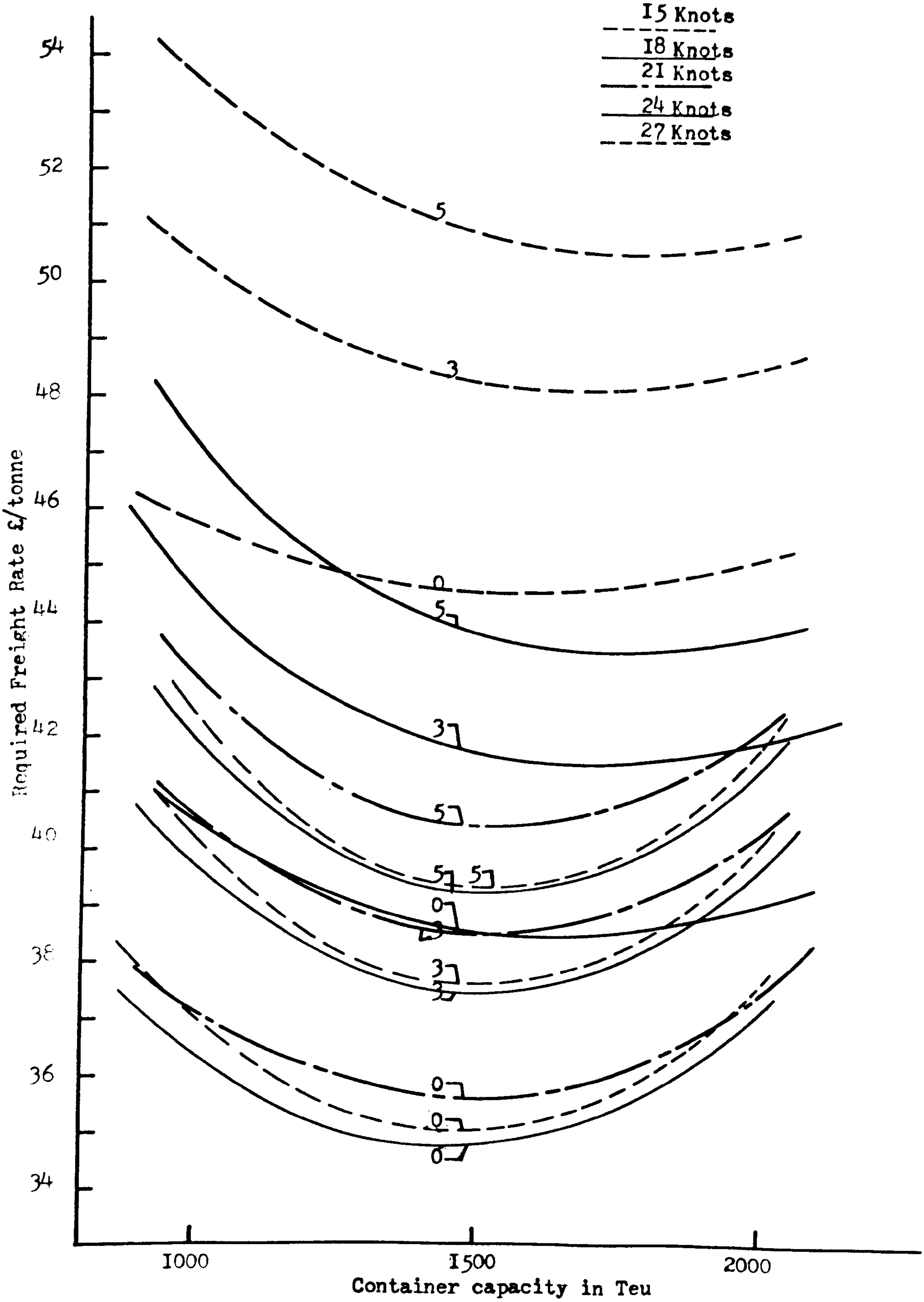


Fig.14.23 Variation in ship size,speed and delays (ship size versus Required Freight Rate)



14.3.4. Variation in Discount Rate, Income Tax and Ship's Life (Case 1).

A ship of container capacity of 1500 Teu and a speed of 21 knots was used to study the effect of variation of Discount Rate and Income Tax on the Required Freight Rate and determine the optimal life of the ship.

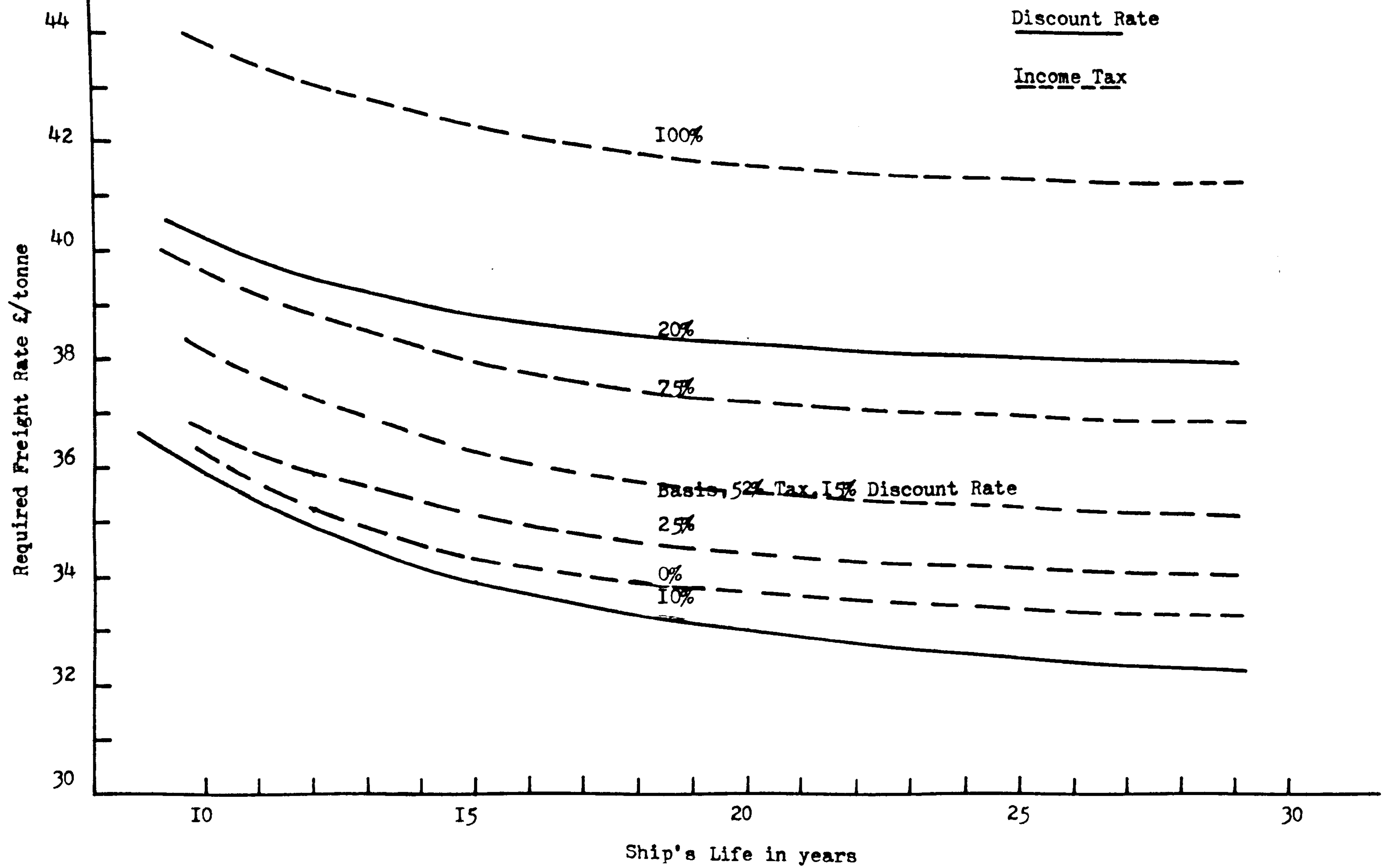
Fig. 14.24 shows the effect on the Required Freight Rate with increasing or decreasing ship's life for various values of Income Tax Rate and Discount Rate.

For the basis ship at 15% Discount Rate and 52% Tax, there is little advantage in extending the life of the ship beyond 24 years. Lowering the Discount Rate to 10% extends the life of the ship beyond 29 years but at those levels of profitability (or implied income) the shipowner will not be willing to invest in new building.

Lowering or raising the value of money or Discount Rate has more effect on the Required Freight Rate than the Tax Rate. Large variations in Tax Rate from no tax position to 75% Tax Rate have less pronounced effect on RFR than doubling the Discount Rate from 10% to 20%.

Free depreciation is assumed in the thesis which means a shipowner is allowed to write off his capital allowances against profit as quickly as profits permit. For some part of the ship's life a shipowner does not pay any taxes therefore the influence of Tax Rate on RFR is less pronounced. It may remain an advantage to pay tax if substantial investment grants exist as a part of the tax system.

Fig.I4.24 Variation in Discount Rate, Income Tax and Ship's Life



CHAPTER 15

EVALUATION OF RISK IN MARINE CAPITAL INVESTMENT

15.0 INTRODUCTION

15.1 APPROXIMATE ESTIMATE OF RISK

15.1.1. SENSITIVITY ANALYSIS IN THE DETERMINISTIC APPROACH

15.1.2. SENSITIVITY ANALYSIS IN THE PROBABILISTIC APPROACH

15.1.3. RANKING OF INFLUENCING VARIABLES

15.2. PROBABILISTIC APPROACH TO RISK ANALYSIS

15.2.1. ANALYTICAL APPROACH

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15.3. APPLICATION OF RISK ANALYSIS TO CAPITAL INVESTMENT

15.3.1. COMPUTER ALGORITHMS

15.3.2. PROGRAM STRUCTURE & INPUT/OUTPUT

15.3.3. REQUIRED FREIGHT RATE ASSUMING NO DEPENDENCIES

15.3.4. REQUIRED FREIGHT RATE ASSUMING DEPENDENCIES

15.0 INTRODUCTION

In the last chapter sensitivity analysis was used to identify the variables which had most influence on the Required Freight Rate. A sensitivity analysis for a pre-defined improvement of 10% was used for this purpose. It was pointed out that in real life a 10% improvement of some of the variables may not be possible. The importance of the uncertainty surrounding each of these variables was identified by merit ranking of the variables and it was explained that effort needs to be expended in getting a better estimate of those variables which had significant influence on RFR.

To account for uncertainty surrounding some of these variables and also to assess the influence of each of these variables on RFR, based on possible variation, rather than an arbitrary 10% variation, a new technique is introduced.

This new technique involves carrying out a sensitivity analysis based on three possible estimates. The user needs to supply, besides the best estimate of a variable as in computer Model I and Model II, two other estimates. These are the 'pessimistic' estimate and the 'optimistic' of a variable. These three values of a variable, representing the uncertainty and also their possible variation are used by computer Model III for merit ranking. Computer Model III forms an extension to the Computer Model I. It also shows how the total risk involved in undertaking a capital investment in containerships can be assessed by Computer Model III. Computer Model III also identifies in an approximate way, the contribution of each of the variables to the overall risk.

'Pessimistic' and 'optimistic' estimates provide an indication of the uncertainty surrounding the best estimate made for a particular variable but, for a complete description of the uncertainty, a probability distribution is required. This is derived by Monte Carlo simulation using Computer Model IV. The usefulness of generating a risk profile of the RFR is indicated together with how dependencies between variables can be ascertained.

15.1. APPROXIMATE MEASURE OF RISK

There are various ways to account for Risk in a deterministic approach to evaluate alternative designs. A few of them are mentioned here.

(a) Pay back Period Method
(b) Risk adjusted Discount Rate
(c) Making conservative adjustment to data values
(d) Raising the minimum acceptable rate of Return
(e) Running Multiple cases.

The various disadvantages of these methods are given by Klausner (204). All the methods a), c), d), e) do not account for risk explicitly and thereby obscure the true risk involved in the capital investment. The most common of these methods is the risk adjusted Discount Rate, which accounts for risk explicitly and is discussed briefly below.

Subjectively discounting for risk

In this technique the acceptable rate of return to reflect the degree of uncertainty felt about the investment outcome is incorporated by discounting at this rate of return. The less certain the investment data values or greater the risk involved the higher the minimum acceptable rate of return. As a consequence, the specification of the appropriate interest rate becomes a matter of subjective judgement without clarifying the risk inherent in the nature of the capital investment and herein lies the principal weakness of the technique.

15.1.1. SENSITIVITY ANALYSIS IN THE DETERMINISTIC APPROACH

This is the traditional approach which was applied in the deterministic stage using Computer Model I and Model II. Most of the estimates of the cost items, weight items and other input variables such as load factors and number of sets of containers were best estimates. Some degree of uncertainty was incorporated by carrying out a sensitivity analysis to identify the variables which had the most influence on the RFR. Further effort is then spent in getting better estimates of only these items. In addition several such sensitivity analyses can be carried out by replacing the best estimates by their pessimistic or optimistic values. The basic idea is simple: if a change in a variable has very little effect on the RFR, then the investment decision is not likely to depend to any great extent on the accuracy of the estimate of that variable. On the other hand, if a change in the estimate produces a large change in the RFR then the uncertainty surrounding the variable may well be a significant consideration when the investment decision is being made. Thus sensitivity analysis can be regarded as a way of quickly identifying those variables which contribute most to the risk of the investment.

The first disadvantage of this model is that it is subject to bias, which occurs if some statistic such as the median or mode is used as the 'best' estimate instead of the expected value (mean) (205).

The model does not formally include uncertainty, and only crude ideas of risk can be obtained. Using pessimistic estimates for all factors, for example, may give an idea of RFR if all goes wrong, but the probability of this occurrence, or the probability of more realistic estimates, is hard to evaluate by sensitivity analysis.

The major disadvantage of sensitivity analysis is that the 10% changes in the most likely estimates may not be directly comparable. For example, a 10% change in operating cost estimate might be quite reasonable, whereas a 10% change in the distance between ports of call may not be achievable. The next section will show how this can be overcome by a new method of sensitivity analysis.

It is also customary to consider only changes in one variable at a time. (The other variables in sensitivity analysis are assumed to be at the 'best' estimates). The effects on the RFR of combinations of changes in different variables is, therefore, largely ignored (4).

A methodological difficulty with sensitivity analysis arises when there is a dependence between two variables, because then it is not strictly correct to consider changes in only one variable at a time (4).

15.1.2. SENSITIVITY ANALYSIS IN THE PROBABILISTIC APPROACH

The ideas presented in this section were developed by Hull '80 (4). Required Freight Rate was the measure of merit selected.

The objective function is then expressed as

$$RFR = f(X_1, X_2, X_3 \ldots\ldots X_n) \qquad \text{Eq. 15.1}$$

which is a non-linear function of independent and dependent variables $X_1, X_2, X_3 \ldots\ldots X_n$. Some of the variables are uncertain variables. A sensitivity analysis generally calculates for a certain variable j:

$$\triangle RFR = f(E_1, E_2, \ldots E_{j-1}, (E_j + \triangle E_j), E_{j+1} \ldots E_n) - f(E_1, E_2 \ldots E_n)$$

Eq. 15.2.

where E_j is the most likely estimate of X_j and $\triangle E_j$ is a change in the value of E_j. For sensitivity analysis in the deterministic approach the value of E_j is usually taken as a fixed percentage of the variable such as a 10% improvement. A methodological difficulty with such an approach is that a 10% improvement in distance is not directly comparable to a 10% improvement in say operating costs primarily because a 10% improvement in operating costs is conceivable whereas in distance it is not. In this new approach the user inputs, besides the most likely estimate two other estimates. These are the pessimistic and the optimistic estimates.

Table 15.1. Sensitivity Analysis, Computer Model III.

Variable	Most Likely Estimate	Opti- mistic estimate	Pessi- mistic estimate	RFR for optimistic estimate RFR_1	RFR for pessi- mistic estimate RFR_2	$(RFR_1 - RFR_2)$ Range of RFR
1	2	3	4	5	6	7

For each of the variables Table 15.1 shows,

(a) The values of RFR when the variable is equal to its optimistic estimate, all other variables being equal to their most likely values (col. 5).

(b) The values of RFR when the variable is equal to its pessimistic estimate, all other variables being equal to their most likely values (col. 6).

(c) Range of RFR, difference of values of RFR in col. 5 and col. 6.

The final column in this table provides a set of numbers which are directly comparable.

The definition of the terms 'optimistic estimate' and 'pessimistic estimate' deserve some consideration. It is not necessary for the optimistic estimate to be the 'best conceivable' value for the variable and for the pessimistic estimate to be the 'worst conceivable' value. It is however necessary to be consistent in the use of the terms. In this thesis it is assumed that U_j is equal to the higher of the optimistic and pessimistic estimates, and L_j is equal to the lower of the two. The optimistic estimate for a variable is not always higher than its pessimistic estimate for example variables such as costs the reverse is true.

The difference between U_j and L_j is referred to as the range of variable j and S_j is the sensitivity coefficient. Where S_j $(j = 1,n)$ can be defined as

$$S_j = f(E_1,E_2 \ldots E_{j-1}, U_j, E_{j+1} \ldots E_n) - f(E_1,E_2,E_{j-1}, L_j,E_{j+1} \ldots E_n) \qquad \text{Eq. 15.3}$$

and can be used to provide an indication of the relative importance of different variables.

<u>A simple linear Model</u>

If the RFR is considered to be a linear Model, then it can be expressed as

$$RFR = f(X_1,X_2 \ldots . X_n) = \sum_{j=1}^{n} a_j X_j \qquad \text{Eq. 15.4}$$

where a_j's are constant and x_j's are independent. This model is appropriate in relatively simple situations, for example where each of the X_j represents an inflow or outflow of cash. However, it is worth examining the model in detail because it suggests results which might be approximately true in a wide range of situations.

It is easy to see that the model implies

$$S_j = a_j(U_j - L_j) \qquad \text{Eq. 15.5}$$

Further

$$\mu_{RFR} = \sum_{j=1}^{n} a_j u_j \qquad \text{Eq. 15.6}$$

and

$$\sigma^2_{RFR} = \sum_{j=1}^{n} a^2_j \ \sigma^2_j \qquad \text{Eq. 15.7}$$

where μ_{RFR} and σ_{RFR} are the mean and standard deviation of RFR and μ_j and σ_j are the mean and standard deviation of X_j. Defining

$$K_j = \frac{\sigma_j}{U_j - L_j}$$

for all j it follows from eq. 15.5 and eq. 15.7 that

$$\sigma^2_{RFR} = \sum_{j=1}^{n} K_j^2 \ S_j^2 \qquad \text{Eq. 15.8}$$

This is an interesting result as it shows that an estimate of σ_{RFR} can be obtained from the sensitivity coefficients and estimates of K_js. If it is assumed that K_j is approximately constant for all j, that is, standard deviation of a variable is approximately proportional to its range, then Eqn. 15.8 implies that it is the square of the sensitivity coefficient of variable j which in effect determines the

contribution of the variable j to σ^2_{RFR}. Therefore it implies that if one variable has half the sensitivity coefficient of another variable then its contribution to σ^2_{RFR} will be one-quarter as much and that less sensitive variables contribute very little to the overall uncertainty.

Hull (4) 1980 who developed this technique applied the above linear model to four well documented case studies. All the case studies involved cash flow models which were non-linear. One of these models was highly non-linear. The objective function RFR given by Eq. 15.1 is also non-linear; not a simple non-linear problem, but one which cannot even be approximated by a series of linear segments. 'Highly non-linear' would be an appropriate term to use (206).

<u>Approximate value of standard deviation of the Required Freight Rate</u>

The first key result produced for the linear model was

$$\sigma_{RFR} = \sqrt{\sum_{j=1}^{n} K_j^2 \ S_j^2} \qquad \text{Eq. 15.9}$$

Application of this relationship to the non-linear models by Hull (4) showed that if variables are independent, Eq. 15.9 gives an approximate measure of the standard deviation of the measure of merit.

Therefore to estimate σ_{RFR} it is necessary to provide

(a) the estimates U_j, L_j and E_j for each variable and

(b) estimate $K_j = \dfrac{\sigma_j}{U_j - L_j}$ for each variable j.

Estimating K_j is not straightforward. Assuming that L_j corresponds to 0.05 fractile and U_j corresponds to 0.95 fractile a reasonable value of K_j is 0.30 for a normal distribution (4).

Therefore the total risk involved in a capital investment in ships as defined by σ_{RFR} can be evaluated by using this form of sensitivity analysis.

<u>Approximate value of the mean of the Required Freight Rate</u>

The usual approach, as applied in the deterministic stage of the design, to obtain the best estimate of RFR is to combine together best estimates of the individual variables, that is

$$\mu_{RFR} = f(E_1, E_2 \ldots E_n) \qquad \text{Eq. 15.10}$$

where $E_1, E_2 \ldots E_n$ are the best estimates of the variables. However Hull (4) has shown that this can lead to serious errors particularly when some distributions are skewed. This is because the best estimate of a variable corresponds to its mode and not to its mean. Also the best estimate of a function is not always the function of the best estimates of the variables (207). Therefore,

$$\mu_{RFR} = f(\mu_1, \mu_2 \ldots\ldots \mu_n) \qquad \text{Eq. 15.11}$$

should be preferred to Eq. 15.10 for calculating the best estimate of Required Freight Rate.

