THE ECONOMIC DESIGN OF BULK CARGO CARRIERS

A. W. Gilfillan, B.Sc.

Summary

During the past few years the computer has gradually been accepted as an essential tool for the naval architect. A large number of programs have been developed to perform every task in the design office. The naval architect is now able to embark upon investigations which previously required a prohibitive amount of computation.

Such an investigation is one in which the computer is used to derive the most favourable combination of length, beam and draft for any design based on the owner's basic requirements of deadweight speed and range of operation. The aim of this thesis and it's associated computer programs is to assist the naval architect to produce a more profitable design, for a bulk cargo carrier. A whole series of suitable designs is synthesised by the computer and the economic performance of each is deduced and assessed by comparison with others.

The criterion for comparing the series of designs is obtained by assessing the minimum cost per ton of cargo deadweight. Requirements other than the minimum cost affect the choice of design. Account must be taken of the operational performance in cargo handling, the loss of speed etc. Unfortunately, no easy relationships have been derived to take these factors into account, and the program system must content itself with producing a large number of designs which are technically acceptable.

In order to obtain the large number of acceptable designs, the program derives a series of designs by methodically varying the three parameters, Length/Beam and Beam/Draft Ratio and the Block Coefficient. The features of each design are derived using well known relationships supplemented by formulae based on detailed analysis of existing bulk carrier designs. The capital cost of each design is estimated using the "Motor Ship Magazine" Bulk Carrier as a basis. The fixed cost items such as crew and insurance are obtained and expressed as a cost per day. A typical route on which the design is expected to operate is simulated as a series of activities and the performance of each design on the route is assessed.

The program has been run to carry out a detailed design study for a typical bulk/

bulk carrier route. The route chosen was:

East Coast U.S.A. to Japan with coal.

Japan to Chile under ballast.

Chile to East Coast U.S.A. with iron ore.

Four series were produced to investigate the effect of changes in deadweight, speed, block coefficient and length. Graphs showing the results of these variations are given.

The background to the bulk cargo trade is described as are the principal features of bulk carrier design.

The uses and possible extensions to the program system are discussed.

E R R A T A.

Page 8 Line 2. Figure 3 should be Figure 4.
Last line Figure 4 should be Figure 3.

Page 13 Second paragraph Posdunine coefficient should be C2 and CI.

Page 16 References 7 and 8 are the wrong way round.

Page 41 Line missing after line 9, the sentence should read "The fixed costs are calculated as costs per annum for each design."

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A.W. Gilfillan, B.Sc.

Submitted as a Thesis for the Degree of

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1966.

SUMMARY

A computer program has been written to carry out the preliminary design of a bulk carrier from the owner's basic requirements of deadweight, speed and range. The program builds up a series of designs and simulates the operation and running costs for each design over a specified route. A study has been made of typical bulk carrier route and a suitable design evolved. The technical and economic methods for preliminary ship design are described. Possible extensions to the program are discussed.

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NOMENCLATURE

AC	Annual fixed Costs
A_m	Area of longitudinal Material at Midships
A_w	Waterplane Area
a	Coefficient in Alexander Type formula
a_o - a_6	Coefficnets for Tabular Freeboard equation
α	Topside Tank Angle
B	Beam
BHP	Brake Horsepower
BM_L	Height of Longitudinal Metacentre above centre of buoyancy.
BM_T	Height of Transverse metacentre above centre of buoyancy.
BP	Bunker price of oil fuel - average round route.
b	Coefficient in Alexander Formula
β	Angle of Side Hopper Tank.
C	Camber -ft.
C_B	Block coefficient
CC	Capital Cost of Ship.
CDWT	Cargo Deadweight
C_e	Establishment Charges
C_m	Cost of Machinery
C_o	Cost of Outfit
C_p	Prismatic Coefficient
C_R	Number of Crew
C_S	Cost of Steelwork
C_W	Waterplane Area Coefficient
C_1	Constant of proportionality - Posdumine Formula
C_2	Constant Proportionality - amended Posdumine Formula
D	Depth

DBH	Double Bottom Height
DD	Annual Dry Docking Cost
DIST	Distance Sailed on Route
DWT	Deadweight
Δ	Displacement
EHP	Effective Horsepower
F	Freeboard before depth correction
FCOST	Fuel cost for route
FF	Total fuel used round route - tons
fcr	Fuel consumption Rate lbs/horsepower hour
fi	Fuel accounted to commodity i $(0 \leq i \leq NCOM)$
F2	Summer freeboard - ins.
GM_L	Longitudinal Metacentre height
hsg	Depth of Hatch side girder below deck at hatch side.
hw	Hatch Width
I, i,	Integer quantities
I_L	Longitudinal second moment of area
I_T	Transverse second moment of area
INS	Annual insurance cost
INT	Total cost of interest
KG	Height of centre of gravity above base
L	Constant of proportionality
L_{AP}	Length of aft peak tank
L_{BP}	Length between perpendiculars
LCB	Longitudinal centre of buoyancy
LCF	Longitudinal centre of flotation
L_{DT}	Length of Deep Tank

L_{ER}	Length of Engine Room
L_{FP}	Length of Fore Peak Tank
L_{SS}	Length of Superstructures
LUB	Cost of Lubrication per annum
L_{WL}	Load waterline length
LWT	Lightweight
MCT	Moment to change time one inch
M	Life of Ships - years.
N	No of years over which loan on new ship is made.
NCOM	No of commodities carried on the route
NYDEP	No of years to deprecite ship to scrap value.
CR	Overtime paid to each crew member ($1 \leqslant n \leqslant cr$).
p	Length/Beam ratio L/B
PC	Proportion of Capital cost of ship on credit
PORT	Port charges round route
P_i	Port charges associated with commodity no i $\leqslant i <$ NCOM.
ptw	pipe tunnel width
q	Beam/Draft ratio B/T
QPC	Quasi Propulsive Coefficient
R	Range of design - miles
R_1	Bilge radius
R_2	Radius of sheerstrake
SW	Width of Shelf Plate
ST	Cost of stores per annum
SURV	Total cost of Special Surveys
SCRAP	Scrap value of ship
SSA	Special survey allowance per annum
T	Draft

TF	Tabular Freeboard
TTW	Tank Top Width
T_R	Rolling period
TIP	Time on Port on Route
t_1	Time on route allocated to Commodity No i $\leqslant 0 \leqslant i$ NCOM
TT	Total Time on route
$TONS_i$	Deadweight of Commodity No i carried on route $0 \leqslant i \leqslant$ NCOM
V	Speed
∇	Immersed Volume
VCB	Vertical centre of buoyancy
VICT	Victualling allowance per man per annum.
W_s	Steel wt.
W_o	Outfit wt.
W_m	Machinery wt.
W_{of}	Wt. of oil fuel
W_n	Basic wage of each member of crew $1 \leqslant n \leqslant CR$
WDS	Working days per annum
X	Variable

1. INTRODUCTION

During the past few years the computer has gradually been accepted as an essential tool for the naval architect. A large number of programs has been developed to perform every day tasks in the design office. The naval architect is now able to embark upon investigations which previously required a prohibitive amount of computation.

The computer may be used to derive the most favourable combination of length, beam and draft for any design based on the owner's basic requirements of deadweight, speed and range of operation.

The need for such an investigation is well illustrated by Figure 1., which shows the dimensions of recent bulk carrier orders superimposed on Figure 2 of Mr. J.M. Murray's paper "Large Bulk Carriers" (reference 1). The Japanese ships in general are much beamier than their British counterparts. It is interesting to note that the British Economy Class Bulk Carrier has a low L/B ratio. One would expect the capital cost of the shorter ships to be less and providing that they do not need excessive power, the effect of shorter length on the shipowner's profit should be beneficial. Do the higher length/beam ratios of the British built ships mean that the shipowner is employing an inherently more expensive design? The purpose of this investigation is to help to provide an answer and to assist the naval architect to produce a more profitable ship. A whole series of suitable designs is synthesised by the computer and the economic performance of each deduced and assessed by comparison with others.

A criteria for judging the economic performance may be obtained by evaluating the capital recovery factor (references 20 & 21) or the maximum profit per ton of cargo deadweight. The latter is a more practical and more easily understood concept as the owner's aim to obtain the maximum profit from his investment. Requirements other than the maximum estimated profit affect the choice of the best design. Account must be taken of the operational performance in cargo handling, the loss of speed in bad weather etc. Unfortunately at the moment insufficient data are immediately available to enable the computer programs to assess the losses or gains arising from the operational efficiency of the design. In the immediate future the program system must content itself with producing a large number of designs which are technically acceptable and indicating the highest profit.

The computer obtains estimates of income and expenditure from the design, checks that it is technically acceptable, simulates a typical route for the ship and estimates the resulting income and expenditure. The income is derived from the loadings and freight rates and the expenditure partly from relevant design quantities and partly from the owner's cost data. The designs must meet the owner's basic requirements of deadweight, speed, range and minimum homogeneous stowage factor. Any design that does not meet the dimension restrictions or stability requirements or that has insufficient capacity must be rejected.

The relative importance of the owner's basic requirements will vary according to ship type. For some types, it will be better to use the cargo deadweight instead of the total deadweight, and for some the stowage factor should be derived from a bale capacity rather than a grain capacity.

For the bulk carrier investigation several simplifications have been made. Only the cost has been evaluated and this has been determined as a cost per ton of cargo deadweight for the route. This is based on the assumption that income may be expressed as income per ton of cargo deadweight for each commodity carried on the route. The maximum profit is then obtained by minimising the running costs including the capital charges.

The calculations required to obtain the costs are so lengthy that it was found necessary for them to be done in two parts in the computer. The answers from the first program are used as data for the second program. Programs have been written to synthesise new designs either from a desired deadweight, speed and range or else from a series of values of length, beam, draft and block coefficient.

The programs have been run to carry out a detailed design study for a typical bulk carrier route. The route chosen was of three legs namely.

East Coast U.S.A. to Japan with coal.

Japan to Chile under ballast.

Chile to East Coast U.S.A. with iron ore.

The range of deadweights considered was from 50,000 dwt to 70,000 dwt and speeds of 14 to 18 knots.

From the results of the investigation it was deduced that the best combination of length, beam, draft and block coefficient was 800, 104, 40 and 0.82 respectively. This gives a ship of approximately 62,000 tons deadweight. An outline general arrangement and a section through the midship cargo hold have been prepared in order to show how far the design can be fixed in the computer during the early design stage.

2. BACKGROUND TO THE INVESTIGATION

2.1 The Bulk Cargo Trades

Bulk cargo carriers have arisen out of the demand for bulk commodities to be carried economically around the world in large consignments. Since the First World War there has been an explosion in the world movement of bulk commodities. To meet this demand, specialist ship designs have been evolved, oil tankers to carry fluids in bulk, ore carriers to carry dense bulk solids and bulk cargo carriers to carry a wide variety of bulk solids and, in some cases, liquids. A number of arrangements for bulk carriers have been developed including the patented "Universal Bulkship".

The seaborne movement of the principal bulk solids is increasing rapidly at the moment and shows no sign of abating. Between 1963 and 1964, world movement of the principal commodities rose by 15% and the proportion of this carried by bulk cargo carriers rose by 28%. The range of commodities to be carried is also expanding as more commodities are produced or mined in sufficient quantities to make transport in bulk carriers economic.

Table I shows the seaborne trade of Bulk Commodities for 1962, 1963 and 1964, which has been abstracted from data supplied by Fearnley and Eger's Chartering Co. (Reference 2). The principal commodities carried are iron ore, grain, coal, manganese ore, bauxite, alumina and phosphates. Bulk carriers are moving into the transport of raw sugar, soya beans, salt, gypsum, scrap iron and coke. Molten sulphur is carried in specially designed bulk carriers.

The returns on the movement of iron ore for 1962 to 1964 have been plotted together with estimates for 1966 and 1970 made in 1963 (Reference 3). In the light of the 1964 figure, these may be underestimates, but may be regarded a safe minimum estimate for the growth of the trade. The

TABLE I

SEABORNE TRADE OF BULK COMMODITIES 1962 - 1964

COMMODITY	STOWAGE FACTOR	SEABORNE TRADE 1000 MILLION TONS 1962	1963	1964	REMARKS	SIZE OF VESSELS ON TRADE
IRON ORE	17 - 22 cu ft/ ton.	102183 64530 63.2%	106753 74700 70%	134205 99790 75%	Total Trade Bulk Carriers Percentage	All sizes.
GRAIN	45 to 70	52643 14260 27.1%	59400 21900 37%	71109 25180 35%	Total Trade Bulk Carriers Percentage	All sizes.
COAL	40 to 54	52940 19490 36.8%	63996 26820 42%	60149 31170 51%	Total Bulk Carriers Percentage	All sizes.
MANGANESE ORE	16 to 19	4763	5424 1830 33.8%	6661 1850 27.8%	Total Bulk Carriers Percentage	Often carried as part of Iron Ore Cargo
BAUXITE AND ALUMINA	34/40 18/24	18076 9250 51.2%	16958 9250 54.5%	18947 11920 63%	Total Bulk Carriers Percentage	20000 to 35000 tons.
TOTAL		230605	274383 136350 49.6%	316966 174640 55.1%	Total Bulk Carrier Percentage	up 15% '63-64 up 28% '63-64
OTHER COMMODITIES						
RAW SUGAR	43		7939	8455		
SOYA BEANS			4330	4494		
SALT	35-41		2567	4117		upto 53,000 t. dwt.
GYPSUM	38-45		4150	4570		10,000 dwt.
SCRAP IRON	48		4934	5744		24,000 dwt.
PETROLEUM COKE			1515	1991		
SULPHUR	30-31			3812		Special Ships
OTHERS			9620	16270		
GRAND TOTAL			309438	360675		

proportion of iron ore carried in tramps will decline further and probably be a negligible proportion of the trade by 1970.

The shipment of grain fluctuates according to the quality and size of harvests throughout the world. The demand for grain shipments will probably take the course of a fluctuating increase over the years as world population outstrips world food production. The bulk carrier may be expected to take an increasing share of the market leaving positive fluctuations for tramp ships. Large shipments of grain have been made in tankers of up to 100,000 deadweight tons and these ships will continue to provide competition for bulk carriers in large grain shipments.

The shipment of coal is a less certain variable. New discoveries of sources of fuel and power, nearer their location of use, could affect the movement of coal. It seems unlikely that sufficient fuel will be found soon enough to affect the demand for coal in the immediate future.

The size of ship required to ship each commodity varies according to the nature and size of the market for the commodity. The distribution of bulk carriers by deadweight for iron ore, grain and coal is shown in Table II. The number of large bulk cargo carriers employed in the iron ore and coal trades has been supplemented recently by ships up to 89,000 tons dwt., and one is currently under construction with 140,000 tons dwt.

TABLE II

SIZE DISTRIBUTION OF BULK CARRIERS EMPLOYED IN THE CARRIAGE OF BULK COMMODITIES.

COMMODITY	NO BY DEADWEIGHT								
	TOTAL	10/14	14/18	18/25	25/30	30 +		TOTAL BULK	OTHERS
GRAIN 1964	100	2	11	18	3	1		35	65
1963	100	2	11	19	4	1		37	63
		10/18				30/40	40 +		
IRON ORE 1964	100	15		18	9	16	17	75	25
1963	100	17		19	5	13	16	70	30
COAL 1964	100	10		23	6	8	4	51	49
1963	100	13		21	3	4	1	42	58

Source. Fearnley & Egers Ltd., Oslo.

(Reference 2).

2.2 Bulk Cargo Carriers

To meet the demand the size of the bulk carrier fleet has increased rapidly in the last few years. (Figure 3). In 1960 there were more ore carriers than general purpose bulk carriers, but by 1965 the total tonnage of bulk carriers was about double that for ore carriers. It is interesting to note that in the years 1963-64, bulk commodity movements increased by 15%, while the bulk carrier fleet rose from 8.45 million tons deadweight to 12.1 million tons, an increase of 43%. The increase in commodities carried by bulk carriers rose by 28%. Appendix A gives an analysis of bulk cargo carriers on order in April 1966.

An efficient bulk cargo carrier design must meet the owner's basic requirements for deadweight, speed and range. In addition the general purpose bulk carrier should have sufficient capacity to carry a full load of coal (stowage factor 48 cu ft per ton) or grain (stowage factor 55 cu ft/ton) using the topside tanks for the latter if necessary. The holds should be accessible through large hatches, for ease and speed in unloading with grabs and conveyors. The holds should be smooth walled and self trimming. The ship should meet the minimum stability requirements for the grain condition and must heel no more than 5° for a 12° grain shift. There must be sufficient provision for water ballast to allow a ballast deadweight of about 40 to 50 percent of the load deadweight. If the ship is to carry ore, the ore must be arranged to give as high a KG as possible in order to reduce the GM, and thus provide an easy rolling period. The ship should be designed to have no trim in the load departure and load arrival conditions, and no trim by the head under any conditions at rest. A number of arrangements have been developed to meet these requirements including the Universal Bulk Ship (reference 4), but the most common arrangement and the most successful one is for the ship to have a cross section arrangement as in Figure 4.

The topside tank angle (α) is generally between 30° and 45° and the hopper tank angle (β) about 40 to 45°. The hatch width is about half the beam and the tank top width arranged so as to let the grabs get into the corners of the hold without rubbing against and damaging the wing tank plating.

Generally the Wing Tanks and the Topside Tanks will be used for ballast, although the latter may be used for light grain, especially when the angle α is large. The double bottoms will be used to carry oil fuel or water ballast. Additional fuel space is often provided in deep tanks forward or in the engine room.

Some of the smaller bulk carriers have cargo handling equipment, but most large and medium size bulk carriers have no such gear.

The factors which affect the decision as to whether self unloading gear should be fitted are:-

(1) The presence or lack of shore-side unloading facilities at ports of call.

(2) Whether or not the ship is to be used on short voyages requiring frequent use of discharging gear.

(3) Whether the route is free of size or dimension restrictions. Self unloading may reduce the deadweight of the vessel on a restricted route to unacceptably low figure.

(4) The relative costs of dock labour and crew.

(5) The presence or absence of suitable locations for the construction of economic shore-side bulk unloading facilities.

The installation of self unloading equipment for the general purpose bulk carrier is believed to add up to 15% to the capital cost. Table III gives some recent cases of large bulk carriers with self unloading gear.

TABLE III

SHIP	DWT	TYPE	MAKE	CAPACITY
SIGHANSA	68,000	Grab & Hopper	MUNK	900 mt/hr.
LA SIESTA	41,000	Conveyor	Bühler	675 ton/hr.
ACHILLEUS	35,250	Conveyor	Bühler	500 ton/hr.

The number and arrangement of holds depends on the ship's size and the type of cargo for which it is designed. Most ships have an odd number of holds (Figure 5), as this eases the loading, shearing forces and bending moments when loaded with ore in alternate holds. Some ships are designed to have alternate short and long holds. For a seven hold design, this would be given four short holds and three long holds. Ore would generally be carried in the four short holds, one or two of which may be used as deep tanks for water ballast.

Most bulk carriers are powered by diesel engines, but a few large ships are turbine propelled. The German nuclear powered merchant ship is a bulk carrier. Appendix B gives a breakdown of make of machinery specified for current bulk carrier orders.

3. PRELIMINARY DESIGN

Preliminary design methods are well known and have been used successfully for many years. D.G.M. Watson (reference 5) has described fully the use of these methods for estimating the preliminary dimensions of cargo and passenger ships. The design process for the bulk carrier described in this section follows well known practice with suitable alterations to formulae and checks on the results obtained.

It is very important that any method for preliminary design should have checks, which are not only effective, but which allow the necessary modifications to be made to meet the original requirements.

The preliminary design method can be illustrated by a flow diagram (Figure 6). Checks are made in preliminary design to ensure that the ship has adequate deadweight and that it has adequate stability. A check could be introduced to ensure that the rolling period was not too short.

The object of the method is to enable the naval architect to start off with the owner's basic requirements of deadweight, speed and range, and to build from these a suitable design that will also meet any limitations placed on dimensions.

3.1 Evaluation of Suitable Leading Dimensions

There are two methods of evaluating a set of leading dimensions, given deadweight, speed and range, but they require that an estimate of displacement must first be made. Analysis of a number of bulk cargo carriers suggests that a deadweight/displacement ratio of 0.80 can be taken to give

$$\text{Displacement} = 1.25 \times \text{Deadweight}$$

The first method for evaluating the leading dimensions is to use simple relationships based on analysis of recent practice. The second method is to choose suitable length/beam, beam/draft ratios and block coefficient, and then evaluate length, beam and draft. The former gives one set of dimensions for any deadweight and speed and the latter is useful in building up a matrix of designs by methodical variation of the three parameters.

3.1.1 Estimate based on Current Practice

This method is useful for making a quick estimate of dimensions and is the usual method when carrying out the design process by hand. Each dimension has to be carefully checked to ensure that it does not violate any dimension restriction.

In order to obtain relationships for this method, an analysis has been made of the dimensions of current bulk carriers on order. Plots have been made of length against deadweight (Figure 7) and beam, draft and depth against length (Figure 1). The scatter on the two diagrams is considerable, especially between deadweight and length and between length and beam. Thus a simple relationship linking length and deadweight will not suffice and a more detailed study is required. Allowing for beam restrictions, a relationship can be produced which gives satisfactory beams.

Each dimension is now considered in turn.

Length

A common method for estimating length is to use a formula of the Posdunine type.

$$L_{BP} = C_1 \times \left(\frac{V}{V+2} \right)^2 \times \Delta^{1/3}$$

If the deadweight/displacement ratio is assumed to be fairly constant then the following is equally true

$$L_{BP} = C_2 \times \left(\frac{V}{V+2} \right)^2 \times DWT^{1/3}$$

where C_1 and C_2 are data from typeships.

The latter formula has been developed for use with bulk carriers.

An analysis of available data for bulk carriers has been made to evaluate a suitable value of C_2 (Table IV). There are several high values of C_2 which resulted from the necessity to make the ship longer in order to satisfy restrictions on other dimensions. The values of C_1 have been plotted against L/B for the designs (Figure 8). British practice favours ships with L/B between 6.8 and 7.2, thus giving a suitable C_1 for current British practice of 24.2.

The relationship between length, deadweight and speed can be written thus.

$$L_{BP} = 24.2 \times \left(\frac{V}{V+2} \right)^2 \times DWT^{1/3}$$

Beam

The beam may be found using the beam/length line given by Mr. J.M. Murray (reference 1). In algebraic terms this is

$$BEAM = 0.146 \times L_{BP} - 3.4$$

If this exceeds the beam restriction, then it must be reduced to permit the restriction.

TABLE IV

EVALUATION OF POSDUNINE COEFFICIENT FOR BULK CARRIERS
(Note. Relationship based on Deadweight)

Deadweight Tons	V Speed knots	$\left(\frac{V}{V+2}\right)^2$	$\left(\frac{V}{V+2}\right)^2 \times DWT^{1/3}$	L_{BP} feet	C_2	L/B
68000	15.5	.784	32	796	24.9	7.5
63500	15.5	.784	31.3	820	26.2	7.89
62300	16.4	.791	30.4	800	26.4	7.57
53500	16	.790	29.6	715	24.2	6.8
51500	16.5	.791	29.4	708.5	24.1	6.86
48000	15.5	.784	28.5	721	25.3	7.32
46000	16.1	.791	28.35	676	23.9	6.77
42700	15	.778	27.65	657	23.7	6.85
41000	15	.778	26.85	685	25.5	7.45
38850	15	.778	26.4	640	24.2	7.11
40000	15	.778	26.6	680	25.6	7.56
38500	16.2	.790	26.7	606.75	22.7	6.6
34650	14.3	.77	25.1	590	23.6	6.55
34000	14.4	.77	25.0	577.4	23.1	6.48
34500	15	.778	25.3	612.5	24.2	7.2

Block Coefficient

The Block coefficient is found using a relationship of the Alexander type.

$$C_B = a - b \frac{V}{\sqrt{L_{BP}}}$$

For bulk carriers it has been found that $a = 0.968$ and $b = 0.269$ fits the existing ships with acceptable accuracy.

Draft

The length, beam, block coefficient are all known. Using the first estimate of displacement, the draft may be evaluated. If the draft is greater than the limiting draft, it be reduced to that draft and a new beam is calculated to maintain the displacement. If the new beam exceeds the limiting beam, then it must be reduced and a new length is calculated. If the length is now too great, it may be possible to increase the block coefficient, otherwise the desired deadweight must be reduced to give acceptable dimensions.

3.1.2 Estimate based on Methodical Variation of L/B, B/T and C_B.

This is especially suitable for deriving a methodical series of designs and is the method used in the computer program. The length/beam and beam/draft ratios and the block coefficient are all methodically varied to provide a matrix of possible dimensions.

By taking one combination of L/B, B/T and C_B, dimensions can be calculated if the displacement is known. For the first estimate, the displacement derived from the deadweight/displacement ratio is used, but for subsequent estimates a corrected displacement will be used.

$$\Delta = L \times B \times T \times C_B \times 1/35$$

if p is the L/B ratio and q is the B/T ratio

$$L = p \times B \quad \text{and} \quad T = B/q$$

giving

$$\Delta = \frac{p}{q} \times \frac{B^3}{35} \times C_B$$

from which B can be evaluated and hence L and T.

Combinations of L/B, B/T and C_B which produce designs with dimensions outside the restrictions are rejected.

3.2 Choice of Form Parameters

It is necessary to choose suitable form parameters, partly from past experience and partly from basic principles. Suitable values for C_W, LCB and LCF must be chosen and values derived for VCB, BMT and MCT 1" for the load condition.

A number of methods for obtaining preliminary hydrostatics have been evolved by Muckle (reference 6), Riddlesworth (reference 7), Munro Smith (reference 8) and Telfer (reference 9). Simple relationships for BM, VCB and MCT have been formulated, with the assistance of the above references. An analysis of bulk carrier data supplemented with some oil tanker data has been made to produce other approximations.

Waterplane Area Coefficient C_W

From the limited amount of data available, a simple equation relating the Waterplane Area Coefficient with Block coefficient has been evolved.

$$C_W = 1.265 \times C_b - 0.146$$

Waterplane Area

$$\text{Waterplane Area} = C_W \times L_{BP} \times B$$

Longitudinal Centre of Buoyancy. L.C.B.

The LCB is chosen to meet optimum power requirement and to obtain acceptable trims. The optimum LCB position for powering has been given in the Series 60 Papers (reference 10). After curve fitting to a base of Prismatic Coefficient, the LCB is evaluated from

$$LCB = 17.5 \times C_p - 12.5$$

$$\text{where} \quad C_p = \frac{C_B}{0.99}$$

Longitudinal Centre of Flotation. LCF

Muckle (reference 6) has evolved the relationship

$$LCF = LCB + \frac{\nabla}{A_W} \times \frac{dC_b}{dT}$$

and $$\frac{dC_b}{dT} = \frac{(C_W - C_b)}{T}$$

∇ is immersed volume $= \Delta \times 35$

and A_N is the waterplane area.

The first equation can be rewritten to give

$$LCF = LCB + \frac{\nabla}{A_W} \times \frac{(C_W - C_b)}{T}$$

i.e. $$LCF = LCB + \frac{C_B}{C_W} \times (C_W - C_B)$$

Vertical Centre of Buoyancy. VCB

Morrish's formula for VCB is

$$VCB = T - 1/3 \ (T/2 + \nabla/A)$$

$$= T - 1/3 \ \left(\frac{T}{2} + \frac{T x C_B}{C_W}\right)$$

which can be simplified to give

$$VCB = T \times \frac{(5C_W - 2C_B)}{6C_W}$$

Transverse Metacentric Height. BM_T

From first principles

$$BM_T = \frac{I_T}{\nabla}$$

Where I_T is the transverse second moment of area of the waterplane at draft T

Now $I_T \quad \alpha \quad$ Area of Waterplane x Beam^2

$\qquad \alpha \quad LB^3 \times C_W$

hence $$BM_T \;\alpha\; \frac{L \times B^3 \times C_W}{L \times B \times T \times C_B}$$

$$BM_T = K \times \left(\frac{B^2 \times C_W}{T \times C_B} \right)$$

Analysis of available bulk carrier data suggests that K should be 0.073.

Moment to Change Trim One Inch MCT 1"

From first principles

$$MCT\ 1" = \frac{\Delta \times GM_L}{12\ L_{BP}}$$

where GM_L is longitudinal metacentric ht.

Now $GM_L = KB + BM_L - KG = BM_L + (KB - KG)$

$(KB - KG)$ is very small compared with BM_L

so $GM_L \doteqdot BM_L$

and $$BM_L = \frac{I_L}{\nabla}$$

where I_L is the longitudinal second moment of area at the draft T.

and as before $I_L \;\alpha\; C_W \times B \times L^3$

Thus $$MCT\ 1" \;\alpha\; \frac{\Delta}{12 \times L_{BP}} \times \frac{C_W \times B \times L^3}{\nabla}$$

i.e. $$MCT\ 1" = \frac{K \times C_W \times B \times L^2}{420}$$

From analysis of available bulk carrier data K = 0.0735

3.3 Powering

There are several well known methods for estimating power, but none of them covers with sufficient accuracy the high block coefficient forms. Furthermore, for this investigation, the powering method used had to be readily available as a computer program as to program one of the powering methods would be a major undertaking not possible in the limited time available. Two methods are available for computer programs. These are the B.S.R.A. methodical series (references 11 - 14) and Troost's power prediction method (reference 15). The former method is only defined up to 0.80 block coefficient, but can be extrapolated up 0.825 block. The latter method is only defined for a small range of B/T ratios, and had to be rejected, leaving the B.S.R.A. Methodical series as the powering method used.

A translation was made from a B.S.R.A. Program in Fortran into Algol. The B.S.R.A. methodical series program in its original form grossly over-estimated the EHP required for high block coefficient ships, so a suitable correction factor had to be devised. Silverleaf (reference 16) has given a diagram produced by the St. Albans Experiment Tank, which shows the improvement in modern forms over the B.S.R.A. methodical series. From this diagram, a simple correction factor has been produced to correct the value of $\copyright_{400}$ in the program.

$$\copyright_{400} = \underset{\text{B.S.R.A.}}{\copyright_{400}} \times \left(0.94 - 0.4 \;\; (V/\sqrt{L_{BP}} \; - \; 0.55)\right)$$

In the program as it was received, it was necessary to specify the blade area ratio for the propeller estimate. In the modified program, the blade area is taken as 0.6 and a cavitation check is made. If the blade area ratio is too small, it is increased by steps of 0.01 until the possibility of cavitation is neglibible.

The cavitation check is made using the Burrill Cavitation Chart (reference 17). The cavitation number is checked against the Burrill line for Merchant ships, which may be expressed as an index equation of the form.

$$\text{Max.Cav. No for Merchant Ships} = 0.268 \times (\text{cavitation No})^{0.595}$$

A further difficulty in the original powering program was that a different propeller was produced for each draft. A separate propulsion estimate for the ballast condition must be made using the propeller designed in the load condition. The ballast powering is further complicated by the alternatives of the ship maintaining its load speed in the ballast condition or maintaining the load condition horsepower. Analysis of available propulsion data showed that the QPC in the ballast condition was 1.15 times greater than the QPC in the load condition.

Calculation of the ballast powering can then proceed as follows:-

a) For Constant Speed

The EHP for the ballast condition is determined using the B.S.R.A. methodical series program. The Ballast Brake Horsepower is then given by

$$BHP_{ball} = \frac{EHP_{ballast} \times \text{Weather Allowance Factor}}{\text{Transmission effy.} \times QPC \times 1.15}$$

b) For Constant Horsepower

The Ballast EHP is given by

$$EHP_{ballast} = BHP \times \left(\frac{\text{Transmission effy} \times QPC \times 1.15}{\text{Weather Allowance}} \right)$$

The EHP at the ballast draft is found for two speeds greater than the service speed in the load condition using the B.S.R.A. methodical series and the ballast speed found by interpolation.

TABLE V

LENGTH OF COMPARTMENTS

L	DWT	MHP	ENGINE ROOM				FORE PEAK		AFT PEAK		NOTES
			MACHY	LENGTH	LENGTH ER	DIFF	LENGTH	L_{FP}/L_{BP}	LENGTH	L_{AP}/L_{BP}	
765	55400	15000	10RD76	60	99	49	38.5	0.05	26	0.034	DT FWD 22.5' 1963
570	28300	13800	6RD90	45.4	80	34.6	38.0	0.0667	22	0.039	1964
565	31211	9300	Man	47	79.6	32.6	28.1	0.050	20.4	0.036	DT FWD 19.5' 1964
580	26250	8640	Sulzer	35.4	80	44.6	32	0.055	20	0.034	
605	31300	10000	Götav		89.5		35.7	0.057	20.1	0.032	
796	63000	20700	Sulzer	65	106	41	40.17	0.05	28	0.035	FWD Pump RM. 13.6'
796	63500	17600	Sulzer	59.55	99.16	39.61	40.75	0.051	28	0.035	
600	33000	13800	Sulzer	45.4	87.5	42.1	39	0.065	20	0.033	Ext. Fore Peak
600	27000	9600	Sulzer	35.4	93.5	58.1	34	0.057	22	0.036	) Corner Tanks
625	33000	13800	Sulzer	45.4	100	54.6	37	0.059	22	0.035	) in E.R.
630	40000	13800	Sulzer	45.4	80	34.6	45	0.071	22	0.035	
630	40000	12600	B.&.W.	43.2	80	36.8	45	0.071	22	0.035	
630	40000	13370	Doxford	41.75	80	38.25	45	0.071	22	0.035	
470	15000	7200	Sulzer	35.1	75	39.9	30.3	0.053	22	0.035	
727	55170	18900	Man	52.1	99.5	47.6	46	0.064	28.6	0.039	Midship Pump Room
632	35525	13800	B.&.W.	43.2	91	47.8	31.6	0.05	21.6	0.034	FWD D.T. 14.4
685	41000	12600	B.&.W.	43.2	108	64.8	47.3	0.069	20.8	0.03	L/B 7.45
796	68150	16800	B.&.W.	53.5	91.5	38.0	37.8	0.047	33.1	0.041	

NOTE: Lengths in feet, wts in tons, powers in British Horsepower.

3.4 Choice of Machinery

A suitable engine is chosen for the design by consulting the engine builders' catalogues. A chart has been drawn (Figure 9) to show weight for power output for various types of machinery. Generally the Doxford J76 offers the lightest engine for a desired power output.

In the program, the computer is supplied with details of the horsepower, number of cylinders, weight and length in ascending number of cylinders, for any number of machinery types, placed in order of preference. The program scans the information until it finds the engine whose maximum horsepower is just greater than the required maximum continuous horsepower. Corresponding values of number of cylinders, weight and engine length are then noted for future reference.

3.5 Length of Compartments of the Design

The longitudinal geometry of the hull must be considered so that estimates of superstructure length may be made in the freeboard estimate. This is done by reference to current practice.

The general arrangement of 19 ships was examined in detail. The lengths of Forepeak, Aftpeak, Engine Room and Deep Tanks (where these exist) were lifted off and tabulated (Table V and Figure 10). The tanks were expressed as a proportion of the length B.P. and the engine room as a function of the length of the main machinery.

From this investigation, the Aft Peak Tank is generally about 3.5% of the length. The fore peak tank is bounded at its aft end by the Collision Bulkhead, which must be placed not less than 5% of L_{BP} abaft the F.P. A number of ships have a forward deep tank aft of the forepeak tank, and some others have a forepeak tank extended aft to give a large deep tank. Ship's which have neither an extended forepeak tank nor a large deep tank forward will have to provide ballasting elsewhere. This may be done by either increasing the Topside Tank angle from 30° to 40° to 45° or try flooding one or more cargo holds up to a level prescribed by the classification society.

The length of the engine room varies with size, machinery requirements, and whether the ballast pumping is controlled from the engine room or from a separate pump room. A general approximation for the length of the engine room is

$$\text{Length of Engine Room} = \text{Length of Main Engine} + 40 \text{ ft.}$$

The length of the holds may be calculated from

$$\text{Length of Hold} = L_{BP} - (L_{AP} + L_{ER} + L_{FP} + L_{DT})$$

Where L_{AP} = Length of aft peak

L_{ER} = Length of engine room

L_{FP} = Length of fore peak

L_{DT} = Length of Deep Tanks

If it is assumed that the superstructure is all aft then the length of erections for the freeboard estimation is given by

$$L_{SS} = L_{AP} + L_{ER} + L_{FP}$$

In some recent ships the after end of the superstructure has been forward of the A.P. In the program this is allowed for by a correction which is expressed as the distance forward of A.P. to the aft end of superstructures. Generally this is zero.

3.6 Estimation of Freeboard

The freeboard estimation has been made using the 1933 Convention Rules.

The length, beam, draft of the design have been evolved, but the depth is not yet known. All the data for the freeboard estimation is known except for depth, which can be neglected for the time being.

The following assumptions are made for the erections and superstructure.

a) The length of the erections in §3.5 is considered fully effective.

b) It is assumed that the total length of erections will not exceed 30% of the freeboard length.

Bulk carriers may be assigned tanker freeboard providing certain conditions are satisfied. In this investigation the depth is found using the steamer freeboard, from which an extreme draft based on tanker freeboard could be assigned. The tabular freeboard and superstructure correction varies from tankers to steamers. Both are incorporated in the freeboard procedure in the program.

The tabular freeboards for steamers and tankers have been faired on the computer over the range 400 ft to 1000 ft of freeboard length. A sixth order polynominal was obtained for each, of the forming

$$TF = a_o + a_1X + a_2X^2 + a_3X^3 + a_4X^4 + a_5X^5 + a_6X^6$$

The coefficients are given in Table VI

TABLE VI

Coefficients for Tabular Freeboard (1933)

COEFFS.	a_o	a_1	a_2	a_3	a_4	a_5	a_6
TANKER FREEBOARD	-6.19193×10	$+1.0423$	-5.67×10^{-3}	$+1.755 \times 10^{-5}$	-2.6867×10^{-8}	$+1.9801 \times 10^{-11}$	-5.647×10^{-15}
STEAMER FREEBOARD	-5.76801	$+2.5457 \times 10^{-1}$	-1.589967×10^{-3}	$+7.4086 \times 10^{-6}$	-1.3219×10^{-8}	$+1.0442 \times 10^{-11}$	-3.P856 $\times 10^{-15}$

By making the above assumptions, the superstructure correction may be reduced to the following relationships.

For tankers, the superstructure correction = $29.4 \times L_{SS}/L_{WL}$ ins

and For steamers, the superstructure correction = $21 \times L_{SS}/L_{WL}$ ins.

Where L_{SS} = Length of superstructures

and L_{WL} = Waterline Length.

The sheer profile and camber corrections may be determined in the normal manner, leaving only the block coefficient and depth corrections to be determined.

The C_B required for the block correction is that at 0.85 x Depth, but an approxiate correction can be made using the C_B at the load draft. A correction for the 0.85 D C_B is made after a first estimate of depth has been made.

The Freeboard uncorrected for depth can be calculated as

$$F = \text{Tabular Freeboard} \times C_b \text{ correction} - \text{Superstructure Correction} + \text{Camber Correction} - \text{Sheer Correction.} \quad \text{ins.}$$

If F2 is the actual freeboard after the depth correction

i.e. $F2 = F + \text{Depth correction}$ ins.

If Assuming that $D > L/15$ and $L_{BP} > 390$ ft.

$$F2 = F + (D - L/15) \times 3 \quad \text{ins.}$$

and $D = T + F2/12$ Where T is draft in ft.

i.e. $D = T + (F + (D - L/15) \times 3)/12$

Which can simplified to give a first estimate of depth.

$$D = 1.3333 \times (T + F/12 - L/60) \text{ ft.}$$

The block coefficient at 0.85 Depth is found and F is recalculated, leading to a second estimate of depth. The process is repeated until the difference between consecutive estimates of block coefficient at 0.85 depth is insignificant.

3.7 Group Weight Estimate

The geometry of the design having been established it is now possible to make estimates of the group weights.

The estimate of group weights is based on analysis of past ships. Unfortunately this is not wholly satisfactory as recent changes in Lloyd's Rules will have an effect on the steel weight. The trend towards automation will affect the outfit and machinery weights. An analysis was made of the small amount of available data on group weights. Unfortunately only shipyard estimates were available for the large bulk carriers as none had been completed until the later stages of the investigation.

3.7.1 Steel Weight

An investigation has been carried out with Mr. T.G. Crouch* to obtain a reasonably simple formula for the steel weight. The steel weight varies according to the ship's classification and to whether high tensile steel is used in the decks and bottom. A method was evolved whereby the required area of longitudinal material for a design was calculated. The calculated area is compared with the area of a ship for which the steel weight is known and a new steel weight is obtained. This gives fairly good correlation for small changes in ship dimensions, and could be adjusted for high tensile steel. As it was based solely on longitudinal material, it tended to overestimate the variation in steel weight for extremely long ships or short "stubby" ships. This is in contrast to the cubic number method which tended to underestimate the variations.

Until data are available based on parametric studies on steel work design by computer, the program in its present form gives a choice between a number of steel weight estimation methods including that based on the area of longitudinal material.

