A COMPUTER BASED STUDY OF THE EFFECTS OF PANAMAX LIMITS ON THE ECONOMIC DESIGN OF BULK CARRIERS.

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To my mother, brothers and sister with all my love

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

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Notation.

B	Ship beam moulded
BAR	Propeller blade area ratio
BM	Metacentric height above centre of buoyancy
BMT	British maritime technology
bhp	British horsepower
BSRA	British ship research association
C	Camber
©	Resistance constant
CAF	Compound amount factor
Cb	ship block coefficient
CDWT	Cargo deadweight
CF	ship model correlation factor
CM	Midship section area coefficient
CMEA	Council of mutual economic aid
CRF	Capital recovery factor
cu.ft	Cubic feet
CW	Water plane area coefficient
D	Ship depth moulded
E	Hull numeral
EEC	European economic community
EHP	Effective horsepower
fob	Free on board
ft.	Feet
g	Grams
GM_T	Transverse metacentric height
grt	Gross register tonnage
gt	Gross tonnage
h	Hour
hfo	Heavy fuel oil
H+M	Hull & machinery insurance
ifo	intermediate fuel oil
IMO	International maritime organization
IRR	Internal rate of return
ISL	Institute of shipping economics and logistics
ITF	International transport workers federation
ITTC	International towing tank conference
KB	Height of centre of buoyancy above keel
kcal	kilo-calories
Kg	Kilograms
KG	Height of centre of gravity above keel
km	Kilometres

KM	Height of metacentre above keel
KN	Knots
KW	kilowatts
L,Lbp	Ship length between perpendiculars
Ⓛ	Froude speed-length constant
LCB	Longitudinal centre of buoyancy
m	Metre
mdo	Marine diesel oil
Mill.	Million
N,rpm	Propeller revolutions per minute
nm	Nautical miles
NPV	Net present value
nrt	Net register tonnage
nt	Net tonnage
Ⓞ	Length constant
OBO	Ore/bulk/oil carrier
OECD	Organization for economic co-operation and development
OPEC	Organization of petroleum exporting countries
O/O	Ore/oil carrier
P/D	Propeller diameter pitch ratio
P&I	Protection and indemnity insurance
PWF	present worth factor
QPC	Quasi propulsive coefficient
RFR	Required freight rate
Ⓢ	Wetted surface constant
SCAF	Series compound amount factor
sfc	Specific fuel consumption
SFF	Sinking fund factor
SHP	Shaft horsepower
SPWF	Series present worth factor
T	Ship design draft moulded
UK	United kingdom
V	Ship speed
Va	Speed of advance
$V/\sqrt{L}$	Speed-length ratio
£	Pounds sterling
$	US dollars
Δ	Ship displacement
η_H	Hull efficiency
η_O	Propeller open water efficiency
η_R	Relative rotative efficiency

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SYNOPSIS.

This thesis deals with the economic design of bulk carriers of Panamax class at the preliminary stage and investigates the effects of the size limits imposed by the Panama Canal.
The computer is used as the principal tool in this thesis where a digital computer program algorithm has been developed to carry out the task. The computer program carries out parametric variation of principal dimensions, generates several synthesised designs and locates the optimum one.
An economic study is incorporated into the program to serve as a base for evaluating economically each design and selecting the one with the highest return. The required freight rate (RFR) is chosen as the economic measure of merit when comparing between alternative designs.
The program is used to carry out a sensitivity analysis for the main design variables. This technique allows the importance of these variables to be assessed.
Subsequently consideration is given to the equivalent size of bulk carriers that would avoid the Panama Canal but give the same required freight rate.
The effect of reducing ballast voyages is considered.
The main trade route used for this study is New Orleans (USA) to Yokohama (Japan) with grain.

The investigation indicated that the best measure of merit was obtained with a vessel of a size to the limit of the Panama Canal locks in length, beam and draft and of high block coefficient of 0.85 with a speed of 13 knots.
Steel weight and installed power are found to be very important design parameters of higher influence on the economic measure of merit. Their estimates should, therefore, be as accurate as possible.
The economic measure of merit is considerably improved by the reduction of the voyage in ballast which stresses the importance of avoiding long distances sailing in ballast.
The importance of the Panama Canal as a short cut route is clearly indicated

by the fact that the size of a bulk carrier not transiting through it, transporting the same commodity between the same ports and yielding the same return is more than twice that of a Panamax.

i. GENERAL INTRODUCTION.

Since its opening in 1914, the Panama Canal has offered to world merchant shipping transport great services by cutting some very long trade distances by half and even more and thus allowing ships to reach their port(s) of destination faster than ever.

According to the size limits imposed by Panama Canal locks, ships have been built based on these size constraints to be able to transit through them. These ships are referred to as Panamax ships.

This thesis, as indicated by its title, deals with the design at the preliminary stage of this class of ships and particularly of bulk carriers type.

The objective was to estimate the optimum combination of ships dimensions bearing in mind the size limits imposed by the Canal and to study the effects of these constraints on the chosen design.

Computer software is developed in such a manner to enable the naval architect not only to select the ship main particulars based on technical aspects but on economic performance as well. Indeed, ship economics which is nowadays accepted as an integrated part of preliminary ship design process is powerful when it comes to compare ships and select the one with the highest return to its owner. It requires making estimates of ship costs, including first cost, for ship operation and revenue derived from freight of cargo carried and thus of expenditure and income for the whole ship's life over a specified trade route.

This economic study is incorporated into the computer program for the purpose of evaluating economically each design deduced and then selecting the best one.

Since income in this case is not predictable, the Required Freight Rate (RFR) is chosen in this thesis as the economic measure of merit when comparing alternative designs. The best design is that one with minimum RFR.

The computer program is based on parametric variation of principal variables of length, beam, draft, block coefficient and speed generating, therefore, an appreciably large number of alternative ship designs and thus giving more "chance" to locate the optimum synthesised design.

The typical trade route simulated in this thesis for which the computer program has been run is

- -port of New Orleans (Gulf coast of USA) to port of Yokohama (Japan) with grain as loaded bulk commodity;
- -port of Yokohama to port of New Orleans in ballast condition.

The round trip distance for this route whose front haul and back haul is via Panama Canal is 18,300 nautical miles.

In order to avoid generating a huge number of derived designs, a beam of 32.2 metres, a very common value to most Panamax bulk carriers, is set fixed. The ranges of deadweight and speed considered in this thesis are respectively from 45,000 to 75,000 ± 2% dwt and 11 to 17 knots.

Any design that does not meet the conditions of Panamax dimensional constraints, minimum homogeneous stowage factor and adequate stability is rejected.

The majority of algorithms or different subroutines are checked and compared with existing bulk carriers data so that valid and reasonable results are output.

Parametric studies and sensitivity analysis are both carried out in this thesis to investigate effects (on RFR) and the relative importance of different design features. Indeed, with parametric studies it becomes possible to quantify both in technical and economic terms the importance of increasing/reducing particular ship variables, the performance of high block coefficient and effects of speed on transport cost.

Sensitivity analysis is used to identify those factors of greater influence on design economics so that during the design process more precautions would be attributed to their estimates. A 10% improvement of different design variables is assumed in this thesis to determine their merit ranking, although this percentage change is not always achievable for some factors in real life.

Other analyses related to Panama Canal size limits and trade route are carried out for the purpose of studying effects of extending the canal size and changing the trade route on the selected design.

Finally, and in order to study the benefit from reduced ballast voyages, the program has been run to carry out detailed simulation of a trade route of four legs, namely,

New Orleans (USA) - Yokohama (Japan) with grain (9150 nm distance through Panama Canal);

Yokohama - Brisbane (Australia) under ballast (3980 nm distance);

Brisbane - Tampico (Mexico) with bulk fertilisers (9200 nm distance through Panama Canal); and

Tampico - New Orleans under ballast (733 nm distance).

CHAPTER 1 : BACKGROUND.

1.1 INTRODUCTION.

The bulk carrier ship, "workhorse" of the seas, has relatively a recent history.

Bulk cargoes have been carried for many years but the modern dry bulk carrier came into being about 35 years ago in response to an increase in demand for the shipment of dry bulk goods and the need to satisfy this demand with an efficient design of ships.

Early dry bulk cargoes were carried in single or two deck vessels in tramping trades and before 1914 many trunk deck designs had come forward to assist in self trimming the holds and limit 'free surface' effects. Even double skin side ballast tanks existed. However, it was many years before the present bulk carrier evolved. Within this type many are designed for specific cargoes on a set route.

The first section of this chapter outlines briefly these developments of the bulk carrier ship and describes its various types.

The world bulk carrier tonnage has enormously increased over the years but during the last few years the rate of increase has slowed down and even declined in 1987. The reasons behind this change are closely analysed in the first section with some statistical data for the last 27 years to illustrate this development.

The second section takes a close look to the major dry bulk commodities namely, iron ore, grain and coal and discusses the recent developments in their seaborne trade.

To illustrate the imbalance which exists between demand and supply in the dry bulk shipping sector, section three of this chapter analyses the freight market of this sector giving freight rates for some typical bulk trade routes for the 1980s.

The Panama Canal after its opening in 1914 had an enormous impact in the world sea transport with some routes shortened by more than a thousand nautical miles. Since most dry bulk cargoes started transiting through Panama Canal, bulk carriers were designed up to the canal locks, known as Panamax bulk carriers. However, the phrase Panamax bulk carrier normally means that the beam is at the Panama Canal lock limit of 32.3 m. The ultimate limit for transit is when the length and draft also reach lock limits. In these circumstances the ratios of main dimensions are dictated from what is considered efficient today although a recent well known design of container ships built to this final limit (American New York class).

The last section of this chapter is devoted to Panama Canal giving a brief history and showing its strategic importance in the shipping movement.

1.2 THE BULK CARRIER.

1.2.1 DEFINITION.

To the world shipping industry the term "bulk carrier" is understood to mean a ship intended for the transportation of unpacked dry cargo.

Although the most common cargoes are grain, coal and ores of every kind, these vessels are employed wherever bulk cargoes of any type have to be transported.

As the nature of the cargo and the service routes involved cannot in many cases be predicted with as much precision as with crude oil carriers, the design of the bulk carrier is more general in character and has changed little over the years catering for as wide a range of cargo mass density as possible.

Fig.1.1a, 1.1b and 1.1c show a typical bulk carrier in profile, and typical mid-ship sections of an ore and bulk carriers are given to show the standard arrangement of hopper-sided hold, the topside wing tank and the double bottom.

The following points summarised the principal requirements of a general bulk carrier :

1- Minimum stowage rate of cargo with satisfactory trim and metacentric

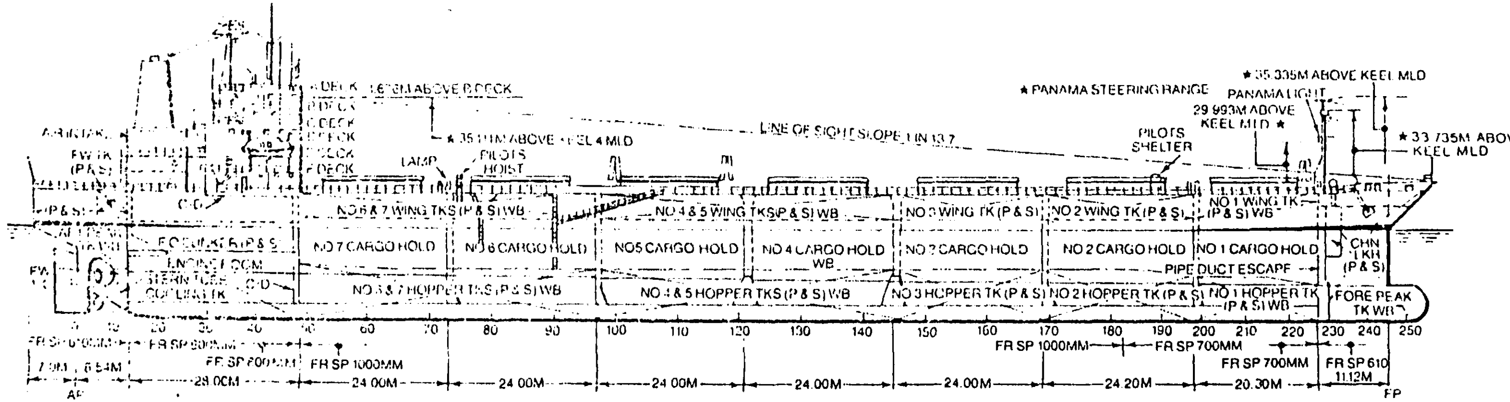


Fig.1.1a PROFILE OF PANAMAX BULK CARRIER 'IRISH SPRUCE'.

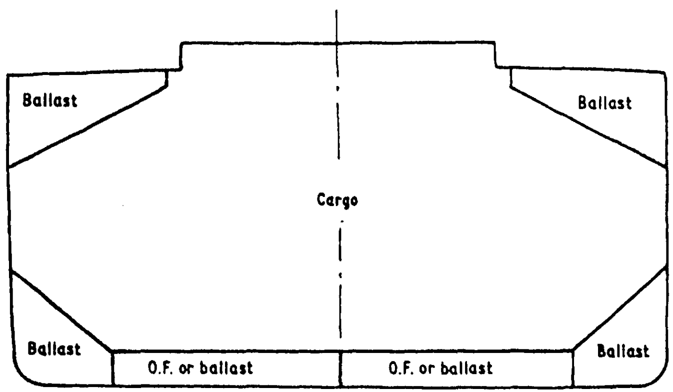


Fig.1.1b TYPICAL BULK CARRIER MIDSHIP SECTION.

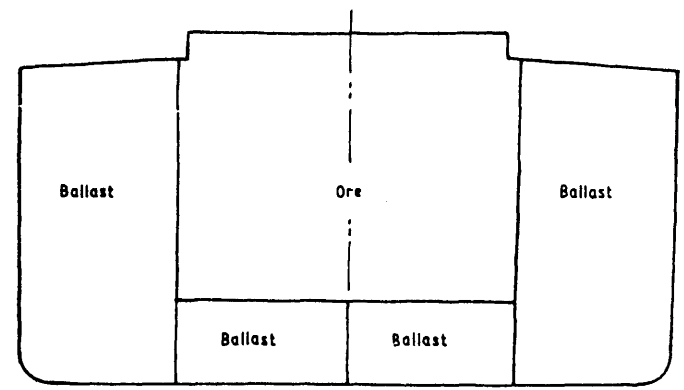


Fig.1.1c TYPICAL ORE CARRIER MIDSHIP SECTION.

height in laden and ballast conditions.

2- Large hatches so that grabs can reach all corners of holds when discharging, and for rapid operations of loading and discharging the cargo.

3- Self-trimming arrangements so that grain may be carried without the use of shifting boards or the need for over stowing.

4- Sufficient ballast capacity for good seakeeping in ballast and for complete immersion of propeller in this condition at a reasonable trim.

5- Dual water/cargo spaces reasonably easy to load and empty completely of suitable bulk commodities and readily cleaned and dried out after ballasting.

6- Low value of metacentric height GM when carrying ore by allowing alternate holds to be empty.

1.2.2 BRIEF HISTORY.

Ships designed for the carriage of large quantities of single homogeneous cargoes have been in service for nearly a century. In those early days their operating role was usually as part of a complete production/transport chain as in the case of a company owning iron ore mines and using its own ships to carry the ore.

By the early 1920s bulk carriers were appearing in what might be called a tramping role capable of carrying various kinds of dry cargo in bulk with stowage factors varying from 15 to 55 cubic feet per ton. These single-deck vessels came to be known as "handy-size bulkers", starting at about 10,000 dwt and by 1939 they had increased in size to 20,000 dwt.

After the second world war the popularity of the handy size bulker continued to increase, both as a general purpose trader and as a carrier of the major bulk cargoes such as iron ore, grain and coal.

Compared with the average all-purpose two deck tramp ship, that is a vessel not operating a regular schedule between specific ports but picking up cargo as and when it became available, the handy size bulker was a cheaper vessel to build in terms of carrying capacity. In many cases it was not fitted with the cargo handling gear. The modern bulk carrier allows bulk cargo to be loaded and discharged quickly from modern automated terminals.

Like container ships these modern bulk carriers were born of economic necessity allowing a cheaper means of carrying bulk cargoes.

During 1969-70 they proved to be one of the most lucrative ships to operate and the largest growing type of ships outside the tanker fleets.

Since then, the bulk carrier has enormously increased in size to over 200,000 dwt with the largest one in service today of about 270,000 dwt (Hitachi Venture, ore carrier, 1981, DWT = 267,889.).

1.2.3 PRINCIPAL TYPES OF BULK CARRIERS.

1.2.3.1 THE STRAIGHTFORWARD BULK CARRIER.

This ship trading most of the time between regular ports is specialised in carrying dry bulk cargoes. The principal commodities carried are iron ore, grain, coal, bauxite, phosphates, manganese ore, alumina and bulk fertilisers with the first three commodities being the majors in world dry bulk trade.

For many years these bulk cargoes were carried by the handy size bulk carrier ship which covers the 10,000 to 40,000 dwt category. In order to reduce the cost per ton of cargo shipped shipowners of this type of ships built larger ones. For many shipowners and operators the critical factor which governed the size of the ship was the breadth of the locks in Panama Canal, 32.3 m (106 ft), since most of these commodities are transiting through this canal. Although the handy size bulk carrier continues to trade carrying dry bulk commodities, these are now usually carried in Panamax vessels and even larger ships when the trade route does not meet any size restriction.

1.2.3.2 THE COMBINED CARRIER.

In the past, oil tankers have in some instances been used for the carriage of grain and certain other bulk cargoes but the high cost of cleaning the tanks for this purpose did not encourage this arrangement.

Today the required flexibility of operation can be achieved by vessels designed to carry oil or ore or bulk and these ships are referred to as combined carriers.

One of the economic problems of tankers and bulk carriers is that they must inevitably spend half their working lives in ballast and therefore not earning freight. To overcome this problem the combined carrier was introduced in the early 1960s to reduce the amount of voyage time in carrying ballast by carrying cargo on the front haul as well as the back haul, switching from the oil trade to the dry cargo trade and vice versa.

The ore/bulk/oil (OBO) carrier , and sometimes referred to just as ore/oil (O/O), is similar in construction to the general purpose bulk carrier but is designed to carry dry cargo or oil in the cargo holds and is fitted with gas tight hatch covers and has specially strengthened bulkheads as well as a strengthened tank top. It does no carry oil and ore at the same time.

The combined carrier has been more expensive to build and in nearly all cases it has higher operating costs and a lower capacity cargo intake in relation to the size of the vessel. It does, however, offer the shipowner the ability to engage in more than one trade and to choose the commodity which is offering the highest prevailing rate of freight as well as the reduction in time spent carrying ballast.

1.2.3.3 THE BULKER/CONTAINER CARRIER.

Similar in concept to the combined carrier which is able to operate in two or more of the major trades the bulker/container is a more recent development.

Known as the conbulker, the vessel allows one hull to be used in container or in bulk trade. Conbulkers have been described as enhanced bulk carriers but their true value is only achieved in container trades where fast handling bulk cargo moves in large volume along one leg of the container route.

1.2.3.4 THE BULK/VEHICLE CARRIER.

Easily distinguished by its very large freeboard,the bulk/vehicle carrier was introduced in the early 1970s in order to offer shipowners and operators the means of increasing their earning capacity.

While the international car market was booming the car/bulker attracted a great deal of attention but as the worldwide movement of cars slowed down the car manufacturers, particularly the Japanese, demanded a tighter scheduling of loading dates which meant that the bulk/car carriers was at a disadvantage because of the time that might be spent collecting its bulk cargo.

For about five years the car/bulkers competed very well with the pure car carriers and this applied particularly to the larger vessels with a capacity of 4,000 to 5,000 units (cars etc.) or 50,000 dwt of bulk cargo.

1.2.4 THE DRY BULK CARRIER FLEET.

The world dry bulk carrier fleet has enormously increased during the last 30 years with a steady growth over the years, but recently the situation seems to be reversed.

This section shows how the fleet grew up and focuses particularly on recent developments by analysing briefly the reasons behind this cutback.

First below, the general actual situation of the world merchant fleet is briefly outlined.

WORLD MERCHANT FLEET.

Between mid-1985 and mid-1986, the world fleet of merchant vessels declined. According to Lloyd's Register of Shipping, the world fleet was reduced from 673.7 in mid-1985 to 647.6 million dwt in mid-1986, a reduction in one year of 4.0 per cent.

This significant cutback can be seen as marking a significant step towards correcting the gross imbalance between supply and demand. Indeed, this imbalance has contributed in a large part to an unhealthy shipping market, particularly in the bulk sector since the beginning of the decade.

Nevertheless, there is still a substantial way to go before a healthy balance is attained in all sectors.

It is instructive to compare the development of different shipping sectors (fig.1.2) during the last 10 years.

The major contributor to the reduction of the world fleet was a further elimination of a large part of the world tanker fleet. During 1985 and the

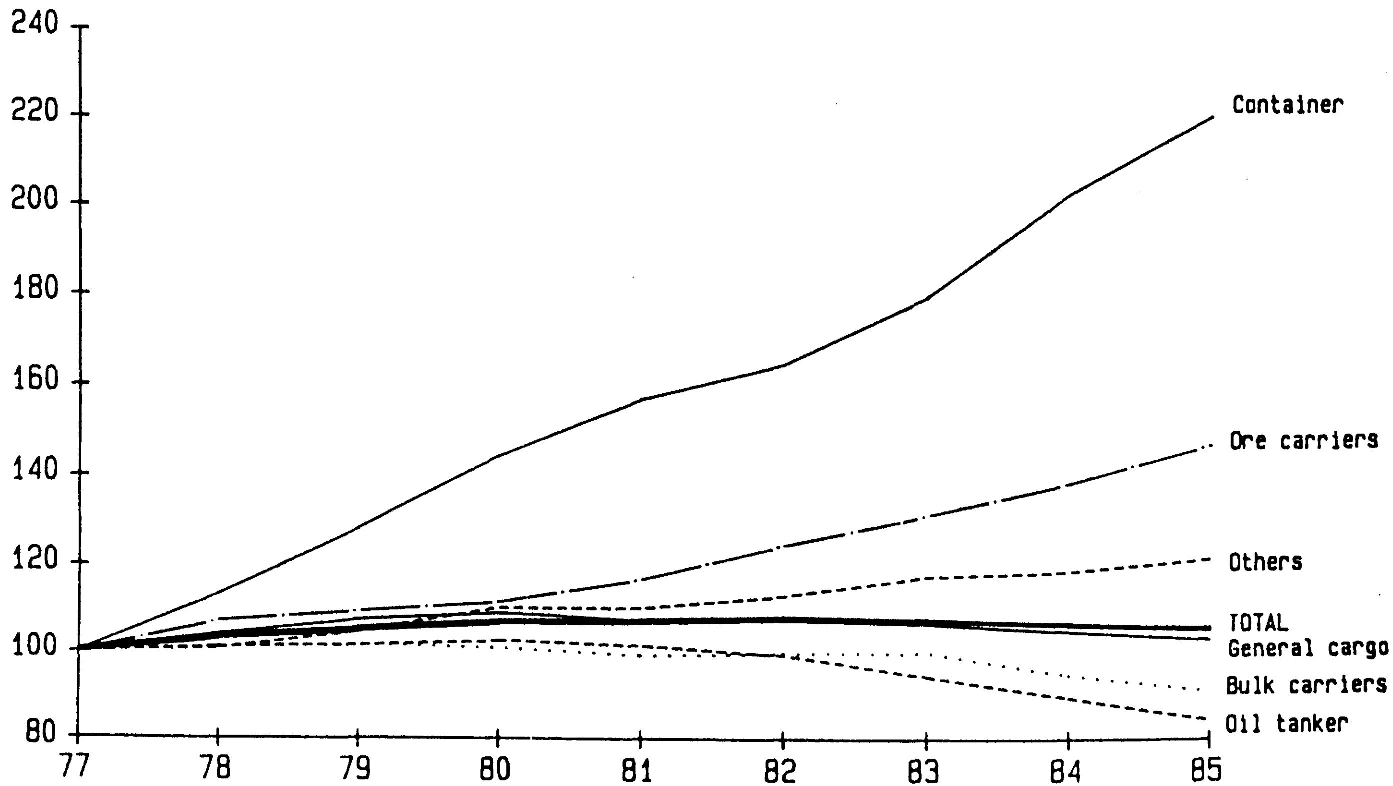


Fig.1.2 DEVELOPMENT OF TOTAL MERCHANT FLEET BY MAJOR SHIP TYPES (grt/gt-index, 1977=100).

Source : Institute of Shipping Economics and Logistics, Bremen 1986.

first months of 1986, the world tanker fleet maintained a level of scrapping which had never previously been reached. In addition, the dry bulk carrier (other than ore carrier) fleet declined slightly. The ore carriers sector saw more tonnage added to its fleet. This underlines the trend towards using larger ships in the transport of the iron ore. The most significant changes have been the rapid expansion of the container fleet. This significant development shows the trend towards using very large capacity vessels which is becoming more apparent for this sector.

The following paragraphs should indicate the depressed situation in which the dry bulk shipping market has difficulties to maintain optimism at least for the near future.

THE DRY BULK CARRIER FLEET.

The world dry bulk carrier fleet had a considerable increase in tonnage over the past years. Fig.1.3 (which includes the great lakes fleet) speaks for itself and does illustrates this growth.

From 1961 to 1970 the fleet over 10,000 dwt increased by more than six times in terms of deadweight from 8.70 to 54.23 million dwt. The fleet continued to grow up from 1970 to 1980 from 54.23 to 137.66 million dwt, an increase by a factor of 2.54. After a vigorous growth which had characterised the previous six years of 1980s, the dry bulk carrier fleet ceased to expand. Indeed, at the beginning of 1987 the dry bulk fleet was 1.5 million dwt less than a year earlier (see fig.1.3). This was in spite of the addition of 200 new vessels with a total tonnage of 11.6 million, ordered during 1983 and 1984. Although there was a continuing flow of new orders during 1986, the world order book at the beginning of 1987 stood at 11.7 million dwt, lower than at any time during the present decade.

The reason for this remarkable turnaround was the astonishing amount of dry bulk tonnage which was disposed of for demolition during 1986. According to Fearnleys, no less than 14 million dwt were scrapped or lost during the year. Indeed, if the dry bulk market continues at its present unprofitable level, the rate of dry bulk scrapping will probably continue.

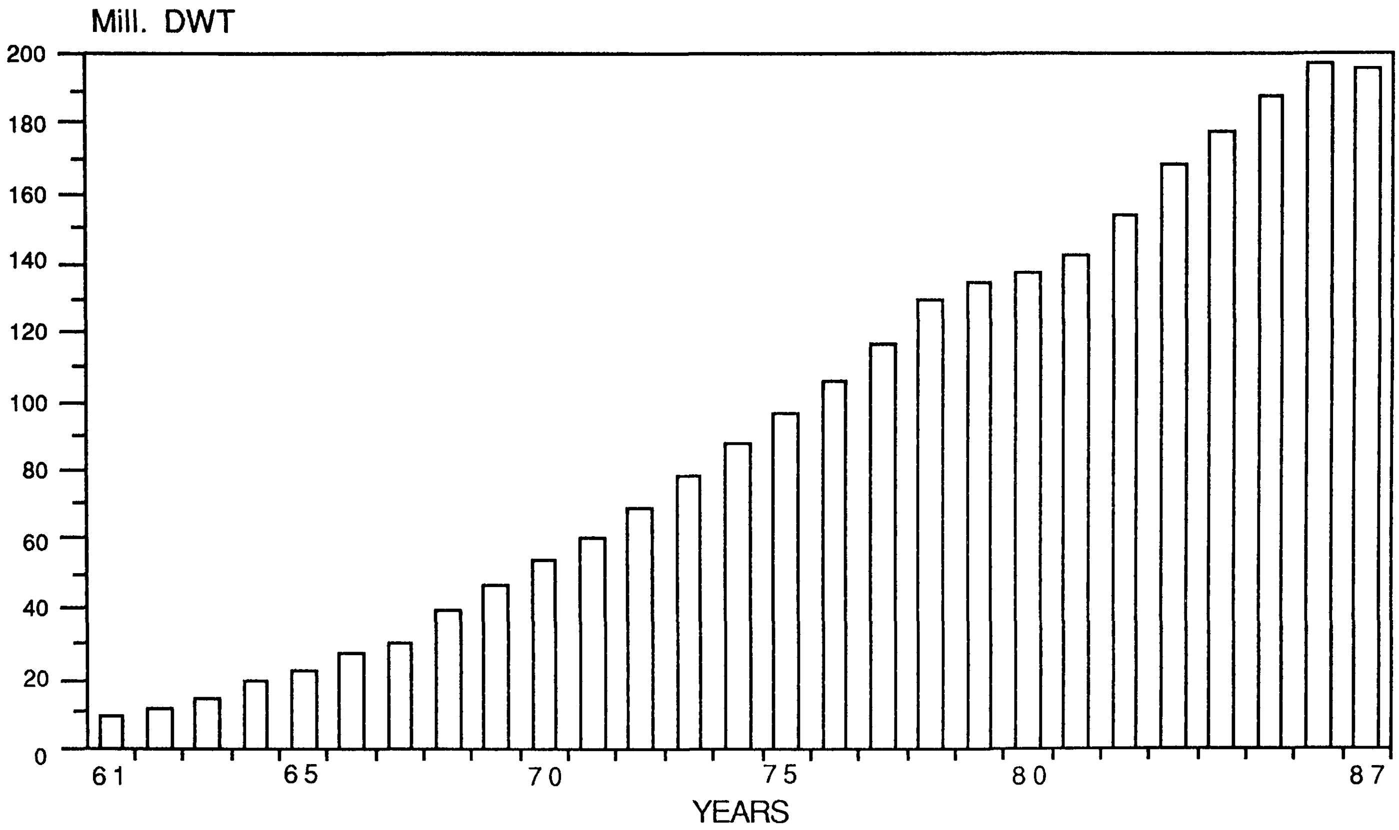


Fig.1.3 THE GROWTH OF THE DRY BULK CARRIER FLEET
(SHIPS OF 10,000 DWT AND OVER)
Source : Fearnleys and Eger's chartering.

However, there seems no doubt that even if the fleet is reduced during 1987 and 1988, there will still be a substantial volume of excess supply. This pessimistic trend is due to the very limited prospects for expansion in the main bulk commodities. However, improvement can only come through avoidance of speculative orders and a continued high level of demolition of the progressively ageing bulk carrier fleet which should lead to a more healthy supply/demand in the far future.

With regard to the size range of the fleet, the trend towards very large bulk carriers has continued, although at a slightly lower rate. Of the new orders placed during the year 1986 , 67 per cent (equivalent to 3.8 million dwt) were for vessels in excess of 100,000 dwt. Over 150,000 dwt range, which are virtually limited to employment in the iron ore trades, 12 extra vessels were ordered during 1986.

The growth of the large size sector (over 100,000 dwt) of the fleet is clearly indicated in table 1.1. While the proportion of ships in the 10-60,000 dwt size range is declining, the other size ranges, 60-100,000 dwt and over 100,000 dwt, are increasing in proportion, with the latter at faster degree.

The reason for this growth of the large size sector in the bulk carrier fleet is that a large number of countries are making efforts to improve and expand their ports, making them able to accept such large vessels. The other reason is that since the iron ore is mainly involved in dedicated trades, more profits can be made by using bigger ships.

With respect to the distribution of the bulk carrier fleet by country groups and division of age in 1986, the OECD group leads the world in tonnage terms (see fig.1.4). However, the dry bulk carrier fleet operating under the flags of OECD member countries has declined. In one single year, between mid-1985 and mid-1986, the cutback of the fleet attained 3.2 million gt.

The tonnage operating under the flags of the formally designated open-registry states (i.e.Liberia, Panama, Cyprus, Bahamas, Lebanon and Vanuatu) has slightly declined between mid-1985 and mid-1986. This slight reduction is rather surprising when considering advantages in costs

TABLE 1.1 PERCENTAGE OF THE WORLD DRY BULK CARRIER FLEET BY SIZE GROUP IN DWT.

SIZE GROUP (IN DWT)	1980	1981	1982	1983	1984	1985	1986	1987
10-60,000	72.1	71.3	67.9	64.6	63.0	62.3	61.5	59.3
60-100,000	15.4	16.0	16.9	18.5	19.8	20.2	19.5	19.2
Over 100,000	12.5	12.7	15.2	16.9	17.2	17.5	19.0	21.5

Source : 'World Bulk Fleet', Fearnleys, Oslo 1980-1987.

saving these countries offer to shipowners and how attractive they are to them. But, the reason for this reduction comes mainly from the fact that immense quantity of bulk carriers was scrapped from the fleets under these flags during 1985. The other reason is that there is a strong competition between these longer-established open registries and a host of newcomers. This was complicated by the rapid expansion of "offshore registers" associated with OECD countries (see section 6.2.1), a trend which is likely to have a very major impact on world shipping in the near future.
For further details about the age distribution of the bulk carrier fleet at mid-1986, see fig.1.5.

1.3 THE DRY BULK COMMODITIES.

The seaborne trade in the three major bulk commodities namely, iron ore, coal and grain, is declining for several reasons which will be discussed briefly, and separately for each commodity.
The steel industry, which is the main industry pointer for dry bulk shipping, since it generates most of the coking coal and all of the iron ore demand, is facing uncertain years. Steam coal is expected to remain static or to increase only marginally; and the grain trades will have to face a

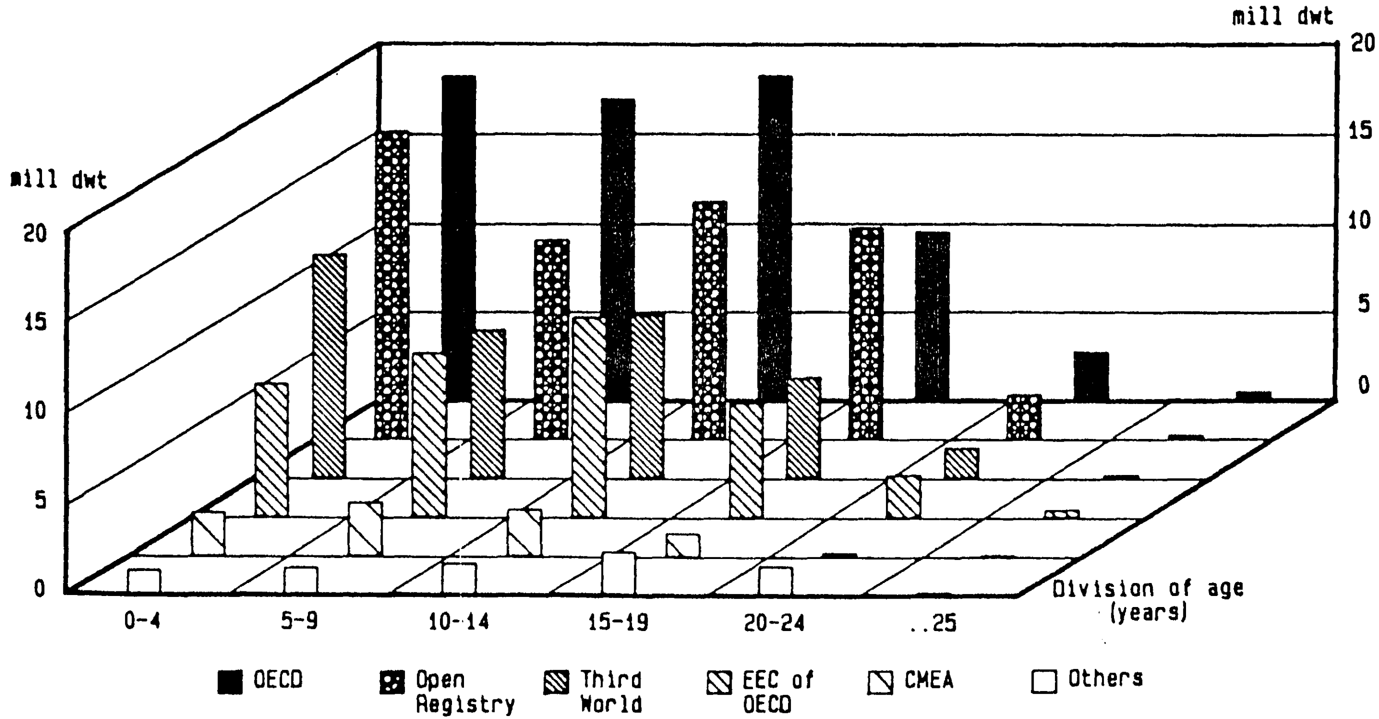


Fig.1.4 BULK CARRIER FLEET BY COUNTRY GROUPS AND DIVISION OF AGE 1986.

Source : Institute of Shipping Economics and Logistics, Bremen.

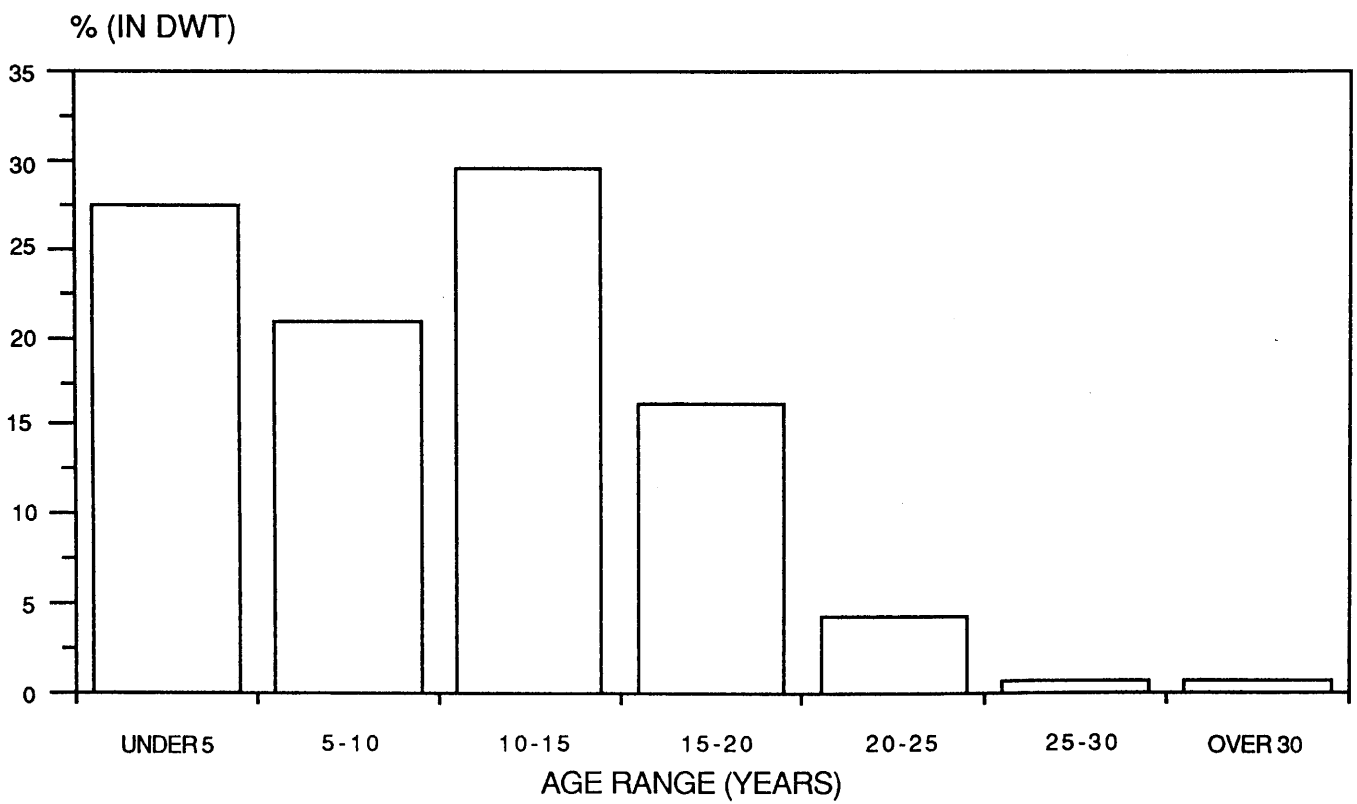


Fig.1.5 AGE DISTRIBUTION OF BULK CARRIER FLEET AT MID-1986
Source : Lloyd's Register of Shipping.

shrinking market because of higher domestic production in the major importer countries.

1.3.1 IRON ORE.

Fierce competition among iron ore producers in an over-supplied and shrinking market characterised the actual seaborne ore shipments.

The iron ore, the most important single dry bulk commodity in world seaborne trade, represented in 1986 about 15 per cent of the volume of the dry cargo trade and about 21 per cent of the tonne-miles. Given the traditional market dominance of Japan and the EEC , its decline in shipment was largely due to lower imports to these two areas during the second half of the year 1986. Among other importers there were much less signs of slackness with significant iron ore importing countries such as South Korea, Taiwan and China continuing to increase their steel output.

The principal reason for a decline in the OECD area was a lower steel demand inside the area as well as a considerable decline in net exports to the rest of the world. There were also considerably lower shipments to China, the USSR and certain countries in the Middle East and Africa.

The substantially lower steel production forced Japanese iron ore importers to cut back their total shipments by about 10 million tons to a total of around 114 million tons. Of the main suppliers, Australia and India were most affected by such cuts, losing out to Brazil, which increased its share in the Japanese market. Imports from these three major sources still made up more than 80 per cent of the total.

Of the EEC countries, Germany continued to be the largest single importer, taking about 37 per cent of the 120 million tons imported into the EEC, followed by Belgium, Italy and France.

With both the EEC and Japanese steel mills cutting back production, iron ore producers were forced to concede price cuts. In real terms, importers made even larger savings as prices are normally fixed in dollars, whose value depreciated against currencies of most importers.

Because of this and although mine production costs have been reduced during recent years, a large number of mining companies had difficulties in achieving a positive result. It was therefore not surprising that 1986 saw continued cutbacks in production capacity, with closures taking place primarily in North America and Western Europe.

Total world volumes of iron ore shipped for the last ten years are shown in fig.1.6.

There are no firm indications that world steel consumption and hence seaborne trade in iron ore will increase in the near future.

With regard to the size of vessels involved in the trade of iron ore, a size breakdown of vessels changed during the year 1986. Indeed, for the first time for many years, less cargo was shipped by vessels above 80,000 dwt, although shipments were still dominated by this size category. Vessels in the the 40 to 80,000 dwt range are estimated to have increased their carryings from about 19 per cent in 1985 to approximately 21 per cent in 1986. This contributed to a reduction in that sector's tonnage surplus. However, it cannot be expected that this trend will continue during the years to come. Developing steel producing countries are making serious efforts to improve their terminal facilities in order to benefit from the economies of scale of larger vessels.

For further details about the iron ore shipped from the main world iron ore exporting countries, see table 1.2.

1.3.2 COAL.

Of the three major dry bulk commodities, coal was the only one which experienced growth in seaborne shipment, mainly due to the expanding trade in steam coal. However, its trade has slightly declined in 1986 (1.4 per cent less than the record 1985 volume) after two years (1983-1985) of significant growth (see fig.1.6).

Overall, coal represented 13 per cent of the volume of total dry cargo shipments in 1986, and 19 per cent in terms of tonne-miles. Therefore, it continued to rank as the second largest dry bulk commodity in seaborne trade.

On the export side,the major trend noted in 1986 was a continuing increase in Australian coal exports in spite of an overall worldwide decline in traded quantities. The underlying factor determining this movement was the policy of diver- sification away from Japan, with Europe, South Korea, Taiwan and other Asian trade areas becoming more important.

Low production costs combined with high coal quality made Australia (the world's largest coal exporter) a strong competitor (see table 1.2). The United States (second largest coal exporter) saw its exports of both steam and coking coal moving down in 1986. The reason came primarily from over-supply and low prices on international markets. With regards to South Africa, its export trade is declining, although it has the world's lowest cost mining operations. The reason, mainly political, is due to action taken by certain European governments to limit or prohibit imports of this country's steam coal.

With respect to the demand side, 1986 was characterised by a decline in the established EEC and Japanese markets and almost static demand in certain developing countries.

In view of the critical state of steel industries in Japan and EEC, most steel mills in these two areas reduced their purchases of coking coal and cut back contractual deliveries in order to prevent an excessive rise in stocks. However, on the steam coal side, upon which many hopes have been pinned, its trade continues to show significant growth. The primary factor influencing steam coal demand results from the countries' policy of decreasing their dependence on oil. When oil prices collapsed in early 1986, the ability of steam coal to compete effectively with oil as a cheap source of energy decreased which urged suppliers to make substantial price concessions in order to keep up the high level of steam coal imports. South Africa and Australia were the leaders in this, reducing their prices below the 1985 average by 32 and 15 per cent respectively. The United States and Canada followed with 7 and 9 per cent. As a whole, European buyers benefited from these developments by a price reduction of about 10 per cent.

Assuming that OPEC's oil price remains around $18 per barrel during the near future, the cost advantage for steam coal will widen again . And in view of a more than adequate supply situation at low prices, this should lead to higher steam coal shipments which will balance the expected decline in coking coal trading.

With respect to the size of bulk carriers involved in the trade of coal , a trend to use bigger ships is becoming apparent. Indeed, a very large proportion of bulk vessels in the above 100,000 dwt size range continues to be used in the long-distance trades from Australia, North America and South Africa to Europe and Japan. The reason is obvious,since the volumes involved are large, substantial cost savings could be made by economies of scale. However, due to the different buying and trading pattern of the steam coal trade, more handy-sized and Panamax vessels were used to transport steam coal than in the coking coal trades.

1.3.3 GRAIN.

Throughout the early 1980s, the grain trades provided the dry bulk carrier market with an important source of stability. More recently, however, this has been less apparent, primarily for two reasons.

Firstly, consistently good harvests in the People's Republic of China, which have reduced the sharp fluctuations in the country's grain import requirements. Secondly, and almost certainly more importantly, growth in the Soviet dry bulk carrier fleet. This has reduced the Soviets' need to charter-in tonnage for its grain cargoes and has, therefore, limited the scope of independent dry bulk carrier owners to profit from Soviet crop shortfalls.

A decline in grain seaborne trade for two successive years brought it down to 160 million tons in 1986, the lowest level since 1978 (see fig.1.6). This reflects the good harvests of cereals in a large number of main importing countries, particularly the USSR. Indeed, the Soviets' total production was estimated in 1986 to have been 210 million tons, about 30 million tons more than the average for the previous 6 years. Although, still remaining the largest single importing country, the USSR reduced shipments from all suppliers, particularly the United States. It has failed, in a number of cases, to take the quantities to which they were committed under long-term grain agreements signed with several important exporting countries. However, the second largest importing country, China, raised its imports in 1986 to meet the general trend in consumption although its overall harvest also increased.

For further details about grain, whose wheat is the principal cargo transported followed by maize, shipped from the main world grain exporting countries see table 1.2.

For dry bulk shipping in general and for owners of the smaller bulk carriers particularly used for grain, the 1986 trade slump had disastrous financial consequences. It was a main contribution to freight rates falling to levels at which owners were lucky to cover operating costs.

As in the past, bulk vessels in the 40-80,000 dwt size range dominated the trade. The volume shipped by vessels of over 100,000 dwt remained small.

1.4 THE DRY BULK FREIGHT MARKET.

There has been two sharply contrasting pictures the last few years. Lower oil prices have revived the tanker sector, with increases in freight rates and second-hand prices providing owners with vastly improved profit-making opportunities.

However, in the dry bulk carrier sector the picture has been one of almost unrelieved gloom, with declining freight rate levels and asset values tightening the financial squeeze on owners. Undoubtedly, lower oil prices, through reduced bunkering costs, have contributed to the decline in dry bulk carrier freight rates.

With freight rates falling to levels at which owners remained far from profitability and had difficulty maintaining optimism, the pressure to assign vessels to lay-up berths is mounting. Indeed, dry bulk carrier lay-up levels have begun to rise with, not for the first time, Greek owners leading the way.

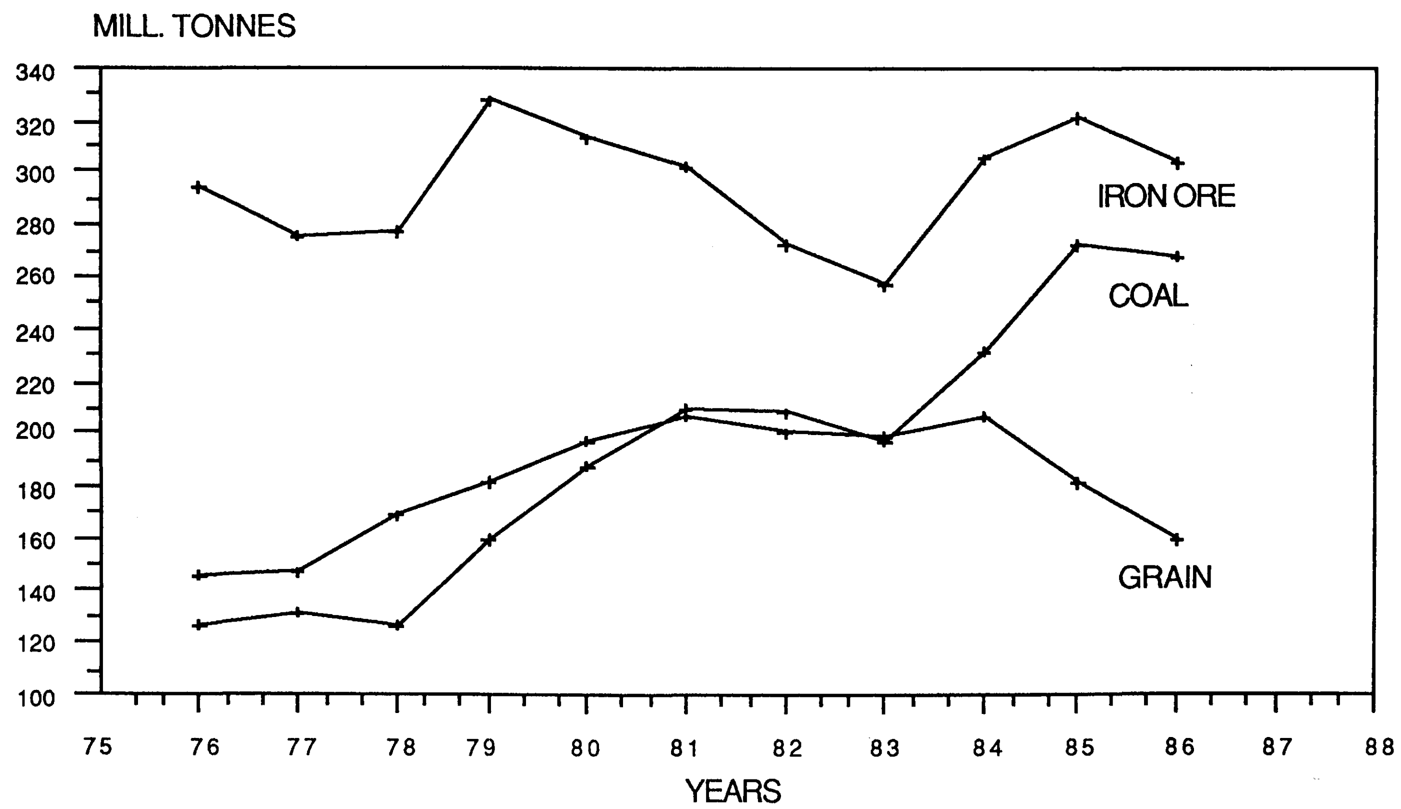


Fig.1.6 WORLD MAJOR BULK COMMODITIES SEABORNE TRADE
Source : Fearnleys, Oslo.

TABLE 1.2 SEABORNE TRADE IN THE MAJOR BULK COMMODITIES BY MAJOR EXPORTING COUNTRIES (OR GROUP OF COUNTRIES).

in thousand metric tons

Iron Ore	1980	1981	1982	1983	1984	1985
Australia	85,696	75,260	74,757	77,086	87,969	87,822
S.America	100,681	104,434	92,660	84,092	104,405	112,454
Asia	29,615	27,456	27,736	24,120	27,675	33,876
N.America	30,205	32,132	21,834	20,531	24,196	27,465
Coal						
Australia	43,144	48,946	48,808	58,347	74,211	85,564
N.America	81,626	102,200	94,487	71,980	79,688	96,747
S.Africa	27,268	28,552	27,025	28,203	35,049	44,100
Grain						
USA	128,333	128,840	121,205	115,458	118,649	93,625
Argentina	11,667	20,128	16,216	23,433	20,140	23,000
Australia	16,220	11,619	15,539	7,833	20,996	20,555
Canada	20,827	21,506	25,745	28,451	25,429	19,524

Source : Fearnleys.

Over the last few years there have been a detectable shift in the composition of the dry bulk carrier market surplus. Although, there was a substantial growth in overall demand for shipping services, this was not enough to restore a market balance in the dry bulk carrier shipping market, particularly in the larger vessel size categories. This growth in the proportion of the trading surplus continued to have a depressive influence on freight rates. For the near future no significant upturn can be expected in the dry bulk markets. Indeed, none of the major bulk commodities is likely to generate an upswing in demand for shipping tonnage, which could conceivably absorb the tonnage surplus estimated at between 15-20 per cent of the present bulk carrier fleet.

Table 1.3 shows, in US dollars, the highest and lowest average price per ton of dry bulk cargo in a number of representative trades for the years 1980-1986. For all three commodities examined (grain,coal and iron ore), whose freight rates have suddenly collapsed in the May/June 1982 period, the overall downward trend in rates continued in 1986.

For grain movements, the decline in rates was less than during the previous year. Rates for a 55,000 dwt shipment on the US Gulf-Continent routes varied from a high of $8.25 to a low of $4.50 or 45.4 per cent fall. For the carriage of 50,000 dwt of grain between the US Gulf and Japan, rates dropped by 45.1 per cent from $13.50 to $7.40 per ton. In the coal sector, for a 120,000 dwt ship operating between Richards Bay and Japan, rates decreased from $9.00 to $6.00 per ton, representing a 33.3 per cent drop.

Lastly, rates for a 120,000 dwt ship carrying iron ore between Brazil and the Continent decreased by 40.0 per cent from $4.50 to a record low of $2.70 per ton.

In summary, doubts over the growth potential in both the iron ore and coal trades, and decreasing volatility in the grain trades, provide little source of optimism for a significant market rebound over the longer term. Therefore, high scrapping rates will need to be maintained for some time to restore a balance between supply and demand and provide the basis for a recovery in freight rates.

TABLE 1.3 PRICE IN US DOLLARS PER TON OF DRY BULK CARGO (1980-1986).

		1980	1981	1982	1983	1984	1985	1986
Grain								
US Gulf-Antwerp/Rotterdam	high	24.15	22.00	12.00	9.00	10.75	11.60	8.25
(55,000 dwt)	low	14.25	8.75	5.75	7.25	7.75	5.65	4.50
US Gulf-Japan	high			21.70	21.00	17.80	16.25	13.50
(50,000 dwt)	low			13.30	14.00	12.75	10.00	7.40
Coal								
Hampton Roads-Japan								
(55,000 dwt : 1982, 83)	high	29.00	28.50	19.50	17.50	11.25	10.95	9.00
Richards Bay-Japan	low	16.50	17.50	10.75	12.00	9.50	8.60	6.00
(120,000 dwt: 84, 85, 86)								
Hampton Roads-Continent	high			9.50	6.00	6.90	6.75	5.25
(55,000 dwt : 1982)	low			4.25	4.85	6.45	4.20	3.25
(60,000 dwt:83,84,85,86)								
Iron Ore								
Brazil-N.W. Europe	high	13.00	15.00	7.00	6.50	5.60	6.05	4.50
(120,000 dwt)	low	9.50	7.00	4.45	5.95	5.50	3.65	2.70

Source : Lloyd's List, Institute of Shipping Economics and Logistics, Bremen.

1.5 PANAMA CANAL.

BRIEF HISTORY.

Canals are artificial waterways which exercise a great influence on the pattern and extent of world trade and world politics.
There are three major canals in the world namely , Panama in Central America, Suez in North East Africa and Kiel in North West Europe.

The construction of a canal across the isthmus of Central America was considered by Spain as early as the sixteenth century. In 1880 an attempt was made by France, to the design of Ferdinand de Lesseps, to build a sea-level waterway over difficult country with dense equatorial forest and steep gradients.
The French attempt was abandoned after a few years because of high costs, but in 1904 the enterprise was began again by the United States to quite a different design involving locks systems. The canal was opened on 15 August 1914.
The Panama Canal connects the Atlantic Ocean, with an entrance at Cristobal, with the Pacific Ocean, with an entrance at Balboa. It has a length of 43.5 nm (80.5 km) and involves a series of locks which raise and lower vessels to and from a height of 25.9 m above sea level.
Since its opening the Panama Canal, which has made Panama an international shipping and trade centre, has been effectively controlled by the United States with gradually increasing participation by the Republic of Panama.
Since 1979 the canal has been operated by the Panama Canal commission, a joint U.S.Panamanian agency which by treaty agreement will take complete control of the canal in the year 2000.
The maximum dimensions of a bulk carrier ship transiting through the canal are 274.3 m length,32.3 m breadth and 12.04 m draft. Transit time is normally 8 to 10 hours.

IMPORTANCE OF PANAMA CANAL.

Panama Canal is one of the two most strategic artificial waterways in the world, the other being the Suez Canal. It is vital to the strategic and commercial intercoastal shipping of the United States, and to the Europe-West coast North and South America trades, especially in bulk commodities.

It has given birth to a new class of ships, called Panamax vessels, designed with a beam equal to the maximum lock beam and perhaps also with lock limits of length and draft. Shipowners of this class of ships trading between the Atlantic and the Pacific ocean shorten their trade route, when using the canal, by thousands of miles reducing their voyage time and increasing the operational cycles of their ships and, therefore ,increasing the profits when the market is prosperous.

Indeed, ships sailing between the east and west coasts of the United States , which would otherwise be obliged to round Cape Horn, shorten their voyage by about 8,000 nautical miles by using the canal. Savings of up to 3,500 nm are also made on voyages between one coast of North America and ports on the other side of South America. These changes made dramatic reduction in prosperity of Cape Horn ports such as Punta Arenas.

CANAL TRAFFIC. .

Traffic through the Panama Canal is a barometer of world trade, rising in years of prosperity and declining in times of recession.

From a low of 807 transits in 1916, traffic rose to a high point of 15,523 transits of all types in 1970. The cargo carried through the canal that year amounted to more than 132,500,000 long tons. Although the total number of transits decreased thereafter, the canal carried more freight than ever because the average size of vessels had increased. The three principal commodity groups carried through the canal in the late 20th century were crude oil and petroleum products, grains, and coal and coke.

Table 1.4 gives for the first 5 years of 1980s some information of the number and tonnage of all ships transiting through the canal.

The principal trade routes served by the Panama Canal are shown in table 1.5, with the trade between the east coast of the United States and Asia dominating the international canal traffic.

TABLE 1.4 PANAMA CANAL SHIPPING TRAFFIC.

TONNAGE IN 1000.

YEARS	LADEN VESSELS		IN BALLAST VESSELS	
	NUMBER	NET TONNAGE	NUMBER	NET TONNAGE
1981	11,156	149,258	2,728	39,398
1982	11,185	158,829	2,824	44,055
1983	9,500	136,654	2,207	32,850
1984	9,328	133,915	1,902	28,420
1985	9,614	139,857	1,886	29,083

Source : I.S.L., Bremen 1986.

TABLE 1.5 PRINCIPAL TRADE ROUTES TRANSITING THROUGH THE PANAMA CANAL.

-UNITED STATES INTERCOASTAL.

-UNITED STATES EAST COAST-HAWAII/EAST ASIAN PORTS.

-EUROPE-WEST COAST OF NORTH AMERICA.

-UNITED STATES EAST COAST-WEST COAST OF SOUTH AMERICA.

-EAST-WEST COASTS OF SOUTH AMERICA.

-WEST INDIES-ASIA.

-EUROPE-ASIA.

-EUROPE-WEST COAST OF SOUTH AMERICA

-EUROPE-AUSTRALIA.

CHAPTER 2 : FIRST ELEMENTS OF PRELIMINARY SHIP DESIGN.

2.1 INTRODUCTION.

The preliminary ship design refers to determination of major ship characteristics affecting cost and performance. The selection of ship principal dimensions being the first stage in preliminary design must satisfy lower costs criteria as well as other requirements such as good seakeeping performance, stability and cargo capacity.

In the overall design process, preliminary design is followed by contract and detail designs. Contract design deals with the development of plans and specifications suitable for shipyard bidding and contract award. Detail design is the shipyard responsibility for further developments of plans required for the construction of the ship.

The preliminary ship design has enormously developed during the last two decades. Indeed, with the application of computers used as principal design tools, the preliminary design has gone beyond its traditional scope becoming more powerful. Instead of the usual repetitive calculations of main dimensions and check against other design features, the naval architect equipped with the computer can generates a large number of design combinations allowing, therefore, more possibilities to be considered. Furthermore, each combination or variation of a particular parameter is assessed against the variation of the chosen design (economic) criterion leading closely to the optimum design. Such investigations were before difficult if not impossible to carry out by hand.

Basically, a ship is a container and a container which has the least surface area for a given volume is a sphere. It follows, therefore, that for economy of construction a ship should approach this shape in accordance with other features of ship design. This concept requires that length, beam, draft and depth should be as maximum as permitted and that block coefficient should be as full as possible.

The choice of these dimensions is of great importance in the development of a design and the technical and economic success of the final product depends on the final choice of dimensions.

This chapter outlines the first steps of the preliminary ship design. The first section discusses briefly the shipowner's basic requirements and cites some aspects of the market research which the shipowner must be involved with in order to make from his investment a good profit. The second section is devoted to the trends in ship size and indicates the benefits from building larger ships.

