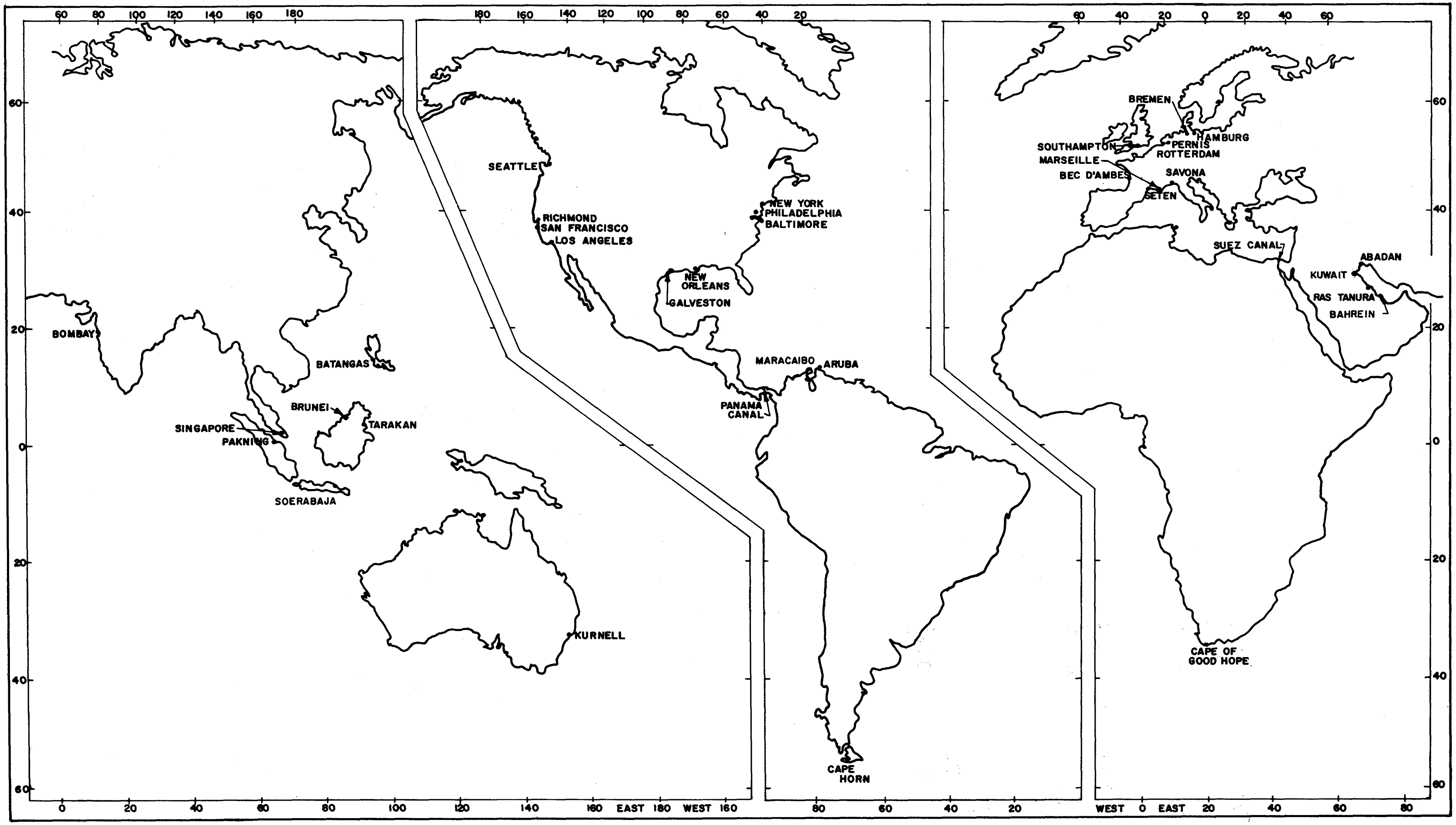


World Map Showing Certain Principal Oil Ports.

enm
UMR 5205

THE UNIVERSITY OF MICHIGAN
INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

ENGINEERING ECONOMY IN TANKER DESIGN

November, 1956

IP-189

ACKNOWLEDGEMENTS

This study would have been impossible were it not for the kind help rendered by the following individuals and their organizations in furnishing factual data and offering encouragement and advice:

Mr. D. Argyriadis, University of Michigan.

Mr. Richard Broad, Newport News Shipbuilding and Dry Dock Co.

Mr. John P. Comstock, Newport News Shipbuilding and Dry Dock Co.

Mr. Z. Coskuner, University of Michigan.

Mr. U. W. Hird, Harco Engineering Co.

Mr. V. Minorsky, George C. Sharp, Inc.

Mr. Robert C. Morrell, Robert W. and Robert C. Morrell.

Dr. H. F. Robinson, Bethlehem Steel Co., Shipbuilding Division.

Professor Wilbert Steffy, University of Michigan.

Mr. S. A. Vincent, Newport News Shipbuilding and Dry Dock Co.

Mr. Lewis Wuertelle, U. S. Maritime Commission.

In addition to the above, there were twelve generous individuals in nine operating companies who supplied the cost data which made possible the studies in the latter part of this paper. The writer is greatly indebted to these men and organizations, whose generosity is exceeded only by their passion for anonymity. So many operators have asked that their names not be disclosed, that in fairness to all it was felt best to refrain from publishing any of them.

To all who have been of assistance, whether named or unnamed above, a heartfelt "thanks" and the sincere wish that this paper may prove interesting and even possibly useful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

SUMMARY

Engineering may be defined as the application of scientific knowledge to the benefit of society. In a free economic system, society expresses its desires through its purchases. The dollar, then, is the best measure of true engineering success.

This paper is concerned with the use of economic studies as tools in the design of tankers. Methods of choosing optimum characteristics are discussed and relative merits established. Sufficient factual information is supplied in the form of curves and formulas to allow cost studies to be made for the determination of optimum size and speed.

Examples of some of the uses of this material are presented in connection with the movement of crude oil from the Persian Gulf to the East Coast. It is shown that tankers too big for the Suez Canal can carry oil around the Cape of Good Hope more economically than vessels designed for service through the Canal. The influence of foreign construction and operating costs is demonstrated and investigations are made into the effect of fuel oil costs and cargo rates on the optimum speed.

A method is presented for the ready estimation of tanker construction costs. Displacement and installed horsepower are shown to be the principal factors in the determination of first cost. A method is given for the prediction of savings resulting from duplication in shipbuilding.

Of particular use to those concerned with preliminary design is a series of curves which may be used to rough out the principal characteristics of a related group of tankers. These curves provide methods for the approximation of speed and power, weights of hull and machinery, principal dimensions and hull form characteristics. The culmination is a family of curves relating deadweight, horsepower, speed and displacement.

A. INTRODUCTION

Work on this paper began innocently enough as a class problem in cost estimating. Tankers were chosen for analysis since such vessels are fairly uniform in design objectives and have relatively simple conditions of operation. Tankers also represent a fairly fertile source of accurate data since so many of them have been built in recent years.

Before turning the problem over to the students, the writer developed a pair of estimating systems for the establishment of weights and costs on a family of tankers with variations in both size and power. These methods are presented in detail in the following sections (Design Analysis and Construction Cost Analysis).

Each student was assigned a different combination of size and power and was required to work out the weight and cost estimates according to the above-mentioned systems. This sort of arrangement makes an ideal class assignment since the students can have the stimulation of working together without any possibility of copying on another's work. The answers so obtained can be plotted by the instructor and only those points missing the general curve need be carefully checked for mistakes.

The results of the weight and construction cost studies proved so worthwhile that the writer essayed to carry the idea one step further. A third system was developed for the operational analysis of tankers allowing economic comparison of various proposed designs. The first two systems resulted in rather convenient families of curves of deadweight coefficients, construction cost per deadweight ton, etc. In the case of operating costs there are just too many variables involved and it was felt best to simply present the system in detail with a few typical examples worked out. Let it be emphasized here that there is nothing really original in the third system. The writer has merely compiled cost data from numerous tanker operators and has attempted to correlate them with deadweight, horsepower and similar criteria. Let it also be emphasized that the writer does not pretend to be an authority on the subject of ship operating costs. A survey of the technical literature clearly shows that those who are authorities do not feel free to publish what they know. A number of them have however generously contributed confidential cost figures for this paper and the figures presented here represent a fair average for the industry today.

B. SCOPE OF STUDIES

1. Size

The various studies covered single-screw tankers ranging in displacement from 15,000 to 100,000 long tons with a corresponding deadweight range of from about 10,000 to about 80,000 tons. The upper limit is probably close to the maximum displacement likely to be found with single-screw propulsion. Very few tankers have been built with displacements over 50,000. The "Grand Bassa" class (Ref. 1) with a displacement of nearly 50,000 tons and the "World Glory" (Ref. 2) with a displacement of 58,000 tons represent the largest tankers which have so far been publicized in the technical press. Investigation into the larger displacement tankers was felt to be desirable, owing to current interest in this class of vessel. The lack of available technical data on larger tankers, while regrettable, was not lethal. A little experimentation with plotting methods usually resulted in essentially straight line plots allowing some confidence in extrapolated values.

2. Power

An installed power range of from 3,000 to 30,000 normal SHP was investigated. The latter figure is considerably in excess of the power installed in any single-screw merchant vessel to date and practical problems such as vibration make it seem that 30,000 SHP is safe as an upper limit for a study of this nature.

The subsequent cost studies have indicated that 30,000 SHP is well beyond the upper limits of economical operation for even the 80,000 DWT tankers.

3. Design

The vessels under consideration were all assumed to follow the same pattern of design and to represent good modern tankers suitable primarily for the crude oil trade. References 1 through 10 may be consulted for typical examples of the type in mind. Appendix I outlines the assumed specifications in some detail.

4. Operations

It was intended that the material presented under the section on operating costs could be used for any combination of factors entering into the picture. These factors include:

American flag vs. foreign flag operation.
American vs. foreign construction costs.

Various trade routes.
Various cargo rates.
Various fuel oil costs.
Various ship sizes.
Various installed powers.
Bunkering arrangements.

The use of the operating cost analysis is shown in a study confined to the movement of crude oil from Kuwait in the Persian Gulf to Philadelphia by various possible routes.

C. DESIGN ANALYSIS

1. Introduction

In order to arrive at a uniformly varying family of tankers, the method outlined in the following pages was developed. This approach differs from previous solutions (Ref. 10, 11, 12), all of which started with arbitrary values of speed and deadweight, and solved for required power and displacement. This seemed to be putting the cart before the horse, so in the present study the reverse procedure was tried, that is: A large group of hypothetical tankers was established with arbitrary and varying values of displacement and power. In each case, solution was made for corresponding deadweight and speed by the method outlined below. It is felt that the system proposed here is an improvement over the older approach since hull and outfitting weights are more directly a function of displacement than deadweight, while machinery weights are tied in quite closely with horsepower but bear only the remotest relationship to speed.

2. Method

Following is the step-by-step procedure established for the solution of weights and other design factors. As an aid to the reader, numerical values are presented for one particular set of design parameters. In order to eliminate minor discrepancies, cross curves were plotted for numerous steps and one or two small changes in calculated values were made in the specific case given here.

1) Displacement = 40,000 long tons, salt water (arbitrary value).

2) Shaft horsepower = 20,000 (arbitrary value).

3) Length = 617 feet. See Figure 1.

There is a clear relationship between length and displacement in modern tankers. All known values plot within 4 percent of the mean line. There is no assurance that the mean line represents the ideal length and in an actual design, further analysis would be in order.

Appendix II deals with a cost study including an investigation into length. This study, while not all-conclusive, tends to confirm the value of the curve in Figure 1.

4) Nominal sea speed: 18.7 knots. See Figure 2.

This approximate relationship between sea speed, power and displacement is derived, primarily from Minorsky's nomograph (Ref. 13). The length-displacement relationship shown in Figure 1 is assumed and Minorsky's

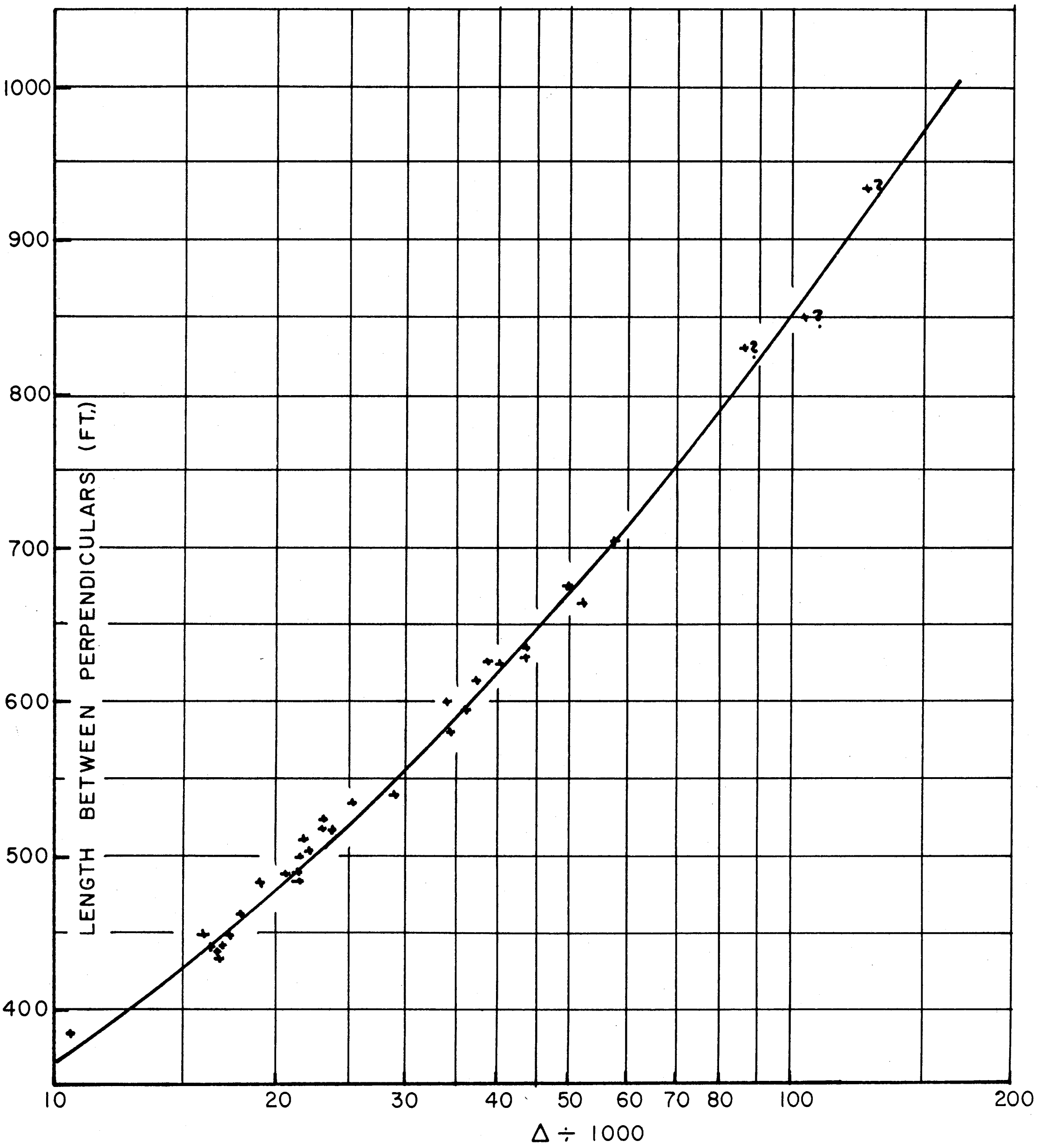


Figure 1. Length vs. Displacement in Modern Tankers.

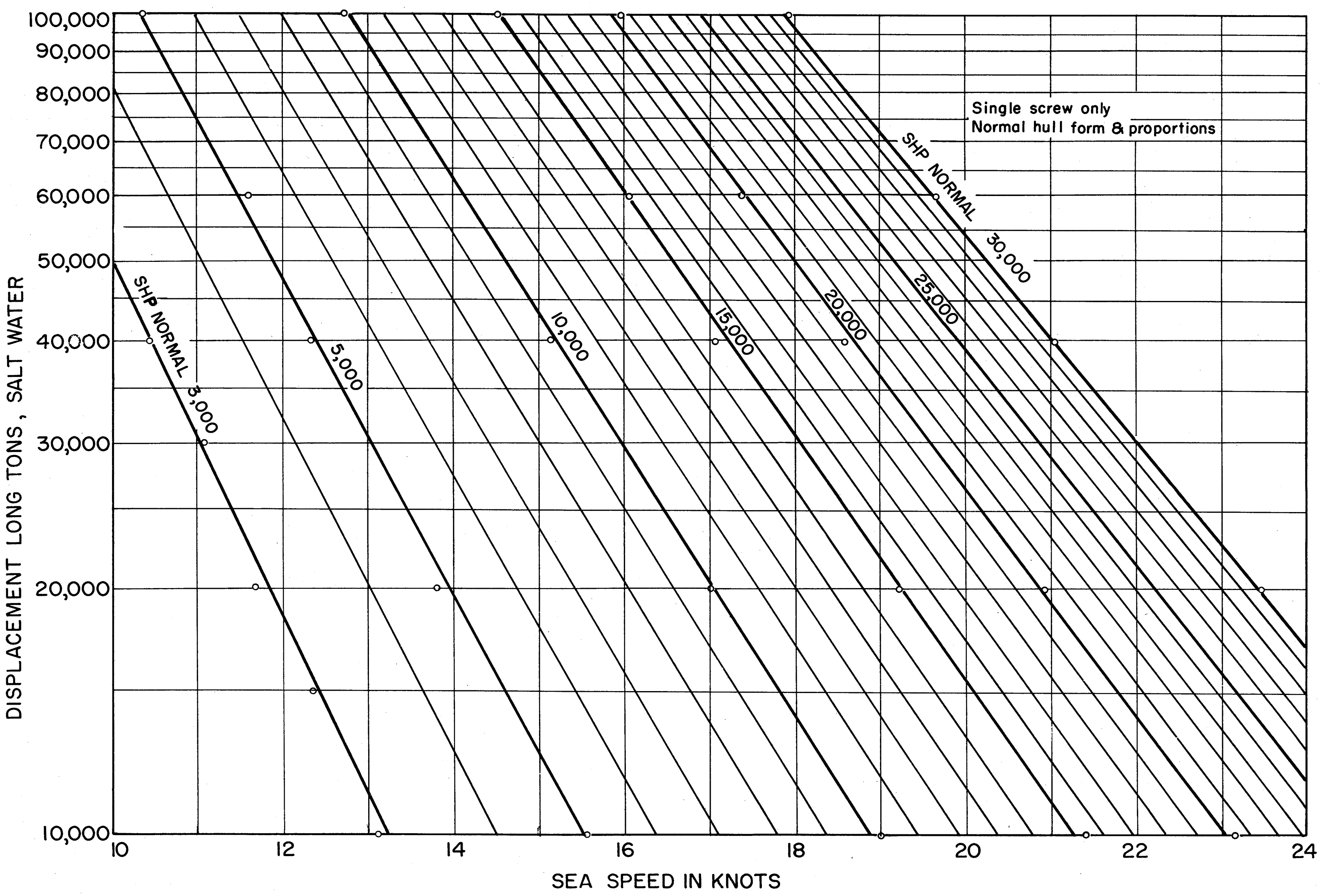


Figure 2. Approximate Sea Speeds for Various Displacements and Powers.

resulting values are modified to bring the chart more nearly into agreement with actual known values for existing tankers.

These curves are based on the assumption that every combination of size and power has its appropriate hull form and propeller. This figure should not be used to try to predict the speed-power curve for any particular vessel.

Such simplified powering estimates, while satisfactory for studies of this nature are of course no real substitute for careful analysis or tank investigations in an actual design.

5) Speed-length ratio $\left(\frac{V}{\sqrt{L}}\right) = 0.7535$

L is taken as the length between perpendiculars throughout this study. Speed is the mean sea speed at normal power.

6) Block coefficient (C_B) = 0.7225. See Figure 3.

The mean line relating block coefficient and speed length ratio, faired through numerous known values, runs somewhat above the line determined by averaging values recommended by a number of authorities. This tendency, also noted by Mr. John F. Watson (Ref. 14) is explained by the fact that tankers operate half the time in ballast.

The study shown in Appendix II indicates that considerable variation in block coefficient may be effected with very little change in operating economics, if we assume a constant displacement.

7) Depth = 44.9 feet. See Figure 4.

The mean line, drawn through numerous data points approaches a length-depth ratio of 14 at the greater length. The cross curves of draft (from an unpublished work by James Krogen and the writer) were used in developing Figure 5. These cross curves were derived from the freeboard regulations (Ref. 15).

8) Draft = 34.2 feet. See Figure 5.

Depth-draft curves derived from Figure 4 were modified somewhat to bring the chart more nearly into agreement with known values.

9) Beam = 91.85 feet.

Beam is equal to $\frac{35\,\Delta}{C_B L d}$.

A check on general proportions should be made at this stage.

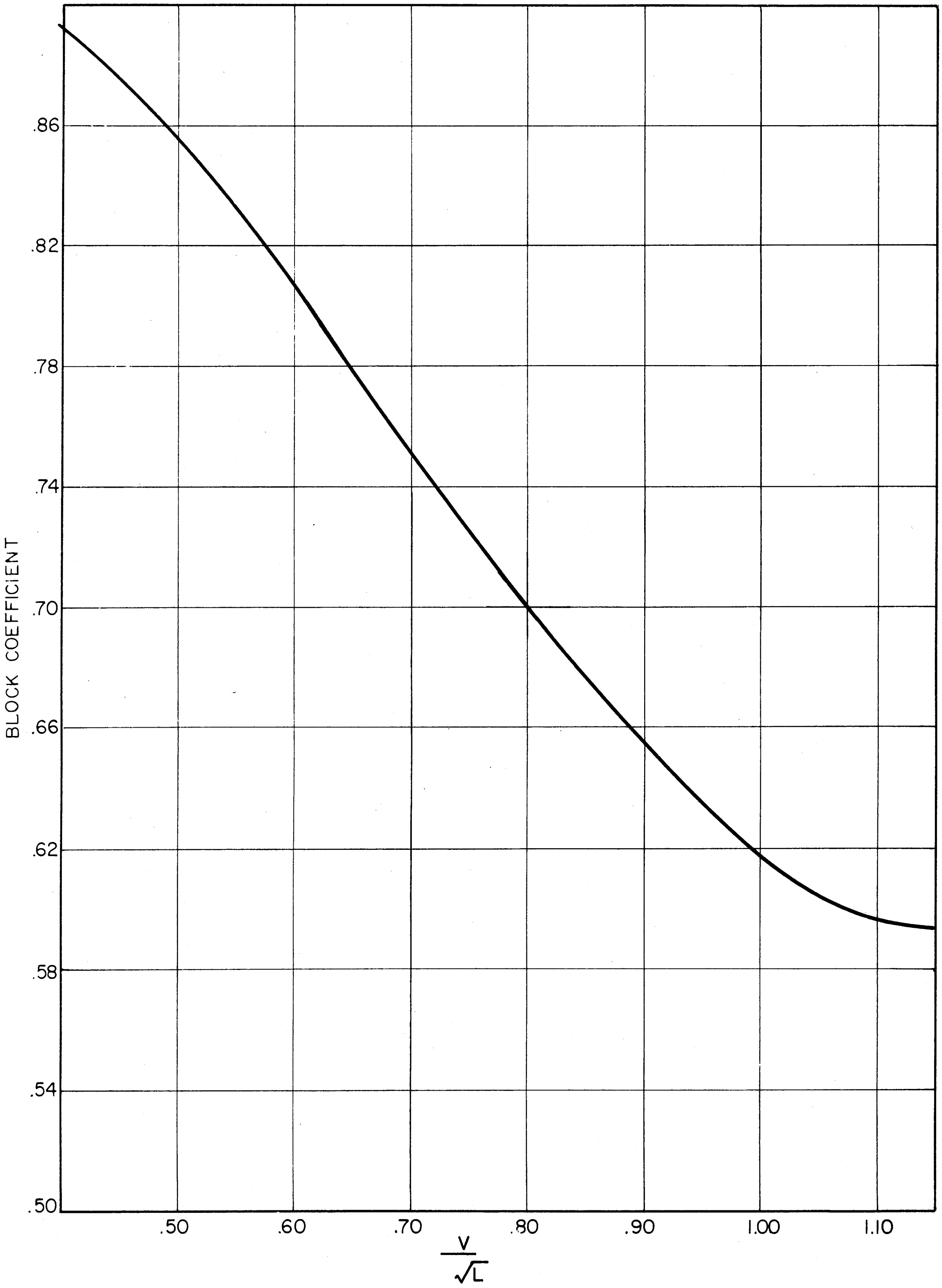


Figure 3. Tankers Approximate Relationship Between Block Coefficient and Speed-Length Ratio.

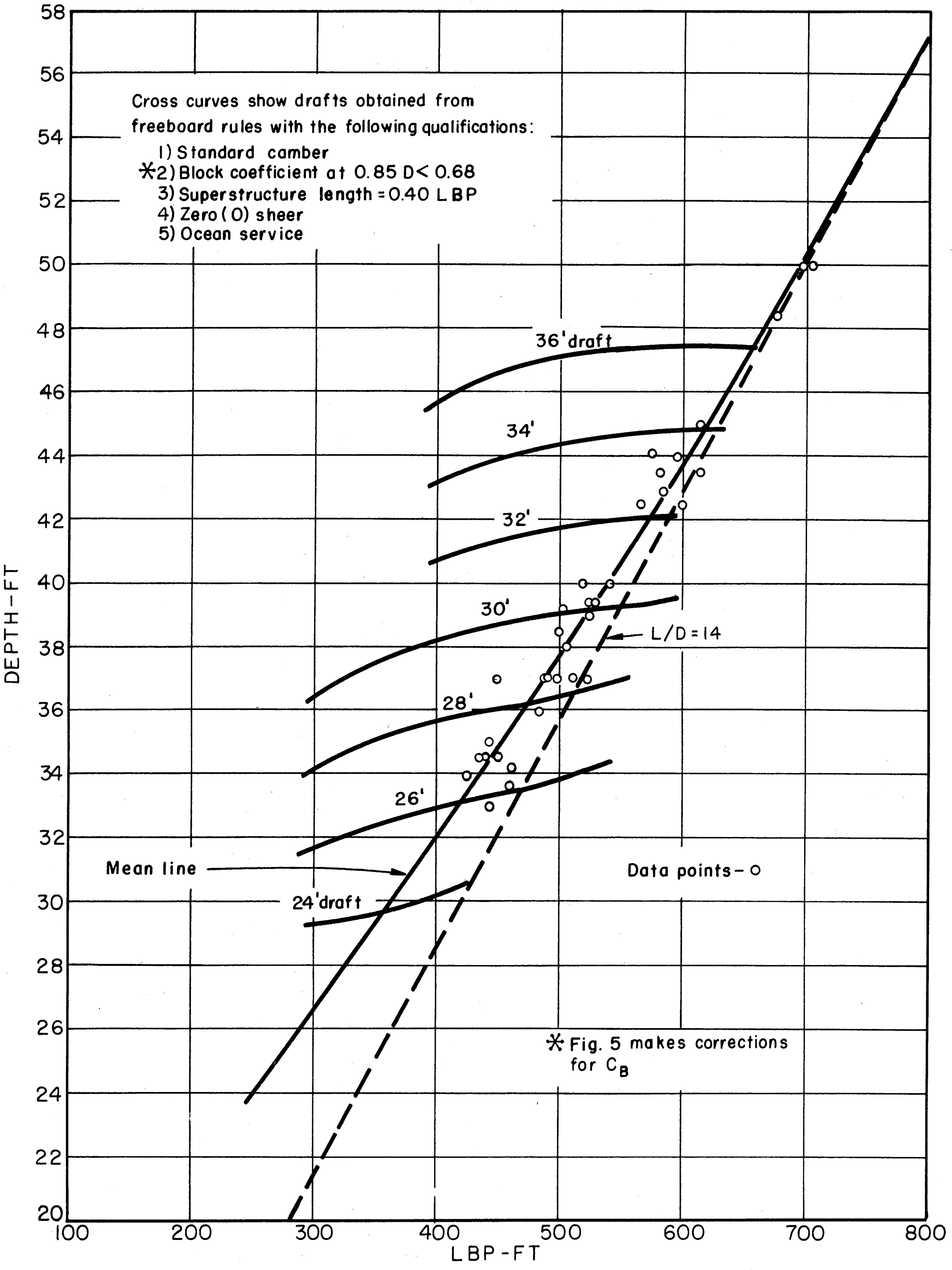


Figure 4. Tankers Relationship Between Length and Depth.

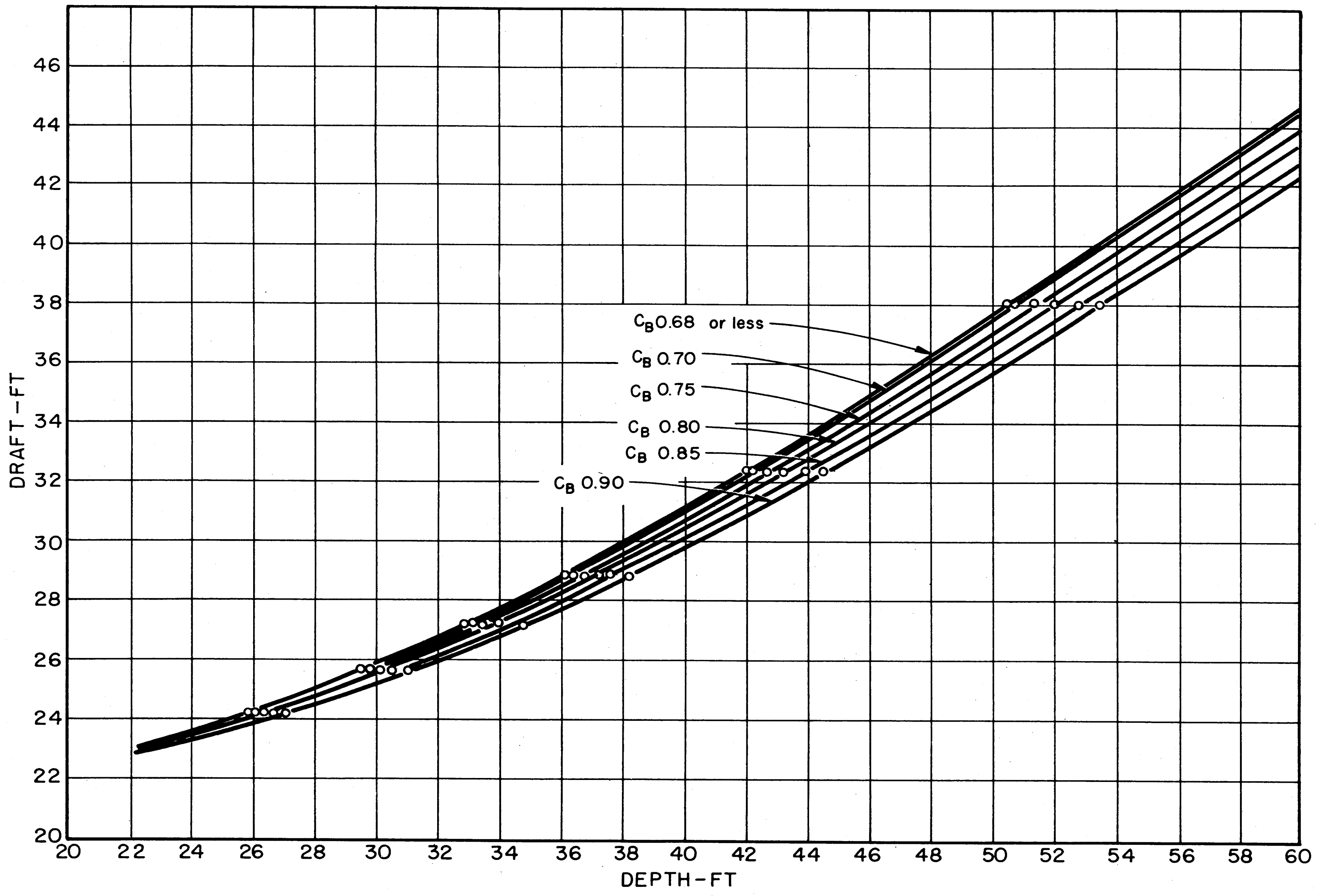


Figure 5. Tankers Relationship Between Depth and Draft.