The mean of the individual variables is then derived from the following formula often used in PERT applications

$$\mu_{j} = 1/6(L_j + 4E_j + U_j) \qquad \text{Eq. 15.12}$$
$$j=1,n$$

This approach is adopted for calculating the expected mean value of RFR.

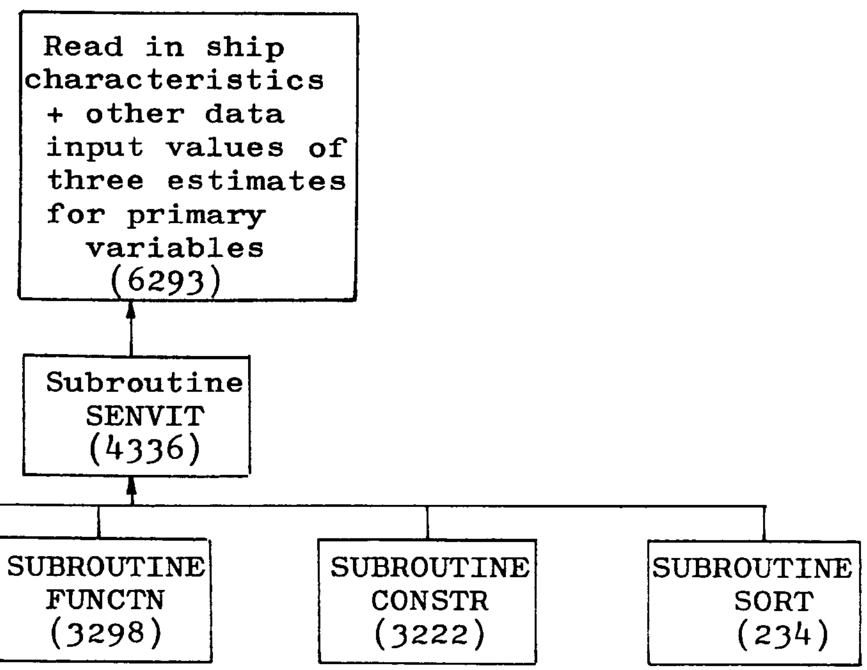
Computer Model

FORTRAN computer codes for carrying out the above sensitivity analysis were developed by Hull (4) 1980. These were modified to suit the requirements of the preliminary ship design problem. The overall program structure is shown in Fig. 15.1. Two subroutines were written for this analysis. These are the subroutine subprograms FUNCTN and CONSTR as developed in computer Model II in the deterministic phase. The subroutine subprogram SENPAR, SENVIT and SORT were modified and adopted from Hull (4) 1980. The main program of computer Model I, was modified to read three values of the input variables. The functions of the various subprograms are discussed below.

a) Main program. This program is the same as in computer Model I and Model II, except that three estimates of each variable are input for which the sensitivity analysis is to be carried out. A sample input data list is shown in Fig. 15.2.

Fig. 15.1. Program structure probabilistic phase, to carry out sensitivity analysis, measure of risk and ranking of variables in order of importance.

(Computer Model III)



(Figures within brackets indicate the program size excluding common statements, Total = 132 K)

Fig.I5.2. Input data, sensitivity analysis,container capacity 2250 Teu and speed of I8 Knots