The choice of main dimensions which are discussed separately is dealt with in the third section. The determination of gross and net register tonnage, and calculation of freeboard are respectively dealt with in the fourth and fifth section.

2.2 SHIPOWNER'S REQUIREMENTS.

Before any action is taken by the naval architect, close attention should be attributed to what exactly is required to design. This is usually referred to as shipowner's requirements. The shipowner's requirements are usually regarded as type of ship, type of propelling machinery, deadweight, homogeneous stowage factor of cargo, speed on service, area of trade and endurance.

The decision by a shipowner to have a ship or ships built is only made after consideration of many factors. Indeed, when making decision, the shipowner in question is usually faced with one or a combination of the following alternatives:

a) replacement of overage tonnage;

b) expansion or modification of services on the existing trade route in an effort to improve profit making from the business;

c) development of a new service in a different trade route; and

d) transport of a different kind of cargo.

A shipowner requires a ship that will give the best possible returns for his initial investment. This means, further to the above considerations, he should analyse the traffic statistics of the commodity in question, examine the existing economic climate and assess future trends likely to develop within the life of the ship, a period which may exceed twenty years.

2.3 TRENDS IN SHIP SIZE.

One of the most successful ways of improving the operational economy of a ship is by increasing its size which must be accompanied simultaneously by an increase of the depth of water and of facilities of ports served. In other words, the larger the size the greater is the economy of the ship mainly because of manning and ship resistance.

Such concept, defined as economy of size or of scale, became much familiar for shipping in the late fifties where the large tanker sector development has been in line with it.

In basic terms, if a size of a ship is increased constructional costs measured on a per tonne deadweight basis decreased while keeping the same crew costs as larger ships can often be operated by crew of about the same number as the smaller ships. Increasing size also brings many benefits in the powering area, with the Froude number reducing for a given speed, allowing both the possibilities of the use of a fuller block coefficient and of a reduction in the resistance per unit displacement. For instance, if the size of ship is doubled the vessel's fuel consumption per tonne mile may be reduced by between 20 and 25 per cent (12) reducing, therefore, the fuel bill.

It is also recognised that bigger ships offer lower operating costs, a figure of 20 per cent reduction and perhaps more could be achieved. This achievement of actual saving will of course depend upon the operating methods of individual shipowners and operators.

It follows, therefore, that although the larger vessel requires a greater initial investment the extra size brings with it many considerable financial advantages. But in real maritime environment an increase in ships size beyond a certain limit is not always achievable as there are several restrictions of water depth in ports and limit size of canals to transit.

With regard to the bulk carrier ship, two variables capital costs and fuel consumption, which are the most significant in their economic effect, depend on the choice of suitable range of proportions. Other operating costs such as crew costs and cargo handling costs, while extremely large, would not be expected to vary appreciably over a practical range of proportions.

When bulk carriers are designed to carry dry bulk cargo such as ore, grain or coal, under long-term contracts in a scheduled route between two ports only, they are built to maximum size in accordance with limits imposed by physical environment such as the case in this study of Panama Canal restrictions.

Another substantial segment of the world's bulk carrier fleet is engaged in tramping role operations. Ships in this fleet range in carrying capacity between 15,000 and 50,000 dwt. This size range is dictated by their need for access to a larger number of ports, as the tramp's competitive potentiality is affected by its ability to pick up any shipment of bulk anywhere in the world.

Finally, it must be said that the most important commercial characteristics of bulk carriers are their deadweights or cargo capacities and associated drafts. Their costs are usually expressed in terms of price per tonne of deadweight. Furthermore, a bulk carrier efficiency is often measured in terms of deadweight to displacement ratio putting, therefore, a premium on reduction in lightship weight and increase in hull fullness. Such a ratio, referred to as deadweight coefficient, is given in reference (1) ranging from 0.72 to 0.77 for an ore carrier and from 0.78 to 0.84 for a bulk carrier.

2.4 PRINCIPAL DIMENSIONS.

The term proportions in this section refers to principal ship dimensions and fullness,i.e. L, B, T, D, Cb and/or their interrelationships such as L/B, B/T, L/D, etc.

The initial selection of proportions may be accomplished by one of the two following methods.

The first method is based on interpolation or extrapolation of data obtained from similar type ships already built or designed. This procedure assumes that the economic performances from operating these ships were satisfactory enough to consider them as basis for the ship or ships to build. This approach, which is suitable for hand calculations, serves only as a rough guide. However, it does provide a quick and fairly reliable starting point when adequate data are available and plotted for ready comparison.

The second method requires a systematic parametric study to focus on optimum proportions. This method based on parametric variation of principal dimensions is particularly useful for computer programming and serves to build up a matrix of a large number of alternatives or designs. It is the method adopted in this thesis where L/B, B/T, Cb and $V/\sqrt{L}$ are varied in typical ranges for a fixed value of beam.

Below are ship main dimensions discussed separately, although it is impracticable to discuss them independently as they are all inter-related.

1. Length.

The length recognised as the most expensive dimension in terms of cost has the greatest influence on the ship displacement required for a given useful load. It is found that an increase in length requires an increase in the weight of the hull structure to avoid excessive stresses which will require a reduction in the useful load.

With regard to fuel costs, which form a significant part of the overall operating costs for a bulk carrier, the most important consideration is the minimisation of the propulsive power needed and long narrow ship finds favor. Indeed, for a required displacement, an increase in length brings a reduction in Froude number which, in turn, generally results in a reduction of total resistance and hence of fuel consumption per mile.

From the resistance point of view, long and narrow ship tends to show to advantage where the wavemaking resistance is a major part of the total resistance. On the other hand, short, beamy, deep and full bodied ship of the same displacement presenting a smaller wetted surface is preferable where frictional resistance is the principal resistance component.

With respect to ship behaviour, the longer the ship the better, in general, is the seakeeping. On the other hand, the shorter ship is may be more manoeuvrable.

Fig.2.1 shows how the length varies with the deadweight of recent delivered bulk carriers.

Length is often influenced by some restrictions such as length of available berths, dry docks and canal locks. In the computer main program a value of 273.4 m imposed by Panama Canal locks is set as the maximum permissible length.

2. Beam.

The beam has greater influence on the magnitude of the transverse metacentric radius and, therefore, on the initial stability than any of the other principal dimensions. Hence, the beam should carefully be estimated so that it gives adequate but not excessive metacentric height (GM) and thus providing the ship with gentle motion.

The beam is often restricted by hydrographic limitations such as repair and berthing facilities and use of canals.

The maximum beam permitted by Panama Canal for a bulk carrier is 32.3 m. Therefore, in the main program and in order not to have too much combinations, the beam is set at a fixed value of 32.2 m which is very common to most Panamax bulk carriers.

3. Draft.

It is very difficult to discuss the draft separately of depth and freeboard as one is the sum of the other two. However, it can be said with regard to seakeeping that an increase in draft improves directional stability and thus makes it possible for a vessel to maintain speed under unfavourable sea conditions. On the other hand, there must be noted the facts that increased draft requires payment of larger pilotage fees, reduces the number of ports and dry docks and other repair facilities, and prevents passage through canals.

The maximum value of fresh water draft for a bulk carrier trading through

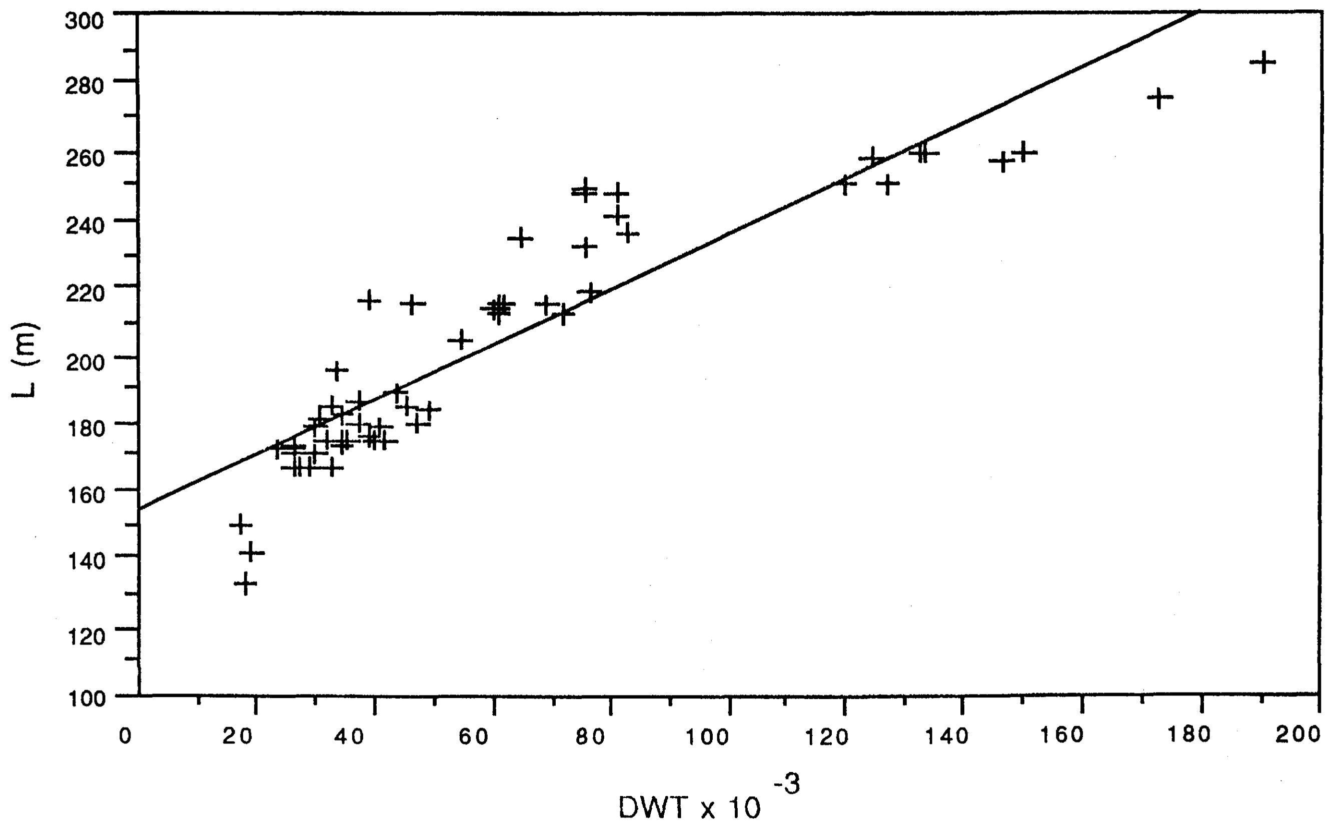


Fig.2.1 Length versus DWT

Panama Canal is 12.04 m. This value is set in the program as the maximum permissible draft.

4. Depth.

The depth has also an effect on stability since the ship centre of gravity (KG), for a given vertical weight distribution, varies directly and linearly with it. An increase in depth results in an increase in KG and a reduction in the metacentric height (GM), unless there is an equal rise in GM.

Furthermore, the depth has an other effect on the longitudinal bending stress. For this purpose, after applying freeboard rules to estimate the depth for a given draft, it is checked against L/D ratio so as to limit hull deflection.

5. Block coefficient.

The principal dimensions give only a limited vision of the shape of the ship since they define only the proportions of the hull. This information regarding the fullness of the hull form is given by the block coefficient (Cb). At the moment there is no universally accepted formula for calculating the block coefficient. There are, however, various relationships giving Cb for preliminary design studies such as

(1) $Cb = 1.137 - 0.6 \frac{V}{\sqrt{L(ft)}}$ (Van Lammeren) (7)

(2) $Cb = 1.06 - 0.5 \frac{V}{\sqrt{L(ft)}}$ (Ayre) (7)

(3) $Cb = 1.22 - 0.709 \frac{V}{\sqrt{L(ft)}}$ (Minorsky) (7)

(4) $Cb = 1 - \frac{3}{8}\left(\frac{B(ft)}{L(ft)+1}\right) x \frac{V}{\sqrt{L(ft)}}$ (Telfer) (7)

(5) $Cb = 0.65 + 0.95 \frac{V}{\sqrt{L(ft)}} - 1.2\left(\frac{V}{\sqrt{L(ft)}}\right)^2$ (Sabit) (7)

(6) $Cb = K - 0.5 \frac{V}{\sqrt{L(ft)}}$ (Alexander) (2)

where K = 1.12 to 1.03 depending on $V/\sqrt{L}$

(7) $Cb = 0.70 + \frac{1}{8} \text{Tan}^{-1} \left(\frac{23 - 100}{4} Fn \right)$ (radians) (Townsin) (8)

Katsoulis (7) suggests that Cb being a function of $V/\sqrt{L}$ and L/B, B/T should also be a function of absolute values of these dimensions.
He gives the following relationship

(8) $Cb = 0.8217 \times f \times L(m)^{0.42} \times B(m)^{-0.3072} \times T(m)^{0.1721} \times V^{-0.6135}$

where f is a correction factor depending on ship type. For bulk carriers f=1.03.
The above empirical formulae do not give the optimum Cb regarding ship technical and economic factors such as fuel bill, capital costs and other features of ship costs. The block coefficient was, therefore, made in the computer main program as an independent variable. Cb is varied from a value of 0.725 to 0.875, a range which covers block coefficients of most bulk carrier ships. With Cb, speed length ratio $V/\sqrt{L}$ is also varied from 0.40 to 0.70, the usual range for Panamax bulk carriers.
The following interrelationships discussed briefly below are given to serve as a guide during the preliminary design process and to show how the ship principal dimensions are closely dependent.

Length to beam relationship (L/B).

For a bulk carrier, Munro (1) suggests the following relationship

$$B = \frac{L}{9} + 6 \text{ (m)}$$

On the other hand, Watson & Gilfillan (2) point out that in modern design practice the relationship linking length and beam is expressed in terms of L/B ratio rather than one of the above form. They give an L/B value of about 6.5 for ships exceeding 130 m in length.
In the main program a ratio of L/B is kept between 5.50 and 8.50.
Fig.2.2 shows how beam varies with length for a number of recent bulk carriers.

Beam to depth relationship (B/D).

This relationship is primarily dictated by stability requirements due to the fact that KG is a function of depth and GM, regarded generally as stability criterion, is largely a function of beam. In reference (1) this relationship for a bulk carrier is expressed as

$$D = \frac{B - 3}{1.5} \quad (m)$$

Bulk carriers have usually a good stability which is well in excess of minimum requirement with depth generally determined by hull deflections. For a bulk carrier a B/D ratio of about 1.90 is suggested in reference (2). The variation of depth with beam is shown in fig.2.5.

<u>draft to depth relationship (T/D).</u>

Draft to depth ratio which is really a representation of freeboard rules is extremely important to large angles stability since it determines the point of deck edge immersion. It also indicates the reserve of buoyancy for survivability.

This relationship has changed primarily as a result of the 1966 Freeboard Convention associated with changes in length, block coefficient, sheer, camber and extent of erections which are now given for a particular depth of ship. It is worth mentioning here that modern bulk carriers do not have sheer. It is, therefore, assumed in the program that the deck is horizontal, i.e. sheer =0.

Under the 'B-60' freeboard, the bulk carrier with the 'B' type freeboard has been given the benefit of a deeper draft.

An approximate relationship linking draft and depth for a bulk carrier is given in reference (1) by

$T = 0.66\ D + 0.9$ (m)

The variation of draft with depth is shown in fig.2.7.

<u>Length to depth relationship (L/D).</u>

For bulk carriers whose stability is greatly in excess of requirements, the value of depth D is mainly controlled by the ratio L/D which has a great influence on the ship structural strength and particularly on the deflection of the hull girder under the bending moments imposed by waves and cargo distribution.

Higher-tensile steel, with which a considerable reduction of weight in scantlings can be achieved, is considerably suitable for use in bulk carriers where deadweight, as mentioned earlier, is a very important parameter. In such a case of using this material L/D ratio has generally smaller value in order to limit the deflection of the hull girder.

For the reason cited above, L/D ratio of 16 is set in the main program as the maximum value , otherwise the design is rejected.

This relationship is shown in fig.2.3.

Draft to length relationship (T/L).

This relationship is of particular interest to ship seakeeping. The bulk carrier occasionally suffers from slamming and particularly in ballast condition when the draft forward is less than required. For the purpose of achieving a good seakeeping in ballast condition, the rules of classification societies state that T/L should be not less than 0.027 to permit maintaining a reasonable speed and still avoid severe slamming in a seaway. For the same reasons, T/L should exceed 0.045 in the load condition.

The variation of the loaded design draft with length is illustrated in fig.2.4.

Beam to draft relationship (B/T).

Beam to draft relationship is of major importance to initial transverse stability and natural period of roll.

From the ship resistance and costs points of view, low B/T values provide minimum resistance with reduction in capital costs. However, low B/T values below a certain limit are not always achievable due to constraints imposed by stability and freeboard rules. This ratio hence should be a compromise in achieving a satisfactory resistance and a good stability.

For most normal ships a B/T value of 2.4 appears to be about the usual value.

In the program the B/T value is kept between 2.25 and 3.0 to take into account size constraints imposed by Panama Canal.

Fig.2.6 shows the above relationship.

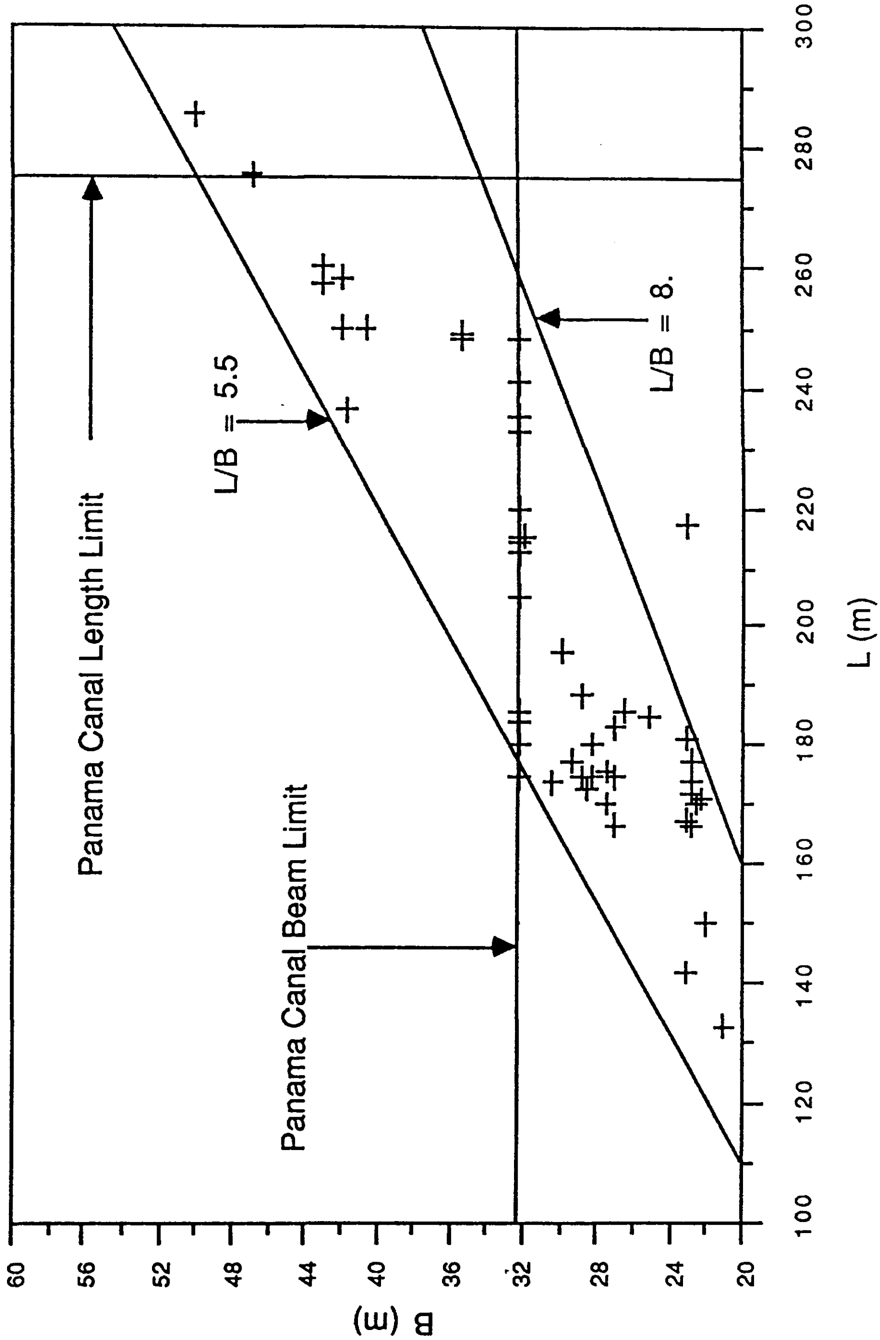


Fig.2.2 Beam versus Length

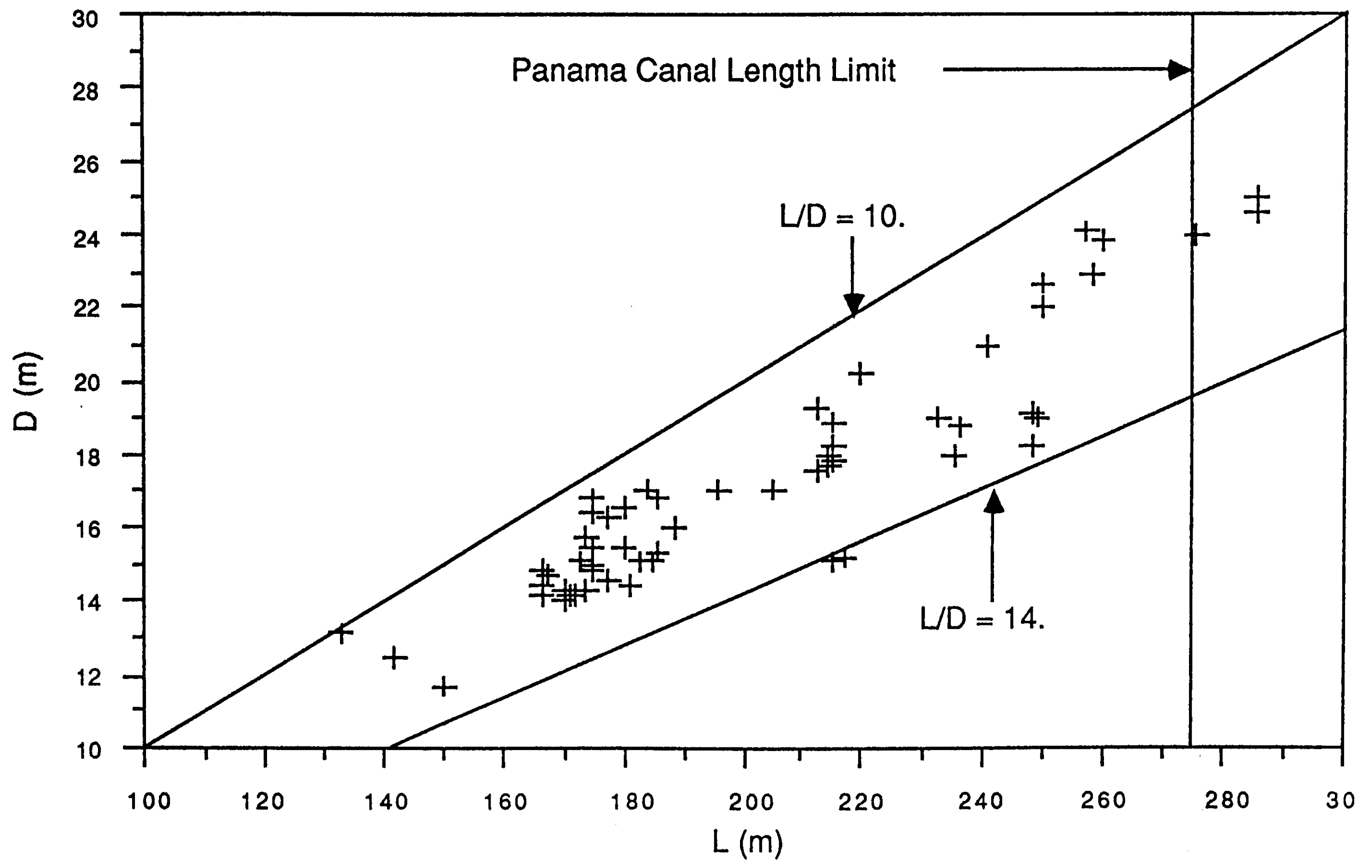


Fig.2.3 Depth versus Length

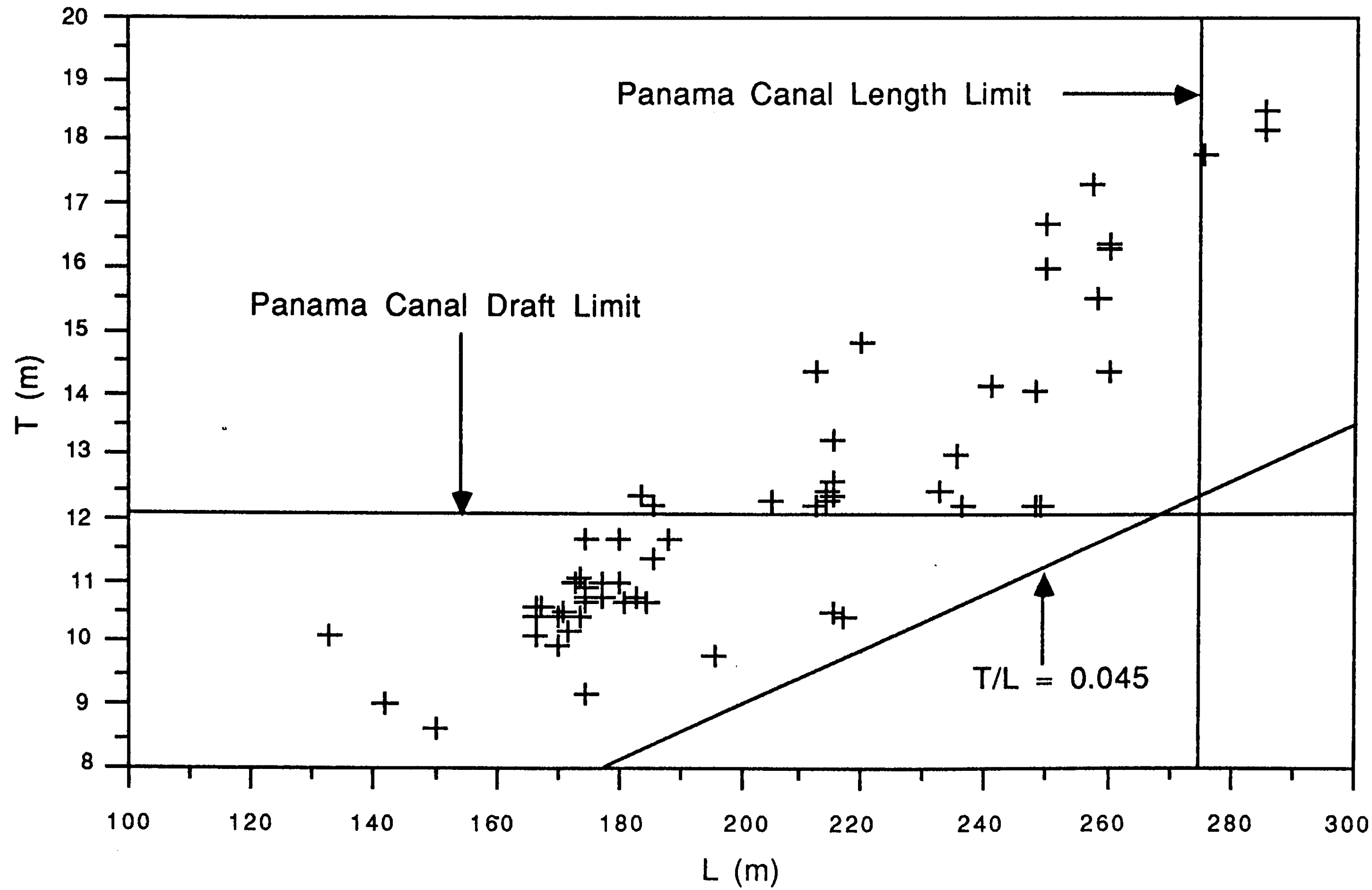


Fig.2.4 Draft versus Length

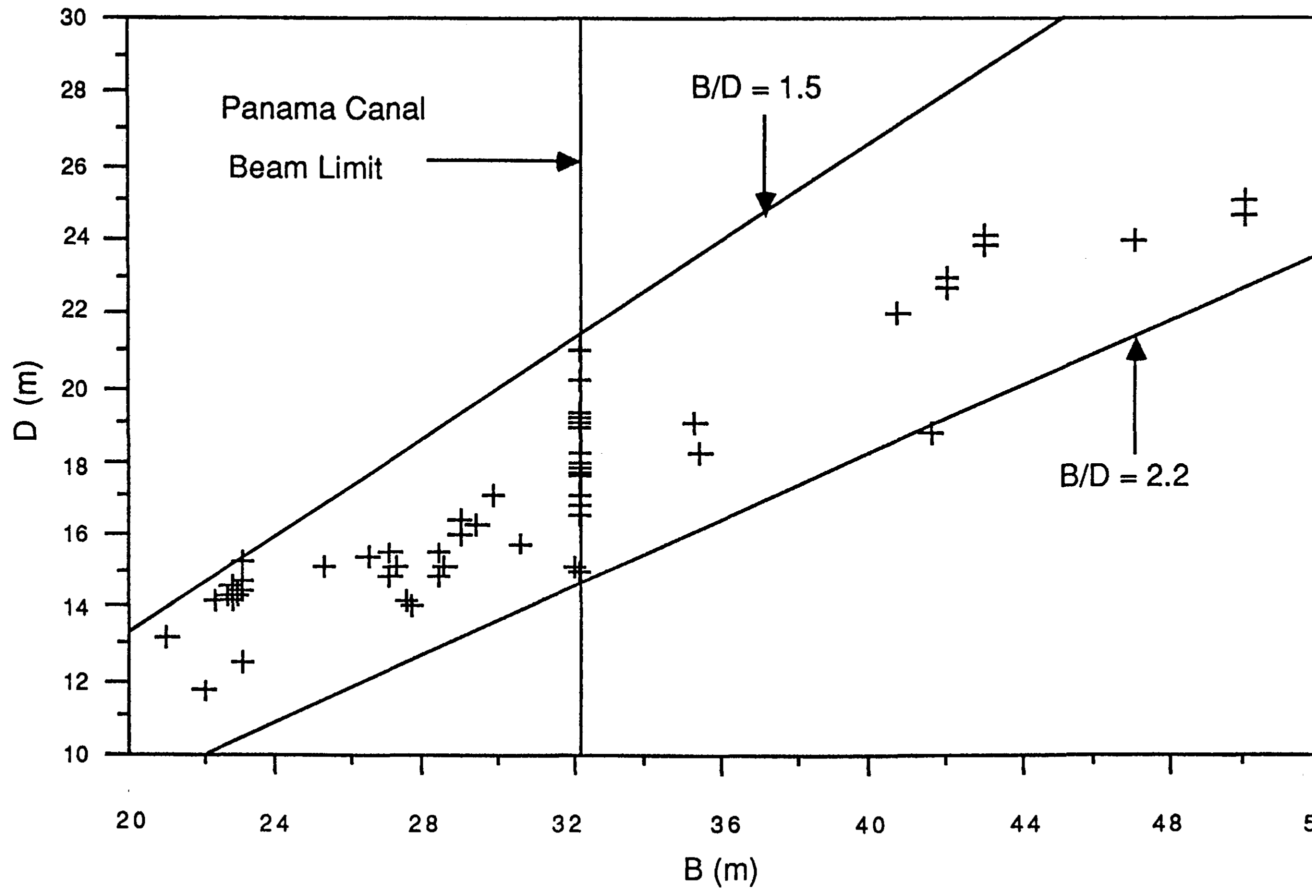


Fig.2.5 Depth versus Beam

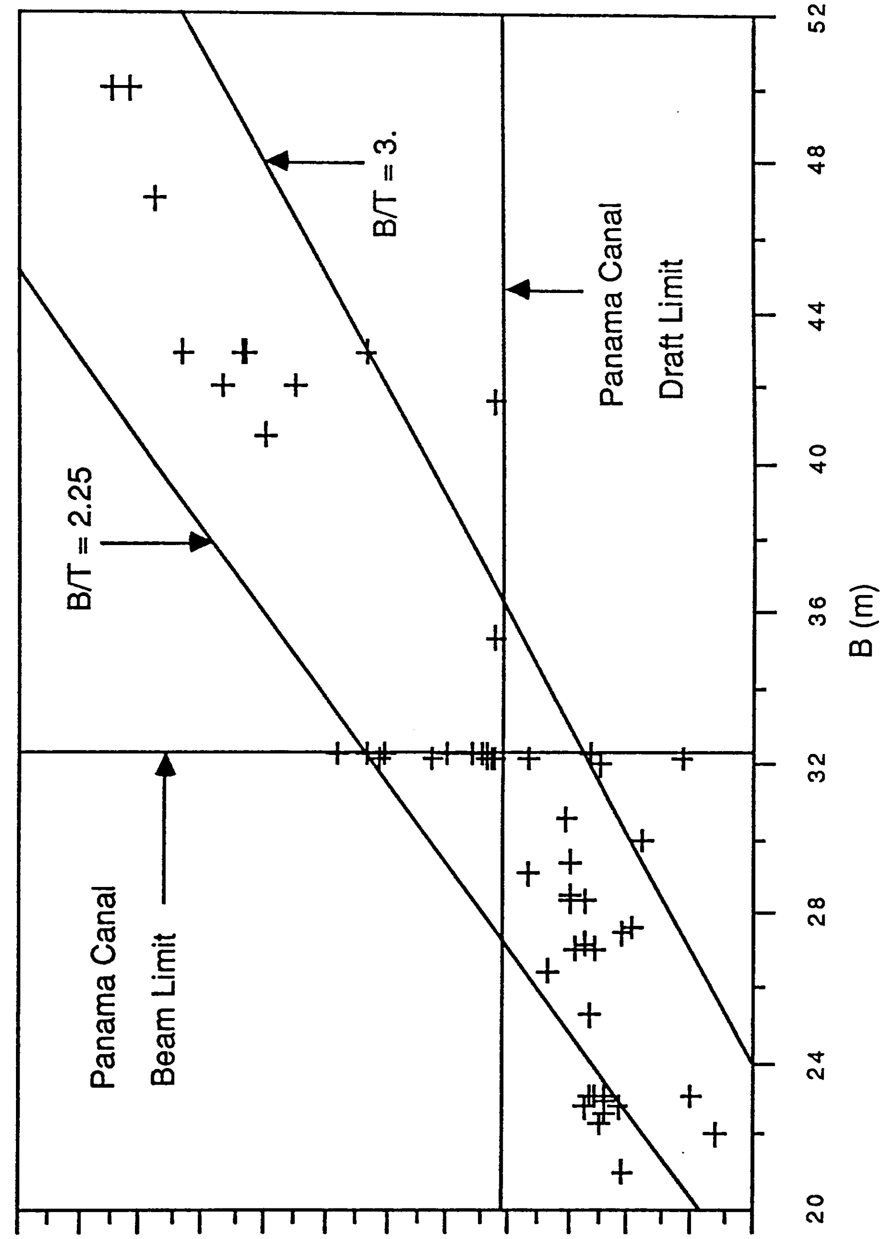


Fig.2.6 Draft versus Beam

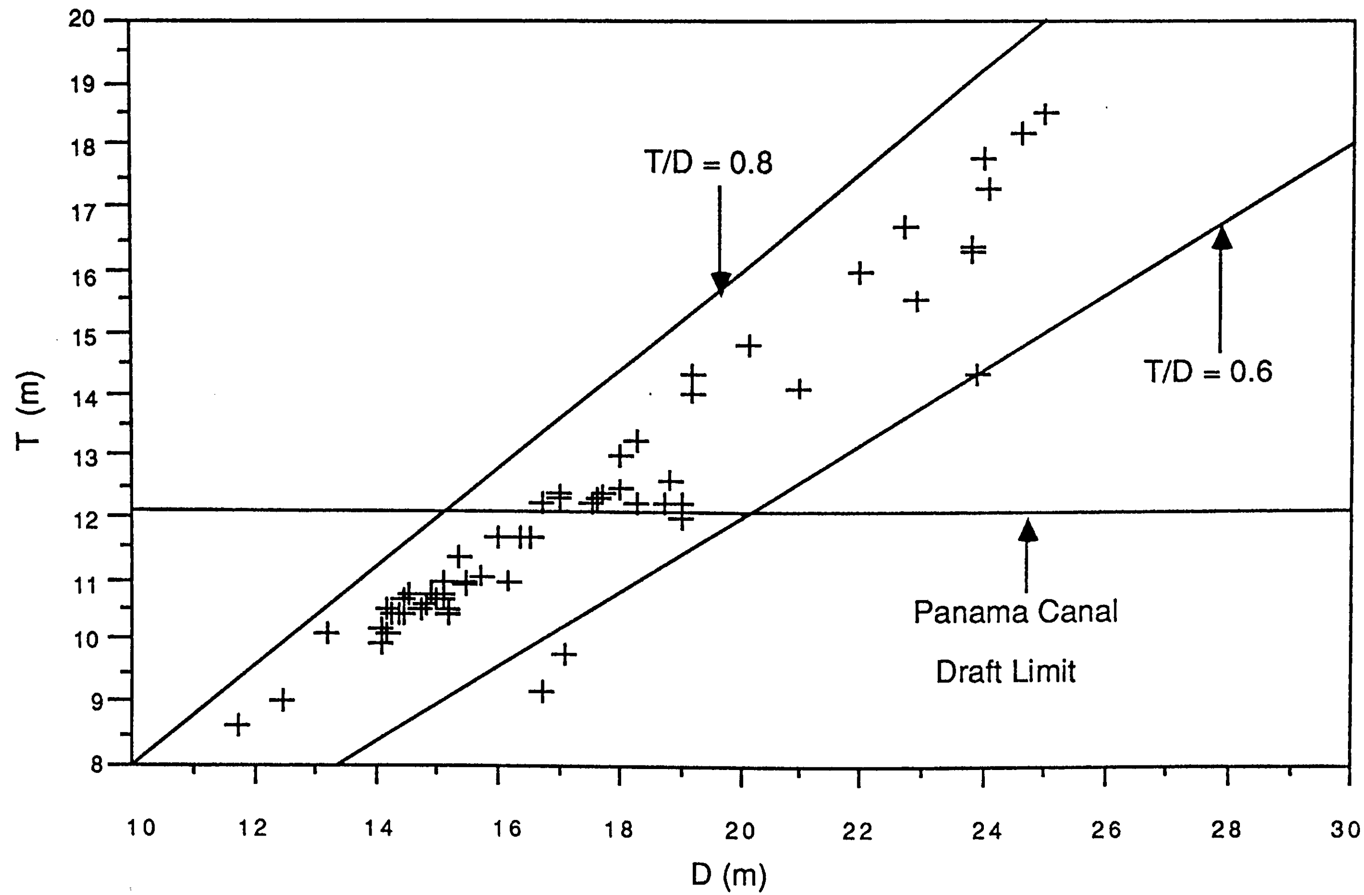


Fig.2.7 Draft versus Depth

2.5 GROSS AND NET TONNAGE.

Gross tonnage can simply be defined as the total enclosed volume of the ship in cubic feet divided by 100. The net or registered tonnage is the total enclosed volume available for cargo in cubic feet divided by 100. These two measurements have a considerable commercial use. Indeed, protection and indemnity insurance, port charges and canal dues are often levied on these measurement tonnages.

Anxious to keep the dues down to a minimum bill, shipowners usually instruct their naval architects to study the rules carefully so as to design a ship to the required capacity with the smallest gross tonnage possible.

There is no standard rule for assessing these measurements as there are at the moment about five basic systems used by the British, Americans, most other maritime nations, Suez Canal Authority and the Panama Canal Authority. For a bulk carrier, for instance, Panama and Suez net tonnages are respectively about 13 and 23 per cent higher than their British counterpart. However, there is no significant differences in gross tonnage.

From a large amount of data of modern bulk carriers, gross registered tonnage (GRT) was fitted as a linear function of the cubic number L x B x D giving a good correlation factor. The net registered tonnage (NRT) was also fitted as a linear function of the obtained GRT with a satisfactory correlation factor.

The two relationships with their correlation factors are given as

$$GRT = 0.281 \times (L \times B \times D) + 247.0 \quad \text{(tons)} \quad \text{[eq.2.1]}$$

corr. = 0.992

$$NRT = 0.720 \times GRT - 942.0 \quad \text{(tons)} \quad \text{[eq.2.2]}$$

corr. = 0.983

The two above relationships are shown in fig.2.8 and fig.2.9.

2.6 FREEBOARD.

The freeboard is the vertical distance between the uppermost continuous deck, marked by the deck line, and the waterline marked by the

Tonnage figures are based on British Measurement from 1967 with an empirical correction factor to obtain Panama tonnage values. The 1969 tonnage convention introduced in 1982 is not used.

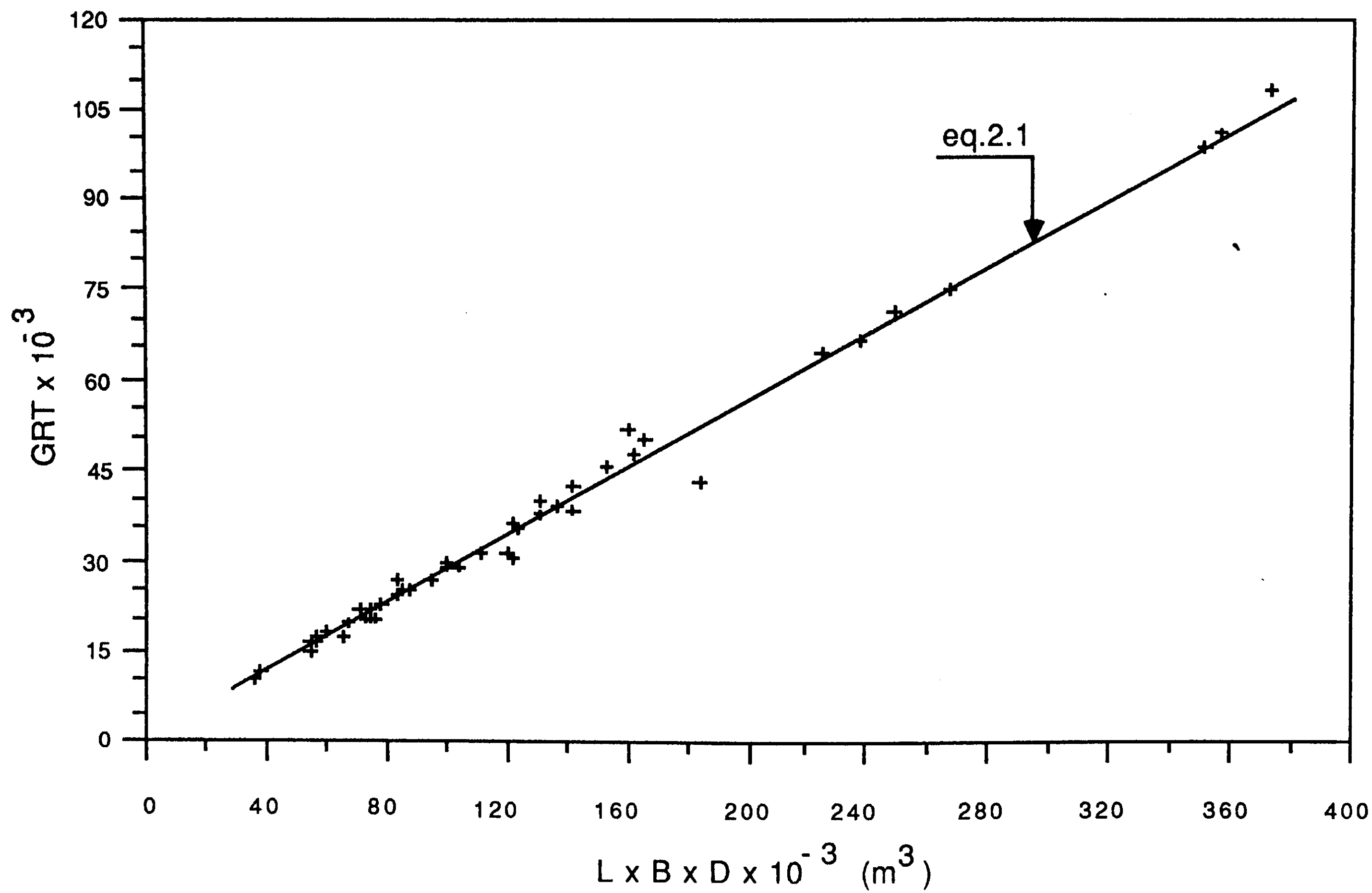


Fig.2.8 GRT versus L x B x D

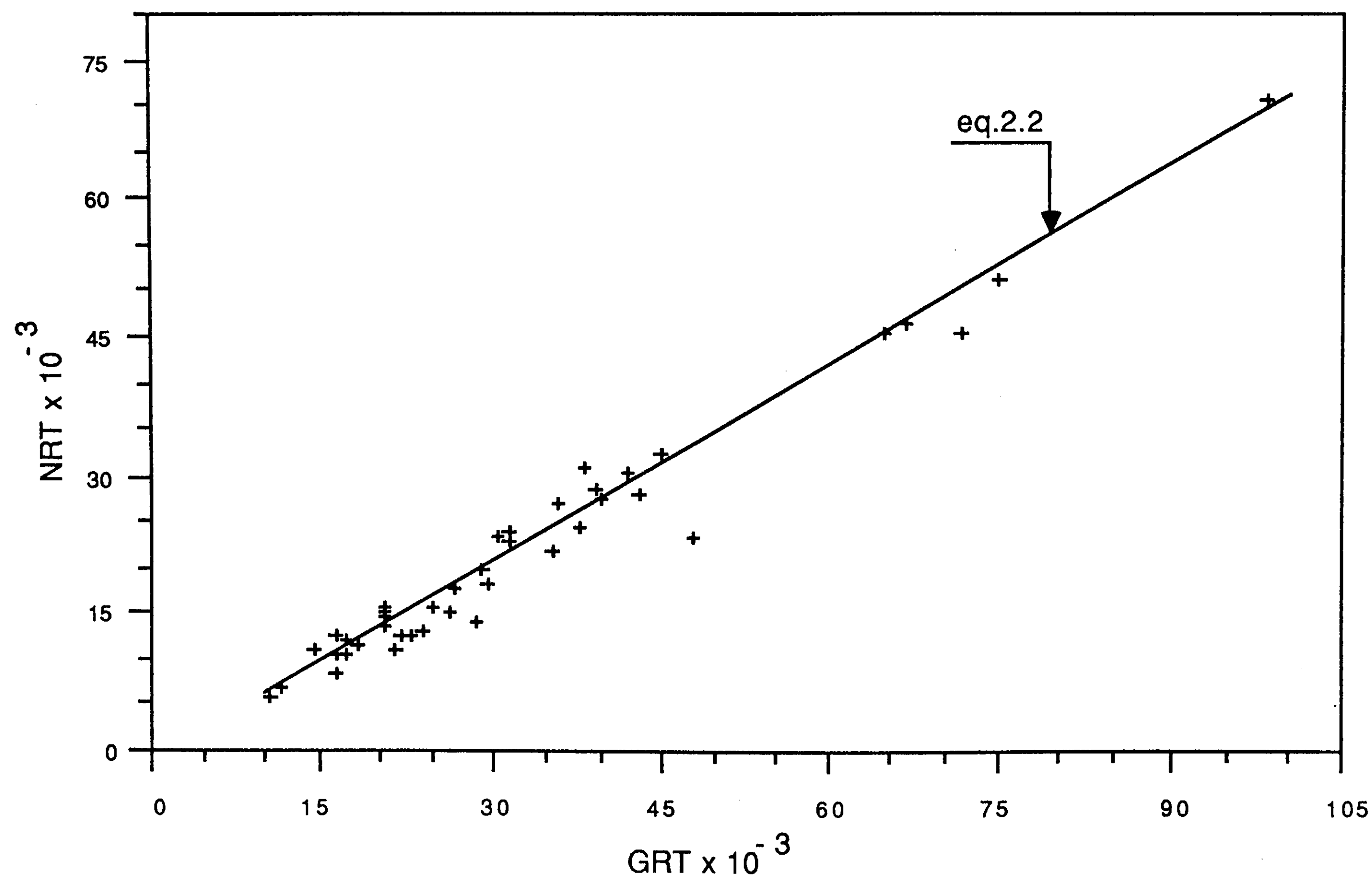


Fig.2.9 NRT versus GRT

load line. The larger the freeboard is the more reserve buoyancy the ship has and the less chance there is of waves breaking over the deck.

The 1966 load line convention divides ships into type A and type B. Ships of type A are those designed to carry liquid cargoes in bulk. Type B ships are those other than type A. Dry bulk carriers are type B.

For each combination of L, B, T and Cb to be considered the freeboard is determined to arrive at a value of depth D. The computer algorithm developed is similar to that developed in (5).

Below are given the corrections to be made in order to calculate the freeboard.

1. Tabular freeborad.

Tabular freeboards for ships from L 100 m to 250 m and L 251 m to 365 m are fitted by two sixth order polynomials (6) by the method of least squares.

Tabular freeboard is then given by the form

$$TABFB = W(1) + W(2) \times L + W(3) \times L^2 + W(4) \times L^3 + W(5) \times L^4 + W(6) \times L^5 + W(7) \times L^6$$

where the coefficients of the two arrays for the two length ranges referred to in the program as W1(7) and W2(7) are given in appendix 4.

2.Superstructure deduction.

The superstructure is assumed to have an effective length of 30% of the ship length and the standard height.

The superstructure deduction is given by

$$SUPDED = 1066.8 \times \left(0.275 - 0.492 \times \frac{L(m)}{800.0} \right) \quad (mm) \quad [eq.2.3]$$

3.Sheer correction.

As stated earlier the ship is assumed to have the deck horizontal. Therefore, a correction for sheer is required.

A standard sheer is given by

$$SHEER = \frac{(200.0 \times L(m) + 6000.0)}{48.0} \quad (mm) \quad [eq.2.4]$$

and thus sheer correction is given by

The freeboard used is type B giving more depth than strictly necessary for the Panama draft limit.

$$SHEERC = \left(0.75 - \frac{S}{2.0} \right) \times SHEER \qquad (mm) \quad [eq.2.5]$$

where S = 0.3

4. Block coefficient correction.

The input value of block coefficient at the design draft is corrected to the block coefficient for freeboard at 85% of the depth.

The correction is given by

$$Cb2 = Cb + (1.0 - Cb) \times \frac{(0.85 \times D - T)}{3 \times T} \qquad [eq.2.6]$$

For Cb2 > 0.68, the tabular freeboard is corrected as

$$TABFB2 = TABFB \times \frac{(Cb2 + 0.68)}{1.36} \qquad (mm) \quad [eq.2.7]$$

and for $Cb2 \leq 0.68$ no correction is required for tabular freeboard (i.e. TABFB2=TABFB)

5. Depth correction.

The first estimation of depth obtained from

$$D = T + (TABFB2 + SHEERC - SUPDED) \times 10^{-3} \qquad (m) \qquad [eq.2.8]$$

is corrected as follows

for D > L/15 the depth correction is

$$DEPTHC = (D - L/15) \times R \qquad (mm) \qquad [eq.2.9]$$

and for $D \leq L/15$ no correction for depth is required.

The value of R is given as follows

for L < 120 (m), R = L(m)/0.48 (mm)

and for $L \geq 120$ (m), R = 250 (mm).

The minimum freeboard is, therefore, obtained from

$$FREBD = TABFB2 + SHEERC - SUPDED + DEPTHC \qquad (mm) \qquad [eq.2.10]$$

and hence the ship depth is given by

$$D = T + FREBD \times 10^{-3} \qquad (m) \qquad [eq.2.11]$$

The above calculations of freeboard with the different corrections made are carried out by subprogram subroutine FREBRD. The input to the procedure are ship length, draft and block coefficient and the output is the ship depth.

The flow chart of the algorithm FREBRD is shown in appendix 1.

In order to check the validity of results given by the computer program, table 2.1 shows comparison between calculated and actual depths of some bulk carriers.

TABLE 2.1 COMPARISON OF ACTUAL AND CALCULATED SHIPS' DEPTHS.

Ship's Name	DWT (metric)	L x B x T (m^3)	Actual D (m)	D (m) (program)	Error (%)
Ingeren	20,721.	149.35 x 22.48 x 9.51	12.50	13.13	5.04
Sophia	28,860.	170.00 x 23.10 x 10.65	14.50	15.02	3.59
British Monarch	28,890.	173.74 x 25.15 x 10.179	14.40	14.36	-0.28
Ektor	30,175.	181.00 x 22.92 x 10.70	14.50	15.26	5.24
Cumbria	32,011.	173.74 x 25.15 x 10.82	14.40	15.21	5.63
Jersey Bridge	33,630.	190.50 x 25.91 x 10.43	14.86	15.03	1.14
Norland	42,367.	202.69 x 28.96 x 11.24	16.31	16.07	-1.47
Stonepool	45,747.	207.27 x 27.43 x 11.835	15.85	17.02	7.38
Oriental Pioneer	59,869.	211.00 x 32.20 x 12.67	17.80	18.19	2.19
Ragna Gorthon	69,888.	235.00 x 32.20 x 12.908	18.588	18.91	1.73
Zaragoza	81,276.	241.00 x 32.20 x 14.15	21.00	20.59	-1.95

CHAPTER 3 : PROPULSION ESTIMATES.

3.1 INTRODUCTION.

The estimation of the propulsive power is one of the most important feature in the preliminary design process. The success or failure of the design depends mainly on the speed which itself is dictated by the conditions of service. It is essential that a designer be able to predict accurately the speed a new design will attain. The fuel bill is a major cost item in the operating costs of any ship, so the designer will be anxious to keep the power needed for the operating speed to a minimum consistent with other design requirements. In this way the weight, cost and volume of the machinery and fuel provided are kept to a minimum. It follows, therefore, that an accurate knowledge of a design's powering characteristics is of considerable importance.

Several methods of estimating the propulsive power are available to the designer. They are

1. use of full-scale data from ships built over a period of years;
2. use of theoretical analysis; and
3. use of models for predicting full-scale resistance.

The approach used in this thesis in estimating the propulsive power is based on the 2nd and 3rd method combined. The method proposed by Moor & Small (13), for single-screw ships, which is most suitable for computer programming has been adopted to estimate the effective horsepower (ehp).

This chapter is divided into two sections. The first explains step by step the Moor & Small method in estimating the effective horsepower. The prediction of the delivered power for propelling the ship, or shaft horsepower (shp), is dealt with in the second section. This is done through determining the propeller characteristic features, cavitation included, and estimating the quasi propulsive coefficient (QPC).

Finally, the computer program results giving the engine output are compared with those of some bulk carriers to check their validity.

3.2 EFFECTIVE HORSEPOWER ESTIMATES.

As pointed out above the estimates of the effective horsepower is based on Moor & Small method.

The method presents the results of an analysis of resistance data of single-screw ships presented in the form of charts of resistance constant circular C (©).

Tabulated values of circular C are given as function of block coefficient (Cb), speed length ratio (V/√L) and longitudinal centre of buoyancy (LCB) position.

The data is presented in terms of the BSRA (now BMT) standard dimensions namely 400 ft.Lbp x 55 ft.beam x 26 ft.draft. To extend the range of data to higher block coefficients which this thesis deals with, results of BSRA 0.85 block coefficient series (15) were used and extrapolation made to arrive at Cb of 0.875. Because of the inaccuracy of the data obtained at Cb of 0.875 by extrapolation, it must be said that at this highest block coefficient the results present somewhat a lack of certainty. It was, therefore, disappointing at the time of the present investigation not to find data for even higher block coefficient.

To simplify the method it was assumed that the longitudinal centre of buoyancy is always close to its best position. This permits to store values of © in a two-dimensional array of Cb and V/√L instead of one of three dimensions.

Computer algorithm.

The © values from (13) updated by being reduced by 5% are tabulated for Cb values of 0.650 to 0.875 at intervals of 0.025 and V/√L values of 0.40 to 0.80 at intervals of 0.05. These two ranges represent the usual ranges of Cb and V/√L of most recent delivered panamax bulk carriers.

The values of © for the the two ranges of Cb and V/√L used as input in the computer program are given in appendix 4.

The input items to the program are speed (V), length (L), beam (B), draft (T) and block coefficient (Cb), with L, B and T in feet, and the output is the effective horsepower (EHP).

The required value of circular C for the given value of Cb and $V/\sqrt{L}$,CIRCM, is first calculated for the required Cb and then for $V/\sqrt{L}$ using Lagrangian three points interpolation subroutine LAGINT.

The value of CIRCM obtained is corrected to a beam and draft of the actual ship for deviation from the standard beam of 55 ft. and draft of 26 ft. using Mumford's indices (13).

After beam correction CIRCM becomes

$$CIRC1 = CIRCM \times \left(\frac{400.}{L} \times \frac{B}{55.} \right)^{x - \frac{2}{3}} \qquad \text{[eq.3.1]}$$

and after draft correction CIRC1 becomes

$$CIRC2 = CIRC1 \times \left(\frac{400.}{L} \times \frac{T}{26.} \right)^{y - \frac{2}{3}} \qquad \text{[eq.3.2]}$$

where for the range of $V/\sqrt{L}$ considered $x = 0.90$ and $y = V/\sqrt{L} \times 1/3 + 0.373$ taken from (5) which gives good correlation factor.

Then, a skin friction correction is applied for deviation from the standard length of 400 ft. using Froude method of circular 0.

Ⓞ versus length taken from (6) is given by

for $100' \leq L \leq 400'$

$$Ⓞ = OA(1) + OA(2) \times L + OA(3) \times L^2 + OA(4) \times L^3 + OA(5) \times L^4 + OA(6) \times L^5 \qquad \text{[eq.3.3]}$$

and for $L > 400'$

$$Ⓞ = OB(1) + 0B(2) \times L + OB(3) \times L^2 + OB(4) \times L^3 \qquad \text{[eq.3.4]}$$

where OA and OB are input arrays given in appendix 4

and Ⓞ correction = Ⓞ - 0.0741 [eq.3.5]

Using Mumford formula (13) the wetted surface is given by

$$S = 1.7 \times L \times T + Cb \times L \times B \qquad \text{[eq.3.6]}$$

and the wetted surface constant Ⓢ follows from

$$Ⓢ = \frac{0.0935 \times S}{\Delta^{2/3}} \qquad [eq.3.7]$$

and Froude speed-length constant is given by

$$Ⓛ = 1.055 \times V/\sqrt{L} \qquad [eq.3.8]$$

The skin friction correction (SFC) from eq.3.5, 3.7 and 3.8 is, therefore, given by

$$SFC = \frac{Ⓞ\,correction \times Ⓢ}{Ⓛ^{0.175}} \qquad [eq.3.9]$$

From eq.3.2 and 3.9 the required value of circular C for the actual ship is

$$© = CIRC2 + SFC \qquad [eq.3.10]$$

Finally, the effective horsepower is given by

$$EHP = \frac{© \times V^3 \times \Delta^{2/3}}{427.1} \qquad [eq.3.11]$$

The flow chart of computer subprogram subroutine EFECHP calculating the effective horsepower is shown in appendix 2.

3.3 DELIVERED HORSEPOWER ESTIMATES.

To arrive at the delivered power by the engine the quasi propulsive coefficient (QPC) must be estimated with both weather allowance and ship model correlation factor taken into consideration.

The QPC can either be calculated directly by quick methods such as that given by Emerson formula i.e

$$QPC = \eta_D = K - \frac{N \times \sqrt{L}}{10,000}$$

where K is a constant and N the propeller speed in revolutions per minute, or broken down into its components which are separately estimated.

The second approach which is more accurate is adopted in this thesis. The QPC is given by

$$QPC = \eta_D = \frac{EHP}{DHP} = \eta_H \times \eta_R \times \eta_O \qquad \text{[eq.3.12]}$$

where DHP is the delivered horsepower;

η_H is the hull efficiency;

η_R is the relative rotative efficiency; and

η_O is the propeller open water efficiency.

In order to calculate the propeller efficiency and define its characteristics with respect to cavitation, open water propeller charts are the usual methods to use.

The Wageningen B series in the form of B_p-δ which is suitable to program is used in this thesis to ascertain the propeller open water efficiency.

Computer algorithm.

The flow chart of subprogram subroutine SHFTHP calculating the shaft horsepower is shown in appendix 2. The input items to the program are speed (V), length (L), beam (B), draft (T), block coefficient (Cb), the effective horsepower (EHP), the propeller speed (RPM) and the control parameter (IREVLD). The output is the shaft horsepower (SHP).

Below are explained the program logic steps to arrive at the shaft horsepower SHP.

1. Ship model correlation factor and service margin.

When test results obtained for models are extrapolated to full size ships under trial conditions a factor which takes into account the ship's hull conditions must be applied. This factor is referred to as the ship model correlation factor. Values of ship model correlation factor (1 + x) are given either in ITTC or Froude notation. It is the latter (6) adopted in the program which is for single screw given by

$$CF = (1 + x)_{Froude} = 0.367 + 2.5 \times L^{-0.25} + 27.5 \times L^{-1.0} \qquad \text{[eq.3.13]}$$

The service margin or weather allowance serves to provide a margin of power required for differences between trial and service conditions of fouling and weather. Usual proportion adopted by shipyards for service margin is from 15 to 20% of the required continuous service power.