10) Cubic number ($\frac{LBD}{100}$) = 25,740.

This is the traditional parameter for use in quick weight estimates. While it is blind to many factors it does have the virtue of simplicity and is quite in order for a study of this nature.

11) Length depth ratio ($\frac{L}{D}$) = 13.74.

Ratio is used in the next step. If Figure 4 (step 7) has been read correctly, the numerical value will be 14.00 or less.

12) Steel weight coefficient (C_s) = 0.268, cross faired to 0.267. See Figure 6.

The steel weight coefficient will vary with L/D ratio, C_B and overall size. Figure 6 attempts to show the effect of the various factors. These curves were obtained by first plotting total weight vs. cubic number through known values with tentative corrections for L/D and C_B. From this, a coefficient curve for a standard L/D and C_B was derived. Corrections for L/D ratio were made averaging values obtained from an earlier analysis of Raben's steel weight coefficients (Ref. 16) and the standard correction factor:

$$\frac{L/D\ (\text{new})}{L/D\ (\text{old})}$$

The C_B correction is based on the premise that a change of ten percentage points in C_B will change the steel weight 4.4 percent. This value was obtained by applying logical corrections to the detailed weights of an actual tanker. It agrees reasonably well with the standard correction factor:

$$\frac{1 + 1/2\ C_B\ (\text{new})}{1 + 1/2\ C_B\ (\text{old})}$$

13) Steel weight = 6880 long tons.

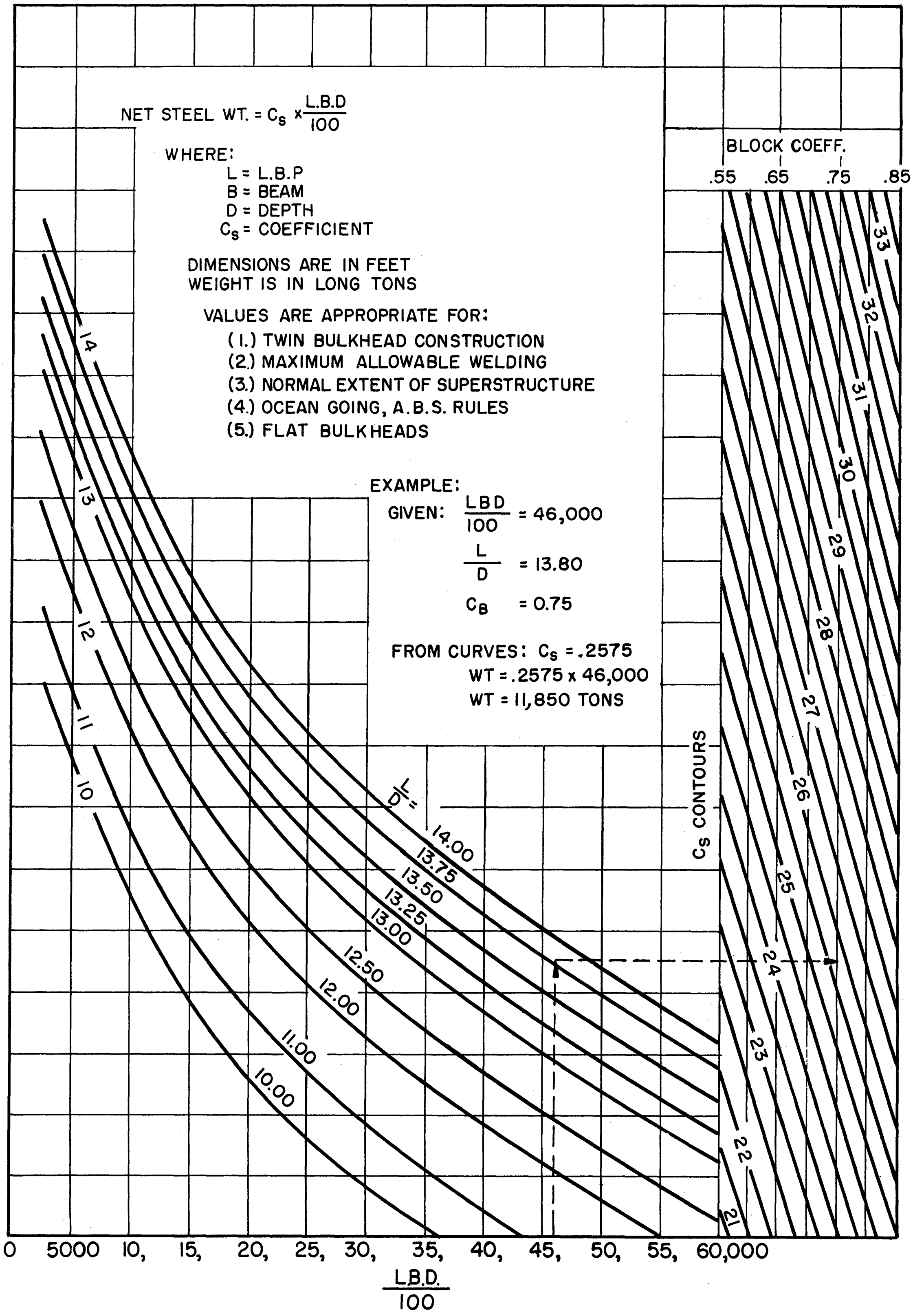
Product of steel weight coefficient (faired value) times cubic number.

14) Outfitting weight coefficient (C_o) = 0.0509. See Figure 7.

Mean line is based on known data and is of course only approximate. Hull engineering items are included here.

15) Outfitting weight = 1310 long tons.

Product of outfitting weight coefficient times cubic number.



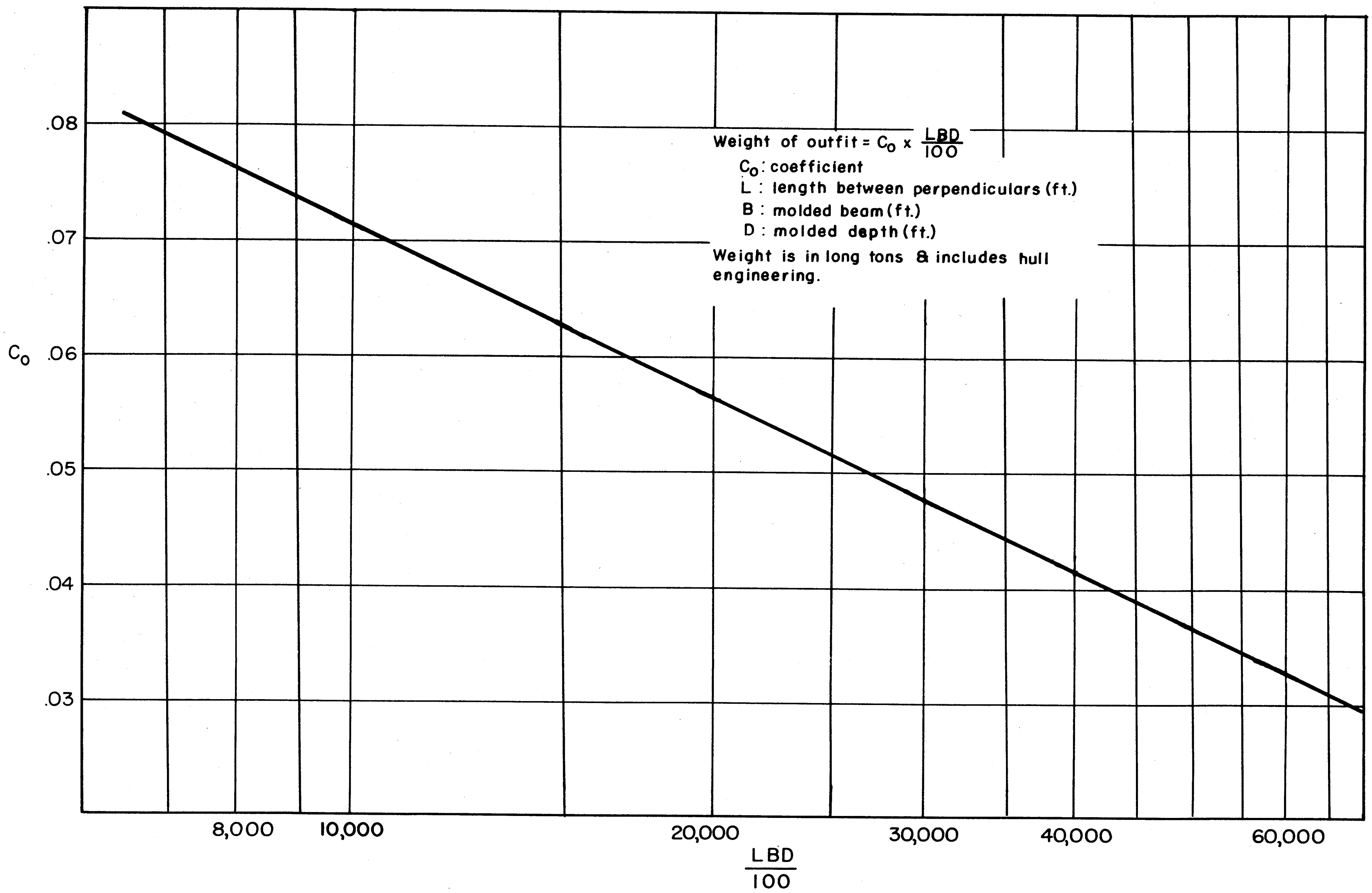


Figure 7. Outfitting Weight Coefficients for Modern Tankers.

16) Machinery weight: pounds per SHP = 118. See Figure 8.

This figure shows an average curve drawn through known data points. Steam conditions, within the normal range, do not appear to have any appreciable effect on weights. This is explained by the greater care exercised in the design of the more expensive plants. Values are appropriate for modern machinery, geared turbines, water tube boilers and may be applied to any single screw vessel.

17) Machinery weight = 1054 long tons.

18) Light ship = 9244 long tons.

Summation of steel, outfitting and machinery weights. No designer's margin is included in this study.

19) Deadweight = 30,756 long tons.

Displacement minus light ship.

3. Results of Design Analysis

The direct culmination of the effort involved in putting some 32 hypothetical vessels through the above procedure was the series of design curves presented in Figures 9, 10, 11, and 12. It is hoped these will prove useful for preliminary design purposes. Figure 9 shows the influence of horsepower and displacement on the deadweight coefficient. When displacement and power are known, this figure allows quick estimation of the resulting deadweight. Figure 10 shows the influence of horsepower and deadweight on the deadweight coefficient. When deadweight and power are known, this figure allows quick estimation of the required displacement.

Figure 11 shows the approximate relationship between speed, power and deadweight. This figure was derived from Figures 2 and 9. While not intended for great accuracy, it is believed that these curves at least give good indication as to the general trends.

Figure 12 illustrates the important influence which allowable draft has on deadweight capacity. Note for example that increasing harbor depths from 30 feet to 40 feet allows deadweight per ship to be tripled.

Figure 13 was required as part of the operating cost analyses and is included here along with the other design curves. This is a useful tool for applications where draft restrictions prevent any given vessel from operating at her designed draft. It shows the effect of reduced draft on displacement and speed. The displacement curves were derived from Ref. 17.

Figure 14 illustrates the distribution of weights, as a percentage of light ship, for various speeds.

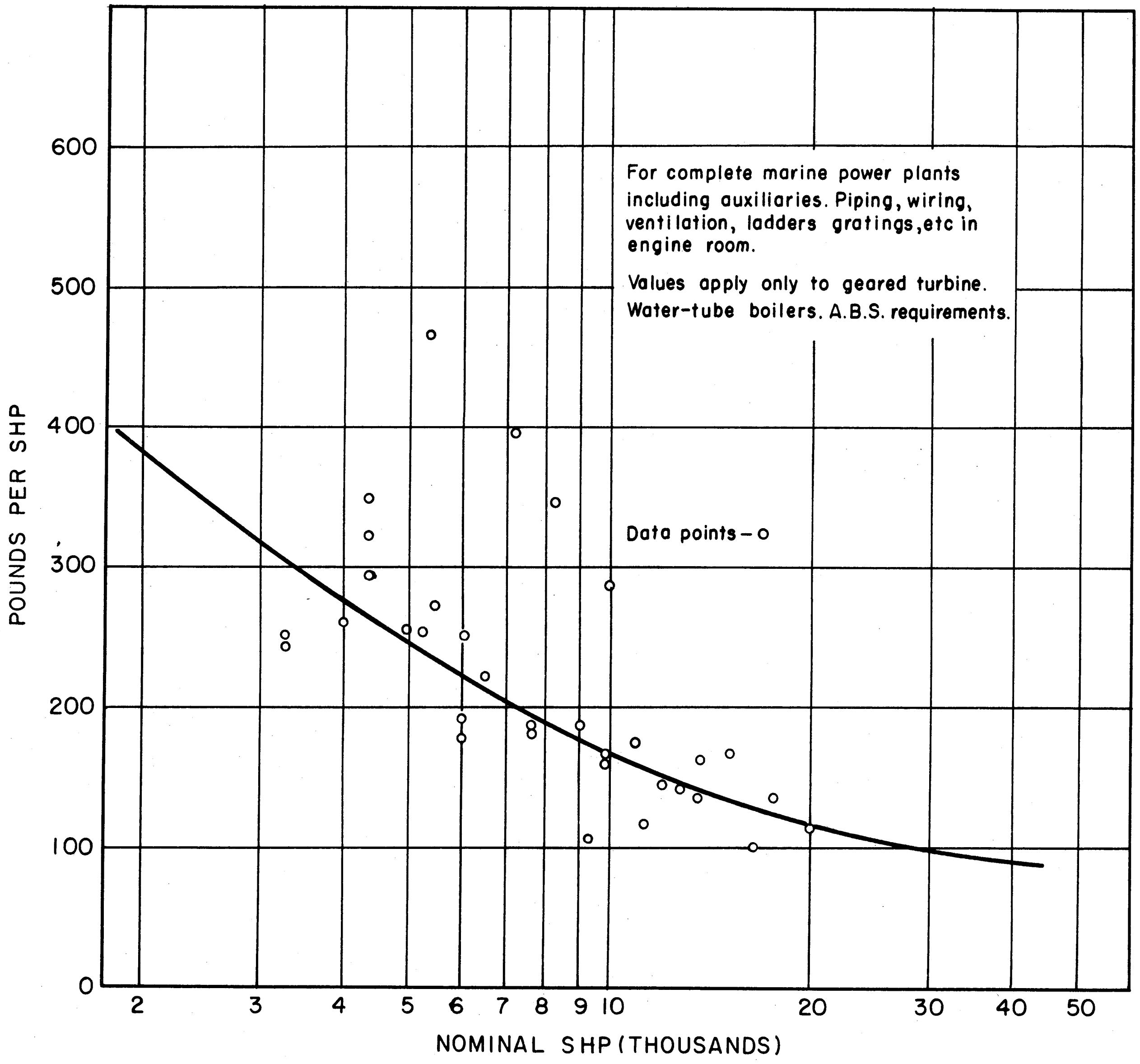


Figure 8. Average Unit Machinery Weights.

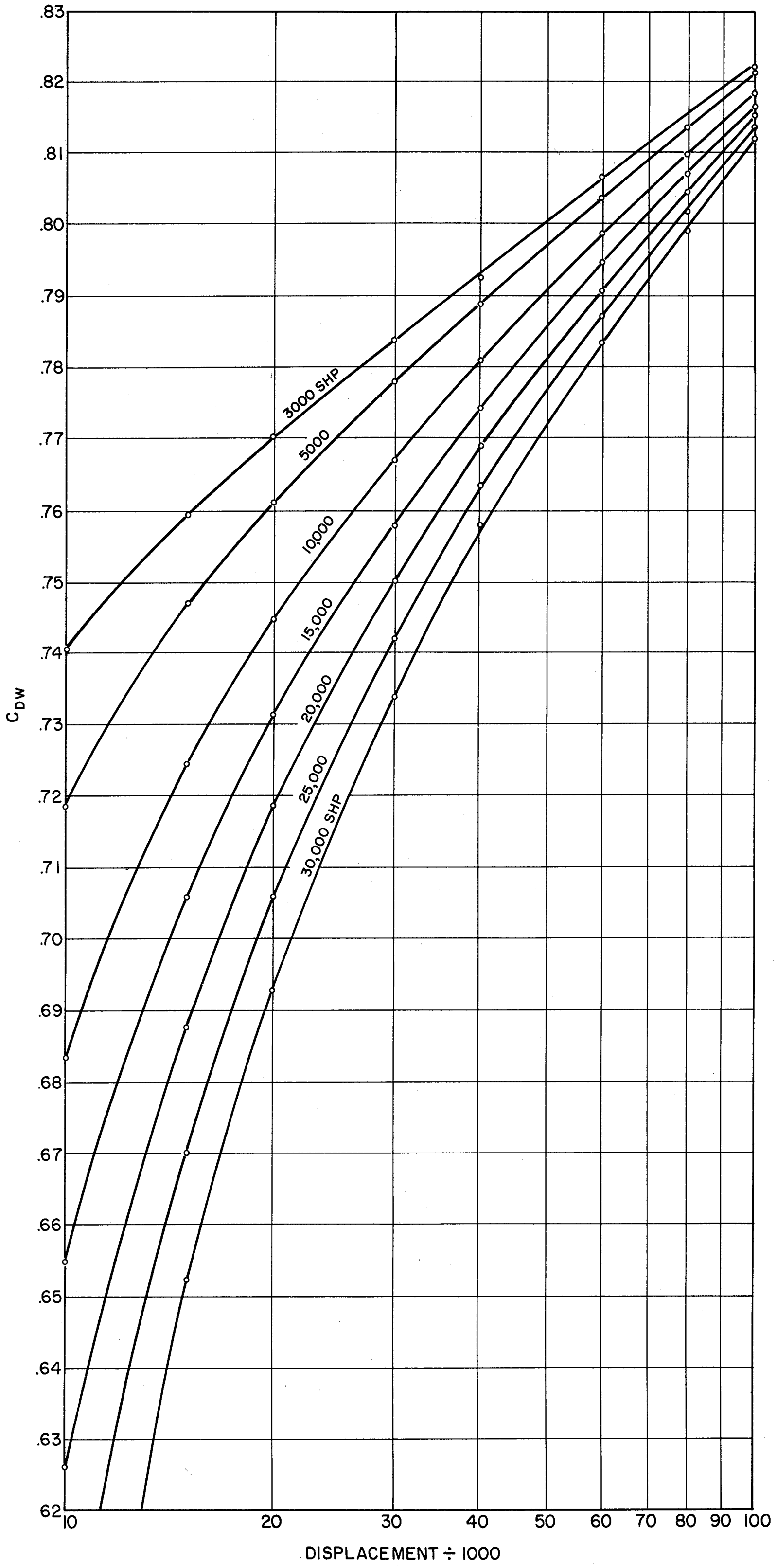


Figure 9. Tankers Deadweight Coefficient vs. Displacement.

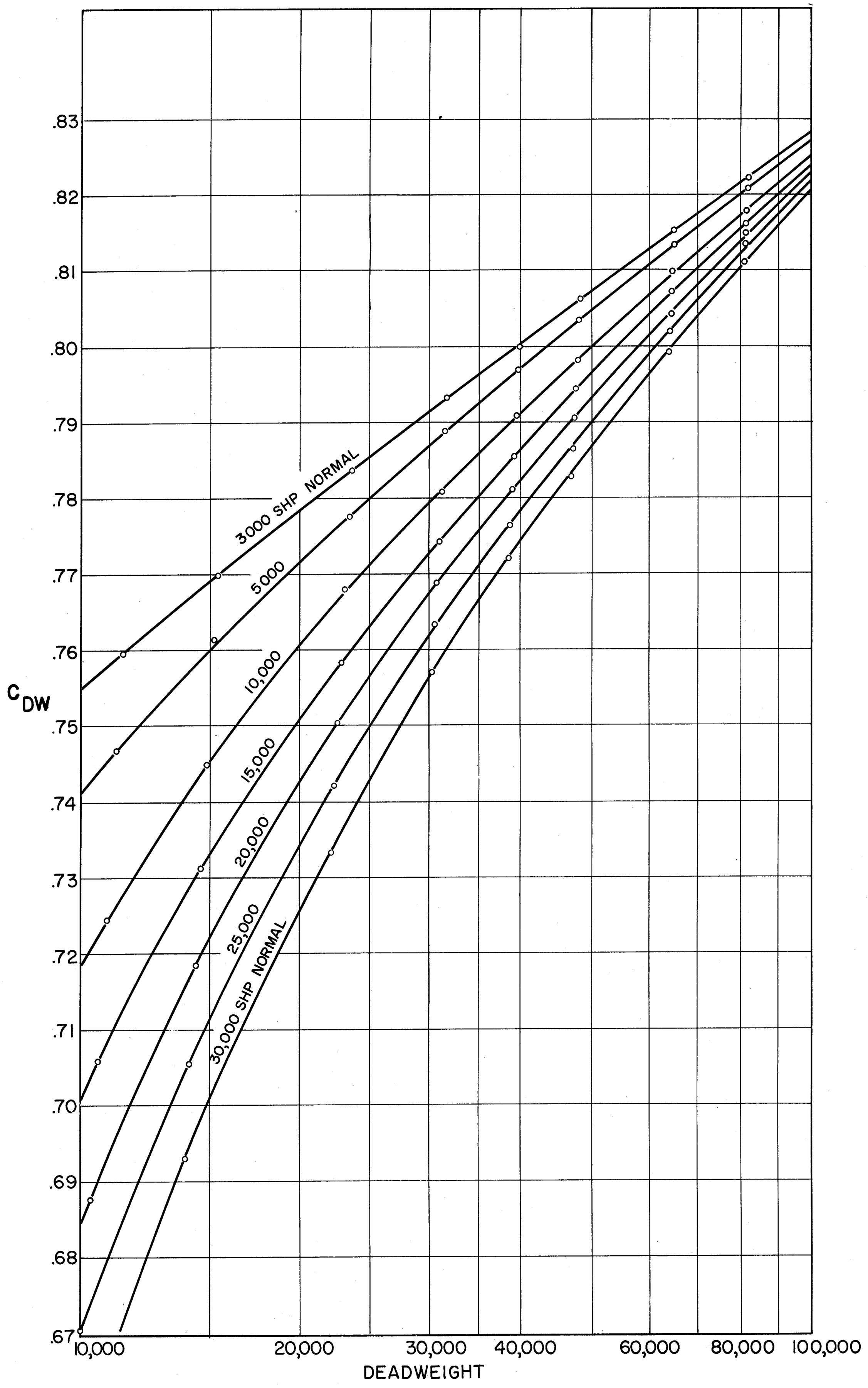


Figure 10. Tankers Deadweight Coefficient vs. Deadweight.

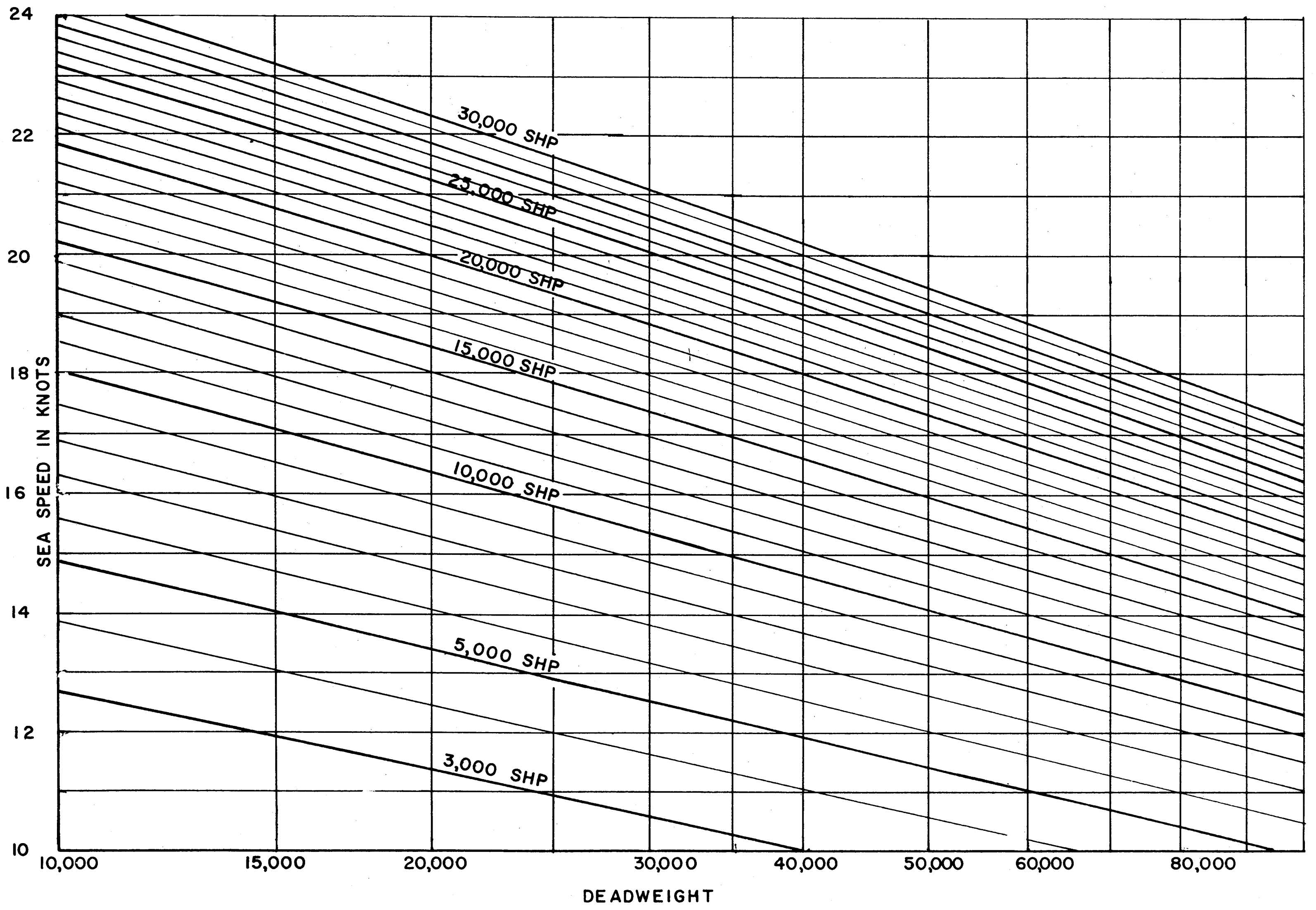


Figure 11. Tankers Approximate Relationship Between Deadweight, Horsepower and Speed.

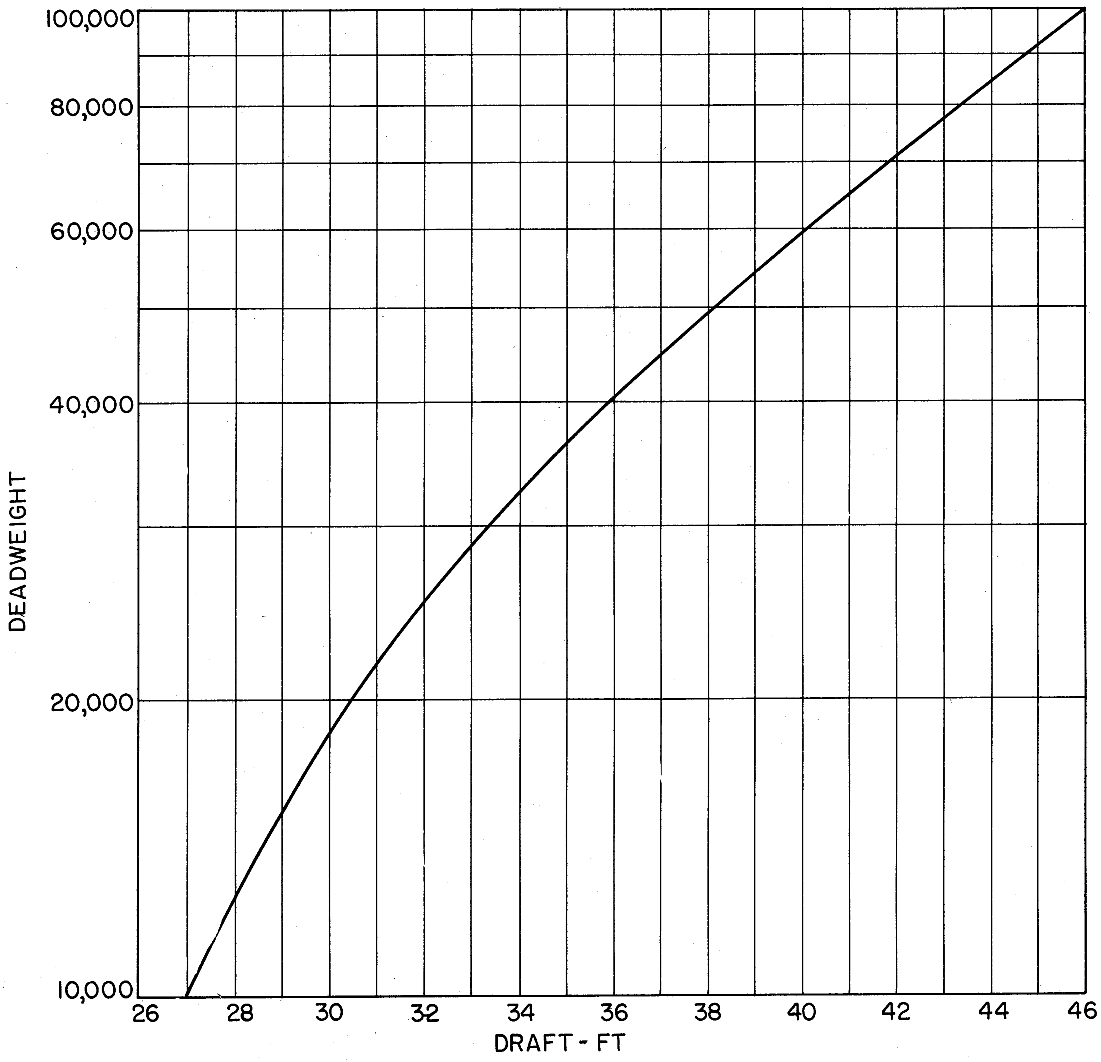


Figure 12. Tankers Influence of Draft on Deadweight (Based on 17 Knots Sea Speed and Normal Proportions).