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* Mr. T.G. Crouch, B.Sc. has been engaged on a parallel investigation into the Design of Steelwork by Computer for Bulk Carriers.

a) The Cubic Number Method

The cubic number method is one of the best known methods and probably the commonest

$$W_s = \text{Steel Wt.} = \frac{L_{new} \times B_{new} \times D_{new}}{L_{old} \times B_{old} \times D_{old}} \times W_{s\ old}$$

Two corrections have to be applied for block coefficient and length/depth ratio.

$$\text{Block coefficient correction} = \frac{(1 + 0.5\ C_{B_{new}})}{(1 + 0.5\ C_{b_{old}})}$$

$$\text{Length/Depth ratio correction} = \frac{(L/D)\ \text{old}}{L/D\ \ \text{new}}$$

b) Longitudinal Area of Material Method

$$W_s = W_{s_{old}} \times \frac{L_{new} \times (\text{Mid Area of Longt. Material})\text{new}}{L \times (\text{Mid Area of Longt. Material})\text{old}}$$

The mid area of longitudinal material can be estimated from the following equation

$$A_m = e^{(325 \times L^{0.14927} \times B^{0.0869} \times D^{-0.022} \times T^{0.01232})}$$

which was developed in the early stages of the investigation by Mr. Crouch, after analysis of available midship sections and plotting on Log - Log graph paper.

c) Mean Value of Methods (a) and (b)

This option is provided to try and cancel out the tendency of methods (a) and (b) to underestimate and overestimate the effect of extreme dimensions on steel weight.

d) Murray's Equation

Another method exists for steel weight estimation for ships without heavy cargo or iron ore classification.

Mr. J.M. Murray has produced the following equation in his paper on Large Bulk Carriers (reference 1).

$$W_s = 1.125 \times 10^{-3} L^{1.65} (B + D + T/2)(0.5C_b + 0.4)/0.8$$

Where L is length, B is beam, D is depth and T is draft.

3.7.2 Outfit Weight

To obtain an accurate estimate of the outfit weights for bulk carriers a detailed analysis of the weight of sub-groups should be made. It was considered that such an analysis would take too long within the time limits set for the present investigation. No detailed outfit weight estimate has been made. Analysis of available data showed that the well tried Square Number approach gives reasonable estimates of outfit weight. The relationship used gives the outfit weight as

$$W_o = W_{o\,\text{basis ship}} \times \left(1 + \frac{L_{new} \times B_{new}}{L_{basis} \times B_{basis}} \right) \times \tfrac{1}{2}$$

3.7.3 Machinery Weight

To obtain an accurate machinery weight a detailed analysis of existing machinery weights is required. However, analysis of available machinery weights, showed that the total weight is a function of main engine weight and horsepower. The machinery weight can be estimated with acceptable accuracy for large bulk carriers using the relationship.

$$W_m = \left(\text{Main Engine Wt.} + \frac{\text{horsepower}}{35} + 200 \right) \text{tons}$$

for diesel machinery.

3.7.4 Margin

As is usual practice in estimating group weight, a margin is added to the sum of the group weights to give the lightweight. Provision exists in the computer program to do this and the margin is expressed as a percentage addition of the sum of the group weights.

3.8 Deadweight Deductions

In order to obtain the cargo deadweight of the design, deductions have to be made for fuel, fresh water, stores, and crew from the deadweight.

The oil fuel weight is a function of the horsepower, range and speed of the vessel and is given by the relationship

$$W_{of} = BHP \times \frac{R}{V} \times \frac{fcr}{2240} \quad \text{tons.}$$

where HP is the service horsepower. R is range in miles.
V is speed in knots and fcr is fuel consumption rate in lbs/horsepower hour.

The weights of fresh water and stores are fixed by owner's practice, the size of crew and length of the voyages. In the program they are treated as fixed items supplied as owner's data.

At this stage the first check on the design must be made, in order to see that the deadweight is satisfactory. The deadweight or cargo deadweight obtained by subtracting the group weights from the displacement must be checked to see that it is within some preset tolerance on the specified deadweight. If it is unsatisfactory then the displacement is modified and a new set of dimensions are recalculated as in paragraph 3.1. The design process is then repeated until a satisfactory deadweight is obtained.

3.9 Midship Cargo Hold Geometry

In order to calculate the capacities and to check that a satisfactory homogeneous stowage factor can be obtained, the geometry of the midship section must be fixed.

Figure 3 shows a typical section through the midship hold. The angle of topside tank (α) is usually 30°, but may be 40° or 45°. The angle of the side hopper tank (β) is about 40° or 45° to facilitate stowage.

The hatch width is generally about half the beam and the tank top width is equal to the hatch width plus an overlap on either side which can vary from about 8 ft to 12 ft for medium and large sized ships. Too large an overlap will cause the double bottom height to be raised above the minimum, and will not permit the grabs to get into the corners of the hold. Too small an overlap will allow the grabs to hit and perhaps damage the hopper sides.

The double bottom height is fixed by the classification society rules and is dependent upon the longitudinal and transverse frame spacings, upon the tank top width and upon the I/Y requirements for the design. A procedure has been written to calculate the double bottom height for any arrangement of double bottoms and frame spacings.

Having fixed the geometry of the cross section, the cross section areas of the tanks can be calculated.

<u>Double Bottom and Side Hopper. Cross Section Area</u>

Cross section area = cross section area of double bottom

+ cross section area of side hopper

− pipe tunnel area (if any).

$$= \left(DBH \times \left(\frac{B}{2} - ptw\right) + \frac{1}{2} \times \left(\frac{B}{2} - TTW\right)^2 \times \tan\beta - 0.214 \times R_1^2\right) \times 2$$

where DBH is the double bottom ht in ft

ptw is the pipe tunnel width in ft per half section

TTW is tank top width for the half section ft.

R_1 is the bilge radius

This assumes no rise of floor, the effect of which will be negligible.

Topside Wing Tank. Cross section area

Cross section area = hatch side girder depth x (beam - hatch width)

+ triangular section of area of tank

$$= (hsg \times (\frac{B}{2} - hw) + \frac{1}{2}(B/2 - hw - sw)^2 \times \tan\alpha$$

$$+ sw \times (\frac{B}{2} - hw - sw) \times \tan\alpha - \frac{1}{2} C \times (B/2 - hw)$$

$$- 0.214 \times R_2^{\ 2}) \times 2$$

where hw = hatch width in ft for the half section in feet

R_2 = radius of sheerstrake in feet

SW = is the shelf plate width in ft (see Figure 3).

hsg = hatch side girder depth in ft.

C is the camber in ft - assumed straight line.

3.10 Capacities

In order to make an estimate of the capacity of the designs, an analysis was carried out of the capacities of bulk carriers, based on the cubic number. The results of the analysis are shown on Figure 11. There is a considerable scatter, due to differences in hold arrangement and angle of tanks etc. Neverless it is possible to contain the capacities within maximum and minimum lines. Maximum hold capacity will be obtained by ships having short engine rooms and 30° topside tank angle. The minimum hold capacity will have 45° tank angle and grain will not be carried in the topside tanks. Bulk carriers which are fitted out to act as car carriers on part of their route will also be on the minimum line.

It is necessary to produce a capacity estimation method, which reflects differences in hold and tank arrangement. The method developed to do this first determines the total underdeck capacity of the cargo carrying length, and then subtracts the capacities of the topside tanks, double bottom

TABLE VI

ANALYSIS OF BULK CARGO CAPACITIES

SHIP	A	B	* C	D	* E	F	G	H	I	J	K
ITEM											
Length BP FT	495	796.4	630	600	796	679.6	667.7	625	600	685	570
Beam FT	67.8	105.6	95	80	104	87.9	89.62	85	85	92	82.5
Depth FT	41.5	63.4	54.75	45.25	60	51.3	51.67	58.75	50.5	54.5	47.3
C_B	0.783	0.82	0.794	0.80	0.83	0.82	0.812	0.812	0.805	0.80	0.793
Deadweight tons.	17250	68000	40000	27000	63500	38000	38000	33000	33000	41000	28000
Hold Length FT	367.3	632.1	483	450.75	608.33	505.6	498.3	466.5	453.5	506.4	430
UNDERDECK											
Cubic No.	809208	3470000	1994690	1304648	3150663	1869507	1873657	1570000	1567052	2031271	1330000
Capacity Cu Ft.	1070000	4150000	2470000	1655000	3780000	2310000	2320000	1970000	1960000	250000	1670000
TOPSIDE TANKS											
Cubic No	89547	340385	20213	191839	327038	216195	172213	245892	229743	317310	115500
Calculated Capty.	90000	315000	192000	181000	303000	205000	164000	231000	217000	295000	113000
Actual Capacity	82950	315118		183606	303150		150882	229384	219160		113500
Error %	+8.4%	-0%		-1.4%	-0%		+8.7%	+0.7%	-0.9%		-0%
DOUBLE BOTTOM AND WING TANKS											
Cubic No	96632	422547	270776	143068	401659	273589	236774	161000	168296	269242	167358
Calculated Capty.	120000	492000	302000	174000	449000	322000	280000	195000	187000	316000	191000
Actual Capacity	122010	490000		163695	447156		269743	192683	177360		188974
Error %	-1.6%	+0.4%		+6.3%	0.5%		3.8%	0.2%	10.2%		1%
Pipe Tunnel Vol.	6360			21400		39000	33600	25000	20900	38500	38000
HOLDS											
Calculated Capty.	853000	3403000	1976000	127800		1744000	1841400	1501000	1535000	1850500	1336000
Actual Capacity	839000	3465000	2000000	128300		1743000	1824000	1504000	1532000	1[illegible]94000	1339000
Error %			-1.2% *	-0.5%	*	+0%	+0.9%	-0%	+0%	+0%	-0%

* Actual Capacities are Shipyard Estimates. Capacities in Cu. Ft.

and side hopper tanks. This allows the hold capacity to be calculated to within an acceptable degree of accuracy.

The data presented in Table VI have been reanalysed (Table VIII) and used to produce diagrams (Figures 12, 13, 14) from which the capacities may be derived.

Three cubic numbers have to be calculated for

a) Underdeck Cubic Capacity

= Beam x Depth x Block coeff. x Length of holds

b) Topside Tank Cubic Capacity

= Length of Holds x Cross section area of topside tanks.

c) Double Bottom Cubic Capacity

= Length of holds x Cross section area of double bottom and side hopper.

The volume of the pipe tunnel has also to be calculated and assuming it to be in the double bottom, its volume is given by.

Pipe Tunnel Vol. = Length of Holds x Double Bottom Ht x Pipe Tunnel Width.

The underdeck capacity is read from Figure 12.

The topside tank capacity is read from Figure 13.

The Double Bottom and Side Hopper capacity is read from Figure 14.

In the double bottom diagram, there is a choice of two lines; the upper line allows for a raised double bottom forward, and the lower gives the capacity for constant double bottom height. For a sloping double bottom forward, the mean of the two diagrams is taken.

In the computer program, the capacities are derived from a straight line relationship forward from figures 12 - 14.

TABLE VII

TONNAGES
(Units - Tons)

GROSS TONNAGE			NETT TONNAGE		
$LxBxDxC_B$	BRITISH	PANAMA	GRAIN CAPACITY FT^3	BRITISH	PANAMA
1106000	12104	9120	873983	6776	8809
1760000	18616	18778	1339394		13972
2520000	26044	26200	1717300	15346	18244
2515000	33190	26103	1800000	16626	18797
2270000	21505		1610616	14454	
1735000	18591		1466606	12071	
4135000			3052000	31400	40820
2103000	22340		1727394	14617	
2070000	21449		1532000	16055	
2750000	28007		1866750	17948	
3570000	35487		2334932	22109	
2103000			1745000	14558	18925

The hold capacity can then be found by subtracting the sum of the Topside Tank Capacity, the Double Bottom and Side Hopper Capacity and the Pipe Tunnel Volume from the total underdeck capacity. No correction for structure is required as this is taken care of in the diagrams.

With the capacities determined it is possible to calculate the limiting stowage factors. Two stowage factors should be calculated, one including and the other excluding the topside tanks. At this stage it is possible to calculate how many of the topside tanks are to be used for carrying grain.

It is possible to calculate the tonnages from the cubic number and two cargo carrying capacity. Table VII gives typical data for tonnages which have been plotted on Figures 15 and 16. The gross tonnage is plotted on a base of a Cubic Number ($L \times B \times D \times C_b$) and the nett tonnage on the base of cargo capacity. The gross tonnage is read from Figure 15 and the nett tonnage from Figure 16. Care must be taken to ensure that the capacity of the topside tanks is not included in the latter estimation if they are to be for water ballast only.

The scatter on Figures 15 and 16 is wide. In view of the small amount of data on gross tonnages, one line has been drawn to cover both British and Panama Gross Tonnage. More data have been available on Nett Tonnages, so separate lines for British and Panama Nett Tonnages have been produced.

3.11 Stability

At this stage in the design calculation, it is necessary to check the stability of the design. Bulk carriers are unlikely to have insufficient stability in the load condition, but in the ore and ballast loading conditions, the GM might become sufficiently large to cause excessive rolling. It is necessary to obtain estimates of KG and KM for the homogeneous load and the ballast conditions.

TABLE VIII

STABILITY INFORMATION FOR RECENTLY COMPLETED BULK CARRIERS

SHIP		A	B	C	D	E
ITEM						
L	ft	570	600	630	470	796
B	ft	85	85	95	66.75	105.6
D	ft	47.25	50.5	54.75	39	63.3
LIGHTSHIP CONDITION						
Lightweight	tons	7302	8845		4680	
Mean Draft	ft	7' 10"	8.38			
KG.	ft	29.39	33.35		26.91	
KG ÷ Depth		0.623	0.66		0.69	
KM	ft	72.60	68.5			
GM	ft	43.21	35.15			
GRAIN AT 45 cu/ft Ton.						
Displacement	tons	35771	41415	48771	19970	84750
Draft	ft	33' 5"	35.24	36	28.33	42.3
KG	ft	27.15	28.73		24.04	
KG ÷ Depth		0.575	0.570		0.617	
KM	ft	34.39	35.07		27.29	
GM	ft	7.24	6.34	9.14	3.25	6.5
ORE IN ALTERNATE HOLDS						
Stowage Factor cu/ft/ton		24	15	15		
Displacement	tons	35771	41415	51043	19970	84750
Draft	ft	33' 5"	35.24	37.3	28.33	42.3
KG	ft	25.28	26.93		28.81	
KG ÷ Depth		0.535	0.533		0.585	
GM	ft	9.11	8.14	15.21	4.48	13.1
BALLAST CONDITION						
Displacement	tons	19308	22151	30403		59725
Draft	ft	19	19.9	22.5		
KG	ft	23.47	29.7			
KG ÷ Depth		0.497	0.587			
GM	ft	14.96	9.27	13.25		12.25

The estimates of KG used in the computer program are based on the data given in Table VIII, which gives the stability information for a number of recently completed designs. The estimate of KM is based on the form parameters and equations derived in paragraph 3.2.

The following relationships are used to obtain an estimate of KG for the complete hull in the preliminary design stage.

For the load condition KG = 0.57 x Depth

For the ballast condition KG = 0.50 x Depth for 30° Topside Tank Angle.

and KG = 0.58 x D for 45° Topside Tank Angle.

The formulae are based on rather a small sample, but as more data become available, the form and constants of the relationships will be revised.

The KM for the load condition has already been calculated in paragraph 3.2. The KM in the ballast condition is found using the same relationship but with the ballast draft.

The Ballast Displacement = LWT + PC x DWT

Where PC is the desired fraction of the load deadweight for the ballast condition.

Generally PC is between 0.40 and 0.50.

The ballast draft is given by expression.

$$T_{ballast} = T \times \left(\frac{\text{Ballast Displ.}}{\text{Load Displ.}} \right)^{C_B/C_W}$$

The GM for the load condition is compared with a desired minimum. If it is too low then the design is rejected.

If the design suffers from excessive stability as measured by GM, then the problem is to increase KG or decrease KM to reduce the GM. The former is a matter of the loading geometry and the latter involves the reduction of the beam. The ballast KG can be raised by having a large topside tank angle, thus having more ballast higher up, but this raises problems of local strength. The possibility of having too large a GM is one of the principal objections to having too "stubby" a design.

3.12 Rolling

It is necessary to calculate the rolling periods for the load and ballast conditions. This is done by using the well known formula for the rolling period.

$$T_R = 0.44 \times \frac{\text{Beam}}{\sqrt{GM}}$$

4. DESIGN EVALUATION

Once the preliminary design process has been completed it is then necessary to analyse the resultant design. The capital cost of building the ship must be estimated and the performance of the design and its running costs must be assessed over its proposed route and compared with others.

4.1 The Cost Equations

Cost equations are set up to compare each design and to choose the best design. Commercially, the best ship should be the one which offers the maximum profit to the Shipowner. But there are other factors which affect the commercial performance of the ship, which are not so easily incorporated into a computer program. Such factors are the ease of loading and unloading of the holds, the arrangement of the holds, the behaviour of the ship in restricted waters and the speed loss due to bad weather. These factors will probably affect the expected profit of each design more or less equally, and so generally it will be sufficient to choose the design which offers the maximum profit to the Shipowner.

Profit is simply the difference between the income and cost on the route.

For a series of designs with constant deadweight, the income is constant and can be expressed as the sum of

(Freight rate) x (Cargo deadweight)
(pounds/ton). (tons)

for each commodity carried.

The maximum profit is produced when the costs are minimised.

Costs = Fixed Costs + Variable Costs

Fixed costs are those which are not directly affected by the choice of route and include wages, insurance and capital charges. Variable costs are those incurred by trading on a particular route and includes fuel and port charges.

The cost equation is written as:

$$\text{COST} = (\text{Crew} + \text{Insurance} + \text{Maintenance} + \text{Capital Cost}) + (\text{Fuel} + \text{Port Charges}).$$

i.e.

$$\text{COST} = \left\{ \left(\sum_{n=1}^{CR} (W_n + O_n) + VICT \times C_R \right) + INS + (ST + DD + LUB) + \frac{(SURV + CC + INT - SCRAP)}{NYDEP} \right\} \times \frac{1}{WDS} \left\{ TIP + \frac{DIST}{V \times 24} \right\} + \left\{ \left(\frac{BHP \times fcr \times DIST}{2240 \times V} \quad BP \right) + PORT \right\} \quad \ldots\ldots\ldots\ldots \text{ I.}$$

Where = W_n = Wages of each crew member p.a.

O_n	=	Overtime cost for each crew member p.a.
VICT	=	Cost of victualling one man p.a.
CR	=	Number of Crew.
INS	=	Marine Insurance (including War Risk and P.&.I.)
ST	=	Cost of stores per annum (Deck, cabin, Engine Room).
DD	=	Cost of annual dry-docking.
LUB	=	Annual Cost of Lubrication.
SURV	=	Total cost of special surveys in ship's lifetime.
CC	=	Capital Cost of ship in pounds.
INT	=	Total Cost of interest charges.
SCRAP	=	Scrap value of ship.
NYDEP	=	No of years to depreciate ship to scrap value.
WDS	=	No of working days p.a.
TIP	=	Time in port for the route.

DIST = Total distance sailed by the ship on the route.

V = Service speed.

BHP = Horsepower.

fcr = Fuel consumption rate (lbs/horsepower hour).

BP = Bunker price of fuel per ton.

PORT = Total port and handling charges for the route.

The fixed costs are thus functions of the crew size and nationality, the value of the ship, the size of the ship, building cost and credit terms available to the Shipowner. The fixed costs per annum be calculated for each design. The variable costs can be calculated if the distances on the route and the port charges are known. The total cost for the route is obtained by multiplying the fixed costs by the time on the route and adding the result to the variable costs.

The equations become more complicated if taxation is introduced, or when dealing with ships carrying a variety of bulk cargoes on each stage of the route, or when sailing at reduced drafts. In the case of a ship trading in more than one commodity, it is necessary to obtain the cost of carrying each commodity. The route on which the proposed design is expected to operate must be broken down into its individual voyages and cargo handling operations. The costs incurred in directly in transporting each commodity must be allocated to that commodity. Any remaining costs can be distributed on a time basis over the commodities.

4.2 Operation Synthesis

The route on which the ship is expected to operate may be simulated as a sequence of activities. The duration and cost involved in each activity can be calculated. The sum for all the activities gives the total costs associated with the route and the total time for completion of a route cycle.

The activities may be of a number of types, of which the five basic types are:-

(1) Unloading cargo.

(2) Loading cargo

(3) Taking on fuel

(4) Lost time, either in port or at sea

(5) Voyage A → B.

Activities (1), (2), (3) and (5) are self explanatory. Activity (4) - Lost time, covers such events as moving the ship from one berth to another, waiting for the tide or breakdowns on route.

For example, an ore carrier on a round route from Norway to Scotland carrying ore could have its route broken down as follows.

Act No.	Type	Commodity	Description
1	5	Ballast	Ship sails Glasgow to Narvik
2	2	Ore	Ship loads ore at Narvik
3	5	Ore	Ship sails Narvik to Glasgow
4	4	Ore	Ship delayed on route - bad weather
5	1	Ore	Ship unloads ore at Glasgow
6	3	Fuel	Ship takes on Fuel

The route cycle is shown diagramatically on Figure 17.

The sequence could be broken down further to separate the voyage from Narvik to the Tail of the Bank from the voyage up the river Clyde to Glasgow, by inserting a cost time activity (Type 4) between the two, to allow for waiting for the tide. The degree to which the route cycle is broken down should be considered and only the minimum number of events that will allow cost to be allocated fairly, should be produced.

Activities, apart from the five basic activities, can be produced to simulate such activities as the ship passing through the Panama or Suez Canals.

The duration, associated costs and fuel used are calculated for each activity, from relevant data supplied to cover cargo handling charges, distance on voyage, bunker prices etc.

4.2.1. The Unloading Activity

The unloading activity assumes that the ship is to be completely unloaded, and the following items should be defined.

(1) The commodity which is being unloaded.

(2) The rate at which the vessel is unloaded.

(3) Cargo handling charges if any.

From which it can be calculated.

$$\text{The time unload Cargo} = \left(\frac{\text{Cargo deadweight}}{\text{Unloading rate per hour} \times 24} \right) \text{ days}$$

4.2.2. The Loading Activity

The loading activity allows the ship to be loaded to a specified draft, which may or may not be the load draft of the ship. The specified draft must not exceed the maximum load draft.

The following items must be specified.

(1) The commodity which is being loaded.

(2) The rate at which it is being loaded.

(3) The cargo handling charges if any.

(4) The draft of the ship before loading commences.

(5) The draft of the ship after loading.

(6) The stowage factor of the cargo.

The following are then calculated.

(1) Displacement before loading $\Delta_b = \dfrac{L \times B \times T_b \times C_B}{35}$

(2) Displacement after loading $\Delta_n = \dfrac{L \times B \times T_n \times C_B}{35}$

(3) Cargo to be loaded $= \Delta_n - \Delta_o$

(4) Time to load $= \dfrac{\Delta_n - \Delta_o}{\text{(Cargo loading rate)}}$

(5) A check must be made to ensure that the ship has sufficient capacity.

Total load of ship after loading.

LOAD $= \Delta_n -$ (Lightweight + Oil Fuel + Stores + Fresh Water).

Required Capacity = LOAD x Stowage Factor.

If the required capacity exceeds the actual capacity, then the draft after loading must be reduced until the capacity requirement is fulfilled. This check is most important where grain cargoes are carried.

4.2.3. Fuel Bunkering Activity

This activity covers the bunkering of the vessel, for which the following items should be specified.

(1) The price of fuel oil at the bunkering station.

(2) The rate of loading of the oil fuel.

(3) Any bunkering charges over and above the price of the fuel.

(4) The amount of fuel used since last bunkering.

It would also be advisable to know whether the fuelling is carried out concurrently with cargo loading or whether the ship is moved to a bunkering berth.

From the above data, the following are calculated.

(1) Time for loading fuel $= \left(\dfrac{\text{Amount of Fuel taken on}}{\text{Fuel loading rate} \times 24} \right)$ days

(2) The cost of fuel loaded

$$= (\text{Amount of fuel taken on}) \times (\text{Bunker price}) + (\text{any extra bunkering charges})$$

4.2.4. Lost Time

This activity covers time not occupied by any of the other activities. It may be used to insert specific charges into the system, such as harbour dues etc., with or without a time lag. It may be used to account for time lost in voyage or port caused by breakdowns, or bad weather. The lost time activity has been broken-down into sub-groups, which allows the costs to be assessed on a variety of bases. The following items must be known for this activity.

(1) The basis on which the cost is to be assessed.

(2) The commodity or account to which the lost time is to be charged.

(3) The duration of the lost time.

(4) The costs as

(a) Cost per gross ton.

or (b) Cost per nett ton.

or (c) Cost per ton deadweight.

or (d) Cost in pounds.

4.2.5. Voyage Activity

This activity covers a voyage of the ship either with cargo or in ballast. The following items must be ascertained for each section of the route.

(1) The commodity with which the ship is sailing.

(2) The draft at which the ship is sailing and the corresponding brake-horsepower.

(3) The distance between the ports of departure and arrival.

and (4) The speed at which the ship is sailing.

From these items, the time and fuel usage can be calculated.

(1) Time on Voyage $= \dfrac{\text{Distance}}{\text{Speed} \times 24}$ days.

(2) Fuel Usage $= \dfrac{\text{BHP} \times \text{fuel consumption ratio} \times \text{Time} \times 24}{2240}$ tons

This system of building up the route as a sequence of activities is fairly complicated but it allows a detailed study of the costs of each part of the voyage to be made.

It would allow the operation of one ship to be studied simultaneously with that of a sister ship or one of a different tonnage. The purpose of such a treatment is to optimise the utilising and scheduling of a future fleet of bulk carriers of varying deadweights, or to ascertain the effect of new ships of various sizes on existing fleet schedules and chartering.

A system has been developed for giving each commodity a cost number or commodity number. For example for a ship working around a route on which it operates on five cargoes, the commodities are allocated cost number 1 to 5. Ballast and lost time which is to be spread over all the commodities on a time basis is allocated cost number zero.

By building up a synthesis of the proposed routes for a design, it is possible to calculate the time round the route and the costs directly associated with each part of the route.

4.3 Crew Costs

Crew costs include wages, overtime, victualling and crew travel allowances. An estimate of the monthly wage bill can be made from figures published in the Year Book of the National Maritime Board. Overtime is estimated from the past experience of Shipowners and is expressed as a fraction of the wage bill.

i.e. Overtime = k x (basic wages)

where k is a factor based on past experience.

The cost of victualling one man for a year is dependent on crew nationality, but is generally independent of route. The total victualling bill per annum is obtained by multiplying up by the total number of crew, as generally there is no difference between victualling crew and officers.

$$\text{Crew Costs} = \text{Wages} + \text{Overtime} + \text{Victualling}$$

$$= W + k \times W + CR \times VICT$$

$$= W(1 + k) + VICT \times CR$$

4.4 Insurance

Insurance covers marine insurance, war risk insurance and P and I club contribution, but not cargo or freight insurance.

Marine insurance is based on the value of the ship and decreases as the ship depreciates. Increases in ship insurance have recently been introduced for older ships and this will effectively limit the life of a ship to a maximum of twenty years.

Marine insurance is by far the largest proportion of the insurance bill, but the other two are significant costs are care assessed on value.

INS = Marine Insurance + War Risk Insurance + P and I Club.

4.5 Maintenance Costs

Maintenance covers the cost of stores, dry-docking, repairs and lubrication.

Stores are generally divided into three groups namely Cabin, Deck and Engine Room Stores.

Generally dry-docking and stores can be regarded as a function of size. Straight line relationships can be used over small ranges of deadweight to obtain the cost of stores and annual dry-docking. However over a large range of deadweight, higher order relationships must be used.

The cost of lubrication varies with size and make of machinery. The variation is considerable and a spot estimate should be made based on machinery of a similar size and make to that required for the proposed design.

4.6 Capital Charges

This covers the cost of special surveys and the capital cost of the ship plus the interest paid on the loan.

4.6.1. Special Survey Allowance

The special survey allowance is regarded as a capital charge, because the total sum involved for all the special surveys, incurred each five years, is considerable. To cover this an allowance is put aside each year to cover the total anticipated cost.

The special survey allowance per annum is calculated from

$$SSA = \frac{(\text{Total cost of all special surveys on ship})}{(\text{No of years in service})}$$

4.6.2. Capital Cost

The capital cost of the design is the sum of the shipbuilder's cost, the cost of extra items added to the ship by the owner and the cost of the loan which is obtained to pay for the ship.

The shipbuilders cost can be broken down into four groups,

(a) Cost of steel work

(b) Cost of outfit

(c) Cost of machinery

which can all be split up into cost of materials and cost of labour.

and (d) Establishment charges or overheads.

The only detailed figures published on shipbuilding costs are those given by the Motor Ship Magazine, which publishes annually estimates of British Shipbuilding costs for various standard designs. Appendix C summarises the analysis of costs for a 23,150 d.w.t. bulk carrier from 1960 to 1966.

In April 1966 the cost of a bulk carrier could be estimated as follows.

C_s = Cost of steel work = £88.6 x steel wt (from § 3.7)

C_o = Cost of outfit = £548 x outfit wt

C_m = Cost of machinery = £430 x machinery wt

C_e = Establishment charge = £28.8 x lightweight

Total Shipyard Cost = $C_s + C_o + C_m + C_e$

The costing method is somewhat crude, but produces estimates of sufficient accuracy. The method assumes that the ship is a one off design. If more than one ship is to be built then there will be a reduction in the cost of each ship. J.G. Couch (reference 22), has produced factors for the cost savings in multiple ship production, which are based on savings expected for American built ships.

An extra cost is added to the capital cost to allow for the cost of items of equipment added by the shipowner at his own initiative outside the builder's contract. This depends on what the shipowner himself supplies and varies from shipowner to shipowner, but contains certain items of furnishings, equipment and fittings. Generally the ship will be partly paid for with a loan. The cost of this loan, i.e. the total interest payment over the life of the ship, has to be calculated and added to the capital cost to give the total capital sum, which has to be recouped over the ship's lifetime.

The cost of the loan is the total interest paid over the total period of the loan.

$$\text{Total Interest} = \sum_{i=1}^{N} \left(\frac{I}{100} \times (PC \times C) \times (N - i + 1) \right)$$

where I is interest rate per cent on loan.

N is no of years over which the loan is to be paid off.

PC is percentage of shipyard cost on credit.

C is the shipyard cost.

The total capital cost is the sum of the shipyard cost, the owner's item cost and the total interest. The cost is recovered by depreciating the ship down to its scrap value. If S is the scrap value of the ship after M years and assuming straight line depreciation over M years, then the capital charge per annum is given by

$$\text{Capital Charge} = \frac{\left(C + O + \sum_{i=1}^{N} \frac{PCxIxC}{100} \frac{(N-i+1)}{N} \right) - S}{M}$$

where O is the owner's items charge, S = scrap.

4.7 Design Evaluation

The annual costs have been calculated and the route synthesis has been built up. The cost per ton for each commodity must be evaluated in order that a break even freight rate can be produced.

From equation I in paragraph 4.1.

The annual fixed costs is given by

$$AC = \left(\sum_{n=1}^{CR} (W+O) + VICT \times CR \right) + INS + (ST+DD+LUB) + \left(\frac{SURV+CC+INT-SCRAP}{NYDEP} \right)$$

and the variable costs are

$$VC = \frac{(BHP \times fcr \times DIST)}{2240 \times LUB} \times BP + PORT$$

In the more detailed treatment of variable costs made using the route synthesis, the individual fuel or port costs have been evaluated for each activity. The costs directly incurred by each commodity have been charged to the commodity. The remaining costs are charged to the "dummy commodity" 0, and are to be distributed over the other commodities on a time basis.

The time incurred by each commodity $= t_i$

where $0 \leqslant i \leqslant NCOM$

where NCOM is the number of commodities on the route,

Port charges or associated costs for each commodity $= p_i$

where $0 \leqslant i \leqslant NCOM$

Fuel used in transporting each commodity $= f_i$

where $0 \leqslant i \leqslant NCOM$

Total Time on Route $= TT = (t_o + t_i + t_2 \ldots t_i + \ldots t_{NCOM})$

Total fuel used $= PF = (f_o + f_1 + f_i + \ldots f_{NCOM})$

Total fuel bill $=$ FCOST.

The final cost per ton of each commodity can be calculated, by summing the associated costs, the fuel cost and the fixed costs.

Time	t_i
Port Charges	p_i
Fuel Cost	$FCOST \times f_i/F$
Fixed Costs	$AC \times t_i/WDS$
Total	$p_i + \frac{f_i}{FF} \times FCOST + AC \times \frac{t_i}{WDS}$

To this total incurred directly by the commodity i has to be added a proportion of the costs allocated to commodity 0.

$$\text{The addition} = \frac{t_i}{(TT - t_o)} \left(p_o + \frac{f_o}{F} \times FCOST + \frac{AC \times t_o}{WDS} \right)$$

Thus the total cost per ton of commodity

$$= \frac{1}{TONS} \left\{ \left(p_i + \frac{f_i}{F} \times FCOST + \frac{AC \times t_i}{WDS} \right) + \frac{t_i}{TT - t_o} \left(p_o + \frac{f_o}{F} \times FCOST + \frac{AC \times t_o}{WDS} \right) \right\}$$

which can be simplified to

$$\text{Cost per ton of ith commodity} = \frac{1}{TONS} \left\{ \left(p_i + \frac{p_o \times t_i}{(TT - t_o)} \right) + \frac{FCOST}{F} \left(f_i + \frac{f_o \times t_i}{(TT - t_o)} \right) + \frac{AC \times t_i}{WDS} \times \left(\frac{TT}{tt - t_o} \right) \right\}$$

5. THE COMPUTER PROGRAMS

A series of programs has been written in Algol to carry out the preliminary design process and the subsequent design evaluation. Due to the length of the calculation it has been necessary to split the computation into two programs, the results from the first program being stored on magnetic tape and used as data for the second program. The flow diagrams for the programs are shown in Figure 18.

The first program (Program A) carries the design process to the point at which the deadweight satisfies the owners' requirements. The second program (Program B) completes the design process, estimates the capital cost and evaluates the cost per ton of cargo deadweight. Each program works on batches of 100 designs at a time. Program B gives a detailed output for each acceptable design, but in order to save computer time and line printer time, a program with summary output for all cases for use in parametric studies, has been produced (Program C). It is often desirable to compare the results of the methodical variation with designs of know dimensions. For this purpose a program, which inputs length, beam, draught and block coefficient has been produced (Program D). The program carried out the design process to the same stage as Program A and feeds the results to Program B for trial design and cost evaluations.

Specimen output for Program B is given in Appendix E together and specimen hand calculation for one design is given in Appendix D.

The programs have been written in such a way as to permit easy modification to any of the design equations or cost evaluation techniques. It is expected that the programs will be extensively altered as improved design techniques become available.

5.1. Program Limitations

There are a number of limitations to the use of the programs in their present form, which should be removed in subsequent versions.

The number of designs that may be produced in are run is limited to 100. This does not allow a satisfactory methodical variation to be made with all three variables C_B, L/B, B/T. It was found that only two of the variables could be methodically varied to produce reasonable results. The program only recommends the least cost design, which it has produced, and does not optimise on the results of all the derived designs. Indeed if the step in the variation of just one of the variables is large, then the best design will probably not be near to the optimum.

In its present form the program is unable to deal with ships working at reduced draughts, but this will be remedied in a subsequent version of the program.

The designs derived in the program are based to a certain extent on past practice, which may not produce satisfactory designs for the future. The steel weight estimation is based on cubic number and area of longitudinal material, which do not reflect savings to be made in the future from the new Lloyds rules or from optimised steel structure design. Outfit weights are based on a square number method, which does not show the effects of automation on the ship of the future. The freeboard calculation is based on the 1933 Freeboard Rules, and does not relect the benefits to be gained from the 1966 convention. Powering is based on the B.S.R.A. methodical series which tends to overestimate the power required by high block coefficient forms. The length of the powering calculation is the major factor in limiting the number of designs to 100. However it does reflect the differences in powering for drastic changes in dimensions.

5.2. Future Development of the Programs.

The programs can both be developed in the future along a broader front and can be improved internally.

The program has been developed for bulk carriers only, but modification to some of the design relationships and to parts of the costing would permit a program for oil tankers to be developed. The production of a general cargo ship design program would be a more lengthy process, but no great difficulty should be encountered as Murphy, Sabat and Taylor (Reference 18) have produced such a program for the United States Maritime Administration.

It should be possible in the future to incorporate the economic design programs into a larger complex of programs, which would produce the detailed design for a proposed ship automatically. The economic design program will produce an estimate of the optimum dimensions and corresponding first estimates of the principle design features, from the owners basic requirements of speed and endurance. The results will be fed automatically into a series of programs, which would produce mathematically a suitable hull form and calculate hydrostatic and stability particulars. An optimised steel structure would be produced with detailed weights, and costing and production data. For the economic design programs to play their part in this design concept, suitable criteria for the optimisation must be found and suitable optimisation methods introduced. One possible method would be use the modified Random Search Technique as outlined by Mandell and Leopold (Reference 19), by which the program would reduce the incremental changes in the methodical variation of the independent variables as it gradually approaches the optimum combination design. This method would allow variations in deadweight, speed and any other desired variable to be assessed readily without the large amount of computer storage required for the present investigations.

Internally the programs can be altered to give a greater degree of accuracy. As more design data become available, the design techniques can be improved so as to provide more detailed information to the designer.

Extensions of the B.S.R.A. methodical series for high block coefficients should lead to improvement in the powering estimates.

The steel weight will be revised so that it is based on the results of parametric studies carried out on steel design programs.

The outfit weight should eventually be estimated by summing detailed estimates of outfit weight subgroups, but this will require that a very extensive analysis of outfit weights be carried out.

The freeboard estimate will be revised so as to satisfy the 1966 convention requirements.

Most important of all, the programs should be modified to deal with ships trading at reduced drafts, as most ships spend a good deal of their time operating at reduced drafts.

In their present form, the programs require a great deal of data, much of which could be given fixed values and incorporated as constants in the program. The presentation of data can be substantially reduced and improved. Provision must be made to allow more items to be varied without having to feed in a complete set of data for each variation as at present.

6. PARAMETRIC STUDIES

The programs have been run to carry out a preliminary design investigation for bulk carriers trading through the Panama Canal. The aim was to suggest an optimum size of ship that would produce the minimum cost for the transportation of coal and iron are through the Canal. The route chosen for investigation is detailed in Table IX and shown diagramatically in Figure 19. It covers the movement of coal from the East Coast of U.S.A. to Japan and of iron ore from Chile to the East Coast U.S.A.

TABLE IX

Bulk Carrier Route for Parametric Studies

	Distance in miles	Commodity
Hampton Roads to Cristobal (Panama)	1778	Coal @ 40 cu ft/ton
Transit through the Panama Canal		Coal
Balboa (Panama) to Kobe (Japan)	7960	Coal
Kobe to Guaycacan (Chile)	9430	Ballast
Guayacan to Balboa	2425	Iron Ore @ 18 cu ft/ton
Cristobal to Baltimore	1904	Iron Ore
Baltimore to Hampton Roads	274	Ballast

The ship is required to fuel only at the exit from the Panama Canal. This means that the ship has to have a range of 22,000 miles for the round trip in the Pacific.

The fact that the ship is passing through the Panama Canal imposes severe dimensional restrictions on the design. When the investigation was started the beam restriction was 104 ft, but has since been raised to 106 ft with 107 ft allowed under certain circumstances. The depth of the Canal varies with the seasons, but is generally between 36 and 39 ft. It was assumed that the ship would pass through the canal with very little fuel oil, thus it could be loaded to 40 ft with full oil fuel tanks. The dimensional restrictions imposed on the design are thus 104 ft beams, 40 ft draught and a nominal length restruction of 950 ft.

The weather allowance factor is taken as 1-2 for the parametric studies.

It was decided that the classification should be Lloyds 1000 A1 strengthened for ore in alternate holds.

The crew was chosen as European and numbering 41. The effects of reduced manning could be considered as as extra investigation, but further information is needed on the savings resulting from and the cost of maintaining automated equipment.

The number of days off hire per annum was fixed at 20 and the annual costs were turns distributed over 345 days.

The capital cost of the vessel was to be paid off as twenty per cent down and eighty per cent credit over 8 years at 7 per cent interest per annum. The life of the ship was to be 15 years after which it would be written off at its scrap value. The effect of recent changes in taxation has not been considered, but could easily be done by reducing the capital cost by 20 per cent, which cover the investment allowance on a British owned ship.

The machinery chosen was the new Doxford J.76 Type with Sulzer RD 90 as second choice. A speed of 15 knots was chosen for the main investigation, but the effect of speed variation has investigated in a speed series.

Parametric studies have been carried out to produce a deadweight variation series and a block coefficient series. Deadweights from 50,000 tons to 70,000 tons and Block coefficients of 0.76 to 0.84 have been investigated. For each value of deadweight and block coefficient a methodical variation was carried out on the parametors L/B and B/T ratios. A diagramatic illustration of the methodical variation is given in Figure 20.