The service margin WEIRA given in (5) is adopted in the program giving the factor for weather allowance 15% at $V/\sqrt{L}$ of 0.45 and 25% at $V/\sqrt{L}$ of 1.05. It is therefore given by

WEIRA = 1.075 + 0.1667 x $V/\sqrt{L}$ [eq.3.14]

2. Hull efficiency and relative rotative efficiency.

The hull efficiency η_H is given by

$$\eta_H = \frac{1.\text{- thrust deduction}}{1.\text{ - wake}} \quad \text{[eq.3.15]}$$

where $\text{wake} = 0.1 + \frac{W1}{W2} + W3$

with $W1 = \frac{4.5 \times B \times Cb^2}{L \times C_W \times C_M}$

$$W2 = \left(7. - \frac{6. \times Cb}{C_W}\right) \times \left(2.8 - \frac{1.8 \times Cb}{C_M}\right)$$

$$W3 = 0.5 \times \left(D \times \frac{0.625}{T} - 0.873 - \frac{D}{B}\right)$$

D is the propeller diameter, and C_W and C_M are respectively the water plane area and midship section area coefficients given by

$$C_W = \frac{1.}{3.} + \frac{2.}{3.} \times Cb$$

$C_M = 0.06 \times Cb + 0.94$

The thrust deduction is given by

thrust deduction = wake x (0.5 + 0.4 x ($V/\sqrt{L}$ - 0.5))

The relative rotative efficiency RRE is equal to 1.02 [eq.3.16]

The equations given above for calculating wake and thrust deduction and the value of RRE are for single screw with which this thesis deals.

3. Propeller design.

The design of the propeller aims to have such objectives as the highest propeller efficiency with the selection of maximum permissible diameter D, lowest blade area ratio BAR higher enough to avoid cavitation erosion and lower value of propeller rotary speed.

Bearing these considerations in mind the computer algorithm is based on the five blade chart with blade area ratio of 0.6.

a. Propeller diameter.

In order to increase the propeller open water efficiency the propeller diameter is chosen as high as possible. The maximum value set in the program is taken as the lesser of 70% of the design draft and 32 ft. to ensure that it is completely immersed.

b. Propeller rotary speed.

The value of the propeller revolutions per minute RPM is inserted as input to the program. To improve the propulsive efficiency the propeller speed should be low and this is best achieved by direct drive slow speed diesel engine with a range of 90 to 120 rpm and even lower.

When the diameter is restricted as it is the case here and the power required large the RPM is allowed to increase to improve the propeller efficiency. This increase (15%) is done in the program by assigning a value 2 to the control parameter IREVLD otherwise a value 1 is assigned.

c. Propeller blade area ratio.

A value of 0.6 taken from the chart is inserted as first value of blade area ratio BAR. Taking into consideration the cavitation phenomenon which could be avoided if BAR is above a certain value, the program selects the smallest value for maximum propeller efficiency.

d. Optimum efficiency.

Assuming a first value of delivered power of 1.5 times the effective horsepower and given the RPM and speed of advance Va, B_p value is calculated. A range given in the chart of B_p values accepted in the program is of 9 to 155, otherwise it is out of range.

In order to obtain the optimum efficiency η_{opt}, optimum diameter pitch ratio P/D and the value of δ, a regression analysis carried out by Sabit (16) is adopted in the program.

The equations giving the above parameters are of the form

$$\delta, \eta_{opt}, P/D = a_0 + a_1 \times (\ln B_p) + a_2 \times (\ln B_p)^2 + a_3 \times (\ln B_p)^3 + a_4 \times (BAR) + a_5 \times (BAR)^2 + a_6 \times (BAR)^3 + a_7 \times (\ln B_p) \times (BAR) + a_8 \times (\ln B_p) \times (BAR)^2 + a_9 \times (\ln B_p)^2 \times (BAR) \quad \text{[eq.3.17]}$$

The coefficients of the array a(9) referred to in the program as F(9), G(9) and Y(9) respectively for δ, η_{opt} and P/D are input arrays given in appendix 4.

If a 4 bladed propeller is chosen instead of one of 5, the change is simply made by changing the array coefficients.

The value of δ at the optimum efficiency line is denoted in the program by basic delta δ_b.

From δ_b the propeller diameter is given by

$$D = \delta_b \times \frac{Va}{RPM} \qquad \text{[eq.3.18]}$$

where Va = V x (1 - wake)

If D is greater than 0.70 x T or 32', the lesser of the two values is taken as the new propeller diameter.

Then, the value of δ which lies away from η_{opt} is recalculated from the new propeller diameter and given by

$$\delta = \frac{RPM}{Va} \times D \qquad \text{[eq.3.19]}$$

and the field efficiency η_O is given by the following empirical relationship from (6) as

$$\eta_O = \eta_{opt} - (1.5 \times (1. - \frac{\delta}{\delta_b}) + 0.065) \times (1. - \frac{\delta}{\delta_b}) \times (\frac{\delta_b}{\delta_b + 10.}) \qquad \text{[eq.3.20]}$$

An initial value of propeller efficiency is assumed in the program as PFBNEW equal to 0.1. If the propeller efficiency η_O = PFNEW is less than PFBNEW, it is accepted as the correct value and the program goes on to the next stage for cavitation check.

The value of quasi propulsive efficiency is calculated with PFNEW, hull efficiency and relative rotating efficiency.

4. Shaft horsepower.

A value of SHP of 52,000 bhp is assumed in the main program to be the maximum power which could be delivered by a single shaft and any power above this value is rejected.

The values of quasi propulsive coefficient, correlation factor and service margin being calculated the new value of shaft horsepower SHPNEW is calculated and given by

$$SHPNEW = \frac{EHP}{QPC} \times CF \times WEIRA \qquad [eq.3.21]$$

This value is compared to the initial value of SHP = 1.5 x EHP. If the difference between the two values is greater than 3% of SHPNEW then this latter becomes the new initial value of SHP and the whole procedure is repeated until the difference between successive values of shaft horsepower is less or equal to 3%. Also the same difference apply to propeller efficiency. If the difference between two successive propeller efficiency values is greater than 3% of η_{opt} the RPM is increased by 15% and PFNEW becomes the new initial value of propeller efficiency and the procedure repeated. When the difference is within 3% the iteration on RPM stops and the program goes on to check for cavitation.

The cavitation check is made for a value of $7^{1/2}$ % back cavitation assumed as the upper acceptable limit. The calculation of the minimum acceptable blade area ratio DBAR which satisfies the cavitation criterion is carried out by subroutine CAVIT. If DBAR is less than BAR of 0.6 assumed initially the cavitation requirements are fulfilled and the propeller design is accepted. Otherwise the procedure is repeated with DBAR as the new initial value of blade area ratio. The range of blade area ratio acceptable in the program is of 0.45 to 1.05.

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

To check the acceptability of the results and validate the shaft horsepower given by the program, data from some bulk carriers were used for this purpose.

Table 3.1 shows the difference between actual ships shaft horsepower and those calculated by the program.

TABLE 3.1 COMPARISON OF ACTUAL AND CALCULATED SHIPS' SHAFT HORSEPOWER (SHP).

Ship's Name	DWT (metric)	Actual SHP	SHP (program)	Error (%)
Ingeren	20,721.	8,700.	8,598.	-1.17
Sophia	28,860.	12,000..	12,300.	2.50
British Monarch	28,890.	11,700.	10,970.	-6.24
Ektor	30,175.	11,200.	10,497.	-6.28
Cumbria	32,011.	10,200.	10,879.	6.66
Jersey Bridge	33,630.	12,600.	12,018.	-4.62
Norland	42,367.	15,000.	14,888.	-0.75
Stonepool	45,747.	13,000.	12,627.	-2.87
Ragna Gorthon	69,888.	14,000.	14,491.	3.51
Zaragoza	81,276.	11,410.	11,858.	3.93

CHAPTER 4 : LIGHTSHIP WEIGHT AND CAPITAL COST.

4.1 LIGHTSHIP WEIGHT.

4.1.1 INTRODUCTION.

The estimation of the lightship weight is one of considerable importance in the preliminary ship design stage due to its bearing on the displacement and cost estimation.

The lightship weight is usually broken down into its following components which are

- steel weight;
- outfit weight;
- machinery weight; and
- margin.

Thus, it is the weight of a ship complete and ready for sea but no cargo, fuel, fresh and feed water, ballast and crew on board. It is the hull weight plus the propulsion plant weight.

There are several methods of estimating the quantities, given above, involved in the lightship weight.

The method adopted in the computer program was developed by Watson & Gilfillan (2) and subdivides the lightship weight as pointed out above.

Bulk carriers, with a deadweight from 20,000 to 80,000 for which weight data were available, are used to check the validity of the result given by the computer program.

The following sections deal with the estimates of each of the lightship weight components.

4.1.2 STEEL WEIGHT.

The steel weight is by far the largest single group weight and may indeed be more than 80 per cent of the lightship weight.

The steel weight is not simple to estimate as it could be influenced by certain factors such as the ship's classification and whether or not high tensile steel, to reduce the lightweight of the hull, is used in decks and bottom. However, many methods for estimating it were derived by regression analysis techniques based on data of existing ships. The method developed by Watson & Gilfillan is based on the hull numeral parameter E. This parameter is particularly useful because it is applicable to a wide range of ship types, and it was found to be directly influenced by the net steel weight.

It is worth mentioning here the two steel weights, invoiced and net. The invoiced or gross steel weight is the total weight recorded in the shipyard steel order book and deemed enough for the construction of the ship. It is the weight used for the shipbuilding cost estimates. On the other hand, the net steel weight is the weight determined by detailed calculations based on ship plans, and required for the deadweight calculation. In other words, the net steel weight is the weight of invoiced steel minus the scrap or wastage made up of cutting from sides and ends of plates, and drainholes.

The following relationships concern the net steel weight.

The hull numeral E is given by

$$E = L \times (B + T) + 0.85 \times L \times (D - T) + A \qquad (m^2) \qquad [eq.4.1]$$

where $A = 0.85\Sigma l_1 h_1 + 0.75\Sigma l_2 h_2$

where l_1, h_1 are length and height of full width erections; and

l_2, h_2 are length and height of houses.

For ordinary cargo ships the value of erections A varies between 200 and 300 m^2 and it is taken in the program as an average value of 250 m^2.

Since the formulation of the E parameter [eq.4.1] do not take into account the fullness of the ship, or block coefficient, which obviously has a considerable effect on the steel weight, this latter is corrected to a standard block coefficient of 0.70 measured at 0.80 of the depth, and is given by

$$W_{S7} = K \times E^{1.36} \qquad (tonnes) \qquad [eq.4.2]$$

where K is a steelweight factor which varies for a bulk carrier from 0.029 to 0.032 for E comprises between 3,000 and 15,000 m^2 validated for a sample of 13 bulk carrier ships. The value of K is taken in the program as an average value of 0.03.

The correction of the steelweight W_S for variation in Cb from 0.70 is made by

$W_S = W_{S7} \times [\ 1. + 0.5 \times (Cb_1 - 0.70)]$ (tonnes) [eq.4.3]

where Cb_1 is the actual block coefficient measured at 0.80 of D, and is given by

$$Cb_1 = Cb + (1. - Cb) \times \frac{(0.8 \times D - T)}{3 \times T}$$

and Cb the block coefficient at the design draft T.

The scrap allowance in percentage or wastage of material required to produce the invoiced steelweight is given as a polynomial function of Cb_1 (2), (6) and is

$SCRAP = S(1) + S(2) \times Cb_1 + S(3) \times Cb_1^2 + S(4) \times Cb_1^3 + S(5) \times Cb_1^4$

The array S is taken as input in the program.

There are many factors which affect the scrap deduction, among them

-the shipyard ordering methods;

-the shipyard construction methods;

-the skill of draughtsmen in utilising material;

-the accuracies of the calculations employed to assess both invoiced and net weights; and

-the type of ship under construction, in particular, its fullness of form.

4.1.3 OUTFIT WEIGHT.

The outfit weight in the hull comprises all items except the net steel and hull castings and forgings.

One difficulty in estimating this group weight is whether some items should be attributed to steel or outfit group weight such as patent steel hatch covers now counted as an outfit weight for bulk carriers.

The outfit weight has been affected by the introduction of modernism to ships and better quality of living aboard such as automation, high standards of crew accommodation, fitting of air conditioning and sewage systems.

However, the methods available for estimating the outfit weight are simpler than in the case of steelweight and are mostly function of the square number L x B.

The method adopted in the program is derived from a graph given by Watson & Gilfillan and gives the outfit weight for a bulk carrier as

$$W_O = \frac{(541.2 - L)}{1625.8} \times (L \times B) \qquad \text{(tonnes)} \qquad [\text{eq.4.4}]$$

where L and B are in metres.

4.1.4 MACHINERY WEIGHT.

The type of machinery assumed in this thesis is a direct drive slow speed diesel engine with which most of bulk carriers in service today are powered.

Indeed, after the sharp rise in oil prices in 1973, the search for fuel economy has become an imperative task to achieve. The diesel engines both slow speed and geared medium speed, were the obvious type of engines that could offer great savings by the reduced specific fuel consumption and the use of relatively cheap fuel. Therefore, many shipowners whose ships were powered by steam or gas turbines, with a huge fuel consumption, were forced to convert their machinery to diesel propulsion.

The machinery weight is subdivided into two groups, the main engine which for a diesel can be obtained from the manufacturer's catalogue, and the remainder or weight of auxiliaries (2).

The weight of the main engine is related to the maximum continuous rating BHP (metric) and the propeller revolutions per minute REVSIN, and given by

$$WMENG = 9.38 \times \left[\frac{BHP}{REVSIN} \right]^{0.84} \qquad \text{(tonnes)} \qquad [\text{eq.4.5}]$$

The weight of remainder for a bulk carrier is given by

$$WRM = 0.56 \times (BHP)^{0.70} \qquad \text{(tonnes)} \qquad [\text{eq.4.6}].$$

Therefore,the total machinery weight is given by

$$W_M = WMENG + WRM \qquad \text{(tonnes)} \qquad [\text{eq.4.7}]$$

4.1.5 LIGHTSHIP WEIGHT.

In order to attain a specified deadweight, a margin is necessary to apply to reflect uncertainty in estimating weight.

As suggested by Watson & Gilfillan, an addition of 1 per cent of the steelweight to allow for weld metal deposited and the rolling margin on the steel, and 2 per cent of the lightweight have been adopted in the program.

The total lightship weight is therefore

$$WLT = (1.01 \times W_S + W_O + W_M) \times 1.02 \quad \text{(tonnes)} \quad \text{[eq.4.8]}$$

where W_S is the steelweight in (tonnes);

W_O is the outfit weight in (tonnes); and

W_M is the machinery weight in (tonnes).

In order to check the acceptability of the result given by the computer program, the lightship weight is validated for actual ship data as shown in table 4.1.

4.2 CAPITAL COST.

4.2.1 INTRODUCTION.

Capital cost is generally acknowledged nowadays as the largest single element of total cost of providing shipping services.

The estimation of shipbuilding costs is an important task needed by different people and for many reasons ranging from political to economic.

A good cost estimate enables political leaders and government planners for decision making in such projects as dredging, lock construction and port planning. Ship cost projections are also needed for decision making in political matters such as subsidy allocations and other forms of support.

Fleet and shipyard managers need cost estimates for purposes of choosing between alternative investment opportunities, deciding whether to make or buy certain items of equipment.

Finally, the naval architect needs cost estimates for preliminary design purposes and for carrying out optimization studies to find the best combination of major design parameters.

There is still no standardisation in estimating shipbuilding costs because of

TABLE 4.1 COMPARISON OF ACTUAL AND CALCULATED LIGHTSHIP WEIGHTS.

Ship's Name	DWT (metric)	Actual Lightship Weight (tonnes)	LightshipWeight (program)	Error (%)
Ingeren	20,721.	5,487.	5,409.	-1.42
Sophia	28,860.	6,460.	6,700.	3.72
British Monarch	28,890.	7,431.	7,303.	-1.72
Ektor	30,175.	7,141.	7,295.	2.16
Cumbria	32,011.	6,989.	7,510.	7.45
Jersey Bridge	33,630.	9,248.	8,575.	-7.28
Norland	42,367.	11,064.	10,318.	-6.74
Stonepool	45,747.	10,331.	10,280.	-0.49
Oriental Pioneer	59,869.	12,897.	13,094.	1.53
Ragna Gorthon	69,888.	14,789.	14,279.	-3.45
Zaragoza	81,276.	14,948.	15,196.	1.66

insufficient information and the natural reluctance of firms to disclose their cost data. However, all cost estimating methods seem to be based either on the ship's functional capability, such as deadweight, or on its technical characteristics, such as the weights of various components. The latter is adopted in the computer program and is based on a method developed by Carreyette (23).

Carreyette recognizes that most ship designs are simple variations on the design of some existing ship. He estimates material and labour costs individually for structure (steel), outfit and machinery based on known costs from similar ships adjusted for key differences in design characteristics. Indeed, breaking the ship down into different major physical components allow a great increase in estimating accuracy because appropriate cost coefficients can be individually applied.

The following sections treat each cost component of capital cost according to 1987 cost levels.

4.2.2 SHIPBUILDING COSTS.

In this thesis the ship is assumed to be built in the U.K and the cost is adjusted to reflect Japanese shipbuilding costs according to 1987 cost levels.

As pointed out, the capital cost can be broken down between labour and material cost components.

4.2.2.1 LABOUR COSTS.

The labour costs can be subdivided into

- steel labour;
- outfit labour; and
- machinery labour costs.

Direct labour costs are estimated on man-hours basis which once estimated, wage rates, overheads and profit margin are applied to get the total labour costs. Overhead costs are those costs necessary to carrying on the business but which cannot logically be ascribed to any given contract (i.e. ship).

They are of two kinds. Those that are more or less fixed regardless of the yard's level of activity, such as salaries of top officers, property taxes and plant depreciation; and those that vary such as supervision, bonus payments to top officers and utilities.

Overhead costs are usually estimated as a fraction of labour costs both direct and miscellaneous. This fraction depends primarily on

a) the level of concurrent work in the yard during the life of the contract (or ship); and

b) the yard's degree of capital intensiveness.

High levels of concurrent work will decrease the fraction, and high degrees of capital intensiveness will increase it.

4.2.2.1.1 STEEL LABOUR COSTS.

The man-hours per tonne of net steel derived by Carreyette is

$$R_h = \frac{K}{Cb \times (W_S/L)^{1/3}} \quad \text{man-hours/tonne} \qquad \text{[eq.4.9]}$$

where Cb is the block coefficient at laden summer draft,

L the length between perpendiculars,

W_S net steel weight, and

K a constant that vary between shipyards.

A value of K = 227. is taken in this thesis.

The total steel working man-hours are therefore

$$H = R_h \times W_S = 227. \times \frac{W_S^{2/3} \times L^{1/3}}{Cb} \quad \text{man-hours} \qquad \text{[eq.4.10]}$$

To convert steel work man-hours to total steel labour costs, a wage rate, overheads and profit margin are necessary to be applied.

The 1987 average wage rate in a british shipyard is £4.2/hour, overheads and profit are respectively taken as 50% and 10%, used as input values in the program where the user can easily modify them if necessary.

Thus, the total steel labour costs are

$$CSL = A_1 \times \frac{W_S^{2/3} \times L^{1/3}}{Cb} \qquad (£) \qquad [eq.4.11]$$

where $A_1 = 227. \times W_R \times (1. + \frac{Overheads}{100.}) \times (1. + \frac{Profit}{100.})$

with W_R the average wage rate in £/hour.

The variation of A_1 with the wage rate and for various values of overheads is shown in fig.4.1.

4.2.2.1.2 OUTFIT LABOUR COSTS.

It is usual to charge subcontracting labour of outfit work to 'materials', that is, as something 'bought in' and therefore not chargeable to the shipyard labour account. Therefore, the outfit labour hours booked by the shipyard were always less than the true number of hours required to complete the work.

From these considerations, Carreyette decides to work in money for total outfit costs rather than in man-hours.

The total outfit labour costs are given by

$$COL = C_1 \times W_O^{2/3} \qquad (£) \qquad [eq.4.12]$$

where W_O is the outfit weight in tonnes,and

$$C_1 = W_R \times K_2 \times (1. + \frac{Overheads}{100.}) \times (1. + \frac{Profit}{100.})$$

with W_R the wage rate in £/hour as given above, and

K_2 a constant taken in this thesis as 2710.

Fig.4.2 shows the variation of the value of C_1 with wage rate for different values of overheads.

4.2.2.1.3 MACHINERY LABOUR COSTS.

As for the outfit labour, the record man-hours for machinery installation suffers the same drawback. Indeed, some of the machinery work is usually contracted which renders the shipyard hours unsuitable for analysis purposes, although the level of machinery subcontracting work is less than that with outfit.

Whereas cost for steel and outfit components are based on weights,

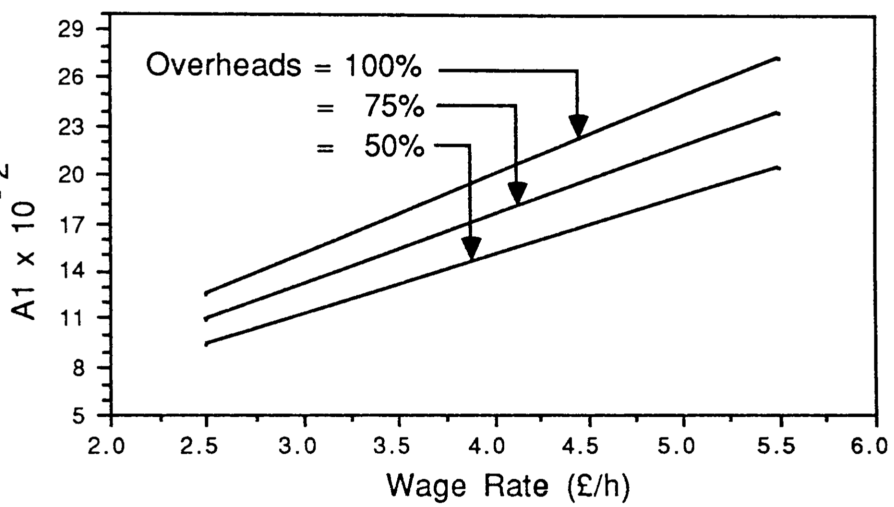


Fig.4.1 STEEL LABOUR COSTS CONSTANT
(PROFIT MARGIN 10%)

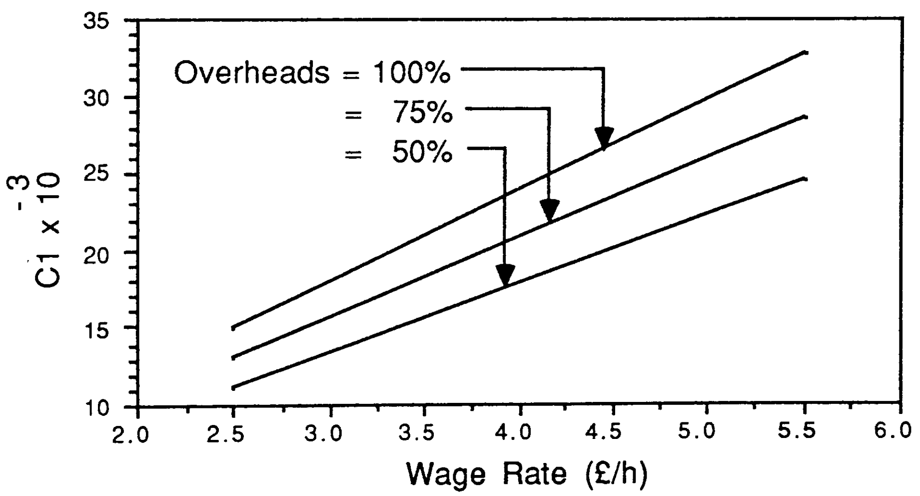


Fig.4.2 OUTFIT LABOUR COSTS CONSTANT
(PROFIT MARGIN 10%)

Carreyette finds better correlation of results in estimating labour, and material, costs for the propulsion plant based on the installed horsepower rather than on the machinery weight.

The total machinery labour costs are given by

$CML = E_1 \times SHP^{0.82}$ (£) [eq.4.13.]

where SHP is total installed horsepower, and

$$E_1 = W_R \times K_3 \times (1. + \frac{\text{Overheads}}{100.}) \times (1. + \frac{\text{Profit}}{100.})$$

with W_R the wage rate in (£/h) as given above, and

K_3 a constant taken in this thesis as 105.

The variation of the value of E_1 with the wage rate for various values of overheads is shown in fig.4.3.

4.2.2.2 MATERIAL COSTS.

As for labour, material costs can be subdivided into

- steel material;
- outfit material; and
- machinery material costs.

Carreyette finds that the equations giving the different material costs are similar in form to those of labour costs. The general form of material costs is thus given as

material costs $= \alpha \times X^n$ (£)

where α is a constant, X a size variable and n an indice less or equal to unity. The indices for the different material costs were found nearer to unity than that of labour costs, except for machinery costs where they are the same.

Results found by Carreyette were satisfactory for n=1 for steel material costs, compared with n =2/3 for steel labour; n=0.95 for outfit material costs, compared with n=2/3 for outfit labour; and n=0.82 for machinery material costs, the same as for machinery labour.

4.2.2.2.1 STEEL MATERIAL COSTS.

The steel material costs are given by

$CSM = B_1 \times W_S$ (£) [eq.4.14]

where W_S is the net steel weight in (tonnes), and

B_1 a constant embracing the cost of steel per tonne, scrap percentage of steel and profit, given by

$$B_1 = STLCOS \times (1. + \frac{SCRAP}{100.}) \times (1. + \frac{Profit}{100.})$$

with STLCOS the cost per tonne of steel taken from (24) as £250 for shipbuilding quality grade A with a thickness up to 50 mm. It is used as an input in the program where the user can easily updated it.

The variation of the value of B_1 with the steel cost per tonne and for various values of scrap (in percentage) is shown in fig.4.4.

4.2.2.2.2 OUTFIT MATERIAL COSTS.

The outfit material costs are given by

$COM = D_1 \times W_O^{\,0.95}$ (£) [eq.4.15]

where W_O is the outfit weight in (tonnes), and

D_1 a constant reflecting the cost of equipment from manufacturer's quotations.

In 1975 D_1 was 1,500, taking this as a basis value, the material index reflecting the year 1987, SINDEX in the program, is 267 per cent , taken as an input value where it can be modified according to inflation.

D_1 is then given by

$$D_1 = 1{,}500 \times \frac{SINDEX}{100.}$$

4.2.2.2.3 MACHINERY MATERIAL COSTS.

The main engine assumed in this thesis is a slow speed diesel engine. The total machinery material costs are given by

$CMM = F_1 \times SHP^{\,0.82}$ (£) [eq.4.16]

where SHP is the total installed horsepower, and

F_1 a constant reflecting the cost of engine and equipment from engine manufacturer's quotations.

In 1975 F_1 was 735, taking this value as a basis, and applying the material index for 1987, SINDEX as given above, F_1 becomes

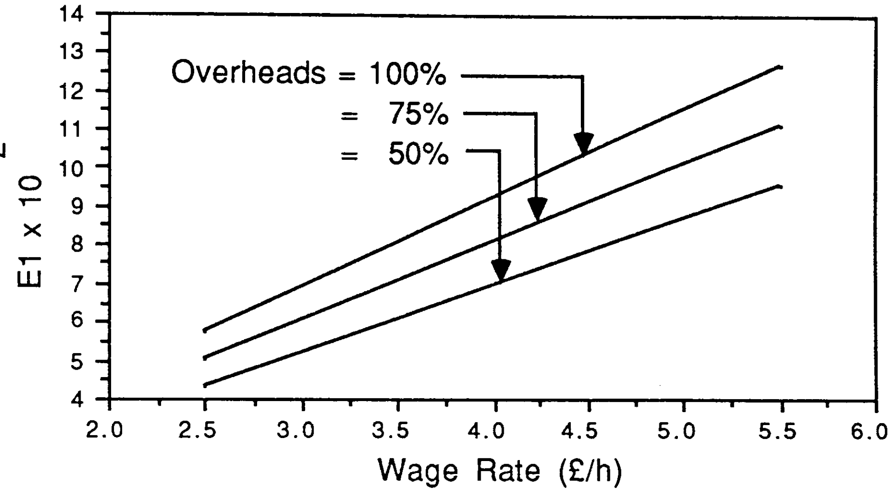


Fig.4.3 MACHINERY LABOUR COSTS CONSTANT
(PROFIT MARGIN 10%)

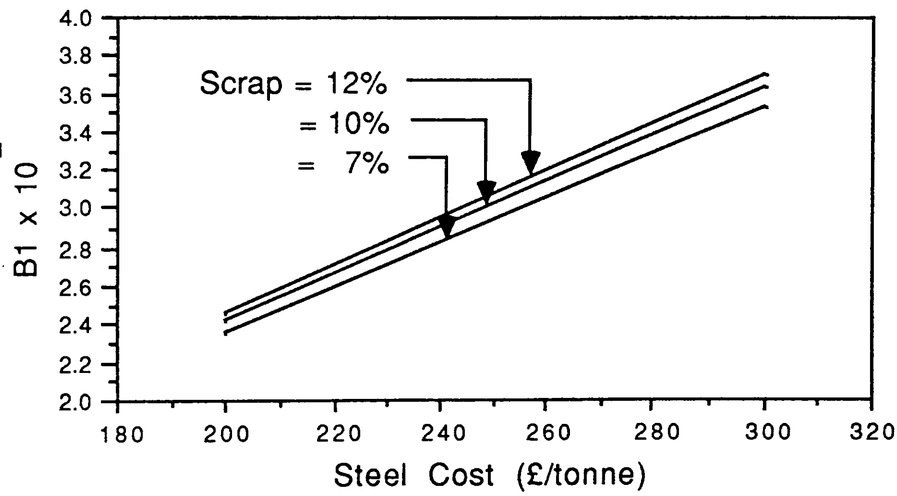


Fig.4.4 STEEL MATERIAL COSTS CONSTANT
(PROFIT MARGIN 10%)

$$F_1 = 735. \times \frac{SINDEX}{100.}$$

Some items such as thrusters, stabilisers are assumed not to be fitted in the ship. The single screw is assumed to be a fixed pitch propeller.

4.2.3 TOTAL SHIPBUILDING COSTS.

The first estimation of total capital cost is given by

$$TOTCOS = CSL + CSM + COL + COM + CML + CMM \quad (£) \qquad [eq.4.17]$$

$$= A_1 \times \frac{W_S^{2/3} \times L^{1/3}}{Cb} + B_1 \times W_S + C_1 \times W_O^{2/3} + D_1 \times W_O^{0.95} + E_1 \times SHP^{0.82}$$

$$+ F_1 \times SHP^{0.82} \qquad (£)$$

The term cost is ambiguous. The shipyard bill is really made up of cost to the yard plus profit. Cost to the shipowner is made up of the yard bill plus a highly variable collection of additional expenses. On the other hand, shipbuilding prices are influenced by a variety of factors such as supply and demand for transport capacity, market conditions, currency exchange rates, inflation, interest rates, level of any subsidy, concurrence and building time.

Shipbuilding prices fluctuate enormously over relatively short periods of time. Table 4.2 shows how the price of a 60,000 dwt bulk carrier ordered at a Japanese shipyard varies with the time. The price was $16 million in the fourth quarter of 1977, increased to $28.1 m in the fourth quarter of 1981 and then decreased to $17.8 m in the fourth quarter of 1983. Within a four year span, from 1977 to 1981, the price had increased by 75%, and decreased by nearly 37% from 1981 to 1983, a two year interval.

To convert and validate the result given by [eq.4.17] with prices given by Japanese shipyards which dominate the world shipbuilding industry, certain changes have been made.

Subsidies provided in the U.K or E.E.C countries to encourage the shipbuilding industry are about 28 per cent.

Taking this aspect into consideration, the subsidised price of the ship becomes

SUBCOS = TOTCOS x 0.72 (£) [eq.4.18].

Converting the price in U.S $, taking the average exchange rate for 1987 (£1.=$1.5), the price becomes

SUBCOS = SUBCOS x 1.5 ($).

The market conditions have a great influence on shipbuilding prices. Fig.4.5 shows how Japanese prices of new bulk carrier ships change with the years.

Prices for 1987 are relatively lower than that of the previous years. To validate the result given by the computer program, it was then necessary to apply a factor reflecting the 1987 market to arrive at a reasonably price.

The market factor, FACMAR, taken as 70% gives good agreement with the 1987 shipbuilding prices. FACMAR is used as an input value in the program where the user can change it according to the market.

The capital cost therefore becomes

CAPCOS = SUBCOS x FACMAR ($) [eq.4.19].

TABLE 4.2 SHIP PRICE MOVEMENTS.

Price of 60,000 dwt dry bulk carrier ordered at Japanese shipyard	US $Millions
Third quarter of 1973	15.0
Fourth quarter Of 1977	16.0
Fourth quarter of 1981	28.1
Fourth quarter of 1983	17.8

Source : Drewry Shipping Consultants (1984).

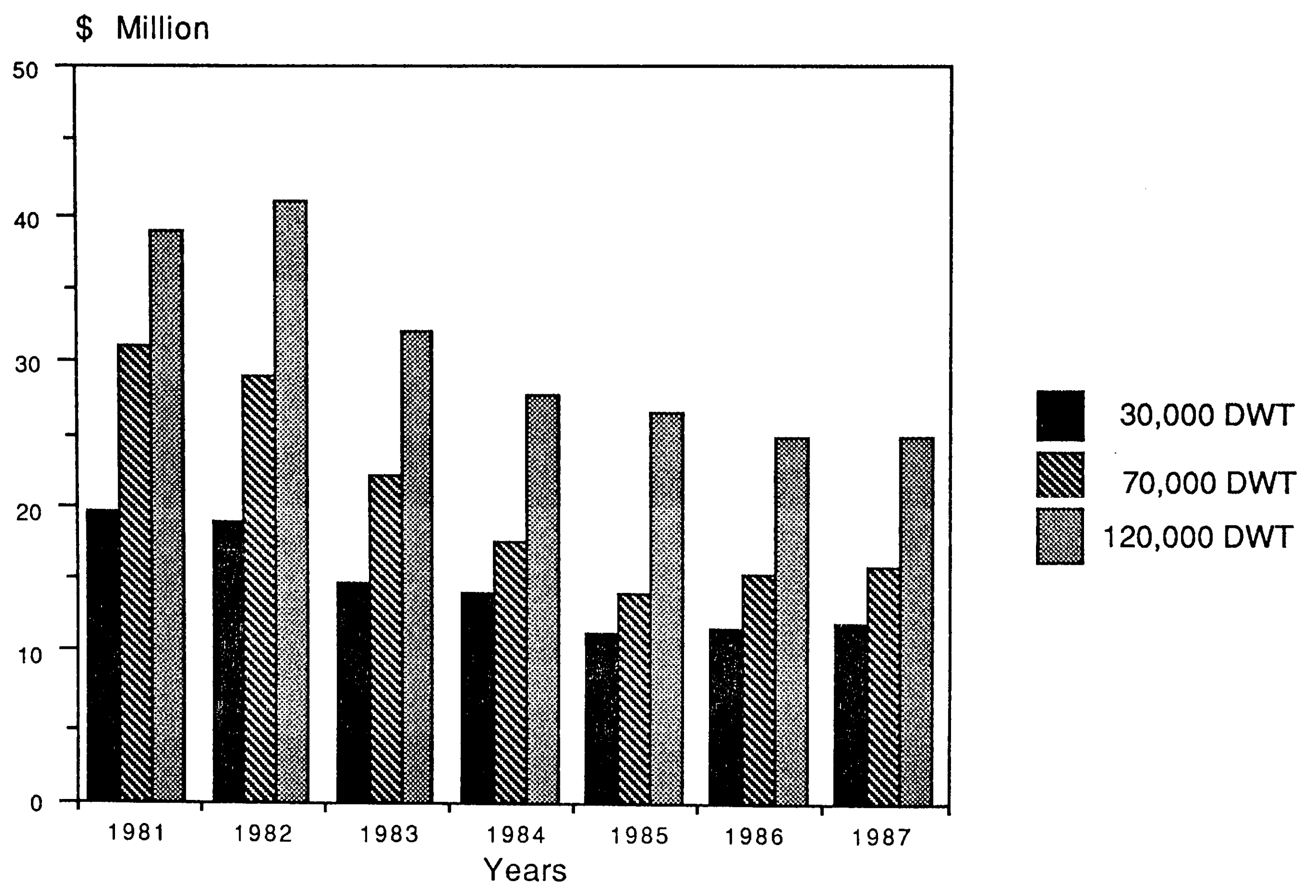


Fig.4.5 BULK CARRIER NEWBUILDINGS AVERAGE PRICE (JAPAN)
Source : Lloyd's Shipping Economist.

CHAPTER 5 : CAPACITY ESTIMATE.

5.1 INTRODUCTION.

During the design process, one of the various features which determine whether the ship to design is profitable or not to the owner is its earning capacity or ability to carry the amount of cargo required.

Indeed, the cargo capacity is one of the fundamental requirements stipulated by the shipowner before any agreement is reached between him and the shipbuilder. It follows, therefore, that the space required for the deadweight must be provided so the ship would satisfy the minimum stowage rate, expressed in cubic metres or feet per tonne, of the commodity for which it is designed to carry.

It is important at this stage of the design to be able to estimate fairly accurately the cargo capacity which is expressed as either grain or bale capacity.

As the topside tanks are usually used to carry water ballast, except for very special cases where they are filled with a bulk commodity (such as grain), two capacities are calculated in this chapter. The two capacities estimated, one including and the other excluding the topside tanks, give two stowage rate factors, the minimum and the maximum. At this stage it is possible to determine how many topside tanks should be filled with a bulk commodity if the minimum stowage factor is not adequate.

In order to calculate the stowage rate factors, the cargo deadweight derived from the deadweight must be known. The deadweight, which is the difference between the ship displacement and lightship weight, is broken down into its elements cargo, fuel, fresh water, stores which are separately estimated. Since fuel, fresh water and stores are mainly function of time spent at sea and in ports, an estimate of the round voyage time (both at sea and in ports) is required.

This chapter is divided into four sections. The first section deals with the estimate of time spent in a round trip. The estimates of the different elements of deadweight and cargo capacity or stowage rate are dealt with respectively in the second and third section. The last section discusses briefly some problems of stability and gives a simple procedure of estimating the criterion of initial stability, the transverse metacentric height (GM_T)

Finally, the results of cargo grain capacity given by the computer program are compared with those of existing bulk carriers to check their validity.

5.2. VOYAGE TIME.

As pointed out previously, the ship in this thesis is assumed to carry grain from the port of New Orleans (USA) to the port of Yokohama (Japan) transiting through the Panama Canal and returning in ballast.

The round voyage time is broken down into

1.time spent at sea, taking into account the increase in speed for ballast voyage;

2.time spent in ports for loading and discharge operations (bunkering is assumed to take place during these operations); and

3.delays in ports due to unexpected circumstances such as waiting for a berth, weekends and holidays, and strikes.

Ballast speed.

Assuming that the propulsive power is kept constant it follows

$$\Delta b^{2/3} \times Vb^3 = \Delta^{2/3} \times V^3 \qquad \text{[eq.5.1]}$$

where Δ is the ship displacement in tonnes and V the speed in knots with the prefix b referring to ballast condition.

Therefore,ballast speed is given by

$$Vb = V \times \left(\frac{\Delta}{\Delta b}\right)^{2/9} = V \times \left(\frac{T}{Tb}\right)^{2/9} \quad \text{(knots)} \qquad \text{[eq.5.2]}$$

where T and Tb are respectively the loaded design and ballast draft.

From Lloyds Register of Shipping (51) an average value of Tb for bulk carriers is given by

$$Tb = 0.03 \times L \qquad \text{[eq.5.3]}$$

where L is the length between perpendiculars.

For a bulk carrier of Panamax size [eq.5.2] gives an average value for ballast speed 15% greater than the loaded design speed.

<u>Time at sea.</u>

The time spent at sea for a round trip is calculated in the program from

RSTIME = STIME + BSTIME (days/round trip) [eq.5.4]

where STIME and BSTIME are respectively the loaded and ballast sea voyage time given by

$$STIME = \frac{DISTCE}{V \times 24.} \quad \text{(days)} \quad \text{[eq.5.5]}$$

$$BSTIME = \frac{DISTCE}{Vb \times 24.} \quad \text{(days)} \quad \text{[eq.5.6]}$$

where DISTCE is the distance between ports in nautical miles.

<u>Time in port.</u>

The time spent in ports is function of the rate of loading and/or unloading the cargo (or port capacity), the working hours of the port personnel and delays.

Such an approach has been adopted in the program.

The time spent in ports is estimated from

$$PORT1 = \frac{CDWT}{(LOADCP \times SHIFT1)} + DELAY1 \quad \text{(days)} \quad \text{[eq.5.7]}$$

$$PORT2 = \frac{CDWT}{(UNLDCP \times SHIFT2)} + DELAY2 \quad \text{(days)} \quad \text{[eq.5.8]}$$

where CDWT is the cargo deadweight in tonnes (see next section);

LOADCP and UNLDCP are respectively the port loading and unloading capacity in tonnes/hour; and

SHIFT are the working hours of the personnel of the port concerned in hours/day.

The values of LOADCP, SHIFT1, UNLDCP and SHIFT2 are input items to the program and obtained from (52) for the ports considered.

In the parametric study the delay, used also as input value, is assumed to be zero.

Round voyage time.

From [eq.5.4], [eq.5.7] and [eq.5.8] the time spent for a round trip is given by

RTRIP = RSTIME + PORT1 + PORT2 (days/round trip) [eq.5.9]

Based on statistics, the ship is assumed to be 15 days off hire per year for dry docking, repair and maintenance.

Therefore, the number of round trips per annum is

$$RTRIPA = \frac{350.}{RTRIP} \qquad [eq.5.10]$$

The above calculations are carried out in the subprogram subroutine VOYTIM. The same procedure can be followed for a number of ports served more than two. In such a case the time spent in ports and at sea can be broken down into time spent transiting from the first port of departure to the next one and so on. This method is adopted to measure the gain from reducing the ballast voyage in the sensitivity analysis where the number of ports served is four (see section 8.3.4).

5.3 CARGO DEADWEIGHT ESTIMATES.

As pointed out the cargo deadweight is the deadweight without the following items

a) weight of crew and effects;

b) weight of stores and provisions;

c) weight of fresh water; and

d) weight of fuel oil (heavy, diesel and luboil).

Sometimes the weight of water ballast is included in the deadweight items but is excluded in this thesis.

The ship as assumed to bunker and take provisions and fresh water at the last foreign port of call, after bunkering , provided with provisions and fresh water, at the first home port. In other words, the distance between consecutive ports represents the ship endurance. Hence, more space will be available for cargo to be carried.

Below are the deadweight items estimated separately.

Weight of crew and effects.

The weight of crew and their effects is given by (6) as

$$WTCREW = \frac{NC}{6.} \qquad \text{(tonnes)} \qquad [eq.5.11]$$

where NC is the total crew number including officers, petty officers and ratings used as input value in the program.

Weight of fresh water.

The weight of fresh water per person per day at sea is estimated in (6) to be 0.167 tonnes. Therefore, the total weight of fresh water for all crew members for one leg of voyage is given by

WFRESH = 0.167 x NC x STIME (tonnes) [eq.5.12]

Weight of stores and provisions.

The weight of stores and provisions is estimated in (6) to be 0.01 tonnes per person per day at sea. Therefore, the total weight of this item for one leg voyage is given by

WSTORE = 0.01 x NC x STIME (tonnes) [eq.5.13]

and the miscellaneous weight is the sum of the above calculated weights, i.e.

WTMISC = WTCREW + WFRESH + WSTORE (tonnes)

Weight of fuel.

The fuel consumed in port has been excluded from the deadweight as it forms only a minor percentage compared with that consumed at sea for a long sea distance as it is the case in this thesis.

The weight of fuel consumed at sea (one leg voyage) is divided into

1. weight of heavy fuel oil (assumed in this thesis to have a viscosity of 380 cSt);
2. weight of marine diesel oil;
3. weight of system luboil; and
4. weight of cylinder luboil.

Weight of main engine heavy fuel oil (hfo) is given by

$$WHVF = sfc \times SHP \times 0.9 \times 24 \times (1 + RESERV) \times STIME \times 10^{-6} \quad \text{(tonnes)} \quad \text{[eq.5.14]}$$

Weight of auxiliary engine marine diesel oil (mdo) is given by

$$WDIESL = sfc2 \times AUXKW \times 1.341 \times 24. \times \frac{0.5}{0.95} \times STIME \times 10^{-6} \quad \text{(tonnes)} \quad \text{[eq.5.15]}$$

Weight of main engine system luboil is given by

$$WSYSLO = 0.2 \times SHP \times 0.9 \times 24 \times STIME \times 10^{-6} \quad \text{(tonnes)} \quad \text{[eq.5.16]}$$

Weight of main engine cylinder luboil is given by

$$WCYLO = 0.5 \times SHP \times 0.9 \times 24 \times STIME \times 10^{-6} \quad \text{(tonnes)} \quad \text{[eq.5.17]}$$

The following assumptions have been made for calculating the fuel weight.

The main engine, a direct drive slow speed diesel engine, runs at 90% of the maximum continuous rating.

The main engine specific fuel consumption sfc is of 123g/bhp.h which is nowadays achievable with this type of machinery.

A 10 per cent of heavy fuel oil weight is taken as a reserve at sea.

Three diesel generators of 500 KW each form the auxiliary engine, giving a total power of 1500 KW (AUXKW), are used for starting the main engine and for generating electricity and running the ventilation plant.

The auxiliary engine, with a specific fuel consumption sfc2 of 142g/bhp.h, operates at 50% of the maximum continuous rating at sea and the efficiency is 95% (36).

0.2 and 0.5 (g/bhp.h) are respectively the system and cylinder luboil consumption.

Hence, the total fuel consumed at sea is

$$TSFUEL = WHVF + WDIESL + WSYSLO + WCYLO \quad \text{(tonnes)} \quad \text{[eq.5.18]}$$

Therefore, the cargo deadweight is given by

$$CDWT = DWT - (WTCREW + WFRESH + WSTORE + TSFUEL) \quad \text{(tonnes)} \quad \text{[eq.5.19]}$$

where DWT is given by

$$DWT = DISPL - WLT \quad \text{(tonnes)} \quad \text{[eq.5.20]}$$

with DISPL and WLT being respectively the ship displacement and the lightship weight.

5.4 CAPACITY ESTIMATE.

An accurate calculation for bulk carriers capacity stipulates that the hull form be completely defined and general arrangement plans of holds, double bottom, wing tanks etc. are available. At the preliminary design stage, where such information is not available , a good estimate of capacity is all that is required.

The total under deck volume capacity of a bulk carrier is composed of holds volume, engine room volume, aft and fore peaks volume, double bottom volume, and side hopper and topside tanks volume.

As mentioned before, two capacities or stowage rate factors are calculated, one referring to the holds volume alone and the other to the holds and topside tanks volume together. This is done to limit the stowage factor between a minimum and maximum value.

The above volumes are generally given as function of the cubic number length x beam x depth (of the volume item concerned) x block coefficient multiplied by an appropriate volume coefficient.

Different volume coefficients have been proposed by different authors such as those given by Lamb (3), Gilfillan (37), Sen (34), Mandel & Leopold (35) and Cameron (5).

The following estimates of total under deck, peaks, double bottom and machinery space volumes are based on the method developed by Sen (34). The ship is assumed to have a standard camber and no sheer as most of modern bulk carriers do not have sheer. The dimensions are in feet.

1. Total under deck volume.

The total under deck volume is given by

$$VTOT = Cb \times K_1 \times L \times B \times \left(D + \frac{camber \times 2/3}{6.} \right) \quad (ft^3) \qquad [eq.5.21]$$

where $camber = \frac{B}{50.}$ (ft), and

K_1 is the under deck volume coefficient given by

$K_1 = 0.333 \times Cb + 0.864$

2. Aft and fore peaks volume.

The combined length of aft and fore peaks is assumed to be 10% of the length between perpendiculars i.e. lp = 0.1 x L.

The volume of both peaks is given by

$VPEAKS = Cb \times K_2 \times lp \times B \times D$ (ft^3) [eq.5.22]

where $K_2 = 0.37$ is the peaks volume coefficient.

3. Double bottom volume.

The height of the double bottom given by Lloyds Register of Shipping (51) and increased by 20% above requirement is

$HDB1 = 1.2 \times \left(28 \times B(m) + 205 \times \sqrt{T(m)}\right)$ (mm)

and $HDB = HDB1 \times 3.2808 \times 10^{-3}$ (ft) [eq.5.23]

The double bottom volume is given by

$VDB = Cb \times K_3 \times (L - lp) \times B \times HDB$ (ft^3) [eq.5.24]

where K_3 is the double bottom volume coefficient given by

$K_3 = 1.2 \times Cb - 0.06$

4. Engine room volume.

The engine room is assumed aft. The length of the engine room is usually a function of the engine horsepower SHP.

Sen gives the following relationship

$ler = 0.0032 \times SHP + 48$ (ft) [eq.5.25]

and the engine room volume follows as

$VER = Cb \times K_4 \times ler \times B \times (D - HDB)$ (ft^3) [eq.5.26]

where $K_4 = 0.85$ is the engine room volume coefficient.

5. Wing tanks volume.

The following assumptions have been made for estimating the side hopper and topside tanks volume (see fig.5.1).

The topside tanks angle α is 30^o and the side hopper tanks angle β is 40^o.

The hatch width is taken as half the beam and the tank top width is taken equal to the hatch width plus an overlap of 8 ft. on either side.

The hatch side girder depth and the shelf plate width are respectively 2.5

and 3 feet.

a. Side hopper tanks volume.

The cross section area of side hopper tanks is given by

$$SHT = \frac{1.}{2.} \times \left(\frac{B}{2.} - TTW\right)^2 \times Tan\,\beta \times 2. \qquad (ft^2) \qquad [eq.5.27]$$

The factor 2 reflects the two side hopper tanks on either side of the ship. Therefore, the volume of side hopper tanks follows as

$$VHT = SHT \times (L - lp - ler) \qquad (ft^3) \qquad [eq.5.28]$$

where (L - lp - ler) being the ship holds length.

b. Topside tanks volume.

The cross section area of topside tanks is given by

$$STT = \Big[HSG \times \left(\frac{B}{2} - HW\right) + \frac{1}{2} \times \left(\frac{B}{2} - HW - HSW\right)^2 \times Tan\,\alpha + HSW \times \left(\frac{B}{2} - HW - HSW\right) \times Tan\,\alpha - \frac{1}{2} \times camber \times \left(\frac{B}{2} - HW\right) \Big] \times 2 \qquad (ft^2)$$

[eq.5.29]

As for the side hopper tanks the factor 2 reflects the two topside tanks on either side of the ship.

Therefore, the volume of topside tanks follows as

$$VTT = STT \times (L - lp - ler) \qquad (ft^3) \qquad [eq.5.30]$$

6. Ship capacity.

Therefore, the minimum grain capacity is given by

$$VGRMIN = (VTOT - 0.95 \times (VPEAKS + VDB + VER + VHT + VTT)) \times 0.9 \qquad (ft^3) \qquad [eq.5.31]$$

and the minimum stowage rate factor follows as

$$STOMIN = \frac{VGRMIN}{CDWT} \qquad (ft^3 / tonne) \qquad [eq.5.32]$$

The maximum grain capacity is given by

$$VGRMAX = (VTOT - 0.95 \times (VPEAKS + VDB + VER + VHT)) \times 0.9 \ (ft^3)$$

[eq.5.33]

with the maximum stowage rate factor following as

$$STOMAX = \frac{VGRMAX}{CDWT} \qquad (ft^3 / tonne) \qquad [eq.5.34]$$

The factors 0.95 and 0.9 are found to match the program values to natural values.

Typical stowage factors for a bulk carrier carrying grain are 45 cu ft/tonne (excluding upper wing tanks) and 55 cu ft/tonne (including upper wing tanks).

Any design which has an inadequate stowage rate factor for the bulk commodity to carry is rejected.

The above calculations for estimating the ship capacity are carried out by subprogram subroutine CAPCIT.

In order to check the validity of computer program results, these are compared with existing ship capacities with the error given in table 5.1.

5.5 STABILITY.

The required stability of a ship is a compromise between the two extreme situations of excessive and inadequate stability. Indeed, inadequate stability will restrict the ship operations and excessive stability will cause the ship to be stiff and, thus uncomfortable to the crew which may cause damage to the cargo due to excessive motions at sea.

Bulk carriers are unlikely to have insufficient stability in the load condition. However, in ore and ballast conditions they suffer from excessive stability due to very high value of metacentric height (GM) causing excessive rolling.

In ballast condition GM can be reasonably reduced by raising the ship centre of gravity (KG). This is usually achieved by having a large topside tank angle so that more ballast capacity will be provided at the top.

When carrying ore, the ship tends to be very stiff and to have a short period of roll since the low stowage rate of ore results in the cargo's being concentrated low down in the ship, thus lowering the centre of gravity (KG) and increasing the metacentric height (GM). This situation is usually

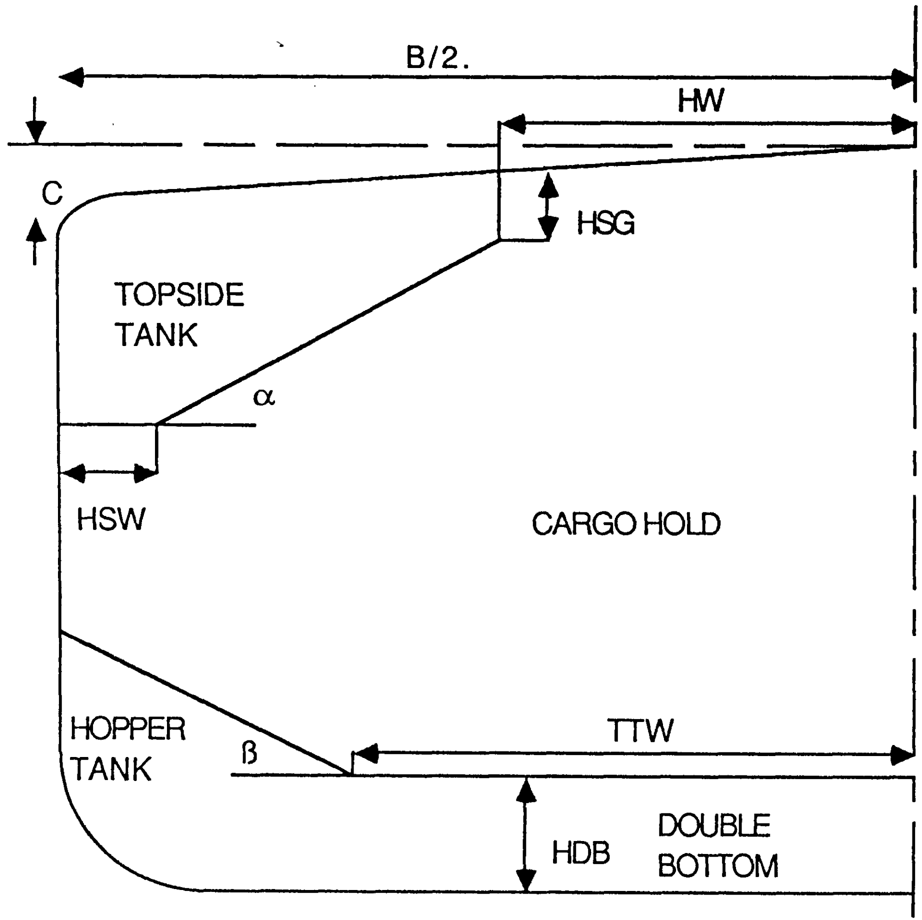


Fig.5.1 MIDSHIP HOLD SECTION.

Assumptions :

$\alpha = 30^{\circ}$
$\beta = 40^{\circ}$
HW = B/4. (ft)
HSG = 2.5 (ft)
HSW = 3.0 (ft)
TTW = HW + 8. (ft)
C = B/50. (ft)

HW = Half Hatch Width
HSG = Hatch Side Girder
HSW = Shelf Plate Width
TTW = Half Tank Top Width
HDB = Double Bottom Height

TABLE 5.1 COMPARISON OF ACTUAL AND CALCULATED SHIPS' GRAIN CAPACITIES.

Ship's Name	DWT (metric)	Actual Capacity 1	Capacity 1 (program)	Error (%)	Actual Capacity 2	Capacity 2 (program)	Error (%)
Ingeren	20,721.	872,569.	902,321.	3.41	974,459.	982,339.	0.81
Sophia	28,860.	1,220,368.	1,262,415.	3.44	1,354,258.	1,356,489.	0.16
British Monarch	28,890.	1,286,244.	1,283,597.	-0.21			
Ektor	30,175.	1,305,253	1,385,412.	6.14			
Cumbria	32,011.	1,347,061.	1,387,827.	3.03	1,477,497.	1,501,694.	1.64
Jersey Bridge	33,630.				1,745,000.	1,699,781.	-2.59
Norland	42,367.	1,904,555.	1,902,839.	-0.09	2,118,236.	2,074,076.	-2.08
Stonepool	45,747.	1,905,610.	2,081,357.	9.22	2,188,330.	2,242,091.	2.46
Ragna Gorthon	69,888.	3,026,357.	3,233,902.	6.86	3,388,063.	3,476,746.	2.62
Zaragoza	81,276.	3,300,671.	3,752,489.	13.69			

Capacity 1 = Hold Grain Capacity (cu. ft.)
Capacity 2 = Hold & Upper Wing Tank Grain Capacity (cu. ft.).

remedied by carrying ore only in alternate holds of shorter length than the empty ones so that the centre of gravity is raised and metacentric height reduced.

Generally, at the preliminary design stage, the stability check can be limited to the calculation of GM through determination of of heights above base of the metacentre and centre of gravity. A simpler procedure carried out by subprogram subroutine STABLE is described below.

1. Centre of gravity of steel weight.

For a bulk carrier the centre of gravity of steel weight is given by Kupras from (6) as

$KG_S = 0.01 \times D \times (46.6 + 0.135 \times (0.81 - Cb) \times (L/D)^2 +$

$(L/B - 6.5) \times 0.008 \times D$ (m) [eq.5.35]

2. Centre of gravity of outfit weight.

The centre of gravity of outfit weight for a bulk carrier given by Kupras is of the form

for $L \leq 125.0$ m

$KG_O = D + 1.25$ (m) [eq.5.36]

for $125.0 < L \leq 250.0$ m

$KG_0 = D + 1.25 + 0.01 \times (L - 125.)$ (m) [eq.5.37]

for $L > 250.0$ m

$KG_O = D + 2.5$ (m) [eq.5.38]

3. Centre of gravity of machinery weight.

For a diesel engine Kupras gives the centre of gravity of machinery weight as

$KG_M = 0.17 \times T + 0.36 \times D$ (m) [eq.5.39]

4. Centre of gravity of lightship weight.

From the above relationships the centre of gravity of lightship weight is

$$KG_{LWT} = \frac{W_S \times KG_S + W_O \times KG_O + W_M \times KG_M}{W_S + W_O + W_M} \quad \text{(m)} \quad \text{[eq.5.40]}$$

where W_S, W_O and W_M are steel, outfit and machinery weight respectively.

5. Centre of gravity of miscellaneous weight.

The miscellaneous weight is in this thesis the total sum of crew, stores and provisions, and fresh water weights.

The centre of gravity of this group weight is given in (35) as

$KG_X = K_X \times D$ (m) [eq.5.41]

where $K_X = 1.0$

6. Centre of gravity of fuel oil in double bottom.

The centre of gravity of fuel oil carried in double bottom is given in (35) as

$KG_{FD} = 0.67 \times HDB$ (m) [eq.5.42]

where HDB is the height of double bottom.

7. Centre of gravity of fuel oil in settler tanks.

The settler tanks are provided as auxiliary spaces for carrying fuel oil. A weight of fuel oil of 150 tonnes (35) is assumed to be carried in these tanks.

The centre of gravity of fuel oil in settler tanks is given in (6) as

$KG_{FS} = HDB + 0.60 \times (D - HDB)$ (m) [eq.5.43]

8. Centre of gravity of cargo deadweight.

From (35) the centre of gravity of cargo deadweight is given by

$KG_C = K_C \times D$ (m) [eq.5.44]

where $K_C = 0.63$

9. Loaded ship centre of gravity.

The centre of gravity of the ship in the full load condition is, therefore, given by

$$KG = (KG_{LWT} \times WLT + KG_X \times WTMISC + KG_{FS} \times WFS + KG_{FD} \times (TSFUEL - WFS) + KG_C \times CDWT) / \Delta$$

(m) [eq.5.45]

where WLT is the lightship weight (tonnes) (see section 4.1.5);

WTMISC is the total miscellaneous weight (tonnes);

WFS is the weight of fuel oil carried in settler tanks assumed to be 150 tonnes in this thesis;

TSFUEL is the total fuel oil carried in double bottom and settler tanks (tonnes); and

CDWT the cargo deadweight (tonnes).

10. Transverse metacentric height (GM).

The centre of buoyancy above keel (KB) and metacentric height above centre of buoyancy (BM) are given in (5) as

$$KB = \frac{(1. + 2. \times Cb)}{(1. + 5. \times Cb)} \times T \qquad (m) \qquad [eq.5.46]$$

$$BM_T = \frac{K \times CW \times B^2}{T \times Cb} \qquad (m) \qquad [eq.5.47]$$

where $CW = \frac{2. \times Cb}{3.} + \frac{1.}{3.}$ is the water plane area coefficient and

K a coefficient equal to 0.073.