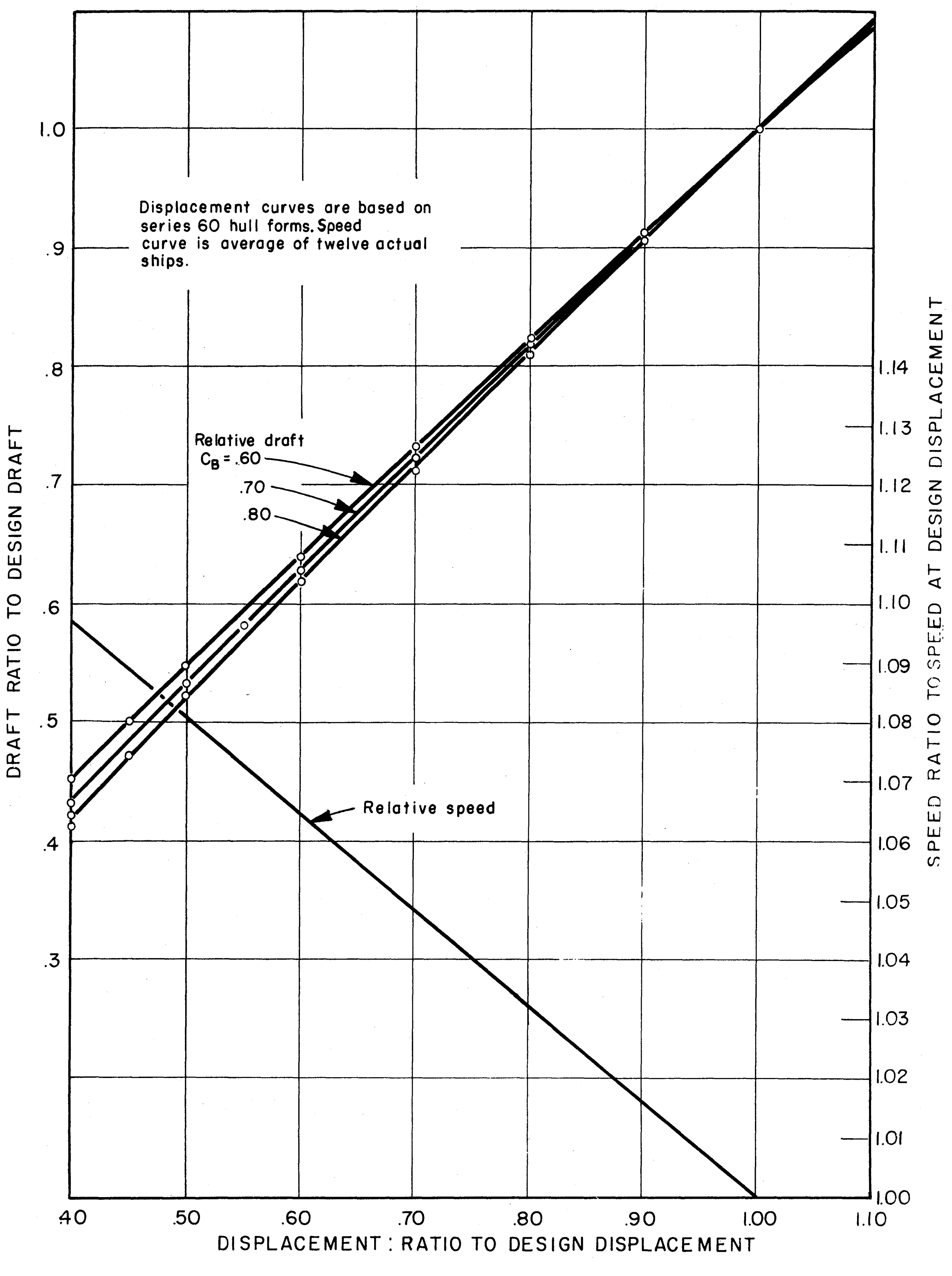


Figure 13. Speed and Displacement at Reduced Draft. Even Keel Loading.

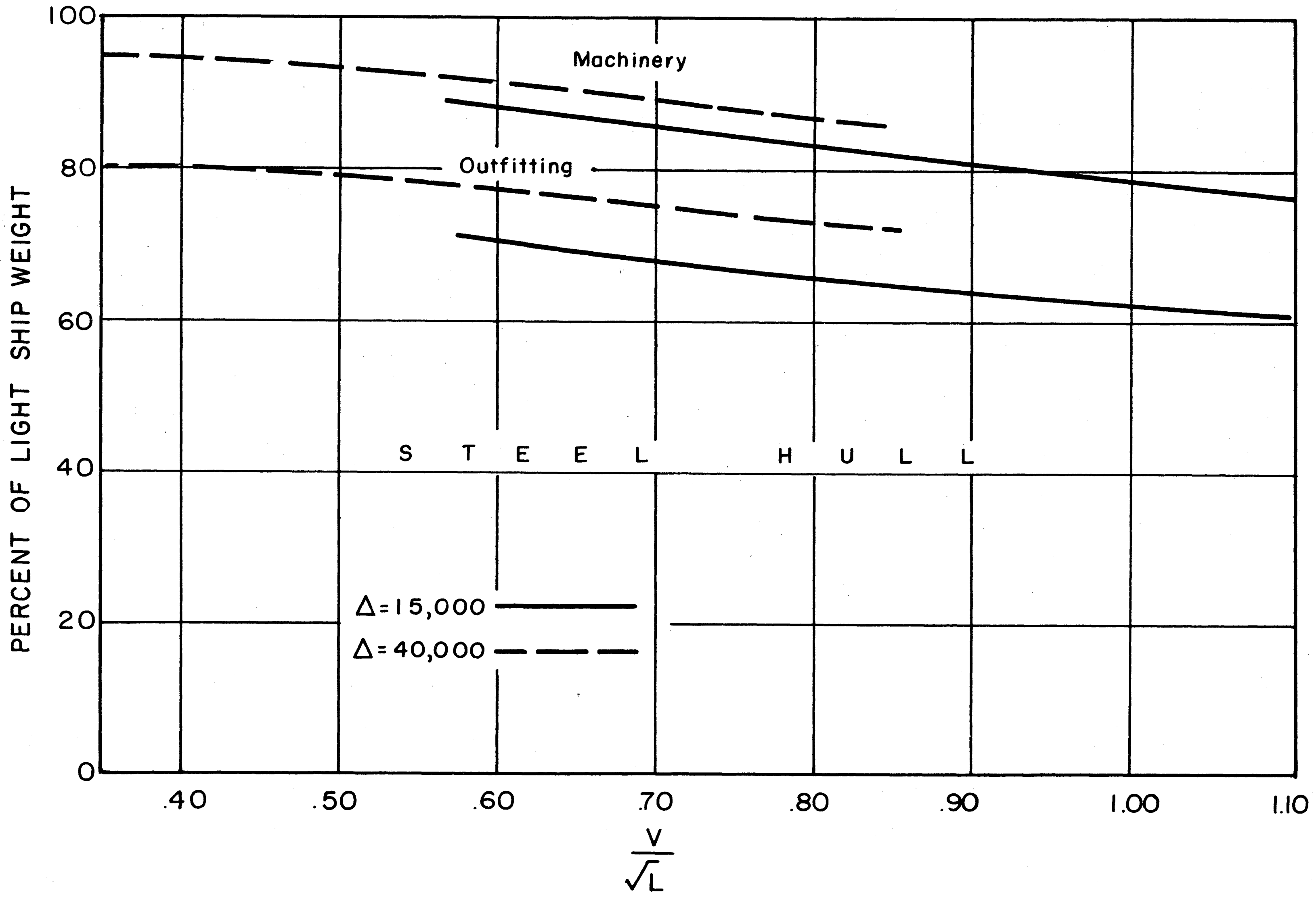


Figure 14. Weight Distribution vs. Speed-Length Ratio as a Percentage of Light Ship.

Figure 15 illustrates the distribution of weights, as a percentage of displacement, for various speeds. Values shown here are considerably lower than those in Figure 1 of Ref. 18, particularly at the higher speeds. This is primarily an indication of weight reductions accomplished in the past 36 years.

Tables I and II below show that deadweights and speeds, predicted by the foregoing analysis, are very close to current design practice.

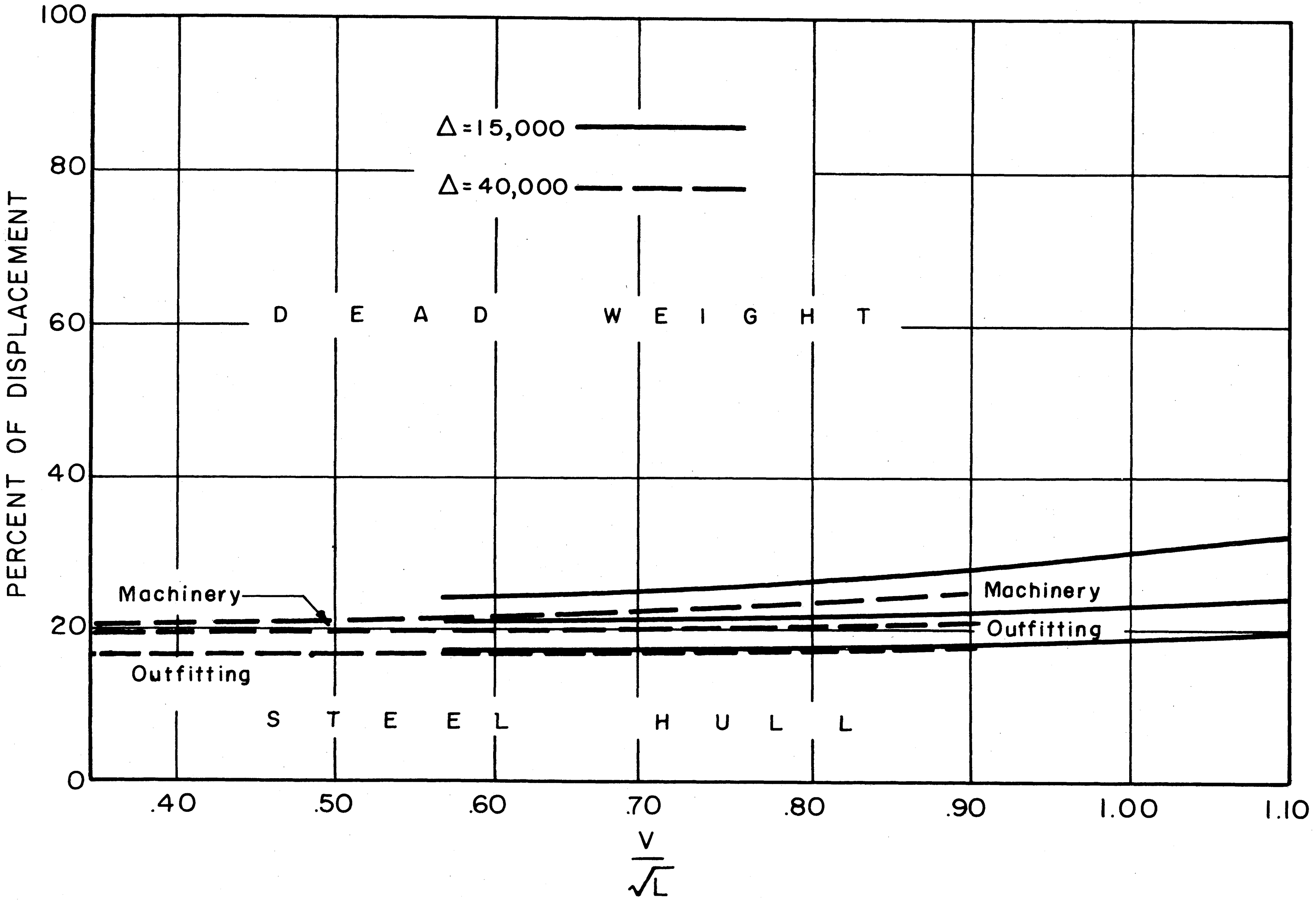


Figure 15. Weight Distribution vs. Speed-Length Ratio as a Percentage of Displacement.

TABLE I. ACTUAL DEADWEIGHTS VS. PREDICTED VALUES FROM FIGURE 9

Vessel	Displacement	Normal SHP	Published Deadweight	Predicted Deadweight	Error
World Glory	58,265	15,000	45,509	46,210	+1.5%
E	25,510	13,650	19,183	19,170	nil
F	34,640	12,500	26,759	26,670	-0.3%
G	49,660	20,000	38,911	38,780	-0.3%
Jahra	36,346	12,500	28,000	28,080	+0.3%
Sovac Pegasus	35,171	12,500	27,000	27,130	+0.5%
				average error:	+0.2%

Vessels E, F, and G in the above table are from Table 1b (Ref. 14).

TABLE II. ACTUAL SEA SPEEDS VS. PREDICTED VALUES FROM FIGURE 2

Vessel	Displacement	Normal SHP	Published Sea Speed	Predicted Sea Speed	Error
World Glory	58,265	15,000	16.1	16.1	0
E	25,510	13,650	18.5	18.0	-0.5 knot
F	34,640	12,500	16.5	16.7	+0.2 knot
G	49,660	20,000	18.0	18.0	0
Jahra	36,346	12,500	16.43	16.5	+0.1 knot
				average error:	-0.04 knot

Vessels E, F, and G in the above table are from Table 1b (Ref. 14).

D. CONSTRUCTION COST ANALYSIS

1. Introduction

The weight analysis developed in the preceding section, while useful for preliminary design work, was primarily intended to furnish a rational basis for the development of tanker construction costs, which depend in part on weights.

There are so many variables entering into the cost of ship construction that there was never any hope of arriving at quantitatively accurate cost predictions. Costs vary from yard to yard and the writer had access to only a restricted quantity of recent cost breakdowns. Despite these drawbacks, the construction cost study was felt to be worthwhile since the results of such an estimate should at least show relative cost trends. An engineer, in using cost studies as a basis for choosing optimum design, is interested in cost differences between various proposals so that qualitative accuracy is all that is required.

Cost estimates in this section are based on single-ship contracts and a correction curve for multiple ship contracts was developed.

2. Method

Cost estimates were made for each of the thirty-odd hypothetical tankers analyzed in the preceding weight study. Following the usual shipyard procedure, man-hours of labor and material costs were estimated for steel hull, outfitting and machinery. Overhead was taken as a fixed percentage of labor cost and these figures together with profit, insurance and drydock charges yielded the estimated shipyard bill. Miscellaneous costs to the owner are specifically excluded in this part of the study.

Following is the step-by-step procedure established for estimating the shipyard bill. As in the previous study, numerical values are presented for a tanker of 40,000 tons displacement and 20,000 SHP. Costs are worked out to the nearest hundred dollars. This is an unwarranted degree of "accuracy" but is helpful in detecting minor differences between various hypothetical ships. The final cost results are considerably rounded off.

1) Steel material cost = $1,001,700.

Delivered cost, per net ton steel taken at 6-1/2 cents per pound.

2) Steel man-hours per ton = 58.2. See Figure 16.

Curve is based on mean line drawn through rather widely scattered data points with similar curve derived from Ref. 19 as a general guide.

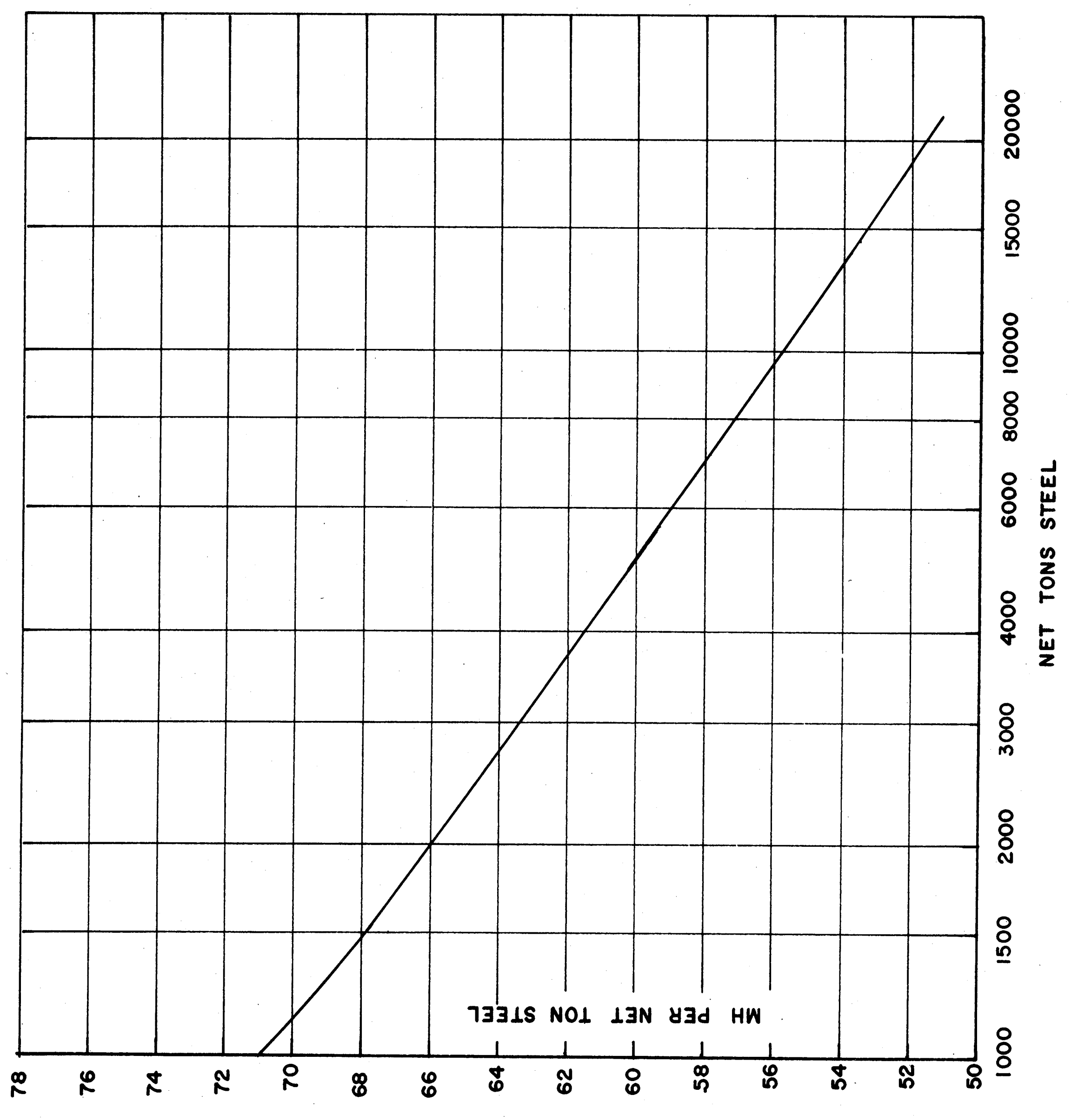


Figure 16. Tankers Man-Hours Per Net Ton Steel.

3) Steel man-hours = 399,900.

Product of man-hours per ton and net tons of steel.

4) Outfitting material cost = $1,467,000.

A figure of 50 cents per net pound of outfit was used throughout. This is obviously a crude approach but probably reflects the general trend in a satisfactory manner. This category includes hull engineering.

5) Outfitting man-hours = 399,600.

A figure of 305 man-hours per net ton was used as an average figure. The remarks under paragraph 4 above also apply here.

6) Unit material cost of machinery = $96.3 per SHP. See <u>Figure 17</u>.

The curves for machinery costs are based on average figures used by three individual estimators in East Coast yards. Machinery costs are generally applicable to other type vessels as well as tankers.

7) Machinery material cost = $1,926,000.

8) Machinery unit labor requirements = 12.45 man-hours per SHP. See Figure 15.

9) Machinery labor man-hours = 249,000.

10) Total man-hours, direct labor = 1,048,500.

Summation of steel, outfit and machinery man-hour requirements. These figures include engineering and drawings.

11) Total material cost = $4,394,700.

Summation of steel, outfit and machinery material costs.

12) Total direct labor cost = $2,411,000.

Based on an average hourly rate of $2.30. This includes a small amount of overtime and/or bonus pay.

13) Overhead cost = $1,808,000.

Taken as 75 percent of total direct labor cost. This figure appears to be a fair average but may vary quite widely.

14) Miscellaneous costs = $532,000. See <u>Figure 18</u>.

These costs include such items as launching, trials, and delivery.

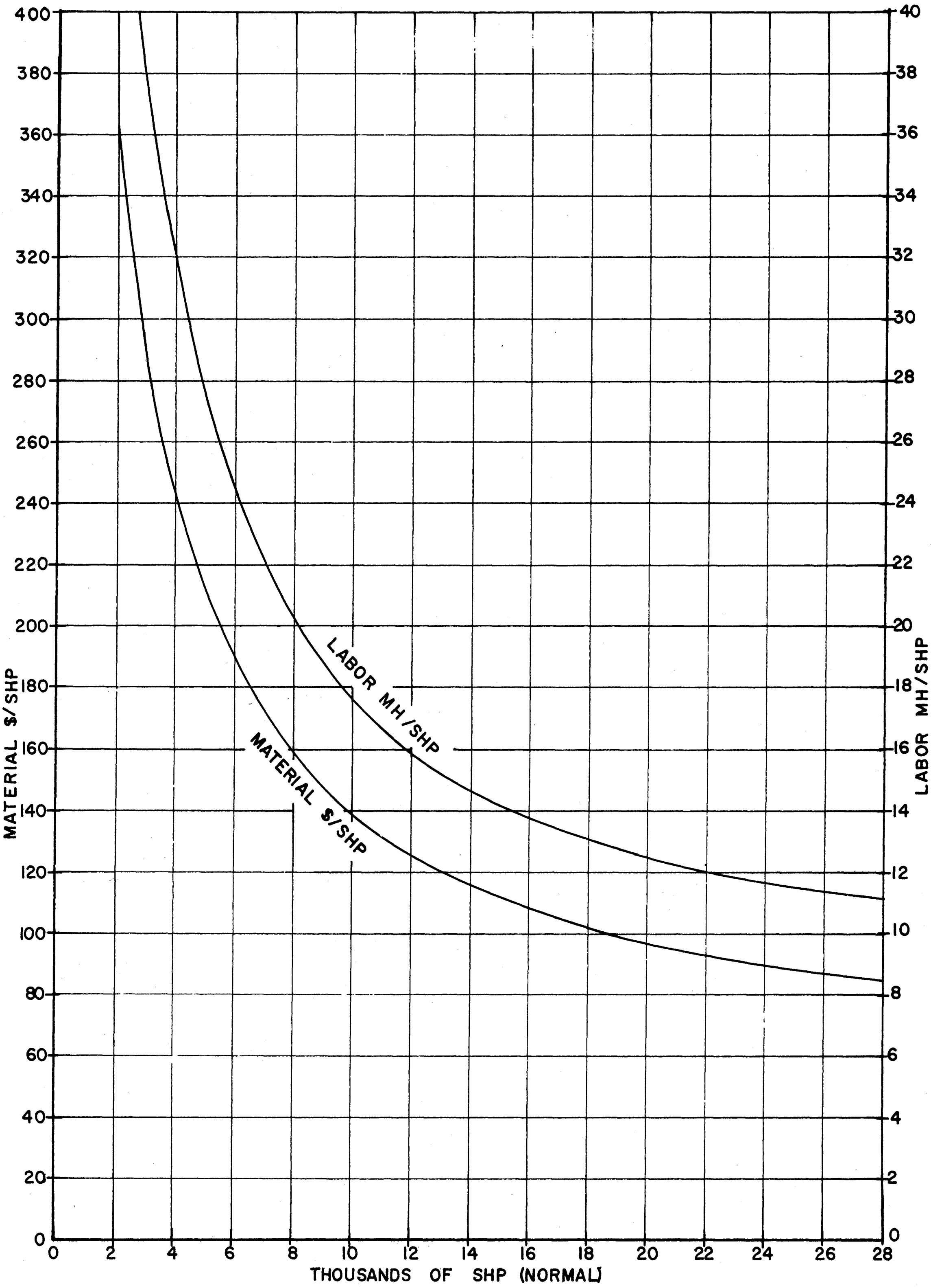


Figure 17. Approximate Machinery Costs.

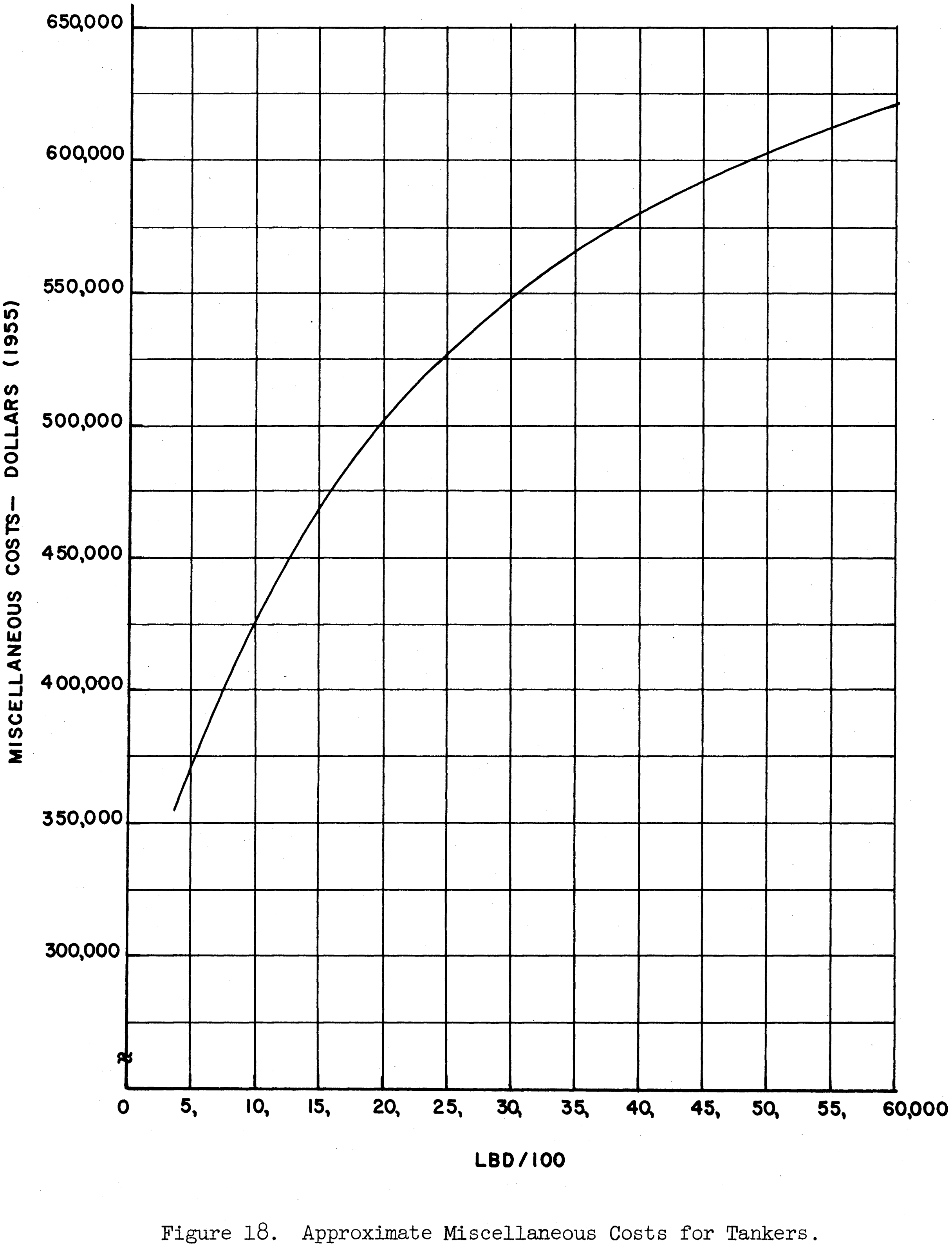


Figure 18. Approximate Miscellaneous Costs for Tankers.

15) Sub-total of above costs = $9,145,700.

16) Profit = $686,000.

A figure equal to 7-1/2 percent of the sub-total was used throughout.

17) Insurance = $45,700.

A figure equal to 1/2 percent of the sub-total was used throughout.

18) Drydock charges = $90,100.

Relating gross tonnage to the cubic number, and taking standard drydock charges, yielded an approximate figure of $3.50 times the cubic number.

19) Shipyard bill = $9,967,500.

Summing up in the usual manner:

Material	$ 4,394,700
Direct Labor	2,411,000
Overhead (75 percent)	1,808,000
Miscellaneous	532,000
Sub-Total	$ 9,145,700
Profit (7-1/2 percent)	686,000
Insurance	45,700
Drydock	90,100
Shipyard Bill	$ 9,967,500

The work outlined above plus considerable cross-fairing resulted in the information compiled in Figures 19, 20, and 21.

Figure 19 can be used to approximate the building cost of tankers. It is based on late 1955, early 1956 dollars and will need correction factors as dollar values continue to fluctuate.

Figure 20 shows the influence of deadweight and power on the cost of construction. Non-dimensional ordinates are introduced to prolong the useful life of the curves.