After running the deadweight variation series, it was found that in order to obtain a sufficient number of acceptable designs it was necessary to increase the L/B ratio to 9.0 for high deadweights.

The grid of the L/B and B/T variation was found to be too large with steps of 0.2 and 0.1 respectively. The designs were either falling well within the dimensional restrictions or well outside them, but few beams and draughts fell near 104 ft and 40 ft respectively, which represents a B/T ratio of 2.6. In order overcome this difficulty a length variation series was set up, using program D and having constant beam of 104 ft and draft of 40 ft.

Four variation series were thus synthesised and each will now be treated in turn.

6.1. Deadweight Variation Series

A deadweight variation series was produced by carrying out the methodical variation of L/B and B/T ratios for a number of deadweights. The deadweight was stepped from 50,000 tons to 70,000 tons in steps of 1,000 tons, upon which was placed a tolerance of ± 300 tons. For each value of deadweight 100 designs were produced, by variation of L/B and B/T ratio from 6.0 to 8.0 and 2.1 to 2.9 respectively. The block coefficient was 0.80 and the speed 15 knots. An extra 78 designs were produced for even thousand deadweights from 60,000 tons to 70,000 tons by extending the range of L/B to 9.0. This produced a total of 2,448 designs of which 360 fully met the owners requirements and the dimensional limitations.

The results of the deadweight series have been plotted to show how the cost per ton of cargo deadweight varies with L/B and B/T for fixed deadweights (Figures 21-25). Cross plots have been made to show how the cost varies with size and L/B for fixed values of B/T. These have been drawn only for B/T's of 2.5, 2.7 and 2.9 as no acceptable designs occur at B/T ratios of 2.3 or 2.1. (Figures 26, 27 and 28).

As the deadweight increases, the acceptable designs increase in L/B until the point is reached when the savings accrued from greater powering efficiency and are neutralised by the penalties incurred by high steel weight and cost. The B/T ratio at which the acceptable design with the lowest cost is produced in each case is 2.6, which is the ratio of 104 ft beam and 40 ft draught.

The conclusion is reached that for routes with severe limitations on beam and draught, only the length and block coefficient need be varied to produce the deadweight variation series. Such a variation will be dealt with in the next section.

A diagram showing the inter-relationship between the various functions affecting the final cost (Figure 29) has been produced for the 60,000 deadweight ship. The curve has contours of B/T and a base of L/B. As the L/B ratio increases, the capital cost of the ship rises more rapidly than the final cost, as the economics of powering the longer ship are felt. However the powering curve also has a minimum which decreases as B/T decrease but increases along the L/B axis.

The curves suggest that in unrestricted seas, if seakeeping problems can be overcome, ships with a very low L/B ratio and a low B/T ratio ($5.5<L/B<6.0$ and $B/T<2.1$) may be an economical proposition in spite of powering problems. The limiting factor would be the depth of water on the continental shelves.

6.2. Length Variation Series.

A series of designs has been produced by varying the length from 600 ft to 900 ft whilst maintaining a constant beam of 104 ft and draught of 40 ft. Three series were produced for block coefficients of 0.78, 0.80 and 0.82. The results are given in Table X which also shows how the depth, deadweight, capital cost and cargo deadweight vary with length increases. In order to make the capital cost comparable with the final running costs, each capital cost per ton of cargo deadweight has been divided by a factor of 20.

TABLE X

RESULTS OF THE LENGTH VARIATION SERIES

BEAM = 104 FT.   DRAUGHT = 40 FT.   SPEED = 15 KNOTS

Length	Dwt tons	No. of Cyls.	Depth ft.	CDWT tons	Capital Cost Points	Running Cost Points
C_B = 0.78						
600	45616	7	57.55	42064	2.575	2.674
620	46974	7	57.78	43451	2.568	2.637
640	48318	7	57.99	44807	2.565	2.606
660	49646	7	58.17	46135	2.565	2.582
680	50959	7	58.32	47436	2.569	2.562
700	52257	7	58.46	48710	2.575	2.546
720	53456	8	58.55	49876	2.626	2.548
740	57416	8	58.65	51095	2.639	2.541
760	55959	8	58.75	52288	2.657	2.537
780	57185	8	58.83	53456	2.676	2.536
800	58394	8	58.91	54600	2.698	2.538
820	59585	8	58.98	55719	2.722	2.542
840	60767	8	59.05	56823	2.745	2.548
860	61852	9	59.08	57822	2.804	2.567
880	62978	9	59.46	58858	2.836	2.582
900	64087	9	59.84	59869	2.870	2.600
C_B = 0.80						
600	46881	8	57.75	43009	2.588	2.708
620	48296	8	57.99	44496	2.569	2.658
640	49692	8	58.21	45942	2.558	2.617
660	51071	8	58.39	47351	2.552	2.585
680	52431	8	58.56	48725	2.552	2.558
700	53774	8	58.70	50065	2.556	2.538
720	55100	8	58.83	51373	2.563	2.523
740	56407	8	58.94	52651	2.575	2.512
760	57697	8	59.04	53898	2.590	2.506

TABLE X (Cont.)

Length	Dwt tons	No. of Cyls.	Depth ft.	CDWT tons	Capital Cost Points	Running Cost Points
780	58969	8	59.13	55117	2.608	2.504
800	60228	8	59.22	56311	2.627	2.503
820	61475	8	59.29	57484	2.645	2.506
840	62615	9	59.33	58539	2.704	2.523
860	63814	9	59.40	59646	2.731	2.533
880	64986	9	59.71	60710	2.764	2.550
900	66141	9	60.10	61745	2.795	2.568
C_B = 0.82						
600	48137	9	57.95	43632	2.614	2.805
620	49590	9	58.20	45238	2.602	2.737
640	51042	9	58.42	46813	2.577	2.677
660	52476	9	58.62	48343	2.561	2.627
680	53889	9	58.79	49813	2.552	2.589
700	55283	9	58.94	51243	2.545	2.560
720	56742	8	59.11	52717	2.513	2.525
740	58016	9	59.20	53989	2.558	2.520
760	59354	9	59.30	55308	2.568	2.508
780	60674	9	59.40	56592	2.582	2.502
800	61976	9	59.49	67843	2.600	2.499
820	63257	9	59.58	59045	2.622	2.503
840	64521	9	59.66	60231	2.645	2.507
860	65768	9	59.73	61372	2.671	2.516
880	67004	9	59.96	62504	2.695	2.527
900	68117	9	60.30	63487	2.760	2.557

The running cost has been plotted on a base of deadweight (Figure 30), producing a surface with contours of length and block coefficient. As the block coefficient increases from 0.78 to 0.80 there is a decrease of about $1\frac{1}{2}$ per cent in the minimum running cost, but as the block coefficient increases from 0.78 to 0.80 there is a decrease of about $1\frac{1}{2}$ per cent in the minimum running cost, but as the block coefficient increases from 0.80 to 0.82, the decrease in the minimum running cost is much less. However the increase in deadweight capacity is about 3,000 tons in each case. No penalty is incurred in increasing the size of ship up to 62,000 deadweight, provided that the block coefficient is increased to 0.82. From this diagram, it would appear that for the best results, the size of the Panama Bulk Carrier should be about 62,000 tons deadweight, and the length about 800 ft. This assumes a beam limit of 104 ft and draught of 40 ft.

Figure 31 shows the running cost per ton and the capital cost plotted on a base of length. From capital cost considerations alone the optimum length would appear to 700 ft, which is 100 ft less than when the running costs are considered. Thus optimisation based on capital cost considerations alone is not good enough, and true optimisation must include running costs. The 700 ft ship has a running cost of about $2\frac{1}{2}$ per cent more than the 800 ft ship. The capital cost of the 800 ft ship is about $2\frac{1}{2}$ per cent more than the capital cost of the 700 ft ship.

In absolute terms, the 800 ft ship with a European crew, should give better results than the 700 ft ship. However a company with a rapidly expanding fleet, and with low cost labour available could operate the 700 ft ship competitively with the 800 ft European crew ship. The initial cost of the 700 ft ship would be £400,000 less or a saving of 13 per cent on the capital cost.

Recent changes in the Panama Canal Limits allow a beam of 106 ft. Assuming a similar L/B and C_B to the 800 ft ship, the revised length would be 815 ft and the deadweight of 63,500 tons.

6.3. Block coefficient Variation Series

A series of designs has been produced to investigate the effect of block coefficient on the running cost for constant deadweight. The range of block coefficients considered was from 0.76 to 0.84 for a deadweight of 60,000 and a speed of 15 knots. This means that in the B.S.R.A. powering estimate, which is only defined up to 0.80 block, extrapolation for the higher blocks must be made.

Curves have been plotted to show how the running cost is affected by block coefficient for constant B/T ratios (Figures 32 - 36). Contours of constant C_B are plotted on a base of L/B. The effect of block coefficient is greatest with designs of a low L/B ratio. From these curves it can be seen that there is a minimum cost around $C_B = 0.78$ for constant deadweight. The block coefficient producing the minimum cost is not affected by L/B or B/T ratios, but these two quantities affect the variation of cost remote from the minimum values of B/T and L/B.

The conclusion that the best C_B is 0.78 may seem to conflict with whe previous section, where a block coefficient of 0.82 was advocated. In the present case the deadweight of the ship has remained the same and has been determined in unrestricted waters. In the previous section the dimensions were fixed by severe restriction limitations and the deadweight increased as the block coefficient increased introducing economics of scale as the C_B increased.

It can be said that the concept of C_B as an independent variable is not justified unless the effect on length, beam and draught are considered as well.

6.4. Speed Variation Series

A series of designs has been produced to show the effect of speed on running costs. Curves have been drawn for fixed B/T ratios, with contours of constant speed on a base of L/B (Figures 37-41). There is an inconsistancy in the diagrams between the 16 and 17 knot designs. This is due to using the turbine weight formulae devised by Watson (Reference 5) for machinery weights with horsepower greater than can be obtained from the specified machinery. The formulas do not apply to bulk carriers, but are included in order to allow the program to pass on to the next design. Normally only diesel powered bulk carriers are considered.

As the speed increases, the running cost increases and at an increasing rate. The increase in cost due to speed is greater for vessels with a low L/B than those with a high L/B. As the speed increases, the L/B at which a minimum cost is obtained increases also.

The economic speed for the rank is the minimum possible speed. Up to 16 knots the speed effect is not very great with only a 2 per cent increase in cost at L/B of 8.0 over 14 knots.

Speed is thus a factor which has to be determined by the shipowner based partly in economic factors outside the design problem and partly on the service speed of his competitor's ships.

6.5. The Economic Design for a Panama Canal Bulk Carrier

In the previous sections, it was deduced that the best combination of length, beam, draught and block coefficient for operation through the Panama Canal are 800 ft, 104 ft, 40 ft and 0.82. This gives a ship of about 62,000 tons deadweight with a speed of 15 knots.

The computer print out giving full preliminary design details is given in Appendix E. An outline general arrangement for the ship has been prepared (Figure 42) showing profile and plans and also a section through the Midship Cargo Hold.

The running costs are based on a British built ship, but an increase or decrease in building cost will affect the running cost. A diagram has been prepared to show the effect of capital cost on the running cost (Figure 44). A 30 per cent reduction in building cost produces only a 10 per cent reduction in running costs.

6.5.1. The effect of changes in Freeboard Regulations on the Panama Bulk Carrier.

Recent changes in the Freeboard rules will generally allow ships to be built to sail at deeper draught for the same depth. A freeboard calculation for the Panama Bulk Carrier is shown in Table XI, and the resulting effect of the changes on the homogeneons stowage factors is shown in Table XII.

Under the new freeboard rules, two types of ships are defined, Type A and Type B. Type A ships consist of tankers and Type B consist of bulk carriers and general cargo ships. Bulk carriers are classed as Type B ships, but generally may have their tabular freeboard reduced by as much as 60 per cent of the difference between Type A and Type B. It will be possible for Bulk Carriers to obtain Type A freeboard if the holds are arranged so as to provide two compartment subdivision. The following conditions must also to be met.

(1) The maximum angle of heel due to unsymmetrical flooding is 15^{o}.

(2) The metacentric height in the flooded condition is positive.

(3) The above requirements must be met with the engine room flooded with a permeability of 0.85.

The effect of the new freeboard rules is to allow the ship to sail at a deeper draught of 43.76 ft for Type B and 45.24 ft for Type A. The ship will be unable to operate through the Panama Canal at these draughts, but would be able to operate on non Panama routes with agreatly increased deadweight. The effect of the freeboard changes on the cargo carrying capability of the Panama Bulk carrier is given in Table XII.

The effect of the new freeboard rules on the design of bulk carriers will be to make capacity an important requirement in design. The engine room will be reduced to an absolute minimum length and current practice of having a deep tank aft of the forward collision bulkhead will be abandoned.

Ballasting requirements will be met by partly flooding one of the holds and all topside tanks will be used for grain. The length of the holds will be arranged so as to allow for two compartment subdivision in order to secure Type A freeboard. The possibility of two freeboard assignments will be considered, in order to obtain the maximum draught with ores, while being unable to do so with less dense solids.

TABLE XI

FREEBOARD CALCULATION UNDER 1966 CONVENTION

Length = either 96 per cent of total length at .85 mld depth

or length between the fore side of stem to axis of rudder stock.

.85 of 59.49 = 50.5 ft.

Length @ 50.5 ft = 830 ft.

96 per cent of 830 ft = 796 ft.

Length between FP and axis of rudder stock = 800 ft.

Freeboard length = 800 ft.

$$C_b = 0.85 \times D = 0.82 \times \left(\frac{50.5}{40}\right) \frac{CW}{C_B} - 1$$

$$= 0.838$$

		Type A Two Compartment	Type B One Compartment
Tabular Freeboard		117	154.8
Difference	37.8		
60 per cent of Difference	22.7		
Revised Tabular Freeboard		117	132.1
C_B factor $= \frac{0.838 + 0.68}{1.36} =$	1.15		
Freeboard corrected for C_B		130.4	147.2
L/15 = 53.3			
Depth Correction = 6.19 x 3		18.57	18.57
Length of superstructure	167 ft.		
Per cent Length	20.9 per cent.		
Percentage deduction	10.45 per cent.		
Superstructure deduction		- 4.38	- 4.38

TABLE XI (Contd)

Corrections so far	+ 14.19	+ 14.19
Freeboard so far	144.59	161.4

Sheer correction.

Station	Actual Sheer	Multiplier	Standard Sheer
AP	24	1	90
- 1/3 L	0	3	40
- 1/6 L	0	3	10
Midships	0	1	0
	24		240
Midships	0	1	0
+ 1/6 L	0	3	20
+ 1/3 L	0	3	80
FP	24	1	180
	24		480

Deficiency of sheer aft $= \frac{240 - 24}{8} = \frac{216}{8} = 27$

Deficiency of Sheer fwd $= \frac{480 - 24}{8} = \frac{456}{8} = 57$

Deficiency for sheer correction $= \frac{57 + 27}{2} = 42$

Sheer correction $= (0.75 - \frac{0.209}{2}) \times 42$

$= 0.65 \times 42 = 27.3$

	Type A	Type B
Carried forward	144.59	161.4
Sheer correction	27.3	27.3
Summer Freeboard	172.29	188.7
	14.35 ft	15.725 ft
Depth	59.49	59.49
Draft	45.14	43.76

TABLE XII

EFFECT OF FREEBOARD CHANGES ON LOAD CARRYING OF BULK CARRIER

Item	1933 Freeboard Tanker	Steamer	1966 Freeboard Type A	Type B
L	800	800	800	800
B	104	104	104	104
D	59.49	59.49	59.49	59.49
T	43.64	40	45.14	43.76
C_B	0.826	0.82	0.83	0.826
Displacement	86,000	77,970	89,200	86,000
Lightship	15,994	15,994	15,994	15,994
Deadweight	70,006	61,976	73,206	70,006
Deductions	4,133	4,133	4,133	4,133
Cargo Dwt	65,873	57,843	69,073	65,873
Holds Plus Topside Tanks.				
Capacity	3,337,887	3,337,887	3,337,887	3,337,887
Stowage Factor	50.7	57.71	48.3	50.7
Holds only				
Capacity	3,067,314	3,067,314	3,067,314	3,067,314
Stowage Factor	46.5	53.03	44.3	46.5

7. CONCLUSIONS

A process has been developed to link the technical methods of ship design with their economic consequences. The technical and economic considerations of ship design are indivisible. Ship design is not an isolated science divorced from economic considerations. A ship is merely part of a system and has to be designed for that system, as much as is possible.

Computer programs have been written to produce a series of ship designs from the owner's basic requirements of deadweight speed and range. It is extremely doubtful whether it is best to start the economic design process at this point, as the fixing of deadweight, speed and range assumes that the owner has chosen the optimum combination, which may not be the case.

The aim of economic design programs is to build up a picture of the transportation system as a whole. The technical implications of changes in the economics must be shown as well as influence of design changes on the economics of the system. The result of such an investigation should not only define the optimum deadweight, speed range and other design characteristics but should also show where one or more ships are needed, taking into account the workings of the existing fleet.

This ideal system and its resultant decision making is complicated by the different chartering practices. Time charters generally introduce a fair degree of certainty into the route patterns, where voyage charters exist from voyage to voyage, with no certain pattern. In the latter case, the movement patterns of such ships tend to be seasonal and it is possible to set up typical routes on which the ship can reasonably be expected to operate. From this the physical limitations to the size of the ship can be defined.

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or a Panama Bulk carrier has length, beam,
40 and 59.49 feet respectively. The
block coefficient is 0.82 and the deadweight 62,000 tons. By comparison with designs, with beams ~~to~~ too large for Panama transit, it has been shown that the Panama Canal Bulk carrier is not particularly competitive on other routes. The open sea bulk carrier could have a L/B ratio of less than 6 and also a very low B/T ratio about 2.1.

The investigation has uncovered as many questions as it set out to answer. The problems of weight estimation bear heavily on the accuracy of the costing estimates. The problem of powering high block coefficient forms with low L/B ratio affects the final balance between the penalties in powering the shorter ships and the savings in weight and capital cost.

The conclusions from the investigation can be summarised as follows:-

(1) Economic design programs can play a large part in helping British shipowners to keep their fleets competitive with world competition especially with fleets from developing countries.

(2) The effect of large changes in dimensions affect capital cost more than running costs, but is significant in both cases.

(3) The most satisfactory criterion for optimisation is running cost per ton of cargo deadweight and not capital cost per ton of cargo deadweight.

(4) Optimisation of ship's operating with severe limitations is carried out with length and block coefficient as variables.

(5) The least cost ship for operation through the Panama Canal is 800 x 104 x 40 x 59.49 x 0.82., based on the routes considered in the investigation, 15 knots.

(6) The difference in length between the least cost ship based on running costs and that based on capital cost ship is considerable, but only $2\frac{1}{2}\%$ difference in running cost per ton.

(7) Analysis of outfit weights to produce estimates of the various subgroups is essential before the effects of automation can be simulated.

(8) There is a great need for an accurate power estimation method for large block coefficient forms.

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APPENDIX A

Analysis of Bulk Carriers on Order

Details of Bulk Carriers on order are published regularly by the "Motor Ship" and the "Fairplay Shipping Journal", and further data is given in "Bulk Carriers" by J. Bes.

The growth of the Bulk Carrier has been one of the main phenomena of the shipping in the sixties. In 1960 there were 2.563 million deadweight tons of bulk carriers, which had risen to 14.104 million deadweight tons by the end of 1965. Indeed in 1965 38.2% of the total number of ore carriers and bulk carriers in operation were less than 4 years old, as can be seen from the age distribution diagram (Figure A/1).

Not only has the number of bulk carriers altered in five years but also the pattern of the orders. (Figures A/2, A/3). In 1960 64 bulk carriers with deadweight between 10,000 and 20,000 tons were on order representing 54.3% of all bulk carrier orders. In 1965 there were 62 representing only 15.4% of the total bulk carrier orders. In 1963 the first 60,000 dwt ton ship was ordered and by 1966 there were 49 ships between 60,000 and 70,000 tons on order represent 10% of the total.

TABLE A.1

NO OF BULK CARRIERS AND ORE CARRIERS ON ORDER OR BUILT

Year	Ore Carriers	Bulk Carriers	Total	On Order
1960	131	179	310	118 (June)
1961	168	241	409	
1962	201	344	545	196 (June)
1963	218	470	688	104 (September)
1964	233	613	846	200 (March) 256 (October)
1965	229	691	920	319 (April) 399 (October)
1966	-			491 (April)

The pattern of growth of bulk carrier and ore carried fleets, compared with the existing fleet is shown in Table A.I and the distribution of newbuildings is shown in Table A.II.

TABLE A.II

Dead Weight \ Date	1.6.60	30.6.62	30.9.63	30.3.64	31.10.64	30.4.65	31.10.65	30.4.66
10,000 - 20,000	64 54.3%	61 31.2%	18 17.3%	31 15.5%	38 14.7%	56 17.6%	62 15.4%	92 18.8%
20,000 - 30,000	49 41.5%	80 40.8%	47 45%	70 35%	71 27.7%	91 28.5%	96 24.0%	110 22.5%
30,000 - 40,000	5 4.2%	41 20.9%	25 24%	73 36.5%	92 35.9%	91 28.5%	95 23.7%	88 18%
40,000 - 50,000		10 5.1%	6 5.8%	12 6%	20 7.8%	30 9.4%	47 11.8%	76 15.5%
50,000 - 60,000		4 2.0%	7 6.7%	9 4.5%	22 8.7%	25 7.8%	34 8.6%	37 7.5%
60,000 - 70,000			1 1%	5 2.5%	10 3.9%	20 6.3%	44 11.0%	49 10%
70,000 - 80,000					3 1.2%	2 0.6%	9 2.5%	27 5.5%
80,000 - 90,000						4 0.1%	8 2.1%	6 1.2%
90,000 - 100,000							3 0.7%	3 0.6%
100,000 plus							1 0.2%	3 0.6%
Total	118	196	104	200	256	319	399	491

It is interesting to study the demand for bulk carriers by examining the pattern of the size distribution of the ships on order (Figure A/4 and A/4a). The last year has seen a large number of orders placed for 40,000 and 46,000 ton bulk carriers. In May 1965, the British Shipbuilders introduced the 40,000 Economy Class Bulk Carrier, for which no orders have been received. They have however shared in the demand for the larger ships notably of 46,000 tons and 67,000 tons deadweight. Indeed the demand for the large bulk carrier with deadweights of 60,000 tons and above has been consolidated and now accounts for 18 per cent of the market. Many of these ships will have their deadweight increased considerably as a result of the 1966 Freeboard Convention. There has also been a large increase in demand for the small bulk carrier in order to meet the demand for transporting more commodities in bulk, but in smaller batches.

Details of bulk carrier orders by country of origin and country of build have been produced (Table AIII) for 31st January 1966. Japan is by far the largest builder having 226 out of 458 bulk carriers on order. Britain, Sweden and Germany follow with 46, 36 and 33 ships order respectively. The largest customer is Norway with 106 bulk carriers on order, followed by Liberia, Japan, Britain and Greece with 76, 46, 46 and 32 ships respectively.

An analysis of the quoted speeds of bulk carriers compared with other ship types was made for ships on order at the end of January 1966. (Table A.IV and Figure A.5). At that time 15 knots was the most popular speed, but in common with other ship types, the speeds will increase over the next few years.

TABLE A.III

ANALYSIS OF BULK CARRIER ORDERS BY COUNTRY OF ORIGIN AND COUNTRY OF BUILDING

	Building		Ships on order Abroad	Net Export +	Total on Order	Total Building
	Home Owned Ships	Ships for Export				
Great Britain	18	28	28	0	46	46
Australia	4	0	0	0	4	4
Belgium	0	0	2	-2	2	0
Brazil	4	0	0	0	4	4
Bulgaria	0	0	3	-3	3	0
Canada	7	0	0	0	7	7
Czechoslovakia	0	0	1	-1	1	0
Denmark	3	7	4	+3	7	10
Eire	1	1	0	+1	1	2
Finland	0	0	2	-2	2	0
France	8	1	2	-1	10	9
Germany	13	20	0	+20	13	33
Greece	0	0	32	-32	32	0
Holland	2	7	1	+6	3	9
India	0	0	11	-11	11	0
Isreal	0	0	6	-6	6	0
Italy	8	4	1	+3	9	12
Japan	46	180	0	+180	46	226
Liberia	0	0	76	-76	76	0
Norway	15	5	91	-86	106	20
Panama	0	0	11	-11	11	0
Phillipines	0	0	5	-5	5	0
Poland	6	0	6	-6	12	6
Rumania	0	0	7	-7	7	0
South Africa	0	0	1	-1	1	0
Spain	3	0	0	0	3	3
Sweden	6	30	6	+24	12	36
U.S.S.R.	7	12	0	+12	7	19
Yugoslavia	7	5	4	+1	11	12

TABLE A.IV

SPEED DISTRIBUTION OF SHIPS ON ORDER

31.1.66.

NUMBER (PERCENTAGE IN BRACKETS)

Speed	Dry Cargo	Tanker	Bulk Carrier
11	22 (2.7%)	13 (3.6%)	0
12	35 (4.3%)	6 (1.6%)	4 (1%)
13	119 (14.8%)	12 (3.3%)	4 (1%)
14	78 (9.7%)	64 (17.5%)	46 (11.7%)
15	114 (14.2%)	35 (9.6%)	191 (48.6%)
16	52 (6.4%)	153 (41.8%)	121 (30.8%)
17	128 (15.9%)	72 (19.7%)	15 (3.8%)
18	85 (10.6%)	1 (0.3%)	12 (3.1%)
19	39 (4.8%)	10 (2.7%)	
20	48 (6.0%)		
21	55 (6.8%)		
22	6 (0.7%)		
23	17 (2.1%)		
24+	7 (0.8%)		

APPENDIX B -

Analysis of Machinery Specified for Newbuildings

An analysis has been made of the machinery specified for current newbuildings of bulk carriers based on data published in the Fairplay Shipping Journal "Ships on Order". The results are given in Table B/I and show Sulzer and B. & W. dominating the Market. There are only three Doxford J Types in the list, although it is believed that several of the unidentified motors are Doxfords. Generally, Diesel Machinery is favoured although some bulk carriers with steam turbines are being built. Apart from the German Nuclear Ship, the steam turbine ships are generally for American or Panamanian Interests.

TABLE B/I

Type	Make	Number	
Motor	Sulzer	166	
Motor	Burmeister & Wain	116	
Motor	MAN	46	
Motor	Götaverken	35	
Motor	Frat	15	
Motor	Doxford	3	
Motor	Fairbanks Morse	2	
Motor	Mitsuibishi	1	
Motor	Unidentified	27	
			411
Turbine	G.E.C.	6	
Turbine	Westinghouse	1	
Turbine	1 H.I.	1	
Turbine	Kawasaki	2	
Turbine	Mitsinbishi	1	
Turbine	Hitachi	2	13
Nuclear/Turbine	German		1
	Total		425

APPENDIX C -

Analysis of Shipbuilding Costs.
(Reference. The Motor Ship).

23,100 ton Deadweight Bulk Carrier.

Principal Dimensions 562 x 71'-10" x 48' x 34'-4"

Machinery. Diesel giving trial speed of 15½ knots.

Estimated Weight Breakdown

Steel	4,500
Outfit	950
Machinery	950
Lt. Wt.	6,400 tons

Construction Costs. April, 1966.

	Materials		Labour		Total	
		%		%		%
Steelwork	236080	15.60	163300	10.79	399380	26.39
Outfit	301750	19.93	218445	14.43	520195	34.36
Machinery	359150	23.72	50390	3.33	409540	27.05
Establishment					184680	12.20

Rise in costs since 1960.

	Steel	Outfit	Machy.	Establishment
End 1960	£ 79	£486	£ 385	£ 25.35
End 1961	79	486	385	25.35
End 1962	81.5	501	396	26.10
End 1963	82.9	513	403	27.40
End 1964	83.7	522	409	28.40
End 1965	86.0	535	418	28.40
April 1966	88.6	548	430	28.8
	Cost per ton steel	Cost per ton Outfit	Cost per ton Machy.	Cost per ton Lightweight

APPENDIX D

Worked Example

Owner's basic requirements.	Deadweight	60,000 Tons
	Speed	15 Knots. Machinery Doxford
	Range	22,000 miles
	Route	East Cost USA to Japan with Coal Japan to Chile under Ballast Chile to East Coast USA with Ore

Route Restrictions L = 950 B = 104 T = 40

Calculation

Basis Ship - Dimensions derived from Posdunine and Alexander Type formulae and from Murrays dimension diagram (IESS 1965).

Dwt/Displacement Ratio = 0.80
Displacement = 60,000/0.80 = 75,000 tons.

I Calculation of Principle Dimensions

Length BP $= 24.2 \times (V/(V+2))^2 \times DWT^{1/3}$

$= 24.2 \times 15/17 \times 60{,}000^{1/3} = 739.$

Beam $= 0.146 \times 739 - 3.4 = 104.28$

which reduces to 104 ft.

C_b = block coefficient $= 0.968 - 0.269 \times V/\sqrt{L}$

$= 0.968 - 0.269 \times 15/\sqrt{739}$

$= 0.968 - 0.148 = \underline{0.82}$

Draft $= 75{,}000 \times 35/(739 \times 104 \times 0.82) = 41.76$

which reduces to 40 ft.

The length has then to be recalculated to give the required displacement.

$$L_{BP} = 75{,}000 \times 35/(104 \times 40 \times 0.82) = 770 \text{ ft.}$$

The principal dimensions are then

Length BP = 770 ft.
Beam = 104 ft.
Draft = 40 ft.
Block Coeff.= 0.82

II **Calculation of suggested form coefficients CB's etc.**

Waterplane Area Coefficient $= 0.265 \times C_B - 0.146$

$= 0.265 \times 0.82 - 0.146 = \underline{0.893}$

Vertical Prismatic Coefficient $= C_B/C_W = 0.82/0.893 = \underline{0.918}$

Prismatic Coefficient $= C_B/C_m$ (C_m is taken as 0.99 say)

$= 0.82/0.99 = \underline{0.828}$

$$\underline{KB} = T \times \frac{(5 \times C_W - 2 \times C_B)}{6C_W} = 40 \times \frac{(5 \times 0.893 - 2 \times 0.82)}{6 \times 0.893} = \underline{21.05 \text{ ft.}}$$

$\underline{LCB} = (7.5 \times C_p - 12.5)\%\ L_{BP} = 7.5 \times 0.828 - 12.5 = 2.0\%$

$$BM = \frac{0.073 \times B^2 \times C_W}{T \times C_B} = \frac{0.073 \times 104^2 \times 0.893}{40 \times 0.82} = 21.5 \text{ ft.}$$

$\underline{KM} = 21.5 + 21.05 = 42.55$ ft.

in the load condition.

III **Powering in the Load Condition**

Use B.S.R.A. Methodical Series.

($L = 770$, $B = 104$, $T = 40$, $C_B = 0.82$)

$V = 15$.

$V/\sqrt{L} = 15/\sqrt{770} = 0.54$

$V_{400} = 10.8$ knots.

LCB = 2% fwd. LCB standard = 2.9% fwd. Difference -0.9%

C_{400} basis $= 0.720$

Corrections LCB deficiency com. factor = 1.02

$B/d = 104/40 = 2.6$ com. factor = 1.01

$L/V^{1/3} = 770/(75{,}000 \times 35)^{1/3} = 5.57$ com. factor = 0.98

$C_{400} = 1.02 \times 1.01 \times 0.98 \times 0.72 = 0.727$

$O_{400} = 0.0741$ $O_{770} = 0.0689$ $L = 1.055 \times 0.54 = 0.57$ $L^{-.175} = 1.1034$

$S = 3.4 + 0.5 \times L/V^{1/3} = 3.4 + 0.5 \times 5.57 = 6.18$

Skin friction corrn. $= (O_{400} - O_{770}) \times S \times L^{-.175} = (0.0741 - 0.0689) \times 6.18 \times 1.1034 = 0.038$

$C_{770} = 0.727 - 0.038 = 0.689$

$EHP = C \times \Delta^{2/3} \times V^3/427.1 = 0.689 \times 1780 \times 15^3/427.1 = 9700$ h.p.

Take Diameter of propeller 20.4 f.

Relative Rotative Effy = 1.01

Transmission Efficiency = 0.97

$D_W = B/\sqrt{(\nabla^{1/3} \times D)} = 104/\sqrt{(75{,}000 \times 35)^{1/3} \times 20.4} = 1.96$

$D_t = BD/\nabla^{2/3} = 104 \times 20.4/(75{,}000 \times 35)^{2/3} = \frac{104 \times 20.4}{19{,}000} = 0.112$

Basis $\frac{wt}{C_B}$ = 0.520 wt_{basis} = 0.52 x 0.82 = 0.4264

correction for LCB(-0.9%A) = + 0.007

wt = 0.433.

td basis = 0.185

correction = for LCB = + 0.018 =

td = 0.203

Hull efficiency = $\frac{1-t}{1-wt} = \frac{1-0.203}{1-0.433} = \frac{0.797}{0.567} = 1.412$

Computer estimates 1.412

Using Japanese Propeller Charts to check computer.

DHP = $\frac{16500}{1\ 025}$ = 16100 h.p. $B_p = \frac{16100^{0.5} \times 115}{8.54^{2.5}} = 69.5$

$\sqrt{B_p} = 8.34$

$\delta = \frac{115 \times 20.41}{8.54} = 265$ with D in metres $\delta = 80.9$

6.55 chart 0.460

η_o

6.70 chart 0.456

for 6.63 computer estimates η_o= 0.467, but may not be using Japanese Data.

QPC = 0.467 x 1.01 x 1.416 = 0.668

BHP = $\frac{9700}{0.668 \times \eta_t} = \frac{9700}{0.668 \times 0.97} = 14{,}950$

HP for Ship powering = $\frac{14950}{(1 - \text{enginederating})} = \frac{14950}{0.9} = 16{,}700$

Service BHP = 16700

Computer 16986

Take computer estimate and round to 17,000 h.p.

IV Choice of Machinery

Doxford 76J8 — Max continuous service at 115 rpm = 17,600 h.p.

Main Engine Wt. = 520 tons.

Length of Engine = 53.5 ft.

(Sulzer 8RD90 — $MCSH_p$ @ 119 rpm = 17600

Main Engine Wt. = 670 tons

Length of Engine = 59.1 ft.

B.&.W. 884VT2BF-180 $MCSH_p$ @ 110 = 16800

Main Engine wt. = 630 tons.

Length of Engine = 53.2 ft)

V Length of Compartments

Aft Peak Length = 0.035 x LBP = 0.035 x 770 = 27'

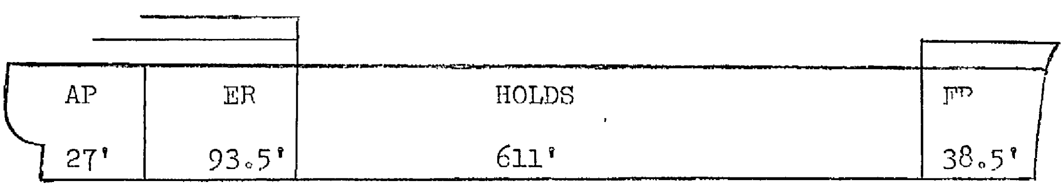
Fore Peak Length = 0.05 x LBP = 38.5 ft. = 38.5

Length of Engine Room = 40 + Length of Engine

= 40 + 53.5 = 93.5

Length of Superstructures. 159.0 ft

Length of Holds = 770 - 159 = 611 ft



$$LWL = K \times L_{BP} \qquad \text{if } K = 1.03$$

$$= L_{WL} = 1.03 \times 770 = 794 \text{ ft.}$$

VI Freeboard and Depth of Ship

Note using steamer freeboard. (1933)
Tabular Freeboard for 794 ft. = 170.9 ins.
Superstructure deductions = 0.21 x 159/794 = 4.2 ins.
Camber correction = $\left(2.08 - \frac{2}{4}\right) \times 12 \times \left(\frac{611}{770}\right)$ = 0.19 ins.

Sheer = 0
Standard Sheer Aft = 0.1 x L_{WL} + 10 = 89.4
Standard Sheer Fwd = 0.2 x L_{WL} + 20 = 178.8
Standard Sheer Ordinate = (0.3 x L_{WL} + 30)/6 = 268.2/6 = 44.7
Deficiency in Sheer = 44.7 ins.

Sheer correction = -44.7 x 1 x (0.75 - 159/(794 x 2)) = -44.7 x (0.65)

= -29.06

C_b correction (C_b load T) = (0.82 + 0.68)/1.36 = 1.5/1.36 = 1.102

Summer freeboards so far = (170.9 x 1.1 - 4.2 ∓ 0.2 + 29.1) = 212.7

Depth = 40 + 212.7/12 = 57.7 ft.

allowing for Depth correction

Depth = 1.3333 (57.7 - 794/60) = 1.3333 (57.7 - 13.2)

= 1.33 x (44.5) = 59.3 ft.

But C_B at .85 depth = 0.82 x $(0.85 \times 59.3/40)^{.893/.82-1}$ = 0.836

C_b correct = 1.516/1.36 = 1.115

Depth without depth corection =

40 + (215.2/12) = 57.9 ft.

Allowing for depth correction

Depth = 1.333 (57.9 - 13.2) = 1.33 x 44.7 = 59.6 ft.

Freeboard = (59.6 - 40) x 12 = 235 ins. (Summer)

VII Group Wt. Estimates

Steel wt. to be taken as 50% Longt Area/50% Cubic Number

Basis ship L = 760 B = 104 D = 59 C_B = 0.82

Area of Longt Mat. = 6683. Steel = 11180. Outfit = 1480 tons.

Midarea of Longt. Material

= exp (2.30258 x exp(0.14927 x ln(L_{BP}) + 0.0869 x ln(BEAM) +
0.022 x ln(D) + 0.01232 x ln(T) -0.007092)

L_{BP} = 770, BEAM = 104, D = 59.6, T = 40.

$$\text{Midarea} = \exp(2.30258 \times \exp(0.14927 \times \ln(770) + 0.0869 \times \ln(104) - 0.022 \times \ln(59.6) + 0.01232 \times \ln(40) - 0.007092)).$$

$$= 6830.$$

$$\text{Cubic No Coeff} = \frac{770 \times \cancel{104} \times 59.6}{760 \times \cancel{104} \times 59} \times \sqrt{\left(\frac{770 \times 59}{760 \times 59.6}\right)} \times \frac{(1 + 0.5 \times 0.82)}{(1 + 0.5 \times 0.82)}$$

$$= 1.023$$

$$\text{Steel wt} = 11180 \times \left(1.023 + \frac{6830 \times 770}{6683 \times 760}\right) \times \frac{1}{2}$$

$$= 11524 \text{ tons.}$$

Steel wt = 11524 tons

$$\text{Outfit wt} = \frac{1480}{2} \times \left(1 + \frac{770 \times 104}{760 \times 104}\right) = 1490 \text{ tons}$$

Machinery wt = Main Engine Wt. + HP/35 + 200

= 520 + 17,000/35 + 200

= 1205

Lightweight Estimate.

Steel	11524
Outfit	1490
Machinery	1205
	14219
+ 5% Margin	711
	14930 tons
Deadweight	60070
	75,000 tons

∴ Deadweight. O.K.

$$\underline{\text{Oil Fuel Capacity}} = 15{,}300 \times \frac{0.38 \times 22{,}000}{2240 \times 15} = 3803 \text{ tons}$$

Fresh water = 200 tons
Others = 100 tons
(OWNER'S DATA)

Deadweight deductions = 100 + 200 + 3803 = 4103

Cargo deadweight = 60,070 − 4,103 = 55,967 tons

VIII Geometry of Midship Section

Hatch Width = BEAM/2 = 52 (half ship = 26)

Tank Top Width for each side = 26 + 8 = 34 ft.

Bilge Radius = $\sqrt{(0.0239 \times B \times T)}$ = 9.95 ft say 10 ft.

for Centre girder ht. estimation LL1 = 705

Bottom Thickness

$$= \frac{\text{Long B.Spacing}}{9.84} \times \frac{(LL1 + 246)}{1000} \times \sqrt{\left(\frac{T}{LL1}\right)}$$

$$= \frac{32}{9.84} \times \frac{705 + 246}{1000} \times \left(\frac{40}{705}\right) = 0.74 \text{ ins.}$$

Inner Bottom Plating Thickness

$$= 0.000375 \times L_{BP} + 0.005 \times \text{Inner Bottom Longt.Spacing} + 0.1375$$

$$= 0.000375 \times 770 + 0.005 \times 32 + 0.1375 = 0.60$$

Centre Inner Bottom Plating Thickness

$$= \text{Inner Bottom Plating Thickness} + 0.20 = 0.60 + 0.20$$

$$= 0.80$$

G.G Height first approximation

$$= L_{BP}/20 + 21 + (T - 30) \times -0.5$$

$$= \frac{770}{20} + 21 + (10) \times 0.5 = 64.6 \text{ ins.}$$

Floor thickness

$$= 1.1 \times ((0.0005 \times L_{BP} + 0.19) + (\text{Transverse} - 0.025 \times L_{BP} - 18.5) \times 0.005)$$

$$= 1.1 \times ((0.0005 \times 770 + 0.19 + (35 - 0.025 \times 770 - 18.5) \times 0.005$$

$$= 0.62 \text{ ins.}$$

Which may be reduced to 0.58 ins.