The height of metacentre above keel is, thus

$$KM_T = KB + BM \qquad (m) \qquad [eq.5.48]$$

Finally, the transverse metacentric height follows as

$$GM_T = KM_T - KG \qquad (m) \qquad [eq.5.49]$$

The minimum value of GM_T given by I.M.O. is 0.15 m and any design which do not satisfy this condition is rejected. Furthermore, and in order not to have excessive rolling period the ratio GM_T/B should be within a reasonable range.

For large cargo ships a range 0.035 - 0.052 is deemed acceptable (3).

The stability subroutine CROSCT (p 228-229) applies the remainder of the IMO criteria for stability.

CHAPTER 6 : SHIP'S OPERATING COSTS.

6.1 INTRODUCTION.

The ship's operating costs are those costs deducted from the shipowner's income to man and run the ship over a specified period.
They are difficult to estimate due to the great heterogeneity of ships and the trade areas in which they are employed. They vary for ship type, flag, size and age of the vessel, trade route, operating pattern, port of call conditions, the commodity carried and the management policy.

An accurate knowledge of operating costs is important to the different parties involved in the shipping business.
From the designer's point of view, it is essential to have a good estimation of all operating costs to select the optimum design of a new vessel. The shipowner needs to have a good basis for cost estimates for the efficient management of his ship, and to be able to account for deviations from those estimates. The shippers or charterers and particularly bulk shippers have a good reason to be interested in operating costs. Indeed, a knowledge of the cost profile of vessels in the world fleet is one factor in forecasting future freight rates.
Port authorities and others providing facilities to be used by ships need to know the benefits derived by shipowners from these facilities. However, their estimates of shipping costs may reasonably be based on average cost figures without a break down among the cost components.

The operating costs are in most cases viewed as falling in two categories. Firstly, the daily running costs or fixed costs which are associated with the decision to operate a ship and which do not vary immediately or significantly with the route served.
They are
-DAILY RUNNING COSTS:

-crew costs;

-maintenance and repair;

-insurance;

-stores and supplies;

-victualling and provision; and

-administration.

Secondly, the voyage costs which are sensitive to the trade route in which the vessel is engaged. They vary with the route structure, the port conditions and the commodity carried.

They are

-VOYAGE COSTS:

-fuel costs;

-port charges;

-cargo handling costs; and

-canal dues.

Table 6.1 indicates the importance of different components of operating costs of two size ranges of bulk carrier ships in 1981.

The type of charter and the division of responsibility for the various items of expenditure between shipowner and charterer is illustrated in fig.6.1.

A brief discussion of each of the above costs with an approach for estimating them in US Dollars for 1987 cost levels are outlined in this chapter.

6.2. DAILY RUNNING COSTS.

The level of daily running costs is controllable. The crew cost element is the most significant cost item in this category. Excluding it and assuming a standard level of operating efficiency, the magnitude of these costs will vary little between like ships of any flag engaged in similar trades.

6.2.1 CREW COSTS.

The crew costs which are the most significant part of the daily running costs in terms of value are the most difficult to rationalise.

The reason is that they vary considerably according to certain factors such as flag of the ship, nationality of the crew and size of the crew.

The different elements of crew costs vary with the flag of operation and are primarily dictated by the conditions of employment agreed between the local or international unions of seafarers (or seamen) and the shipowner or his national association.

In general, most agreements encompass the following points

-basic wage;

-overtime payments;

-supplementary payments-efficient service and certificate pay;

-leave pay and compensation for extra hours and holidays worked;

-medical expenses and sick leave pay;

-training and maintenance allowances and study leave pay;

-personal and national insurance contributions;

-pensions; and

-travelling and repatriation expenses.

All owners are in constant pressure to maintain a certain level of wages. The principal pressure emanates from the annual round of wage demands from well organised national unions each seeking to maintain or improve the relative position of their membership in the domestic inflationary climate.

Table 6.1 shows the importance in proportion of crew costs in 1981. The crew costs represent about 50% of the daily running costs and about 10% of the total operating costs including capital cost for the two size ranges of bulk carriers.

In the developed countries of North America, North Europe, Scandinavia and Japan which represent the highest crew expenses, the incentive is high to reduce these costs.

Owners from these countries usually seek to reduce their crew costs by whatever methods are available ranging from reducing their crew number, changing the crew nationality (employing low cost foreign seamen) to "flagging-out".

CAPITAL CHARGES	DAILY RUNNING COSTS	VOYAGE COSTS	
First Cost Loan Repayments Loan interest Tax Return After Tax	Crew Costs Maintenance & Repair Insurance Stores & Supplies Victualling	Fuel Costs Port Costs Canal Dues	Cargo Handling Cargo Claims

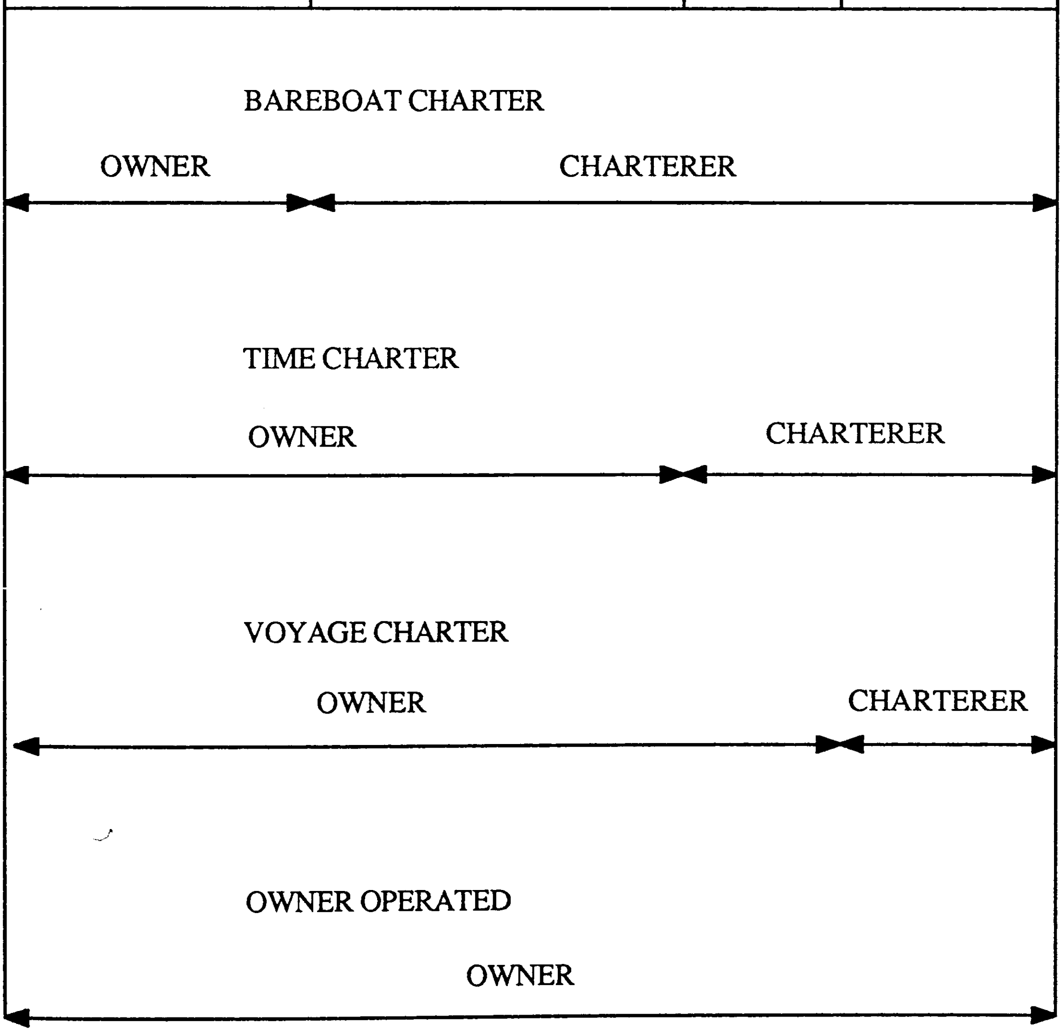


Fig.6.1 DIFFERENT OPERATING PATTERNS (41).

TABLE 6.1 PERCENTAGE OF TOTAL COSTS BY COST COMPONENT (1981).

	25,000 DWT BULK CARRIER		110,000 DWT BULK CARRIER	
CAPITAL COST		40		42
DAILY RUNNING COSTS		23		18
MANNING	12		9	
SUPPLIES & SPARE PARTS	3		2	
MAINTENANCE & REPAIRS	3		3	
INSURANCE	3		2	
ADMINISTRATION	2		2	
VOYAGE COSTS		37		40
FUEL	30		37	
PORT	4		3	
CANAL FEES	3			
TOTAL		100		100

Source : Drewry Shipping Consultants, Ltd.

Indeed, crew reduction has been achieved by automation which is becoming more improved on modern vessels.

National regulatory bodies generally dictate minimum manning scales for domestic flag merchant ships required to ensure the safety of life at sea and safe operation of the vessel. The majority of manning regulations are based on a scale of tonnage, either gross registered tonnage or deadweight for deck personal and engine power for engineers.

It must be kept in mind that any reduction of crew number below a certain limit would face an opposition from the traditional seamen's unions seeking to maintain and increase employment opportunities for nationals.

The free flag operators, however, have certain freedom of choice in the interpretation of manning regulations. Liberian regulations, for example, stipulate a minimum manning scale for officers but would appear to leave the rating structure to the discretion of the shipowner.

Crew nationality.

Absolute freedom of choice in the engagement of seafarers is in general available only to free flag operators.

Shipowners operating tonnage under national flags seldom retain such flexibility.

Here is a brief summary of national restrictions of some European countries in the employment of non-domiciled seafarers.

Norwegian law permits the employment on non-nationals up to a total of one third of the total manning but at the same wages as domiciled crews. There are, however, special provisions which allow certain Norwegian ships trading in the Far East to employ complete crews domiciled in the trading area.

In the United Kingdom, imposed restrictions have limited the traditional flow of ratings from Commonwealth countries and a plan designed to progressively phase out the wage differential between such ratings and domiciled crews came into operation in April 1978.

In the Netherlands, non-Asian ratings who are not domiciled receive the same wages as Dutch seafarers. Chinese and Indonesian seamen, on the other hand, are paid in accordance with their own national agreements, whilst those from the Indian sub-continent are paid in accordance with the ITF (International Transport Federation) wage level understanding of 1973.

Under West Germany flag, wage rates for all seamen are determined by collective bargaining between trade unions and shipowners' associations. In practice, rates may vary between nationalities employed. West German owners, however, retain the ability to trade under the flags of Panama, Liberia, Cyprus and Singapore.

Under French flag, the recruitment of non-domiciled seafarers is generally restricted to those from former French dependencies, usually in accordance with reciprocal agreements with the countries concerned.

Greek shipowners operating national flag tonnage are allowed to man their fleets with a greater number of low cost foreign seamen in order to remain competitive. Greek legislation requires that a minimum of 75 per cent of national flag crews must be Greek nationals and that foreigners be paid the same basic wage as their Greek counterparts.

Although a great increase in wage rates has been noticed these last few years, the Greek flag is considered as low cost compared with those of Scandinavia and Northern Europe.

Table 6.2 shows the basic wage of an able seaman in some representative countries in 1987.

TABLE 6.2 MONTHLY BASIC WAGE OF AN ABLE SEAMAN (MARCH 1987).

COUNTRIES	AB's BASIC WAGE (US $ per Month)
Liberia (a)	821
Liberia (b)	739
Greece	439
U. K.	650
Norway	912
Japan	1,270
USA	1,488

Notes :
(a) : ITF world wide rate
(b) : ITF Far East rate
Source : Lloyd's Shipping Economist.

Ship's registration.

Every ship must be registered somewhere in order to acquire the nationality of the state in which it is registered. It flies the flag of that state and is governed by its laws. Under the 1958 Geneva Convention on the high sea : "Each state shall fix the conditions for the grant of its nationality to ships for the registration of ships in its territory and for the right to fly its flag".

Many factors influence the decision about the country in which the vessel is registered and the nationality of the crew employed. The factors include the financing conditions available for the vessel and the tax regime under which it may operate.

The registry of a ship can affect operating costs when it is associated with certain constraints on operation. High safety standards, for example, are required by certain countries which raise maintenance costs but may reduce insurance costs. Constraints may exist on the nationality and, therefore, on the cost of the crew.

In recent years registration of ships seems to have become an industry in itself. Indeed, there are currently pressures around Europe for the creation of even more "offshore registers". The offshore register is not a new invention. They have been in existence, for example, in Bermuda and the Netherlands Antilles for many years.

They are based on the concept of the maintenance of administration control and the supervision of internationally-accepted standards while providing flexibility from the point of view of taxation, corporate organisation, and the absence of constricting labour agreements.

France,. for example, established the Kerguelen register which is open to non-oil bulk vessels which are enable to use the French flag but employ up to 75 per cent of non-French seamen.

In the United Kingdom, there has been a very extensive transfer of shipping to the Isle of Man. The attractiveness of the Isle of Man has been the proposed introduction of regulations for ship management, low personnel and corporate taxation, the absence of an annual registration fee and, most importantly, its acceptance by the International Transport

Workers' Federation as not being a flag of convenience. A flag of convenience is that of a country whose laws are more flexible in employing lower-cost crew, avoiding corporation tax, and in some cases international regulations.

This trend around Europe towards establishing more offshore registers came primarily as a defensive reaction to the continuous flow of flagging-out by shipowners under the flags of the open-registry countries, those which provide flags of convenience. Indeed, these countries have for many years attracted shipowners, whose national flags are subject to stringent conditions, to trade under their flags, and that by their reduced tax regime, lower annual tonnage fees and the flexibility of their manning agreements in recruiting low cost foreign seamen.

These open registry countries which include Liberia, Panama, Cyprus, Bahamas, Lebanon and Vanuatu, own actually fleets equal to over 30 per cent of world tonnage.

Table 6.3 shows the annual tonnage fees of some of the open-registry states and Malta which is considered as a new more-or-less open-registry.

TABLE 6.3 ANNUAL REGISTRATION TONNAGE FEES (US $)

TONNAGE / COUNTRIES	21,000 DWT	89,000 DWT	VLCC
Cyprus	2,700	6,300	9,900
Bahamas	1,800	4,600	11,800
Liberia	2,500	11,900	30,000
Malta	2,600	10,400	30,600

Source : Seaways, September 1987.

In the present economic climate for international shipping it has to be said immediately that any switch in registration is likely to be motivated by an opportunity to reduce operating costs.

In international trade, the reduction in crew costs from employing low cost crews may be large and the question of how much an owner saves by reflagging, of course, depends on which flag he is using before changing.

In the program, an approach to estimate the total crew costs has been carried out. It consists of multiplying the annual AB's basic wage by the total crew number and by a factor called multiplier.

As the annual AB's basic wages in different countries are generally available, the method is easy and quick in estimating total crew costs to the owner under different flags (as every country has its own multiplier). Multipliers may also be used to give an approximation of crew numbers in a competitive situation.

The costs to the owner covered by this method include the different crew cost items cited above and shore-side personnel administration costs.

A Greek crew has been adopted in the program with a representative multiplier factor of 8.0 which gives a reasonable result. Both the annual Greek AB's basic wage and crew number are input items.

Therefore, the total annual crew costs are

Crew costs = annual AB's basic wage x crew number x 8.0 ($) [eq.6.1]

6.2.2 MAINTENANCE AND REPAIR COSTS.

The maintenance and repair costs are usually those costs related to work carried out by repair yards, maintenance of engines and their equipment. They exclude those maintenance costs that are a part of crew wages or store and supplies.

They vary with ship size, machinery, age and could be expected to vary also between trades as the vessel is affected by the sea conditions under which it operates. Operating, for example, for a long period in the North Atlantic or North Pacific will place different stresses on vessels than would operating in generally calmer areas.

These costs could be reduced by changing crew arrangement and seeking high skills for crew members which may enable more routine maintenance but may increase crew costs.

The cost components of maintenance and repair were subdivided into hull and outfit, and machinery maintenance and repair costs.

The hull and outfit maintenance costs which comprise mainly of drydocking costs are usually expressed as a function of the cubic number (LxBxD) (6),(39).

Machinery maintenance and repair costs are, on the other hand, usually expressed as a function of the the total engine horsepower (6),(39). They represent a substantial part of the total maintenance and repair costs, particularly for diesel machinery plant.

These costs were updated from (6), they are

$$\text{M \& R costs} = 1096. \times \left(\frac{L \times B \times D}{100.} \right)^{0.67} + 7.97 \times SHP \qquad (\$) \qquad \text{[eq.6.2]}$$

6.2.3 MARINE INSURANCE.

6.2.3.1 BRIEF HISTORY.

Before the first century, vessels would not venture far from any coast line nor would they sail in anything but the most pleasant of weather. Hence, it was deemed not essential to protect the so-called adventure, although there were some form of covers being available to merchants.

It was not until the 13th century that merchants were persuaded to protect their property by a form of insurance.

The first enactment relating to marine insurance insurance became law in 1601 under the title 'An Act Touching Policies of Assurance Used Among Merchants'.

Since that time developments took place until it was decided in 1779 that a common form of policy should be introduced.

The first Marine Insurance Act was passed in 1745 and this was not repealed until the Marine Insurance Act of 1906. This act was passed following certain previous decisions, and to this day the Act remains on the Statute Book and all marine insurance policies are subject to its provisions.

Nowadays, ships are becoming much more sophisticated and designed for their specialised trade with the consequent revision of particular policies to cater for their various demands.

6.2.3.2 MARINE INSURANCE.

The modern marine insurance protects shipowners from different types of liabilities.

When fixing the cost for insurance, several factors are taken into consideration, such as

1.type of vessel, its size, age, propelling machinery, flag and classification society;

2.valuation of the vessel;

3.area of operation;

4.conditions of insurance; and

5.management and past claims experience.

There are actually three forms of insurance, hull and machinery (H+M) insurance, protection and indemnity (P&I) insurance and war risk insurance. Each form covers shipowners and operators from a specific type of liabilities.

They are considered briefly below.

6.2.3.2.1 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 records. The (H+M) insurance cost is usually taken as a fraction of the ship's first cost (6),(31),(39). A fraction of 0.4 per cent was adopted in the program.

Therefore, the cost of (H+M) insurance is given by:

$$(H + M)\ \text{cost} = \frac{0.4}{100.} \times \text{capital cost} \qquad (\$) \qquad [\text{eq.6.3}]$$

6.2.3.2.2 PROTECTION AND INDEMNITY INSURANCE.

The principal function of protection and indemnity insurance which is formed by shipowners themselves and, thus which is a non-profit making body, is to cover third party risks. For example, it protects the shipowner against law suits brought against him by his own crew members. The (P&I) insurance also covers liability for loss of or damage to cargo which arises in connection with the operation of the ship.

(P&I) rates are usually based on gross registered tonnage (6),(39).The cost of protection and indemnity insurance was updated from (6), and is given by

(P&I) cost = 3.0 x GRT (\$) [eq.6.4]

6.2.3.2.3 WAR RISK INSURANCE.

The war risk insurance covers a shipowner against damage in case of hostilities. This cost was ignored in this thesis because of its negligible proportion in comparison with (H+M) and (P&I) insurance costs.

6.2.4 STORES AND SUPPLIES COSTS.

This category includes such items as paint, cleaning materials and the cabins stores. It also includes engine and deck stores such as mooring lines.

Stores and supplies costs are usually taken as a function of the crew number (6),(38),(39).They are updated from (6) and given by

Stores and supplies costs = 4061. x crew number (\$) [eq.6.5]

6.2.5 VICTUALLING AND PROVISIONS COSTS.

This category covers costs of provisions such as food and drink. These costs are usually expressed as a function of the crew number.

They are updated from (6) and given by

vict. and provis.costs = 1950. x crew number (\$) [eq.6.6]

6.3 VOYAGE COSTS.

Voyage costs are largely composed of fuel expenses which vary for a particular vessel with the number of days spent in port and at sea, with the sailing speed and conditions, and with the location at which fuel is purchased. The importance of fuel costs as a major component in the operating costs is considered in this section with a discussion of some alternative solutions to optimize them. The estimation of fuel and other voyage item costs are also outlined.

6.3.1 FUEL COSTS.

In 1973, prior to the Arab-Israeli war of 1973/74, the price of Residual Fuel Oil was about US $22 per tonne. In less than a year, it had risen to about $72 per tonne and after a slow rise to $79 per tonne in 1979, there was a sharp rise to about $170 per tonne in 1980. After being relatively constant over the first half of the 1980s, it started to decline at the end of 1985 until August 1986 where it attained its lowest value at about $60 per tonne, and then started to recover again.

Marine Diesel Oil, from a higher price of about $40 in 1973, has risen to about $340 per tonne in 1980. Like the residual fuel oil, its price started to decline during the end of 1985 and attained the lowest value at about $136 per tonne in August 1986 where it began to recover.

Even when taking into account the inflation in those years, the increase of fuel prices was considerable.

The significance of this to the shipowner is that whilst all his costs may have increased since 1973, the fuel bill has increased disproportionately and became the major cost component in his operating costs.

To illustrate this point, the relative importance of voyage costs (mainly composed of fuel costs) for the two size ranges of bulk carriers, already considered above, in 1973 and 1981 is shown in fig.6.2 and fig.6.3.

In 1973, voyage costs represented just 15% of the operating and capital costs for a handy-sized bulk carrier of 25 000 dwt. In just 8 years, the relative proportion of voyage costs jumped by a factor of 2.47 to 37% of the total costs.

For the large bulk carrier of 110 000 dwt, the increase in proportion of voyage costs is more significant being increased by a factor of 2.85 from just 14% to 40%.

Although, there was a reduction of oil prices in the late 1985 and early 1986, the relative importance of fuel costs has remained unchanged.

As a consequence of fuel costs being in proportion as important as capital cost, attention has been focussed on the necessity of designing ships for fuel economy during the design process, and seeking solutions of reducing fuel costs during the operational life of the ship.

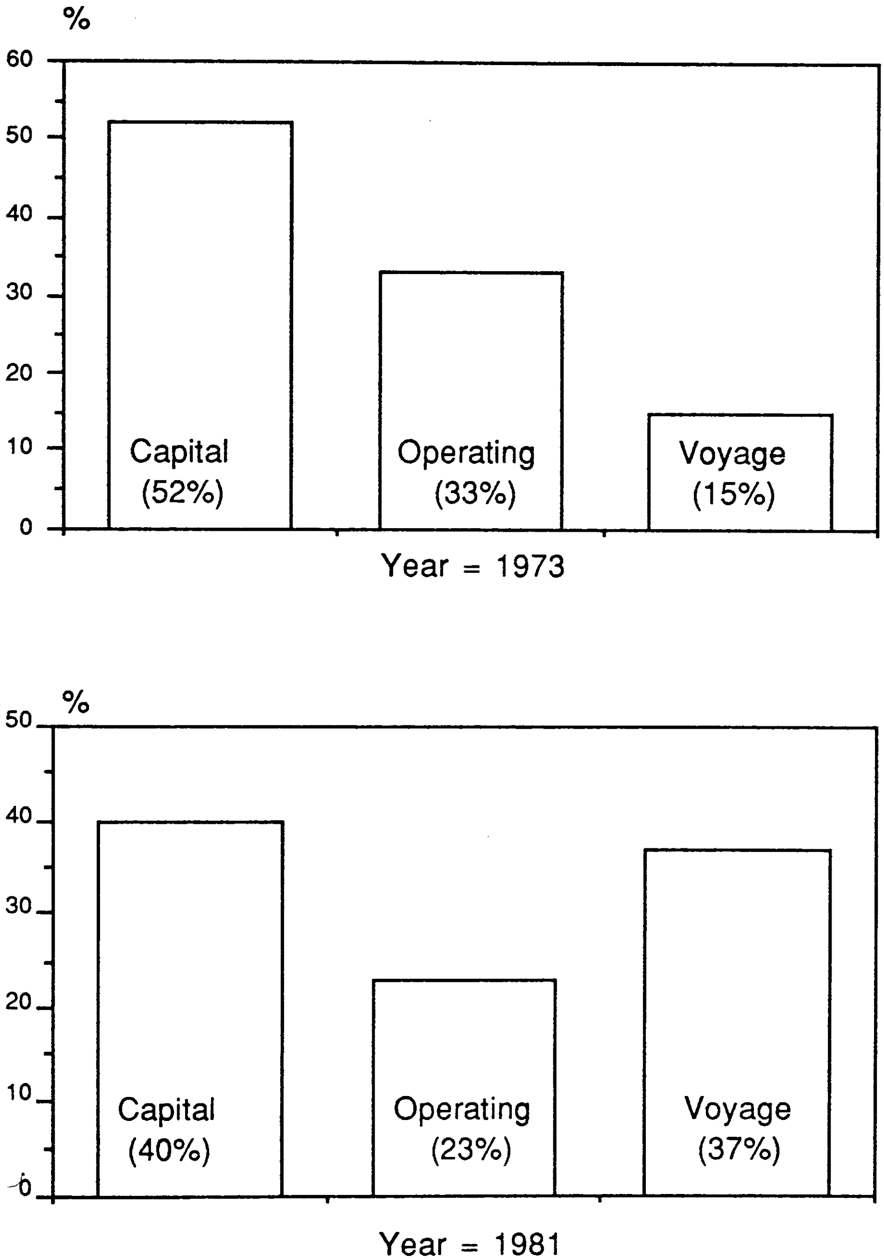


Fig.6.2 PERCENTAGE OF TOTAL MAJOR COST COMPONENTS
(25,000 DWT BULK CARRIER)

Source : Drewry Shipping Consultants Ltd.

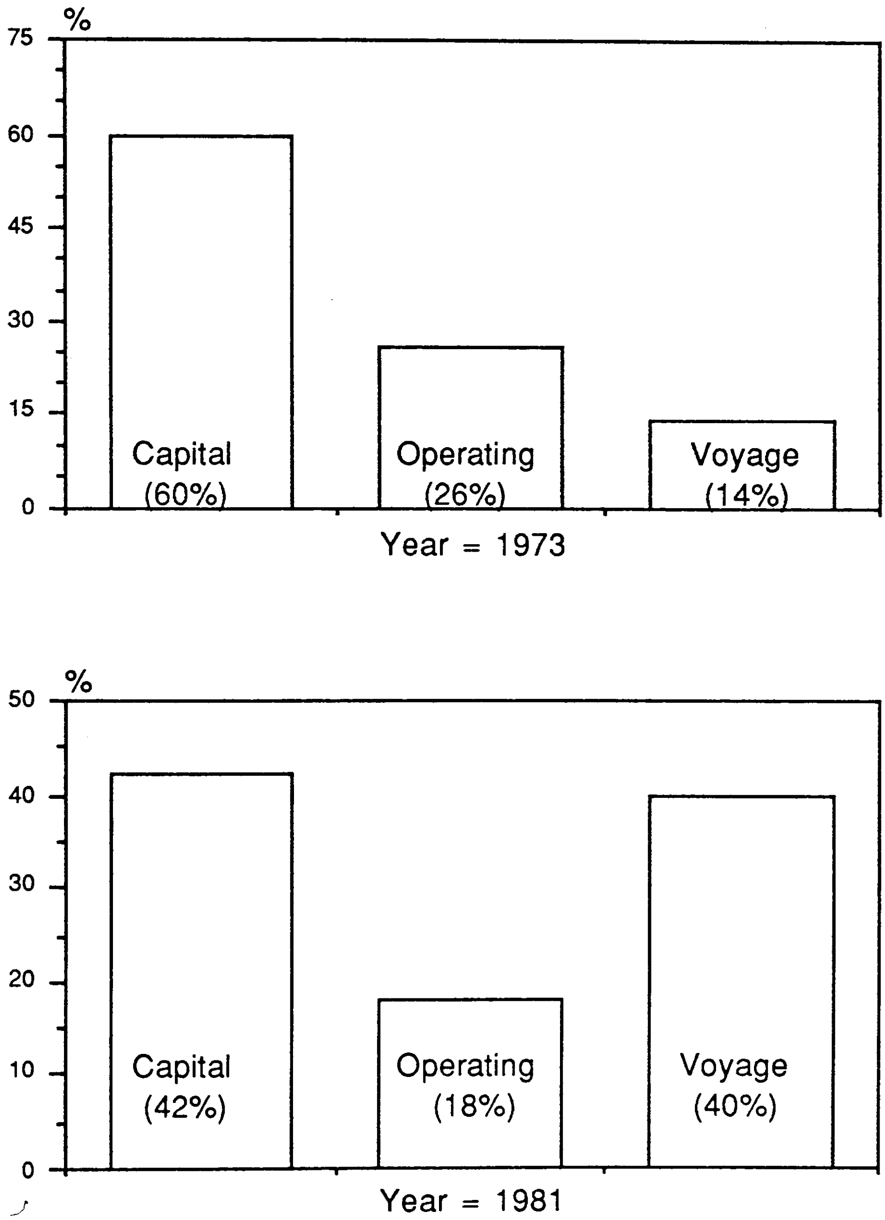


Fig.6.3 PERCENTAGE OF TOTAL MAJOR COST COMPONENTS
(110,000 DWT BULK CARRIER)
Source : Drewry Shipping Consultants Ltd.

6.3.1.1 FUEL ECONOMY

The search for fuel economy did not start in 1973. Long before then the fuel economy was recognised as an important design factor. Most ships were fitted with what was generally regarded as the most fuel-efficient form of propulsion, a single screw propeller powered by a diesel engine burning heavy marine fuel oil.

Commercial shipping is an international and highly competitive industry. Shipowners operate in a market which is so free that, in general, they have to accept freight rates determined by the market place and can only pursue their profit-maximising aims by controlling their costs.

That became more apparent after the rapid increase of fuel costs over the 1970s which has given to shipowners an incentive to reduce them by any practical means ranging from the use of heavy fuel oil to the energy recovery by regenerating waste heat.

There is a number of methods in which fuel economy can be achieved, with some of them still being in the field of research. The following are some of them discussed briefly.

1.Ship's speed.

Fuel economy starts with the choice of a judicious economic design speed. Indeed, reduction in speed brings an immediate and proportionately large reduction in shaft power and, therefore, in fuel consumption. In a slow speed ship in which skin friction predominates in the ship resistance, a 10% reduction in speed will bring a 21% reduction in power and fuel costs for propulsion. In a high speed ship in which wave making becomes a significant part of the resistance, this reduction could increase to 30% or more (8).

Today, contracts for modern ships specify that the ship must be designed for an accurately determined speed. Compared with former ship designs, modern ships have lower propulsive power because the design speed has been reduced and/or the propulsion efficiencies have been improved.

Apart from reducing the speed of the ship, the only saving in cost that can directly be made is the reduction of either the fuel quality or the specific fuel consumption of the engines (main and auxiliary).

Essentially, engine (or fuel) economy means the ability to use low-grade fuels and low fuel consumption whilst maintaining reliability.

2.Heavy fuel oil.

Indeed, heavy fuel oil (h.f.o) offers the possibility of significantly improved costs in most situations. Diesel engines which were used to run in the past with relatively light fuel oil (at a higher cost) are today capable of burning and manoeuvring on h.f.o of 380 cSt which is now guaranteed by the majority of engine builders, with some of them claiming to go above this viscosity.

It must be kept in mind that increasing the viscosity of the fuel causes the attendant problems of increased maintenance costs.

The trend of events in the petroleum industry has also contributed to a serious deterioration in marine fuels and consequently optimization of total operating costs is important. Deterioration in fuel quality is not necessarily associated with an increase in viscosity but depends more on the type of refining process used, the quality of the crude oil and the mixing of oils.

Saving in cost can also be made on the auxiliary machinery. Again, the first consideration is to reduce the fuel quality. At present most machines run on gas oil or marine diesel oil (m.d.o) and relatively few on heavy fuel oil. The drawback of using intermediate fuel oil (i.f.o) in auxiliary engines is the increase of maintenance which is strongly dependent on the make and type of engine, its operational requirements, average load and variations, and fuel quality.

In addition, the capital cost of the diesel generators is considerably increased by using h.f.o instead of m.d.o. At present m.d.o must be used in most cases for diesel generators..

3.Specific fuel consumption.

The other important aspect in the search for fuel economy is the specific fuel consumption (s.f.c). The s.f.c has successfully been achieved through several stages (fig.6.4). Some recently delivered bulk carriers powered by a direct drive slow speed diesel engine have a typical lower value of 123 g/bhp.h s.f.c and even lower.

The specific fuel consumption has a great effect in the variability in fuel costs and earning of shipowners. A regression analysis of bulk carriers in 1980 suggested that a one tonne per day saving in fuel commanded an extra $93 per day in time charter hire (29). That suggests that owners of more fuel efficient ships may expect some recompense.

It should be said that it is often the charterer who pays for the fuel, particularly on time charter. Such ships will be declared by the owner with a certain speed and fuel consumption.

The s.f.c can also be used as a criterion in the selection of the most efficient engine. When, for example, comparisons are limited to ships of the same speed and same deadweight capacity powered by engines burning the same type of fuel, the easiest criterion of fuel economy to use is the fuel consumption.

It must be kept in mind, that the shipowner is not only concerned with the fuel consumption of the main engine but also in what the ship as a whole system consumes, as only the final fuel bill he has to pay counts.

Another correction, often overlooked, is for the lower calorific value of the fuel. Ordinary fuels in practice may have on average only 9600 kcal/kg, whereas the fuel for which s.f.c values are given by engine manufacturers is assumed to have 10200 kcal/kg. Thus, the fuel has in practice around 6 per cent less calorific value. Consequently, the real consumption will increase by this percentage for a given power output.

However, no chief engineer of a ship will run his engines continuously at 100 per cent power. It is common practice to run the propulsion plant at, say 90 or 85 per cent to protect the engines. The fuel consumption will, therefore, decrease.

Minimizing fuel costs therefore requires minimizing daily fuel consumption at any particular speed.

There are many ways in which the fuel consumption of new ships can be reduced. Among them

-reduced ship speed;

-bigger ships;

-more efficient main and auxiliary engines;

-larger propeller diameters/reduced r.p.m;
-improved hull forms; and
-more effective use of waste heat.

4.Energy recovery.

Fuel economy also means generating energy from waste heat. When considering the conversion of energy into mechanical work, the diesel engine with an efficiency of nearly 50 per cent is considered the most efficient of machines.

By using correctly chosen techniques in the design of the engine and the ancillary equipment the loss of energy can be a recoverable source of income.

In a diesel engine there are four main sources of heat: the exhaust gas, the cooling water, the scavenge air and the lubricating oil, with the exhaust gas containing the largest percentage of heat.

Saving in secondary energy can be attained by generating useful energy from primarily waste heat and by reducing energy consumption.

A modern two stroke engine will lose 20 to 25 per cent of its fuel energy (i.e.40 to 50 per cent of its shaft power) in the exhaust gases (fig.6.4), from which only 35 per cent can be made useful in a steam system and about 7 per cent in electric energy. This means that about 3.5 per cent of engine's output could be regenerated into electric power when it is running at 85 per cent of the maximum rating.

5.Propeller efficiency.

The propeller efficiency is fixed by hydrodynamic design, its speed and diameter, and the afterbody of the vessel (wake pattern).

It is essential in the case of direct coupled two stroke engines that the engine speed is matched to the optimal propeller design speed. That means the engine builder must work closely with the ship designer in the search for fuel economy. Propeller efficiency has been achieved by designing diesel engines more powerful (per cylinder) and by reducing the propeller rotary speed. Fig.6.4 shows this development for two-stroke slow speed diesel engines which power most of the recently delivered bulk carriers.

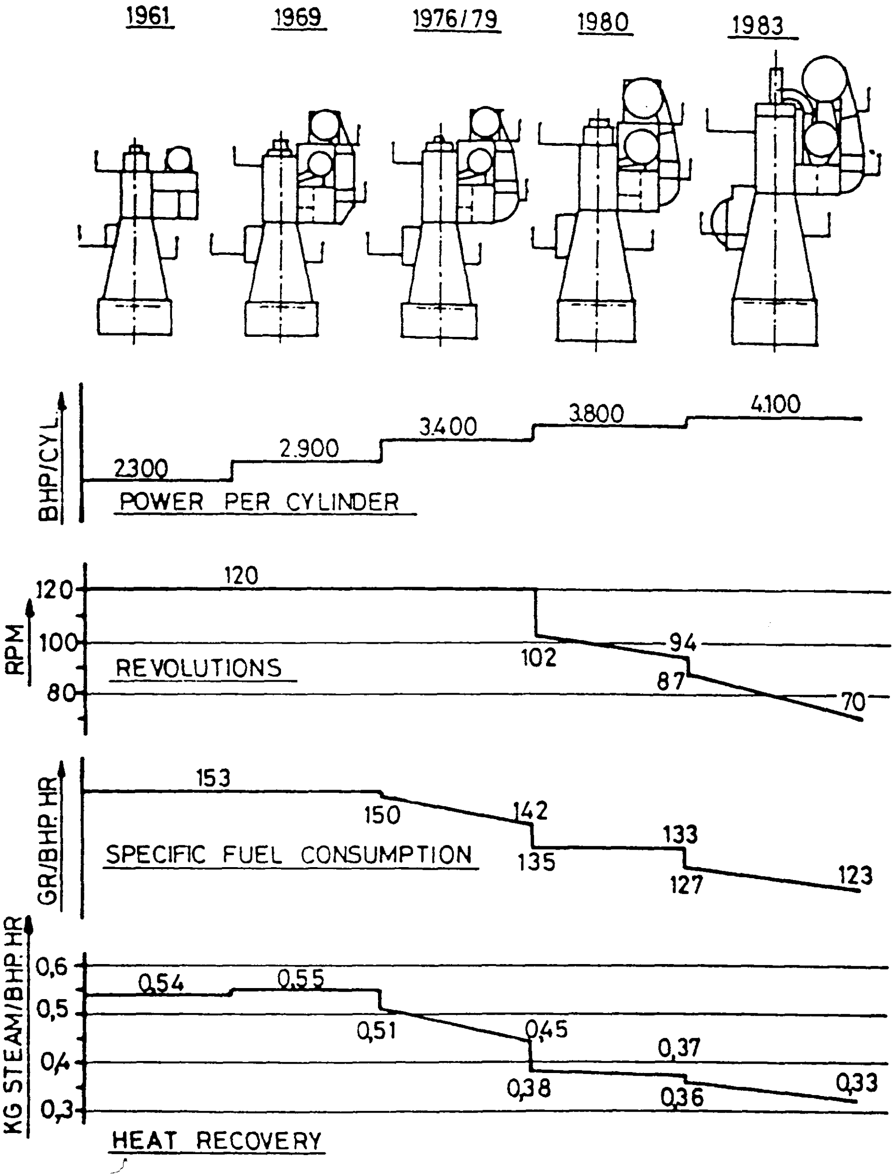


Fig.6.4 DEVELOPMENT OF TWO-STROKE DIESEL ENGINES.

Source : The Motor Ship (May 1985).

<u>6.Hull and treatment.</u>

The final aspect in the search for fuel economy concerns the hull and its condition.

Fuel economy can be achieved by minimizing the resistance by good design of the lines, the construction of the ship with well faired and finished steelwork coated with a high quality paint system.

Apart from the required speed, the fuel consumption of a proposed vessel is mainly determined by the hull shape and its roughness. Indeed, it has been known for many years that the fuel consumption can be reduced by the elimination of roughness in all its forms. The surface treatment and paint system add considerably to total hull resistance and in deterioration in service. Self polishing paints applied on existing vessels have proven to reduce the propulsion power by 6 to 8 per cent. Some recent investigations (40) in this subject have clearly demonstrated that there are substantial long term overall savings in fuel costs to be made by spending a larger amount on achieving smoother ship's bottoms.

The operating economics of the engine room are a decisive factor in the total economics of operating a ship. Good engine performance derived from compact design, low fuel consumption, ability to use heavy fuels together with a high level of reliability and ability to convert waste heat into a source of energy, all affect the economics to a significant degree.

It must be mentioned that higher fuel costs have brought about their own correction mechanisms. Today's ships sail with slower speed, about 10 per cent less than the early 1970s, have more efficient machinery and are operated with a better housekeeping or management.

Finally, it is worth mentioning some recent developments. The current situation regarding ship propulsion has meant that steam and gas turbines have virtually disappeared as prime movers for new merchant ships. Indeed, the turbine is uncompetitive with diesels, though it can burn the poorest fuel, because of its huge specific fuel consumption.

Of the types in use, two stroke and four stroke diesel engines, two stroke types are supreme in direct drive applications where low revolutions are vital for propeller efficiency. Four stroke types are universal for high speed engines and both types compete in medium speed engines.

It is not intended in this thesis to make an economic comparison between the two types. However, it should be said that the most important reason for this development is that two stroke diesel engine manufacturers can still point to a few grams lower s.f.c and can apply longer experience with burning low grade heavy fuels.

There is, in the case of two stroke slow speed diesel engine, a fierce competition between traditional manufacturers of this type. Fig.6.5 illustrates that for the last ten years and shows the change in leading in 1980s by Man B&W after their fusion in the late 1970s.

6.3.1.2 FUEL COSTS.

The fuel costs were subdivided into heavy fuel oil costs, marine diesel oil costs and lubricating oil costs.

Some cost estimators include lub.oil in engine room stores and not in fuel oil category. Given that most of it will be used when the engine is running and is not associated with the passage of time, it has been decided in this thesis that it should be a part of the latter category.

The costs were estimated from the weights of oil consumed at sea and in ports.

The ship was assumed to bunker at the last foreign port of call, after bunkering at the first home port. That means more space will be available for cargo to be carried. A 10 per cent reserve for h.f.o was also assumed.

Three diesel generators of 500 kw each, giving a total power of 1500 kw were assumed to be used at sea and in ports for generating electricity and running the ventilation ventilation plant.

The main engine considered is a slow speed direct drive diesel engine capable of burning and manoeuvring on 380 cSt fuel and the generators capable of burning m.d.o.

The fuel costs are therefore,

<u>at sea:</u>

cost of h.f.o = 123. x SHP x 0.9 x 24. x (1+reserve) x sea time x round trips per annum x 10^{-6} x cost of h.f.o per tonne (\$) [eq.6.7]

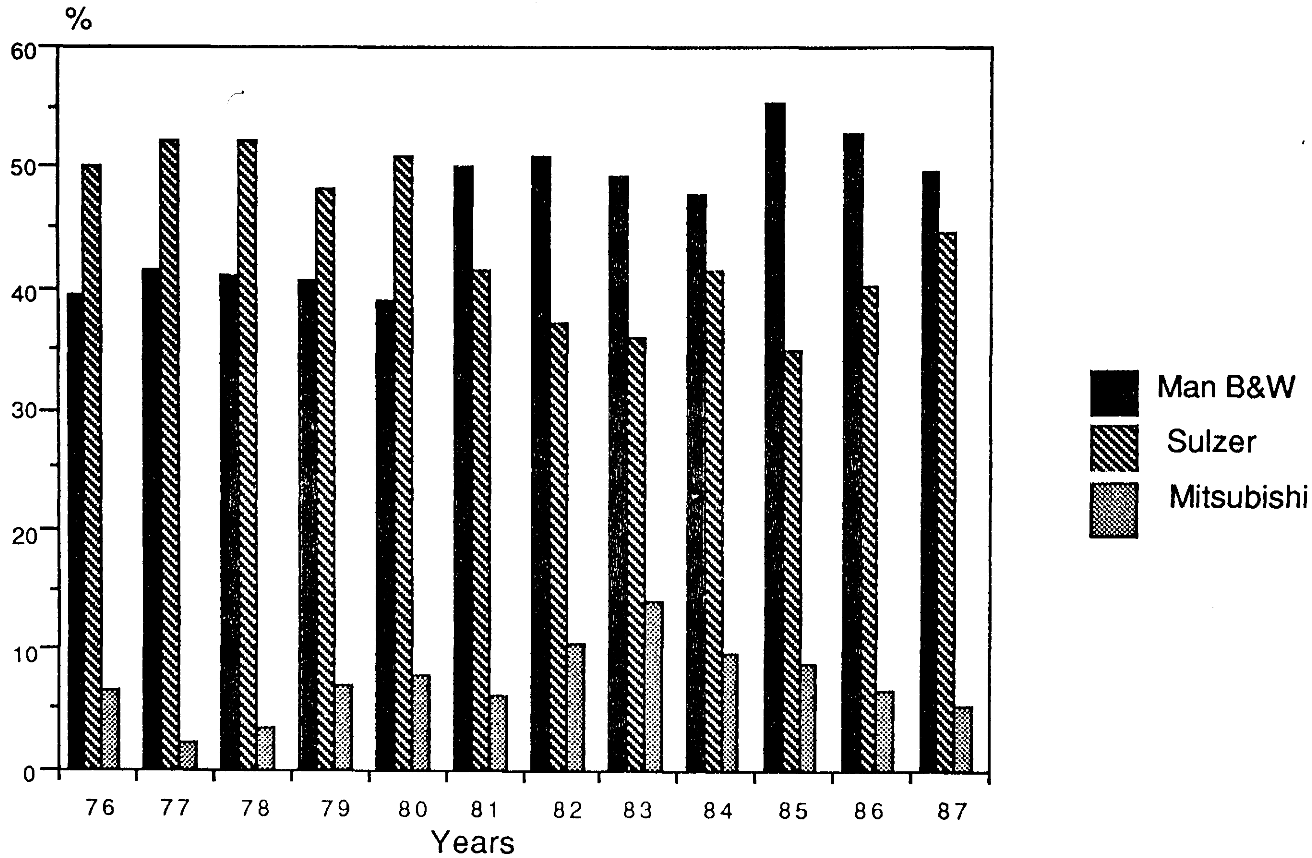


Fig.6.5 PERCENTAGE OF WORLD MAJOR LOW-SPEED DIESEL ENGINES INSTALLED ANNUALLY

Source : The Motor Ship.

$$\text{cost of m. d. o.} = 142. \times AUXKW \times 1.341 \times 24. \times \frac{0.5}{0.95} \times \text{sea time} \times \text{round trips per annum} \times 10^{-6} \times \text{cost of m.d.o. per tonne} \quad (\$) \quad [eq.6.8]$$

cost of system luboil = 0.2 x SHP x 0.9 x 24. x sea time x round trips per annum x 10^{-6} x cost of sys.luboil per tonne ($) [eq.6.9]

cost of cylinder luboil = 0.5 x SHP x 0.9 x 24. x sea time x round trips per annum x 10^{-6} x cost of cyl.luboil per tonne ($) [eq.6.10]

in port:

$$\text{cost of m.d.o.} = 142. \times AUXKW \times 1.341 \times 24. \times \frac{0.75}{0.95} \times \text{port time} \times \text{round trips per annum} \times 10^{-6} \times \text{cost of m.d.o. per tonne} \quad (\$) \quad [eq.6.11]$$

The following assumptions have also been made for calculating fuel costs.
The main engine is running at 90% of the maximum continuous rating, with a specific fuel consumption of 123 g/bhp.h.
The auxiliary engine, with a specific fuel consumption of 142 g/bhp.h, operates at 50% of the maximum continuous rating at sea and at 75% in port, and the efficiency is 95% (36).
0.2 and 0.5 (g/bhp.h) are respectively the system and cylinder luboil consumption. Costs of h.f.o, m.d.o, cylinder and system luboil per tonne are average costs in 1987, and are input values in the program. They are h.f.o, $94/tonne; m.d.o, $165/tonne;
cylinder.luboil, $1512/tonne; system.luboil, $1344/tonne.

6.3.2 PORT CHARGES.

Port costs comprise a miscellany of expenses such as port dues, lighthouse dues, pilotage tugs and port agents' fees.
They vary enormously from port to port around the world. The lowest costs are usually found for large ships in ports with few facilities, while the highest tend to apply to small ships in ports with an extensive range of facilities.
Total port costs are usually expressed as a function of cargo deadweight

(34) or, as many ports do charge now, they are expressed as a function of net or gross registered ton (41).
In this thesis, port costs are taken as an average cost from (41), they are
port costs = 2. x round trip per annum x 1.68 x NRT ($) [eq.6.12]
The factor 2 reflects the two ports of call per round trip.

6.3.3 CARGO HANDLING CHARGES.

Most of bulk carriers in service today are not fitted with cargo gear, they, consequently, rely on shore discharging gear provided by ports of call.
Cargo handling costs also vary widely between ports, especially for break-bulk general cargo. Discharging in a port with low labour costs (e.g. in the Far East) does not cost as much as it does in high cost areas such as North America.
Bulk cargo handling costs are not usually paid by the shipowner. Loading costs are usually small for cargoes such as coal or grain, while those of discharging are more expensive, sometimes more than twice the loading costs.
Cargo handling costs are expressed as a function of the total cargo deadweight and taken as an average cost from (41), they are
cargo handling costs = (0.79 x cargo dwt + 1.73 x cargo dwt) x round trips per annum ($) [eq.6.13]

6.3.4 CANAL DUES.

The ship will operate through the Panama Canal with two transits per round trip, full laden during the outward voyage and in ballast during the homeward voyage. Consequently, canal dues are applicable.
Dues per transit, through the Panama Canal, per Panamax measured net ton are $1.83 laden and $1.46 in ballast (54).
The Panamax measured net ton for bulk carriers is taken as 13% higher than the British one (3) which actually gives a reasonable value for Panama net tonnage measurement.

Therefore, the canal dues per annum are:

PNT = 1.13 x NRT

canal dues = (1.46 x PNT + 1.83 x PNT) x round trips per annum

($)   [eq.6.14]

CHAPTER 7 : ENGINEERING ECONOMICS.

7.1 INTRODUCTION.

Economics in all scientific fields may be defined as the task of elimination of the waste of both human and natural resources when undertaking a project.

Engineering may be defined as the application of scientific knowledge for the good of humanity.

In a free-market economy, society makes its needs known through its purchases. It is therefore the task of engineers to use all their technical and economic genius when making design decisions.

Economics is then an important aspect of engineering and a potentially valuable tool at every level of design which no one can afford to ignore it.

In marine technology, engineering economy was of little use to naval architects in the days of sail, depending on the weather which did not allow quantitative economic analysis to be considered. That situation changed with the introduction of steam propulsion which made possible the application of cost studies to the determination of ship characteristics.

Nowadays, ship design assisted by computers involves countless decisions (or alternative designs) which are studied and analysed.

This analysis is carried out in order that an objective measure of an investment's worth can be determined and a rank order of desirability established between the different investment alternatives.

It must be mentioned that this economic analysis of capital investment projects is one of the most difficult aspects of capital planning. Forecasting future costs and revenues is generally a very difficult and critical task in an investment analysis. This aspect is worse in the marine economic environment which is noted for its instability and where the difficulty in estimating future levels of the freight market can be attributed to uncertainties in both supply and demand determinants of the market rate. A shipowner considering a ship investment, for example, cannot know with certainty how many other shipowners might build similar ships which will compete for the freight movement he anticipates.

This chapter, mostly based on (41), (43) and (44), outlines the basic principles of engineering economy calculations and the choice of economic criterion when evaluating alternative designs and shows how to integrate the related economic factors into the technical design, taking into account some economic complexities such as tax, depreciation and inflation.

7.2 INTEREST RELATIONSHIPS.

Time has an appreciable effect on money. As the time passes the same amount of money becomes more valuable. Therefore, the notion of time value of money has a great significance in all economic calculations that no engineer can afford to ignore.

This notion is expressed in terms of reward or in economic terms of interest. Interest can be defined as a charge expressed in per cent of funds or loan borrowed fixed by the lender or bank in agreement with the borrower, paid annually or sometimes semi-annually.

Interest may either be

- contracted, e.g.agreed rate paid on bank loans, mortgages and bonds; or
- a rate of return, which is the effective equivalent interest rate generated by the excess of income over expenditure.

Interest may either be simple or compound, with the latter being usually the method adopted in real life cash flows involved in ship purchase and operation.

7.2.1 SIMPLE INTEREST.

The total repayment after N years is expressed as

$$F = P\,(1+Ni) \qquad (\$) \qquad [eq.7.1]$$

7.2.2 COMPOUND INTEREST.

In this method the interest is compounded annually, and the total repayment after N years is expressed as

$F = P\ (1+i)^N$ ($) [eq.7.2]

where: F = future sum of money;

P = principal (investment), or a present sum of money;

N = number of years (e.g. life of ship or period of loan);

i = interest or discount rate per annum expressed as a fraction.

7.3 TIME ADJUSTING MONEY VALUES.

In economy, there are six useful factors which enable the economist to convert a present sum of money into a future one and vice versa, or to convert a present or future sum of money into an uniform annual amount (series of payments) and vice versa.

7.3.1 COMPOUND AMOUNT FACTOR AND PRESENT WORTH FACTOR.

These two factors only apply to single future payments (fig.7.1).The compound amount factor (CAF) is the multiplier to convert a present sum (P) into a future sum (F) and expressed as

$F = (\ CAF\ ) \times P$ ($)

where $CAF = \frac{F}{P} = (\ 1 + i\ )^N$ [eq.7.3]

Rarely in the marine industries interest may be compounded T times per year. In such case, (CAF) becomes

$$CAF = (\ 1. + \frac{i}{T}\ )^{NT}$$

The reciprocal of the compound amount factor is the present worth factor (PWF) which is the multiplier to convert a future sum of money into a present one and is expressed as

$P = (PWF) \times F$ ($)

where $PWF = \frac{P}{F} = \frac{1.}{CAF} = (\ 1. + i\ )^{-N}$ [eq.7.4]

In the program, given the year and the discount rate, PWF is calculated by the subroutine sub-program PRESWF.

A discount rate of 12% per annum which reflects the 1987 shipping market (41) is assumed in the thesis as an input value.

7.3.2 CAPITAL RECOVERY FACTOR AND SERIES PRESENT WORTH FACTOR.

These two factors only apply to a series of payments uniformly due in time (fig.7.2). When a loan is repaid by a series of regular (e.g.annual) installment of principal plus interest, there are two common arrangements

a- Principal repaid in equal installments, and interest paid on the declining balance. This arrangement which is the usual method with shipbuilding loans is adopted in the subprogram subroutine CAPCHR to calculate the building account (see section 7.6.).

b- Uniform payments, which is the usual method for house mortgages, interest predominating in early years and repayments of principal in later years.

The capital recovery factor (CRF) enables an initial capital investment to be converted into an equivalent capital charge which includes both principal and interest repaid uniformly over a number of time periods, usually annual.

CRF is the ratio between this uniform annual amount (A) and the principal (P) and is expressed as

$A = (CRF) \times P \qquad (\$)$

$$\text{where } CRF = \frac{A}{P} = \frac{i(1.+i)^{N}}{(1.+i)^{N} - 1.} = \frac{i}{1.-(1.-i)^{-N}} \qquad \text{[eq.7.5]}$$

The reciprocal of the capital recovery factor is the series present worth factor (SPWF), which is the multiplier to convert a number of regular (say annual) payments into a present sum , and is expressed as

$P = (SPWF) \times A \qquad (\$)$

where $SPWF = \frac{P}{A} = \frac{1.}{CRF} = \frac{(1.+i)^N - 1.}{i(1.+i)^N}$ [eq.7.6]

7.3.3 SINKING FUND FACTOR AND SERIES COMPOUND AMOUNT FACTOR.

These two factors are less frequently used in the marine industries. The sinking fund factor (SFF) enables a future sum of money to be converted into a regular (annual) amount of money (fig.7.3), and is expressed as

A = (SFF) x F ($)

where $SFF = \frac{A}{F} = \frac{i}{(1.+i)^N - 1.}$ [eq.7.7]

The reciprocal of the sinking fund factor is the series compound amount factor (SCAF), which is the the multiplier to convert a regular amount of money into a future sum of money, and is expressed as

F = (SCAF) x A ($)

where $SCAF = \frac{F}{A} = \frac{1.}{SFF} = \frac{(1.+i)^N - 1.}{i}$ [eq.7.8]

7.4 ECONOMIC MEASURE OF MERIT.

There are several valid economic criteria available to the engineer. Each one is used depending upon the circumstances in which the economic comparison is to be made. Income can be predicted in some cases but not in others, returns may be uniform from year to year or they may fluctuate, one proposed ship may have a longer life expectancy than another. Such circumstances will influence choice of criterion.

Three of them which are used in most economic evaluation and of particular interest to bulk carrier sector are discussed in this section.

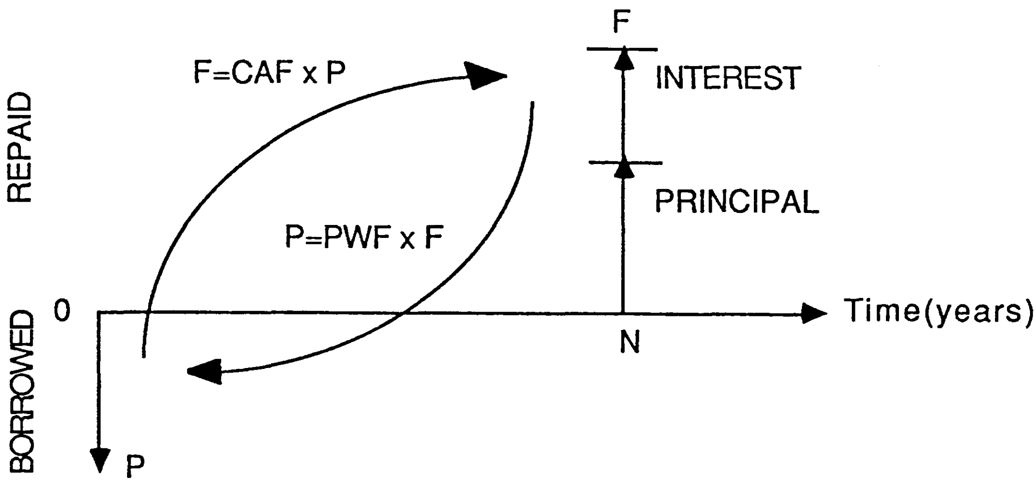


Fig.7.1 Compound Amount Factor and Present Worth Factor

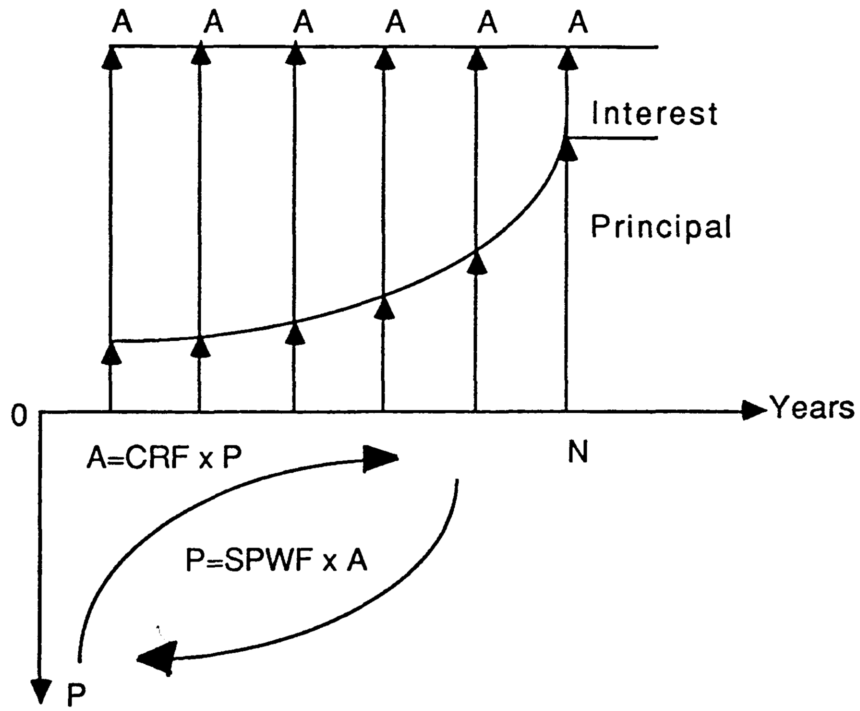


Fig.7.2 Capital Recovery Factor and Series Present Worth Factor

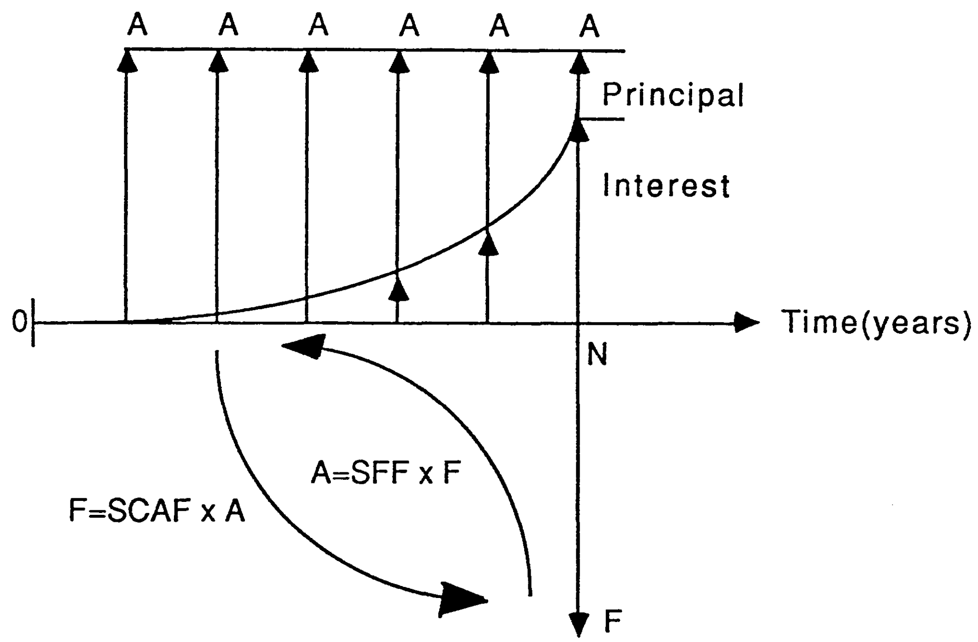


Fig.7.3 Sinking Fund Factor and Series Compound Amount Factor

7.4.1 NET PRESENT VALUE.

The net present value (NPV) is the algebraic sum of the present value of all cash flows (income and expenditure) discounted to present time at a stipulated discount rate, often calculated in tabular form.

