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The conclusions of this study are derived from an extensive compilation of factual data gathered from many sources. While much of this information is commonly available, the most valuable portions of it were privately submitted by industrial concerns and government agencies. This confidential information makes the project both unique and reliable. If the report proves useful to industry, the following contributors deserve the credit:

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(Continued on Inside of
Back Cover)

THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering

Final Report

GENERAL CARGO SHIP ECONOMICS AND DESIGN

Harry Benford

ORA Project 04465

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This report supersedes the report entitled <u>Status of Research into Engineering Economy in the Design of General Cargo Ships</u>, September, 1961.

PREFACE

This is a report of a research study carried out under a grant from The University of Michigan's Office of Research Administration. While the immediate project terminates with this publication, the work reported here is but a first step which makes possible many larger projects which can now be programmed and solved by means of the computer. The realization of such projects would allow the shipowner and naval architect to use rational methods in the preliminary design of general cargo ships, methods founded on an orderly combination of commercial requirements and technological capabilities rather than guesswork, rule of thumb, and conventionalized imitation.

The tenor of this study is implied in the definition of a ship as a capital investment which earns its returns as a socially useful instrument of water transport; and the ideal ship is the one which fulfills these functions most effectively.

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ABBREVIATIONS

ABS: American Bureau of Shipping

B: Beam

B-1, B-1.8: Arbitrary designations for standard design families

C_B: Block coefficient based on design draft, design displacement and length between perpendiculars

C_{DWT}: Deadweight coefficient; ratio of deadweight to displacement at design draft.

C_P: Prismatic coefficient with same basis as C_B

C_x: Maximum section coefficient at design draft

CN: Cubic number $= \frac{LBD}{100}$

d: Design draft

d_{fb}: Draft at minimum allowable freeboard

d_S: Scantling draft

D: Depth to uppermost continuous deck

D_M: Modified depth which corrects for extent of superstructure

DWT: Deadweight at design draft

Δ : Displacement in salt water at design draft

EBC: Equivalent bale capacity. See Chapter IV

$(EBC)_M$: Equivalent bale capacity of machinery space

H & M: Hull and machinery

L or LBP: Length between perpendiculars

L_S: Length of superstructure within the fore and aft perpendiculars

M & R: Maintenance and repair

MH: Man-hours

N: Number of identical ship

N_C: Number in crew

P & I: Protection and indemnity

r: Freeboard ratio related to freeboard of the B-1 Series

Reefer: Refrigerated

SHP_N: Normal installed shaft horsepower (equals maximum power $\div$ 1.10)

V: Volume of displacement

V_K: Nominal sea speed in knots, taken as trial condition speed at 80 percent normal power, assuming operation at design draft

W_C: Weight of cargo

W_{HE}: Net weight of hull engineering (wet)

W_M: Net weight of machinery (wet)

W_O: Net weight of outfitting

W_S: Net weight of steel

Z: Voyage length, usually round trip

Notes

1. Other abbreviations are explained wherever used.
2. All dimensions are in feet, weights in long tons, distances in nautical miles.
3. Unless otherwise specified, all terms such as displacement, deadweight, cargo weight, etc., apply to the ship when loaded down to the design draft. This draft will usually be less than the freeboard or scantling drafts.

FIGURES

TABLES

GENERAL INTRODUCTION

The intent of this report is twofold. The long term purpose is to provide a first step in the eventual development of a completely rational approach to general cargo ship design. The more immediate aim is to present the detailed technical-economic conclusions reached to date -- conclusions which, while necessarily restricted in scope, should nevertheless prove of interim usefulness in ship design.

One traditional difficulty in preliminary design is that astute shipowners usually express their needs in terms of trade route requirements: amount and type of cargo to be transported annually, ports to be serviced, and so forth (10)*. Preliminary studies then lead to various alternative fleet concepts, each of which meets the specified functional requirements and from among which the most profitable can be found. The component ship of the most profitable fleet will then be defined in terms of its own functional capabilities; cargo weight and volume, sea speed, and endurance. The naval architect, however, cannot delineate the ship until he has converted speed to horsepower. But this he cannot do until he has first converted cargo weight to displacement, which again he cannot do until he knows horsepower and on and on. Thus, he is usually forced to guess at the relationships between these factors and to waste time working on a series of gradually closing loops in the cycle of design (40). One aim of this study is to provide a tool that will eliminate much of this repetitive labor. This aim is accomplished through systematic analyses which start with the naval architect's technical parameters (displacement and horsepower) and from which are synthesized corresponding commercial transport capabilities (speed, distance, cargo weight and bale capacity). Generalizations are thereby made which allow the reverse procedure to be carried out in actual practice. Thus, given any reasonable requirements for speed, length of voyage, cargo weight and bale capacity, the naval architect can within minutes block out the principal technical characteristics of a suitable ship.

The above process, complemented by systematic studies of operating economics, makes it reasonably easy to conduct engineering economy studies on large numbers of alternative, functionally equivalent ships, or fleets, in order to find the one of greatest profitability potential.

---

*Numbers in parentheses correspond to publications listed in the Reference.

The factual information on which the study is based is drawn both from publications and from confidential data supplied by various informed individuals. Interpretation of such data is always difficult; frequently the information is unusable as received and needs guess work in application; some data points represent fleet averages, some ship class averages and some, individual vessels; as frequently happens, most plotted points are clustered near the middle of the chart with few points at the extremes. In short, the available figures are hardly suitable for conventional statistical analysis; rather, common sense and judgment based on past experience with other types of ships have been used to propose what order may lie in the plotted chaos.

So that the results of the study may be applied to ships of unconventional size or speed, most of the parameters are allowed to extend well beyond currently practical limits. The final results are somewhat less radical in scope than originally planned largely because the higher speeds were found to demand impossible combinations of horsepower and displacement, leading to negative deadweight or bale capacity (based on conventional machinery requirements). Table I shows the range of factors considered both initially and finally. Of course, not every combination of the final extremes would be technically, much less economically, feasible.

Where propulsion machinery is a factor, single screw, geared steam turbines are assumed. In several cases reference is also made to twin screws, diesel or gas turbine installations. In the sections dealing with cargo weights and volumes, operation both with and without evaporators is considered. All of the above variations merit further research.

All cost factors are based on ships built in U. S. yards and operated under U. S. flag. Subsidy support and foreign costs are already well covered in other references (69, 78, 96 and 134) so are dealt with only briefly in this study.

Table II shows a skeleton specification for what is considered an average ship for purposes of this study.

It may be noted that Table II places no direct restrictions on the size or speed of our typical ship; thus we are free to study economic factors over a wide range of technological combinations. Within such a framework it is necessary to set up restrictions which allow systematic study of bite-sized portions. These restrictions are only temporary, however, and may be methodically shifted as each increment of the analysis is completed. In this study, two limited areas are investigated; and although these are widely separated, they are so related that all intermediate areas may be readily understood. Our first limited grouping, identified as the B-1 Series, is intended

TABLE I

RANGE OF FACTORS CONSIDERED

(Dimensions are in feet, weights are in long tons)

Item	Initial Proposal		Final Range	
	Minimum	Maximum	Minimum	Maximum
Length (BP)	180	800	100	800
Beam	30	110	30	110
Depth	10.5	65	10	65
Draft	8	40	10	46
Displacement	1,000	75,000	1,500	70,000
Deadweight	750	60,000	1,000	60,000
Cubic Number	500	60,000	5,000	60,000
Sea Speed, knots	8	38	12	28
SHP_N (single screw)	0	40,000	5,000	40,000
SHP_N (twin screw)	0	70,000	2,000	70,000
Block Coefficient	0.50	0.90	0.50	0.90
Cargo Weight	-	-	1,000	50,000
Bale Capacity, cu.ft.	-	-	0	3,500,000

TABLE II

TYPICAL GENERAL CARGO SHIP

Machinery Location: amidships.

Machinery Type: single screw, geared steam turbine with two, two drum, bent tube boilers; electric auxiliaries; evaporators.

Steam Conditions: 600 psi, 850° F.

Cargo Gear: conventional kingpost and boom arrangement; 5- to 10-ton booms plus a 60-ton jumbo.

Holds: mechanically ventilated, 50% dehumidified; moderate capacity for liquid and refrigerated cargoes; hydraulically operated hatch covers at all decks.

Construction: ABS, maximum welding, scantling draft.

Hull Form: standard sheer and camber; forecastle (20% LBP); see B-1 Series, Chapter I for proportions.

Accommodations: one and two-man rooms, semi-private baths, air conditioned.

Passengers: 12.

Regulatory Requirements: ABS, Maritime Administration, U. S. Coast Guard, U. S. Public Health Service.

(See References 25, 72, 87, 103, 107, 112 and 119).

to represent average modern U. S. practice in general cargo ship design but with wide latitude in size and speed. The second, or B-1.8 Series, is similar in every respect except that freeboards are arbitrarily increased 80 percent over those of the first series, with beam and draft adjusted to maintain stability. Freeboard is thereby introduced as a variable, permitting fuller insight into the design impact of increased cargo stowage factors. The following chapter explains the development of the B-1 and B-1.8 Series in detail.

Future studies should make further methodical shifts in the restrictions mentioned or implied above. Chapter X suggests several such possibilities.

Although the typical specification shown in Table II is derived from modern U. S. ships in berth line operation, it could also be applied to tramp ships. The chief difference would be caused by the fact that the latter would presumably be unsubsidized and hence less influenced by the direct and indirect pressures of the 1936 Act. Also, tramp ships would have complete freedom in choice of speed since fixed schedules are inappropriate.

Chapter I, immediately following, is in effect a summary of the findings of much of the rest of the report. It presents the design development and functional capabilities of the ships of the B-1 and B-1.8 Series. It also shows their estimated building costs and principal dimensions. Estimation of functional capabilities necessarily employs several assumptions which any particular operator may find at variance with his own conditions. If these variations are numerous or extreme, he may prefer to reassemble the conclusions of Chapter I using his own bits and pieces. If such is the case, the details presented in Chapters II through VII may be helpful; they should also prove useful in future research extending beyond current limitations.

Chapters II through VI discuss the many considerations (such as proportions, weights and building costs) that provide the foundation for economic analysis of cargo ship design.

Chapters VII and VIII, which are not altogether amalgamated into the first chapter, deal with ship scheduling factors and operating costs. Chapter IX clarifies the use of the report by means of a numerical example while Chapter X outlines further research needs.

Estimating retains much of the black art and the researcher who wishes to explore the subject must defer to the confidential dictates of his sources of information. The usual requirement allows the researcher to analyze the data and publish his conclusions; the reader cannot make his own analysis, however, because dissemination of the basic data is nearly always verboten. This is unfortunate since a good deal of judgment is necessarily employed for reasons already stated. Hence any other student of the subject would, no doubt, reach somewhat different conclusions. Having made these apologies, the following points are given as an aid in evaluating the reliability of the less well-documented findings:

1. The majority of the building cost details are confined to recent Maritime Administration ships with displacement ranging from 16,000 to 21,000 tons. Costs for three larger containership or roll-on designs indirectly extend the displacement range to 50,000 tons.

2. Weight information includes, in addition to the above, numerous warmed over figures from the old C-1, C-2 and C-3 designs, as well as several assorted vessels. The range is thereby enlarged to displacements as low as 12,000 in several cases, with a few of less than half that amount.

3. Ship operators have submitted estimated operating costs for vessels ranging in displacement from 7500 to 40,000 tons with horsepowers ranging from 5000 to 30,000. In most cases the estimates show only fair agreement with one another.

4. Conclusions regarding steel weights are probably correct to within three to five percent for cubic numbers between 7000 and 20,000 and within seven percent outside those limits.

5. Most actual machinery weights should fall within five percent of the predicted figures.

6. Outfitting and hull engineering weights show wide scattering as indicated by the maximum and minimum coefficients reported in Chapter V.

7. Building costs also show wide scattering as indicated by the coefficients shown in Chapter VI. As an example, two shipyards which submitted breakdowns on the same ship indicated a difference of two to one in the estimated man-hours for steel hull construction; and steel hull is among the easier costs to estimate.

CHAPTER I

SUMMARY OF THE B-1 AND B-1.8 SERIES

Introduction

The B-1 Series is intended to represent average modern U. S. cargo ship design but without restriction on size or speed. The B-1.8 Series is a variation in which (for corresponding designs) length, displacement and block coefficient are unchanged, but freeboard is arbitrarily increased by 80 percent; beam and draft are also modified as needed to maintain stability. This variation results in radically increased stowage factors (cubic feet of hold per ton of cargo) and, as shown in Appendix I, straight line interpolation and extrapolation are reasonably accurate between and somewhat beyond the two series.

For purposes of identification, a design halfway between a B-1 and B-1.8 Series would be part of the B-1.4 Series.

Method of Development

The B-1 Series is developed as follows. The basic variables are speed and displacement and these are arbitrarily put into many combinations. For each combination, length is found by means of Equation 4 (see Chapter II). Speed-length ratio is then calculated leading to the establishment of the block coefficient, taken from Figure 18. Tentative values of beam and draft, found from Equations 8 and 9, are used to establish the beam-draft ratio. These two dimensions are then modified so as to balance the equation between block coefficient and displacement; beam-draft ratio is left unchanged, however. Depth is arbitrarily set at a value equal to the length divided by 11.5, which is an average value for modern designs. Freeboard is found by subtraction and is, in all cases, greater than the minimum required by regulation.

In the B-1.8 Series, length, displacement and block coefficient are held the same as in any given combination of speed and displacement in the B-1 Series. Freeboard, however, is increased by 80 percent. Beam and draft are then varied from the B-1 values in order to maintain the same relative transverse stability. This is done by multiplying the beam and dividing the draft by the cube root of 1.8 (Appendix III proves this relationship.) Depth is found by adding draft to freeboard.

Owing to restrictions on time, no definitive study is made of the relationship between power and speed for the various hypothetical designs. As an expedient Figure 19, based primarily on Minorsky's nomograph (84), is used to find the approximate horsepowers required for the B-1 Series. Because of its greater beam-draft ratio, any given design of the B-1.8 Series is assumed to have a sea speed four percent less than that of the corresponding B-1 design of equal power. This is an average figure based on limited analysis.

Throughout this paper (unless otherwise specified) speed, power, draft, freeboard, displacement, deadweight, cargo weight and all other characteristics are those at the designed condition.

Delineation

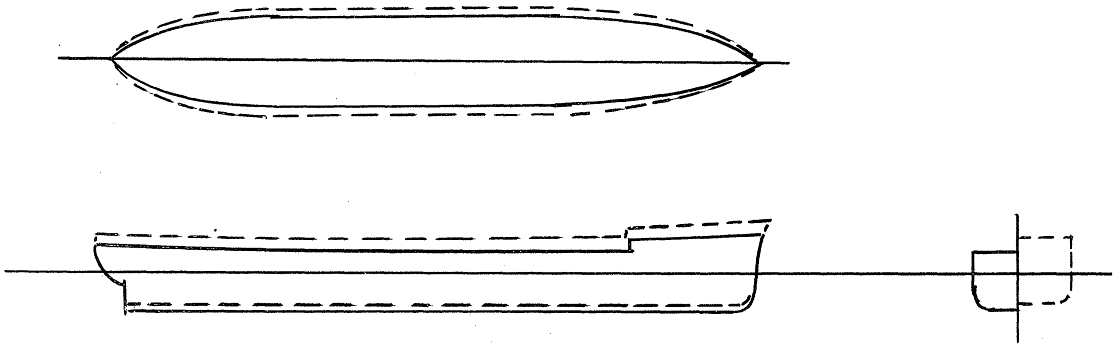
Figures 1 through 4 show the principal dimensions of the B-1 Series while Figure 5 shows block coefficients. Table III shows how these values may be modified in order to define the B-1.8 Series or any intermediate design. Figure 6 shows cubic numbers for both series. The undulations in many of the contours are caused by the characteristic relationship between block coefficient and speed-length ratio as shown in Figure 5.

TABLE III

CORRECTION FACTORS FOR VARIATION FROM B-1 SERIES

Item	Factor for B-1.8 Series	Factor for any Variation
Freeboard	1.8	r
Length	1.0	1.0
Displacement	1.0	1.0
Block Coefficient	1.0	1.0
Beam	1.216	$\sqrt[3]{r}$
Draft	$\frac{1}{1.216}$	$\frac{1}{\sqrt[3]{r}}$
Speed	1.0	1.0
Horsepower	See note below	

Note: Horsepower for the B-1.8 series is taken as that power required to drive the corresponding B-1 Series vessel at a speed increased by the factor 1/0.96. For other variations the denominator in the factor would be 1.05 - (r/20).



Typical B-1 Hull: ————————————

Corresponding B-1.8 Hull: — — — — — — — — — — — —

FIG. I

LENGTH, SPEED & DISPLACEMENT FOR B-1 SERIES

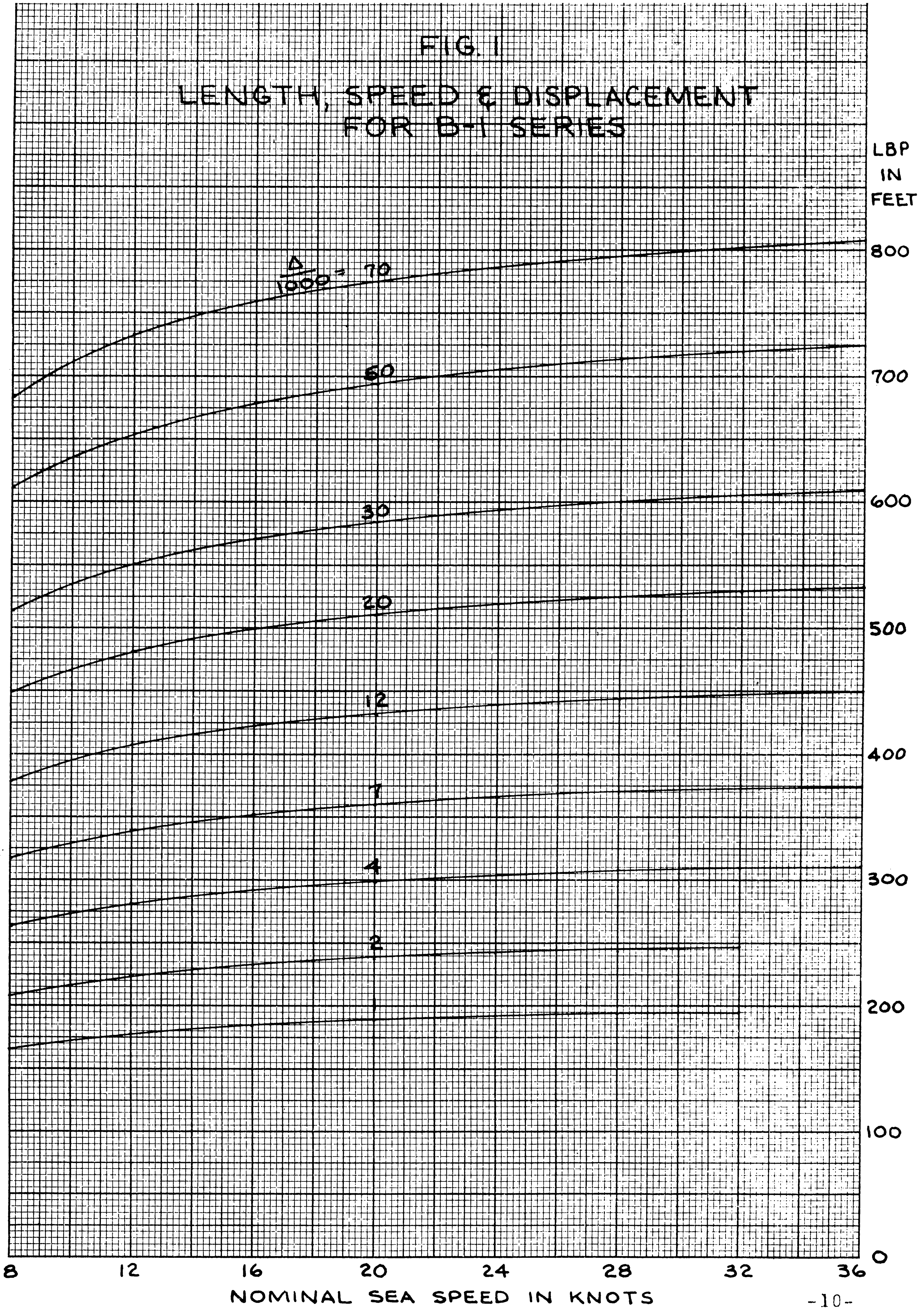


FIG. 2

FREEBOARD FOR B-1 SERIES

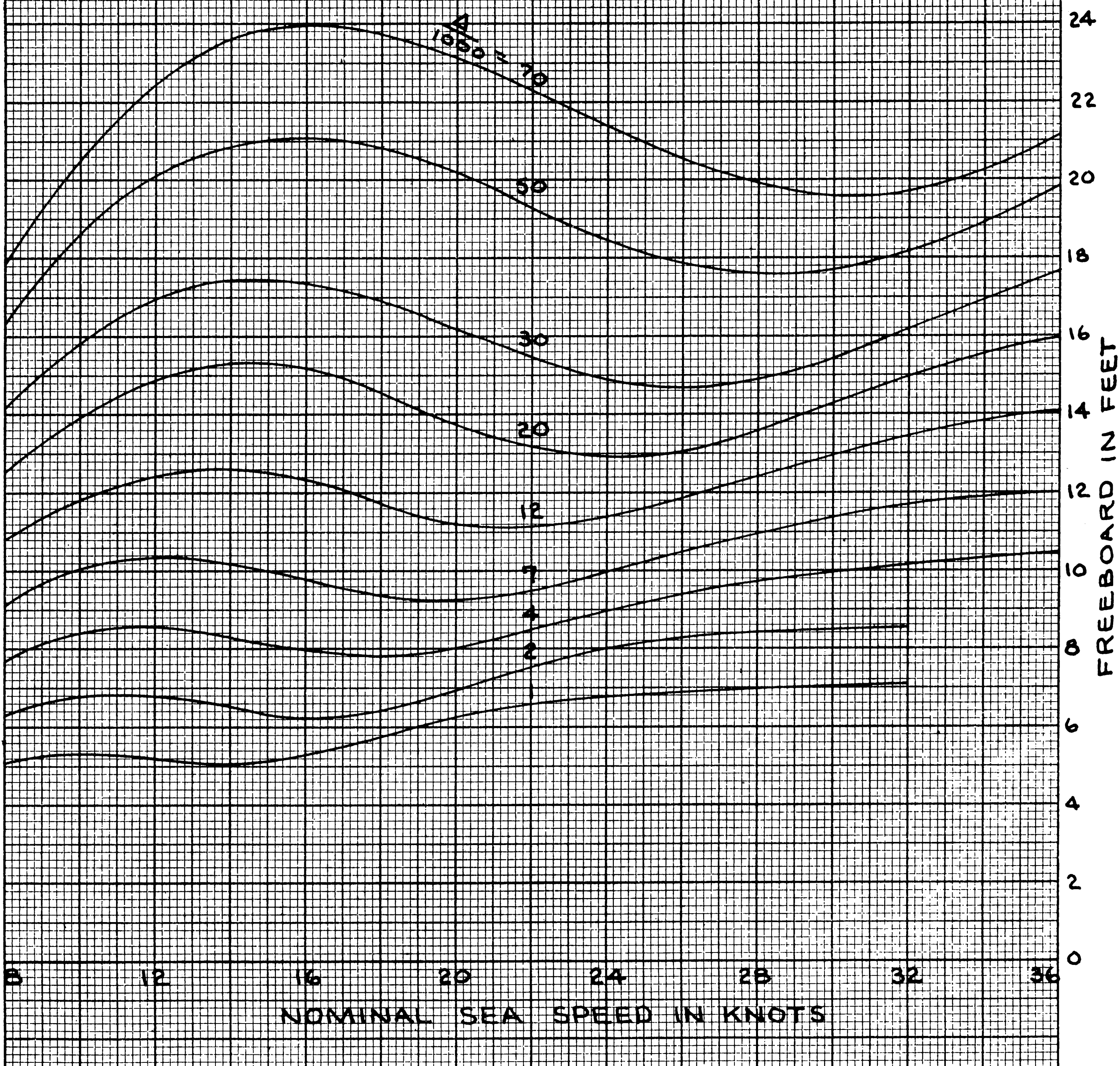
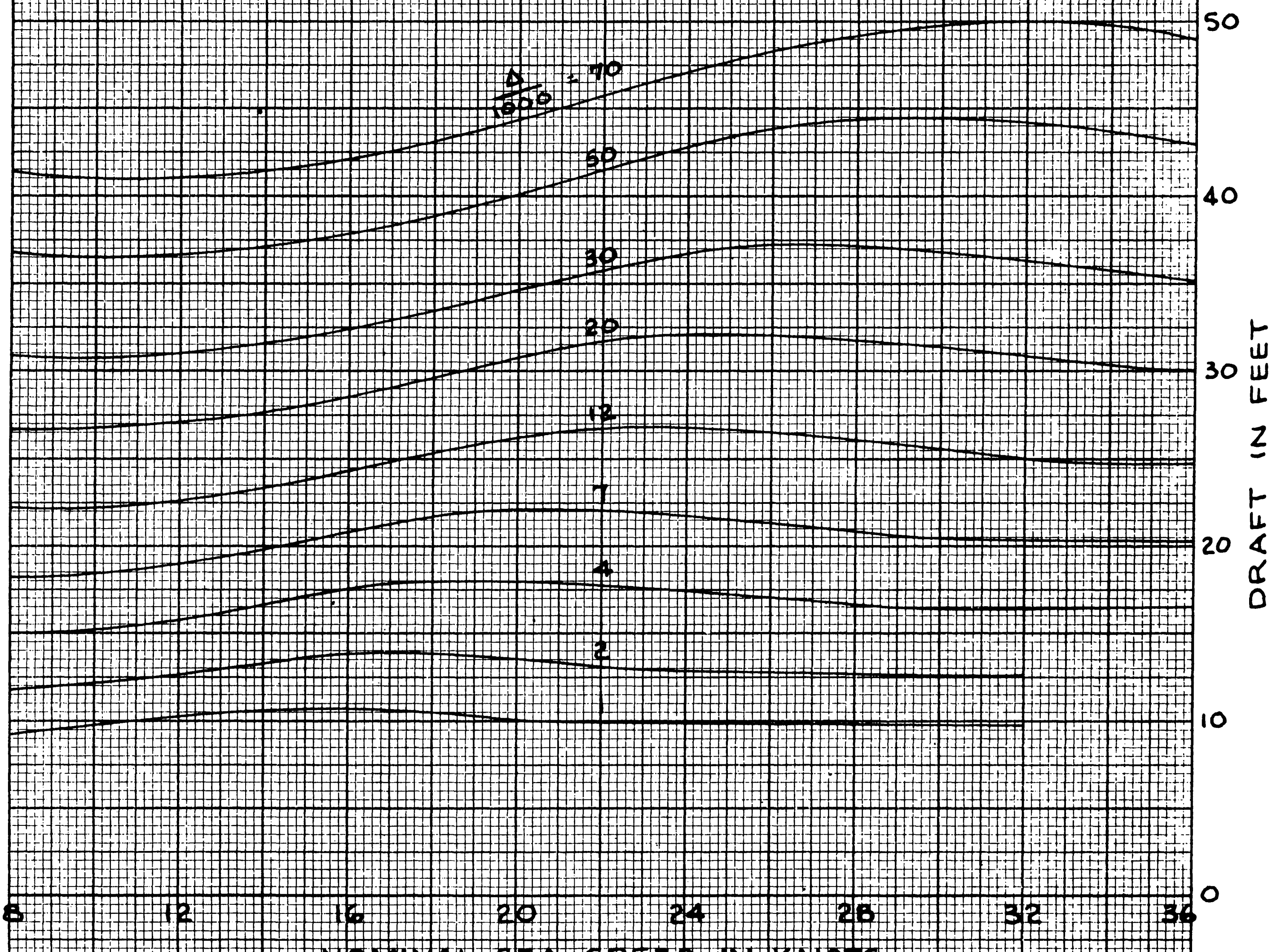


FIG. 3

DRAFT FOR B-1 SERIES



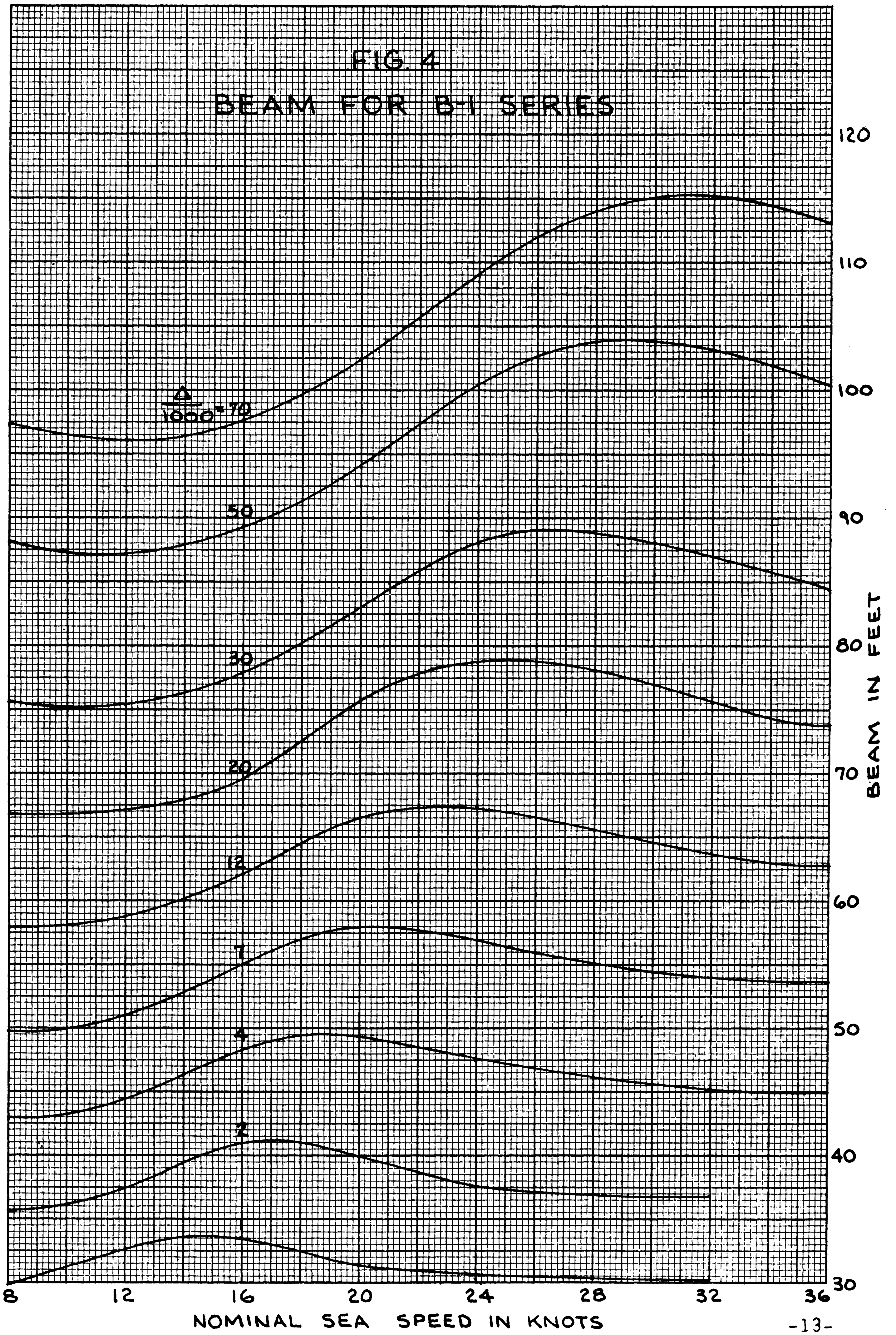


FIG. 4

BEAM FOR B-1 SERIES

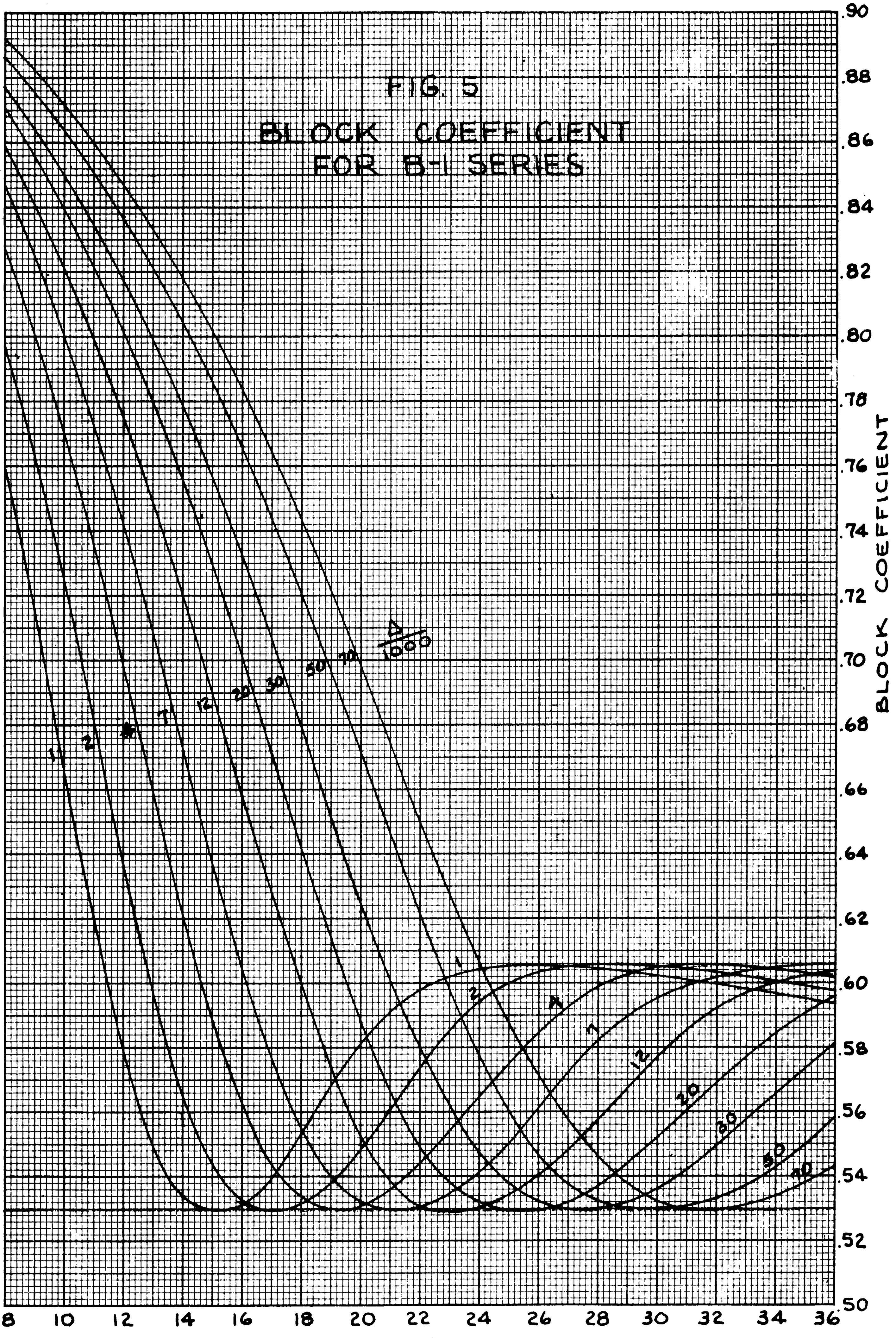


FIG. 5

BLOCK COEFFICIENT FOR B-1 SERIES

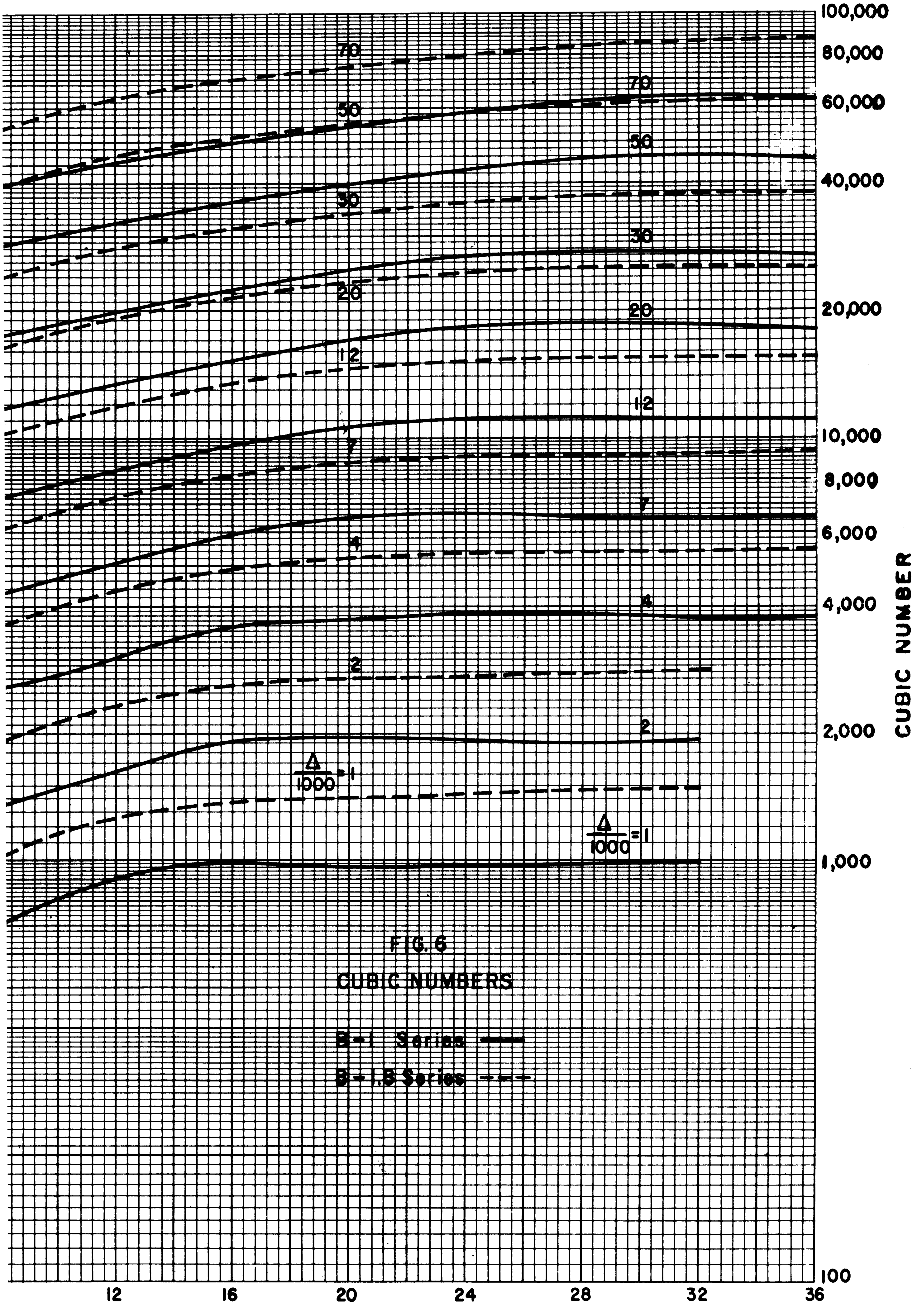


FIG. 6

CUBIC NUMBERS

NOMINAL SEA SPEED IN KNOTS

Deadweight Coefficients

Figures 7A through 8B show the relationship between deadweight, displacement and horsepower for both the B-1 and B-1.8 Series. Figures 9A and 9B are similar to Figures 8A and 8B except that approximate sea speeds are substituted for horsepower. The potential usefulness of these figures is obvious. Table IV confirms the relative accuracy of the curves; the departures are caused largely by variations in the elaboration of outfitting and hull engineering in the individual ships.

Chapter V explains the methods of estimation used in the development of these curves.

TABLE IV

PUBLISHED vs PREDICTED DEADWEIGHTS AND BALE CAPACITIES

Notes:

1. Predicted deadweights are from Figure 7A.
2. Predicted bale capacities are from Figure 11A
3. Tabulated values of deadweight and bale capacity are in thousands of long tons and thousands of cubic feet, respectively.
4. Published values of deadweight and bale capacity are from Reference 103. Bale capacities include reefer and liquid cargoes uncorrected for relative volumetric requirements.
5. The ratio shown in each case is the predicted value divided by the published value.

(Cont'd.)

TABLE IV (Cont'd.)