TIBAREA = 2 x 35 x 0.80 = 56

TIBAREA = 2 x 35 x 0.74 = 51.8

C = 0.0026

Required centre girder modulus.

$$= C \times (2 \times \text{Tank Top Width} + 5)^2 \times \frac{\text{Transverse spacing}}{6} \times D$$

$$= 0.0026 \times (2 \times 34 + 5)^2 \times \frac{35}{6} \times 59.6$$

$$= 0.0026 \times (73)^2 \times \frac{35}{6} \times 59.6 = 1860$$

IBYY = (56, CGH, 0.58, 51.8)

$$IBYY = 56 \times 64.6 + 0.58 \times \frac{64.6^2}{6}(1 + (51.8 - 56)/(51.8 + 0.5 \times 0.58 \times 76.4))$$

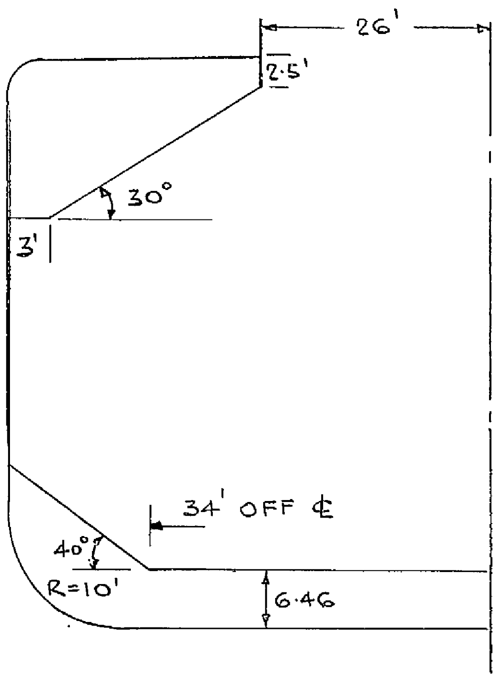
The IBYY is unsatisfactory as IBYY < Required modulus.

The GG Height is raised by 1 until a satisfactory I/Y is obtained at GG Height = 77.6

G.G. Height = 77.6/12 = 6.46 ft.

Topside Tank Angle = 30° Hopper Side Angle = 40°

Shelf Plate Width = 3.0 ft. Hatch Side Girder = 2.5 ft.



B = 104'

T = 40'

D = 59.6'

bb = B/2 - hw - SPW = 52-26-3 = 23

IX Capacities

Cross sectional Area of Topside Tank at Midships.

$$= \left(\frac{B}{2} - hw\right) \times \left(bb \tan(30^o) + hsg\right) - \frac{bb^2}{2} \tan(30)$$

$$= \left(\frac{104}{2} - 26\right) \times (23 \times \tan(30) + 2.5) - \left(\frac{23^2}{2} \tan(30)\right) = 260.5 \text{ ft}^2.$$

Camber correction = 2 x (26)/2 = 26

Topside Tank Area (Midships) = $260.5 - 26 - 0.213 \times 2.5^2 = 233.2 \text{ ft}^2$.

Double Bottom Cross Sectional Area = $\frac{B}{2} \times \text{cgheight} + \frac{1}{2}\left(\frac{B}{2} - \text{TTwidth}\right)^2 \tan(40) - 0.213 \times 10^2 - \text{ptw} \times \text{GGheight}.$

$$= \frac{104}{2} \times 6.46 + \frac{1}{2}(52 - 34)^2 \tan(40) - 21.3 - 8.5 \times 6.46$$

$$= 395.9 \text{ ft}^2.$$

Topside Tank Cu No. = Topside Tanka Area x Length of Holds x 2

= 233.2 x 611 x 2 = 284,900

Double Bottom Tank Cubic No. = Double Bottom Tank Area x Length of Holds x C_b x 2

= 395.9 x 611 x 0.82 x 2

= 396,700

Hold Volume Cubic No. = B x D x C_b x Length pf Holds.

= 104 x 59.6 x 0.82 x 611 = 3,105,522

Total Capacity = 1.162 x Tot.Cu.No. + 140,000

= 3,608,600 + 140,000 = 3,748,600

Topside Tank Capacity = 0.905 x Topside Cu.No. + 8000

= 0.905 x 284,900 + 8000

= 257834 + 8,000 = 265,834

Double Bottom Tank Capacity = 1.142 x DB Cu.No. + 8000

= 1.142 x 396,700 + 8000

= 453031 + 8000 = 461,031

Hold Capacity = 3,021,735

Capacities Summary

	Capacity	Homogeneous Stowage
Holds	3,021,735 cu ft	56 cu ft/ton
Topside Tanks	265,834 cu ft	
	3,287,569	60.8 cu ft/ton
D.B. Tanks	461,031 cu ft	

X Stability

KG in loaded condition = 0.57 x D = 0.57 x 59.6 = 34 ft.

KM from II = 42.55 ft.

GM loaded = 8.55 ft.

Now Ballast Displacement

= LWT + PC x DWT = 14930 + 60070 x 0.40 = 38930

$$\text{Ballast Draft} = \text{Ld T} \times \left(\frac{\text{Bal. Displ}}{\text{LD. Displ}}\right)^{C_B/C_W (= \text{Cpv})}$$

$$= 40 \times (38,930/75,000)^{0.918} = .546 \times 40 = 21.9 \text{ ft.}$$

Ballast C_B = 38930 x 35/(770 x 104 x 21.9) = 0.775

Ballast C_W = 1.265 x 0.775 - 0.146 = 0.834

$$\text{Ballast BM} = 0.073 \times \frac{104^2 \times 0.834}{21.9 \times 0.775} = 38.8 \text{ ft.}$$

$$\text{Ballast KM} = 38.8 + 21.9 \times \frac{(5 \times 0.834 - 2 \times 0.775)}{6 \times 0.834} = 50.45 \text{ ft.}$$

Ballast KG = K x D = 35.7 ft.

BGM = 14.75 ft.

XI Power in Ballast Condition

Ship maintains same speed in Ballast Condition as in the ld. cond.

draft = 0.546 of ld. Draft.

$L/\nabla^{1/3} = 770/(38930 \times 35)^{1/3} = 6.95$

S = 3.4 + 0.5 x $L/\nabla^{1/3}$ = 6.87

interpolation factor = 5 - 5 x 0.546 = 2.27

B/d = 2.6 LCBV = -0.9% C_B = 0.82

	21 ft.	16 ft.
T_{400} Chart		
Com. for LCB	1.01	1.01
B/d	1.03	1.05
$L/\nabla^{1/3}$	0.99	1.00
Com. Factor	1.03	1.06
Ⓒ$_{400}$ basis	0.759	0.772
Ⓒ$_{400}$ corrected	0.782	0.817

$$Ⓒ_{400} = 0.782 + 0.817 \times 2.27 - 0.782 \times 2.27$$

$$= 0.862$$

Skin friction com $= -(0.0741 - 0.0689) \times 6.87 \times 1.1034 = -0.042$

$$Ⓒ_{770} = 0.820$$

$$EHP = \frac{0.820 \times 38930^{2/3} \times 15^3}{427.1} = 7460 \text{ h.p.}$$

$$\text{Ballast Horsepower} = \frac{\text{EHP x Weather Allowance}}{(\text{Transmission effy x } QPC_{1d} \text{ x KS})} \quad \text{KS = Constant } (= 1.15)$$

$$= \frac{7460 \times 1.2}{0.97 \times 1.15 \times 0.668}$$

$$= 12{,}000 \text{ h.p.}$$

XII Rolling

$$\text{Period} = \frac{0.44 \times \text{BEAM}}{\sqrt{GM}}$$

In the Load condition

$$\text{Period} = \frac{0.44 \times 104}{\sqrt{8.55}} = 15.65$$

In the Ballast condition

$$\text{Period} = \frac{0.44 \times 104}{\sqrt{14.75}} = 11.9$$

XIII Capital Cost

Cost of Steelwork = Steelweight x 83.7

= 11524 x 83.7 = £965,000

Cost of Outfit = Outfti wt x 522

= 1490 x 522 = £777,000

Cost of Machinery = Machy wt x 409

= 1205 x 409 = £492,000

Cost of Establishment = Lut x 28.4

= 14930 x 28.4 = £425,000

Total Builder's Cost £2,659,000

Capital Cost = £2,659,000

+ Owners Cost = 50,000

£2,709,000

Initial Payment = £531,800

Plus = £2,177,200

over 8 years at 7% interest.

$$\text{Interest Total} = \frac{\text{Interest Rate}}{100} \times \frac{\text{Capital Cost}}{\text{No of years to pay}} \times \sum_{i=1}^{\text{No years to pay}} \qquad (i)$$

$$= \frac{7}{100} \times \frac{2,177,200}{8} \times \sum_{1}^{20} i$$

$$= \frac{7}{100} \times \frac{2,177,200}{8} \times 36 = £685,000$$

Total Payment for 15 years = £2,177,200

+ 685,000

£2,762,200

Annual Capital Charge = £184,000

XIV Fixed Running Costs

Working Days per annum = 345 Crew No. = 33.

Annual Fixed Payments

Marine Insurance	32987	
War Risk Insurance	675	
P and I Club Contribution	2937	
Engine Room Stores	2400	
Cabin Stores	1300	
Deck Stores	4750	
Repair Yd. Allowance	35000	
Lubricating Oil	9000	
	£88,949	
Wages =	29,352	
Victualling = 33 x 164.5	5,400	34,752
Carried fwd.	88,949	
Crew	34,752	
Special Survey Allowance	7,240	
Other costs including annual fee for entering Chile waters.	9,240	
	140,181	
Capital Cost	184,000	
Total	324,181 p.a. = £939 per day.	

XV Analysis of Route and Performance of Ship

1) Lost Time/Ballast/1 day/cost = 0 Panama

4; 0; 1; 0;

	Commodity	0 Ballast	1 Coal	2 Ore
	Time	1	0	0
Assoc.	Costs	0	0	0

2) Ship sails Panama → Japan/Coal/8200 miles/Assoc Cost 0

5; 1; 8200; 0;
Time = 8200/15 x 24 = 22.8 days
Fuel Usage = $\frac{17000 \times 22.8 \times 24 \times 0.38}{2240}$ = 1580 tons

FUEL = 1580

	Owners Ballast	Coal	Ore
TIME	1	22.8	0
COSTS	0	0	0

3) Unload Japan/Coal/3000 T per hr/Cost £3571

Load 54,331 Tons
Time = Load/Rate = 54,331/3000/24 = 0.75

	Owners Ballast	Coal	Ore
TIME	1	23.55	0
COSTS	0	£3571	0

4) Ship sails Japan → Chile/Ballast/9640 miles/
0 cost.

Time = 9640/15 x 24 = 26.8 days
Power = 12,000
Fuel Usage = 12000 x 26.8 x 24 x 0.38/2240
= 1307 tons
Fuel = 1580 + 1307 = 2887 tons.

	Owners Ballast	Coal	Ore
TIME	27.8	23.55	0
COSTS	0	£3571	0

5) Ship loads Chile/Ore/@ 3000 T per hr/£1786
H/Costs

Time = $\frac{54.331}{3000}$ = 0.75 days.

Fuel = 2887 T.

	Owners Ballast	Coal	Ore
TIME	27.8	23.55	0.75
COSTS	0	£3571	£1786

6) Ship looses day in Chile/Change to Ballast/
1 day/cost £100

	Owners Ballast	Coal	Ore
TIME	28.8	23.55	0.75
COST	£100	£3571	£1786

7) Ship sails Chile → Panama/Ore/1980 miles/
assoc cost 0.

Time = 1980 /(15 x 24) = 5.5
Fuel usage = 17000 x 5.5 x 24 x 0.38/2240
= 381 tons.
Fuel = 32268

	Owners Ballast	Coal	Ore
TIME	28.8	23.55	6.25
COSTS	£100	£3571	£1786

8) Ship passes through Panama Canal

9) Cost £15,000/Ore/45 miles.

Duration = 3/24 + 1 = 1.125
Fuel Usage = 17000 x .125 x 24 x 0.38/2240
= 9 tons.
Fuel = 3277

	Owners Ballast	Coal	Ore
TIME	28.8	23.55	7.4
COSTS	£100	£3571	£16786

		Owners Ballast	Coal	Ore
10) Ship sails Panama → B/more/ore/1904/£0 extra. Time = 1904/15 x 24 = 5.27 Fuel Usage = 17,000 x 5.27 x 24 x 0.38/2240 = 364 tons.				
Fuel = 3641	TIME	28.8	23.55	12.67
	COST	£100	£3571	£16786
11) Ship looses day due to breakdown/ charge to owners/1 day/£100 extra cost	TIME	29.8	23.55	12.67
	COST	£200	£3571	£16786
12) Ship unloads B/more/ore/3000 ton per hr/ cost 1786				
Time = 54,331/(3000 x 24) = 0.75	TIME	29.8	23.55	13.4
	COST	£200	£3571	£18572
13) Ship sails to coal wharf/charge to owners/ 274 m/0 cost Time = 274/15 x 24 = 0.76 Fuel Usage = $\frac{17000 \times 0.76 \times 24 \times 0.38}{2240}$ = 52.7				
Fuel = 3641 + 52.7 = 3694	TIME	30.56	23.55	13.4
	COST	£200	£3571	£18572
14) Ship loads/coal/3000 T per hr/cost £3571				
Time = 0.75	TIME	30.56	24.3	13.4
	COST	£200	£7142	£18572
15) Ship looses time/charge to owners/1 day/ zero cost	TIME	31.56	24.3	13.4
	COST	£200	£7142	£18572
16) Ship sails to Panama/coal/1778 mls/zero cost Time = 1778/(15 x 24) = 4.95 Fuel Usage = 17000 x 4.95 x 24 x 0.38/2240 = 314				
Fuel = 3694 + 314 = 4008 tons	TIME	31.56	29.25	13.4
	COST	£200	£7142	£18572

		Owners Ballast	Coal	Ore
17/18) Ship passes through the Panama Canal/ coal/45 miles/looses 1 day/£15,000 canal dues. Time = 1.125 Fuel Usage = 9 tons. Fuel = 4017 tons.	TIME COST	31.56 £200	30.4 £22142	13.4 £18572
19) Ship takes on fuel/£5.3 per ton/1000 ton/hr /zero extra cost. Time = 4017/100 = 0.16 Fuel cost = 0 + 4017 x 5.3 = £21,200	TIME COST	31.7 £200	30.4 £22142	13.4 £18572
Distribute fuel cost on time bases.	FUEL COST	£8870	£8650	£3740
Overtime = 20% of daily wage bill x time $= 20\% \text{ of } \frac{29352}{345} \times \text{ time}$				

XVI Summary of Costs

For the complete route cycle the costs are summarised as follows;

Commodity Item	Owners/Ballast	Coal	Ore	TOTAL
Time	31.7	30.4	13.4	75.5
Fixed Charges	29766	28545	12583	70894
Fuel Charges	8870	8650	3740	21260
Associated Costs	200	22142	18572	40914
Overtime	540	517	228	1285
TOTAL	39376	59854	35123	£134,353

Cost per ton cargo deadweight 2,401

Cost per day £1779.51

APPENDIX E

COMPUTER PRINTOUT OF

PANAMA BULK CARRIER.

DESIGN NO 42

LENGTH BEAM RATIO 7.692 BEAM DRAFT RATIO 2.600 CB 0.820 DESIGN O K

LENGTH 800.00 BEAM 104.00 DEPTH 59.49 DRAFT 40.00 FREEBOARD 233.89

LOAD DRAFT CB 0.820 CP 0.828 CW 0.891 CPV 0.920 LCB +1.99 LCF +2.06 VCB 21.07 KM 42.52
BALLAST DRAFT CB 0.779 CW 0.839 KB 11.55 BM 38.61

GROUP WTS	STEEL	12396				
	OUTFIT	1519				
	MACHINERY	1318				
	MARGIN	762				
	LIGHTWEIGHT		15994			
	CARGO DEADWEIGHT	57843		BALLAST		20657
	FUEL	3833				
	FRESH WATER	200				
	CREW STORES ETC.	100				
	DEADWEIGHT		61976	BAL DEADWEIGHT		24790
	LD DISPLACEMENT		77970	BAL DISPLACEMENT		40785
	KM		42.52			50.15
	KG		33.91			29.75
	GM		+8.61			+20.41
	DRAFT		40.00			22.04

POWERING SERVICE BHP 16946 AT 15.00 KNOTS EHP 9496 QPC 0.686 HULL EFFY 1.408
PROPELLER 5 BLADE DIAMETER 20.65 BAR 0.600 OPEN WATER EFFY 0.482
MACHINERY TYPE 1 9 CYLINDERS MAX CONTINUOUS HP 20000 AT 115.00 RPM

BALLAST HP 16946 AT 16.73 KNOTS

CAPACITIES	HOLD CAPACITY CUBIC	3067314	LIMITING STOWAGE FACTOR	53.03
	TOPSIDE TANK CAPACITY	270573		
	SUM HOLDS AND TOPSIDE TANKS	3337887	LIMITING STOWAGE FACTOR	57.71
	FORE PEAK TANK	0		
	DOUBLE BOTTOM TANKS	499280		
	AFT PEAK TANK	0		

EXTRA BALLAST CAPACITY TO BE PROVIDED IN DEEP TANK
TOTAL WATER BALLAST 20657 TONS 723007 CU FT

CENTRE GIRDER HT 6.42 HATCH WIDTH 26.00 TOPSIDE TANK ANGLE 30.00 HOPPER SIDE ANGLE 39.99
TANK TOPWIDTH 34.00 BILGE RADIUS 9.97 MIDSHIP AREA COEFFICIENT 0.990

ROLLING PERIOD LD CONDITION 15.59 BAL CONDITION 10.13

CONSTRUCTIONS COSTS	POUNDS	
	STEEL	1098270
	OUTFIT	832383
	MACHINERY	566726
	ESTABLISHMENT	460638
	TOTAL	2958018
	OWNERS ITEMS	50000
	TOTAL COST	3008018

SERVICE COSTS
INITIAL PAYMENT 591604
PLUS 2416414 OVER 8 YEARS AT 7 PERCENT INTEREST RATE PER ANNUM
NO OF YEARS TO DEPRECIATE TO SCRAP VALUE 15
SCRAP VALUE 431848
DEPRECIATION CHARGE PER ANNUM 221439

ANNUAL COSTS POUNDS	
WAGES	34980
VICTUALLING	6744
INSURANCE	37499
P AND I CLUB	3123
STORES	8450
LUBRICATION	9000
MISCELLANEOUS CHARGES	43228
CAPITAL CHARGES	221439
SURVEY ALLOWANCE	9733
TOTAL	374197

NO OF WORKING DAYS PER ANNUM 345.00
DAILY FIXED CHARGES 1085
FUEL COST PER DAY FOR ROUTE 317

ROUTE CYCLE SUMMARY

COMMODITY	0	1	2	TOTAL
TIME	27	31	16	74
COSTS				
FIXED CHARGES	29668.2	33175.3	17527.7	80371.2
FUEL COST	8670	9695	5122	23487
ASSOCIATED COSTS	0	21371	17801	39173
OVERTIME	555	620	328	1503
TOTAL	38893	64862	40779	144533

NOTE COMMODITY 0 SIGNIFIES BALLAST CONDITION PLUS CHARGES TO BE
DISTRIBUTED ON A TIME BASIS

OUTLAY XPER TON OF CARGO DEADWEIGHT 2.499

FIG. 1.
PRINCIPAL DIMENSIONS OF BULK CARRIERS.

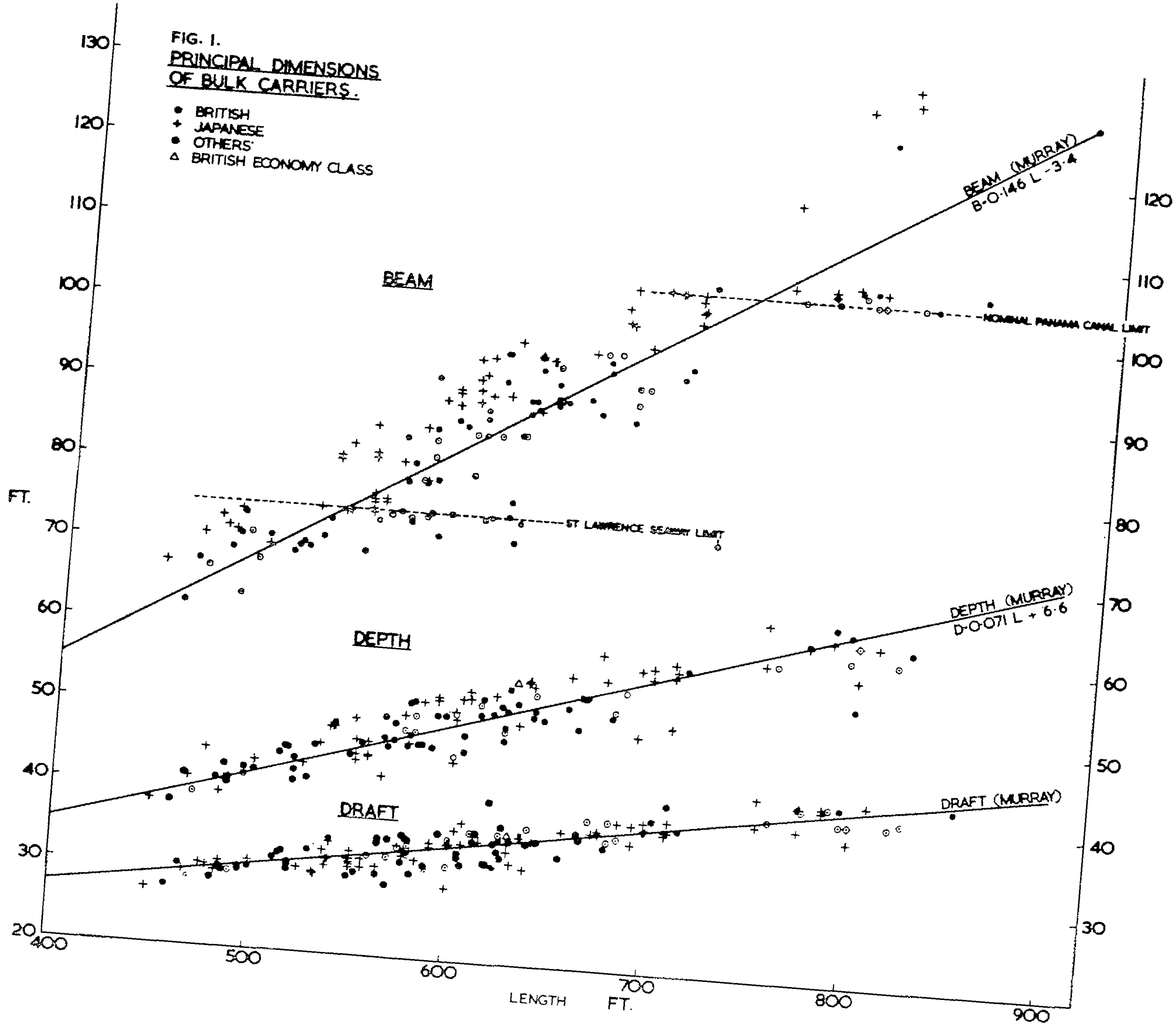


FIG 2.

GROWTH OF THE IRON ORE TRADE
1962 - 1970.

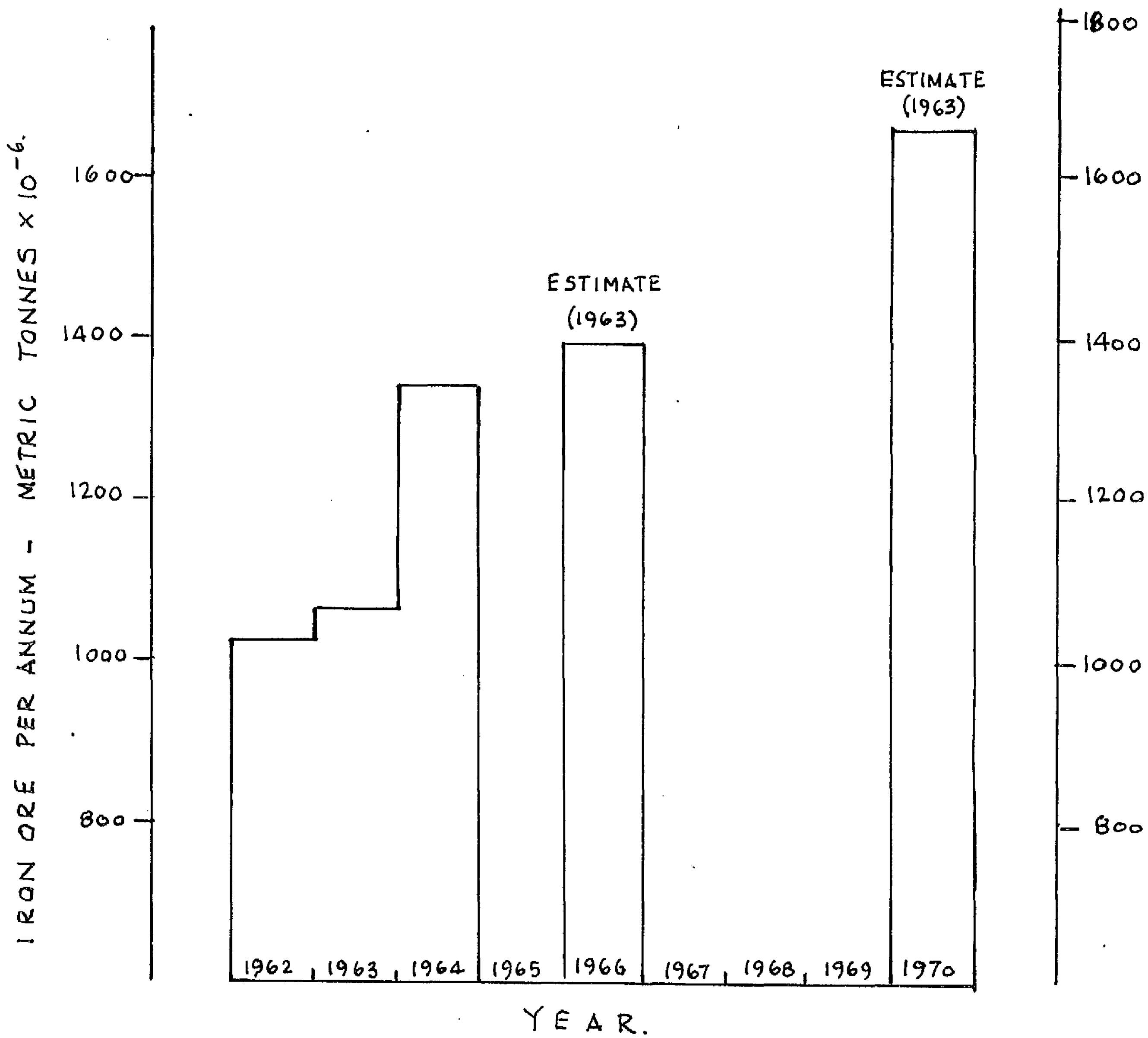


FIG. 3.

SECTION THRO' MIDSHIP HOLD.

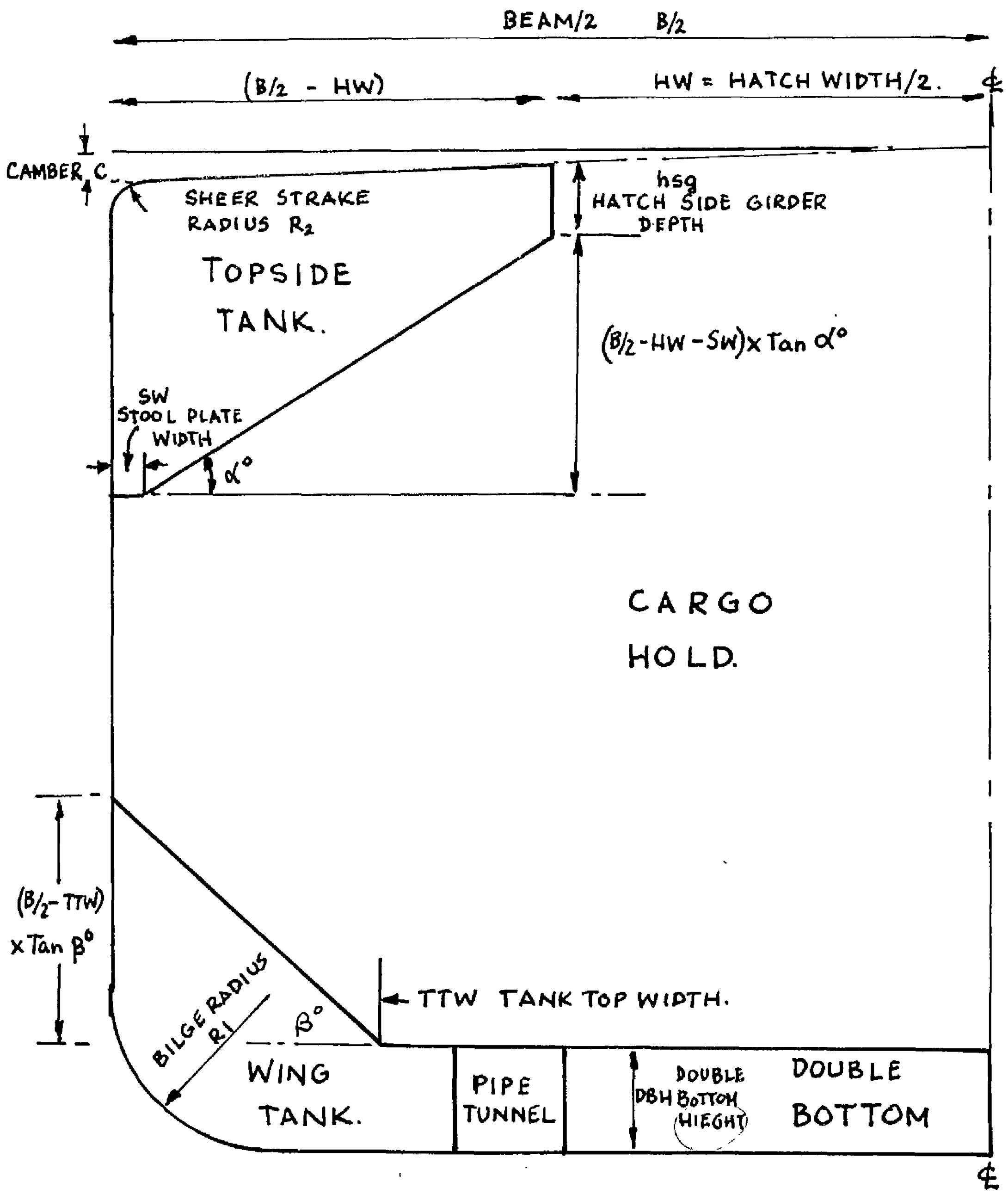


FIG. 4.

GROWTH OF THE BULK CARRIER FLEET.

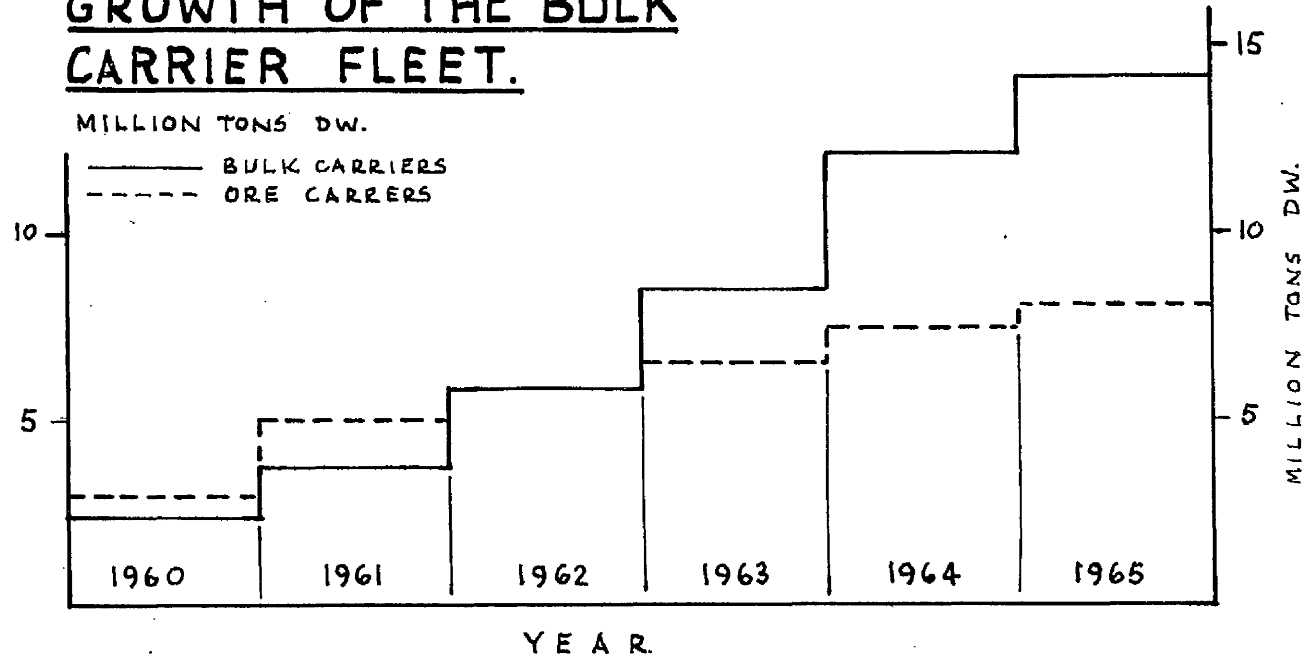


FIG. 5.

NO. OF HOLDS OF BULK CARRIERS.

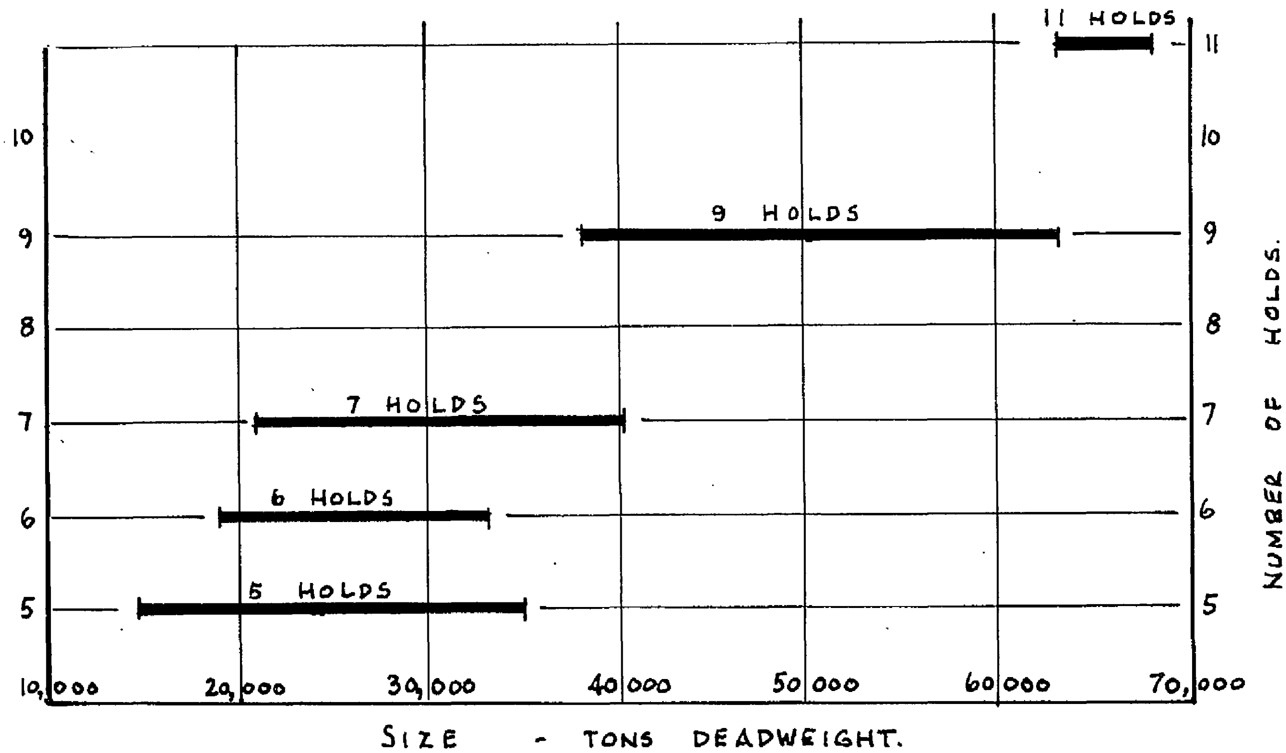


FIG 6.

FLOW DIAGRAM FOR PRELIMINARY DESIGN METHOD.

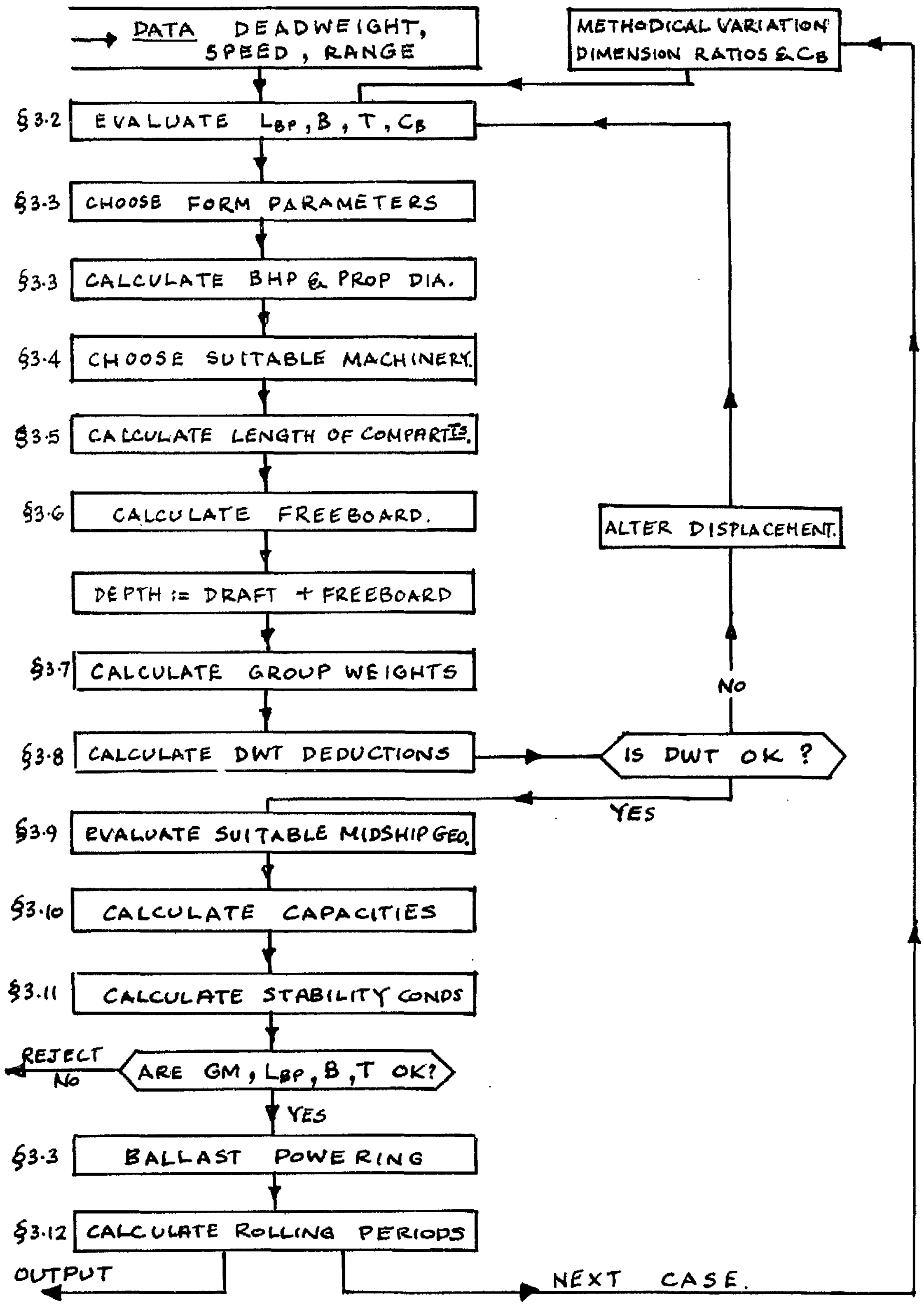


FIG 7.

LENGTH - DEADWEIGHT.