The general form for calculating NPV is given by

$$NPV = \sum_{0}^{N} [\ PWF(\text{annual cargo tonnage x freight rate}) - PWF(\text{annual operating costs}) - PWF(\text{ship acquisition cost})\ ] \quad (\$) \qquad \text{[eq.7.9]}$$

Designs with the highest NPVs are sought.

NPV is widely selected as an economic criteria in those cases in which income can reasonably be predicted (fig.7.4).

7.4.2 REQUIRED FREIGHT RATE.

The required freight rate (RFR) is the freight income needed per unit of cargo to cover all operating costs and provide the required rate of return on the capital invested in the ship. In other terms, it is the freight rate which produces equal present worths of income and expenditure, i.e. zero NPV.

In general, it is given by

$$RFR = \sum_{0}^{N} \left[\frac{PWF\ (\text{annual operating costs}) + PWF\ (\text{ship acquisition cost})}{PWF\ (\text{annual cargo tonnage})} \right] \quad (\$/\text{tonne})$$

[eq.7.10]

The RFR, or sometimes referred to as "shadow price", can be regarded as a calculated freighting cost which can then be compared with actual freight rates given by the shipping market.

In general, the design with the lowest RFR is best.

The RFR is useful as an economic criterion in the many cases where incomes are non predictable (fig.7.4). It is particularly useful when comparing alternative ship sizes, as a single freight rate cannot be expected to apply to all ship sizes.

As in the marine field it is not always possible to predict income over the life of a ship, the required freight rate in this thesis is chosen as the economic criterion when comparing and evaluating alternative designs.

7.4.3 INTERNAL RATE OF RETURN.

The internal rate of return (IRR) or yield is the discount rate of return or equivalent interest rate of return which gives zero NPV.

Designs offering the highest IRR are sought.

IRR can be used as a criterion when the freight rate or income is known (fig.7.4). It is particularly useful when measuring the degree of risk involved in investment for additional pieces or equipment on the ship.

Fig.7 4 gives a summary in the decision making for selecting the economic criterion given the amount of information available.

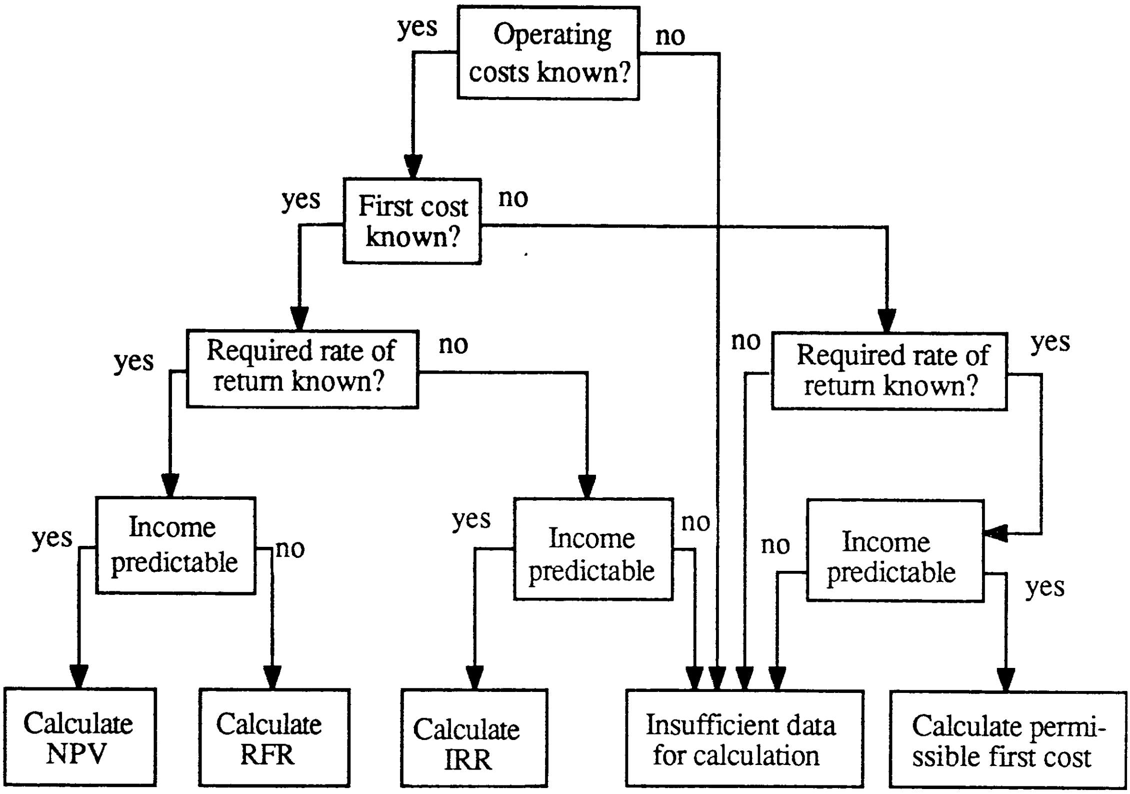


Fig.7.4 DECISION CHART FOR CHOICE OF ECONOMIC MEASURE OF MERIT (41).

7.5 ECONOMIC COMPLEXITIES.

7.5.1 LOANS.

Most countries throughout the world through their central sources offer loans for ship purchase. These loans at reduced rates of interest are made available in order to stimulate the national shipbuilding industries and encourage owners to place orders.

Typical values for shipbuilding industry are loans around 80 per cent of the capital cost for a duration of 8 or 8.5 years repayable at an interest rate of 7.5 per cent. Generally the loan or credit is advanced to the shipowner in

several installments with interest made payable before the ship delivery. Repayment of the loan is usually in equal amounts, at six-monthly or annual intervals after delivery, plus interest on the declining balance.
For further details see section 7.6.

7.5.2 TAX.

Tax is assessed after the shipowner's annual accounts are made up. For British shipowners, for example, this tax is levied at a certain rate on taxable profit which is

income - operating expenses - loan interest - depreciation allowances.

Free market conditions make freight rates sensitive to taxes. When taxes are raised price must also be raised to reflect the added charge.

Until 1984 the tax rate was 52%, now being reduced to 35% with declining balance depreciation type.

For further details see section 7.8.

7.5.3 INFLATION.

In real economic life all the shipowner's expenses as well as his income may be subject to a rise over the years. Therefore, in an economic study calculations may either be carried out in real terms (i.e.with constant purchasing power) or money terms (i.e. including an allowance for inflation).

The first method appears to be less realistic but it gives acceptable results as long as the discount rate used is properly defined as inflation is essentially an increase to the discount rate and only differential inflation among cost components needs serious treatment for inflation. The exact increase in discount rate for inflation is perhaps impossible to forecast.

Most practitioners of economic evaluation of ship use money rather than real terms. Use of money terms means that it is easier to incorporate the almost universal use of shipbuilding loans, it uses units that the ship operator uses in his own projections, it allows tax considerations to be included and it forces a great attention on escalation rates for costs and freight revenue.

Inflation can be neglected when income and costs rise at the same rates. This is possible as long as the shipowner is free to raise his prices to offset his rising costs. However, high inflation rate is found to reduce the shipowner's yield and increase his effective tax rate (47). Table 7.1 shows this trend.

TABLE 7.1 YIELD AND EFFECTIVE TAX RATE UNDER VARIOUS LEVELS OF INFLATION (STRAIGHT LINE DEPRECIATION) (47).

ASSUMED ANNUAL RATE OF INFLATION (%)	DERIVED VALUE OF YIELD (%)	EFFECTIVE TAX RATE (%)
0.	11.1	50.0
8.	9.9	56.5
12.	9.5	58.5
16.	9.3	59.6
20.	9.1	60.6
24.	8.9	61.3

Escalation rates of operating costs and how to incorporate them in the program are indicated in section 7.7.

In the parametric studies, operating costs over the years are taken as non-escalating costs in most cases since the purpose of such studies is not to calculate the shadow price but to investigate the effect of changing some design parameters.

7.5.4 DEPRECIATION.

Depreciation is a book transaction mainly used for tax accounting purposes to assess the profit available to shipowners.

There are different depreciation patterns which affect the amount of tax payable. They are straight-line depreciation, declining balance and free depreciation.

The declining balance method in which annual allowances are taken as a certain percentage of the residual value of the ship each year is actually used by British shipowners after its introduction in 1984.

In the program free depreciation is assumed, which means the shipowner is allowed to extinguish all liability for tax until the depreciation allowances have been exhausted.

For further details see section 7.8.

7.6 CAPITAL CHARGES.

Taking as input the capital cost of the ship, the loan as a percentage of capital cost with an interest on loan repayment, the period of loan and the discount rate, the building account of the ship is calculated. The calculations involved are discounted to a base year which is the year of starting the construction of the ship.

The procedure given by Buxton (43) is carried out in subprogram subroutine CAPCHR with the following assumptions

1- the loan taken by the shipowner is 80% of the capital cost, the remaining 20% are paid by the shipowner;

2- 1% extra of the capital cost is paid by the shipowner for supervision, own supply items, fees for arranging loan and owner's technical staff;

3- the period of loan is 8 years set at an interest rate of 7.5% per annum;

4- the discounting is done with a present worth factor of 12% discount rate;

5- year 0 is the year of signing the contract and year 2 is the year of ship's delivery;

6- building installments: the shipowner pays 10% of the capital cost plus 1% when the contract is signed (i.e. year 0) and 10% in year 1; 30% of the loan is paid in year 1; another 30% in year 1.5 and 20% when the ship is delivered (i.e. year 2); and

7- the loan is repaid in equal installments over the loan period at annual interval, with the interest payable at end of each time interval.

The flow chart of subroutine CAPCHR is given in appendix 3.

The interest payable on the loan is stored in an array PINTT(K) to be set off against profits as tax allowances (see section 7.8.). The present value of the building account is accumulated in BLDCF.

The subprogram CAPCHR was validated by carrying out step by step hand calculation.

7.7 REQUIRED FREIGHT RATE BEFORE TAX.

The required freight rate as defined in section 7.4.2 is taken as the economic measure of merit in this thesis.

Since the cash flows are not uniform, the calculations are carried out year by year from the year of delivery (i.e. year 2).

In order to determine the exact freight rate which gives zero NPV with taxes and depreciation allowances included, a first estimation of freight rate before tax is carried out in subprogram subroutine ECONOM.

The flow chart of the algorithm adopted is shown in appendix 3, and below are described the main steps.

The different cost items are escalated at different rates each year. The escalation factor of cost i in year y at an escalation rate RIcost i (in percentage) is stored in an array given by

$$\text{Ecost i (I)} = \left(1. + \frac{\text{RIcost i}}{100.}\right)^{y} \qquad \text{[eq.7.11]}$$

Following are the operating cost items assumed to be escalated at different rates.

1. Crew costs: ECREW(I), RICREW.
2. Maintenance & repair, store and supplies costs: EMARE(I), RIMARE.
3. Insurance (H & M and P & I) costs: EINS(I), RIINS.
4. Fuel costs: EFUEL(I), RIFUEL.
5. Port, canal and cargo handling costs: EPORT(I), RIPORT.

After multiplying each cost i by its correspondent escalation factor Ecost i the result is stored in an array AIcost i (I) which is given by

AI cost i (I) = cost i x Ecost i (I) ($) [eq.7.12]

Then the sum of all costs given above AT cost (I) in year y is discounted and stored in array given by

DT cost (I) = AT cost (I) x PWF (\$) [eq.7.13]

where PWF is the present worth factor for year y.

The cargo carried per annum is given by

CDWTA = CDWT x RTRIPA [eq.7.14]

where RTRIPA is the number of round trips per annum; and

CDWT is the cargo deadweight in tonnes.

The cargo carried annually then obtained is discounted in year y and stored in an array given by

PWCDWT(I) = CDWTA x PWF (tonne) [eq.7.15]

The same procedure is repeated from year 3 until the life of the ship has expired with the costs accumulated in TRDCF (present value of operating costs) and cargo carried in DCFDWT.

Using the present value of the building account BLDCF calculated by subroutine CAPCHR, the freight rate before tax is then given by

$$CFR = \frac{TRDCF + BLDCF}{DCFDWT} \quad (\$/tonne) \quad [eq.7.16]$$

Using CFR as a first estimation of income, the subroutine ECONOM calls another subroutine ECATAX which calculates the exact required freight rate taking into account tax and depreciation allowances.

7.8 REQUIRED FREIGHT RATE.

The determination of the required freight rate, as pointed out above, is carried out by subprogram subroutine ECATAX.

The subprogram flow chart is shown in appendix 3, and below is described the procedure adopted.

Given the freight rate estimated before tax, the annual income and expenditure of the ship in year y are respectively given by

AINCOM(I) = CFR x CDWTA (\$) [eq.7.17]

EXPEND(I) = ATCOST(I) (\$) [eq.7.18]

note y is I+2, as the ship starts operating in year 2, hence the first income is made in year 3 (i.e.I=1).

Therefore, the cash flow before tax is

CASHBT(I) = AINCOM(I) - EXPEND(I) ($) [eq.7.19]

The net cash flow (i.e.cash flow after tax) is given by

CASHAT(I) = CASHBT(I) - TAX(I) ($) [eq.7.20]

where $TAX(I) = TAXPRO(I) \times \frac{PTAX}{100.}$ ($)

with TAXPRO being an array containing the taxable profit for each year and PTAX the tax percentage rate.

Up to the end of loan period (YRLOAN) interest is set off as a tax allowance and depreciation allowance adjusted to make taxable profit zero each year and that until YRLOAN -1.

Therefore, depreciation (free depreciation being adopted in the program) allowance is used to extinguish all liability for tax until the capital cost of the ship and owner's extra are exhausted.

The cash flow after tax is then discounted and stored in an array given by

PWCASH(I) = CASHAT(I) x PWF ($) [eq.7.21]

and accumulated in DCF which is at the end of calculation the present value of the operating account.

The scrap value of the ship is assumed zero in the program.

Using the present value of the building account BLDCF calculated by subroutine CAPCHR, the net present value of the investment (or ship) is then calculated as

CALNPV = DCF - BLDCF ($) [eq.7.22]

To determine the exact freight rate which gives zero CALNPV (i.e.RFR) the whole procedure is repeated for two other values of CFR, 1.2 CFR and 0.8 CFR, which give two other values of CALNPV.

Then, by three points Lagrangian interpolation performed by subroutine LAGINT, the required freight rate giving zero CALNPV is determined.

The design which gives the minimum value of RFR is chosen as the best one (or optimum design).

CHAPTER 8 : PARAMETRIC STUDIES AND SENSITIVITY ANALYSIS.

8.1 INTRODUCTION.

Preliminary ship design requires making a large number of assumptions when going through its different stages. Acceptability or success of the whole procedure depends upon accuracy of these assumptions. It is, therefore, necessary to know to what extent the design is affected by these assumptions and see how it varies in response to changes made on them. Furthermore, it is also often useful to calculate the effects of varying one specific design parameter to discover how influential it is, e.g. to assess effects on the overall ship costs by making small changes in each dimension. Such investigations are usually carried out in parametric studies.

Sensitivity analysis is particularly useful to quantify the effect of variation in the value of a single element on the design measure of merit. This analysis determines the outcome effect of over/under estimating an element's value and highlights the relative importance of accurately estimating each one. Sensitivity analysis, therefore, permits the identification of the more sensitive elements of the design so that estimating efforts would be concentrated where they count most.

As stated previously the economic measure of merit when comparing alternative designs and measuring effects of varying parameters is chosen as the required freight rate (RFR).

Parametric studies are carried out in the first section of this chapter. Systematic variation of ship size and speed are described with their optimum values illustrated. Other parameters are also varied in the first section for different values of speed to locate the optimum value of this latter.

In the second section of this chapter a sensitivity analysis is carried out to find the relative importance of some parameters deemed of influence on the final design. Sensitivity tests on assumptions related to Panama Canal and trade route such as extension of Panama Canal size, reduction of ballast voyage and change of trade route are also carried out in the second section to measure the gain involved from these ameliorations.

The computer program described throughout the thesis is kept the same for carrying out parametric studies and sensitivity analysis except the main program where some transformations occurred in order to vary appropriate parameters within specific ranges.

Finally, and in order to limit a large number of generated design models the beam and draft of the ship are kept constant giving therefore a single value of B/T ratio.

8.2 PARAMETRIC STUDIES.

Parametric studies are carried out for the following assumptions.

The ship transports grain from the port of New Orleans on the east gulf coast of USA to the port of Yokohama in Japan passing through the Panama Canal and returning in ballast. The ship, therefore, sails a round trip distance of 18,300 nautical miles. Bunkering is made at each port of call giving thus an endurance of half round voyage distance, i.e. endurance = 9150 nm.

Discount Rate	12%
Tax Rate	35%
Loan Interest	7.5%
Loan Period	8 Years
Type of Depreciation	Free
Ship's Life	15 Years
Annual Escalation of Ship's Operating Costs and Freight Rate	none
Specific Fuel Consumption	123 g/bhp.h

8.2.1 SHIP SIZE AND SPEED VARIATION SERIES.

The ship size is varied from a value of 45,000 to 75,000 dwt in steps of 5,000 dwt. Ship speed is varied from a value of 11 to 17 knots in steps of 1 knot. To vary the ship deadweight within the above range, the block coefficient is varied from a lower value of 0.775 to a higher value of 0.850. Results for block coefficient of 0.875 are omitted in this thesis as data of powering bloc for this highest value of Cb are mainly obtained by extrapolation and hence doubtful.

The variation of Cb with contours of dwt against ship speed and RFR is shown in fig.8.1 to fig.8.4. Fig.8.5 to fig.8.10 show the variation of dwt with contours of block coefficient against speed and RFR.

For the same block coefficient, the optimum speed giving the lowest value of RFR increases with ship size (fig.8.1 to 8.4). However, the rate of increase in optimum speed becomes less as the block coefficient increases.

The economy of scale is clearly illustrated by the reduced value of RFR for bigger size. For the lower value of Cb of 0.775, an increase of dwt by 20,000 dwt from 45,000 to 65,000 dwt brings a reduction in RFR from 22.10 to 20.00 $/tonne, a reduction of 9.50%. For the higher value of Cb of 0.850, the same increase of 20,000 in deadweight from 55,000 to 75,000 dwt reduces RFR from a value of 20.60 to 18.75 $/tonne, a reduction of 8.98%.

For the range of deadweight considered, the increase of RFR resulted from increase of speed is very noticeable. Above the speed of 14 knots the increase is very fast particularly for lower values of deadweight (fig.8.1 to 8.4). This increase of RFR with speed puts a premium on the choice of service speed which must be carefully made to avoid unnecessary financial penalties.

Ship costs which are influenced by economy of scale are crew and fuel costs, major cost items for bulk carriers particularly for the longer trade routes as it is the case in this study. Other costs that are functions either of cargo deadweight or ship first cost are practically not dependent on the distance travelled. Therefore, any increase in ship size brings an immediate benefit and this is measured by the reduction of RFR.

Fig.8.5 to 8.10 show that in order to achieve a certain deadweight with constant B/T value, it is better to increase the block coefficient and decrease L/B value with lower speed to maintain a relatively constant Froude number rather than to decrease the block coefficient and increase L/B value with higher corresponding speed. This is mainly due to capital cost which is mostly affected by the ship length, the most expensive dimension in terms of cost, and speed which increases the operating costs if it is chosen too high. However, this change in RFR is not very pronounced.

8.2.2 OPTIMUM SPEED.

Modern bulk carriers operate nowadays with lower speed than they were 15 years ago. The high cost of fuel, since its rise in 1973, has led ships of this type capable of operating at 15 knots, for example, to steam at about 12.5 knots.

When it comes to specifying the design service speed of a new vessel by a shipowner, two approaches are considered. If a bulk carrier is destined for an owner operator, then the vessel's optimal speed is that which minimises the overall cost per tonne of cargo in the transport system. If, on the other hand, the ship is intended for chartering out then it is the optimum speed which maximises the profits. It is the first approach considered defining the optimum speed as the cheapest.

The speed is varied with other parameters, other than dimensional, and evaluated against RFR. A ship of 70,000 dwt with a block coefficient of 0.800 is chosen for this purpose.

8.2.2.1 EFFECT OF FUEL COSTS.

The prices of heavy fuel oil, marine diesel oil and lubricating oil are increased by 25 and 50 per cent and reduced by 25 cent to measure the effect on optimum speed (fig.8.11).

For an increase of fuel costs of 25 and 50 per cent the optimum speed of 13.42 knots falls respectively to 13.0 and 12.0 knots. On the other hand, the speed increases to 14.10 knots for a 25 per cent reduction in fuel costs.

For a long trade route, as it is the case here, where fuel costs represent a major part of operating costs the service speed is very sensitive to this cost item. Fig.8.11 shows that for higher fuel costs the optimum speed must be reduced to offset the extra cost and increased when fuel prices go down.

8.2.2.2 EFFECT OF CREW COSTS.

Crew costs are escalated annually at 4, 6, 8 and 10 per cent relative to other operating costs to see how the optimum speed is affected (fig.8.12).

An increase in crew costs causes an increase in speed due to the fact that crew costs depend on the duration of the voyage. An annual escalation of 10 per cent brings the optimum speed up by about 1.1 knots.

8.2.2.3 EFFECT OF SHIP FIRST COST.

The shipbuilding is increased successively by 25 and 50 per cent and reduced by 25 per cent.

As illustrated by fig.8.13, the optimum speed increases with shipbuilding cost but the rate of increase is not significant.

8.2.2.4 EFFECT OF DISCOUNT RATE.

The discount rate of 12% is increased to 15 and 18% and decreased to 9%. Fig.8.14 shows the effect of variation of discount rate on optimum speed which is very small.

8.2.2.5 EFFECT OF CORPORATION TAX RATE.

Corporation tax rate at 35% is increased to 40, 60, 80 and 100%.

The effect on optimum speed by increasing the tax rate is small as shown in fig.8.15.

It is worth noticing that RFR increases disproportionately with tax rate. The fast increase of RFR from a rise in tax rate from 80 to 100% shows a situation where a shipowner makes a declining profit as tax rate rises and finds himself with no profit at all at 100% tax rate recovering only what he spent operating the ship.

8.2.2.6 EFFECT OF LIFE.

The basis ship's life of 15 years is extended to 15, 20, 25 and 30 years. The effect of such variation on optimum speed is very small as shown in fig.8.16. However, the figure suggests that it is better to extend the ship's life beyond 15 years as the drop in RFR from increasing the life

8.2.2.6.A Effect of ship's life

The basis ship's life of 15 years is varied from 10 to 30 in step of 5 years. The effect of such variation on the economic performance of the ship is assessed using another criterion (other than RFR).

As income is not known in this study (where the Net Present Value NPV can be calculated), the negative equivalent annual cash flow of building account and operating costs is taken as the new criterion.

From fig.8.16A & 8.18A it can be seen that beyond 15 years , the benefit from extending the ship's life is very small. With a life less than 15 years, however, the ship (or investment) is relatively not economic, although the change in the negative equivalent annual cash flow is still small.

to 20 years is significant.

Extending the ship's life over 25 years is not imperative since the gain obtained by reduction in RFR is small.

It is assumed in the computer program that the service speed is kept constant during the whole ship's life. In real conditions the service speed drops as the ship goes old due to deterioration of hull by external agents of fouling and corrosion. However, this drop in speed can be reduced considerably by modern techniques of hull treatments such as emission of antifouling, fit of anti-corrosive coatings and blasting.

8.2.2.7 EFFECT OF ENDURANCE.

As mentioned earlier, the endurance is defined as half round voyage distance.

As shown in fig.8.17 the variation of endurance has practically no effect on optimum speed.

8.2.3 OPTIMUM SHIP'S LIFE.

The same ship assumed above with a service speed of 14 knots is used to study the effect of variation of discount rate and corporation tax rate on optimum ship's life.

The discount rate is increased from 10 to 20% and corporation tax rate from the position of no tax to successively 25, 50, 75 and 100% (fig.8.18).

As in section 8.2.2.6, the figure indicates that for the basis ship of 12% discount rate and 35% tax rate the gain from extending the ship's life over 25 years is small due to the very reduced effect on RFR beyond this value. However, below 20 years where the variation of life has more effect on RFR the ship is not economic and particularly between 10 and 15 years where the slope measuring the reduction in RFR is very sharp.

Another important aspect is that discount rate has more effect on optimum life than tax rate. Reducing the discount rate to 10% extends optimum ship's life to 30 years while increasing it to 20% reduces by nearly 10 years the optimum life bringing it down to 20 years. The discount rate has also more effect on RFR than tax rate. Increasing the discount rate from 10 to 20% has more effect on RFR than increasing tax rate from no tax to 75%. This aspect is mainly due to the fact that the value of money or discount rate is involved in cash flow calculations during the whole ship's life and even before the ship is launched, while tax , with free depreciation assumed, is levied on profit after the ship has spent some years operating (in the program 8 years).

Finally, it is worth noticing that at 100% tax rate, with of course higher RFR, there is no optimum life. This can be explained by the fact that at 100% tax rate, an unrealistic value in real financial environment, the shipowner makes no profit recovering what he invested and whatever the ship's life the situation of "giving" and "receiving" the same investment will remain unchanged.

Incentives for shipowning may remain even with a 100% tax rate as employment is maintained and changes in second hand values may allow the vessel to be sold at a profit unless capital gains taxes are also total.

8.3 SENSITIVITY ANALYSIS.

As pointed out , sensitivity analysis identifies those external parameters of the design which affect more the economic performance of the ship.

A sensitivity analysis is carried out to determine the order of merit of some parameters which are of influence on RFR and to study the effect of changing some features related to the Panama Canal.

8.3.1 MERIT RANKING.

Eighteen (18) parameters are improved by 10% from their original values, including the extension of ship's life from 15 to 20 years, one at a time to measure the resulted effect on RFR and then set their order of merit. The same ship assumed above with the same assumptions given in section 8.2 is used for this purpose. Furthermore, the calculations are carried out for two cases.

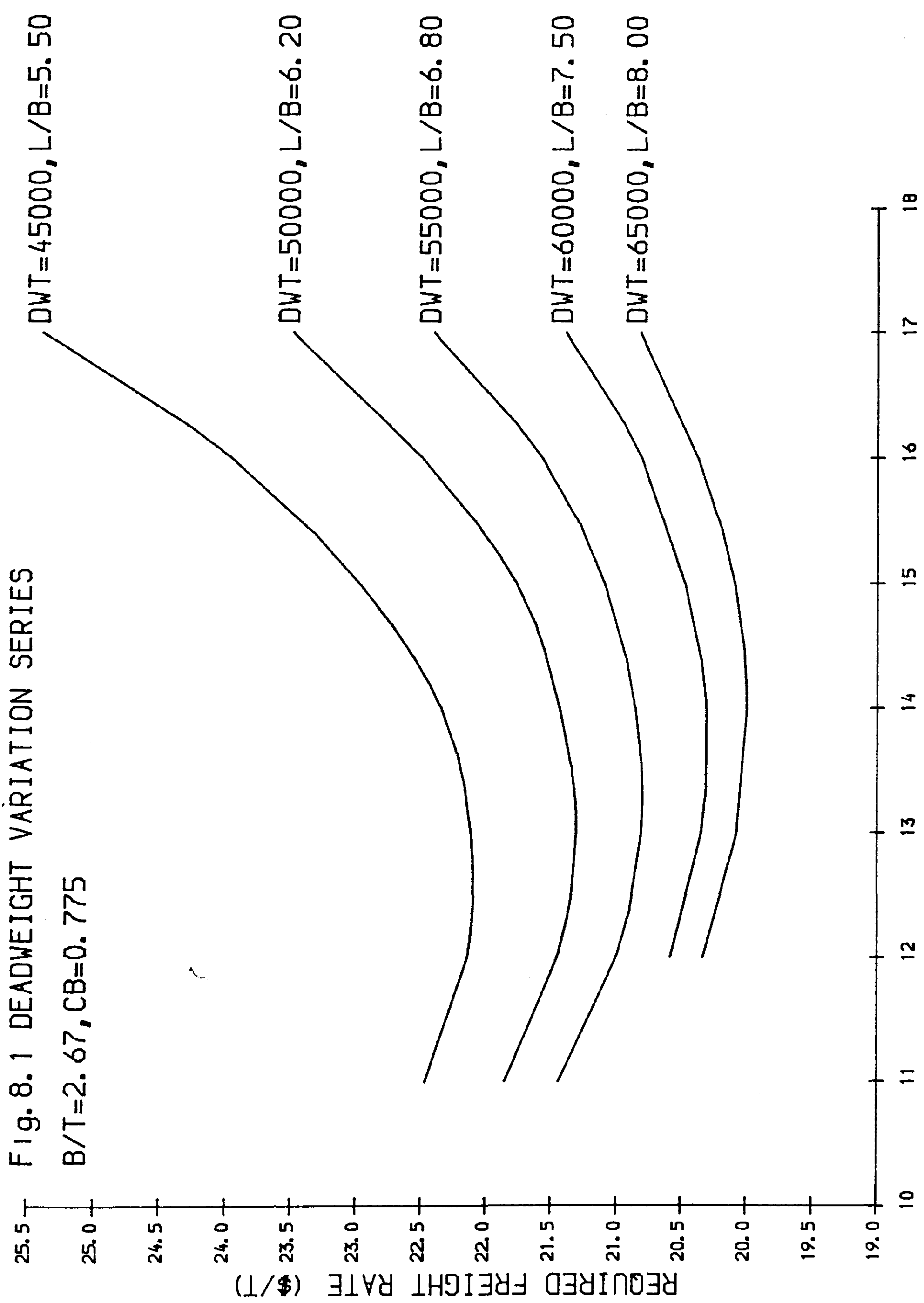


Fig. 8.1 DEADWEIGHT VARIATION SERIES
B/T=2.67, CB=0.775

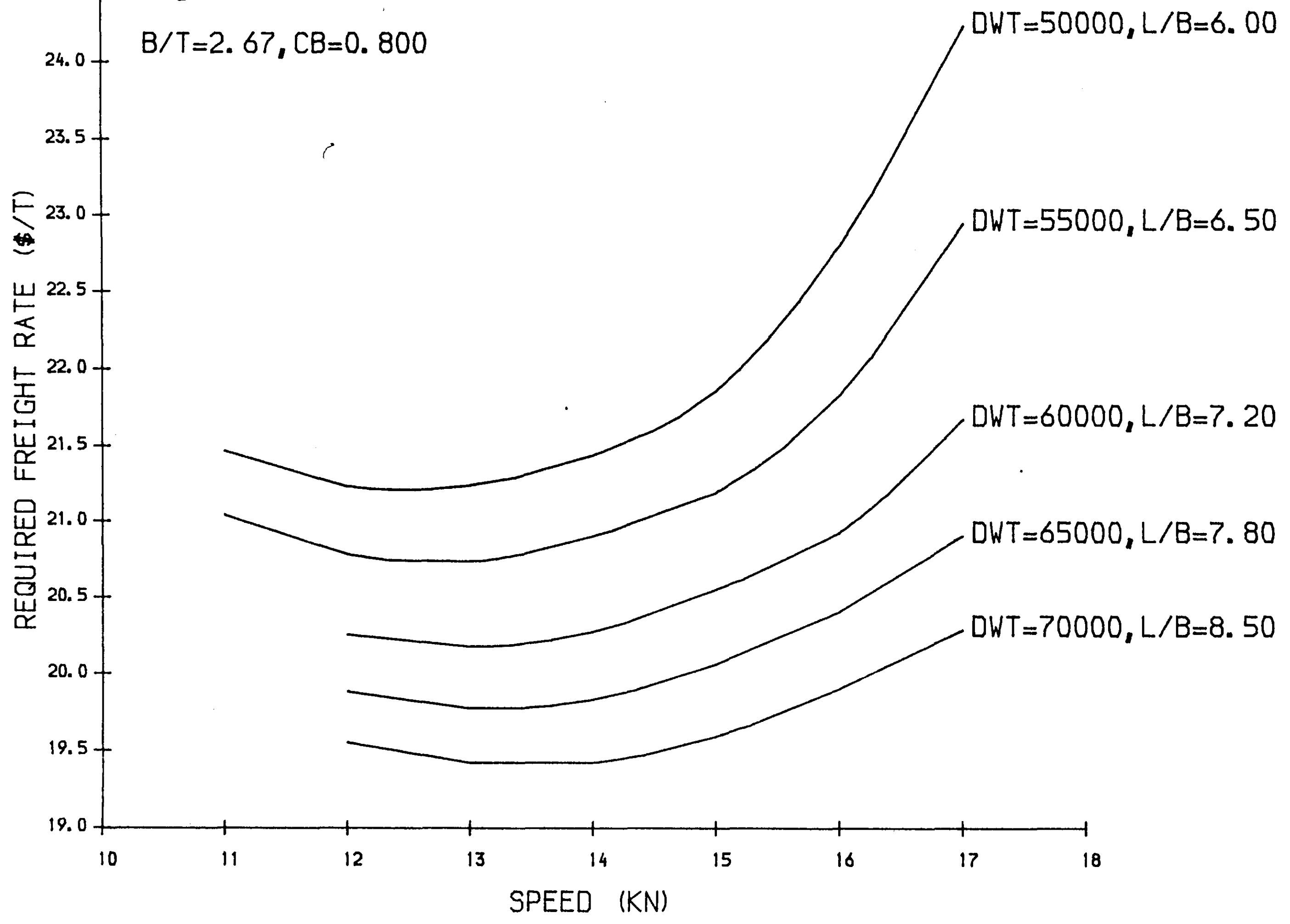


Fig. 8.2 DEADWEIGHT VARIATION SERIES

Fig. 8.3 DEADWEIGHT VARIATION SERIES
B/T=2.67, CB=0.825

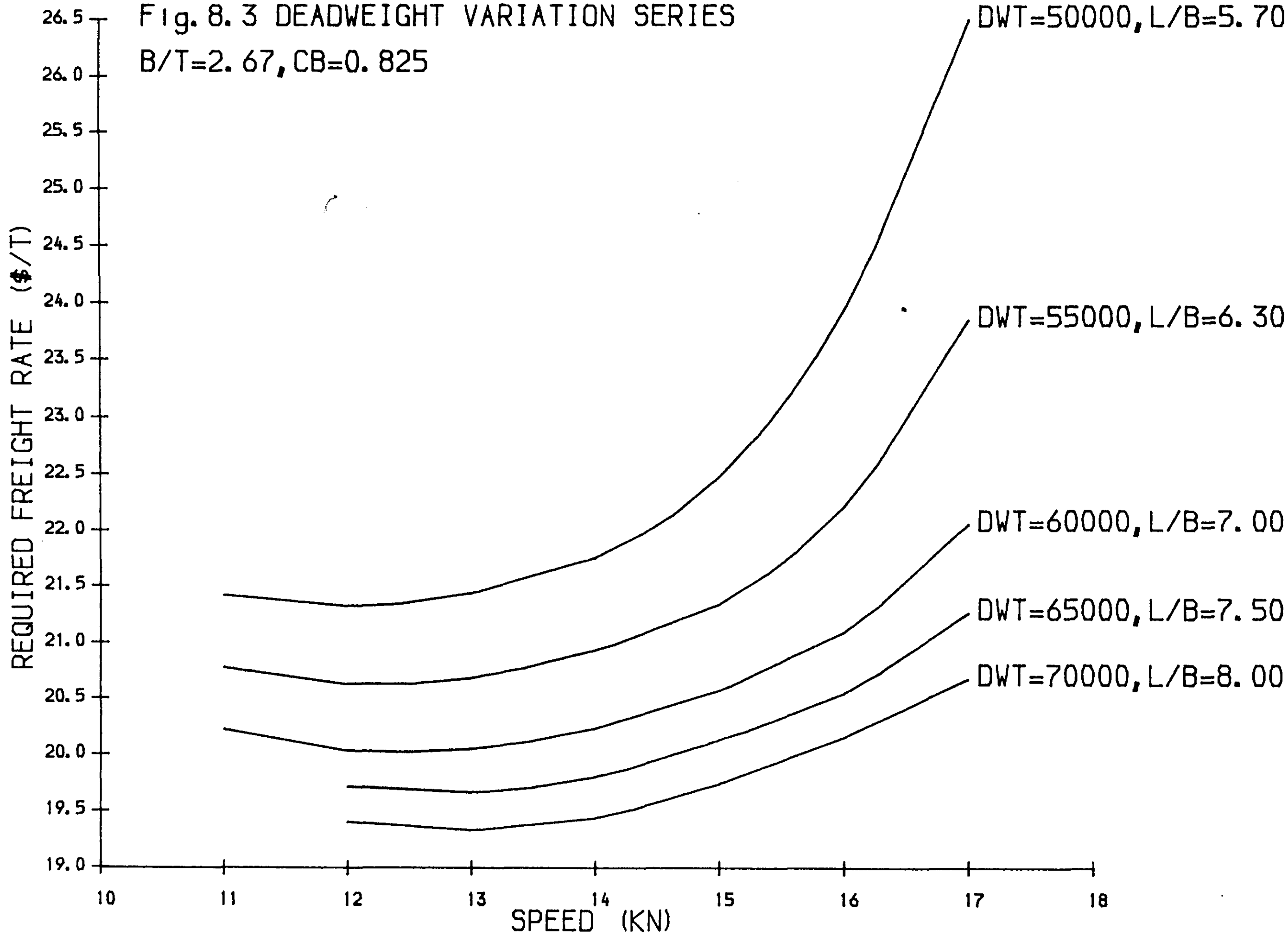
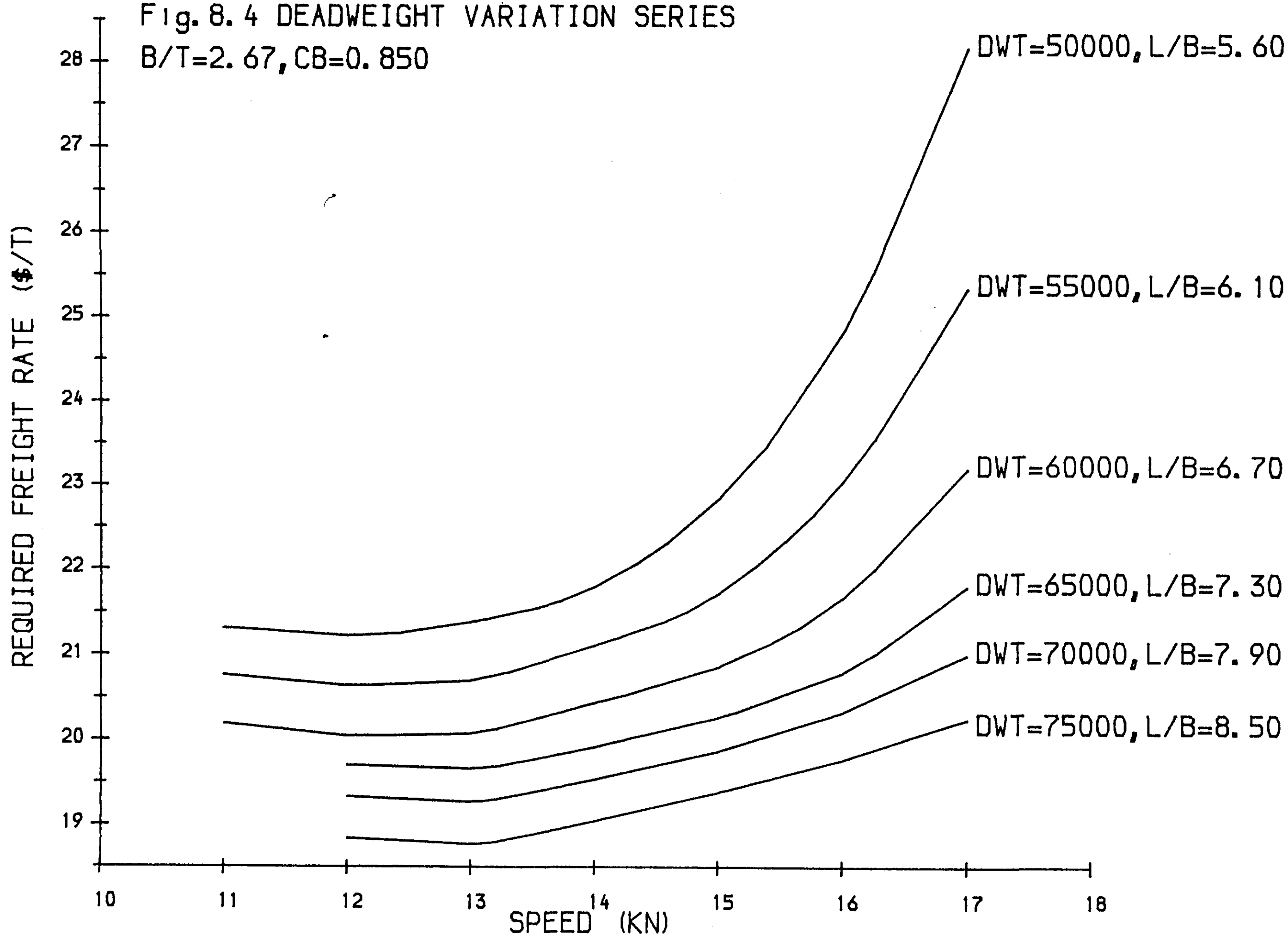


Fig. 8. 4 DEADWEIGHT VARIATION SERIES
B/T=2. 67, CB=0. 850



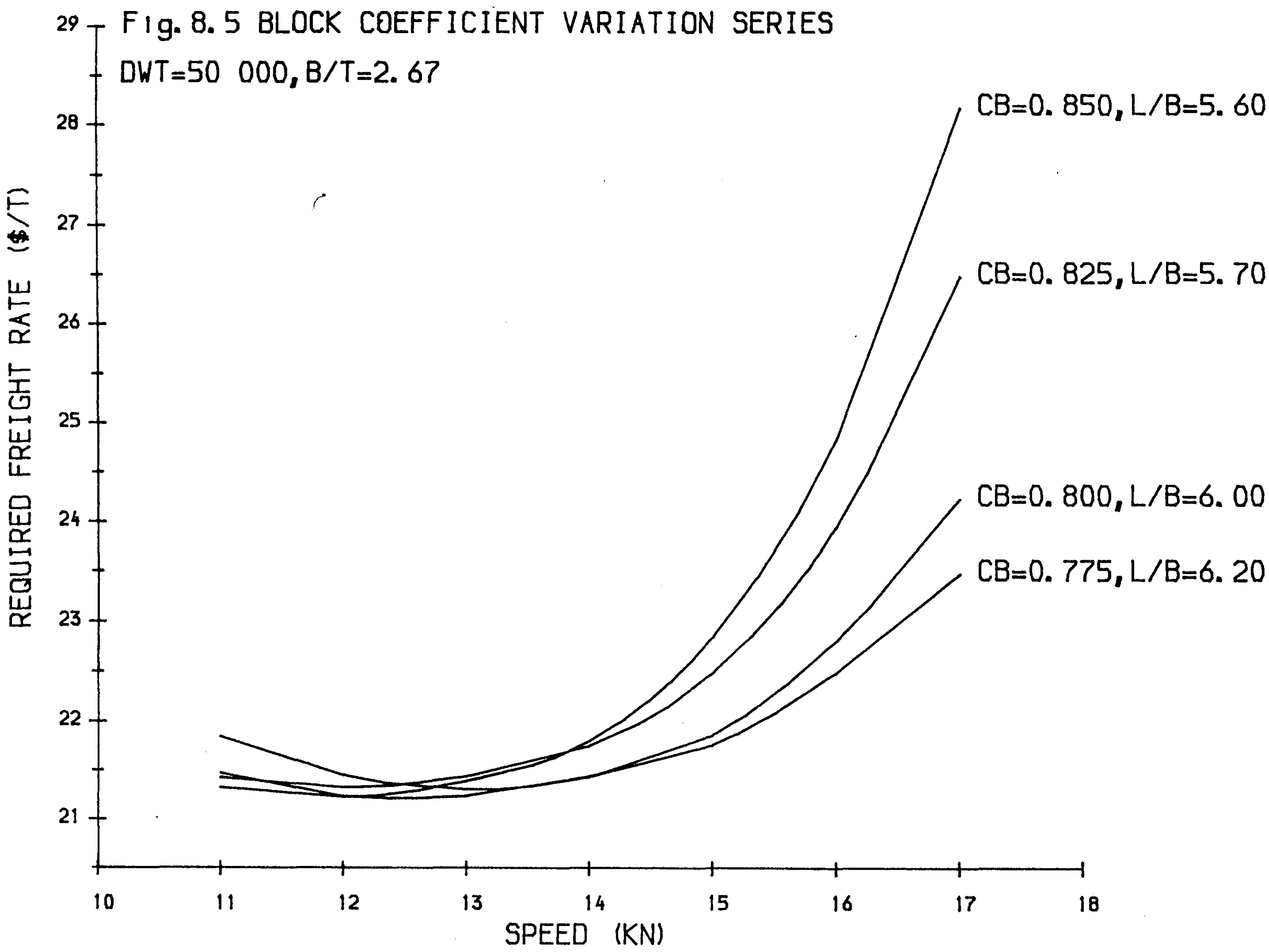


Fig. 8.5 BLOCK COEFFICIENT VARIATION SERIES

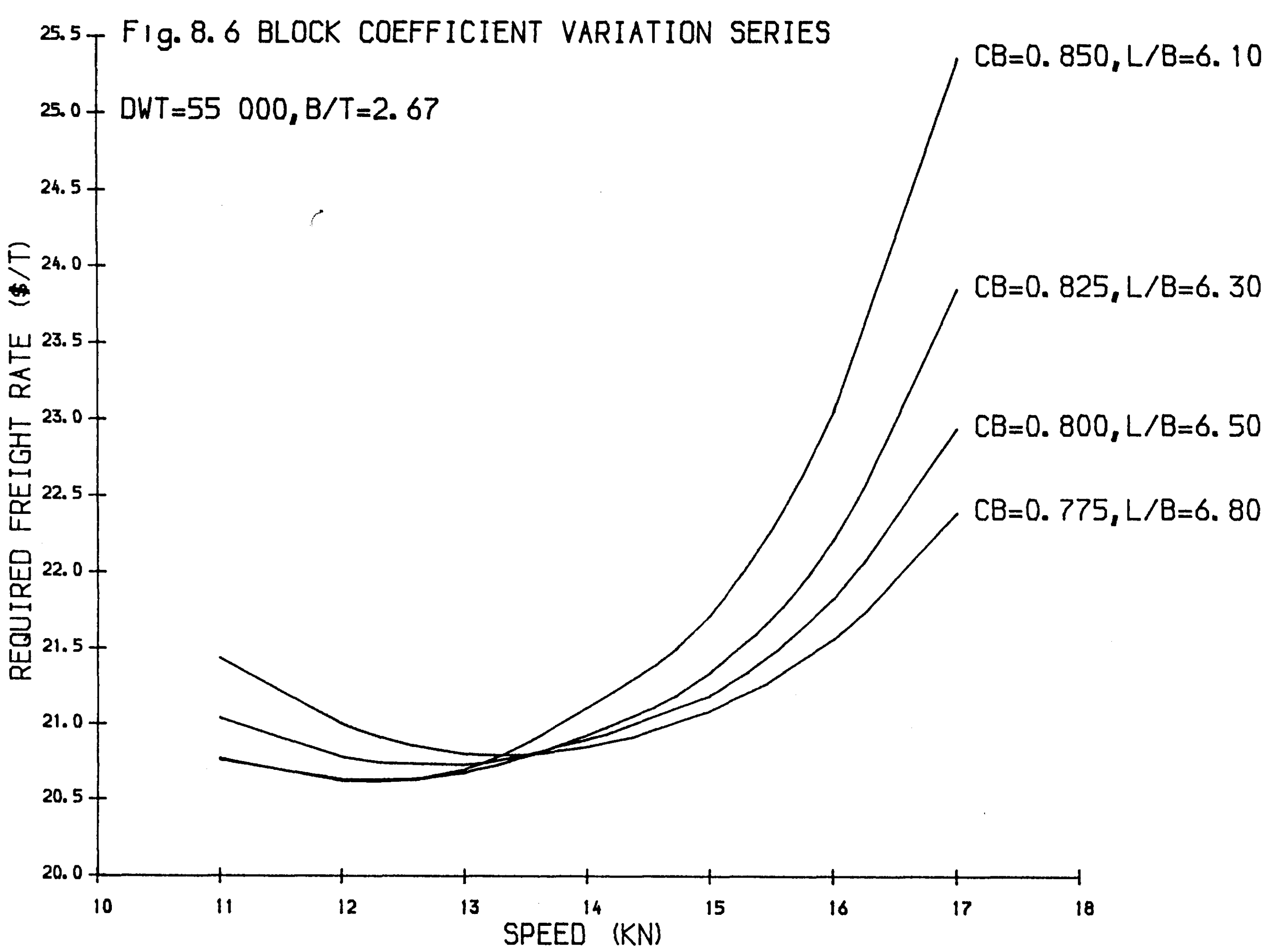
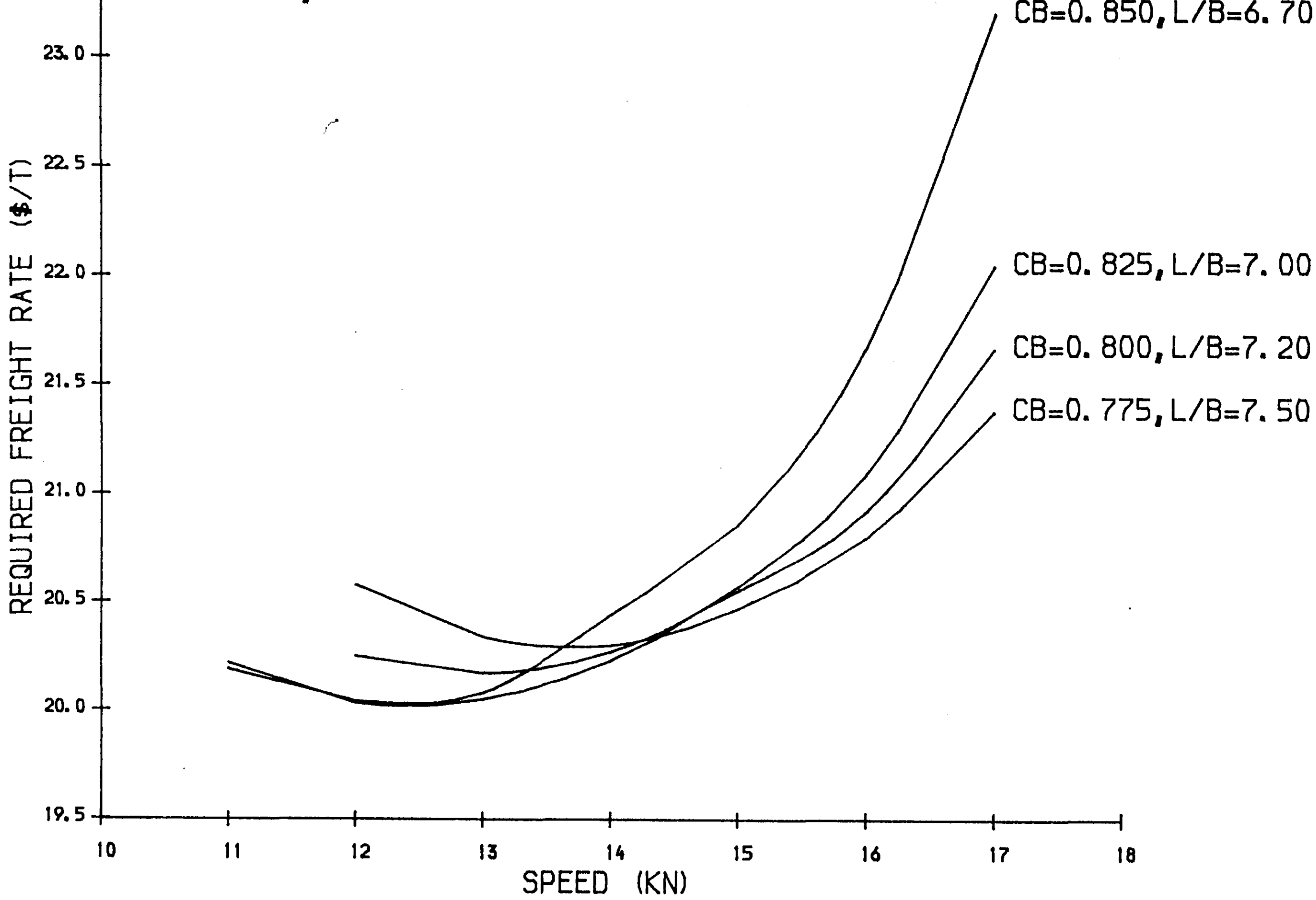


Fig. 8.6 BLOCK COEFFICIENT VARIATION SERIES
DWT=55 000, B/T=2.67
CB=0.850, L/B=6.10
CB=0.825, L/B=6.30
CB=0.800, L/B=6.50
CB=0.775, L/B=6.80
REQUIRED FREIGHT RATE ($/T)
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
21.0
20.5
20.0
10
11
12
13
14
15
16
17
18
SPEED (KN)

Fig. 8.7 BLOCK COEFFICIENT VARIATION SERIES
DWT=60 000, B/T=2.67



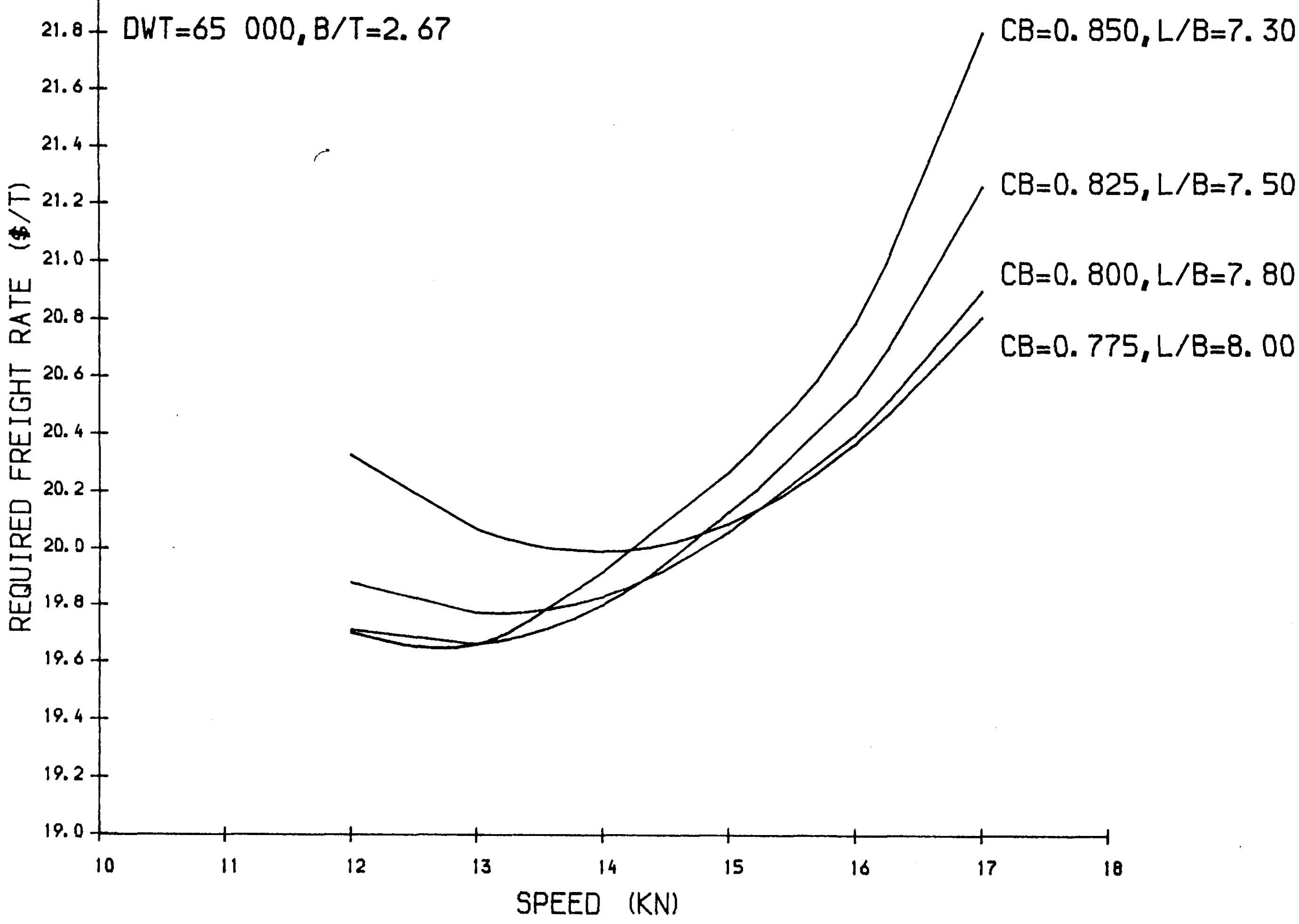


Fig. 8.8 BLOCK COEFFICIENT VARIATION SERIES

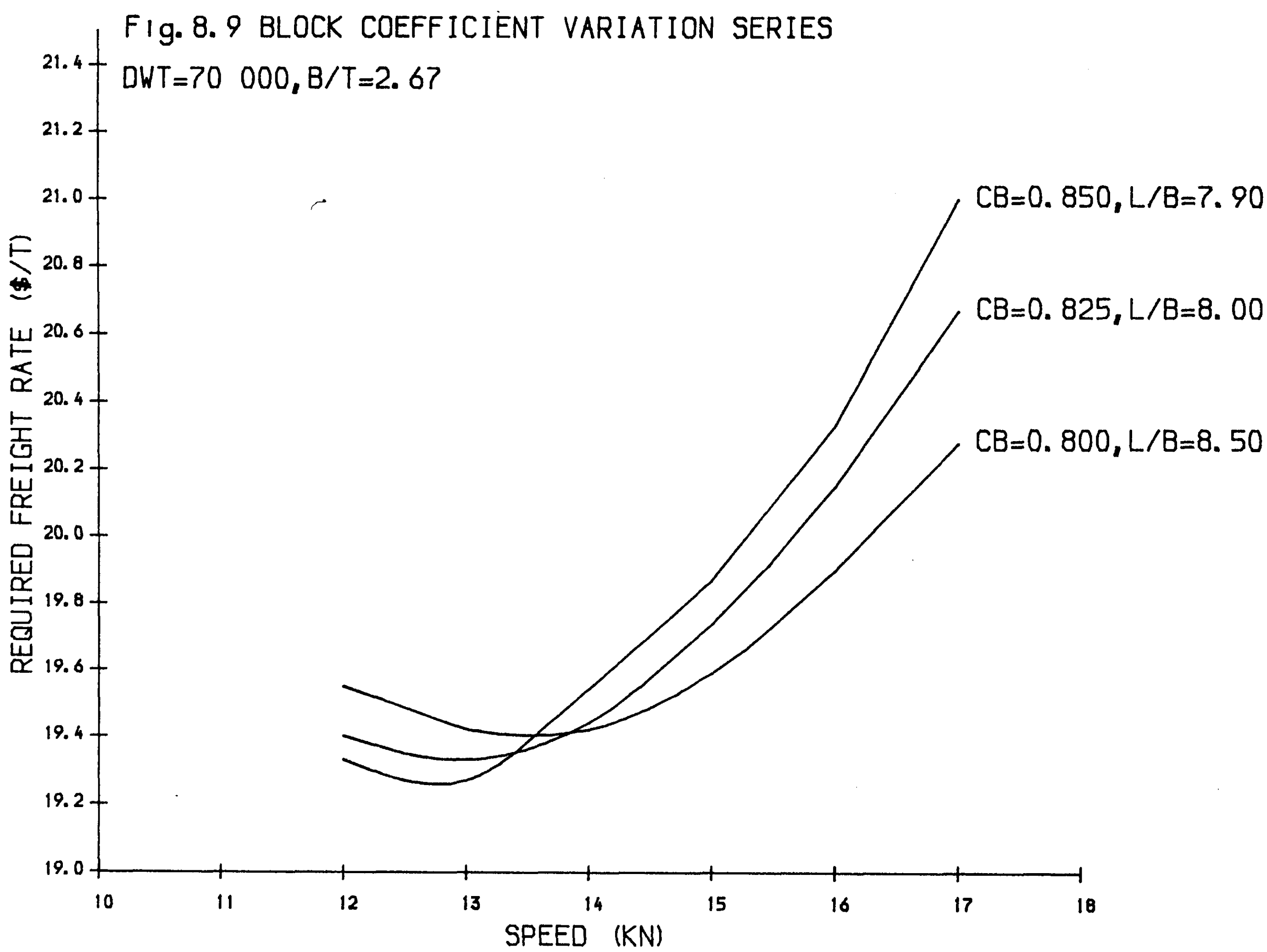
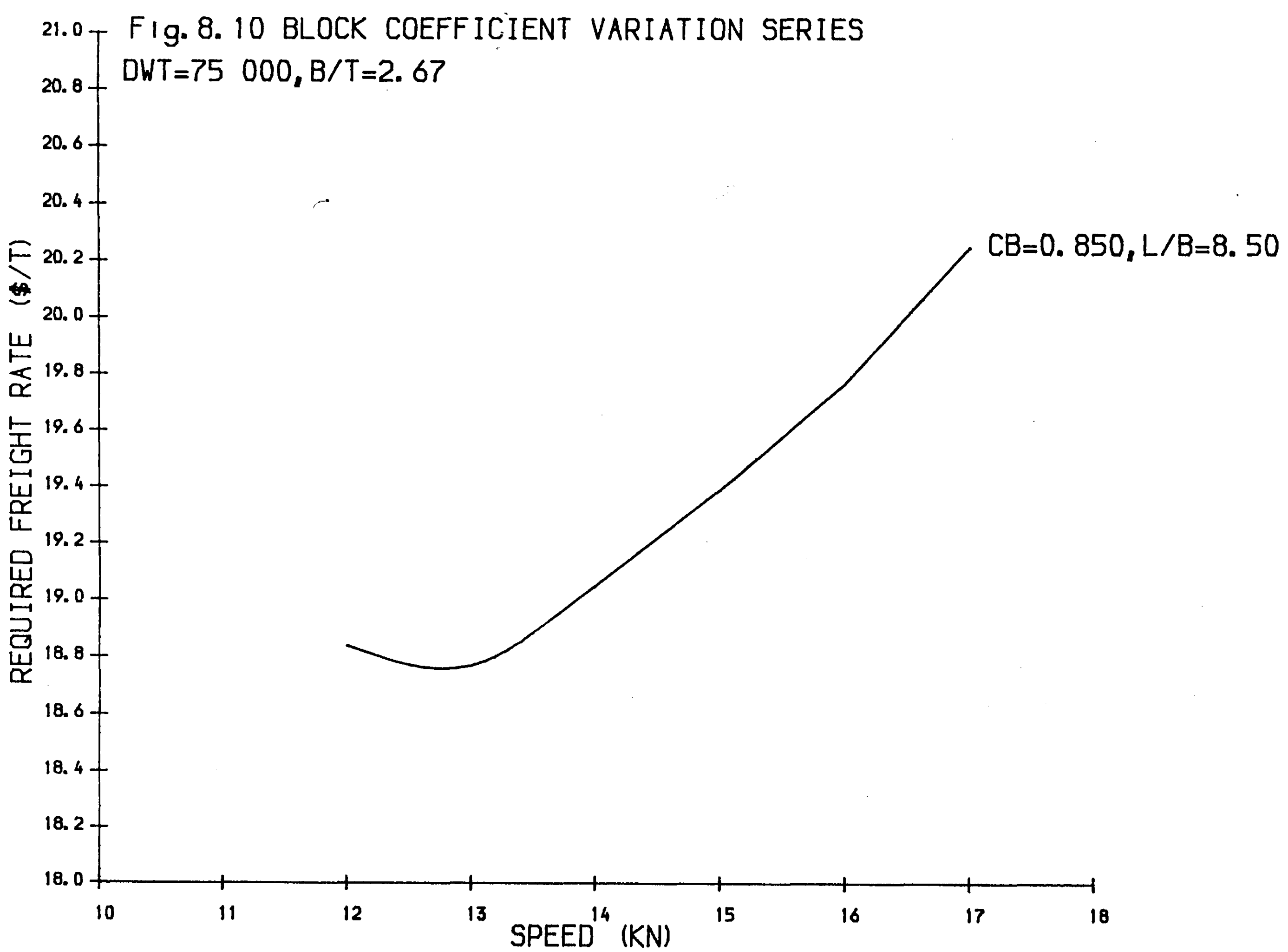