SENSITIVITY ANALYSIS

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  36NVAR
OVHEAD             100.000    90.000   200.000
WR                   2.400     2.000     3.000
STLCOS             214.000   200.000   250.000
SINDEX             169.300   150.000   200.000
PROFIT              15.000    20.000     5.000
CHANDL              50.000    40.000    60.000
CLUBCY             560.000   500.000   600.000
CLUBSY             470.000   400.000   500.000
CDESL              145.000   125.000   180.000
COFUEL              80.000    60.000   100.000
WOFF              8400.000  8000.00010000.000
WPO               5400.000  5000.000  7000.000
WCREW             5300.000  5000.000  6000.000
PCINT               12.000    10.000    15.000
YRLOAN               7.000     8.000     9.000
STEELF               0.032     0.029     0.035
OUFITF               0.320     0.300     0.340
SLIFE               20.000    25.000    15.000
DISCNT              15.000    12.000    18.000
ALFO                 0.850     0.900     0.750
ALFI                 0.800     0.850     0.700
CLIFE                8.000    10.000     6.000
SETCNT               2.500     1.800     3.000
CPINT               10.000     9.000    12.000
COSCNT            2500.000  2250.000  3000.000
PCFD                 2.700     1.500     3.300
PCFF                 2.100     1.500     3.300
PECFD                7.600     3.600    11.600
PECFF               11.600     3.600    11.600
RLABF                0.390     0.280     0.500
RLABD                0.680     0.500     0.920
OFF                 12.000    10.000    15.000
PO                   6.000     6.000     8.000
CREW                20.000    18.000    24.000
TAXPCT              52.000    50.000    55.000
DELAY                1.000     0.000     2.000
        INPUT VALUES AS READ IN THE DATA FILE
2250.00CNT 18.00V   3383.0ENDUR  6766.0DIST 1.0PORTF 1.0PORTD
4NCLPH  0.00ABALST 0.03 RGMRB
  9.0SROWS 10.0FROWS 11.0STIER 13.0FTIER 0.550SCB 0.700FCB 10.0ROWS 13.0TIERS
10.00L/DMIN14.50L/DMAX 0.40V-/L 1.50V-/L 6.00L/B 9.00L/B 2.25B/T 3.75B/T
120.00REVSIN2IREVLD2IBALAS 1IPMC 2ISTEEL
 0.00ACONT 0.00ACMANT 0.00ACINS
 0.0AWAGES 0.0ACREW 0.0APROV 0.0ASTORE
 0.0APIINS 0.0AWHINS 0.0AADMIN 0.0ARMANT
 0.0APORT 0.0AFUEL 0.0AHANDL
```

b) Subroutine FUNCTN. This subprogram calculates the objective function, Required Freight Rate after tax and is the same as used in Computer Model II.

c) Subroutine CONSTR. This subprogram checks if any constraints such as minimum dimensions for a given configuration of midship hold tiers and rows, stability, freeboard, seakeeping and others are violated.

d) Subroutine SENVIT. This carries out the sensitivity analysis by the above technique and also calculates the standard deviation and the mean value of RFR. This subroutine is used to output the results as shown in Fig. 15.3.

e) Subroutine SENPAR. This subroutine is used to store the input variables on which the sensitivity analysis is to be carried out in an array W(I).

f) Subroutine SORT. This subroutine uses a straightforward iterative procedure for arranging in order of influence on RFR, the various variables.

Subroutines, such as those to calculate, the weights, costs and other design parameters are as developed for Computer Model I and Model II in the deterministic phase and shown in Fig. 13.10.

15.1.3. RANKING OF INFLUENCING VARIABLES

A computer program was written for the purpose of carrying out this type of sensitivity analysis. The structure of the main program of computer Model I in the deterministic phase was changed. Thirty six input items were chosen to carry out the sensitivity analysis by computer model III. These items were chosen because of their inherent variability. Items such as distance, specific fuel consumption, and installed power were excluded from this list since these will be known at the initial design stage and by their very nature are not subject to much variation. The influence of major items such as ships First Cost or the operating costs on RFR were left to be determined from sensitivity analysis of the more basic variables of labour wage rates, cost of steel, crew wage rates, and cost of fuel. It was felt that

Fig.I5.3. Output,Sensitivity Analysis,container capacity 2250 Teu and speed of I8 knots

VARIABLE NAME	BEST ESTIMATE	OPT. ESTIMATE	PESS. ESTIMATE	PERF. MEAS. AT OPT. EST.	PERF. MEAS. AT PESS. EST.	RANGE OF PERF. MEAS.	RANGE COEFF	PERCENT OF VAR
SETCNT	2.500	1.800	3.000	51.987	57.295	5.308	1.00	18.18
DISCNT	15.000	12.000	18.000	46.526	50.870	4.344	0.82	12.18
WR	2.400	2.000	3.000	39.991	44.188	4.197	0.79	11.37
COSCNT	2500.000	2250.000	3000.000	56.463	60.606	4.143	0.78	11.08
OVHEAD	100.000	90.000	200.000	37.978	41.670	3.691	0.70	8.79
CHANDL	50.000	40.000	60.000	41.943	45.275	3.332	0.63	7.17
DELAY	1.000	0.000	2.000	60.703	63.797	3.093	0.58	6.17
ALFI	0.800	0.850	0.700	50.871	53.670	2.799	0.53	5.05
PROFIT	15.000	5.000	20.000	43.608	46.317	2.709	0.51	4.73
ALFO	0.850	0.900	0.750	49.727	52.182	2.455	0.46	3.89
CLIF	8.000	10.000	6.000	52.841	55.084	2.244	0.42	3.25
PCINT	12.000	10.000	15.000	45.657	47.416	1.759	0.33	2.00
SLIF	20.000	25.000	15.000	47.044	48.654	1.610	0.30	1.67
COFUEL	80.000	60.000	100.000	44.696	46.152	1.456	0.27	1.37
SINDEX	169.300	150.000	200.000	44.136	45.414	1.278	0.24	1.05
OUFITF	0.320	0.300	0.340	46.582	47.551	0.969	0.18	0.61
CPINT	10.000	9.000	12.000	57.026	57.843	0.817	0.15	0.43
STLCOS	214.000	200.000	250.000	44.017	44.629	0.612	0.12	0.24
PCFD	2.700	1.500	3.300	60.287	60.766	0.479	0.09	0.15
TAXPCT	52.000	50.000	55.000	61.788	62.236	0.447	0.08	0.13
RLABO	0.680	0.500	0.920	61.060	61.470	0.411	0.08	0.11
PCFF	2.100	1.500	3.300	60.645	61.008	0.363	0.07	0.08
OFF	12.000	10.000	15.000	61.320	61.669	0.348	0.07	0.08
CREW	20.000	18.000	24.000	61.687	61.962	0.274	0.05	0.05
RLABF	0.390	0.280	0.500	60.995	61.238	0.243	0.05	0.04
CDESL	145.000	125.000	180.000	45.196	45.424	0.228	0.04	0.03
PECFD	7.600	3.600	11.600	60.896	61.121	0.225	0.04	0.03
YRLOAN	7.000	9.000	8.000	47.074	47.243	0.169	0.03	0.02
PECFF	11.600	3.600	11.600	60.953	61.121	0.168	0.03	0.02
PO	6.000	6.000	8.000	61.669	61.787	0.119	0.02	0.01
WOFF	8400.000	8000.000	10000.000	46.129	46.247	0.118	0.02	0.01
WCREW	5300.000	5000.000	6000.000	46.269	46.358	0.090	0.02	0.01
WPO	5400.000	5000.000	7000.000	46.235	46.295	0.061	0.01	0.00
CLUBCY	560.000	500.000	600.000	45.272	45.277	0.006	0.00	0.00
CLUBSY	470.000	400.000	500.000	45.275	45.279	0.004	0.00	0.00
STEELF	0.032	0.029	0.035	47.074	47.074	0.000	0.00	0.00

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR BEST ESTIMATES= 38.31

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR OPTIMISTIC ESTIMATES= 24.34

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR PESSIMISTIC ESTIMATE= 67.89

ESTIMATE OF MEAN OF RFR BASED ON PERT ESTIMATES OF THE MEANS OF VARIABLES= 38.88

ESTIMATE OF S.D. OF RFR BASED ON AN S.D TO RANGE RATIO OF 0.3 FOR THE VARIBLES= 3.73

it is easier to estimate subjectively or objectively the 'pessimistic' the 'most-likely' and the 'optimistic' values of crew wages or labour wage rates than the operating costs and the ship's First Cost.

To assess the variability of say, operating costs, would require the expertise and judgement of an expert. In real life working within the environment of a shipyard design office or with a shipowner's design team this type of co-operation between different departments would be possible. Therefore in real life this technique would incorporate major items like operating costs where the variability could be provided by an expert.

The thirty six items which were included in the list to carry out sensitivity analysis using Computer Model III are listed below in the sequence shown in Fig. 15.2.

1) Shipyard's overhead (OVHEAD) as a percentage
2) Shipyard labour wage rate (WR) in £/hr
3) Cost of steel (STLCOS) in £/tonne
4) Material price index (SINDEX)
5) Shipyard's profit (PROFIT) as a percentage
6) Container handling cost (CHANDL) per Teu per lift
7) Cost of luboil for cylinder (CLUBCY) £/tonne
8) Cost of luboil for system (CLUBSY) £/tonne
9) Cost of diesel oil (CDESL) £/tonne
10) Cost of main engine fuel oil (COFUEL) £/tonne
11) Average wage of officers (WOFF) £/annum assuming 12 officers
12) Average wage of Petty officers (WPO) £/annum assuming 6 PO's
13) Average wage of ratings (WCREW) £/annum assuming 20 ratings
14) Percentage interest on shipbuilding loan (PCINT) in percentage/annum
15) Number of years of repayment of loan (YRLOAN)
16) Steel factor (STEELF), if steel weight estimation method 8 (Section 6.1) was used as the option
17) Outfit factor (OUFITF), used as an input data for calculating the outfit weight (see Section 6.2)
18) Ship's life (LIFES) in years

19) Discount Rate (DISCNT) in percent/annum
20) Outbound load factor (ALFO) in percent
21) Inbound load factor (ALFI) in percent
22) Life of container (CLIFE) in years
23) Number of sets of containers (SETCNT)
24) Interest on container financing (CPINT) in percent/annum
25) Cost of a container (COSCNT) in £/Teu
26) Port daily cost factor (PCFD) home ports (Section 10.7)
27) Port daily cost factor (PCFF) foreign ports (Section 10.7)
28) Port entry and exit cost factor (PECFD) home ports (Section 10.7)
29) Port entry and exit cost factor (PECFF) foreign ports (Section 10.7)
30) Labour ratio (RLABF) foreign ports (Section 10.7)
31) Labour ratio (RLABD) domestic ports (Section 10.7)
32) Number of officers (OFF)
33) Number of Petty officers (PO)
34) Number of ratings (CREW)
35) Tax Rate (TAXPCT) in percent
36) Delay in ports (DELAY) in days.

The above is not an exhaustive list, the user can easily add more variables to this input list. Besides these input values which require three estimates as shown in Fig. 15.2, the user must supply the main dimensions of the ship to be studied. Fig. 15.2 is for a ship of container capacity 2250 Teu and a speed of 18 knots. Other input values are the same as in Computer Model I or Computer Model II.

The three estimates required to carry out the sensitivity analysis using computer Model III are the best estimate as in computer Models I and II and the pessimistic and the optimistic estimates of these items.

The computer Model III then calculates the Required Freight Rate for a particular item with the value of the optimistic estimate of the item while all other items are kept at their best estimates. This procedure is repeated for all the other items in column 1 (Fig. 15.3). A similar procedure is followed and the Required Freight Rate with the pessimistic estimate of the items is calculated as shown in Fig. 15.3, column 6. The range of RFR as defined before is the difference between the RFR calculated with the pessimistic estimate and the RFR calculated with the optimistic estimate. The optimistic estimate for a variable is not always higher than its pessimistic estimate, for variables such as costs the reverse is true. Instead of putting the optimistic estimate of an item in column 3 (Fig. 15.2) and the pessimistic estimate of an item in column 4 (Fig. 15.2) the user can do the reverse. The computer Model III sorts out for each variable which of the final two estimates is the pessimistic estimate and which is the optimistic estimate depending on the value of the RFR and lists them in col. 3 and col.4 (Fig. 15.3) as output.

The range of the RFR col. 7 Fig. 15.3 is termed the sensitivity coefficient as explained earlier. It is the range of values of RFR which can be produced by varying the value of the items between its optimistic and pessimistic estimate. The range coefficient col. 8 Fig. 15.3 is the sensitivity coefficient col. 7 of the item under consideration divided by the sensitivity coefficient of the most sensitive item, in this case SETCNT. The final col. 9 of Fig. 15.3 shows an estimate of the percentage of the variance of the RFR which is accounted for by the different variables. This is produced on the assumption of linearity as described earlier.

The value of the RFR when all the variables are put equal to their best estimates, is the same as that produced either by computer Model I or Model II, and is shown in Fig. 15.3. Similarly the next two lines of Fig. 15.3 is the value of RFR when all the variables are put equal to their optimistic estimates and pessimistic estimates respectively. These two values of RFR are extreme values of RFR and are highly unlikely. The mean value of the Required Freight Rate is shown together with the standard deviation under Fig. 15.3. The derivation of this mean value of the Required Freight was described earlier. The standard deviation is based on the assumption

$$\frac{\text{Standard deviation of the variable}}{\text{Difference between optimistic and pessimistic estimates}} = 0.3$$

and also described in Section 15.1.2. The figure 0.3 in the above equation can be changed by the user.

The mean estimate of RFR of 38.88 £/tonne based on the PERT type estimate is greater than the value of 38.31 £/tonne calculated by computer Model II. This Required Freight Rate takes account of the variability of each of the 36 variables and reflects the expected Required Freight Rate rather than the best estimate of RFR. This will be the Required Freight Rate that can be expected to be achieved under conditions of uncertainty. The contribution of the variability of the RFR by each of the variables are shown in col. 9.

The ranking of the variables given in Fig. 15.3 is based on the sensitivity coefficient and therefore reduces the variation of each variable to a common denominator. The ranking also takes into account the achievable variation rather than an arbitrary 10% variation as in Chapter 14. It also shows that 62% of the variation of RFR can be accounted for by the first five items on the list; SETCNT, DISCNT, WR, COSCNT, OVHEAD and 98% of the variation of the RFR by the first fifteen items on the list. This gives the user a measure of assessing the importance of elements in the list in relation to the RFR. It shows that most of the effort should be expended in improving say the first five items and what will be left uncertain is the remaining 38% variability of RFR. Assessing the Risk involves the knowledge of the standard deviation of the RFR.

The standard deviation of the RFR was calculated using the Monte Carlo Technique in computer Model IV, to check the value of standard deviation of 3.73 calculated by computer Model III. Computer Model IV gives a value of $\sigma = 3.317$ (Fig. 15.12) which is very close to the value of $\sigma = 3.73$ calculated by computer Model III. Therefore computer Model III may be used also to assess the total risk inherent in the project.

This type of analysis was also carried out for a containership of capacity 1500 Teu and speed 18 knots. The two methods of steel weight estimation of the program were used in this study. There was uncertainty surrounding the value of the steel factor (STEELF) in the steel weight estimation method by Watson and Gilfillan (35). Fig. 15.4 shows the merit ranking of the variables using Chapman's method (46) for steel weight estimation. The steel factor (STEELF) is shown to be last in the list because it is used as an input data only for steel weight estimation by Watson and Gilfillan's method. Fig. 15.5 shows the merit ranking of the variables using Watson and Gilfillan's method for steel weight estimation, where the value of the steel factor is chosen as 0.032 as the best estimate, 0.029 as the optimistic estimate, and 0.035 as the pessimistic estimate. As shown in Fig. 15.5 the steel weight factor is ranked 1st in the merit order ranking and the last column shows that the percentage of the variance of the RFR which is accounted for by this variable is quite significant.

In actual practice, with the help of detailed knowledge the range of the variables will be more realistic than those considered in this thesis, therefore the merit ranking will change. For example the variation in the number of sets of containers has a significant influence on RFR. This variation is based on a theoretical model developed by Edmond and Wright (134), see Fig. 11.1, which shows that the Box/slot ratio is highly dependent on the box turnaround time. For a particular company the Box/slot ratio may have less variability and hence its significance on RFR will be less pronounced.

Fig.I5.4. Output ,Sensitivity Analysis ,container capacity I500 Teu and speed I8 Knots(Steel weight estimation method 4)

VARIABLE NAME	BEST ESTIMATE	OPT. ESTIMATE	PESS. ESTIMATE	PERF. MEAS. AT OPT. EST.	PERF. MEAS. AT PESS. EST.	RANGE OF PERF. MEAS.	RANGE COEFF	PERCENT OF VAR
SETCNT	2.500	1.800	3.000	49.284	53.799	4.515	1.00	15.45
DISCNT	15.000	12.000	18.000	43.811	47.647	3.837	0.85	11.15
WR	2.400	2.000	3.000	37.409	41.108	3.699	0.82	10.37
COSCNT	2500.000	2250.000	3000.000	53.061	56.584	3.523	0.78	9.40
DELAY	1.000	0.000	2.000	56.510	59.865	3.354	0.74	8.52
CHANDL	50.000	40.000	60.000	38.935	42.269	3.334	0.74	8.42
OVHEAD	100.000	90.000	200.000	35.635	38.888	3.253	0.72	8.02
ALFI	0.800	0.850	0.700	47.648	50.713	3.065	0.68	7.12
ALFO	0.850	0.900	0.750	46.372	49.084	2.712	0.60	5.57
PROFIT	15.000	5.000	20.000	40.602	42.989	2.387	0.53	4.32
CLIFE	8.000	10.000	6.000	50.009	51.917	1.908	0.42	2.76
COFUEL	80.000	60.000	100.000	41.591	43.307	1.717	0.38	2.23
PCINT	12.000	10.000	15.000	42.947	44.495	1.548	0.34	1.82
SLIFE	20.000	25.000	15.000	44.268	45.692	1.424	0.32	1.54
SINDEX	169.300	150.000	200.000	40.928	42.193	1.265	0.28	1.21
OUFITF	0.320	0.300	0.340	43.679	44.717	1.038	0.23	0.82
CPINT	10.000	9.000	12.000	53.570	54.235	0.665	0.15	0.33
OFF	12.000	10.000	15.000	57.139	57.583	0.445	0.10	0.15
STLCOS	214.000	200.000	250.000	40.988	41.416	0.428	0.09	0.14
CREW	20.000	18.000	24.000	57.607	57.993	0.386	0.09	0.11
TAXPCT	52.000	50.000	55.000	57.838	58.203	0.366	0.08	0.10
PCFD	2.700	1.500	3.300	56.350	56.702	0.351	0.08	0.09
RLABD	0.680	0.500	0.920	56.947	57.296	0.349	0.08	0.09
CDESL	145.000	125.000	180.000	42.175	42.449	0.274	0.06	0.06
PCFF	2.100	1.500	3.300	56.613	56.879	0.266	0.06	0.05
PECFD	7.600	3.600	11.600	56.759	57.000	0.241	0.05	0.04
RLABF	0.390	0.280	0.500	56.899	57.096	0.197	0.04	0.03
PECFF	11.600	3.600	11.600	56.821	57.001	0.180	0.04	0.02
PO	6.000	6.000	8.000	57.583	57.735	0.152	0.03	0.02
YRLOAN	7.000	9.000	8.000	44.195	44.342	0.147	0.03	0.02
WOFF	8400.000	8000.000	10000.000	43.278	43.425	0.147	0.03	0.02
WCREW	5300.000	5000.000	6000.000	43.452	43.564	0.112	0.02	0.01
WPO	5400.000	5000.000	7000.000	43.410	43.486	0.076	0.02	0.00
CLUBCY	560.000	500.000	600.000	42.265	42.272	0.007	0.00	0.00
CLUBSY	470.000	400.000	500.000	42.269	42.274	0.005	0.00	0.00
STEELF	0.032	0.029	0.035	44.195	44.196	0.000	0.00	0.00

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR BEST ESTIMATES= 35.93

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR OPTIMISTIC ESTIMATES= 22.96

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR PESSIMISTIC ESTIMATE= 63.55

ESTIMATE OF MEAN OF RFR BASED ON PERT ESTIMATES OF THE MEANS OF VARIABLES= 36.46

ESTIMATE OF S.D. OF RFR BASED ON AN S.D TO RANGE RATIO OF 0.3 FOR THE VARIBLES= 3.45

Fig.15.5. Output Sensitivity Analysis,container capacity 1500 Teu and 18 Knots(Steel weight estimation method 8

VARIABLE NAME	BEST ESTIMATE	OPT. ESTIMATE	PESS. ESTIMATE	PERF. MEAS. AT OPT. EST.	PERF. MEAS. AT PESS. EST.	RANGE OF PERF. MEAS.	RANGE COEFF	PERCENT OF VAR
STEELF	0.032	0.029	0.035	35.129	39.507	4.378	1.00	16.21
SETCNT	2.500	1.800	3.000	43.934	48.028	4.095	0.94	14.18
DISCNT	15.000	12.000	18.000	39.166	42.498	3.333	0.76	9.39
COSCNT	2500.000	2250.000	3000.000	47.386	50.584	3.198	0.73	8.65
DELAY	1.000	0.000	2.000	50.535	53.494	2.959	0.68	7.41
WR	2.400	2.000	3.000	31.581	34.523	2.942	0.67	7.32
CHANNL	50.000	40.000	60.000	32.691	35.576	2.885	0.66	7.04
ALFI	0.800	0.850	0.700	42.499	45.230	2.731	0.62	6.31
OVHEAD	100.000	90.000	200.000	30.171	32.758	2.587	0.59	5.66
ALFO	0.850	0.900	0.750	41.385	43.779	2.393	0.55	4.84
PROFIT	15.000	5.000	20.000	34.133	36.052	1.919	0.44	3.11
CLIFE	8.000	10.000	6.000	44.591	46.322	1.731	0.40	2.53
COFUEL	80.000	60.000	100.000	34.984	36.481	1.497	0.34	1.90
PCINT	12.000	10.000	15.000	36.208	37.453	1.245	0.28	1.31
SLIFE	20.000	25.000	15.000	39.563	40.800	1.238	0.28	1.30
SINDEX	169.300	150.000	200.000	34.311	35.413	1.101	0.25	1.03
OUFITF	0.320	0.300	0.340	39.064	39.954	0.889	0.20	0.67
CPINT	10.000	9.000	12.000	47.821	48.452	0.631	0.14	0.34
OFF	12.000	10.000	15.000	51.061	51.493	0.432	0.10	0.16
PCFD	2.700	1.500	3.300	50.371	50.691	0.320	0.07	0.09
RLABC	0.680	0.500	0.920	50.915	51.233	0.318	0.07	0.09
CREW	20.000	18.000	24.000	51.514	51.831	0.317	0.07	0.08
TAXPCT	52.000	50.000	55.000	51.697	52.013	0.317	0.07	0.08
STLCOS	214.000	200.000	250.000	34.440	34.736	0.296	0.07	0.07
PCFF	2.100	1.500	3.300	50.611	50.853	0.242	0.06	0.05
CDESL	145.000	125.000	180.000	35.494	35.733	0.239	0.05	0.05
PECFD	7.600	3.600	11.600	50.743	50.963	0.220	0.05	0.04
RLABF	0.390	0.280	0.500	50.871	51.051	0.179	0.04	0.03
PECFF	11.600	3.600	11.600	50.799	50.964	0.165	0.04	0.02
PO	6.000	6.000	8.000	51.493	51.630	0.136	0.03	0.02
WOFF	8400.000	8000.000	10000.000	36.456	36.584	0.128	0.03	0.01
YRLOAN	7.000	9.000	8.000	37.213	37.331	0.119	0.03	0.01
WCREW	5300.000	5000.000	6000.000	36.608	36.705	0.097	0.02	0.01
WPO	5400.000	5000.000	7000.000	36.571	36.637	0.066	0.02	0.00
CLUBCY	560.000	500.000	600.000	35.573	35.579	0.006	0.00	0.00
CLUBSY	470.000	400.000	500.000	35.576	35.581	0.004	0.00	0.00

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR BEST ESTIMATES= 30.41

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR OPTIMISTIC ESTIMATES= 18.47

VALUE OF RFR WHEN ALL VARIABLES EQUAL THEIR PESSIMISTIC ESTIMATE= 56.69

ESTIMATE OF MEAN OF RFR BASED ON PERT ESTIMATES OF THE MEANS OF VARIABLES= 30.84

ESTIMATE OF S.D. OF RFR BASED ON AN S.D TO RANGE RATIO OF 0.3 FOR THE VARIBLES= 3.26

15.2. PROBABILISTIC APPROACH TO RISK ANALYSIS

'Pessimistic' and 'optimistic' estimates provide an indication of the uncertainty surrounding the best estimate made for a particular variable, but for a complete description of that uncertainty, a probability distribution is required. The probability distribution is a curve such that the area under the curve between two points is equal to the probability of the variable lying between those two points. One way of defining risk is by means of a probability distribution of Required Freight Rate and this is sometimes referred to as its 'risk profile'. Much of the work which has been carried out in the area of risk analysis has been concerned with deriving the 'risk profile' of the measure of merit.