Ship	Deadweight			Bale Capacity		
	Publ.	Predict.	Ratio	Publ.	Predict.	Ratio
C3-S-33a	10.46	10.22	0.977	563	624	1.107
C3-S-37b	10.99*	10.68	0.972	605	660	1.090
C3-S-38a	10.21	10.38	1.016	643	628	0.976
C3-S-46a	10.18	10.46	1.027	750	632	0.842
C3-S-43a	10.98	10.56	0.962	682	653	0.958
C4-S-1q	12.54	13.25	1.057	751	774	1.029
C4-S-1s	11.97	11.42	0.954	787	654	0.831
C4-S-1t	12.22	13.25	1.083	744	774	1.039
C4-S-1u	12.82	13.25	1.033	817	774	0.947
C4-S-58a	12.39	12.48	1.006	703	732	1.041
C4-S-57a	10.71	10.83	1.011	703	617	0.878
Average			1.009			0.977

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* Value is for maximum deadweight; design value is not published.

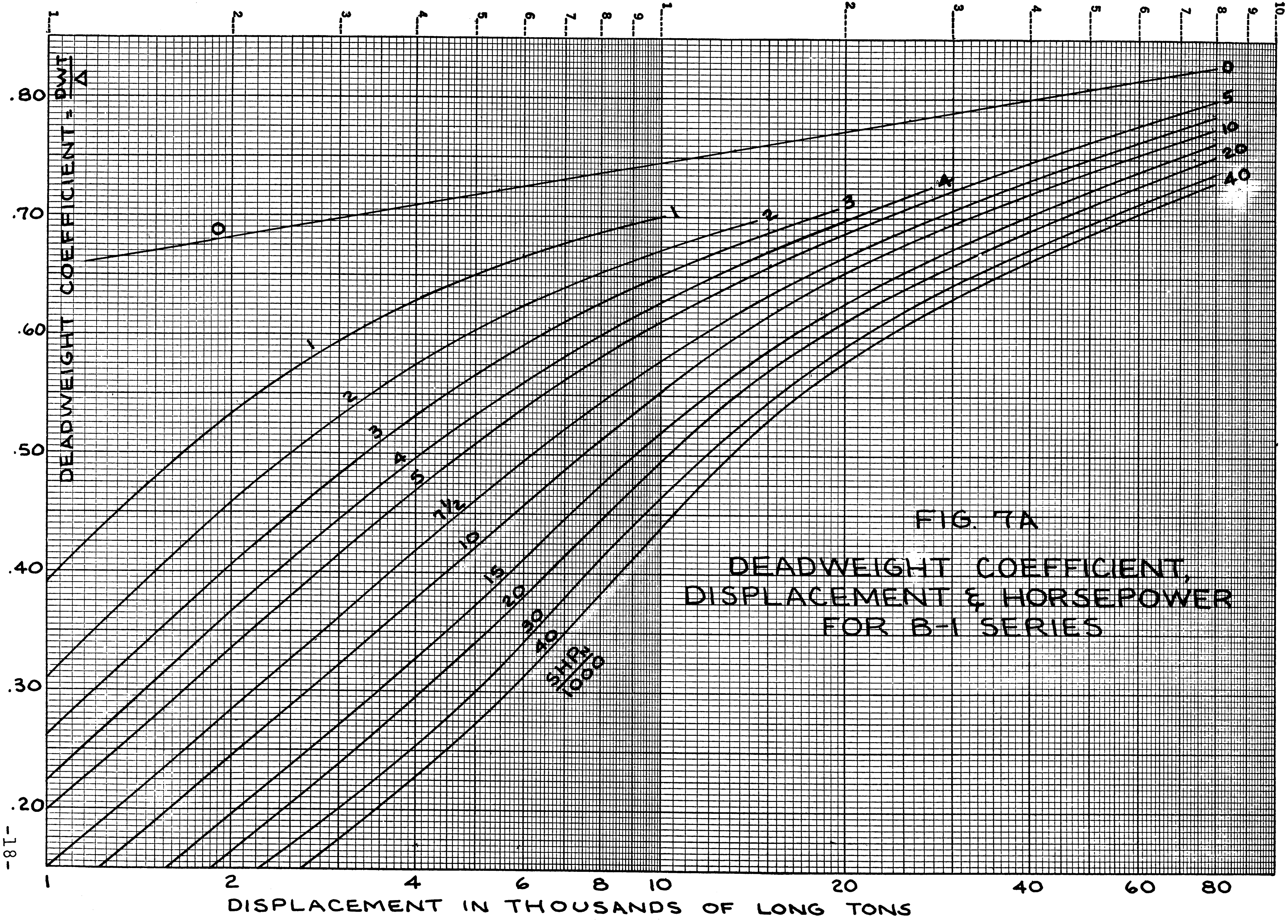


FIG. 7A

DEADWEIGHT COEFFICIENT, DISPLACEMENT & HORSEPOWER FOR B-1 SERIES

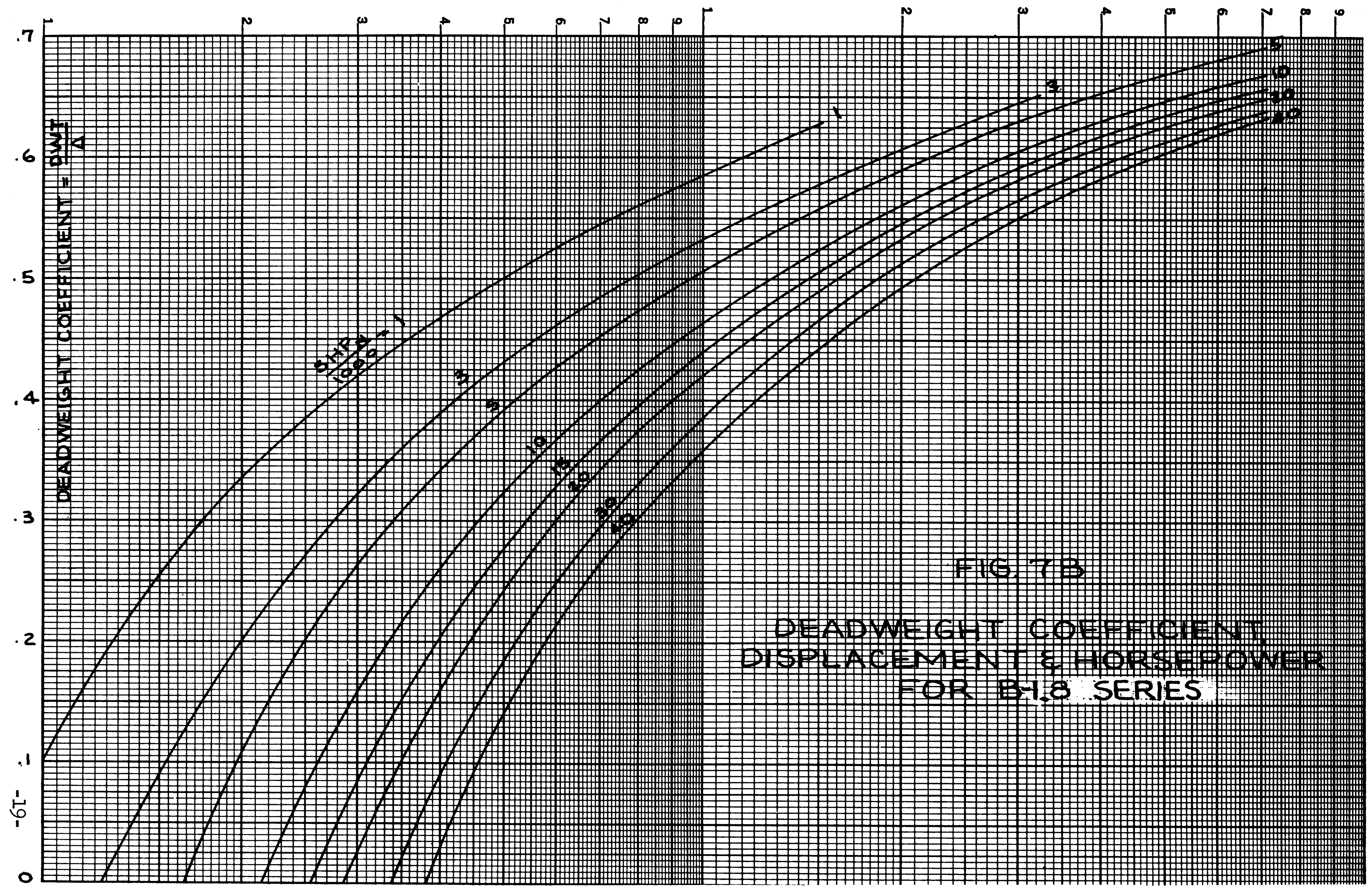


FIG. 7B

DEADWEIGHT COEFFICIENT,
DISPLACEMENT & HORSEPOWER
FOR B-1.8 SERIES

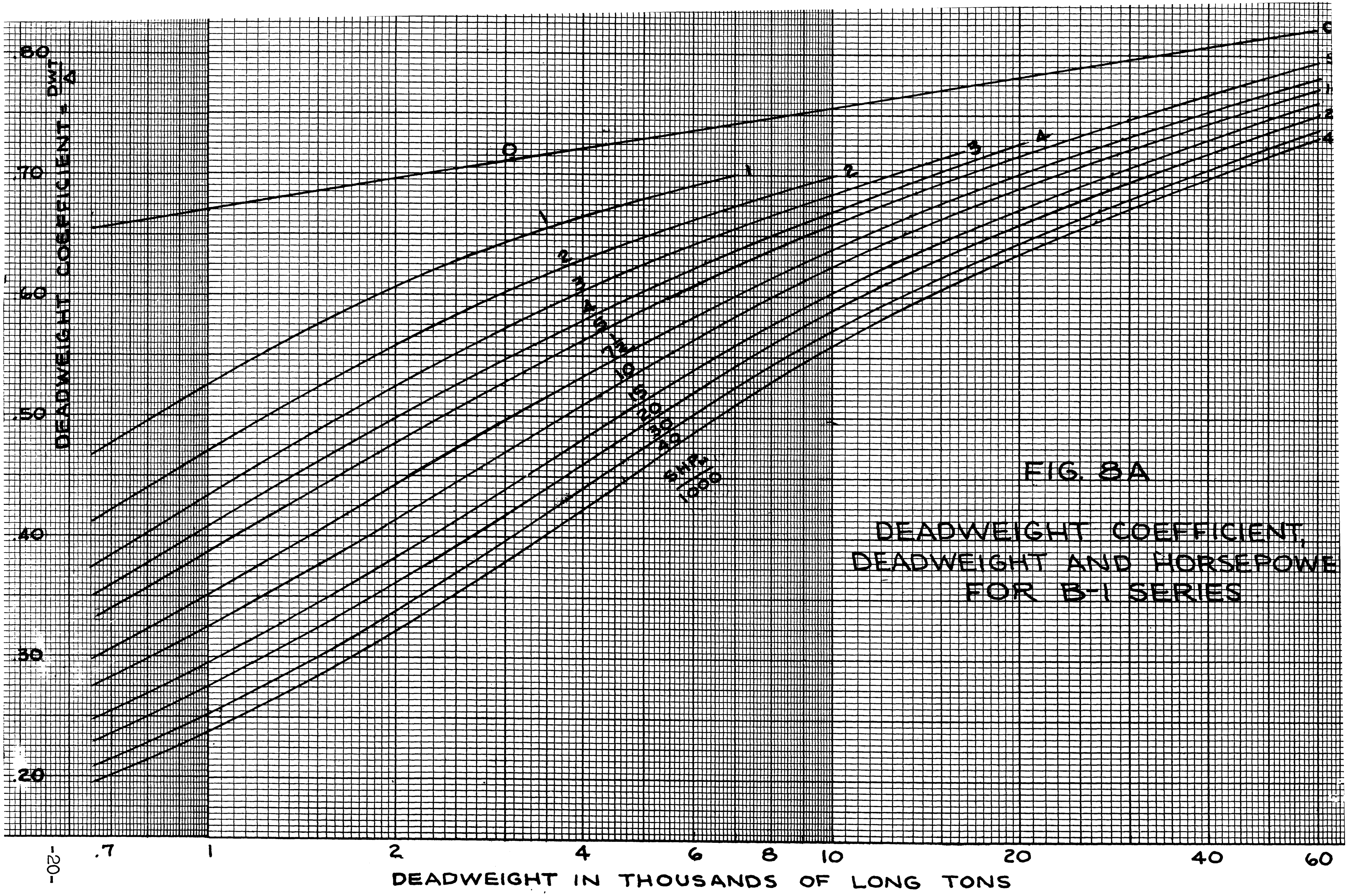


FIG. 8A

DEADWEIGHT COEFFICIENT,
DEADWEIGHT AND HORSEPOWE
FOR B-1 SERIES

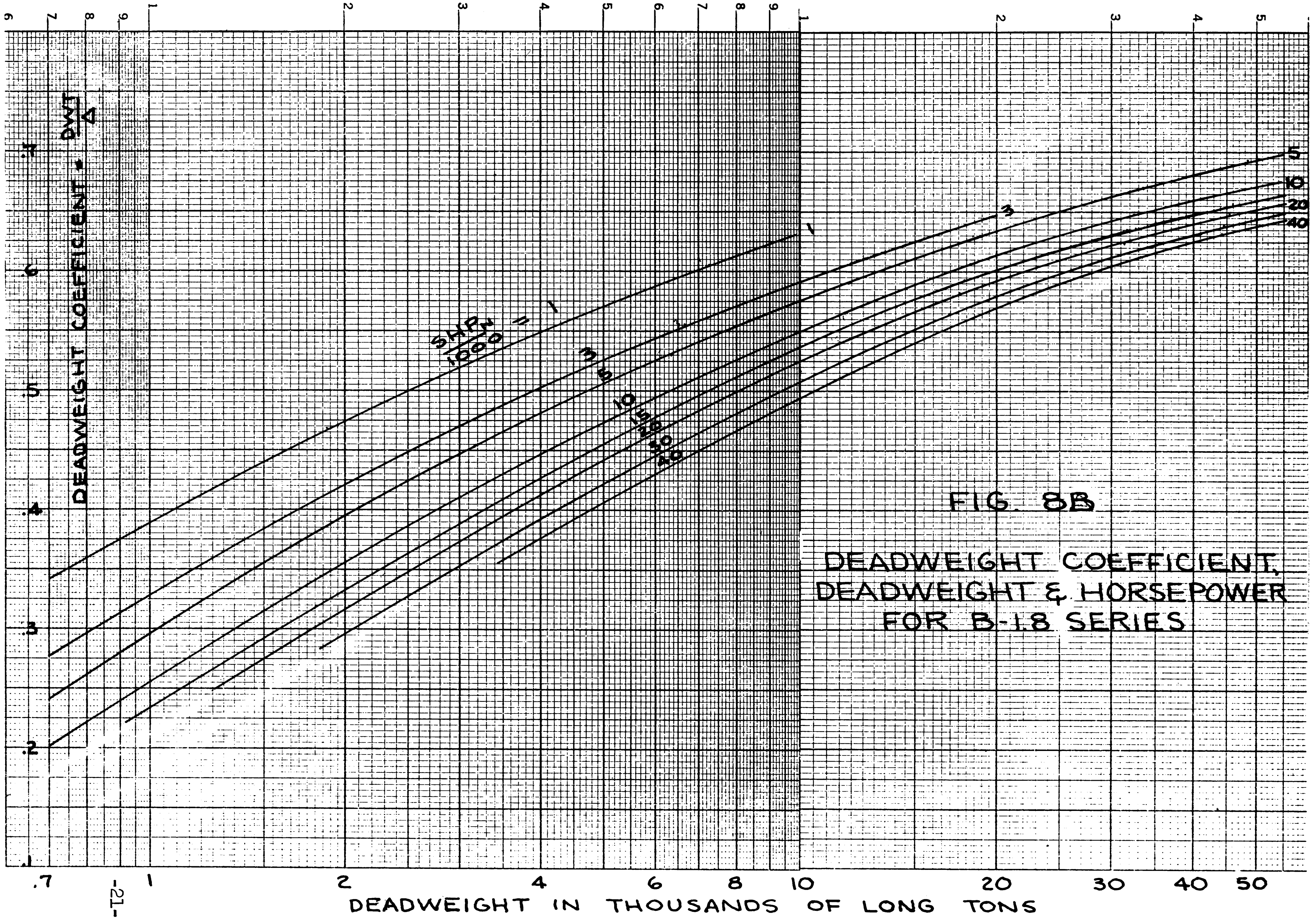


FIG. 8B

DEADWEIGHT COEFFICIENT,
DEADWEIGHT & HORSEPOWER
FOR B-18 SERIES

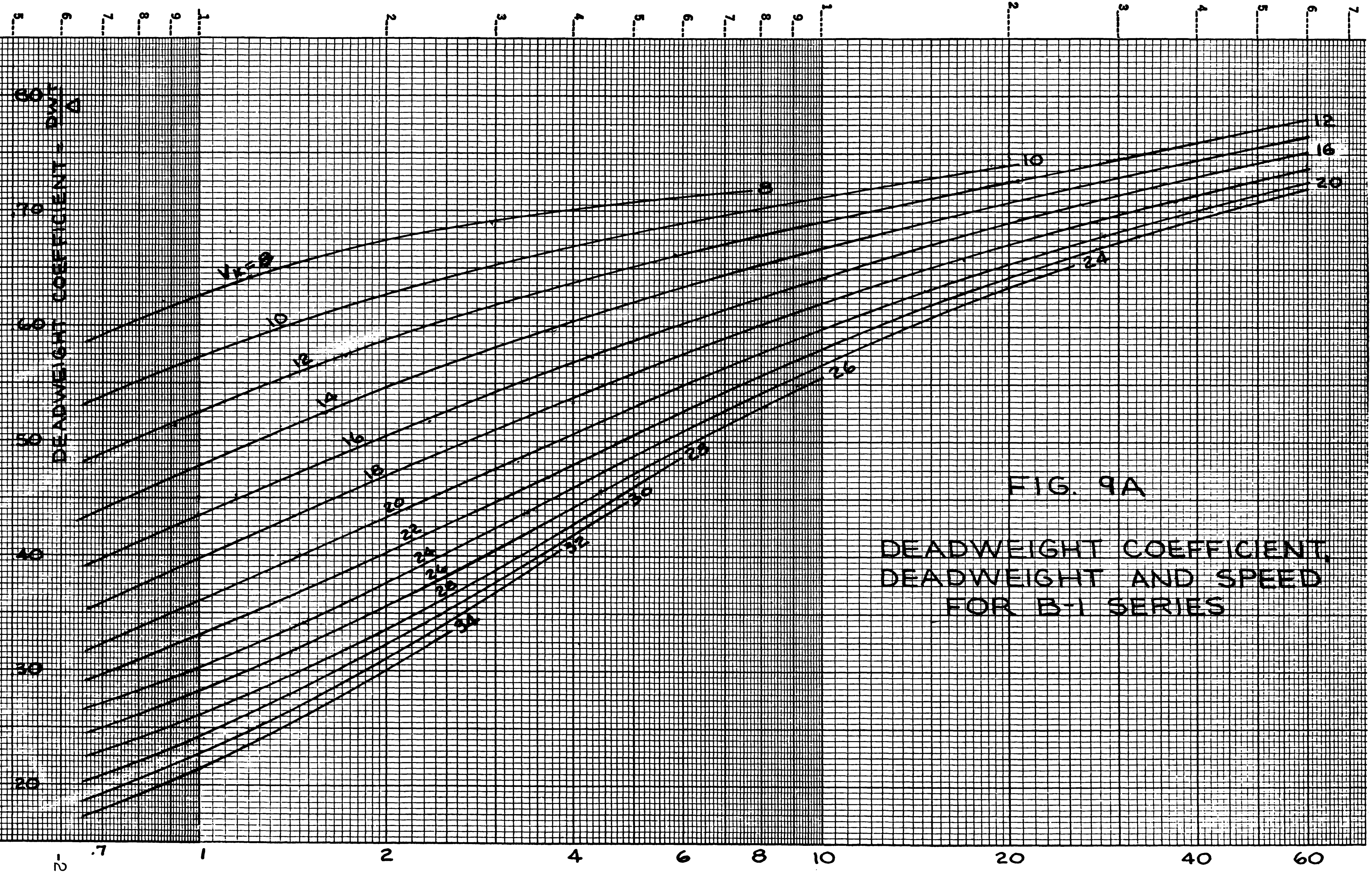


FIG. 9A

DEADWEIGHT COEFFICIENT,
DEADWEIGHT AND SPEED
FOR B-1 SERIES

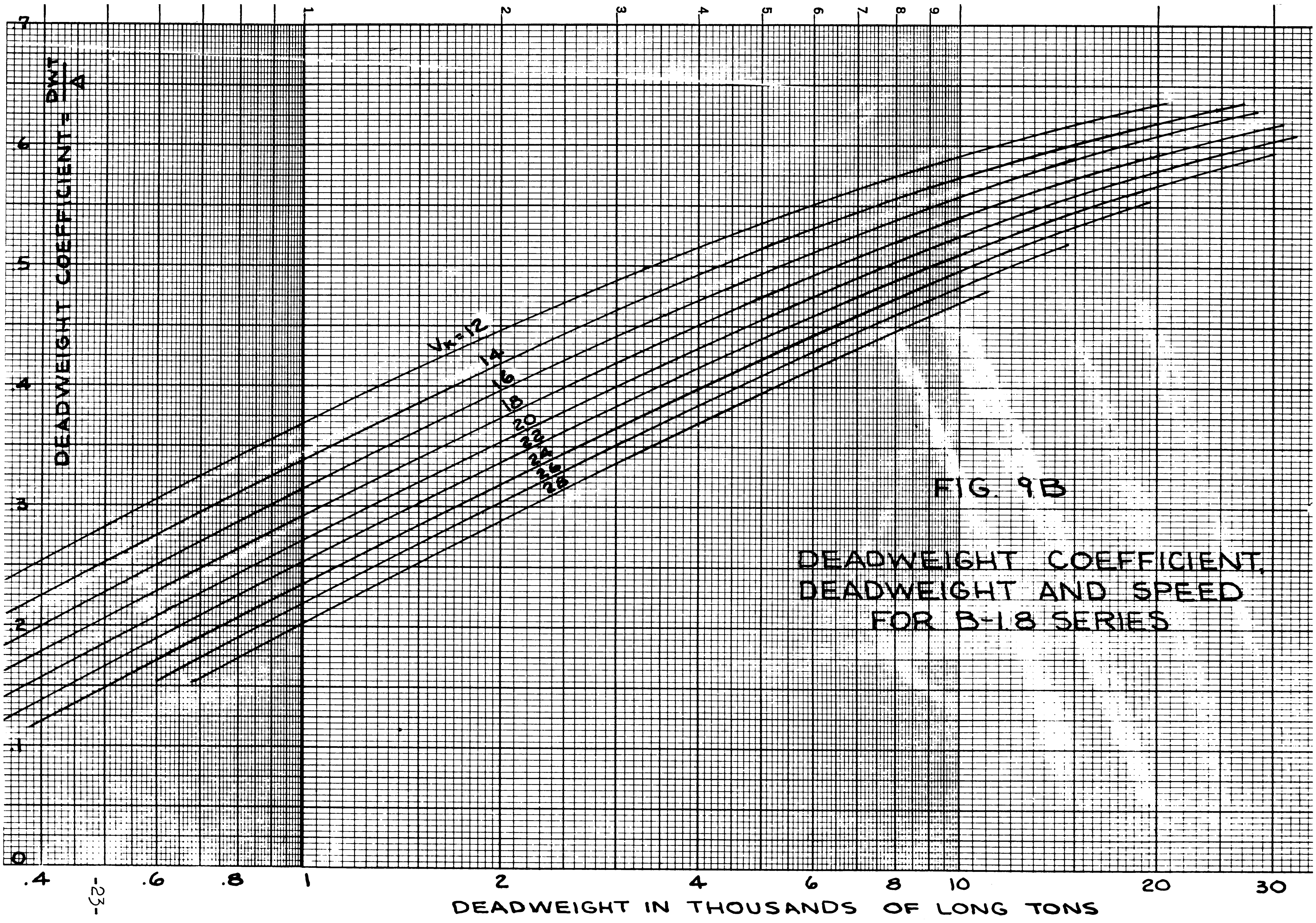


FIG. 9B

DEADWEIGHT COEFFICIENT, DEADWEIGHT AND SPEED FOR B-18 SERIES

Cargo Weight vs Deadweight

Total deadweight includes -- in addition to cargo weight -- weight of fuel, feed water, domestic water (washing and potable), lubricating oil, diesel oil for emergency generator, dunnage, provisions and stores, plus passengers, crew and effects. All of these non-payload items are lumped together in the term "lost deadweight". Thus, cargo weight plus lost deadweight equals deadweight.

The amount of lost deadweight hinges on many factors, principally distance between fueling ports, horsepower, overall size and presence or absence of evaporators. Despite the discouragement of so many considerations, a parametric study is made of hypothetical ships on typical voyages. This study leads to generally applicable conclusions relating cargo weight to deadweight. The analysis is based principally on zero and 20,000-mile round trip distances plus enough intermediate ranges to establish the accuracy of straight line interpolation.

The results of the lost deadweight analysis are summarized in Figures 10A through D. These may be used to convert cargo weight to deadweight or vice versa. The dashed line in each figure represents the relationship at any speed for zero round trip distance, the solid contours represent the relationship for a 20,000-mile round trip voyage. Values for intermediate distances may be found by simple interpolation. Four figures are required in order to indicate the two standard series both with and without evaporators since this factor will have an appreciable influence on the amount of fresh water carried in reserve.

Cargo Volume

Differing trade routes put differing requirements on the relative amounts of ordinary dry cargo, liquid cargo, refrigerated cargo and containerized cargo. In order to put all these into a single common denominator the concept of "equivalent bale capacity" (EBC) is introduced. The equivalent bale capacity of a ship is that bale capacity it would have if all provisions for special cargo were eliminated and the spaces given over to the accommodation of ordinary break-bulk dry cargo. The details of this calculation may be found in Chapter IV. In the average modern ship the equivalent bale capacity is usually about equal to the sum of the actual capacities of dry cargo holds, refrigerated holds and cargo tanks.

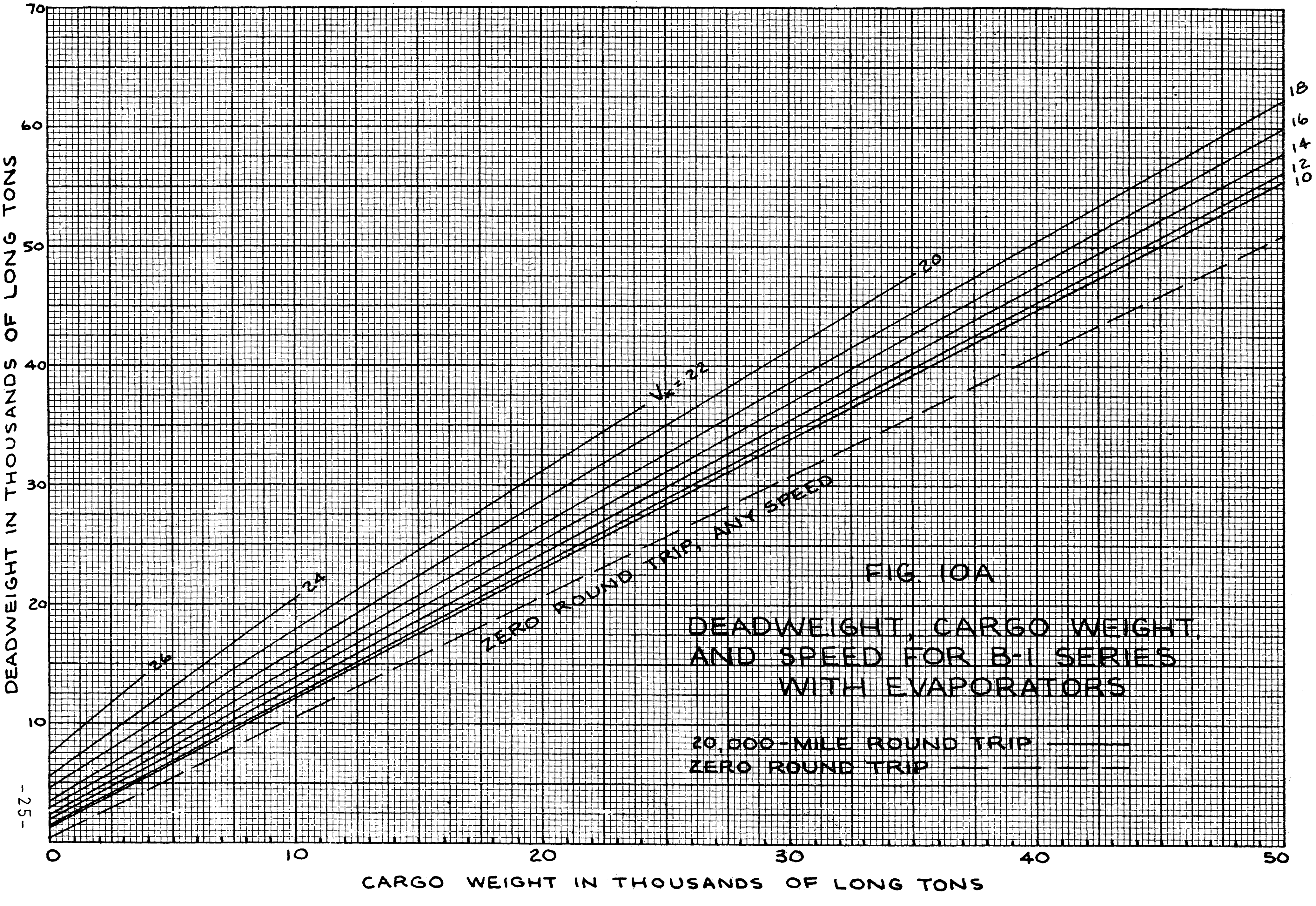


FIG. 10A

DEADWEIGHT, CARGO WEIGHT AND SPEED FOR B-1 SERIES WITH EVAPORATORS

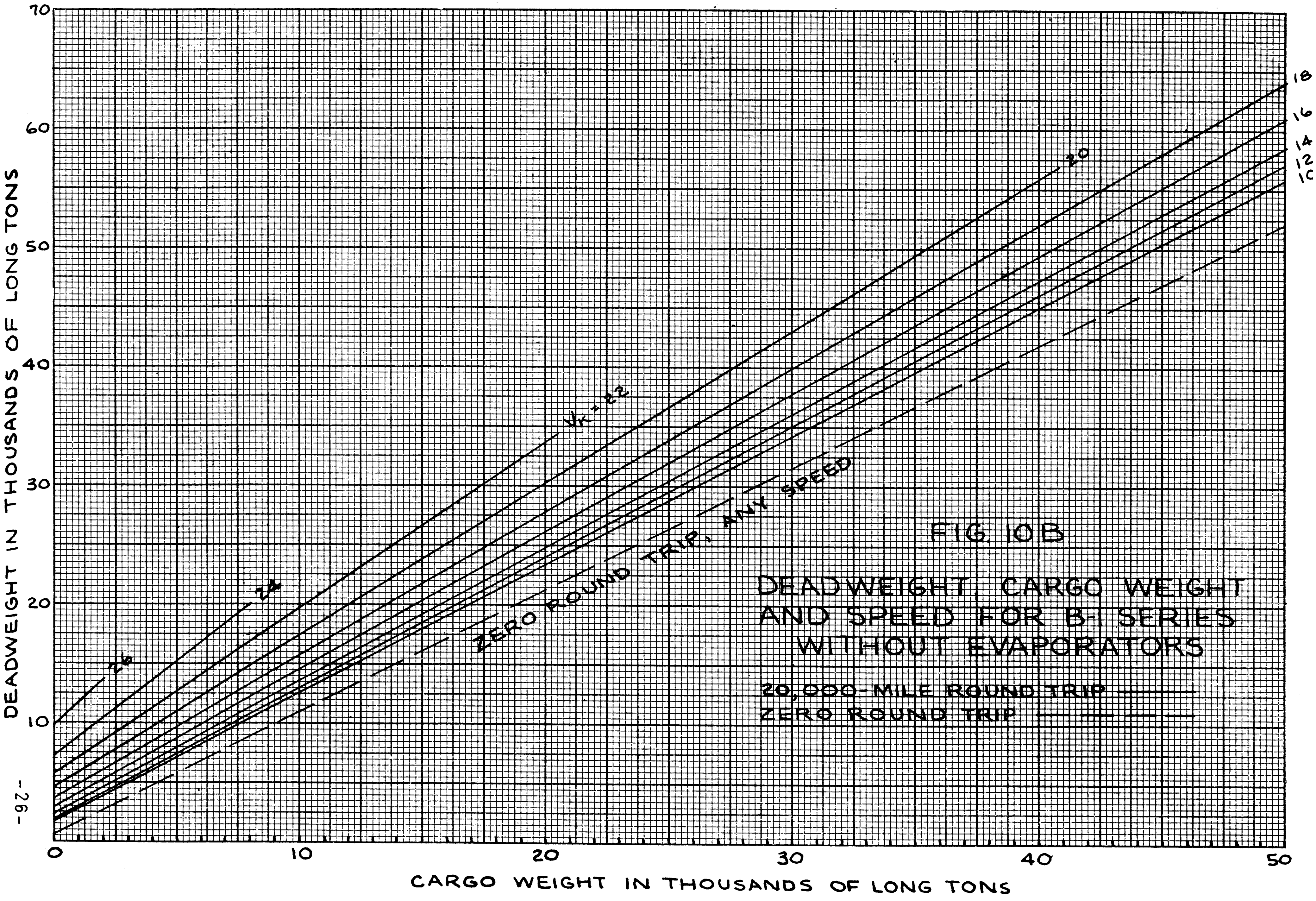


FIG. 10B

DEADWEIGHT, CARGO WEIGHT AND SPEED FOR B-1 SERIES WITHOUT EVAPORATORS

FIG. 10C

DEADWEIGHT, CARGO WEIGHT AND SPEED FOR B-1.8 SERIES WITH EVAPORATORS

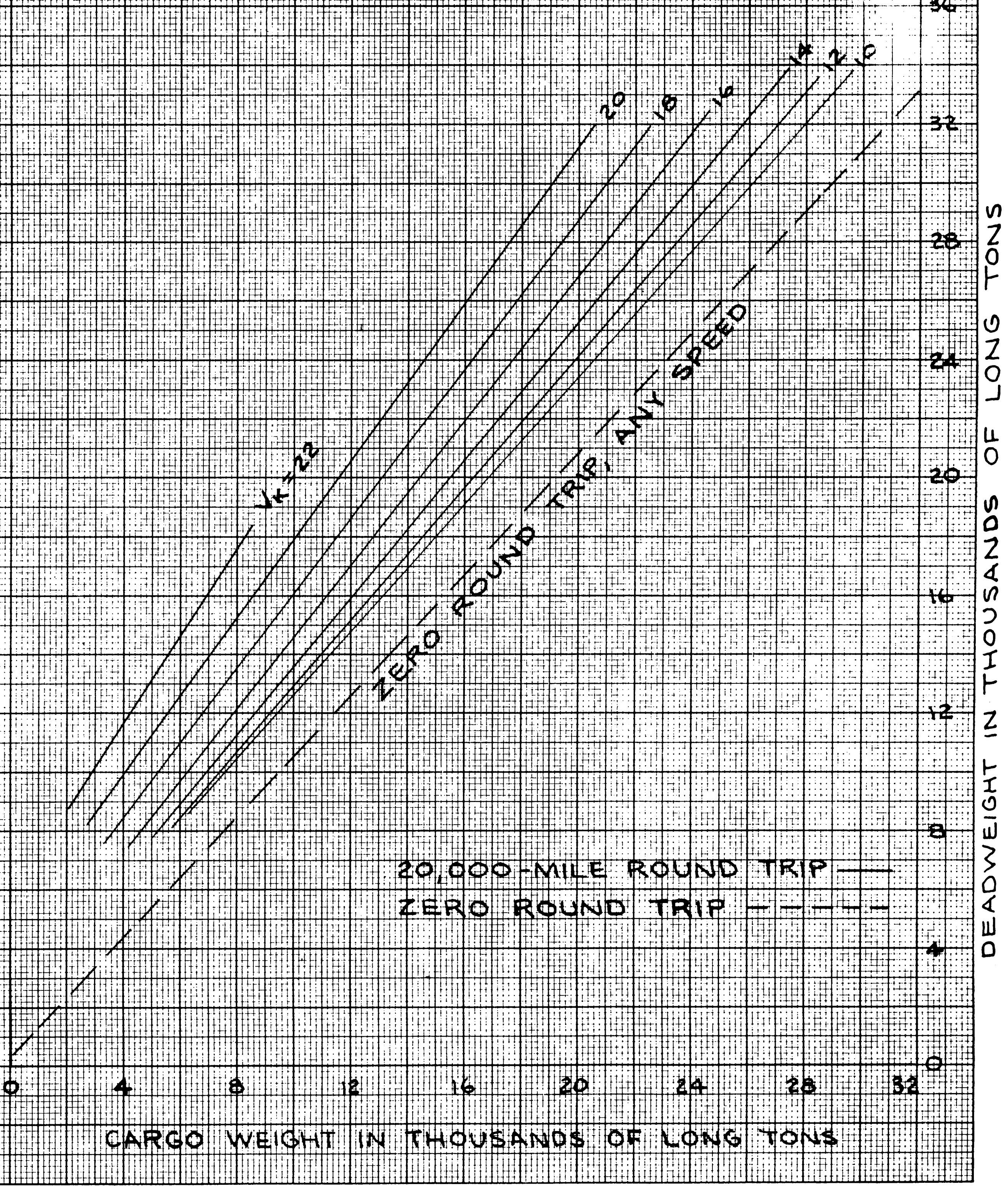
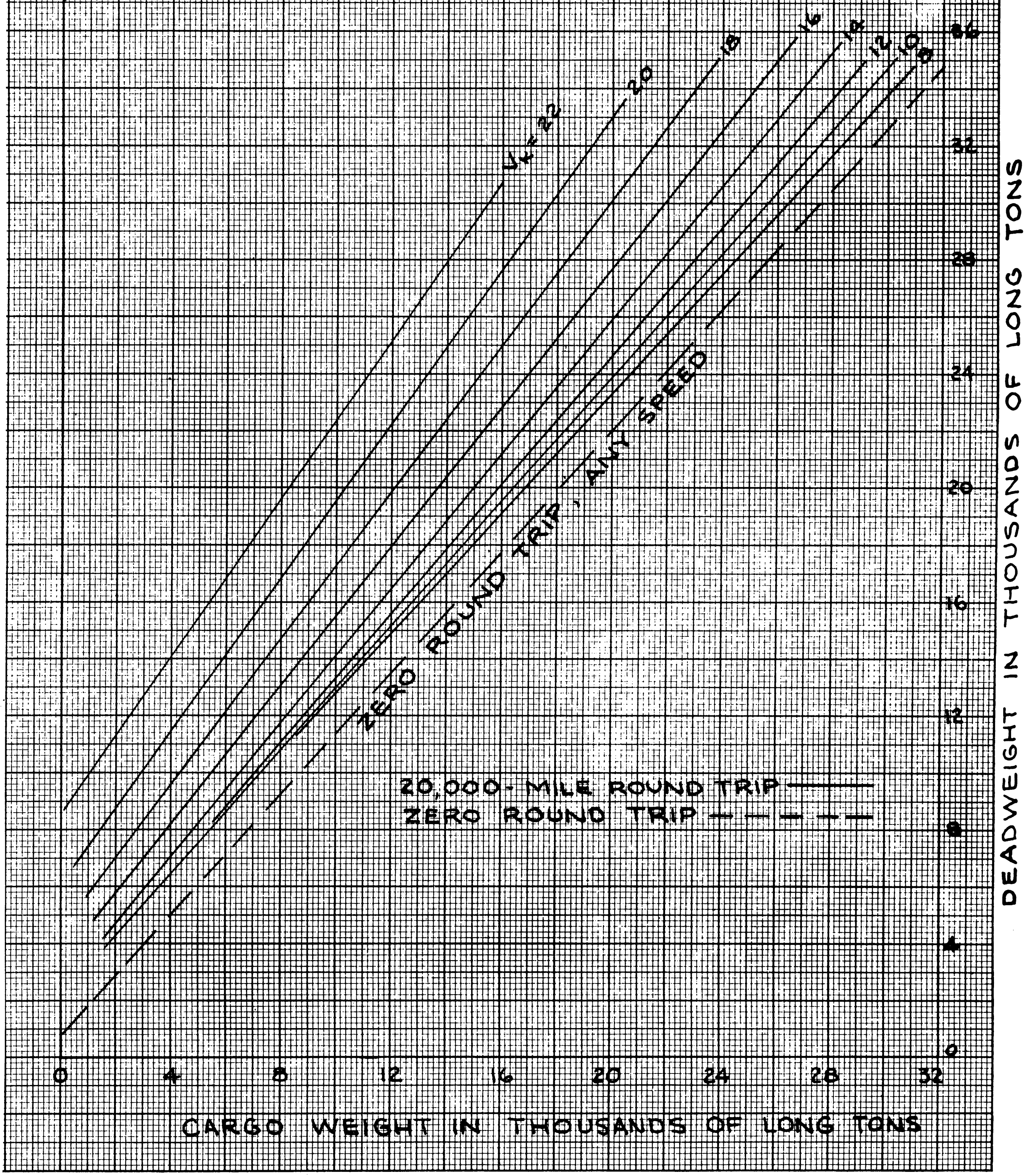


FIG 10D

DEADWEIGHT, CARGO WEIGHT
AND SPEED FOR B-1.8 SERIES
WITHOUT EVAPORATORS



Figures 11A and B show the relationship between equivalent bale capacity, displacement and horsepower for the B-1 and B-1.8 Series. Values are obtained by methods developed in Chapter IV. These values assume an average amount of deep tankage devoted to feed water and fuel oil. As an integral part of the previously discussed analysis of lost deadweight, equivalent bale capacities are modified to suit estimated fuel and feed water encroachments. The final conclusions of that part of the analysis are summarized by the following equation:

$$EBC = a + bZ + \left(c + d\,\frac{Z}{1000}\right) W_C \qquad [1]$$

where

EBC = Equivalent bale capacity in cubic feet
a, b, c, & d: see Table V for values
Z = Round trip distance in nautical miles
W_C = Weight of cargo in long tons

TABLE V

NUMERICAL VALUES FOR
EQUIVALENT BALE CAPACITY FORMULA

		Values			
Series	Evaporators	a	b	c	d
B-1	Yes	0	6	66	0.40
B-1	No	20,000	7.5	66	0.40
B-1.8	Yes	0	15	107.5	0.80
B-1.8	No	100,000	15	107.5	0.80

The above-mentioned relationship between cargo weight, bale capacity and freeboard (as implied by the designations of the B-1 and B-1.8 Series) may be manipulated in order to estimate the amount of freeboard required under any actual set of conditions. Freeboard ratio is defined as design freeboard divided by freeboard of the corresponding B-1 Series design, representing average practice.