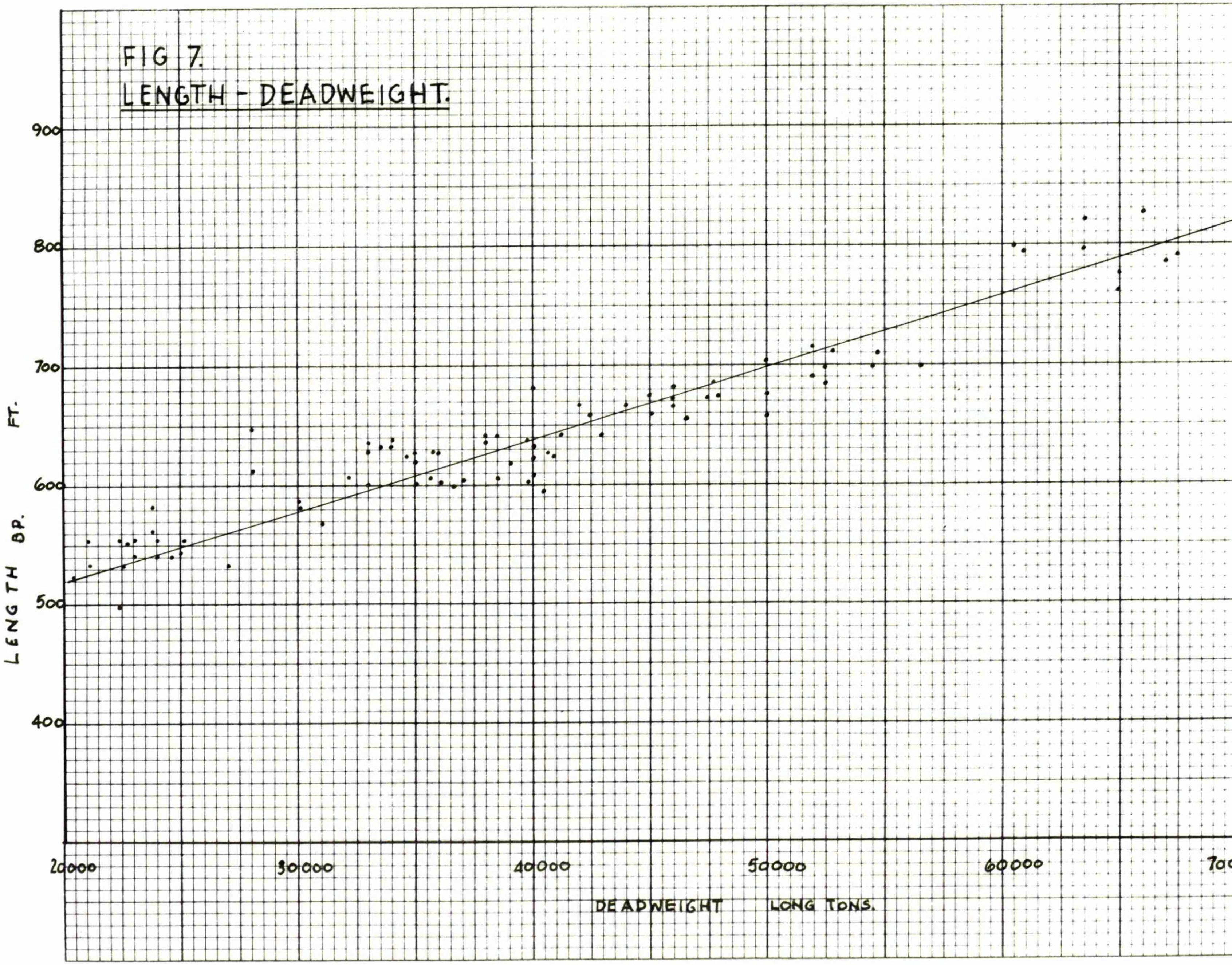


FIG 8

POSDUNINE COEFFICIENT.

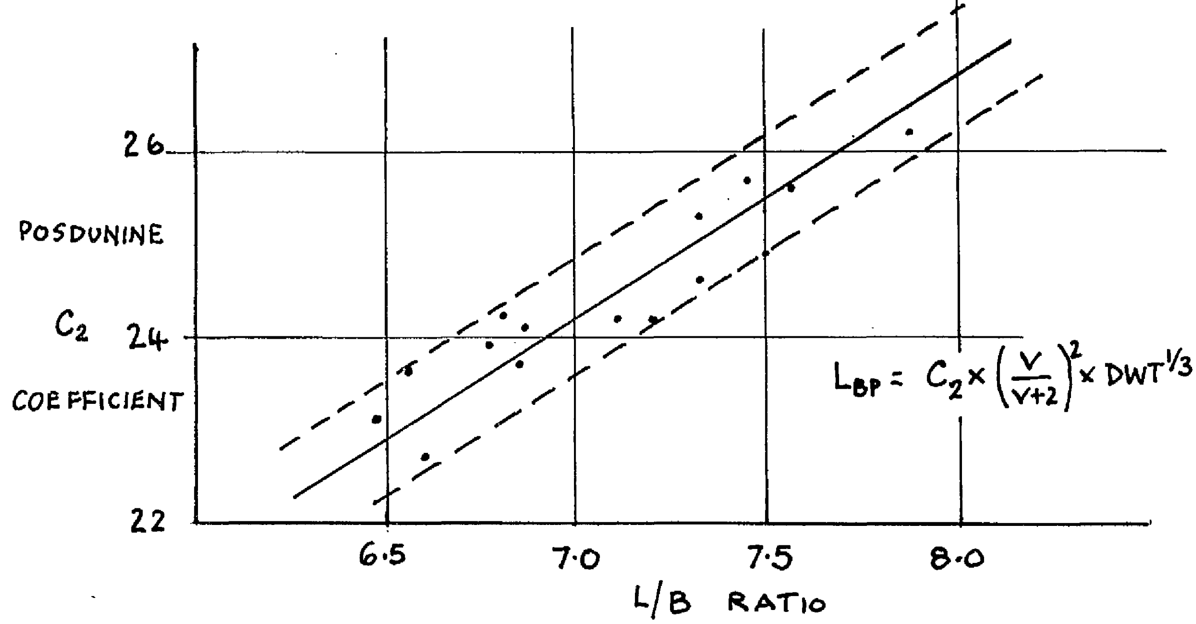


FIG 9.

MAIN ENGINE WT - HORSEPOWER.

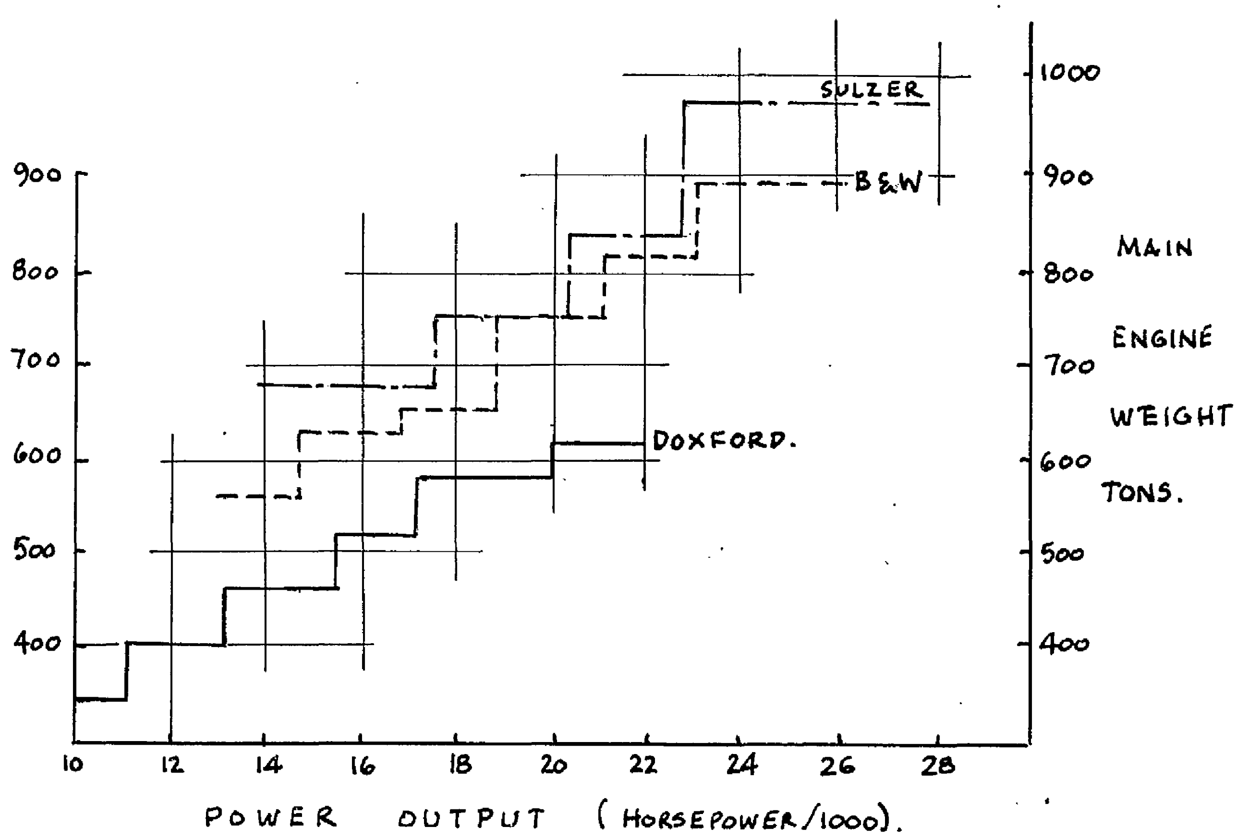


FIG 10.

LENGTH OF COMPARTMENTS.

PROFILE

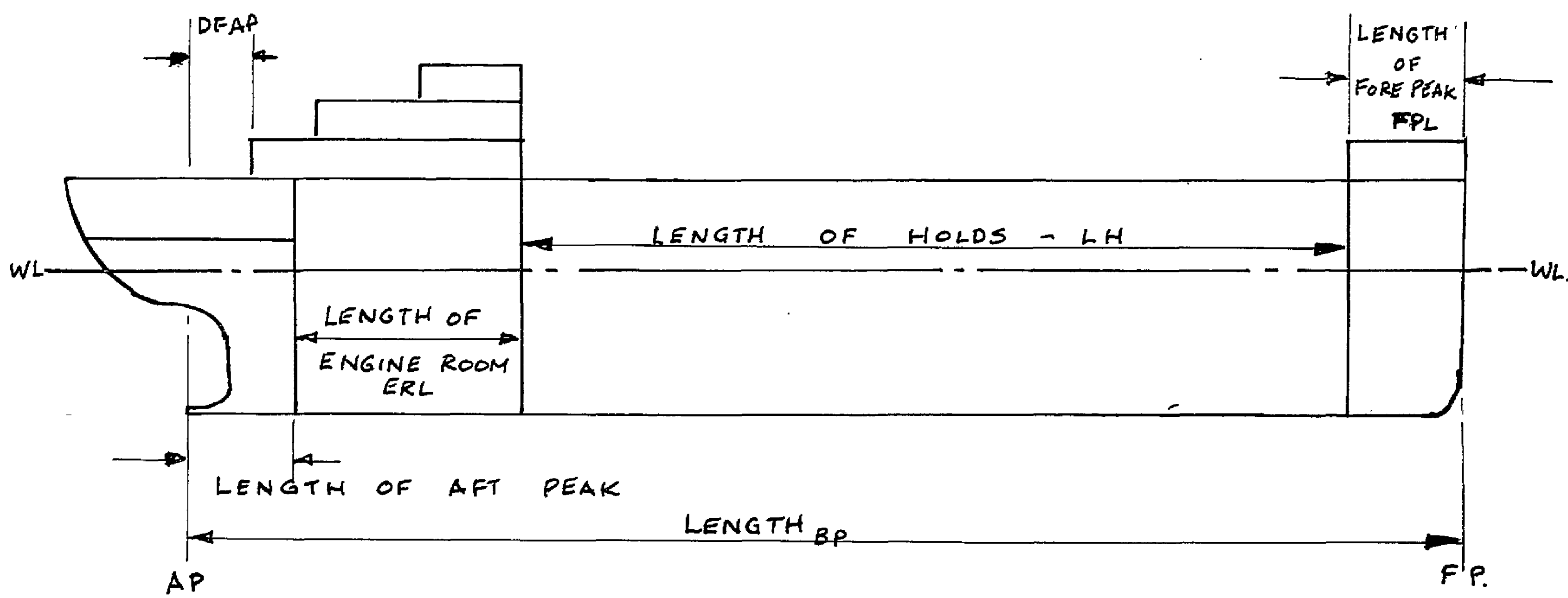
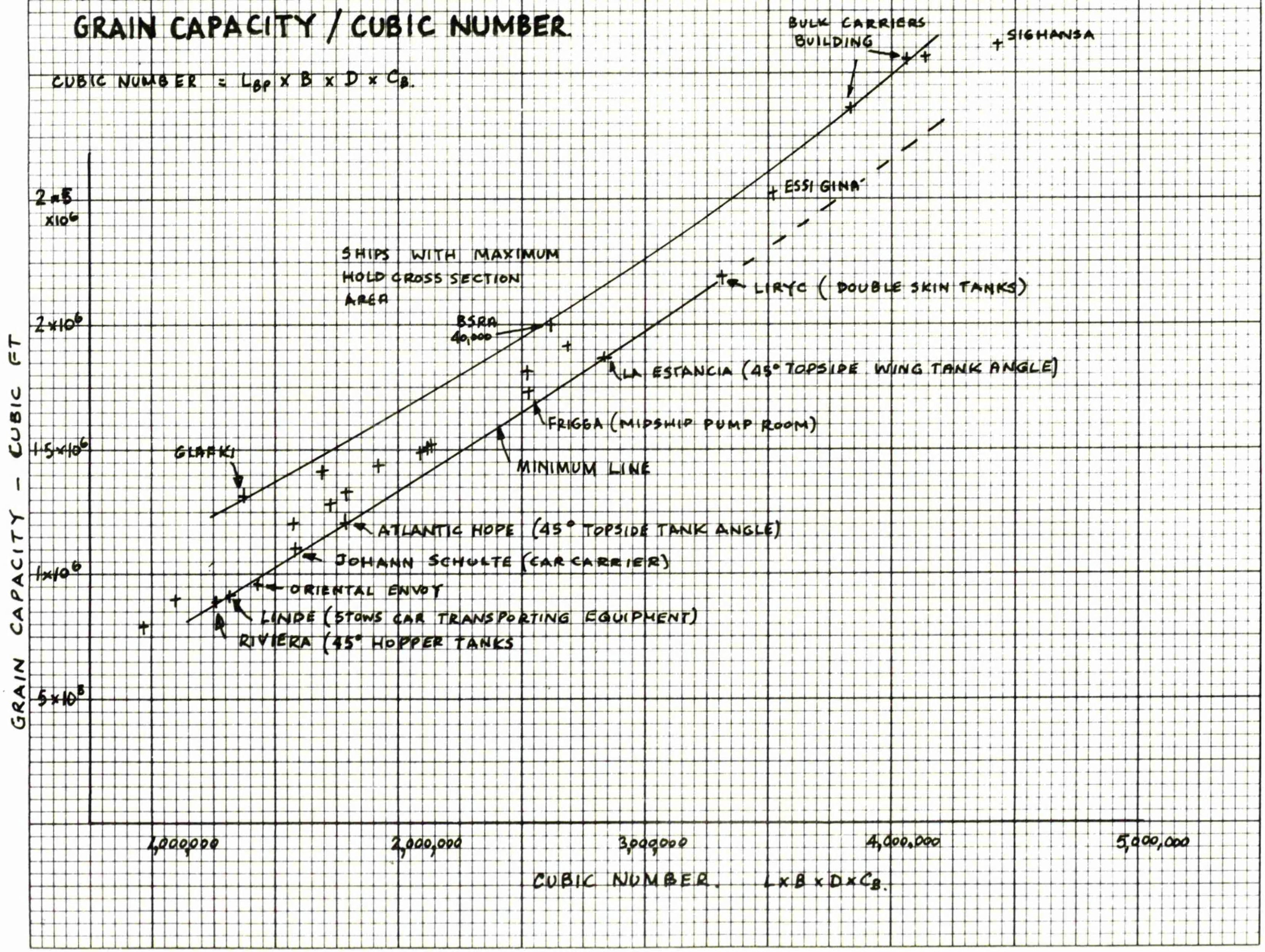


FIG 11.

GRAIN CAPACITY / CUBIC NUMBER



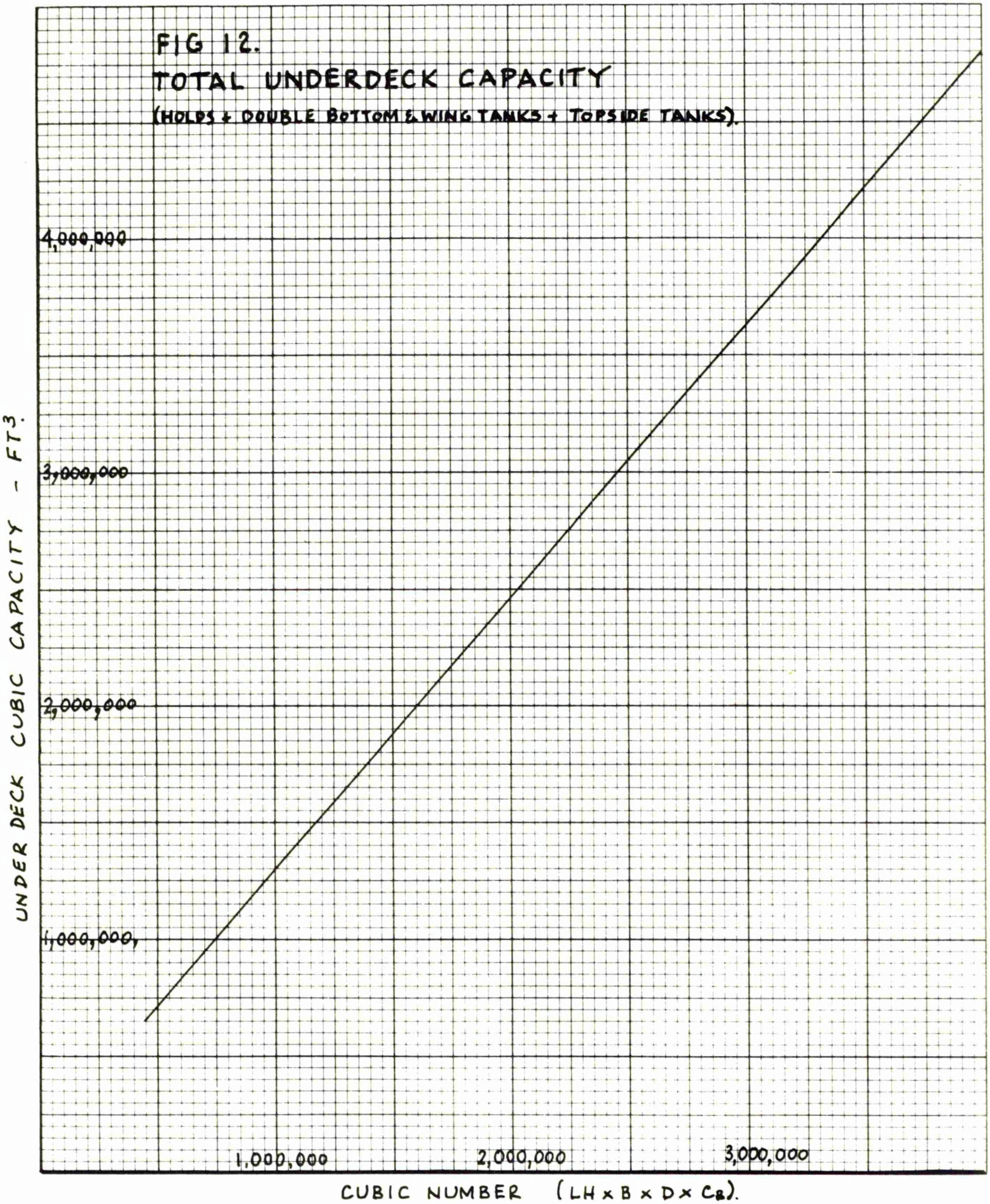


FIG 12.
TOTAL UNDERDECK CAPACITY
(HOLDS + DOUBLE BOTTOM & WING TANKS + TOPSIDE TANKS).
4,000,000
3,000,000
2,000,000
1,000,000
UNDER DECK CUBIC CAPACITY - FT³.
1,000,000
2,000,000
3,000,000
CUBIC NUMBER (LH x B x D x CB).

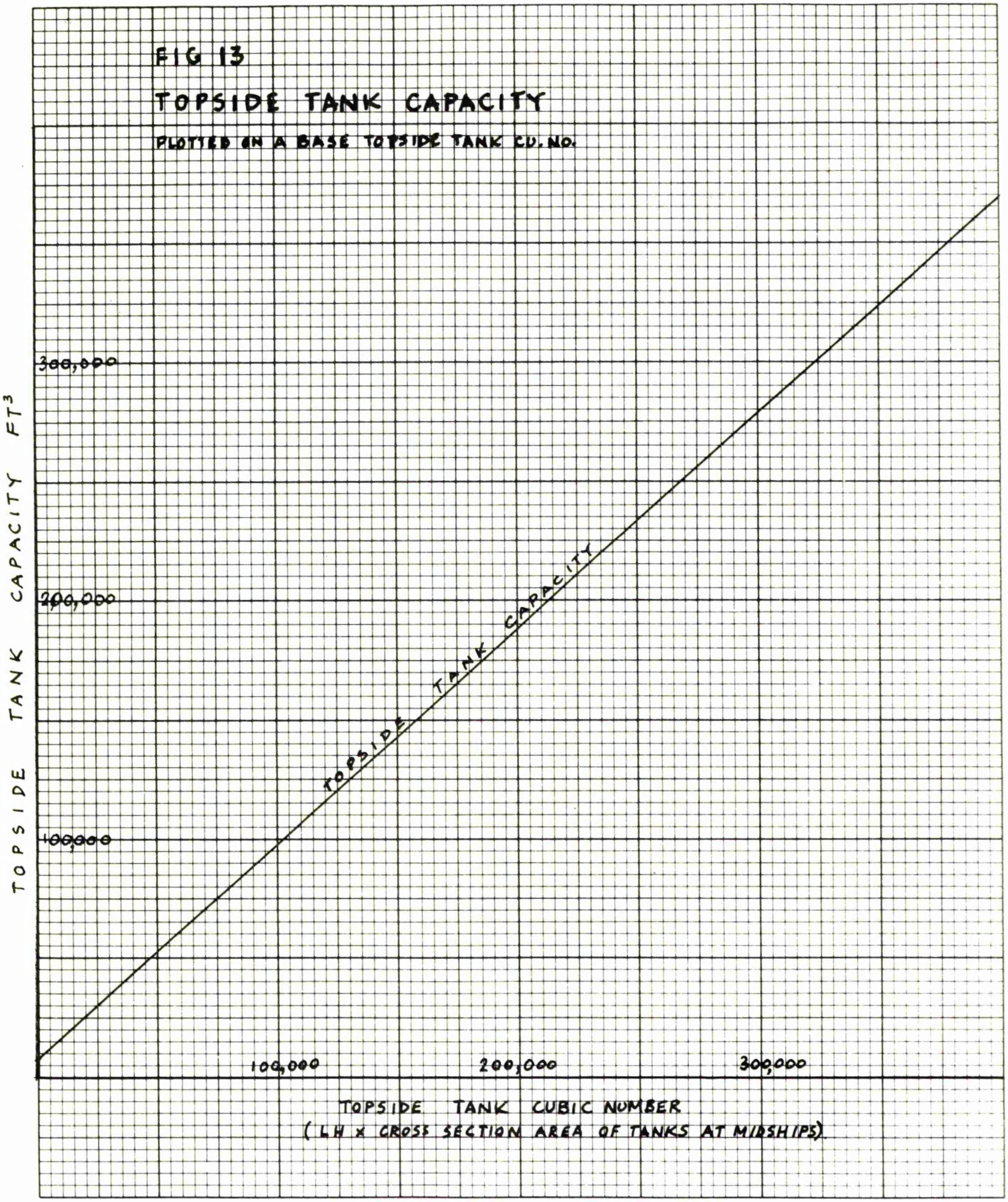
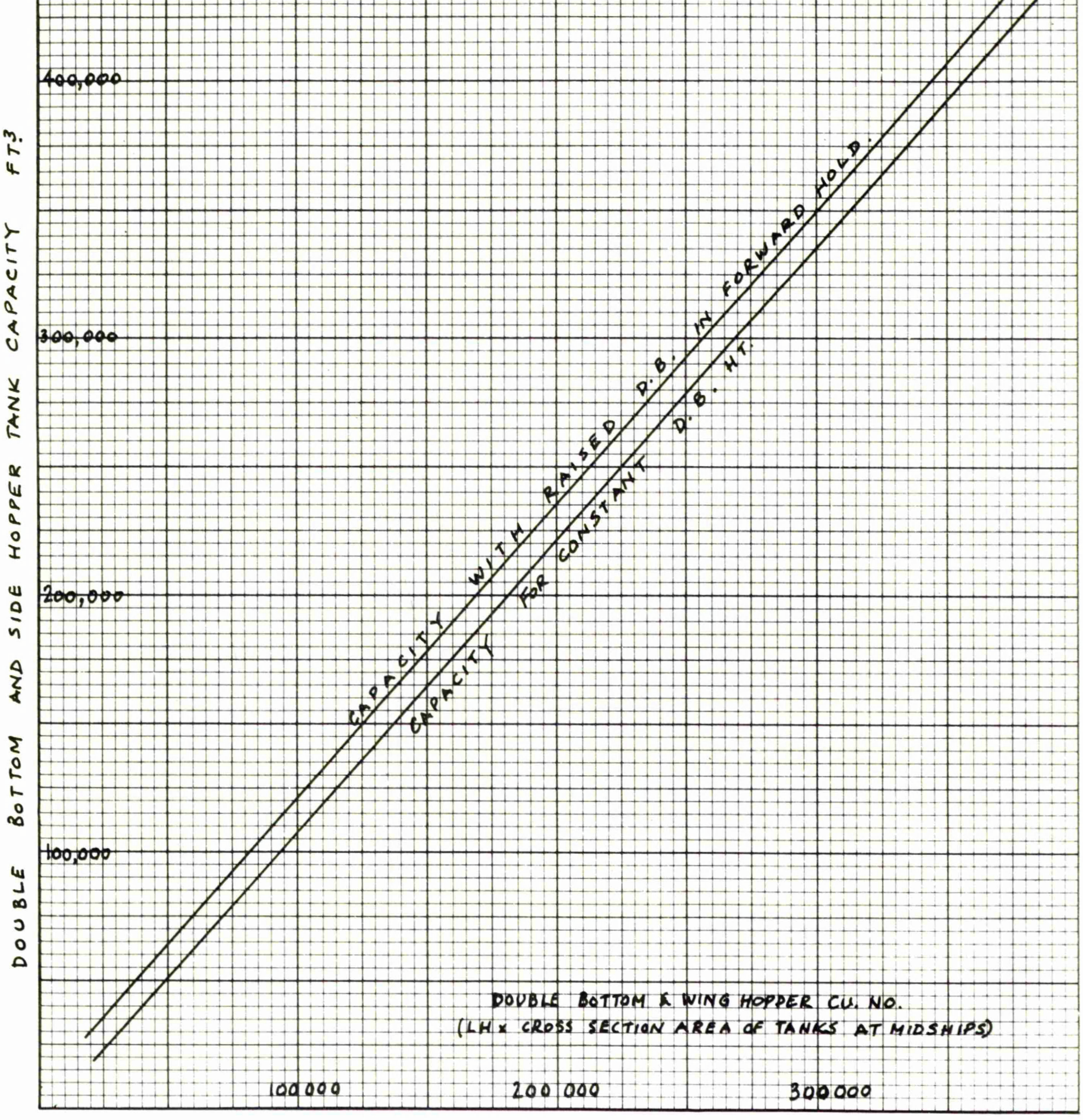


FIG 13
TOPSIDE TANK CAPACITY
PLOTTED ON A BASE TOPSIDE TANK CU. NO.
TOPSIDE TANK CAPACITY FT³
300,000
200,000
100,000
TOPSIDE TANK CAPACITY
100,000
200,000
300,000
TOPSIDE TANK CUBIC NUMBER
(LH x CROSS SECTION AREA OF TANKS AT MIDSHIPS)

FIG 14

DOUBLE BOTTOM AND SIDE HOPPER CAPACITY.

PLOTTED ON A BASE OF DOUBLE BOTTOM & SIDE HOPPER CU.NO.



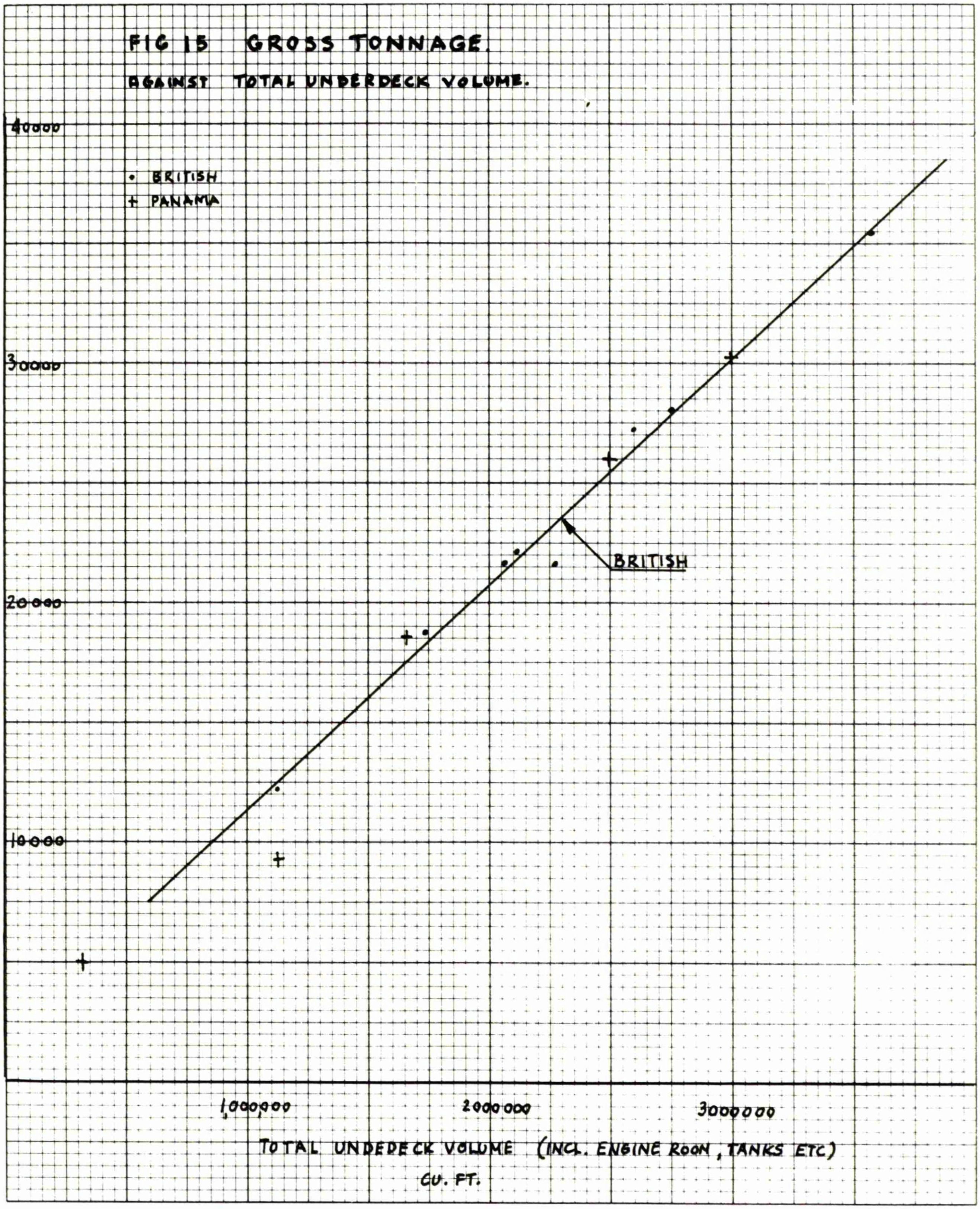


FIG 15 GROSS TONNAGE.
AGAINST TOTAL UNDERDECK VOLUME.
40000
30000
20000
10000
• BRITISH
+ PANAMA
BRITISH
GROSS TONNAGE
1000000
2000000
3000000
TOTAL UNDEDECK VOLUME (INCL. ENGINE ROOM, TANKS ETC)
CU. FT.

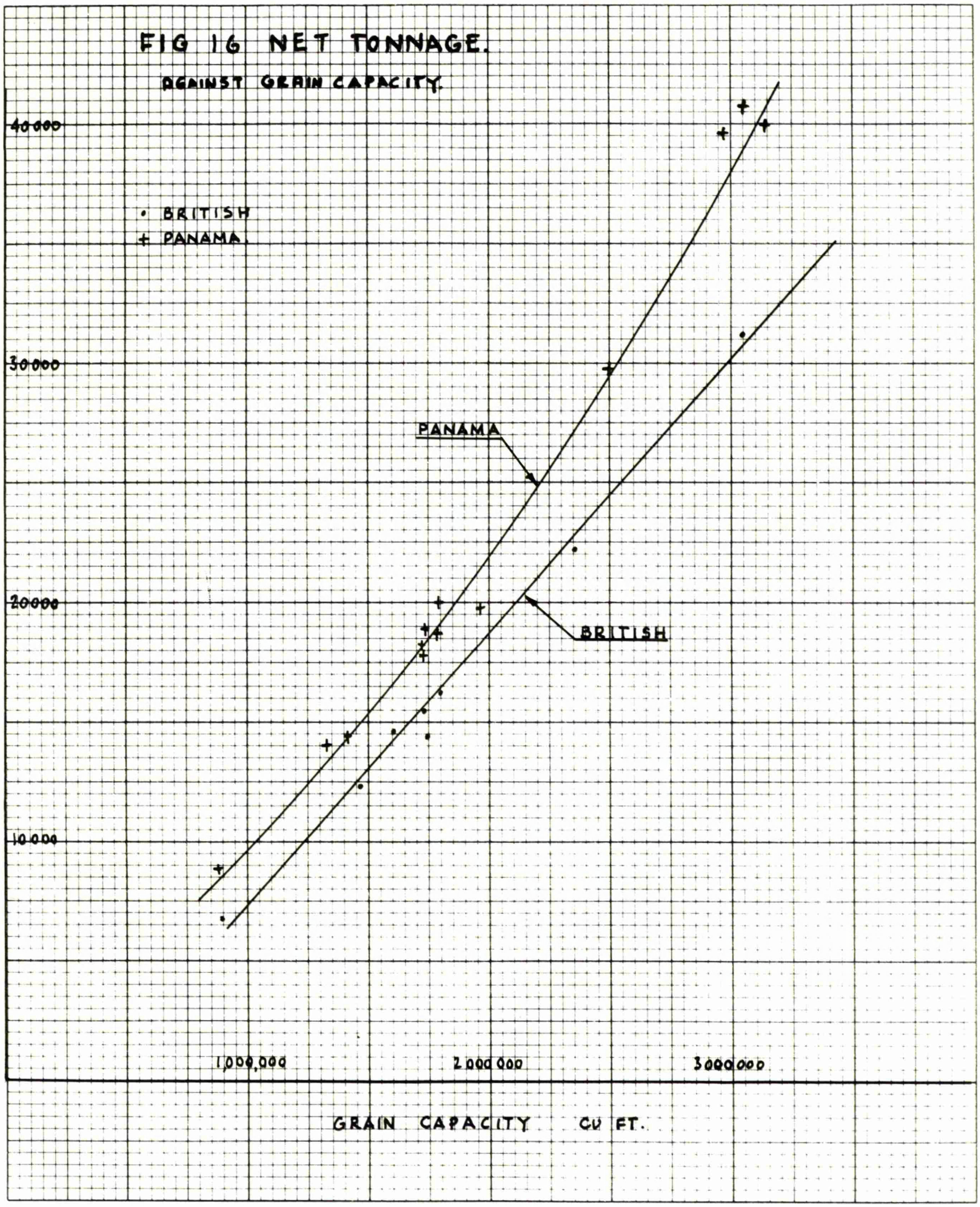


FIG 16 NET TONNAGE.
AGAINST GRAIN CAPACITY.
• BRITISH
+ PANAMA.
PANAMA
BRITISH
40000
30000
20000
10000
NET TONNAGE TONS
1,000,000
2000000
3000000
GRAIN CAPACITY CU FT.

FIG. 17 ROUTE DIAGRAM.

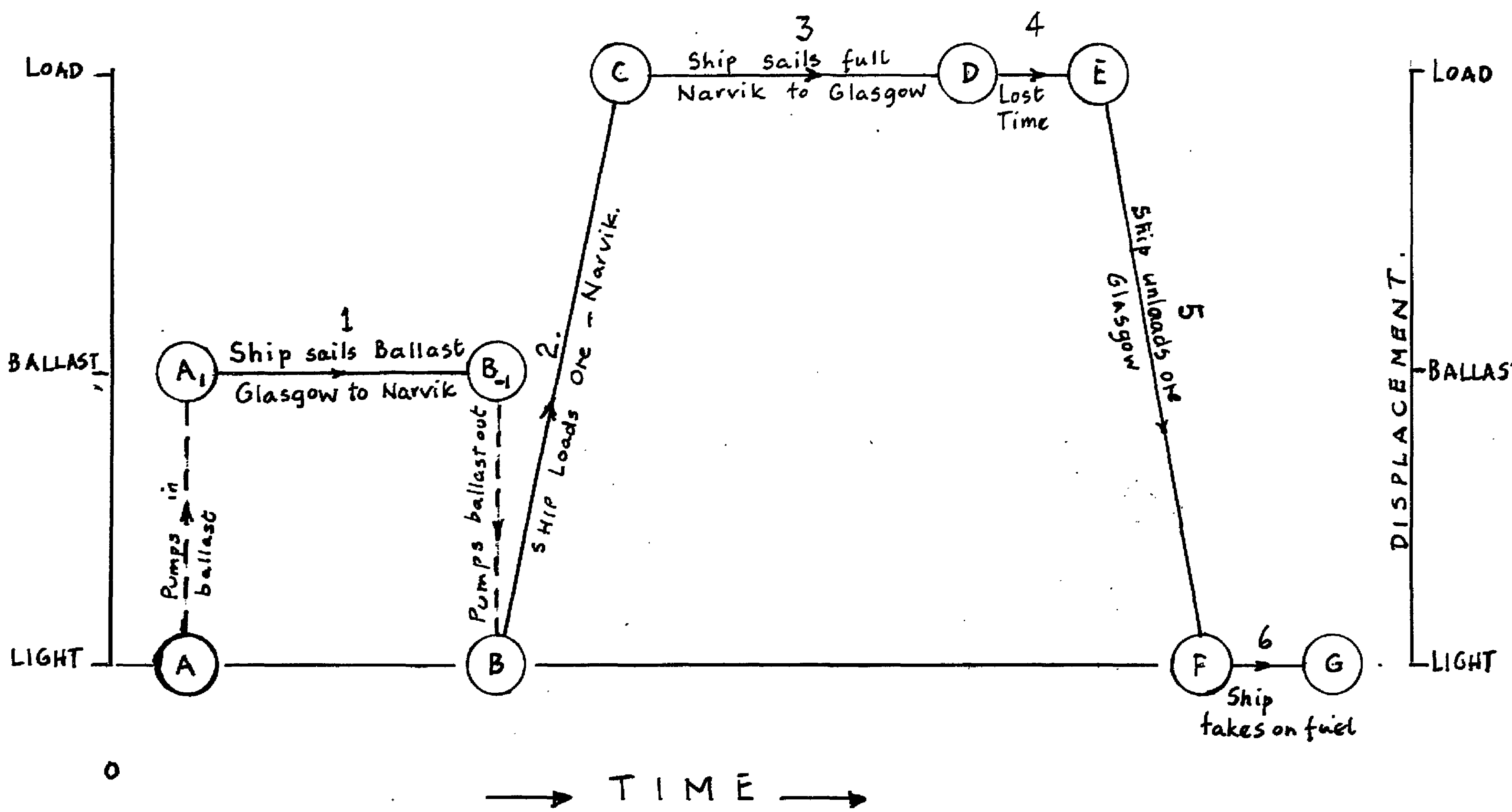


FIG. 18. FLOW DIAGRAM FOR BULK CARRIER DESIGN PROGRAMS.