A sensitivity analysis as pointed out earlier provides a useful first step in analysis of risk in capital investment. It involves using computer Model III to derive the mean and the standard deviation of the RFR and the merit ranking of variables in order of importance as contributors to the total risk. The next step is then the production of the risk profile for the capital investment.

The probabilistic approach to risk analysis can be subdivided into three broad categories,

(a) Analytical approach

(b) Other methods of Risk Analysis

(c) Monte Carlo Simulation.

Each of these methods are discussed in turn with more emphasis on Monte-Carlo simulation, which was chosen as the method to evaluate the risk in marine capital investment.

15.2.1. (a) Analytical approach

In the analytical approach the two most popular methods are,

(i) Hillier's Model (217)

(ii) Taylor Series Approach (211)

Hillier's model was developed in 1963 and modified further by Wagle (218) in 1967 and Zinn and Lesso (219) 1977.

The Hillier model is based on the properties of statistical distribution, for derivation of the probability distribution of two profitability criteria NPV and IRR from the estimated mean and variance of the individual cash flows for each year.

Instead of producing a complete distribution of NPV or IRR or the risk profile, it calculates only the mean and the variance of NPV and IRR.

The major disadvantage of the Hillier Model is that it cannot deal with types of cash flows generally encountered in marine capital investment. The model deals only with the sum of variables (205) and the calculation of the cash flows in calculating the economic measure of merit in marine investment generally involve products, non-linearities, discontinuities, etc.

(ii) Taylor Series Approach

Taylor Series Approach has been successfully applied to ship design by Wolfram (211) 1979. Wolfram argues that the Taylor series approach is better than the Monte Carlo approach since it can be carried out by hand calculation compared to computer based Monte Carlo simulation. However as the complexity of the problem to be formulated increases, recourse to computer based Monte Carlo simulation becomes necessary. This is because to formulate the ship design problem analytically can be an arduous task.

(iii) Integral Transform Theory

The analytical approach based on Integral Transform theory is one of the latest analytical techniques developed since Hillier's model (217) in 1963. A complete exposition of the technique can be found in Barnes (220) and is mentioned here for completeness of the review.

Most of these above approaches depend on derivation of highly mathematical and precise formulation of the probability density function of the economic measure of merit. Such preciseness is illusory since the cost data estimates on which they operate are in most cases approximate values.

15.2.2.(b) Other methods of Risk Analysis

Each of the methods mentioned below are either extensions to already existing techniques or modifications to suit a particular type of problem.

(a) Parameter method, developed by Cooper and Davidson (216) 1976 is a simplification of the Monte Carlo simulation technique. The parameter method is so named because it deals with the parameters of the probability distributions involved rather than the distribution in their entirety. This method can easily be undertaken by a desk calculator. It assumes three values of the uncertain variables as in the computer Model III and for these variables the mean and variance is calculated assuming a triangular distribution. Knowledge of the two parameters, mean and variance of each uncertain variable then allows one to calculate the mean and variance of the economic measure of merit.

However it assumes that the probability density function of the economic measure of merit is a normal distribution and the uncertain variables are independent.

(b) Risk Analysis based on Risk Preference Theory (227). This technique forms an extension to the risk analysis by the Monte Carlo simulation technique. The 'risk profile' which is generated by the Monte Carlo simulation technique is used to calculate the 'certainty equivalent value'. The method incorporates the risk preference of the decision maker in a formal manner. Derivation of risk preference characteristics of a decision maker is based on subjective assessment. This method is mentioned here to complete the review. There are other methods which account for the probability of future cash flows and timing of these cash flows, one of these is given by Krappinger (228) for marine investment problems.

The advantages and disadvantages of the different techniques to evaluate the risk of an individual capital investment is given by Bonini (205) and some of these are summarised in Table 15.2.

Table 15.2. Advantages and disadvantages of various Risk Analysis approach.

Description	Certainty model One number 'best estimates' with Sensitivity Analysis	Hillier Model Analytical formula developed from sums of random variables to determine mean and variance of NPV	Taylor Series Approach	Monte Carlo Model Cash flow model plus random samplings from distributions of unknown variables to estimate distribution of NPV
Incorporation of various types of relationships (1) Accounting type model of cash flow	Satisfactory as far as one number estimates go. Can have bias from non-linearities or discontinuities in relationships.	Difficult to include all but additive relationships. Subject to some biases from non-linearities and discontinuities.		Quite flexible
(2) Statistical relationships between variables within same time period	One point estimates only.	Included as covariances. Easily incorporated.		Can be incorporated but with some difficulty.
(3) Time series relationship	One point estimates only.	Easily incorporated.		Can be incorporated but with some difficulty.
(4) Uncertainty about project life	Not directly included.	Included with some difficulty.		Easy to include
		Discrete discounting and discrete cash flows		

Table 15.2. (Contd.).

Description	Certainty model One number 'best estimates' with Sensitivity Analysis	Hillier Model Analytical formula developed from sums of random variables to determine mean and variance of NPV	Taylor Series Approach	Monte Carlo Model Cash flow model plus random sampling from distributions of unknown variables to estimate distribution of NPV
Computational Requirements (1) Simple model	Simple hand calculation with calculator	Hand calculation with calculator	Hand calculation with calculator	Computer program; but may be relatively inexpensive to build. Also computer package programs available.
(2) Complex model	Simple calculations - may be programmed for computer if extensive sensitivity analysis desired.	Requires extensive calculations probably necessitating a computer program	Can be difficult to formulate the problem analytically.	Rather extensive computer program required. Since it is a sampling technique quite a large number of runs are required.

15.2.3. MONTE CARLO SIMULATION

Monte Carlo simulation was first proposed by Hess and Quigley (207) in 1963 and made popular by Hertz (208,209) in 1964, 1968, who also coined the word Risk analysis in his classical paper (208) in the Harvard Business Review. A complete description of the technique can be found in (204), (207), (208), (209), (210). The advantages and disadvantages of this technique can be found in (205), (211). Use of this technique in ship investment problems has been limited so far, but application in other industries can be found extensively in the literature, particularly in oil recovery projects (212), commerical manganese nodule mining (213) and the chemical industry. One of the earliest papers advocating this technique was by Klausner (204) 1970 for shipbuilding investments. Wolfram (211) in 1979 proposed an analytic approach. Application to container shipping problems have been mentioned by Webster in 1970 (210). Other references such as (214) by Woodward et al in 1968 mention use of the Monte Carlo technique for the strategy type of decision making such as in container allocation problems in container shipping.

The Monte Carlo simulation technique is outlined in Fig. 15.6. Each of these steps will be discussed in turn.

<u>Defining the Variables</u>

This initial step is the obvious starting point of any quantitative analysis: define the measure of merit, in this case RFR, and all the variables which affect it. These would include independent variables as well as the dependent variables. Initially the designer should not worry too much about dependency between variables, but dependencies are important and reference will be made later in the section on how to deal with them.

<u>Sorting the variables into Groups</u>

The variables identified in the previous step are sorted out into two groups. The first group consists of all the variables and parameters for which exact values are known. The second group includes all the variables and

Fig. 15.6. Monte Carlo Simulation Technique.

1. Define all variables
   Specify the measure of merit RFR, NPV or IRR and all the variables affecting it. The variables are described in terms of the probability density function

2. Transform each of the probability-density functions into cumulative probability scale

3. Generate random numbers uniformly distributed between 0 and 1, by a random number generator

4. Sample for each variable, by setting equal to the numerically equivalent percentile and the corresponding value of the random variable

Repeat N times for second set of different random numbers

Repeat N times for first set of random numbers

5. For each set of the random values of the uncertain variables, calculate the Required Freight Rate

6. Store the results from each pass

7. Compute the mean and standard deviation of the RFR for N passes

8. Is the mean and standard deviation of RFR from the two separate streams of random numbers sufficiently close. If not increase the number of passes

9. Store the values of the RFR into frequency classes, and output the result as a histogram of probability distribution of RFR, or cumulative probability distribution, which is the risk profile of RFR

parameters for which there is some uncertainty about their values. Most variables might fall into the second category but as pointed out earlier, only those variables, the change in which produces the maximum change in RFR, need be considered. In this case they amounted to 36 variables.

15.2.4. DEFINING DISTRIBUTIONS FOR THE UNKNOWN, RANDOM VARIABLES

This is the step where professional expertise and judgement of a designer is involved. This is one of the most important steps in the whole analyses. The final distribution of RFR will generally depend on the distribution of the variables that is: if all variables are independent and are represented by a normal distribution, then it is known from the central limit theorem (211) that the distribution of RFR will also be normal. The following guidelines should be observed when defining the distribution.

(a) The distribution can be of any shape, range or form. Standard statistical distributions such as normal and log normal may not be used. The distribution can be discrete or continuous. If variables are related to one another, the dependency relationship must be defined.(see Section 15.2.5).

(b) The judgement about the distribution need not be defined by a single person, but the expertise of the various staff knowledgeable about a variable may be consulted.

(c) The distribution can be assessed either objectively based on experimental data, nature of the variable or past historical record, or subjectively.

(d) If the opinions vary as to the nature, range, form, shape of the distribution then the various possible combinations can be tried for each complete run of the Monte Carlo analysis. As a result of such a sensitivity analysis, it may be found that the variable may not be critical.

In the program four types of distribution are found to be adequate to describe most of the variables. These distributions are listed in Table 15.3. Some writers (215) (4) (216) on simulation have taken the position that it is rare that values other than the minimum, most likely and the maximum of a variable are known at the preliminary design stages, therefore the triangular distribution can be used to describe the variables.

Table 15.3. Different types of distribution.

Integer	Meaning
1	Variable is to be described in the simulation by a single estimate provided by the user.
2.	Variable is to be described in the simulation by a PERT estimate of its mean which will be based on optimistic, pessimistic and best estimates provided by the user.
3	Variable is to be described in the simulation by a triangular distribution. The mean and standard deviation of the triangular distribution will be equal to the PERT estimates of the mean and standard deviation of the variable. These will be based on optimistic, pessimistic and best estimates provided by the user.
4	Variable is to be described in the simulation by a histogram which will be provided by the user as a pair of data values and the probability associated with such a value.

Indeed a uniform and triangular distribution would be adequate in most circumstances. The normal type of distribution for costs shown by Klausner (204) are difficult to estimate subjectively.

Some errors in defining triangular distributions

(a) Frequently there is an error in defining minimum and maximum. To illustrate the problem, suppose we have the following set of data of a random variable X:

10, 11, 12, 12, 12, 12, 16, 17, 19, 24

If this set of data is represented by a triangular distribution, then 10 is the minimum, 12 is the most likely and 24 is the maximum. The resulting triangular distribution would be as shown in Fig. 15.7.

But now suppose, instead, that the available data of the random variable X is:

10,10,10,11,11,12,12,12,12,12,14,17,18,20,23,24

Again 10 is the minimum value, 12 occurs most frequently and 24 is the maximum value and we may end up with a triangular distribution. These two sets of data are not the same, so we cannot represent both of them by the same triangular distribution. Thus a more rationale representation would be as shown in Fig. 15.8. The whole point to remember here is that when minimum and maximum value of a triangular distribution is mentioned, values for which the probability of occurrence vanishes to zero are implied as ranges closer and closer to the limits are considered.

(b) The best estimate is not necessarily the midpoint of the range of maximum or minimum but is the most probable value, which can be on either side of the range i.e. the triangular distribution need not be symmetrical.

(c) Triangular distribution generally give very poor representation of highly skewed data, see Fig. 15.9.

Fig. 15.7.

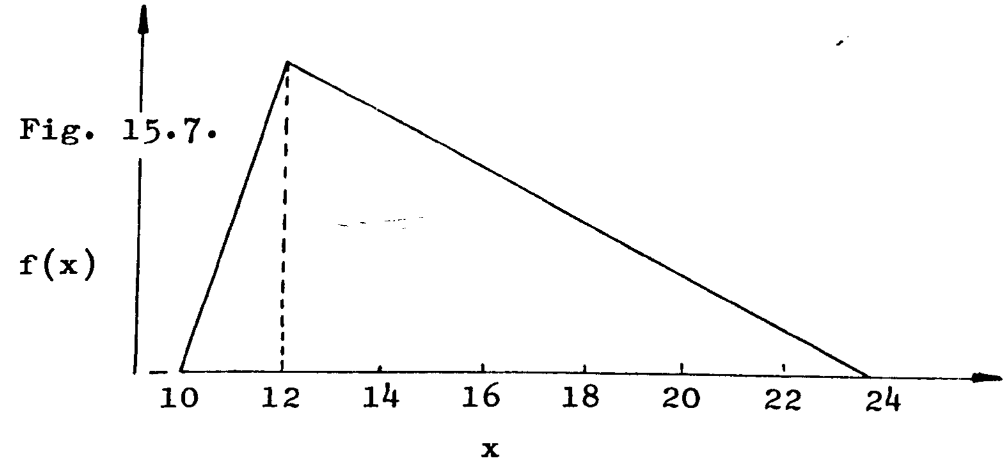


Fig. 15.8.

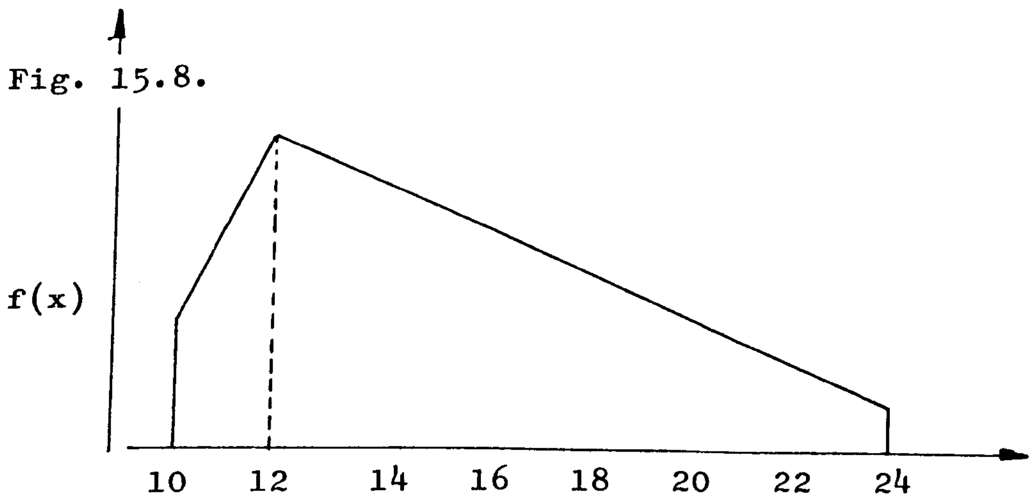
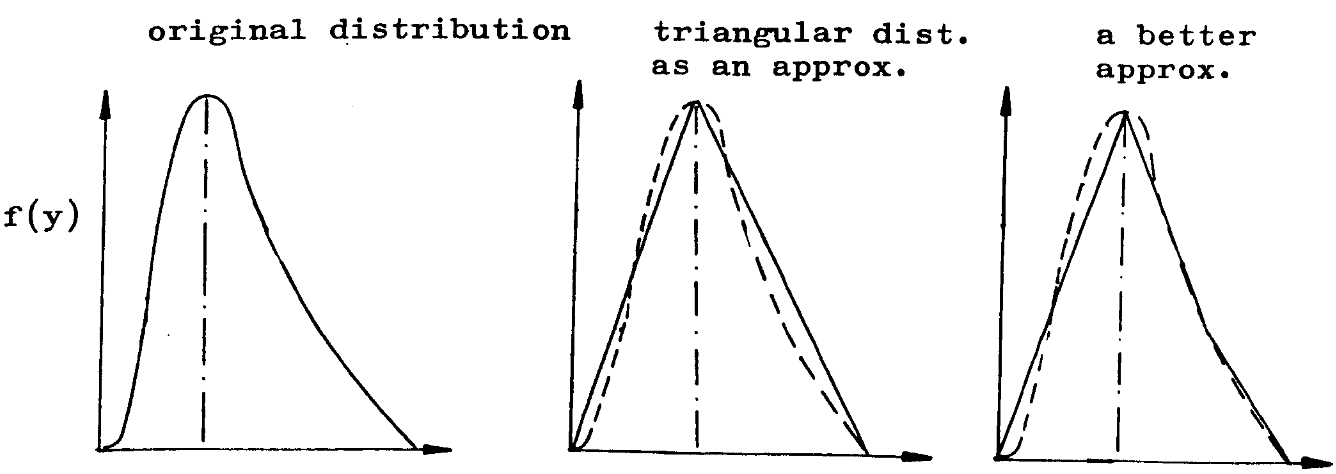


Fig. 15.9. Triangular distribution as an approximation to highly skewed distribution



15.2.5. DEALING WITH DEPENDENCIES

Two variables are dependent if a knowledge of the value of one of them would influence estimates made for the other. Suppose there are two variables "life of ship" and 'salvage value' of the ship and the best estimates for the ship's life is 20 years and for salvage value is zero. Now if the ship's life is changed to 15 years, will salvage value change, if the answer is yes, then the two variables are dependent. On the other hand if the estimate of salvage value remains unchanged then they are independent.

Dependencies cause problems in risk simulation because, when they are present, it is not correct to sample independently from the probability distribution of the different variables. Theoretically, the simulation should first sample from the distribution of the life of the ship and then, depending on the precise value obtained, choose an appropriate distribution for salvage value and sample from it.

The sensitivity analysis can, in many cases, be used to provide a rough indication of the effect of a dependence on the standard deviation of RFR. But it cannot be used to indicate the effect of the dependence on the mean of RFR or any other characteristic of the distribution of RFR (4).

One useful way of analysing dependencies is, to calculate

(a) the distribution of RFR assuming no dependence; and

(b) the distribution of RFR assuming total dependence.

Total dependence between two variables X and Y is defined as positive when X takes a value equal to its Kth fractile, Y also takes a value equal to its Kth fractile. X and Y are totally negatively dependent if X takes a value equal to its Kth fractile, Y takes a value equal to its (1-K)th fractile. When the independent distributions of X and Y happen to be of the same shape then total dependence, implies that the coefficient of correlation ρ is +1 or -1. This is what is taken in this program, i.e. either total positive dependence or total negative dependence.

A brief review of other more sophisticated ways to deal with dependencies is given by Hull (4).

15.3. APPLICATION OF RISK ANALYSIS TO CAPITAL INVESTMENT

The Monte Carlo simulation was used to derive the probability density function of the risk profile of RFR. The various subroutine subprograms developed in this section can also be used for other ship types. The Computer Model IV is used to generate the risk profile curve of the RFR. The program structure, input and output of the subroutines are discussed and the computer Model IV is used to show its applicability in certain situations. The discussion is mainly about capital investment in containership, but is equally applicable to other ship types.

15.3.1. COMPUTER ALGORITHMS

Generally well developed and tested, general purpose algorithms for carrying out Monte Carlo simulation are available. Berger (221) and Fliescher and Lubin (222) give information about these various program packages. Based on this information various sources were contacted. Many of these program packages are highly sophisticated and therefore expensive to acquire and implement. Therefore three general purpose algorithms were selected because of their low cost and these are given below.

a) GRASP (222). Generalized Risk Analysis Package developed by Department of Industrial Engineering, Iowa State University. The programs were in PL/1, which meant it had to be rewritten in FORTRAN and therefore was not accepted. It is well documented and inexpensive.

b) ERRCAL (224). A general purpose Monte Carlo program. The source program is in FORTRAN, and was developed for CDC 6600. This package could not be implemented on the ICL 2976 with the VME/B operating system because the source program is not well documented and therefore the program logic was difficult to unscramble for errors during compilation.

c) UPFAR (225). A Utility Program For the Analysis of Risk. This package could not be acquired because copyrights had not been established. This program uses Risk Preference Theory to generate the risk profile curve based on the utility function of the decision maker, and if available in future could form an extension to the computer algorithm developed in this thesis.

A literature survey revealed two algorithms to carry out the Monte Carlo simulation. These were:

1) PLADE (226). This suite of programs is the most comprehensive package found to carry out Risk analysis, both for situations where a single accept/reject decision have to be made and others where sequential investment decisions have to be made. That is situations where several decisions on an investment have to be made over a period of time such as the strategy type of decision making in container allocation problems in container shipping as given by Woodward et al. (214). This program is well documented but will need certain modifications before it can be applied for marine capital investment.

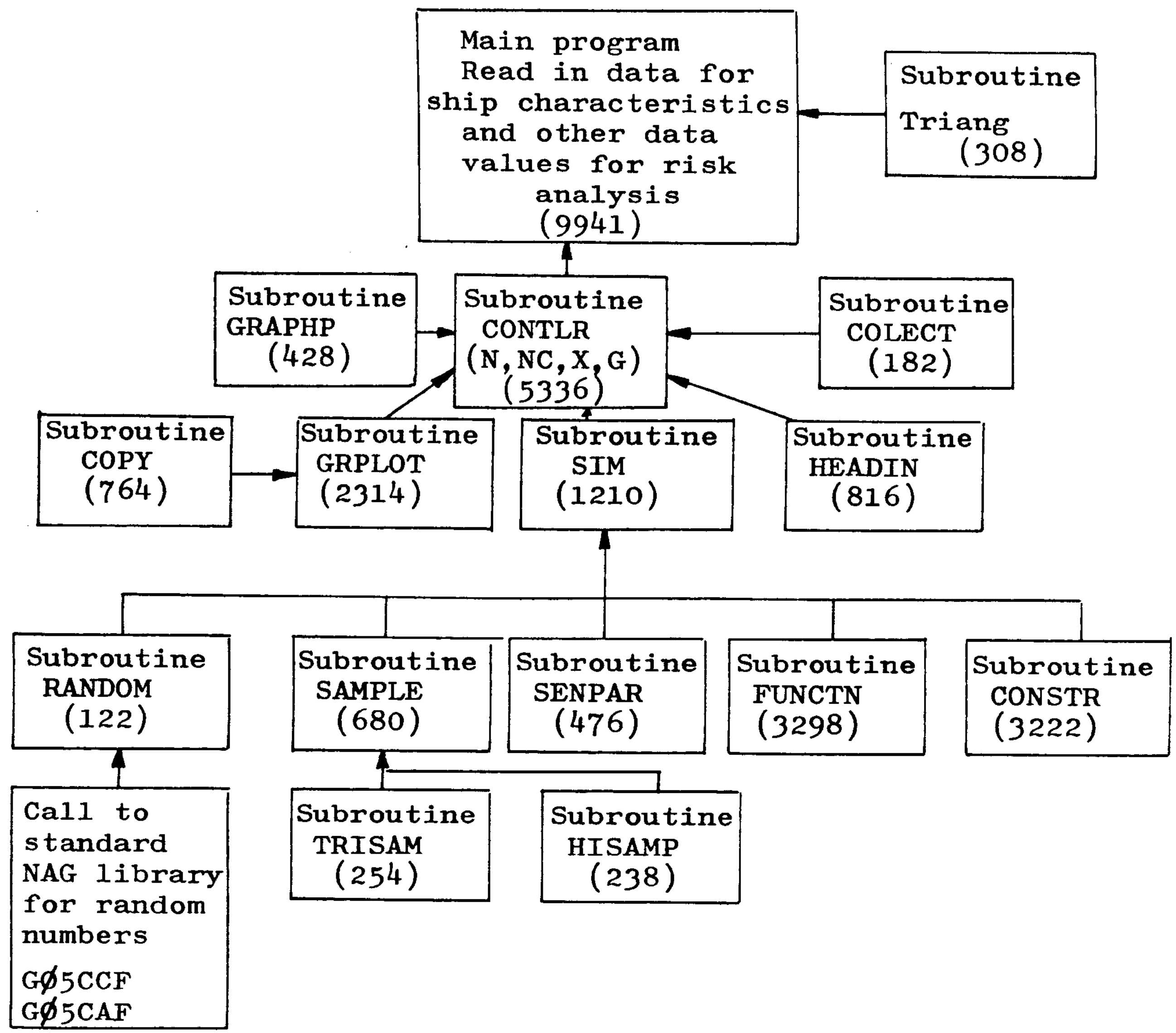
2) RISKANAL2 (4) This suite of program is well suited to the accept/reject type of decisions usually made in marine capital investment. It needed fairly little modification and was therefore implemented on the ICL 2976 with VME/B operating system at Glasgow University.

15.3.2. PROGRAM STRUCTURE AND INPUT/OUTPUT

The overall program structure of Computer Model IV which carries out the Risk Analysis is shown in Fig. 15.10. The main program of computer Model II was modified to input data values of the distribution of the uncertain variables. The user can assign four types of distribution for the uncertain variables as shown in Table 15.3. The thirty six variables chosen in Section 15.1.3. were also used for carrying out the Risk analysis.

The functions of the various subroutines are well documented by Hull (4) 1980. Some of these subroutines needed minor modifications, others which were developed for

Fig. 15.10. Program structure, probabilistic phase to carry out risk analysis and generation of risk profile. (Computer Model IV).



(Note. Figures in the bracket indicates the program size excluding common statements, Total = 146K).

this thesis are mentioned briefly.

RANDOM - This subroutine is used to generate pseudorandom numbers from 0-1 and is uniformly distributed. This subroutine depends on the type of computer used and the source program is in machine language. Standard NAg (Numerical Algorithm Group) subroutine was used.

SENPAR - This subroutine is the same as developed for Computer Model III.

FUNCTN & CONSTR - This subroutine is the same as developed for Computer Model II.

COPY - This subroutine is used for copying K characters from array A to array B starting at the Ith character in A and Jth character in B.

Subroutines which calculate the costs, weights and other design and economic values are as developed in Computer Model I.

A sample input data for carrying out a Risk analysis with Computer Model IV is shown in Fig. 15.11.

The input data values are similar to the one given in Computer Model III Fig. 15.2 except that the type of distribution is associated with each of the thirty six variables.

Simulation analysis by Monte Carlo technique usually takes a lot of computer time, therefore the minimum number of simulation runs to be made had to be determined. An analysis of the number of runs as shown below, indicates that no improvement in the value of standard deviation or the mean of Required Freight Rate is obtained after 4000 simulation runs.

Unfortunately there are no prescribed rules to tell exactly how many passes are required (215). In the absence of a rule the above method is the usual practice.

Fig.I5.II. Input data,Risk Analysis,container capacity 2250 Teu and speed I8 knots.