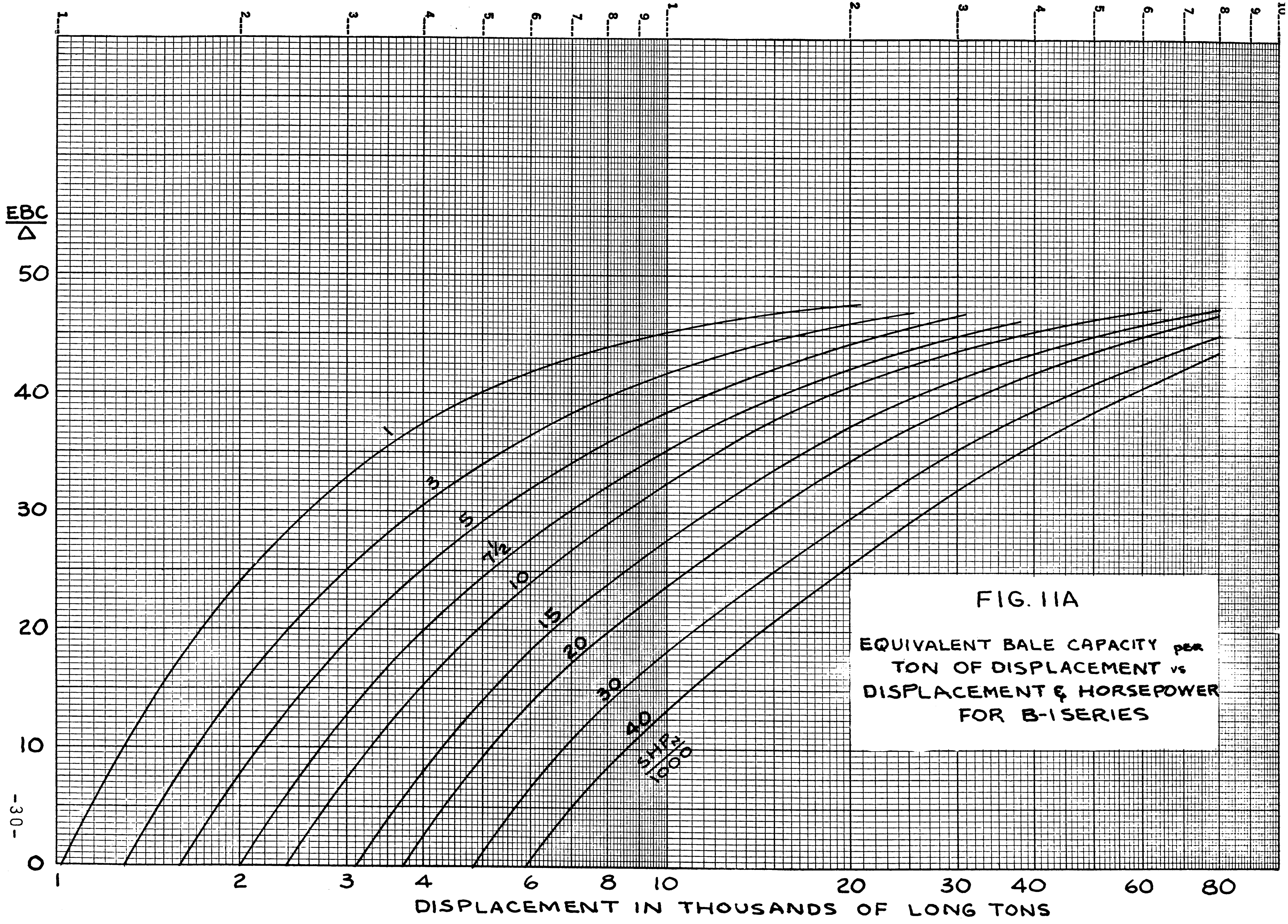


FIG. 11A

EQUIVALENT BALE CAPACITY per TON OF DISPLACEMENT vs DISPLACEMENT & HORSEPOWER FOR B-1 SERIES

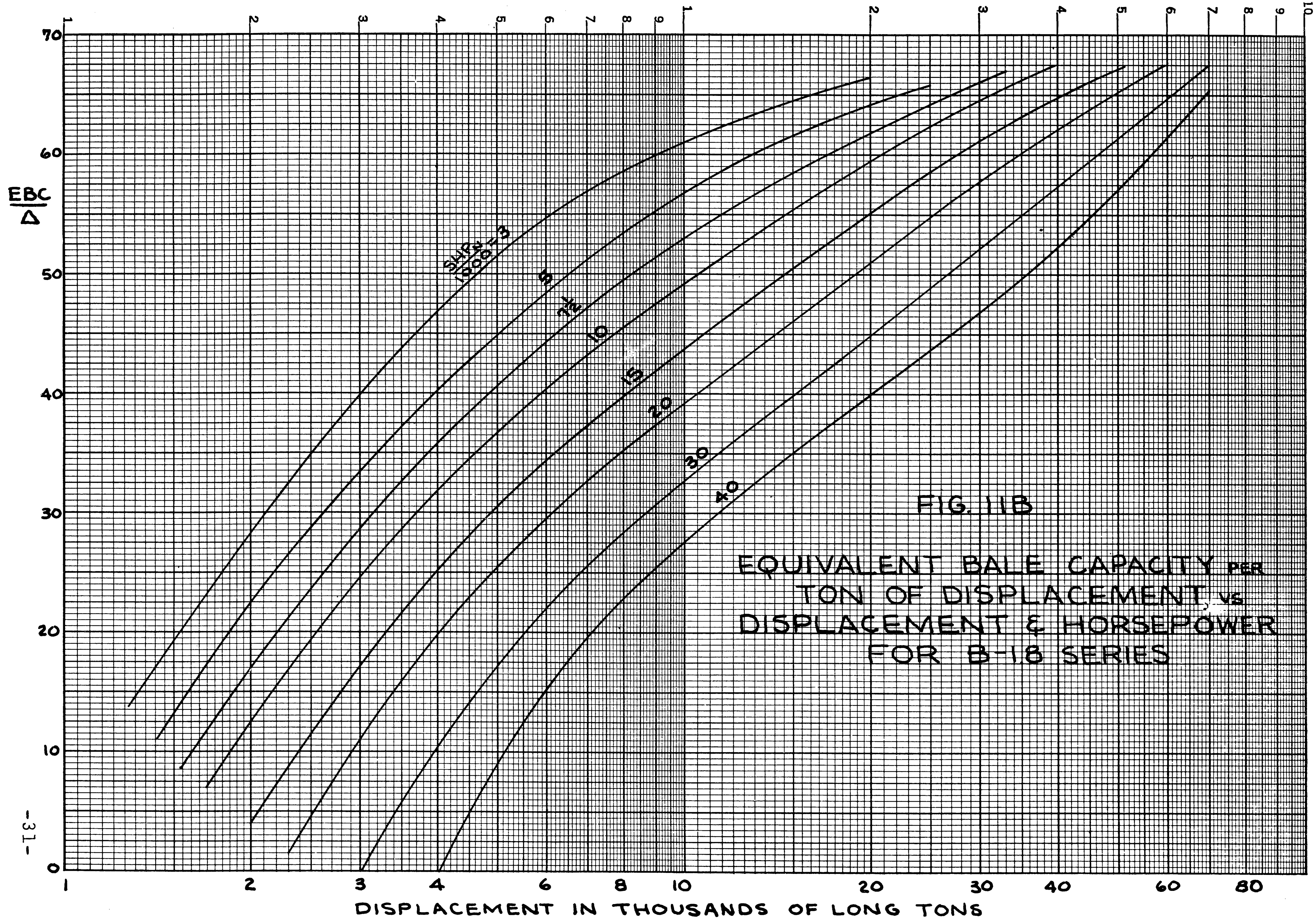


FIG. 11B

EQUIVALENT BALE CAPACITY PER TON OF DISPLACEMENT VS DISPLACEMENT & HORSEPOWER FOR B-18 SERIES

Using straight line interpolation between the two series, one derives the following expression for ships with evaporators:

$$r = \frac{EBC + 5.25Z - 14.1W_C + 0.1\frac{7}{1000}W_C}{11.25Z + 51.9W_C + 0.5\frac{7}{1000}W_C} \qquad [2]$$

Ships without evaporators will have somewhat different freeboard requirements because of greater quantities of reserve fresh water required:

$$r = \frac{EBC + 80{,}000 + 1.875Z - 14.1W_C + 0.1\frac{Z}{1000}W_C}{100{,}000 + 9.375Z + 51.9W_C + 0.5\frac{Z}{1000}W_C} \qquad [3]$$

where r = freeboard ratio and other terms are as just defined.

Recognizing the awkwardness of the above expressions, Figure 12 summarizes the findings in a form making it convenient to find the proper freeboard ratio. In the example shown on the chart, a ratio of 1.16 is found by graphic interpolation. Thus, one can block out a suitable ship by interpolating 20 percent of the way between the B-1 and B-1.8 Series as delineated in Figures 1 through 6. Similarly, weights, capacities and other technical characteristics can be estimated by interpolation between the values of Figures 7A and 7B, 8A and 8B, etc.

In converting from cargo weight and density to required bale capacity it is important to remember that, on the average, some 15 percent of the bale capacity will be lost owing to broken stowage. Appendix IV treats this subject in more detail.

Table IV indicates the degree of reliability one may place in using Figure 11A. The overall average is quite good and the wide range of individual departures can be explained by variations in relative freeboard, extent of superstructure and so forth.

Building Costs

Figure 13 shows trends in construction costs for general cargo ships of various sizes and horsepower. Cubic number rather than displacement is used as the size parameter since ships of the same

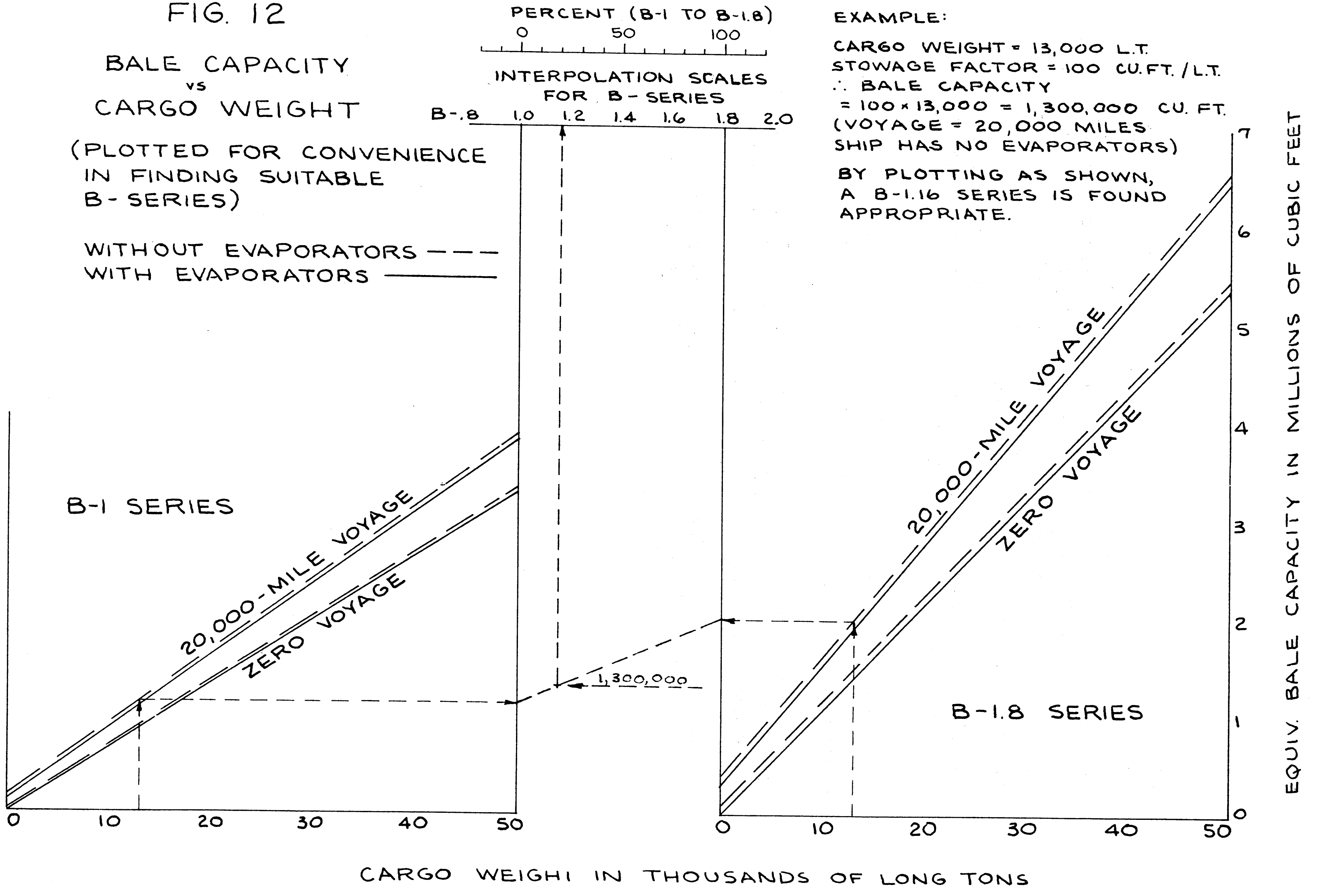
P 32, Equation 2: Change $\frac{7}{1000}$ to $\frac{2}{1000}$ both above and below the line.

P 33, Fig. 12: Vertical and horizontal axes should be subdivided every two centimeters (0.787 inch.)

FIG. 12

BALE CAPACITY
vs
CARGO WEIGHT

(PLOTTED FOR CONVENIENCE IN FINDING SUITABLE B-SERIES)



EXAMPLE:

CARGO WEIGHT = 13,000 L.T.
STOWAGE FACTOR = 100 CU. FT./L.T.
∴ BALE CAPACITY
= 100 × 13,000 = 1,300,000 CU. FT.
(VOYAGE = 20,000 MILES
SHIP HAS NO EVAPORATORS)

BY PLOTTING AS SHOWN, A B-1.16 SERIES IS FOUND APPROPRIATE.

displacement may have altogether different amounts of freeboard. The contours are based on an analysis of the B-1 Series but additional calculations show that the values are equally applicable to the B-1.8 Series and, by inference, to intermediate designs. Actual shipbuilding costs will of course depart from the values shown in Figure 13; inflation, market conditions, duplicate ship savings and relative elaboration are a few of the more obvious reasons. The trend, however, is believed to be accurate and, as is true in most engineering economy studies, an accurate trend is all that is usually needed. Where absolute costs are desired, the curves can be used to estimate departures from the known cost of some other recent ship.

Figure 14 is derived from Figure 13. It shows unit, rather than total, costs and the finer scale allows more accurate interpretation.

Figure 15 applies only to the B-1 Series. It is introduced merely as an interesting illustration of the influence of sea speed and cargo deadweight on building cost.

All three of the foregoing cost curves are synthesized by means of estimating methods detailed in Chapter VI.

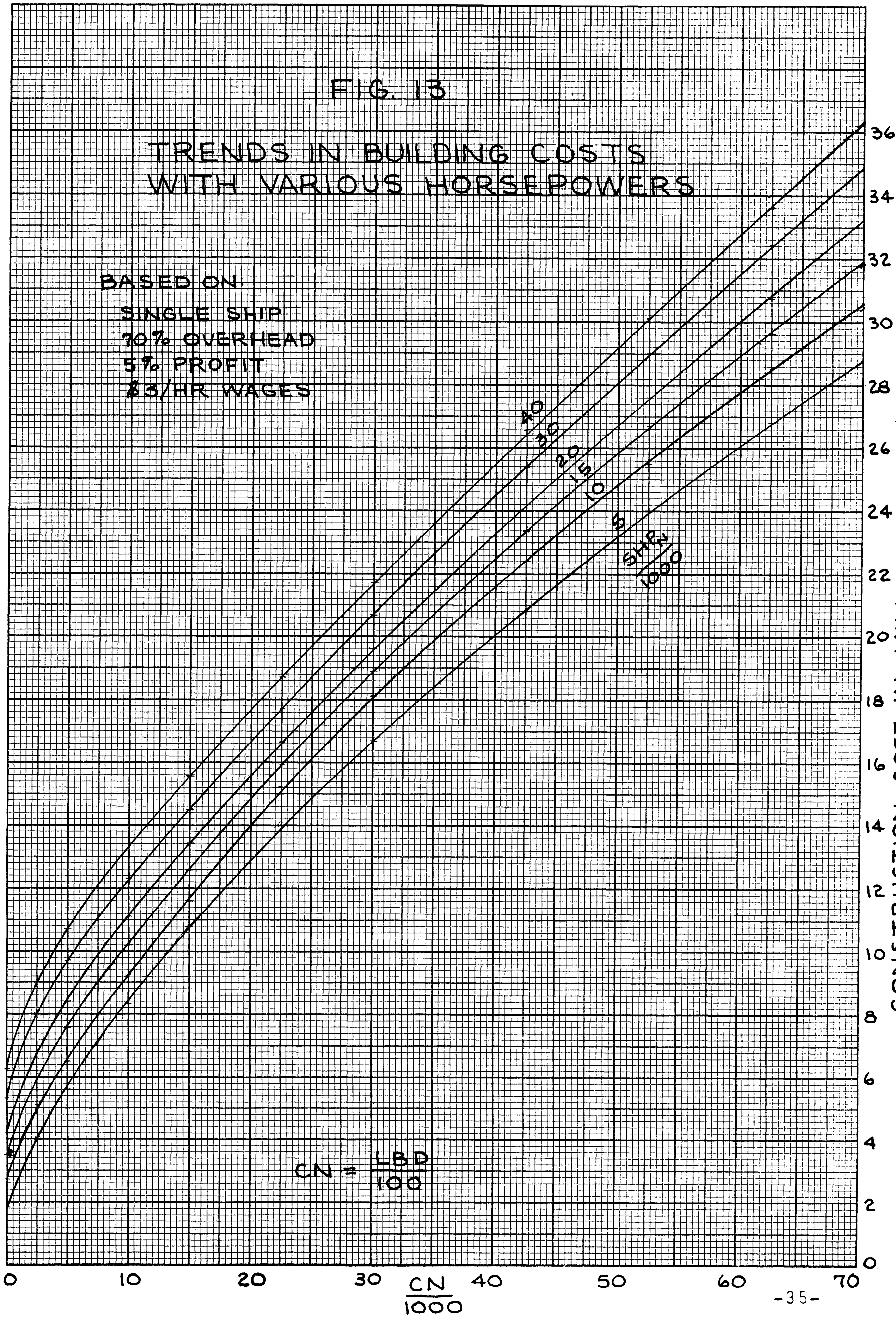


FIG. 13

TRENDS IN BUILDING COSTS
WITH VARIOUS HORSEPOWERS

BASED ON:
SINGLE SHIP
70% OVERHEAD
5% PROFIT
$3/HR WAGES

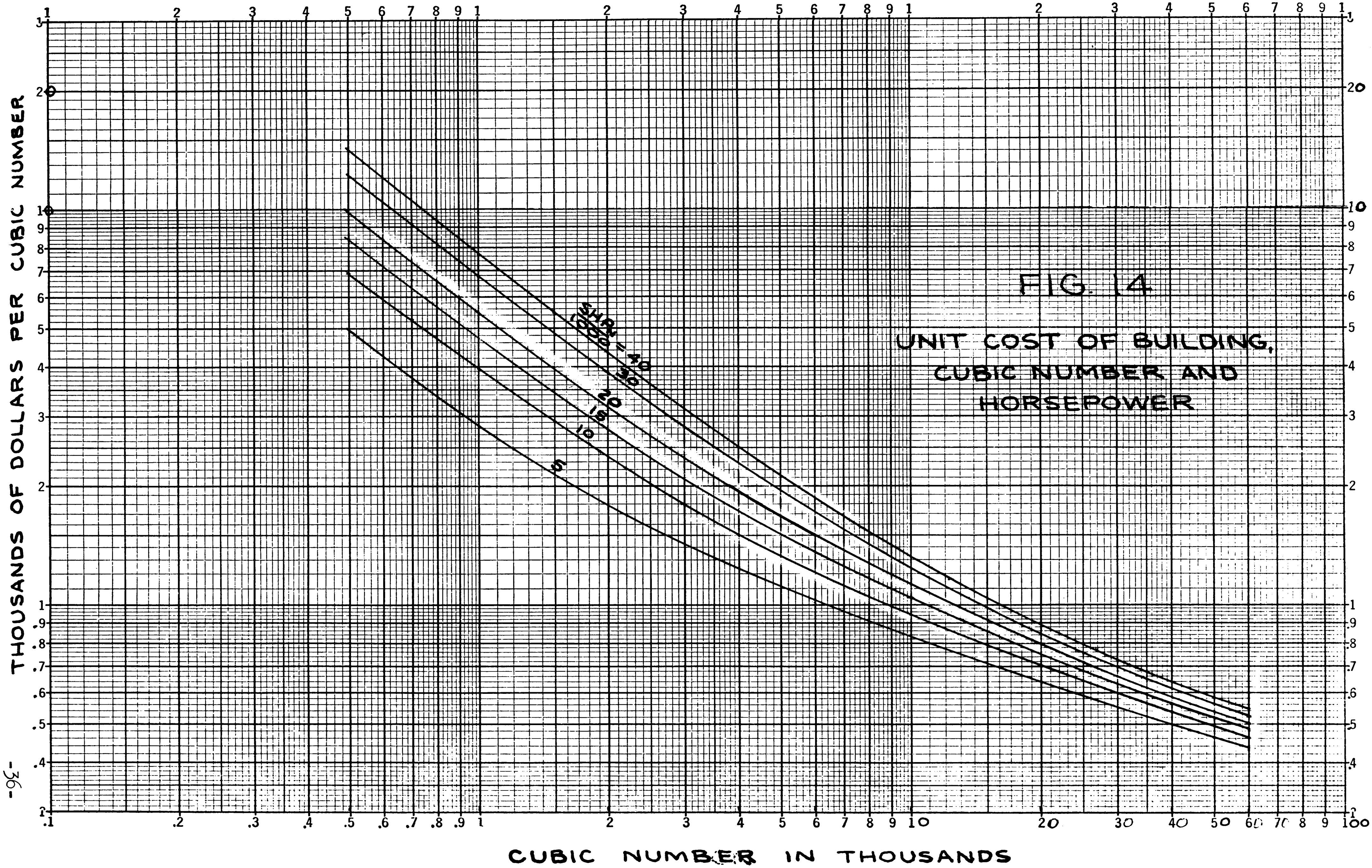
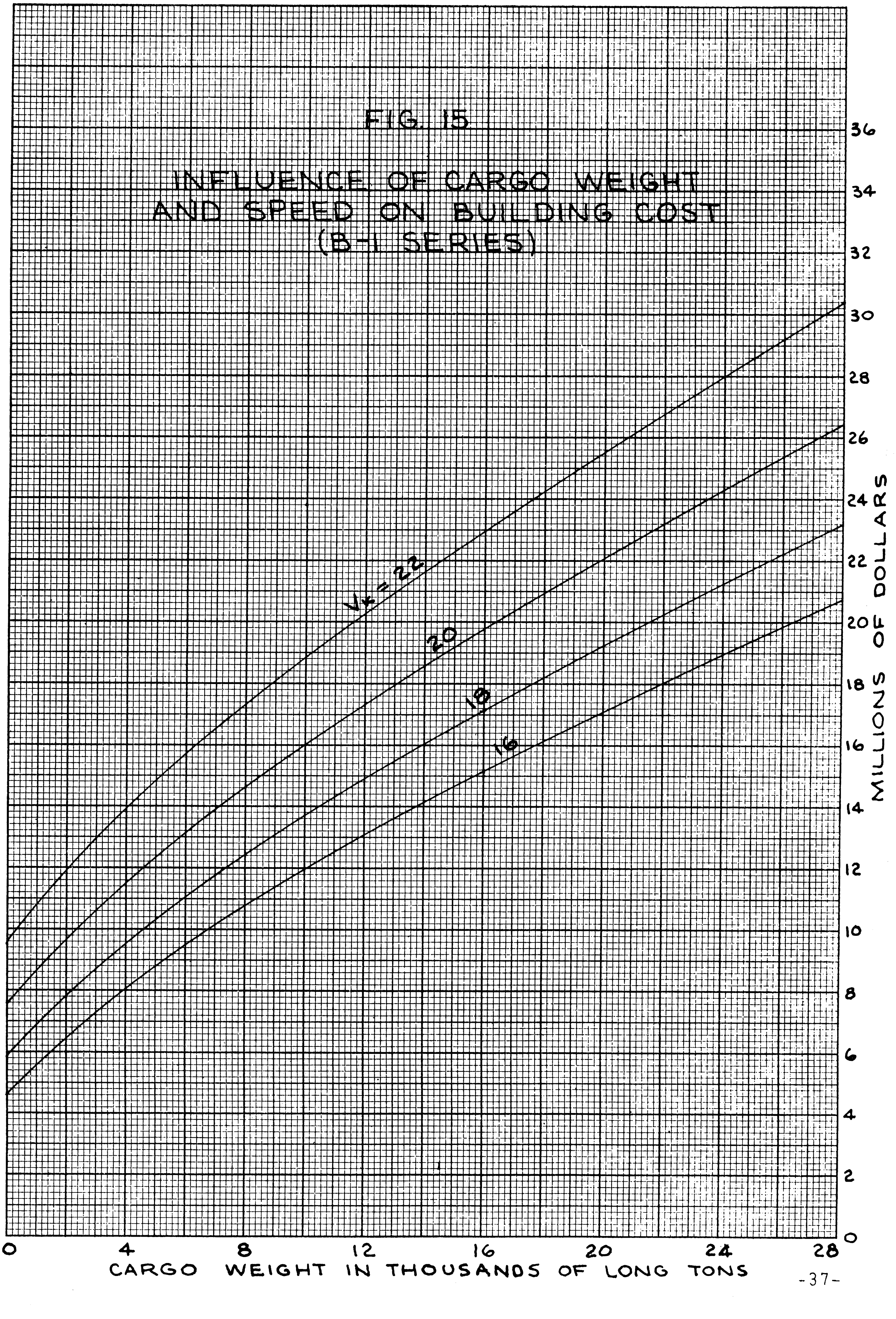


FIG. 14

UNIT COST OF BUILDING, CUBIC NUMBER AND HORSEPOWER

FIG. 15

INFLUENCE OF CARGO WEIGHT AND SPEED ON BUILDING COST (B-1 SERIES)



CHAPTER II

HULL FORM, PROPORTIONS AND SPEED

General

This chapter deals with the relationship between a ship's speed and its hull form and proportions. It progresses through a review of modern European practice to an analysis of recent U. S. cargo ship designs. (The analysis of U. S. ships is used as a basis for the B-1 Series).

Neither this chapter nor any other attempts a direct presentation of optimum design. Our claims are more modest; we merely explain how one can make the tools with which to fashion a systems analysis leading eventually to an optimum ship. The B-1 and B-1.8 Series are but two samples of the tools proposed. In short, this chapter is largely confined to indications of conventional practice, variations on which must be studied in our search for the ideal.

Processionary wormism is a frequent foible of the marine industry so the young naval architect is advised to respect but not worship the work of his predecessors. Having developed this healthy skepticism and having gained thereby a creative frame of mind, he should then learn to apply his skepticism with double emphasis to his own arithmetic and spelling. He should also try to distinguish between those elements of current practice which are more or less inevitable (such as beam-draft ratio required for stability) and those which are largely matters of opinion (such as block coefficient vs speed-length ratio.)

One complicating factor in general cargo ship design is the problem of partial draft. To start with, in actual operation, these ships seldom put to sea loaded down to their marks; either there is not enough cargo or it is of unsuitable density. This leads to changes in speed and power relationships, fuel consumption etc. Secondly, since most general cargo is pretty low in density, minimum freeboard is seldom a requirement and freeboard drafts are more likely to be set by scantlings than by geometry of the ship. Further complications arise from such factors as the carriage of dense raw materials on the homeward voyage, and availability of commodities suitable for deck cargo. Thus each trade route makes its own particular impact on the design of the ship and the uniformity of purpose found in bulk carriers is missing, particularly in the ships of the liner trade.

The subject of freeboard is so critical to the analysis of general cargo ship design that it is assigned its own chapter immediately following.

General discussions of the technology of preliminary design may be found in References 1, 12, 22, 26, 28, 33, 43, 64, 65, 66, 71, 88, 89, 91, 104, 109, 137, 138, 140 and 143.

Proportions

Figures 16 and 17 show the proportions of recently designed ships of both U. S. and European origin. These figures should be studied along with most of the paragraphs which follow.

Various authorities, including Posdunine and G. S. Baker, have shown that length seems to vary with speed and displacement according to the following empirical relationship

$$L = C\left(\frac{V_K}{V_K + 2}\right)\Delta^{\frac{1}{3}} \qquad [4]$$

where C = coefficient which ranges from 20.1 to 21.95 in recent U.S. designs, with an average value of 20.7.

One of the major restrictions of this study is the confinement of length to a C value of 20.7. Greater lengths will lead to increased steel weights and construction costs. Smaller lengths will tend towards high resistance, poor seakeeping characteristics and, possibly, cramped cargo handling arrangements. However, variations in both directions should be made a part of future studies.

Design draft is normally chosen as large as possible considering the probable loading conditions at each of the intended ports of call and intermediate canals. European cargo ships average about 25.5 feet design draft while recent U. S. designs average about 29.5 feet. A design draft greater than 31 feet is rare, however. European coasters may have design drafts more like 20 feet and drafts as small as 17.5 feet are not uncommon.

The length-draft ratio is an important criterion. Excessive values may lead to slamming damage forward and increased danger of propeller emersion. The classification societies maintain certain minimum limits on scantling draft in the case of long bulk cargo ships (16) and would no doubt impose similar restrictions in the case of

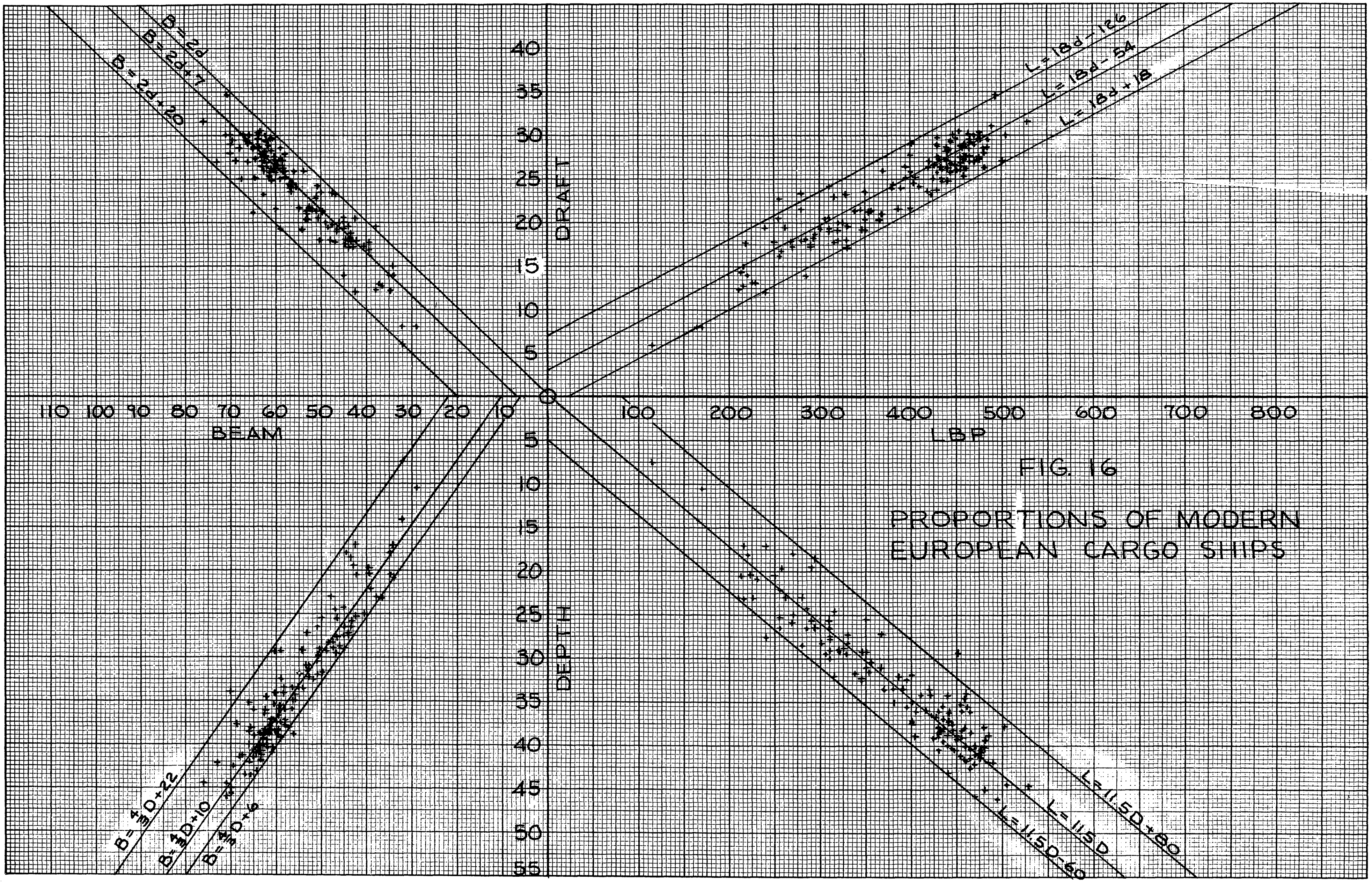


FIG. 16

PROPORTIONS OF MODERN EUROPEAN CARGO SHIPS

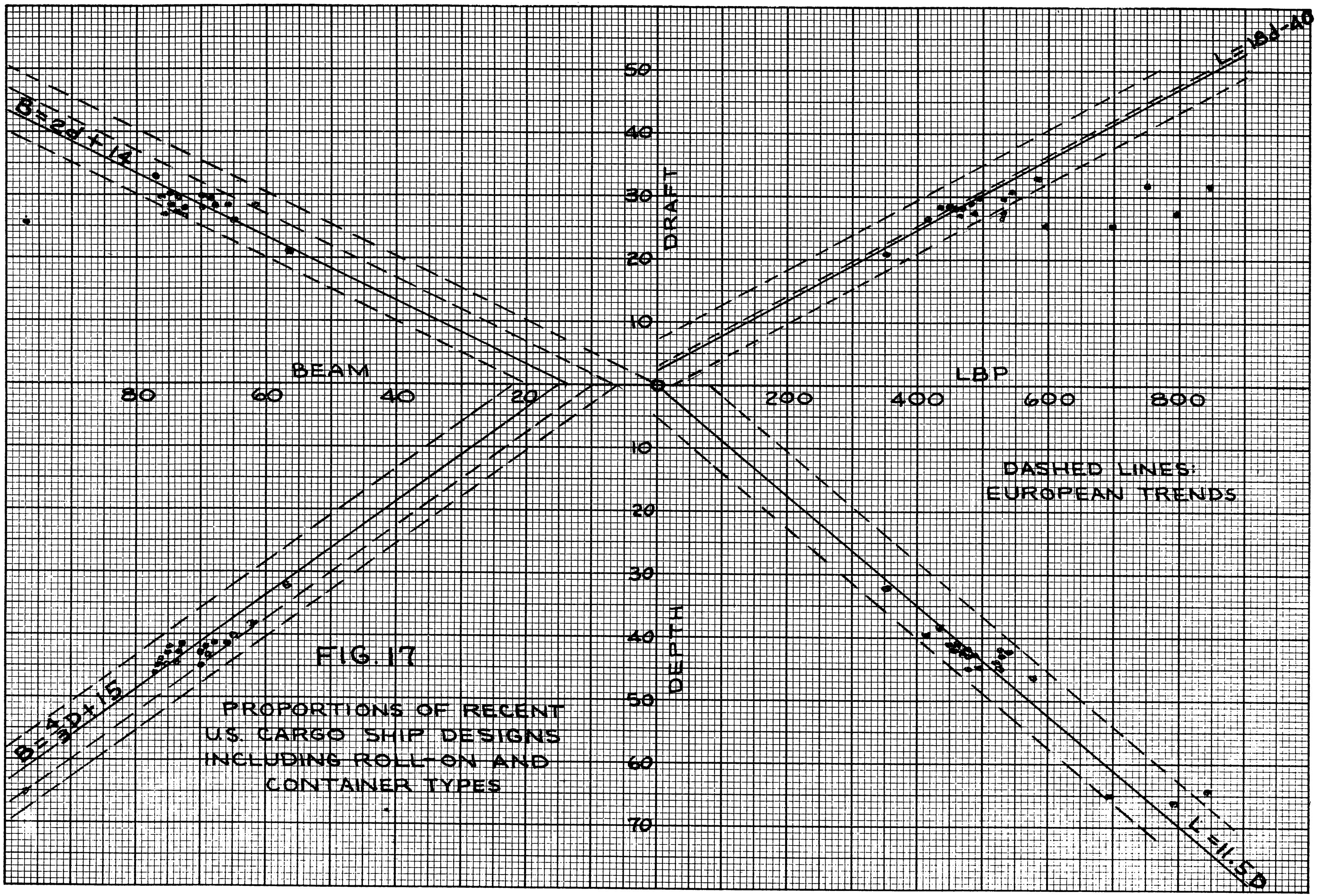


FIG. 17

PROPORTIONS OF RECENT
U.S. CARGO SHIP DESIGNS
INCLUDING ROLL-ON AND
CONTAINER TYPES

abnormally proportioned general cargo ships. Of course, scantling draft can be considerably greater than design draft if conditions warrant.

European cargo ships have an average relationship of

$$L = 18d - 54 \text{ feet} \qquad [5]$$

or

$$d = \frac{L}{18} + 3 \text{ feet} \qquad [6]$$

Recent U. S. designs indicate a slightly greater length, on the average

$$L = 18d - 40 \text{ feet} \qquad [7]$$

or

$$d = \frac{L}{18} + 2.22 \text{ feet} \qquad [8]$$

In recently proposed containership and roll-on designs, practical draft restrictions, coupled with great length requirements, have resulted in length-draft ratios ranging up to 29!

Beam may be limited by external restrictions such as locks, building ways or dry docks. It may also be influenced by its proportion to other dimensions, principally draft. Increases in beam draft ratios (for a given length, draft and displacement) allow decreases in block and prismatic coefficients, the net result, frequently, being a reduction in resistance. Stability considerations also set both maximum and minimum limits on the ratio of beam to draft; and stability, in turn, is affected by cargo density (through its influence on freeboard, as discussed later), type of cargo handling gear, extent of deck erections, and other practical considerations.