Fig. 8.9 BLOCK COEFFICIENT VARIATION SERIES
DWT=70 000, B/T=2.67

Fig. 8.10 BLOCK COEFFICIENT VARIATION SERIES
DWT=75 000, B/T=2.67



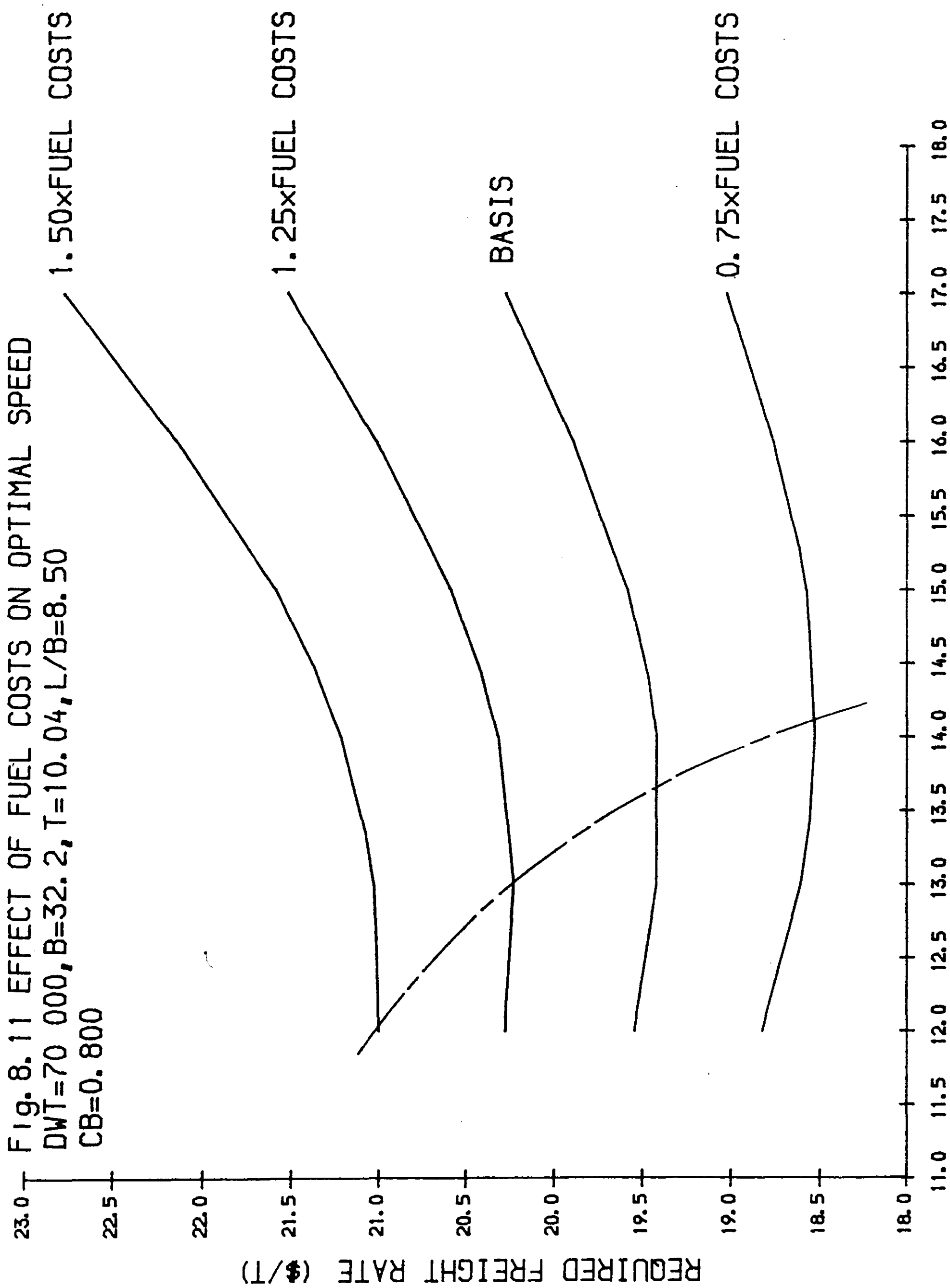


Fig. 8.11 EFFECT OF FUEL COSTS ON OPTIMAL SPEED
DWT=70 000, B=32.2, T=10.04, L/B=8.50
CB=0.800

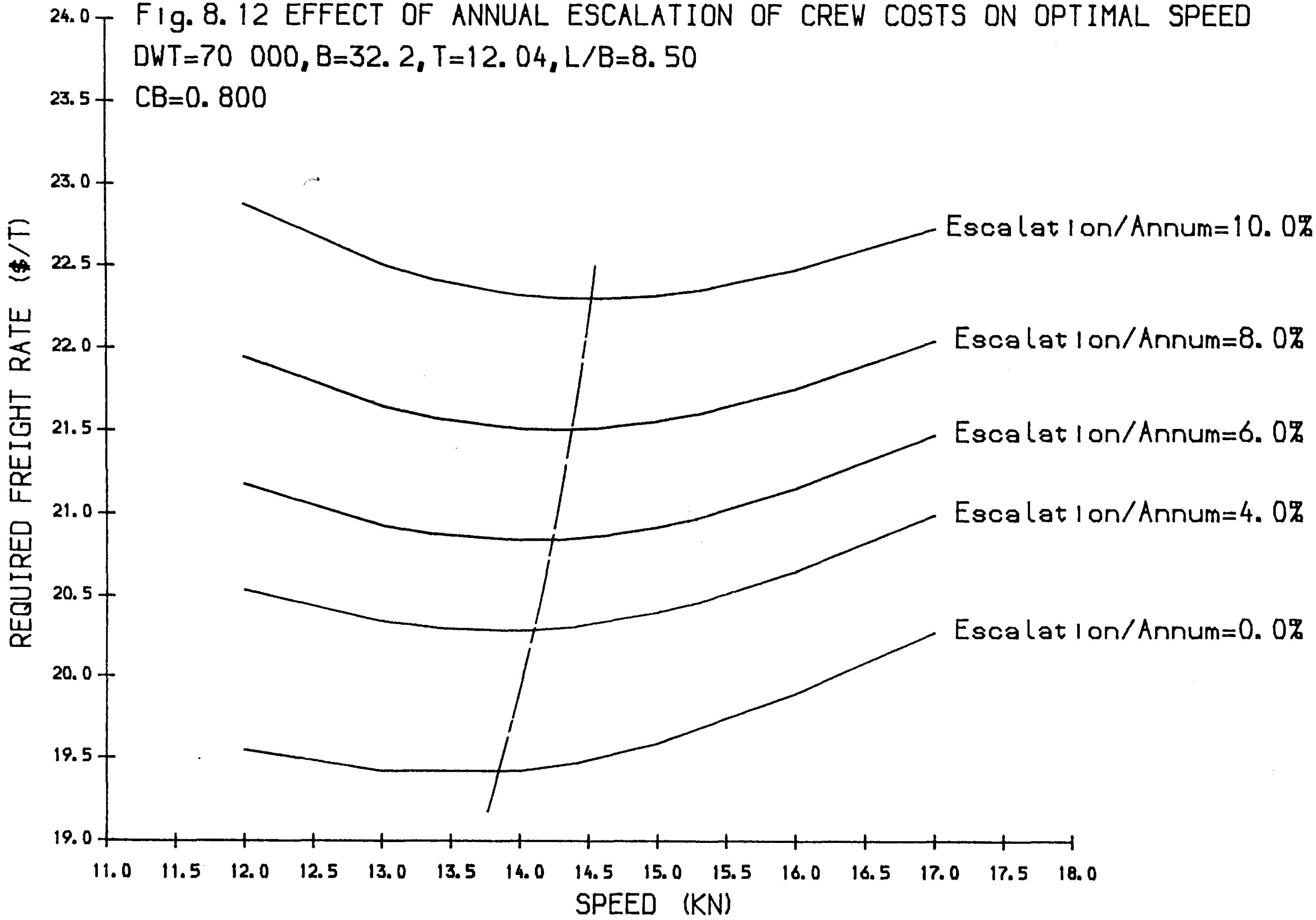


Fig. 8.12 EFFECT OF ANNUAL ESCALATION OF CREW COSTS ON OPTIMAL SPEED
DWT=70 000, B=32.2, T=12.04, L/B=8.50
CB=0.800

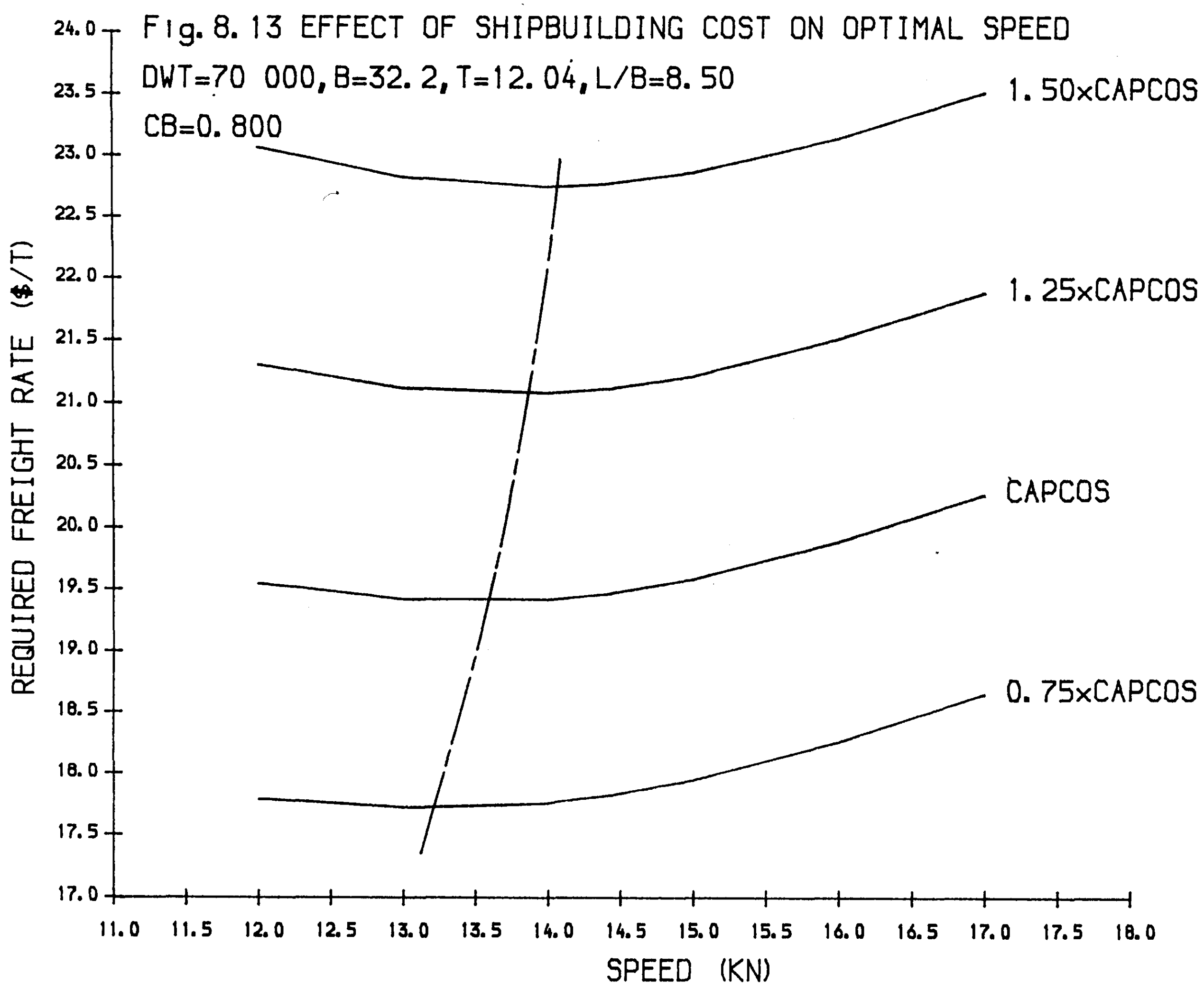


Fig. 8.13 EFFECT OF SHIPBUILDING COST ON OPTIMAL SPEED

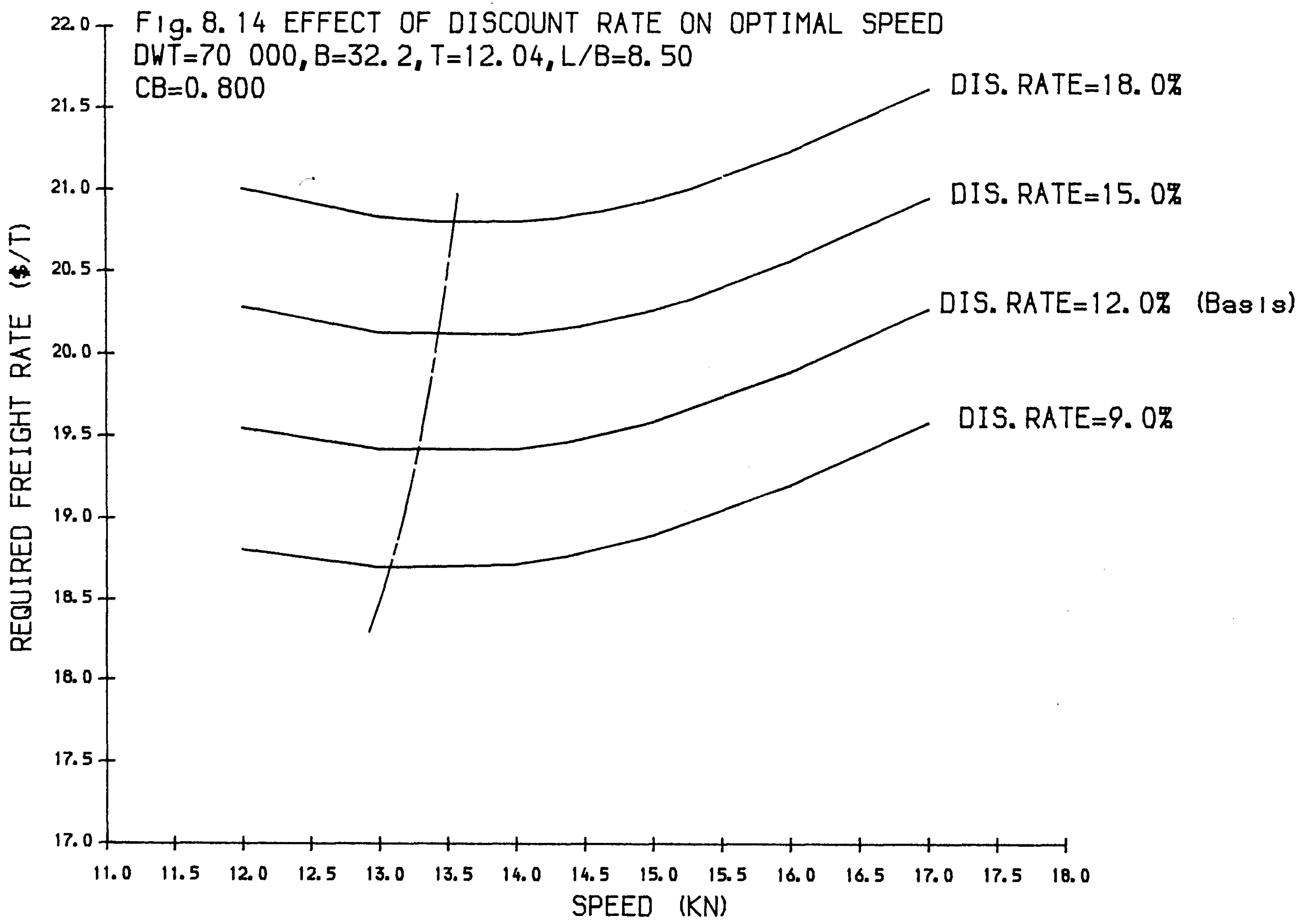


Fig. 8.14 EFFECT OF DISCOUNT RATE ON OPTIMAL SPEED
DWT=70 000, B=32.2, T=12.04, L/B=8.50
CB=0.800

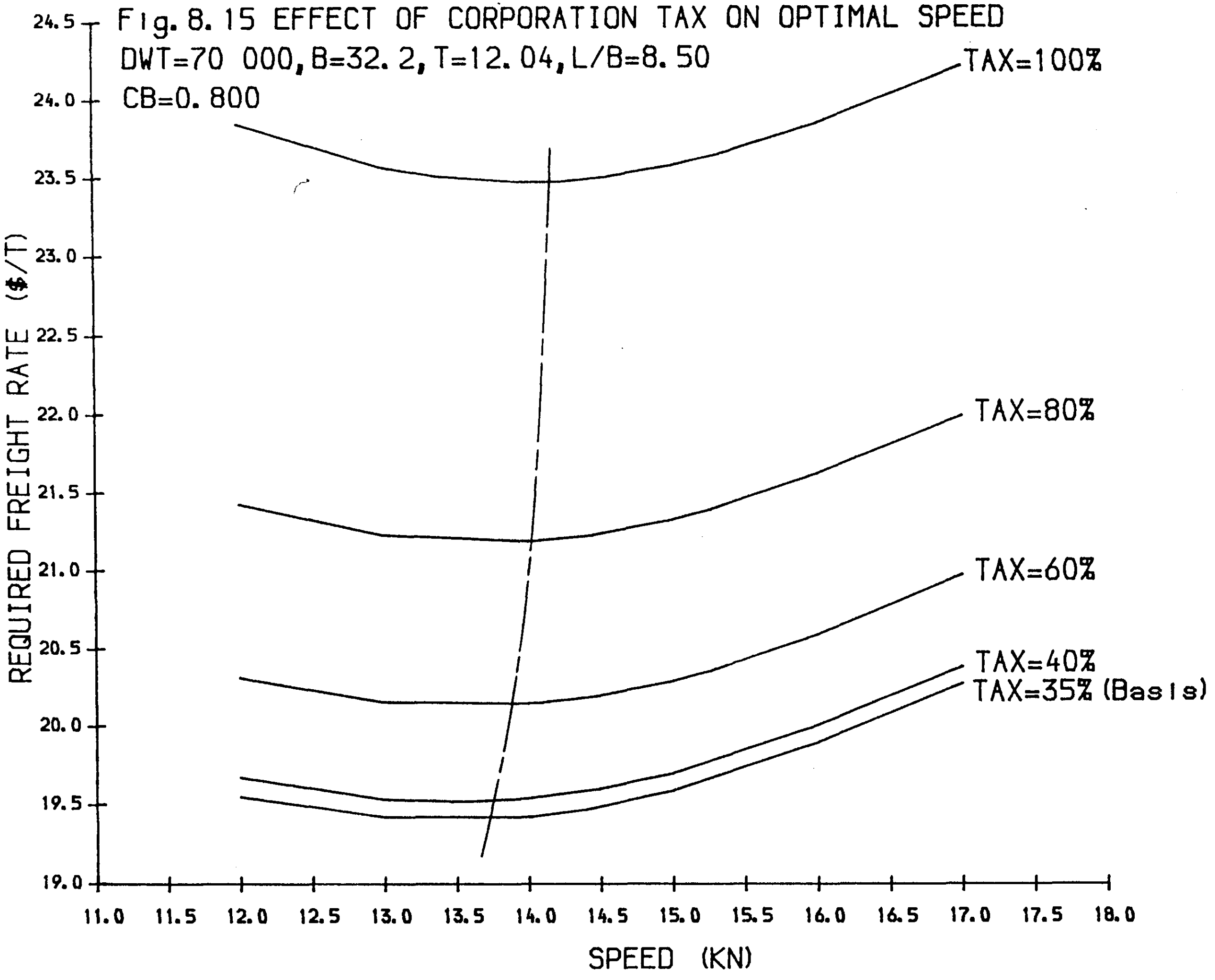


Fig. 8.15 EFFECT OF CORPORATION TAX ON OPTIMAL SPEED
DWT=70 000, B=32.2, T=12.04, L/B=8.50
CB=0.800

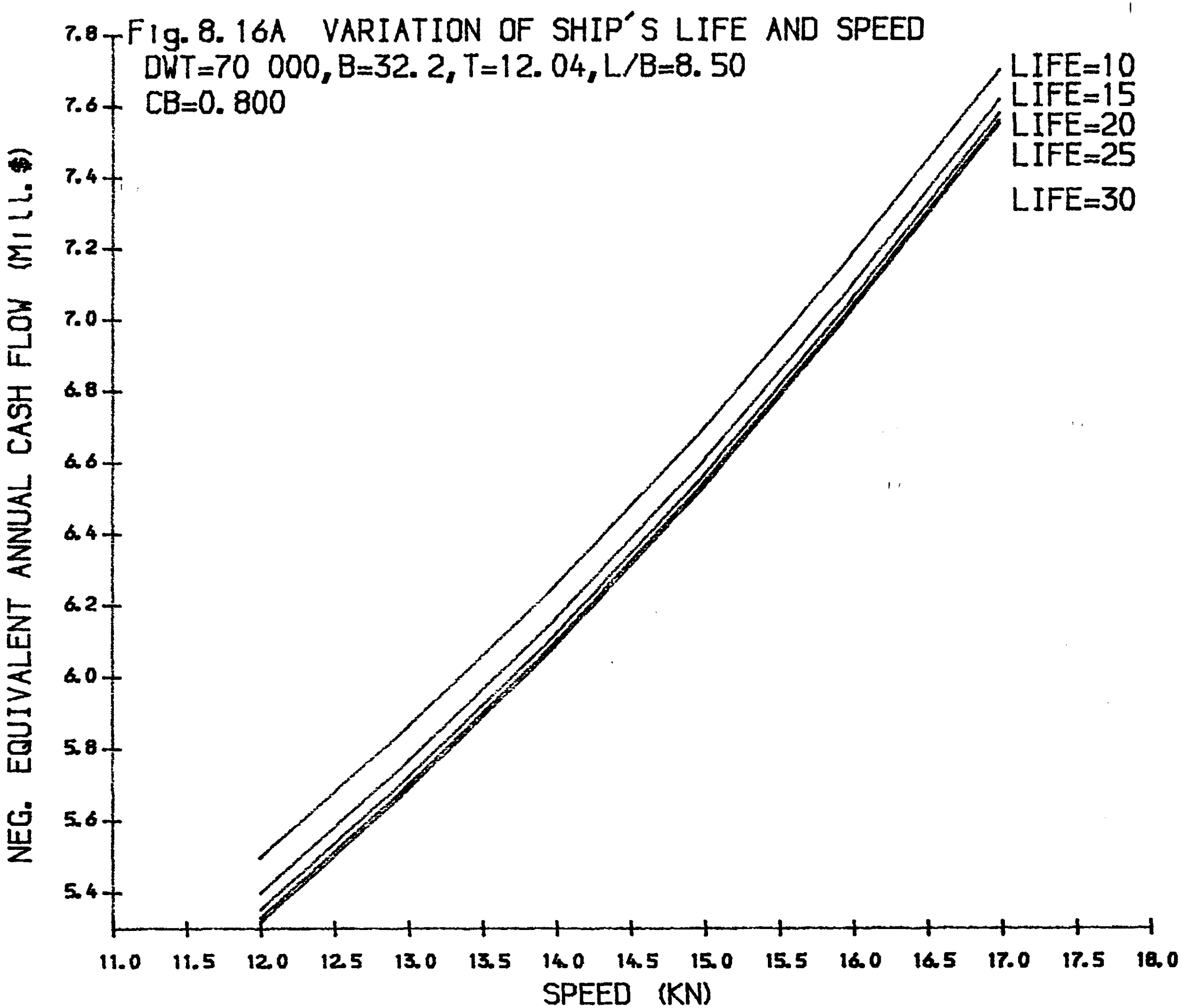


Fig. 8. 16A VARIATION OF SHIP'S LIFE AND SPEED
DWT=70 000, B=32. 2, T=12. 04, L/B=8. 50
CB=0. 800
LIFE=10
LIFE=15
LIFE=20
LIFE=25
LIFE=30
NEG. EQUIVALENT ANNUAL CASH FLOW (MILL. $)
SPEED (KN)
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0

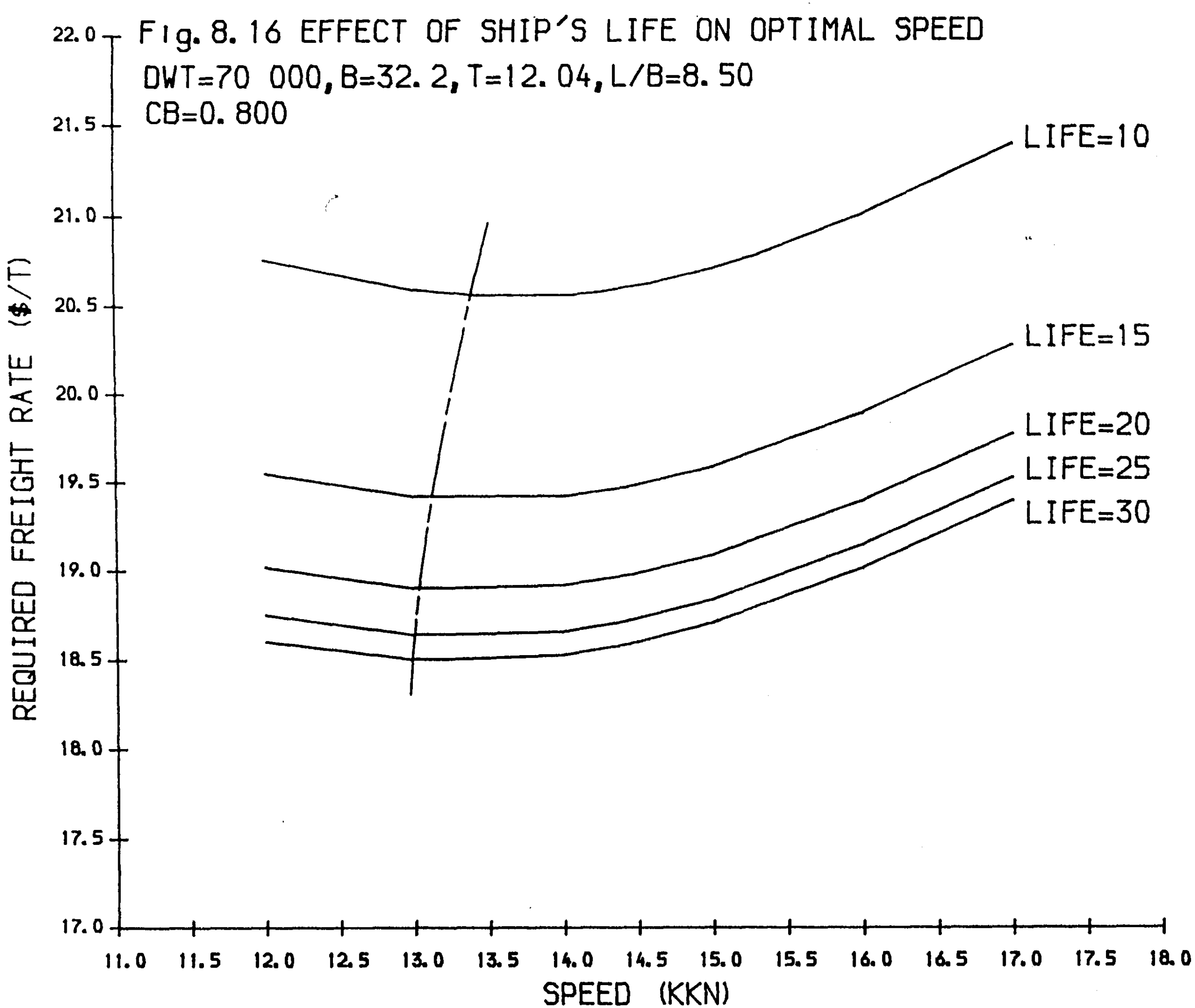


Fig. 8.16 EFFECT OF SHIP'S LIFE ON OPTIMAL SPEED
DWT=70 000, B=32.2, T=12.04, L/B=8.50
CB=0.800

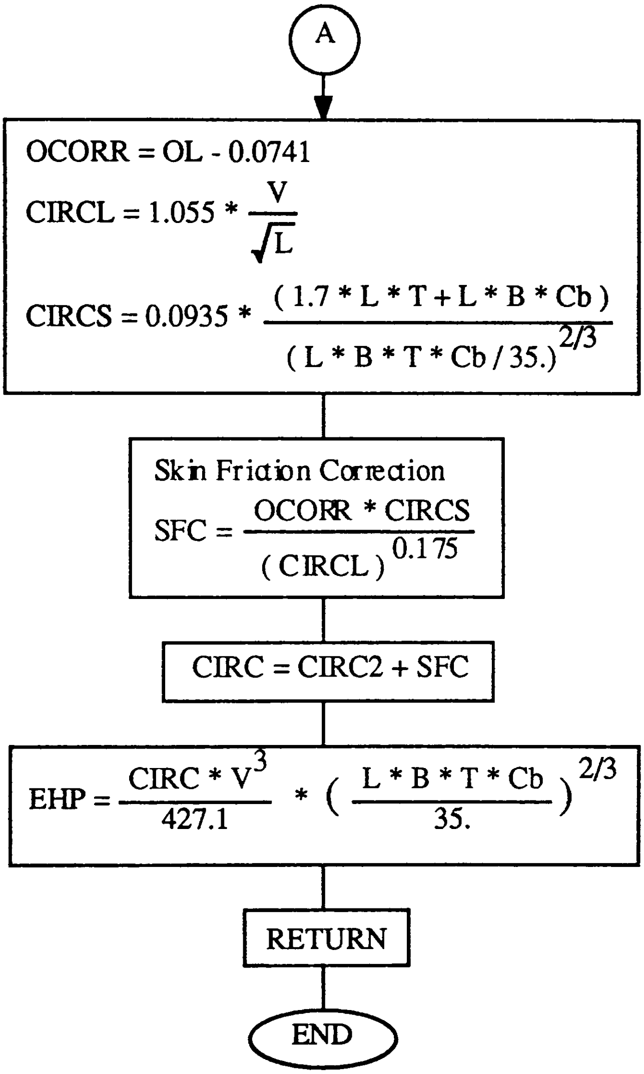
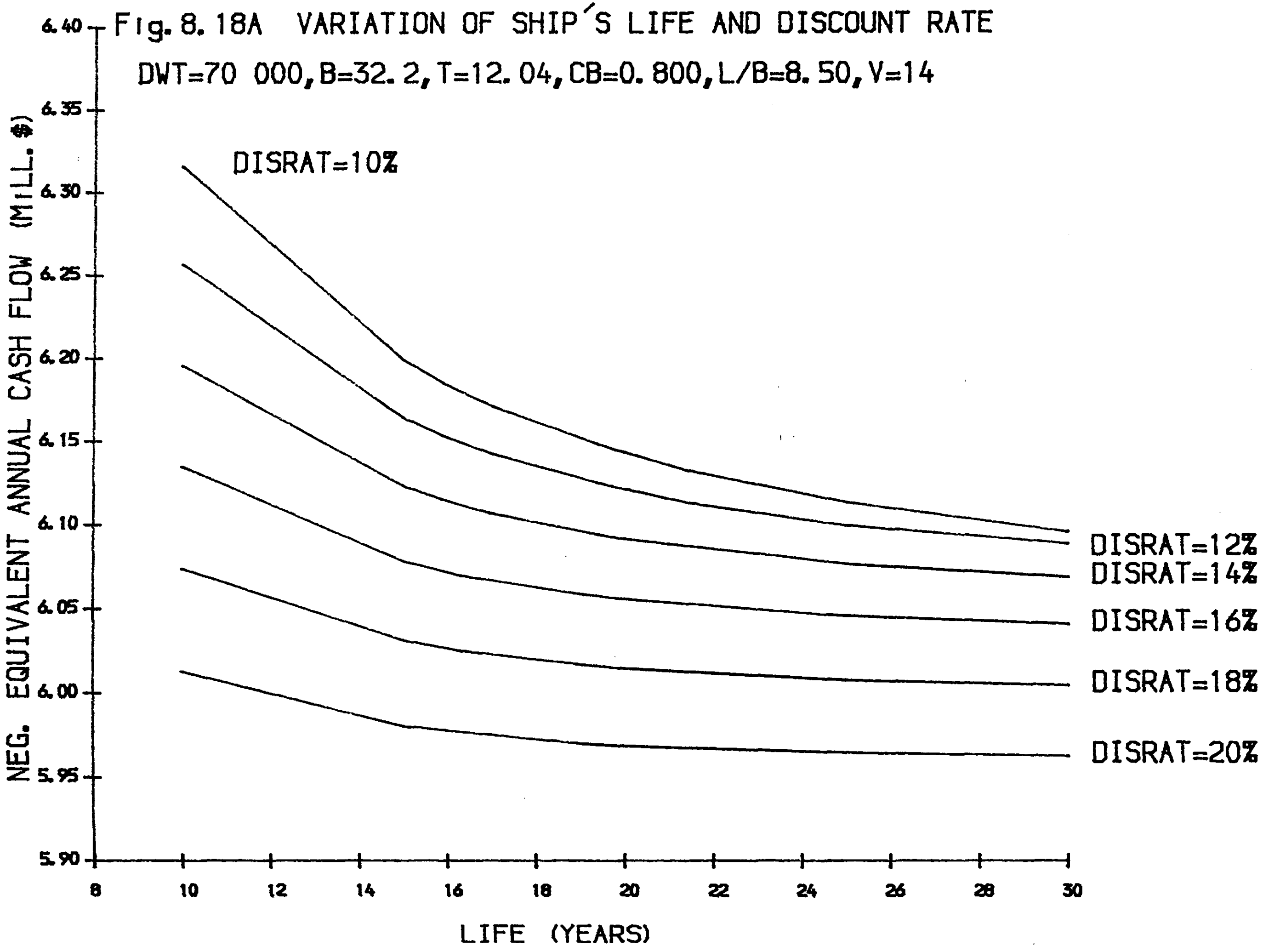

A
OCORR = OL - 0.0741
CIRCL = 1.055 * V / √L
CIRCS = 0.0935 * (1.7 * L * T + L * B * Cb) / (L * B * T * Cb / 35.)^2/3
Skin Friction Correction
SFC = OCORR * CIRCS / (CIRCL)^0.175
CIRC = CIRC2 + SFC
EHP = CIRC * V^3 / 427.1 * (L * B * T * Cb / 35.)^2/3
RETURN
END

Fig. 8. 18A VARIATION OF SHIP´S LIFE AND DISCOUNT RATE

DWT=70 000, B=32. 2, T=12. 04, CB=0. 800, L/B=8. 50, V=14



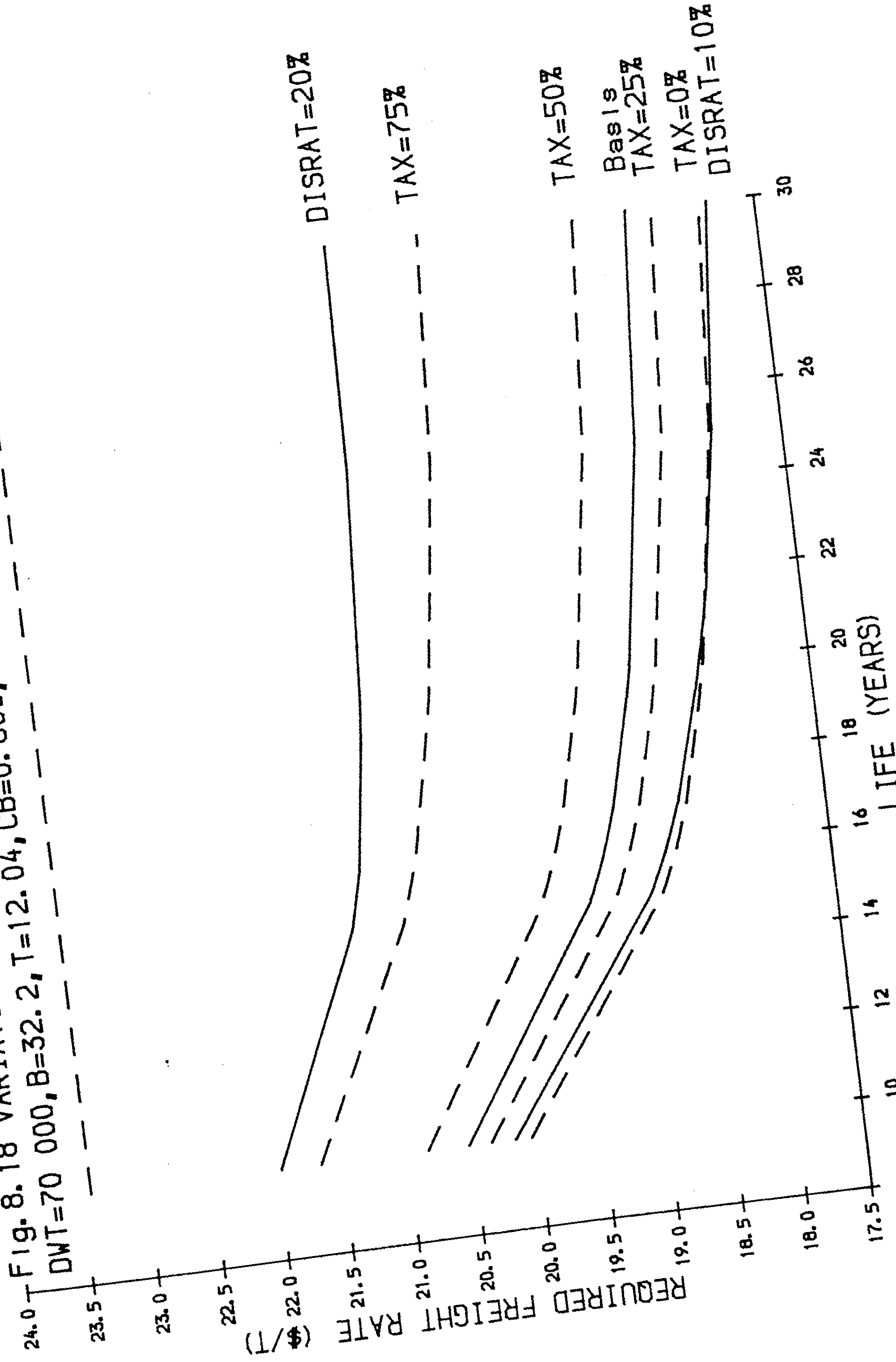


Fig. 8.18 VARIATION OF CORPORATION TAX, DISCOUNT RATE AND SHIP'S LIFE

Case 1 assumes no relative escalation of either freight rate or operating cost items. This is the case where the shipowner is free to adjust his freight rates to offset any increase in his operating costs. Case 2 assumes a relative escalation of crew costs of 5% per annum. Crew costs are chosen to escalate relative to others because it is the cost item which is likely to increase faster over the years.

Table 8.1 and 8.2 give the results of 10% improvement in the different parameters with their order of merit for case 1 and case 2.

These parameters are discussed separately below in their order of merit and resulted changes in percentage of other features given.

8.3.1.1 ROUND VOYAGE DISTANCE.

The round voyage distance of 18,300 nm is reduced by 10%. This reduction brings the number of round trips per annum up by 10.06% increasing, therefore, the amount of cargo transported annually by 10.25%. Due to these changes, the annual fuel costs are reduced by 0.72%, port costs, cargo handling charges and canal dues are respectively increased by 10.10, 10.29 and 10.10% totalizing a 4.28% increase in total operating costs.

A reduction of trade distance is not obvious since the distance between the two ports considered is chosen as the shortest. Therefore, the shipowner would not be interested in this particular improvement if the ship is destined to serve permanent ports giving a fix trade distance. However, the required freight rate is very sensitive to trade distance which ranks in first position for both cases.

8.3.1.2 TOTAL OPERATING COSTS.

Total operating costs including daily running costs and voyage costs are reduced by 10%. RFR is also very sensitive to this improvement which shows that operating costs, and particularly fuel, crew and cargo handling costs are of considerable importance to bulk carriers. A reduction in operating costs can in many ways be achieved since a shipowner has the ability of choosing low crew costs, investing in automation and thus reducing his manning or reducing his fuel bill by selecting a more economic propulsion plant of reduced fuel consumption.

8.3.1.3 CAPITAL COST.

Capital cost is also an important parameter and its reduction depends less on the shipowner than the competitive situation between shipyards and levels of wage rates in the country of construction. Therefore, a shipowner is always tempted to go to the shipyard with the least bid price and acceptable period of construction.

A reduction of 10% in capital cost reduces hull and machinery insurance by 10.00% since this cost item is estimated from it.

8.3.1.4 STEEL WEIGHT.

For bulk carriers steel weight forms a high proportion of the lightship weight. For the range of ships considered the steel weight to lightship weight ratio is found to vary between 75 and 81%. Therefore, any reduction in steel weight has an appreciable repercussion on other ship features including capital cost.

For the ship under study, a reduction of 10% in steel weight, for constant displacement, increases the deadweight by 1.95% due to reduction in lightship weight, a value of 8.52%. Capital cost is decreased by 3.75% bringing hull and machinery insurance cost down by the same percentage. The ship deadweight being increased, cargo deadweight transported annually is increased by 1.82% with a slight decrease in the number of round trips per annum, fuel , port and canal costs and increase in cargo handling costs.

As a result, RFR is found to be very sensitive to steel weight.

Reduction of steel weight depends upon methods employed in shipyards of estimation and skill in utilising economically material during the construction. Use of higher tensile steel, although more expensive, could bring some of this reduction.

8.3.1.5 INSTALLED POWER.

A 10% reduction in installed power performed in the program brings the lightship weight down by 0.45% due to resulted reduction in machinery weight, 7.87%. As a consequence, the capital cost is decreased by 2.09%. The more sensitive parameters to reduction in installed power is the fuel which is decreased in weight by 9.07% and in annual costs by 8.61%. Other operating costs affected by this reduction are maintenance and repair, and hull and machinery insurance which are respectively reduced by 3.86 and 2.09%. Port and cargo handling charges are not very much affected. From these changes, total operating costs are reduced by 2.55%.

Reduction in installed power is not easy to achieve due to possible deterioration in hull condition with passage of time causing the opposite effect of increasing this power to maintain a schedule speed. Therefore, a shipowner would not be very concerned in reducing this parameter in the search for more profit.

8.3.1.6 SHIP'S LIFE.

As discussed in section 8.2.2.6 and 8.2.3 and illustrated in fig.8.16 and 8.18, an increase of ship's life from 15 to 20 years brings a fairly important reduction in RFR. However, in case 2 the ship's life is less important ranking in 11th position while in case 1 it ranks in 6th position with the installed power.

8.3.1.7 FUEL COSTS.

Fuel costs are the most significant cost item in total operating costs. They have dramatically increased since 1973 urging shipowners to reduce them by any possible means. As a direct consequence of the rise of fuel prices, operating speed has been reduced to minimise their costs.

For the ship under study fuel costs represent about 27.82% of total operating costs. A 10% reduction in fuel (heavy fuel, marine diesel and lub oil) costs reduces operating costs by 2.78%.

Fuel prices are very unstable depending on production quota agreed between countries producing this source of energy, e.g. OPEC countries. Therefore, it is of great importance that the design must not be too much dependent on them as their sudden movement, if it happen to be a rise, would require a slow steaming and reduce the competitiveness of the ship.

8.3.1.8 GROSS TONNAGE.

Gross tonnage has a commercial importance due to the fact that some charges are levied on either it or net tonnage such as port costs, canal dues and protection and indemnity insurance.

A 10% reduction in gross registered tonnage causes a decrease of protection and indemnity insurance by 10.00% and of port costs and canal dues by the same percentage of 10.30%. This reduction results, therefore, in 2.76% decrease of operating costs.

Reducing gross tonnage for the same required ship capacity is possible. Shipowners usually aim to design their ship(s) with the smallest gross tonnage possible based on rules related to this measurement and giving the same initial requirements.

8.3.1.9 LABOUR WAGE RATES.

A 10% reduction in shipbuilding wage rates brings the shipbuilding labour cost down by the same percentage and decreases, therefore, capital cost by 4.77% which in turn reduces hull and machinery insurance by the same percentage.

Wage rates are unlikely to be reduced as they are dictated by the general economic environment and supported by national labour unions. They are, on the contrary, more subject to increases over the years. The shipowner, however, has the freedom to choose the country of construction with lower level of wage rates.

8.3.1.10 SPECIFIC FUEL CONSUMPTION.

Specific fuel consumption is a very important parameter in the selection of machinery plant. It is this parameter which governs more the reduction of fuel costs.

A reduction of 10% in specific fuel consumption (main engine) permits to reduce respectively fuel weight and annual costs by 9.03 and 8.05%. Resulted changes in port, canal and cargo handling costs are almost negligible. With reduction in sfc operating costs are reduced by 2.22%.

Reduction in specific fuel consumption is being achieved by modern diesel engines particularly after the introduction of uniflow scavenged long bore engines with very low propeller revolutions per minute.

8.3.1.11 CARGO HANDLING COSTS.

These costs vary largely from port to port and particularly for bulk cargoes. Generally, they are not paid by the shipowner as cargo is often

charged free on board (f.o.b). They are, however, taken into consideration in the program and included in operating costs.
For the ship under study, this cost item forms about 19.5% of total operating costs.
A 10% improvement in this parameter reduces operating costs by about 1.95%.

8.3.1.12 CREW COSTS.

A reduction of crew costs, the most important cost item in daily running costs, a percentage which may indeed exceed 50%, depends on constraints upon shipowners to choose their crew. Shipowners of developing countries flagging under flags of convenience have more flexibility to employ crew of lower wage than those under national flags employing more nationals with higher costs. Another alternative in reducing these costs is to automate the ship and then reduce crew number. This solution supposes that the shipowner is willing to invest in automation and to face traditional opposition from national unions of seamen seeking to maintain high employment opportunities for their members.
A 10% reduction in crew costs reduces operating costs by about 1.83%. For case 2 where this cost item is escalated 5% annually, crew costs rank at more important position of 8 while 12 is for case 1.

8.3.1.13 CANAL DUES.

This cost, for Panama Canal transit, is levied on Panama net tonnage measurement. The only way, therefore, to reduce it is to decrease gross tonnage as discussed in section 8.3.1.8.
In the program a 10% reduction in canal dues reduces operating costs by 1.29%.

8.3.1.14 PORT COSTS.

As for canal dues, port costs are also levied on net tonnage and their reduction can be achieved if gross tonnage is reduced. In real terms, this cost item vary enormously between ports and degree of facilities they offer.
A 10% improvement in port costs is found to reduce operating costs by 1.16%.

8.3.1.15 STEEL COST.

A 10% reduction in the cost per tonne of steel decreases ship capital cost by 1.68% which in turn reduces hull and machinery insurance by the same percentage.

The cost per tonne of steel is fixed by manufacturers depending on the market condition and world steel production. However, the overall steel cost can be reduced if the weight of steel ordered by shipyards is optimised by minimising scrap percentages.

For the basis ship RFR is found not to be very influenced by this cost.

8.3.1.16 PORT TIME PER ROUND TRIP.

For the trade route assumed a 10% reduction in port time has the following consequences. Fuel costs are increased by 0.65% due to increase in the number of annual round trips, 0.81%, port, canal and cargo handling costs are increased by the same percentage of 0.82%. Operating costs are, therefore, increased by 0.54% but met with an increase of the amount of cargo carried annually of 0.81%.

As it can be seen from the small changes given above, RFR is found not very sensitive to time spent in ports. This is mainly due to the long trade distance considered in this study where time spent at sea represents a very high proportion of time spent per round trip.

8.3.1.17 UPKEEP COSTS.

Upkeep costs are those costs related to machinery & repair, and deck & engine stores.

A 10% reduction in these costs brings only a reduction of 0.62% in operating costs. Therefore, these costs do no affect RFR appreciably.

8.3.1.18 TIME OUT OF SERVICE.

A 15 days per annum, assumed in the program to be spent for dry docking and repair, is decreased by 10% to measure the effect on RFR.

This reduction increases the number of round trips per annum by 0.32%, fuel costs by 0.42% and port,canal and cargo handling charges by 0.43%. With these changes operating costs are increased by 0.31% and cargo carried annually by 0.32%. As a result of these very small changes, time out of service has practically no effect on RFR.

TABLE 8.1 RELATIVE IMPORTANCE OF 10% IMPROVEMENT IN DIFFERENT FEATURES OF SHIP'S PERFORMANCE (CASE 1 : NO RELATIVE ESCALATION).

Ship's Features	Initial Value	Final Value	RFR ($/T)	% from Basic RFR	Order of Merit
Basic Ship			19.388		
Endurance (n.m)	9,150.	8,235.	18.080	6.749	1
Total Operating Costs ($ Mill.)	5.535	4.981	18.097	6.659	2
Capital Cost ($ Mill.)	17.802	16.022	18.724	3.425	3
Steel Weight (T)	13,406.	12,065.	18.832	2.868	4
Instal. Power (hp)	11,963.	10,772.	18.881	2.615	5
Life (years)	15.	20.	18.881	2.615	5
Fuel Costs ($/T) (h.f.o, m.d.o, sys.&cyl. lub.)	110. 165. 1,344. 1,512.	99. 148.5 1,209.6 1,360.8	19.029	1.852	7
G.R.T	44,467.	40,020.	19.032	1.836	8

Basic Ship :
L = 273.7 ; B = 32.2 ; T = 12.04 ; D = 17.86 ; Cb = 0.800 ; DWT = 70,800.
V = 14.

TABLE 8.1 (continued)

Ship's Features	Initial Value	Final Value	RFR ($/T)	% from Basic RFR	Order of Merit
Basic Ship			19.388		
Labour Wage Rate (£/h)	4.2	3.78	19.071	1.635	9
S.F.C (g/hp.h)	123.	110.7	19.078	1.599	10
Cargo Handling Costs ($ Mill.)	1.080	0.972	19.136	1.300	11
Crew Costs ($Mill.)	1.011	0.910	19.152	1.217	12
Canal Dues ($ Mill.)	0.711	0.640	19.222	0.856	13
Port Costs ($ Mill.)	0.643	0.579	19.238	0.774	14
Steel Cost (£/h)	250.	225.	19.277	0.573	15
Port time Per Round Trip (days)	4.60	4.14	19.300	0.454	16
Upkeep Costs ($ Mill.)	0.344	0.310	19.308	0.413	17
Time Out of Service (days)	15.	13.5	19.345	0.222	18

TABLE 8.2 RELATIVE IMPORTANCE 0F 10% IMPROVEMENT IN DIFFERENT FEATURES OF SHIP'S PERFORMANCE (CASE 2 : ESCALATION OF CREW COSTS = 5%).

Ship's Features	Initial Value	Final Value	RFR ($/T)	% from Basic RFR	Order of Merit
Basic Ship			20.515		
Endurance (n.m)	9,150.	8,235.	19.102	6.888	1
Total Operating Costs ($ Mill.)	5.535	4.981	19.111	6.844	2
Capital Cost ($ Mill.)	17.802	16.022	19.850	3.242	3
Steel Weight (T)	13,406.	12,065.	19.939	2.808	4
Instal. Power (hp)	11,963.	10,772.	20.005	2.486	5
Fuel Costs ($/T) (h.f.o, m.d.o, sys.&cyl. lub.)	110. 165. 1,344. 1,512.	99. 148.5 1,209.6 1,360.8	20.155	1.755	6
G.R.T	44,467.	40,020.	20.158	1.740	7
Crew Costs ($Mill.)	1.011	0.910	20.166	1.701	8

Basic Ship :
L = 273.7 ; B = 32.2 ; T = 12.04 ; D = 17.86 ; Cb = 0.800 ; DWT = 70,800.
V = 14.

TABLE 8.2 (continued)

Ship's Features	Initial Value	Final Value	RFR ($/T)	% from Basic RFR	Order of Merit
Basic Ship			20.515		
Labour Wage Rate (£/h)	4.2	3.78	20.198	1.545	9
S.F.C (g/hp.h)	123.	110.7	20.203	1.521	10
Life (years)	15.	20.	20.220	1.438	11
Cargo Handling Costs ($ Mill.)	1.080	0.972	20.263	1.228	12
Canal Dues ($ Mill.)	0.711	0.640	20.349	0.809	13
Port Costs ($ Mill.)	0.643	0.579	20.365	0.731	14
Steel Cost (£/h)	250.	225.	20.403	0.546	15
Port time Per Round Trip (days)	4.60	4.14	20.418	0.473	16
Upkeep Costs ($ Mill.)	0.344	0.310	20.434	0.395	17
Time Out of Service (days)	15.	13.5	20.467	0.234	18

8.3.2 EXTENSION OF PANAMA CANAL SIZE.

A study considering possible extension of the lock size of the Panama Canal is carried out to measure its effects on economic criterion RFR.

Two dimensions are assumed to be extended together at a time and then all are increased giving four possible combinations. Length are draft are increased from their maximum permissible value by 10% and beam is increased from 32.2 to 40 m, an increase of 24.2%.

The same assumptions given in section 8.2 are kept with a chosen basis ship of a higher block coefficient of 0.850 sailing at a speed of 13 knots.

Panama Canal dues levied on net tonnage are assumed not to increase as no information of what would be the canal tolls if it is increased is available.

The summary of the results is given in table 8.3.

8.3.2.1 LENGTH AND BEAM EXTENSION.

As a result of length and beam extension, the following changes occurred. The deadweight is increased by 34.94% bringing the cargo transported annually up by about 30.38%. Capital cost and total operating costs are respectively increased by 25.23 and 22.11%.

Required freight rate resulted from these changes is found to be 5.55% less.

8.3.2.2 LENGTH AND DRAFT EXTENSION.

From this extension the deadweight is increased by 21.41% causing an increase of cargo transported per annum of 19.64%. Capital cost and total operating costs are respectively brought up by 8.54 and 10.37%. Consequently, the reduction caused in RFR is about 8.26%.

8.3.2.3 BEAM AND DRAFT EXTENSION.

With beam and draft extended, the ship deadweight obtained is of 39.08% higher giving an increase of cargo transported annually of 36.20%. Capital cost and total operating costs are respectively increased by 21.61 and 24.06%.

RFR being reduced by 9.52% is found more sensitive to this extension.

8.3.2.4 LENGTH, BEAM AND DRAFT EXTENSION.

With length, beam and draft extended together, the ship deadweight is increased by 51.59% rising the amount of cargo carried annually by 45.92%.

Capital cost and total operating costs are respectively increased by 28.49 and 29.31%.

As a result, required freight rate is reduced by 11.57%, a very important reduction.

TABLE 8.3 EXTENSION OF PANAMA CANAL SIZE.

Draft :	12.04 →	13.244	(10%)
Beam :	32.20 →	40.00	(24.2%)
Length :	274.3 →	300.00	(10%)

Basic Ship :
L = 274.3 ; B = 32.2 ; T = 12.04 ; D = 18.21 ; Cb = 0.850 ; V = 13. ;
DWT = 76,030. ; RFR = 18.770

1) Length and Beam Extension

DWT = 102,597. (34.94%)
RFR = 17.729 (-5.55%)

2) Length and Draft Extension

DWT = 92,309. (21.41%)
RFR = 17.219 (-8.26%)

3) Beam and Draft Extension

DWT = 105,742. (39.08%)
RFR = 16.983 (-9.52%)

4) Length, Beam and Draft Extension

DWT = 115,255 (51.59%)
RFR = 16.598 (-11.57%)

8.3.3 CHANGE OF TRADE ROUTE.

The purpose of this study is to find out what would be the minimum deadweight for a ship trading the same commodity between the same two ports but not transiting the Panama Canal and giving the same return as the Panamax basis ship.

Two trade routes are examined in this study. The first is via Cape of Good Hope with a round trip distance of 31,294 nm and an endurance of 15,647 nm.

The second route is via Cape Horn giving a higher round trip distance of 33,220 nm and an endurance of 16,610 nm.

The same basis ship of 0.850 block coefficient and 13 knots speed is assumed in this study.

Table 8.4 summarises the results.

8.3.3.1 ROUTE VIA CAPE OF GOOD HOPE.

The minimum deadweight for a ship requiring the same freight rate of 18.770 $/tonne and trading this longer route is found 113.28% higher than that of the Panamax basis ship.

This increase in size, permitted by the lifting of any size restrictions, brings the amount of cargo carried annually up by 26.23%. Capital cost and total operating costs, in which no canal dues are charged, are respectively increased by 43.73 and 17.36%.

Due to the longer route, the number of round trips taking place annually is considerably reduced, a figure of 40.56%.

8.3.3.2 ROUTE VIA CAPE HORN.

The minimum deadweight for a ship trading this route with the same RFR is found 145.48% higher. With this bigger size the cargo carried annually is increased by 35.77% in a number of annual round trips reduced by 44.41%.

This increase in size brings respectively capital cost and total operating costs, again with no canal dues to be charged, up by 56.16 and 25.44%.

Via the Suez Canal, with a round trip distance of 28,748 nm, no ship is found capable of giving the same return due to constraint on maximum deadweight, 150,000 dwt, imposed by the Suez Canal.

It can be concluded from the above results that Panama Canal is of considerable importance in world of shipping transport making some longer routes shortened considerably and giving more opportunities for profits to be made.

TABLE 8.4 CHANGE OF TRADE ROUTE.

Ports of Call : New Orleans (USA) - Yokohama (Japan).

1) Through The Panama Canal
Endurance = 9,150. n.m

Optimum Ship :
L = 274.3 ; B = 32.2 ; T = 12.04 ; D = 18.41 ; Cb = 0.850 ; V = 13. ;
DWT = 76,030. ;
Round Trips Per Annum = 5.72 ;
RFR = 18.770

2) Via Cape of Good Hope
Endurance = 15,647. n.m

L = 272.0 ; B = 45.0 ; T = 17.59 ; D = 25.10 ; Cb = 0.850 ; V = 13. ;
DWT = 162,156. (113.28%) ;
Round Trips Per Annum = 3.40 (-40.56%) ;
RFR = 18.770

3) Via Cape Horn
Endurance = 16,610. n.m

L = 281.0 ; B = 48.0 ; T = 18.30 ; D = 26.04 ; Cb = 0.850 ; V = 13. ;
DWT = 186,637. (145.48%) ;
Round Trips Per Annum = 3.18 (-44.41%)
RFR = 18.770

8.3.4 REDUCTION OF BALLAST VOYAGE.

The program is run to measure the gain or reduction in RFR by reducing the voyage in ballast and, therefore, increasing the amount of cargo carried annually.

It must be said that with actual depressed bulk market and surplus tonnage it is not obvious for a bulk carrier to carry more than one cargo in a round voyage.

However, this study is carried out to see how RFR reacts to reduced ballast voyage in a event of a prosperous market where more bulk commodities are available throughout the world to be carried.