```
                                   SIMULATION OF 2250 TEU CONTAINER SHIP 18 KNOTS SPEED
     INPUT VALUES AS READ IN THE DATA FILE
SIMULATION OF 2250 TEU CONTAINER SHIP 18 KNOTS SPEED
 2250.00CNT 18.00V   3383.0ENDUR   6766.0DIST 1.0PORTF 1.0PORTD
 4NCLPH  0.00ABALST 0.03 RGPRB
   9.0SROWS 10.0FROWS 11.0STIER 13.0FTIER 0.550SCB 0.700FCB 10.0ROWS 13.0TIERS
 10.00L/DMIN14.50L/DMAX 0.40V-/L 1.50V-/L 6.00L/B 9.00L/B 2.25B/T 3.75B/T
 120.00REVSIN2IREVLD2IBALAS 1IPMC 0IPRINT 2ISTEEL
  0.00ACONT 0.00ACMANT 0.00ACINS
  0.0AWAGES 0.0ACREW 0.0APROV 0.0ASTORE
  0.0APIINS 0.0AWHINS 0.0AADMIN 0.0ARMANT
  0.0APORT 0.0AFUEL 0.0AHANDL
    5N   22NC   36NVAR
  273.772LENGTH 32.165BREADTH 10.125DRAFT 24.197DEPTH 0.657BLOCK COEFF.
 4000NRUN     0NDEP
3 3 3 3 3 3 3 3 3 3 3 3 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 2 2 2 3 2 TYPE OF DISTRIBUTION
OVHEAD          3      100.000     90.000    200.000
WR              3        2.400      2.000      3.000
STLCOS          3      214.000    200.000    250.000
SINDEX          3      169.300    150.000    200.000
PROFIT          3       15.000     10.000     20.000
CHANDL          3       50.000     40.000     60.000
CLUBCY          3      560.000    500.000    600.000
CLUBSY          3      470.000    400.000    500.000
CDESL           3      145.000    125.000    180.000
COFUEL          3       80.000     60.000    100.000
WOFF            3     8400.000   8000.000  10000.000
WPO             3     5400.000   5000.000   7000.000
WCREW           3     5300.000   5000.000   6000.000
PCINT           3       12.000     10.000     15.000
YRLOAN          2        7.000      8.000      9.000
STEELF          2        0.032      0.029      0.035
OUFITF          2        0.320      0.300      0.340
SLIFE           3       20.000     15.000     25.000
DISCNT          3       15.000     12.000     18.000
ALFO            3        0.850      0.750      0.900
ALFI            3        0.800      0.700      0.850
CLIFE           3        8.000      6.000     10.000
SETCNT          3        2.500      1.800      3.000
CPINT           3       10.000      9.000     12.000
COSCNT          3     2500.000   2250.000   3000.000
PCFD            3        2.700      1.500      3.300
PCFF            3        2.100      1.500      3.300
PECFD           3        7.600      3.600     11.600
PECFF           3        9.600      3.600     11.600
RLABF           3        0.390      0.280      0.500
RLABD           3        0.680      0.500      0.920
OFF             2       12.000     10.000     15.000
PO              2        6.000      6.000      8.000
CREW            2       20.000     18.000     24.000
TAXPCT          3       52.000     50.000     55.000
DELAY           2        1.000      0.000      2.000
```

Table A. 2250 Teu Ship and speed = 18 knots.

No. of Simulation Runs	Computer Time in secs.	Required Freight Rate £/tonne	
		Mean	Standard deviation
500	116	38.627	3.203
1000	216	38.292	3.158
2000	408	38.054	3.079
4000	794	38.086	3.481
6000	1193	37.930	3.428
7000	1382	37.936	3.561

15.3.3. REQUIRED FREIGHT RATE ASSUMING NO DEPENDENCIES

Containerships of 1500 Teu and 2250 Teu both with a speed of 18 Knots were selected for assessing the risk involved in these two investment decisions. Fig. 5.13 shows the risk profile or the probability distribution of RFR for the 1500 Teu ship and Fig. 15.12 shows the probability distribution of RFR of the 2250 Teu ship. The results are tabulated below.

Table B.

£/tonne

	1500 Teu	2250 Teu
RFR, computer Model II	35.93	38.310
Mean RFR, computer Model III	36.46	38.880
Mean RFR, computer Model IV	35.713	38.136
Std. dev., computer Model III	3.45	3.73
Std. dev., computer Model IV	3.060	3.317

For the 1500 Teu and 2000 Teu ship the value of RFR calculated by computer Model IV is less than those calculated by computer models III and II. And the value of RFR calculated by computer model II is the lowest as would be expected when the best estimates are made.

Fig.I5.I2. Output,Risk profile,container capacity 2250 Teu and speed I8 Knots

DISTRIEUTION OF REQUIRED FRIEGHT RATE
NO DEPENDENCIES ASSUMED
MEAN= 38.136 S.D.= 3.317

RANGE		PROB	
LESS THAN	25.0	0.0000	I
25.0 TO	25.5	0.0000	I
25.5 TO	26.0	0.0000	I
26.0 TO	26.5	0.0000	I
26.5 TO	27.0	0.0000	I
27.0 TO	27.5	0.0000	I
27.5 TO	28.0	0.0002	I
28.0 TO	28.5	0.0002	I
28.5 TO	29.0	0.0005	I
29.0 TO	29.5	0.0007	I
29.5 TO	30.0	0.0025	IXX
30.0 TO	30.5	0.0023	IXX
30.5 TO	31.0	0.0033	IXX
31.0 TO	31.5	0.0057	IXXX
31.5 TO	32.0	0.0080	IXXXX
32.0 TO	32.5	0.0110	IXXXXXX
32.5 TO	33.0	0.0173	IXXXXXXXXX
33.0 TO	33.5	0.0155	IXXXXXXXX
33.5 TO	34.0	0.0240	IXXXXXXXXXXXX
34.0 TO	34.5	0.0330	IXXXXXXXXXXXXXXXXX
34.5 TO	35.0	0.0345	IXXXXXXXXXXXXXXXXX
35.0 TO	35.5	0.0425	IXXXXXXXXXXXXXXXXXXXXX
35.5 TO	36.0	0.0428	IXXXXXXXXXXXXXXXXXXXXX
36.0 TO	36.5	0.0560	IXXXXXXXXXXXXXXXXXXXXXXXXXXXX
36.5 TO	37.0	0.0618	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
37.0 TO	37.5	0.0595	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
37.5 TO	38.0	0.0745	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
38.0 TO	38.5	0.0580	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
38.5 TO	39.0	0.0585	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
39.0 TO	39.5	0.0535	IXXXXXXXXXXXXXXXXXXXXXXXXXXX
39.5 TO	40.0	0.0538	IXXXXXXXXXXXXXXXXXXXXXXXXXXX
40.0 TO	40.5	0.0538	IXXXXXXXXXXXXXXXXXXXXXXXXXXX
40.5 TO	41.0	0.0478	IXXXXXXXXXXXXXXXXXXXXXXXX
41.0 TO	41.5	0.0375	IXXXXXXXXXXXXXXXXXXX
41.5 TO	42.0	0.0328	IXXXXXXXXXXXXXXXX
42.0 TO	42.5	0.0230	IXXXXXXXXXXXX
42.5 TO	43.0	0.0220	IXXXXXXXXXXX
43.0 TO	43.5	0.0153	IXXXXXXXX
43.5 TO	44.0	0.0135	IXXXXXXX
44.0 TO	44.5	0.0080	IXXXX
44.5 TO	45.0	0.0082	IXXXX
45.0 TO	45.5	0.0047	IXX
45.5 TO	46.0	0.0052	IXXX
46.0 TO	46.5	0.0020	IXX
46.5 TO	47.0	0.0035	IXX
47.0 TO	47.5	0.0007	I
47.5 TO	48.0	0.0013	IXX
48.0 TO	48.5	0.0000	I
48.5 TO	49.0	0.0007	I
49.0 TO	49.5	0.0002	I
49.5 TO	50.0	0.0000	I
50.0 TO	50.5	0.0000	I
50.5 TO	51.0	0.0000	I
51.0 TO	51.5	0.0002	I
GREATER THAN	52.0	0.0000	I

Fig.I5.I3. Output ,Risk profile,container capacity I500 Teu and speed I8 Knots

```
                                   DISTRIEUTION OF REQUIRED FRIEGHT RATE
                                   NO DEPENDENCIES ASSUMED
                                   MEAN=  35.713      S.D.=   3.060