The beam of the average modern European cargo ship is about 2d + 7 feet, with 2d as a practical minimum and 2d + 20 feet as a practical maximum. In recent U. S. designs, beams range from 2d + 5 feet to 2d + 22 feet, with 2d + 14 feet as an average. In the case of the previously mentioned roll-on designs, beams run as high as 2d + 46 feet.

The ratio of length to beam is another useful criterion. Large values suggest long, skinny ships with good rectangular holds but relatively low stability. Perhaps the chief virtue of the ratio lies in the fact that practical values seem to fall within moderately narrow bands; thus any tendency towards non-conformity warns one to proceed with caution. Analysis of large numbers of ships indicates that length and beam can be related as

$$L = 9B - C \qquad [9]$$

where C has the values listed in Table VI.

TABLE VI

C VALUES RELATING LENGTH AND BEAM

	European Practice	U. S. Practice
Average	117	166
Minimum	65	115
Maximum	170	200

All of the dimensions discussed up to this point have been concerned with the underwater portion of the hull and provisions of proper displacement and deadweight capacity. The final principal dimension, depth, introduces problems of freeboard and the provision of proper volumetric capacity. In some cases, questions of hull girder requirements may also prove critical.

The length-depth ratio must be considered in light of its influence on hull girder strength, rigidity and steel weight. The average ratio is about 11.5 in both U. S. and European practice, with a length distribution ranging from 60 feet less, to 80 feet greater than this value. The related problem of freeboard is discussed in the next chapter.

The ratio of beam to depth deserves consideration. Low values suggest a possible deficiency in stability; values greater than 2.0 may require special consideration in calculation of section modulus unless longitudinal bulkheads are present. (Reference 129 considers beams only within range of L/10 + 5 to L/10 + 20.)

Cubic Number

One of the most convenient measures of overall ship size is the well known cubic number, abbreviated "CN" in many of the charts and formulas of this paper:

$$CN = \frac{LBD}{100} \qquad [10]$$

Occasionally situations arise in which the length of a ship is known but depth and/or beam are unknown. In such cases, the cubic number can be estimated as follows:

$$CN \fallingdotseq 100 \left(\frac{L}{100}\right)^{3.15} \qquad [11]$$

It can be shown that the cubic number bears the following relationship to the design displacement:

$$CN = \frac{0.35}{C_B} \times \frac{D}{d} \times \Delta \qquad [12]$$

Substituting average values for C_B and D/d, one obtains the approximation

$$CN \fallingdotseq 0.87\Delta \qquad [13]$$

Values of the constant will approach 0.95 for high-cubic ships and 0.80 for low-cubic ships, based on U. S. practice. See also Figure 6.

Hull Form

Much has been written on the subject of hull form and it is not the purpose of this report to duplicate such efforts. However, two resistance factors deserve special mention here: fullness of form and fatness ratio. Beam-draft ratio has already been discussed in an earlier section.

Fullness of form can be expressed either as block coefficient (C_B) or prismatic coefficient (C_P). In commercial ships, the maximum section coefficient (C_X) is so close to unity that block and prismatic coefficients are almost synonymous.

Fullness of form, by itself, is not a complete criterion of resistance. For example, a tugboat having any given prismatic coefficient is more resistful per ton of displacement than, say, a racing shell of equal prismatic. The reason is that the tug has its displacement squeezed into a very short length. This relative distribution of displacement can be expressed by the traditional displacement-length ratio $\Delta/(L/100)^3$ or by the newer (and truly dimensionless) volumetric coefficient V/L^3.

Over the years, many experts have attempted to establish the proper relationship between fullness of form (block or prismatic coefficients) and speed as measured by speed-length ratio ($V_K/\sqrt{L}$). For a given deadweight capacity, a high block or prismatic requires a relatively small set of dimensions with consequent savings in building and upkeep costs. On the other hand, low coefficients require relatively low horsepower with consequent savings in machinery and fuel costs. Within the range of normal speed, as speed-length ratio is increased, wave resistance becomes more crucial and the optimum block or prismatic drops. While all of the published curves of block or prismatic vs speed-length ratio have been drawn with the above thought in mind, as far as is known, none has been directly based on economics.

Earlier studies (15) tentatively conclude that, in general cargo ship design, block and prismatic may be varied widely with only negligible effect on overall ship profitability. If this can be verified, designers will be given new latitude in choosing hull form coefficients.

Watson (140) rightfully argues that prismatic coefficient must not be chosen without concurrent consideration of displacement-length ratio. Upon completion of the current study, a rigorous reanalysis should be made of the economically optimum prismatic coefficient and displacement-length ratio. It is probable that contours, rather than a single curve, can be developed, each suitable to a given typical trade route requirement.

Figure 18 is representative of modern U. S. design practice in the relationship of block and prismatic coefficients and speed-length ratio. The curve of prismatic coefficients is derived from References 109 and 140. Block coefficients, in turn, are found using the Series 60 maximum section coefficients (125).

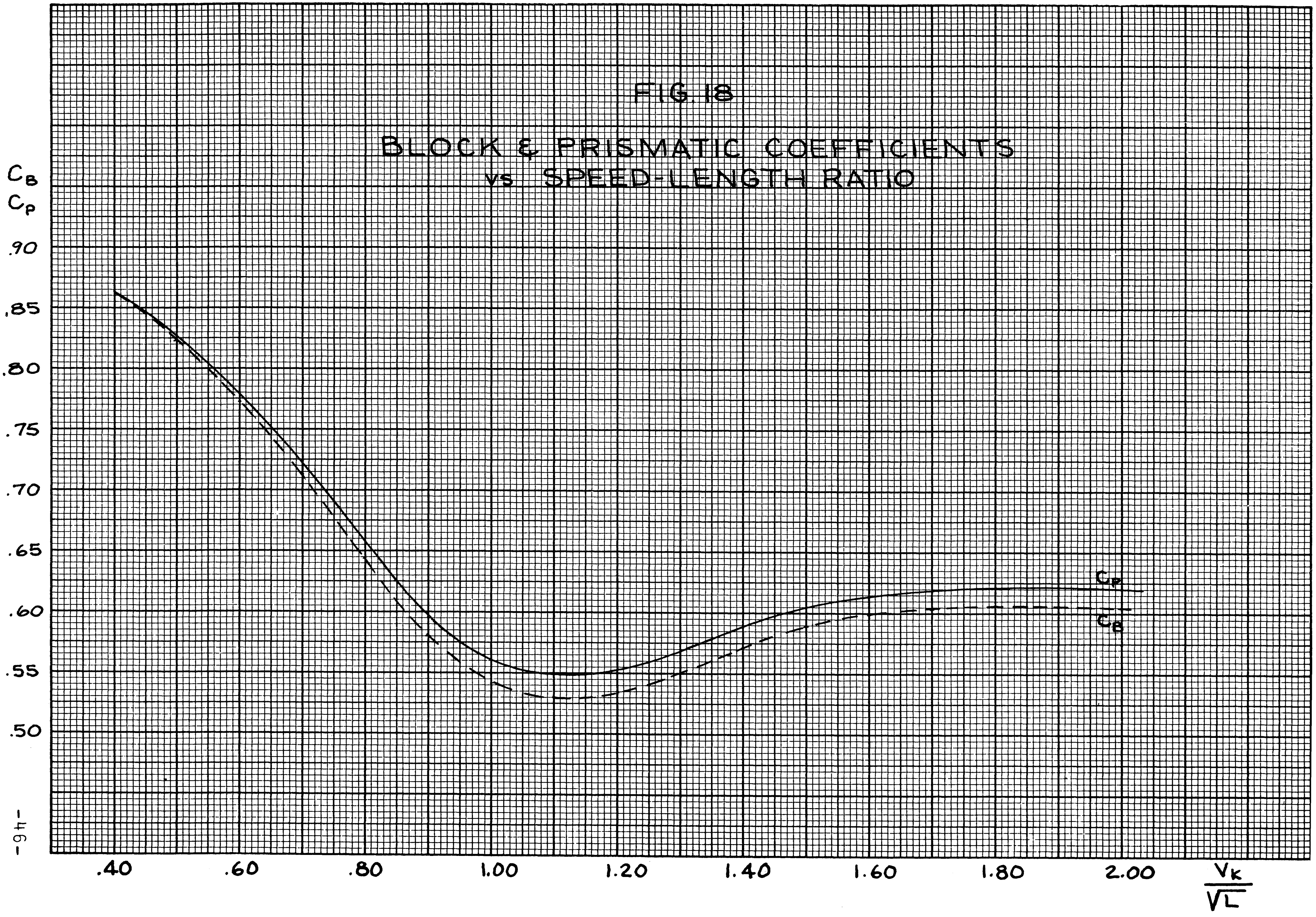


FIG. 18

BLOCK & PRISMATIC COEFFICIENTS
VS SPEED-LENGTH RATIO

Speed and Power

Pending further studies, Figure 19 may be used to estimate speed and power for single screw merchant ships of normal proportions and fullness of form. The figure also contains contours of length based on Equation 4.

Figure 20 may be used for speed and power estimation for twin screw merchant ships of normal proportions and fullness of form. Contours are derived from data taken from Reference 5, with an arbitrary increase of 17 percent to allow for twin rather than single screw propulsion. (Twin screws have lower propulsive efficiency and greater appendage resistance.)

Further studies are required to develop definite relationships between proportions and powering requirements. Such work, which could be based on the Series 60 results (126), would allow economic analysis of varying proportions including hulls of rather abnormal design.

Figure 19 is used for estimating speed and power in the B-1 Series. The B-1.8 Series would have slightly different values owing to greater beam-draft ratios. Studies show that, for a given displacement and horsepower, the typical B-1.8 design would be four percent slower than indicated by Figure 19. For a given speed, then, power for a B-1.8 design can be estimated by entering the curves with speed increased by the factor 1 ÷ 0.96. This factor can be generalized for intermediate series as

$$\text{Speed Correction Factor} = \frac{1}{1.05 - \frac{r}{20}} \qquad [14]$$

where r is the ratio of actual freeboard to freeboard for the B-1 Series.

References 85, 86 and 127 may also be consulted.

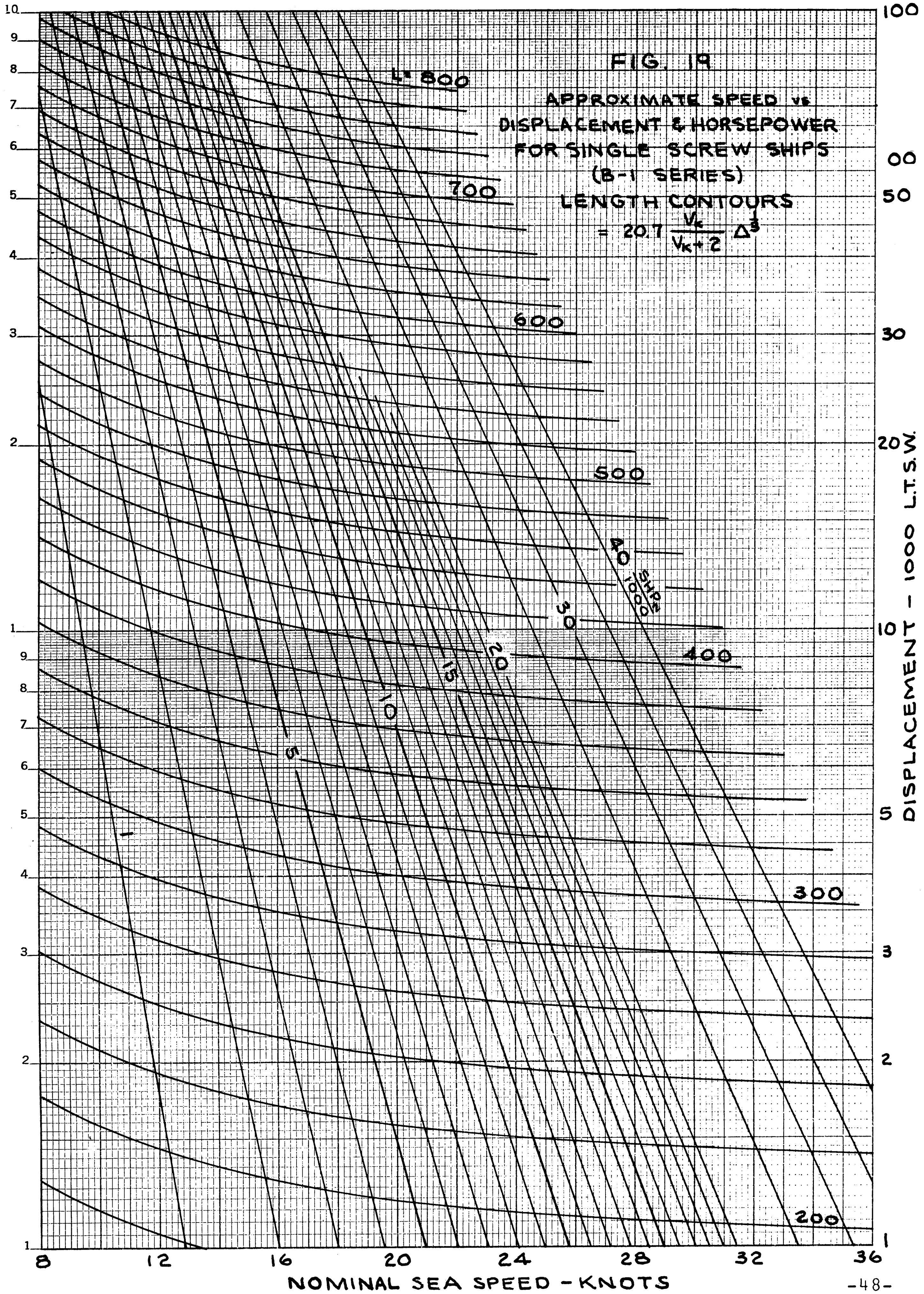


FIG. 19

APPROXIMATE SPEED vs DISPLACEMENT & HORSEPOWER FOR SINGLE SCREW SHIPS (B-1 SERIES)

LENGTH CONTOURS $= 20.7 \frac{V_K}{V_K+2} \Delta^{\frac{1}{3}}$

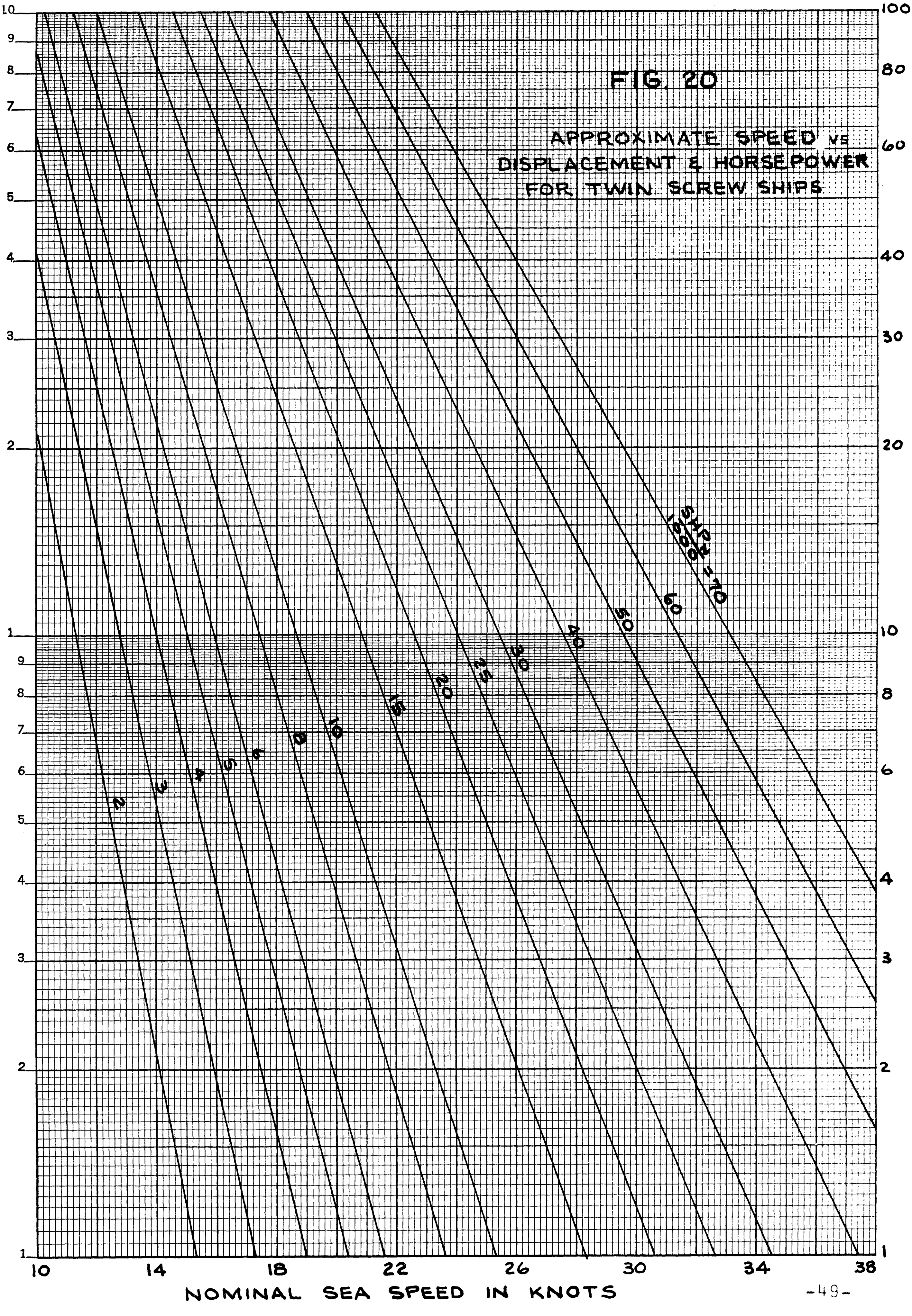


FIG. 20

APPROXIMATE SPEED vs DISPLACEMENT & HORSEPOWER FOR TWIN SCREW SHIPS

CHAPTER III

FREEBOARD

Definitions

A number of terms should be clarified before freeboard is discussed. First, one must remember that the regulatory measure of cargo ship freeboard is taken as the maximum of either of two values. One, aimed at protection of hatches, is set by the geometry of the ship, being a direct measure of freeboard based on such considerations as length, extent of superstructure and amount of sheer. It is indicated by the letter G in Figure 21. The other is an indirect measure of freeboard, being that allowed by the scantling draft (which affects local strength scantlings as well as hull girder section modulus). Scantling draft is denoted by the letter S in Figure 21.

The freeboard deck is the uppermost continuous deck with all closures weathertight.

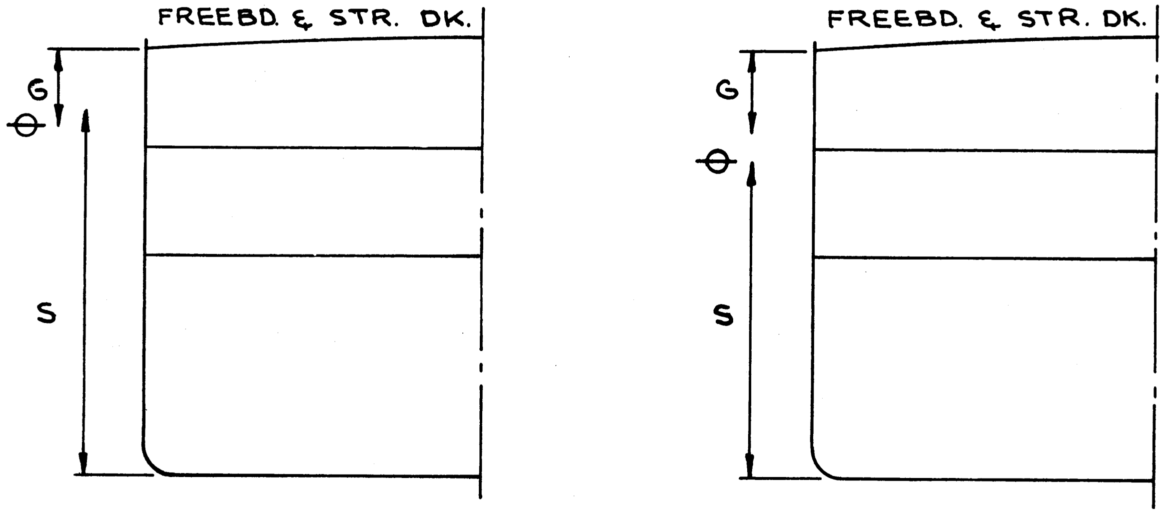
A full scantling ship is one in which the uppermost continuous deck is the freeboard deck and in which the scantlings are sufficient to permit a draft at least equal to that set by the geometry of the ship. See Sketch A, Figure 21.

A scantling draft ship is similar to a full scantling ship except that scantlings are insufficient to allow a draft as great as that permitted by the geometry of the ship. See Sketch B, Figure 21.

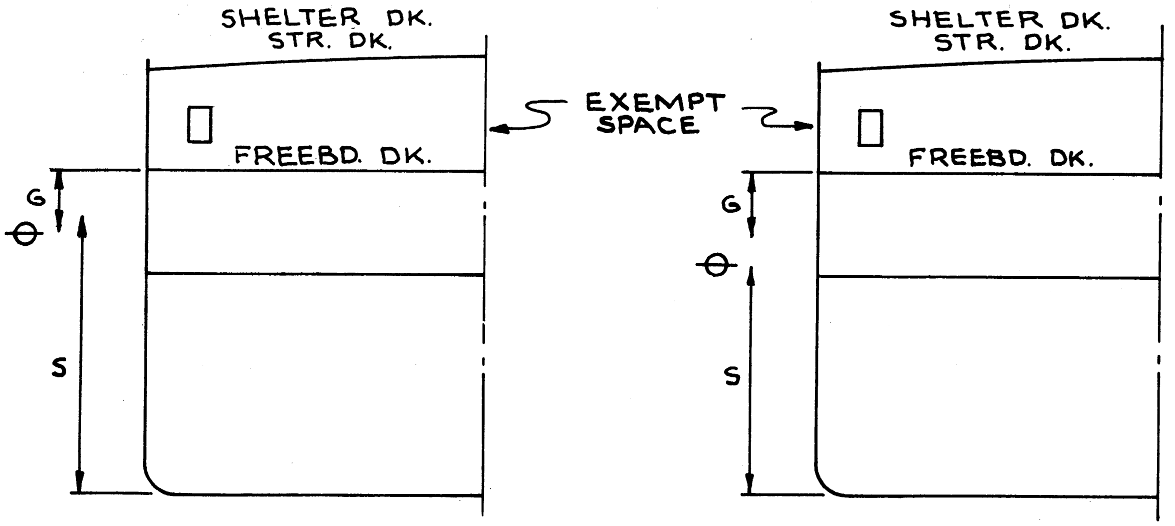
A shelter deck ship is one designed to beat the tonnage rules. A small non-weathertight hatch in the uppermost deck and non-weathertight openings in the upper 'tween deck bulkheads make the upper 'tween deck space into the legal equivalent of a long open-to-the-weather superstructure, which is exempt from tonnage measurement. The uppermost deck is disqualified as the

FIG. 21

FREEBOARD TERMINOLOGY



A. FULL SCANTLING SHIP B. SCANTLING DRAFT SHIP



C. SHELTER DECK SHIP D. SHELTER DECK SHIP WITH SCANTLING DRAFT

ABBREVIATIONS:

FREEBD: FREEBOARD
STR: STRENGTH
G: MINIMUM POSSIBLE FREEBOARD ALLOWED BY THE GEOMETRY OF THE SHIP.
S: SCANTLING DRAFT
⊖: PLIMSOLL MARK INDICATING MAXIMUM PERMISSIBLE DRAFT.

freeboard deck because it contains the non-weathertight tonnage hatch, so freeboard is measured from the second deck instead. Sketches C and D in Figure 21 show how a shelter deck ship may have its freeboard set either by scantlings, Sketch D, or geometry of the ship, Sketch C.

The term "closed shelter deck ship" is a common misnomer. It implies a ship in which the tonnage openings are permanently sealed but in which freeboard is still measured from the second deck. This concept is in error since permanently sealing the tonnage hatch automatically shifts the freeboard deck upward resulting in either a full scantling ship (Sketch A) or, more likely, a scantling draft ship (Sketch B).

Shelter Deck Ships

It is clear that tonnage openings reduce a vessel's seaworthiness and, in point of fact, the shelter deck design presents one of the world's most pitiful examples of how engineering degenerates when contaminated by poor law. World-wide pressures for revision of the tonnage laws offer hope that shelter deck ships will before long become outmoded curiosities. The remainder of this paper, then, is confined to normal designs, either full scantling or scantling draft.

Full Scantling vs Scantling Draft

The choice between full scantling and scantling draft design hinges on the expected density of the cargo on the one hand, and on the size and speed of the ship and the length of voyage on the other. Under average conditions, a full scantling (minimum freeboard) ship will be full and down (full of cargo and down to its Plimsoll mark) with cargo stowed at about 55 cubic feet per ton, including broken stowage. This figure will vary with length of voyage, type of machinery, sea speed, overall size and possible use of lightweight materials. If the expected cargo has a stowage factor (corrected for broken stowage) smaller than this critical value, the ship should be of full scantling design. That is, it should have minimum allowable freeboard and some wasted internal volume must be accepted. On the other hand, if the cargo has a higher stowage factor, then freeboard should be increased and a scantling draft design becomes desirable. The preponderance of general cargo today is relatively low in density and, except under unusual circumstances, scantling draft ships are appropriate.

Full scantling design allows little leeway in the relationship between cargo weight and hold capacity. Scantling draft design, on the contrary, allows complete freedom in this respect and the designer can adjust freeboard until the hold volume is just sufficient to accommodate that weight of cargo allowed by the ship's displacement and other weight characteristics. Methods for doing this are discussed in Chapters I and II.

If it is uncertain whether conditions warrant a full scantling or scantling draft design, one can tentatively assume the latter and find the freeboard required for full and down operation. The minimum freeboard, based on geometry of the ship, can then be estimated by means of Figures 22 and 23, or by Figure 20 in Reference 114 if ship is without sheer. If minimum freeboard as thus determined is greater than that required for hold volume, then a full scantling ship is in order, otherwise not.

Appendix II contains examples showing the use of Figures 22 and 23. Figure 24 shows the minimum allowable freeboard for the B-1 Series.

Draft Considerations

A further complication is introduced by the fact that in most cases a scantling draft ship is designed around an intended operating draft which is even less than the scantling draft (which is in turn less than the minimum freeboard draft based on geometry of the ship). The excess of scantling draft over design draft is a matter for joint decision between owner and naval architect. Prudence encourages a healthy margin, perhaps ten or fifteen percent; cost and weight saving encourage a minimum, usually a matter of one to six inches. A large margin provides a safer and more versatile ship which may on occasion benefit financially from increased weight lifting capability. The extra steel weight required is discussed in Chapter V.

Depth Considerations

Freeboard must also be considered in light of its relationship to depth. On occasion, length-depth ratio may prove to be the limiting factor and extra freeboard may be required for that reason alone. Freeboard regulations (129) limit depth to strength

FIG. 22

FLUSH DECK MINIMUM FREEBOARD DRAFTS

BASED ON:
STANDARD CAMBER
STANDARD SHEER
$C_B \leq 0.68$

d_{fb} = DRAFT ALLOWED BY MINIMUM FREEBOARD

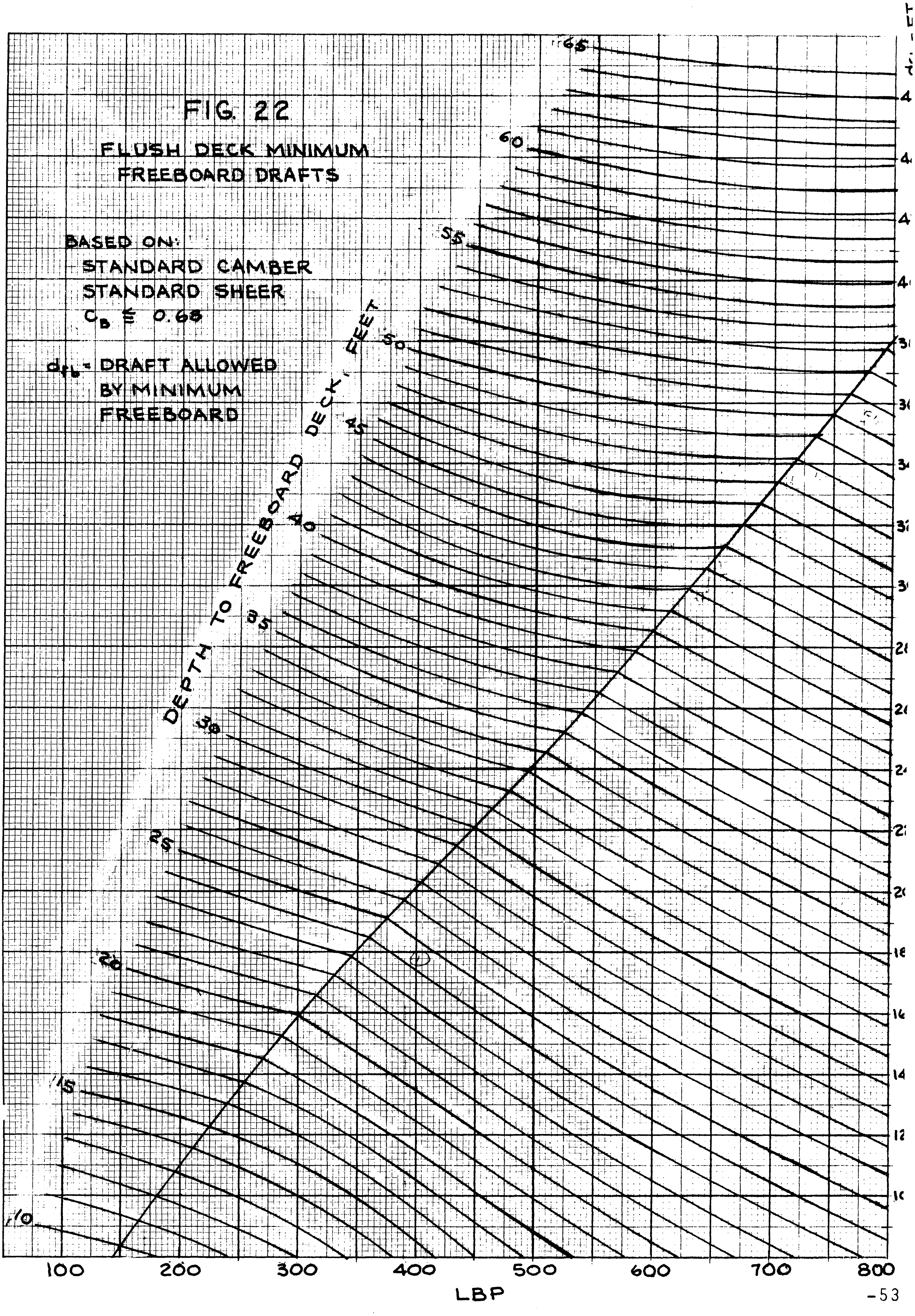
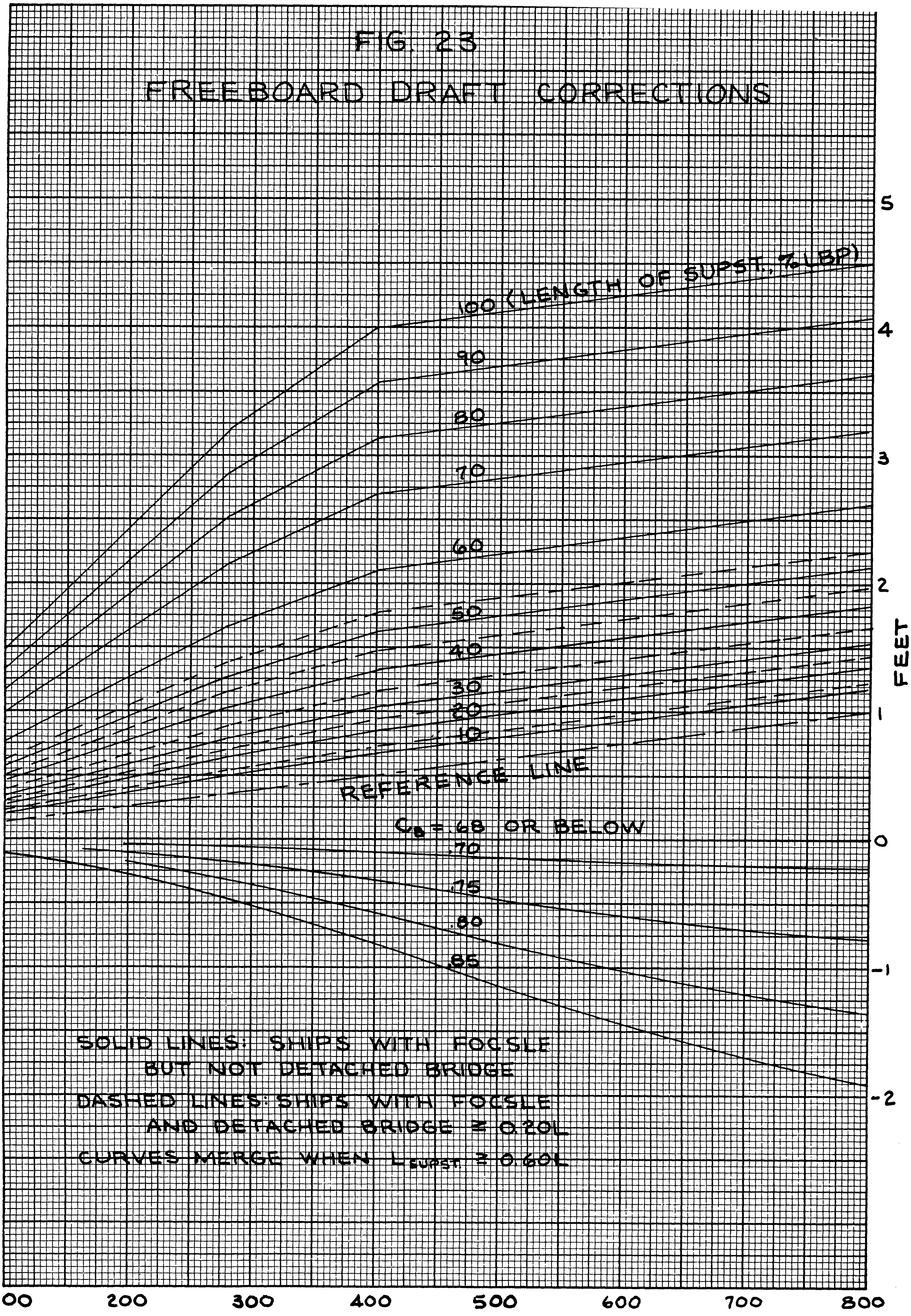


FIG. 23

FREEBOARD DRAFT CORRECTIONS

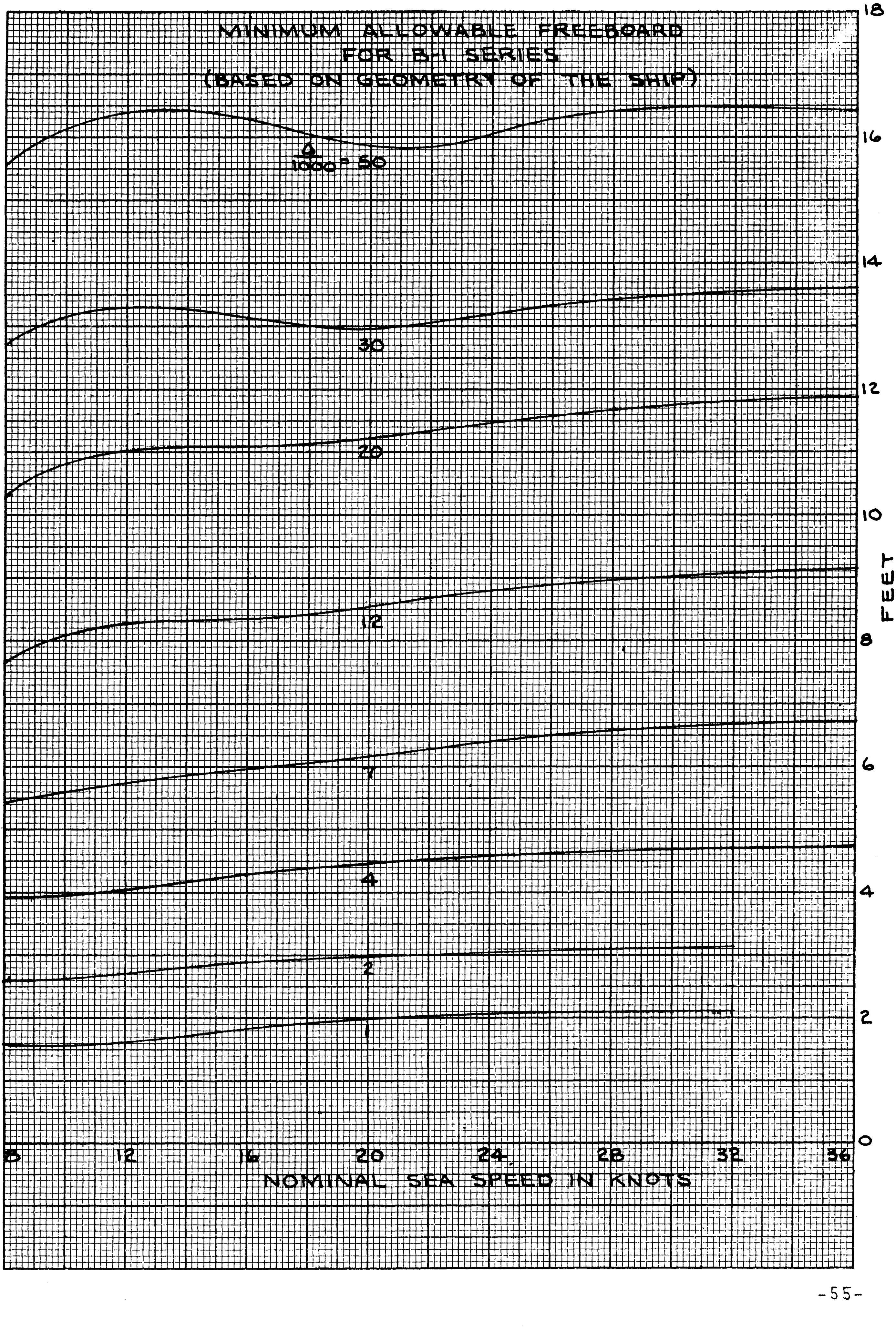


SOLID LINES: SHIPS WITH FOCSLE
BUT NOT DETACHED BRIDGE

DASHED LINES: SHIPS WITH FOCSLE
AND DETACHED BRIDGE ≥ 0.20L

CURVES MERGE WHEN $L_{SUPST.}$ ≥ 0.60L

FIG. 24



MINIMUM ALLOWABLE FREEBOARD FOR B-1 SERIES (BASED ON GEOMETRY OF THE SHIP) deck to L/10 to L/13.5 while Table 12 of Reference 3 indicates maximum permissible length-depth ratios varying from about 14.4 in a ship of 115-foot length to about 12.2 in a ship of 755-foot length. The possibility of greater length-depth ratios should not be excluded from future studies, however.

A final observation is that cargo density and availability may vary widely on different legs of the proposed voyage, that seasonal variations will exist and that most cargo predictions are based on shaky assumptions. It thus becomes wise to allow considerable latitude in this phase of the design. These complications are dealt with more fully in Chapter VII.

CHAPTER IV

VOLUMES

Bale Capacity

In designing a general cargo ship, the provision of sufficient cargo hold volume is just as important as the provision of sufficient displacement; and the configuration of the cargo holds merits the same attention as that given to the underwater hull form (20, 24). Surprisingly enough, the literature contains relatively little information on methods for estimating hold volumes. References 8, 22, 88, 89 and 113 comprise most of the available sources, a microscopic quantity indeed contrasted with current outpourings in hull form and resistance. (The Sorcerer's Apprentice isn't the only fellow who has trouble keeping up with his hydrodynamics.) Without wishing to detract from the desirability of further efforts in the latter field, here is this writer's contribution to a better understanding of cargo hold volumes.

The parameters having most direct influence on hold capacity are length, beam, depth, extent of superstructure, sheer, block coefficient, required machinery cubic, and volume of fuel oil and fresh water carried outside the doublebottom. It is assumed that the designer will try to maximize the hold volume and minimize the working spaces and non-payload deep tanks.