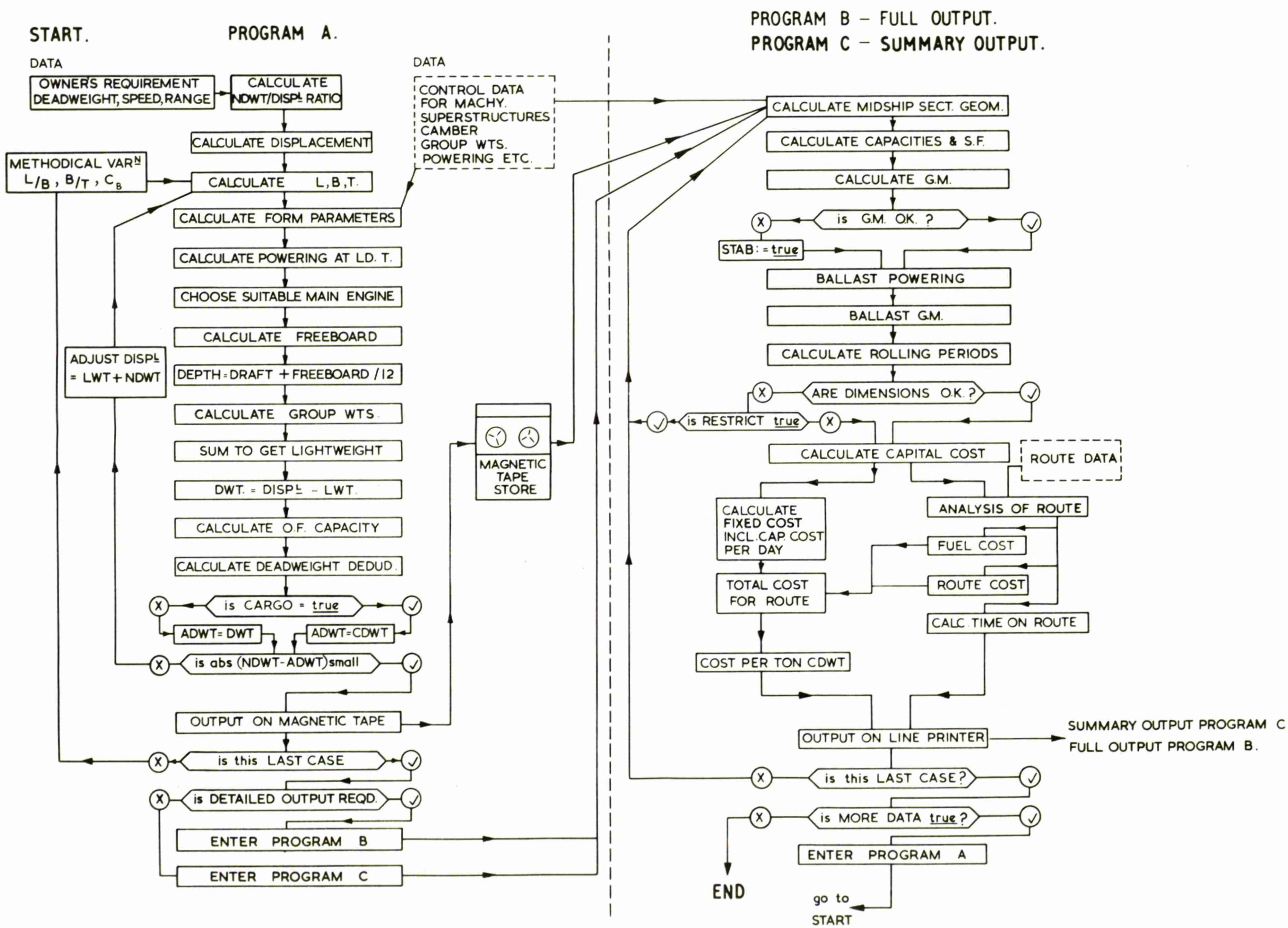


FIG 19. DIAGRAMATIC REPRESENTATION OF PANAMA ROUTES

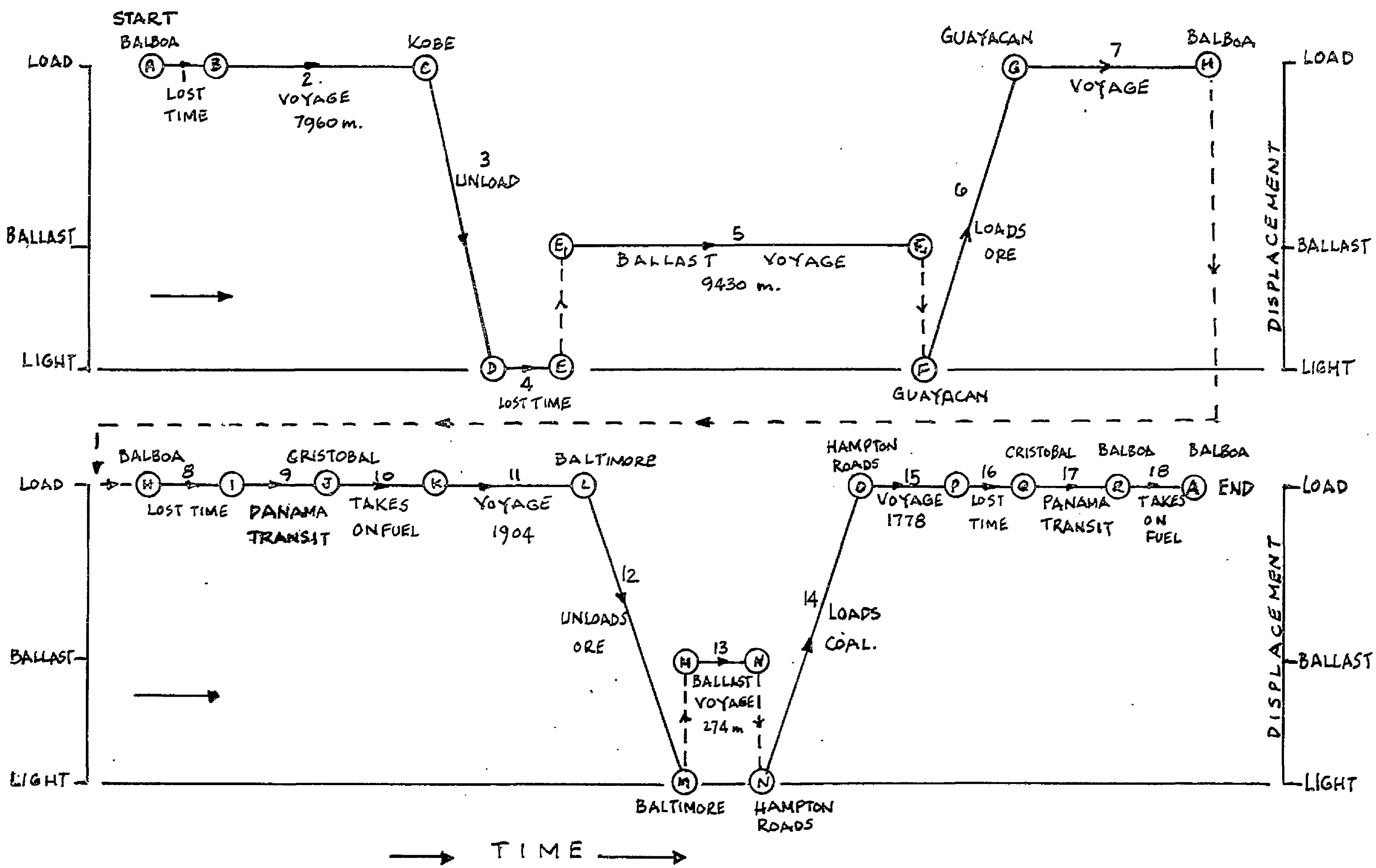


FIG 20.

DIAGRAMATIC SCHEME

OF METHODICAL VARIATION.

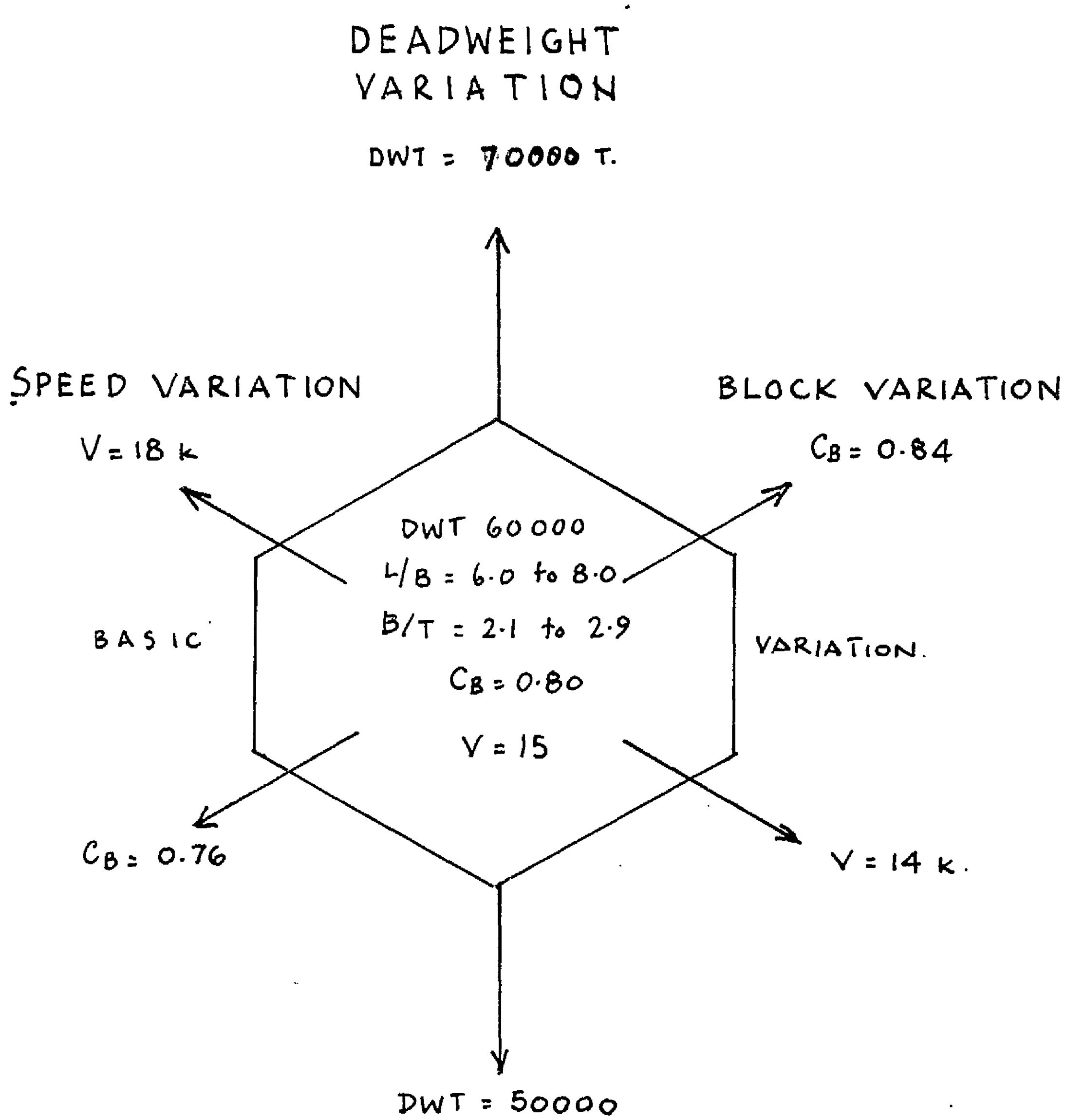


FIG. 21

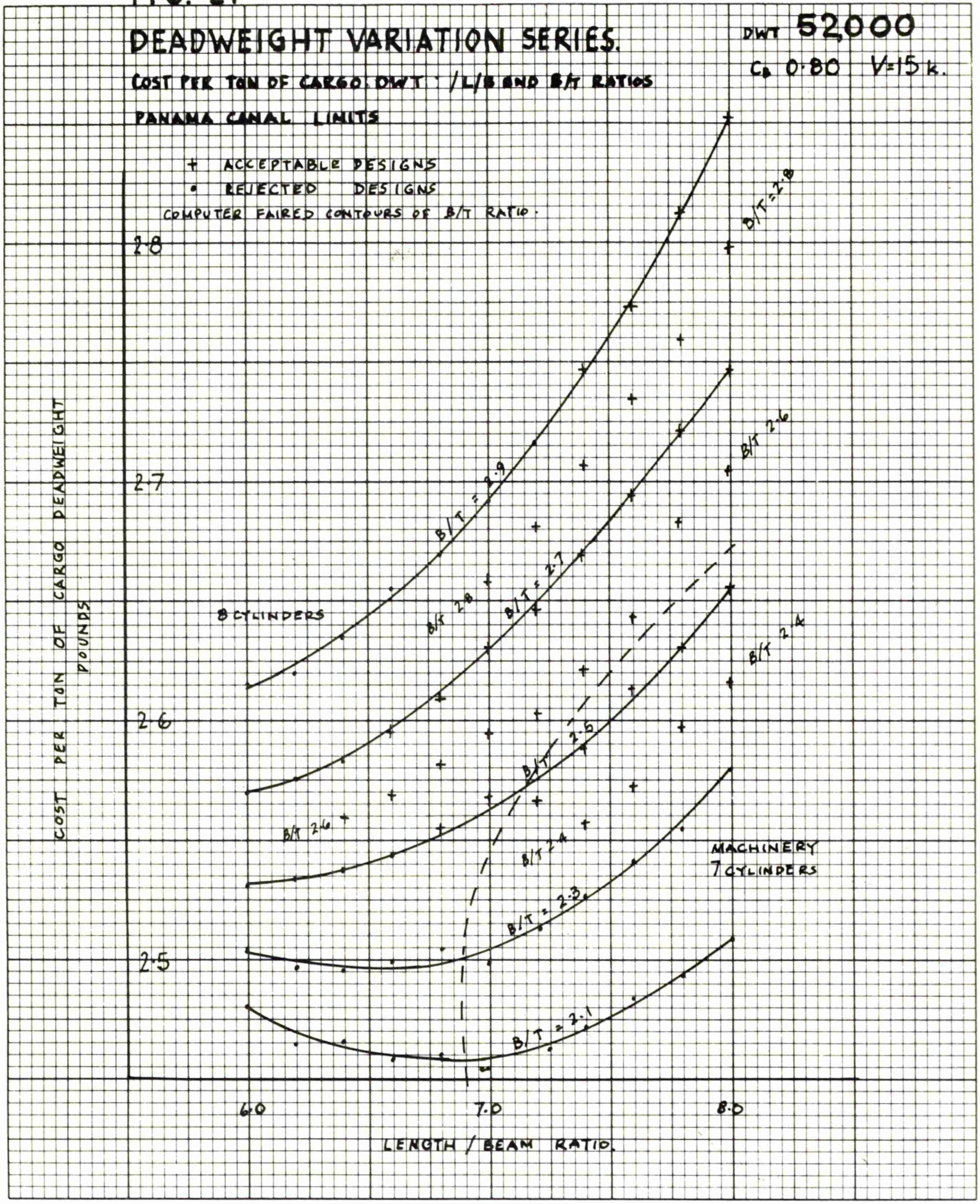

DEADWEIGHT VARIATION SERIES.
COST PER TON OF CARGO DWT : L/B AND B/T RATIOS
PANAMA CANAL LIMITS
DWT 52000
C_B 0·80 V=15 k.
+ ACCEPTABLE DESIGNS
• REJECTED DESIGNS
COMPUTER FAIRED CONTOURS OF B/T RATIO.
2·8
2·7
2·6
2·5
B/T = 2·8
B/T 2·6
B/T 2·4
B/T = 2·9
B/T 2·8
B/T = 2·7
B/T = 2·5
B/T 2·6
B/T 2·4
B/T = 2·3
B/T = 2·1
8 CYLINDERS
MACHINERY
7 CYLINDERS
COST PER TON OF CARGO DEADWEIGHT
POUNDS
6·0
7·0
8·0
LENGTH / BEAM RATIO.

FIG 22.

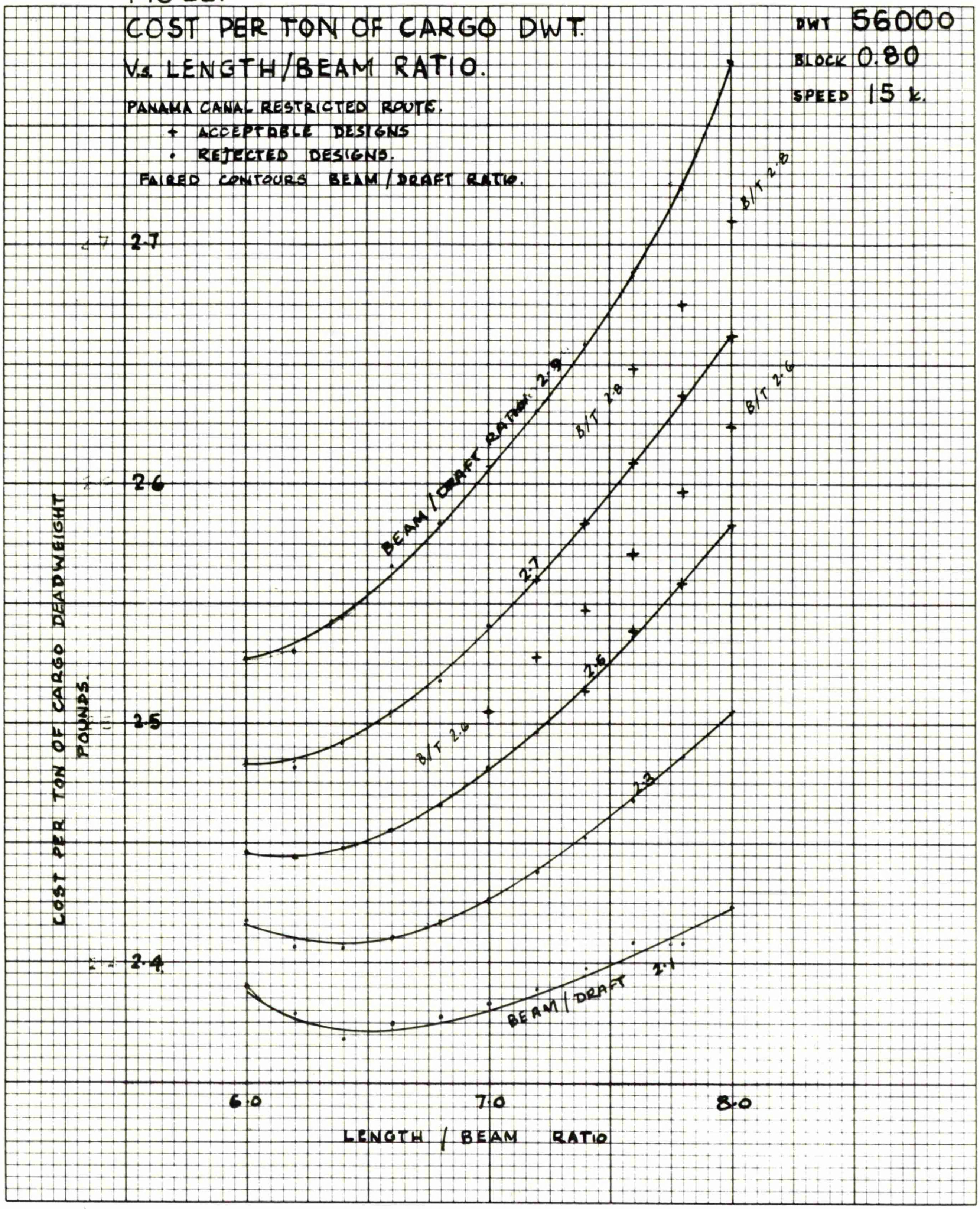

COST PER TON OF CARGO DWT.
Vs. LENGTH/BEAM RATIO.
PANAMA CANAL RESTRICTED ROUTE.
+ ACCEPTABLE DESIGNS
• REJECTED DESIGNS.
FAIRED CONTOURS BEAM/DRAFT RATIO.
DWT 56000
BLOCK 0.80
SPEED 15 k.
2.7
2.6
2.5
2.4
COST PER TON OF CARGO DEADWEIGHT POUNDS.
BEAM/DRAFT RATIO 2.9
B/T 2.8
2.7
2.6
2.3
BEAM/DRAFT 2.1
B/T 2.8
B/T 2.6
B/T 2.6
6.0
7.0
8.0
LENGTH / BEAM RATIO

FIG 23

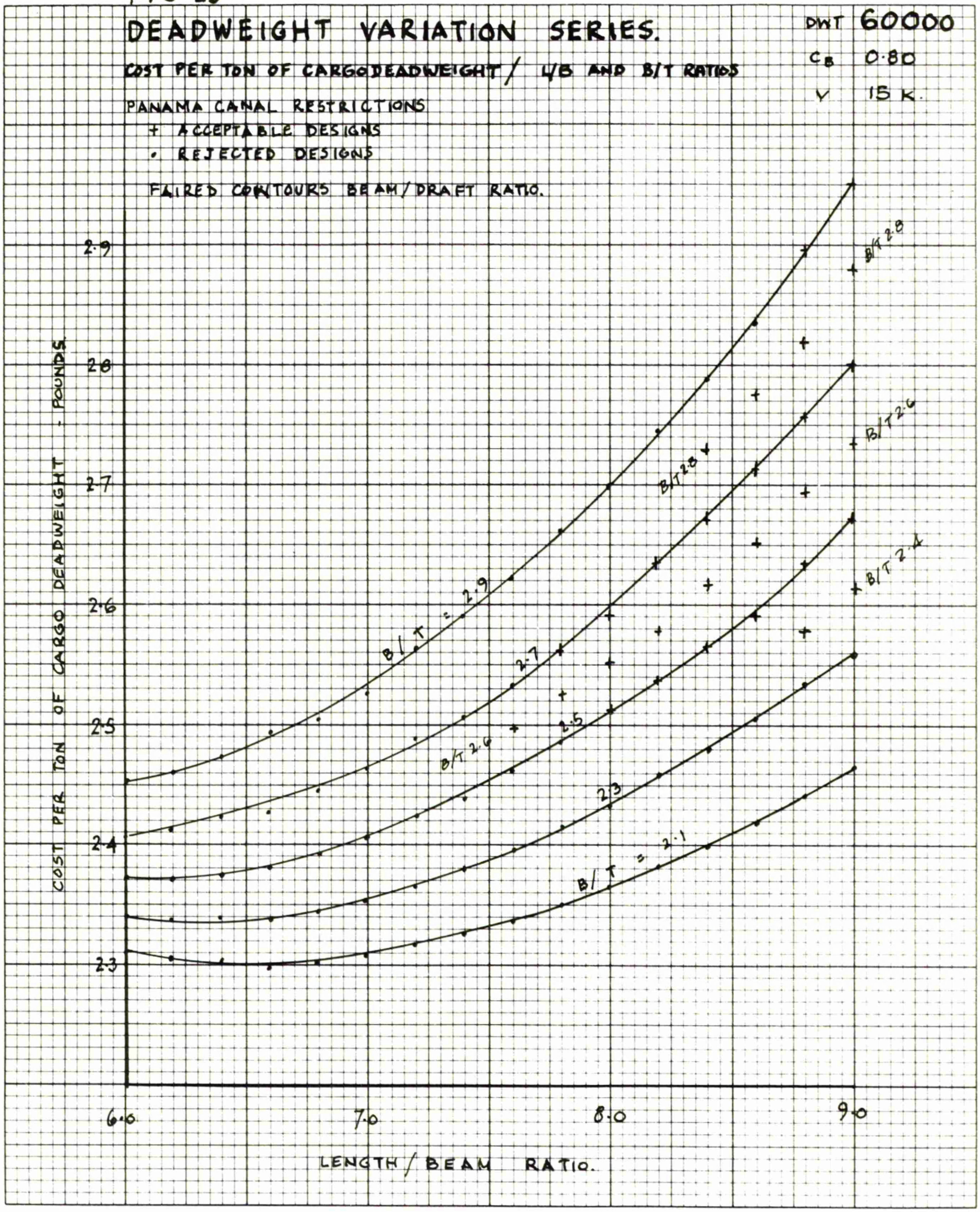
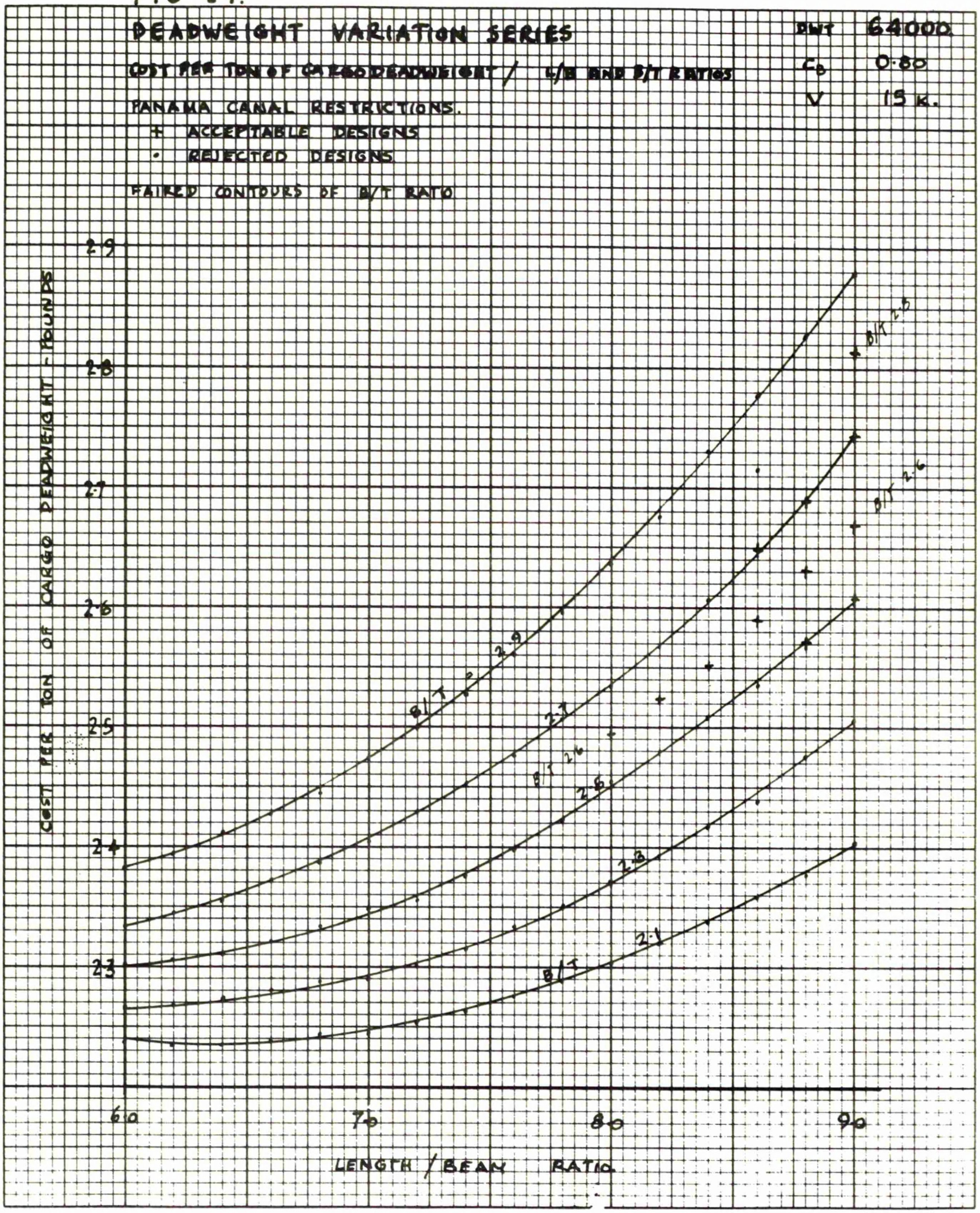
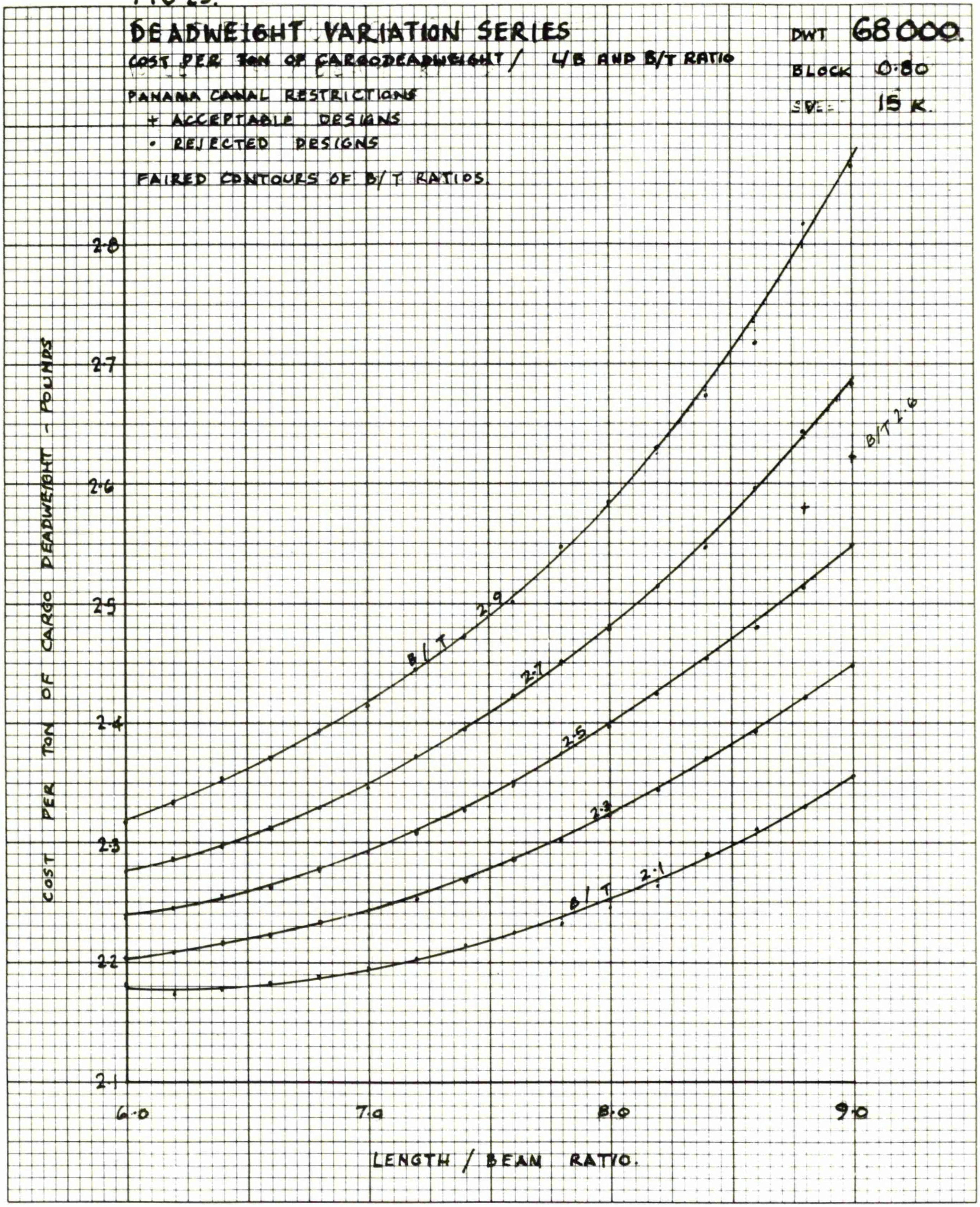

DEADWEIGHT VARIATION SERIES.
COST PER TON OF CARGO DEADWEIGHT / L/B AND B/T RATIOS
PANAMA CANAL RESTRICTIONS
+ ACCEPTABLE DESIGNS
· REJECTED DESIGNS
FAIRED CONTOURS BEAM/DRAFT RATIO.
DWT 60000
CB 0·80
V 15 K.
COST PER TON OF CARGO DEADWEIGHT - POUNDS
2·9
2·8
2·7
2·6
2·5
2·4
2·3
B/T = 2·9
2·7
2·5
2·3
B/T = 2·1
B/T 2·6
B/T 2·8
B/T 2·8
B/T 2·6
B/T 2·4
6·0
7·0
8·0
9·0
LENGTH / BEAM RATIO.

FIG 24.



DEADWEIGHT VARIATION SERIES
COST PER TON OF CARGO DEADWEIGHT / L/B AND B/T RATIOS
PANAMA CANAL RESTRICTIONS.
+ ACCEPTABLE DESIGNS
· REJECTED DESIGNS
FAIRED CONTOURS OF B/T RATIO
DWT 64000
C_B 0·80
V 15 K.
COST PER TON OF CARGO DEADWEIGHT - POUNDS
2·9
2·8
2·7
2·6
2·5
2·4
2·3
B/T 2·5
B/T 2·6
B/T = 2·9
2·7
B/T 2·6
2·6
2·3
2·1
B/T
6·0
7·0
8·0
9·0
LENGTH / BEAM RATIO

FIG 25.



DEADWEIGHT VARIATION SERIES
COST PER TON OF CARGODEADWEIGHT / L/B AND B/T RATIO
PANAMA CANAL RESTRICTIONS
+ ACCEPTABLE DESIGNS
• REJECTED DESIGNS
FAIRED CONTOURS OF B/T RATIOS.
DWT 68000.
BLOCK 0·80
15 K.
B/T 2·9
2·7
2·5
2·3
B/T 2·1
B/T 2·6
2·8
2·7
2·6
2·5
2·4
2·3
2·2
2·1
6·0
7·0
8·0
9·0
COST PER TON OF CARGO DEADWEIGHT - POUNDS
LENGTH / BEAM RATIO.

FIG 26.

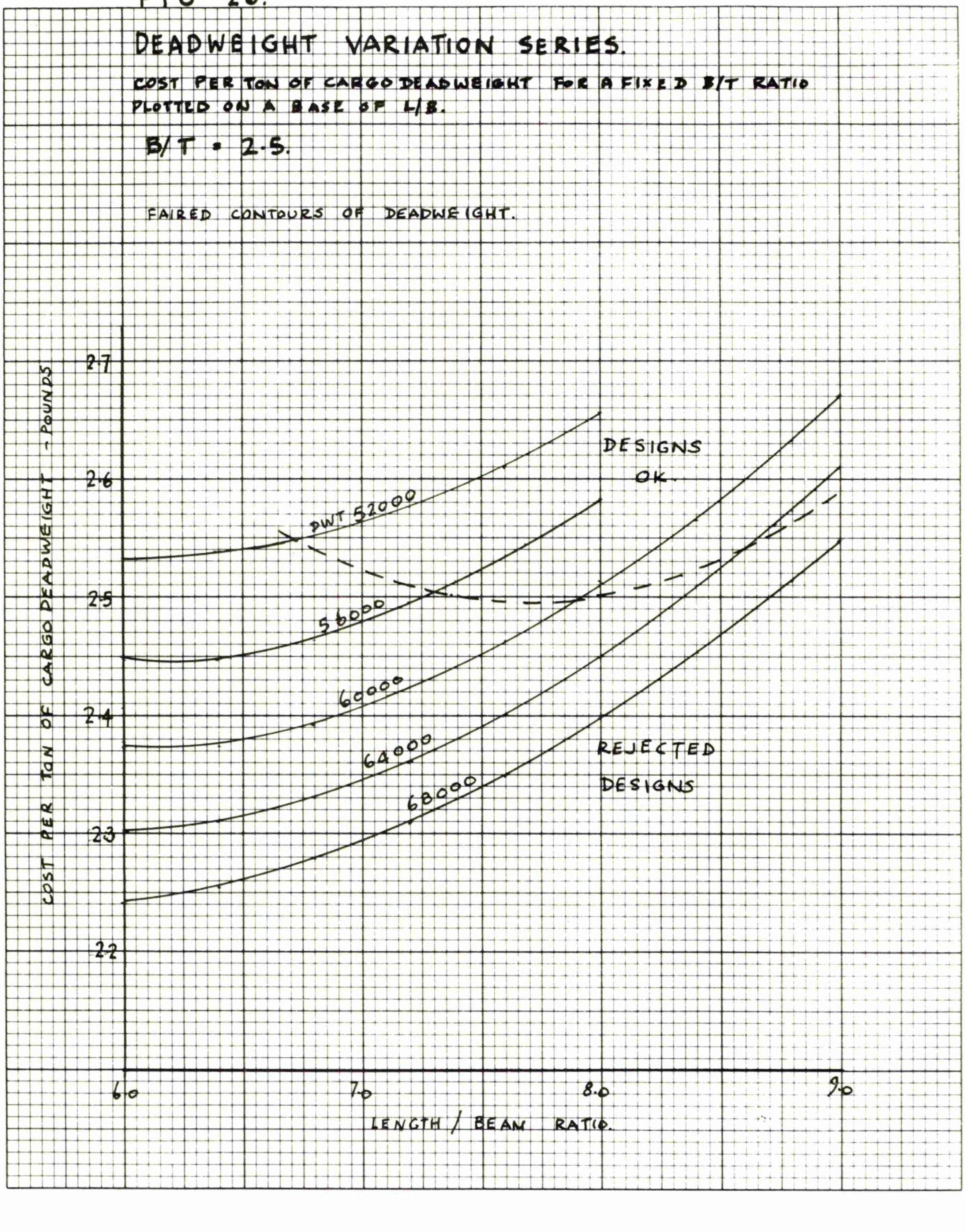
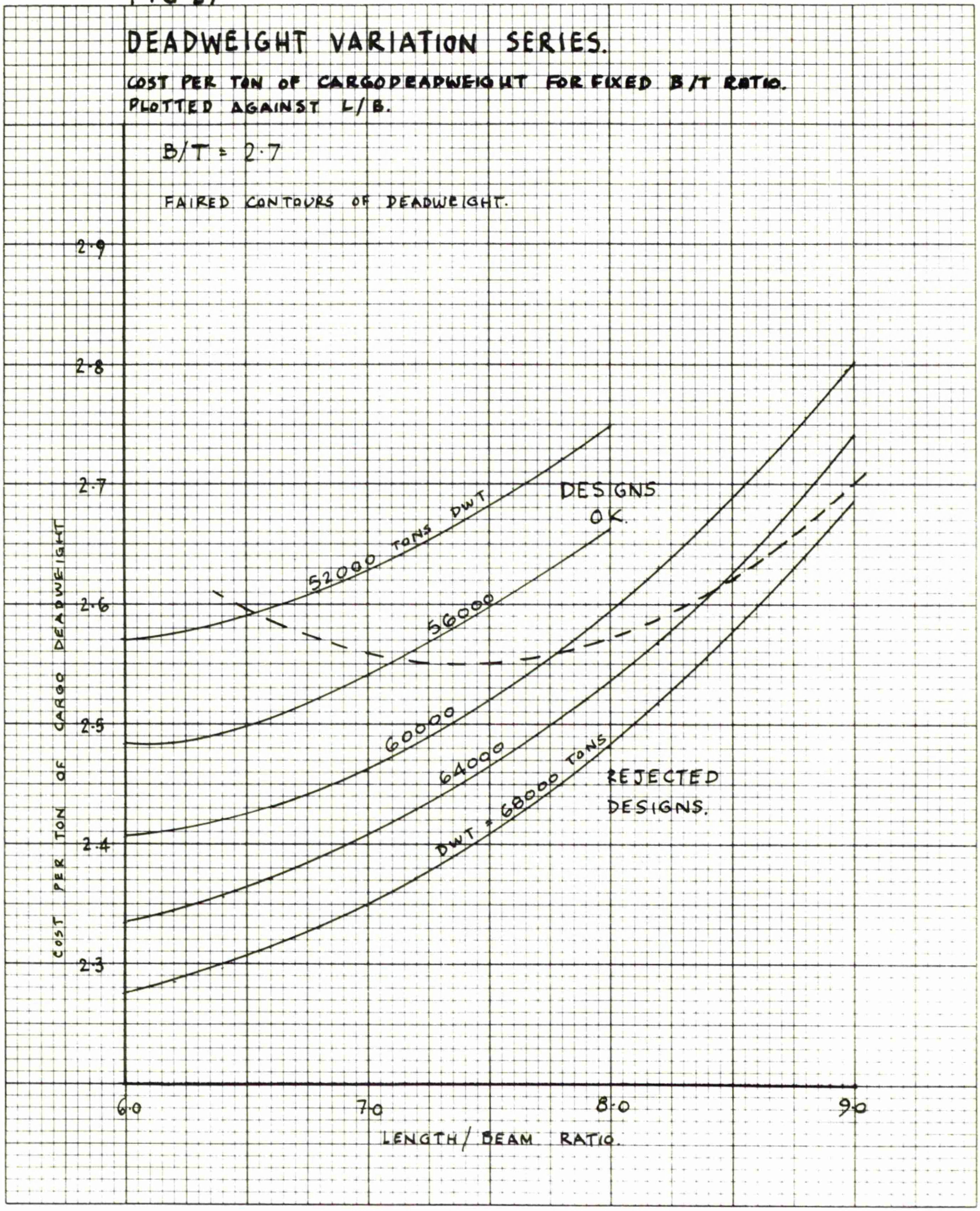

DEADWEIGHT VARIATION SERIES.
COST PER TON OF CARGO DEADWEIGHT FOR A FIXED B/T RATIO PLOTTED ON A BASE OF L/B.
B/T = 2.5.
FAIRED CONTOURS OF DEADWEIGHT.
DESIGNS OK.
REJECTED DESIGNS
DWT 52000
56000
60000
64000
68000
2.7
2.6
2.5
2.4
2.3
2.2
6.0
7.0
8.0
9.0
COST PER TON OF CARGO DEADWEIGHT - POUNDS
LENGTH / BEAM RATIO.