    RANGE                PROB

LESS THAN       24.0  0.0000   I
 24.0  TO       24.5  0.0000   I
 24.5  TO       25.0  0.0000   I
 25.0  TO       25.5  0.0000   I
 25.5  TO       26.0  0.0000   I
 26.0  TO       26.5  0.0000   I
 26.5  TO       27.0  0.0000   I
 27.0  TO       27.5  0.0000   I
 27.5  TO       28.0  0.0013   IXX
 28.0  TO       28.5  0.0013   IXX
 28.5  TO       29.0  0.0018   IXX
 29.0  TO       29.5  0.0047   IXX
 29.5  TO       30.0  0.0050   IXXX
 30.0  TO       30.5  0.0120   IXXXXXX
 30.5  TO       31.0  0.0153   IXXXXXXXX
 31.0  TO       31.5  0.0220   IXXXXXXXXXXX
 31.5  TO       32.0  0.0293   IXXXXXXXXXXXXXXX
 32.0  TO       32.5  0.0403   IXXXXXXXXXXXXXXXXXXXXX
 32.5  TO       33.0  0.0405   IXXXXXXXXXXXXXXXXXXXXX
 33.0  TO       33.5  0.0583   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 33.5  TO       34.0  0.0613   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 34.0  TO       34.5  0.0682   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 34.5  TO       35.0  0.0585   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 35.0  TO       35.5  0.0695   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 35.5  TO       36.0  0.0675   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 36.0  TO       36.5  0.0625   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 36.5  TO       37.0  0.0568   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 37.0  TO       37.5  0.0588   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 37.5  TO       38.0  0.0515   IXXXXXXXXXXXXXXXXXXXXXXXXXXX
 38.0  TO       38.5  0.0480   IXXXXXXXXXXXXXXXXXXXXXXXXX
 38.5  TO       39.0  0.0360   IXXXXXXXXXXXXXXXXXXX
 39.0  TO       39.5  0.0243   IXXXXXXXXXXXXX
 39.5  TO       40.0  0.0263   IXXXXXXXXXXXXXX
 40.0  TO       40.5  0.0188   IXXXXXXXXXX
 40.5  TO       41.0  0.0155   IXXXXXXXX
 41.0  TO       41.5  0.0115   IXXXXXX
 41.5  TO       42.0  0.0108   IXXXXX
 42.0  TO       42.5  0.0075   IXXXX
 42.5  TO       43.0  0.0055   IXXX
 43.0  TO       43.5  0.0033   IXX
 43.5  TO       44.0  0.0018   IXX
 44.0  TO       44.5  0.0023   IXX
 44.5  TO       45.0  0.0010   IXX
 45.0  TO       45.5  0.0005   I
 45.5  TO       46.0  0.0010   IXX
 46.0  TO       46.5  0.0000   I
 46.5  TO       47.0  0.0000   I
GREATER THAN    47.5  0.0002   I
```

However uncertainty surrounding the variables have less pronounced effect on RFR of a 1500 Teu ship compared to a 2250 Teu ship. The standard deviations calculated by both the computer Models III and IV are in good agreement. This indicates that computer Model III gives a fairly good approximation to the total risk.

Table C. RFR for 4000 simulation runs (RFR in £/tonne)

	4000 runs μRFR	σRFR	Value of RFR Model II	Teu
18 knots	35.929	3.174	35.700	1500 Teu
21 knots	36.707	3.122	36.600	
24 knots	39.540	3.286	39.580	
27 knots	45.841	3.901	45.750	

Further an analysis with increasing speed showed that the expected value of RFR, μ_{RFR}, in the probabilistic phase is similar to the one calculated in the deterministic phase. Therefore for a 1500 Teu ship the deterministic phase with Computer Model II may be adequate. And a rough measure of total risk can be obtained from Computer Model III.

Change in distribution

The user can also carry out a sensitivity analysis with the probabilistic approach. For a ship of 1500 Teu, 18 Knots the first six variables in the input list (Fig. 15.11) were assigned uniform rectangular distribution instead of a triangular distribution. The results are as shown below.

Table D. Values of mean RFR and standard deviation. (RFR in £/tonne)

	μ_{RFR}	σ RFR
Variables with Distribution as shown in Fig. 15.11	35.929	3.174
First six variables changed to a rectangular uniform distribution, Type 2	36.561	2.676

The above Table D shows that changing the distribution of certain variables has some influence on the μ_{RFR} and σ_{RFR}. Such a sensitivity analysis can be carried out for change in distribution of other variables to ascertain whether the probability distribution representing the uncertainty surrounding these variables can be neglected or can be replaced by a simpler distribution. Finally a cumulative probability curve, 1 shown in Fig. 15.15 is drawn from the probability histogram Fig. 15.13. This shows that there is a 54.5% chance that the Required Freight Rate will be less than the expected RFR, μ_{RFR} of £35.713/tonne. Conversely there is a 45.5% chance that the RFR will exceed this value. Also the range of probable value of RFR is relatively narrow (Fig. 15.13). Similarly the cumulative probability curve 2 for a containership of 2250 Teu at 18 knots speed was derived from Fig. 15.12 and shown in Fig. 15.15. The expected Required Freight Rate for this ship is £38.136/tonne and the cumulative distribution shows that there is 52.5% chance that the RFR will be less than the μ_{RFR}.

However as the curves show, capital investment in the 2250 Teu ship is less risky, than the investment in the 1500 Teu ship and there is a slightly greater chance of achieving the expected RFR of £38.136 /tonne in the case of the 2250 Teu ship. At their respectivelevel of expected RFR the Risk involved in case of both ships are similar as indicated by the area under the curve.

15.3.4. REQUIRED FREIGHT RATE ASSUMING DEPENDENCIES

The Computer Model IV in the last section was used for evaluation of Risk assuming that all the variables were independent. Dependencies can be tested by Computer Model IV. The following dependencies were checked.

(a) positive dependence between shipbuilding labour wage rate and overheads and is shown in Fig. 15.14.
(b) positive dependence between Inbound and Outbound Load factor.
(c) positive dependence between steel cost and overheads.

Fig.I5.I4. Output Risk profile,container capacity I500 Teu and speed I8 Knots (Assuming dependency)

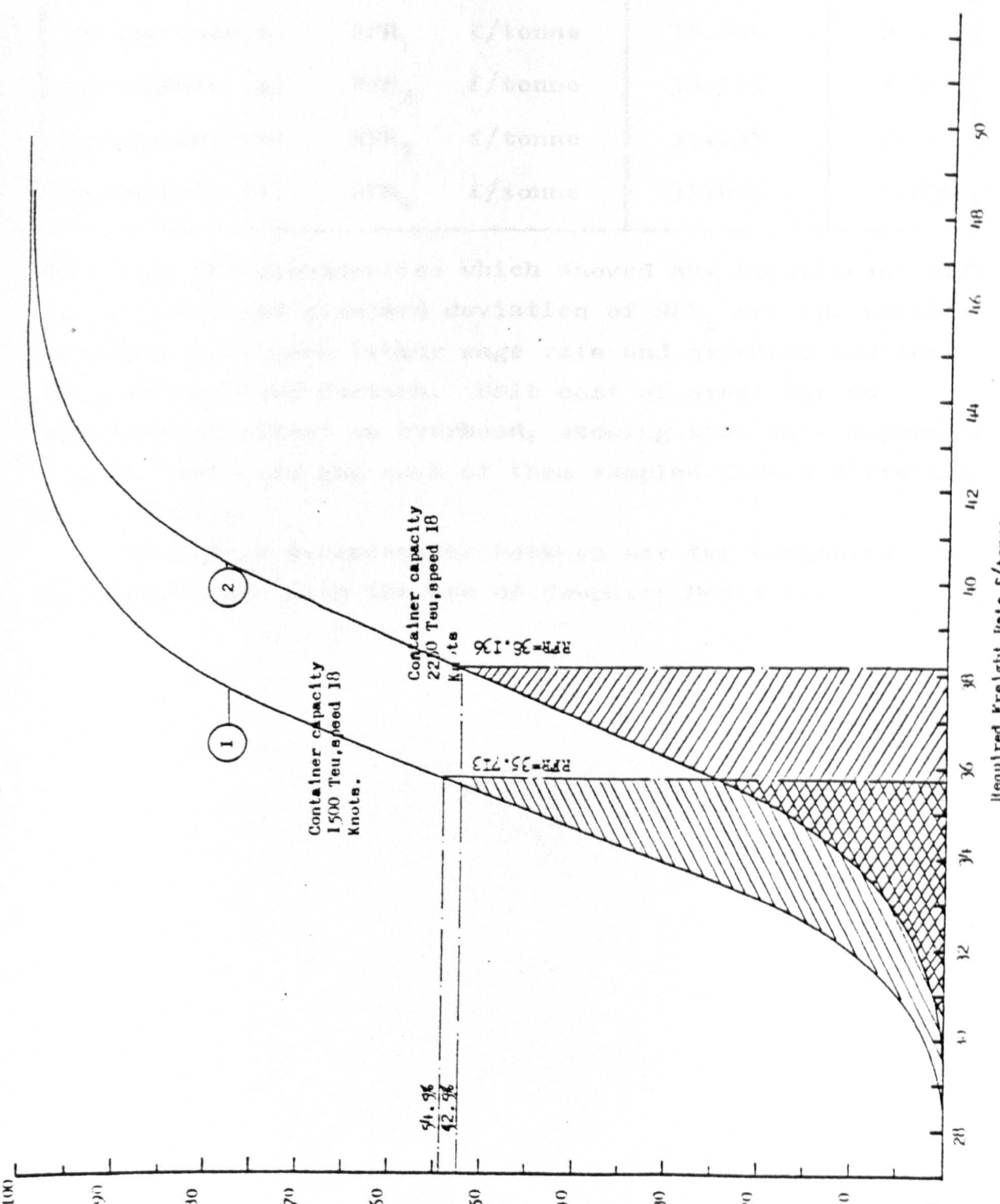
DISTRIBUTION OF REQUIRED FREIGHT AT

OVHEAD ASSUMED TO BE POSITIVELY DEPENDENT ON WH

MEAN= 36.113 S.D.= 3.652

RANGE			PROB	
LESS THAN		24.0	0.0000	I
24.0	TO	24.5	0.0000	I
24.5	TO	25.0	0.0000	I
25.0	TO	25.5	0.0000	I
25.5	TO	26.0	0.0000	I
26.0	TO	26.5	0.0000	I
26.5	TO	27.0	0.0004	I
27.0	TO	27.5	0.0020	IXX
27.5	TO	28.0	0.0016	IXX
28.0	TO	28.5	0.0024	IXX
28.5	TO	29.0	0.0028	IXX
29.0	TO	29.5	0.0040	IXX
29.5	TO	30.0	0.0068	IXXX
30.0	TO	30.5	0.0088	IXXXX
30.5	TO	31.0	0.0152	IXXXXXXXX
31.0	TO	31.5	0.0140	IXXXXXXX
31.5	TO	32.0	0.0220	IXXXXXXXXXXX
32.0	TO	32.5	0.0288	IXXXXXXXXXXXXXX
32.5	TO	33.0	0.0360	IXXXXXXXXXXXXXXXXXX
33.0	TO	33.5	0.0388	IXXXXXXXXXXXXXXXXXXX
33.5	TO	34.0	0.0564	IXXXXXXXXXXXXXXXXXXXXXXXXXXXX
34.0	TO	34.5	0.0516	IXXXXXXXXXXXXXXXXXXXXXXXXXX
34.5	TO	35.0	0.0624	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
35.0	TO	35.5	0.0696	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
35.5	TO	36.0	0.0604	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
36.0	TO	36.5	0.0664	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
36.5	TO	37.0	0.0744	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
37.0	TO	37.5	0.0600	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
37.5	TO	38.0	0.0608	IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
38.0	TO	38.5	0.0496	IXXXXXXXXXXXXXXXXXXXXXXXXX
38.5	TO	39.0	0.0348	IXXXXXXXXXXXXXXXXX
39.0	TO	39.5	0.0388	IXXXXXXXXXXXXXXXXXXX
39.5	TO	40.0	0.0348	IXXXXXXXXXXXXXXXXX
40.0	TO	40.5	0.0220	IXXXXXXXXXXX
40.5	TO	41.0	0.0204	IXXXXXXXXXX
41.0	TO	41.5	0.0180	IXXXXXXXXX
41.5	TO	42.0	0.0100	IXXXXX
42.0	TO	42.5	0.0076	IXXXX
42.5	TO	43.0	0.0048	IXX
43.0	TO	43.5	0.0048	IXX
43.5	TO	44.0	0.0020	IXX
44.0	TO	44.5	0.0024	IXX
44.5	TO	45.0	0.0016	IXX
45.0	TO	45.5	0.0020	IXX
45.5	TO	46.0	0.0008	I
46.0	TO	46.5	0.0000	I
46.5	TO	47.0	0.0000	I
47.0	TO	47.5	0.0000	I
GREATER THAN		48.0	0.0000	I

Fig.15.15. Cumulative probability distribution.



1500 Teu ship, 18 knots, 2500 runs.

			μ_{RFR}	σ_{RFR}
No dependency	RFR_1	£/tonne	35.684	2.927
Dependency (a)	RFR_2	£/tonne	36.113	3.052
Dependency (b)	RFR_3	£/tonne	35.738	2.987
Dependency (c)	RFR_4	£/tonne	35.671	2.856

The only two dependencies which showed any significant effect on the mean and standard deviation of RFR_1 are the positive dependency between labour wage rate and overhead and that between the load factors. Unit cost of steel has no significant effect on overhead, showing that this dependency can be neglected and each of them sampled from a different distribution.

Therefore dependencies between any two variables can be ascertained with the use of Computer Model IV.

CHAPTER 16

DISCUSSION, CONCLUSION AND FUTURE DEVELOPMENTS

16.1. GENERAL

The application of the digital computer to ship design and operation has created many preliminary design and operation programs over the past two decades. Since the use of such programs is still not commonplace when preliminary design is being carried out further improvement and development of these programs is required. This thesis describes a digital computer model for the preliminary design and operation of cellular containerships which offer the user four modes of operation to be used individually or in sequence. The last mode produces a risk profile for the design.

16.2. DISCUSSION

A complete overview of the computer aided containership design at the preliminary design stage as incorporated in this thesis is shown in Fig. 16.1.

It was not difficult to build the logic of the computer programs to carry out preliminary design studies. Most of the effort involved matching the various subprograms to give reasonable results within an acceptable range of ship size and speed. Although some of the subprograms were available to carry out certain design calculations, they had to be rewritten to suit the requirements and range acceptable for containership studies.