As a means of recognizing the volume within the superstructure, depth (D) is replaced by a modified depth (D_M). Assuming a superstructure height of eight feet

$$D_M = D + \frac{L_S}{L} 8 \qquad [15]$$

where

L_S = length of superstructure within fore and aft perpendiculars in feet

(L_S/L averages about 20 percent in recent U. S. designs and this figure is assumed in the B-1 and B-1.8 Series.)

A further sophistication is required to put all kinds of cargo spaces into the common denominator of required volume of enclosing structure. Bale capacity is chosen as the most common measure and special cargo spaces are corrected to the bale capacity they would provide if designed for dry cargo. The corrected sum of all cargo spaces is called "equivalent bale capacity" (EBC) and is expressed as follows:

$$\text{EBC} = \text{Bale Capacity} + (C_R \times \text{Reefer Cargo Volume}) + (C_L \times \text{Liquid Cargo Volume}) + (C_C \times \text{Below-Deck Containerized Cargo Volume}) \qquad [16]$$

where C_R, C_L and C_C are coefficients relating refrigerated, liquid, and containerized cargo volumes, respectively, to equivalent bale capacity. Based on the references previously cited, the following values are recommended for average conditions:

C_R = 1.21 for 'tween deck reefer cargo spaces

C_L = 0.90 for cargo deep tanks

C_C = 1.15 for cargo containers (based on external volume of container)

Thus, for any required apportionment of reefer, liquid, containerized and regular dry cargo, one can quickly estimate the required equivalent bale capacity.

Armed with the above concepts, the following formula is derived from capacity data from known ships. This assumes standard sheer and an average volume of non-payload deep tanks:

$$\text{EBC} = (C_B - 0.10)LBD_M - (\text{EBC})_M \qquad [17]$$

where

EBC = equivalent bale capacity in cubic feet

C_B = block coefficient at designed draft

L = length between perpendiculars in feet

(Cont'd.)

B = beam in feet

D_M = modified depth in feet (see above)

$(EBC)_M$ = equivalent bale capacity of the machinery space in cubic feet

The equivalent bale capacity of single screw steam turbine machine spaces may be estimated as

$$(EBC)_M = C + 6.75\ SHP_N \qquad [18]$$

where, for machinery amidships $C \approx 46{,}000$ and for machinery aft, $C \approx 85{,}000$.

The average ship's doublebottom will accommodate fuel oil and feed water to the extent of about 10.5 percent of the design displacement. Greater quantities require deep tanks which encroach on hold volume. The ships which provide the data for the previously mentioned expression for EBC accommodate fuel and feed water to an average extent of 15 percent of design displacement. If, in an actual case, fuel and feed water requirements are materially different than this, bale capacity estimates will require adjustment at a rate of about 34 cubic feet per ton of excess or deficiency ($34 = C_L$ times weighted average stowage factor of oil and water). The maximum negative correction is reached when the amount of such liquids is small enough to allow accommodation entirely within the doublebottom.

Calling the combined weight of fuel oil and feed water W_{FF}, the bale capacity corrections are summarized below:

1. If $W_{FF} = 0.15\,\Delta$, EBC needs no correction
2. If $W_{FF} > 0.15\,\Delta$, subtract $34\,(W_{FF} - .15\,\Delta)$
3. If $W_{FF} < 0.105\,\Delta$, add $1.53\,\Delta$
4. If $W_{FF} > 0.105\,\Delta$ and $< 0.15\,\Delta$, add $34\,(.15\,\Delta - W_{FF})$

The methods discussed above are used to establish the bale capacities for the B-1 and B-1.8 Series vessels on voyages of different length as reported in Chapter I.

Tonnage

Quick methods for estimating registered tonnage may occasionally be useful in preliminary design. Analysis of recent ships leads to the following:

$$\text{Tonnage Measurement} = C(CN \times C_B - 1000) \qquad [19]$$

where C has the approximate values listed in Table VII.

Further studies will be in order when the tonnage laws are finally changed. And horsepower and type of machinery should probably be introduced as additional parameters.

TABLE VII

TONNAGE COEFFICIENTS

Tonnage	Ship Type	
	Shelter Deck	Normal
Gross	0.95	1.25
Net	0.55	0.77

CHAPTER V

WEIGHTS

General

The conclusions of this chapter are largely derived from 15 recent designs, weight data for which were supplied by nine different organizations. Known weights from older ships were also used, principally to clarify the influence of ship size.

Reference 114 may be consulted for methods of estimating weights for containerships.

Categories

For purpose of preliminary design, weights should be subdivided into a reasonably small number of groups. Considerable compromise is required here because of the following considerations:

1. For simplicity, the number of groups should be small; this inevitably leads to widely scattered data points, analysis of which is difficult owing to compounding of design variables.

2. The weight breakdown must bear close relationship to that used by the various shipyards which supply factual data. These breakdowns are tied to history and contain many anomalies.

3. The same breakdown must also be suitable for calculating building costs, most of which are based on weights.

In this study, weights are divided into the four conventional categories: steel hull, outfitting, hull engineering (wet) and propulsion machinery (wet). The exact definition is that detailed by Watson (140).

Weights of fuel, water, stores, etc., are dealt with in Chapter VII.

Future studies might benefit from a complete reevaluation of the outfitting and hull engineering categories. The breakdown used here leaves much to be desired in its application to weight or cost estimation.

Steel Hull Weights

Empirical analysis of many actual general cargo ships, leads to the following simplified expression for the net weight of the steel hull*

$$W_S = 340 \left(\frac{CN}{1000}\right)^{0.9} \times C_1 \times C_2 \times C_3 \qquad [20]$$

where

$$CN = \text{cubic number} = \frac{LBD}{100} \qquad [10]$$

$$C_1 = 0.675 + (1/2)C_B \qquad [21]$$

$$C_2 = 1 + 0.36 \frac{L_S}{L} \qquad [22]$$

$$C_3 = 0.00585\left(\frac{L}{D} - 8.3\right)^{1.8} + 0.939 \qquad [23]$$

and

L = length between perpendiculars in feet
B = beam in feet
D = depth to uppermost continuous deck in feet
C_B = block coefficient at design draft
L_S = length of superstructure within fore and aft perpendiculars in feet

These figures are appropriate for hulls employing little or no special steels or aluminum alloys.

---

*All weights are in long tons

Figures 25 and 26, derived from the above formulation may be convenient. These use the familiar steel weight coefficient based on cubic number ($W_S = C_S \times CN$) and assume a superstructure of 20 percent of the ship's length. Figure 26 carries a superimposed correction factor for other lengths of superstructure. This factor can be applied to coefficients from either chart.

A somewhat more rational, but apparently less accurate, approach to steel weight estimation is based on freeboard rule requirements (129) for section modulus of the hull girder. This method has the merit of automatically correcting for differences in scantling draft and is also possibly superior in predicting steel weights of very large ships

$$W_S = \left(1.285 - 0.0786 \frac{N}{1000}\right) N \times C_1 \times C_2 \qquad [24]$$

where

$$N = 1.11 \frac{Bd_S}{D} \left(\frac{L}{100}\right)^{8/3} \quad \text{for } L > 200 \qquad [25]$$

and

$$N = 1.5 \frac{Bd_S}{D} \left(\frac{L}{100}\right)^{9/4} \quad \text{for } 200 > L > 160 \qquad [26]$$

while C_1, C_2, L, L_S, B and D are as just defined and d_S = scantling draft in feet.

The above formulation is based on a method first suggested by engineers of Bethlehem Steel Company's Shipbuilding Division, Quincy.

Several other steel weight estimating methods are presented in References 60, 88, 123 and 140. However most of these are somewhat too complicated for use in parametric design studies. No matter what method is used, however, one must remember that such approaches are accurate only for revealing trends and should not be relied upon for actual individual cases.

When steel weights are estimated on any system other than that of Equation 24, the problem of correcting for differences in scantling draft becomes exceedingly difficult. Increasing the scantling draft of course requires a proportionate increase in the hull girder section modulus. However it is not easy to predict how this will change the steel weight. In some instances

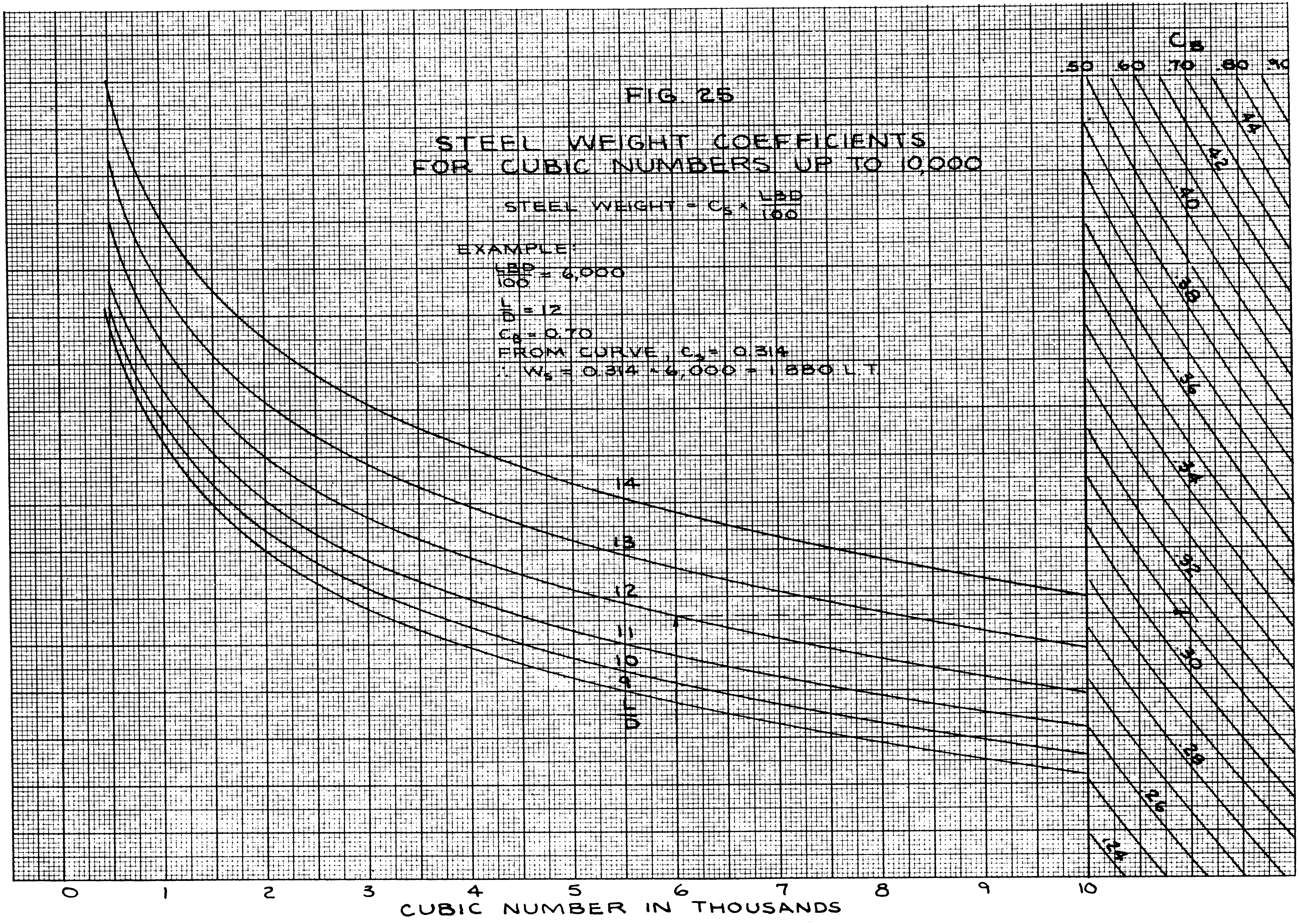


FIG. 25

STEEL WEIGHT COEFFICIENTS
FOR CUBIC NUMBERS UP TO 10,000

STEEL WEIGHT = $C_S \times \frac{LBD}{100}$

EXAMPLE:

$\frac{LBD}{100} = 6{,}000$

$\frac{L}{D} = 12$

$C_B = 0.70$

FROM CURVE, $C_S = 0.314$

$\therefore W_S = 0.314 \times 6{,}000 = 1{,}880$ L.T.

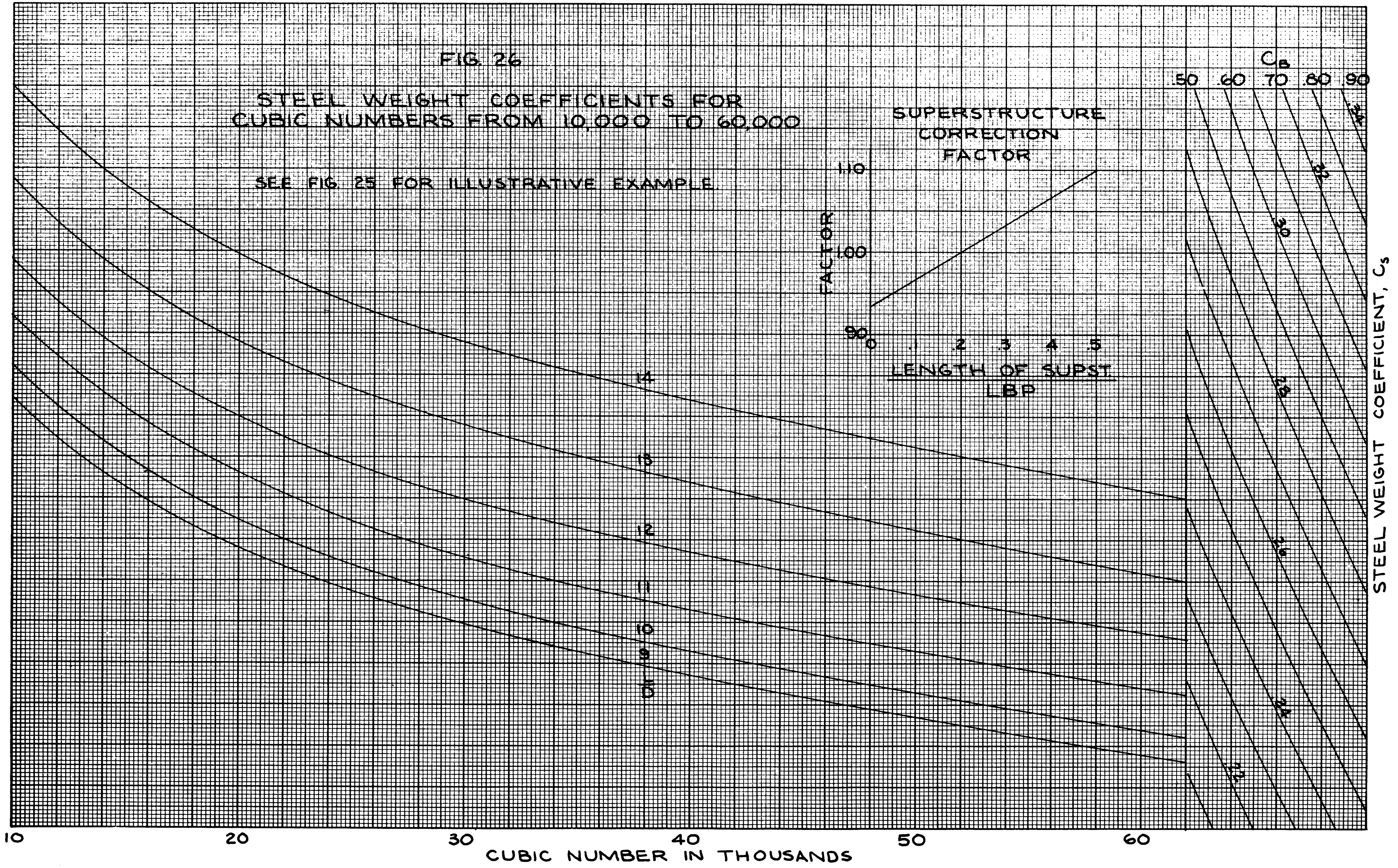


FIG. 26

STEEL WEIGHT COEFFICIENTS FOR CUBIC NUMBERS FROM 10,000 TO 60,000

SEE FIG. 25 FOR ILLUSTRATIVE EXAMPLE

large increases in section modulus can be effected by slightly increasing the thickness of the main deck stringer. The influence of this added weight is magnified by the concurrent favorable upward shift in the neutral axis. In other cases the neutral axis is already near mid-depth and this advantage does not occur. As an example of this irregularity, two known actual cases were matched on a comparable basis and one was found to change steel weight three times as much as the other. In short, it appears that the effect of scantling draft on steel weight is beyond quantitative analysis in the preliminary stages of design. Equation 24 will of course indicate general trends but it too may be misleading for specific comparisons.

Although variations in scantling draft are difficult to analyze weightwise they are, fortunately, relatively modest in impact. This is borne out by various experts (113) who estimate that, for a given overall size of ship, a shelter deck design will save from 4 to 6.5 percent in steel weight; another finds that, for a given displacement, a shelter deck design will increase steel weight by four percent.

Reference 113 also publishes figures, attributed to Roester and shown in Table VIII, which may be used to modify steel weight estimates where the number of decks differ between comparisons.

TABLE VIII

INFLUENCE OF ADDED DECK ON STEEL WEIGHT

$\frac{L}{D}$	Percent Increase in Steel Weight for the Addition of One Complete 'Tween Deck
10	3
11	4.25
12	5.5
13	6.75
14	8
15	9.25

The same authority estimates a two percent change in steel weight for every ten percent change in length-beam ratio.

One final nugget concerns the influence of the open deck or all-hatch design. Goldman (46,47) finds that such ships save from three to five percent steel compared with ships of conventional design. However, it is possible that some of this weight saving is eaten up by the extra weight of hatch covers.

Outfitting Weights

The weight of outfitting in tons may be expressed as

$$W_O = C_O \left(\frac{CN}{1000} \right)^{0.825} \qquad [27]$$

where CN is the cubic number and C_O is a coefficient ranging from 109 in austere designs to 160 in elaborate designs, with a value of 125 in average designs.

This relationship is arrived at empirically from data based on modern U. S. practice. Figure 27 presents this formulation graphically.

Hull Engineering Weights

The wet weight of hull engineering in tons may be expressed

$$W_{HE} = C_{HE} \left(\frac{CN}{1000} \right)^{0.825} \qquad [28]$$

where C_{HE} is a coefficient ranging from 53 in austere designs to 82 in elaborate designs, with a value of 62 in average designs.

Again, these relationships are based on recent U. S. cargo ships. Figure 28 has contours corresponding to the above.

Additional weight information for both outfitting and hull engineering may be found in References 18 and 140.

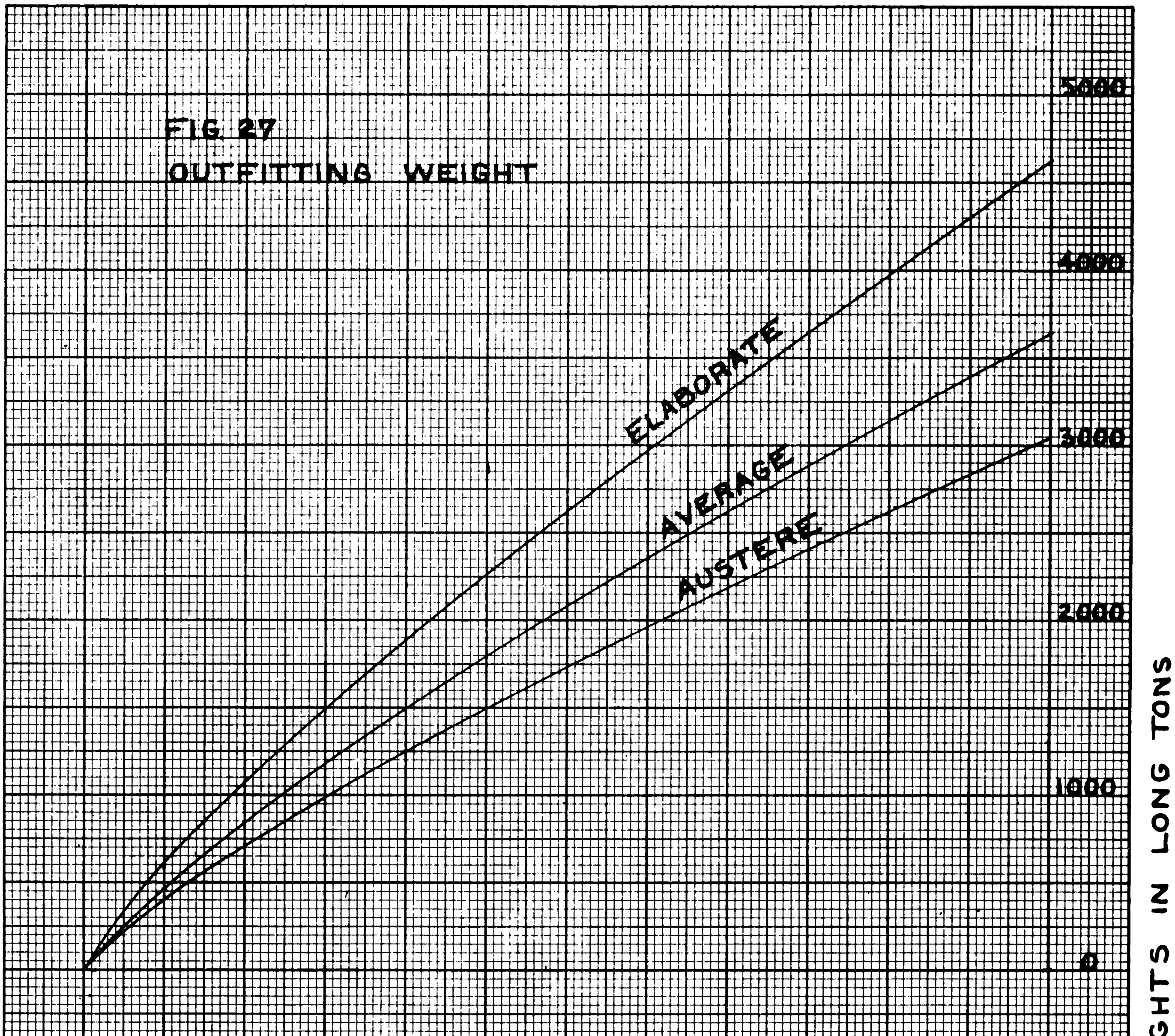


FIG. 27
OUTFITTING WEIGHT

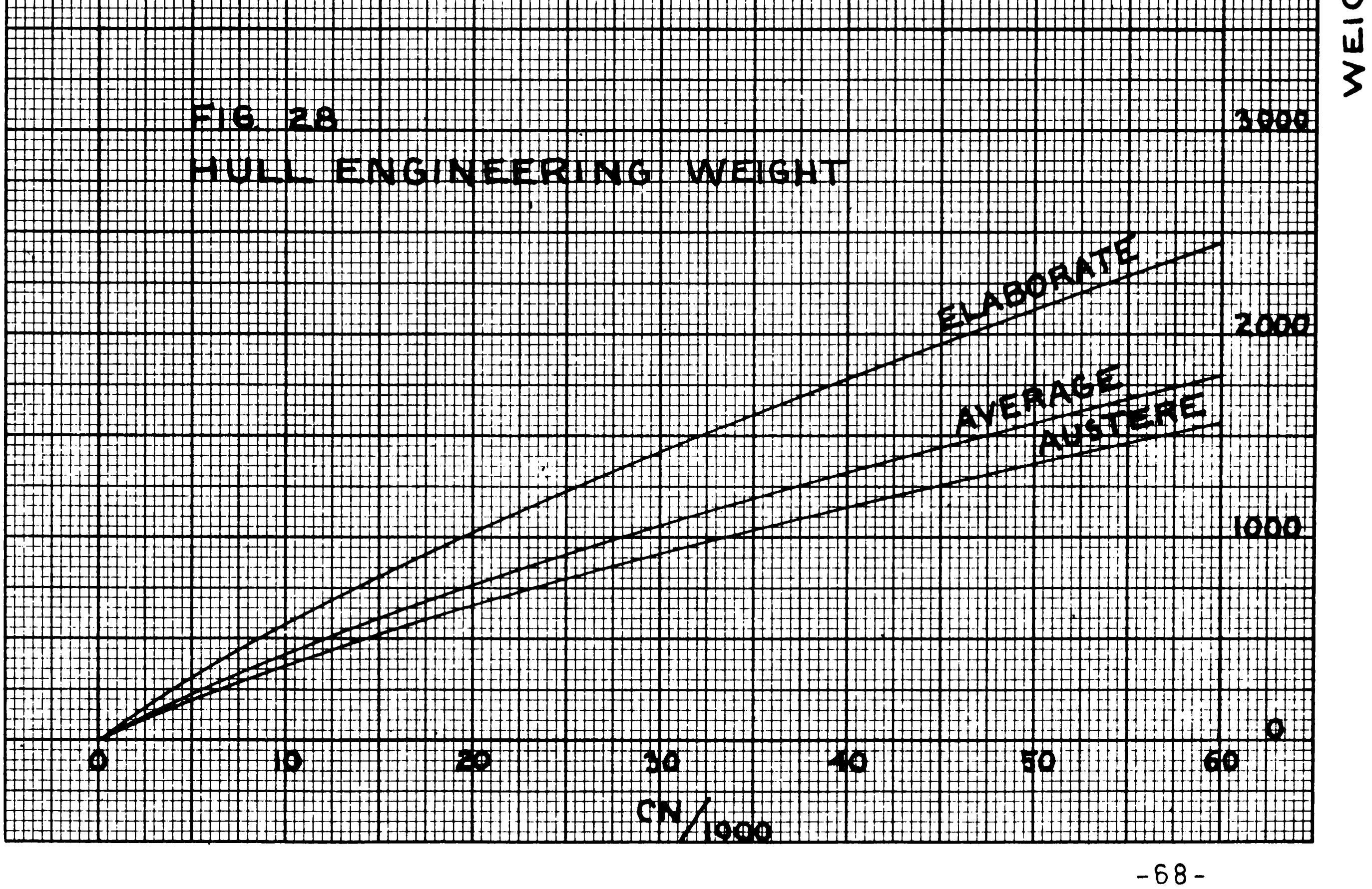


FIG. 28
HULL ENGINEERING WEIGHT

Machinery Weights

Steam turbine propulsion machinery has weight characteristics which vary with the square root of the horsepower:

$$W_M = C_M \sqrt{\frac{SHP_N}{1000}} \qquad [29]$$

where

W_M = wet weight of propulsion machinery in tons

SHP_N = normal installed shaft horsepower

C_M = machinery weight coefficient; see Table IX

TABLE IX

VALUES OF MACHINERY WEIGHT COEFFICIENT, C_M

Arrangement	Machinery Location	
	Amidships	Aft
Single Screw, average	247	225
Single Screw, minimum	230	213
Twin Screw, average	313	301
Twin Screw, minimum	301	289

References 6, 29, 30, 31, 59, 67, 68, 100, 117, 121, and 142 may be consulted for methods and data which can be used in estimating weights of machinery other than conventional steam turbine plants.

Accommodation Weights

The advent of shipboard automation raises the question of how much saving can be made in light ship weight if radical reductions are made in size of crew. Current weight recording systems are ill fitted to answer this. However, it is estimated that if only one man were carried there would be about 70 tons of weight in his accommodation. This includes the steel deck house, joiner work, deck covering, furniture, hotel services (including piping, wiring and duct work as well as air conditioning system and added electrical capacity). It also includes food services, safety equipment such as lifeboat, radio and other items which would be useless on a totally unmanned ship. With a 58-man crew, the corresponding weight is estimated to be 608 tons. While no intermediate values have been calculated, it is believed that the weight would vary exponentially with the number in the crew:

$$W_A = 70\ N_C^{0.535} \qquad [30]$$

Owing to the difficulty of establishing the inputs, it is probably appropriate to simplify the above expression into

$$W_A = 80\ \sqrt{N_C} \qquad [31]$$

where

W_A = weight of accommodations in tons

and

N_C = number in crew

Each passenger accommodated would add about 12 tons to the above.

Deadweight

The deadweight coefficient curves shown in Chapter I are synthesized from weights estimated according to the foregoing methods. Steel weights are based on the cubic number system assuming a superstructure equal in length to 20 percent of the ship's length. Length-depth ratio and block coefficient are as determined for each individual hypothetical ship. Outfitting, hull engineering and machinery weights are based on the average values cited and it is assumed that machinery is located amidships.

CHAPTER VI

BUILDING COSTS

General

As in the case of the weight analysis, the conclusions presented in this chapter are based on cost and man-hour breakdowns submitted in confidence by individuals in nine different organizations. Figures were supplied in 28 sets covering 15 different designs. Information was also gleaned from References 9, 35 and 54.

Categories

As a matter of convenience, building costs are put into the same subdivisions used in the preceding weight analysis. In addition, consideration is given to miscellaneous costs such as drafting and staging which involve no weights in the finished ship.

Steel Hull Costs

Steel material costs average $220 per ton of steel, net weight. This includes transportation and covers special shapes, welding rod, castings, forgings and a nominal quantity of aluminum as well as the regular shipbuilding steel. And JFK is doing his little best to make this figure inviolate, but all other prices herein are subject to change without notice.

Steel man-hours can be estimated as

$$MH = C\left(\frac{W_S}{1000}\right)^{0.85} \qquad [32]$$

where W_S is the net weight of steel and C is a coefficient which varies from 68,000 in a well equipped and efficient yard to

140,000 in an average small and inexperienced yard. In a typical large yard, C will run around 90,000. The complexity of structure will also influence this figure; values given are for an average U. S. cargo ship of recent design.

Outfitting Costs

Outfitting material costs per ton (net) range from \$720 to \$1250 with an average of \$980.

Outfitting man-hours may be estimated as follows:

$$MH = C\left(\frac{W_O}{100}\right)^{0.9} \qquad [33]$$

where W_O is the net weight of outfitting in tons and C is a coefficient which ranges from 15,000 to 27,5000 with an average value of 20,000.

The above breakdown assumes little or no subcontracting of joiner work or deck covering.

Hull Engineering Costs

Material costs for hull engineering vary between \$2000 and \$3400 per ton (net). An average value is \$2700 per ton.

Hull engineering man-hours can be estimated as

$$MH = C\left(\frac{W_{HE}}{100}\right)^{0.75} \qquad [34]$$

where W_{HE} is net weight of hull engineering in tons and C is a coefficient which falls between 39,000 and 72,000 with an average value of 51,000.

Machinery Costs

Machinery material costs can be estimated on the following basis:

$$\text{Material Cost} \approx \$440{,}000\left(\frac{\text{SHP}_N}{1000}\right)^{0.6} \qquad [35]$$

Machinery man-hours can be estimated as

$$\text{MH} \approx 25{,}400\left(\frac{\text{SHP}_N}{1000}\right)^{0.6} \qquad [36]$$

This breakdown assumes that the major machinery components will be purchased by the shipyard rather than being yard-built.

Since both material and labor costs vary with the six-tenths power of the shaft horsepower, a simple expression for total cost of installed machinery may be arrived at:

$$\text{Machinery Cost} = C\left(\frac{\text{SHP}_N}{1000}\right)^{0.6} \qquad [37]$$

Assuming 70 percent overhead, 5 percent profit and \$3 per hour labor rate, C will come to about \$600,000. If, in addition, miscellaneous costs are included, C will increase to \$690,000.

The above figures are based on single screw, geared steam turbine machinery located amidships. Certain other conditions can be estimated by application of the following coefficients to both material and labor costs (or total costs, if preferred):

Single screw aft : 0.91
Twin screw amidships: 1.27
Twin screw aft : 1.24

References 6, 51, 59, 82, 83, 117, and 122 give information on other types of machinery. Reference 51 also deals in relative costs of twin vs single screw.

Miscellaneous Costs

Many important costs involve work with which none of the ship's weight categories are concerned. These include drafting, purchasing, blueprints, scheduling, model tests, material handling, cleaning, launching, staging, drydock, tests and trials, insurance, classification, bond, patents and so forth.

On the average, the subtotal of material costs for steel hull, outfitting, hull engineering and machinery should be increased by ten percent for miscellaneous materials. Similarly, labor costs should be increased by 33 percent for miscellaneous direct labor.

Owner's expenses are discussed separately in a later section.

Overhead Costs

Indirect costs are usually taken as a percentage of the direct plus miscellaneous labor costs. An average figure is 70 percent. These include all costs which cannot be directly charged to any one contract, such as officers' salaries, taxes, depreciation, watchmen, utilities and so forth.

Hourly Rates

For the year 1961, an average hourly rate, including a normal amount of overtime and piecework bonus, would be about $2.90. For the year 1962, a rate of $3.00 is assumed.

Profit

Profit is generally calculated as a percentage of the summation of all the material and labor costs, including overhead, although this method does not give a meaningful measure of return on stockholders' investment. The average markup is perhaps 7.5 percent in good times. In average times, five percent is more likely and that figure is used in this study.

Summary of Building Cost Factors

For ease of use, average values of the more important cost factors are summarized in Table X.

TABLE X

SUMMARY OF AVERAGE BUILDING COST FACTORS

	Material		Man-Hours	
	Direct	Direct + Misc.	Direct	Direct + Misc.
Steel Hull	$\$220\ W_S$	$\$242\ W_S$	$90{,}000\left(\frac{W_S}{1000}\right)^{0.85}$	$120{,}000\left(\frac{W_S}{1000}\right)^{0.85}$
Outfit	$\$980\ W_O$	$\$1080\ W_O$	$20{,}000\left(\frac{W_O}{100}\right)^{0.9}$	$26{,}600\left(\frac{W_O}{100}\right)^{0.9}$
Hull Eng.	$\$2700\ W_{HE}$	$\$2970\ W_{HE}$	$51{,}000\left(\frac{W_{HE}}{100}\right)^{0.75}$	$68{,}000\left(\frac{W_{HE}}{100}\right)^{0.75}$
Mach'y*	$\$440{,}000\left(\frac{SHP_N}{1000}\right)^{0.6}$	$\$484{,}000\left(\frac{SHP_N}{1000}\right)^{0.6}$	$25{,}400\left(\frac{SHP_N}{1000}\right)^{0.6}$	$33{,}800\left(\frac{SHP_N}{1000}\right)^{0.6}$

*Single screw, steam turbine, amidships

Figures 29, 30, 31 and 32 show average values of man-hours, material costs and total costs for steel hull, outfitting, hull-engineering and machinery, respectively. Miscellaneous costs are included in every case. The total costs are based on \$3 per hour labor rates, 70 percent overhead and five percent profit margin. Machinery costs apply to single screw, steam turbine machinery located amidships. Single ship contracts are assumed throughout.

Factors shown in Table X are used to synthesize the curves of total costs shown in Chapter I (Figures 13, 14 and 15). These are costs for a single ship before correction for duplicate savings. Owner's expenses are not included.

Analysis of the resulting curves leads to the following approximate relationship:

$$\text{Building Cost} = C_1\left(\frac{CN}{1000}\right)^{3/4} + C_2\left(\frac{SHP_N}{1000}\right)^{0.6} \qquad [38]$$

also

$$\text{Building Cost} = C_3\left(\frac{SHP_N}{1000}\right)^{1/10}\left(\frac{\Delta}{1000}\right)^{2/3} + C_2\left(\frac{SHP_N}{1000}\right)^{0.6} \qquad [39]$$

where, under average conditions today

$C_1 = \$1,200,000$

$C_2 = \$\ \ 690,000$

$C_3 = \$1,000,000$

Equation 39 is the more restricted of the two and should be applied only to general cargo ships of average freeboard. Equation 38 can be applied regardless of freeboard but tends to give high answers when cubic number is less than 8000.