FIG 27



DEADWEIGHT VARIATION SERIES.
COST PER TON OF CARGO DEADWEIGHT FOR FIXED B/T RATIO.
PLOTTED AGAINST L/B.
B/T = 2·7
FAIRED CONTOURS OF DEADWEIGHT.
COST PER TON OF CARGO DEADWEIGHT
2·9
2·8
2·7
2·6
2·5
2·4
2·3
52000 TONS DWT
56000
60000
64000
DWT = 68000 TONS
DESIGNS OK.
REJECTED DESIGNS.
6·0
7·0
8·0
9·0
LENGTH/BEAM RATIO.

FIG 28.

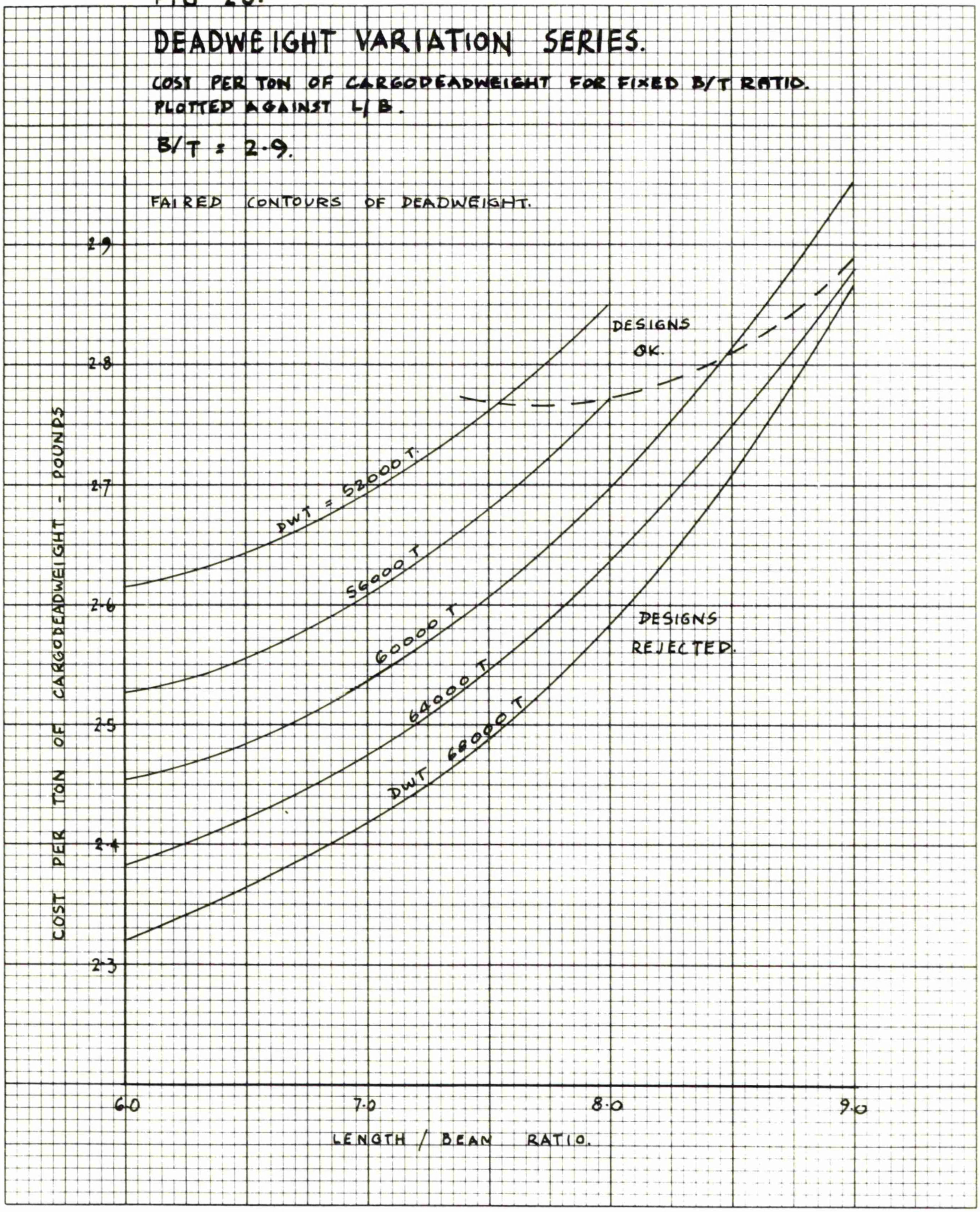

DEADWEIGHT VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT FOR FIXED B/T RATIO.
PLOTTED AGAINST L/B.
B/T = 2·9.
FAIRED CONTOURS OF DEADWEIGHT.
DESIGNS OK.
DESIGNS REJECTED.
DWT = 52000 T.
56000 T
60000 T
64000 T
DWT 68000 T
2·9
2·8
2·7
2·6
2·5
2·4
2·3
6·0
7·0
8·0
9·0
COST PER TON OF CARGODEADWEIGHT - POUNDS
LENGTH / BEAM RATIO.

FIG 29

CURVES. OF WTS, DISPLACEMENT, POWER AND COSTS

ON A BASE OF L/B RATIO.

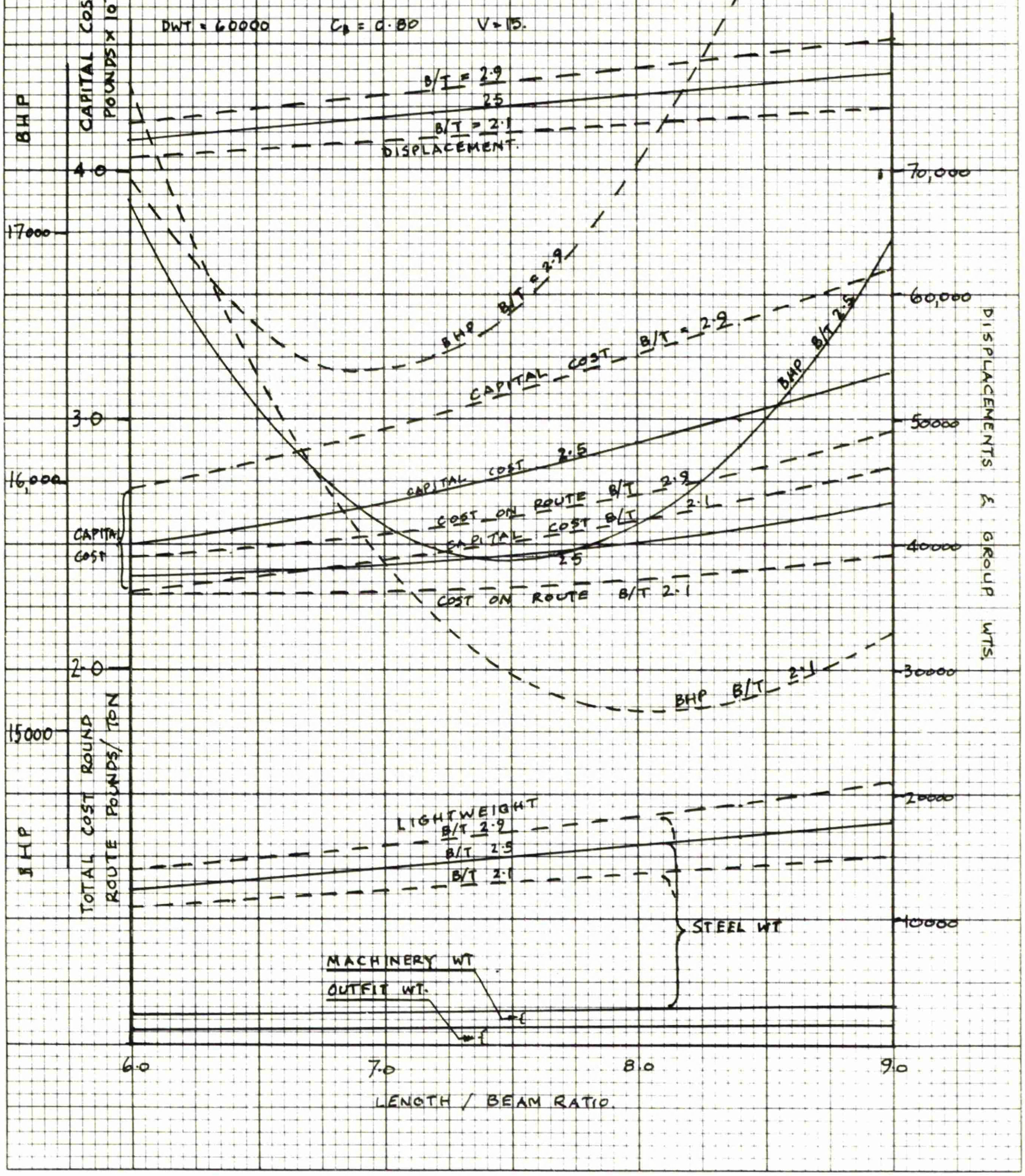


FIG 30.

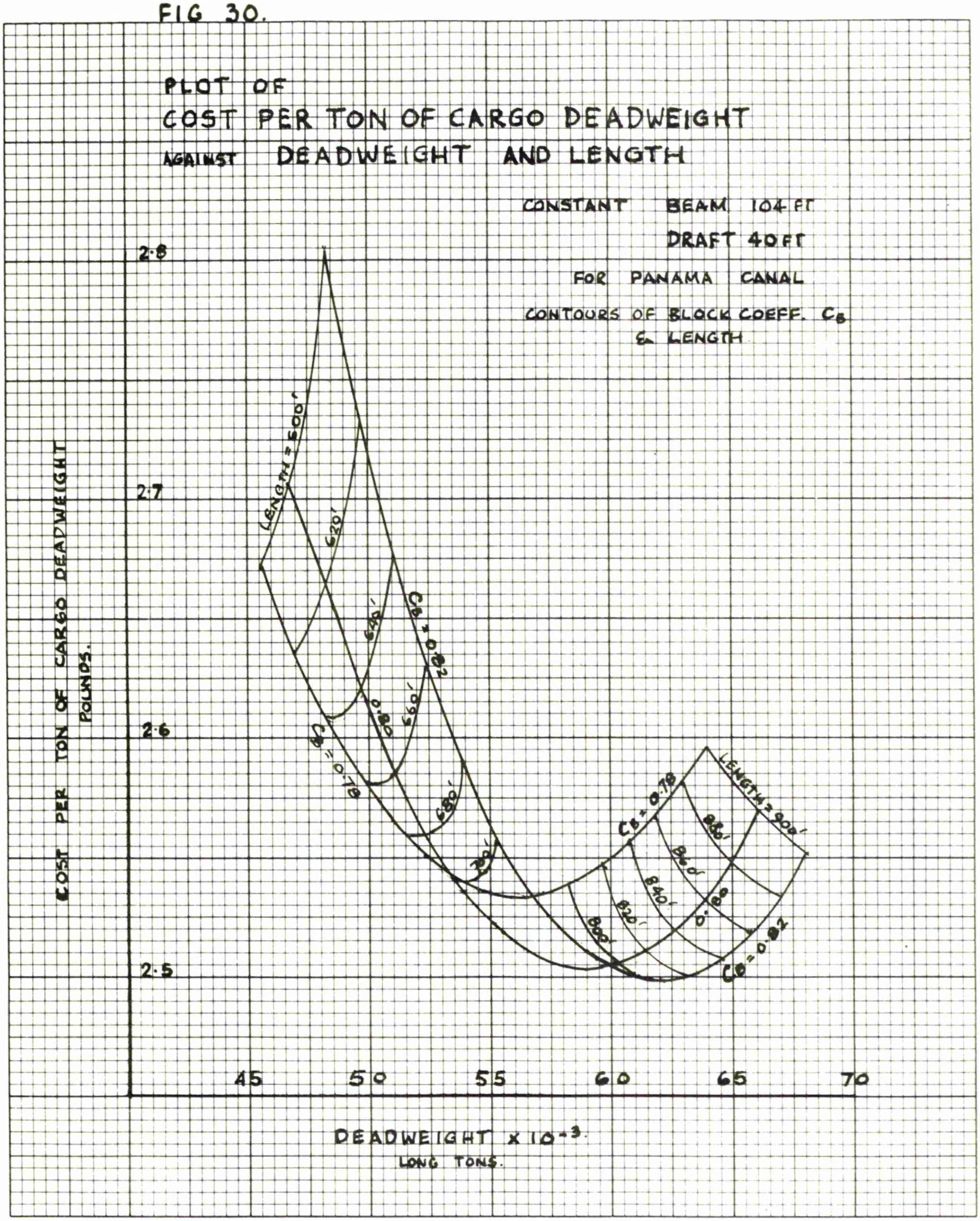

PLOT OF
COST PER TON OF CARGO DEADWEIGHT
AGAINST DEADWEIGHT AND LENGTH
CONSTANT BEAM 104 FT
DRAFT 40 FT
FOR PANAMA CANAL
CONTOURS OF BLOCK COEFF. C_B
& LENGTH
COST PER TON OF CARGO DEADWEIGHT
POUNDS.
2·8
2·7
2·6
2·5
45
50
55
60
65
70
DEADWEIGHT x 10⁻³
LONG TONS.
LENGTH = 600'
620'
640'
660'
680'
700'
800'
820'
840'
860'
880'
LENGTH = 900'
C_B = 0·82
C_B = 0·78
0·80

FIG 31.

COMPARISON BETWEEN CAPITAL COST AND TOTAL COST AS OPTIMISATION CRITERIA.

CONSTANT BEAM = 104' DRAFT = 40' C_B = 0.82

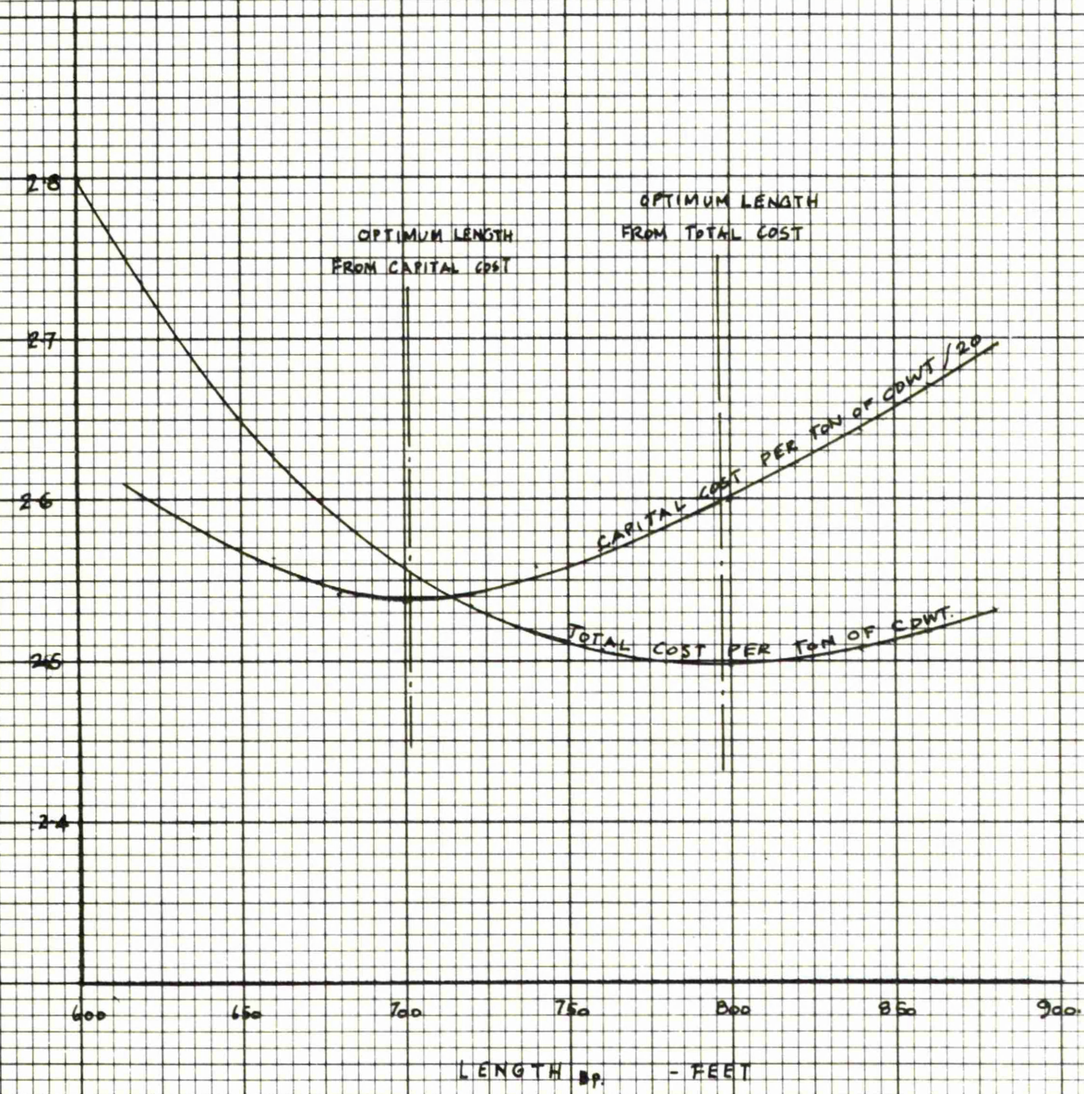


FIG 32.

BLOCK COEFFICIENT VARIATION SERIES.

COST PER TON OF CARGO DEADWEIGHT

CONTOURS OF C_B.

B/T = 2·1. DWT = 60000

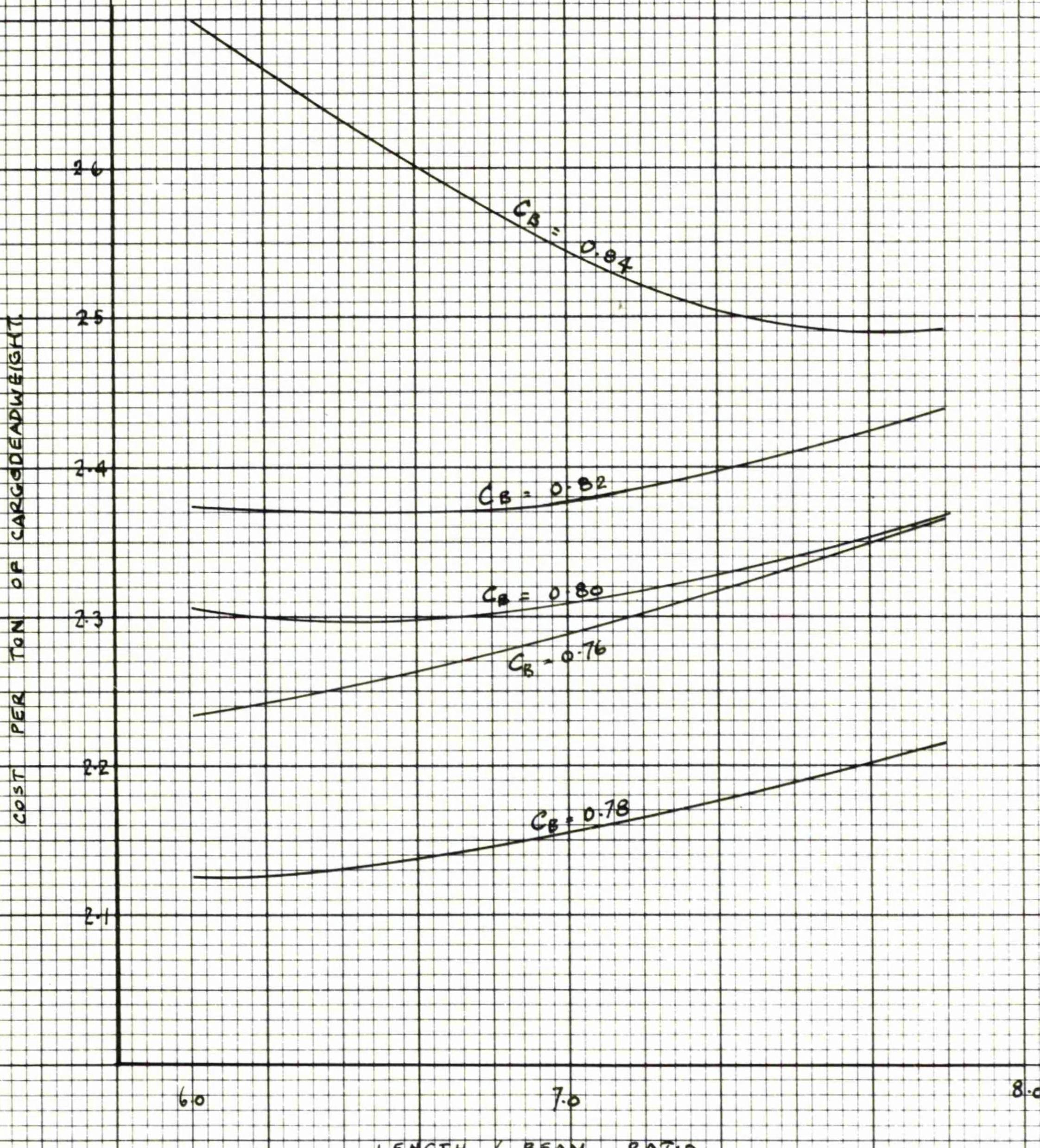


FIG 33

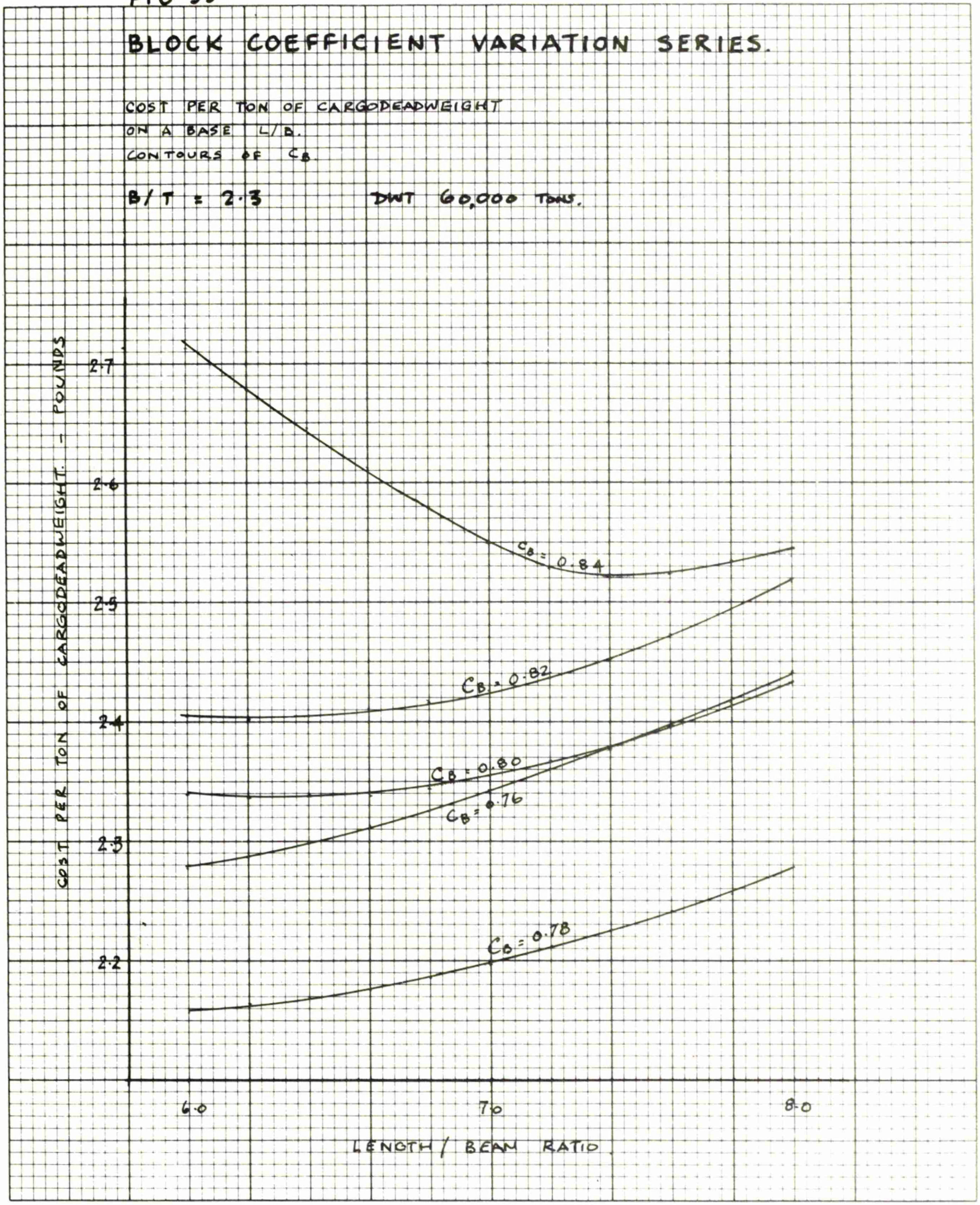

BLOCK COEFFICIENT VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON A BASE L/B.
CONTOURS OF C_B.
B/T = 2·3
DWT 60,000 TONS.
COST PER TON OF CARGODEADWEIGHT - POUNDS
2·7
2·6
2·5
2·4
2·3
2·2
C_B = 0·84
C_B = 0·82
C_B = 0·80
C_B = 0·76
C_B = 0·78
6·0
7·0
8·0
LENGTH / BEAM RATIO

FIG 34.

BLOCK COEFFICIENT VARIATION SERIES.

COST PER TON OF CARGO DEADWEIGHT
ON A BASE OF L/B.

CONTOURS OF C_B.

B/T = 2·5. DWT 60000

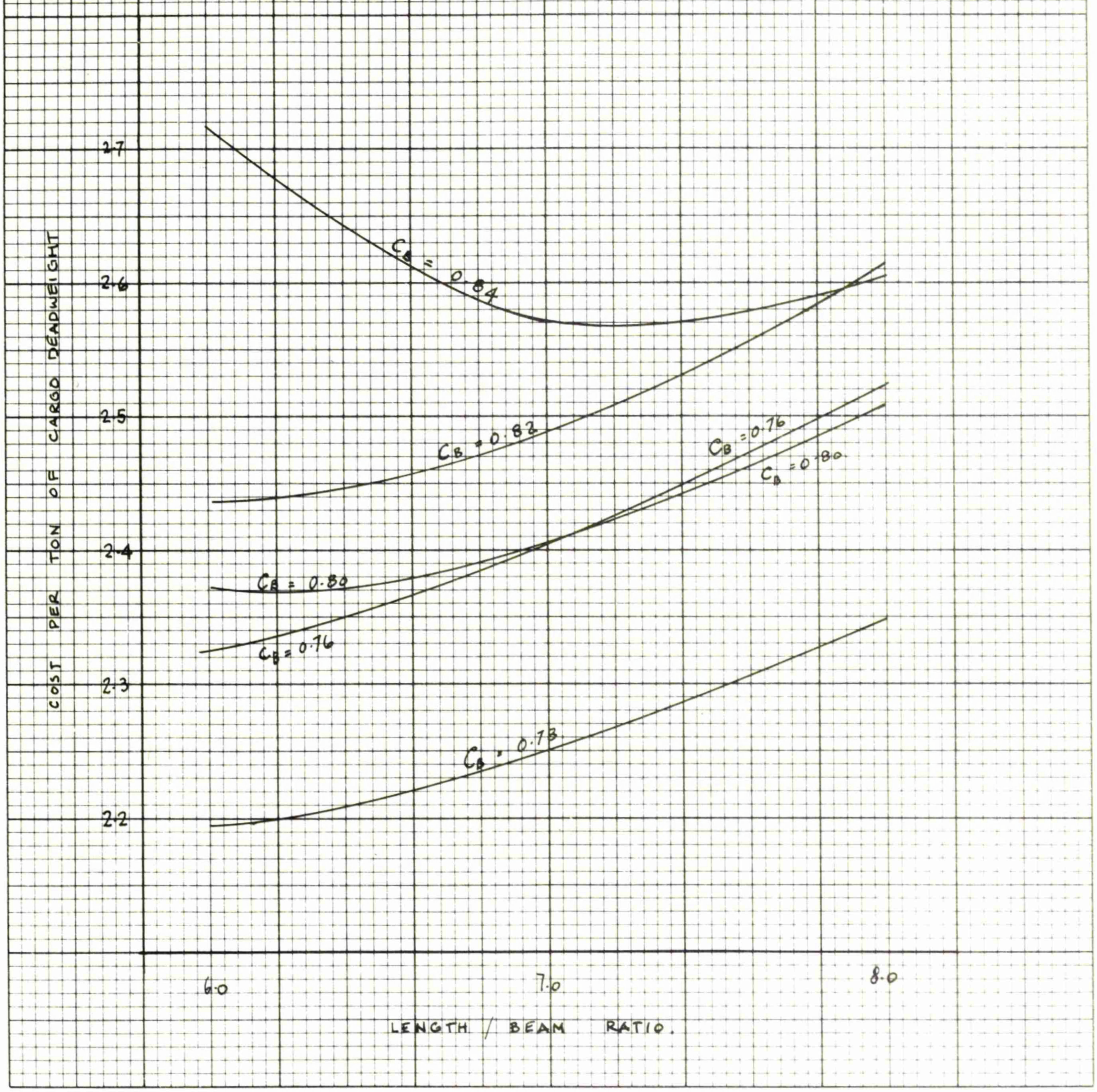


FIG 35.

BLOCK COEFFICIENT VARIATION SERIES.

COST PER TON OF CARGODEADWEIGHT
ON A BASE OF L/B

CONTOURS OF C_B.

B/T = 2·7 DWT 60,000

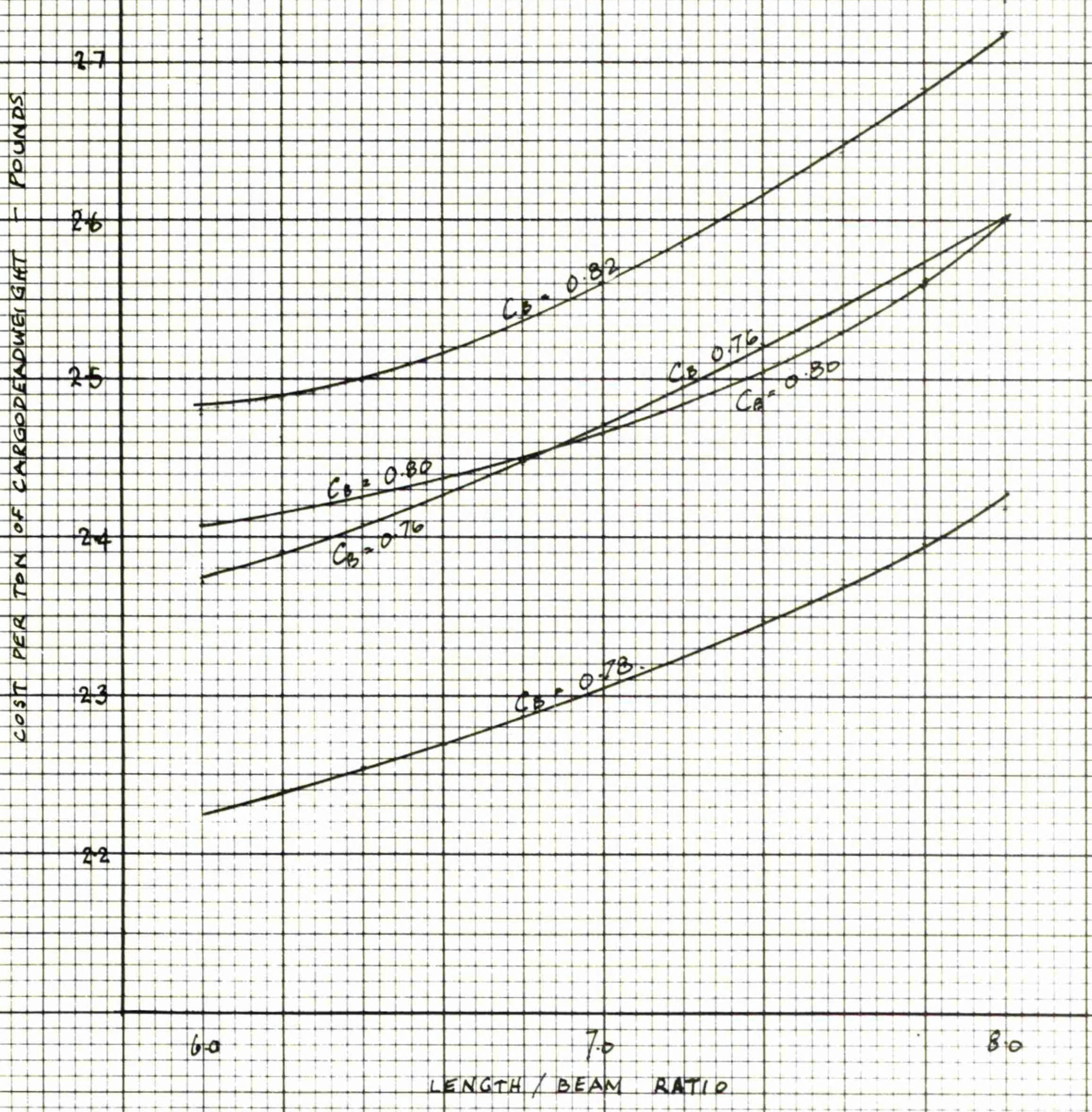


FIG 36.

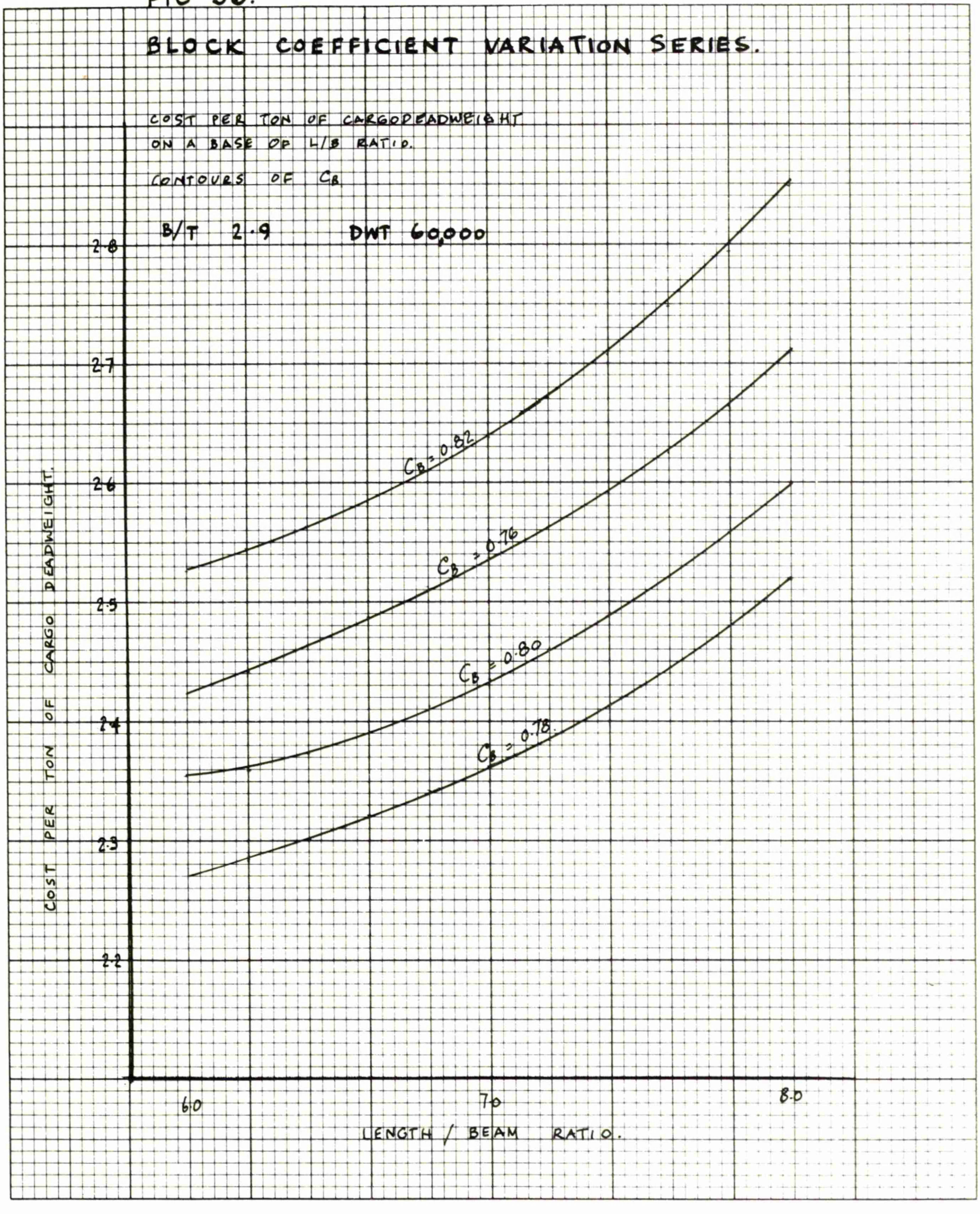
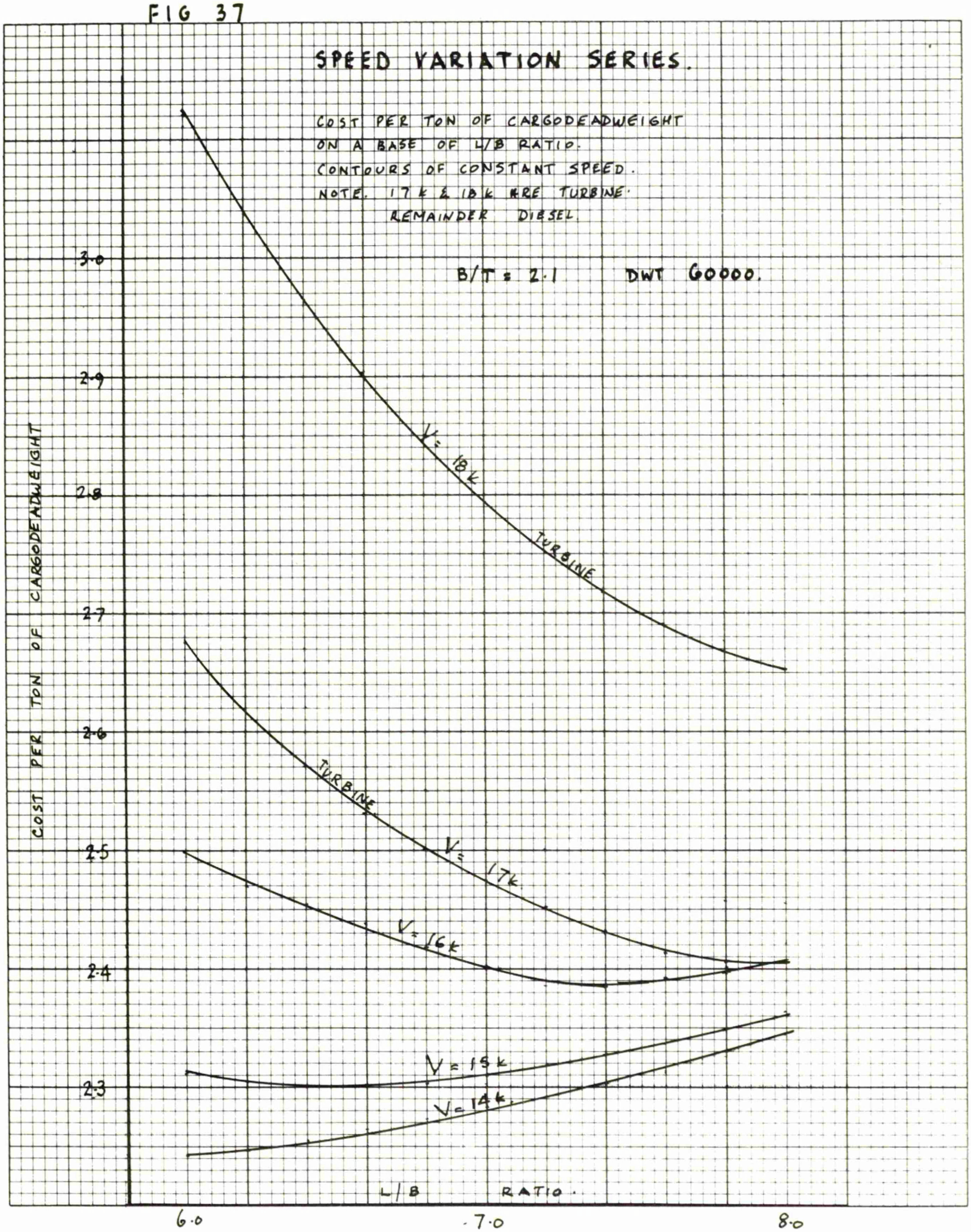

BLOCK COEFFICIENT VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON A BASE OF L/B RATIO.
CONTOURS OF CB
B/T 2·9
DWT 60,000
2·8
2·7
2·6
2·5
2·4
2·3
2·2
COST PER TON OF CARGO DEADWEIGHT.
CB = 0·82
CB = 0·76
CB = 0·80
CB = 0·78
6·0
7·0
8·0
LENGTH / BEAM RATIO.