There were two types of facilities available, as shown in Fig. 16.1, for submission of work to the computer. One was the batch mode through job control cards, the other was the batch mode through a terminal. The submission of jobs through a terminal was preferred in most cases. It allowed the user a limited amount of interactive facility. One of the major attractions of using the terminal mode of computing was that in most instances the running of the program could be interrupted. This suppressed unnecessary amounts of output which might be generated. Secondly in many instances the automated decision logic or path embedded in the programs could be changed or overridden.

Fig. 16.1. A complete overview of the computer aided design procedure.

	Computer Model		Type of mode possible	Type of mode preferable	Computer time including compilation time
Deterministic Phase	I	Parametric variation of principal dimensions of large number of designs and location of optimum design manually. May be possible to automate the search procedure by simple sorting routines.	1	1	1500 secs for three C_b values in steps of 0.01
		or			
	II	Optimisation Technique for locating the optimum design.	1 or 2	2	200 secs for three C_b values in steps of 0.01.
Deterministic Phase / Probabilistic Phase	I or II	Sensitivity analysis	1 or 2	2	18 secs for variation in only one value
Probabilistic Phase	III	Sensitivity analysis with an approximation to total risk of the project	1 or 2	2	25 secs for one ship
	IV	Generation of Risk Profile of Required Freight Rate	1 or 2	2	4000 simulation runs, 1500 secs. Initial interactive 100 simulation runs

Notes: 1 = Batch mode with submission of work through job control cards.

2 = Batch mode with submission of work through a terminal, with limited interactive facility and output on a VDU.

Computer used:- ICL 2976, with VME/B operating system.

More than a decade has gone by since the containership was introduced but it is still difficult for many to understand that the 'container capacity' expressed solely as teu's does not adequately identify the size of the vessel. It was shown that for a given value of average weight of each container, operational metacentric height and container stowing procedure the designer can determine the container capacity and the associated draft. Therefore containerships should be compared for their carrying ability, only when these other factors have been defined.

One of the factors which reduces the acceptability of preliminary design programs are the large number of empirical relationships used to estimate the design parameters. These empirical relationships need to be improved especially for weight, centre of gravity and cost estimation. It was found that steel weight had a significant influence on the Required Freight Rate so emphasising the need for better expressions for steelweight and centre of gravity.

Any investment decision is concerned with a choice among alternatives, and it is always subject to an unknown future environment. An investment policy, if it is to guide management's choices among investment alternatives must embody two components both incorporated in this thesis. There were:

(a) An economic criteria by which to measure the relative economic attributes of investment alternatives.
(b) Decision rules, which make use of Risk analysis or otherwise seek to force uncertainty into account for selecting an acceptable investment.

The first component, economic criteria have been the subject of much analysis and discussion. On the other hand, the second component, the rules for making choices, particularly under uncertainty, have been given less attention in the past. It was shown how this could be incorporated and the risk profile of the investment generated. Of course no pre-established decision policy can take into account all considerations, human, organisational, strategic and financial that typically enter into any major capital investment decision. In this thesis, however, we are concerned with the question of financial policy which does lend itself to be formulated quantitatively.

Such a risk analysis based policy then specifies how management would prefer to attain a particular value of Required Freight Rate. The risk analysis model (computer model IV) also acts as a tool for testing and analysing past and future capital investment decisions. The management can analyse its own past investment data by generation of a risk profile and determine whether the past decisions have been consistent. If not, a more consistent decision policy can be formulated.

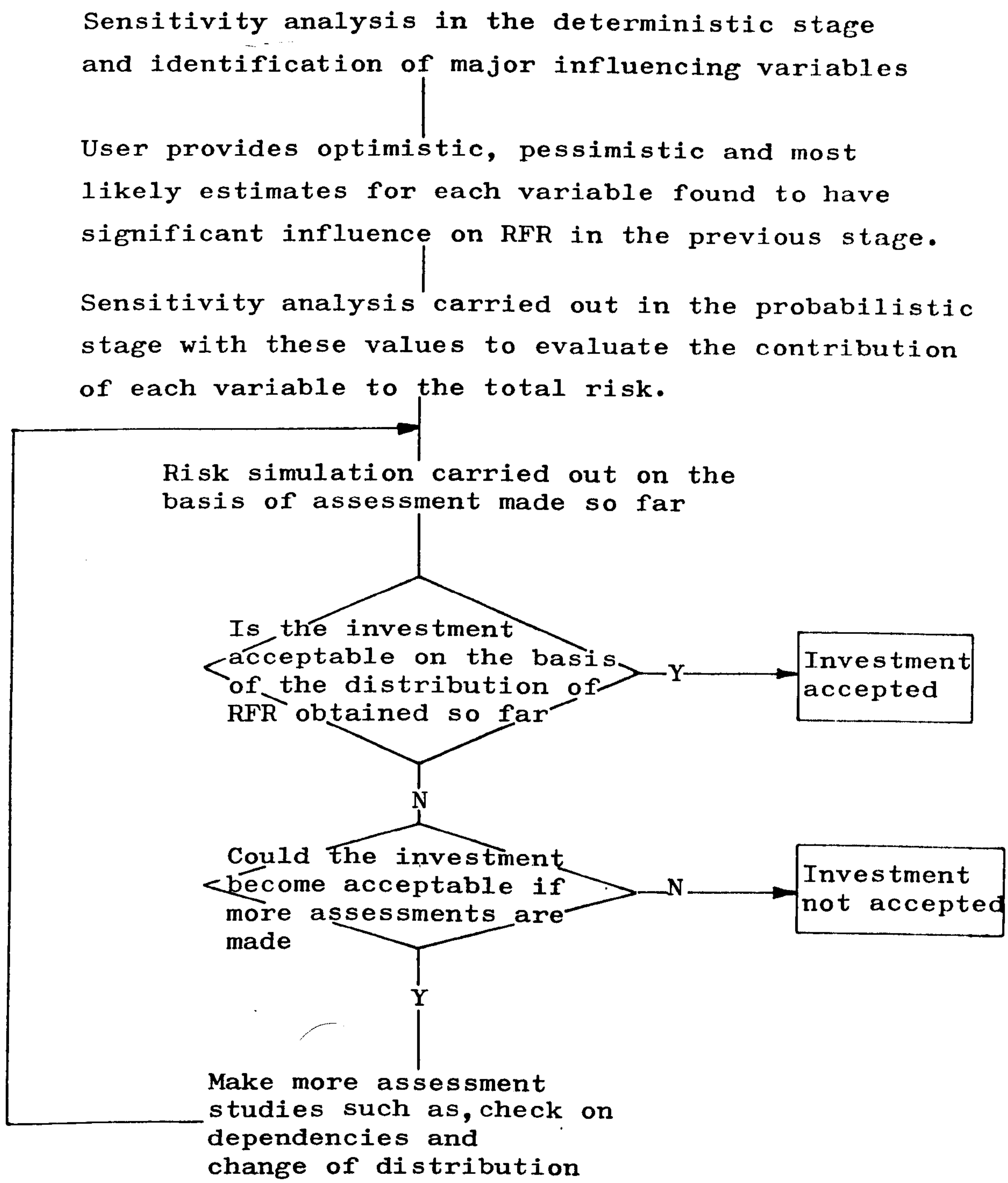
The probabilistic approach was designed with two key observations about risk simulation in mind.

(a) A major reason why risk simulation has not been widely accepted in marine capital investment is because of the large number of probability assessments which a designer or user is typically required to make to undertake such a risk analysis.

(b) The cost of computer time used to carry out a risk simulation can be significant.

Therefore the essence of the approach adopted in this thesis was that assessments are only made at the probabilistic stage for variables which show significant influence on RFR at the deterministic stage. One significant advantage of subdividing the design process into the two stages, that is deterministic and probabilistic, was that it obviates the need to expend unnecessary effort in getting better estimates of the variables which have been found to have little or no influence on Required Freight Rate in the previous stage. The difficulty of assigning probability distribution to variables was overcome by assuming simpler distributions. A number of risk analyses showed that it is not wasteful in terms of computing cost since such analyses will be necessary for one or two competing cases only. This approach is outlined in Fig. 16.2.

Fig. 16.2. Decision chart for evaluation of Risk.



Finally it has been shown in this thesis that a computer aided preliminary containership design program should incorporate uncertainties since influence of some parameters to overall risk can be significant. Explicit consideration of risk inherent in a project must form a part of the preliminary design programs.

16.3. CONCLUSIONS

(1) On the North Atlantic Route, for two ports of call a ship of container capacity 1500 teu to 1750 teu and speed of 16 to 18 knots gives a lower Required Freight Rate compared to other ship sizes and speeds.

(2) Sensitivity analysis based on a probabilistic approach gives a better measure for ranking of the variables.

(3) A sensitivity analysis based on a probabilistic approach may be adequate in some circumstances to assess the total risk of the capital decision.

(4) The preliminary design procedure should incorporate risk analysis to evolve a more consistent decision making policy for capital investments.

(5) The preliminary design procedure should be subdivided into various stages, which allow one to identify the important variables and their influence on the RFR. This obviates the need to expend effort in getting better estimates of the variables which have been found to have little or no significance on the RFR in the previous stage of the design.

16.4. FUTURE DEVELOPMENT

Results from programs must be as accurate as possible and such accuracy demands a long period of tuning of the program to ensure that the many internal relationships both scientific and empirical are as accurate as possible. An extension to this type of tuning is the replacement of simple empirical relationships by more complex scientific ones. In particular this is required for the subroutines concerned with structural design, seakeeping and service performance. Sensitivity analysis may be used to choose areas worthy of improvement but the cost and the possibility of improvement must also be considered.

The Required Freight Rate must be established per Teu as well as per tonne enabling a wider range of studies to be carried out and ballasting considered in detail.

The maintenance effort required to update a program even without major changes must be carefully allowed when considering the future.

Although interactive computing takes up a great deal of terminal time it allows the experience of the user to be applied more readily and the program needs to be adjusted to permit more interaction. Graphical output is also useful to supplant and to supplement numerical output.

A containership can be viewed as one link in a door to door transport chain. Optimising this link may not be of benefit to the whole chain and an extension of the program to door to door container transport would be valuable. Other competitive modes of transport cannot be ignored and need their own computer programs.

In its present form the program needs modification to apply to fleets of containerships. However many of the subroutines can be applied by themselves in separate sea transport studies, especially those concerned with resistance and propulsion and finance.

The Required Freight Rate ignores income and it may be worth considering how to incorporate numerical routines to gauge the benefit of attracting more income.

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MT - Marine Technology.
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APPENDIX I

FLOW CHART FOR CALCULATION OF EFFECTIVE HORSEPOWER

READ IN

SPEED, LENGTH B.P., BREADTH MLD, DRAFT DESIGN, BLOCK COEFFICIENT

CIRCULAR C DATA STORED AS AN ARRAY FOR BLOCK COEFF. OF 0.52 TO 0.72 INTERVALS OF .02 AND SPEED-LENGTH RATIO $V/\sqrt{L}$ FROM 0.40 to 1.15 INTERVALS OF 0.05

$0.48 \leqslant CB \leqslant 0.72$ — N → RETURN

$0.40 \leqslant V/\sqrt{L} \leqslant 1.5$ — N → RETURN

INTERPOLATE FOR REQD. CB

INTERPOLATE FOR REQD. $V/\sqrt{L}$

CORRECTION FOR BEAM AND DRAFT USING MUMFORD'S INDICES

BEAM CORRECTION

CIRC1 = CIRCM * (400.0 * B/(L * 55.0))**0.2333

$P^{Y-2/3} = 0.447 * V/\sqrt{L} - 3.606$

DRAFT CORRECTION

CIRC2 = CIRC1 * (400.0 * T/(L*18.0))**P