Reference 69 indicates that for identical cargo weights and volumetric capacity (inside containers) and identical sea speed, a cellular containership should cost ten percent more than a conventional ship. Reference 114 may be consulted for detailed

FIG 29

STEEL HULL COSTS

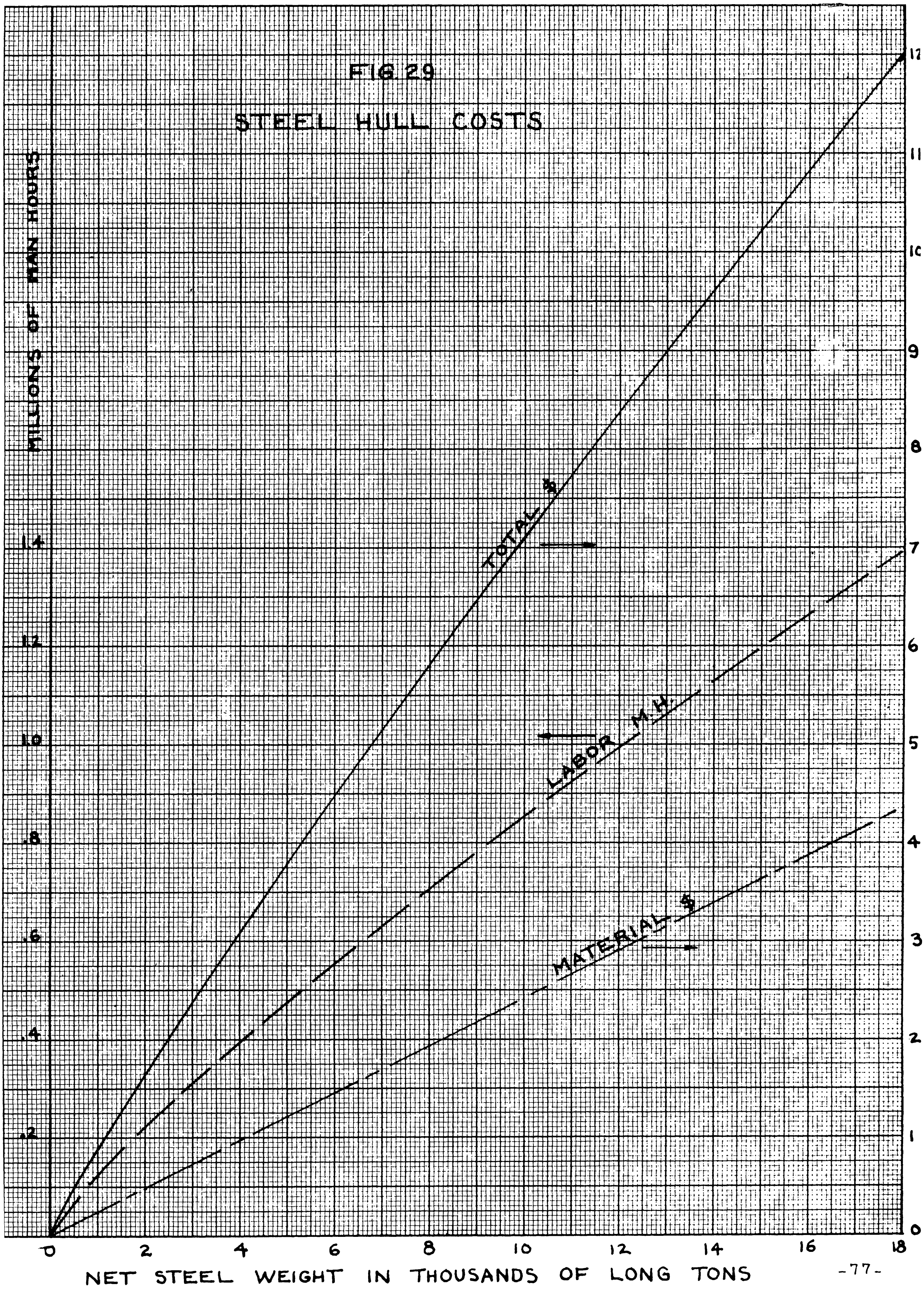


FIG. 30

OUTFITTING COSTS

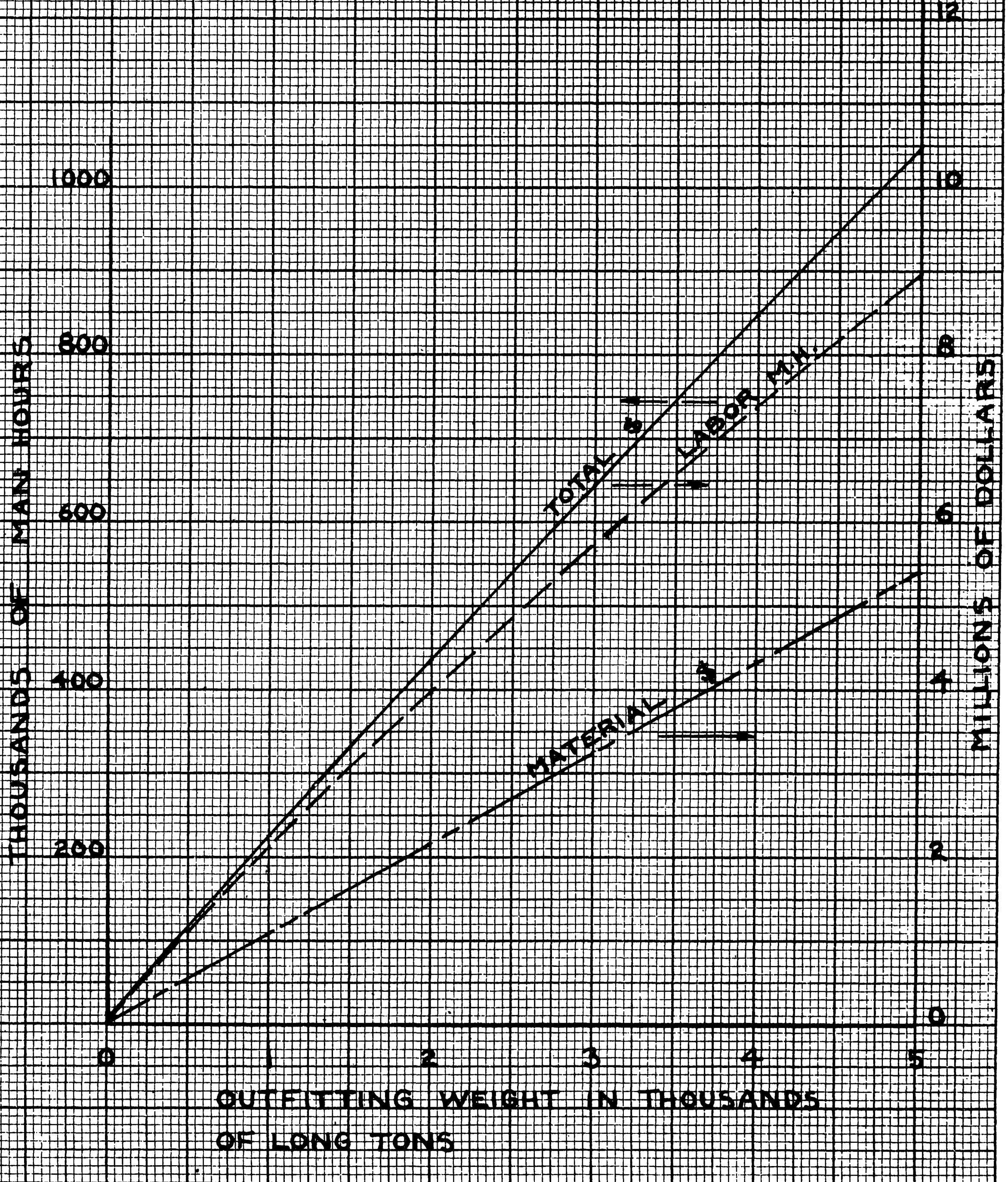
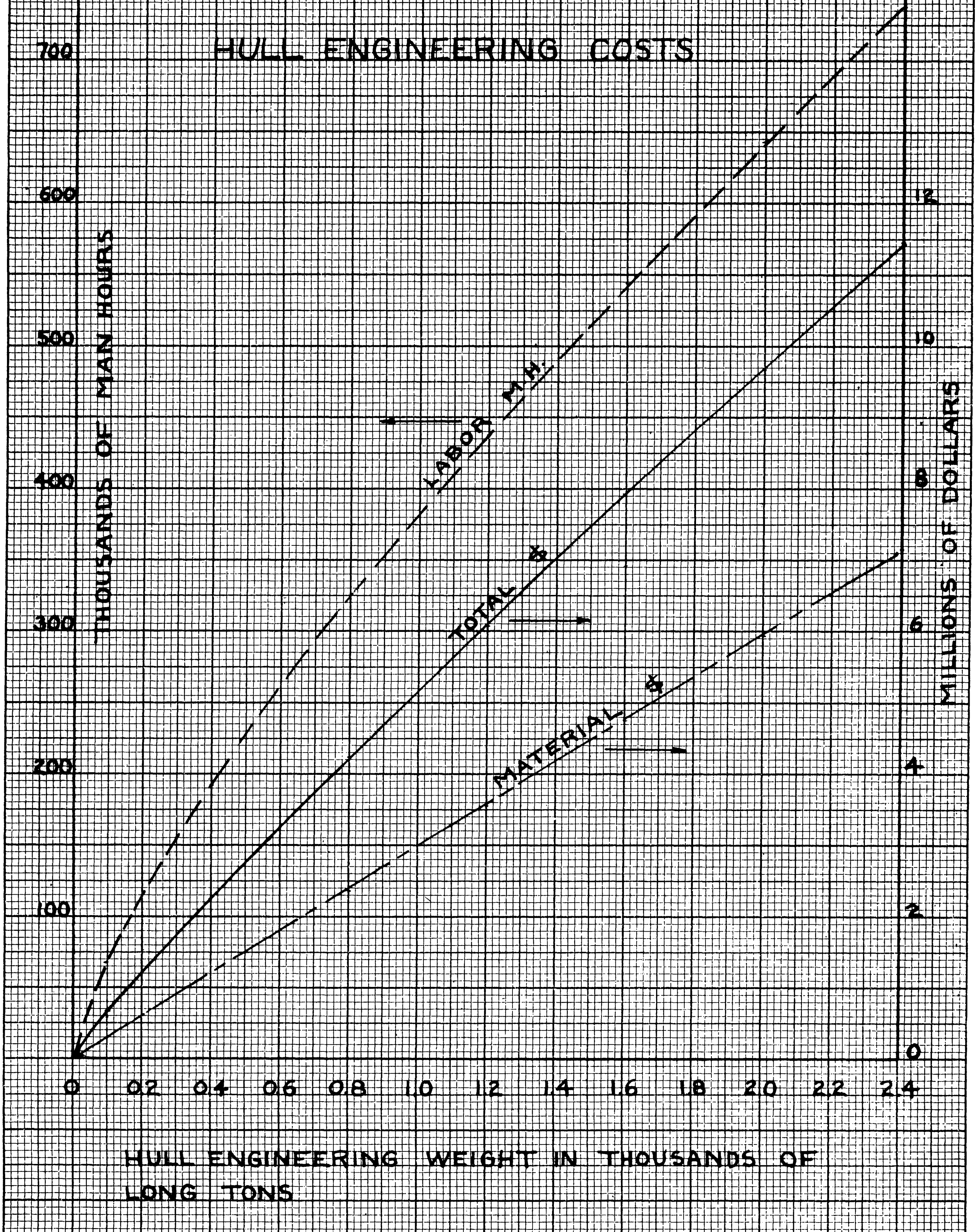


FIG. 31



HULL ENGINEERING COSTS

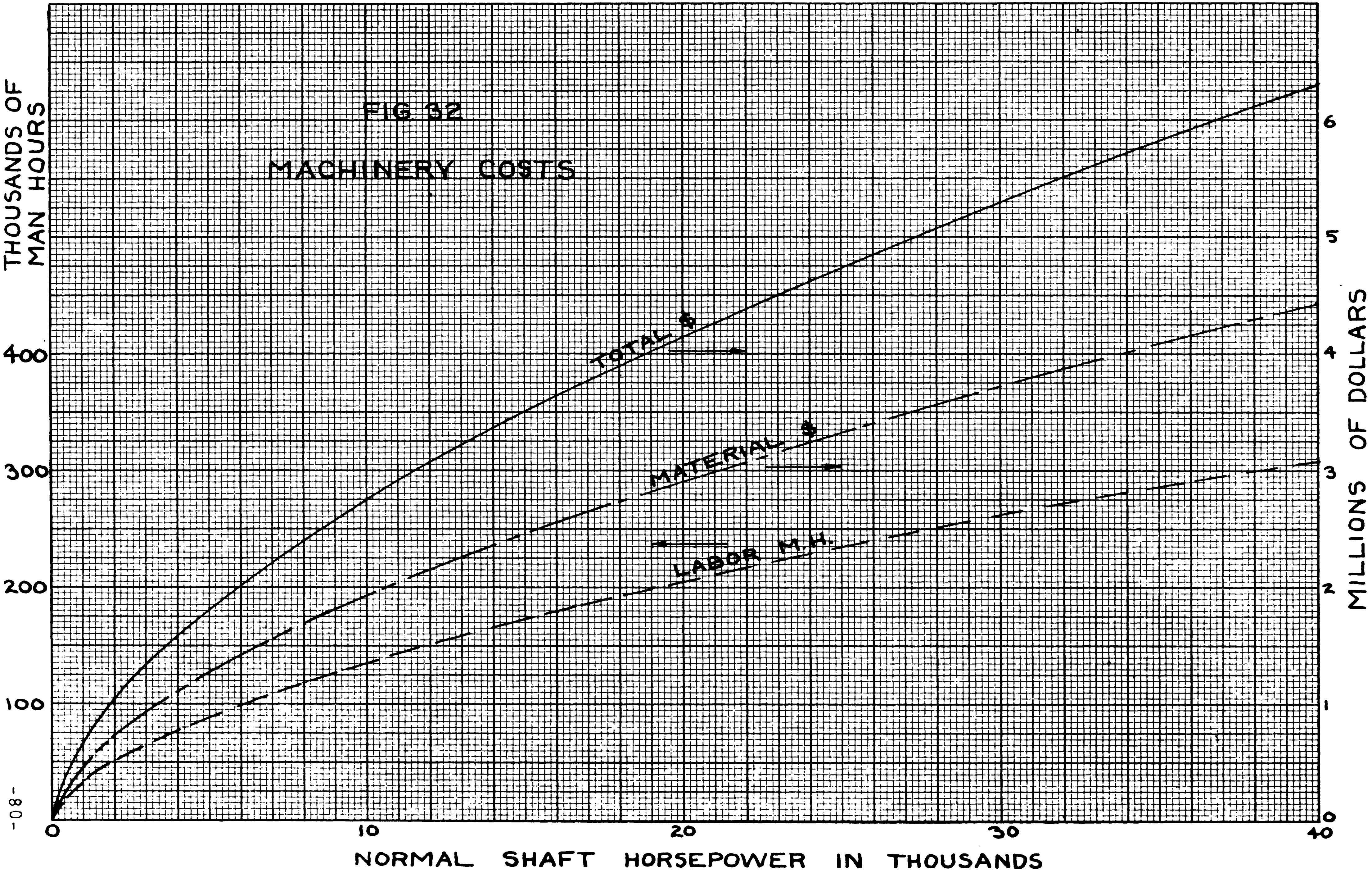


FIG 32

MACHINERY COSTS

methods of estimating containership costs. Figures shown in that reference should be raised somewhat to include miscellaneous material and labor costs. The costs of containers must of course also be included.

One interesting fact brought out in this study concerns the influence of ship speed on building cost. Figure 15 shows building cost plotted against cargo weight capacity with contours for different speeds. In a typical case, say 8000-ton cargo and 18 knots, an 11 percent increase of speed to 20 knots will raise the cost nearly 18 percent. The pertinent point is that of this 18 percent increase, less than 5 percent can be charged against the extra horsepower. Most of the difference is explained by the larger hull required for the higher speed.

Duplicate Ship Savings

All of the above cost figures are based on a single ship contract and include drawings, templates, purchase orders and other non-recurring needs. In the case of multiple ship contracts, the cost per ship will be reduced according to the following relationship:

$$\text{Cost per Ship} = \frac{\text{Cost of Single Ship}}{N^x} \qquad [40]$$

where N = number of identical ships and x is an exponent which varies from 0.055 to 0.145, with an average value of about 0.100.

These figures apply to normal merchant ships. Simple craft such as barges would have lower exponents, naval vessels would have higher. Also, an inexperienced yard should have a relatively high exponent because its labor force learns much from the earlier ships.

Converting the foregoing to the cost for each additional ship, we have

$$\text{Cost for the Nth Ship} = \text{Cost for the 1st Ship}\left[N^{1-x} - (N-1)^{1-x}\right] \qquad [41]$$

Table XI puts these findings into tabular form.

TABLE XI

MULTIPLE SHIP COST REDUCTION FACTORS

Number of Ships in Contract	Ratio of Average Cost per Ship to Cost of Single Ship			Ratio of Cost of Each Additional Ship to Cost of Single Ship		
	Min.	Aver.	Max.	Min.	Aver.	Max.
1	1.000	1.000	1.000	1.000	1.000	1.000
2	0.904	0.933	0.9625	0.808	0.866	0.925
3	0.8525	0.896	0.940	0.749	0.822	0.897
4	0.818	0.871	0.926	0.713	0.794	0.882
5	0.792	0.851	0.916	0.688	0.774	0.872
6	0.772	0.836	0.906	0.670	0.758	0.863
7	0.754	0.823	0.8985	0.654	0.746	0.855
8	0.740	0.812	0.892	0.640	0.735	0.847
9	0.728	0.802	0.8865	0.628	0.726	0.839
10	0.717	0.794	0.881	0.617	0.719	0.832

Owner's Costs

In addition to the predicted shipyard bill, the owner must not overlook several other costs incidental to the newbuilding. These include naval architect's fees for contract plans, specifications, working plan approval and inspection. They also include special consulting fees such as for interior design, owner's outfit, interest on money paid before delivery, bonds, and attorney's fees.

Based on details furnished by two subsidized operators, it is concluded that owner's costs may be estimated as a percentage of the shipyard bill for a single ship. This percentage comes to about 3 plus 1.75 times the number of ships. Reference 5 uses eight percent without specifying the number of identical ships involved. Non-subsidized owners would probably have lower costs than those indicated above because of fewer complications in methods of doing business.

In comparative cost studies it is frequently acceptable practice specifically to omit owner's costs from the calculations.

Accommodation Costs

One of the more favorable aspects of shipboard automation is the potential saving in cost of accommodations. Standards for crew quarters have grown to such an extent that this particular cost segment has attained major proportions. Using methods and assumptions similar to those discussed under Weights it is found that, under current conditions, accommodation costs can be estimated as follows:

$$\text{Steel Cost} = \$\,27{,}000\ N_C^{0.56}\ (+\ \$\,63{,}000) \qquad [42]$$

$$\text{Outfit Cost} = \$\,75{,}000\ N_C^{0.56}\ (+\ \$188{,}000) \qquad [43]$$

$$\text{Hull Engineering Cost} = \$\,78{,}000\ N_C^{0.56}\ (+\ \$169{,}000) \qquad [44]$$

$$\text{Total Accommodation Cost} = \$180{,}000\ N_C^{0.56}\ (+\ \$420{,}000) \qquad [45]$$

where N_C = number in crew and figures in parentheses are to be added if 12 passengers are accommodated.

These figures are on a first-of-kind basis. They could be reduced for multiple ship contracts but should also be increased for owner's furnished materials.

Figure 33 presents the above formulation in graphic form.

Lest there be any misunderstanding, all previously discussed costs have included the accommodations.

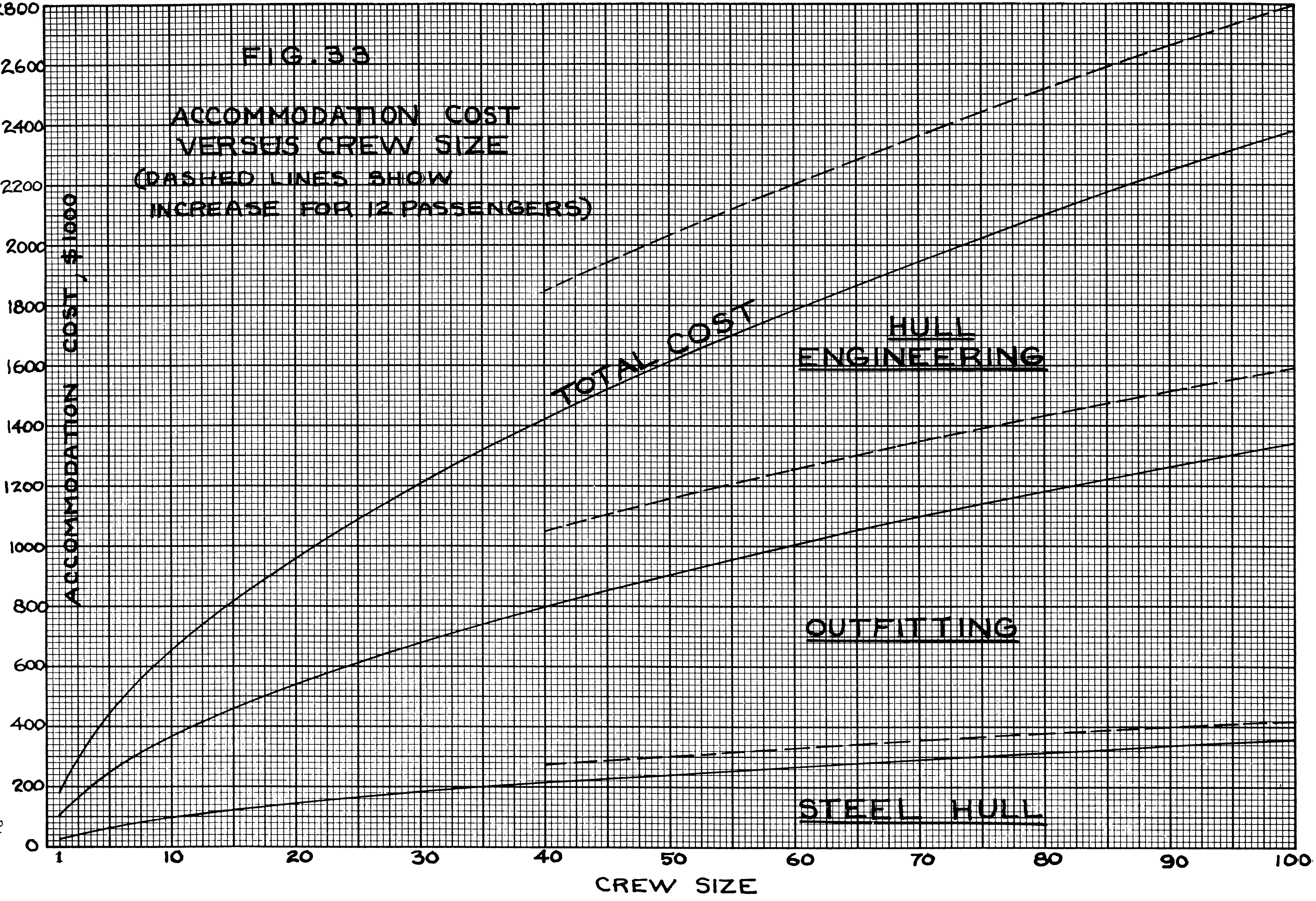


FIG. 33

ACCOMMODATION COST VERSUS CREW SIZE

(DASHED LINES SHOW INCREASE FOR 12 PASSENGERS)

Foreign Building Costs

In the lower cost foreign nations shipbuilding prices are currently between 45 and 50 percent of U. S. prices for identical ships. For the more austere (but perhaps less productive) foreign ships, the net building cost may be only 35 percent of the cost of a typical subsidized U. S. ship of identical speed and cargo capacity.

See References 39, 63 and 98.

CHAPTER VII

SCHEDULING AND OTHER OPERATING FACTORS

Introduction

Any careful analysis of general cargo ship operations must face the complication of frequent operation at partial draft. There will also be variations in power utilization resulting from the combined influences of partial loading and maintenance of practical schedules. Changes in power utilization lead further to changes in fuel rate. Other considerations include analysis of weight of non-payload items and methods of estimating annual transport capability.

Scheduling Requirements

It is difficult to generalize about cargo ship schedules except to say that a tramp ship has none whereas liner operators find it almost mandatory to stick to some rigorous periodic service. Assuming a design for the liner trade, the naval architect should be given the details of the distances, scheduled speeds and predicted cargo quantities for each leg of the voyage. Samples of such schedules are shown in Tables XII and XIII, and Appendix V is also of interest. Scheduling information is prerequisite to an accurate estimate of operating costs, particularly as regards fuel requirements. It is also necessary for accurate assessment of deadweight lost to fuel and fresh water. Lacking the details of the intended operation, the naval architect can still make an estimate of average conditions and arrive at reasonably dependable figures. The studies reported in References 69, 105 and 136 serve as examples of how imaginary typical schedules can be used to establish economic patterns, and Reference 34 gives a good idea of the complexities involved in planning a multi-port operation.

One should be cautioned against placing too much emphasis on any given schedule. Cargo quantities are difficult to predict with accuracy and it is impossible to say what changes may shortly occur in any given trade route requirement. Nor must the possible future resale value be forgotten. In short, a certain amount of versatility is essential in any design.

Table XII shows a typical cargo liner schedule while Table XIII, from Reference 87, shows a 'round-the-world schedule.

See also References 19, 62, 80, 120 and 124.

TABLE XII

TYPICAL OCEANGOING CARGO LINER SCHEDULE

(Four 18-knot vessels sailing from New York fortnightly, 56-day turnaround)

Port	Miles	Speed	Steaming Time	Long Tons Load	Long Tons Disch.	Port Time	Arrive	Sail
New York				2665				Fri 1700
A (US outport)	286	17.0	00-17	250		00-14	Sat 1000	Sat 2400
B (US outport)	497	16.5	01-16	400		00-17	Mon 0600	Mon 2300
C (enter canal)	1577	18.0	03-16		190	00-15	Fri 1500	Sat 0600
D (leave canal)	42	trans	00-09				Sat 1500	Sat 1500
E	356	18.0	00-20		180	00-09	Sun 1100	Sun 2000
F	565	18.0	01-10	21,000 bananas	85	00-13	Tue 0600	Tue 1900
G	687	18.0	01-17		750	01-23	Thu 1200	Sat 1100
H	452	17.5	01-02		200	00-16	Sun 1300	Mon 0500
I	52	slow	00-04		175	00-15	Mon 0900	Mon 2400
J	82	slow	00-06	50	275	00-11	Tue 0600	Tue 1700
K	322	18.0	00-18	290	175	00-09	Wed 1100	Wed 2000
L	169	17.0	00-10	1315	85	00-13	Thu 0600	Thu 1900
M	230	18.0	00-13		75	00-09	Fri 0800	Fri 1700
N	201	15.5	00-13	400	2200 + 21,000 bananas	04-18*	Sat 0600	Wed 2400
O	42	slow	00-06	1350	55	00-14	Thu 0600	Thu 2000
K	606	18.0	01-10	1075		00-13	Sat 0600	Sat 1900
P	110	slow	00-11	65		00-09	Sun 0600	Sun 1500
I	273	18.0	00-15	1960		00-18	Mon 0600	Mon 2400
G	507	17.0	01-06	1860		01-18	Wed 0600	Thu 2400
Q	259	17.0	00-15	1500		00-12	Fri 1500	Sat 0300
F	429	18.0	01-03	18,000 bananas		00-12	Sun 0600	Sun 1800
D (enter canal)	733	18.0	01-22			00-14	Tue 1600	Wed 0600
C (leave canal)	42	trans	00-09				Wed 1500	Wed 1500
New York	1956	18.0	04-13		3260 + 18,000 bananas	02-00	Mon 0400	Wed 0400
X (US outport)	30	slow	00-04		2630	01-03	Wed 0800	Thu 1100
Y (US outport)	265	slow	00-20	675	3775	02-11	Fri 0700	Sun 1800
Z (US outport	94	slow	00-12	455	200	00-13	Mon 0600	Mon 1900
New York	240	16.0	00-15			03-07	Tue 1000	Fri 1700

* Extra time allowed for calls at other outports as seasonal requirements vary

TABLE XIII

TYPICAL 'ROUND-WORLD CARGO LINER SCHEDULE

(Twenty-knot vessels, 112-day turn-around. See also Appendix V)

Port	Arrive	Sail	Cargo Aboard*	Miles	Sea Time	Port Time	Speed
New York		0 @ 0100	2930				
Cristobal	4 @ 0400	4 @ 0800		1954	4-03	-04	19.8
Balboa	4 @ 1800	4 @ 1800		43	-10	-	Various
Los Angeles	10 @ 1500	12 @ 2400		2913	6-00	2-09	20.3
San Francisco	13 @ 1800	17 @ 2000	9230	368	-18	4-02	20.5
Yokohama	29 @ 0700	31 @ 0800	4990	5000	10-18	2-01	19.4
Pusan	32 @ 1800	33 @ 1800		665	1-10	1-00	19.6
Kobe	34 @ 1200	35 @ 2000		361	-18	1-08	20.1
Okinawa	37 @ 0600	38 @ 1200		653	1-10	1-06	19.3
Keelung	39 @ 0600	40 @ 0800		335	-19	1-02	17.7
Hong Kong	41 @ 0700	42 @ 0800		440	-23	1-01	19.2
Saigon	44 @ 0600	46 @ 1600	2690	917	1-22	2-10	20.0
Singapore	48 @ 0600	51 @ 2000		649	1-15	3-14	16.7
Pt.Swettenham	52 @ 0600	56 @ 2000		193	-10	4-14	19.3
Penang	57 @ 0600	58 @ 1200	5990	153	-10	1-06	15.3
Colombo	61 @ 0600	62 @ 0900		1285	2-20	1-03	18.9
Cochin	63 @ 0600	64 @ 2000		318	-21	1-14	15.2
Mangalore**	65 @ 0600	65 @ 1800		193	-10	-12	19.3
Bombay	66 @ 1400	68 @ 2000		399	-20	2-06	20.0
Karachi	70 @ 0600	72 @ 0800	6240	504	1-10	2-02	14.9

*Includes 140 tons empty van weight

**Omits Mangalore during Monsoon season (May-Sept)

(continued)

TABLE XIII (Cont'd.)

Port	Arrive	Sail	Cargo Aboard	Miles	Sea Time	Port Time	Speed
Suez	78 @ 0200	78 @ 0800	6240	2777	5-21	-06	19.7
Pt. Said	78 @ 2200	78 @ 2200		88	-14	-	Various
Naples	81 @ 0600	81 @ 2400		1116	2-09	-18	19.6
Barcelona	83 @ 0600	83 @ 2000		558	1-06	-14	18.6
Marseille	84 @ 0600	84 @ 2000		187	-10	-14	18.7
Genoa	85 @ 0600	87 @ 2400	9630	200	-10	2-18	20.0
Leghorn	88 @ 0600	89 @ 1200		78	-06	1-06	13.0
New York	98 @ 0600	102 @ 1600	2690	4089 Via CCC	9-00	4-10	19.0
Boston	103 @ 0800	104 @ 1600		216 Via CCC	-16	1-08	13.5
Philadelphia	105 @ 1800	106 @ 0600		406 Via C&D	1-02	-12	15.7
Baltimore	106 @ 1600	107 @ 2000		95	-10	1-04	9.5
Hampton Roads	108 @ 0700	109 @ 1200		150	-11	1-05	13.7
New York	110 @ 0600	112 @ 0100	2930	245	-18	1-19	13.7
				27548	61-16	50-08	

Port Time

Port time is relatively independent of cargo capacity. This is because ships are equipped with cargo gear commensurate with cargo capacity. For example, a survey of recent U. S. cargo ships (74) shows the following relationship to be fairly accurate:

$$\text{Pairs of Cargo Booms} = 1 + 1.425\,\frac{\text{Bale Capacity}}{100{,}000} \qquad [46]$$

The biggest factor in port time is the cargo handling system. Break-bulk methods are assumed here. Container cargo can, of course, be handled in a fraction of the time and palletized cargo would be somewhere in between. See References 69, 73, 74, 75, 76 and 114.

Another factor would be the number of ports serviced. The typical cargo liner operation involves overnight waits at numerous ports where only a small amount of cargo may be handled. The number of ports, in turn, appears to be related to the length of voyage. Analysis of three typical operations shows close agreement with the following formula:

$$\text{Port Days per Round Trip} = 10 + 1.5\,\frac{Z}{1000} \qquad [47]$$

where Z is the round trip distance.

Information on cargo handling speeds may be found in References 46, 47, 69, 74, 102, 105 and 114.

Operating Days per Year

Most general cargo ship operators figure on 350 operating days per year, the remaining days being devoted to shipyard repairs. Fast turnaround ships such as containerships might figure 340 days, closely akin to values found appropriate for ore carriers (16) and tankers (15). The ten-day difference is explained by the lack of time for routine dockside repairs in the fast turnaround ships. One containership operator, however, reports an average of 360 operating days per year.

Simpson (117) estimates 355 operating days for a steam turbine ship versus 340 for a diesel ship. Diesel purveyors may confirm the numbers but switch the sequence.

Cruising Radius

Strictly speaking, a ship's cruising radius is that distance which it can cover, while proceeding under normal power, without stopping to take on fuel, fresh water or other consumables or to handle cargo. The cruising radius of most recent U. S. cargo ships is from 10,000 to 16,000 miles with some as high as 20,000 miles. Actual interport distances are considerably lower being only about 3000 miles in the North Atlantic trades and 8000 miles in the Pacific. Moreover, cruising radius, as such, is not too meaningful when one considers that fuel and stores are consumed even in port, that emergency fuel margins must be alloted, that much time is spent at partial horsepower, and that most consumables can be readily replenished at various ports along the way. In short, cruising radius should not be taken literally in ship design. Instead, one should study each case individually and compute the necessary quantities of fuel and other consumables. Again, versatility should be kept in mind. Many of the details of this procedure are discussed in the following sections.

Power Required for Speeds and Displacements Other Than Designed

Figures 34A, B and C can be used to estimate the power required at speeds and/or displacements other than the designed values. Each figure contains a family of contours for each of three block coefficients. Three figures are required: one for over-powered ships, one for normally-powered ships and one for under-powered ships; that is, for ships which are relatively full, normal, or fine-lined considering their speed-length ratios. These contours are derived from Reference 49.

Fuel Consumption

Average modern marine steam turbine plants, when operated at designed power, should have normal all-purpose fuel rates close to those shown in Reference 45 for the 600 psi - 850° F cycle, arrangement G. Converted to daily consumption, these are approximately equivalent to

(Cont'd.)

$$\text{Barrels per Day} = 50 + 34.2 \frac{SHP_N}{1000} \qquad [48]$$

or

$$\text{Tons per Day} = 8 + 5.18 \frac{SHP_N}{1000} \qquad [49]$$

In addition, for every ten tons of reefer and air conditioning capacity add 1.5 barrels, or 0.226 tons, per day. Average large U. S. cargo liners require about 13 barrels or two tons per day for this purpose.

The above fuel rates should be modified when vessels operate at considerably reduced horsepower. Figure 35 and Table XIV may be consulted for correction factors which may be applied.

References 5, 6, 24, 31, 32, 45, 55, 59, 82, 83, 95, 101, 111, 117, 118, 121 and 122 give fuel rates for propulsion units other than conventional steam turbines of average steam condition.

Reference 21 has useful figures on hotel load and other miscellaneous requirements.

TABLE XIV

EXPLANATION OF CURVES IN FIGURE 35

Curve	Type of Machinery	Reference
(1)	Steam turbines, average values	115
(1A)	Steam turbine, 17,500 SHP	107
(2)	Steam turbine	110
(3)	Gas turbine, 6000 SHP	95
(4)	Gas turbine (all purpose), 6000 SHP	83
(5)	Gas turbine (propulsion only), 6000 SHP	83
(6)	Gas turbine, 3340 SHP	121
(7)	Gas turbine, 10,500 SHP	121
(8)	Diesel (direct, geared, electric), average values	115
(9)	Diesel, 9200 BHP, direct	55
(10)	Diesel, 15,000 BHP, direct	55
(11)	Diesel, 6000 SHP, geared	95
(12)	Free piston gas turbine, 6000 SHP	95

FIG. 34A

VARIATIONS IN SEA SPEED WITH CHANGES IN DISPLACEMENT & HORSEPOWER

OVER-POWERED SHIPS $\left(C_B = 1.08 - \frac{V}{2\sqrt{L}}\right)$

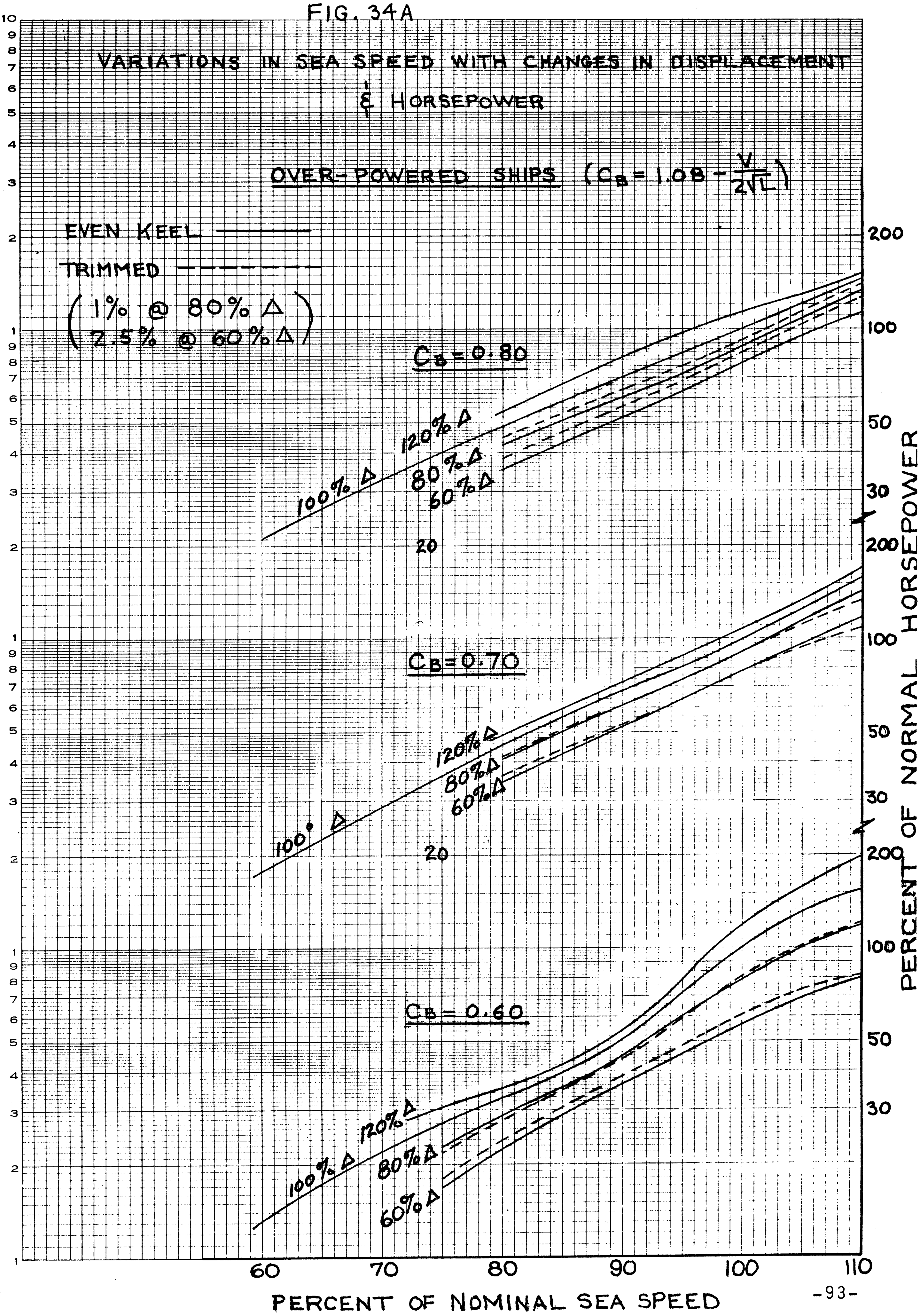
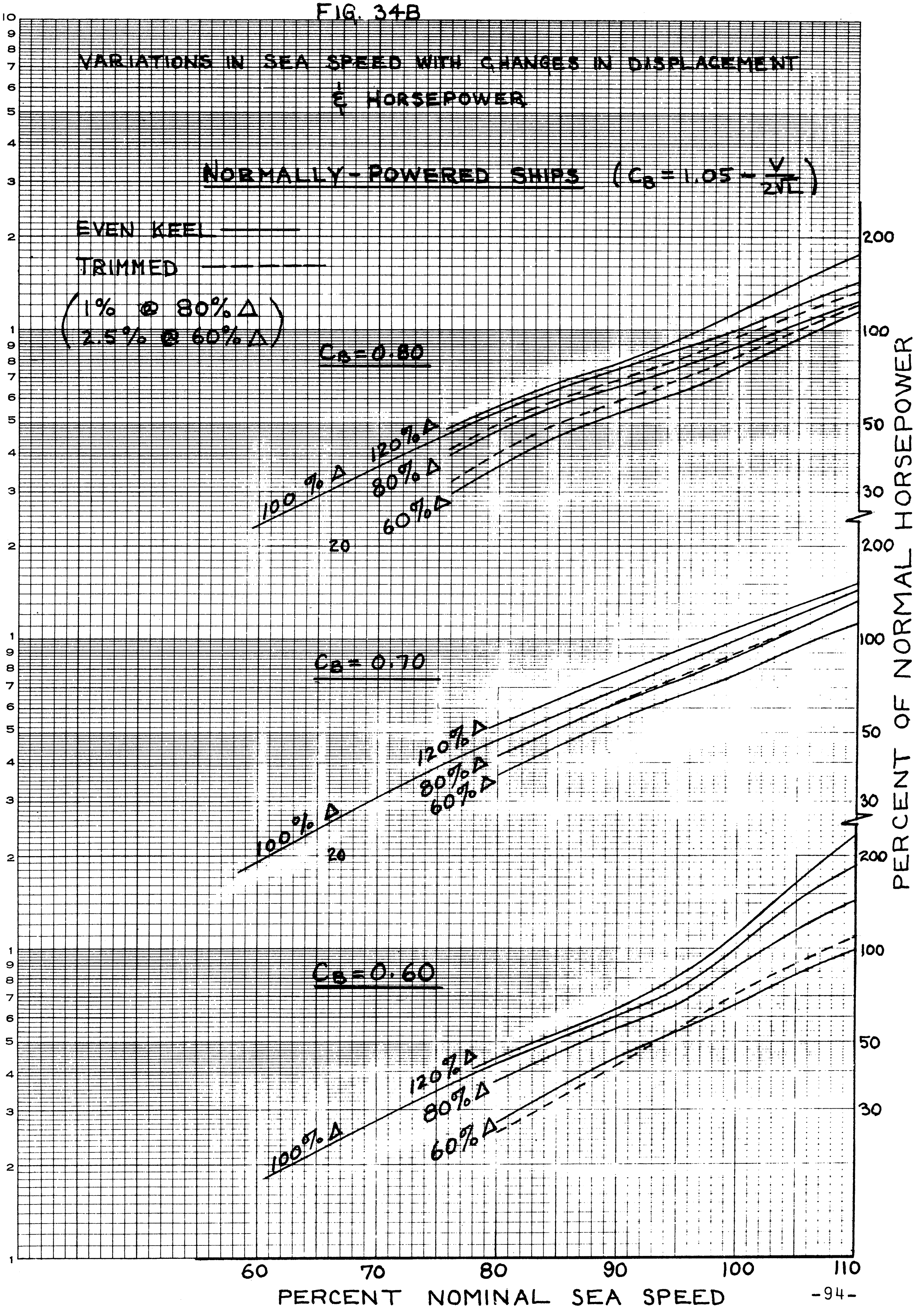