FIG 37



SPEED VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON A BASE OF L/B RATIO.
CONTOURS OF CONSTANT SPEED.
NOTE. 17k & 18k ARE TURBINE.
REMAINDER DIESEL.
B/T = 2.1
DWT 60000.
COST PER TON OF CARGODEADWEIGHT
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
V = 18k
TURBINE
TURBINE
V = 17k
V = 16k
V = 15k
V = 14k
L/B RATIO.
6.0
7.0
8.0

FIG 38.

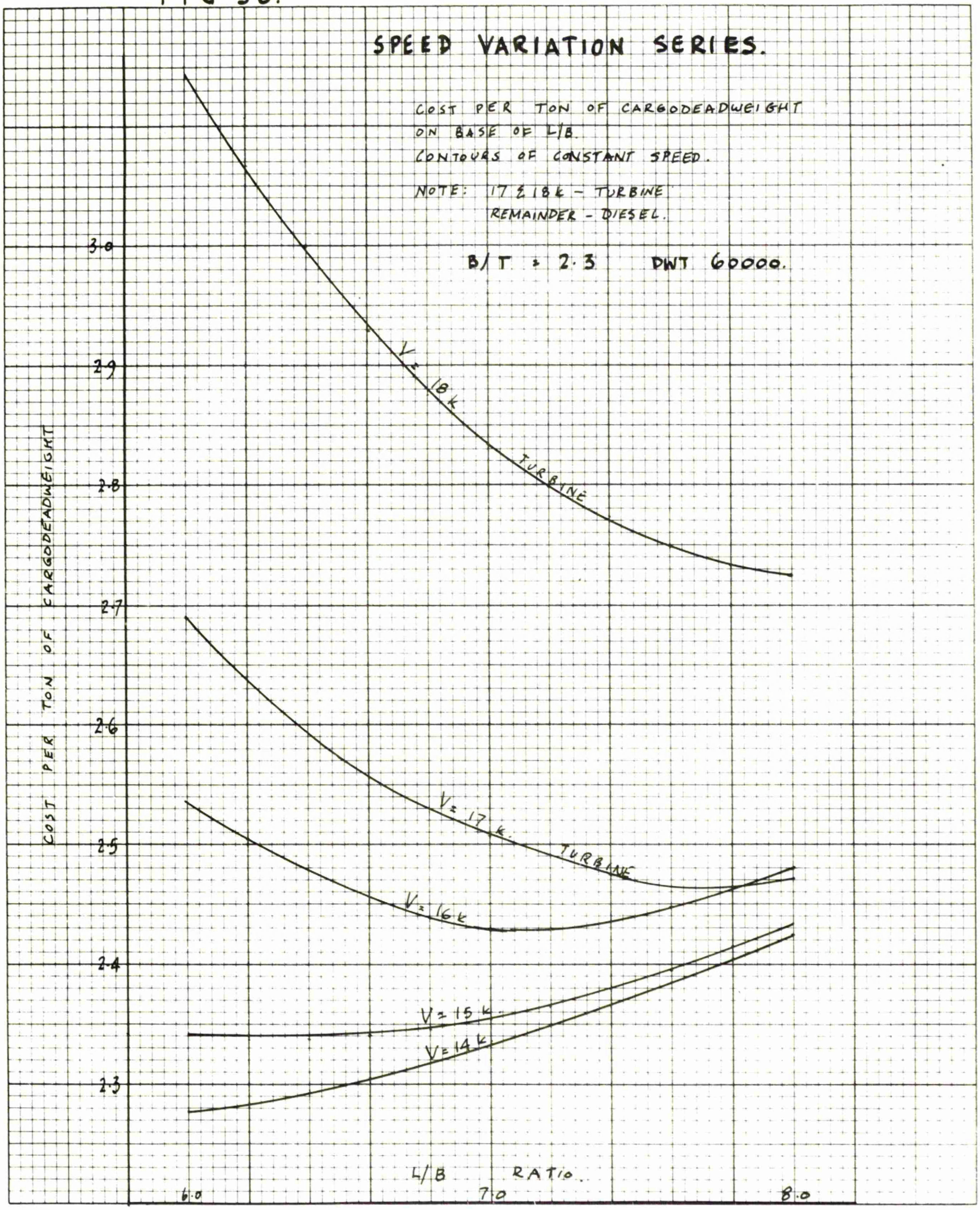

SPEED VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON BASE OF L/B.
CONTOURS OF CONSTANT SPEED.
NOTE: 17 & 18k – TURBINE
REMAINDER – DIESEL.
B/T = 2·3 DWT 60000.
V = 18 k
TURBINE
V = 17 k
TURBINE
V = 16 k
V = 15 k
V = 14 k
3·0
2·9
2·8
2·7
2·6
2·5
2·4
2·3
COST PER TON OF CARGODEADWEIGHT
L/B RATIO.
6·0
7·0
8·0

FIG 39.

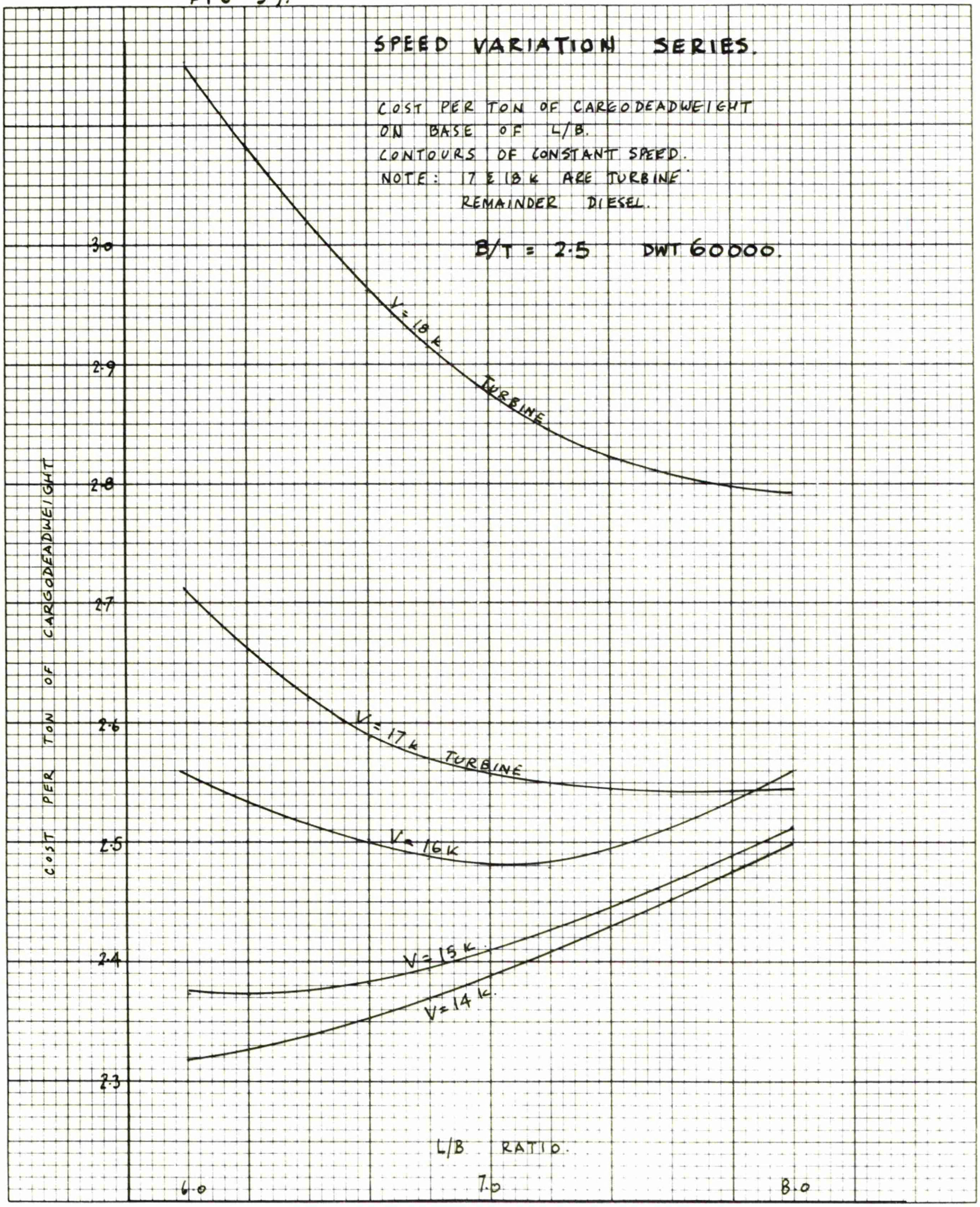
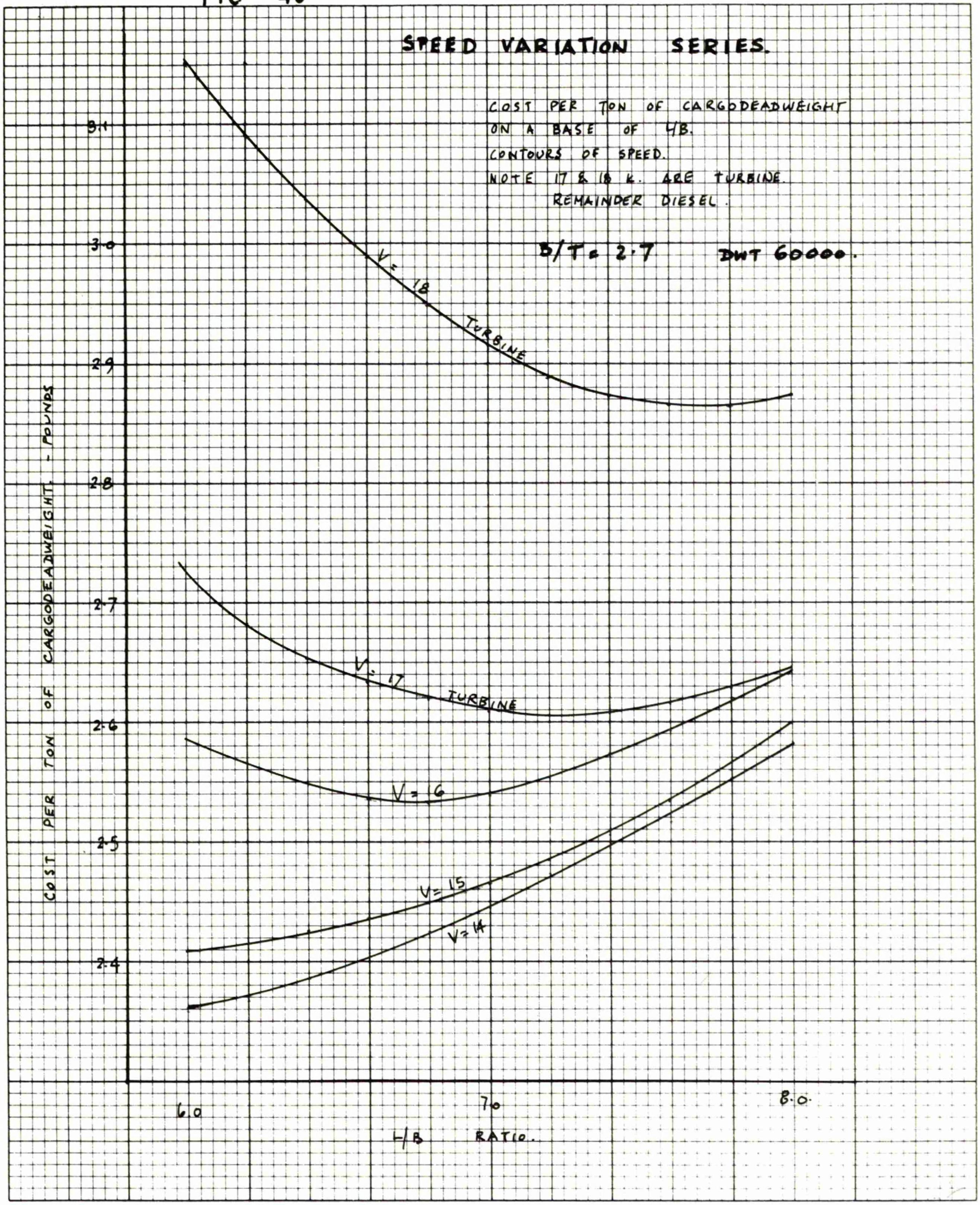

SPEED VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON BASE OF L/B.
CONTOURS OF CONSTANT SPEED.
NOTE: 17 & 18 K ARE TURBINE
REMAINDER DIESEL.
B/T = 2·5 DWT 60000.
V = 18 K
TURBINE
V = 17 K TURBINE
V = 16 K
V = 15 K
V = 14 K
COST PER TON OF CARGODEADWEIGHT
3·0
2·9
2·8
2·7
2·6
2·5
2·4
2·3
L/B RATIO.
6·0
7·0
8·0

FIG 40



STEED VARIATION SERIES.
COST PER TON OF CARGODEADWEIGHT
ON A BASE OF L/B.
CONTOURS OF SPEED.
NOTE 17 & 18 K. ARE TURBINE.
REMAINDER DIESEL.
B/T = 2·7
DWT 60000.
V = 18
TURBINE
V = 17
TURBINE
V = 16
V = 15
V = 14
3·1
3·0
2·9
2·8
2·7
2·6
2·5
2·4
COST PER TON OF CARGODEADWEIGHT. - POUNDS
6.0
7.0
8.0.
L/B RATIO.

FIG 41.

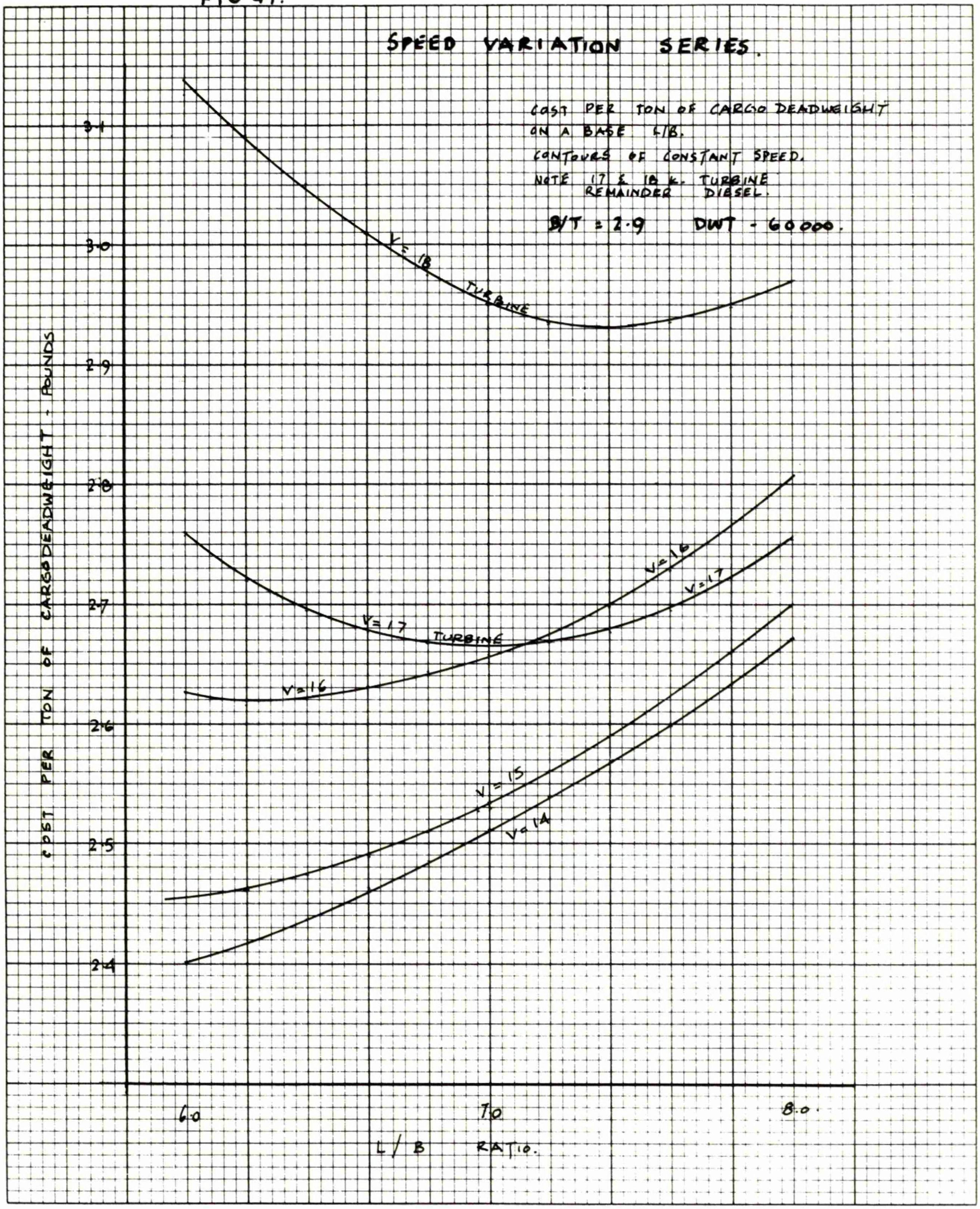

SPEED VARIATION SERIES.
COST PER TON OF CARGO DEADWEIGHT
ON A BASE L/B.
CONTOURS OF CONSTANT SPEED.
NOTE 17 & 18 K. TURBINE
REMAINDER DIESEL.
B/T = 2·9 DWT - 60000.
V = 18
TURBINE
V = 16
V = 17
V = 17
TURBINE
V = 16
V = 15
V = 14
3·1
3·0
2·9
2·8
2·7
2·6
2·5
2·4
COST PER TON OF CARGO DEADWEIGHT - POUNDS
6·0
7·0
8·0
L / B RATIO.

FIG 42

ARRANGEMENT OF PANAMA CANAL BULK CARRIER.

L = 800' B = 104' T = 40' D = 59.49'

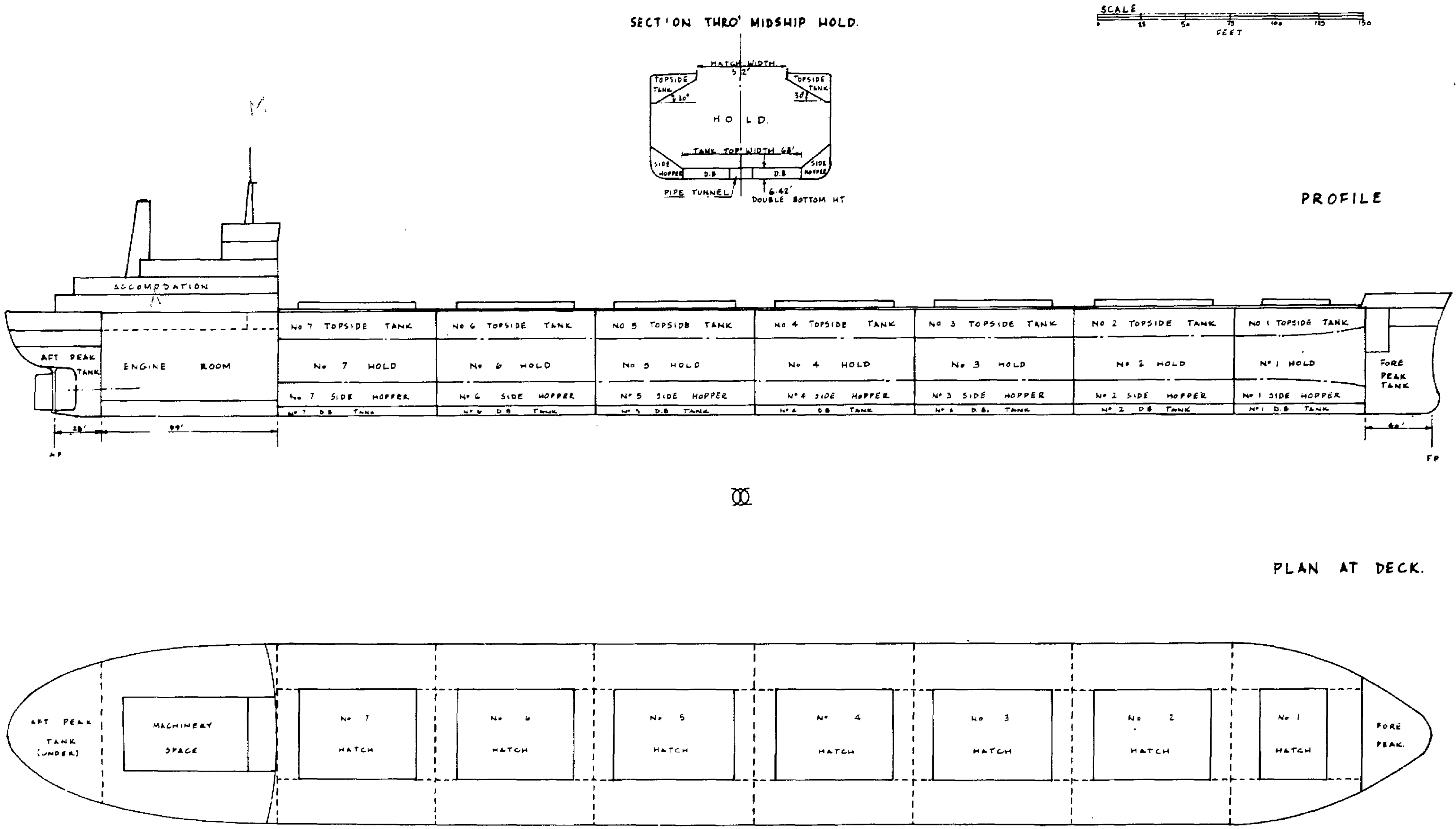
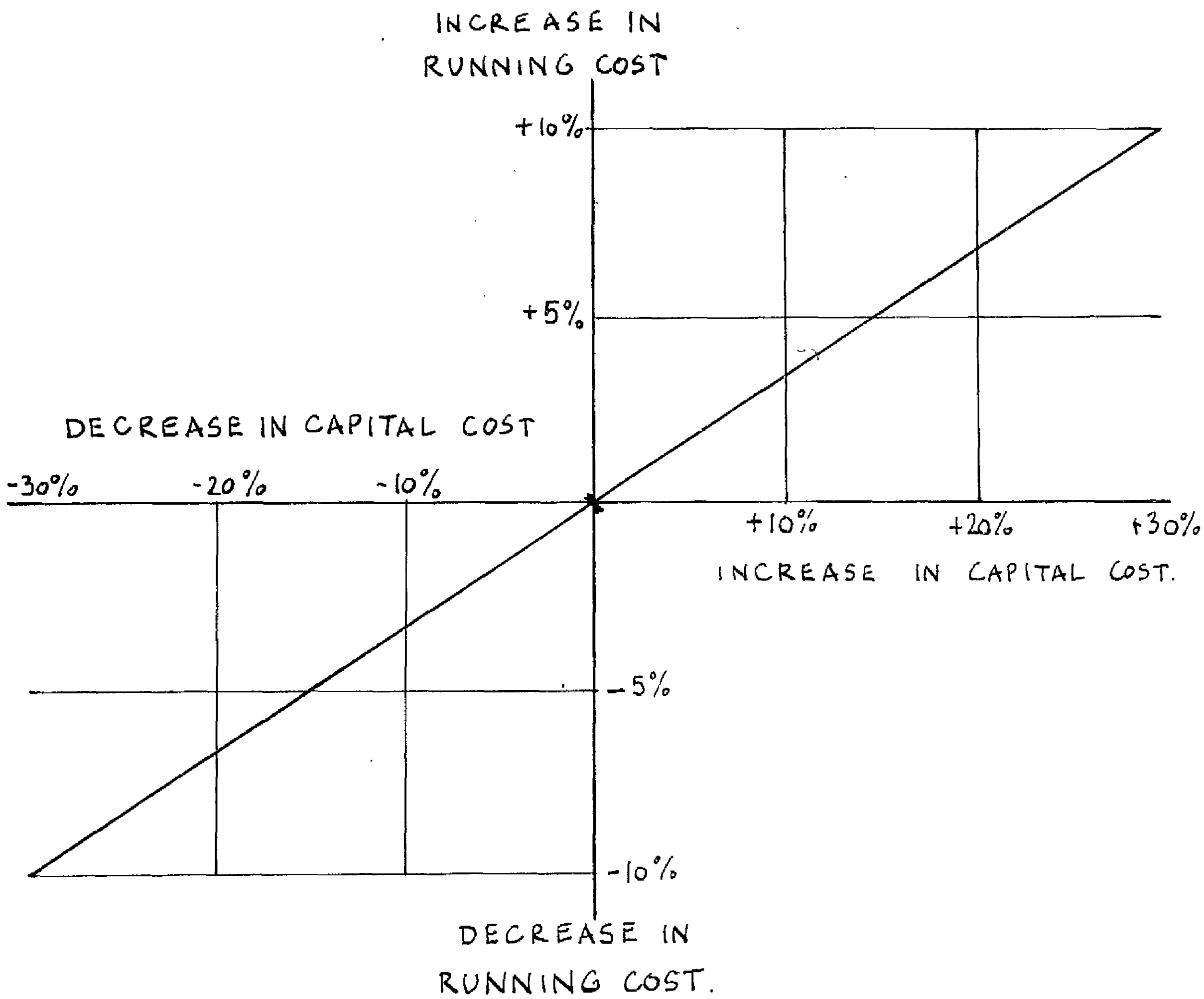


FIG 43.

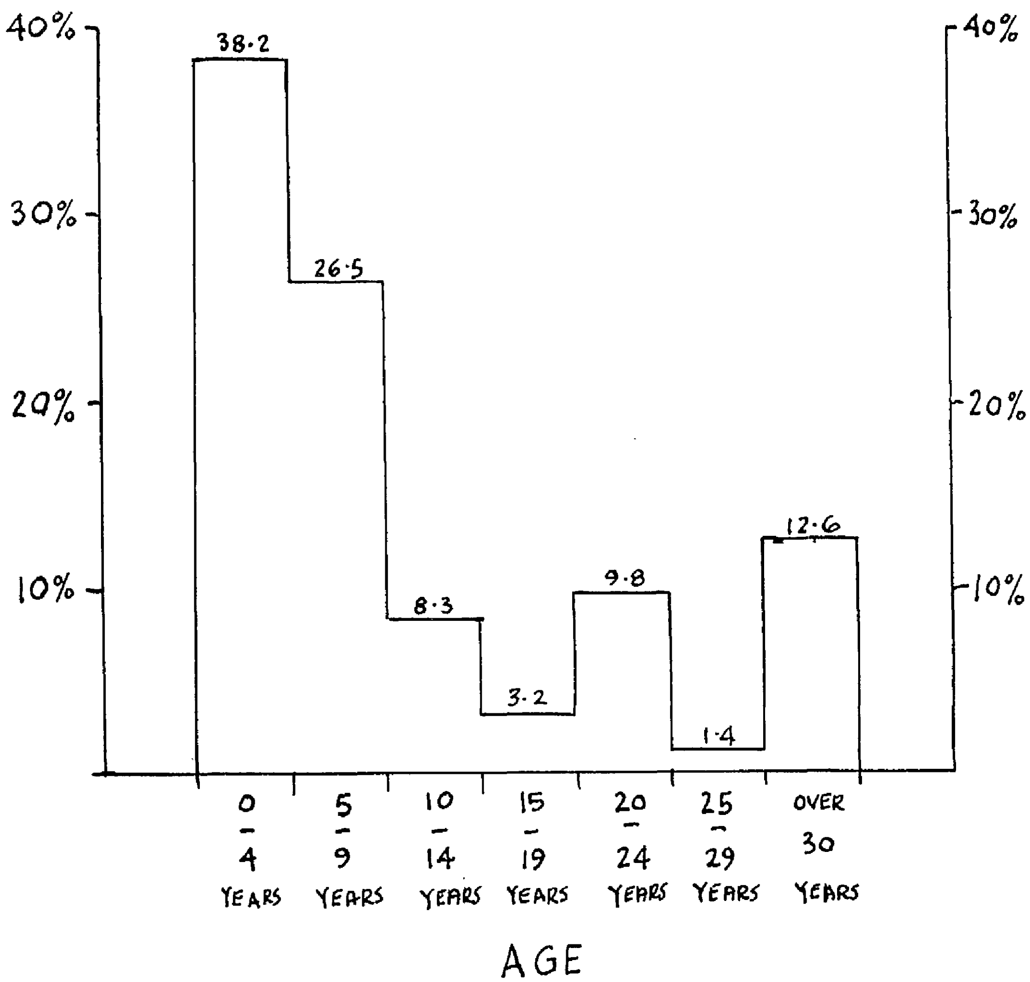
EFFECT ON RUNNING COST OF CHANGE IN CAPITAL CHARGES.



PANAMA BULK CARRIER.

FIG A/1.

AGE DISTRIBUTION OF BULK CARRIERS AND ORE CARRIERS 1965.



SOURCE : LLOYDS STATISTICAL TABLES 1965.

FIG A/2.

NUMBER OF BULK CARRIERS ON ORDER 1960-1966.

CONTOURS OF DWT.

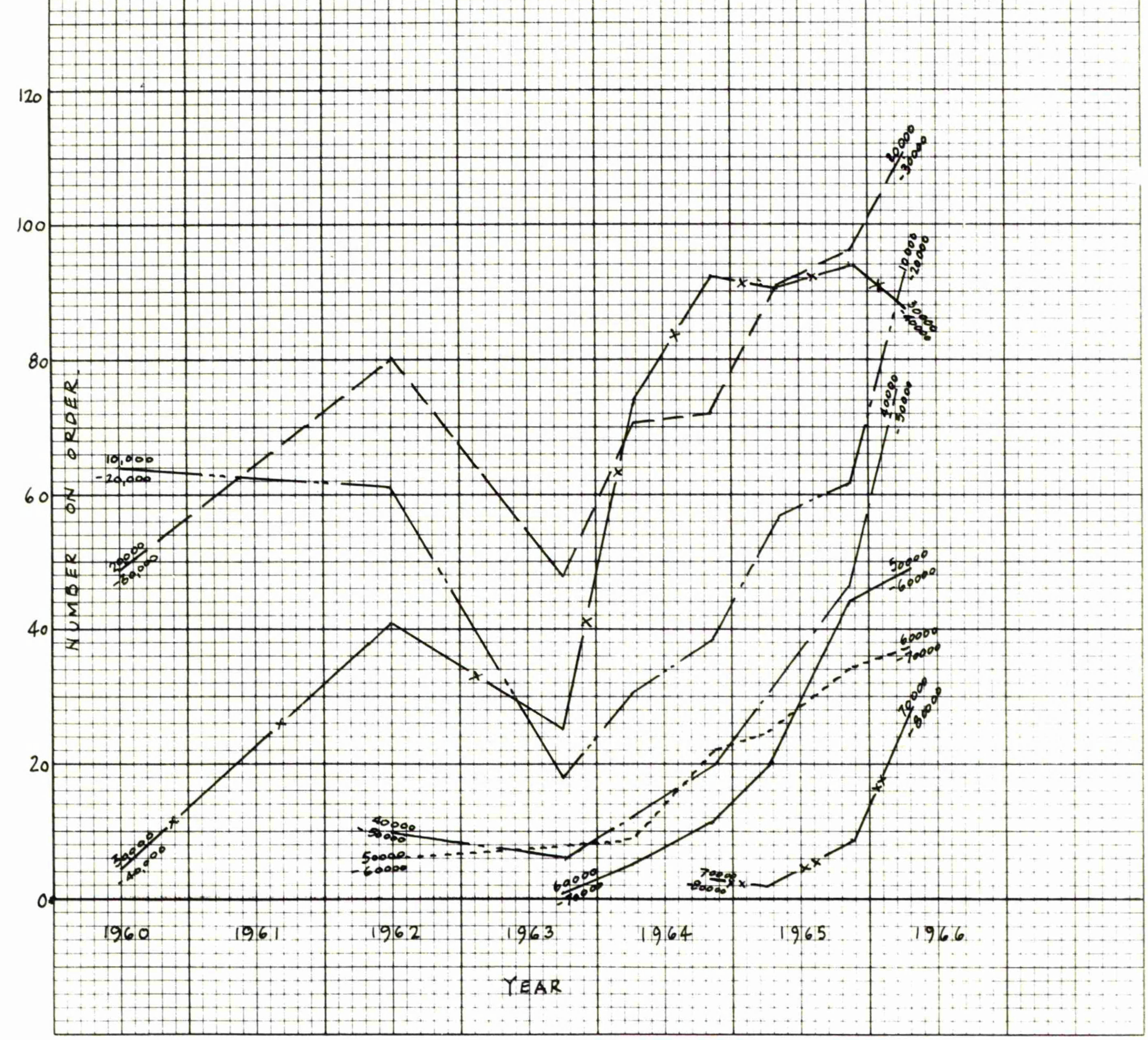


FIG A/3

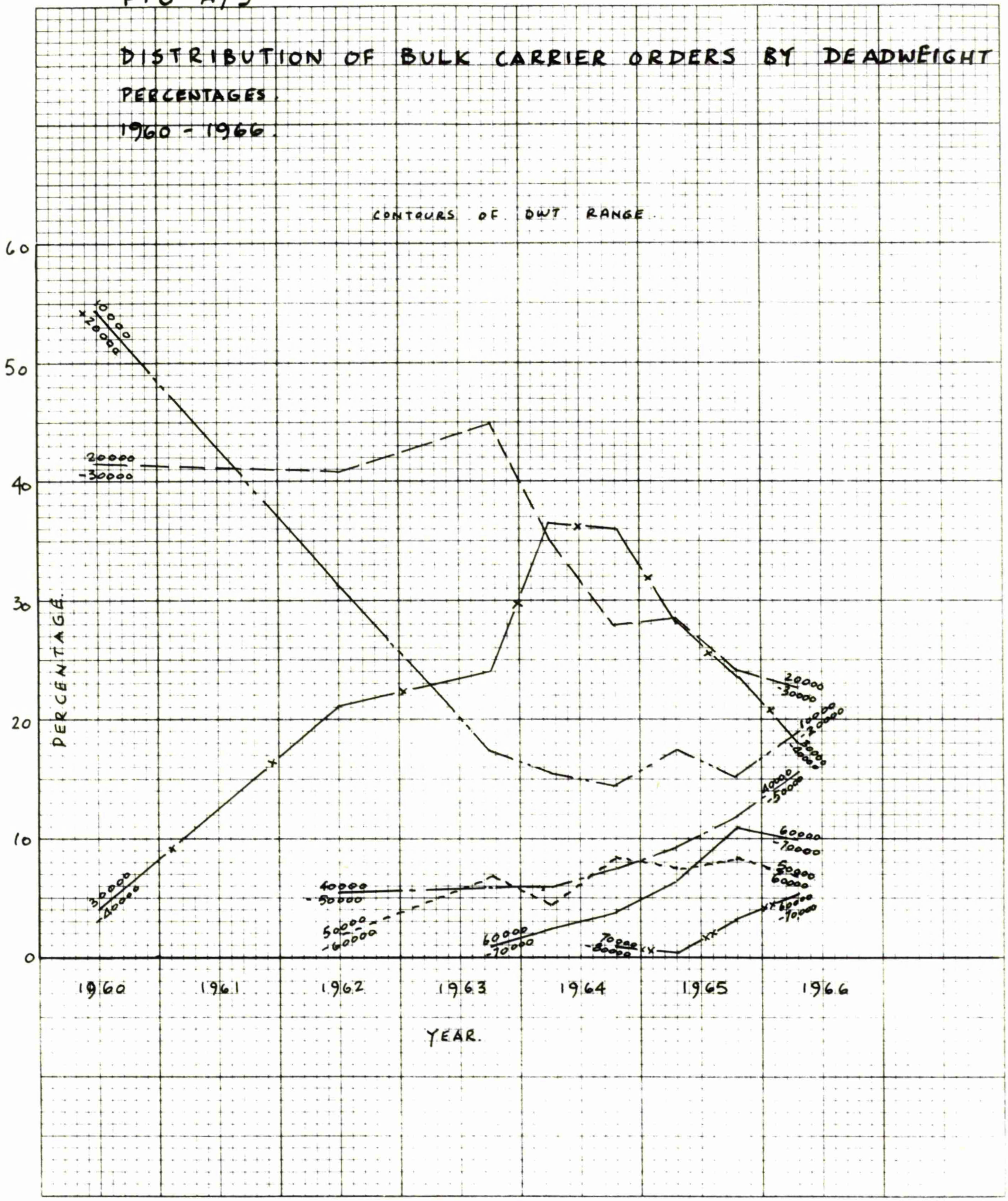

DISTRIBUTION OF BULK CARRIER ORDERS BY DEADWEIGHT
PERCENTAGES.
1960 - 1966.
CONTOURS OF DWT RANGE
60
50
40
30
20
10
0
PERCENTAGE
10000 -20000
20000 -30000
30000 -40000
40000 -50000
50000 -60000
60000 -70000
70000 -80000
1960
1961
1962
1963
1964
1965
1966
YEAR.

FIG. A/4 BULK CARRIERS ON ORDER.
ANALYSIS BY DEADWEIGHT.

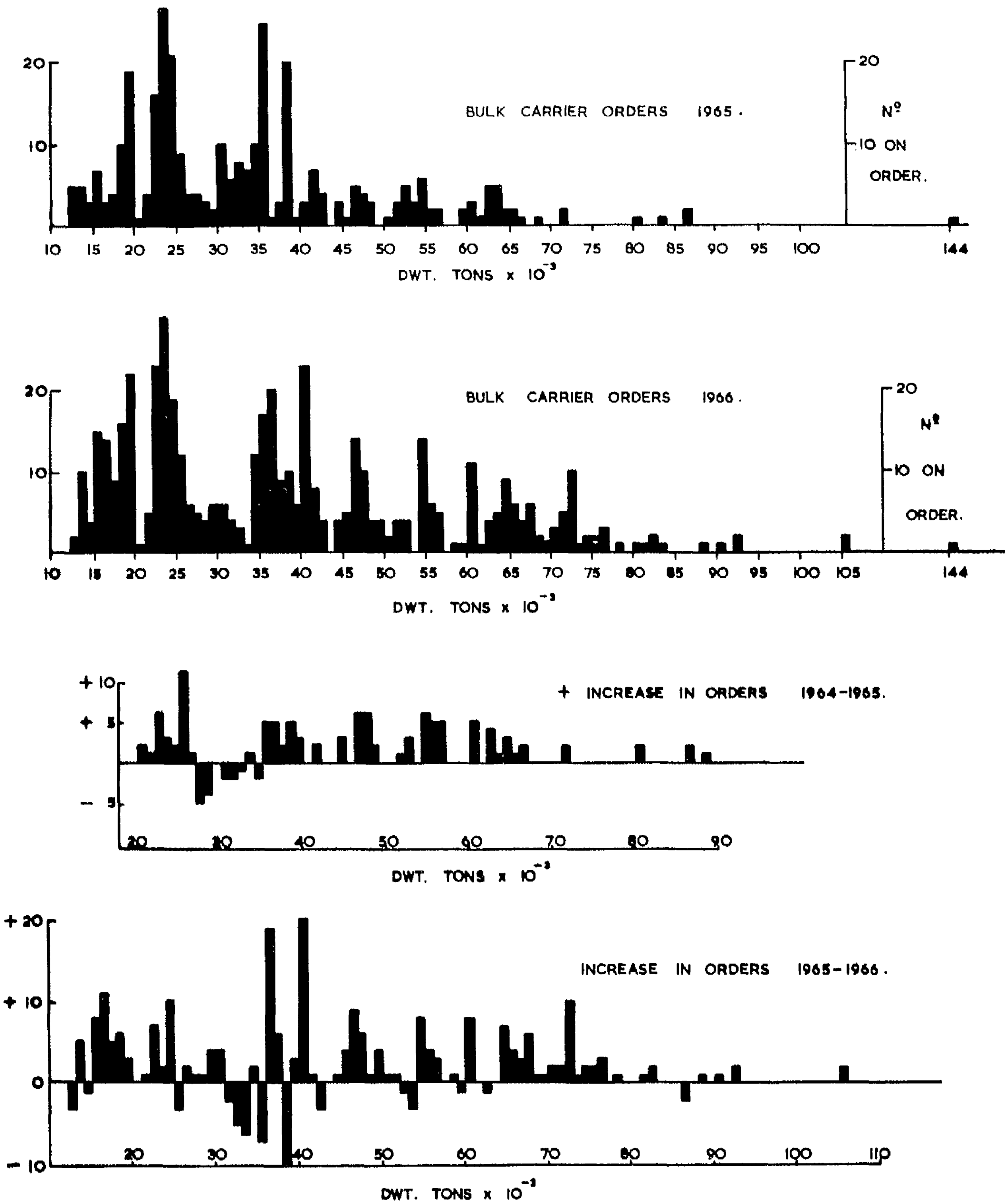


FIG A/5.

SPEED DISTRIBUTION OF BULK CARRIERS, TANKERS AND DRY CARGO SHIPS.