Figure 21 illustrates the influence of deadweight and speed on the cost of construction. Non-dimensional ordinates are again used. Mr. J. A. Pennypacker (Ref. 11) made studies similar to these but for dry cargo ships. His conclusions, based on deadweights between 3,000 and 18,000 are essentially borne out by the more extensive investigations presented here. The only exception to this is noted in the summary of his conclusions which follow:

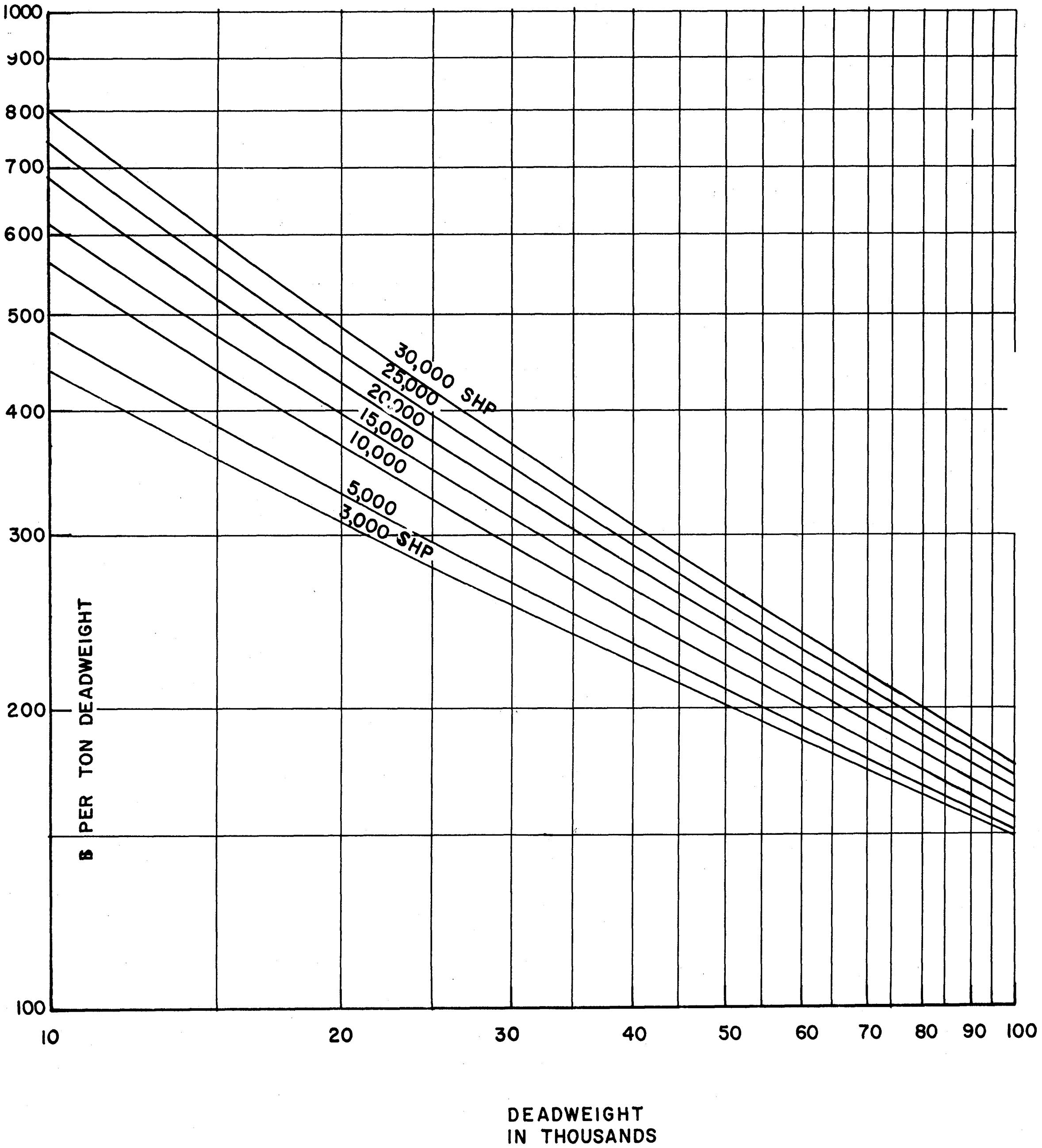


Figure 19. Tankers Cost Per Ton Deadweight vs. Deadweight.

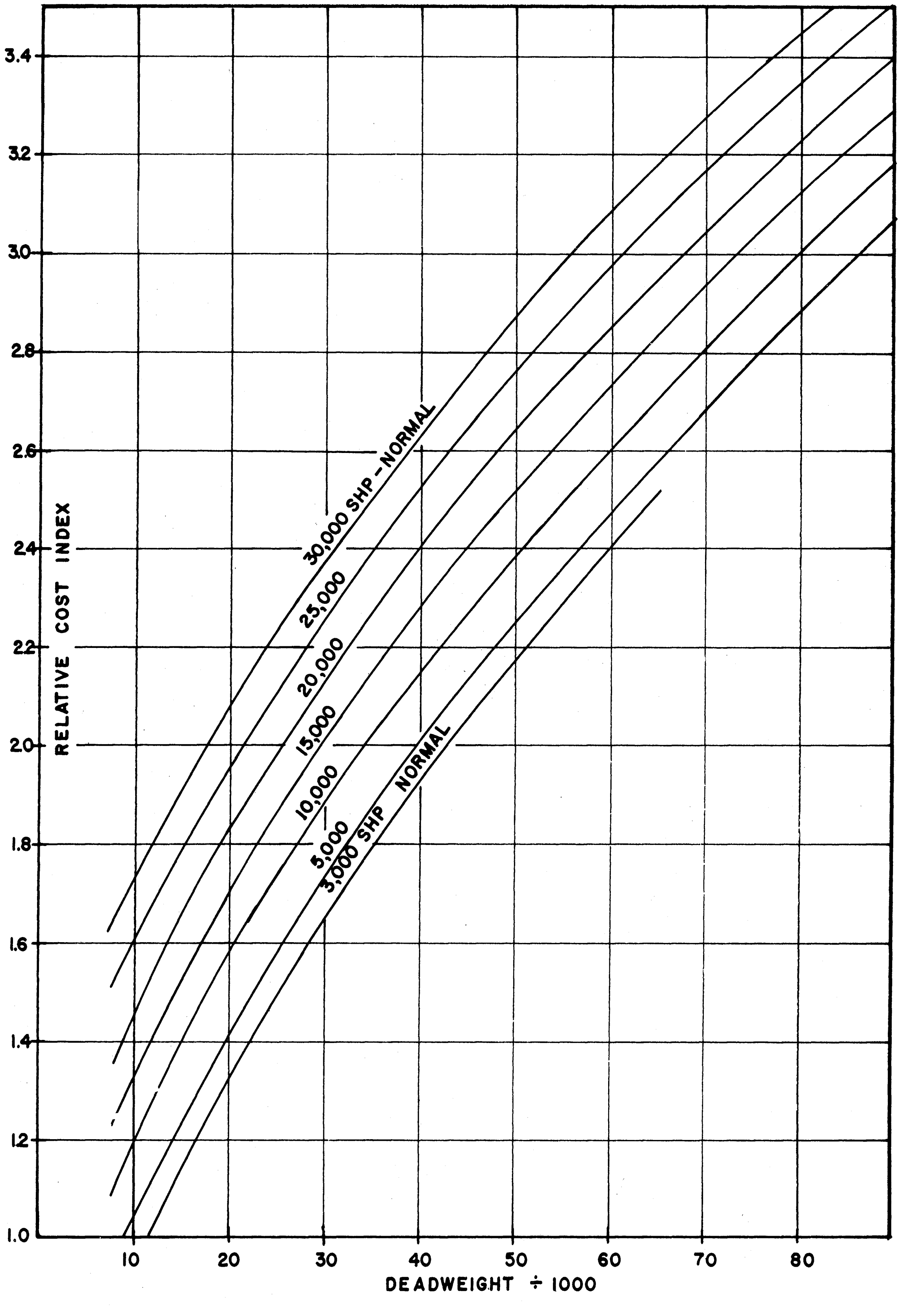


Figure 20. Tankers Relative Construction Costs.

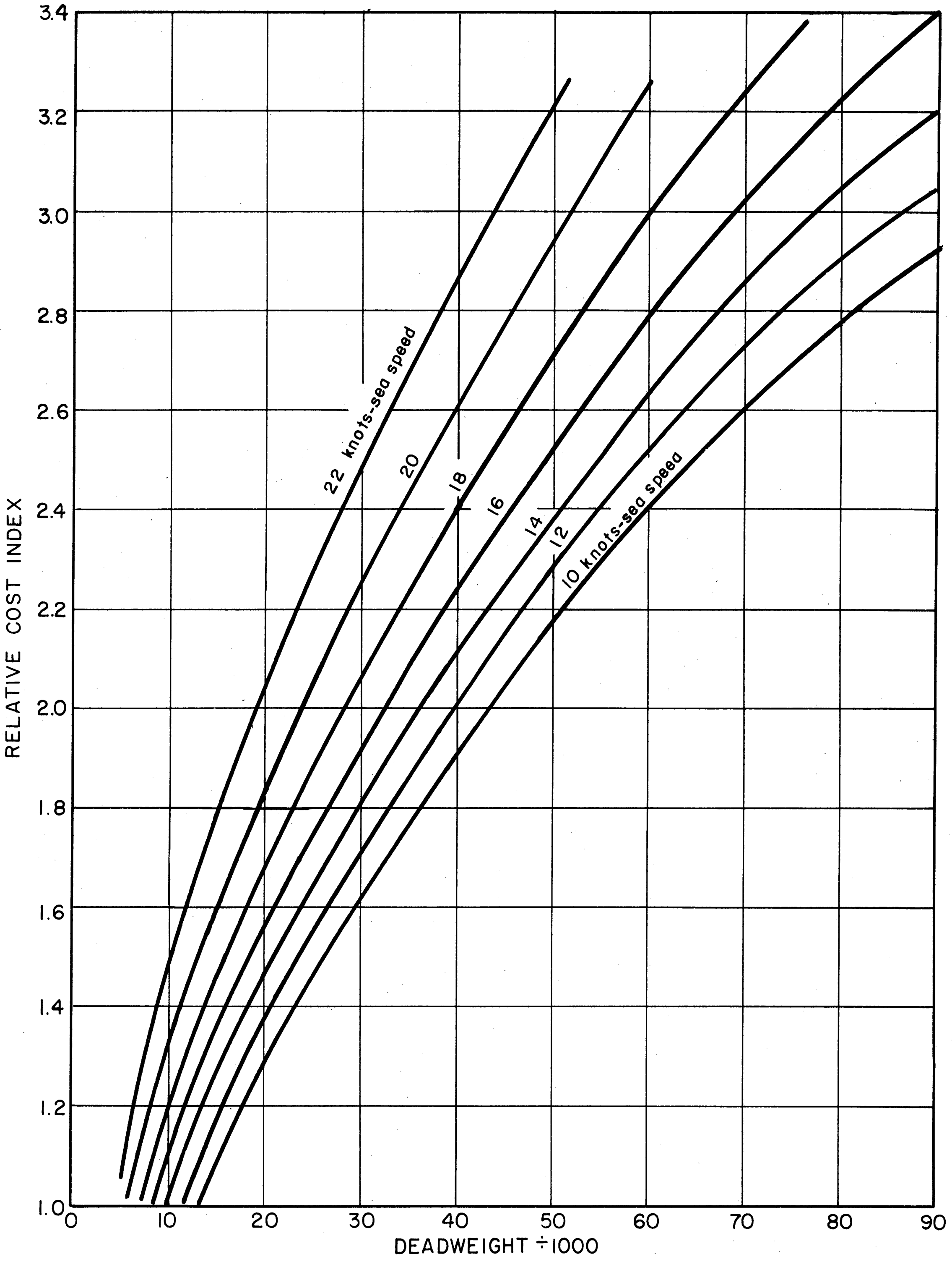


Figure 21. Tankers Influence of Speed and Deadweight on Construction Cost.

1) Speed has greater effect than does size on cost. This appears to be true below deadweights of about 20,000 tons. Above that point it is not always true, particularly within the lower speed ranges. For example, increasing the size of a 40,000 deadweight 10 knot tanker 25 percent would increase cost 14 percent. Increasing speed 25 percent would increase cost only 6-1/2 percent. In the case of a 16 knot tanker of 40,000 deadweight, these figures would be 12-1/2 percent and 16-1/2 percent, respectively.

2) It costs more to increase the speed of a large vessel by a certain amount than to increase the speed of a smaller vessel by the same amount. This is rather obvious from the fan-like shape of the speed curves.

3) An increase in deadweight of a certain amount is more expensive in a high speed vessel than in a slow speed vessel. This is shown by the steeper contours found in the higher speeds.

4) For a given speed, the cost per ton of deadweight decreases as the deadweight increases.

3. Duplication

Figure 22 presents a method of estimating the savings possible through multiple-ship contracts. It is a mean line drawn through data points from bids on four different classes of tankers. Reference 20 discusses in detail the various factors causing reductions in cost through duplication.

4. Foreign Costs

Estimates of foreign shipyard construction costs range from 60 percent to 70 percent of American East Coast shipyard costs.

5. Distribution of Costs

Figure 23 shows the approximate distribution of costs for 40,000 ton displacement tankers of various speeds. Note the strong influence of machinery costs as speeds increase.

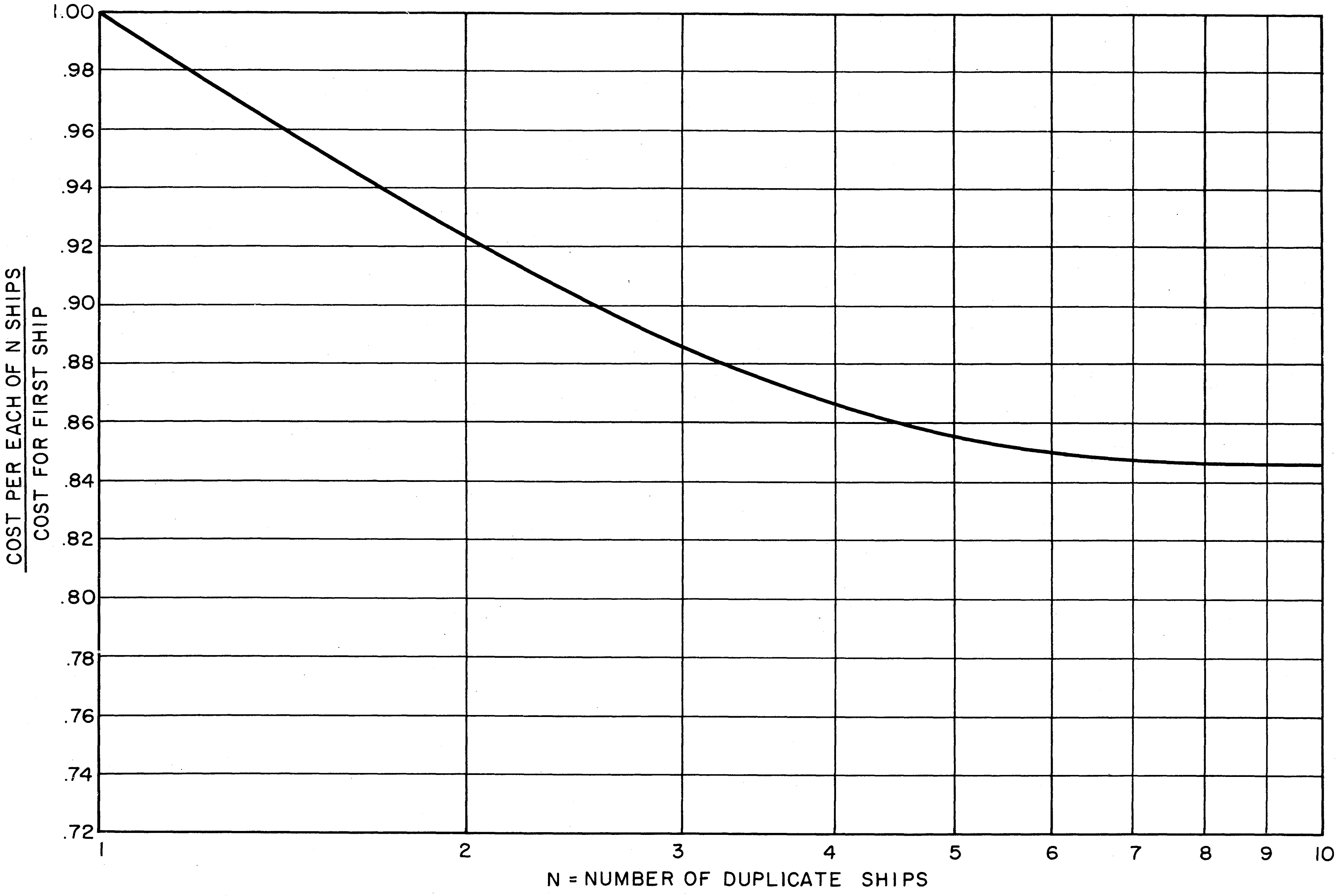


Figure 22. Effect of Duplication on Construction Costs of Tankers.

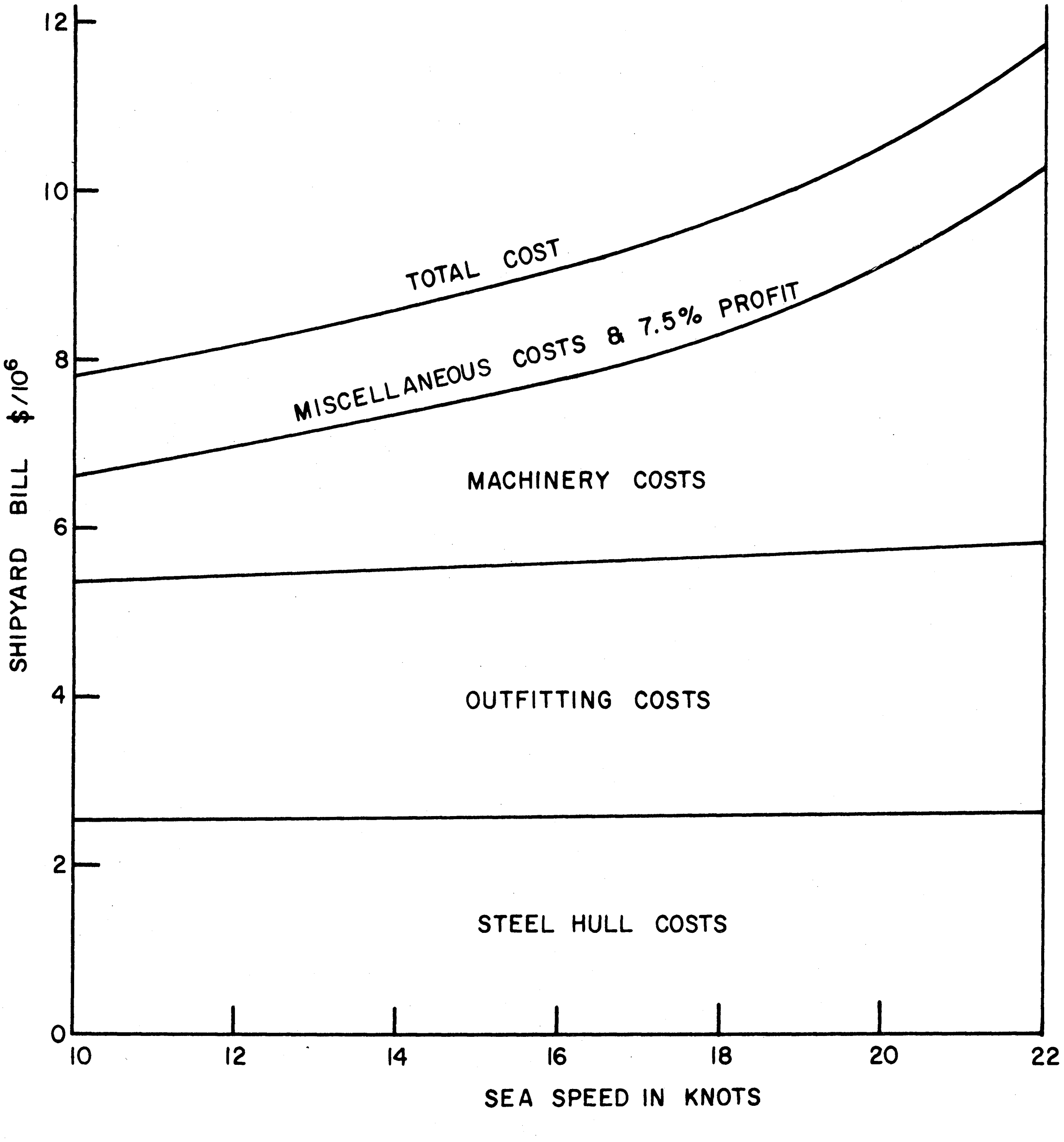


Figure 23. Distribution of Construction Costs. 40,000 Ton Displacement (about 30,000 Tons DWT) Tankers for Speeds from 10 to 21 Knots.

E. ECONOMIC CRITERIA

1. Introduction

Before making a cost study an engineer must settle in his own mind exactly what he is looking for. His aim of course is to set up an economic analysis that will allow a fair comparison of the "money earning" capacities of various possible designs. "Money earning" is put in quotation marks to call attention to the fact that there exists widespread confusion and disagreement as to the proper criterion for comparing the probable success of two or more proposed designs. It is hoped that the following paragraphs will help point the way to clearer thinking in respect to engineering economy in ship design.

First of all, a tanker's usefulness to humanity is principally in the movement of petroleum, a highly desirable commodity in our world today. Employment of crew members and gainful work for shipyards are of secondary importance. But how can we measure how well a tanker fulfills her main purpose? In a socialistic economy, or in the case of a navy oiler, there is no easy answer. In our free enterprise system however, society expresses its wants and desires through its purchases and the almighty dollar is the best measuring stick of social usefulness. From this it follows that one factor to be considered is the expected income to be earned during the life of the ship.

Income by itself is rather meaningless and must be balanced against operating costs, the difference each year, the annual profit or loss, being an indication of the vessel's net good to society.

The final factor, namely the initial investment, must also be considered so as to indicate whether the risk of investment is justified by the net gain. If two proposed ships will earn equal net profits, the cheaper of the two is obviously the more desirable investment, all other things being equal. Once again social usefulness plays a leading role since society's desires (as reflected in income) dictate to the prospective investor whether he should gamble his money on a ship, in a uranium mine, or possibly put it in the bank at 2-1/2 percent interest. Unless the ship investment can show a prospective rate of return considerably in excess of the 2-1/2 percent "no risk" bank investment, the chances are that the money would either be banked or put into some other venture where the needs of society would result in a greater return on the investment.

2. Recommended Method: Capital Recovery Factor

All of the above factors can be conveniently brought together into the following expression, which appears to this writer to be the best available criterion for engineering economy studies:

$$\text{C.R.F. (Capital Recovery Factor)} = \frac{\text{average annual profit}}{\text{initial investment}}$$

The reciprocal of the capital recovery factor is of course the "pay-off period" or "years to return investment".

Please note that the annual profit, as here defined, is simply the annual income minus the summation of the operating costs (crew wages, fuel, repairs, etc.) without consideration of depreciation or interest although this is not necessarily the commonly understood meaning of the term. A brief discussion of the place of these items follows.

3. Depreciation

The word "depreciation" has at least four distinct meanings (see Ref. 21). The one most common to cost studies is the accounting concept. An accountant looks upon the building cost of a ship as merely a prepaid operating expense which must be systematically apportioned among the years of the vessel's life. Based on a predicted life of twenty years, the accountant will divide the first cost of the ship (with or without a small credit for scrap value) by twenty and include the resulting figure among the annual operating costs. This is generally a bookkeeping trick, pure and simple, since the establishment of a sinking fund for purposes of replacing an asset is seldom carried out. It should also be noted that the accountant deals only in terms of actual dollar cost and ignores changing values of the dollar.

Depreciation charges definitely belong in cost studies aimed at determining operating costs per ton of cargo or profit per year. In studies such as the one advocated here (capital recovery factor), the inclusion of depreciation as an operating expense wrongfully complicates the issue by double introduction of the influence of first cost into the calculation. This is perhaps easier to see in the "years to pay-off" approach. If depreciation is deducted from the annual profit, then the calculation of the pay-off period will yield a figure which says, in effect, that such and such a ship should repay the investment in (say) eleven years with a margin of 11/20 of the first cost left over.

4. Interest

"Interest" is a fact of life simply because most of us would rather have our hands on a dollar now than a year from now. This time value of money is often overlooked in ship economy studies. The reasons for such an oversight are two-fold:

1) All ships are assumed (usually) to have the same expected 20 year life so that the time element is constant, making interest less important than in situations where major differences exist.

2) Accounting records form the most fertile source of information for engineering cost studies. Most large organizations operate on money obtained by the sale of stocks where there is no fixed rate of interest. Unless the company actually has paid specific interest charges (such as on a bank loan) the accountant will not include interest charges among operating expenses.

In virtually every cost comparison the required investment will be a variable. In addition to differences in repayment of first cost, there must also be differences in return owing to the time value of money. It is axiomatic that the larger investment must be justified by a larger profit. This, of course, means nothing to the accountant. His job is to record what has already actually happened to the money. He is in no way concerned with the engineer's problem of making a rational choice between a number of possible designs.

(Reference 21 is highly recommended to anyone interested in the proper place of depreciation and interest in cost studies.)

As in the case of depreciation, interest charges definitely belong in cost studies which are aimed at determining minimum operating costs per ton of cargo or maximum profit per year. As shown in Table III, this makes a material difference in results. Going one step further, it may be stated that interest charges belong in every cost study involving a lapse of time between investment and repayment. Omission is justifiable, however, in the use of the capital recovery factor or pay-off period methods. As shown in Table III, the omission of interest does not affect the resulting prediction of optimum design. This is simply explained by the fact that the point of highest rate of return, before interest, remains the highest point after interest.

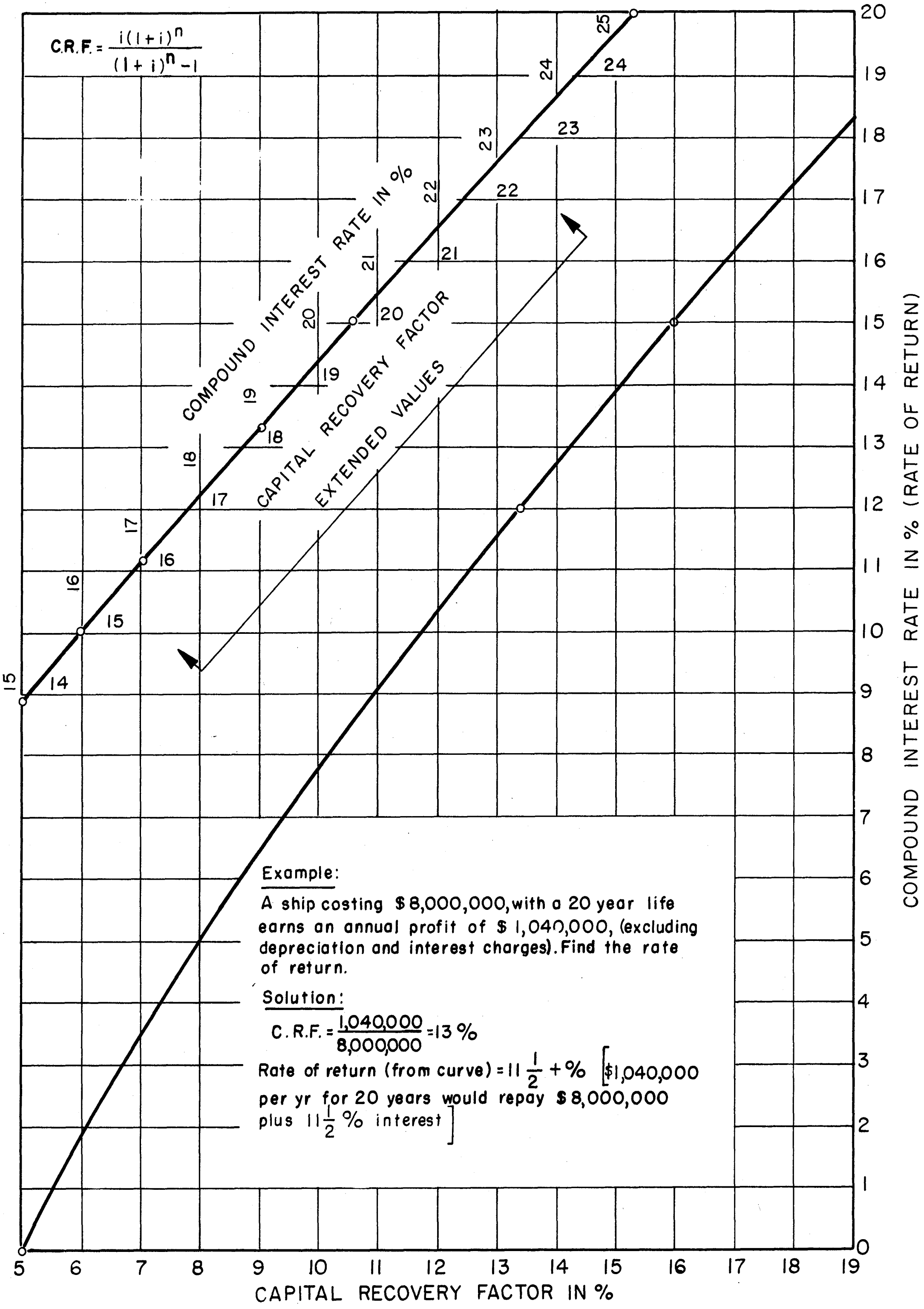
If one cares to make interest the unknown quantity to be solved by economic studies, Figure 24 relates the rate of return on investment to the capital recovery factor. Handling interest in this manner seems to be preferable to including it as a fixed percentage among the operating costs. There is, of course, a difference in the exact meaning of the word "interest" in each case.

5. Amortization

The accountant's concept of depreciation, previously discussed, is perhaps best described as "capital recovery without interest". If we recognize the reality of the time value of money, we can see that the logical approach would be to combine depreciation and interest charges into a single series of annual payments. Such uniform payments are known as "amortization". This method is universally familiar since it is used in home mortgage payments and installment buying in general. Under this plan, the earlier payments may be predominantly interest charges with small residual reductions in debt. As the debt is whittled down the interest charges gradually dwindle with a corresponding increase in the rate of debt reduction.