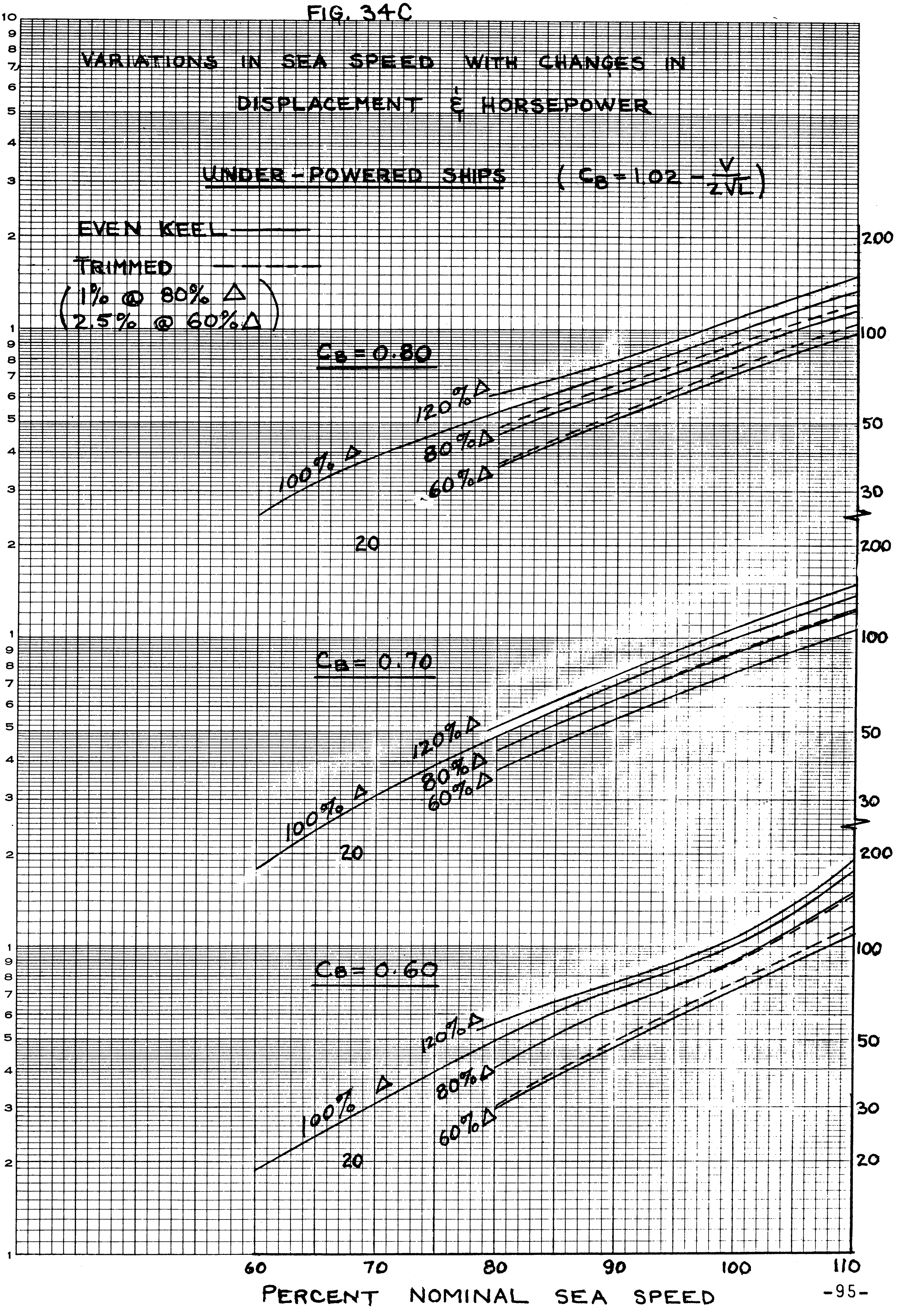
FIG. 34B



VARIATIONS IN SEA SPEED WITH CHANGES IN DISPLACEMENT & HORSEPOWER

NORMALLY-POWERED SHIPS ($C_B = 1.05 - \frac{V}{2\sqrt{L}}$)

FIG. 34C



VARIATIONS IN SEA SPEED WITH CHANGES IN DISPLACEMENT & HORSEPOWER

UNDER-POWERED SHIPS $\left(C_B = 1.02 - \frac{V}{2\sqrt{L}} \right)$

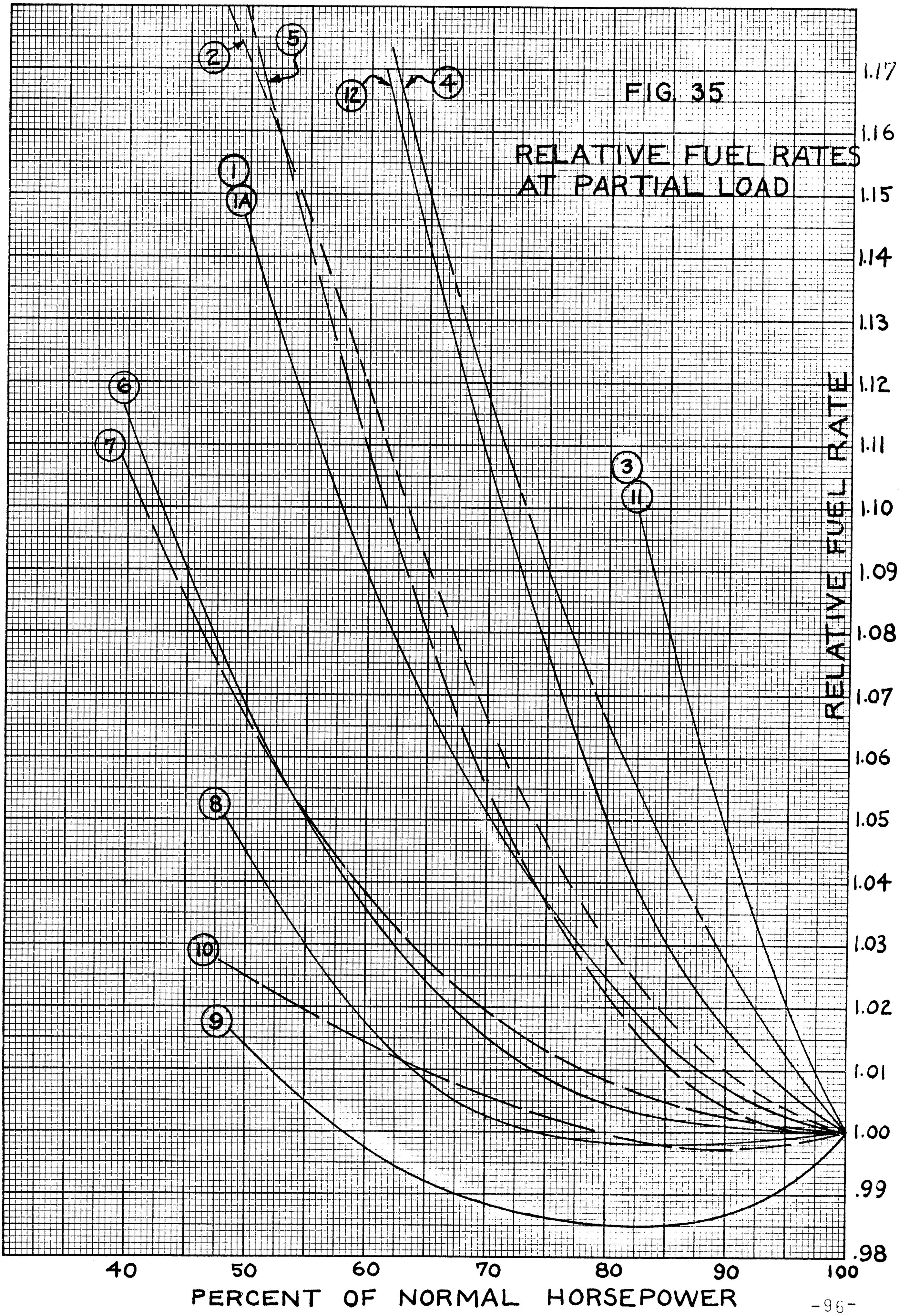


FIG. 35

RELATIVE FUEL RATES AT PARTIAL LOAD

Table XV is included as a convenient means of converting from one means of expression of fuel rate to another. Readers as simple minded as the writer will join him in taking comfort in the availability of these magic numbers. All known Anglo-American usages are included with the exception of hundredweights per fortnight.

Table XVI is derived from figures presented in Reference 5. It provides a rough indication of the fuel savings which result from operation at less than designed deadweight. Normal shaft horsepower is assumed.

Fuel Margins

Prudence dictates the carriage of more fuel than is actually thought to be required. The proper margin is a function of the probable severity of conditions on the trade route and the distance involved in the critical leg of the voyage. The critical leg is usually the one leading to the bunkering end of the voyage. In other words there is no point in basing the margin on the total round trip distance if one can replenish any emergency fuel utilization at ports along the way.

Most operators carry a 20 to 25 percent fuel margin based on a one way trip.

Port Fuel

Fuel is burned in port in order to maintain hotel services and to provide power for handling cargo. The rate of fuel utilization in port is thus influenced by the rate of cargo handling, a difficult factor to predict.

A study mentioned in Reference 110 calculates a fuel rate of 0.1771 barrels of bunker oil per ton of cargo handled in or out. However, the typical break-bulk cargo ship spends considerable port time nights and weekends when cargo handling is halted but hotel service is not. Allen and Sullivan (2) cite a figure of 40 barrels per day when idle, 55 when working cargo, in the case of the Mariners. Mac Millan and Westfall (69) use 66.3 barrels per day for a 12,000 deadweight ton conventional ship and 100 barrels per day for a 14,000 deadweight containership. An average figure based on the above and other sources (42, 74, 120 and 136) leads to the following estimate:

$$\text{Barrels per Port Day} \approx 4.5 \, \frac{\text{DWT}}{1000} \qquad [50]$$

or

$$\text{Tons per Port Day} \approx 0.678 \, \frac{\text{DWT}}{1000} \qquad [51]$$

TABLE XV

BUNKER C FUEL OIL CONVERSION FACTORS

Basic Relationships

One long ton of fuel oil occupies, on the average, 6.63 barrels or 278.46 gallons.
One barrel = 42 gallons = 5.615 cubic feet.
One pound of oil is assumed to contain 18,500 BTU.

Cost Conversions:

$$\$/\text{ton} = 6.63\ (\$/\text{bbl}) = 2.7846\ (\text{¢}/\text{gal})$$

$$\$/\text{bbl} = \frac{(\$/\text{ton})}{6.63} = 0.42\ (\text{¢}/\text{gal})$$

$$\text{¢}/\text{gal} = \frac{(\$/\text{ton})}{2.7846} = \frac{(\$/\text{bbl})}{0.42}$$

Other Conversions:

To convert A to B multiply A by factor shown below

B A	Pounds per SHP-Hr	Tons/Day	Tons/Mile	Bbl/Day	Bbl/Mile	Gal/Day	Gal/Mile
Pounds per SHP-Hr	1	$\frac{SHP}{93.33}$	$\frac{SHP}{2240V_K}$	$\frac{SHP}{14.08}$	$\frac{SHP}{337.9V_K}$	2.98SHP	$\frac{SHP}{8.04V_K}$
Tons/Day	$\frac{93.33}{SHP}$	1	$\frac{1}{24V_K}$	6.63	$\frac{1}{362V_K}$	278.5	$\frac{11.6}{V_K}$
Tons/Mile	$\frac{2240V_K}{SHP}$	$24V_K$	1	$159.1V_K$	6.63	$6683V_K$	278.5
Bbl/Day	$\frac{14.08}{SHP}$	$\frac{1}{6.63}$	$\frac{1}{159.1V_K}$	1	$\frac{1}{24V_K}$	42	$\frac{1.75}{V_K}$
Bbl/Mile	$\frac{337.9V_K}{SHP}$	$3.62\ V_K$	$\frac{1}{6.63}$	$24\ V_K$	1	$1008V_K$	42
Gal/Day	$\frac{1}{2.98\ SHP}$	$\frac{1}{278.5}$	$\frac{1}{6683V_K}$	$\frac{1}{42}$	$\frac{1}{1008V_K}$	1	$\frac{1}{24V_K}$
Gal/Mile	$\frac{8.04V_K}{SHP}$	$\frac{V_K}{11.6}$	$\frac{1}{278.5}$	$\frac{V_K}{1.75}$	$\frac{1}{42}$	$24V_K$	1

TABLE XVI

REDUCTION IN FUEL CONSUMPTION PER THOUSAND TONS REDUCTION IN DEADWEIGHT

$\frac{V_K}{\sqrt{L}}$	Tons per 100 Miles	Barrels per 100 Miles
0.50	0.120	0.80
0.55	0.146	0.97
0.60	0.178	1.18
0.65	0.217	1.44
0.70	0.266	1.76
0.75	0.323	2.14
0.80	0.396	2.63
0.85	0.482	3.20
0.90	0.587	3.89
0.95	0.718	4.76
1.00	0.877	5.81

Idle Status Fuel

Fuel used in the round trip to the repair yard and during the repair time adds an increment to the annual fuel bill. The amount is relatively small but will vary widely depending on circumstances. Excluding this item from preliminary design studies is usually acceptable.

Feed Water

Marine engineers traditionally plan on make-up feed water to the extent of one percent of the water rate. Assuming average steam conditions and converting to convenient units, this comes to 0.887 long tons per 1000 SHP_N per day.

Domestic Water

Potable water and washing water are usually combined into a single system referred to here as domestic water. An allotment of 45 gallons or 0.167 ton per person per day is generally considered appropriate. See References 54 and 58.

Evaporators

Earlier studies such as those of Reference 58 have long been accepted as ample justification for the installation of evaporators in most ships. Reanalysis of these studies, however, shows that assumed interest rates were much lower than what would be considered minimum in these days of high corporate profits tax. If realistic before-tax interest rates are applied, evaporators lose much of their appeal. This is part of a developing realization that our innate urge to decrease fuel rates has in many instances carried us beyond the economically optimum steam conditions. The future may see a movement toward simplified propulsion plants with somewhat higher fuel rates. This is particularly germane to the development of automated steam plants.

Most operators find it prudent to carry considerable reserve fresh water, both feed and domestic, even though evaporators are installed. An average reserve, measured in rate of utilization, seems to be sufficient for about ten days. While this may seem overly generous, there are probably few home offices that can influence the chief engineer to carry any less.

Except under unusual circumstances, a 40-day supply of water appears to be satisfactory for ships without evaporators. This may easily be reduced in many trade routes.

Lubricating Oil

As regards the weight of lubricating oil, extensive research leads to inexorable agreement with Lord Basingstoke's well-known remark that the subject is indeed a slippery one (11). Practice varies to an extreme and some operators carry a supply which should last for several years. There is also a pronounced contrast in the requirements of the various types of machinery. After unsuccessfully attempting to relate weight of lubricating oil to horsepower, sea days and so forth, it was finally found desirable to estimate it simply on a basis of the type of propulsion plant; see Table XVII. However, some fairly reliable figures for utilization were uncovered and these are also included in the table. These should be of value to anyone comparing operating costs of differing types of machinery. See References 59 and 117.

Newell and Chwirut (95) used an average lubricating oil cost of 90 cents per gallon in 1959.

TABLE XVII

LUBRICATING OIL WEIGHTS

Type Machinery	Utilization in pounds per 1000 SHP-Days			Tons Carried (arbitrary)
	Min.	Recommended for General Estimates	Max.	
Steam Turbine	3	10	10	10
Gas Turbine	3	7	10	10
Free Piston Gas Turbine	80	90	100	30
Direct Connected Diesel	17	25	61	15
Medium Speed Geared Diesel	46	65	80	20
High Speed Geared Diesel	130	155	180	40

Emergency Diesel Generator Oil

The weight of fuel required for the emergency diesel generator is almost negligible. An arbitrary allotment of five tons is ample for most cases.

Provisions and Stores

The required amounts of both provisions and stores are largely a function of the number of persons carried and the days between replenishment. The total weight is not large and it is probably best to allow for a complete round trip. A figure of 0.01 ton per person per day is reasonable.

Passengers, Crew and Effects

The weight of the people carried plus their personal belongings may be estimated on a basis of one-sixth of a ton per person.

Dunnage

The final item to be considered in this chapter is the weight of dunnage. This usually runs from 1.5 to 2 percent of the cargo carried.

Summary and Parametric Study

The cumulative impact of the foregoing lost deadweight items is analyzed for a number of hypothetical ships on typical voyages ranging from zero distance to 20,000 miles round trip. It is assumed that fuel oil is loaded only once per round trip but that other necessities are added at reasonable intervals. Other assumptions of the study are as follows:

1. Twelve passengers but no cadets are carried.

2. Ship with evaporator carries a ten-day supply of fresh water, and ship without carries a 40-day supply.

3. The ship always operates at full load and full normal power when at sea.

4. A five percent margin is allowed over total calculated fuel requirements.

(The optimism of item 4 above is intended to offset the pessimism of item 3.)

5. All ships are propelled by steam turbine machinery.

Table XVIII summarizes the above plus other assumptions used in the analysis.

The conclusions of this phase of the project are presented in Figures 10A through 10D in Chapter I.

Reference 52 may be consulted for further information on this subject.

TABLE XVIII

ASSUMPTIONS FOR LOST DEADWEIGHT ANALYSIS

(Z = Length of voyage in nautical miles)

Item	Calculation	
Sea Days per Voyage	$\frac{Z}{24V_K}$	
Port Days per Voyage	$10 + 1.5\,\frac{Z}{1000}$	
Crew	See Figure 37 (add 2 for passengers)	
Passengers	12	
Cadets	0	
Sea Fuel, all-purpose, incl. reefer cargo, long tons	$\left(10 + 5.18\,\frac{SHP_N}{1000}\right)$ (sea days per voyage)	
Port Fuel, long tons	$0.678\left(\frac{DWT}{1000}\right)$ (port days per voyage)	
Fuel Margin	5% over total sea and port fuel per voyage	
Lubricating Oil plus Diesel Oil, long tons	15	
Passengers, Crew and Effects, long tons	(1/6)(persons)	
Provisions and Stores, long tons	(1/100)(persons)(total days per voyage)	
Dunnage, long tons	1.75% (cargo weight)	
Evaporators	yes	no
Feed Water, long tons	$8.87\left(\frac{SHP_N}{1000}\right)$	$35.5\left(\frac{SHP_N}{1000}\right)$
Domestic Water, long tons	1.67 (persons)	6.7 (persons)

CHAPTER VIII

OPERATING COSTS AND REVENUE

Introduction

Published information on cargo ship operating costs is fairly plentiful as witnessed by References 2, 4, 6, 24, 27, 41, 43, 46, 59, 66, 69, 74, 76, 77, 79, 82, 94, 96, 102, 110, 117, 122, 128, 130, 132, 136, 139 and 145. Unfortunately, however, much of what is available is less than satisfactory for use in parametric studies. It was therefore felt desirable to bolster the published data with fresh figures, particularly in the categories of wages, maintenance and repair, and stores and supplies. To this end 11 ship operating companies were asked to estimate the above costs on each of six imaginary ships of widely ranging sizes and horsepowers. Nine companies responded and their replies form a valuable and unique basis for much of the work reported here. Individuals in the Maritime Administration and Maritime Cargo Transportation Conference also contributed useful information.

Entire books could be written about such cost categories as cargo handling or crew wages. For preliminary design purposes, such elaborateness of detail is neither necessary nor desirable. This chapter therefore essays to relate operating costs to only the most basic parameters; it concentrates on those costs which have the greatest potential influence on technological-economic decisions and gives only short shrift to costs, such as agency fees, which have negligible impact.

Accounting Procedures

Elden (38) calls attention to the fact that our sacred-cow accounting procedures fail to give a meaningful breakdown of operating costs. For example, many ships carry a crew which is considerably larger than that required for operation, the extra men being employed primarily in routine maintenance which could alternatively be done ashore. Dollars paid to these men should, logically, be charged to maintenance and repair rather than to operating wages.

Carrying this reasoning further, the maintenance and repair account should absorb all other costs incidental to the presence of these extra men. Such costs would include prorated increments of subsistence, fuel for hotel services, capital costs of accommodations, insurance, and overhead. In addition, every three to five maintenance men require one more man in the Steward's Department and his wages, subsistence, accommodations, etc., should in turn be charged to maintenance and repair. Many other examples could be cited to illustrate the complete lack of logic in our dogmatic accounting methods.

Of course not all owners make a practice of carrying the aforementioned maintenance men on their ships. These owners' books would show lower costs for wages, etc., but higher costs for maintenance and repair. Thus, while individual cost categories may show wide variation between owners, the differences would tend to cancel one another and the total costs would be less divergent.

Operating Subsidy

Table XIX shows operating differential subsidies in the form of percent paid by the government. Column A is based on actual averages (presented in Reference 94) for the year 1959. Column B is from Reference 69 and presumably represents estimated averages over the next 20 or 25 years.

It may be noted that wages are currently subsidized to the extent of 70 to 75 percent whereas maintenance and repair is subsidized to less than half these amounts. This fact, coupled with the observation that subsidized U. S. ships seem to be more heavily manned than unsubsidized U. S. ships, leads to the implication that the subsidy law inadvertently encourages shipboard maintenance that would normally be done by shoreside labor. Most of the operating companies which furnished cost data for this study are subsidized and the aforementioned economic factor no doubt has an appreciable influence on the conclusions of this chapter.

Cost Trends

U. S. tax laws do not permit recognition of changing dollar values in the computation of depreciation or capital gains. Replacement decisions are thereby frequently distorted by inflation. Optimization decisions, on the other hand, are seldom influenced by variable dollar values, it being logical to expect that freight rates will adjust to meet changing operating and replacement costs. Certain

TABLE XIX

OPERATING SUBSIDIES
Percent Paid by Government

Category	A Reference 94	B Reference 69
Wages	71	75
Subsistence	20	25
Maintenance & Repair	33	20
Stores, Supplies, etc.	0	0
H & M Insurance	18	20
P & I Insurance	68	20
P & I Deductible	43	20
Fuel	0	0
Port Charges	0	0
Cargo Handling	0	0

costs, however, have shown historic trends of growth which far excee general inflation. Figure 36, based on References 37, 69, 94 and 13 shows that crew wages and stevedoring costs are the two principal villains in this respect. Since the most meaningful economy studies are based on future rather than current annual costs, it follows that crew wages and stevedoring costs should be projected to some appropriate future date. Such extrapolations should spring from historic costs but not before correction for inflation.

Automation

The subject of shipboard automation will not be discussed here except to supplement what has already been said elsewhere (69, 78 and 96). The chapters on weights and building costs make reference to possible savings through reduction in crew accommodations. The section of this chapter dealing with wages touches on the potential savings in that category as well.

Wages

The first step in estimating wages is to figure the crew size. This is best done by department and, for each such division, actual practice varies widely among different operators. After careful study of all available data, the following relationship is suggested:

$$N_C = C_{ST}\left[C_{DK}\left(\frac{CN}{1000}\right)^{1/6} + C_{ENG}\left(\frac{SHP_N}{1000}\right)^{1/5} + \text{Cadets}\right] \quad [52]$$

where

N_C = total number in crew, including officers
C_{ST} = coefficient for steward's department
C_{DK} = coefficient for deck department
C_{ENG} = coefficient for engine department
CN = cubic number
SHP_N = normal shaft horsepower

Table XX lists appropriate values for the various coefficients.

TABLE XX

CREW SIZE COEFFICIENTS

Item	Notes	Min.	Aver.	Max.
C_{ST}	Steward's Department	1.20	1.25	1.33
C_{DK}	Deck Department	11.5	13	14.5
C_{ENG}	Engine Department:			
	Steam turbine, single screw	11	12	15
	Steam turbine, twin screw	13.75	15	16.5
	Diesel, single screw*	8.5	10	11

* For diesel machinery substitute for the second term within the parentheses in Equation 52

$$C_{ENG}\left(\frac{BHP_N}{1000}\right)^{1/3}$$

where

BHP_N = normal brake horsepower.

FIG. 36

OPERATING COST TRENDS

COST LEVELS SHOWN ARE AT MID-YEAR AND ARE BASED ON 1948 COST = 100.

ALL LEVELS HAVE BEEN CORRECTED FOR INFLATION.

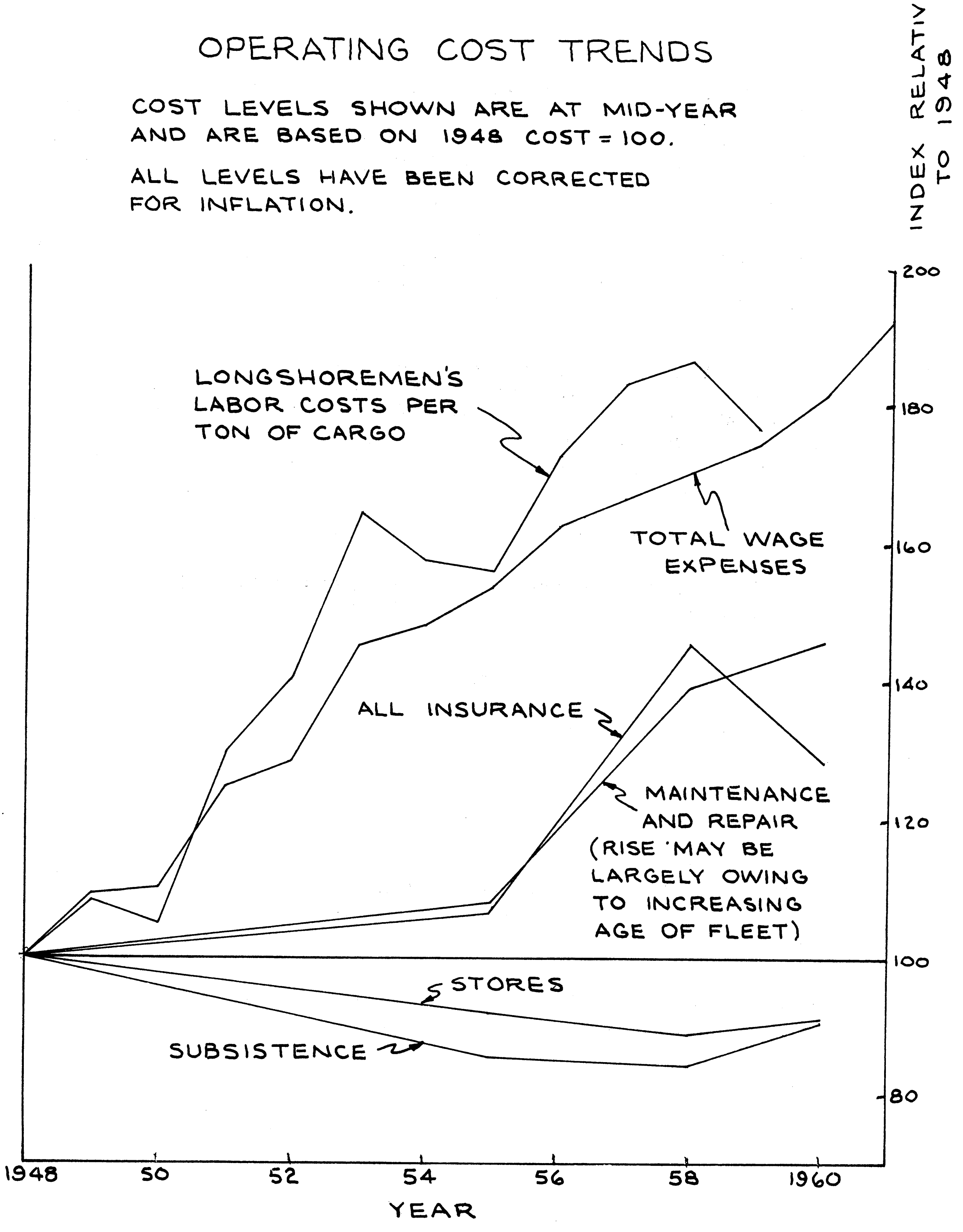


Figure 37 shows the relationship between ship size, horsepower and number in crew. It is based on average values from Table XX assuming single screw, steam turbine machinery, no passengers and no cadets. If 12 passengers are carried, add two to the crew.

Under current levels, the average annual total crew cost including fringe benefits but not subsistence is about $10,800 per man. Reference to Figure 36 makes it appear reasonable to estimate an annual cost per man of at least $17,000 by ship's mid-life, say 15 years hence. However, the mere possibility of shipboard automation may in the future attenuate this historical gradient.

If automation is introduced aboard ship, it will primarily replace men in the lower end of the wage scale. The average wage per man will therefore immediately rise. Estimates of total wages for various crew rosters leads to the following approximation, for current total wage levels, including overtime and fringe benefits:

$$\text{Total Annual Crew Cost} = \$23{,}300 \left(N_C \right)^{4/5} \qquad [53]$$

The following references may be consulted for further information on crew costs: 2, 4, 69, 74, 93, 94, 96 and 128.

Subsistence

An average figure for annual subsistence costs is $770 per person.

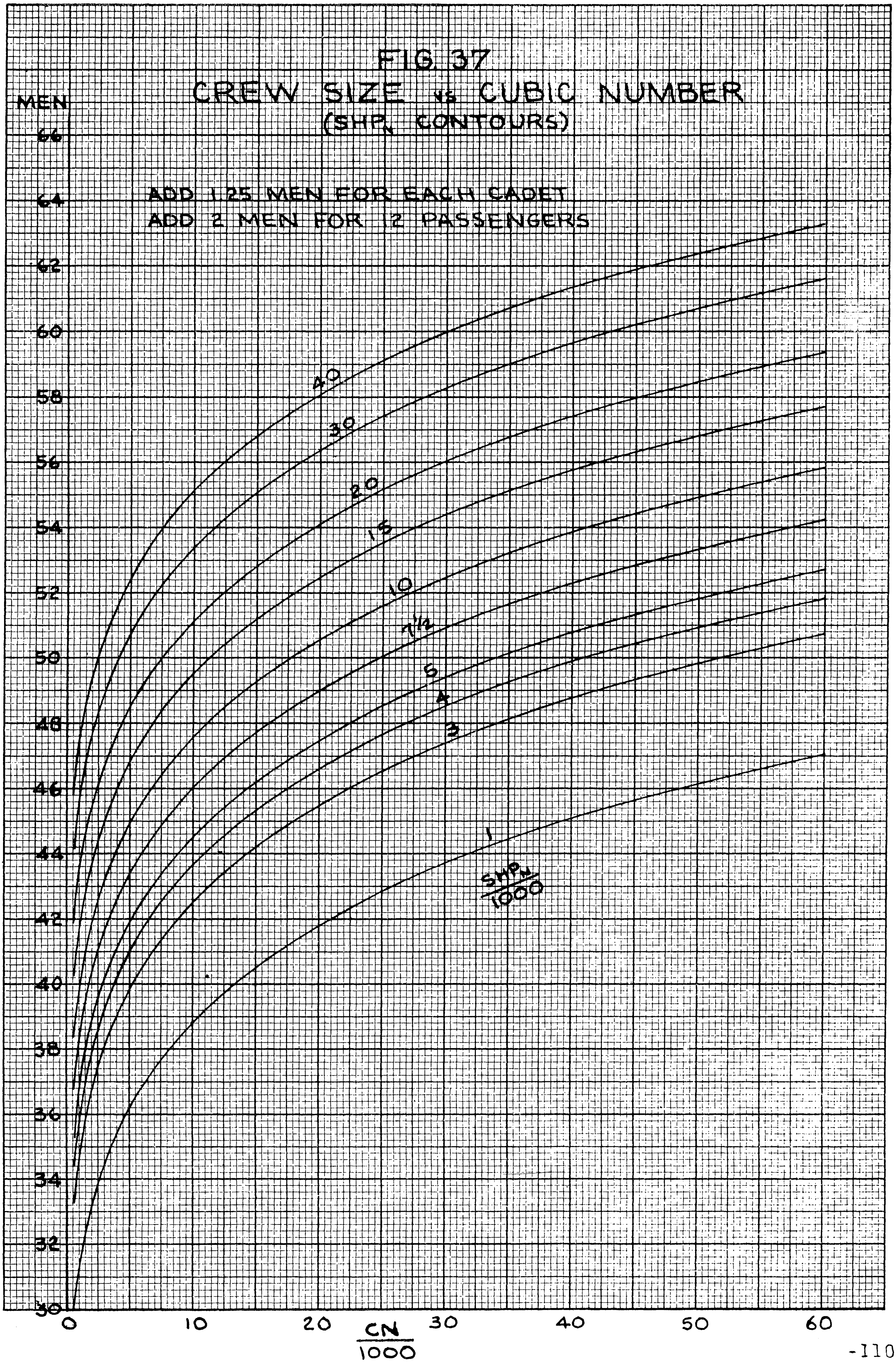
Fuel

Fuel consumption is discussed in the previous chapter. A good average figure for Bunker C is $2.50 per barrel or $16.575 per ton. Actual costs vary widely between different parts of the world and this particular cost item deserves special attention in actual trade route studies.

Reference 14 shows that bunker oil costs are relatively stable when measured in constant dollar values.

FIG. 37

CREW SIZE vs CUBIC NUMBER
(SHP$_N$ CONTOURS)



ADD 1.25 MEN FOR EACH CADET
ADD 2 MEN FOR 12 PASSENGERS

Maintenance and Repair

Costs of maintenance and repair vary widely. Some trade routes involve more storm damage than others. Some owners assign much maintenance work to the crew, which disguises that cost under the headings of wages, and stores and supplies. Some owners are satisfied with lower standards of upkeep than others. Some hull forms are more prone to slamming damage, and so forth. This item, then, is one of the most difficult to analyze. For estimating purposes, the following approximations are suggested for mid-life averages:

$$\text{Annual Cost of Hull M \& R} \approx \$10{,}000\left(\frac{CN}{1000}\right)^{2/3} \qquad [54]$$

and

$$\text{Annual Cost of Machinery M \& R} \approx \$4{,}800\left(\frac{SHP_N}{1000}\right)^{2/3} \qquad [55]$$

Figure 38, based on the above formulas, may be found convenient.

See References 38 and 97.

Stores and Supplies

This category comprises paint, cleaning materials and lubricating oil. Most of these items are used for maintenance and are applied by the crew. Hence the annual cost should be a function of the crew size, N_C. Analysis of many widely scattered data points leads to the following approximations.

For crews of 50 men or less:

$$\text{Annual Cost of Stores and Supplies} \approx \$80\left(\frac{N_C}{10}\right)^{4} \qquad [56]$$

For crews which number over 50

$$\text{Annual Cost of Stores and Supplies} \approx \$50{,}000 + \$4{,}000\,(N_C - 50) \qquad [57]$$

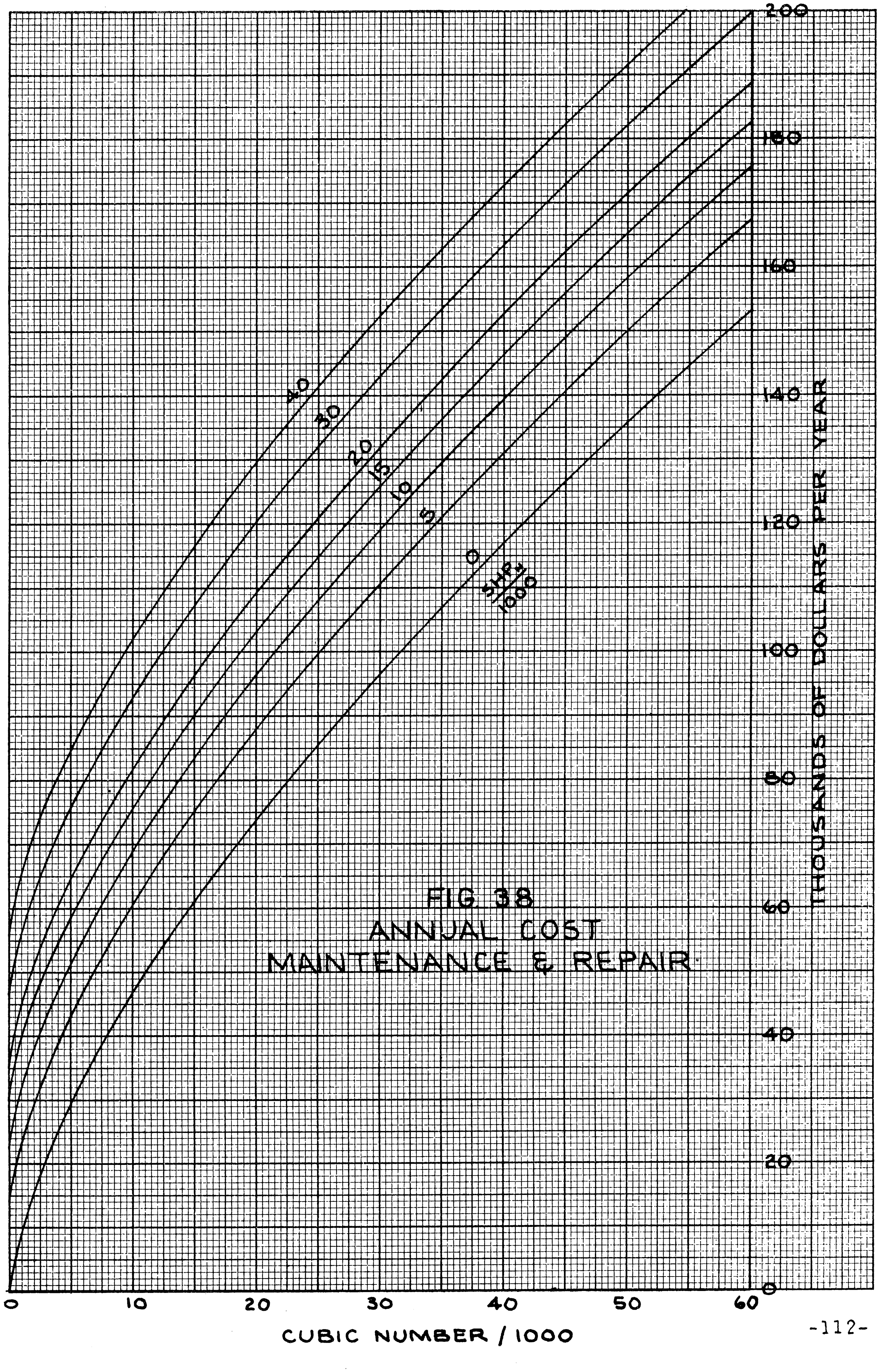


FIG. 38
ANNUAL COST
MAINTENANCE & REPAIR

These costs are shown in Figure 39 in terms of dollars per man per year.

Protection and Indemnity Insurance

Protection and indemnity insurance is carried to protect the owner against law suits, most of which arise from his own crew members. While rates are quoted on a gross tonnage basis, actual levels are more logically related to crew size:

$$\text{Annual Cost of P \& I Insurance} \approx \$965(N_C) \qquad [58]$$

In the case of semi-automated ships, the above formulation might be tempered as follows:

$$\text{Annual Cost of P \& I Insurance} \approx \$770\left(N_C + \frac{GT}{1000}\right) \qquad [59]$$

where

N_C = number in crew
GT = gross tonnage

Gross tonnage, in turn, may be estimated on a basis of cubic number and block coefficient as shown in Chapter IV, Equation 19.

Hull&Machinery Insurance

The cost of insuring the hull and machinery against damage or total loss will vary with the owner's past safety record. Also, some companies prefer self-insurance; but even so, funds should be allocated to this cost category. An average figure may be estimated on the following basis:

$$\text{Annual Cost of H \& M Insurance} \approx \$10{,}000 + 0.7\% \text{ of Invested Cost} \qquad [60]$$

War Risk Insurance

War risk insurance can be taken as 0.1 percent of invested cost.

Overhead and Miscellaneous

This category includes office expenses, telephone and telegraph costs, crew transportation, survey fees, laundry and other miscellaneous administrative costs. Some authorities estimate this as a percentage addition to the total of all direct operating costs; others use a fixed amount regardless of other costs. A survey of many estimates leads to the following approximation:

$$\text{Annual Cost for Overhead and Miscellaneous Items} = \$65{,}000 + C(CN) \qquad [61]$$

where C is approximately \$2 and CN = Cubic Number.