$100 \leqslant L \leqslant 400$ — Y → OL=FUNC1(L)

OL = FUNC2(L)

OCORR=OL-0.0741

CIRL=1.055 * $V/\sqrt{L}$

CIRCS = 0.0935*(1.7*L*T+CB*L*B)/(L*B*T*CB/35.0)*0.666)

SKIN FRICTION CORRECTION

SFC = OCORR * CIRCS/(CIRCL**0.175)

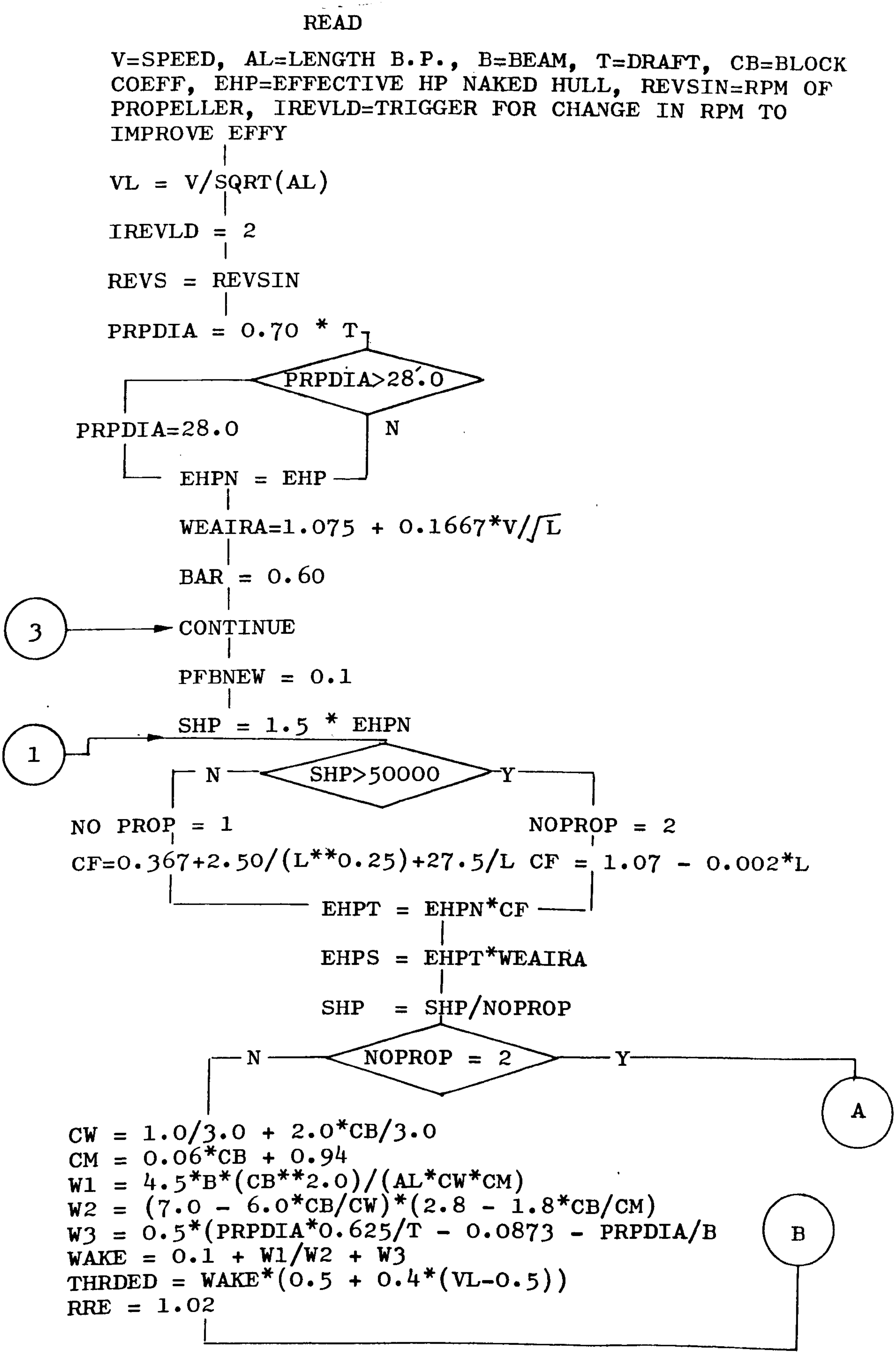
CIRC = CIRC2 + SFC

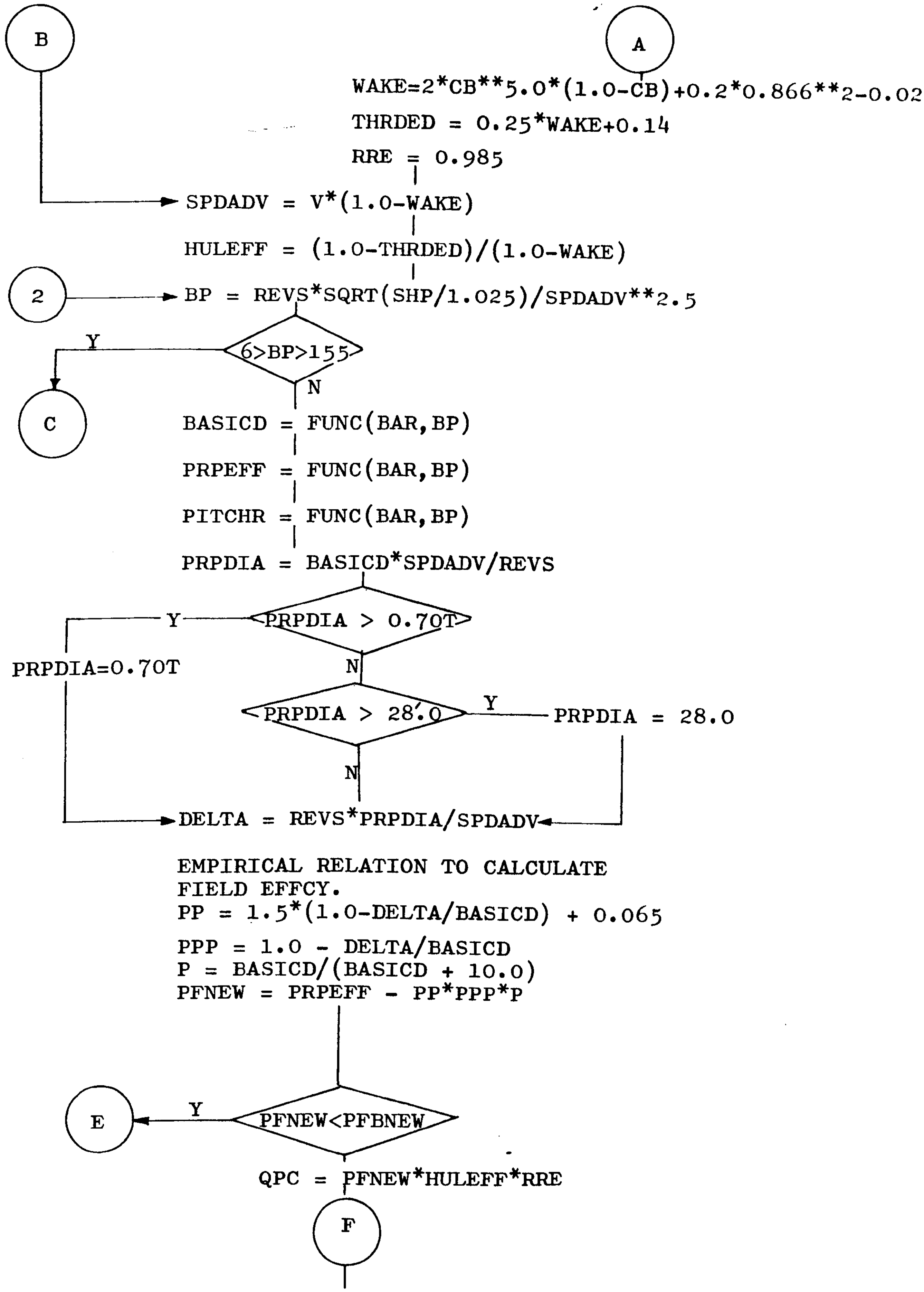
EHP = CIRC*(V**3.0)*((L*B*T*CB/35.0)**0.667)/427.1

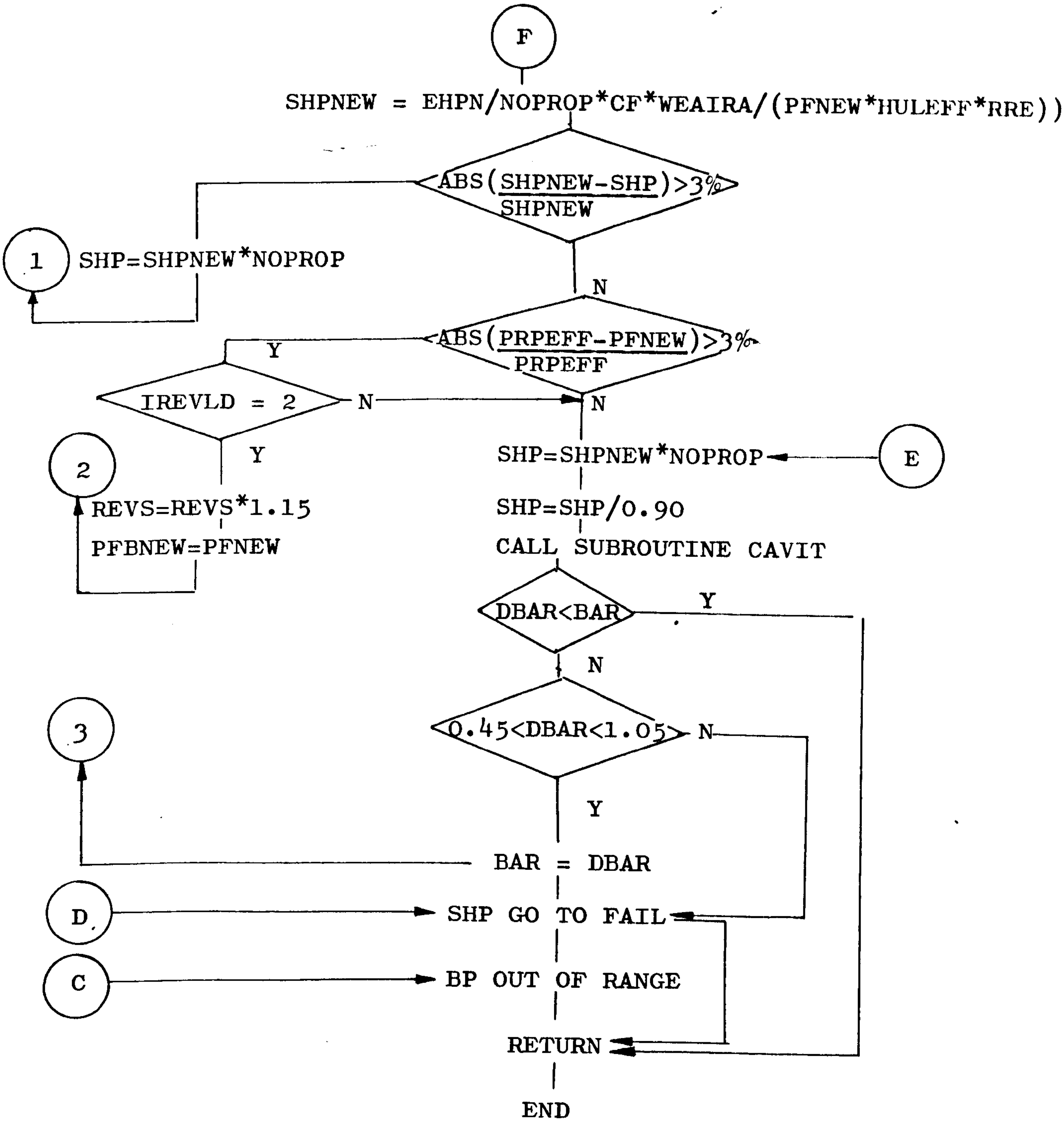
RETURN

END

CALCULATION OF SHAFT HORSE POWER AND CHOICE OF PROPELLER

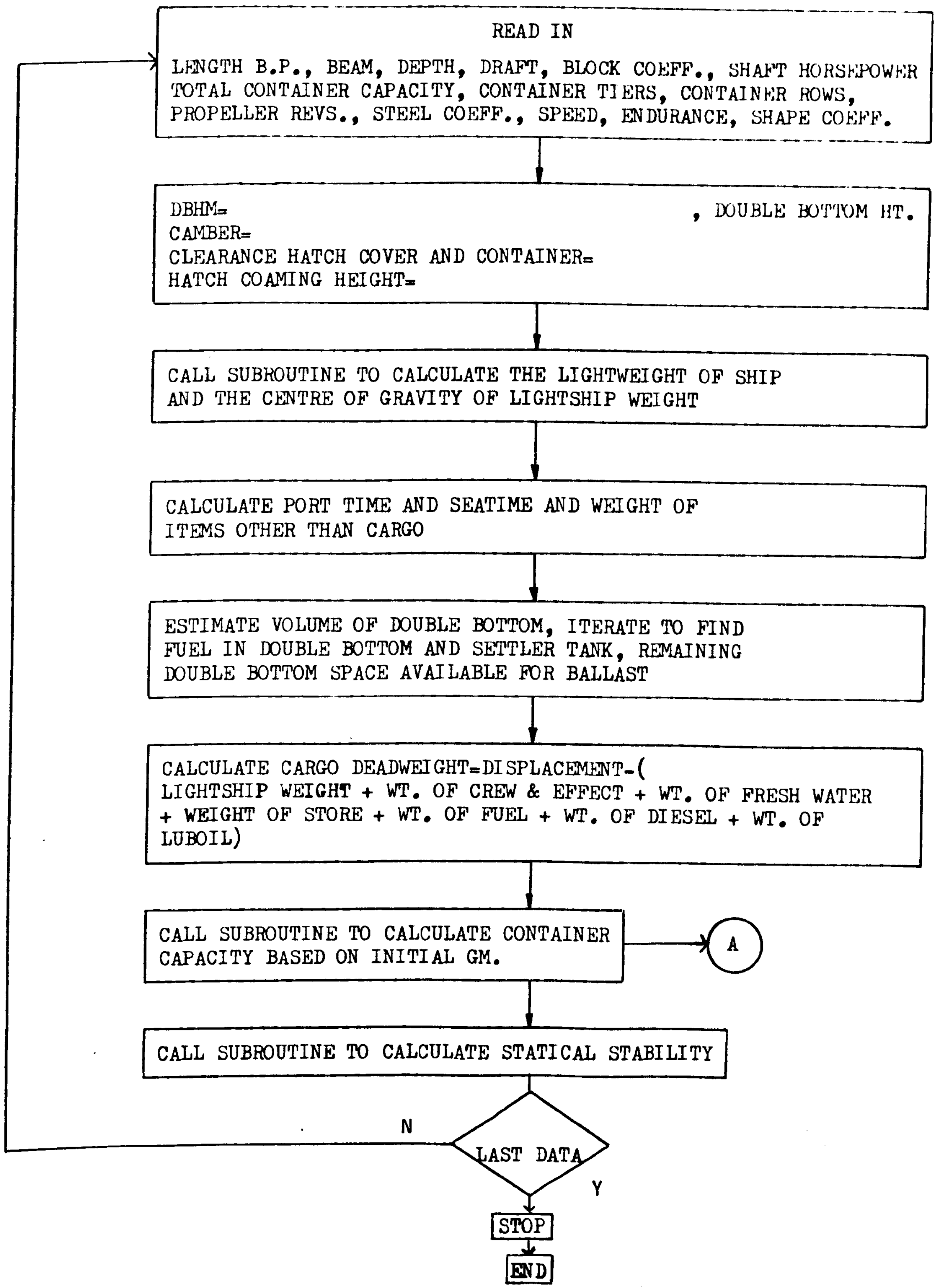


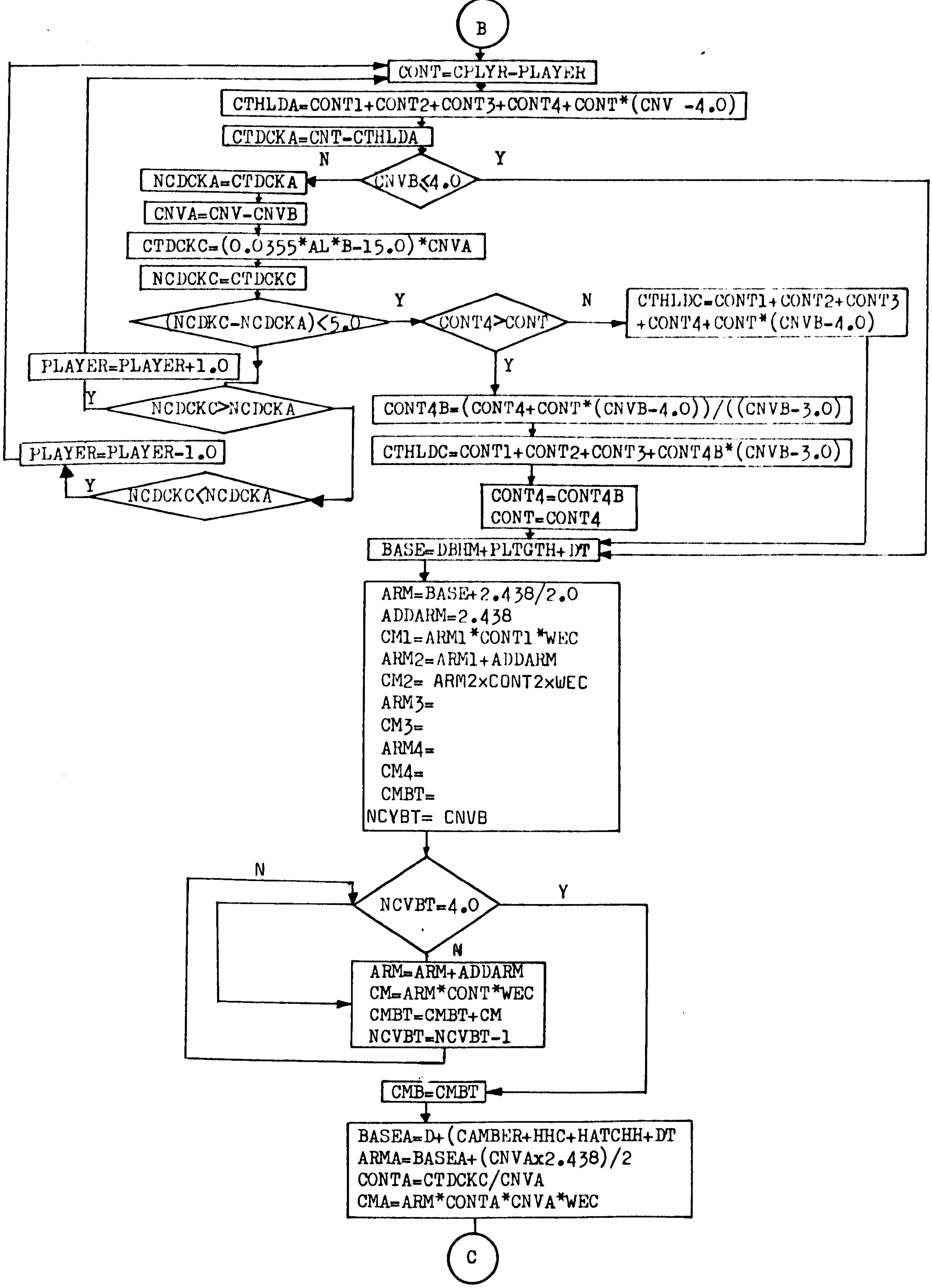

B
A
WAKE=2*CB**5.0*(1.0-CB)+0.2*0.866**2-0.02
THRDED = 0.25*WAKE+0.14
RRE = 0.985
SPDADV = V*(1.0-WAKE)
HULEFF = (1.0-THRDED)/(1.0-WAKE)
2
BP = REVS*SQRT(SHP/1.025)/SPDADV**2.5
6>BP>155
Y
N
C
BASICD = FUNC(BAR,BP)
PRPEFF = FUNC(BAR,BP)
PITCHR = FUNC(BAR,BP)
PRPDIA = BASICD*SPDADV/REVS
PRPDIA > 0.70T
Y
PRPDIA=0.70T
N
PRPDIA > 28.0
Y
PRPDIA = 28.0
N
DELTA = REVS*PRPDIA/SPDADV
EMPIRICAL RELATION TO CALCULATE
FIELD EFFCY.
PP = 1.5*(1.0-DELTA/BASICD) + 0.065
PPP = 1.0 - DELTA/BASICD
P = BASICD/(BASICD + 10.0)
PFNEW = PRPEFF - PP*PPP*P
E
Y
PFNEW<PFBNEW
QPC = PFNEW*HULEFF*RRE
F

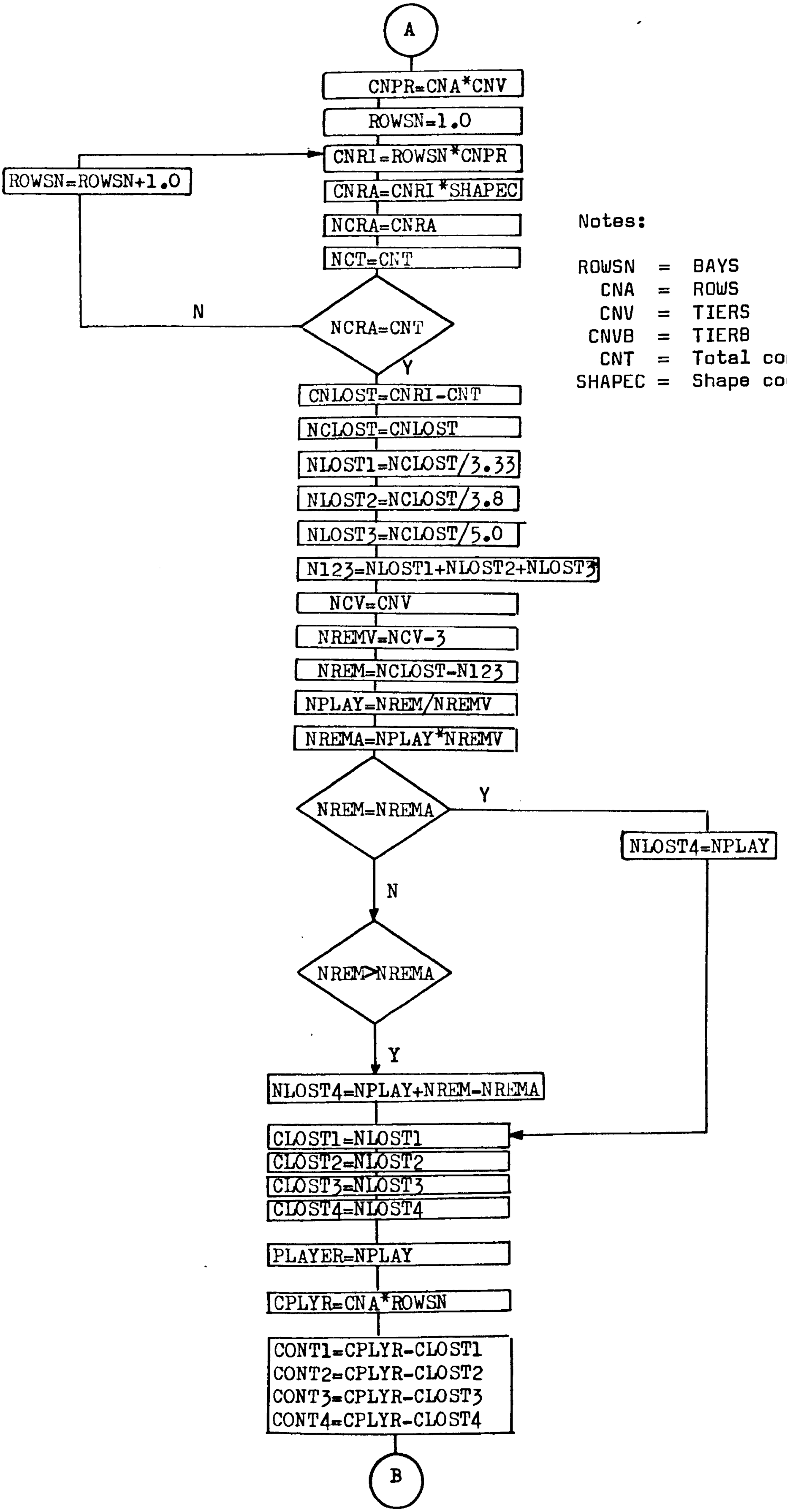

F
SHPNEW = EHPN/NOPROP*CF*WEAIRA/(PFNEW*HULEFF*RRE))
ABS(SHPNEW-SHP)/SHPNEW > 3%
1
SHP=SHPNEW*NOPROP
N
ABS(PRPEFF-PFNEW)/PRPEFF > 3%
Y
IREVLD = 2
N
N
Y
2
REVS=REVS*1.15
PFBNEW=PFNEW
SHP=SHPNEW*NOPROP
E
SHP=SHP/0.90
CALL SUBROUTINE CAVIT
DBAR<BAR
Y
N
3
0.45<DBAR<1.05
N
Y
BAR = DBAR
D
SHP GO TO FAIL
C
BP OUT OF RANGE
RETURN
END

APPENDIX 2.

FLOW CHART OF THE COMPUTER ALGORITHM
FOR DETERMINATION OF THE CONTAINER CAPACITY

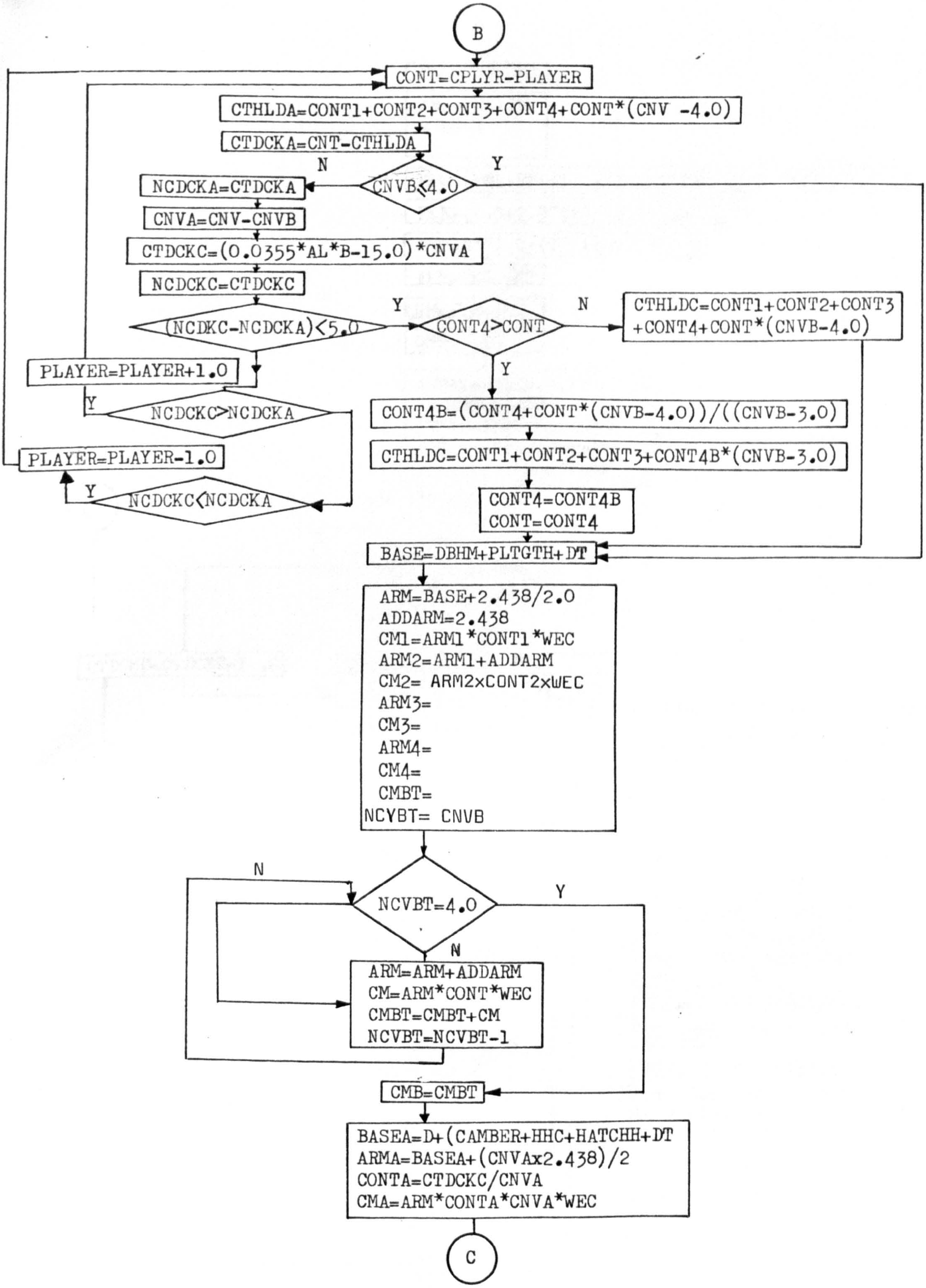


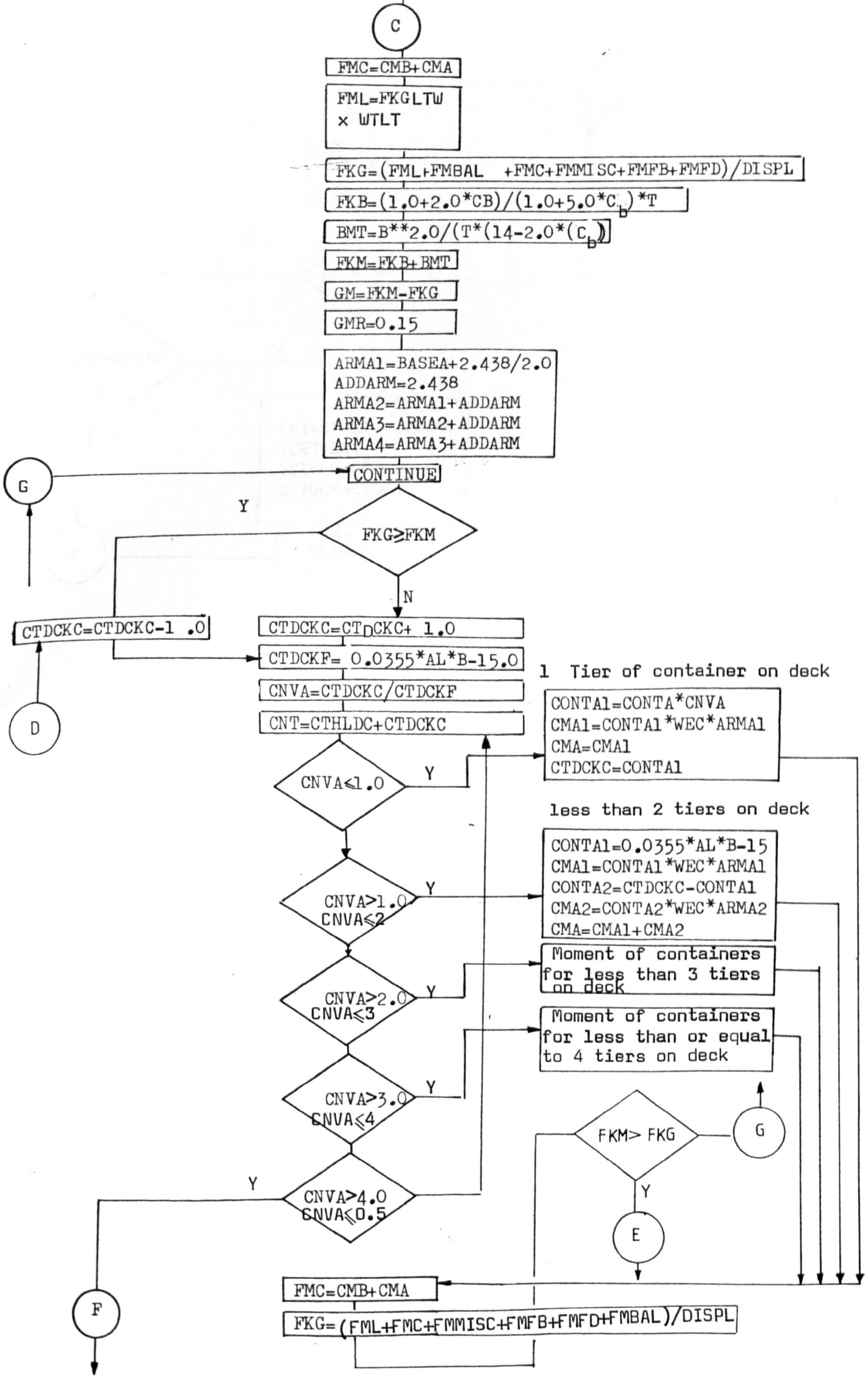

B
CONT=CPLYR-PLAYER
CTHLDA=CONT1+CONT2+CONT3+CONT4+CONT*(CNV -4.0)
CTDCKA=CNT-CTHLDA
N
Y
CNVB≤4.0
NCDCKA=CTDCKA
CNVA=CNV-CNVB
CTDCKC=(0.0355*AL*B-15.0)*CNVA
NCDCKC=CTDCKC
(NCDKC-NCDCKA)<5.0
Y
CONT4>CONT
N
CTHLDC=CONT1+CONT2+CONT3
+CONT4+CONT*(CNVB-4.0)
PLAYER=PLAYER+1.0
Y
Y
NCDCKC>NCDCKA
CONT4B=(CONT4+CONT*(CNVB-4.0))/((CNVB-3.0)
PLAYER=PLAYER-1.0
CTHLDC=CONT1+CONT2+CONT3+CONT4B*(CNVB-3.0)
Y
NCDCKC<NCDCKA
CONT4=CONT4B
CONT=CONT4
BASE=DBHM+PLTGTH+DT
ARM=BASE+2.438/2.0
ADDARM=2.438
CM1=ARM1*CONT1*WEC
ARM2=ARM1+ADDARM
CM2= ARM2xCONT2xWEC
ARM3=
CM3=
ARM4=
CM4=
CMBT=
NCVBT= CNVB
N
Y
NCVBT=4.0
N
ARM=ARM+ADDARM
CM=ARM*CONT*WEC
CMBT=CMBT+CM
NCVBT=NCVBT-1
CMB=CMBT
BASEA=D+(CAMBER+HHC+HATCHH+DT
ARMA=BASEA+(CNVAx2.438)/2
CONTA=CTDCKC/CNVA
CMA=ARM*CONTA*CNVA*WEC
C

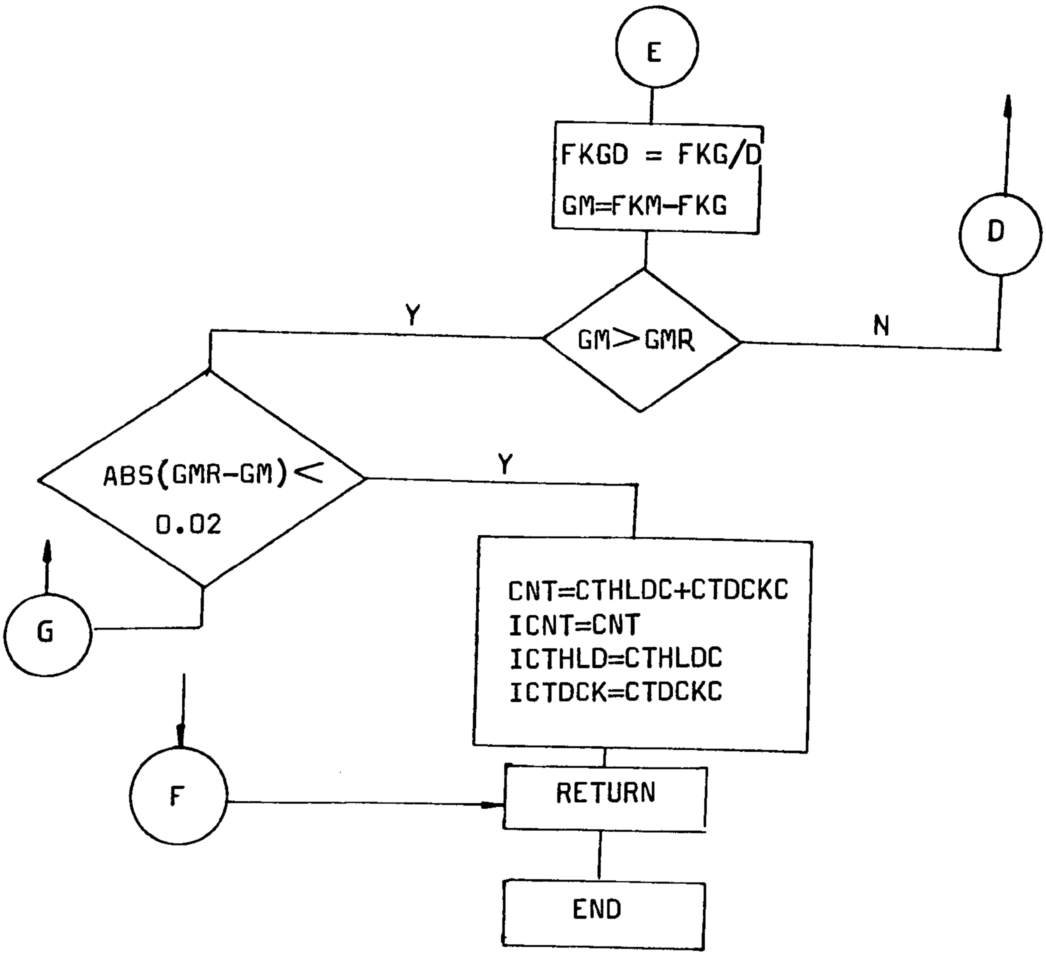


Notes:

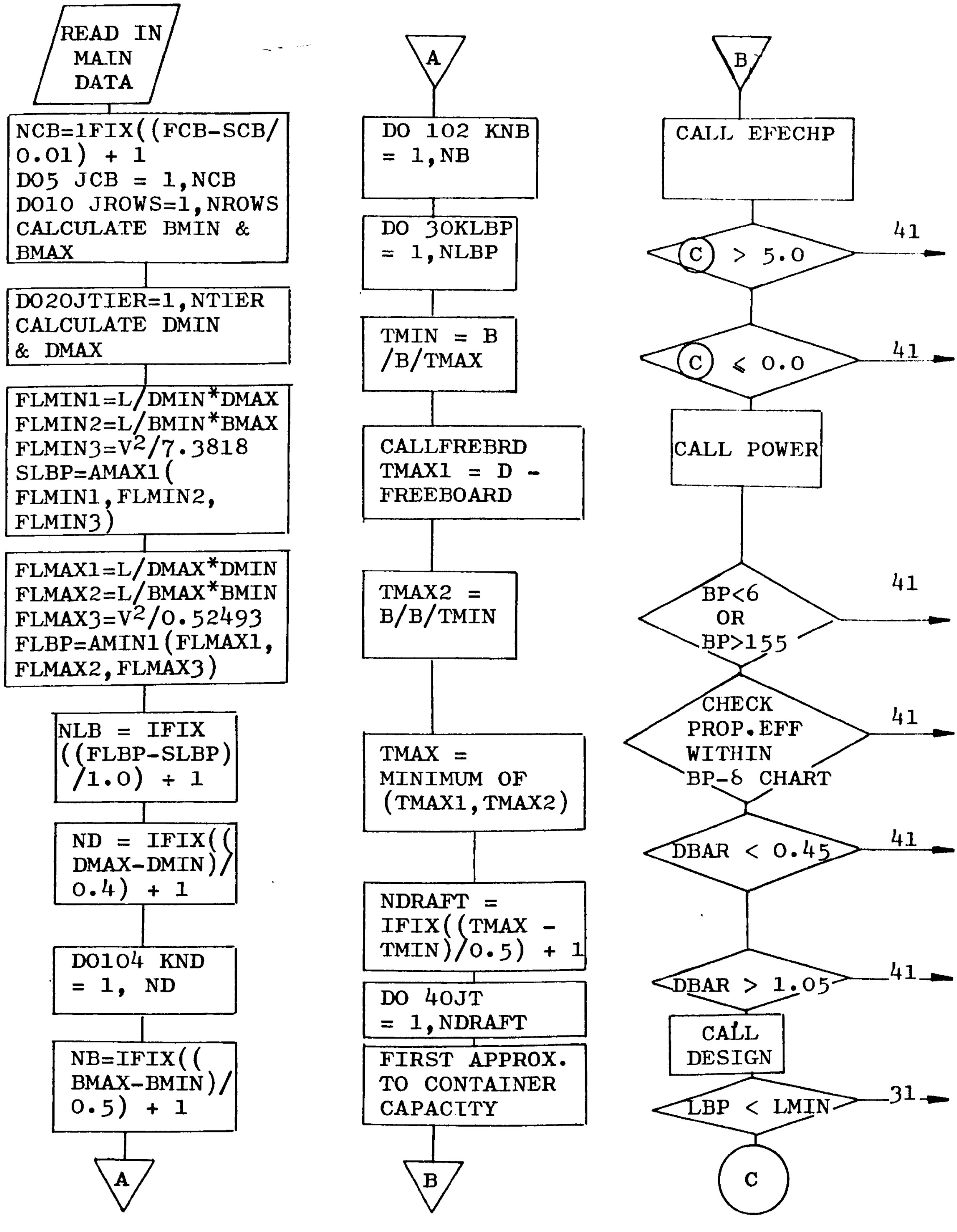
ROWSN = BAYS
CNA = ROWS
CNV = TIERS
CNVB = TIERB
CNT = Total containers, Teu
SHAPEC = Shape coefficient

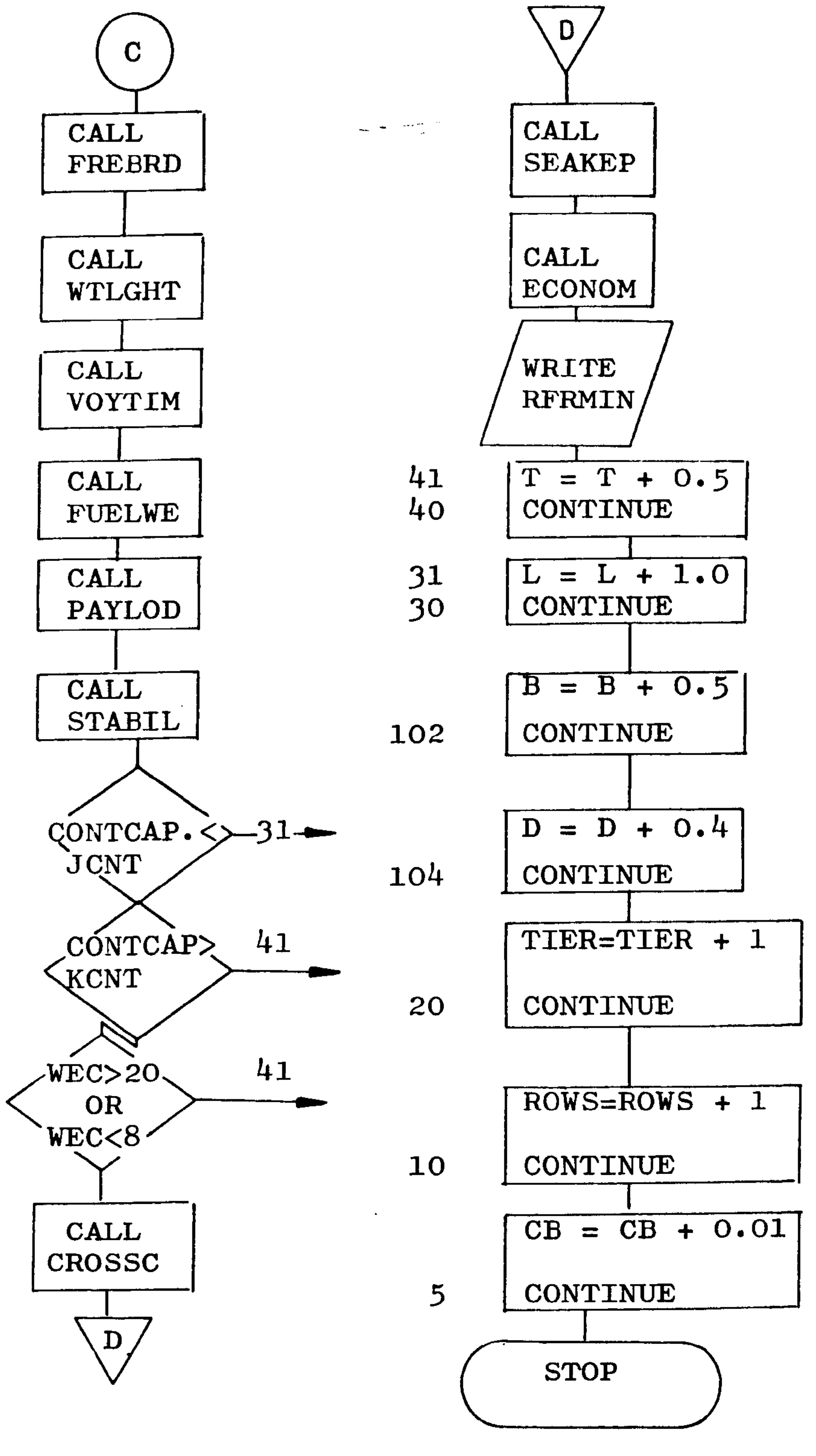

B
CONT=CPLYR-PLAYER
CTHLDA=CONT1+CONT2+CONT3+CONT4+CONT*(CNV -4.0)
CTDCKA=CNT-CTHLDA
N
Y
CNVB<4.0
NCDCKA=CTDCKA
CNVA=CNV-CNVB
CTDCKC=(0.0355*AL*B-15.0)*CNVA
NCDCKC=CTDCKC
(NCDKC-NCDCKA)<5.0
Y
CONT4>CONT
N
CTHLDC=CONT1+CONT2+CONT3
+CONT4+CONT*(CNVB-4.0)
PLAYER=PLAYER+1.0
Y
NCDCKC>NCDCKA
Y
CONT4B=(CONT4+CONT*(CNVB-4.0))/((CNVB-3.0)
CTHLDC=CONT1+CONT2+CONT3+CONT4B*(CNVB-3.0)
PLAYER=PLAYER-1.0
Y
NCDCKC<NCDCKA
CONT4=CONT4B
CONT=CONT4
BASE=DBHM+PLTGTH+DT
ARM=BASE+2.438/2.0
ADDARM=2.438
CM1=ARM1*CONT1*WEC
ARM2=ARM1+ADDARM
CM2= ARM2xCONT2xWEC
ARM3=
CM3=
ARM4=
CM4=
CMBT=
NCYBT= CNVB
N
NCVBT=4.0
Y
N
ARM=ARM+ADDARM
CM=ARM*CONT*WEC
CMBT=CMBT+CM
NCVBT=NCVBT-1
CMB=CMBT
BASEA=D+(CAMBER+HHC+HATCHH+DT
ARMA=BASEA+(CNVAx2.438)/2
CONTA=CTDCKC/CNVA
CMA=ARM*CONTA*CNVA*WEC
C


C
FMC=CMB+CMA
FML=FKGLTW × WTLT
FKG=(FML+FMBAL +FMC+FMMISC+FMFB+FMFD)/DISPL
FKB=(1.0+2.0*CB)/(1.0+5.0*Cb)*T
BMT=B**2.0/(T*(14-2.0*(Cb))
FKM=FKB+BMT
GM=FKM-FKG
GMR=0.15
ARMA1=BASEA+2.438/2.0
ADDARM=2.438
ARMA2=ARMA1+ADDARM
ARMA3=ARMA2+ADDARM
ARMA4=ARMA3+ADDARM
G
CONTINUE
Y
FKG≥FKM
N
CTDCKC=CTDCKC-1 .0
CTDCKC=CTDCKC+ 1.0
CTDCKF= 0.0355*AL*B-15.0
CNVA=CTDCKC/CTDCKF
CNT=CTHLDC+CTDCKC
D
1 Tier of container on deck
CONTA1=CONTA*CNVA
CMA1=CONTA1*WEC*ARMA1
CMA=CMA1
CTDCKC=CONTA1
CNVA≤1.0
Y
less than 2 tiers on deck
CONTA1=0.0355*AL*B-15
CMA1=CONTA1*WEC*ARMA1
CONTA2=CTDCKC-CONTA1
CMA2=CONTA2*WEC*ARMA2
CMA=CMA1+CMA2
CNVA>1.0
CNVA≤2
Y
Moment of containers for less than 3 tiers on deck
CNVA>2.0
CNVA≤3
Y
Moment of containers for less than or equal to 4 tiers on deck
CNVA>3.0
CNVA≤4
Y
FKM> FKG
G
Y
E
Y
CNVA>4.0
CNVA≤0.5
F
FMC=CMB+CMA
FKG=(FML+FMC+FMMISC+FMFB+FMFD+FMBAL)/DISPL


E
FKGD = FKG/D
GM=FKM-FKG
GM>GMR
Y
N
D
ABS(GMR-GM)<
0.02
Y
G
CNT=CTHLDC+CTDCKC
ICNT=CNT
ICTHLD=CTHLDC
ICTDCK=CTDCKC
F
RETURN
END

APPENDIX 3. MAIN PROGRAM FLOW CHART BY PARAMETRIC VARIATION OF PRINCIPAL DIMENSIONS




C
CALL FREBRD
CALL WTLGHT
CALL VOYTIM
CALL FUELWE
CALL PAYLOD
CALL STABIL
CONTCAP.<> JCNT
31
CONTCAP> KCNT
41
WEC>20 OR WEC<8
41
CALL CROSSC
D
D
CALL SEAKEP
CALL ECONOM
WRITE RFRMIN
41
T = T + 0.5
40
CONTINUE
31
L = L + 1.0
30
CONTINUE
B = B + 0.5
102
CONTINUE
D = D + 0.4
104
CONTINUE
TIER=TIER + 1
20
CONTINUE
ROWS=ROWS + 1
10
CONTINUE
CB = CB + 0.01
5
CONTINUE
STOP

APPENDIX 4. CONTAINER SHIP DATA

REF.	NAME	LENGTH in m.	BEAM in m.	DEPTH in m.	CB	TOTAL CONT.	CONT. U. DECK	CONT. 1 TIER	ABOVE DECK 2	3	4	CONTAINER SIZE IN FT. UNITS	U. DK. ROWS/TIERS/BAYS	ABV. DK. ROW/TIER/BAYS	M/C POSITION		V	U. DK. SHAPE COEFF.
1	A	268.38	32.15	19.51	0.536	1104	694			410		35'x8'x8.5'	10/7/15 (35')	10/3/15 (35')	3/4 AFT	26(20')	31.10	
2	B	282.74	32.00	19.51	0.538	2258	1248			1010		20'x8'x8.5'	9/7/29 (20')	12/3/30 (20')	3/4 AFT		26.80	0.683
3	C	231.42	31.70	18.29	0.572	849	561		288			40'x8'x8.5'	9/7/26 (20')	12/2/26 (20')	AFT		24.60	0.685
4	D	224.0	30.50	19.20	0.535	816	544		272			40'x8'x8.5'	9/7/26 (20')	11/2/28 (20')	3/4 AFT		25.80	0.664
5	ENCOUNTER BAY	213.36	30.48	16.46	0.600	1300	782			518		20'x8'x8'	9/6/18 "	10/3/18	AFT		22.00	0.805
6	F	205.74	28.96	16.46	0.582	1018	562			456		24'x8'x8.5'	8/6/12 (24')	11/3/14 (24')	AFT	16(20')	22.20	
7	ACT-1,2,3	205.74	28.96	15.93	0.605	1134	754		380			20'x8'x8'	8/6/20 (20')	10/2/21	AFT		21.60	0.785
8	AUSTRAL ENVOY	190.5	27.4	16.20	0.575	1186	706				480	20'x8'x8'	8/6/- "		AFT		22.60	
9	C6-S 85Cd	234.4	27.4	16.20	0.646	1708	1186				522	20'x8'x8'	8/6/- "		AFT		22.00	
10	SYDNEY EXP.	210.0	30.50	16.40	0.601	1589	861				728	20'x8'x8.5'	9/6/- "	12/4/-	AFT		22.00	
11	COLOUMBUS VICT.	151.30	25.50	13.70	0.660	775	409			366		20'x8'x8'	7/5/14 "	7/3/12	AFT		18.00	0.835
12	CITY OF PLYMOUTH	96.31	16.50	8.10	0.630	300	132			168		20'x8'x8.5'	5/3/10 "	5/3/10	AFT		15.00	
13	ORIGINAL RES.	192.00	30.50	18.19	0.585	1480	908			572		20'x8'x8'	- "	-	AFT		23.35	0.880
14	DART-CANADA	205.90	31.00	16.52	0.625	1480	840			640		20'x8'x8'	- "	-	AFT		22.30	
15	KASHU MARU	175.00	25.70	15.30	0.569	700	500		200			20'x8'x8'	7/6/17 "	8/2/15	3/4 AFT		22.50	0.700
16	JAPAN ACE	175.00	25.20	15.30	0.566	723	489		234			20'x8'x8'	7/6/17 "	8/2/15	3/4 AFT		22.80	0.685
17	GOLDEN GATE BR	175.00	25.00	15.40	0.580	716	484		232			20'x8'x8'	7/6/18 "	8/2/16	3/4 AFT		22.25	0.640
18	HAKONE MARU	175.00	26.00	15.50	0.560	752	486		266			20'x8'x8'	7/6/17 "	8/2/15	3/4 AFT		22.60	0.681
19	AMERICA MARU	175.00	25.00	15.50	0.570	708	488		220			20'x8'x8'	7/6/18 "	8/2/17	3/4 AFT		22.40	0.646
20	ASTRONOMER	193.10	30.80	18.80	0.620	1416	878			538		20'x8'x8'	9/7/16 "	11/2/18	AFT		21.00	0.871
21	GODWIT	207.00	32.20	19.00	0.622	1466	854			612		20'x8'x8'	9/7/- "	12/3/-	AFT		22.40	
22	JEDDAH CROWN	104.00	18.90	8.15	0.590	318	198		120			20'x8'x8'	6/4/10 "	6/2/10	AFT		17.00	0.825
23	FIERY CROSS ISLE	133.6	21.50	10.50	0.570	400	256		144			20'x8'x8'	7/4/12 "	7/2/12	AFT		22.00	0.762
24	TOKYO BAY	274.32	32.26	24.60	0.595	2300	1944	356				20'x8'x8'	10/9/28 "	13/1/28	3/4 AFT		26.00	0.771
25	"	"	"	"	"	3000	1944			1056		20'x8'x8'	10/9/28 "	13/3/28	"		26.00	
26	KAMAKURA MARU	245.02	32.21	19.51	0.590	1838	1604	234				20'x8'x8'	10/9/- "	10/9/-	3/4 AFT		26.15	
27	MANCH. VIGOUR	103.10	15.55	10.65	0.735	316	206		110			20'x8'x8'	5/4/11 "	5/2/11	AFT		15.50	0.936
28	VERRANZANO BRD.	248.0	32.20	19.90	0.594	2068	1056				1012	20'x8'x8'	9/7/26 "	12/4/26	3/4 AFT		26.56	0.645
29	"	"	"	"	"	1908	1056			852		20'x8'x8'	9/7/26 "	12/3/26	3/4 AFT		26.56	
30	KISHU MARU	242.0	32.20	19.50	0.590	1836	984			822		20'x8'x8'	/7/25 "	12/3/25	AFT		26.00	
31	REMUERA	236.0	32.08	20.73	0.645	1655	1151		504			20'x8'x8'	9/8/20 "	11/3/20	3/4 AFT	Part Reefer	23.00	0.799
32	EUROLINER	224.96	30.00	19.20	0.550	1632	1088		544			20'x8'x8.5'	9/7/26 "	11/2/26	3/4 AFT		26.00	0.664
33	"	"	"	"	"	1906	1088			818		20'x8'x8.5'	9/7/26 "	11/3/26	"			
34	CALIFORNIA STAR	178.00	25.85	15.29	0.610	871	596		275			20'x8'x8'	8/6/19 "	10/2/19	3/4 AFT		21.50	0.654
35	TAEPING	192.00	30.50	18.19	0.510	1394	856			538		20'x8'x8'	9/7/20 "	12/3/20	AFT		23.41	0.679
36	"	"	"	"	"	1312	856			456		20'x8'x8'	9/7/20 "	12/3/20	AFT			
37	DART AMERICA	218.01	30.48	18.60	0.610	1556	1140			416		20'x8'x8'	9/7/23 "	10/3/23	AFT		22.00	0.787
38	ARAFURA	200.0	30.00	16.70	0.560	976	632		344			20'x8'x8'	8/6/19 "	10/2/18	3/4 AFT		23.00	0.693
39	PORT ROYAL	198,00	32.20	18.80	0.605	1512	892			620		20'x8'x8'	10/7/18 "	10/3/18	3/4 AFT		22.60	0.708
40	SEA WITCH	177.34	23.77	16.61	0.640	928	612		316			20'x8'x8.5'	7/6/18 "	9/2/18	AFT		20.00	0.810
41	ORIENTAL CHEV.	192.00	26.00	16.12	0.620	985	693		292			20'x8.5'x8'	8/6/18 "	8/2/19	AFT		21.70	0.802
42	ELBE MARU	252.0	32.20	24.40	0.572	1842	1580	262				20'x8'x8'	10/9/27 "	10/1/27	3/4 AFT		26.25	0.650
43	SELANDIA	257.6	32.21	23.90	0.545	2272	1662		610			20'x8'x8'	10/9/27 "	12/2/27	3/4 AFT		26.00	0.684
44	ATLANTIC MARS.	154.70	23.00	14.63	0.637	704	469		235			20'x8'x8'	7/5/16 "	7/2/18	AFT		19.00	0.838
45	SEA FREIGHT LIN	111.56	16.15	8.53	0.670	218	162	56				20'x8'x8'	5/3/12 "	5/1/12	AFT		13.50	0.900
46	ELBE EXPRESS	155.00	24.50	14.60	0.612	736	508		228			20'x8'x8'	7/6/15 "	9/2/13	AFT		20.00	0.806
47	MANCH. CHALLENGE	151.79	19.35	14.63	0.600	532	452	80				20'x8'x8'	6/6/14 "	6/1/14	AFT		19.50	0.897
48	C.P. VOYAGEUR	153.00	25.60	15.25	0.648	707	503		204			20'x8'x8'	7/6/14 "	8/2/14	AFT		18.00	0.855

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