6. Depreciation plus Interest

While the amortization approach really makes sense, it is not often used in ship cost studies. The reason for this is that management, used to thinking in accountants' terms, wants to see depreciation set out as a separate item in the cost analysis. If the engineer is discreet, he will



Example:

A ship costing $8,000,000, with a 20 year life earns an annual profit of $1,040,000, (excluding depreciation and interest charges). Find the rate of return.

Solution:

$$C.R.F. = \frac{1,040,000}{8,000,000} = 13\,\%$$

Rate of return (from curve) = $11\frac{1}{2}$ +% [$1,040,000 per yr for 20 years would repay $8,000,000 plus $11\frac{1}{2}$ % interest]

Figure 24. Relationship Between Capital Recovery Factor and Rate of Return on Investment Based on Twenty Year Life.

go along with this and will add interest as a separate item even though this method is somewhat inaccurate. The inaccuracy can be minimized by the use of an average interest figure arrived at as follows:

$$\text{Annual interest charge} = \frac{Pi}{2} \left(\frac{n + 1}{n}\right)$$

where

P = first cost of ship

i = desired rate of interest

n = anticipated years in life of ship

If the salvage value at the end of n years is appreciable, the formula becomes:

$$\text{Annual interest charge} = (P-L) \left(\frac{i}{2}\right) \left(\frac{n + 1}{n}\right) + Li$$

where

L = anticipated salvage value

Interest rates currently used by ship operators run between 4 percent and 5 percent. With the usual twenty year life, an annual interest charge of 3 percent of the first cost seems a good average figure. Scrap values can be taken somewhere between 1-1/2 percent and 2 percent of first cost. Many naval architects prefer to ignore scrap value. Its omission simplifies the calculation and helps offset the inevitably overlooked expense items.

Lest there be any misunderstanding, let it be reiterated that the capital recovery approach to economy studies, as used in this report, does not involve depreciation charges and generally ignores interest charges.

7. Taxes

Present United States corporate taxes amount to a seizure of 52 percent of the annual net profit (with allowances for depreciation). Foreign flag operations are generally considerably less taxed and registry inevitably gravitates towards the country with the lowest tax rate.

Taxes are specifically omitted from this study because they will have only a small influence on choice of optimum design and are subject to frequent and arbitrary changes.

8. Cost Study Methods

The writer has run across no less than eight basically different criteria used by various individuals to gauge the relative merits of two or more proposed ships. These are listed below, together with one or two comments in each case:

1) Minimum Operating Cost per Ton of Cargo

This is by far the most common approach in the marine field today. Its use consistently results in a choice of speed lower than that which would return the highest rate on the investment. A faster vessel will carry enough more oil per year (at a slightly higher cost per ton) to exceed the annual profit of the slower vessel. The influence of cargo rates is of course lost in the cost per ton calculation.

In the usual case where the tanker company is a subsidiary of a petroleum corporation, there is a natural tendency to go along on the minimum cost per ton basis. This is rationalized along the lines that: "We're not out to make a profit but to carry oil for our parent company. The cheaper we can do this, the better." This reasoning neglects the corporation's point of view which recognizes that there are really two choices at hand:

a) Pay independent operators to haul oil at the current charter rates, allowing investment of capital in expansion of, say, refineries with an expected rate of return of about 15 percent.

b) Invest in a ship. This will be the wiser choice only if the money saved by so doing amounts to about 15 percent of the capital investment. If the prospective savings are less than 15 percent, the net corporation earnings would be greater if they were to pay an independent operator to move their oil.

Minimum cost per ton will give an accurate picture of relative values only in the rare case where the various possible designs have identical first costs and fixed incomes.

2) Maximum Profit per Year

It was pointed out in the preceding paragraphs that increasing the speed over that appropriate for minimum costs per ton will result in greater total profits. It must, however, be recognized that higher speeds require greater investments. The maximum profit approach goes beyond the point of diminishing returns on the investment and leads inevitably to excessive speeds. This is shown graphically in <u>Figure 37</u>.

Anticipated cargo rates will affect the point of maximum profit, increased rates resulting in higher optimum speeds in an almost straight line relationship.

After the design decisions are made and the ship is built, invested cost is no longer a variable. Maximum profit per year then becomes the best method of approach in choosing optimum speeds for various fluctuating conditions of wages, fuel costs and cargo rates. Obviously, once the investment is fixed, the speed giving maximum annual profit will also be the speed yielding the maximum capital recovery factor. It is also quite immaterial whether interest and depreciation charges are included since these remain the same regardless of the speed one chooses to operate any given ship. The same is largely true of wages, subsistence, repair, overhead, insurance and supplies.

3) Maximum Capital Recovery Factor

This is the method advocated in this paper for reasons previously given.

$$\text{C.R.F.} = \frac{\text{average annual profit}}{\text{initial investment}}$$

The reciprocal of C.R F., the years to return investment, is perhaps easier to visualize:

$$\text{Years to return investment} = \frac{\text{initial investment}}{\text{average annual profit}}$$

Depreciation charges should not be included in these calculations. Interest may or may not be included, this having absolutely no effect on the choice of optimum design. Where numerical values of C.R.F. or years to pay off are presented, these should specify whether or not interest has been charged. If interest has not been charged, Figure 24 may be used to determine the true rate of return.

As in the previous method, anticipated cargo rates will affect the choice of optimum design. The effect is only about half as pronounced, however. See Table III.

4) Return on Extra Investment

If the ship speed yielding maximum return (C.R.F.) is exceeded, the extra investment required will yield a constantly decreasing rate of return. Determination of the point where this falling rate reaches some arbitrary figure, say 10 percent, has been advocated as a design criterion. There may be merit to this approach where only one or two ships are proposed. The argument still arises, however, that the extra cost might better be invested elsewhere.

5) Minimum Required Cargo Rate to Return Investment in N Years

A design chosen by this method will not be as efficient as one chosen by the maximum C.R.F. method unless the minimum cargo rate so obtained happens to coincide with the actual average cargo rate over the life of the ship.

6) Maximum "Efficiency"

Efficiency as here defined is annual gross income divided by annual expenditures, including depreciation and interest charges. Like other systems requiring depreciation charges, inaccuracy is bound to occur unless the true pay-off period happens to coincide with the twenty year life of the ship.

Use of this method without depreciation and interest removes all reference to first cost and makes the ratio altogether meaningless in economy studies.

7) Minimum Construction Cost to Move X Tons Y miles per Year

Use of this system results in ships of excessive speed since this method ignores the large fuel costs associated with high speeds.

8) Break-Even at Cargo Rate 20 Percent Below USMC Flat Rate

A vessel chosen by this method would be the best investment only under the most unusual combination of circumstances.

9. Summary of Comments on Economic Criteria

If the reader will agree that rate of capital recovery is the proper measure of probable success, then Table III below shows that all seven other criteria are wrong. This is specifically pointed out because there may be those who assume, for instance, that the ship with the lowest operating cost per ton is also the one with the highest profit per year and automatically the best money-earner.

10. Comparison of Optimum Design Speeds Based on Various Criteria

Table III was prepared to demonstrate the wrong answers obtainable by the use of various cost study methods. The eight criteria previously discussed were applied to a uniform series of hypothetical tankers with installed power (hence speed) as the basic variable. In most cases, variations in the basic methods were introduced so that the total number of methods reached eighteen. Three different cargo rates were applied giving a grand total of 54 combinations.

These cost studies applied to 40,000 deadweight tankers operating between the Persian Gulf and the East Coast of the United States via the Suez Canal.

TABLE III. COMPARISON OF OPTIMUM SPEEDS PREDICTED BY VARIOUS CRITERIA

Method	Incl. Depr.	Incl. Int.	Calculated Optimum Speeds					
			USMC V_k	-20% Error*	USMC V_k	Flat Rate Error*	USMC V_k	-20% Error*
Min. operating cost per ton	yes	no	13.25	-1.35	13.25	-1.90	13.25	-2.40
ditto	yes	yes	14.05	-0.55	14.05	-1.10	14.05	-1.60
Max. profit per year	yes	no	15.32	+0.72	16.28	+1.13	17.25	+1.60
ditto	yes	yes	15.01	+0.41	16.00	+0.85	17.00	+1.35
Max. capital recovery factor	no	no	14.60	0	15.15	0	15.65	0
ditto	no	yes	14.60	0	15.15	0	15.65	0
Return on extra investment	yes	no	13.04	-1.56	14.48	-0.67	15.92	+0.27
reaches 15%	no	no	13.82	-0.78	15.07	-0.08	16.32	+0.67
reaches 10%	yes	no	13.88	-0.72	15.10	-0.05	16.33	+0.68
	no	no	14.53	-0.07	15.65	+0.50	16.77	+1.12
reaches 5%	yes	no	14.57	-0.03	15.68	+0.53	16.78	+1.13
	no	no	15.19	+0.59	16.22	+1.07	17.26	+1.61
Min. required revenue per ton to repay investment in 8 yrs.	no	no	14.75	+0.15	14.75	-0.40	14.75	-0.90
10 yrs.	no	no	14.70	+0.10	14.70	-0.45	14.70	-0.95
Max. "efficiency"	yes	yes	14.05	-0.55	14.10	-1.05	14.05	-1.60
	no	no	optimum speed falls below range investigated					
Min. construction cost to move 10^6 tons per year	no	no	17.37	+2.77	17.37	+2.22	17.37	+1.72
Break-even at USMC - 20%	yes	yes	All lost money at USMC - 20%					

*Error is measured as difference in speed between that arrived at by various methods and that yielding maximum return on investment (C.R.F.).

11. Intangible Factors

No matter what system one may use in studies of this nature, there will always be a number of influential factors which are irreducible to dollar values. A cost study, to be really complete, should contain mention of these items. Some typical examples might be:

1) Publicity value of exceptional size or speed.

2) Likelihood of resale at some future date.

3) Conformity with existing fleet.

4) Cargo capacity suitable to shoreside facilities.

5) Relative risk.

12. Accuracy in Economy Studies

Since the engineer may be looking for fairly small differences between two or more alternatives, he is justified in carrying his predicted costs to several significant figures. It is of course important that he not take his resulting quantitative answers too seriously. Certainly, no one can predict with accuracy how the cost structure will change over the twenty year life of the vessel. Labor disturbances, accidents, breakdowns; these are all apparently part of the normal circumstances under which a vessel must operate. Predicted earnings are invariably based on the rosy view that none of these disruptive influences will occur. Any quantitative presentation of results should be plainly labeled: "Potential Earning Capacity".

13. Influence of Inflation

The continuing inflationary trend of the past two decades brings the possible influence of inflation into the picture. There is a tendency to assume an indefinite continuation of this development owing to government monetary policies, labor demands, etc. On this basis, there is a natural inclination to slant engineering decisions toward faster, more expensive ships on the theory that tomorrow's cheaper dollar will make it easy to pay today's debt. Such an attitude seems wrong to this writer, at least for long-term investments. When the dollar goes down in value, the general cost of living goes up, crew wages and fuel costs go up and presumably the cargo rates go up no more than a commensurate amount. It is true that the initial investment stays the same in dollar cost but it does not stay the same in value. This is brought home quite strongly to the shipowner who has gone through the past years setting aside only 5 percent of first cost each year towards replacement of his ship. At the end of twenty years of inflation this system supplies him with the cash to purchase only half a ship. This trap is set by law since corporations are not allowed to recognize inflation in their depreciation charges. There is reason to argue, then, that cost studies can ignore inflation on the presumption that relative values will remain more or less the same.

14. Changing Relative Costs

Figure 25 shows how costs of ship construction, fuel oil and seamen's wages have fluctuated since 1940. These figures are corrected for changing dollar values. It is obvious that seamen's wages have more than doubled in real cost, whereas the other major items have remained within 15 percent of their 1940 value. If the engineer has reason to believe these trends will continue, he can take them into account by basing his costs on what he predicts will be average figures over the twenty year life of his ship. In this case, higher relative wages justify higher speeds. Data for Figure 23 came from References 22 through 25 and from the United States Maritime Administration.

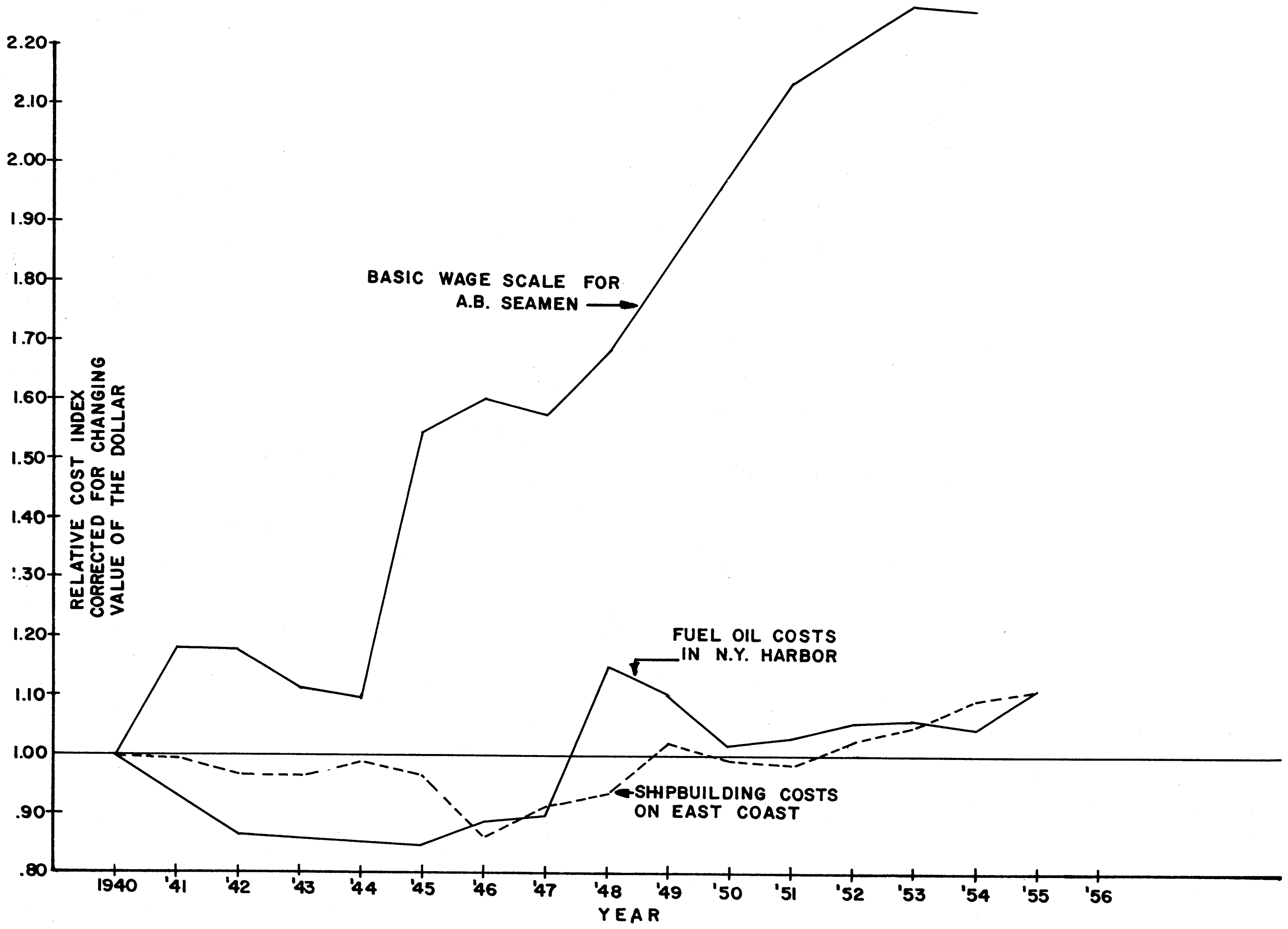


Figure 25. Fluctuation of Factors Affecting Ship Operating Costs Since 1940.

F. OPERATING COST ANALYSIS

1. Introduction

As in the weight and construction cost analyses, it was felt that most of the components of operating economics could be related more or less directly to the displacement or the horsepower. Other variables entered the picture, however, to such an extent that no attempt at any final family of curves was felt to be practicable. These additional variable factors included:

American flag vs. foreign flag operation.
American vs. foreign construction costs.
Various trade routes.
Various cargo rates.
Various fuel oil costs.
Bunkering arrangements.

All studies and figures in this paper are confined to tankers in the crude oil trade.

Some uses of the operating cost relationships presented in this section are illustrated by a number of studies, the results of which are presented in Section G.

With the generous cooperation of nine different tanker operating companies, the author was able to compile operating cost figures which are believed to come fairly close to industry-wide averages. There was, as expected, wide divergences of opinion on certain elements of cost, but an honest effort has been made to reconcile these differences, particularly with an eye towards the establishment of correct trends.

2. Method for Analysis of Operating Costs

There follows a series of paragraphs explaining the method set up for the determination of operating economics. The goal of this system is to arrive at the relative potential capital recovery factors of a series of tankers with any combination of the variable factors outlined above. References 26 and 27 contain detailed information on the make-up of the various operating cost categories.

1) Primary Variables

Since engineering cost studies are principally useful for comparing two or more alternatives, it follows that any such study will set up a series of hypothetical designs with a systematic variation in a single basic factor. In ship operating analyses, the most common variables are either speed or deadweight although any other single factor may be used instead. Speed and deadweight are wedded to displacement and shaft horsepower as shown in Section C so that any one of these four factors may be used with equal facility.

Numerical values taken from some of the curves are apt to be a bit crude. Since we are looking for small differences between large numbers it is necessary to plot a certain number of cross curves to ensure a fair relationship. For this reason it is strongly recommended that each study cover five or preferably six arbitrary values of the basic variable. As one weather beaten old naval architect says: "Three points *can't* give you a curve, four *won't*, five *may*!"

2) Sea Speed

The nominal sea speed relationships worked out in Section C are based on summer loadline displacements. Ballast speeds are usually six to ten percent higher. This difference is generally neglected, the potential gain helping to offset the inevitable unexpected delays in operation as well as the possible loss in cargo deadweight during the winter season.

3) Shaft Horsepower

It is assumed that the full normal SHP is used as much as possible while at sea.

4) Deadweight and Displacement

The relationship between deadweight and displacement for various SHP's (and speeds) is assumed to be that worked out in Section C.

5) Sea Distances

The following approximate round trip sea distances represent typical tanker trade routes:

Aruba to Philadelphia:	3,500 sea miles
Singapore to San Francisco:	15,000 sea miles
Pakning to Batangas:	3,000 sea miles
Sidon to Southampton:	6,500 sea miles
Ras Tanura to Kurnell:	14,500 sea miles
Sidon to Pernis:	6,800 sea miles
Sidon to Savona:	3,000 sea miles
Pakning to Richmond:	15,000 sea miles
Ras Tanura to Yokohama:	13,200 sea miles
Ras Tanura to Bec D'Ambres:	12,000 sea miles
Sidon to Bec D'Ambres:	6,100 sea miles
Kuwait to Philadelphia via Suez:	17,000 sea miles
Kuwait to Philadelphia via Cape of Good Hope	24,000 sea miles

Abadan to N. Y., via Suez: 17,500 sea miles
Abadan to N. Y., via Cape of Good Hope: 25,200 sea miles
Abadan to Southampton via Suez: 13,000 sea miles
Abadan to Southampton via Cape of Good Hope: 23,200 sea miles
Abadan to Marseilles via Suez: 10,000 sea miles
Abadan to Marseilles via Cape of Good Hope: 23,000 sea miles
Bombay to Southampton via Suez: 12,200 sea miles
Bombay to Southampton via Cape of Good Hope: 22,500 sea miles
New Orleans to New York: 3,400 sea miles
Galveston to New York: 3,800 sea miles

6) Port Time

Tanker operators have found it desirable to let their vessels remain in "home" port somewhat longer than is strictly necessary. This is principally a matter of crew morale and greater port lay-overs are appropriate for longer voyages. Figure 26 shows the port days per round trip used in this study.

7) Canal Time

Two days per round trip is assumed for Suez Canal passage, where applicable. This figure is high enough to include a normal amount of delay time.

8) Operating Days per Year

Estimates by eight different tanker operators as to average operating days per year over the lifetime of the ship varied from 329 to 359. The average of the figures given was 342.

9) Variable Weights: General Comments

The calculation of cargo deadweight involves the subtraction of the variable deadweight items from the total deadweight. The complication here is that the restrictions on draft are not always set at the loading port. Cognizance must therefore be taken of the changes in draft which result from the consumption of fuel oil and stores between the loading port and the place in which draft is restricted.

As an example, a 40,000 deadweight tanker taking on cargo at Abadan can load to 35 feet 6 inches and arrive at Suez with a draft of exactly 35 feet. This same vessel will not have to worry about draft restrictions entering the winter zone in the North Atlantic because consumption of fuel and stores will give her more than ample winter freeboard. Vessels rounding the Cape of Good Hope may or may not consume sufficient variable weights to bring them up to their winter marks.

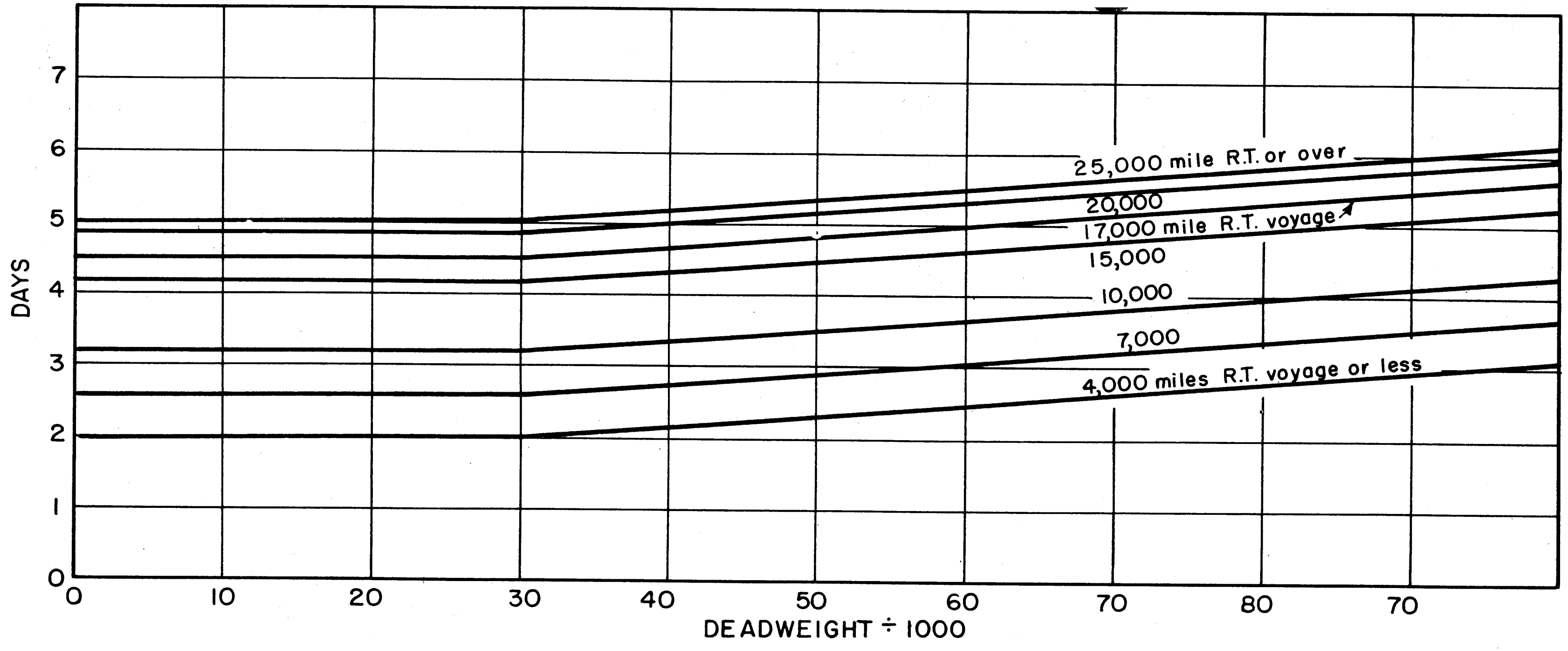


Figure 26. Tankers Port Days Per Round Trip.

In the case of nuclear powered ships, the variable weights will be relatively small and corrections of this nature will assume a different aspect.

Most crude oil tankers bunker for a round trip at the discharge port, this being where Bunker C is generally cheapest. Where round-trip bunkers are taken on at the loading port, a corresponding reduction must be made in the cargo deadweight.

10) Fuel Oil at Sea

The following all-purpose fuel consumption figures seem appropriate for modern steam turbine driven tankers. These assume some loss in efficiency over the life of the ship:

SHP	Lbs/SHP-Hr	Tons/Day	Bbls/Day
3,000	0.6063	19.49	129.2
5,000	0.5877	31.48	208.7
10,000	0.5653	60.57	401.6
15,000	0.5527	88.82	588.9
20,000	0.5446	116.70	773.7
25,000	0.5388	144.32	956.8
30,000	0.5346	171.83	1139.2

For convenience of interpolation, Figure 27 shows the specific fuel d tons per day for various SHP's.

11) Reserve Fuel Oil

Normal caution dictates the carriage of a certain amount of reserve fuel oil in case of emergency. An average figure may be arrived at, in terms of days' supply, as follows:

Days' reserve = 1 + 1/5 sea days, one way.

Figure 28 shows this reserve amount worked out as a factor to be applied to the normal sea fuel requirements.

12) Miscellaneous Fuel Oil Requirements

Figure 29 may be used to approximate the fuel required for:

port operations
Suez Canal passage
idle status requirements

The latter item covers oil used during repair period.

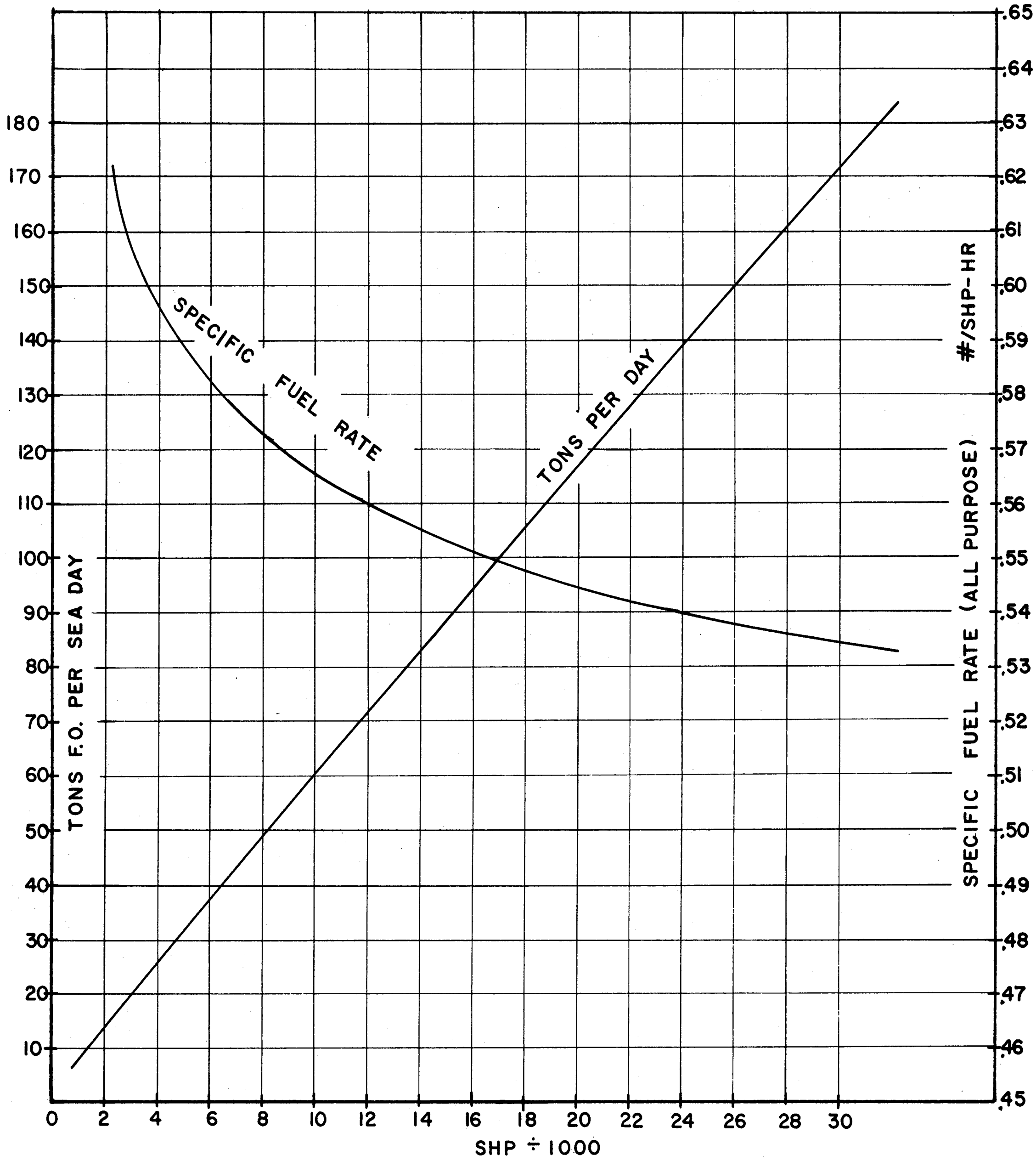


Figure 27. Steam Turbine Tankers All-Purpose Fuel Consumption Based on Expected Average Plant Efficiency. Heat Value Over 20 Year Life and Bunker C Heat Value.