The same basis ship is assumed to transport grain from the port of New Orleans (USA) to the port of Yokohama (Japan), via the Panama Canal, and then sail in ballast to Brisbane in Queensland (Australia). After loading bulk fertilisers at the port of Brisbane the ship sails, through the Panama Canal, to the port of Tampico in the Gulf of Mexico where the cargo is discharged. Finally, the ship returns in ballast to New Orleans making a total round trip distance of 23,063 nm. The ship is also assumed to bunker at each port of call, during the operation of loading or unloading, allowing therefore more cargo to be carried.

The results are summarised in table 8.5.

With the reduction of the voyage in ballast, the combined amount of cargo carried annually is increased by 39.31% in a number of annual round trips reduced by 30.42%.

Among operating costs, fuel costs and canal dues are respectively reduced by 9.04 and 22.51%, and port and cargo handling costs increased by about the same percentage of 39.32% due to more time spent in ports and less time at sea.

Finally, RFR is found very sensitive to reduction in ballast voyage being reduced by a high percentage of 24.78%.

TABLE 8.5 REDUCTION OF BALLAST VOYAGE.

Ports of Call :
New Orleans (USA) ;
Yokohama (Japan) ;
Brisbane (Australia) ;
Tampico (Mexico).

Basis Ship :
L = 274.3 ; B =32.2 ; T = 12.04 ; D = 18.21 ; Cb = 0.850 ; V =13. ;
DWT = 76,030.

1) New Orleans - Yokohama

Distance = 9,150. n.m
Commodity Carried = Grain

2) Yokohama - Brisbane

Distance = 3,980. n.m
In Ballast

3) Brisbane - Tampico

Distance = 9,200. n.m
Commodity Carried = Bulk Fertilisers

4) Tampico - New Orleans

Distance = 733. n.m
In Ballast

Round Distance = 23,063. n.m
Round Trips Per Annum = 3.98 (-30.42%)
RFR = 14.118 (-24.78%).

CHAPTER 9 : DISCUSSION, CONCLUSION AND FUTURE DEVELOPMENT.

9.1 GENERAL DISCUSSION.

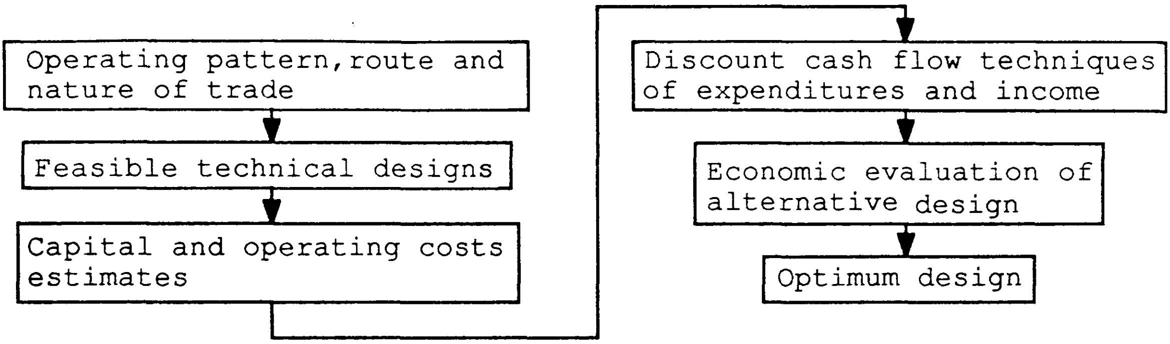
Since the widespread availability of computers in the mid-1960s, a large number of computer programs dealing with preliminary ship design have been developed. However, none of them has been universally adopted nor kept in use over a long period of time. Two main reasons are behind this.

Firstly, preliminary ship design requires a lot of empirical relationships which could be different in their results from one designer to the other depending upon the amount of data they each have in their possession, thus resulting in changing the acceptability of the same programs. The second reason emerges from the cost of updating the program limiting therefore its usefulness over a relatively long time period.

The computer program model described throughout the thesis has been carefully prepared so that it could be updated in the future without excessive alterations and practically with no need to check through it as all the data and most of assumptions made are kept in a separate input data file. Furthermore, it could be applied easily to other ship types simply by correcting some variables, and if not operating through the Panama Canal, by lifting size constraints.

The economic study incorporated into the program, which should always be a fully integrated part of ship design, serves as a base for comparison between alternative solutions and as a basis to measure any consequence of technical variable changes. Required freight rate (RFR), since income is in most cases not predictable, is in this thesis the economic measure of merit when selecting the optimum design. It is also a more realistic criterion when comparing ships of different sizes and speeds.

The approach of linking technical aspects with their economic consequences used in the computer program can be illustrated as :



For the route set up between New Orleans and Yokohama transiting the Panama Canal with resulting size limits, the computer program gives the following synthesised ship spending half of its life in ballast as optimum :
274.3 m length, 32.2 m beam, 12.04 m draft, 18.21 m depth, 0.85 block coefficient, 76 030 dwt and speed of 13 knots. Many existing Panamax bulk carriers are about this deadweight although rather shorter in length and perhaps higher in block coefficient. This indicates that the largest ship possible within the Panama Canal lock system is the preferred choice. This result shows that it is best to accept the unusually high L/B value of about 8.5 in order to gain the greatest economy of scale. It runs counter to the trend to reduction in L/B ratios where Panamax constraints do not apply.
The dimensions give a rather high value of L/D ratio and it could be best to build such a vessel with greater depth and thus greater draft even though the draft would only be useful when not trading through the canal and accept a reasonably higher RFR than minimum.
About optimality, it must be said that determining the optimum point is less important than finding the reasonable range covering a small variation from the best attainable value of the measure of merit. Working in a range rather than at a point will give the designer a wide menu of designs allowing him more freedom in introducing new considerations.

Sensitivity analysis is of considerable importance in preliminary ship design as it permits the identification of those parameters which are of greater influence on the design measure of merit. It, therefore, shows the areas where most effort of improvement should be concentrated, namely

steel weight and installed power, and others of less importance where excessive efforts spent in getting improvements are less necessary such as upkeep costs.
The sensitivity analysis has the disadvantage to ignore the fact that all the controlling parameters are liable to vary together. However, once the effects of each alone are known by sensitivity analysis then the sum of the separate influences is usually an adequate approximation for the total effect.

The extension of Panama Canal size carried out in the program to measure its outcome on the economic measure of merit assumed no rise in transit tolls. But in real life tolls would increase and probably sharply if the canal is widened although so might the traffic.
There have been some rumours of a widening program the past few years but there seem to be some doubts recently. Indeed, the plans for widening are behind a market forecast predicting requirements of growth in the number of large ships using the canal over a 10 year period. The doubts in question are result of figures showing the rate of growth slowing down.
Actually, projections of the future use of Panama Canal and widening program scheme are still debatable. Some of the managers at the Panama Canal commission have anticipated that the widening work, estimated at $400 million cost, would have to be started in two or three years and could take 15-20 years to complete (*), a period well beyond the scheduled December 1999 date of US handover the canal to Panamanian authority.

9.2 CONCLUSIONS.

The conclusions from this thesis can be summarised in the following points :
1. On the trade route considered, transiting the Panama Canal and with two ports of call, a ship of 274.3 m Lbp x 32.2 m B x 12.04 m T x 18.21 D and Cb of 0.85, tonnage of 76 030 dwt and speed of 13 knots offers the lowest required freight rate.

(*) 'Panama Maritime Community', Lloyd's Ship Manager (supplement), April 1988.

2. Sensitivity analyses give steel weight and installed power as very important and influential factors on the measure of merit, and their estimates should be made accurately with the best possible empirical relationships.

3. More powering data for high block coefficient forms are needed to ensure more accurate power estimate.

4. Reduction of the voyage in ballast brings the required freight rate down considerably which highlights the fact that a shipowner before engaging in any trade should consider the route with the least ballast voyage.

5. The minimum deadweight of a ship trading the same commodity between the same two ports of call and not transiting through the Panama Canal is more than twice that of a Panamax one yielding the same return.

6. Panamax size constraints have a considerable effect on ship design and economics.

7. Extending the Panama Canal size would have a great effect on the measure of merit.

9.3 APPLICATION AND FUTURE DEVELOPMENT.

The elaborated computer program could be transferred into a micro-computer with an adequate central memory capacity which would save money in the running operations. The up to date operation incorporating improvements should be allowed without excessive costs. Perhaps two weeks per year would be enough to update the program. The operator must be a qualified person understanding all the steps of the program and having a good feeling for evaluating the results so that their accuracy could be judged.

As mentioned previously, preliminary ship design is mainly based upon a large number of empirical relationships and it would be specially useful if more accurate and more scientifically based ones were available to match the potential of the more advanced computing techniques giving this branch of naval architecture a more scientific aspect.

One of the big uncertainties is whether the Panama Canal will be widened or not and if so to what extent and what would be the canal tolls? In such an event it would be interesting to use the program with new proposed tolls. Measuring the improved return for ships of increased size using the canal, and bearing in mind the future prospects for bulk commodities and future availability of ports facilities, would give some guidance on the value of an enlarged canal.

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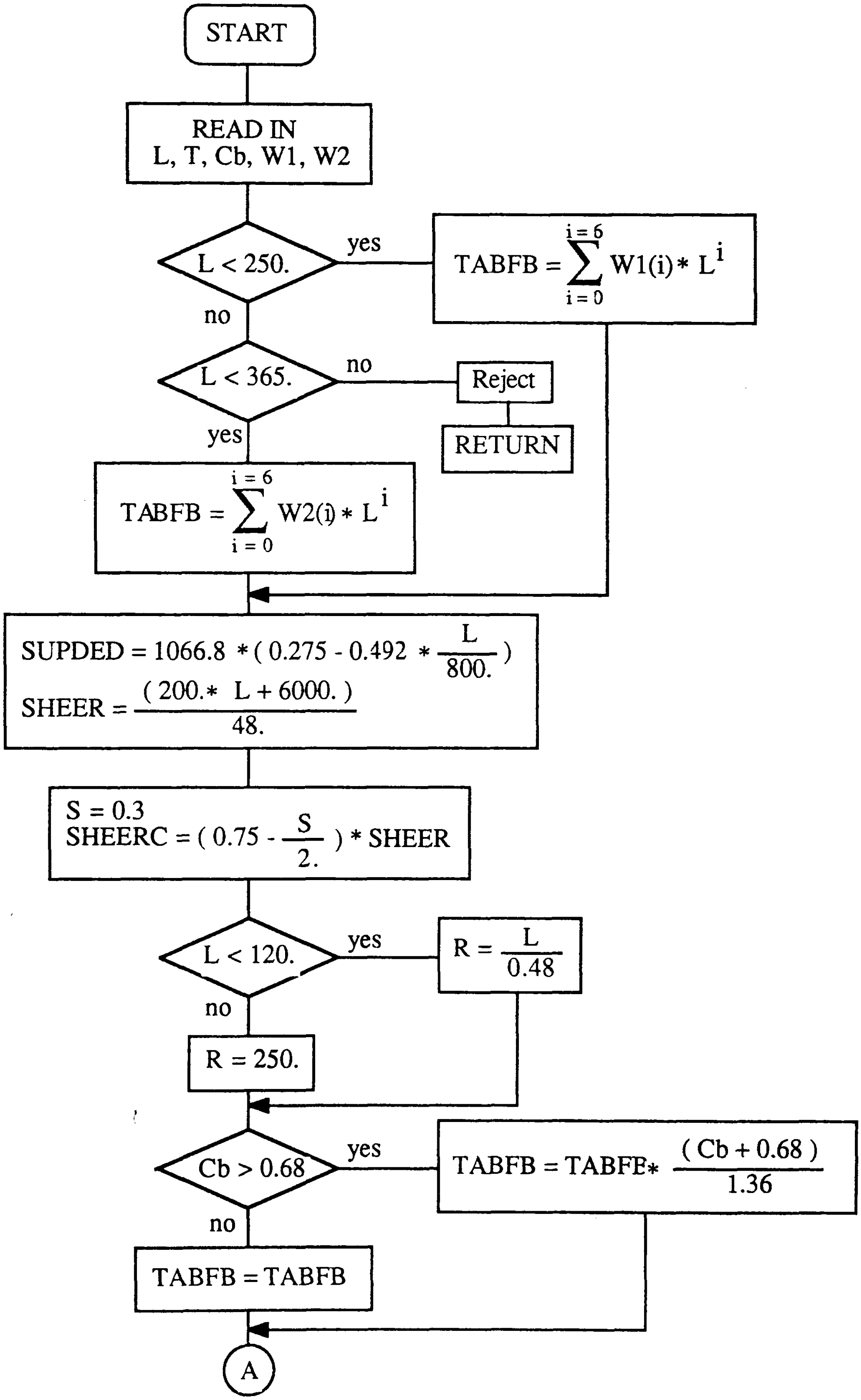
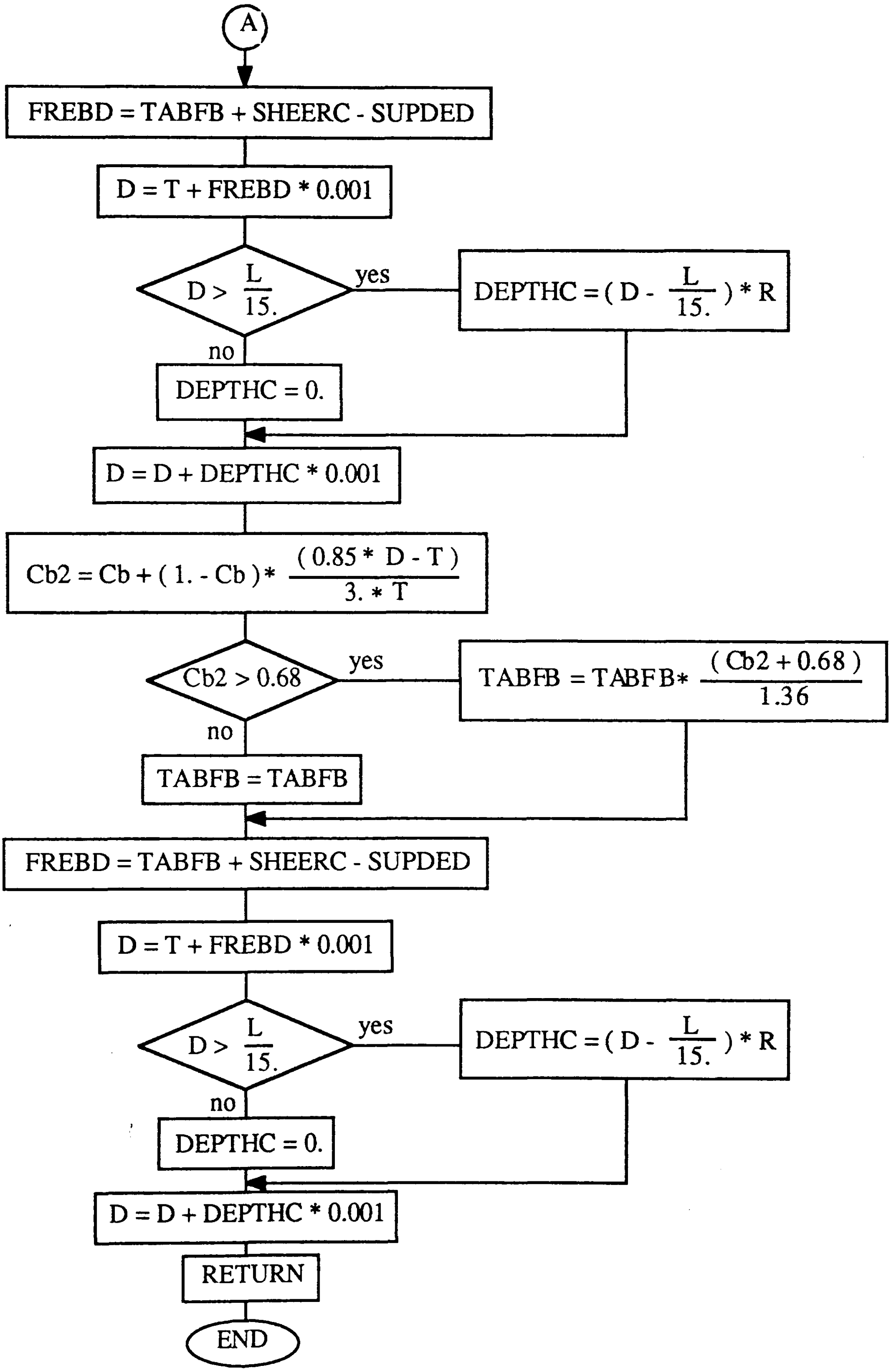
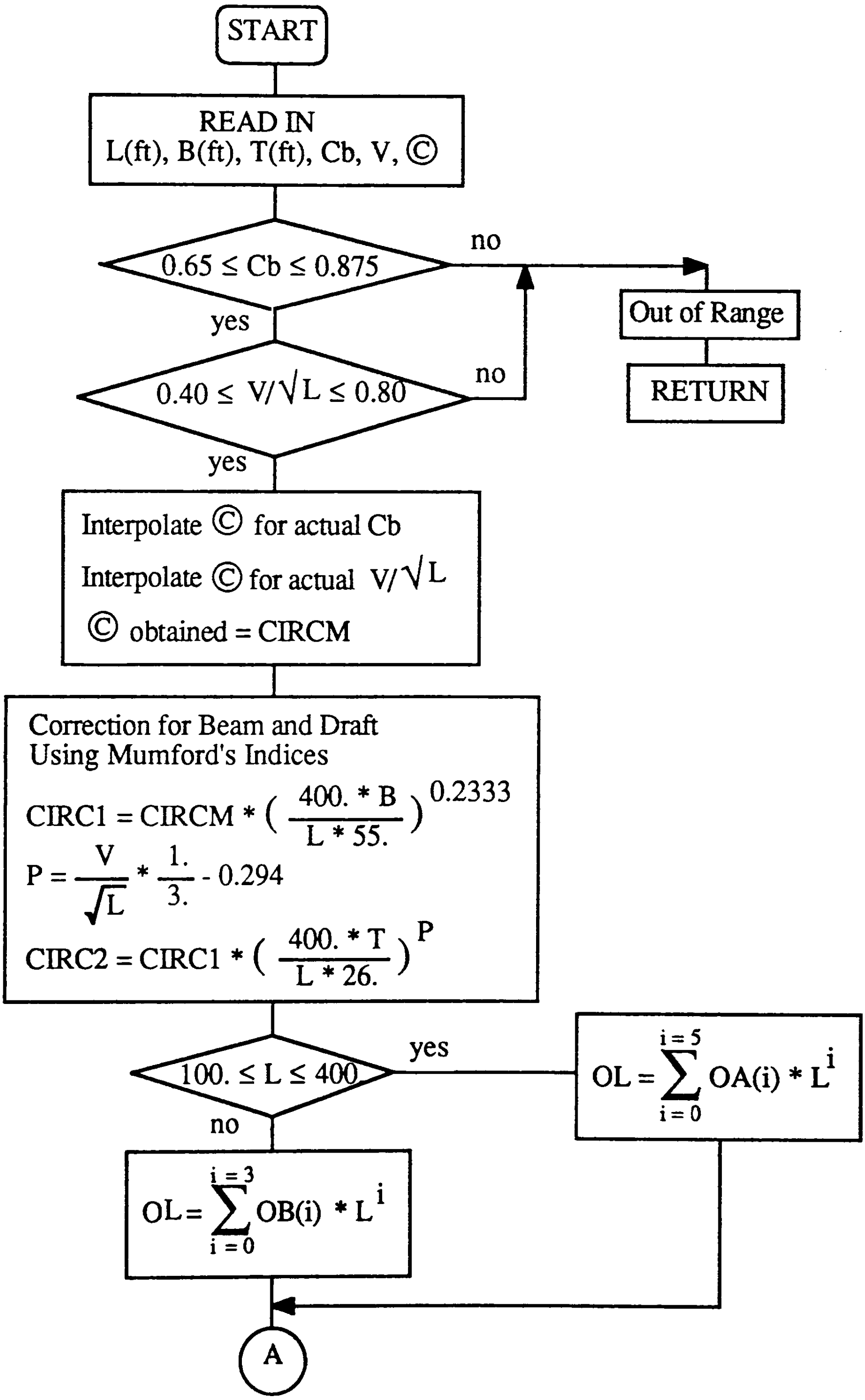
APPENDIX 1. Freeboard algorithm (FREBRD) flow chart.

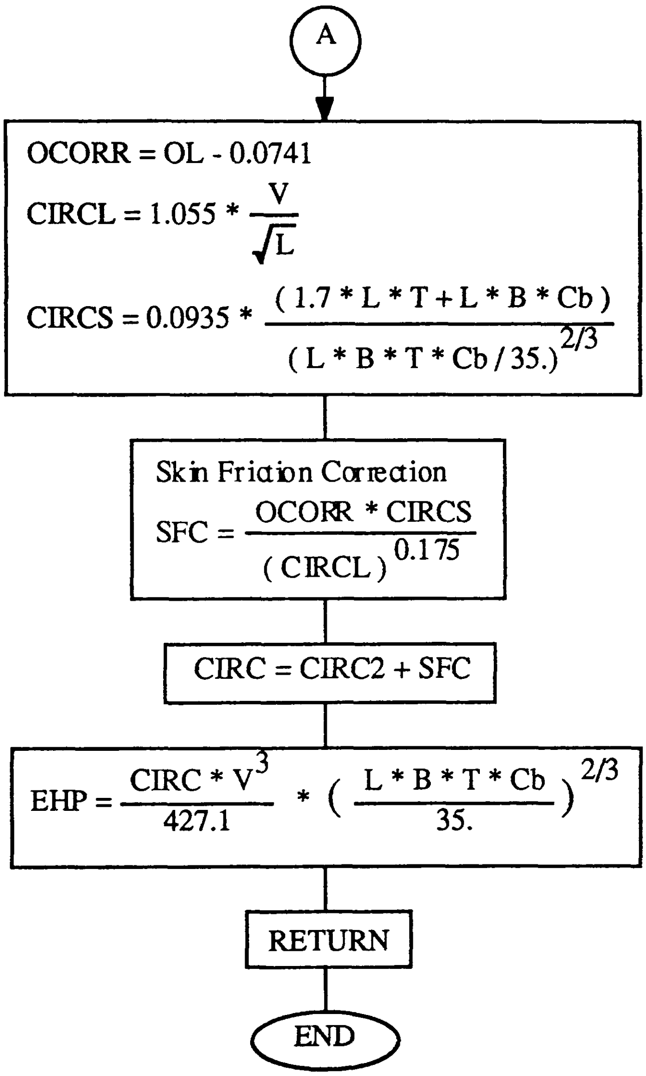



A
FREBD = TABFB + SHEERC - SUPDED
D = T + FREBD * 0.001
D > L/15.
yes
DEPTHC = (D - L/15.) * R
no
DEPTHC = 0.
D = D + DEPTHC * 0.001
Cb2 = Cb + (1. - Cb)* (0.85 * D - T) / 3. * T
Cb2 > 0.68
yes
TABFB = TABFB* (Cb2 + 0.68) / 1.36
no
TABFB = TABFB
FREBD = TABFB + SHEERC - SUPDED
D = T + FREBD * 0.001
D > L/15.
yes
DEPTHC = (D - L/15.) * R
no
DEPTHC = 0.
D = D + DEPTHC * 0.001
RETURN
END

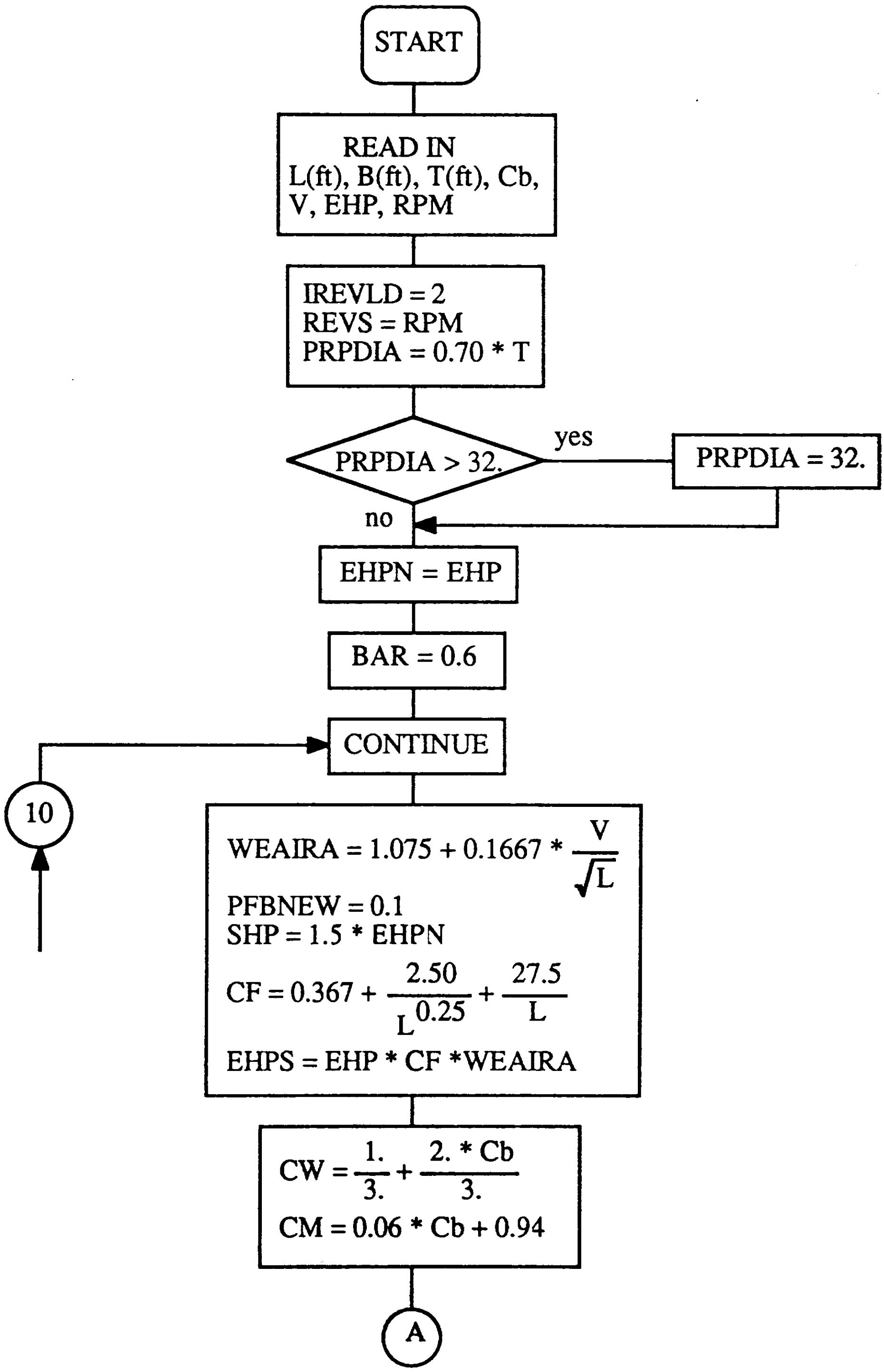
APPENDIX 2.

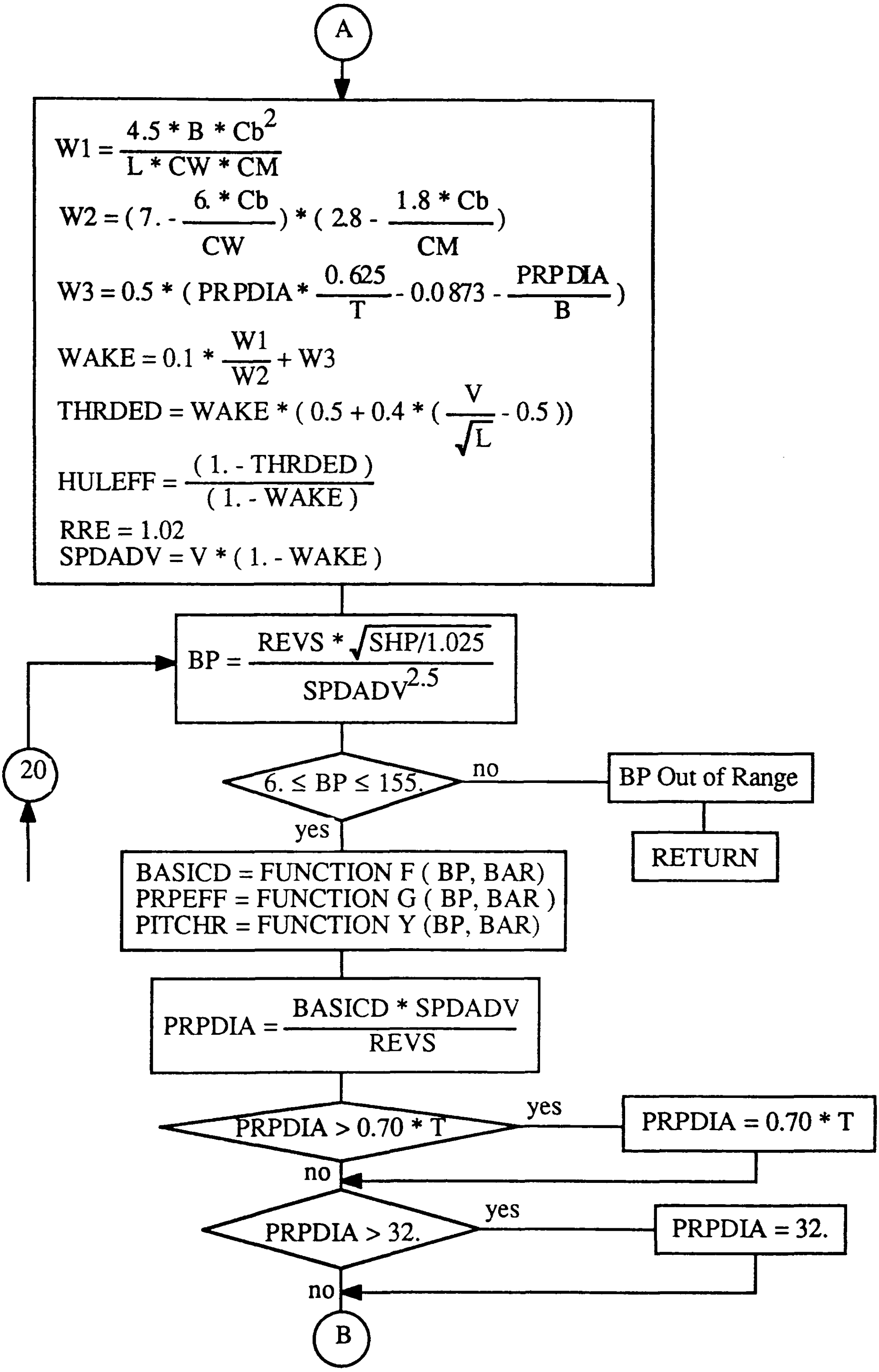
Effective horsepower algorithm (EFECHP) flow chart.

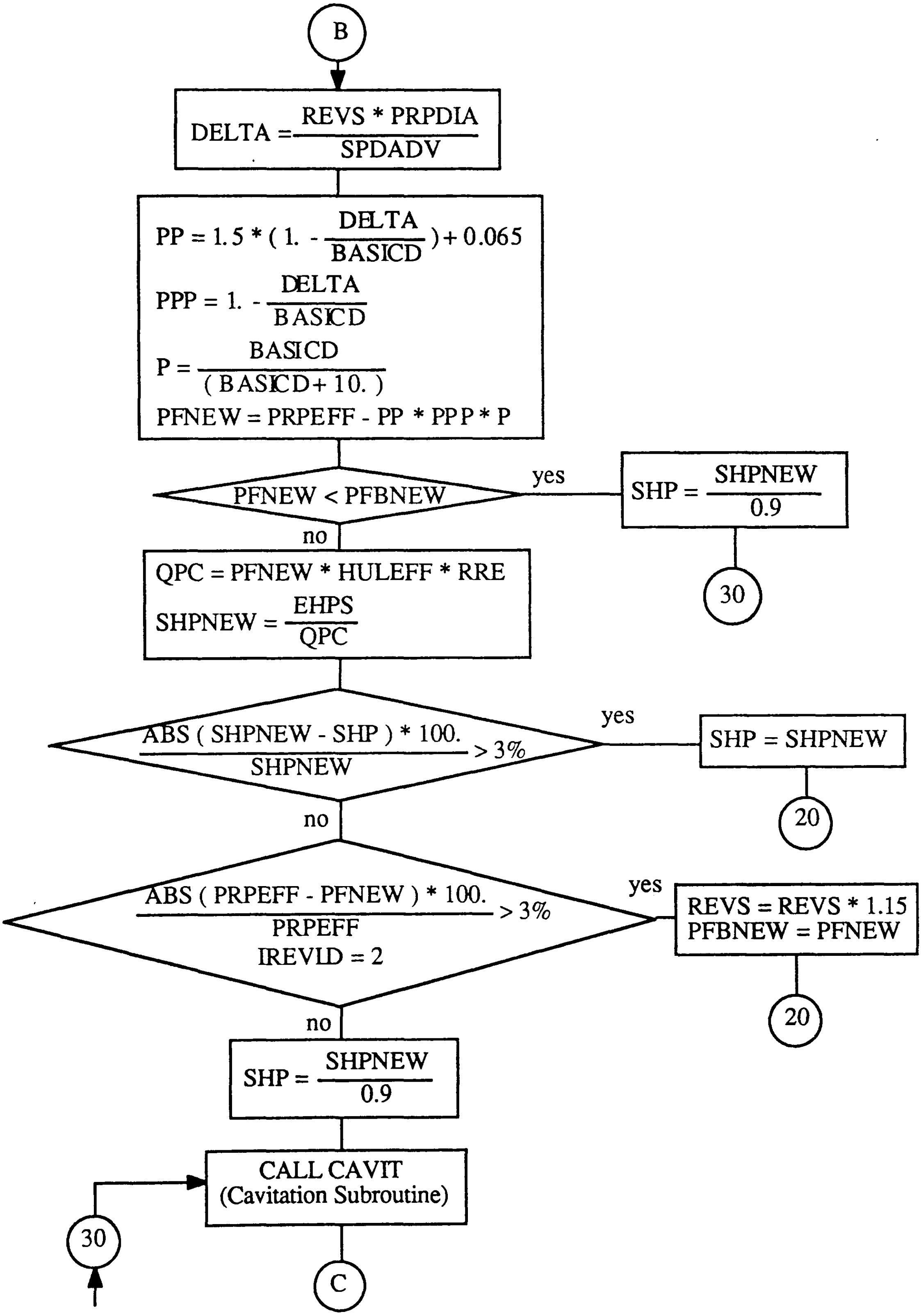


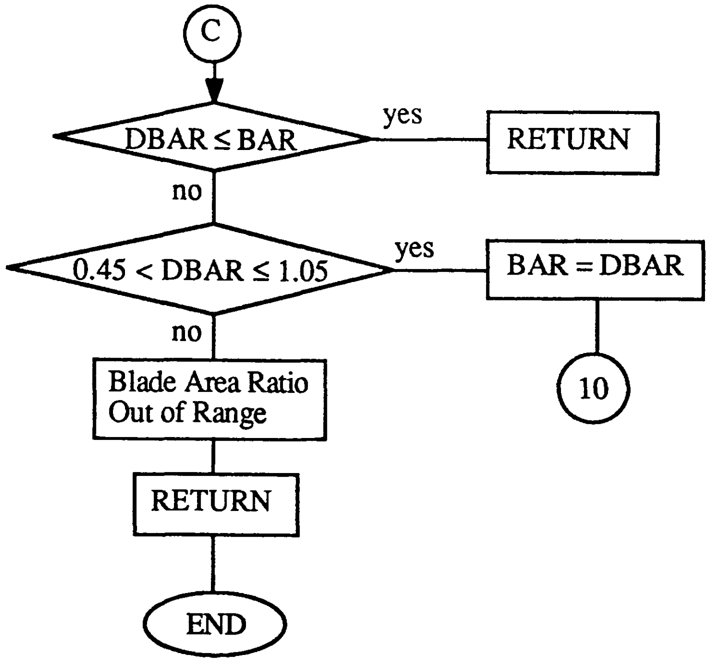

A
OCORR = OL - 0.0741
CIRCL = 1.055 * V / √L
CIRCS = 0.0935 * (1.7 * L * T + L * B * Cb) / (L * B * T * Cb / 35.)^2/3
Skin Friction Correction
SFC = OCORR * CIRCS / (CIRCL)^0.175
CIRC = CIRC2 + SFC
EHP = CIRC * V^3 / 427.1 * (L * B * T * Cb / 35.)^2/3
RETURN
END

Shaft horsepower algorithm (SHFTHP) flow chart.



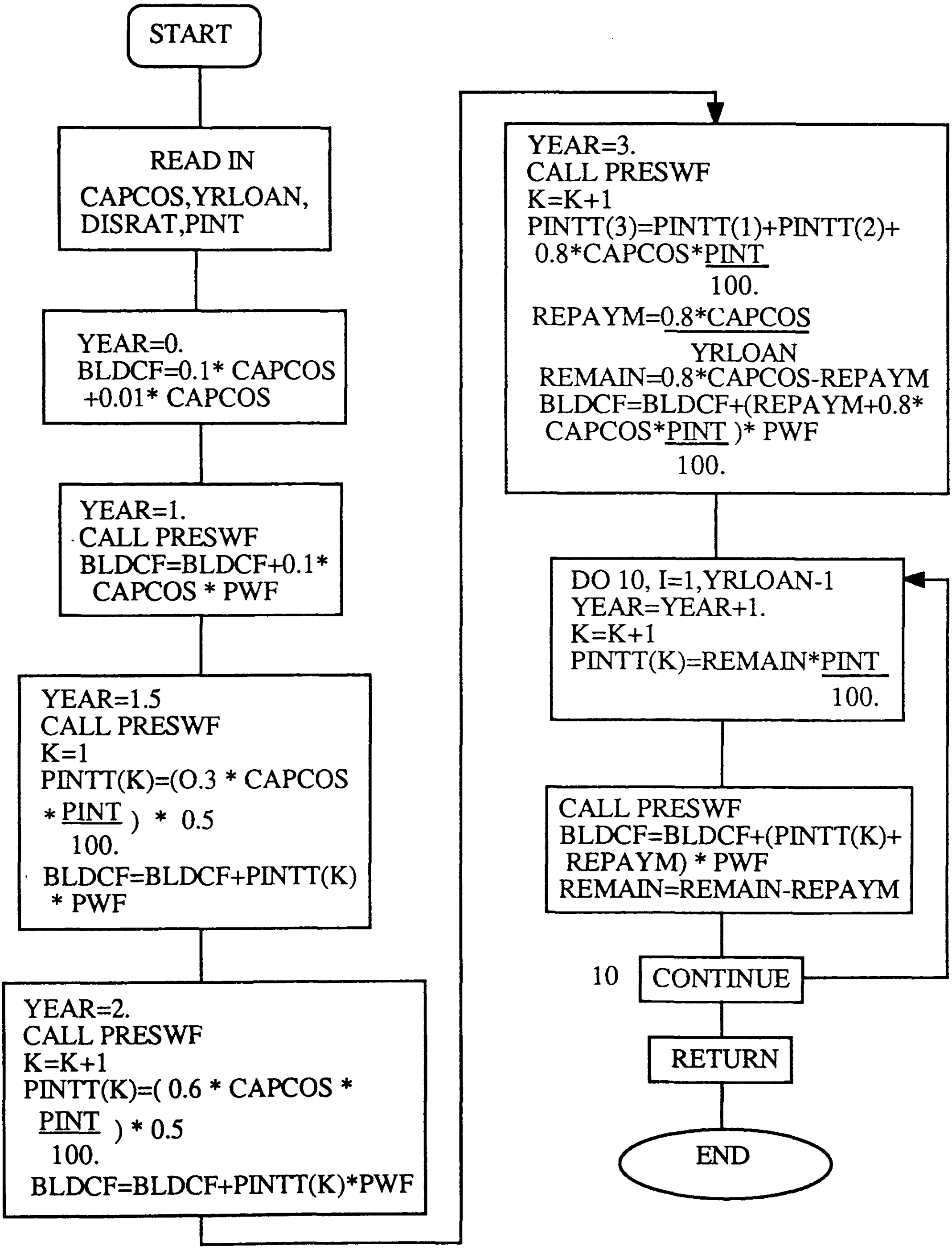

A
W1 = 4.5 * B * Cb^2 / (L * CW * CM)
W2 = (7. - 6. * Cb / CW) * (2.8 - 1.8 * Cb / CM)
W3 = 0.5 * (PRPDIA * 0.625 / T - 0.0873 - PRPDIA / B)
WAKE = 0.1 * W1 / W2 + W3
THRDED = WAKE * (0.5 + 0.4 * (V / √L - 0.5))
HULEFF = (1. - THRDED) / (1. - WAKE)
RRE = 1.02
SPDADV = V * (1. - WAKE)
BP = REVS * √(SHP/1.025) / SPDADV^2.5
20
6. ≤ BP ≤ 155.
no
BP Out of Range
RETURN
yes
BASICD = FUNCTION F (BP, BAR)
PRPEFF = FUNCTION G (BP, BAR)
PITCHR = FUNCTION Y (BP, BAR)
PRPDIA = BASICD * SPDADV / REVS
PRPDIA > 0.70 * T
yes
PRPDIA = 0.70 * T
no
PRPDIA > 32.
yes
PRPDIA = 32.
no
B


B
DELTA = REVS * PRPDIA / SPDADV
PP = 1.5 * (1. - DELTA / BASICD) + 0.065
PPP = 1. - DELTA / BASICD
P = BASICD / (BASICD + 10.)
PFNEW = PRPEFF - PP * PPP * P
PFNEW < PFBNEW
yes
SHP = SHPNEW / 0.9
30
no
QPC = PFNEW * HULEFF * RRE
SHPNEW = EHPS / QPC
ABS (SHPNEW - SHP) * 100. / SHPNEW > 3%
yes
SHP = SHPNEW
20
no
ABS (PRPEFF - PFNEW) * 100. / PRPEFF > 3%
IREVLD = 2
yes
REVS = REVS * 1.15
PFBNEW = PFNEW
20
no
SHP = SHPNEW / 0.9
CALL CAVIT
(Cavitation Subroutine)
30
C

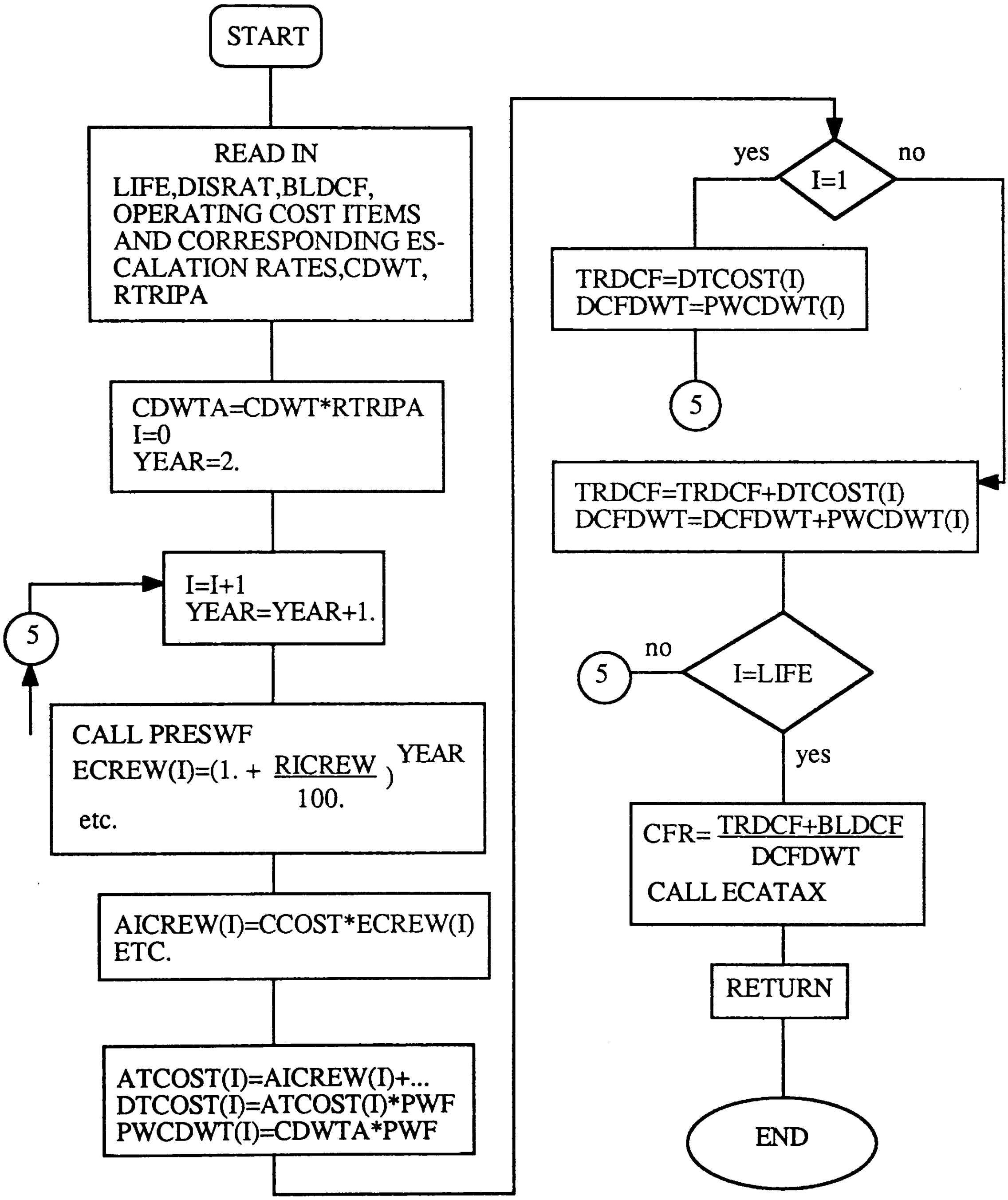

C
DBAR ≤ BAR
yes
RETURN
no
0.45 < DBAR ≤ 1.05
yes
BAR = DBAR
10
no
Blade Area Ratio Out of Range
RETURN
END

APPENDIX 3.

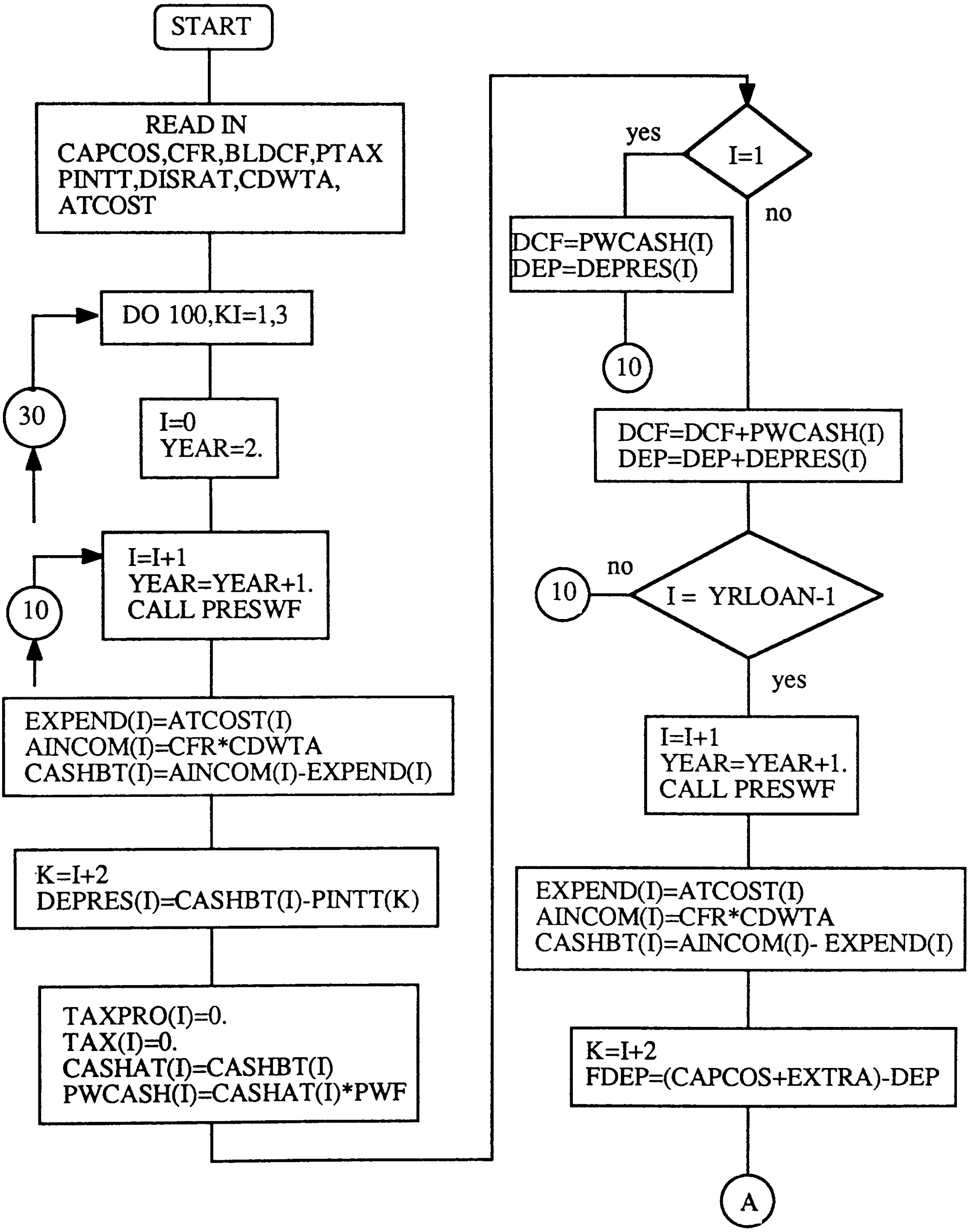
Capital charges algorithm (CAPCHR) flow chart.

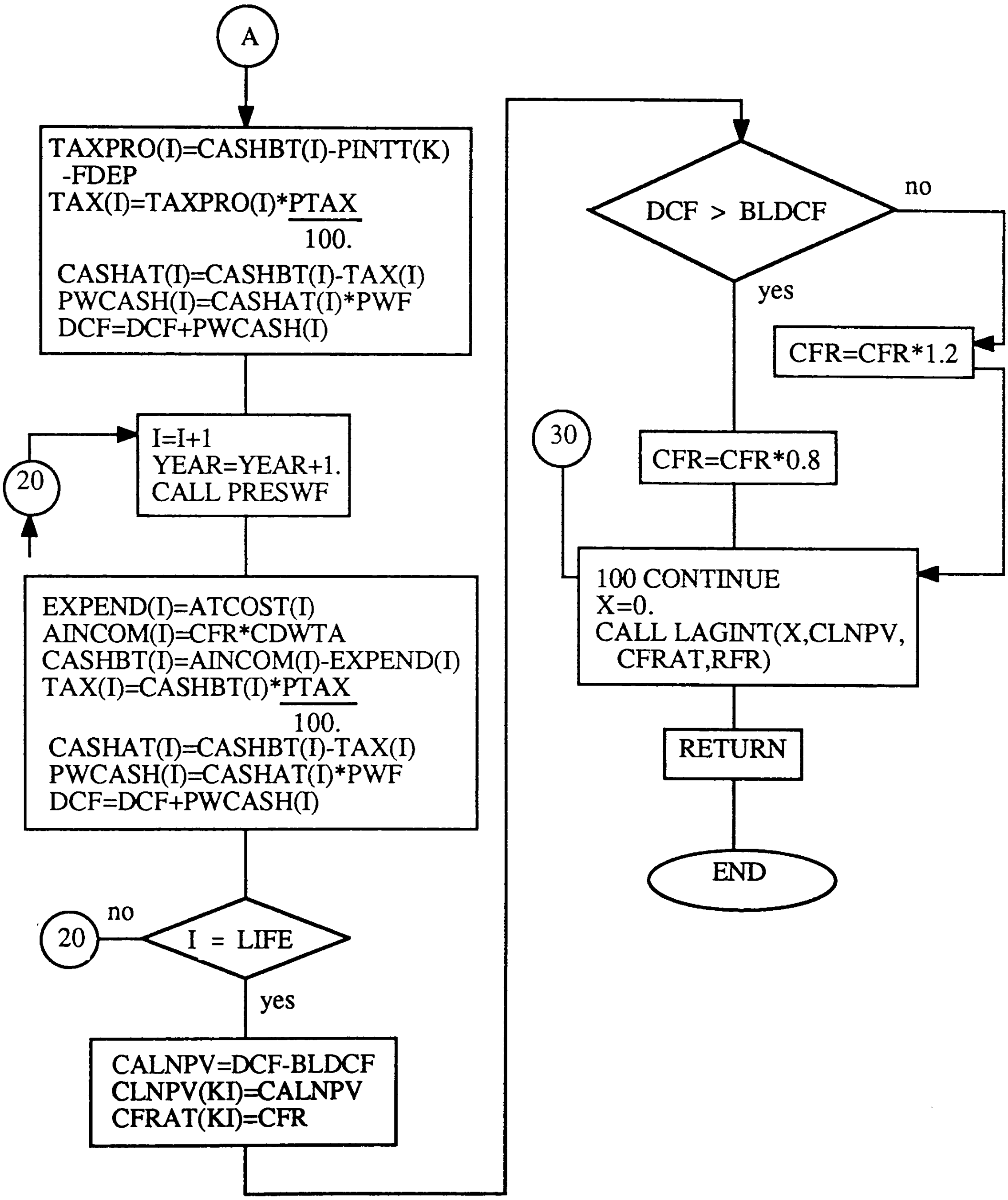


RFR before tax algorithm (ECONOM) flow chart.



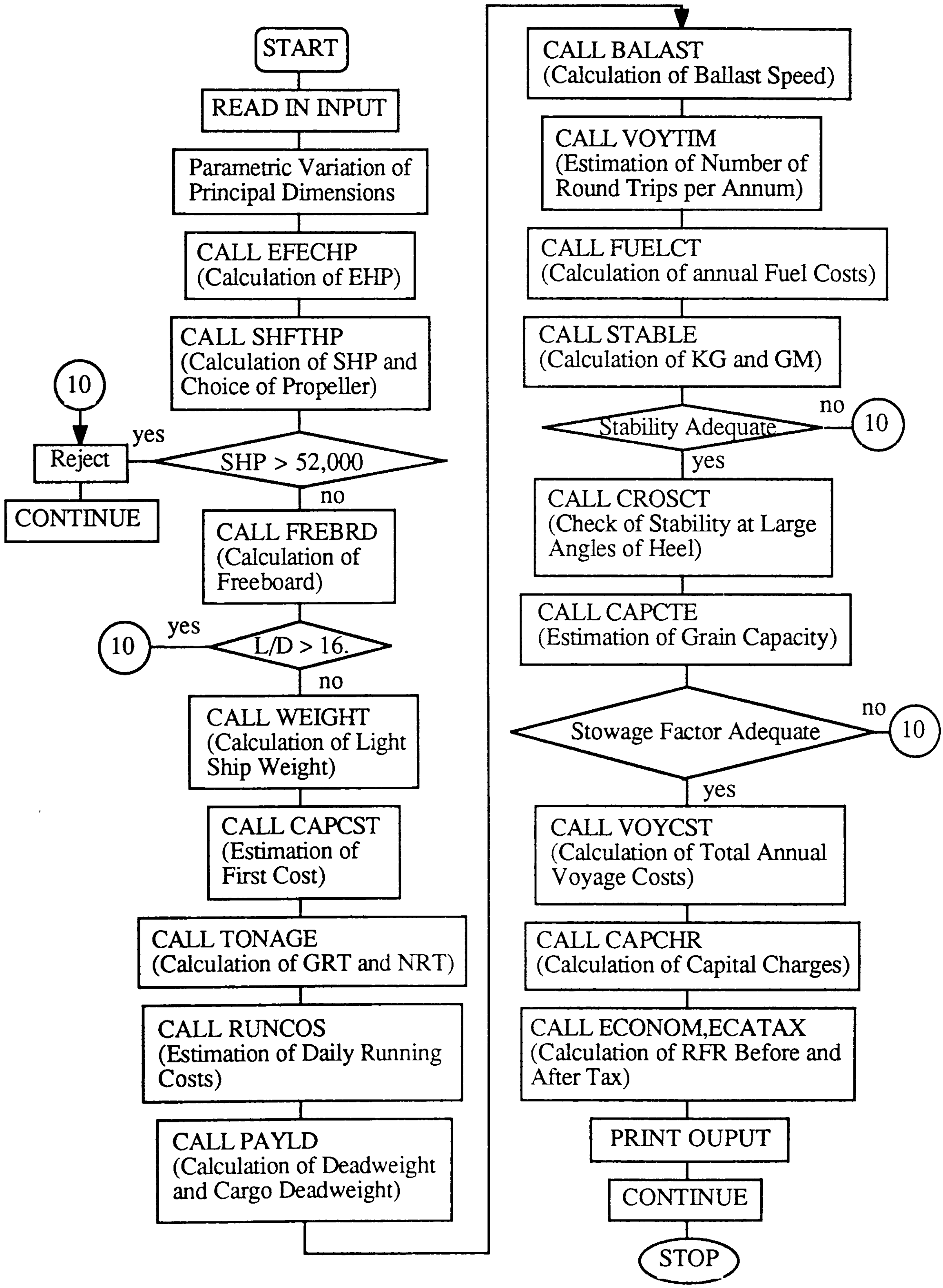
RFR after tax algorithm (ECATAX) flow chart.





A
TAXPRO(I)=CASHBT(I)-PINTT(K) -FDEP
TAX(I)=TAXPRO(I)*PTAX / 100.
CASHAT(I)=CASHBT(I)-TAX(I)
PWCASH(I)=CASHAT(I)*PWF
DCF=DCF+PWCASH(I)
20
I=I+1
YEAR=YEAR+1.
CALL PRESWF
EXPEND(I)=ATCOST(I)
AINCOM(I)=CFR*CDWTA
CASHBT(I)=AINCOM(I)-EXPEND(I)
TAX(I)=CASHBT(I)*PTAX / 100.
CASHAT(I)=CASHBT(I)-TAX(I)
PWCASH(I)=CASHAT(I)*PWF
DCF=DCF+PWCASH(I)
20
no
I = LIFE
yes
CALNPV=DCF-BLDCF
CLNPV(KI)=CALNPV
CFRAT(KI)=CFR
DCF > BLDCF
no
yes
CFR=CFR*1.2
30
CFR=CFR*0.8
100 CONTINUE
X=0.
CALL LAGINT(X,CLNPV, CFRAT,RFR)
RETURN
END

APPENDIX 4. The computer Program.
Computer main program flow chart.



COMPUTER INPUT.

0.11009E00,-0.39871E-03,0.23773E-05,-0.81420E-08,0.14452E-10,
-0.10329E-13
0.85479E-01,-0.37757E-04,0.26166E-07,-0.74973E-11
0.614,0.613,0.613,0.616,0.622,0.628,0.636,0.652,0.676,0.708
0.606,0.604,0.595,0.599,0.608,0.618,0.639,0.661,0.694,0.739
0.613,0.608,0.604,0.604,0.610,0.622,0.646,0.669,0.700,0.738
0.610,0.614,0.617,0.617,0.621,0.633,0.654,0.683,0.720,0.769
0.620,0.622,0.630,0.634,0.645,0.665,0.695,0.736,0.794,0.866
0.642,0.640,0.647,0.654,0.673,0.702,0.755,0.840,0.924,1.038
0.650,0.650,0.653,0.669,0.716,0.769,0.836,0.955,1.120,1.320
0.653,0.653,0.678,0.732,0.813,0.884,0.969,1.073,1.225,1.350
0.654,0.655,0.705,0.817,0.999,1.137,1.229,1.305,1.370,1.425
-17.964554,67.889057,-11.647089,2.8843426,34.396307,-62.878629,
36.672642,8.3573930,-6.0546061,-1.0135629
0.7254688,0.0467418,-0.0513415,0.0045453,0.3745467,-0.7990566,
0.3707377,0.0606887,-0.0176966,-0.0026614
2.8048996,-1.0897952,0.1989154,-0.0128642,-0.3837079,0.4105813,
-0.1401343,0.0255904,0.0127727,-0.0050917
-0.6950206E-01,0.1296007E01,-0.2641235E01,0.3507301E01,
-0.27030429E01,0.1116339E01,-0.19140047
105.0
0.2300959E03,-0.5925297E01,0.2450741,-0.9130795E-03,
0.7967773E-06,0.2394580E-08,-0.5083802E-11
-0.1599663E05,0.3734531E03,-0.3367033E01,0.1712062E-01,
-0.4909359E-04,0.7444288E-07,-0.4646534E-10
184.82824,-792.63721,1367.0498,-1069.4777,315.24512
4.2,10.0,50.0,250.0,267.0
9150.,9200.,3980.,733.,10.,1500.,24
110.,165.,1344.,1512.
3000.,1700.,16.,13.,0.,0.
1500.,800.,14.,14.,0.,0.
15,7.5,12.,8.
0.,0.,0.,0.,0.,35.,70.

SAMPLE OF COMPUTER PRINTOUT.

Lbp = 274.30   B = 32.20   D = 18.21   T = 12.04   CB = 0.850   V = 13.0
DWT = 76030. GRT = 45440. NRT = 31775. SHP = 10817.
First Cost = 17327392.

Steel Weight =	13864.
Outfit Weight =	1450.
Machinery Weight =	843.
Lightship Weight =	16621.
Cargo Deadweight =	74864.
Crew Weight =	4.
Stores Weight =	7.
Fresh Water Weight =	118.
Fuel Weight =	1038.
Displacement =	92651.