Port Expenses

This category includes pilotage, customs entrance fees, tonnage tax, immigration fees, tug service, line handling, and quaratine inspection. It excludes cargo handling and terminal use charges. Most of the costs in this group would vary with the ship size; some would vary with the number of port calls, others with the time spent in port. Walton (74) presents contours based on the above considerations. His values, modified for differences in definition of cubic number, are shown here as Figure 40. These may be expressed analytically as

$$\text{Port Expenses per Call} = \$233 + \$19.25\,\frac{CN}{1000} \qquad [62]$$

plus

$$\text{Port Expenses per Day} = \$20 + \$8.20\,\frac{CN}{1000} \qquad [63]$$

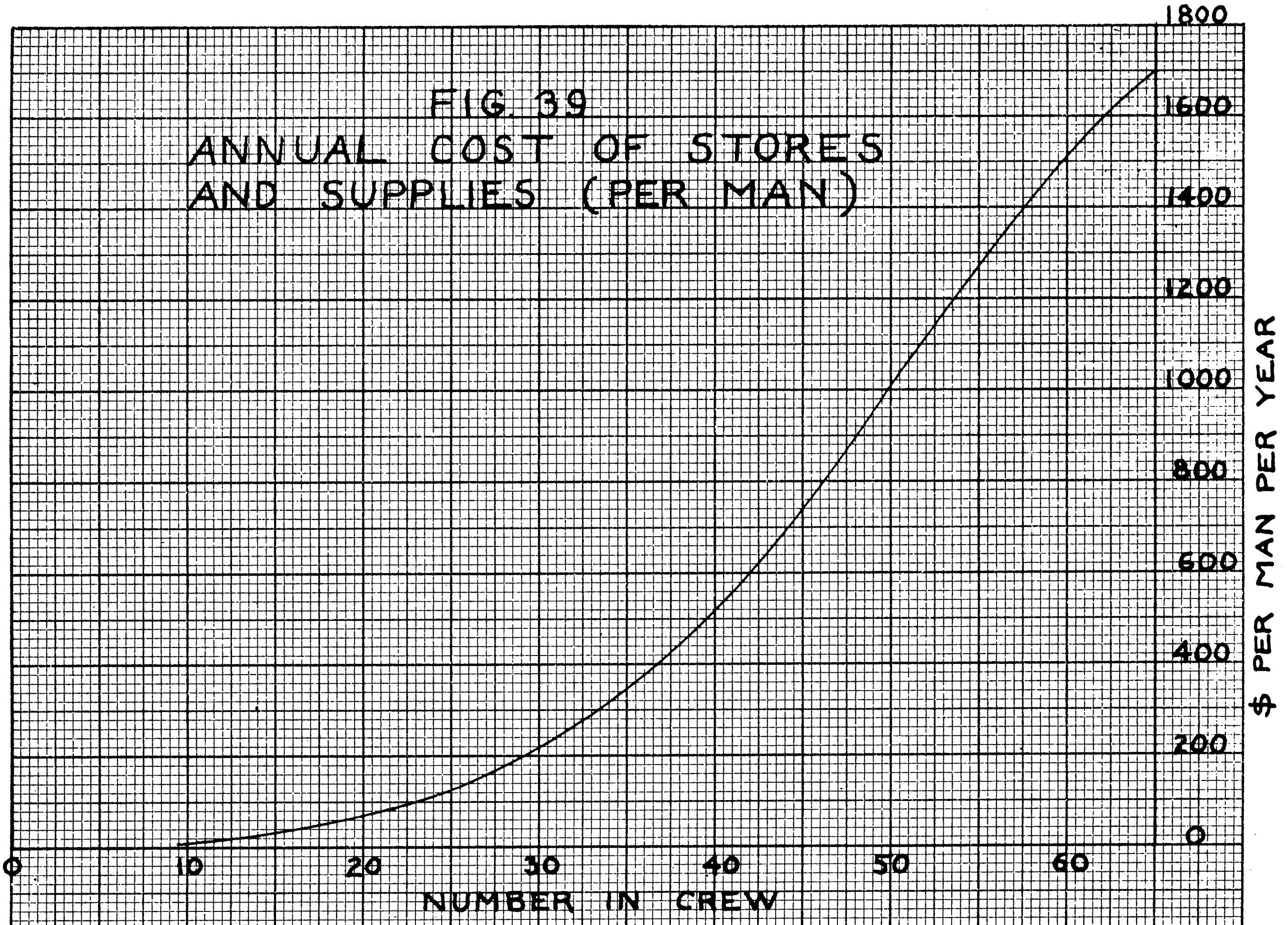


FIG. 39
ANNUAL COST OF STORES AND SUPPLIES (PER MAN)

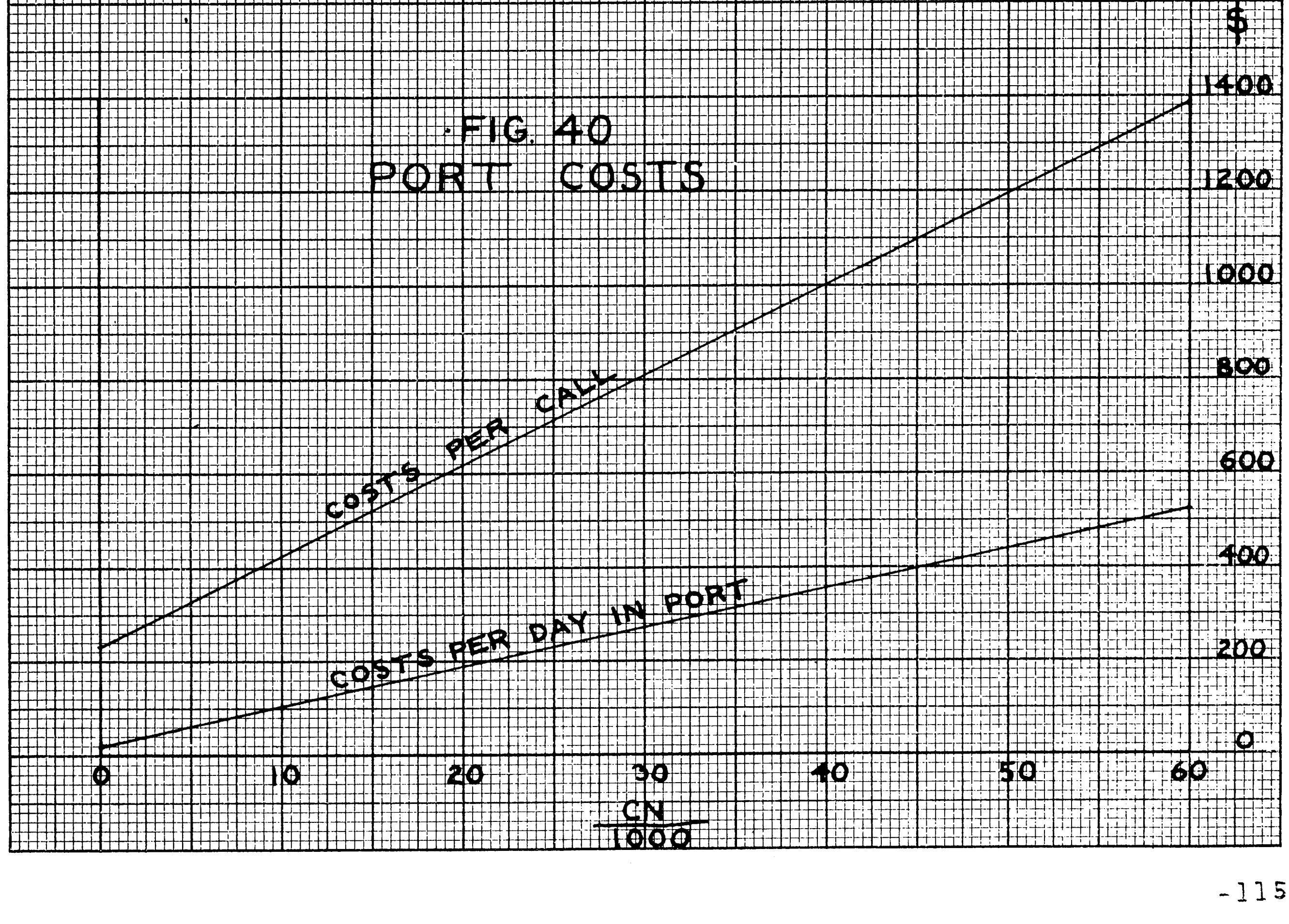


FIG. 40
PORT COSTS

Canal fees, if any, would be added to the above. Reference 15 contains a convenient summary of certain canal charges.

Cargo Handling Costs

Cargo handling costs include not only stevedore costs but also terminal use charges, receiving clerks and checkers, watchmen, dunnage, fire insurance and other miscellaneous expenses.

This subject is already well covered in References 69, 74, 102 and 105 so will be treated only in outline form here.

Regarding stevedore costs, Walton (74) found the following conditions in New York Harbor in 1959. The average gross loading rate for break-bulk general cargo was 18.75 long tons per gang-hour (19-man gang). The hourly cost to the shipowner for such a gang was \$85 for straight time and \$122 for overtime. Discharge rates were estimated to be 85 percent of the rate given above. For straight time work, then, Walton's average figures would come to \$4.53 per long ton loading and \$5.34 per long ton unloading. These total \$9.87 per long ton in-and-out. The average foreign stevedoring cost was estimated to be only 53 percent of the above or \$5.24 per long ton in-and-out, assuming no overtime. These figures are from points-of-rest within terminals. In addition, Walton found that cleaning, dunnage, marking and other miscellaneous costs added about \$2.40 per long ton in-and-out. This did not include terminal use charges, however.

MacMillan and Westfall (69) conclude that cargo handling costs are actually higher than the foregoing figures from Reference 74. They show an average in-and-out figure of \$12.20 per revenue ton* (\$19.50 per long ton at 64 cubic feet per ton). This assumes a normal amount of overtime and operation out of New York and other East Coast ports to ports abroad. It also includes miscellaneous costs other than terminal use charges.

Redal (102), having studied operations in the Seattle area in 1961, concluded that average in-and-out costs per long ton were \$7.63 from 8AM to 3PM, \$10.15 from 3 to 5PM and \$10.83 during

---

*A revenue ton is usually a long ton or a measurement ton (40 cubic feet) whichever yields the higher figure.

nights, weekends, and holidays. The average loading rate was 12 long tons per gang hour; the average discharge rate, 15. These figures are from ship side to ship side and must be increased for additional handling into and out of the shed before comparing with figures given by Walton.

Redal also found the following costs, in addition to stevedoring:

> Wharfage (terminal use): 80¢ per short ton or measurement ton of 40 cubic feet, whichever yields the larger figure. This averages $1.02 per long ton of cargo at 51 cubic feet per ton. Double these costs for in-and-out.
>
> Cargo handling (from ship's gear to first place of rest on the wharf): $2.46 per short ton or measurement ton. This averages $3.14 per long ton of general cargo at 51 cubic feet per ton. This charge is frequently handled directly by the stevedore, in which case it would be added to the figures previously given. Double these costs for in-and-out.
>
> Miscellaneous service charges (lighting, facility use charges, documentation, etc.): $2.99 per long ton of cargo in-and-out.

All three of the foregoing references may be consulted for details of containerized cargo handling costs. See also References 7, 27, 36, 74, 76, 77, 79 and 114.

The influence of hull design on cargo handling costs is discussed in References 20 and 34. Figure 36 indicates historic upward trends in the cost of longshore labor. In studies where cargo handling cost is of critical importance, mid-life projections would therefore be desirable. One fact worth noting, however, is that the Maritime Cargo Transportation Conference has had an encouraging beginning in its efforts to increase the productivity of longshore labor (75).

In many ship economic studies cargo handling cost will be the same in all of the various alternatives. When such is the case it is best to omit such costs from the study since their magnitude tends to obscure the other cost factors. This practice is actually followed in some charter parties where the charterer deals directly with the stevedore and pays the shipowner only for transportation services.

Other Cargo Costs

This category includes brokerage fees and cargo damage claims.

Reference 69 uses 40 cents per revenue ton as an average value for cargo claims. Reference 74 uses 30 cents per long ton for break-bulk cargo, zero for containerized. Reference 102 uses $1.25 per long ton for break-bulk cargo, 25 cents for containerized.

Brokerage fees are usually figured as a percentage of the revenue.

This cost category is of little interest in engineering economy studies. The only instance where it would influence design decisions would be in a comparison between break-bulk and containerized cargo ships.

Revenue and Economic Criteria

Grossman's volume on ocean freight rates (48) offers direct proof that entire books can be written on this one subject. Normally the owner can give the naval architect estimated revenue per ton of cargo inbound or outbound. Other typical rates may be found in Reference 69.

Where freight rates are unknown it is probably safe to assume that free market competition will bring them to such a level that the average foreign operator's after-tax profits will repay his investment at about ten percent interest over the life of the ship. Foreign operating costs vary widely. They can be estimated by deducing the subsidized U. S. owner's share of costs from Table XIX. Foreign building costs are discussed in Chapter VI.

Foreign corporate profit taxes provide another complication. A brief study of typical maritime nations leads to the tentative conclusion that 40 percent of profits is an average tax burden among our foreign competitors.

Reference 17 explains the principles involved in the various economic criteria which may be applied to ship design. The only additional complication worth mentioning is the certitude that there will always be ups and downs in the availability of general cargo. Thus, it would be advisable to predict the nature of future cargo availability and to find, by trial and error, the most economic size of ship.

CHAPTER IX

SAMPLE STUDY

Introduction

Most of the foregoing presentations are in a logical sequence of development. They are totally out of order, however, for a person who wishes to use them for an operational analysis. The purpose of this sample study, then, is to demonstrate a sequence in which the curves and formulas may be used to convert a functional specification (speed, cargo, etc.) to a technical specification of a suitable ship. In addition, estimates are made of building costs and other pertinent characteristics.

The sample ship is arbitrarily taken as one generally similar to the EXPORT AMBASSADOR (C3-S-38a design). In most cases, the known value for the actual ship is placed in parentheses immediately following the estimated value. Overall agreement is shown to be fairly close although individual differences do, of course, exist.

Draft, displacement, etc., refer to the design conditions in each case.

Supplementary steps illustrating methods of analysis of operating requirements for fuel, water, etc., could have been presented. And further steps might also show how the operating costs could be estimated. However, these factors are relatively easy to dig out of the paper and therefore are not illustrated with an example.

Statement of Problem

An owner specifies the following functional requirements for a new ship:

Cargo capacities:

Dry cargo: 6100 tons with average stowage factor of 82.5 cubic feet per ton.

Reefer cargo: 240 tons with average stowage factor of 89 cubic feet per ton

Liquid cargo: 1360 tons with average stowage factor of 39 cubic feet per ton

(Stowage factors are before correction for broken stowage)

Round trip distance: 15,000 nautical miles

Nominal see speed: 18.5 knots

Maximum permissible draft: 29.5 feet

Passengers: 12

Other specifications are typical of modern U. S. design: steam turbine, single screw machinery located amidships, conventional cargo gear. Evaporators are fitted and there is a forecastle of 20 percent of the vessel's length.

Solution

1. We first summarize the cargo weight and volume requirements as shown in Table XXI.

TABLE XXI

CARGO WEIGHTS AND VOLUMES FOR SAMPLE SHIP

Item	Weight	Cu. Ft. per Ton		Vol. 1000 cu.ft.	Factor	EBC 100 cu.ft.
		Cargo	Stowed			
Dry Cargo	6100	82.5	95	580	1.00	580
Reefer	240	89	100	24	1.21	29
Liquid	1360	39	39	53	0.90	48
Total	7700			657*		657*

*Identical values by coincidence only.

2. Figure 12 shows that our sample ship coincides almost exactly with the B-1 Series; therefore, interpolation will not be required in this particular example.

3. From Figure 10A we find, that for 7700 tons of cargo, 18.5 knots and 15,000-mile voyage, the required deadweight is 11,000 (vs 10,210).

4. Figure 9A shows a deadweight coefficient of 0.622. Thus, displacement would equal 11,000 ÷ 0.622 = 17,700 (vs 16,810).

5. Figure 1 shows a length between perpendiculars of 485 feet (vs 470). The calculated value from Equation 4 is 485 feet, also.

6. Figure 2 shows a freeboard of 13.7 feet (vs 15.2).

7. Figure 3 gives a draft of 29 feet (vs 27). (If this were greater than the minimum allowable, it would be appropriate to use the minimum value and to make a corresponding increase in the beam determined in Step 9 below. And the freeboard, Step 6, should be decreased by the same percentage if cargo stowage factor is to be held the same.)

8. Summing Steps 6 and 7, we obtain a depth of 42.7 (vs 42.2).

9. Figure 4 indicates a beam of 71.5 feet (vs 73).

10. Figure 5 shows a block coefficient of 0.616 (vs 0.634). The calculated value is (35 x 17,700) ÷ (485 x 71.5 x 29) = 0.616 also.

11. Figure 6 indicates a cubic number of 14,600 (vs 14,500). This is checked by the calculated figure of 14,800. In subsequent steps the cubic number will be takes as 14,800.

12. Length-depth ratio = 485 ÷ 42.7 = 11.35 (vs 11.13).

13. Beam-draft ratio = 71.5 ÷ 29 = 2.46 (vs 2.7).

14. Figure 19 shows a normal shaft horsepower requirement of 12,800 (vs 12,500).

15. Figure 11 A indicates an equivalent bale capacity of 37.3 cubic feet per ton of displacement. Thus, bale capacity = 37.3 x 17,700 = 660,000 cubic feet. This is probably close enough to

the required 657,000 cubic feet. The comparative actual ship has an equivalent bale capacity of about 650,000 cubic feet.

16. Figure 24 shows that the minimum freeboard requirement would be 10.3 feet. This compares with the designed value of 13.7 feet and indicates the appropriateness of a scantling draft design.

17. Figure 26 shows a steel weight coefficient of 0.2625. The net weight of steel would then be 0.2625 x 14,800 = 3885 long tons (vs 3830).

18. Figure 27 shows an outfitting weight of 1170 long tons (vs 1380).

19. Figure 28 shows a hull engineering weight of 600 long tons (vs 550).

20. Machinery weight, by Formula 29 would equal $247 \sqrt{12.8}$ or 885 long tons (vs 840).

21. Light ship would equal the sum of Steps 17 through 20, or 6540 long tons (vs 6600).

22. Deadweight would equal displacement minus light ship, or 11,160 (vs 10,210). This compares with the figure of 11,000 found in Step 3.

23. Figure 37 shows a crew of 52 or 53 men (vs 55).

24. The building cost may be estimated by reference to Figures 13 or 14. Figure 13 indicates a cost of $12,100,000. Figure 14 shows a unit cost of $830 per cubic number or $830 x 14,800 = $12,280,000. Table XXII summarizes the components of cost derived from Figures 29 through 32 with assumptions of $3 per hour wage rate, 70 percent overhead and 5 percent profit. Miscellaneous costs are included in each case. The total figure arrived at by this method is $11,851,000. Using an average factor from Table XI, the cost for each of two ships would be 0.933 x $11,851,000 = $11,060,000. This is in excellent agreement with the published contract cost of $11,000,000 for each of two ships of C3-S-38a design which was charged by an East Coast shipyard in 1958.

The above cost estimates are further confirmed by Equation 38 which yields a prediction of $12,185,000 and Equation 39 which predicts a cost of $11,882,000, each for single ship contracts.

TABLE XXII

SUMMARY OF COSTS FOR SAMPLE SHIP

(All in thousands)

Item	Steel	Outfitting	Hull Engineering	Mach'y	Total
Mat'l	$ 941	$1263	$1634	$2230	$ 6068
(MH)	(380)	(243)	(244)	(156)	(10,230)
Labor	1140	729	732	468	3069
70% Overhead	798	511	513	328	2150
Subtotal	2879	2503	2879	3026	11,287
5% Profit	144	125	144	151	564
Total	$3023	$2628	$3023	$3177	$11,851

CHAPTER X

SUGGESTIONS FOR FURTHER WORK

As stressed throughout this paper, much further research remains to be done. In order to keep the current project within reasonable size, several major and minor paths have been left largely or totally unexplored. As stated in the General Introduction, future studies should methodical·shift the restrictions imposed in the present endeavor. A number of the more important possibilities are listed below.

1. Length should be allowed to vary from the value imposed by Equation 4.

2. Curves of block coefficient vs speed-length ratio should be tried at locations above and below that shown in Figure 18.

3. The speed and horsepower relationship should be more carefully analyzed as was done in Reference 16.

4. Comparative economics of twin screw propulsion should be fully explored, especially for highspeed ships.

5. Diesels, gas turbines and other types of machinery should be studied relative to their impact on hull design and choice of optimum characteristics.

6. Simplification of steam turbine machinery deserves serious consideration. In particular, elimination of freshwater evaporators may prove desirable in many operations.

7. The impact of automated operation on optimum ship and machinery characteristics should be studied.

8. Most of the findings of this report would require modification before proper application to containership design. Several of the references (7, 46, 47, 69 and 114)

give helpful clues, but a definitive study would be valuable. Reference 114 is the most advanced in this direction.

9. The quantitative influence of sea state and other weather conditions on ship speed is still imperfectly understood. Once the researchers have solved that problem, its application to economic analysis will be welcome. See References 65, 66, 116 and 135.

10. Major trade route requirements should be analyzed with a view to determination of optimum ship characteristics and sensitivity to departures therefrom. Such information might be used in the development of a limited number of standard hulls and standard propulsion plants which could be used in various combinations leading to important economies in the U. S. maritime industry.

11. For any given trade route requirement, the optimum general cargo ship can be found only through analysis of hundreds of combinations of alternative proposals; the need for computer aid is therefore obvious. The conclusions of this report, plus future findings, should be programmed for computer and the flow diagrams made available to the industry. Steamship companies could then easily apply this powerful tool to their own individual needs and other researchers would be encouraged to carry out further useful investigations. <u>This recommendation transcends all others.</u>

Most of the findings of this study are presented in equation as well as graphic form so that translation into computer language should be fairly straightforward. Of course, anyone using this paper should make intelligent modification in the various inputs to suit the special conditions of his company or client.

APPENDIX I

CHARACTERISTICS OF DEADWEIGHT AND BALE CAPACITY WITH VARIATIONS IN FREEBOARD

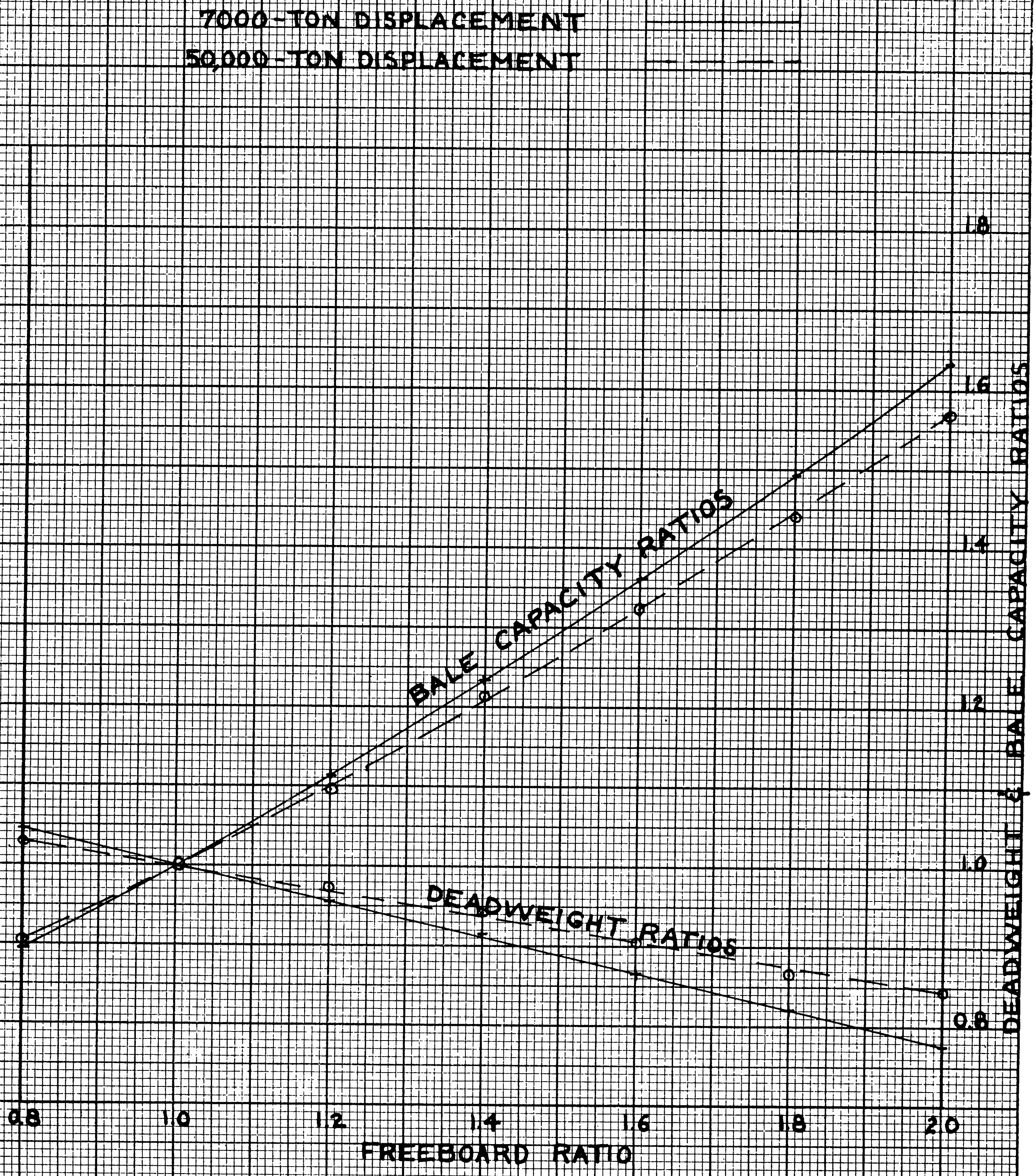
This subsidiary study shows that changes in freeboard (as specified in the B-1 & B-1.8 Series relationship) cause changes in deadweight and bale capacity which have nearly straight line characteristics. Thus it is concluded that a good understanding of all the technical and economic characteristics, over the entire range of practical freeboards, can be established through analysis of but two related studies such as the B-1 and B-1.8 Series.

This part of the investigation considers two families of hypothetical ships of widely differing displacements. The ships of the smaller family have displacements of 7000 long tons and horsepowers of 2000. The larger ones have displacements of 50,000 long tons and horsepowers of 30,000. In each case, freeboards are allowed to vary from 80 percent of normal (as defined by the B-1 Series) to 200 percent of normal. At each of several points along the way beam and draft are found as are deadweight and bale capacity. Length, displacement, block coefficient and horsepower are held constant for each family.

Figure 41 summarizes these findings in non-dimensional form. In each case freeboard, deadweight and bale capacity are related to corresponding values for the B-1 Series. The near-linear relationship is obvious.

FIG. 41

INFLUENCE OF FREEBOARD ON DEADWEIGHT & BALE CAPACITY



APPENDIX II

SAMPLE USE OF FREEBOARD CURVES

Figure 22 shows drafts allowed by minimum freeboard requirements (based on geometry of the ship) while Figure 23 shows corrections based on block coefficient and length of superstructure. Both figures are derived from Reference 129. The following examples illustrate the use of these two figures. The first example starts with a known depth and finds maximum allowable draft. The second starts with a known draft and finds minimum allowable depth. The rules (129) were written with the first sequence in mind so the figures are more easily understood when used in that manner. However they are still valid for the second requirement.

Problem 1: Given a cargo ship of the following characteristics, find the maximum allowable draft:

LBP = 390 feet
Depth = 30.5 feet
$C_B = 0.711$
Superstructure length = 0.494 LBP
(Superstructure includes a detached bridge)

Solution:

	feet
Uncorrected draft, Figure 22	23.20
Superstructure correction, Figure 23	+ 1.75
C_B correction, Figure 23	- 0.20
Estimated freeboard draft	24.75

Problem 2: Given a cargo ship of the following characteristics, find the minimum allowable depth:

LBP = 390 feet
Draft = 24.75 feet
C_B = 0.711
Superstructure length = 0.494 LBP
(Superstructure includes detached bridge)

Solution:

	feet
C_B correction, Figure 23	- 0.20
Superstructure correction, Figure 23	+ 1.75
Total correction	+ 1.55

(Since the corrections are to be applied to what is already a corrected draft, the sign must be reversed as shown below.)

Draft	24.75
Total correction	- 1.55
Uncorrected draft for use in Figure 22 ..	23.20
Depth, Figure 22	30.5

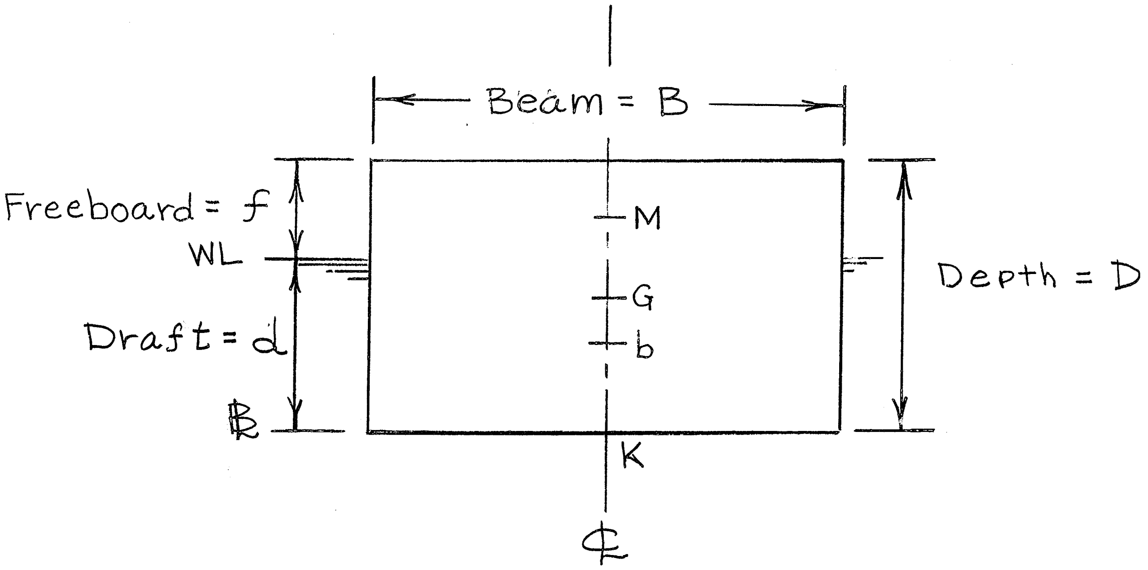
The above examples are taken from the detailed freeboard calculations shown in Reference 106.

APPENDIX III

INFLUENCE OF FREEBOARD ON BEAM-DRAFT RATIO REQUIRED FOR CONSTANT STABILITY

The B-1 Series establishes a family of ships of average proportions and hull form. Other related families (such as the B-1.8 Series) have, for corresponding designs, the same displacement, length and block coefficient. Freeboard however is changed and since this will affect the vertical center of gravity, it is important that beam and draft be adjusted as required to maintain stability. The influence of freeboard on beam and draft is analyzed here.

Assume that our ship is equivalent to a homogeneously loaded rectangular barge as shown in section below with traditional identification of vertical centers (except that center of buoyancy is called b). Letters without subscripts refer to the B-1 Series.



By observation

$$Kb = \frac{d}{2} \qquad [64]$$

and

$$KG = \frac{D}{2} \qquad [65]$$

From classical naval architecture

$$bM = \frac{I}{V} = \frac{LB^3}{12\ LBd} = \frac{B^2}{12d} \qquad [66]$$

and

$$KM = Kb + bM \qquad [67]$$

therefore

$$KM = \frac{d}{2} + \frac{B^2}{12d} \qquad [68]$$

The metacentric height (GM) is normally quite small in a loaded cargo ship. If we assume it is zero, then:

$$GM = 0 \qquad [69]$$

therefore

$$KG = KM \qquad [70]$$

Substituting Equations 65 and 68 into 70:

$$\frac{D}{2} = \frac{d}{2} + \frac{B^2}{12d} \qquad [71]$$

$$D = d + \frac{B^2}{6d} \qquad [72]$$

therefore

$$\frac{B^2}{6d} = D - d \qquad [73]$$

but

$$D - d = f \qquad [74]$$

therefore

$$\frac{B^2}{6d} = f \qquad [75]$$

or

$$B^2 = 6df \qquad [76]$$

In our standard series, length, displacement and block coefficient remain unchanged as we vary freeboard. Therefore, the product of beam times draft must also remain unchanged. Or

$$Bd = \text{constant} \qquad [77]$$

If r is the ratio of any new freeboard to the original freeboard (in this case that of the B-1 Series) and if we identify new dimensions with the subscript r, then

$$r = \frac{f_r}{f} \qquad [78]$$

so

$$f_r = rf \qquad [79]$$

and, based on Equation 77

$$B_r d_r = Bd \qquad [80]$$

therefore

$$d_r = \frac{Bd}{B_r} \qquad [81]$$

while, from Equation 76

$$\frac{B^2}{6df} = \frac{B_r^2}{6d_r f_r} \qquad [82]$$

so

$$\frac{B^2}{df} = \frac{B_r^2}{d_r f_r} \qquad [83]$$

and

$$B_r^2 = \frac{B^2}{df} d_r f_r \qquad [84]$$

Substituting Equations 79 and 81 into 84:

$$B_r^2 = \frac{B^2}{df} \frac{Bd}{B_r} rf \qquad [85]$$

or

$$B_r^{\ 3} = B^3 r \qquad [86]$$

therefore

$$B_r = B \sqrt[3]{r} \qquad [87]$$

and

$$d_r = \frac{d}{\sqrt[3]{r}} \qquad [88]$$

In the case of the B-1.8 Series

$$B_{1.8} = B \sqrt[3]{1.8} = B \times 1.216 \qquad [89]$$

and

$$d_{1.8} = \frac{d}{\sqrt[3]{1.216}} \qquad [90]$$

APPENDIX IV

STOWAGE FACTORS

Two stowage factors must be considered. One is a function of the density of the material and the wasted volume within its crate, box, barrel or whatever. The second accounts for the empty space between the outside of the crate and inside of the ship. The latter factor is influenced by the shape of crate; shape of ship; interference from webs, pillars, shaft tunnels, ladders and pipes; amount of dunnage; access aisles and so forth.

Table XXIII, from Reference 133 provides estimates of the percentage of bale capacity which is lost to the second factor. As stressed in Reference 34, however, such lost space is not necessarily uneconomic if it allows quicker port turnaround.

TABLE XXIII

PERCENTAGE OF BALE CAPACITY LOST TO BROKEN STOWAGE IN AN AVERAGE GENERAL CARGO SHIP

Type of Cargo	Percent
Miscellaneous Package Freight (average probably 15 percent)	10 - 25
Standard Package Freight:	
Bales	2 - 20
Sacks	0 - 12
Barrels	10 - 50
Hogshead	17 - 25
Cases	4 - 20
Carboys	10 - 22
Drums	8 - 25
Rolls	10 - 25
Pails	10 - 40
Coils	10 - 25

Containerships have double broken stowage with another loss of about 15 percent between internal units and container.

Table XXIV cites stowage factors for a number of typical commodities. These are for the material as packed for export shipment and before correction for broken stowage. Reference 133 appears to be the definitive work in this area (although somewhat dated) and should be consulted for further details.

TABLE XXIV

STOWAGE FACTORS FOR VARIOUS
COMMODITIES AS PACKED FOR SHIPMENT

Commodity	Packing	Cubic Feet per Long Ton		
		Ref. 106	Ref. 133	Ref.57
Apples	Boxes	80	95	90
Autos	Disassembled & crated	110	127-308	
Autos	Assembled & uncrated	270	303-406	
Bananas	Stems		122-130	90
Barbed Wire	Rolls	55		
Barley	Bags		61	59
Beans	Bags	60	52	
Beef	Frozen,packed		46	93
Beef	Hung in quarters			125
Butter	Cases	60	60	70
Canned Goods	Cases	48	50	
Cement	Bags	35	27	
Cloth Goods	Cases		70	87

(Cont'd.)

Commodity	Packing	Cubic Feet per Long Ton		
		Ref. 106	Ref. 133	Ref. 57
Coal	Loose, average	46	42-48	43
Coffee	Bags	58	55-107	61
Cotton	Bales, average	52	63-152	114
Dry Goods	Boxes	100	182-283	
Electric Motors	Boxes		34-61	
Electric Fans	Cartons		100-247	
Fish	Barrels, iced	50		60
Fish	Boxes		100	95
Flour	Bags	48	52-69	47
Flour	Barrels	73	65	60
Furniture	Crated	156	156	
Glassware,Assorted	Crated		151	
Grapefruit	Boxes	70	62	
Hardware	Boxes	50	25-138	
Hides	Bales,compressed	80	86	
Iron, Pig	Neat stowage	10	10	10
Jute	Bale		58	58
Lead, Pig	Neat stowage	8	6-11	8
Machinery	Crated	50	29-162	
Meat	Cold storage	95	90	
Nails	Kegs		17-51	21
Newspapers	Bales	120	64-90	

(Cont'd.)

Commodity	Packing	Cubic Feet per Long Ton		
		Ref. 106	Ref. 133	Ref. 57
Newsprint	Rolls		44-74	
Nitrate	Bags	26	35	32
Oil, Petroleum	Barrels	50		
Oil	Drums	45		
Optical Goods	Boxes		78	
Oranges	Boxes	78	75	90
Oysters	Barrels	60	61	60
Paint	Cans	36	31-33	
Paper	Rolls			120
Potatoes	Bags	60	55	55
Radios	Cases		113-331	
Railroad Rails	Neat stowage	15	15	
Refrigerators	Cases		126-284	
Rice	Bags	58	50-65	48
Rope	Coils	90	86	
Rubber	Bundles	140		
Rum	Hogsheads	70	77	70
Rum	Casks	60	65	
Salt	Barrels	52		52
Shoes	Boxes		116-268	
Silk	Bales	110		125
Soup	Cartons		43-47	

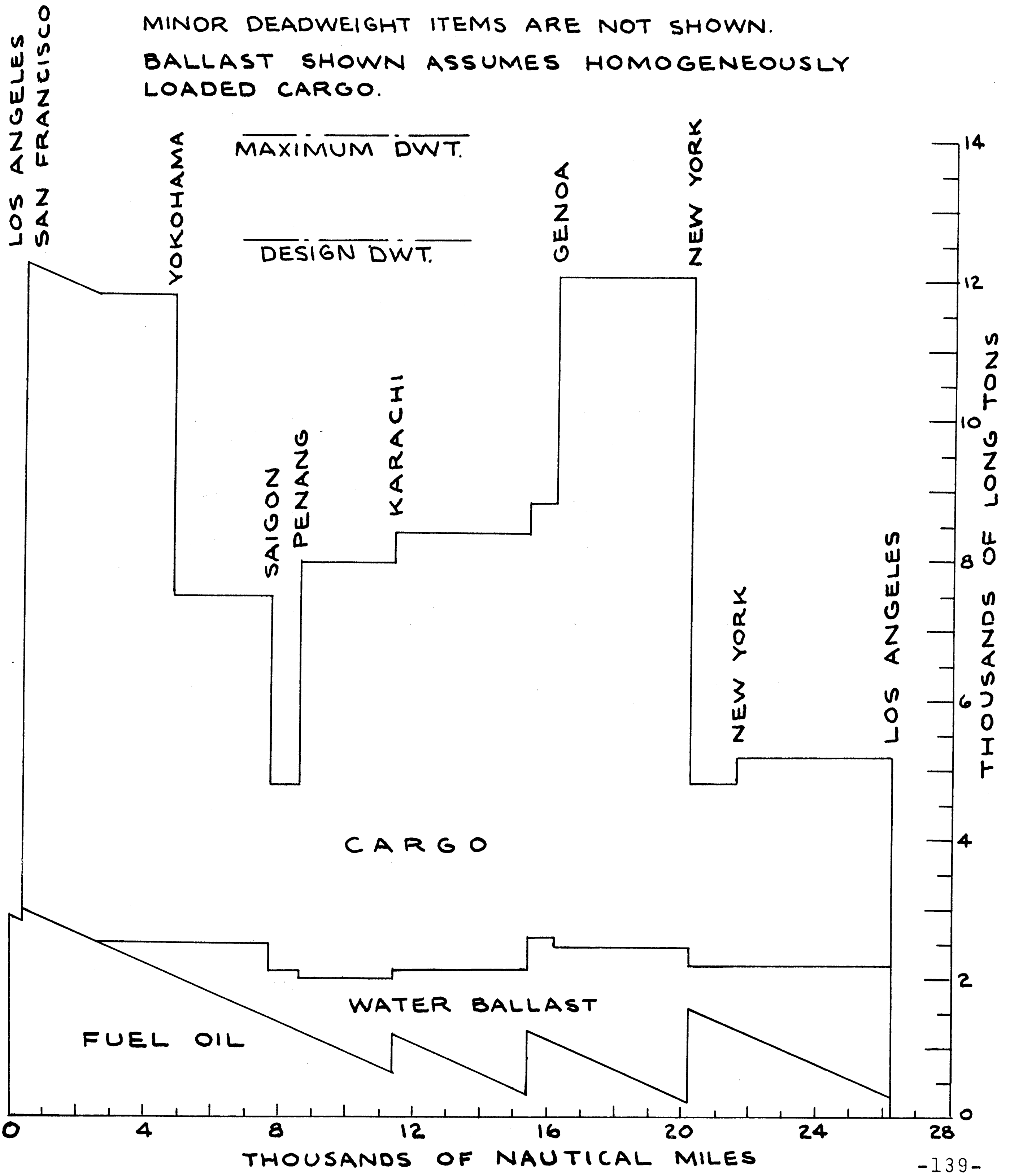
(Cont'd.)

Commodity	Packing	Cubic Feet per Long Ton Ref. 106	 Ref. 133	 Ref. 57
Steel Bolts	Kegs	21		
Steel Plates	Loose		7	
Steel Sheets	Crated	36	15-21	
Sugar	Bags	47	51	56
Sugar	Barrels	54	50	
Tea	Cases	100	109	54
Textile Machinery	Crates or boxes		62-149	
Timber	Fir planks	65		65
Timber	Oak planks	39		
Tires, Auto	Boxes		76-132	
Wheat	Bulk	47	47-49	
Wheat	Bags	52	42-53	52
Wool	Bales, pressed		122-160	100

Reference 87 also contains valuable information on cargo stowage requirements.

APPENDIX V
(FIG. 42)

DEADWEIGHT DISTRIBUTION ON TYPICAL 'ROUND-WORLD SCHEDULE



MINOR DEADWEIGHT ITEMS ARE NOT SHOWN.
BALLAST SHOWN ASSUMES HOMOGENEOUSLY LOADED CARGO.

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RINA: Royal Institution of Naval Architects

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