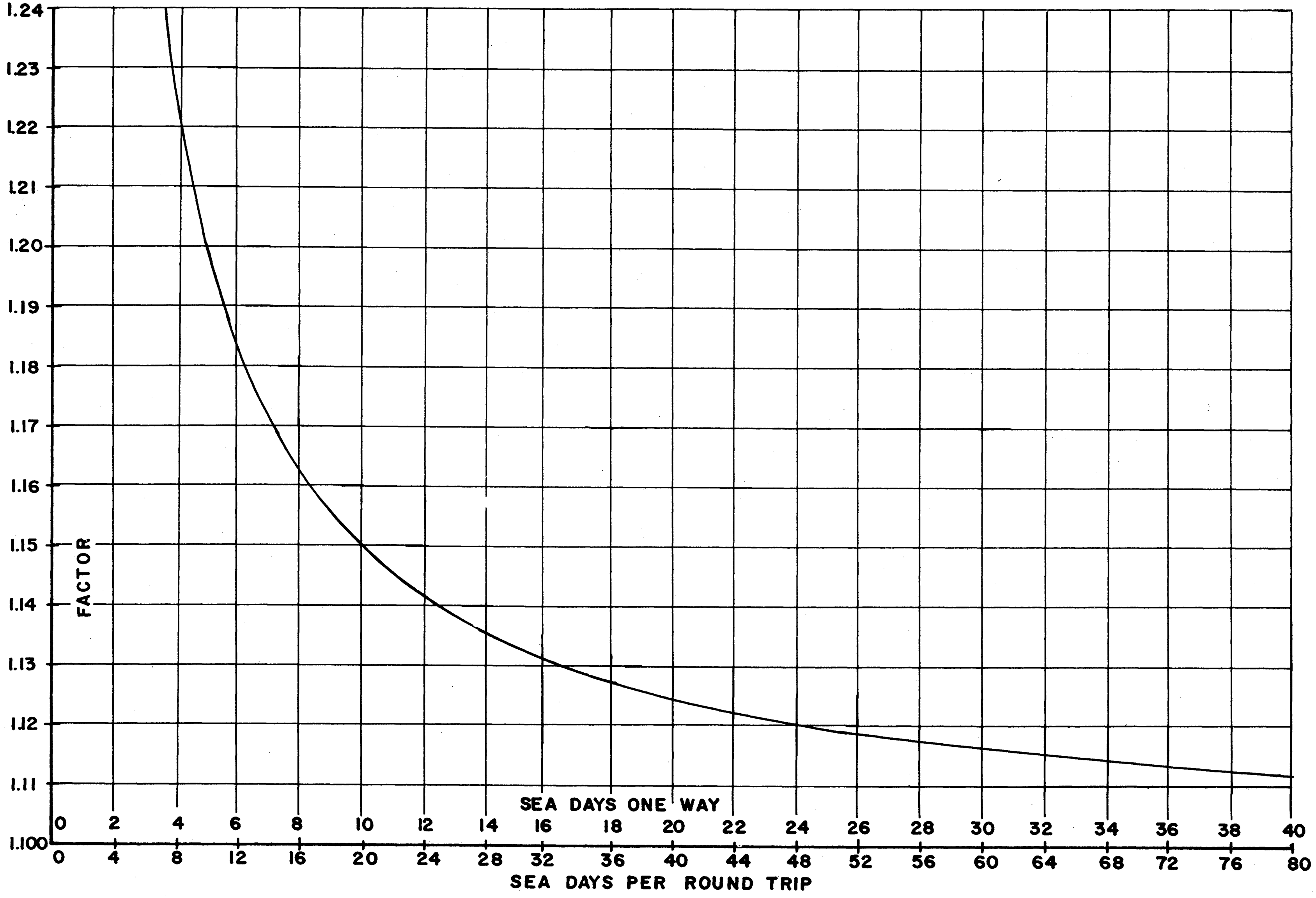


Figure 28. Fuel Oil Reserve Factors Based on Days Reserve Fuel Oil.

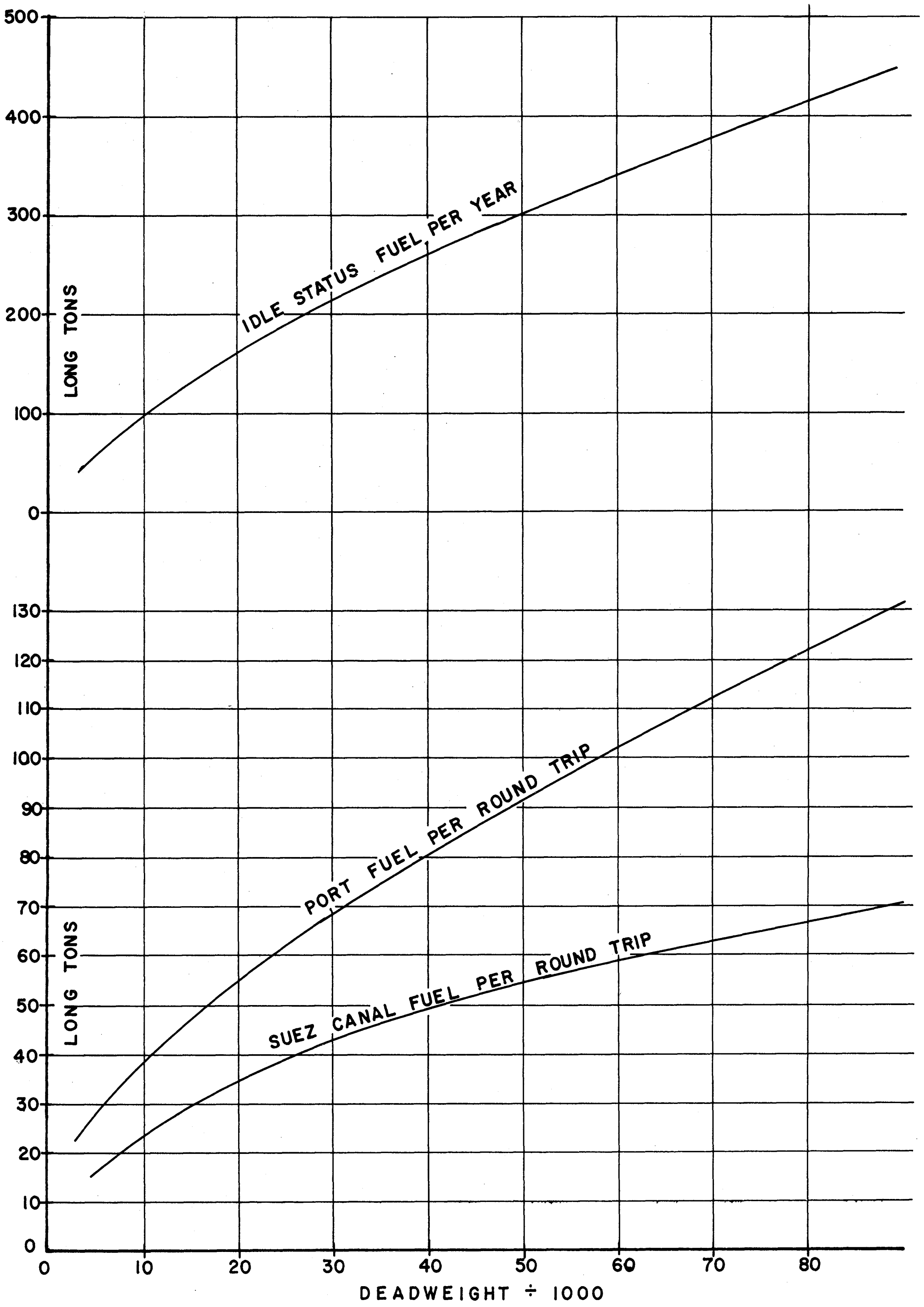


Figure 29. Tankers Miscellaneous Fuel Oil Requirements (Steam Turbine).

13) Miscellaneous Deadweight Items

Figure 30 may be used to estimate the total weight of such items as:

make-up feedwater
washing water
drinking water
stores and provisions
lube oil
crew and effects.

Evaporators are assumed to be installed.

The principal item is that of lube oil and a plotting base of SHP was felt to be logical. The effects of variations in speed and in deadweight were investigated and found to be small enough to permit omission from a calculation of this nature.

14) Fuel Oil Costs

Recent figures on fuel oil costs are:

\$2.80 per barrel north of Cape Hatteras,
\$2.20 per barrel in United States Gulf ports.

Variations from \$2 to \$3 per barrel were investigated and \$2.50 per barrel was a figure used for averages in the cost studies shown in Section G.

15) Port and Canal Fees

a) Port charges showed wide variations from point to point. A reasonable general estimate may be made as follows:

$$\text{Port charges per round trip} = \$1000 + \frac{\text{Deadweight}}{10}$$

b) Suez Canal fees are based on Suez Canal tonnage as follows:

Vessel with cargo: 34 piasters (\$0.98) per net ton

Vessel in ballast: 15-1/2 piasters (\$0.45) per net ton

In addition, there is a flat fee of about \$490 per round trip.

In order to simplify estimates, the above factors were related to the deadweight and the following approximation resulted:

$$\text{Suez Canal fees per round trip} = \$500 + \$0.75\ \text{Deadweight}$$
(Loaded one way, return in ballast)

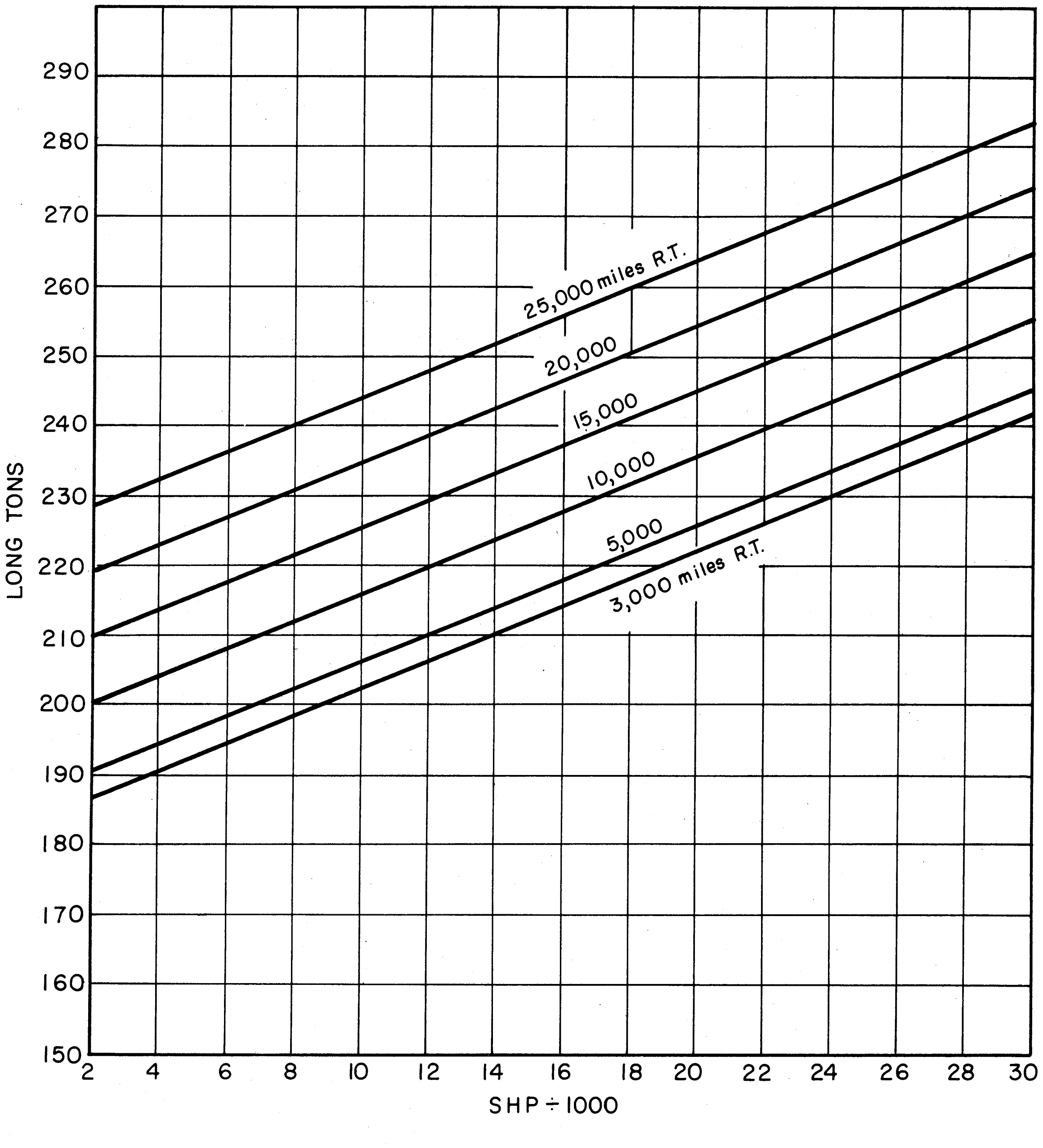


Figure 30. Tankers Approximate Weight of Miscellaneous Deadweight Items

16) Crew Wages

An analysis of crew costs was made on the following assumptions:

a) Deck crew wages vary with displacement
b) Engine crew wages vary with SHP
c) Galley crew wages amount to 14 percent subtotal and a and b.

Unfortunately, very few of the companies furnishing cost data were able to provide a breakdown between departments. There were, in addition, the usual differences caused by variations in crew size for identical ships, wage scales and extent of fringe benefits. Some operators prefer a relatively small maintenance crew, preferring to accept a larger annual shipyard repair bill. Taking all of the above into account, the final estimate of crew wages shown in <u>Figure 31</u> can make no claim to quantitative accuracy. The general trends are felt to be reasonably correct, however.

For foreign flag operations, a straight percentage of American flag crew costs was found to be totally inaccurate. American flag tankers of moderate size have very large crews and large increases in size can be effected without commensurate increases in crew. This is not true in the case of foreign vessels, however, so an independent study of crew wages was made for foreign flag operation. European rather than Oriental crews were assumed. <u>Figure 32</u> shows the results of this study.

17) Overhead and Miscellaneous

Overhead and miscellaneous costs show considerable variation between companies. An average figure may be approximated as follows:

$$\text{Annual overhead and miscellaneous costs} = \$44{,}500 + \$15\ \frac{\text{Deadweight}}{1000}$$

The above approximation is suitable for foreign as well as United States flag operations.

18) Maintenance and Repair Costs

Figures for annual costs of maintenance and repair must reflect average costs during the life of the ship.

A study was made of these costs broken down between hull and machinery. Results are presented in <u>Figure 33</u>.

The remarks regarding accuracy in the notes under paragraph 16, above, apply here also.

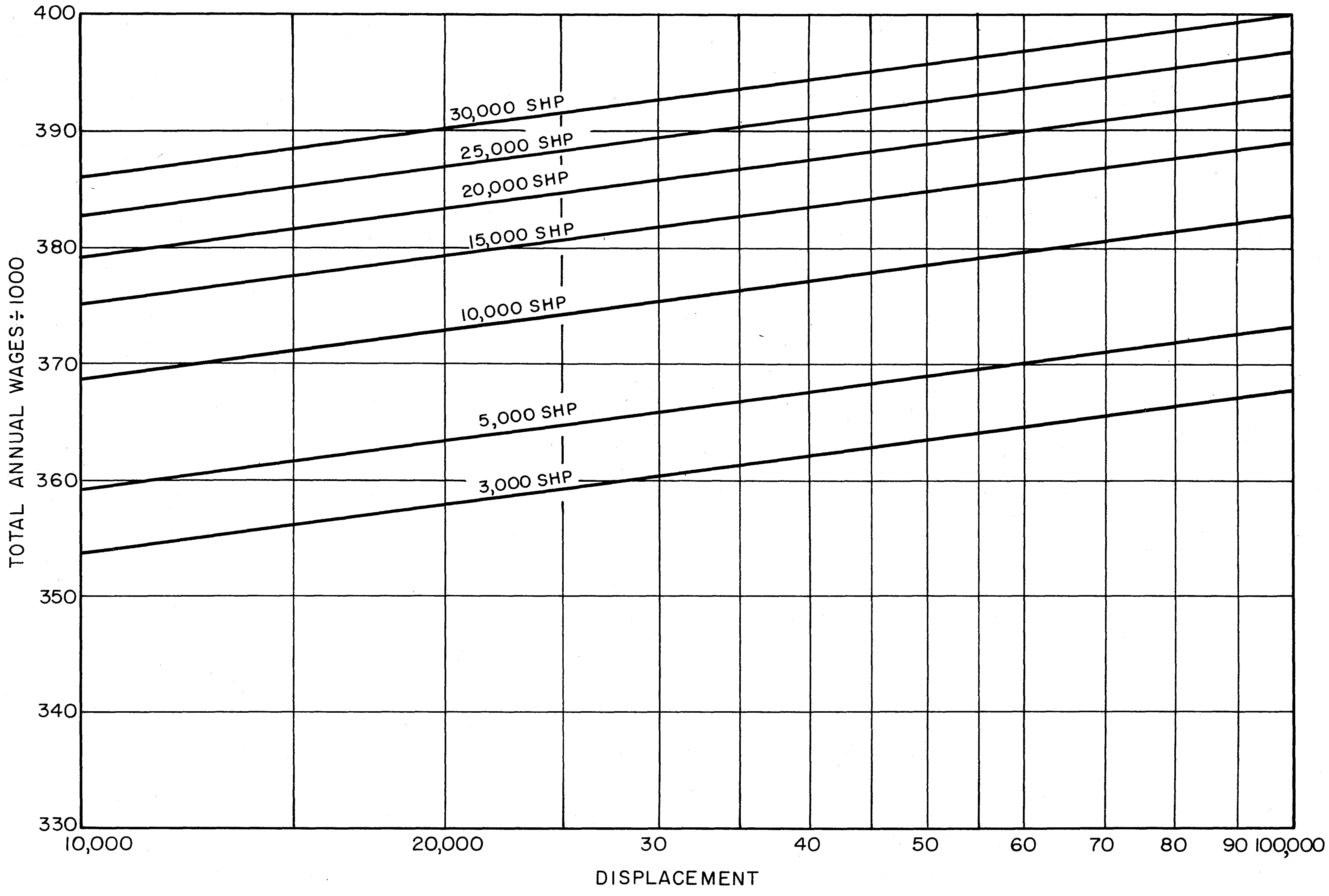


Figure 31. Tankers Total Wages (American Flag).

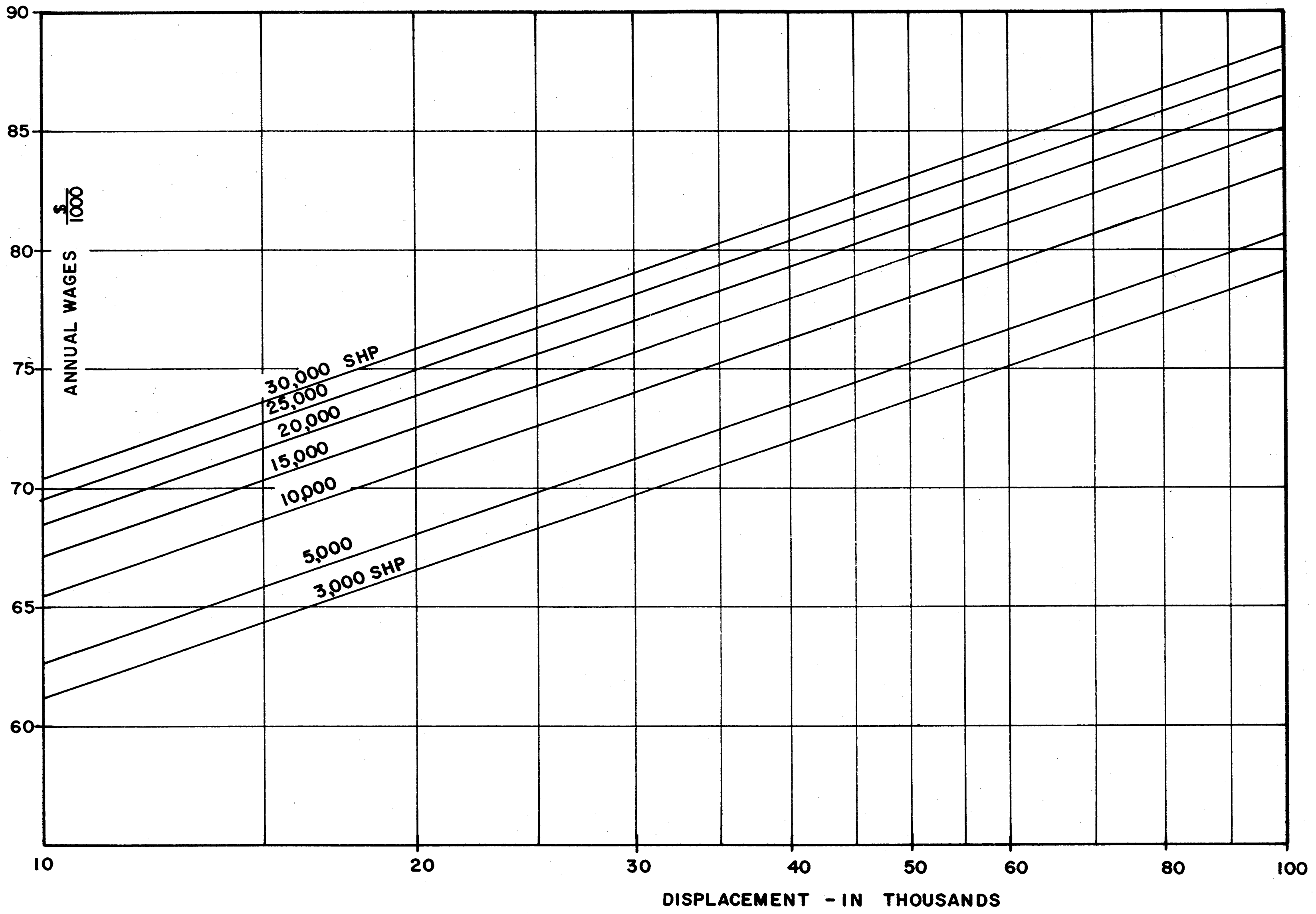


Figure 32. Tankers Total Wages (Foreign Crew).

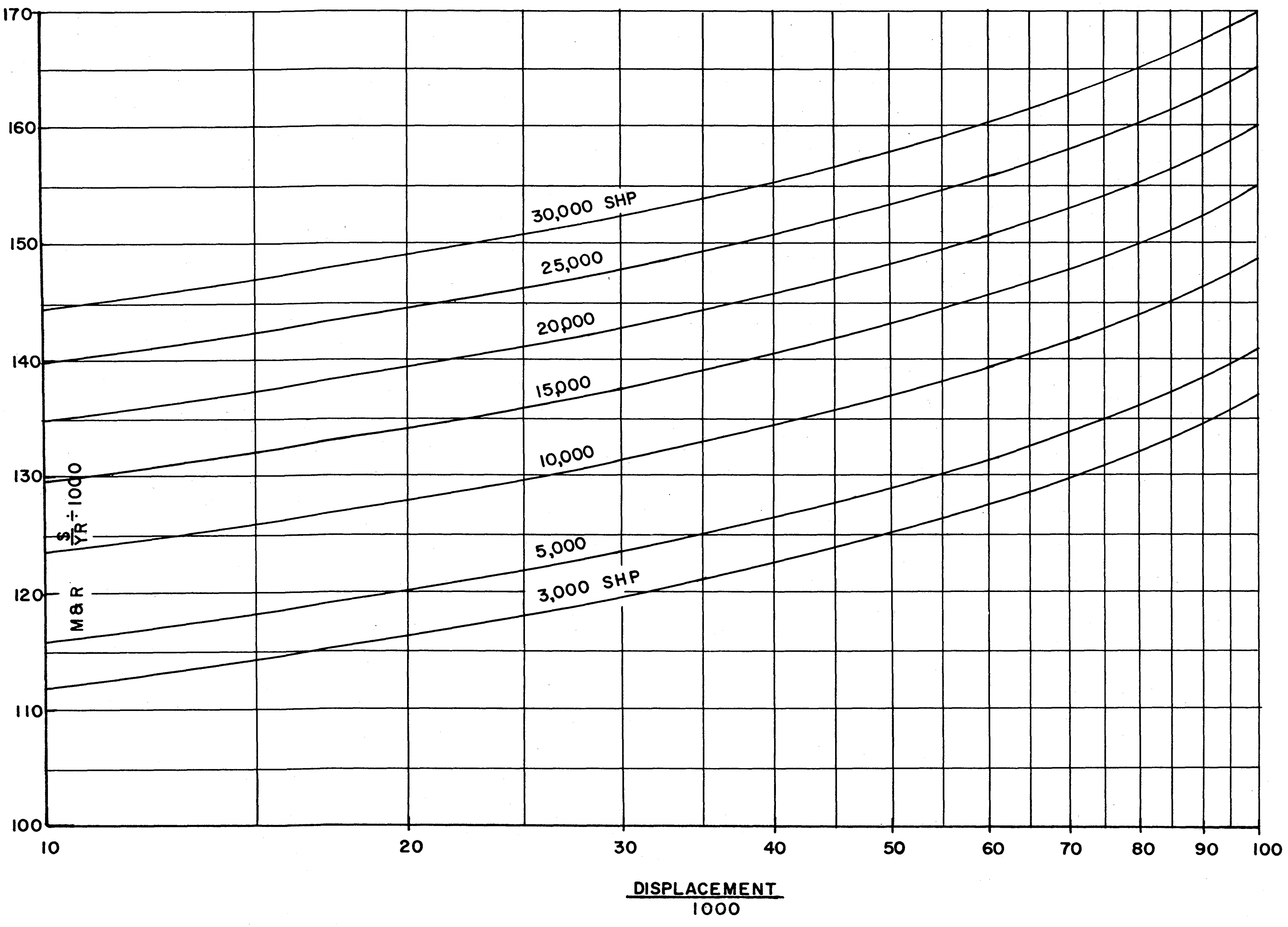


Figure 33. Crude Oil Tankers Approximate Annual Cost of Maintenance and Repairs. 1956 Dollars.

As regards repair costs in foreign yards, these will generally be considerably lower than those shown in Figure 33. Repairs abroad are slower, however, so that repair bill savings are counterbalanced by loss in revenue. For the cost studies which follow, the costs shown in Figure 33 were used for foreign flag as well as United States flag operations. The flag a vessel flies does not, as a rule, dictate where repairs shall be made, in any event.

19) Cost of Stores and Supplies

As in the previous case, a study of costs of stores and supplies was made with a breakdown between departments. Galley stores (not including food) were taken at $100 per year per man. Engine stores were varied with SHP and deck stores with deadweight. Figure 34 presents the culmination of this analysis. Note that lube oil costs are included.

These figures are suitable for either foreign or United States flag operations.

20) Insurance

An average figure for total annual insurance costs may be approximated as follows:

U. S. Built:

Annual insurance cost = $5000 + 1.2% invested cost.

Foreign Built:

Annual insurance cost = $4000 + 1.5% invested cost.

Invested cost includes miscellaneous owner's expenses in addition to the shipyard bill.

21) Subsistence Costs

In order to simplify estimates, the annual cost of food supplies was related to annual wages. This was found to average as follows:

U. S. Flag:

Annual subsistence costs = 9.4% annual wages.
(about equal to $2 per man per day)

Foreign Flag:

Annual subsistence costs = 25% annual wages.

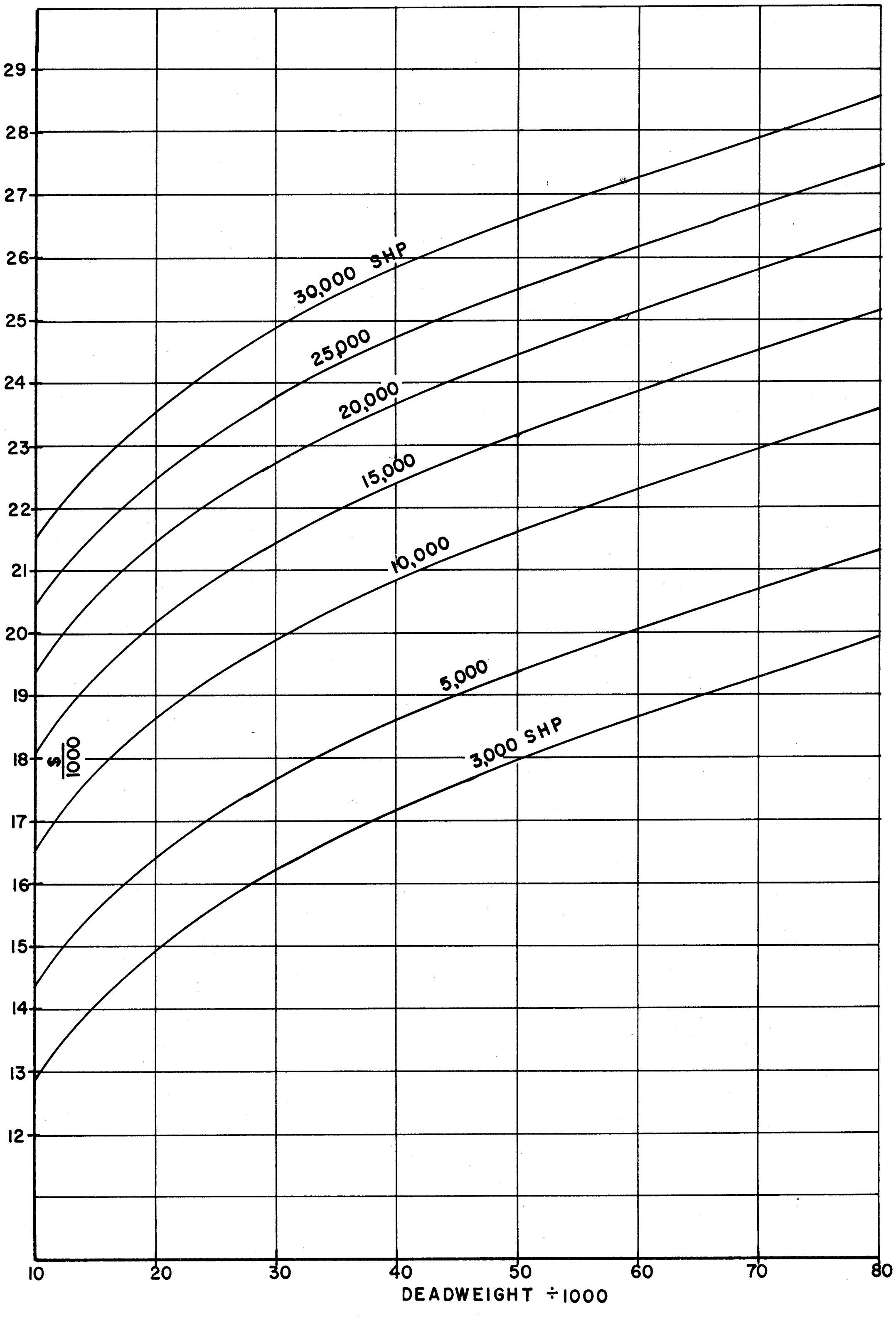


Figure 34. Annual Cost of Stores and Supplies (Deck, Engine and Steward, Including Lube Oil).

22) Annual Income

The total tons of cargo oil moved per year can be established by the information already presented. Cargo rates fluctuate in a mercurial manner and it may pay to investigate the effect of changing rates on optimum design considerations. In one recent analysis, the single-voyage charter rates on a certain route jumped around since 1950 between minus 45 percent and plus 75 percent of the U. S. Maritime Commission flat rate. The average was within 6 percent of the flat rate however.