Maximum Grain Capacity =	4006833.
Minimum Grain Capacity =	3712222.
Maximum Stowage Factor =	53.52
Minimum Stowage Factor =	49.59

THE COMPUTER PROGRAM.

```
      COMMON/BULK1/WR,PROFIT,OVHEAD,STLCOS,SINDEX
      COMMON/BULK2/CBVL(9,10),OA(6),OB(4)
      COMMON/BULK3/AUXKW,DISTC1,DISTC2,DISTC3,DISTC4,RESERV
      COMMON/BULK4/PINT
      COMMON/BULK5/DISRAT
      COMMON/BULK6/YRLOAN
      COMMON/BULK7/LIFE
      COMMON/BULK8/PTAX
      COMMON/BULK9/RICREW,RIMARE,RIINS,RIVICT,RIFUEL,RIPORT
      COMMON/BULK11/LODCP1,UNLDC1,SHIFT1,SHIFT2,DELAY1,DELAY2
      COMMON/BULK12/LODCP2,UNLDC2,SHIFT3,SHIFT4,DELAY3,DELAY4
      COMMON/BULK13/COFUEL,CODISL,COSYLO,COCYLO
      COMMON/BULK14/NC
      COMMON/BULK15/CAV(7)
      DIMENSION CBT(10),VLT(9),A1(3),B1(3),CCT(3),A2(3),
     *F(10),G(10),Y(10),S(5),W1(7),W2(7),PINTT(20),SIGMA(10)
      DIMENSION ECREW(40),EMARE(40),EINS(40),EVICT(40),EFUEL(40),
     *EPORT(40),AICREW(40),AIMARE(40),AIINS(40),AIVICT(40),AIFUEL(40),
     *AIPORT(40),ATCOST(40),DTCOST(40),PWCDWT(40)
      DIMENSION EXPEND(40),AINCOM(40),CASHBT(40),DEPRES(40),
     *TAXPRO(40),TAX(40),CASHAT(40),PWCASH(40),CLNPV(3),
     *CFRAT(3),CLDCF(3)
      REAL AL,B,T,CB,V,CIRCM,CIRC1,CIRC2,OL,OCORR,CIRCL,CIRCS,SFC,
     *CIRC,EHP ,BKBASE,VLBASE,VL,
     *REVSIN,BAR,BP,CF,DBAR,EHPS,HULEFF,PFNEW,PRPDIA,PRPEFF,
     *QPC,REVS,SHP,THRDED,WAKE,WEAIRA,EHPN,PFBNEW,SPDADV,
     *BASICD,PITCHR,DELTA,SHPNEW,RRE,
     *THRUST,HEAD,SPVP,RVPR,SIGMA,TCOEFF,TAPRAT,AP,APARAT,
     *CB1,E,WS7,WS,WO,BHP,WMENG,WRM,WM,WLT,
     *SCRAP,CAPCOS,TOTCOS,SUBCOS,CLAB,CMAT,CSL,CSM,COL,COM,CML,CMM,WR,
     *PROFIT,OVHEAD,STLCOS,SINDEX,
     *D,CB2,TABFB,SUPDED,SHEER,SHEERC,FREBD,DEPTHC,
     *CAMBER,SHERAF,SHERFD,VTOT,ALPEAK,VPEAKS,HDB,VDB,ALER,VER,ALFA,BETA,
     *HW,TTW,VWT,HSG,HSW,VTT,VGRMIN,VGRMAX,STOMIN,STOMAX,K1,K2,K3,K4,
     *FIXCOS,CCOST,CMTRP,CHMINS,CPIINS,CMISC,CVICT,CSTORE,
```

```
     *STIME1,STIME2,VB,TB,DISTC1,WDISL1,WSYSL1,WCYLO1,WHVF1,TFUEL1,
     *BSTIM1,BSTIM2,DISTC2,DISTC3,DISTC4,WHVF2,WSYSL2,WCYLO2,TFUEL2,
     *PORT3,PORT1,PORT2,LODCP1,UNLDC1,SHIFT1,SHIFT2,DELAY1,DELAY2,
     *COFUEL,CODISL,COSYLO,COCYLO,SFUEL1,ASDISL,ASYSLO,ASCYLO,
     *TCFUEL,APDISL,BASWAG,HAMEL
      REAL WTCREW,WSTORE,WFRESH,WTMISC,DISPL,CDWT1,CDWT2,DWT,
     *GM,AKM,AKB,BM,AKG,AKGS,AKGO,AKGM,AKGLWT,GM2,AKG2,
     *AKX,AKGX,AKGFS,AKC,AKGC,WFS,AKGFD,
     *AKN10,AKN20,AKN30,AKN40,AKN50,AKN60,GZ0,GZ10,GZ20,GZ30,GZ40,
     *GZ50,GZ60,AREA30,AREA40,AR3040,GZMAX,CHANDL,
     *TNEW,FREHP,GRT,RTRIP,RTRIPA,CFUELS,CFUELP,CPORT,PCDUES,CSTVOY,
     *ANRT,PCNRT,PINT,DISRAT,YRLOAN,BLDCF,PWF,REMAIN,REPAYM,YEAR,
     *CDWTA,RICREW,RIMARE,RIINS,RIFUEL,RIPORT,TRDCF,DCFDWT,CFR,
     *PTAX,DCF,DEP,FDEP,CALNPV,RFR,FACMAR,
     *SFUEL2,SFUEL3,SFUEL4,SHIFT3,SHIFT4,DELAY3,DELAY4,PORT4,
     *LODCP2,UNLDC2,WDISL2,WSTOR1,WSTOR2,WFRES1,WFRES2,WTMIS1,WTMIS2
      INTEGER IC,IV,IREVLD,NC,LIFE
C
      READ(5,*)(OA(K),K=1,6)
      READ(5,*)(OB(L),L=1,4)
      M=9
      N=10
      DO 70 I=1,M
      READ(5,*)(CBVL(I,J),J=1,N)
   70 CONTINUE
      READ(5,*)(F(K),K=1,10)
      READ(5,*)(G(K),K=1,10)
      READ(5,*)(Y(K),K=1,10)
      READ(5,*)(CAV(K),K=1,7)
      READ(5,*)REVSIN
      READ(5,*)(W1(K),K=1,7)
      READ(5,*)(W2(K),K=1,7)
      READ(5,*)(S(K),K=1,5)
      READ(5,*)WR,PROFIT,OVHEAD,STLCOS,SINDEX
      READ(5,*)DISTC1,DISTC2,DISTC3,DISTC4,RESERV,AUXKW,NC
      READ(5,*)COFUEL,CODISL,COSYLO,COCYLO
      READ(5,*)LODCP1,UNLDC1,SHIFT1,SHIFT2,DELAY1,DELAY2
      READ(5,*)LODCP2,UNLDC2,SHIFT3,SHIFT4,DELAY3,DELAY4
```

```
READ(5,*)LIFE,PINT,DISRAT,YRLOAN
 READ(5,*)RICREW,RIMARE,RIINS,RIFUEL,RIPORT,PTAX,FACMAR
 DO 10,RLB=5.5,8.5,0.5
 DO 10,RBT=2.25,3.0,0.25
 DO 10,CB=0.725,0.875,0.05
 DO 10,VL=0.4,0.6,0.05
B=32.2
AL=RLB*B
T=B/RBT
V=VL*(AL*3.2808)**0.5
IF(T.GT.12.04) GOTO 10
IF(AL.GT.274.3) GOTO 10
 CALL EFECHP(AL,B,T,CB,V,VL,EHP,CIRC2,CIRCL,CIRCS,OCORR)
 CALL SHFTHP(AL,B,T,CB,V,F,G,Y,EHP,SHP,QPC,REVSIN,BAR,DBAR,PRPDIA,
*REVS)
 IF(SHP.GT.52000.0)GOTO 10
CALL FREBRD(AL,T,D,CB,TABFB,W1,W2)
IF(AL/D.GT.16.) GOTO 10
 CALL WEIGHT(AL,B,T,D,CB,SHP,REVSIN,WS,WO,WM,WLT,S,SCRAP)
  CALL CAPCST(AL,CB,SHP,WS,WO,SCRAP,CAPCOS,CLAB,CMAT,CSL,CSM,COL,
 *COM,CML,CMM,S,FACMAR)
CALL TONAGE(AL,B,D,GRT,ANRT)
 CALL RUNCOS(AL,B,D,SHP,CAPCOS,FIXCOS,CCOST,CMTRP,CHMINS,
*CPIINS,CVICT,CSTORE,GRT)
CALL PAYLD(AL,B,T,CB,V,WLT,WTMIS1,TFUEL1,CDWT1,DISPL,DWT,WHVF1,
*WDIESL,WSYSLO,WCYLO,SHP,STIME,WTCREW,WSTORE,WFRESH,CDWT2,WHVF2)
CALL BALAST(AL,T,TB,V,VB)
 CALL VOYTIM(STIME1,STIME2,PORT1,PORT2,V,VB,CDWT1,RTRIP,RTRIPA,
*BSTIM1,BSTIM2,CDWT2,PORT3,PORT4)
 CALL FUELCT(SHP,STIME1,STIME2,RTRIPA,PORT1,PORT2,TCFUEL,ASFUEL,
*ASDISL,ASYSLO,ASCYLO,APDISL,BSTIM1,BSTIM2,PORT3,PORT4,
*WHVF1,WHVF2)
CALL STABLE(AL,B,T,D,CB,WS,WO,WM,WLT,DWT,CDWT1,DISPL,WTMIS1,
*TFUEL1,GM,AKG)          IF(GM.LT.0.15) GOTO 10
 CALL CROSCT(AL,B,T,D,CB,AKG2,GZMAX,AREA30,AREA40,AR3040,GZ0,
*GZ10,GZ20,GZ30,GZ40,GZ50,GZ60)
 CALL CAPCTE(AL,B,T,D,CB,SHP,STOMAX,STOMIN,CDWT1,VGRMIN,VGRMAX)
 CALL VOYCST(RTRIPA,GRT,ANRT,TCFUEL,PCNRT,CPORT,PCDUES,CHANDL,
```

```
     *CDWT1,CDWT2,CSTVOY)
      CALL CAPCHR(CAPCOS,BLDCF,PWF,PINTT)
      CALL ECONOM(RTRIPA,TCFUEL,CPORT,BLDCF,CDWT1,CDWT2,CCOST,CMTRP,
     *CHMINS,CPIINS,CVICT,CSTORE,CAPCOS,ATCOST,DTCOST,PWCDWT,
     *CFR,PWF,YEAR,CDWTA,CHANDL,PCDUES,PINTT,CLNPV,RFR,CFRAT,CLDCF)
      WRITE(6,90) OUTPUT
   90 FORMAT( )
   10 CONTINUE
      STOP
      END
```

```
      SUBROUTINE EFECHP(AL,B,T,CB,V,VL,EHP,CIRC2,CIRCL,CIRCS,OCORR)
C     CALCULATES THE EFFECTIVE HORSEPOWER USING MOOR&SMALL METHOD
C     OF CIRCULAR C
C     T.RINA, 1960
C
      COMMON/BULK2/CBVL(9,10),OA(6),OB(4)
      DIMENSION CBT(10),VLT(9),A1(3),B1(3),CCT(3),A2(3)
      REAL AL,B,T,CB,V,CIRCM,CIRC1,CIRC2,OL,OCORR,CIRCL,CIRCS,SFC,
     *CIRC,EHP,VL,CCC,P,BKBASE,VLBASE
      INTEGER IC,IV
C
      AL=AL*3.2808
      B=B*3.2808
      T=T*3.2808
      VL=V/(AL**0.5)
C
C     COLUMN BOUND OF BLOCK COEFFICIENT
      BKBASE=(CB-0.650)/0.025+1.0
      IF(BKBASE.LT.1.0.OR.BKBASE.GT.11.0) GOTO 200
      IC=BKBASE
      IF(IC.EQ.1)IC=2
      IF(IC.EQ.10)IC=9
C
C     ROW BOUND OF SPEED LENGTH RATIO
      VLBASE=(VL-0.40)/0.05+1.0
      IF(VLBASE.LT.1.0.OR.VLBASE.GT.10.0) GOTO 200
      IV=VLBASE
      IF(IV.EQ.1)IV=2
      IF(IV.EQ.8)IV=7
C
C     STORES VALUES OF VL FROM 0.40 TO 0.8 AT INTERVALS OF 0.05
C     STORES VALUES OF VL AS AN ARRAY VLT
      TT=0.4
      DO 10 II=1,8
      VLT(II)=TT+0.05
      TT=VLT(II)
   10 CONTINUE
```

```
C
C   STORES VALUES OF CB FROM 0.65 TO 0.875 AT INTERVALS OF 0.025
C   STORES VALUES OF CB AS AN ARRAY CBT
      TT=0.625
      DO 15 II=1,10
      CBT(II)=TT+0.025
      TT=CBT(II)
   15 CONTINUE
C
C   INTERPOLATION FOR CIRCULAR C FOR THE REQUESTED VALUE OF CB
      IJ=IC-1
      IJJ=IC+1
      IV1=IV-1
      IV3=IV+1
      KP=1
      DO 40 II=IV1,IV3,1
      KK=IJ
      DO 30 JJ=1,3
      A1(JJ)=CBT(KK)
      B1(JJ)=CBVL(II,KK)
      KK=KK+1
   30 CONTINUE
      CALL LAGINT(CB,A1,B1,CCC)
      IF(CCC.GT.5.0)GOTO 200
      IF(CCC.LT.0.0)GOTO 200
      CCT(KP)=CCC
      KP=KP+1
   40 CONTINUE
C
C   INTERPOLATION FOR CIRCULAR C FOR THE REQUESTED VALUE OF VL
      IP=IV1-1
      DO 50 JI=1,3
      IPP=IP+JI
      A2(JI)=VLT(IPP)
   50 CONTINUE
      CALL LAGINT(VL,A2,CCT,CIRCM)
C
C   CORRECTION FOR BEAM AND DRAFT USING MUMFORD'S INDICES FOR
```

```
C     DEVIATION FROM STANDARD DIMENSIONS OF 400*55*26 (FEET)
C     WITHIN THE RANGE OF VL FROM 0.45 TO 0.8 THE VALUE OF X=0.9
C     LINEAR FIT FOR Y-2/3 FOR DRAFT CORRECTION
C
      CIRC1=CIRCM*(400.0*B/(AL*55.0))**0.2333
      P=VL/3.0-0.294
      CIRC2=CIRC1*(400.0*T/(AL*26.0))**P
C
C     SKIN FRICTION CORRECTION FOR DEVIATION FROM STANDARD LENGTH
      IF(AL.LE.400.0.AND.AL.GE.100.0) THEN
     OL=OA(1)+OA(2)*AL+OA(3)*AL**2+OA(4)*AL**3+OA(5)*AL**4+OA(6)*AL**5
      ELSE
     OL=OB(1)+OB(2)*AL+OB(3)*AL**2+OB(4)*AL**3
      ENDIF
      OCORR=OL-0.0741
      CIRCL=1.055*VL
C
C     WETTED SURFACE CALCULATED BY MUMFORD'S FORMULA
      CIRCS=0.0935*(1.7*AL*T+CB*AL*B)/((AL*B*T*CB/35.0)**0.6667)
       SFC=OCORR*CIRCS/(CIRCL**0.175)
       CIRC=CIRC2+SFC
C
      EHP=CIRC*(V**3.0)*((AL*B*T*CB/35.0)**0.6667)/427.1
      GOTO 60
  200 WRITE(6,20)
   20 FORMAT(5X,'OUT OF RANGE')
   60 AL=AL/3.2808
      B=B/3.2808
      T=T/3.2808
      RETURN
      END
```

```
      SUBROUTINE LAGINT(X,A,D,Z)
C     PERFORMS THREE POINTS LAGRANGIAN INTERPOLATION
C
      DIMENSION A(3),D(3)
      M=0
      Z=0
    3 M=M+1
      F=1.0
      DO 1 K=1,3
      IF(M-K)2,1,2
    2 F=F*(X-A(K))/(A(M)-A(K))
    1 CONTINUE
      Z=D(M)*F+Z
      IF(M.LT.3) GOTO 3
      RETURN
      END
```

```
      SUBROUTINE SHFTHP(AL,B,T,CB,V,F,G,Y,EHP,SHP,QPC,REVSIN,BAR,DBAR,
     *PRPDIA,REVS)
C     CALCULATES THE QPC AND SHAFT HORSEPOWER
C     USING BP-DELTA CHARTS FOR FIVE BLADED PROPELLER
C     AND TAKING INTO ACCOUNT THE CAVITATION PHENOMENON
C
      DIMENSION F(10),G(10),Y(10)
      REAL AL,B,T,CB,V,EHP,REVSIN,BAR,BP,CF,DBAR,EHPS,HULEFF,
     *PFNEW,PRPDIA,PRPEFF,QPC,REVS,SHP,THRDED,WAKE,WEAIRA,VL,
     *EHPN,PFBNEW,SPDADV,BASICD,PITCHR,DELTA,SHPNEW,
     *RRE,CW,CM,W1,W2,W3
      INTEGER IREVLD
C
      AL=AL*3.2808
      B=B*3.2808
      T=T*3.2808
      VL=V/(AL**0.5)
      IREVLD=2
      REVS=REVSIN
      PRPDIA=0.70*T
      IF(PRPDIA.GT.32.0)PRPDIA=32.0
      EHPN=EHP
C
C     SERVICE ALLOWANCE IS TAKEN AS FUNCTION OF VL VARYING
C     LINEARLY FROM 1.15 AT VL OF 0.45 AND 1.25 AT VL OF1.05
C     REF. ECONOMIC SHIP DESIGN PH.D-THESIS 1970 R.M.CAMERON
C
      WEAIRA=1.075+0.1667*VL
      BAR=0.6
   20 CONTINUE
      PFBNEW=0.1
      SHP=1.5*EHPN
   40 CF=0.367+2.50/(AL**0.25)+27.5/AL
      EHPS=EHPN*CF*WEAIRA
      CW=1./3.+2.*CB/3.
      CM=0.06*CB+0.94
      W1=4.5*B*(CB**2.)/(AL*CW*CM)
      W2=(7.-6.*CB/CW)*(2.8-1.8*CB/CM)
```

```
      W3=0.5*(PRPDIA*0.625/T-0.0873-PRPDIA/B)
      WAKE=0.1+W1/W2+W3
      THRDED=WAKE*(0.5+0.4*(VL-0.5))
      RRE=1.02
      SPDADV=V*(1.-WAKE)
      HULEFF=(1.-THRDED)/(1.-WAKE)
   50 BP=REVS*((SHP/1.025)**0.5)/(SPDADV**2.5)
      IF(BP.LT.6.0.OR.BP.GT.155.0)GOTO 100
      BASICD=F(1)+F(2)*ALOG(BP)+F(3)*(ALOG(BP))**2+F(4)*(ALOG(BP))
     ***3+F(5)*BAR+F(6)*BAR**2+F(7)*BAR**3+F(8)*ALOG(BP)*BAR
     *+F(9)*ALOG(BP)*BAR**2+F(10)*(ALOG(BP))**2*BAR
C
      PRPEFF=G(1)+G(2)*ALOG(BP)+G(3)*(ALOG(BP))**2+G(4)*(ALOG(BP))
     ***3+G(5)*BAR+G(6)*BAR**2+G(7)*BAR**3+G(8)*ALOG(BP)*BAR
     *+G(9)*ALOG(BP)*BAR**2+G(10)*(ALOG(BP))**2*BAR
C
      PITCHR=Y(1)+Y(2)*ALOG(BP)+Y(3)*(ALOG(BP))**2+Y(4)*(ALOG(BP))
     ***3+Y(5)*BAR+Y(6)*BAR**2+Y(7)*BAR**3+Y(8)*ALOG(BP)*BAR
     *+Y(9)*ALOG(BP)*BAR**2+Y(10)*(ALOG(BP))**2*BAR
C
      PRPDIA=BASICD*SPDADV/REVS
      IF(PRPDIA.GT.0.7*T)PRPDIA=0.7*T
      IF(PRPDIA.GT.32.)PRPDIA=32.0
      DELTA=REVS*PRPDIA/SPDADV
C
      PP=1.5*(1.-DELTA/BASICD)+0.065
      PPP=1.-DELTA/BASICD
      P=BASICD/(BASICD+10.)
      PFNEW=PRPEFF-PP*PPP*P
      IF(PFNEW.LT.PFBNEW)THEN
      SHP=SHPNEW/0.9
      GOTO 60
      ELSE
      QPC=PFNEW*HULEFF*RRE
      SHPNEW=EHPS/QPC
      IF(ABS(SHPNEW-SHP)*100./SHPNEW.GT.3.)THEN
      SHP=SHPNEW
```

```
      GOTO 40
      ELSE
      IF(ABS(PRPEFF-PFNEW)*100./PRPEFF.GT.3.0.AND.IREVLV.EQ.2)THEN
      REVS=REVS*1.15
      PFBNEW=PFNEW
      GOTO 50
      ELSE
   30 SHP=SHPNEW/0.9
      ENDIF
      ENDIF
      ENDIF
      CALL CAVIT(EHPS,PRPDIA,REVS,SPDADV,T,THRDED,V,PITCHR,DBAR)
      IF(DBAR.LE.BAR)GOTO 60
      IF(DBAR.GT.0.45.AND.DBAR.LE.1.05)THEN
      BAR=DBAR
      GOTO 20
      ELSE
      WRITE(6,200)
  200 FORMAT(5X,'BLADE AREA RATIO OUT OF RANGE')
      ENDIF
      GOTO 60
  100 WRITE(6,150)
  150 FORMAT(5X,'BP OUT OF RANGE')
   60 AL=AL/3.2808
      B=B/3.2808
      T=T/3.2808
      RETURN
      END
```

```
      SUBROUTINE CAVIT(EHPS,PRPDIA,REVS,SPDADV,T,THRDED,V,PITCHR,DBAR)
C     CALCULATES THE MINIMUM BLADE AREA RATIO BASED ON BURRILL
C     CAVITATION DIAGRAM
C
      COMMON/BULK15/CAV(7)
       REAL THRUST,EHPS,THRDED,V,HEAD,T,PRPDIA,SPVP,RVPR,SPDADV,REVS,
      *SIGMA,TCOEFF,TAPRAT,AP,APARAT,PITCHR,DBAR
      THRUST=EHPS*33000./((1.-THRDED)*V*101.33)
      HEAD=T-PRPDIA/2.
       SPVP=14.45+0.45*HEAD
       RVPR=(SPDADV/7.12)**2+(REVS*PRPDIA/329.)**2
       SIGMA=SPVP/RVPR
      TCOEFF=CAV(1)+CAV(2)*SIGMA+CAV(3)*SIGMA**2+CAV(4)*SIGMA**3+
     *CAV(5)*SIGMA**4+CAV(6)*SIGMA**5+CAV(7)*SIGMA**6
       TAPRAT=TCOEFF*RVPR
       AP=THRUST/(TAPRAT*144.)
       APARAT=1.067-0.229*PITCHR
      DBAR=AP/(APARAT*ATAN(1.)*PRPDIA**2)
       RETURN
      END
```

```
      SUBROUTINE FREBRD(AL,T,D,CB,TABFB,W1,W2)
C     CALCULATES THE FREEBOARD AND DEPTH BASED ON THE
C     1966 LOAD LINE CONVENTION
C
      DIMENSION W1(7),W2(7)
      REAL AL,T,D,CB,CB1,CB2,TABFB,SUPDED,SHEER,SHEERC,FREBD,R
C
      IF(AL.LT.250.)THEN
      TABFB=W1(1)+W1(2)*AL+W1(3)*AL**2+W1(4)*AL**3+W1(5)*AL**4+W1(6)
     **AL**5+W1(7)*AL**6
      ELSE IF(AL.GE.250.0.AND.AL.LT.365.)THEN
      TABFB=W2(1)+W2(2)*AL+W2(3)*AL**2+W2(4)*AL**3+W2(5)*AL**4+W2(6)
     **AL**5+W2(7)*AL**6
      ELSE
      GOTO 10
      ENDIF
      SUPDED=1066.8*(0.275-0.492*AL/800.)
      SHEER=(200.*AL+6000.)/48.
      S=0.3
      SHEERC=(0.75-S/2.)*SHEER
      IF(AL.LT.120.)THEN
      R=AL/0.48
      ELSE
      R=250.
      ENDIF
      IF(CB.GT.0.68)THEN
      TABFB=TABFB*(CB+0.68)/1.36
      ELSE
      TABFB=TABFB
      ENDIF
      FREBD=TABFB+SHEERC-SUPDED
      D=T+FREBD*0.001
      IF(D.GT.(AL/15.))THEN
      DEPTHC=(D-AL/15.)*R
      ELSE
      DEPTHC=0.
      ENDIF
      D=D+DEPTHC*0.001
```

```
      CB2=CB+(1.-CB)*((0.85*D-T)/(3*T))
      IF(CB2.GT.0.68)THEN
      TABFB=TABFB*(CB2+0.68)/1.36
      ELSE
      TABFB=TABFB
      ENDIF
      FREBD=TABFB+SHEERC-SUPDED
      D=T+FREBD*0.001
      IF(D.GT.(AL/15.))THEN
      DEPTHC=(D-AL/15.)*R
      ELSE
      DEPTHC=0.
      ENDIF
      D=D+DEPTHC*0.001
   10 RETURN
      END
```

```
      SUBROUTINE WEIGHT(AL,B,T,D,CB,SHP,REVSIN,WS,WO,WM,WLT,S,SCRAP)
C     CALCULATES THE SHIP GROUP WEIGHT
C     BASED ON REF."SOME SHIP DESIGN METHODS"
C     BY WATSON & GILFILLAN, T.RINA, 1977
C
      DIMENSION S(5)
      REAL D,CB1,CB,T,E,WS7,WS,WO,BHP,WMENG,WRM,WM,WLT,K,SCRAP
C
C     NET STEEL WEIGHT(TONNES)
      K=0.03
      CB1=CB+(1.-CB)*(0.8*D-T)/(3.*T)
      SCRAP=S(1)+S(2)*CB1+S(3)*CB1**2+S(4)*CB1**3+S(5)*CB1**4
      E=AL*(B+T)+0.85*AL*(D-T)+250.0
      WS7=K*E**1.36
      WS=WS7*(1.+0.5*(CB1-0.7))
C
C     OUTFIT WEIGHT(TONNES)
      WO=((541.2-AL)/1625.8)*AL*B
C
C     MACHINERY WEIGHT(DIESEL ENGINE)
C     MACHINERY WEIGHT IS DIVIDED BY TWO COMPONENTS
C     MAIN ENGINE AND REMAINDER
      BHP=SHP*1.014
      WMENG=9.38*(BHP/REVSIN)**0.84
      WRM=0.56*(BHP)**0.7
      WM=WMENG+WRM
C
C     LIGHTSHIP WEIGHT
C     WELDING ALLOWANCE ASSUMED TO BE 1% OF THE NET STEEL WEIGHT
C     ALLOWANCE ASSUMED TO BE 2% OF THE LIGHTSHIP WEIGHT FOR MARGIN
      WLT=(1.01*WS+WO+WM)*1.02
      RETURN
      END
```

```
      SUBROUTINE CAPCST(AL,CB,SHP,WS,WO,SCRAP,CAPCOS,CLAB,CMAT,CSL,
     *CSM,COL,COM,CML,CMM,S,FACMAR)
C     ESTIMATES THE SHIP CAPITAL COST
C     BASED ON REF."PRELIMINARY SHIP COST ESTIMATION"
C     BY CARREYETTE, T.RINA, 1978
C
      COMMON/BULK1/WR,PROFIT,OVHEAD,STLCOS,SINDEX
      REAL AL,CB,SHP,WS,WO,SCRAP,CAPCOS,CLAB,CMAT,CSL,CSM,COL,COM,
     *CML,CMM,WR,PROFIT,OVHEAD,STLCOS,SINDEX,A1,B1,C1,D1,E1,F1,FACMAR,
     *TOTCOS,SUBCOS
C
C     DIVIDES THE COSTS INTO LABOUR AND MATERIAL COSTS
C
C     STEEL LABOUR AND MATERIAL COSTS
      A1=WR*227.*(1.+OVHEAD/100.)*(1.+PROFIT/100.)
      B1=STLCOS*(1.+SCRAP/100.)*(1+PROFIT/100.)
      CSL=A1*WS**0.667*AL**0.333/CB
      CSM=B1*WS
C
C     OUTFIT LABOUR AND MATERIAL COSTS
      C1=WR*2710*(1.+OVHEAD/100.)*(1.+PROFIT/100.)
      D1=1500.0*SINDEX/100.0
      COL=C1*WO**0.667
      COM=D1*WO**0.95
C
C     MACHINERY LABOUR AND MATERIAL COSTS
      BHP=SHP
      E1=WR*105.*(1.+OVHEAD/100.)*(1.+PROFIT/100.)
      F1=735.0*SINDEX/100.0
      CML=E1*BHP**0.82
      CMM=F1*BHP**0.82
C
C     COVERTION OF THE 'EEC' PRICES (28% SUBSIDIES) TO JAPANESE
C     PRICES AND MULTIPLIYING THE WHOLE COST BY A MARKET FACTOR
C     FACMAR TO TAKE INTO ACCOUNT THE MARKET CONDITION
C
      TOTCOS=CSL+CSM+COL+COM+CML+CMM
      SUBCOS=TOTCOS*1.5*0.72
```

```
CAPCOS=SUBCOS*FACMAR/100.
CMAT=CSM+COM+CMM
CLAB=CSL+COL+CML
RETURN
END
```

```
      SUBROUTINE TONAGE(AL,B,D,GRT,ANRT)
C     CALCULATES THE GROSS AND NET TONNAGE
C
      REAL AL,B,D,GRT,ANRT
      GRT=0.281*AL*B*D+247.
      ANRT=0.720*GRT-942.
      RETURN
      END
```

```
      SUBROUTINE RUNCOS(AL,B,D,SHP,CAPCOS,FIXCOS,CCOST,CMTRP,CHMINS,
     *CPIINS,CVICT,CSTORE,GRT)
C     CALCULATES THE ANNUAL OPERATING FIXED COSTS
C     (WITHOUT INCLUDING VOYAGE COSTS)
C
      COMMON/BULK14/NC
      REAL CCOST,CMTRP,CHMINS,CPIINS,CMISC,CVICT,CSTORE,FIXCOS,BASWAG,
     *GRT
C
C     ANNUAL CREW COSTS(BASIC WAGES,BENEFITS,ETS.)
C     GREEK CREW ASSUMED
      BASWAG=439.
      CCOST=BASWAG*12.*NC*8.
C
C     ANNUAL MAINTENANCE&REPAIR COSTS
      CMTRP=1096.*(AL*B*D/100.)**0.67+7.97*SHP
C
C     HULL&MACHINERY INSURANCE
      CHMINS=0.4/100.*CAPCOS
C
C     PROTECTION&INDEMNITY INSURANCE
      CPIINS=3.*GRT
C
C     ANNUAL DECK&ENGINE STORES COSTS
      CSTORE=4061.*NC
C
C     VICTUALLING AND PROVISIONS COSTS
      CVICT=1950.*NC
      FIXCOS=CCOST+CMTRP+CHMINS+CPIINS+CSTORE+CVICT
      RETURN
      END
```

```
      SUBROUTINE PAYLD(AL,B,T,CB,V,WLT,WTMIS1,TFUEL1,CDWT1,DISPL,DWT,
     *WHVF1,WDIESL,WSYSLO,WCYLO,SHP,STIME,WTCREW,WSTORE,WFRESH,CDWT2,
     *WHVF2)
C     CALCULATES THE DEADWEIGHT AND THE CARGO DEADWEIGHT
C
      COMMON/BULK3/AUXKW,DISTC1,DISTC2,DISTC3,DISTC4,RESERV
      COMMON/BULK14/NC
      REAL DISPL,AL,B,T,CB,DISTC1,RESERV,TFUEL1,WTMIS1,CDWT1,WSTOR1,
     *WTCREW,WFRES1,WLT,DWT,WHVF1,SHP,V,WDISL1,WSYSL1,WCYLO1,AUXKW,
     *DISTC2,TFUEL2,WTMIS2,CDWT2,WSTOR2,WFRES2,WHVF2,WDISL2,WSYSL2,
     *WCYLO2
C
      DISPL=AL*B*T*CB*1.025
      STIME1=DISTC1/(V*24.)
      STIME2=DISTC2/(V*24.)
C
C     WEIGHT OF CREW AND EFFECT
      WTCREW=NC/6.
C
C     WEIGHT OF STORES AND PROVISIONS
      WSTOR1=0.01*NC*STIME1
      WSTOR2=0.01*NC*STIME2
C
C     WEIGHT OF FRESH WATER
      WFRES1=0.167*NC*STIME1
      WFRES2=0.167*NC*STIME2
C
C     MISCELLANEOUS WEIGHT
      WTMIS1=WFRES1+WSTOR1+WTCREW
      WTMIS2=WFRES2+WSTOR2+WTCREW
C
C     WEIGHT OF FUEL CONSUMED AT SEA
      WHVF1=123.*SHP*0.9*24.*(1.+RESERV/100.)*STIME1*1./1000000.
      WHVF2=123.*SHP*0.9*24.*(1.+RESERV/100.)*STIME2*1./1000000.
      WDISL1=142.*AUXKW*1.341*24.*0.5/0.95*STIME1*1./1000000.
      WDISL2=142.*AUXKW*1.341*24.*0.5/0.95*STIME2*1./1000000.
      WSYSL1=0.2*SHP*0.9*24.*STIME1*1./1000000.
      WSYSL2=0.2*SHP*0.9*24.*STIME2*1./1000000.
```

```
      WCYLO1=0.5*SHP*0.9*24.*STIME1*1./1000000.
      WCYLO2=0.5*SHP*0.9*24.*STIME2*1./1000000.
      TFUEL1=WHVF1+WDISL1+WSYSL1+WCYLO1
      TFUEL2=WHVF2+WDISL2+WSYSL2+WCYLO2
C
C     CARGO DEADWEIGHT
      CDWT1=DISPL-(WTMIS1+TFUEL1+WLT)
      CDWT2=DISPL-(WTMIS2+TFUEL2+WLT)
C
C     DEADWEIGHT
      DWT=DISPL-WLT
      RETURN
      END
```

```
      SUBROUTINE BALAST(AL,T,TB,V,VB)
C     CALCULATES THE SPEED FOR THE BALLAST VOYAGE
C
      REAL AL,T,TB,V,VB
      TB=0.03*AL
      VB=V*((T/TB)**(2./9.))
      RETURN
      END
```

```
      SUBROUTINE VOYTIM(STIME1,STIME2,PORT1,PORT2,V,VB,CDWT1,RTRIP,
     *RTRIPA,BSTIM1,BSTIM2,CDWT2,PORT3,PORT4)
C     CALCULATES THE TIME SPENT AT SEA AND IN PORTS PER SINGLE
C     AND ROUND TRIP,AND NUMBER OF ROUND TRIPS PER ANNUM
C
      COMMON/BULK11/LODCP1,UNLDC1,SHIFT1,SHIFT2,DELAY1,DELAY2
      COMMON/BULK12/LODCP2,UNLDC2,SHIFT3,SHIFT4,DELAY3,DELAY4
      COMMON/BULK3/AUXKW,DISTC1,DISTC2,DISTC3,DISTC4,RESERV
      REAL LODCP1,UNLDC1,SHIFT1,SHIFT2,DELAY1,DELAY2,DISTC1,V,
     *LODCP2,UNLDC2,SHIFT3,SHIFT4,DELAY3,DELAY4,DISTC2,STIME2,CDWT2,
     *STIME1,PORT1,PORT2,PORT3,PORT4,CDWT1,RTRIP,RTRIPA,VB,
     *BSTIM1,BSTIM2,DISTC3,DISTC4
C
C     DAYS AT SEA PER SINGLE AND ROUND TRIP
      STIME1=DISTC1/(V*24.)
      STIME2=DISTC2/(V*24.)
      BSTIM1=DISTC3/(VB*24.)
      BSTIM2=DISTC4/(VB*24.)
C
C     DAYS IN PORTS (PORTS OF DEPARTURE AND ARRIVAL)
      PORT1=CDWT1/(LODCP1*SHIFT1)+DELAY1
      PORT2=CDWT1/(UNLDC1*SHIFT2)+DELAY2
      PORT3=CDWT2/(LODCP2*SHIFT3)+DELAY3
      PORT4=CDWT2/(UNLDC2*SHIFT4)+DELAY4
C
C     TOTAL TIME SPENT IN ROUND TRIP AND NUMBER OF ROUND TRIPS
C     PER ANNUM
      RTRIP=STIME1+STIME2+BSTIM1+BSTIM2+PORT1+PORT2+PORT3+PORT4
      RTRIPA=350./RTRIP
      RETURN
      END
```

```
      SUBROUTINE FUELCT(SHP,STIME1,STIME2,RTRIPA,PORT1,PORT2,TCFUEL,
     *ASFUEL,ASDISL,ASYSLO,ASCYLO,APDISL,BSTIM1,BSTIM2,PORT3,PORT4,
     *WHVF1,WHVF2)
C     CALCULATES THE ANNUAL FUEL COSTS (INCLUDING HEAVY FUEL OIL,
C     MARINE DIESEL OIL,SYSTEM AND CYLINDER LUB.OIL COSTS)
C
      COMMON/BULK3/AUXKW,DISTC1,DISTC2,DISTC3,DISTC4,RESERV
      COMMON/BULK13/COFUEL,CODISL,COSYLO,COCYLO
      REAL SHP,RSTIME,RTRIPA,PORT1,PORT2,TCFUEL,ASFUEL,ASDISL,
     *ASYSLO,ASCYLO,CSFUEL,APDISL,AUXKW,DISTCE,RESERV,COFUEL,
     *CODISL,COSYLO,COCYLO,
     *SFUEL1,SFUEL2,SFUEL3,SFUEL4,STIME1,STIME2,BSTIM1,BSTIM2,
     *WHVF1,WHVF2,PORT3,PORT4
C
C     COSTS OF FUEL CONSUMED AT SEA PER ANNUM
      SFUEL1=WHVF1*COFUEL*RTRIPA
      SFUEL2=WHVF2*COFUEL*RTRIPA
      SFUEL3=123.*SHP*0.9*24.*BSTIM1*1./1000000.*COFUEL*RTRIPA
      SFUEL4=123.*SHP*0.9*24.*BSTIM2*1./1000000.*COFUEL*RTRIPA
      ASDISL=142.*AUXKW*1.341*24.*0.5/0.95*1./1000000.
     **RTRIPA*CODISL*(STIME1+STIME2+BSTIM1+BSTIM2)
      ASYSLO=0.2*SHP*0.9*24.*1./1000000.*RTRIPA*COSYLO
     **(STIME1+STIME2+BSTIM1+BSTIM2)
      ASCYLO=0.5*SHP*0.9*24.*1./1000000.*RTRIPA*COCYLO
     **(STIME1+STIME2+BSTIM1+BSTIM2)
C
C     COSTS OF DIESEL OIL CONSUMED IN PORTS PER ANNUM
      APDISL=142.*AUXKW*1.341*24.*0.75/0.95*(PORT1+PORT2+PORT3+PORT4)
     **1./1000000.*RTRIPA*CODISL
C
C     TOTAL ANNUAL FUEL COSTS
      TCFUEL=SFUEL1+SFUEL2+SFUEL3+SFUEL4+ASDISL+ASYSLO+ASCYLO+APDISL
      RETURN
      END
```

```
      SUBROUTINE STABLE(AL,B,T,D,CB,WS,WO,WM,WLT,DWT,CDWT1,DISPL,WTMIS1,
     *TFUEL1,GM,AKG)
C     CALCULATES THE METACENTRIC HEIGHT AND CENTRE OF GRAVITY
C
      REAL AL,B,T,D,CB,DWT,DISPL,WS,WO,WM,WLT,GM,CW,AKM,AKB,BM,
     *CDWT1,AKG,AKGS,AKGO,AKGM,AKGLWT,AKGX,AKGFD,AKGFS,AKGC,
     *WTMIS1,TFUEL1,HDB,WFS,AKX,AKC
C
      AKB=T*(1.+2.*CB)/(1.+5.*CB)
      CW=CB*2./3.+1./3.
      AK=0.073
      BM=AK*CW*(B**2.)/(T*CB)
      AKM=AKB+BM
C
C     CENTRE OF GRAVITY OF STEEL WEIGHT
      AKGS=0.01*D*(46.6+0.135*(0.81-CB)*((AL/D)**2.))
     *+(AL/B-6.5)*0.008*D
C
C     CENTRE OF GRAVITY OF OUTFIT WEIGHT
      IF(AL.LE.125.)THEN
      AKGO=D+1.25
      ELSE IF(AL.GT.125.0.AND.AL.LE.250.)THEN
      AKGO=D+1.25+0.01*(AL-125.)
      ELSE
      AKGO=D+2.5
      ENDIF
C
C     CENTRE OF GRAVITY OF MACHINERY WEIGHT
      AKGM=0.17*T+0.36*D
C
C     CENTRE OF GRAVITY OF LIGHTSHIP WEIGHT
      AKGLWT=(WS*AKGS+WO*AKGO+WM*AKGM)/(WS+WO+WM)
C
C     CENTRE OF GRAVITY OF MISCELLANEOUS WEIGHT
      AKX=1.
      AKGX=AKX*D
C
C     CENTRE OF GRAVITY OF FUEL WEIGHT IN DOUBLE BOTTOM
```

```
      HDB=1.2*(28.*B+205.*(T**0.5))*1./1000.
      AKGFD=0.67*HDB
C
C     CENTRE OF GRAVITY OF FUEL WEIGHT IN SETTLER TANKS
      AKGFS=HDB+0.6*(D-HDB)
C     WEIGHT OF FUEL IN SETTLER TANKS
      WFS=150.
C
C     CENTRE OF GRAVITY OF CARGO DEADWEIGHT
      AKC=0.63
      AKGC=AKC*D
C
      AKG=(AKGLWT*WLT+AKGX*WTMIS1+AKGFS*WFS+AKGFD
     **(TFUEL1-WFS)+AKGC*CDWT1)/DISPL
C
      GM=AKM-AKG
      RETURN
      END
```

```
      SUBROUTINE CROSCT(AL,B,T,D,CB,AKG2,GZMAX,AREA30,AREA40,
     *AR3040,GZ0,GZ10,GZ20,GZ30,GZ40,GZ50,GZ60)
C     CHECKS THE STABILITY AT LARGE ANGLES OF HEEL
C
      REAL AL,B,T,D,CB,AKG2,SHEER,AKN10,AKN20,AKN30,AKN40,AKN50,
     *AKN60,GZ0,GZ10,GZ20,GZ30,GZ40,GZ50,GZ60,AREA30,AREA40,
     *AR3040,GZMAX
C
      SHEER=0.0
      IF(D/B.LT.0.58)THEN
      AKN10=1.025*(0.004+2.5*D/B-0.004*B/T)*B/20.
      AKN20=1.025*(-0.305+0.1333*SHEER/B+5.*D/B+0.1*B/T)*B/20.
      AKN30=1.025*(-1.641-0.1*CB+0.6467*SHEER/B+7.3*D/B+0.65*B/T)*B/20.
      AKN40=1.025*(-2.815-0.2*CB+1.1333*SHEER/B+9.25*D/B+1.1*B/T)*B/20.
      AKN50=1.025*(-3.0325-0.3*CB+1.6*SHEER/B+10.375*D/B+1.23*B/T)*B/20.
      AKN60=1.025*(-2.4045-0.5*CB+2.*SHEER/B+11.125*D/B+1.036*B/T)*B/20.
      ELSE IF(D/B.GE.0.58.AND.D/B.LT.0.62)THEN
      AKN10=1.025*(0.671+1.35*D/B-0.004*B/T)*B/20.
      AKN20=1.025*(-0.0876+0.1333*SHEER/B+4.625*D/B+0.1*B/T)*B/20.
      AKN30=1.025*(-2.192-0.1*CB+0.6467*SHEER/B+8.25*D/B+0.65*B/T)*B/20.
      AKN40=1.025*(-3.83-0.2*CB+1.1333*SHEER/B+11.*D/B+1.1*B/T)*B/20.
      AKN50=1.025*(-4.1925-0.3*CB+1.6*SHEER/B+12.375*D/B+1.23*B/T)*B/20.
      AKN60=1.025*(-3.492-0.5*CB+2.*SHEER/B+13.*D/B+1.036*B/T)*B/20.
      ELSE
      AKN10=1.025*(1.043+0.75*D/B-0.004*B/T)*B/20.
      AKN20=1.025*(1.3385+0.1333*SHEER/B+2.325*D/B+0.1*B/T)*B/20.
      AKN30=1.025*(-0.301-0.1*CB+0.6467*SHEER/B+5.2*D/B+0.65*B/T)*B/20.
      AKN40=1.025*(-2.28-0.2*CB+1.1333*SHEER/B+8.5*D/B+1.1*B/T)*B/20.
      AKN50=1.025*(-2.9525-0.3*CB+1.6*SHEER/B+10.375*D/B+1.23*B/T)*B/20.
      AKN60=1.025*(-2.407-0.5*CB+2.*SHEER/B+11.25*D/B+1.036*B/T)*B/20.
      ENDIF
      AKG2=0.61*D
      GZ0=0.
      GZ10=AKN10-AKG2*0.173648
      GZ20=AKN20-AKG2*0.34202
      GZ30=AKN30-AKG2*0.5
      GZ40=AKN40-AKG2*0.64279
      GZ50=AKN50-AKG2*0.76604
```

```
      GZ60=AKN60-AKG2*0.86603
C
C     AREA UNDER THE CURVE FROM 0-30 IN METRE-RADIANS BY SIMPSON
      AREA30=10.*3./8.*(1.*GZ0+3.*GZ10+3.*GZ20+1.*GZ30)
      AREA30=AREA30*0.01745
      IF(AREA30.LT.0.055)GOTO 80
      GZMAX=AMAX1(GZ30,GZ40,GZ50,GZ60)
      IF(GZMAX.LT.0.2)GOTO 90
      IF(GZMAX.LE.GZ10)GOTO 90
      IF(GZMAX.LE.GZ20)GOTO 90
      GOTO 20
C     AREA UNDER THE CURVE FROM 0-40 IN METRE-RADIANS BY SIMPSON
   20 AREA40=10./3.*(1.*GZ0+4.*GZ10+2.*GZ20+4.*GZ30+1.*GZ40)
      AREA40=AREA40*0.01745
      IF(AREA40.LT.0.09)GOTO 80
      AR3040=AREA40-AREA30
      IF(AR3040.LT.0.03)GOTO 80
      GOTO 100
   80 WRITE(6,85)
   85 FORMAT(2X,'AREA UNDER THE CURVE IS LESS THAN REQUESTED')
   90 WRITE(6,95)
   95 FORMAT(2X,'MAXIMUM GZ IS LESS THAN REQUESTED')
  100 RETURN
      END
```

```
      SUBROUTINE CAPCTE(AL,B,T,D,CB,SHP,STOMAX,STOMIN,CDWT1,
     *VGRMIN,VGRMAX)
C     CALCULATES THE CARGO GRAIN CAPACITY OF THE SHIP AND
C     THE STOWAGE RATE
C
      REAL AL,B,T,D,CB,SHP,CDWT1,K1,CAMBER,SHERAF,SHERFD,VTOT,ALPEAK,
     *K2,VPEAKS,HDB,K3,VDB,ALER,K4,VER,ALFA,BETA,HW,TTW,VWT,HSG,HSW,
     *VTT,VGRMIN,VGRMAX,STOMIN,STOMAX,LHOLD,CB85,VHOLD,VHOLD2,
     *VHOLD3,MXGRF,MNGRF
C
      AL=AL*3.2808
      B=B*3.2808
      T=T*3.2808
      D=D*3.2808
C
C     TOTAL VOLUME UNDER DECK
      K1=0.333*CB+0.864
      CAMBER=(B/50.)
      SHERAF=0.0
      SHERFD=0.0
      VTOT=CB*K1*AL*B*(D+(SHERAF+SHERFD+2.*CAMBER/3.)/6.)
C
C     TOTAL VOLUME OF PEAKS
      ALPEAK=0.1*AL
      K2=0.37
      VPEAKS=ALPEAK*B*CB*K2*(D+(SHERAF+SHERFD)/2.)
C
C     TOTAL VOLUME OF DOUBLE BOTTOM
      HDB=1.2*(28.*B/3.2808+205.*((T/3.2808)**0.5))*3.2808/1000.
      K3=1.2*CB-0.06
      VDB=(AL-ALPEAK)*B*HDB*CB*K3
C
C     TOTAL VOLUME OF ENGINE ROOM
      ALER=0.0032*SHP+48.
      K4=0.85
      VER=ALER*B*(D-HDB)*CB*K4
C
C     TOTAL VOLUME OF HOPPER WING TANKS
```

```
      ALFA=0.5236
      BETA=0.698
      HW=B/4.
      TTW=HW+8.
      VWT=((1./2.)*(B/2.-TTW)**2.*TAN(BETA))*2.*(AL-ALPEAK-ALER)
C
C     TOTAL VOLUME OF TOPSIDE TANKS
      HSG=2.5
      HSW=3.0
      VTT=(HSG*(B/2.-HW)+(1./2.)*(B/2.-HW-HSW)**2.*TAN(ALFA)
     *+HSW*(B/2.-HW-HSW)*TAN(ALFA)-(1./2.)*CAMBER*(B/2.-HW))*2.
     **(AL-ALPEAK-ALER)
C
C     MINIMUM GRAIN CAPACITY(CUBIC FEET)
      VGRMIN= (VTOT-0.95*(VPEAKS+VDB+VER+VWT+VTT))*0.9
C     MAXIMUM GRAIN CAPACITY(CUBIC FEET)
      VGRMAX= (VTOT-0.95*(VPEAKS+VDB+VER+VWT))*0.9
C     STOWAGE RATE FACTOR MINIMUM AND MAXIMUM
      STOMAX=VGRMAX/CDWT1
      STOMIN=VGRMIN/CDWT1
      AL=AL/3.2808
      B=B/3.2808
      D=D/3.2808
      T=T/3.2808
      RETURN
      END
```

```
      SUBROUTINE VOYCST(RTRIPA,GRT,ANRT,TCFUEL,PCNRT,CPORT,PCDUES,
     *CHANDL,CDWT1,CDWT2,CSTVOY)
C     CALCULATES THE ANNUAL VOYAGE COSTS
C
      COMMON/BULK3/AUXKW,DISTC1,DISTC2,DISTC3,DISTC4,RESERV
      REAL RTRIPA,GRT,ANRT,TCFUEL,PCNRT,CPORT,PCDUES,CHANDL,CDWT,
     *CSTVOY
C
C     PORT DUES
      CPORT=4.*RTRIPA*ANRT*1.68
C
C     CANAL DUES
C     PANAMA CANAL TOLL RATES:
C     LADEN:$1.83 PER PC NET TON
C     BALLAST:$1.46 PER PC NET TON
C     PC NET TON ABOUT 13% HIGHER THAN BRITISH NRT
      PCNRT=1.13*ANRT
      PCDUES=RTRIPA*(1.83*PCNRT+1.83*PCNRT)
C
C     CARGO HANDLING CHARGES
      CHANDL=(0.79*CDWT1+1.73*CDWT1)*RTRIPA+
     *(0.79*CDWT2+1.73*CDWT2)*RTRIPA
C
C     TOTAL VOYAGE COSTS PER ANNUM.
      CSTVOY=TCFUEL+CPORT+PCDUES+CHANDL
      RETURN
      END
```

```
      SUBROUTINE CAPCHR(CAPCOS,BLDCF,PWF,PINTT)
C     CALCULATES THE CAPITAL CHARGES OF THE SHIP
C      ASSUMES THE LOAN 80% OF THE CAPITAL COST AND 8 YEARS THE
C     LOAN PERIOD
C     YEAR O IS THE YEAR OF SIGNING THE CONTRACT
C     YEAR 2 IS THE YEAR OF DELIVERY
C     THE SHIPOWNER PAYES 10% OF THE CAPITAL COST IN THE YEAR 0
C     PLUS 1% EXTRA AND 10% IN THE YEAR 1
C     30% OF THE LOAN IS PAID IN THE YEAR 1 AND 30% IN  THE
C     YEAR 1.5 AND 20% WHEN THE SHIP IS DELIVERED.
C
      COMMON/BULK4/PINT
      COMMON/BULK5/DISRAT
      COMMON/BULK6/YRLOAN
      DIMENSION PINTT(20)
       REAL CAPCOS,PINT,DISRAT,YRLOAN,BLDCF,PWF,REMAIN,REPAYM
C
      YEAR=0.
       BLDCF=0.1*CAPCOS+0.01*CAPCOS
      YEAR=1.
      CALL PRESWF(DISRAT,YEAR,PWF)
      BLDCF=BLDCF+0.1*CAPCOS*PWF
      YEAR=1.5
      CALL PRESWF(DISRAT,YEAR,PWF)
      K=1
      PINTT(K)=(0.3*CAPCOS*PINT/100.)*0.5
      BLDCF=BLDCF+PINTT(K)*PWF
      YEAR=2.
      CALL PRESWF(DISRAT,YEAR,PWF)
      K=K+1
      PINTT(K)=(0.6*CAPCOS*PINT/100.)*0.5
      BLDCF=BLDCF+PINTT(K)*PWF
      YEAR=3.
      CALL PRESWF(DISRAT,YEAR,PWF)
      K=K+1
      PINTT(K)=PINTT(1)+PINTT(2)+0.8*CAPCOS*PINT/100.
      REPAYM=0.8*CAPCOS/YRLOAN
```

```
      REMAIN=0.8*CAPCOS-REPAYM
      BLDCF=BLDCF+(REPAYM+0.8*CAPCOS*PINT/100.)*PWF
      DO 10,I=1,YRLOAN-1.
      YEAR=YEAR+1.
      K=K+1
      PINTT(K)=REMAIN*PINT/100.
      CALL PRESWF(DISRAT,YEAR,PWF)
      BLDCF=BLDCF+(PINTT(K)+REPAYM)*PWF
      REMAIN=REMAIN-REPAYM
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PRESWF(DISRAT,YEAR,PWF)
C     CALCULATES THE PRESENT WORTH FACTOR ASSUMING A CERTAIN
C      DISCOUNT RATE
C
      PWF=1./((1.+DISRAT/100.)**YEAR)
      RETURN
      END
```

```
      SUBROUTINE ECONOM(RTRIPA,TCFUEL,CPORT,BLDCF,CDWT1,CDWT2,CCOST,
     *CMTRP,CHMINS,CPIINS,CVICT,CSTORE,CAPCOS,ATCOST,DTCOST,PWCDWT,
     *CFR,PWF,YEAR,CDWTA,CHANDL,PCDUES,PINTT,CLNPV,RFR,CFRAT,CLDCF)
C     CALCULATES THE CHARTER FREIGHT RATE CFR ASSUMING NO TAX
C
      COMMON/BULK5/DISRAT
      COMMON/BULK7/LIFE
      COMMON/BULK9/RICREW,RIMARE,RIINS,RIFUEL,RIPORT
      COMMON/BULK6/YRLOAN
      DIMENSION ECREW(40),EMARE(40),EINS(40),EFUEL(40),
     *EPORT(40),AICREW(40),AIMARE(40),AIINS(40),AIFUEL(40),
     *AIPORT(40),ATCOST(40),DTCOST(40),PWCDWT(40),EXPEND(40),
     *AINCOM(40),CASHBT(40),DEPRES(40),PINTT(20),TAXPRO(40),
     *TAX(40),CASHAT(40),PWCASH(40),CLNPV(3),CFRAT(3),CLDCF(3)
C
      REAL CDWTA,CDWT1,RTRIPA,YEAR,PWF,DISRAT,CCOST,CMTRP,CHMINS,
     *CPIINS,CMISC,CSTORE,CFUELP,CFUELS,CPORT,CAPCOS,TRDCF,CHANDL,
     *DCFDWT,CFR,BLDCF,RICREW,RIMARE,RIINS,RIFUEL,RIPORT,PCDUES,
     *DCF,DEP,YRLOAN,FDEP,PTAX,CALNPV,CDWT2,RFR
C
      INTEGER LIFE
      CDWTA=(CDWT1+CDWT2)*RTRIPA
      I=0
      YEAR=2.
    5 I=I+1
      YEAR=YEAR+1.
      CALL PRESWF(DISRAT,YEAR,PWF)
      ECREW(I)=(1.+RICREW/100.)**YEAR
      EMARE(I)=(1.+RIMARE/100.)**YEAR
      EINS(I)=(1.+RIINS/100.)**YEAR
      EFUEL(I)=(1.+RIFUEL/100.)**YEAR
      EPORT(I)=(1.+RIPORT/100.)**YEAR
C
      AICREW(I)=CCOST*ECREW(I)
      AIMARE(I)=(CMTRP+CSTORE)*EMARE(I)
      AIINS(I)=(CHMINS+CPIINS)*EINS(I)
      AIFUEL(I)=TCFUEL*EFUEL(I)
      AIPORT(I)=(CPORT+CHANDL+PCDUES)*EPORT(I)
```

```
C
      ATCOST(I)=AICREW(I)+AIMARE(I)+AIINS(I)+AIFUEL(I)+AIPORT(I)
      DTCOST(I)=ATCOST(I)*PWF
      PWCDWT(I)=CDWTA*PWF
      IF(I.EQ.1)GOTO 10
      GOTO 20
   10 TRDCF=DTCOST(I)
      DCFDWT=PWCDWT(I)
      GOTO 5
   20 TRDCF=TRDCF+DTCOST(I)
      DCFDWT=DCFDWT+PWCDWT(I)
C
      IF(I.EQ.LIFE)GOTO 30
      GOTO 5
   30 CFR=(TRDCF+BLDCF)/DCFDWT
      CALL ECATAX(PWF,YEAR,ATCOST,CFR,CDWTA,PINTT,
     *BLDCF,CLNPV,CAPCOS,RFR,CFRAT,DCF,CLDCF)
      RETURN
      END
```

```
      SUBROUTINE ECATAX(PWF,YEAR,ATCOST,CFR,CDWTA,PINTT,BLDCF,CLNPV,
     *CAPCOS,RFR,CFRAT,DCF,CLDCF)
C     CALCULATES THE REQUIRED FREIGHT RATE RFR AFTER TAX
C
      COMMON/BULK5/DISRAT
      COMMON/BULK6/YRLOAN
      COMMON/BULK7/LIFE
      COMMON/BULK8/PTAX
      DIMENSION EXPEND(40),ATCOST(40),AINCOM(40),CASHBT(40),
     *DEPRES(40),PINTT(20),TAXPRO(40),TAX(40),CASHAT(40),PWCASH(40)
      DIMENSION CLNPV(3),CFRAT(3),CLDCF(3)
C
      REAL YEAR,DISRAT,PWF,CFR,CDWTA,DCF,DEP,YRLOAN,FDEP,CAPCOS,PTAX,
     *CALVPV,BLDCF,RFR
      INTEGER LIFE
      DO 100,KI=1,3
      I=0
      YEAR=2.
    5 I=I+1
      YEAR=YEAR+1.
      CALL PRESWF(DISRAT,YEAR,PWF)
      EXPEND(I)=ATCOST(I)
      AINCOM(I)=CFR*CDWTA
      CASHBT(I)=AINCOM(I)-EXPEND(I)
      K=I+2
      DEPRES(I)=CASHBT(I)-PINTT(K)
      TAXPRO(I)=0.
      TAX(I)=0.
      CASHAT(I)=CASHBT(I)-TAX(I)
      PWCASH(I)=CASHAT(I)*PWF
      IF(I.EQ.1)GOTO 10
      GOTO 15
   10 DCF=PWCASH(I)
      DEP=DEPRES(I)
      GOTO 5
   15 DCF=DCF+PWCASH(I)
      DEP=DEP+DEPRES(I)
```

```
      IF(I.EQ.YRLOAN-1.)GOTO 20
      GOTO 5
   20 CONTINUE
      I=I+1
      YEAR=YEAR+1.
      CALL PRESWF(DISRAT,YEAR,PWF)
      EXPEND(I)=ATCOST(I)
      AINCOM(I)=CFR*CDWTA
      CASHBT(I)=AINCOM(I)-EXPEND(I)
      K=I+2
      FDEP=1.01*CAPCOS-DEP
      TAXPRO(I)=CASHBT(I)-PINTT(K)-FDEP
      TAX(I)=(PTAX/100.)*TAXPRO(I)
      CASHAT(I)=CASHBT(I)-TAX(I)
      PWCASH(I)=CASHAT(I)*PWF
      DCF=DCF+PWCASH(I)
   25 CONTINUE
      I=I+1
      YEAR=YEAR+1.
      CALL PRESWF(DISRAT,YEAR,PWF)
      EXPEND(I)=ATCOST(I)
      AINCOM(I)=CFR*CDWTA
      CASHBT(I)=AINCOM(I)-EXPEND(I)
      TAX(I)=(PTAX/100.)*CASHBT(I)
      CASHAT(I)=CASHBT(I)-TAX(I)
      PWCASH(I)=CASHAT(I)*PWF
      DCF=DCF+PWCASH(I)
      IF(I.EQ.LIFE)GOTO 30
      GOTO 25
   30 CLDCF(KI)=DCF
      CALNPV=DCF-BLDCF
      CLNPV(KI)=CALNPV
      CFRAT(KI)=CFR
      IF(DCF.GT.BLDCF)THEN
      CFR=0.8*CFR
      GOTO 100
      ELSE
      CFR=1.2*CFR
```

```
      ENDIF
  100 CONTINUE
      X=0.
      CALL LAGINT(X,CLNPV,CFRAT,RFR)
      RETURN
      END
```