Following are the USMC flat rates for black oil on some typical runs:

Ras Tanura to Philadelphia via Suez:	$12.70 per ton
Ras Tanura to Philadelphia via Cape of Good Hope:	$14.95 per ton
Ras Tanura to San Francisco:	$16.30 per ton
Aruba to Philadelphia:	$ 2.70 per ton
Bahrein to Los Angeles:	$16.60 per ton

23) Invested Cost

The total cost of a ship, to the owner, includes certain miscellaneous expenses in addition to the shipyard bill. This might cover such items as naval architect's fee, inspection, transportation expenses, etc. The added transportation expense of building a ship abroad is offset by the lower design fees involved.

An average cost of these miscellaneous appended expenses may be approximated as follows:

Miscellaneous owner's expense = $350,000 + 1.5% shipyard bill.

The shipyard bill may be estimated by the methods outlined in Section D, with appropriate reductions in the case of multiple orders.

Note that it is the total invested cost to the owner which should be used in operating cost studies.

Invested costs in foreign-built ships were taken at 65 percent of the comparable figure for ships built in this country.

3. Summary

The cost approximations presented in this section may prove useful to those who do not have access to confidential operating costs. Where actual cost figures are available, the curves showing effect of size and power may be of benefit in extrapolation. While figures given here may not be precise, they are felt to reflect trends correctly and should be sufficiently reliable for comparative studies. A typical example worked out in detail in the next section illustrates use of the operating cost methods discussed in the preceding paragraphs.

G. APPLICATION OF OPERATING COST ANALYSIS

1. Introduction

The purpose of this section is to illustrate the use of the operating cost analysis by application to a number of specific problems.

The optimum designs predicted by the following studies are intended to represent general averages for the shipping industry today. Individual operators, each with his own special set of circumstances, may find it desirable to depart to some extent from the numerical values arrived at in the following studies. Irreducible influences must also be weighed before settling on any given design as the "best of all possible".

2. Basic Assumptions

The studies in this section are confined to the following basic conditions except as specifically noted:

1) Crude oil movement from Kuwait in the Persian Gulf to Philadelphia on the East Coast.

2) Tanker specifications as detailed in Appendix I.

3) Cargo rates taken at the USMC flat figure:

via Suez	- $12.70 per ton
via Cape of Good Hope	- $14.95 per ton

4) Fuel oil costs taken at $2.50 per barrel ($16.75 per ton).

5) Maximum allowable draft entering the Suez Canal taken at 36'0". This was the projected figure which had definite possibilities of ultimate fulfillment at the time this study was initiated. Allowable drafts at the loading port are somewhat greater owing to the consumption of fuel and stores enroute.

6) Operating days per year taken at 342.

7) Invested costs based on two-ship contracts.

8) Fuel oil carried from loading port for one way only.

3. Variables

In many of the following examples the primary variable was SHP (with resulting variations in speed) since most of the component curves in Section F are based on SHP. This was simply a matter of convenience and the end results were readily expressed in terms of speed.

Deadweight was generally used as the size parameter, this being the conventional practice.

Other variables investigated in individual studies were:

1) Fuel oil costs.

2) Cargo rates.

3) American flag vs. foreign flag operations.

4) American vs. foreign construction costs.

5) Changing crew costs.

The relative merits of the following three sea routes were investigated:

1) Persian Gulf to East Coast via Suez.

2) Persian Gulf to East Coast via Cape of Good Hope.

3) Persian Gulf to East Coast via Cape of Good Hope, return via Suez.

Appendix II presents a partial study of the influence of hull form characteristics on operating economics.

4. Mathematical Solutions

Having arrived at a series of curves and simple formulas for the establishment of the various components of income and expenditures, it is a relatively straight-forward task to add, subtract, multiply and divide as required to produce the plotting points necessary for the graphical solution of the point of optimum design. As will be seen in the worked-out example which follows shortly, the multiplicity of steps makes this sort of solution a time consumer. Naval architects of strong mathematical bent usually feel motivated to establish a complete overall equation and solve for the maximum point on the curve by differential calculus. There is no reason why such a solution should not be considered although the following facts tend to make such an approach unsatisfactory:

1) Influence of various components of cost are hidden from view and are not easily subjected to individual investigation.

2) Simplifying assumptions generally grow bolder as the developing complexity of the equation becomes more overpowering.

3) The amount of labor involved in setting up and solving the equation will, as a rule, exceed that of the more pedestrian tabular method.

4) Allocation of routine calculations to a subordinate is an unlikely possibility.

5) Errors are more likely to occur and are more difficult to detect.

6) While end results may be correct, the lack of graphical solution removes basis for judgment relative to effects of minor departures from optimum point.

Where digital computer facilities are available, the aforementioned criticisms are greatly weakened. It seems safe to predict that future years will see many extensive cost studies handled by such means.

5. Example

The object in this example was to choose the optimum speed for a tanker operating between Kuwait and Philadelphia via the Cape of Good Hope. An arbitrary deadweight of 80,000 was assigned. American construction and operation were assumed. Other assumptions were as earlier specified.

The step-by-step solution of this problem is worked out in tabular form as follows on pages

Figure 35 shows a method for the graphical solution of the optimum speed and corresponding maximum value of the capital recovery factor. As an aid in finding the precise values of SHP and speed, the curve of differences in CRF is plotted. This curve crosses zero at the optimum SHP. The results of this solution are:

optimum speed - 16-1/4 knots

maximum CRF - 28.4 percent

Figure 36 shows the relationship between investment, annual profit and optimum speed for the above study. The influence of speed is more potent in smaller vessels. Figure 37 comes as a result of a study exactly the same as the above except the deadweight is 40,000 rather than 80,000. Note that in either case, deviations of a knot one side or the other of the optimum speed will cause only a small reduction in the rate of return. Intangible influences may therefore justify significant departures from the speed chosen by straight-forward analysis alone.

6. Effect of Variations in Cargo Rates and Fuel Oil Costs

Figure 38 shows influence of the cargo rates and fuel oil costs on the optimum speed and CRF. These figures were based on the same conditions

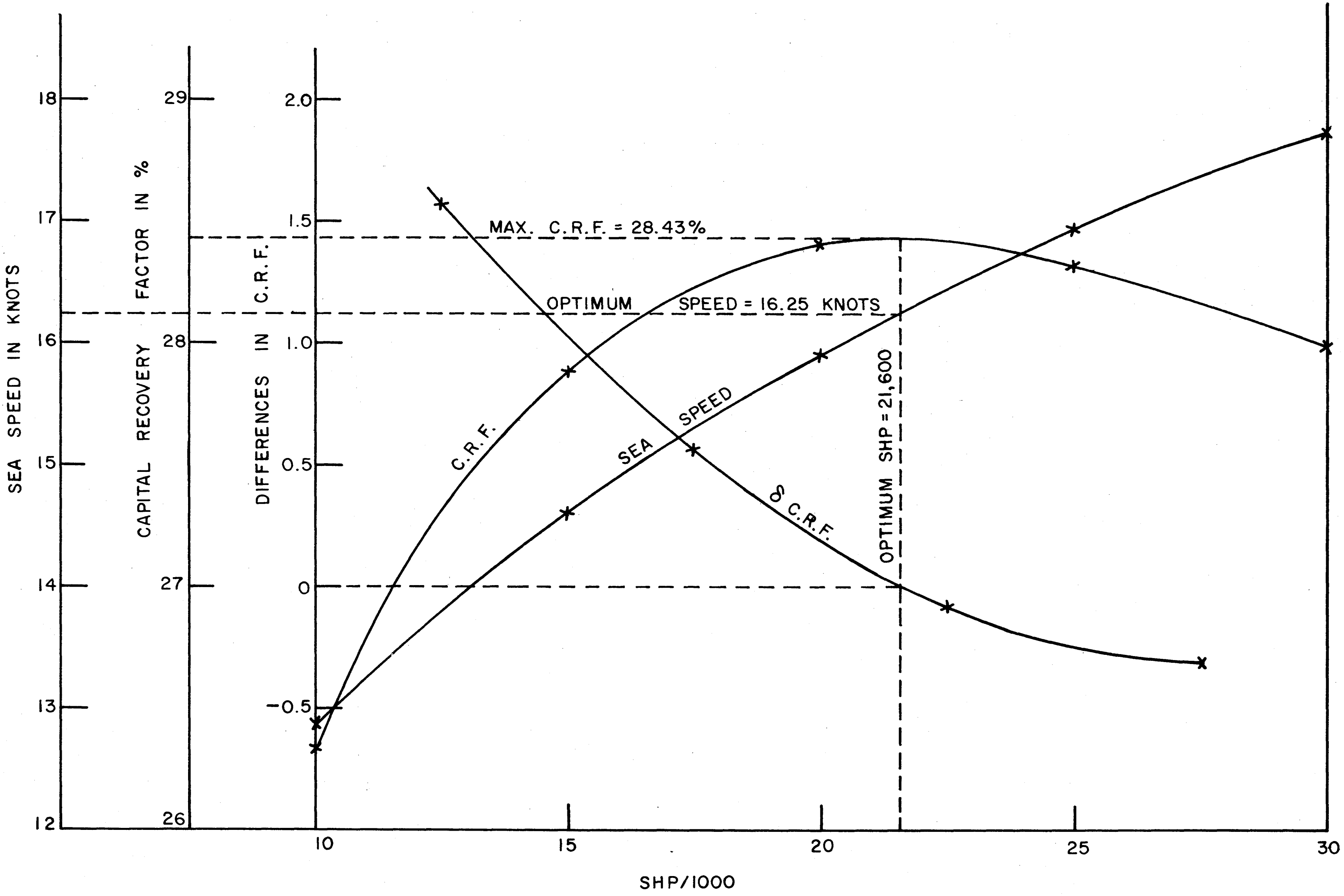


Figure 35. Graphical Solution of Optimum Speed and Maximum Capital Recovery Factor.

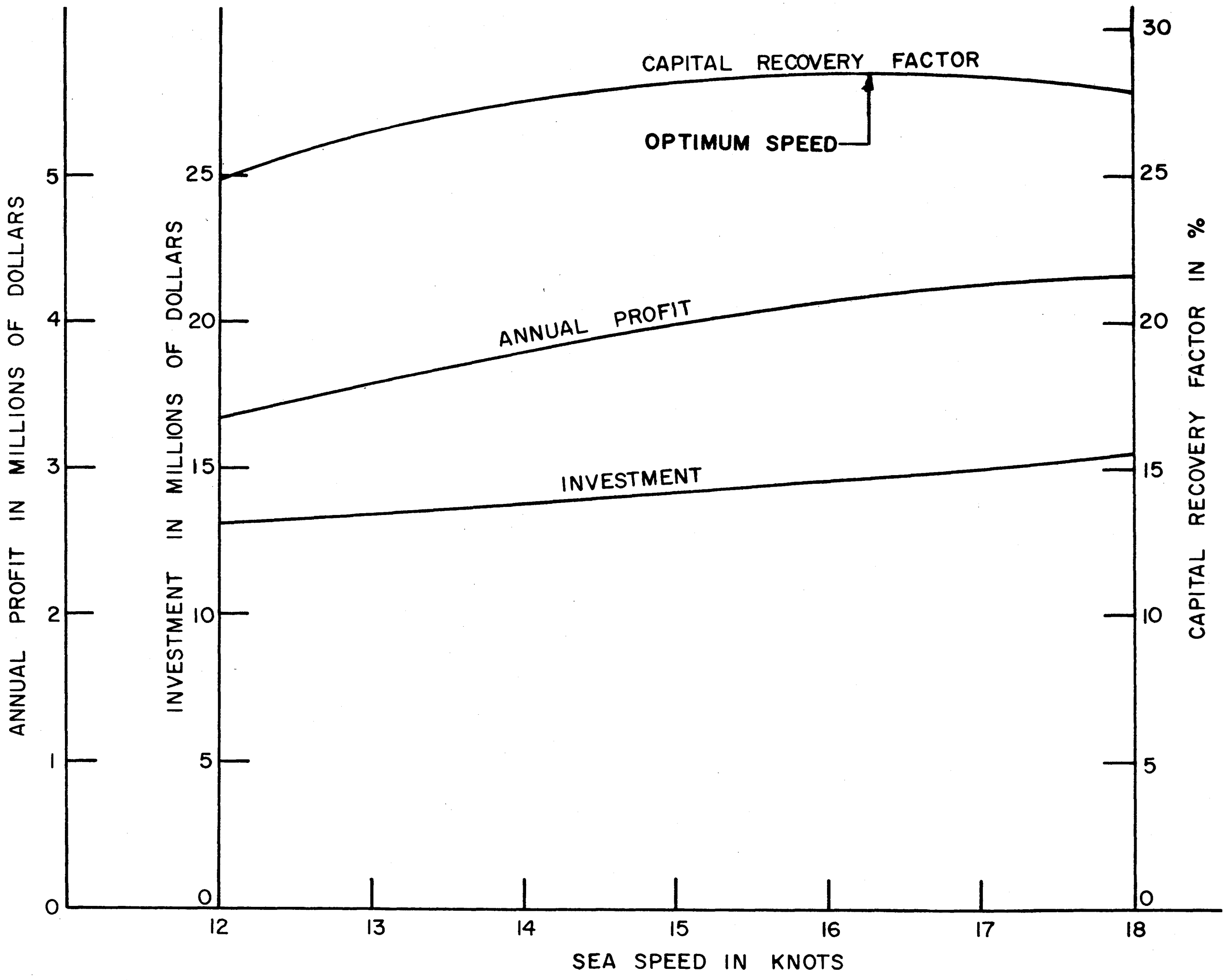


Figure 36. Relationship Between Investment, Annual Profit and Optimum Speed (80,000 DWT Tanker, 24,000 Miles R.T.).

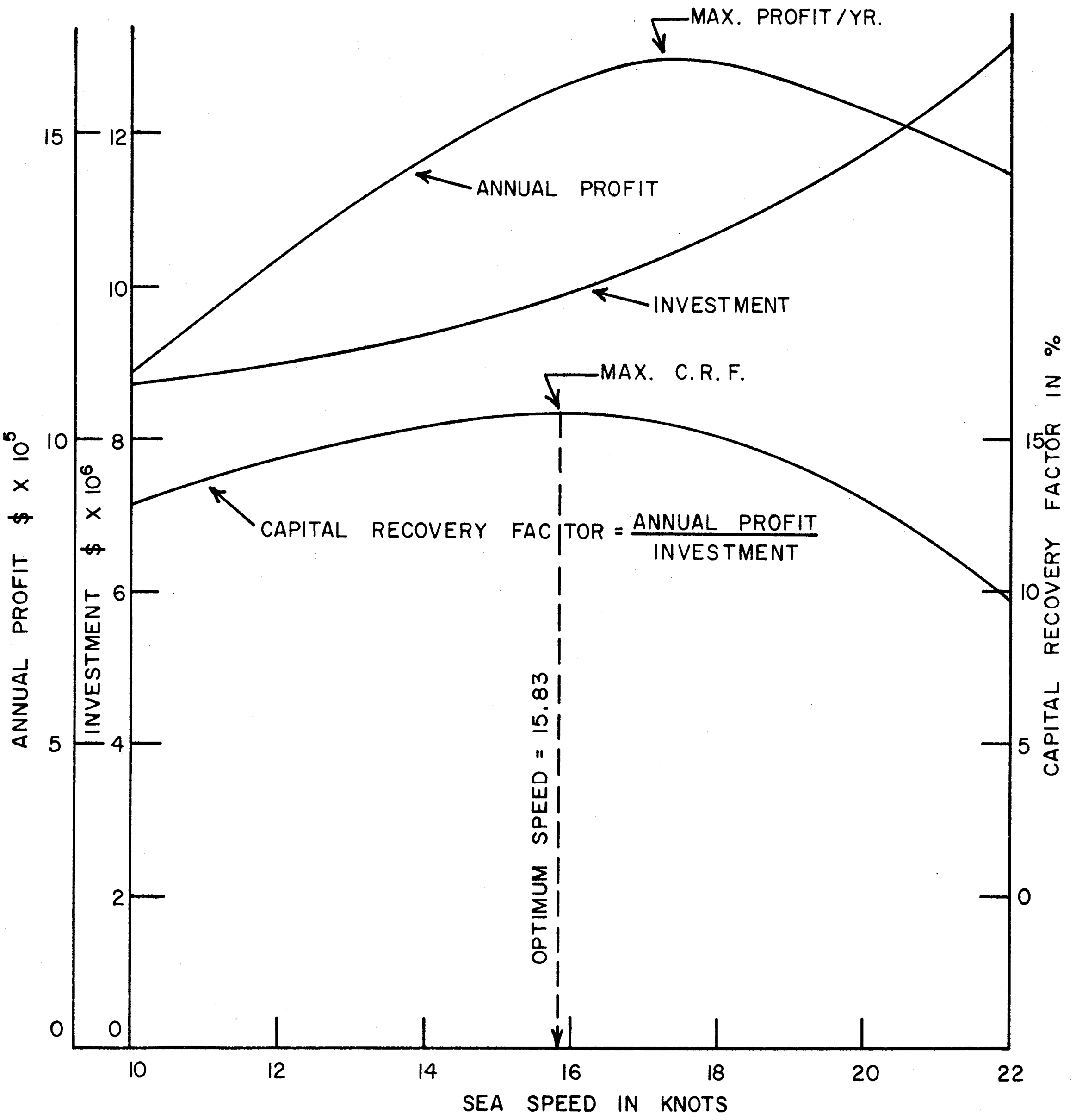


Figure 37. Relationship Between Investment, Annual Profit and Optimum Speed (40,000 DWT Tanker, 24,000 Miles R.T.).

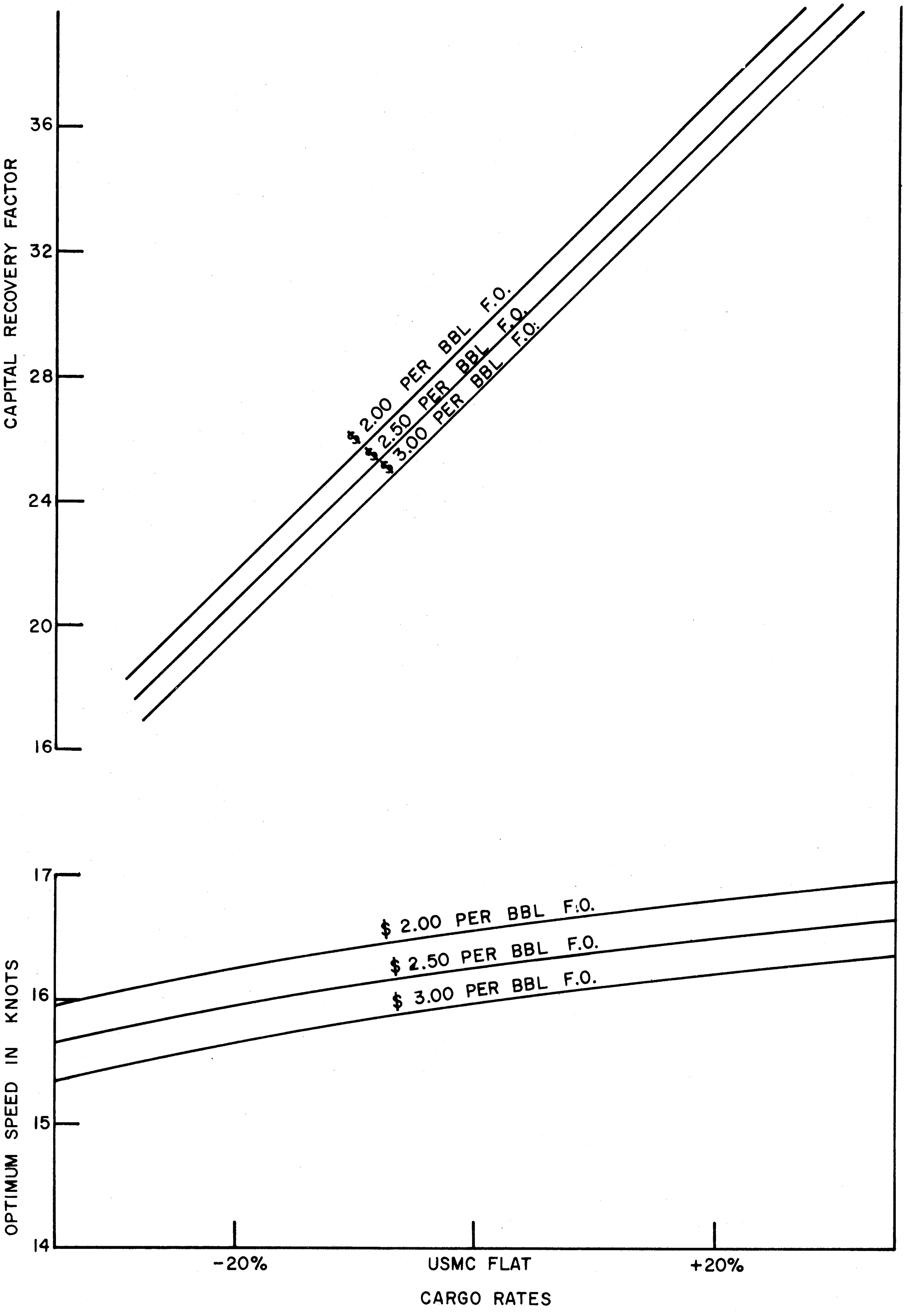


Figure 38. Variation in Optimum Speed and C.R.F. with Changes in Cargo Rates and Fuel Oil Prices.

DWT: 80,000
ROUND TRIP DISTANCE: 24,000
VESSEL CONSTRUCTED IN U. S.
VESSEL OPERATED UNDER U. S. FLAG
WEIGHTS ARE GIVEN IN LONG TONS
COSTS ARE GIVEN IN $ ÷ 1000

Line	Item	Notes					
General:							
1	SHP (normal)	Arbitrary values	10,000	15,000	20,000	25,000	30,000
2	Deadweight coefficient	Figure 10	0.8173	0.8156	0.8140	0.8123	0.8105
3*	Displacement	80,000 ÷ line 2	97,880	98,081	98,283	98,486	98,690
Operations:							
4*	V_k	Figure 2	12.83	14.59	15.90	16.93	17.81
5	Sea days per R.T.	24,000 ÷ 24 V_k	77.94	68.54	62.89	59.07	56.15
6	Port days per R.T.	Figure 24	5.8	5.8	5.8	5.8	5.8
7	Canal days per R.T.	Not applicable	0	0	0	0	0
8	Total days per R.T.	Sum of lines 5, 6, and 7	83.74	74.39	68.69	64.87	61.95
9	Round trips per year	342 ÷ line 8	4.084	4.601	4.979	5.272	5.521
Weights:							
10	Reserve F.O. factor	Figure 26	1.113	1.114	1.116	1.117	1.118
11	F.O. tons per day at sea	Figure 25	60.57	88.82	116.70	144.32	171.83
12	Sea F.O. one way	1/2 product of lines 10,11,and 5	2,627	3,392	4,095	4,760	5,390
13	Canal F.O.	Figure 27 (not applicable	0	0	0	0	0
14	Stores, water and crew	Figure 28	242	252	262	272	282
15	Cargo tons per R.T.	80,000 minus lines 12, 13, and 14	77,131	76,356	75,643	74,968	74,320
16	Cargo tons per year	product of lines 9 and 15	315,000	351,310	376,630	395,230	410,320

* Indicates values are cross faired to eliminate minor discrepancies.

Line	Item	Notes					
Investment:							
17	$/Ton DWT. one ship	Figure 17	173	180	187	193	198.5
18	Shipyard bill for each of two ships	80,000 x 0.924 x line 17 (see Figure 20)	Combined with step 19				
19*	Total investment $\frac{\$}{1000}$	350,000 + 1.015 line 18	13,425	14,010	14,511	14,977	15,404
Fuel Utilization:							
20	Sea F.O. per R.T.	product lines 15 and 11	4,721	6,088	7,339	8,525	9,648
21	Port F.O. per R.T.	Figure 27	122	122	122	122	122
22	Canal F.O. per R.T.	Figure 27 (not applicable)	0	0	0	0	0
23	Sub-total	Sum of lines 20, 21, 22	4,843	6,210	7,461	8,647	9,770
24	Productive F.O. per yr.	product of lines 9 and 23	19,779	28,572	37,148	45,587	53,940
25	Idle status F.O. per yr.	Figure 27	415	415	415	415	415
26	Total F.O. per yr.	sum of lines 24 and 25	20,184	28,987	37,563	46,002	54,355
27	F.O. costs per yr. at $2.50 per bbl.	$16.575 x line 26	334.5	480.4	622.6	762.5	900.9
Port and Canal Charges per R. T.:							
28	Port fees per R.T.	$1000 plus $\frac{\text{DWT}}{10}$	9.0	9.0	9.0	9.0	9.0
29	Canal fees per R.T.	not applicable	0	0	0	0	0
30	Port and Canal per R.T.	sum of lines 28 and 29	9.0	9.0	9.0	9.0	9.0
Operating Costs per Year:							
31	Crew Wages	Figure 29	382.6	388.9	393.0	396.7	399.9
32	Overhead and misc.	$44,500 + $15 $\frac{\text{DWT}}{1000}$	45.7	45.7	45.7	45.7	45.7
33	Maint. and repair	Figure 31	148.2	154.5	159.7	164.9	169.7

* Indicates values are cross faired to eliminate minor discrepancies.

Line	Item	Notes					
34	Stores and supplies	Figure 32	23.6	25.2	26.4	27.5	28.6
35	Insurance	$5000 + .012 line 19	166.8	174.1	180.0	186.2	191.1
36	Subsistence	.094 line 31	36.0	36.6	36.9	37.3	37.6
37	Port and canal	product lines 9 and 30	36.8	41.4	44.8	47.4	49.7
38	Total oper. cost excl. F. O.	sum of lines 31 through 37	839.7	866.4	886.5	905.7	922.3
39	Total oper. cost per yr.	sum of lines 27 and 38	1174.2	1346.8	1509.1	1668.2	1823.2
Capital Recovery:							
40	Income per year	$14.95 times line 16	4709.2	5252.1	5630.6	5908.7	6134.3
41*	Profit per year	line 40 minus line 39	3535.0	3905.3	4121.5	4240.5	4311.1
42	Capital Recovery Factor	line 41 ÷ line 19	26.33%	27.88%	28.40%	28.31%	27.99%

* Indicates values are cross faired to eliminate minor discrepancies.

as in the preceding example. For this particular set of circumstances the following conclusions can be drawn:

1) An increase of 50 percent in the cost of fuel oil decreases the optimum speed by about half a knot. The capital recovery is decreased by two percentage points.

2) An increase of 50 percent in the cargo rate increases the optimum speed by about half a knot and effects a jump of fifteen percentage points in capital recovery.

3) Variations in fuel prices and cargo rates have, for all practical purposes, a straight line relationship with both optimum speed and capital recovery.

7. Weight Distribution

Figures 39 and 40 allow a comparison between tankers of 10,000 DWT and 40,000 DWT relative to the allotment of weights. Note the exaggerated influence of speed, in the smaller tanker, on the loss of cargo deadweight. On long voyages, such as the one under consideration here, the weight of bunker oil for even a one way voyage will more than equal the weight of all the machinery and equipment within the engine and boiler rooms.

8. Cost Distribution and Profit

Figure 41 shows the distribution of annual operating costs in the case of the 40,000 DWT tanker operating on the 24,000 mile R. T. voyage. It is quite apparent that speeds above 17 or 18 knots are uneconomical largely because of rapidly increasing fuel costs.

9. Influence of Construction Costs

The 80,000 DWT tanker analyzed in the earlier example was assumed built in the United States and operated under American flag. Table IV below compares optimum speed and capital recovery based on foreign rather than American construction costs. Compare lines A and B.

10. Influence of Foreign Flag Operation

Table IV shows the effect of foreign (European) crew costs etc. on the optimum speed and capital recovery. Compare lines A and C.

11. Combined Influence of Foreign Construction and Operating Costs

Table IV allows comparison between vessels built and operated here and abroad. See lines A and D.

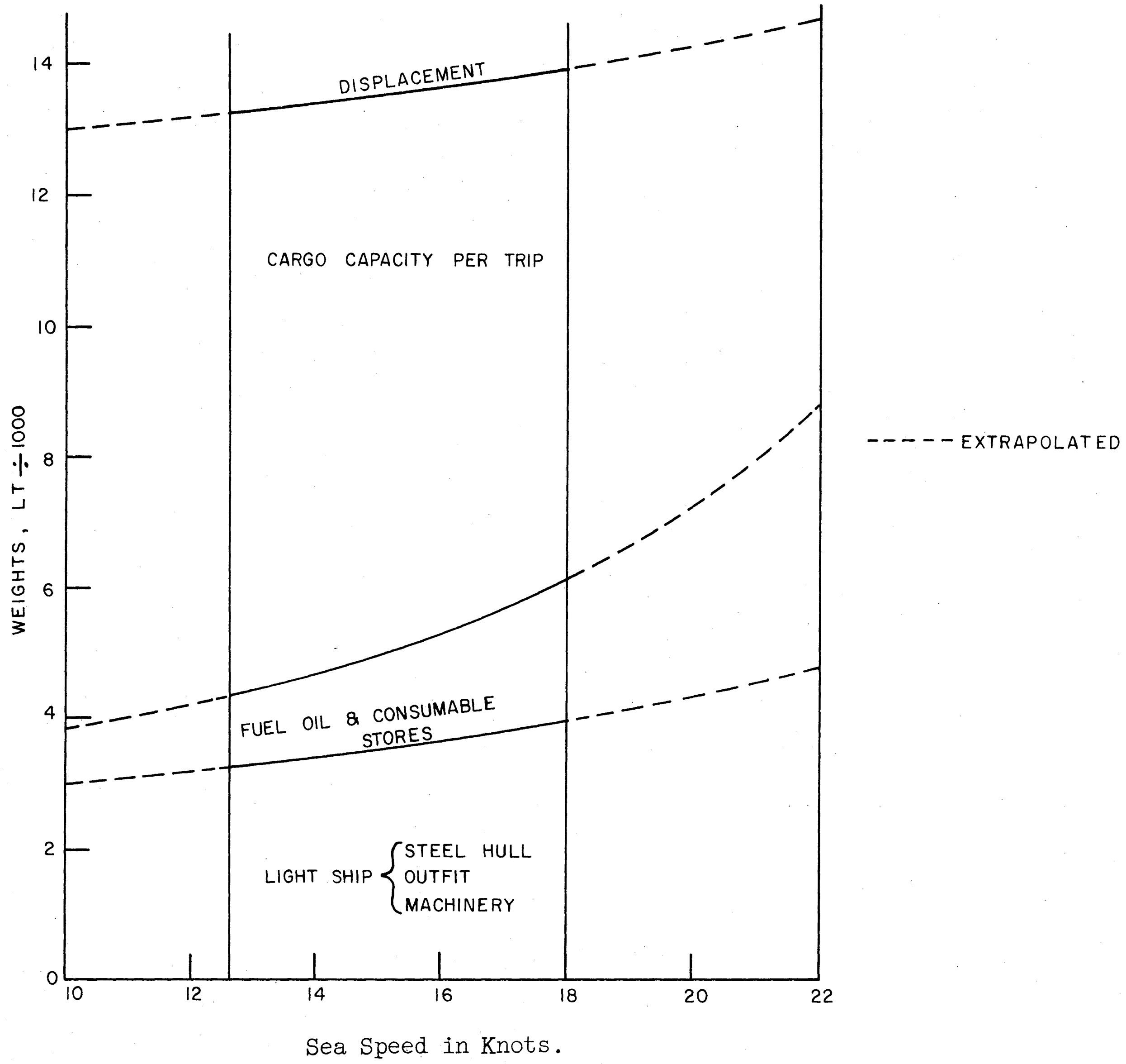


Figure 39. DISTRIBUTION OF WEIGHTS 10,000 DWT. TANKER

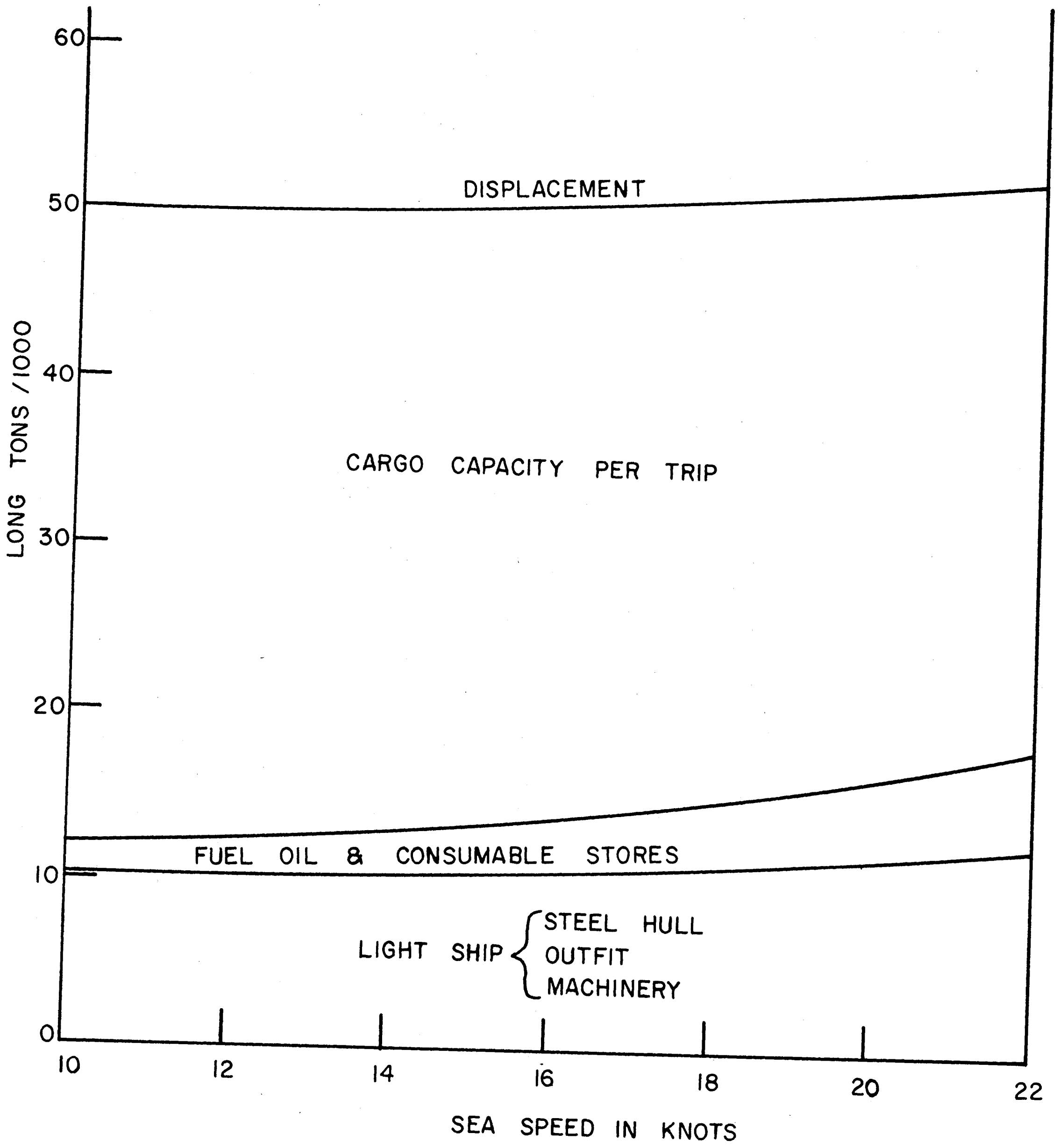


Figure 40. Distribution of Weights. 40,000 DWT Tanker.

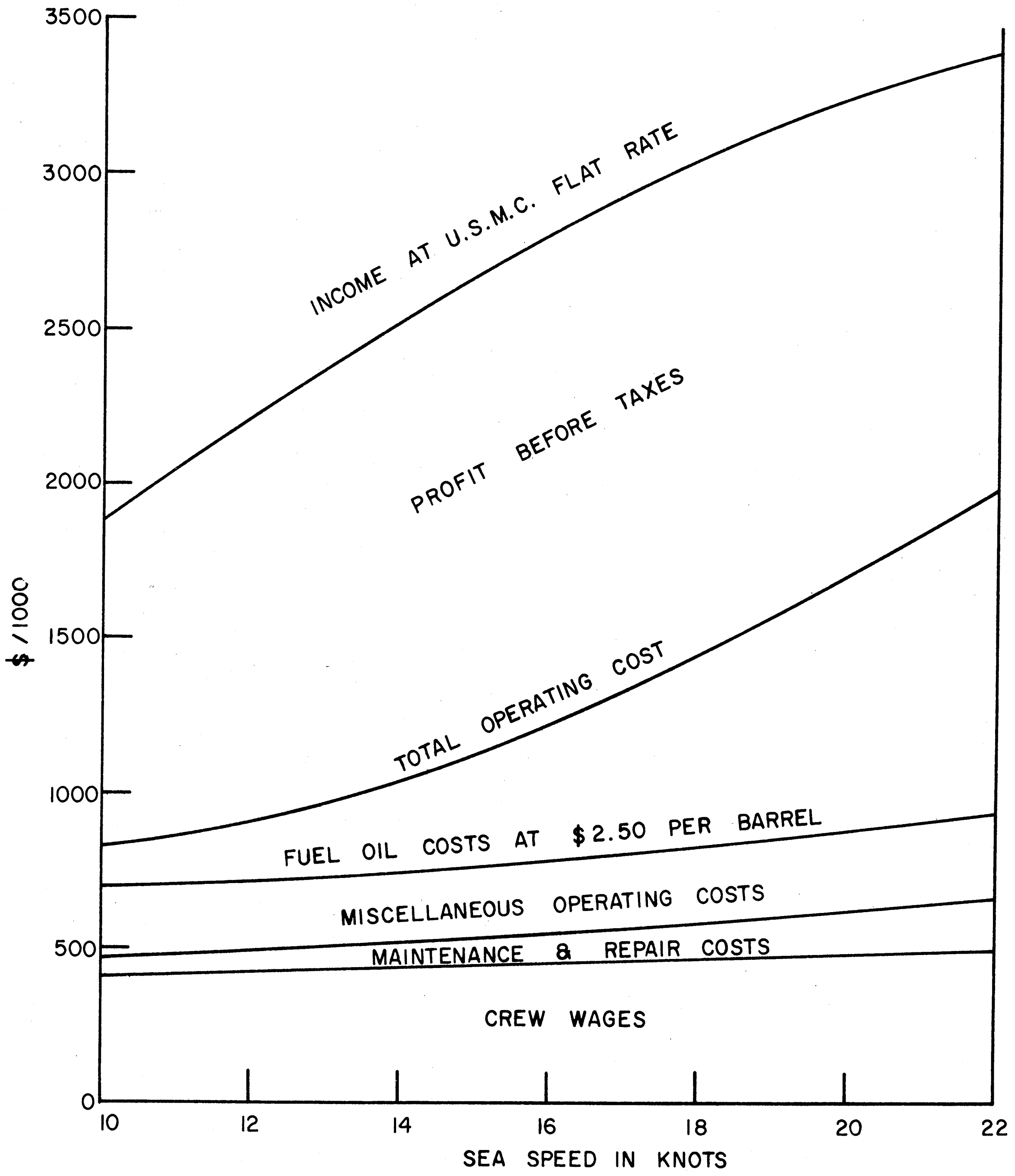


Figure 41. Annual Income and Distribution of Costs. 40,000 DWT Tanker, Persian Gulf to East Coast of U. S. via Cape of Good Hope. U. S. Flag Operation.

TABLE IV. INFLUENCE OF CONSTRUCTION COSTS AND CREW COSTS ON OPTIMUM SPEED AND CAPITAL RECOVERY

Line	Construction	Flag	Optimum Speed	Capital Recovery Factor
A	U. S.	U. S.	16.25	*28.4%
B	Foreign	U. S.	16.4	*43.7%
C	U. S.	Foreign	16.0	31.0%
D	Foreign	Foreign	16.1	47.6%

* CRF is before taxes.

12. Conclusions from Table IV

1) For the stated conditions, it is apparent that high crew costs justify high speeds while high construction costs dictate lower speeds. This is as reason predicts although the net difference is surprisingly small.

2) Conclusions relative to going abroad for new construction and crew are both obvious and painful.

13. Influence of Crew Costs

Figure 25 shows that relative crew wages have more than doubled since 1940. If this trend continues, somewhat higher speeds will be in order. The table below shows the effect of doubling the crew wages and food costs in the case of the 40,000 DWT tanker operating around the Cape of Good Hope.

Conditions	Optimum Speed	CRF
Present-day costs	15.8	15.8%
Double crew and food costs	16.3	11.6%

14. Optimum Suez Canal Size

The traditional view that a ship should be tailor-made to the maximum draft limitations of certain harbors or canals has recently been disproved. In the case of tankers operating through the Suez Canal, for example, oversize vessels at partial displacements have been found to be better money earners than vessels whose dimensions were designed around the canal draft. This is a bit disquieting to the naval architect who has always felt that draft limitations represented one of the fixed values in preliminary design work.

The purpose of this particular study was to determine the optimum size tanker for the Persian Gulf to East Coast trade via Suez. Cost studies similar to the one in the example were made for tankers of 30,000, 40,000, 45,000, and 50,000 tons deadweight. It should be noted that tankers tailor-made for the canal are of about 40,000 DWT. Vessels of greater nominal deadweight must move through the canal at only partial cargo capacity. Figure 13 was used to determine speed and capacity at reduced drafts.

Figure 42 shows the influence of size and power on the money-earning potential of United States built and operated Suez Canal tankers. It is evident from these curves that 40,000 DWT tankers are about two percentage points less efficient than are those of 50,000 DWT. The best vessel appears to be about as follows:

Deadweight - 50,000
SHP - 15,500
Displacement - 62,800
Normal draft - 38' 3"
Nominal sea speed - 16.1 knots
Maximum CRF - 20.7%

A similar study was carried out for foreign built and operated tankers. Unfortunately the range of sizes investigated did not extend high enough for this combination of factors, and time did not permit additional calculations. Most of the components of cost plotted in fairly straight lines and these were extrapolated to allow a rough estimate of optimum conditions. The indications were that these would be about as follows:

Deadweight - 60,000
SHP - 14,000
Displacement - 73,400
Normal draft - 40' 3"
Nominal sea speed - 15.1 knots
Maximum CRF - 36%

It can be concluded from these studies that, in general, vessels should be built oversize for their draft limitation. Such ships can carry enough extra cargo, owing to their greater length and beam, to more than offset their increased construction and operating costs. The ideal extent of over-sizing can only be determined by cost studies. These statements assume the availability of cargo in unlimited supply and would not apply to ordinary dry cargo ships.

15. Alternate Routes Between Persian Gulf and East Coast

Having established approximate optimum designs for vessels operating through the Suez Canal, it was of interest to investigate the possibilities offered by the alternate routes. By-passing Suez, while not quite a

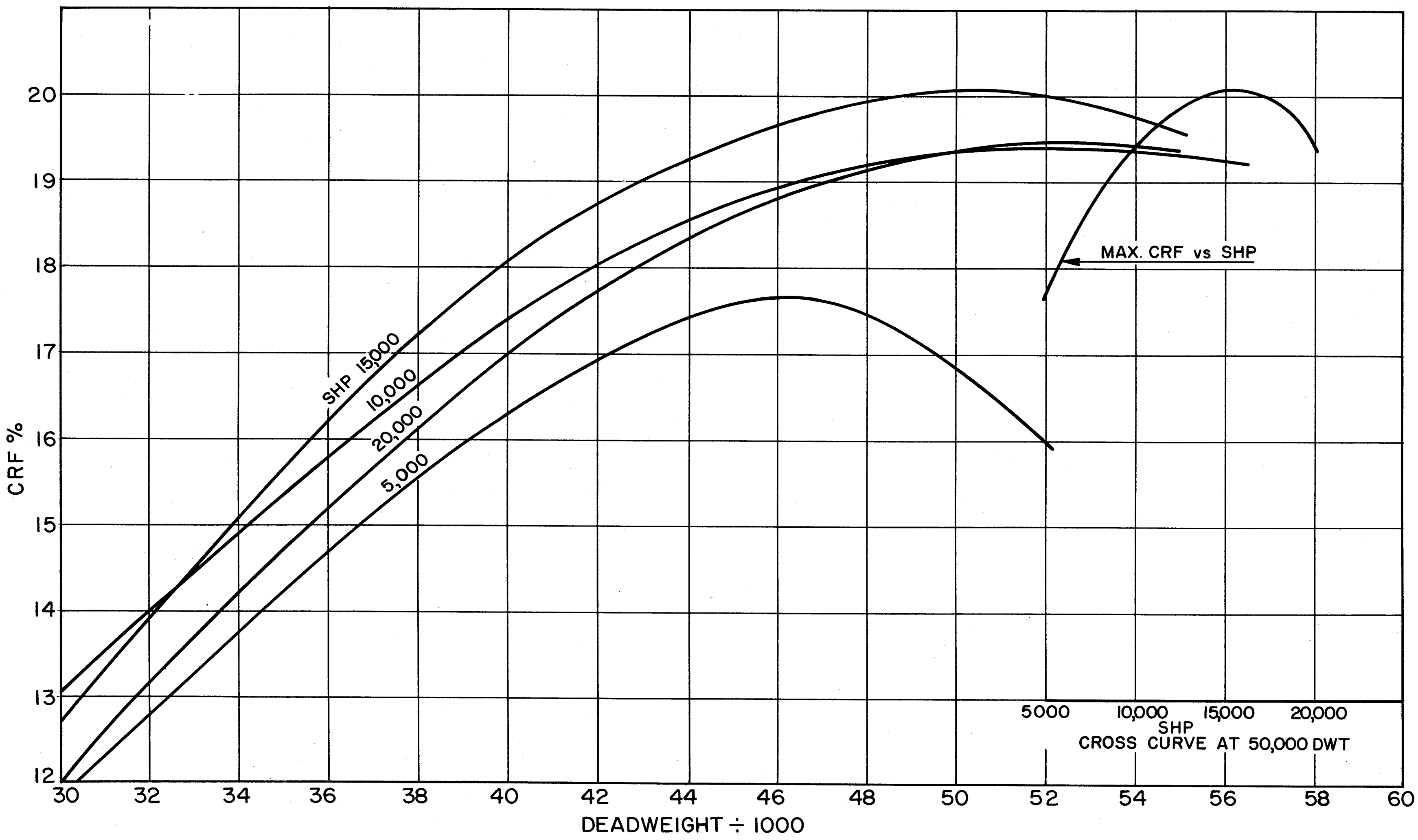


Figure 42. Influence of Deadweight and SHP on Suez Canal Tanker Economics (U. S. Built and Operated).

necessity at the time of this study, gave promise of being a desirable move on economic grounds alone.

It is a well-known fact that where the cargo is available, the biggest ship, within reason, will be the most efficient. Elimination of Suez draft restrictions allows greatly increased deadweight capacities as shown by Figure 12. Among the intangibles that must be considered are the problems the 80,000 ton tankers would present at the unloading terminals as a result of their drafts (about 43' 6"). A glance at the comparative economics should convince the reader that additional expenditures required for handling 80,000 DWT tankers are justifiable.

As discussed earlier, 80,000 DWT was chosen as the top limit for this work since it was felt that vessels of such size were near the limit of single screw propulsion. Twin screws have so many drawbacks (less propulsive efficiency, increased building costs, increased crew requirements, etc.) that it is believed there is no advantage in the use of twin screws to increase size unless the deadweight is jumped to 100,000 or more. In any event, the introduction of twin screws as another variable was felt to be beyond the scope of this paper.

Cost analyses were made for tankers of 40,000 and 80,000 tons deadweight operating around the Cape of Good Hope. In addition, the 80,000 DWT vessel was analyzed on the basis of rounding the Cape loaded but returning through the Suez Canal on the return voyage.

The cargo rate was taken at the USMC flat rate of $14.95 per ton. As long as both routes are open it seems a bit incongruous to pay more for oil carried one way than the other. One of the comparisons presented below removes this artificial advantage and shows the route around the Cape to be superior on its own merits.

Table V summarizes the results of these investigations.

16. Conclusions from Alternate Route Studies

1) The optimum tankers for use through the Suez Canal are not as efficient as larger tankers operating around the Cape of Good Hope.

2) The most efficient arrangement is to carry the oil around the Cape in the largest practical tanker (about 80,000 DWT) returning through Suez in ballast.

3) Vessels built in this country and operated under the American flag cannot compete on equal footing with foreign vessels.

TABLE V. COMPARATIVE ECONOMICS OF ALTERNATE METHODS FOR MOVING OIL FROM THE PERSIAN GULF TO THE EAST COAST

	Route				U.S. Built & Operated		Foreign Built & Operated	
Deadweight	Loaded	Ballast	Cargo Rate	Notes	Speed Knots	*CRF	Speed Knots	*CRF
40,000	Suez	Suez	12.70	Tailor-made size for canal	16.5	18.1%	15.8	33.2%
40,000	Cape	Cape	14.95		15.8	15.8%	--	--
50,000	Suez	Suez	12.70	Optimum size for canal, U.S. built and operated	16.1	20.7%	--	--
60,000	Suez	Suez	12.70	Ditto, foreign built and operated	-	-	15.1	36%
80,000	Cape	Cape	14.95		16.25	28.4%	16.1	47.6%
80,000	Cape	Cape	12.70		16.0	22.6%	--	--
80,000	Cape	Suez	14.95		16.35	33.1%	16.2	54.7%

* Capital recovery factor does not include 52% federal tax.

APPENDIX I. SPECIFICATIONS

Following is a brief specification, in outline form, for the tankers dealt with in this paper:

1) Normal proportiona and hull form.
2) Single screw propulsion.
3) Normal extent of superstructure.
4) Zero sheer in way of cargo tanks.
5) Classed A.B.S A1 Ⓔ - Oil Carrier, AMS.
6) Minimum allowable riveting, maximum welding.
7) Twin bulkhead construction, possibly going to triple in the largest sizes.
8) Flat bulkhead construction.
9) Longitudinal framing.
10) Single cargo pumping system.
11) Geared turbines, water tube boilers with steam conditions average modern practice for installed SHP.
12) Volumetric capacity for loading full and down with gasoline cargo.

APPENDIX II. HULL FORM STUDY

Figure 3 shows the assumed relationship between block coefficient and speed-length ratio. The slope of curves such as this are based on tank research. The quantitative values are adjusted to suit the general average of existing ships of the type, on the theory that the more successful ships are the ones most frequently reproduced. It was felt desirable to make an economic study to determine if this average curve represented optimum design or was merely an advanced case of naval architectural inbreeding.

These studies required individual estimation of horsepower (based on Taylor's Standard Series with a correction factor to bring agreement with moder vessels) and a complete reworking of weights, construction costs and operating costs for each of 23 distinct designs. In each case the vessel was held at 50,000 tons displacement and the operation was confined to the movement of oil from the Persian Gulf to the East Coast via Suez. Foreign costs were assumed and the cargo rate and fuel oil costs were held constant.

The study was done in two parts. In the first instance, the block coefficient was held at 0.75 and length was arbitrarily varied. The draft was held constant and beam adjusted to hold the displacement to 50,000 tons. Installed power was also introduced as a variable so that the optimum speed (hence speed-length) could be determined for each length. The conclusion from this part was that for a given displacement, block coefficient, and draft, the ship should be as short and wide as regulatory bodies and/or practical considerations will allow.

In the second half of the study, displacement and draft were held the same as before while the speed-length ratio was arbitrarily set at 0.60 and the block coefficient was varied from 0.74 to 0.82. From the preliminary study, the value of B -(L/10) was set at 26, this being the approximate beamiest proportion found in modern ships of this size. For each block coefficient there was then only one possible combination of length, beam and speed suiting the above restrictions. These hypothetical designs were analyzed and the results are shown in the table following.

Conclusions

1) For a given displacement, block coefficient, and draft, the vessel should be as short and wide as practical considerations will allow.

2) For a given displacement and draft, the block coefficient can be varied widely with negligible effects on rate of return.

Smaller block coefficients call for longer, high powered and hence more expensive ships, principally because of greater machinery costs. The increased speed and annual income of the finer lined vessels almost exactly

(all costs are in $/1000)

Block coefficient	0.74	0.76	0.78	0.80	0.82
Length	690	680	670	660	650
Beam	95	94	93	92	91
Draft	36	36	36	36	36
Midship Coef.	0.985	0.985	0.985	0.985	0.985
Prismatic Coef.	0.751	0.772	0.792	0.812	0.832
Sea Speed	15.78	15.66	15.54	15.41	15.30
SHP	12,340	12,170	11,735	11,330	10.970
Deadweight	39,440	39,450	39,475	39,490	39,510
Cargo per R.T.	37,530	37,560	37,610	37,680	37,720
Cargo per year	249,100	247,600	246,300	244,900	243,600
Fuel oil costs per year	381.4	375.3	367.0	354.9	346.2
Total operating costs per year	1014.3	1005.8	995.0	980.1	968.9
Income per year (USMC flat rate)	3163.2	3144.9	3127.7	3110.6	3094.3
Profit per year	2148.9	2139.1	2132.7	2130.5	2125.4
Invested cost	6365.2	6353.9	6321.8	6297.4	6277.5
Capital recovery factor - %	33.8	33.7	33.7	33.8	33.9

balance the greater investment and operating cost. The net effect produces the situation of operational efficiency being independent of the block coefficient under the stated conditions.

3) The above study allows the further inference that for a given length, beam and draft, the most efficient tanker will be the one whose displacement, hence block coefficient is as large as questions of seaworthiness allow. This figure will be a function of weather conditions on the intended sea route. In this respect it may be pointed out that a number of existing ore carriers have block coefficients of from 0.80 to 0.83 whereas tanker blocks seldom exceed 0.77. If sea conditions permit, it seems quite probable that improvements over modern tankers could be effected through increases in the block coefficient. One intangible, of course, is the greater loss in speed experienced by the fuller vessel in heavy weather.

APPENDIX III. REFERENCES

1. "Cities Service Supertankers --," Marine Engineering, Nov. 1954.

2. "The Supertanker, World Glory," Marine Engineering, Oct. 1954.

3. "The Flying-A Supertankers," Marine News, Dec. 1954.

4. "Jersey Standard's Tanker Esso Zurich," Marine Engineering, May 1949.

5. "27,000 Ton Class of Supertankers," Marine Engineering, March 1950.

6. "Bethlehem-Built Supertanker Jahra," Marine Engineering, Nov. 1949.

7. "--Delaware Sun Class Ships," Marine Engineering, Sept. 1953.

8. "New Class of Coastwise Tanker," Marine Engineering, Nov. 1953.

9. "Tanker Olympic Games," Marine Engineering, Mar. 1949.

10. Morrell, Robert W., Oil Tankers, Simmons-Boardman, 1931.

11. Pennypacker, J. A., "Cost of Cargo Ships," Marine Engineering and Shipping Age, Oct. 1931.

12. Robertson, Alfred J. C., "Economical Cargo Ships," Trans. SNAME, Vol. 27, 1919.

13. Minorsky, V., "A Nomograph for the Preliminary Powering of Merchant Ships," International Shipbuilding Progress, Vol. 2, No. 9, 1955.

14. Arnott, et al., "Design and Construction of Steel Merchant Ships," SNAME publication, 1955.

15. "Load Line Regulations," USCG publication.

16. Raben, H., "Vertical Centre of Gravity of Ships' Steel Hulls," Shipbuilder and Marine Engine Builder, April 1949.

17. Jansson, Jan-Erik, "Influence of Essential Quantities on End Launching Condition," Svenska Tekniska Vetenskapsakademein, Finland.

18. Shipbuilding Cyclopedia, Simmons Boardman, 1920.

19. Kari, Alexander, Design and Cost Estimating --, Technical Press, 1948.

20. Ferguson, W. B., Shipbuilding Cost and Production Methods, Cornell Maritime Press, 1944.

21. Grant, Eugene L., Principles of Engineering Economy, Ronald Press, 1950.

22. Statistical Yearbook - 1953, United Nations.

23. Commodity Yearbook - 1956, Commodity Research Bureau.

24. Statistical Abstracts of the United States - 1956, U. S. Department of Commerce.

25. World Almanac - 1956, N. Y. World Telegram and Sun.

26. Grossman, William L., Ocean Freight Rates, Cornell Maritime Press, 1956.

27. Bross, Steward R., Ocean Shipping, Cornell Maritime Press, 1956.

APPENDIX IV. ADDITIONAL BIBLIOGRAPHY

1. Telfer, E. V., "Economic Speed Trends," Trans. SNAME, Vol. 59, 1951.

2. Slater, John E., "Economic Considerations in the Design of Future Combination Passenger and Cargo Ships," Trans. SNAME, Vol. 52, 1944.

3. Telfer, E. V., "The Structural Weight Similarity of Ships," Trans. N.E. Coast, Vol. 72, 1955-56.

4. Broad, R., Outfit Estimating Coefficients for Ships, Thesis, University of Michigan, 1956.

5. Fassett, et al., "The Shipbuilding Business in the United States of America," SNAME publication, 1948.

6. Manning, George C., The Theory and Technique of Ship Design, Technology Press of M. I. T. and John Wiley and Sons, 1956.

7. Allen, W. G., and Sullivan, Kemper, "Operation in Service of the Mariner-Type Ship," Trans. SNAME, Vol. 62, 1954.

8. Johansen, Helge, "The Factors Involved in a Comparison Between Direct-Driven Diesel Installations and Geared Steam-Turbine Installations," International Shipbuilding Progress, Vol. 2, No. 8, 1955.

9. Schad, Harry G., "The Tanker Outlook," Marine News, Jan. 1955.

10. Edstrand, Hans, "Experiments with Tanker Models," Trans. N.E. Coast, Vol. 72, 1955-56.

11. Hicks, J. S., and Steffen, L. R., "Cost Estimating and Decision Making," Chemical Engineering Progress, May 1956.

12. Tielrooy, Jack, "Capital Cost Estimates," Chemical Engineering Progress, May, 1956.

13. Vincent, Sydney A., "The Economics of Future European-Great Lakes Freighter Service," Trans. SNAME, Vol. 64, 1956.

14. Robinson, Roeske and Thaler, "Modern Tankers," Trans. SNAME, Vol. 56, 1948.

15. Couch, R. B., and St. Denis, M., "Comparison of Power Performance of Ten 600-Foot Single-Screw Tanker Hulls as Predicted from Model Tests," Trans. SNAME, Vol. 56, 1948.

16. Pluymert, N. J., "Modern Tanker Design," Trans. SNAME, Vol. 47, 1939.

17. Lindblad, Anders F., "Some Factors Affecting the Economy of Operation of the Lake Freighters," Trans. SNAME, Vol. 31, 1923.

18. Houlden, G. H., "Ship Tendering and Factors Influencing Building Costs," Trans. N. E. Coast, Vol. 71, 1954-55.

19. Gebbie, J. Ramsey, "Fast or Less Fast Ships," Trans. N. E Coast, Vol. 59, 1942-43.

20. Biles, John, "The Draught and Dimensions of the Most Economical Ship," Trans. INA, Vol. 73, 1931.

21. Biles, John, "The Relative Commercial Efficiency of Steam Turbine and Diesel Machinery for Cargo Vessels," Trans. INA, Vol. 68, 1926.

22. Anderson, John, "The Most Suitable Sizes and Speeds for General Cargo Steamers," Trans. INA, Vol. 60, 1918.

23. Anderson, John, "Further Notes on the Dimensions of Cargo Steamers," Trans. INA, Vol. 62, 1920.

24. Tutin, John, "The Economic Efficiency of Merchant Ships," Trans. INA, Vol. 64, 1922.

25. Lovett, W. J., "Comparative Freight Economics of a Cargo Vessel with Reciprocating and with Diesel Machinery," Trans. INA, Vol. 68, 1926.

26. Davis, A. W.,"Trends in the Choice of Machinery for Ocean-Going Merchant Vessels," Trans. Inst. Engineers and Shipbuilders in Scotland, Vol. 93, 1949-50.

27. Holly, Hobart, and Pennypacker, James A., "Economic Aspects of American Merchant Ship Design," Trans. SNAME, Vol. 61, 1953.

28. "Economics of Repowering Lakes Vessels," Marine Engineering, Aug. 1951.

29. "Why U. S. Merchant Ships Cannot Be Competitively Operated," Marine News, Oct. 1947.

30. "Relative Earning Power of American Seamen," Marine News, April, 1952.

31. Davidson, Kenneth S. M., "What Price Speed?-Long Range Trends in Overseas Transportation," SNAME Bulletin, Feb. 1955.

32. Jung, Ingvar, "A Report on Shipbuilding in Scandinavia," The Log, July 1953.

33. "Earnings of American Seamen from 1945-1952," Marine News, July 1953.

34. Schokker, Neuerburg, and Vossnack, The Designs of Merchant Ships, N. V. Technische Uitgeverij, H. Stam--Haarlem--Holland,

APPENDIX V. SYMBOLS AND ABBREVIATIONS

bbl. - Barrel

C.R.F. - Capital recovery factor

C_B - Block coefficient

D - Depth of hull in feet

DWT - Deadweight in long tons

Δ - Displacement in long tons, salt water

L - Length between perpendiculars

R.T. - Round trip distance in nautical miles

SHP - Shaft horsepower

USMC - United States Maritime Commission

V or V_k - Normal sea speed in knots